U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

DIATOM STRATIGRAPHY OF SELECTED SISQUOC FORMATION SECTIONS, SANTA MARIA BASIN, CALIFORNIA

by

John A. Barron[1] and Pedro C. Ramirez[2]

Open-File Report 92-197

[1]U.S. Geological Survey, Menlo Park, CA 94025
[2]Dept. of Geological Sciences, California State University at Los Angeles, Los Angeles, CA 90032

CONTENTS

FIGURES

TABLES

INTRODUCTION

Throughout much of the Santa Maria and Santa Barbara basins, the Monterey Formation is overlain by diatom-bearing mudstones and sandstones of the Sisquoc Formation. As much as 1524 m (5000 ft) of the Sisquoc Formation are exposed in the Santa Maria Basin alone according to Woodring and Bramlette (1950).

In the Santa Maria Basin 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 also includes some siliceous mudstone, porcellanite, silt- to sand-rich mudstone, and chert. (See Issacs, 1981 or Ramierez, 1990 for definition of these lithologic terms). Outcrops of this facies are found throughout the Santa Maria Basin and along the Santa Barbara coast (Woodring and Bramlette, 1950; Dibblee, 1966). A poorly indurated sandstone, the Tinaquaic sandstone member, dominates the marginal facies and is exposed only in the northeastern portion of the Santa Maria Basin (Woodring and Bramlette, 1950).

Studies of the diatoms of the Sisquoc Formation include those of Woodring et al. (1943), Simonsen and Kanaya (1961), Wornardt (1963, 1967) and Barron and Baldauf (1986) on the Harris Grade section; Barron (1974, 1975 a,b) on the Johns-Manville Quarry section; Barron (1974), Dumont (1986), and Akers et al. (1987) on the Sweeney Road section; Hornafius et al. (1982) and Wornardt (1986) on the Point Pedernales section; and Arends and Blake (1986) on the Naples Beach section)(Fig. 1). The Simonsen and Kanaya (1961) study was restricted to the genus <u>Denticula</u> (now <u>Denticulopsis</u> and <u>Neodenticula</u>), and the studies by Woodring et al. (1943) and Wornardt (1963, 1967) were restricted to diatoms visible at X 250, failing to document diatoms smaller than 30 um.

This paper extends the first author's studies of the diatoms in the Sisquoc Formation to additional sections measured at Point Pedernales, Mussel Rock, Lompoc Hills, and Casmalia (Fig. 1) and places the formation into a biochronologic framework by providing correlation of sections studied by Ramirez (1990) in his synthesis of the Sisquoc Formation lithologic and depositional environments.

METHODS AND MATERIALS

Stratigraphic sections were measured and samples were taken for diatom studies by Ramirez (1990) as part of his Ph.D. dissertation studies at the University of California, Santa Cruz. Strewn slides were prepared for diatoms following the techniques outlined in Barron and Baldauf (1986). Acids were not needed in the preparation of the material, because of the low to absent content of calcium carbonate found in these these rocks and the abundance of diatoms. At least one slide per sample (cover glass size 22 X 30 mm) was examined in its entirety under the light microscope at a magnification of X 500. Identifications were checked at X 1250.

The reader is referred to Barron (1985), Koizumi and Tanimura (1985), Akiba (1986), Fryxell et al. (1986), Barron and Baldauf (1986), and Dumont et al. (1986) for the taxonomy of the diatom taxa appearing in the tables.

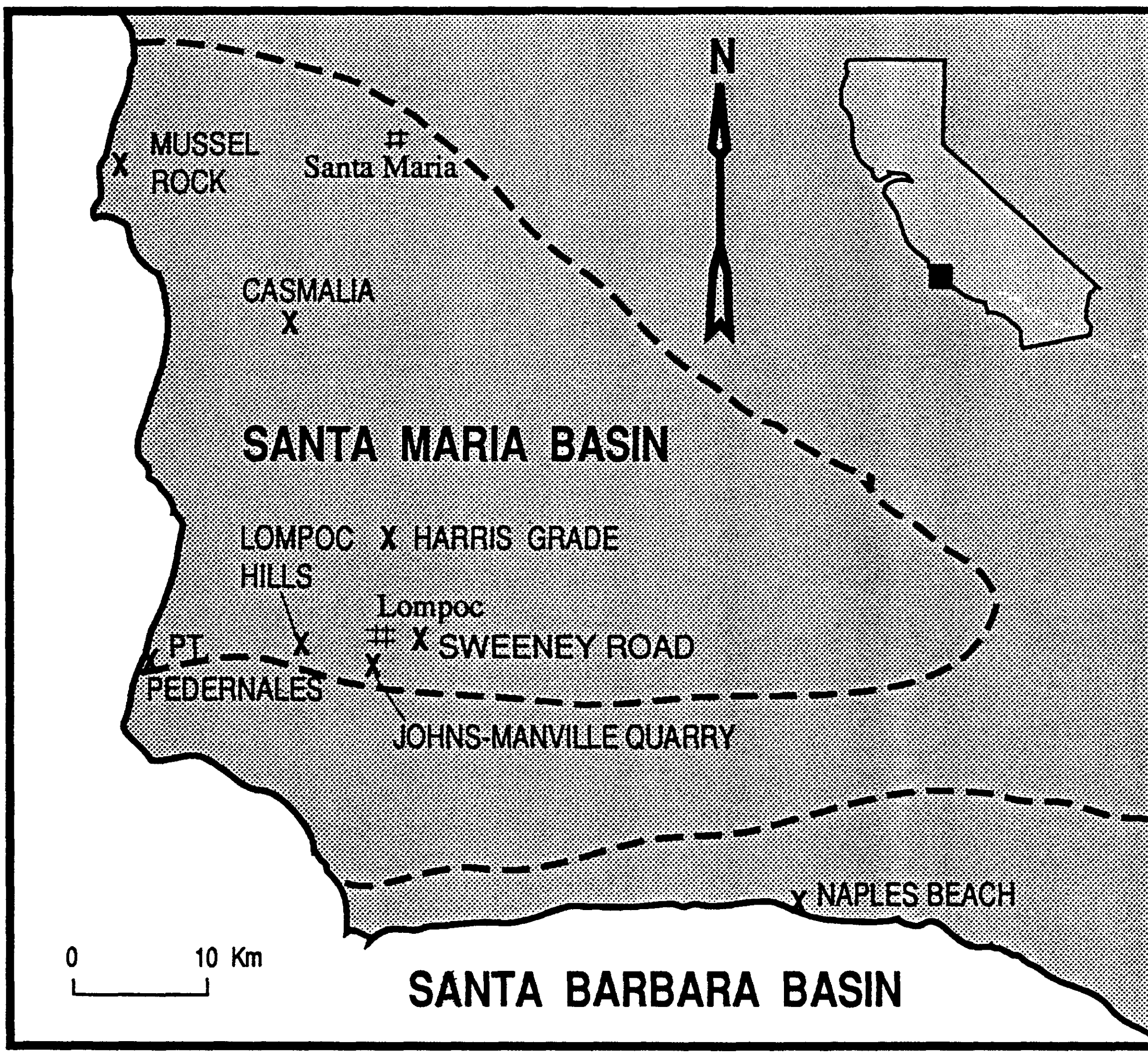

Figure 1. Location of Sisquoc Formation stratigraphic sections discussed within the Santa Maria and Santa Barbara basins of southern California.

DIATOM ZONATION

Study of diatoms from the Sisquoc Formation in the Sweeney Road section by Dumont (1986) and from the Sisquoc Formation in the Harris Grade section by Barron and Baldauf (1986) provides the framework for constructing a diatom biostratigraphy for the Sisquoc Formation (Fig. 2). This zonation merges the California diatom zonation of Barron (1986) with zones proposed by Dumont (1986)(Fig. 2).

Dumont (1986) subdivided Baldauf and Barron's (1986) Subzone b of the Nitzschia reinholdii Zone into three zones. In ascending order these three zones are the Thalassiosira miocenica / Nitzschia miocenica Interval Zone, the Thalassiosira hyalinopsis Partial Range Zone, and the Thalassiosira praeoestrupii Partial Range Zone. The T. miocenica/N. miocenica Interval Zone is defined as the interval above the last common occurrence of Rouxia californica and below the first occurrence of Thalassiosira hyalinopsis which contains the nominative species. The overlying T. hyalinopsis Partial Range Zone is the interval from the first occurrence of T. hyalinopsis to the first occurrence of T. praeoestrupii. The interval between the first T. praeoestrupii and the first T. oestrupii is referred to as the T. praeoestrupii Partial Range Zone.

Barron's (1986) Subzone a of the Nitzschia reinholdii Zone was renamed by Dumont (1986) to be the Rouxia californica Partial Range Zone. This zone encompasses the range of common or consistent Rouxia californica above the last occurrence of Thalassionema schraderi.

Correlation of this zonation to the geologic time scale and the ranges of some key stratigraphic markers are provided on Figure 2. Age estimates for the three zones of Dumont (1986) are derived from paleomagnetic stratigraphy of the Santa Cruz section of the Purisima Formation completed by Madrid et al. (1986)(see Dumont et al., 1986). Age estimates for older diatom zones and taxon ranges are mostly through indirect correlation to paleomagnetic stratigraphy and/or radiometric dates (Barron, 1986), while age estimates for early Pliocene diatom ranges within the T. oestrupii Zone are based on extrapolated sedimentation rates within the Harris Grade section of the Sisquoc Formation (Barron and Baldauf, 1986).

