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John A. Barron
USGS

Jack G. Baldau
Ocean Drilling Program, Texas A&M University, College Station, Texas 77843-3469

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Diatom stratigraphy of the lower Pliocene part of the Sisquoc Formation, Harris Grade section, California

John A. Barron¹ and Jack G. Baldauf²

¹U.S. Geological Survey, Menlo Park, California 94025

²Ocean Drilling Program, Texas A&M University, College Station, Texas 77843-3469

ABSTRACT: Lower Pliocene diatoms were studied from the Sisquoc Formation and lowermost Foxen Mudstone, exposed along Harris Grade north of Lompoc, California, to refine the diatom biostratigraphy of post-Monterey Formation sediments in California. Sixty-seven diatom taxa were identified in the 25 samples examined from the 790-m thick (2950-ft) section. The diatoms are assignable to the uppermost *Nitzschia reinholdii* Zone and *Thalassiosira oestrupii* Zone of Barron (1981), and five tentative subzones for local correlation are proposed. Regional correlations and taxon occurrence are discussed, and the base of the *Nitzschia reinholdii* Zone is redefined as at the last occurrence of *Thalassionema schraderi*.

INTRODUCTION

Middle Miocene to lower Pliocene strata of coastal California are well known for their extensive deposits of diatomaceous rocks (Ingle 1981). Typically, these deposits contain hemipelagic diatomaceous shales of the Monterey Formation (upper lower Miocene to upper Miocene) overlain by more massive, detritus-rich diatomaceous mudstones of the Capistrano Formation, the Malaga Mudstone Member of the Monterey Formation, the Sisquoc Formation, or the Purisima Formation (uppermost Miocene to lower Pliocene) (Ingle 1981; Barron 1986).

Studies by Barron (1975a, 1975b, 1976a, 1976b, 1976c, 1981), Rowell (1981), Baldauf and Barron (1982), and Barron and Keller (1983) have established a workable diatom biostratigraphy for the Monterey Formation. In contrast, few detailed biostratigraphic studies exist for the overlying diatomaceous units, especially the Sisquoc Formation.

Classical exposures of the Monterey and Sisquoc Formations are located in the Johns-Manville Quarry south of Lompoc, California (text-fig. 1). Although Barron (1975a, 1975b), following Dibblee (1950), assigned the majority of the quarry section to the Sisquoc Formation, this sequence properly belongs to the Monterey Formation (Woodring and Bramlette 1950; Wornardt 1967; Barron 1976c; Isaacs 1981). Only the three uppermost samples (ARL-2, -4, and -8) studied by Barron (1975a, 1975b) are actually assignable to the Sisquoc Formation.

In the Santa Maria Basin as much as 1524 m (5000 ft) of Sisquoc Formation are exposed (Woodring and Bramlette 1950). Woodring and Bramlette (1950) recognized both a basinal facies and a marginal facies in the Sisquoc Formation. The fine-grained basinal facies consists mostly of diatomaceous mudstone but includes some porcelaneous mudstone and claystone. This facies is exposed throughout the central Santa Maria Basin and along the Santa Barbara coast (Woodring and Bramlette 1950; Dibblee 1966). The marginal facies is predominantly composed of sandstone, the Tinaquaic Sandstone Member, and it is exposed only in the northeast portion of the Santa Maria Basin (Woodring and Bramlette 1950).

Geologic studies of the Sisquoc Formation in the Santa Maria

Basin have included those of Porter (1932), Woodring et al. (1943), Woodring and Bramlette (1950), Dibblee (1950), and Wornardt (1963). Each of these studies made use of the Harris Grade section which is exposed along former California State Highway 1 as it crosses the Purisima Hills north of Lompoc (text-fig. 1). At this locality, the lower portion of the Sisquoc is truncated by a fault. The section's base, therefore, is taken as the axis of the Purisima Anticline of Woodring and Bramlette (1950). The section extends from this anticlinal axis northward for 3 km across the crest of the Purisima Hills. Woodring and Bramlette (1950) measured 899 m (2950 ft) of Sisquoc Formation overlain by 244 m (800 ft) of the lower Foxen Mudstone in this section. Wornardt (1963) also recorded 244 m (800 ft) of Foxen Mudstone in this section, but he reported the thickness of the Sisquoc Formation as 1067 m (3500 ft) (table 1).

Diatoms from the Harris Grade section are discussed by Woodring et al. (1943), Simonsen and Kanaya (1961), and Wornardt (1963, 1967). Simonsen and Kanaya's (1961) study was restricted to the genus *Denticulopsis*, but Woodring et al. (1943) and Wornardt (1963, 1967) followed the practice of earlier diatom biostratigraphers by concentrating on diatoms visible at $\times 250$, and failing to document the stratigraphically useful smaller forms (5–30 μm), such as *Thalassiosira*, which dominate Sisquoc Formation assemblages (Barron 1975a, 1975b). Recent studies have stressed the importance of smaller forms in late Neogene biostratigraphy of the middle latitude northeastern Pacific (Burckle and Opdyke 1977, 1985; Barron 1981; Dumont 1984; Whiting and Schrader 1985). These studies indicate the need to document such forms in the Harris Grade section and other exposures of the Sisquoc Formation in order to improve the stratigraphic correlation and resolution of onshore sections.

Although the base of the Sisquoc Formation is not exposed in the Harris Grade section, the Sweeney Road section east of Lompoc contains about 700 m (2300 ft) of lower Sisquoc Formation where it unconformably overlies the Monterey Formation (Dibblee 1950; Barron 1974). A reconnaissance study of the diatoms of the Sweeney Road section was completed by Barron (1974), and a more thorough study is presently under way by Dumont (1984) as part of a Master's Thesis at the University of California, Berkeley. Earlier work

TEXT-FIGURE 1

Location of Harris Grade section in Santa Barbara County, California, and location of samples studied along Harris Grade. H-1, lowest sample studied (barren of diatoms) is 7 m (20 ft) stratigraphically above axis of Purisima Anticline.

(John Ruth, oral communication 1973) suggested that the upper part of the Sweeney Road section correlates with the lower part of the Harris Grade section, a conclusion which is supported by our reconnaissance studies. The Harris Grade study when combined with Dumont's (1984) ongoing study of the Sweeney Road section, helps to refine the latest Miocene to early Pliocene diatom biostratigraphy of California.

MATERIALS AND METHODS

A total of 25 samples were collected from the Harris Grade section during the 1983 and 1984 field seasons (text-fig. 1). The stratigraphic intervals of these samples were estimated by their measured bedding attitudes and horizontal distance along the highway, as well as by comparison with the sample intervals of Simonsen and Kanaya (1961) and Woodring and Bramlette (1950).

