

## 42. DIATOM BIOSTRATIGRAPHY AND LAMINATED DIATOMACEOUS SEDIMENTS FROM THE GULF OF CALIFORNIA DEEP SEA DRILLING PROJECT LEG 64<sup>1</sup>

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### INTRODUCTION

Diatoms and other opal skeletal debris are abundant and well preserved in the hemipelagic–pelagic sequences recovered during DSDP Leg 64. This chapter will discuss the occurrence of biostratigraphically useful diatom and silicoflagellate species and present biostratigraphic results in the context of recently developed zonations and datum levels, including those of Burckle (1978), Burckle and Trainer (1979), Barron (1980), Burckle (1977), Burckle and Opdyke (1977), and others. These authors have correlated diatom data to the paleomagnetic stratigraphy. Using this correlation and K–Ar dating of the paleomagnetic scale as presented in Mankinen and Dalrymple (1979), one may assign ages to diatom datum levels (Table 1). In Figures 1–8, these ages are plotted vs. depth for the cores from DSDP Leg 64 to estimate sedimentation rates.

It is not my intention to evaluate the various biostratigraphic schemes used in this study. Complete characterizations of diatom zones—that is, long lists of Quaternary species in the recovered sections—are not presented here. Nor is extended taxonomy presented. The full potential of these diatomaceous sediments will be exploited by paleoclimatic research rather than by biostratigraphic studies.

Samples taken during the first part of the leg were arbitrarily selected by shipboard scientists, and only later was I able to choose samples. As a matter of policy, all samples had to be shared with David Bukry for silicoflagellate studies. Preparation and counting procedures followed those described in Schrader (1974) and Schrader and Gersonde (1978).

#### Site 474

Marine diatoms were abundant and well preserved at Site 474 above Sample 474A-10-1, 30–32 cm, approximately 250 meters sub-bottom (Fig. 1). Marker fossils, including *Rhizosolenia matuyamai*, *Mesocena quadrangula*, *Nitzschia reinholdii*, *N. fossilis*, and *Pseudo-notia doliolus* were common, along with a flood of *Thalassiothrix longissima*. Sample 474A-9-3, 50–53 cm contained some *R. barboi/curvirostris* individuals, suggesting a strong influx of California Current waters during this time (similar to Sample 474A-9-1, 93–95 cm). *R.*

Table 1. Diatom and silicoflagellate datum levels.

<i>Rhizosolenia curvirostris</i> , (T), 0.26 Ma, Barron (1980).
<i>Nitzschia reinholdii</i> , (T), 0.63 Ma, Barron (1980).
<i>Mesocena quadrangula</i> , (T), 0.79 Ma, Barron (1980).
<i>Rhizosolenia matuyamai</i> , (T), 0.9 Ma, Burckle, Hammond and Seyb (1978).
<i>Mesocena quadrangula</i> , (B) 0.9 Ma, inferred from published ranges.
<i>Rhizosolenia matuyamai</i> , (B), 0.99 Ma, Burckle, Hammond, and Seyb (1978).
<i>Rhizosolenia barboi</i> , (T), 1.1 Ma, Koizumi (1975).
<i>Rhizosolenia barboi</i> — <i>R. curvirostris</i> , (E), 1.3 Ma, Koizumi (1975).
<i>Rhizosolenia curvirostris</i> , (B), 1.5 Ma, Barron (1980).
<i>Pseudo-notia doliolus</i> , (B), 1.8 Ma, Barron (1980), after Burckle (1978).
<i>Thalassiosira convexa</i> , (T), 2.1 Ma, Barron (1980), after Burckle (1978).
<i>Cussia tatsunokuchiensis</i> , (T), 2.5 Ma, Koizumi (1975).
<i>Nitzschia jouseae</i> , (T), 2.6 Ma, Barron, (1980), after Burckle (1978).
<i>Nitzschia cylindrica</i> , (T), 4.3 Ma, Burckle (1978).
<i>Denticula hustedtii</i> , (T), 4.2 Ma, inferred from published ranges.
<i>Coscinodiscus insignis</i> , (T), 4.4 Ma, Barron (1980).
<i>Nitzschia jouseae</i> , (B), 4.5 Ma, Barron (1980).

Note: (T) = top; (B) = bottom; (E) = evolutionary transition

*matuyamai* was last observed in Sample 474A-7-3, 53–55 cm. Thus the interval from 250 meters to 222 meters sub-bottom falls into the range of *R. matuyamai* and is approximately equivalent to the Jaramillo Event (within the Matuyama Reversed Epoch). *M. quadrangula* recurs in Sample 474A-1-1, 107–109 cm and was found in Sample 474-18-1, 125–127 cm, which suggests that these two samples might represent equivalent stratigraphic horizons between the two Holes 474A and 474. Samples above this horizon contained *P. doliolus* and *N. reinholdii*. *M. quadrangula* reoccurred in the interval represented by Samples 474-7-5, 114–116 cm through 474-6-3, 56–58 cm. The last occurrence of *N. reinholdii* was in Sample 474-6-2, 36–38 cm (~42 m sub-bottom).

Diatom floras are generally typical of tropical to subtropical waters and have only a minute admixture of shallow-water benthic associations. Horizons which are different and contain a flora characteristic of colder waters were found at the following levels: Sample 474-17-2, 17–19 cm, floods of *T. longissima*; Sample 474A-1-1, 107–109 cm, with some *R. barboi*; Sample 474A-9-1, 93–95 cm, with some *R. barboi*; Sample 474A-9-3, 50–53 cm, with some *R. barboi*; and Sample 474A-10-1, 30–32 cm, *T. longissima*, indicating stronger California Current activity at this site during “glacial” periods.

#### Site 475

Abundant and well-preserved diatom floras occurred at Sample 475-17-3, 89–91 cm with the following species: *Cussia tatsunokuchiensis*, *Coscinodiscus temperei*, *Nitzschia jouseae*, and *N. reinholdii* (Fig. 2). *Thalassiosira convexa* occurred first in Sample 475-17-1, 91–93

<sup>1</sup> Curray, J. R., Moore, D. G., et al., *Init. Repts. DSDP*, 64: Washington (U.S. Govt. Printing Office).