The Harris Grade section, which is located about 10 km north of Lompoc on old California Highway 1, contains a 900 m-thick section of Sisquoc Formation overlying a faulted anticline (Fig. 1). The relatively diatom-poor Foxen Mudstone conformably overlies the Sisquoc Formation in the Harris Grade section, and Barron and Baldauf (1986) demonstrated that the top of the Sisquoc Formation in the Harris Grade section is well above (at least 900 m) the Miocene/Pliocene boundary. Barron and Baldauf (1986) followed Stanley and Surdham (1984) in estimating that the Sisquoc-Foxen contact at the top of the Harris Grade section corresponded with the 4.2 Ma sea level fall identified in the global eustatic curve by Haq et al. (1987).

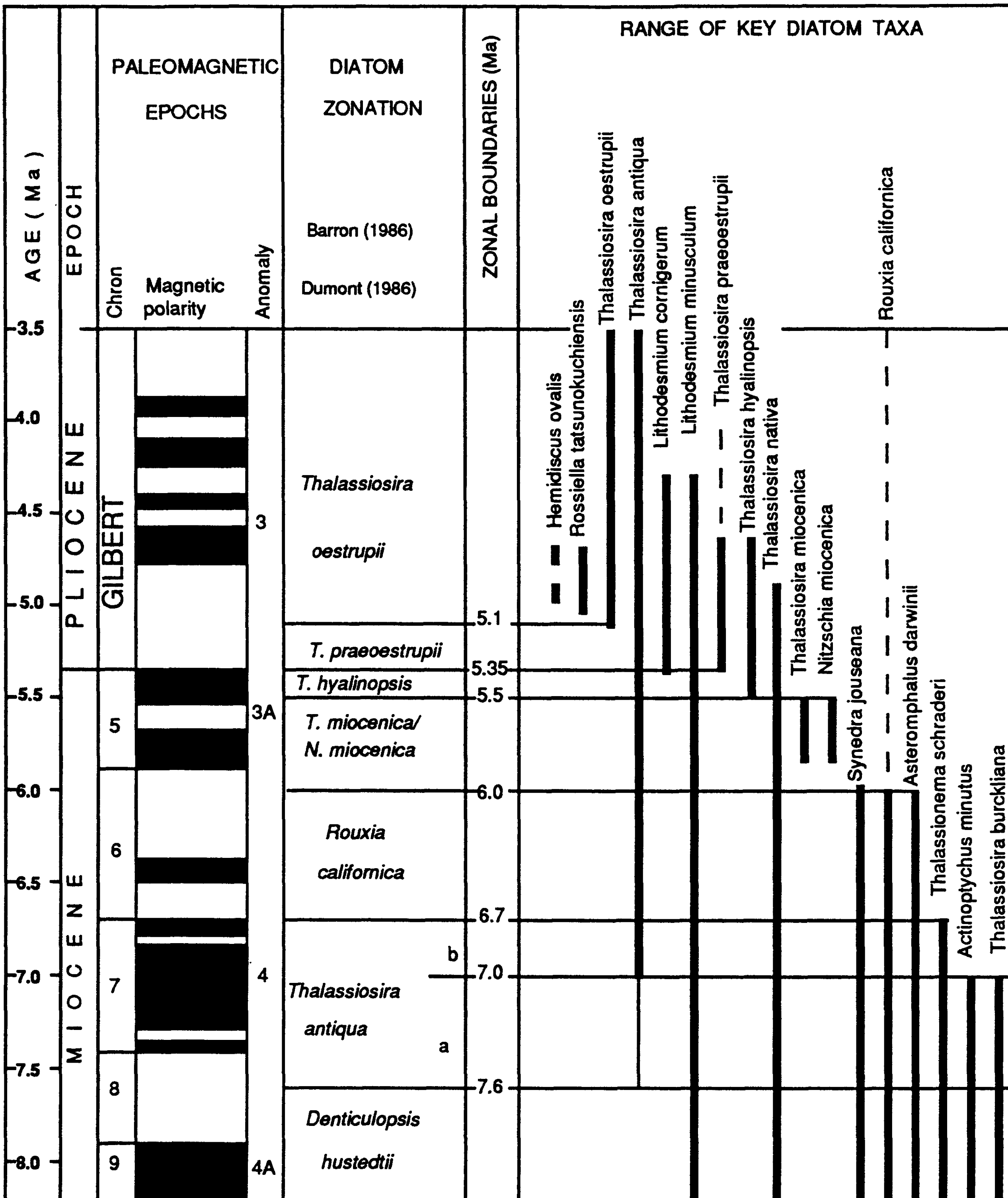

Figure 2. Diatom zonation used (Barron, 1986; Dumont, 1986) and ranges of key diatoms correlated to the magnetic polarity time scale of Berggren et al. (1985). Only the correlation between 6.0 and 5.1 Ma is direct to paleomagnetic stratigraphy.

Figure 3 shows a composite section of the complete Sisquoc Formation in the central Santa Maria Basin formed by overlapping the Sweeney Road section of Dumont (1986) with the Harris Grade section of Barron and Baldauf (1986). Overlap of the upper part of the Sweeney Road section with the lower part of the Harris Grade section and similar accumulation rates for both sections are suggested by the presence of a similar sequence of diatom datum levels in both sections at roughly equal stratigraphic distances (namely, the first occurrence of Thalassiosira oestrupii followed by the first occurrences of Hemidiscus ovalis and Rhaphoneis fatula) (Barron and Baldauf, 1986; Dumont, 1986) (Fig.3).

Diatom datum levels in the Sweeney Road section suggest a post-compaction sediment accumulation rate of 540 m/m.y. (Fig. 3). This rate was determined using Dumont's (1986) estimated thickness of 540 m for the Sisquoc Formation in the Sweeney Road section, Dumont's (1986) diatom biostratigraphy (modified in part based on unpublished notes by the senior author), and absolute age estimated for selected diatom datum levels that have been tied to paleomagnetic stratigraphy at Santa Cruz by Dumont et al. (1986). Dumont's (1986) estimate of 540 m for the thickness of the Sisquoc Formation in the Sweeney Road section was used rather than estimates for this thickness of 700 m by Barron (1974), 484 m by Akers et al. (1987), and 360 m by Ramirez (1990). Dumont (1986) measured the Sweeney Road section with the senior author using Brunton compass and tape. The resulting post-compaction sediment accumulation rate of 540 m/m.y. for the Sisquoc Formation in the Sweeney Road section is in good agreement with estimated rates of 600 m/m.y for the Casmalia section and and 580 m/m.y. for the Point Pedernales sections, which were calculated by Ramirez (1990) using the diatom stratigraphy of this report.

Barron and Baldauf's (1986) stratigraphic placement of diatom events in the Harris Grade section is used in extrapolating the sediment accumulation rate of 540 m/m.y. up through the Sisquoc Formation to the contact with the overlying Foxen Mudstone. The successive first occurrences of Thalassiosira oestrupii, Rhaphoneis fatula, and Hemidiscus ovalis in the top of the Sweeney Road section and the lower part of the Harris Grade section provide a stratigraphic overlap for correlation of the two sections. An extrapolated age of 3.8 Ma age for the Sisquoc Formation-Foxen Mudsone contact (Fig. 3) coincides with the 3.8 Ma sea level fall of the eustatic curve of Haq et al. (1987), rather than the 4.2 Ma sea level fall for this lithologic contact, which was favored by Stanley and Surdham (1984). With this age model for the Harris Grade section the last occurrence of Thalassiosira nativa (sensu Schrader, 1973) is approximated at 4.9-4.8 Ma, the last occurrence of T. hyalinopsis falls at 4.65 Ma, and the last occurrences of Lithodesmium cornigerum and L. minusculum are between 4.4 and 4.2 Ma (Fig. 3). These three age estimates agree very well with age estimates for these diatom datum levels at DSDP Site 32 off central California (Barron, in press, a), lending further support to the age model of Figure 3.