Because the Sisquoc Formation contains little or no calcareous material, the samples were not processed in acid. Rather, strewn slides were prepared using the following technique. A sample measuring approximately 1 cub cm was placed into a 4-dram vial. The vial was filled with distilled water and the sample was disaggregated mechanically with a stirring rod and by agitation of the vial. Strewn slides were prepared following the techniques of Schrader and Gersonde (1978).

At least two slides (cover glass size 30 × 22 mm) were examined in their entirety under the light microscope at a magnification of × 500. Species identifications were confirmed at × 1250. The relative abundance of each species was estimated in the following manner: abundant, two or more specimens per field of view (× 500); common, one specimen in two fields of view; few, one specimen in each horizontal traverse (length 30 mm); and rare, if a specimen was encountered less frequently.

TABLE 1
Comparison of lithologic units of Woodring and Bramlette (1950) and Wornardt (1963).

	Woodring and Bramlette (1950)	Wornardt (1963)
Lower Foxen Mudstone	244 m (800 ft) mudstone, clayey siltstone and thin beds of silty sandstone.	244 m (800 ft) clayey siltstone, thin beds of silty sandstone, and a few layers of diatomaceous shale.
Upper Sisquoc Formation	236 m (775 ft) light colored diatomaceous mudstone. Forms bare outcrops, between which are stands of brush.	274 m (900 ft) light colored diatomaceous mudstone, shale, and diatomite.
Sisquoc Formation	76 m (250 ft) clayey diatomaceous mudstone containing few diatoms. Supports growth of grass.	152 m (500 ft) clayey diatomite, shale.
Sisquoc Formation	434 m (1425 ft) light colored diatomaceous mudstone. Forms bare outcrops, between which are stands of brush. Diatomite may be laminated.	457 m (1500 ft) light colored diatomaceous mudstone.
Lower Sisquoc Formation	91 m (300 ft) porcelainous shale with thin, cherty layers. Thickness uncertain due to folding and faulting at crest of anticline.	182 m (600 ft) porcelainous shale interbedded with diatomaceous mudstone.

Sample preservation is judged by the abundance of finely silicified forms such as *Actinocyclus ehrenbergii* Ralfs, *Cocconeis* spp., and *Nitzschia* spp. compared with the abundance of more robust forms such as *Coscinodiscus marginatus* Ehrenberg, *C. oculus-iridis* Ehrenberg, *Lithodesmium cornigerum* Brun, *Rhizosolenia barboi* Brun, and *Thalassionema nitzschioides* Grunow.

DIATOM BIOSTRATIGRAPHY

Diatom zonation

Text-figure 2 correlates the diatom zones of Koizumi (1973) and Barron (1980) for the northwest Pacific with the diatom zones of Barron (1981) for the northeast Pacific. The base of the *Denticulopsis kamtschatica* Zone of Koizumi (1973) is defined at the first occurrence of *Denticulopsis kamtschatica* (Zabelina) Simonsen while its top is defined by the first occurrence of *D. seminae* var. *fossilis* (Schrader) Simonsen. Barron (1980) proposed three subzones for the *D. kamtschatica* Zone based on the last occurrences of *Rouxia californica* M. Peragallo and *Coscinodiscus insignis* Jousé.

In the northwest Pacific and Bering Sea, *D. kamtschatica* first occurs in the uppermost Miocene (ca 6.5 Ma); however, its first occurrence in California sections was delayed until the Pliocene (ca 5.2 Ma) (Barron, 1976a; Harper, 1977; Burckle

and Opdyke, 1985). Consequently, it is inappropriate to use the *D. kamtschatica* Zone in California, and Barron (1976a) proposed using refined versions of Schrader's (1973) North Pacific Diatom (NPD) Zones X and IX for this latest Miocene to early Pliocene interval in California. Later, Barron (1981) renamed NPD Zones X and IX the *Nitzschia reinholdii* and *Thalassiosira oestrupii* Zones, respectively.

The *Nitzschia reinholdii* Zone is defined by Barron (1981) as the interval from the first occurrence of *Nitzschia reinholdii* Kanaya ex Barron et Baldauf to the first occurrence of *Thalassiosira oestrupii* (Ostenfeld) Proshkina-Lavrenko. *Nitzschia reinholdii* is sporadic and sparse throughout the *N. reinholdii* Zone, and is a poor marker for the base of the *N. reinholdii* Zone (Barron 1981; Barron and Keller 1983). The last occurrence of *Thalassiosira schraederi* Akiba, on the other hand, is a useful stratigraphic marker throughout the middle-latitude North Pacific (Akiba 1982; Maruyama 1984; Barron 1985). The last occurrence of *Thalassiosira schraederi* correlates with the upper part of polarity Chron 7 (ca 6.7 Ma) according to Barron (1980) and Koizumi (1985), and is slightly below the first occurrence of *N. reinholdii* (ca 6.5 Ma). Consequently, the last occurrence of *T. schraederi* appears to be a better marker for the base of the *Nitzschia reinholdii* Zone than the first occurrence of *N. reinholdii*. The base of the *Nitzschia reinholdii* Zone of Barron (1981), there-

TEXT-FIGURE 2

Comparison of diatom zonation of Koizumi (1973) and Barron (1980) for northwestern Pacific with diatom zonation of Barron (1981) for middle-latitude northeastern Pacific. F = first occurrence datum; L = last occurrence datum.

fore, is herein redefined at the last occurrence of *T. schraderi*. It should be pointed out that *Thalassionema hirosakiensis* (Kanaya) Schrader as identified by Barron (1981) and Barron and Keller (1983) in California sections is assigned to *T. schraderi* by Akiba (1982). The first occurrence of *Thalassiosira oestrupii*, Barron's (1981) marker for the top of the *N. reinholdii* Zone, is retained.

NPD Zone X is divisible into two subzones by the last consistent occurrence of *Rouxia californica* (Barron 1976a), so the *Nitzschia reinholdii* Zone can be similarly subdivided. The last consistent occurrence of *R. californica* is correlated with the uppermost part of polarity Chron 6 (ca 6 Ma), based on the paleomagnetic studies of Madrid et al. (in press) on the Purisima Formation at Santa Cruz in northern California, a result consistent with the extrapolations of Barron (1981) and Barron and Keller (1983). The last occurrence of *R. californica* recorded by Barron (1980) off Japan, however, approximates the Miocene/Pliocene boundary (ca 5.2 Ma), attesting to the diachroneity of this datum level reported by Harper (1977).

The *Thalassiosira oestrupii* Zone is the interval between the first occurrence of *Thalassiosira oestrupii* and the first occurrence of *Denticulopsis seminae* var. *fossilis*, and it is therefore equivalent to Subzones b and c of the *D. kamtschatica* Zone (Barron 1981).