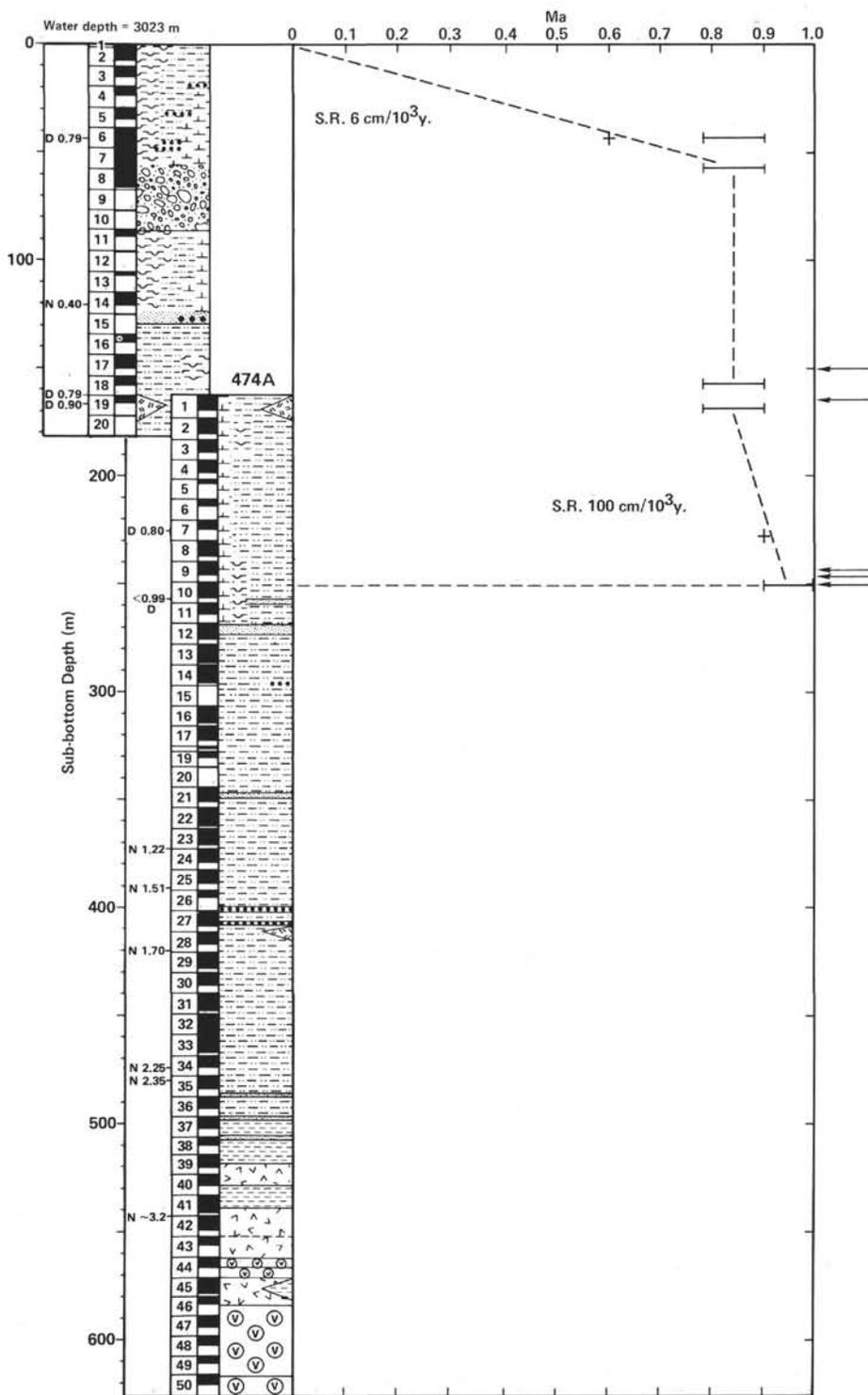


Figure 1. Occurrence of diatom/silicoflagellate datum levels at Site 474 and inferred sedimentation rate. Arrows indicate cold water influx.

cm. *N. jouseae* ranged through Sample 475-16-2, 60-62 cm, and *T. convexa* occurred last, in Sample 475-13-2, 75-77 cm. This latter sample also contained rare amounts of *Denticula hustedtii*, but this might have resulted from reworking. *Cussia tatsunokuchiensis* was absent above Sample 475-11-6, 45-47 cm just below the

interval between Samples 475-11-2, 57-59 cm through 475-7-1, 62-64 cm, which contained only rare and moderate to poorly preserved diatom assemblages. Diatom floras reoccurred in Sample 475-6-5, 58-60 cm, with *N. reinholdii*, *N. fossilis*, *Pseudoeunotia doliolus*, and *Mesocena quadrangula*. *M. quadrangula* was last seen

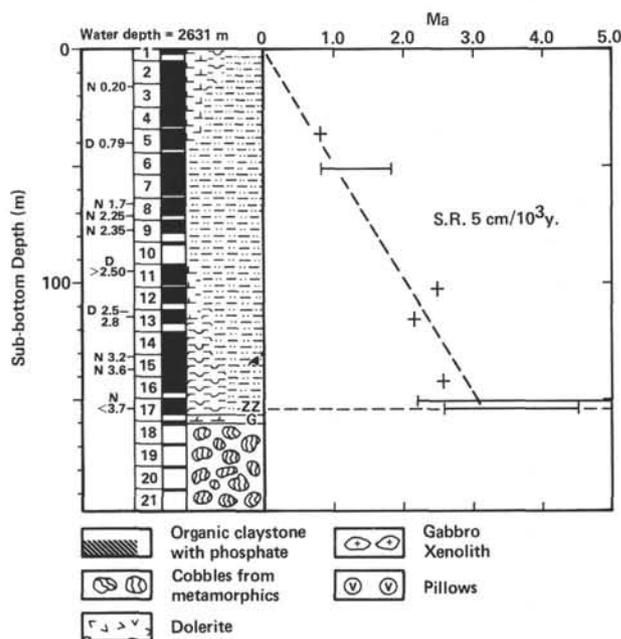


Figure 2. Occurrence of diatom/silicoflagellate datum levels at Site 475 and inferred sedimentation rate.

in Sample 475-5-2, 37–39 cm and *N. reinholdii* disappeared in Sample 475-3-1, 70–72 cm. Distinct cold water influence was observed only in Sample 475-3-3, 116–118 cm, in which there were few specimens of *Rhizosolenia curvirostris*.