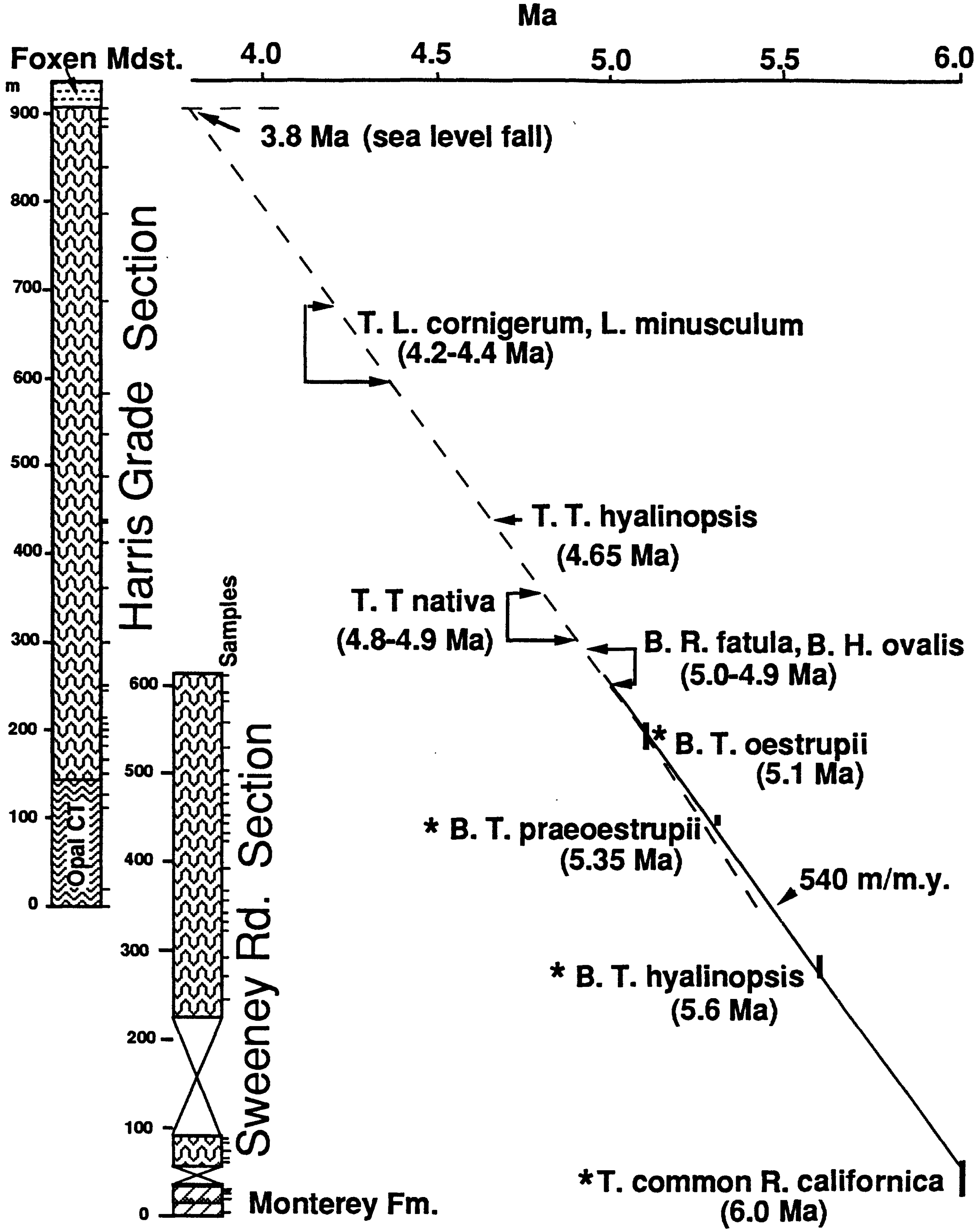

Figure 3. Age vs. stratigraphic height plot of a composite section of the Sisquoc Formation from the Sweeney Road and Harris Grade sections. Diatom biostratigraphy after Dumont (1986) with slight modification for the Sweeney Road section and after Barron and Baldauf (1986) for the Harris Grade section. * = Diatom datum levels tied directly to paleomagnetic stratigraphy by Dumont et al. (1986).

STRATIGRAPHIC SECTIONS

The stratigraphic sections at Lompoc Hills, Point Pedernales, Mussel Rock, and Casmalia (Fig. 1) are presented in the following section utilizing the lithologic symbols shown in Figure 4.

Lompoc Hills Section

The Lompoc Hills section lies in the hills approximately 2 1/2 kilometers west of Lompoc. A dirt road opposite Floradale Avenue where it meets Highway 246 provides access to the top of the section. The top of the section is located in the southwest quarter of Section 33, T.7N, R.34W. A 200 m section of interbedded massive and laminated beds of the Sisquoc Formation overlying porcellaneous beds of the Monterey Formation was measured at this locality (Fig. 5). The lower 20 m of the measured Monterey section consists of finely laminated, lenticular to continuous porcellaneous beds which are 3-8 cm thick (Ramirez, 1990). These porcellaneous beds alternate with 30-50 cm-thick packages of massive and laminated diatomaceous strata. Above the porcellanites are banded and massive beds of the Sisquoc Formation dominate the section. The Monterey/Sisquoc boundary is placed at the change from finely laminated to banded rocks, which also approximates the change from opal-CT rocks below to opal-A rocks above. The Sisquoc section is truncated by sandstones and siltstones of the Pliocene Careaga Formation (Woodring and Bramlette, 1950).

The age diagnostic and other important diatom taxa of the Lompoc Hills section are tabulated in Table 1. The absence of Thalassiosira hyalinopsis, T. praeoestrupii, and T. oestrupii in the Lompoc Hills section suggests that the section is older than the T. hyalinopsis Zone. Sporadic occurrences of Nitzschia miocenica from sample 1-6 through sample 8-0 and the absence of Rouxia californica and Synedra jouseana in all samples above the rare occurrence in of these two species in sample 2-3 argues for correlation of the bulk of the Sisquoc Formation in the Lompoc Hills section with the Thalassiosira miocenica/ Nitzschia miocenica Zone. Basal samples 2-3 (23 m) and 106 (6 m) are tentatively correlated with the Rouxia californica Zone.

The alternating laminated and massive rocks of the basal Sisquoc Formation in the Lompoc Hills section closely resemble those of the basal Sisquoc Formation at Sweeney Road, 10 km to the east (Ramirez, 1990). Both units correlate with the Thalassiosira miocenica / Nitzschia miocenica Zone.

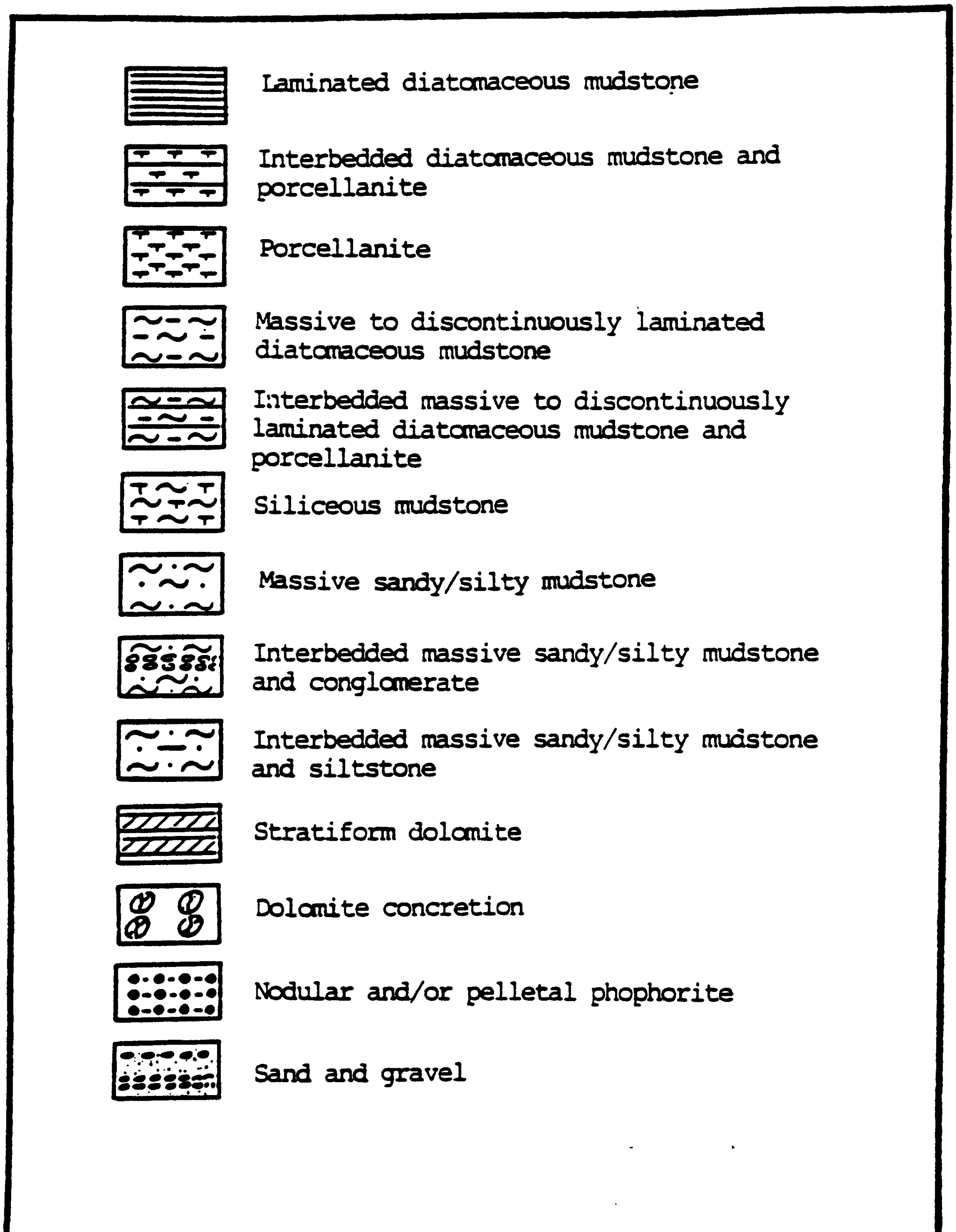

Figure 4. Key to lithologic symbols used in describing sections.