Harris Grade biostratigraphy

The occurrences of diatom taxa encountered in the 23 samples from the Harris Grade section are shown on table 2. Samples H-1 (39 m) and H-2 (58 m) are barren of diatoms, which is to be expected as they are from the lower 100-m-thick porcelaneous shale unit of Woodring and Bramlette (1950). Sample H-15 (905 m) is from the basal Foxen Mudstone, approximately 6 m above the contact with the Sisquoc Formation.

The first occurrence of *Thalassiosira oestrupii* in Sample H-3C (160 m) marks the base of the *T. oestrupii* Zone. Because *Denticulopsis seminae* var. *fossilis* does not occur in the overlying samples, the entire upper portion of the Harris Grade section is assigned to the *T. oestrupii* Zone. The presence of *Nitzschia reinholdii* and the absence of both *Rouxia californica* and *Thalassionema schraderi* in Samples H-2A (100 m) through H-3B (151 m), places the lower diatom-bearing interval of the Harris Grade section in Subzone b of the *Nitzschia reinholdii* Zone.

Further biostratigraphic subdivision of the Harris Grade section is suggested by the range of selected species. At least five subzones can be recognized. Samples H-2A through H-3B lack *Thalassiosira oestrupii* but contain *T. praeoestrupii* Dumont, Baldauf and Barron (1986) and *Lithodesmium cornigerum*, and are assignable to Subzone 1 within the uppermost part of the *Nitzschia reinholdii* Zone. Samples H-3C through H-6 contain the stratigraphic overlap of *T. oestrupii* and *T. nativa* Sheshukova-Poretzkaya and constitute a lower subzone (= Subzone 2) of the *T. oestrupii* Zone. In Samples H-9 through H-8, *T. praeoestrupii* and *T. hyalinopsis* Barron range above the last occurrence of *T. nativa* (= Subzone 3). Samples H-9A through H-11 are tentatively assigned to Sub-

zone 4 wherein *Lithodesmium cornigerum* and *L. minusculum* Grunow range stratigraphically above the last occurrences of *T. praeoestrupii* and *T. hyalinopsis*. Finally, Samples H-11A through H-15 are distinguished by the range of *Denticulopsis kamtschatica* and *T. oestrupii* above the range of *Lithodesmium* species (= Subzone 5).

Further studies are required to determine whether these various subzones are useful throughout the Santa Maria Basin of California. Subzone 1 has been recognized in the lower Capistrano Formation and in the Purisima Formation (Barron and Keller 1983 and Barron unpublished data).

Age of the Harris Grade section

Thalassiosira oestrupii first occurs in Sample H-3C and ranges to the top of the Harris Grade section. The first occurrence of *Thalassiosira oestrupii* falls in the lower reversed event of the Gilbert Reversed Polarity Chron in the Equatorial Pacific, slightly above the Miocene/Pliocene boundary (Burckle 1978; Barron et al. 1985). The isochroneity of this datum level in the middle latitude North Pacific has been demonstrated by Burckle (1978) and Barron (1980, 1981) implying that Sample H-3C lies slightly above the Miocene/Pliocene boundary. Koizumi and Tanimura (1985) reported that the first occurrence of *T. oestrupii* coincides with the top of polarity Chron 5 at northwest Pacific DSDP Site 578; however, these two events fall at the break between Cores 578-12 and 578-13, so the correlation is implied.

Underlying Samples H-2a through H-3B at Harris Grade contain *Thalassiosira praeoestrupii*, a diatom which first occurs at the top of Chron 5 in California according to the paleomagnetic studies of Madrid et al. (in press) and Dumont et al. (1986) at Santa Cruz. Because Berggren et al. (1985) placed the Miocene/Pliocene boundary at the top of polarity Chron 5, Sample H-2A, the lowermost Harris Grade Sample containing diatoms, would be earliest Pliocene in age.

Lithodesmium cornigerum also occurs in Sample H-2A. Early diatom workers (Woodring et al. 1943; Hanna 1930; Wordardt 1963, 1967) considered *L. cornigerum* to be a marker for the Pliocene, but this has been poorly substantiated by correlations with the international geologic time scale. Schrader (1973) reported *L. cornigerum* in his North Pacific Diatom Zone IX, which is equivalent to the *Thalassiosira oestrupii* Zone or early Pliocene. Barron (1976a) noted the first occurrence of *L. cornigerum* in his sample N-14a from the lower Capistrano Formation at Upper Newport Bay in southern California, about 10 m stratigraphically above sample N-14 where *T. oestrupii* sensu Barron (1976a) first occurs. *Thalassiosira oestrupii* sensu Barron (1976a) is actually *T. praeoestrupii* (see Taxonomic Notes and Barron and Keller 1983), so near coincidence of the first occurrences of *T. praeoestrupii* and *L. cornigerum* in the lowermost Capistrano Formation at Upper Newport Bay is suggested. The near coincidence of the first occurrences of these two species has also been observed in the Sweeney Road section of the Sisquoc Formation by M. Dumont (oral communication 1985). Arends (oral communication 1985), on the other hand, has observed *L. cornigerum* ranging into the latest Miocene part of the *N. reinholdii* Zone in southern California.

TABLE 2

Stratigraphic occurrence and abundance of diatom species and varieties observed from Harris Grade samples. Stratigraphic interval in meters above base of section (= axis of the Purisima Anticline). R = rare, F = few, C = common, A = abundant, r = reworked, P = poor, M = moderate, G = good.