#### Site 476

Abundant and mostly well-preserved marine diatom assemblages were found above Sample 476-20-2, 89–91 cm, with the silicoflagellate *Mesocena circulus* and *Thalassiosira convexa* (Fig. 3). Sample 476-19-6, 84–86 cm contained *Cussia tatsunokuchiensis*, *Cosmiodiscus insignis*, *Coscinodiscus temperei*, *Nitzschia fossilis*, *N. jouseae*, *N. cylindrica*, and *N. reinholdii*. *Cussia tatsunokuchiensis* and *N. jouseae* occurred last in Sample 476-16-4, 34–36 cm, whereas *T. convexa* occurred last in Sample 476-11-5, 93–95 cm. *M. quadrangula* appeared in Sample 476-9-2, 73–75 cm and *Pseudoeunotia doliolus* in Sample 476-6-1, 64–66 cm. *M. quadrangula* disappeared above Sample 476-5-5, 36–38 cm and *N. reinholdii* above Sample 476-2-1, 95–97 cm. Distinct horizons, representing colder water influence, were found at the following intervals (from bottom to top): Sample 476-8-3, 68–70 cm, with a few *Rhizosolenia barboi*; 476-3-4, 49–51 cm, with a few *R. barboi*; and 476-1-2, 88–90 cm, with abundant *Thalassiothrix longissima*.

#### Site 477

Samples below 477-15-1, 56–58 cm were barren in opaline microfossils (Fig. 4). Above this level, diatomaceous sediments were rich in well-preserved marine diatom assemblages with a minimal admixture of marine benthic species. The flora were very similar to present-day taphocoenoses found in the Central Gulf area. I

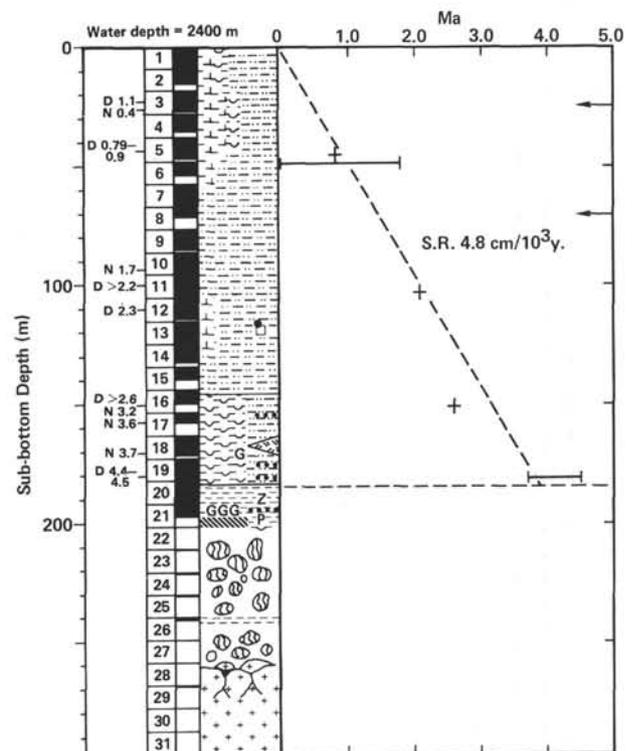


Figure 3. Occurrence of diatom/silicoflagellate datum levels at Site 476 and inferred sedimentation rate. Arrows indicate cold water influx.

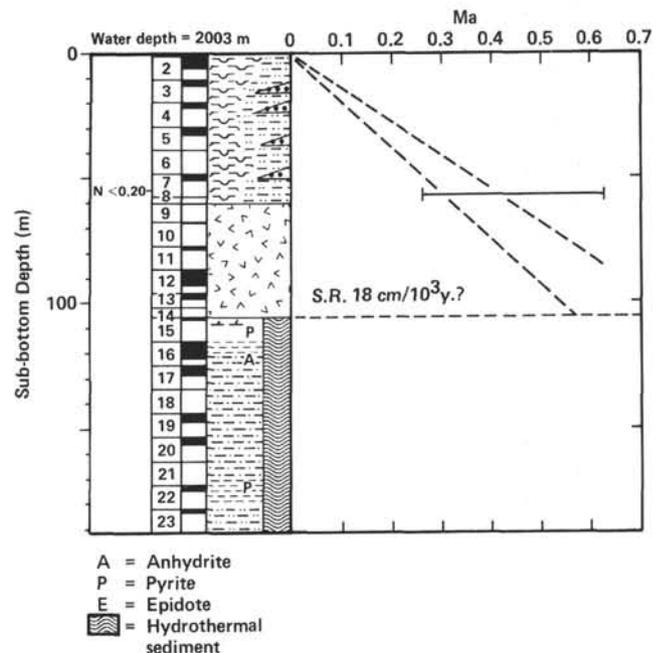


Figure 4. Occurrence of diatom datum levels at Site 477 and inferred sedimentation rate.

observed no biostratigraphic marker fossils, indicating that the whole section above 58 meters sub-bottom is younger than the youngest tropical/subtropical diatom datum level of *Nitzschia reinholdii*. No sample indicative of the influence of colder waters was observed.