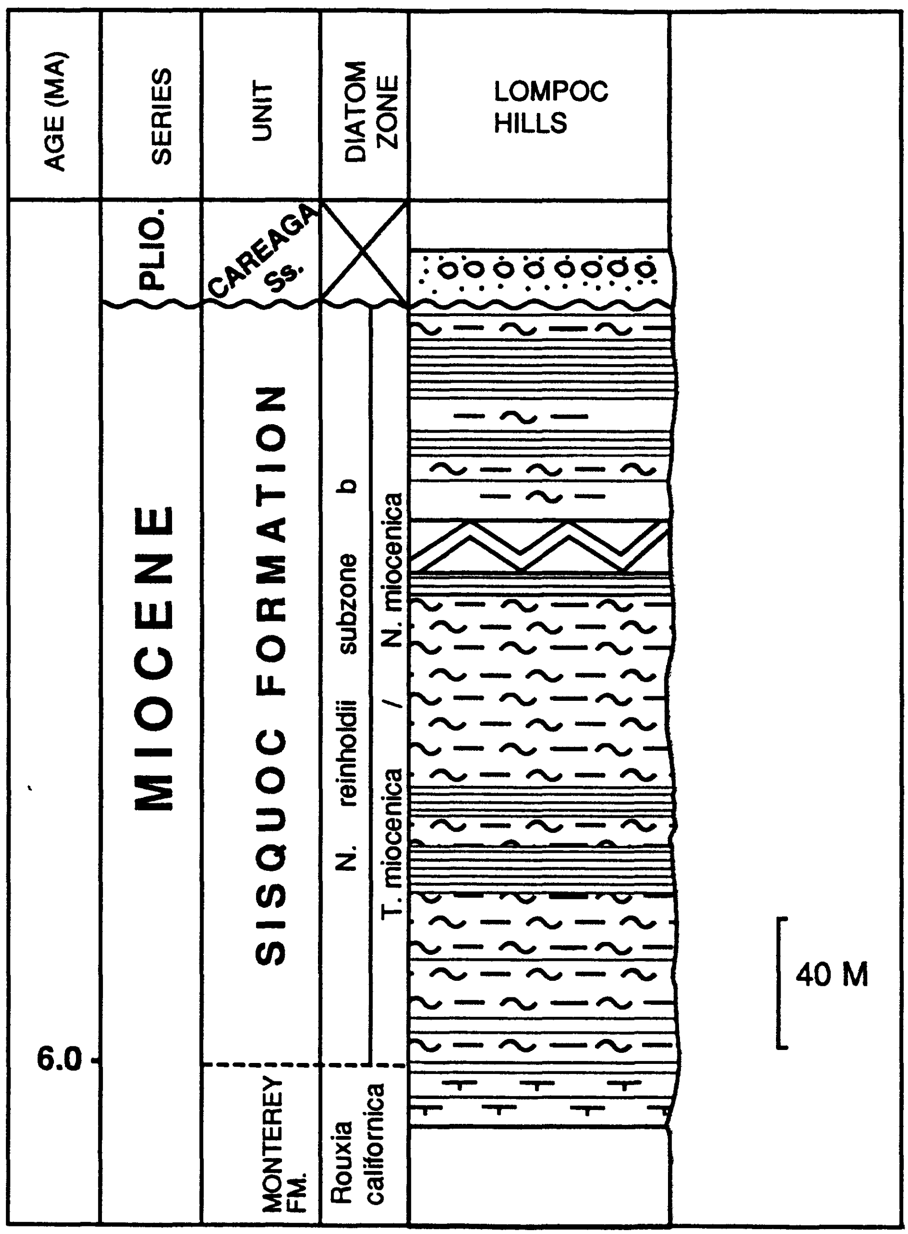

Figure 5. Lompoc Hills stratigraphic section of Ramirez (1990) showing diatom zonation.

Sample LPH- Taxon/Interval (m)	1-0A 241	2-0A 221	3-0A 201	4-0A 181	5-0A 161	8-19 159	8-0 140	7-0 120	6-0 100	5-0 80	4-0 60	3-0 40	2-3 23	1-6 6
Actinocyclus ehrenbergii	R	-	F	F	-	R	-	R	R	-	R	R	R	R
Azpeitia cf. vetustissimus	R	R	-	-	-	-	R	R	R	-	R	R	-	-
Coscinodiscus subtilis	-	R	F	-	-	R	-	-	-	-	F	R	-	-
Delphineis sachalinensis	F	F	-	R	R	R	F	R	-	R	R	-	R	-
Denticulopsis hustedtii	-	-	R	-	-	-	R	-	-	R	R	-	R	-
Lithodesmium minusculum	-	-	-	-	-	-	R	-	R	-	-	R	-	-
Nitzschia marina	-	-	-	-	-	R	-	-	-	-	-	-	-	-
N. miocenica	-	-	-	-	-	-	R	-	-	-	R	R	-	R
N. reinholdii	-	-	R	-	-	-	-	R	-	-	-	-	-	-
N. rolandii	R	-	R	R	R	R	-	-	-	-	R	-	-	-
Rhaphoneis amphiceros var. elongata	R	-	-	R	R	-	-	-	R	-	-	-	R	-
Rouxia californica	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Synedra jouseana	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Thalassiosira antiqua	C	F	F	R	R	C	F	C	F	F	C	F	F	-
T. leptopus	F	-	-	-	F	-	R	R	R	-	-	-	-	-
T. miocenica	-	-	-	-	-	-	-	-	-	-	-	R	-	-
T. nativa	-	-	-	-	-	-	-	-	-	-	R	R	-	-
T. sp. (small form)	-	-	-	R	-	-	-	-	-	-	-	F	-	-
Zone	Thalassiosira miocenica/Nitzschia miocenica												Rouxia californica?	

Table 1. Occurrence of selected diatoms in the Lompoc Hills section. R, rare; F, few; C, common; A, abundant; P, poor; M, moderate; G, good; B, barren.

Point Pedernales Section

The Point Pedernales section is located along the coast (northernmost central portion of Section 22, T.10N, R.3E) approximately 5-6 kilometers southwest of the southeast entrance to Vandenberg Airforce Base. At Point Pedernales Ramirez (1990) measured and described approximately 400 meters of mostly well exposed strata of the Monterey and Sisquoc formations along steep sea cliffs containing exposures up to 4 m in height (Fig. 6). The strata consist largely of alternating massive and laminated diatomaceous units ranging from less than 0.5 to greater than 5 m in thickness (Ramirez, 1990). The lower 10 m of the section was assigned to the Monterey Formation by Ramirez (1990) based on biostratigraphic correlation with the Monterey-Sisquoc boundary at Mussel Rock. Biostratigraphic correlation of the formational contact was necessary, because the Sisquoc Formation grades into and is lithologically indistinct from the underlying Monterey Formation and because insufficient samples were taken from the Monterey Formation to compositionally distinguish it from the Sisquoc Formation (Ramirez, 1990).

Hornafius et al. (1982) placed the Monterey-Sisquoc contact near the top of the Point Pedernales section where they believed the section changes from predominantly laminated to predominantly massive. Ramirez (1990) did not observe such a change and states that the section never becomes more massive.

Table 2 shows the occurrences of stratigraphically important diatom taxa in the Pedernales section. The basal sample 0-0B (0 m) is assigned to the Rouxia californica Zone based on the presence of rare Rouxia californica and Synedra jouseana. The interval from sample 0-10B (10 m) through sample 9-10 (350 m) is placed in the T. miocenica/N. miocenica Zone below first occurrence of Thalassiosira hyalinopsis in sample 4-15 (355 m) based on the sporadic occurrence of Thalassiosira miocenica in this interval. The first occurrence of Coscinodiscus subtilis in sample 0-10B (10 m) is supportive of this correlation (Barron and Baldauf, 1986). The T. hyalinopsis Zone then extends from sample 4-15 (355 m) upsection to a level immediately below the first occurrence of Thalassiosira praeoestrupii in sample 14-16 (456 m), the highest sample taken in the section. Whereas Hornafius et al. (1982) reported Thalassiosira oestrupii from the upper part of the Point Pedernales section, we did not observe this diatom and assign the top of the Pedernales section to the older Thalassiosira praeoestrupii Zone (5.35-5.1 Ma)(Fig. 6, Table 2).