TAXON / SAMPLE	H- Stratigraphic Interval (m)	15 905	14 893	13 884	12A 838	12 785	11A 686	11 582	10A 535	10 486	9A 437	8 434	7 411	9 360	6 299	5 250	4B 244	4A 213	4 206	3C 200	3B 191	3A 181	3 165	2A 149
<i>Actinocyclus curvatus</i>							R				R				R					R			R	R
<i>A. divinus</i>									R		R	R	R		R	R		R	R	R			R	R
<i>A. ehrenbergii</i>		R	R				R		R	R	R	R	R		R	R		R	R	R		F	R	R
<i>A. ehrenbergii</i> var. <i>tenellus</i>							R		R		R				R	R				R	R	R	R	R
<i>A. ellipticus</i>			R																					
<i>A. ingens</i>		r	r	r	r			r			r			r			r	r		R	R			r
<i>A. sp.</i>								R		R	R					R			R	R				
<i>Actinopteryx senarius</i>		R	R	R			R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	F	R
<i>Arachnoidiscus</i> sp.									R	R						R		R	R				R	R
<i>Bacteriastrium varians</i>		R		R							R					R		R	R				R	R
<i>Chaetoceros cinctus</i>							R				R					R		R	R				R	R
<i>Cocconeis costata</i>																R								
<i>C. scutellum</i>				R																				
<i>C. vitrea</i>							R																	
<i>C. sp.</i>			R					R			R									R			R	
<i>Coscinodiscus asteromphalus</i>										R	R						R		R			R	R	
<i>C. marginatus</i>		R	F	F		R	R	F	R	F	F	F	F	R	F	R		R	F	F	R	R	R	R
<i>C. nodulifer</i>							R					R	R	R		R			R				R	R
<i>C. oculus-iridis</i>		R	R					R			R				F			R	F	R				
<i>C. radiatus</i>								R			R													
<i>C. subtilis</i>		R					R				R													
<i>C. sp. cf. C. vetustissimus</i>		R						R				R	R		R									
<i>Cymbella</i> sp. cf. <i>C. prostrata</i>				R																				
<i>Delphineis sachalinensis</i>		R			R			R	F		R	R	R	R	F	R	R	R	R	R	R	R	F	R
<i>D. simbirskiana</i>							R			R	R	R	R		R		R						R	R
<i>Denticulopsis hustedii</i>		R	R	R		R		R							R				R				R	R
<i>D. kamtschatica</i>		R	R	R			F			R					R									
<i>D. lauta</i>				R																				
<i>Diploneis</i> sp.			R				R				R					R			R	R			R	
<i>Grammatophora angulosa</i>					R					R	R									R	R			
<i>Hemidiscus cuneiformis</i>		R					R																	
<i>H. ovalis</i>												R				R								
<i>Hyalodiscus dentatus</i>				R								R	R	R	R	R		R	R	F		R	R	R
<i>Lithodesmium cornigerum</i>								R	R	R	R	R	R		R	R	R		R			R	R	R
<i>L. minusculum</i>																								
<i>Navicula hennedyi</i>							R																R	R
<i>N. lyra</i>							R																R	R
<i>N. optima</i>													R	R	R	R	R	R					R	R
<i>N. sp.</i>		R																						
<i>Nitzschia fossilis</i>																								
<i>N. granulata</i>																								
<i>N. reinholdii</i>				R		R	R				R	R	R	R	R	R	R	R	R	R	R	R	R	R
<i>N. rolandii</i>						R																		
<i>N. sp.</i>		R	R								R				R	R	R	R	R	R			R	R
<i>Odontella aurita</i>				R						R														
<i>Paralia sulcata</i>		R	R			R		R	F			F	F	R					R	R			R	R
<i>P. sulcata</i> var. <i>biseriata</i>																								
<i>P. sulcata</i> var. <i>coronata</i>							R								R			R	R	R				
<i>Pleurosigma</i> sp.		R																						
<i>Rhaphoneis ampiceros</i>		R						R				R			R					R	R		R	
<i>R. ampiceros</i> var. <i>elongata</i>																						R	R	
<i>R. angularis</i>																								
<i>R. fatula</i>												R	R	R										
<i>R. gemmifera</i>																								
<i>Rhizosolenia barboi</i>		R	R				R																R	R
<i>R. hebetata</i> f. <i>hiemalis</i>							R					R	R	R	R	R	R	R	R			R	R	R
<i>R. styliformis</i>		R	R					R			R				R	R			R			R	R	R
<i>R. sp.</i>		R																		R	R		R	R
<i>Rossiella</i> sp. cf. <i>R. tatsunokuchiensis</i>										R														
<i>Rouxia</i> sp.																								
<i>Stephanogonia polyacantha</i>		R	R					R																
<i>Stephanopyxis turris</i>			R				R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
<i>Thalassionema nitzschioides</i>		F	F	F	R		F	F	F	R	F	F	R	F	C	C	F	F	F	F	F	F	F	F
<i>T. nitzschioides</i> var. <i>parva</i>			R		R		R	F	F	F	F	F	R	F	F	F	F	F	F	F	F	F	F	F
<i>Thalassiosira antiqua</i>		C	R	R		R	F	C	F	F	F	F	F	F	C	F	F	F	C	F	R	C	F	F
<i>T. eccentrica</i>		R	R	R			R																	
<i>T. eccentrica</i> (fine)												R	R	R										
<i>T. hyalinopsis</i>								R							R				R					
<i>T. jacksonii</i>																								
<i>T. sp. aff. T. kryophila</i>																								
<i>T. leptopus</i>				R			R				R	R	R		R	R			R	R			R	R
<i>T. multipora</i>				R			R																	
<i>T. nativa</i>															F	F		F				R	R	R
<i>T. oestrupii</i>			R	R			R	R	R	R	R				R	R	R	R	R	R				
<i>T. sp. aff. T. plicata</i>																								
<i>T. praeoestrupii</i>																								
<i>T. symbolophora</i>																								
<i>T. sp. cf. T. zabelinae</i>																								
<i>Thalassiothrix longissima</i>		R	R	R			R	R	R	F	R				F	R		R	R	R	R	R	R	F
ABUNDANCE		C	A	F	F	R	F	C	C	C	F	F	F	F	A	C	F	F	C	C	F	F	A	F
PRESERVATION		G	G	P	M	P	M	G	M	M	M	M	M	M	M	G	P	M	M	M	M	M	M	M
BIOSTRATIGRAPHIC UNIT		Subzone 5						Subzone 4				Subzone 3				Subzone 2					Subzone 1			

The upper age constraint on the Harris Grade section samples is provided by the absence of *Denticulopsis seminae* var. *fossilis*, a diatom which first occurs in the uppermost part of the Gilbert Reversed Polarity Chron (ca 3.7 Ma) in the middle-latitude North Pacific (Koizumi and Tanimura, 1985). Because *D. seminae* var. *fossilis* is recorded in DSDP Sites 467 and 469 off southern California by Barron (1981), it seems unlikely that it was ecologically excluded from the Santa Maria Basin area. Accordingly, the entire Harris Grade section appears to be early Pliocene in age.

The early Pliocene age assignment of the Harris Grade section is supported by the occurrence of Delmontian Stage foraminifers in the upper part of the Siquoc exposed in the section (Woodring and Bramlette 1950). According to Warren (in Kleinpell 1980), the Delmontian Benthonic Foraminiferal Stage does not range younger than about 4.0 Ma or early Pliocene.