## Site 478

Diatoms were abundant in all pelagic-hemipelagic sequences in Site 478 (Fig. 5). They were generally excellently preserved, with delicate species (*Skeletonema costatum*) throughout. Diatom abundance decreased sharply in Core 478-39 and, at the same depth, preservation became poor, so that only strongly silicified valves were present in Core 478-40.

Displaced freshwater and marine benthic species occurred throughout, but never exceeded 1% of the total diatom population, indicating a constant supply of terrigenous and/or shallow water marine debris to this site.

Assemblages consisted of such pelagic subtropical to tropical species as *Pseudoeunotia doliolus*, *Coscinodiscus nodulifer*, *Thalassionema nitzschioides* and var. *parva*. In addition, as a minor component, there was a meroplanktonic group of species, including *Actinocyclus ehrenbergii*, *Actinoptychus undulatus*, and *Cy-*

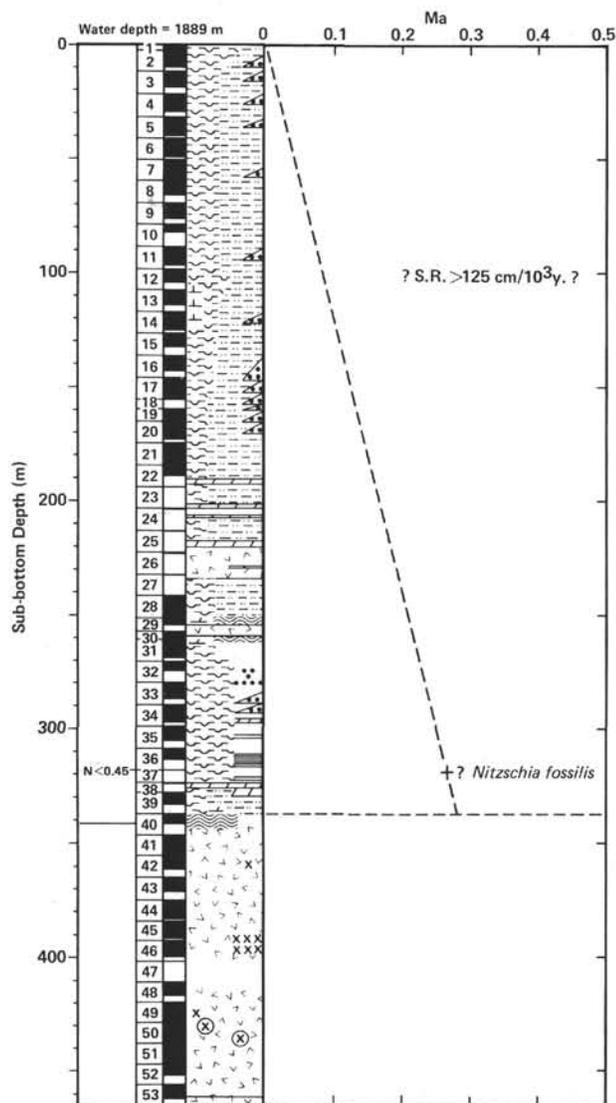


Figure 5. Occurrence of diatom datum levels at Site 478 and inferred sedimentation rate.

*clotella striata* a.o. Occasionally, two distinct assemblages could be differentiated, one (A) with dominant *Thalassionema nitzschioides* and another (B) with dominant *Coscinodiscus nodulifer* and *Thalassiosira oestrupii*. Assemblage A may represent more vigorous mixing of surface waters (increased upwelling), whereas B may represent more stable surface water conditions. The varved intervals in Core 478-37 were dominated by the tropical species *Thalassionema nitzschioides* var. *parva*.

I did not find reworked older species, which indicates that no older strata are exposed along the flanks of this basin.

## Site 479

Diatoms and silicoflagellates were abundant and commonly well preserved at Site 479 (Fig. 6), though their degree of preservation and abundance dropped sharply below Core 479-43. Samples below Core 479-44 were barren of diatoms and silicoflagellates.

Diatom assemblages were dominated by a meroplanktonic component consisting of *Actinocyclus ehrenbergii*, *Stephanopyxis turris*, *Actinoptychus undulatus* a.o. Assemblages varied highly within short intervals, perhaps representing species succession in sediments underlying coastal upwelling (Schuette and Schrader, 1979). A laminated section in Sample 479-39, CC revealed the following assemblages within 5 cm: (1) *Thalassiosira oestrupii* (over 90%), (2) *T. oestrupii* (~50%) and an oceanic component (~20%), and (3) *S. turris*, with almost no *Chaetoceros* bristle fragments or spores. Similarly high variation within the varved interval of Core 479-36 was observed. An increase in the oceanic component, with *Pseudoeunotia doliolus* and *Rhizosolenia bergonii*, also commonly occurred and will be useful in determining the influence of oceanic Pacific waters at distinct intervals.

Displaced marine benthic species were frequent throughout this site, whereas I found no displaced freshwater diatoms. Reworked(?) older index fossils were observed only in Sample 479-35, CC where *R. barboi* and *R. curvirostris* were abundant. This period of co-occurrence, representing an evolutionary transition, is established in the North Pacific at around the Pliocene/Pleistocene boundary. Both species do occur only in colder environments.

Though *Nitzschia fossilis* datum was not observed at this site, the *Mesocena quadrangula* extinction datum, placed at ~0.7 Ma, did occur in Sample 479-32, CC and the first occurrence datum, ~0.93 Ma, in Sample 479-39, CC. Thus, the oldest diatom-bearing sediments in Core 479-43 probably do not date from earlier than ~0.99 Ma (the extinction level of *R. matuyamai*). I found *N. reinholdii*, together with *R. barboi*, in Sample 479-43-2, 58-60 cm. *M. quadrangula* occurred first in Sample 479-40-6, 7-9 cm and disappeared after Sample 479-23-2, 85-87 cm. *R. matuyamai* was first observed in Sample 479-28-6, 41-43 cm and disappeared after Sample 479-28-4, 104-106 cm. *N. reinholdii* was last found in Sample 479-21-2, 74-76 cm; *N. fossilis* disappeared after Sample 479-16-3, 64-66 cm; and *P. doliolus* ranged throughout the diatom-bearing section.