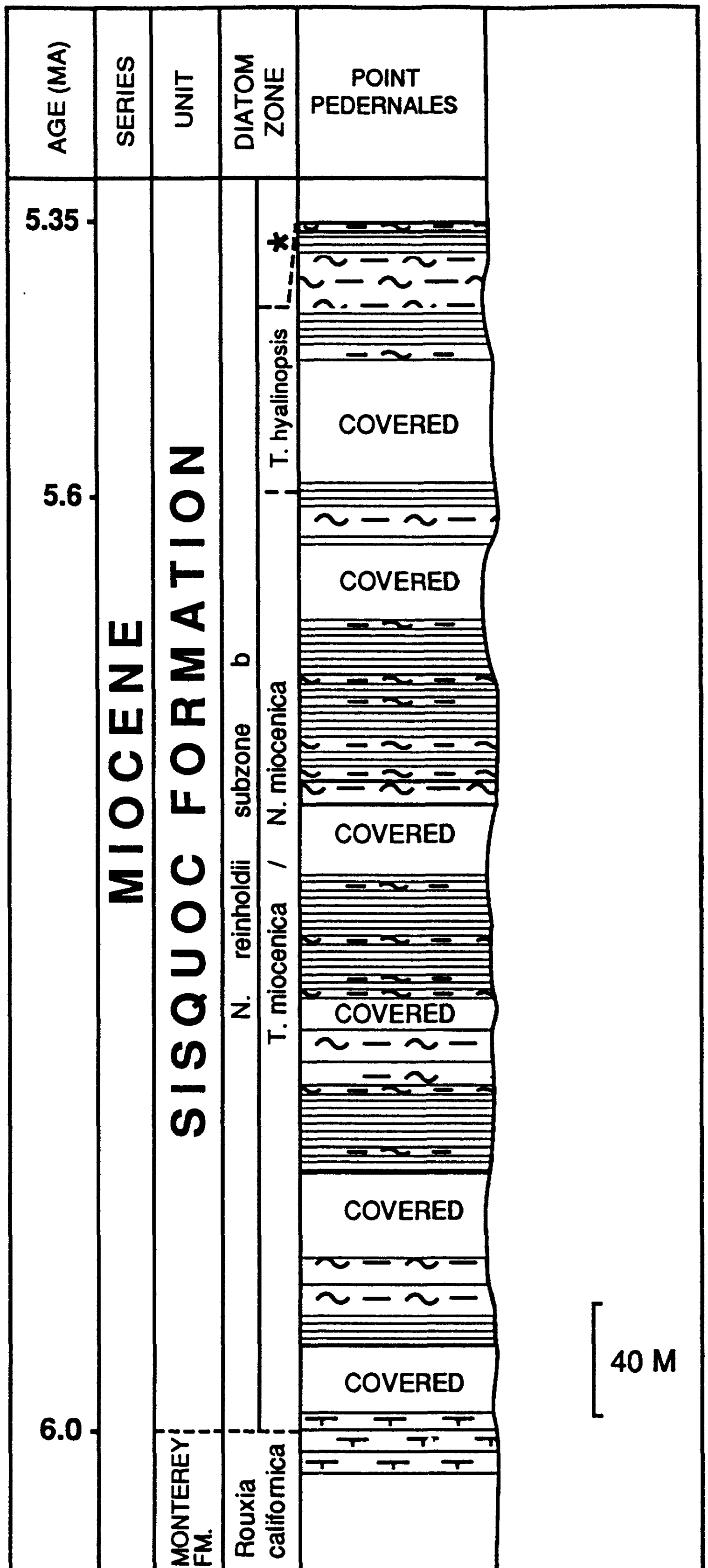

Figure 6. Point Pedernales stratigraphic section of Ramirez (1990) showing diatom zonation. * = Thalassiosira praeoestrupii Zone.

Sample PP- Taxon/Interval (m)	14-16 456	13-5 425	13-0 420	12-10 410	9-15 355	9-10 350	9-5 345	7-10 310	5-10 270	4-10 250	2-15 215	2-10 210	2-10B 50	0-10B 10	0-0B 0
Actinocyclus ehrenbergii	F	F	R	R	F	-	F	F	F	R	F	R	-	F	R
Azpeitia cf. vetustissimus	R	R	R	R	-	-	R	R	R	R	R	-	-	R	-
Coscinodiscus subtilis	F	F	F	F	F	R	-	R	R	-	R	-	-	R	-
Delphineis sachalinesis	R	F	F	F	F	F	R	R	F	R	R	R	-	-	R
Denticulopsis hustedtii	-	R	R	R	R	-	-	-	R	-	-	-	R	R	-
Hemiaulus polymorphus	-	-	-	r	-	-	-	-	-	-	-	-	-	-	-
Neodenticula kamtschatica	cf	R	R	R	-	-	-	-	-	-	-	-	-	-	-
Nitzschia granulata	R	R	-	-	R	-	-	-	-	-	-	-	-	-	-
N. miocencia	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-
N. reinholdii	-	R	R	R	R	-	R	-	R	-	R	-	-	R	-
N. rolandii	F	F	C	R	F	R	R	-	-	-	-	-	R	-	-
Rhaphoneis amphiceros var. elongata	-	R	R	-	R	R	-	-	-	-	-	-	-	-	R
Rouxia california	-	-	-	-	-	R	-	-	-	-	-	-	-	-	R
Stellarima sp.	-	-	-	-	R	-	-	-	-	-	-	-	-	F	-
Synedra jouseana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R
Thalassiosira antiqua	F	F	F	R	F	F	R	F	R	F	F	R	F	F	F
T. eccentrica (fine)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. hyalinopsis	-	-	R	-	R	-	-	-	-	-	-	-	-	-	-
T. jacksonii	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
T. miocenica	-	-	-	-	-	cf	-	R	-	R	cf	-	R	-	-
T. multipora	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-
T. nativa	-	R	-	R	-	-	-	R	-	R	-	-	R	R	-
T. oestrupii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. praeoestrupii	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zone	T.prae- oestrupii	T. hyalinopsis					Thalassiosira miocenica/ Nitzschia miocenica								Rx. calif.

Table 2. Occurrence of selected diatoms in the Point Pedernales section. R, rare; F, few; C, common; A, abundant; r, reworked; cf, compared specimens; P, poor; M, moderate; G, good; B, barren.

Mussel Rock Section

The Mussel Rock section is exposed along the coast southwest of the town of Guadalupe. Access to the coast is possible by traveling west from Guadalupe on West Main Street. West Main Street ends near the beach, and the top of the Mussel Rock section is located approximately 3 kilometers south of where the road ends or in the northeast corner of Section 22, T.10N, R.36W. A 400 m-thick section was measured from the opal-A to opal-CT transitional zone of the upper Monterey Formation to the top of exposed rocks of the Sisquoc Formation (Fig. 7). An additional 300+ m of Monterey Formation strata crops out to the south along the shore below the measured section according to Pisciotto (1981). Interbedded finely laminated porcellaneous and diatomaceous mudstones occur in the lower 20 meters of the measured section and give way to about 130 m of finely laminated diatomaceous mudstones which are distinctly layered (Fig. 7). These layered rocks, which are assigned to the Monterey Formation, contrast sharply with the overlying massive and intensively bioturbated rocks of the Sisquoc Formation, which become increasingly conglomeritic upsection. A distinct phosphatic conglomerate marks the contact between the layered Monterey and massive Sisquoc formations. This phosphatic conglomerate was measured at 23 cm thick, but it apparently varies laterally in thickness.

Table 3 documents the occurrence of stratigraphically important diatom taxa in the measured Mussel Rock section. In general, the diatom biostratigraphy is straightforward. The last occurrence of Thalassionema schraderi in sample 10-1 (28 m) marks the top of the Thalassiosira antiqua Zone and the base of the overlying Rouxia californica Zone (Barron and Baldauf, 1986; Dumont, 1986). The last common occurrence of R. californica in sample 16-14, which was taken in the uppermost Monterey Formation, defines the top of the R. californica Zone, a correlation which is supported by the last occurrences of Synedra jouseana and Hemiaulus polymorphus in the same sample. Thalassiosira miocenica occurs sporadically between sample 17-1 (161 m) and sample 19-10 (208 m), but the first occurrence of Thalassiosira hyalinopsis in sample 18-10 (189 m) apparently defines the base of the T. hyalinopsis Zone. The T. miocenica/N. miocenica Zone thus occurs from sample 15-17 (158 m) at the base of the Sisquoc Formation through sample 18-1 (180 m). The bases of the T. praeoestrupii and T. oestrupii Zones are recognized by the successive first occurrences of T. praeoestrupii in sample 25-18 (330 m) and T. oestrupii in sample 28-7 (376 m). The first occurrence of Lithodesmium cornigerum in sample 25-18 coincides with the base of the T. praeoestrupii Zone in agreement with the diatom biostratigraphy of Barron (1986) and Dumont (1986), whereas the first occurrence of Neodenticula kamtschatica in sample 31-1 (427) lies slightly higher than it does in Barron's (1986) biostratigraphy, just above the base of the T. oestrupii Zone.