Stanley and Surdham (1984) equate an unconformity separating the Siquoc Formation with the overlying Foxen Mudstone to a 4.2 Ma drop in global sea-level shown by Vail and Hardenbol (1979), based on correlations of mollusks, benthic foraminifers and gross lithology. Similarly, Barron (1981, 1986) observed that diatom-rich sediments, which are prevalent in the middle Miocene through earliest Pliocene of California, do not range above 4.0 to 4.5 Ma. The absence of diatoms described from both the equatorial Pacific (*Nitzschia jouseae* Burckle and *N. cylindrica* Burckle) and the northwest Pacific (*Coscinodiscus insignis* and *Coscinodiscus temperei* Brun) with datum levels between 4.5 and 4.0 Ma in the Harris Grade section prevents confirmation of the suggestions by Stanley and Surdham (1984) and Barron (1986) that the top of the Siquoc Formation is older than 4.0 Ma. Although it is possible that the entire Harris Grade section predates the first occurrence of *N. jouseae* (4.5 Ma), it is more likely that transitional paleotemperatures and the inshore site of deposition of the Harris Grade section combined to actively exclude *N. jouseae* from the area. This conclusion is supported by the absence of *N. jouseae* in the lower Pliocene parts of DSDP Sites 467 and 469 off southern California.

Most of the lower Pliocene at DSDP Site 173 is absent due to a hiatus (Keller 1979; Barron and Keller 1983), so that Site 173 cannot be used as a lower Pliocene reference section for comparison with the Harris Grade section. It is hoped that study of the lower Pliocene diatomaceous sections of DSDP Sites 32 and 34 now under way by Baldauf and Dumont (in prep.) will allow refined age resolution of the lower Pliocene of California.

Comparison with earlier studies

Earlier studies by Woodring et al. (1943) and Wornardt (1963, 1967) emphasized larger diatom taxa visible at lower power (about $\times 250$) which were concentrated in part by sieving. The different techniques employed by us and our emphasis on planktonic species of *Thalassiosira*, *Nitzschia*, and *Denticulopsis* make direct comparison of our results with those of Woodring et al. (1943) and Wornardt (1963, 1967) difficult. Modern diatom biostratigraphic studies emphasize smaller taxa and are completed at $\times 500$ or greater. Generally, at least one unsieved slide containing 500 or more spec-

imens is examined in its entirety before a sieved slide is examined.

Woodring et al. (1943) identified 220 species and varieties of diatoms in samples collected from the lower portion of the Harris Grade section. Their samples were not arranged stratigraphically. They characterized the basinal facies of the Siquoc Formation by the following diatom species: *Melosira clavigera* Grunow, *M. recedens* Schmidt, *Stephanopyxis turris* var. *cylindrus* Grunow, *Endictya robusta* (Greville) Hanna & Grant, *Coscinodiscus aeginensis* Schmidt, *C. intersectus* Brun, *C. obscurus* Schmidt, *C. stellaris* Roper, *C. vetustissimus* Pantocsek, *Actinocyclus ehrenbergii*, *Actinocyclus marmoreus* Brun, *A. perisetosus* Brun, *Lithodesmium cornigerum*, *Xanthiopyxis ovalis* Lohman, and *Thalassionema nitzschioides*. They also noted that pelagic species compose about two-fifths of the observed taxa.

Wornardt (1963) tabulated 120 diatom species and varieties from 17 samples collected from Harris Grade and illustrated them in a later paper (Wornardt 1967). He distinguished a lower flora characterized by *Actinocyclus ehrenbergii*, *Bacteriastrum varians* Lauder, *Coscinodiscus eccentricus* [= *Thalassiosira antique* (Grunow) Cleve Euler], *C. marginatus*, *C. lineatus* [= *T. leptopus* (Grunow) Hasle et Fryxell], *C. radiatus* Ehrenberg, *Lithodesmium cornigerum*, *Nitzschia pliocena* [= *N. reinholdii*], and *Rhaphoneis ischaboensis* [= *Delphineis sachalinensis* (Sheshukova-Poretzkaya) Barron et Baldauf]. This was followed by a middle flora wherein *Coscinodiscus asteromphalus* Ehrenberg, *C. obscurus*, *Biddulphia aurita* (Lyngbye) Brébisson [= *Odontella aurita* (Lyngbye) Agardh], and *Hemidiscus simplicissimus* Hanna et Grant make their first appearance. *Lithodesmium cornigerum* and *R. ischaboensis* become rare near the upper limit of the middle flora. Wornardt's (1967) upper flora contains the first occurrences of *Arachnoidiscus ehrenbergii*, *Asteromphalus arachne* (Brébisson) Ralfs, *Coscinodiscus lineatus* var. *convexus* (Ehrenberg) Wornardt (= *Thalassiosira leptopus*) and *Coscinodiscus robustus* var. *herculus* J. Brun, while including the last appearances of *L. cornigerum* and *R. ischaboensis*.

The diatom occurrences in table 2 do not reveal Wornardt's (1967) three Harris Grade floras. Although some of Wornardt's (1967) taxa were not recognized in our study (note that *Hemidiscus simplicissimus* was not separated from *H. cuneiformis* Wallich), those that can be compared do not show the restriction in the Harris Grade section that Wornardt (1967) claimed. An exception is *Lithodesmium cornigerum*, which is also absent from the upper part of the section in our study.

Wornardt (1967) compared the Harris Grade diatom assemblage to the type Delmontian diatom assemblage, which he considered to be latest Miocene in age. It is now known that the type Delmontian section near Monterey is latest middle Miocene to earliest late Miocene in age (Barron 1976b). Based on this comparison with the type Delmontian section, as well as molluscan correlations and superpositional relationships, Wornardt (1967) assigned the Harris Grade section to the lower Pliocene. This age assignment is supported by our refined diatom correlations.

Simonsen and Kanaya (1961) studied the *Denticulopsis* species in 10 samples from the Harris Grade section; seven from the Siquoc Formation and three from the overlying Foxen Mudstone. They noted the first occurrence of *Denticulopsis kamtschatica* in their sample 17, approximately 686 m (2250 ft) above the section base. Simonsen and Kanaya (1961) placed the Miocene/Pliocene boundary immediately below their sample 17 based on provincial benthonic foraminiferal stratigraphy. That sample approximates our Sample H-11A, where *D. kamtschatica* is relatively common, but we record *D. kamtschatica* down to our Sample H-5, over 450 m (1476 ft) lower in the section.

SISQUOC FORMATION FLORA

Barron (1975b) defined a *Thalassiosira hyalinopsis* Assemblage Zone in samples from the basal Siquoc Formation (see Barron 1976b) in the Johns-Manville Quarry, and he noted its presence (Barron 1975b) in the Siquoc Formation along Sweeney Road east of Lompoc. Barron (1975b) characterized the assemblage as containing greater than 5% *Thalassionema nitzschoides*, *Thalassiosira antiqua*, *T. lineata* Jousé (= *T. leptopus*), and *T. hyalinopsis*, but he also noted the presence of *Bacteriastrum delicatulum* Cleve, *B. varians*, *Thalassiosira kryophila* (Grunow) Jorgensen, *T. oestrupii*, and *Coscinodiscus subtilis* Ehrenberg, taxa which are not found in the Monterey Formation. This assemblage was not observed in the Harris Grade section, because the basal portion of the Siquoc Formation is missing.