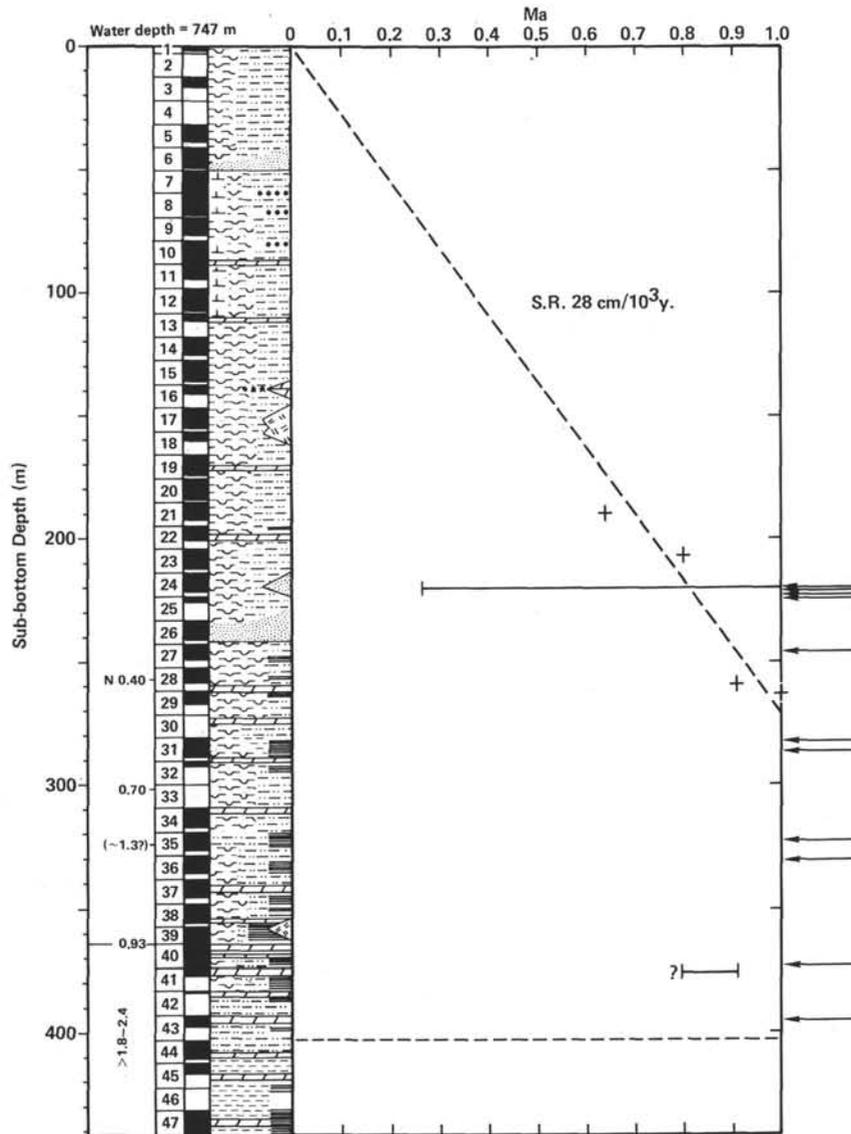


Figure 6. Occurrence of diatom/silicoflagellate datum levels at Site 479 and inferred sedimentation rate. Arrows indicate cold water influx.

Distinct colder water intrusions were marked by the presence of *R. curvirostris* (*R.c.*) and/or *R. barboi* (*R.b.*) in the following samples: 479-43-2, 58–60 cm (*R.b.*); 479-36-1, 59–61 cm (*R.b.*); 479-35-3, 90–92 cm (*R.c.*); 479-31-2, (?) (*R.c.*); 479-31-1, 38–40 cm (*R.c.*); 479-27-3, 72–74 cm (*R.c.*); 479-24-7, 26–28 cm (*R.c.*); 479-24-6, 45–47 cm (*R.c.*); 479-24-4, 104–106 cm (*R.c.*); 479-24-3, 72–74 cm (*R.c.*). Floods of the silicoflagellate *Distephanus speculum* also suggest cold water intrusion in Sample 479-40-4, 78–80 cm.

#### Site 481

Siliceous phytoplankton skeletons were abundant and mostly well preserved in the hemipelagic sequences drilled at Site 481 to a depth of 328 meters sub-bottom (Fig. 7). Turbidite and mud-flow sequences contained less abundant and moderately well-preserved diatom assemblages. The oldest recovered sediments, from Sample 481-31-1, 134–135 cm, contained well-preserved com-

mon diatoms. *Pseudoeunotia doliolus* occurred frequently in this sample, but though I studied about 500 individuals, I did not find one resembling the shape of its ancestor *Nitzschia fossilis*. This, in addition to the absence of *Nitzschia reinholdii*, indicates that the whole section above Core 481-31 is younger than 0.63 Ma. Diatoms and silicoflagellates were the first microfossils to disappear above the sill contact in Core 481-12 (contact is in Core 481-14). They occurred in trace amounts in Core 481-18 and constituted ~15% in Core 481-20.