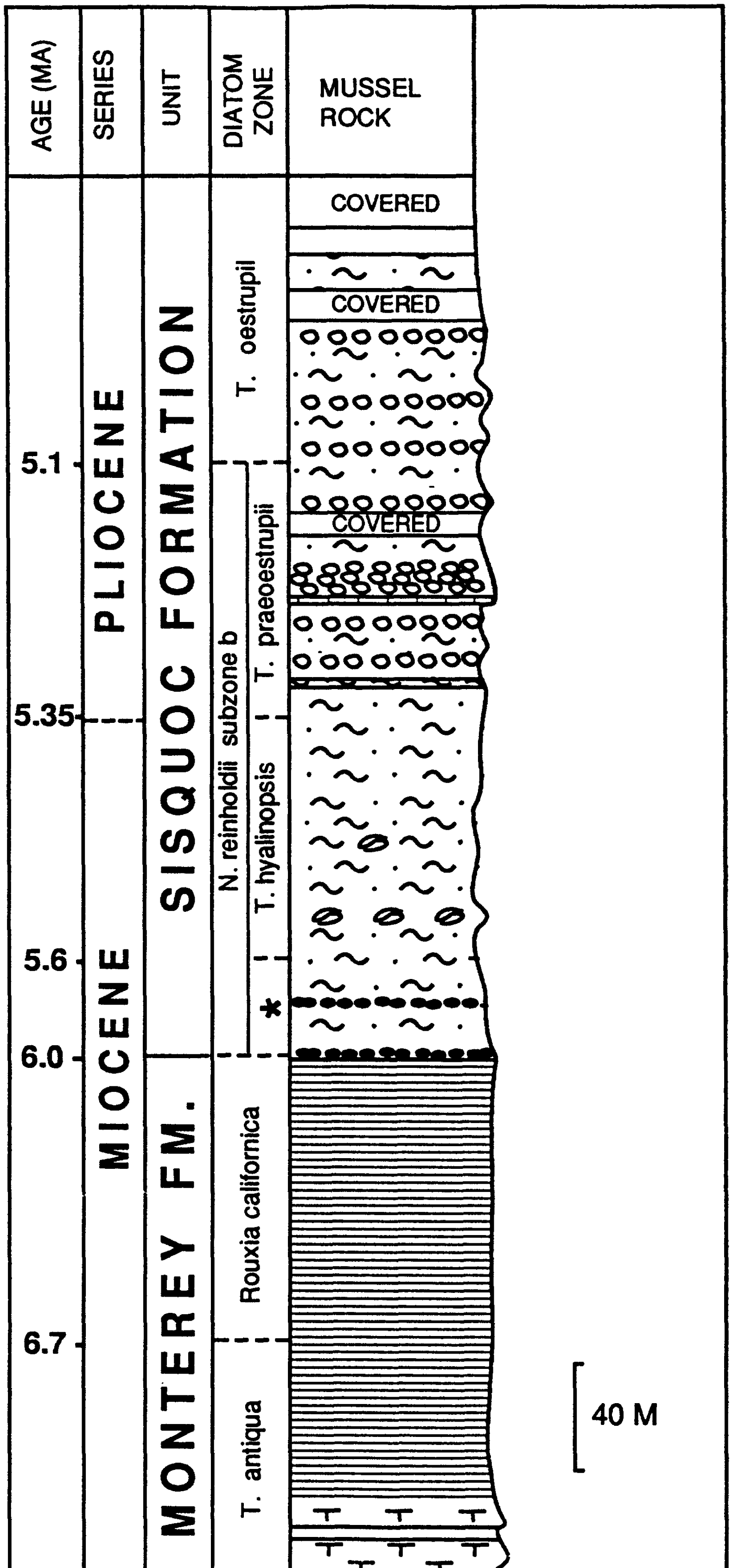

Figure 7. Mussel Rock stratigraphic section of Ramirez (1990) showing diatom zonation. * = Thalassiosira miocenica / Nitzschia miocenica Zone.

Sample MR- Taxon/Interval (m)	31-1 427	28-7 376	26-5 336	25-18 330	24-1 294	23-2 276	22-13 268	22-10 265	22-1 256	19-10 208	18-10 189	18-1 180	17-12 172	17-1 161	16-17 158	16-14 157	14-10 113	13-6 100	12-10 85	10-1 28	8-1 0	7-12 -8
Actinocyclus ingens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	r	-	-	-	R	R	F
Azpeitia cf. vetustissimus	-	-	-	-	R	R	-	F	R	-	R	-	R	-	R	-	-	-	-	-	-	-
Coscinodiscus subtilis	-	-	F	R	R	R	R	R	R	R	R	-	R	-	-	-	-	-	-	-	-	-
Delphineis sachalinesis	R	R	A	F	R	R	-	R	R	R	F	R	R	R	F	F	R	F	F	-	F	-
Denticulopsis hustedtii	-	-	-	-	-	R	-	R	-	-	R	R	-	-	-	R	R	R	R	-	-	-
Hemiaulus polymorphus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	R	-	-	R	-	-
Lithodesmium cornigerum	-	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
L. minusculum	-	-	-	-	R	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-
Neodenticula kamtschatica	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitzschia granulata	-	R	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N. miocenica	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-
N. porteri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-
N. reinholdii	-	-	-	-	-	-	-	R	-	-	-	-	R	R	R	-	-	-	-	-	-	-
N. rolandii	-	-	-	-	R	-	-	-	-	R	R	-	-	R	R	R	R	-	-	-	-	-
Rhaphoneis amphiceros																						
var. elongata	-	R	-	-	R	-	-	-	-	-	R	-	-	R	R	R	R	F	F	R	R	-
Rossiella tatsunokuchiensis	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rouxia californica	r	-	-	-	-	-	-	-	-	-	-	-	-	-	-	C	F	F	F	F	F	R
Stellarima sp.	-	-	-	-	-	R	-	R	-	-	R	R	R	R	-	-	R	-	R	-	-	-
Synedra jouseana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	R	F	R	-	R	R
Thalassionema schraderi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	F	-
Thalassiosira antiqua	F	F	A	F	F	F	F	F	R	F	F	R	F	F	F	F	F	F	F	F	F	F
T. convexa aspinosa	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. hyalinopsis	-	-	R	R	-	-	R	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-
T. kryophilia	-	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. miocenica	-	-	-	-	-	-	-	-	-	R	-	-	R	R	-	-	-	-	-	-	-	-
T. multipora	-	R	R	R	R	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. nativa	-	-	F	R	R	F	R	F	R	R	C	R	F	F	F	F	F	R	F	F	F	-
T. oestrupii	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. praeoestrupii	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. punctata	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-
T. sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
T. sp. small form	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unit	Sisquoc Fm.															Monterey Fm.						
Zone	T. oestrupii		Thalassiosira praeoestrupii		Thalassiosira hyalinopsis							T. miocenica/ N. miocenica				Rouxia californica				T. antiqua		

Table 3. Occurrence of selected diatoms in the Mussel Rock section. R, rare; F, few; C, common; A, abundant; P, poor; M, moderate; G, good; B, barren.

Casmalia Section

A 700 m-thick composite section containing the uppermost Monterey Formation, the entire Sisquoc Formation, and the basal Foxen Mudstone was measured along Black Road and along the railroad tracks which run parallel to the road (Ramirez, 1990). The section runs along the eastern margin of the northwest quarter of Section 13, T.9N., R.35W. The lowermost 30 m of the measured section consists of continuously to discontinuously banded and finely laminated porcellaneous rocks assigned to the Monterey Formation. Upsection, platy-weathering rocks of the Monterey Formation pass into massive, dense, siliceous mudstones of the Todos Santos Claystone Member of the Sisquoc Formation (Fig. 8)(Ramirez, 1990).

The successive first occurrences of T. hyalinopsis, T. praeoestrupii, and T. oestrupii in samples 17-0 (437 m), 11-0 (557 m), and 5-0 (677 m) mark the respective bases of the T. hyalinopsis, T. praeoestrupii, and T. oestrupii zones. As in the Mussel Rock section, the first occurrence of Lithodesmium cornigerum coincides with the base of the T. praeoestrupii Zone and the first occurrence of Neodenticula kamtschatica lies within the T. oestrupii Zone. Similarly, as at Mussel Rock, Rossiella tatsunokuchiensis first occurs at the base of the T. oestrupii Zone, an interval slightly younger than that recorded by Barron (in press b). The Sisquoc-Foxen contact is estimated to fall at 5.0 Ma in the Casmalia section.

The lowest sample containing well preserved diatoms, 24-10 (287 m) contains Coscinodiscus subtilis and lacks common Rouxia californica and Synedra jouseana. This and the overlying biostratigraphy suggest correlation of the basal diatom-containing interval between samples 24-10 and 18-0 (417 m) to the T. miocenica/N. miocenica Zone. Unfortunately, Thalassiosira miocenica was only observed in sample 21-0 (357 m) and Nitzschia miocenica was not recorded from the Casmalia section.

CORRELATION OF SISQUOC SECTIONS

Figure 9 shows the Point Pedernales, Mussel Rock, Lompoc Hills, and Casmalia sections correlated to the geologic time scale through diatom biostratigraphy (Fig. 2). Additional sections of the Sisquoc Formation from Harris Grade, Sweeney Road, the Johns-Manville Quarry, and Naples Beach (see Fig. 1 for section locations) are also included based on the diatom biostratigraphy of Barron and Baldauf (1986), Dumont (1986), Barron (1975 a, b), Barron (1986), and Arends and Blake (1986), respectively.

The Monterey-Sisquoc boundary consistently falls at about 6.0 Ma, or at the boundary between the Rouxia californica and Thalassiosira miocenica/Nitzschia miocenica zones of Dumont (1986) or the Subzone a-Subzone b boundary of the Nitzschia reinholdii Zone of Barron (1986). The top of the Sisquoc Formation is eroded in the Sweeney Road, Johns-Manville Quarry, Naples Beach, Point Pedernales, Mussel Rock, and Lompoc Hills sections, all of which range no younger than about 5.0 Ma (basal Thalassiosira oestrupii Zone). In the Harris Grade and Casmalia sections, where the Sisquoc Formation is overlain by the Foxen Mudstone, the top of the Sisquoc Formation is approximately 3.8 and 5.0 Ma, respectively.