Additional taxa that are absent from the Monterey Formation but present in the Siquoc Formation and other post-Monterey rocks in California include: *Denticulopsis kamtschatica*, *Hemidiscus ovalis* Lohman, *Nitzschia granulata* Grunow, *Rhaphoneis fatula* Lohman, *Rossiella* sp. cf. *R. tatsunokuchiensis* (Koizumi) Gersonde, *Thalassiosira jacksonii* Koizumi et Barron, *T. multipora* Whiting et Schrader, *T. praeoestrupii*, *T. symbolophora* Schrader, and *T. sp.* cf. *T. zabelinae* Jousé.

CONCLUSION

The diatoms from 23 samples of the Siquoc Formation and the basal Foxen Mudstone along Harris Grade north of Lompoc, California, are assignable to the uppermost *Nitzschia reinholdii* Zone and *Thalassiosira oestrupii* Zones of Barron (1981) and are early Pliocene in age. The Harris Grade diatom assemblage can also be locally subdivided into five subzones: Subzone 1 = the occurrence of *T. praeoestrupii* and *Lithodesmium cornigerum* prior to the first occurrence of *T. oestrupii*; Subzone 2 = the stratigraphic overlap of *T. oestrupii* and *T. nativa*; Subzone 3 = the range of *T. praeoestrupii* and *T. hyalinopsis* above the last occurrence of *T. nativa*; Subzone 4 = the range of *Lithodesmium minusculum* Grunow and *L. cornigerum* above the last occurrences of *T. praeoestrupii* and *T. hyalinopsis*; and Subzone 5 = the range of *T. oestrupii* and *Denticulopsis kamtschatica* above the last occurrence of *Lithodesmium* species.

FLORA LIST

Listed are citations for the diatom taxa shown on table 2. These taxa are illustrated and discussed in Lohman (1938),

Wornardt (1967), Barron (1975a, 1976a, 1981), and Whiting and Schrader (1985). Citation to figures in this paper appear in parenthesis. A formal taxonomic section does not appear here. Comments are added for taxa that occur in the Siquoc Formation but are absent from the Monterey Formation.

Actinocyclus curvatus Janisch in Schmidt et al.
Actinocyclus divisus (Grunow) Hustedt
Actinocyclus ehrenbergii Ralfs in Pritchard
Actinocyclus ehrenbergii var. *tenellus* (Brébisson) Hustedt
Actinocyclus ellipticus Grunow
Actinocyclus ingens Rattray

Actinopteryx senarius (Ehrenberg) Ehrenberg. *Synonym: A. undulatus* (Bailey) Ralfs.

Bacteriastrum varians Lauder, in Schmidt et al. 1874–1959, pl. 328, figs. 1–5; Barron 1975a, pl. 4, fig. 8. *Remarks:* Although specimens of *Bacteriastrum* are present in the uppermost Monterey Formation at Upper Newport Bay (Barron unpublished data), they are usually restricted to post-Monterey rocks in California.

Chaetoceros cinctus Gran
Coconeis costata Gregory
Cocconeis scutellum Ehrenberg
Cocconeis vitrea Brun
Coscinodiscus asteromphalus Ehrenberg
Coscinodiscus marginatus Ehrenberg
Coscinodiscus nodulifer Schmidt
Coscinodiscus oculus-iridis Ehrenberg
Coscinodiscus radiatus Ehrenberg

Coscinodiscus subtilis Ehrenberg; Lohman 1938, pl. 21, fig. 6; Barron 1975a, pl. 7, figs. 17, 18 (pl. 2, fig. 8). *Remarks:* This species occurs in post-Monterey rocks in California, including the Siquoc Formation (Barron 1975a; this paper), the Etchegoin and San Joaquin Formations (Lohman 1938), and the Purisima Formation (Barron unpublished data).

Coscinodiscus sp. cf. *C. vetustissimus* Pantocsek. *Remarks:* Specimens observed are similar to *C. vetustissimus* Pantocsek of Lohman 1938, pl. 20, fig. 7 (pl. 2, fig. 6).

Cymbella sp. cf. *C. prostrata* (Berkeley) Grun

Delphineis sachalinensis (Sheshukova-Poretzkaya) Barron et Baldauf, n. comb. *Basionym:* *Rhaphoneis sachalinensis* Sheshukova-Poretzkaya, 1967, pl. 42, fig. 2. *Illustrations:* Schrader, 1973, pl. 23, fig. 20, pl. 25, figs. 5, 7, 8, 14–16; Barron 1975a, pl. 12, fig. 3. *Remarks:* Specimens possess typical *Delphineis* apices, which are penetrated by two fine pores.

Delphineis simbirskiana (Grunow) Barron et Baldauf, n. comb. *Basionym:* *Rhaphoneis simbirskiana* Grunow in Pantocsek 1886, p. 36, pl. 18, fig. 162. *Illustrations:* Barron 1975a, pl. 12, fig. 4 (pl. 3, fig. 6). *Remarks:* Specimens possess the typical *Delphineis* apices, which are penetrated by two fine pores.

Denticulopsis hustedtii (Simonsen et Kanaya) Simonsen

Denticulopsis kamtschatica (Zabelina) Simonsen (pl. 2, fig. 4). *Remarks:* The true forms with no more than six pseudoseptae in 10 μ m do not range below the Pliocene in California (Harper 1977; Barron 1976a). This species is observed in the Siquoc Formation (Simonsen and Kanaya 1961; this paper), the Capistrano Formation (Barron 1976a), and the Purisima Formation (Addicott et al. 1978).

Denticulopsis lauta (Bailey) Simonsen
Grammatophora angulosa Ehrenberg

Hemidiscus cuneiformis Wallich. *Remarks:* *H. simplicissimus* Hanna et Grant is tabulated in this manuscript with *H. cuneiformis*.

Hemidiscus ovalis Lohman 1938, pl. 22, fig. 9; Andrews 1980, pl. 2, fig. 10; pl. 5, fig. 9 (pl. 2, fig. 3). *Synonym*: *Hemidiscus weissflogi* sensu Koizumi 1972, pl. 43, fig. 14. *Remarks*: *H. ovalis* was described from the San Joaquin Formation and has not been observed in the Monterey Formation. Andrews (1980) figured it from lower Pliocene strata exposed in Petersburg, Virginia, and suggests that it is a brackish water form.