Laminated pieces of hemipelagic sediments occurred in Cores 481-29 and 481-30. This lamination might indicate stagnant conditions, with depleted oxygen near the bottom preventing the sediments from being bioturbated. I counted about 28 laminae per cm in pieces from Sample 481-30-5, 27–29 cm, this representing approximately 14 years of deposition. Detailed analysis of individually separated white and greenish laminae revealed that the white laminae contained a diatom floral

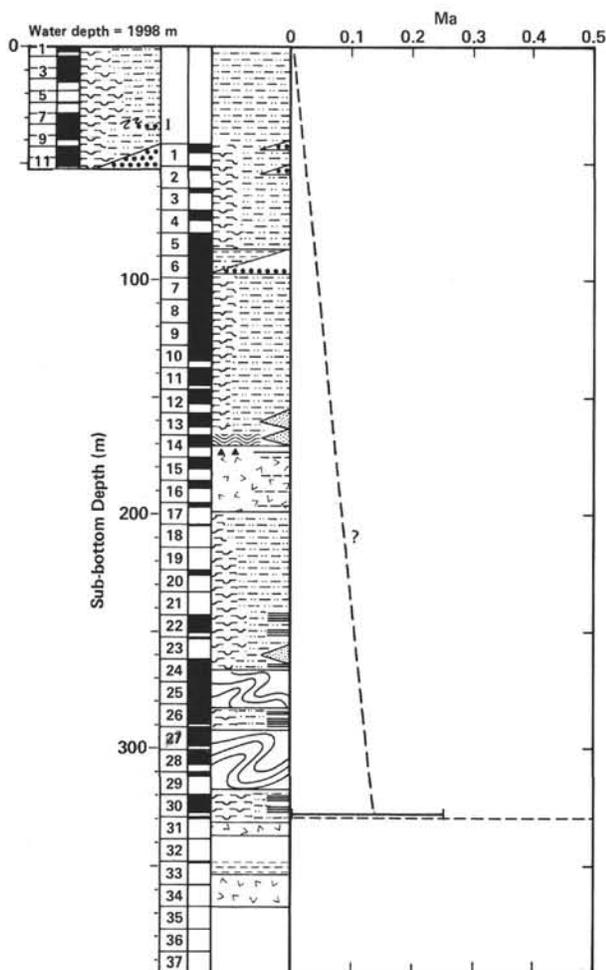


Figure 7. Occurrence of diatom datum levels at Site 481 and inferred sedimentation rate.

assemblage almost identical to the greenish ones, the only obvious difference being in clay content: ~60% in greenish laminae and ~10% in white laminae. Both laminae contained calcareous nannofossils. I conclude that the mechanics of varve formation at this site for this period must be different from those at Site 480. In Site 481, the mechanics proposed by Calvert (1966) seem to apply, that is, diatom production is uniform over the two seasons represented by adjacent laminae, with terrigenous input during the wet season responsible for the formation of distinct varves.

Diatom assemblages in the hemipelagic sequences of Hole 481 consisted mostly of *Coscinodiscus nodulifer*, *Pseudoenotia doliolus*, *Thalassionema nitzschioides*, *Cyclotella striata*, *Actinoptychus undulatus*, *Octactis pulchra* (silicoflagellate), *Thalassiosira oestrupii*, and rare *Rhizosolenia bergonii* and *Thalassiosira lineata* a.o. Diatom assemblages in the hemipelagic sequences of Hole 481A are generally similar, and, in a few cases only, showed enrichment by an oceanic component, with *Coscinodiscus nodulifer*, *Nitzschia marina*, *Ropelia tessellata*, and *Thalassionema nitzschioides* var. *parva* (Samples 481-4,CC; 481-9,CC; and 481-11,CC). An-

other laminated piece, from Core 481-30-4, 2–4 cm, showed 16 white and greenish laminae in 1 cm. Planktonic foraminifers were enriched in the white layers and could easily be detected in broken surface pieces. Occasionally I observed white to greenish-white bands of diatomaceous ooze within a muddy diatomaceous ooze (e.g., in Sample 481-8-3, 33–34 cm). These bands, sometimes 1 cm thick, contained an excellently preserved diatom assemblage with floods of *Chaetoceros* bristles and thin *T. nitzschioides* specimens. Evidence that these layers are not redeposited includes the abundance of delicate forms and the absence of marine-benthic species. The layers may represent times of increased productivity and decreased terrigenous input.

Core 481-2 contained numerous layers of redeposited muddy diatomaceous ooze. The white top layers contained about 75% diatoms and only about 10% clay. Diatom assemblages were again well preserved, with no indication of transport, which would have dissolved *Chaetoceros* bristles. The absence of any marine benthic species and the preservation of fragile diatomaceous fragments indicate an autochthonous character for these assemblages; this might be explained by increased productivity associated with decreased terrigenous input.

As was the case in samples from Sites 479 and 480, components of the well-preserved diatom assemblages *Chaetoceros* (bristles), *T. spp.*, and *Thalassiothrix* spp. were mechanically broken into small fragments by the grazing of zooplankton. This aggregation (which promotes high settling rates) may, together with downwelling fronts, account for rapid sedimentation through the water column and quick burial of the sediment/water interface.

Surprisingly, no diatomaceous layer with excellently preserved assemblages contained visible fecal pellets, which may result from rapid oxidation and degradation of organic matter at the sediment/water interface. I did not calculate sedimentation rates for this site since no diatom levels were observed.

#### Site 480

A total of 152 meters of hemipelagic sediments were continuously piston cored at Site 480, recovery being generally above 80% (Fig. 8). The section can be visually subdivided into finely laminated and homogeneous intervals, the spacing between which seems not to be cyclic. All sediments except for a few narrow sand and turbidite layers are very rich in diatoms and silicoflagellates, offering a unique opportunity to study the floral changes in detail and to relate these to local and over-regional climatic events.

The varved sediments present a good opportunity for defining an absolute chronology by counting annual laminae pairs. The first test was to confirm that laminated sediments in the deeper cores represent varves as defined for short cores from the Gulf by Calvert (1964) and as later amended by Baumgartner et al. (1978).