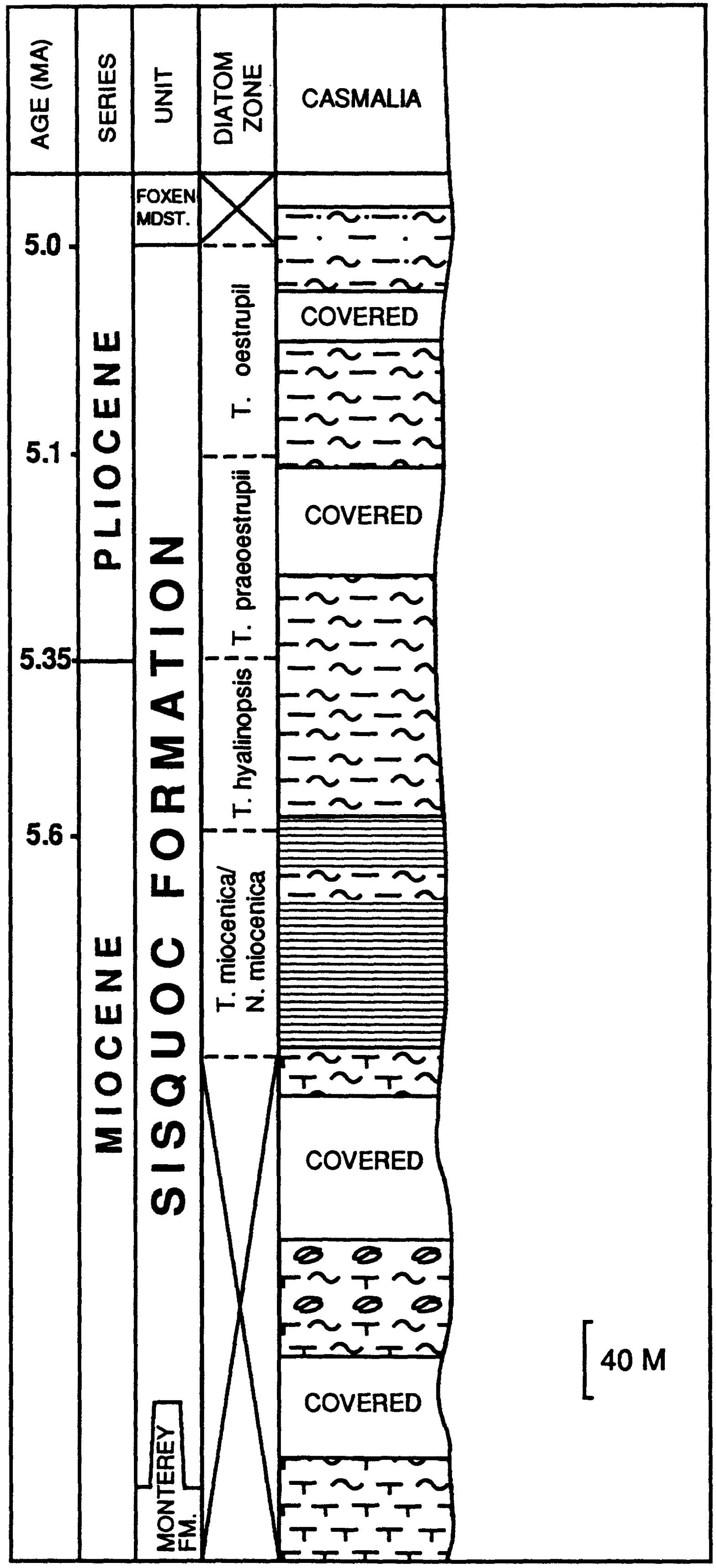

Figure 8. Casmalia stratigraphic section of Ramirez (1990) showing diatom zonation.

Sample CH- / Taxon/Interval (m)	0-15 767	1-0 757	3-0 717	4-0 697	4-5 692	5-0 677	8-0 657	10-3 574	10-15 562	11-0 557	13-13 504	14-5 492	14-10 467	17-0 437	18-0 417	19-0 397	20-0 377	21-0 357	23-0 317	24-5 292	24-10 287
Actinocyclus ehrenbergii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	F	C	-	R	R	F	F
Azpeitia cf. vetustissimus	-	-	R	-	R	R	-	-	R	-	-	-	-	R	-	R	R	F	R	F	F
Coscinodiscus subtilis	-	-	-	-	R	R	R	R	R	R	-	R	-	R	R	R	R	R	R	R	R
Delphineis sachalinesis	-	-	R	R	F	F	R	F	F	R	F	-	F	F	F	F	R	R	F	F	-
Denticulopsis hustedtii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-
Lithodesmium cornigerum	-	-	-	-	R	R	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-
L. minusculum	-	-	-	-	R	-	-	-	-	R	-	-	R	F	R	F	R	-	F	R	R
Neodenticula kamtschatica	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitzschia granulata	-	-	-	-	R	-	R	R	R	-	-	-	-	-	-	-	-	-	-	-	-
N. reinholdii	-	-	-	R	R	-	R	R	R	-	-	R	-	R	-	R	R	-	-	-	-
N. rolandii	-	-	-	-	-	-	-	-	R	-	F	F	F	F	R	R	R	-	R	R	R
Rhaphoneis amphiceros var. elongata	-	-	-	-	R	-	-	-	-	-	-	-	-	R	R	R	F	-	-	-	-
R. fatula	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rossiella tatsunokuchiensis	-	-	-	R	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stellarima sp.	-	-	-	-	-	-	R	-	R	-	-	-	-	-	-	-	-	-	R	-	-
Synedra jouseana	-	-	r	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thalassiosira antiqua	-	R	-	F	C	C	F	F	C	C	C	C	F	F	F	F	F	F	F	F	-
T. eccentrica (fine)	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. hyalinopsis	-	-	-	-	R	-	F	-	R	F	F	R	R	R	-	-	-	-	-	-	-
T. jacksonii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	R	-
T. kryophilia	-	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. miocenica	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-
T. multipora	-	-	-	R	R	-	R	R	R	R	R	-	-	R	R	R	R	-	R	-	-
T. nativa	-	-	-	-	-	-	F	-	F	F	F	R	R	-	-	-	F	-	-	R	R
T. oestrupii	-	-	-	-	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T. praeoestrupii	-	-	-	-	R	R	-	R	-	R	-	-	-	-	-	-	-	-	-	-	-
T. sp. (small form)	-	-	-	-	-	-	-	-	R	F	-	-	R	F	R	F	C	F	F	F	F
Unit	Foxen Mdst.	Sisquoc Fm.																			
Zone	Thalassiosira oestrupii						Thalassiosira praeoestrupii				Thalassiosira hyalinopsis				Thalassiosira miocenica/ Nitzschia miocenica						

Table 4. Occurrence of selected diatoms in the Casmalia section. R, rare; F, few; C, common; A, abundant; r, reworked; P, poor; M, moderate; G, good; B, barren.

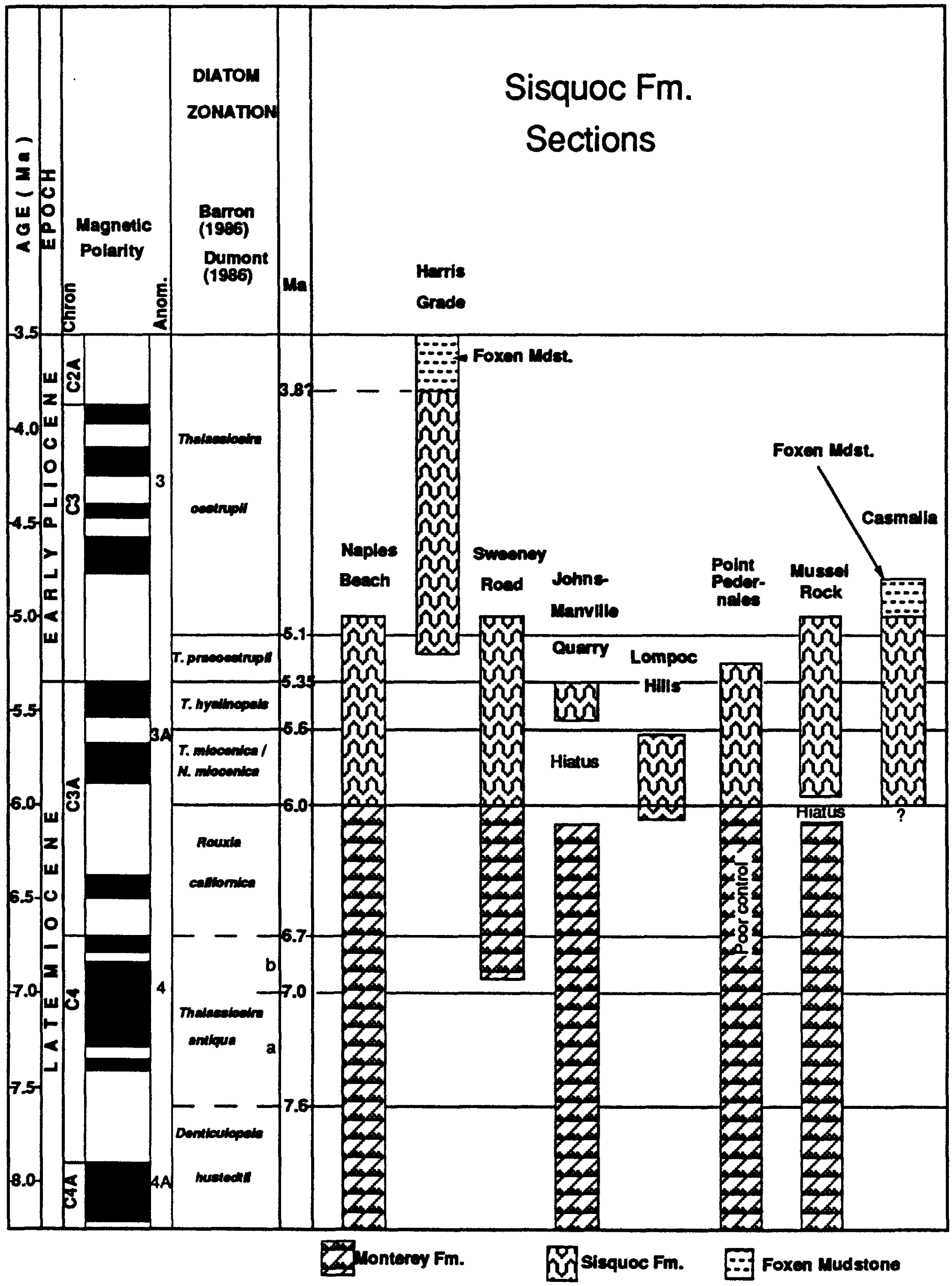

Figure 9. Correlation of various Sisquoc Formation sections to the geologic time scale.