Hyalodiscus dentatus Korotkevich

Lithodesmium cornigerum Brun (pl. 3, figs. 1, 3, 5). *Remarks*: Two forms are observed in the Harris Grade flora, a form with long extended apices as recorded by Hanna 1930, pl. 14, figs. 9, 10 and Wornardt 1967, fig. 131 (pl. 3, figs. 3, 5) and a form with shorter apices, which is equivalent to *L. cornigerum* of Barron 1976a, pl. 1, fig. 14 (pl. 3, fig. 1). Both forms are included together in this manuscript, because they are found together in the same populations and appear to have the same stratigraphic range. *Lithodesmium cornigerum* is not present in the Monterey Formation; however, it occurs in the Siquoc Formation, the lower Capistrano Formation (Barron 1976a), the Etchegoin Formation (Lohman 1938), and the Purisima Formation (Barron unpublished data).

Lithodesmium minusculum Grunow in Van Heurck

Navicula hennedyi Wm. Smith

Navicula lyra Ehrenberg

Navicula optima Hanna

Nitzschia fossilis (Frenguelli) Kanaya et Koizumi

Nitzschia granulata Grunow; Lohman 1938, pl. 22, fig. 10; Barron 1976a, pl. 3, fig. 2. *Remarks*: This post-Monterey diatom has been observed in the Capistrano Formation (Barron 1976a), the Etchegoin, San Joaquin, and Tulare Formations (Lohman 1938), and the Capistrano Formation (Barron unpublished data).

Nitzschia reinholdii Kanaya ex Barron et Baldauf (pl. 2, fig. 7)

Validation: Kanaya first proposed *Nitzschia reinholdii* in Kanaya and Koizumi (1970), but he failed to designate a type specimen and gave a very brief description in Japanese. More complete descriptions were given by Koizumi (1972, p. 351) and Schrader (1973, p. 708), but both these workers continued to refer the species to Kanaya and failed to designate a type. Simonsen (1974, p. 54) recognized that Kanaya could not be considered the author, and he considered Schrader (1973) as the author of the species. Unfortunately, neither Schrader (1973) nor other workers discussing *N. reinholdii* (e.g. Ko-

izumi 1972; Simonsen 1974; Akiba and Yanagasawa 1986) have designated a type specimen, and *N. reinholdii* remains invalid according to Article 37 of the International Code of Botanical Nomenclature (Sancetta et al. 1985).

Wornardt (1967) provided some of the earliest good illustrations of *N. reinholdii*, but he referred to the specimens as *N. pliocena* (Brun) Wornardt. Nevertheless, Wornardt's (1967) illustrations have been referred to *N. reinholdii* Kanaya by Koizumi (1972), Schrader (1973), and most other modern workers. Both of Wornardt's (1967) illustrated specimens are labeled with hypotype numbers and are stored at the California Academy of Sciences, San Francisco. Therefore, it is proposed that figure 212 of Wornardt (1967) (CAS no. 3858) from locality 27295-29 (CAS), Harris Grade, Santa Barbara County, California, be the holotype for *N. reinholdii* Kanaya, emend. Koizumi (1972), Schrader (1973), ex Barron et Baldauf. Figure 213 of Wornardt (1967) (CAS no. 3859) from the same locality as the holotype is proposed as an isotype.

Description: From Schrader (1973, p. 708)—“Valves elliptical with slightly convex margins, 42–65 μm long, 9–12 μm wide. Apices slightly acute, broadly rounded. Transapical costae 10–12 in 10 μm , between the costae (intercostal membranes) two transapical rows, near the costae, about 20 in 10 μm . Rows punctate, about 22 in 10 μm . Punctae in decussate arrangement forming oblique rows. Transapical costae and rows slightly rounded near the apices. Two apical lines near the raphe-lacking margin at the interior side of the valves forming the inner openings of the inner pores. Inner pores small elliptical. Raphe marginal, keel strong. About 13 keel punctae in 10 μm .”

Remarks: The similarity of *N. reinholdii* to *N. marina* Grunow is discussed by Kanaya and Koizumi (1970), Koizumi (1972), Schrader (1973), Baldauf (1984), and Akiba and Yanagasawa (1986). Basically, *N. reinholdii* has margins that are somewhat more convex than those of *N. marina*, and the raphe of *N. reinholdii* is not inturned at the apices as it is in *N. marina*. Baldauf (1984) illustrated forms that are intermediate between the two species.

Nitzschia rolandii Schrader

Odontella aurita (Lyngbye) Agardh. *Synonym*: *Biddulphia aurita* (Lyngbye) Brébisson.

Paralia sulcata (Ehrenberg) Cleve. *Synonym*: *Melosira sulcata* (Ehrenberg) Kützing.

PLATE 1

- 1 *Thalassiosira praeoestrupii* Dumont, Baldauf and Barron
Sample H-7, diameter 33 μm .
- 2 *Thalassiosira* sp. aff. *T. plicata* Schrader
Sample H-1, diameter 48 μm .
- 3 *Thalassiosira oestrupii* (Ostenfeld) Proshkina-Lavrenko
Sample H-11, diameter 19 μm .
- 4 *Thalassiosira hyalinopsis* Barron
Approaching *T. nativa* sensu Schrader (1973) in morphology. Sample H-2A, diameter 23 μm .
- 5 *Thalassiosira hyalinopsis* Barron
Sample H-2A, diameter 25 μm .
- 6 *Thalassiosira nativa* Sheshukova-Poretzkaya sensu Schrader
Sample H-4A, diameter 19 μm .
- 7 *Thalassiosira antiqua* (Grunow) Cleve-Euler
Scanning electron microscope photograph. Sample H-3C.
Scale bar = 10 μm .
- 8 *Thalassiosira* sp. aff. *T. kryophila* (Grunow) Jørgensen
Sample H-11, diameter 48 μm .
- 9 *Thalassiosira hyalinopsis* Barron
Scanning electron microscope photograph. Sample H-3C.
Scale bar = 10 μm .

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Paralia sulcata var. *biseriata* (Grunow) Cleve

Paralia sulcata var. *coronata* (Ehrenberg) Cleve

Rhaphoneis amphiceros Ehrenberg

Rhaphoneis amphiceros var. *elongata* Peragallo

Rhaphoneis angularis Lohman 1938, pl. 22, figs. 6–8.

Rhaphoneis fatula Lohman 1938, pl. 22, fig. 5 (pl. 3, fig. 8). *Remarks:* This post-Monterey diatom is present in the Siquoc Formation (this paper), the San Joaquin Formation (Lohman 1938), and the Purisima Formation (Barron unpublished data).

Rhaphoneis gemmifera Ehrenberg; Andrews 1975, pl. 2, figs. 28, 29; pl. 4, figs. 56–60; pl. 5, figs. 69, 70.