White and greenish laminae were separated by slicing them as accurately as possible from a 0.5-cm interval of diatomaceous mud from Sample 480-29,CC. A total of

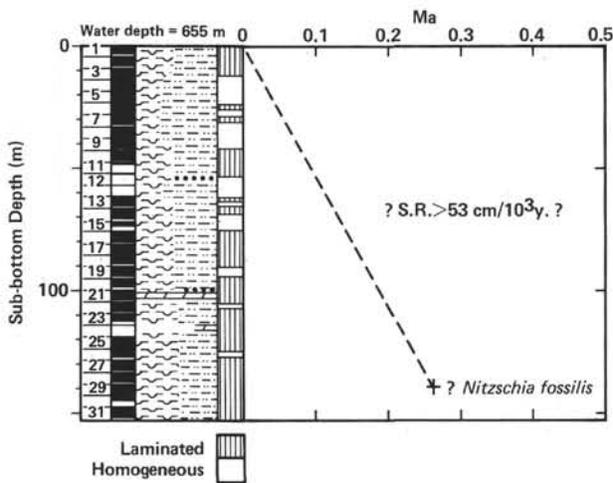


Figure 8. Occurrence of diatom datum levels at Site 480 and inferred sedimentation rate.

26 laminae were mounted separately and analyzed microscopically for diatom content. Characteristics of the two types of laminae are as follows:

#### Greenish laminae

- 1) Contain sublaminiae.
- 2) Are thicker than white laminae.
- 3) Contain abundant clay.
- 4) Opal phytoplankton excellently preserved.
- 5) Contain phytoplankton; primarily *Chaetoceros* spores, meroplanktonic species, *Thalassionema nitzschioides*, and oceanic species in much lower abundance.

#### White laminae

- 1) Contain no sublaminiae.
- 2) Contain no clay.
- 3) Show poor preservation of opal phytoplankton.
- 4) Contain phytoplankton—primarily *Coscinodiscus nodulifer/asteromphalus*.

On the basis of sediments underlying areas of recent coastal upwelling off Peru (Schuette and Schrader, 1979) and southwest Africa (Schuette, 1980) which contain similar floral elements, I interpret the greenish laminae with well-preserved meroplanktonic diatoms to represent coastal upwelling seasons, whereas I believe the white laminae with poorly to moderately preserved, almost monospecific assemblages (*Coscinodiscus nodulifer* in Sample 480-29,CC and *C. asteromphalus* in Sample 480-16,CC) represent nonupwelling seasons.

The greenish (coastal upwelling) laminae (Type 1) are generally thicker (in Samples 480-29,CC and 480-16,CC) than are the white ones, containing, in addition to the well-preserved diatom component, a substantial amount of clay (up to 60%). The white (nonupwelling) laminae (Type 2) are thinner, containing almost no clay or silty terrigenous components. Frequently, as will be discussed, calcareous nannofossils were observed with the white laminae. The white laminae should represent times of lower sedimentation.

The 26 laminae distinguished visually in Sample 480-29,CC can be characterized on the basis of the criteria previously outlined, as follows: (1) nonupwelling (2) upwelling, (3) nonupwelling, (4) upwelling, (5) nonup-

welling, (6, 7, 8) upwelling, (9) nonupwelling, (10, 11) upwelling, (12) nonupwelling, (13) upwelling, (14, 15) nonupwelling, (16) upwelling, (17) nonupwelling, (18) upwelling, (19) nonupwelling, (20) upwelling, (21, 22, 23) nonupwelling, and (24, 25, 26) upwelling. In summary, a total of 9 nonupwelling seasons and 9 upwelling seasons could be distinguished.

The sublaminiae within the greenish intervals is faint, representing species fluctuations and succession during the highly variable upwelling season. Several typical populations within these "upwelling" layers could be distinguished: (1) *Chaetoceros* spores (<80%), meroplanktonic component (~10%); (2) *Pseudoeunotia doliolus* (40%), *Chaetoceros* spores (30%); (3) *Chaetoceros* spores (50%), *Thalassionema nitzschioides* (thin) (30%), *Coscinodiscus nodulifer* (10%); (4) *Chaetoceros* spores (40%), *Thalassiosira oestrupii* (20%).

The white layers are generally homogeneous and contain only one or two species, *Coscinodiscus nodulifer* and/or *P. doliolus*. The size distribution of *C. nodulifer* seems to be climatically controlled, and these layers offer one a good opportunity to correlate the size distribution in the Gulf to that of the eastern Equatorial Pacific, where it has been tied into the  $\delta^{18}\text{O}$  stratigraphy (Burckle and McLaughlin, 1977; compare also Murray and Schrader, this volume).

Four smear slides from a homogeneous section contained the following distinct floras (in the discussion, A = abundant, T = trace, R = rare, F = few, and C = common).

1) Sample 480-4-1, 70 cm: *C. nodulifer* (A), *Pseudoeunotia doliolus* (T), no marine benthics, and no freshwater diatoms. Preservation was poor (representing a nonupwelling season).

2) Sample 480-4-2, 15 cm: *Chaetoceros* spores (C), *P. doliolus* (F), *T. oestrupii* (F), *Rhizosolenia semispina* (R), marine benthics, excellently preserved ~2%, and freshwater diatoms ~1%. Preservation excellent (representing an upwelling season).

3) Sample 480-4-2, 70 cm: *Thalassionema nitzschioides* (C), *Cyclotella striata* (F), *Chaetoceros* spores (F), *P. doliolus* (F), *Coscinodiscus nodulifer* (R), trace marine benthics poorly preserved, no freshwater diatoms. Preservation moderate.

4) Sample 480-4-3, 70 cm: *C. nodulifer* (A), marine benthics (T) (poorly preserved), no freshwater diatoms. Preservation poor (representing a nonupwelling season).

Calcareous nannoplankton, because of their oceanic habitat and environmental requirements as compared with diatoms, should be more common in those intervals interpreted as nonupwelling. The following percentages were found in the smear slide samples just discussed: Sample 480-4-1, 70 cm: ~10% and Sample 480-4-3, 70 cm: ~12% nannofossils.

A slab of Sample 480-16,CC about 1 cm thick revealed 12 white and 11 greenish layers; again, the greenish layers were generally 50% thicker and showed a sublaminiae similar to that in Sample 480-29,CC.