ACKNOWLEDGMENTS

We thank Michael P. Dumont of ARCO Oil and Gas Company and Kris McDougall of the U.S. Geological Survey for their helpful review of this report. Kevin Purcell of the U.S. Geological Survey is thanked for assistance with drafting.

REFERENCES

Akiba, F., 1986, Middle Miocene to Quaternary diatom biostratigraphy in the Nankai Trough and Japan Trench, and modified lower Miocene through Quaternary diatom zones for middle-to-high latitudes of the North Pacific, in Kagami, H., Karig, D.E., Coulbourn, W.T., et al., Initial Reports, Deep Sea Drilling Project, vol., 87: Washington, D.C., U.S. Govt. Printing Office, p. 393-481.

Akers, W. H., Marolt, R. E., and Navarette, R. R., 1987, Late Miocene and early Pliocene siliceous microfossils from the upper Monterey and lower Sisquoc Formations, Sweeny Road, Santa Barbara County, California, Tulane Studies in Geology and Paleontology, v. 20, no.1-3, p. 1-112, 8 pls.

Arends, R.G. and Blake, G.H., 1986, Biostratigraphy and paleoecology of the Naples Bluff coastal section based on diatoms and benthic foraminifera, in Casey, R.E. and Barron, J.A. (Editors), Siliceous Microfossil and Microplankton of the Monterey Formation and Modern Analogs, Pacific Section, S.E.P.M., Book 45, p. 121-135.

Barron, J. A., 1974, The late Miocene-early Pliocene marine diatom assemblage of southern California, Ph.D. dissertation, University of California, Los Angeles, 289 pp.

Barron, J. A., 1975a, Marine diatom biostratigraphy of the upper Miocene-lower Pliocene strata of southern California, Journal of Paleontology, v. 49, p. 619-632.

Barron, J. A., 1975b, Late Miocene-early Pliocene marine diatoms from southern California, Palaeontographica, v. 151, pt.B, p. 97-170, pls. 1-15.

Barron, J.A., 1985, Miocene to Holocene planktic diatom stratigraphy, in Bolli, H.M, Saunders, J.B., and Perch-Nielsen, K., eds., Plankton Stratigraphy: Cambridge, U.K., Cambridge Univ. Press, Cambridge, U.K., p. 763-809.

Barron, J.A., 1986, Updated diatom biostratigraphy for the Monterey Formation of California, in Casey, R.E. and Barron, J.A. (Editors), Siliceous Microfossil and Microplankton of the Monterey Formation and Modern Analogs, Pacific Section, S.E.P.M., Book 45, p. 105-119.

Barron, in press a, Paleoceanographic and tectonic controls on the Pliocene diatom record of the northeastern Pacific, in Tsuchi, R. and Ingle, J.C., Jr., eds., Proceedings of the Vth International Congress on Pacific Neogene Stratigraphy, Shizuoka, Japan, October 6-10, 1991. Tokyo, Tokyo University Press.

Barron, J. A., in press b, Neogene diatom datum levels in the equatorial and North Pacific, in Saito, T. and Ishizaki, K., eds., "The Centenary of Japanese Micropaleontology", a commemorative volume for Professor Y. Takayanagi. Tokyo, Terra Scientific Publishing Company.

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, no. 4, p. 357-371, pls. 1-3.

Berggren, W.A., Kent, D.V., Flynn, J.J., and Van Couvering, J.A., 1985, Cenozoic geochronology, Geol. Soc. Amer. Bull., v. 96, no. 11, p. 1407-1418.

Dibblee, T. W., Jr., 1966, Geology of the central Santa Ynez Mountains, Santa Barbara County, California, California Division of Mines & Geology, Bulletin 186, p.1-99, maps.

Dumont, M.P., 1986, The Miocene/Pliocene Epoch boundary as determined by diatom biostratigraphy in the California coastal region, M.A. thesis, University of California, Berkeley, 115 p.

Dumont, M.P., Baldauf, J.G., and Barron, J.A., 1986, Thalassiosira praeoestrupii - a new diatom species for recognizing the Miocene/Pliocene Epoch boundary in coastal California, Micropaleontology, v. 32, no. 4, p. 372-377.

Fryxell, G.A., Sims, P.A., and Watkins, T.P., 1986, Azpeitia (Bacillariophyceae): Related genera and promorphology, Systematic Botany Monographs, vol. 13, p. 1-74.

Haq, B.U., Hardenbol,J., and Vail, P.R., 1987, Chronology of fluctuating sea level since the Triassic, Science, v. 235, p. 1156-1167.

Hornafius, J. S., Grivetti, M. C., and Lagle, C. W., 1982, Structure and stratigraphy of the Monterey Formation near Point Pedernales, Santa Barbara County, California: Geology and Mineral Wealth of the California Transverse Ranges, South Coast Geol. Soc, Guidebook no. 10, p. 331-336.

Issacs, C. M., 1981, Field characterization of rocks in the Monterey Formation along the Coast near Santa Barbara, California. In, Issacs, C. M., ed., Guide to the Monterey Formation in the California coastal area, Ventura to San Luis Opispo: Pacific Section, American Association Petroleum Geologists, Spec. Pub., 52, p. 39-53.

Koizumi, I. and Tanimura, Y., 1985, Neogene diatom biostratigraphy of the middle latitude western North Pacific, Deep Sea Drilling Project Leg 86, In, Heath, G.R., Burckle, L.H. et al, Initial Reports, Deep Sea Drilling Project, v. 86: Washington, D.C, U.S. Govt. Printing Office, p. 269-300

Madrid, V. M., Stuart, R. M., and Verosub, K. L., 1986, Magnetostratigraphy of the late Neogene Purisima Formation, Santa Cruz County, California, Earth and Planetary Science Letters, v. 79, p. 431-440.

Pisciotto, K. A., 1981, Notes on Monterey rocks near Santa Maria, California, in Isaacs, C. M., ed., Guide to the Monterey Formation in the California Coastal Area, Ventura to San Luis Obispo. Pacific Section AAPG, no.

52, p. 73-81.
Ramirez, P. C., 1990, Stratigraphy, sedimentology, and paleoceanographic implications of the late Miocene to early Pliocene Sisquoc Formation, Santa Maria area, California, Ph.D. dissertation, University of California, Santa Cruz, 384 pp.
Schrader, H.J., 1973, Cenozoic diatoms from the northeast Pacific, Leg 18. In, Kulm, L.D., von Huene, R., et al., eds.: Initial Reports, Deep Sea Drilling Project, v. 18: Washington, D.C., U.S. Govt. Printing Office, p. 673-797.
Simonsen, R. and Kanaya, T., 1961, Notes on the marine species of the diatom genus Denticula Kützing, Internationale Revue der Gesamten Hydrobiologie, v. 46, p. 498-513.
Stanley, K. O. and Surdham, R. C., 1984, The role of wrench fault tectonics and relative changes of sea level on deposition of the upper Miocene-Pliocene Pismo Formation, Pismo Syncline, California, in SEPM Guidebook No.2, Stratigraphic, tectonic, thermal, and diagenetic histories of the Monterey Formation, Pismo and Huasna Basin, California, Mid-year meeting, Society of Economic Paleontologists and Mineralogists, August 13-16, 1984, San Jose, California, p. 21-34.
Woodring, W. P. and Bramlette, M. N., 1950, Geology and paleontology of the Santa Maria district, California, U.S. Geological Survey, Professional Paper no., 222, p. 1-142, maps.
Woodring, W. P., Bramlette, M. N., and Lohman, K. E., 1943, Stratigraphy and paleontology of the Santa Maria district, California, American Assoc. Petrol. Geologists Bulletion 27, no., 10, p. 1335-1360.
Wornardt, W. W., Jr., 1963, Stratigraphic distribution of diatom floras from the "MIO-Pliocene" of California. Ph.D. dissertation, University of California, Berkeley, 208 pp.
Wornardt, W. W., Jr., 1967, Miocene and Pliocene marine diatoms from California, California Academy of Sciences, Occasional Papers, no. 63, p. 1-108, 217 figs.
Wornardt, W. W., Jr., 1986, Diatom biostratigraphy from diatomaceous dolomites and shales in the Monterey Formation, Rodeo Canyon, Point Pedernales and Lion's Head sections, southwest Santa Barbara County, California, in Casey, R.E. and Barron, J.A. (Editors), Siliceous Microfossil and Microplankton of the Monterey Formation and Modern Analogs, Pacific Section, S.E.P.M., Book 45, p. 141-147.