Rhizosolenia barboi Brun

Rhizosolenia hebetata f. *hiemalis* Gran

Rhizosolenia styliformis Brightwell

Rossiella sp. cf. *R. tatsunokuchiensis* (Koizumi) Gersonde. *Synonym:* *Rhaphoneis tatsunokuchiensis* Koizumi 1972, pl. 42, figs. 3, 4; *Cuscia tatsunokuchiensis* (Koizumi) Schrader; Koizumi, 1975, pl. 4, figs. 33–35. *Remarks:* *R. tatsunokuchiensis* is not present in the Monterey Formation, but it has been observed in the Siquoc Formation (this paper) and the Etchegoin Formation (Barron unpublished data).

Stephanogonia polyacantha Forti

Stephanopyxis turris (Greville et Arnott) Ralfs

Thalassionema nitzschioides Grunow in Van Heurck

Thalassionema nitzschioides var. *parva* Heiden et Kolbe

Thalassiosira antiqua (Grunow) Cleve-Euler (pl. 1, fig. 7)

Thalassiosira eccentrica (Ehrenberg) Cleve

Thalassiosira eccentrica (Ehrenberg) Cleve, fine form (pl. 3, fig. 7). *Remarks:* Tabulated here are forms with small areolae (9–10 in 10 μ m) and a center which is slightly indented.

Thalassiosira hyalinopsis Barron 1975a, pl. 13, figs. 12, 15 (pl. 1, figs. 4, 5, 9). *Remarks:* This species intergrades with *T. nativa* Sheshukova-Poretzkaya sensu Schrader 1973. *Thalassiosira hyalinopsis* occurs in the Siquoc Formation (this paper), and it is sparse and sporadic in the Capistrano Formation (Barron 1976a), the Etchegoin Formation (Barron unpublished data), and the Purisima Formation (Barron unpublished data).

Thalassiosira jacksonii Koizumi et Barron in Koizumi 1980, pl. 1, figs. 11–14 (pl. 2, fig. 5). *Remarks:* This species does not occur in the Monterey Formation.

Thalassiosira sp. aff. *T. kryophila* (Grunow) Jørgensen; Koizumi 1972, pl. 43, fig. 9; Barron 1975a, pl. 14, fig. 1 (pl. 1, fig. 8). *Synonym:*

Thalassiosira plicata sensu Whiting and Schrader 1985, pl. 2, figs. 20, 21. *Remarks:* This species is not present in the Monterey Formation.

Thalassiosira leptopus (Grunow) Hasle et Fryxell (pl. 3, figs. 2, 4). *Synonym:* *Thalassiosira lineata* Jousé sensu Barron 1975a, pl. 14, fig. 2.

Thalassiosira multipora Whiting et Schrader 1985, p. 258, pl. 2, figs. 11, 16, 17 (pl. 2, fig. 1). *Remarks:* This species has also been observed in the Purisima Formation (Barron unpublished data), but it does not occur in the Monterey Formation.

Thalassiosira nativa Sheshukova-Poretzkaya sensu Schrader 1973, pl. 11, figs. 23, 24. Barron 1975a, pl. 14, figs. 4–6 (pl. 1, fig. 6).

Thalassiosira oestrupii (Ostenfeld) Proshkina-Lavrenko; Schrader 1973, pl. 11, figs. 16–22, 26–33, 36, 39–45; not Barron 1976a, pl. 2, fig. 19 (pl. 1, fig. 3). *Remarks:* This Pliocene to Holocene diatom is present in the Siquoc Formation (this paper), the Capistrano Formation (Barron and Keller 1983), the Malaga Mudstone Member (Rowell 1981); and the Purisima Formation (Barron unpublished data).

Thalassiosira sp. aff. *T. plicata* Schrader 1974, pl. 3, figs. 4–6, 7–9 (pl. 1, fig. 2).

Thalassiosira praeoestrupii Dumont, Baldauf and Barron (pl. 1, fig. 1). *Synonym:* *Thalassiosira oestrupii* sensu Barron 1976a, pl. 2, fig. 19. *Remarks:* In this species, the central accessory pore (strutted process) is separated from the submarginal pore (process) by at least four areolae (Dumont et al. 1986). In *T. oestrupii*, the separation of the two pores is 2–3 areolae.

Thalassiosira symbolophora Schrader 1974, pl. 4, figs. 1–8 (pl. 2, fig. 2). *Remarks:* This diatom has not been observed in the Monterey Formation.

Thalassiosira sp. cf. *T. zabelinae* Jousé; Schrader 1973, pl. 14, figs. 1, 2. *Remarks:* This typically cold-water species has not been observed in the Monterey Formation.

Thalassiothrix longissima Cleve et Grunow; Schrader 1973, pl. 23, figs. 7, 17, 18.

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PLATE 2

- 1 *Thalassiosira multipora* Whiting et Schrader
Sample H-11, diameter 48 μ m.
- 2 *Thalassiosira symbolophora* Schrader
Sample H-11, diameter 32 μ m. Low and high focus.
- 3 *Hemidiscus ovalis* Lohman
Sample H-8, length 22 μ m.
- 4 *Denticulopsis kamtschatica* (Zabelina) Simonsen
Sample H-11, length 13 μ m.
- 5 *Thalassiosira jacksonii* Koizumi et Barron
Sample H-9, diameter 28 μ m.
- 6 *Coscinodiscus* sp. cf. *C. vetustissimus* Pantocsek
Sample H-8, diameter 51 μ m.
- 7 *Nitzschia reinholdii* Kanaya ex Barron et Baldauf
Sample H-3A, length 52 μ m.
- 8 *Coscinodiscus subtilis* Ehrenberg
Sample H-8, diameter 63 μ m.

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PLATE 3

- 1 *Lithodesmium cornigerum* Brun
Form with short apices. Scanning electron microscope photograph. Sample H-3C. Scale bar = 10 μ m.
- 2 *Thalassiosira leptopus* (Grunow) Hasle et Fryxell
Scanning electron microscope photograph. Sample H-3C, scale bar = 10 μ m.
- 3 *Lithodesmium cornigerum* Brun
Form with long apices. Sample H-3A. Base 48 μ m.
- 4 *Thalassiosira* sp. cf. *T. leptopus* (Grunow) Hasle et Fryxell
Sample H-11, diameter 28 μ m.
- 5 *Lithodesmium cornigerum* Brun
Form with long apices. Sample H-8, base 49 μ m.
- 6 *Delphineis simbirskiana* (Grunow) Barron et Baldauf
Sample H-4A, length 25 μ m.
- 7 *Thalassiosira eccentrica* (Ehrenberg) Cleve
Fine form. Sample H-11, diameter 26 μ m.
- 8 *Rhaphoneis fatula* Lohman
Sample H-8, length 42 μ m.

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