Another distinct feature—apparent on dry laminated pieces though not on the original wet samples (even when these were examined microscopically)—was a

layer composed of fish scales at the bottom of each greenish layer (Fig. 9). Such cyclic occurrence of fish scales might be related to the depletion of available phytoplankton at the termination of an upwelling cycle.

Three other samples from a homogeneous section were available from Core 480-14:

1) Sample 480-14-1, 100 cm: clayey diatomaceous ooze: *T. nitzschioides* (A), *Thalassiosira oestrupii* (F), *Chaetoceros* spores (F), *Octactis pulchra* (F), *Cyclotella striata* (R), preservation of opal phytoplankton excellent, with the presence of *Skeletonema costatum* as one index. Surprisingly, this sample contained about 10% calcareous nannoplankton, differing in this high proportion from otherwise similar samples (compare previous discussion).

2) Sample 480-14-1, 110 cm: dark diatomaceous ooze with volcanic glass: *Thalassionema nitzschioides* (A), *Chaetoceros* spores (R), *Octactis pulchra* (F), meroplanktonic component (T), preservation of opal phytoplankton excellent. Again, as at 100 cm, high values (about 7-8%) for calcareous nannoplankton were observed.

3) Sample 480-14-2, 70 cm: muddy diatomaceous ooze: *T. nitzschioides* (A), *Chaetoceros* spores (C), *Dityocha fibula* (F), marine benthics ~2% (moderately well preserved), *Actinoptychus undulatus* (F), *Pseudoeunotia doliolus* (F), *Cyclotella striata* (F), *Coscinodiscus nodulifer* (R), preservation moderate.

The homogeneous interval in Sections 480-14-1 and 480-14-2 may carry the seasonal upwelling/nonupwelling signal, but it is blurred by terrigenous input. On the other hand, the relatively high percentages of calcareous nanofossils may indicate decreased primary productivity and a consequent decrease in intensity of the oxygen minimum, allowing ultimately for the possibility of bioturbation at the site.

Thus far I have detected no enrichment trends of cold or warm water species. Biostratigraphic index species were observed only in Sample 480-29, CC where about 1% of the *Pseudoeunotia doliolus*—*Nitzschia fossilis* individuals consisted of *N. fossilis*. Because of the scarcity of these two species in Core 480-P29, and the fact that *P. doliolus* sometimes occurs also in symmetrically shaped valves, this biostratigraphic interpretation is speculative.

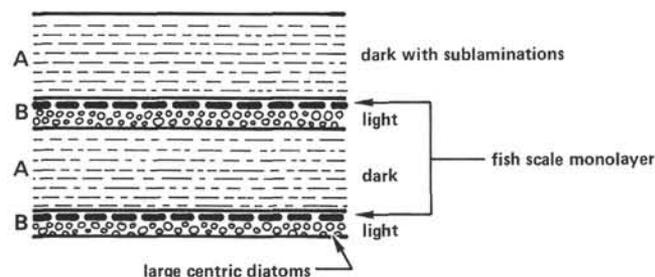


Figure 9. Schematic laminae sequence from Samples 480-26, CC and 480-16, CC with an alternation of white, diatomaceous, and dark terrigenous-rich laminae. The upper boundary of the white laminae is represented by a monolayer of fish scales. The dark laminae are thicker and show sublamination.

## Summary and Discussion

Calvert's (1966) assumption that diatom production in the Central Gulf is constant over most of the year could be tested at Hole 481A, where we observed varved units in Section 481A-30-5. The diatom flora in both the white and greenish layers (a total of 28 laminae were observed in a 1.5-cm thick laminated piece of sediment) were almost identical, the only obvious difference being clay content (~60% clay in the greenish layer and ~10% clay in the whitish layers). Calvert's interpretation depended upon core samples taken between 28° and 29°N in a region of deposition strongly affected by tidal mixing (Ballenas Channel), which supports persistent phytoplankton production throughout the year. The mechanics of varve formation for the entire circum-Central Gulf cannot be attributed simply to seasonal terrigenous floods (and continuous diatom production). Seasonal diatom blooms in addition to seasonal terrigenous input affect varve formation in certain areas of the Gulf. Both signals may be highly variable and may differ depending on the area of deposition. Varve formation on the Guaymas Slope is controlled by seasonal coastal upwelling and seasonal terrigenous input.

The rainy season in the area of Guaymas has precipitation values of about 50 mm and lasts from July through September (Roden, 1964). Precipitation decreases during October and November and increases slightly during December; the weather is generally dry from January through June. The main terrigenous load being transported into the Gulf by the Yaqui River should follow this pattern closely.

Data on wind patterns and surface currents are limited, but a general picture can be obtained using CALCOFI data. During the dry season (January through June), northwesterly winds prevail, causing a general northwesterly surface current distribution. This wind pattern is thought responsible for the formation of extended coastal upwelling along the eastern side of the Gulf. During the rainy season (July through December), southeasterly winds together with southeasterly currents produce coastal upwelling along the western side of the Gulf.

"Recent" sedimentation rates are on the order of 250 cm/10<sup>3</sup> years (Baumgartner, et al., 1978). "Fossil" sedimentation rates, using varve counts from Core 16, revealed 11 upwelling and nonupwelling laminae within 1 cm and are on the order of 90 cm/10<sup>3</sup> y. Counts from Core 29 revealed 9 upwelling and 9 nonupwelling laminae within a 0.5 cm-interval, suggesting a rate of approximately 50 cm/10<sup>3</sup> y. Compaction rates as determined by porosity measurements are on the order of 15% below 40-50 meters downhole. They could not account for the high observed differences in sedimentation rates, and it is obvious that both productivity and terrigenous input oscillated during the period under discussion.

The occurrence of laminated and nonlaminated intervals associated with turbidite sequences puts into

question the placement of the sediment sequence in a proper chronological framework. However, at present, I am assuming that homogeneous sequences are associated with low sea level stands and laminated intervals with sea level stands similar to today's (Barbados I, ~82,000; II, ~105,000; III, ~127,000; another terrace, ~60,000; Bé, et al., 1976).

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