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LATE MIOCENE CALCAREOUS NANNOPLANKTON

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TECHNICAL REPORT

*Prepared for the National Science
Foundation under Grants OCE 77-
82149 and OCE 79-18286 (CENOP).*

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Approved for Distribution:

John I. Ewing, Chairman
Department of Geology and Geophysics

PREFACE

This is a draft of the manuscript we submitted for publication in "Cenozoic Paleooceanography Symposium" volume. In response to a number of requests, we are circulating it as a technical report to make the techniques we describe and the results and data we have accumulated immediately available. Although this manuscript has already been reviewed, we welcome and would greatly appreciate your critical comments and will try to incorporate any suggestions in the published paper.

ABSTRACT

An analysis of the variability in the composition and distribution of Pacific Late Miocene calcareous nannoplankton about their average biogeography shows that there are primarily two environmental factors causing that variability, climate and dissolution. Climate produces a latitudinal, biogeographic differentiation of the Late Miocene nannoflora, while selective dissolution superimposes a bathymetric differentiation of the nannoflora on that due to climate. Together, these two factors produce three distinct Late Miocene nannofloral assemblages, a high-latitude, temperate assemblage characterized by Reticulofenestra pseudoumbilica and Coccolithus pelagicus, and two tropical assemblages, their differences in composition depending on water depth and surface-water productivity: (1) in shallower water and beneath areas of higher organic productivity there is an undissolved assemblage characterized by sphenoliths, small elliptical placoliths and Coccolithus pataecus; (2) in deeper water and areas of lower productivity there is a dissolved assemblage dominated by discoasters.

Selective dissolution produces most of the apparent biogeographic variation in Pacific Late Miocene nannoplankton compositions, the variation in compositions observed between the 17 sites studied. Dissolution preferentially removes the more soluble constituents of the tropical nannoflora so that increasing dissolution tends to give tropical nannoflora a cooler water aspect. At the same time, selective dissolution shifts the composition of the warmer water component towards

its more resistant taxa. This produces an assemblage typical of deeper tropical waters and areas of lower productivity.

Nannoplankton records show a period of greatly decreased calcite dissolution in deep tropical and temperate South Pacific sites between 8 and 10 m.y. ago. This decrease is strongly correlated with an increase in the $\delta C-13$ composition of Pacific deep waters. Calcite dissolution increased during this same period in the deep North Pacific.

Nannoplankton records of Late Miocene climate in the tropics are distinctly different from those at higher, south temperate latitudes. Tropical records show a sharp warming in the earliest Late Miocene after a generally cool late Middle Miocene. This was followed by a temporary cooling, nearly to Middle Miocene levels, about 7 m.y. ago. Toward the end of the Late Miocene, the tropical Pacific warmed again and remained warm into the Pliocene. Warming of temperate climates was much more gradual. Not until latest Miocene did the southern temperate latitudes warm appreciably; they continued warming into the Pliocene. This rapid warming of the tropics and gradual warming farther south produced a temporary increase in the latitudinal climatic gradient across the southern Pacific Ocean 8 to 10 m.y. ago.

On the basis of the nannoplankton oceanographic records we postulate that beginning 10 m.y. ago the production of deep and bottom waters in the Southern Ocean increased. This produced the northward decrease in calcite preservation, the increase in benthic $\delta C-13$, and the strong climatic gradient across southern latitudes. This period of increased deep Pacific circulation ended 7.5 m.y. ago.

INTRODUCTION

A primary objective of CENOP (Cenozoic Paleoceanography) is to characterize, paleontologically, the preglacial Early Miocene and glacial Late Miocene oceans. The direct way of doing this, the approach most favored by CENOP, is to construct synoptic biogeographic maps for these times of special interest. Although this approach is conceptually simple, it has the strict requirement that any errors in time correlation be somewhat less than the time scales of biogeographic variability. Identification of such precisely correlatable time horizons throughout the world ocean is a major task, one which occupied most of CENOP's research effort during its first two years.

The study we present here creates and follows an alternate strategy. Since the accuracy of reconstructions of Miocene oceans is so dependent on the extent to which time can be precisely resolved, we designed an approach that minimizes the effects of any such limitation. The basis of our strategy is the characterization of the Late Neogene oceans by their average biogeographies.

Certain attributes, such as the natural frequencies of ocean change, cannot be determined without a precise time base. However, other attributes, such as the source, amplitudes, modalities, and spatial variability of these changes can be determined without a precise chronology simply

by an analysis of the manner in which the ocean varies about its average state. Biogeographic data averaged over time intervals are much less susceptible to errors introduced by miscorrelation than are synoptic data on a single time horizon. Furthermore, a mean biogeography based on a number of samples averaged throughout a time interval is more representative of that time as a whole than one determined for a precisely defined, but arbitrarily selected, time horizon.

Ultimately, CENOP aims to interpret Early and Late Miocene biogeographic patterns in terms which reflect the dynamics of the preglacial and glacial world oceans. This paper presents the results we obtained for the Late Miocene of the Pacific. It gives our interpretations of the environmental factors which determine the assemblage compositions and distributions of Pacific calcareous nannoplankton, and it outlines the Late Miocene oceanography of the Pacific that these fossils record.

METHOD

We chose to begin our work in the Pacific Ocean because its surface circulation pattern is relatively simple compared to the number of Deep Sea Drilling sites available to study it. The distribution of suitable drill sites in the Pacific compared to the scale and complexity of its surface circulation is more closely spaced and more uniform than in other oceans.

We chose to use the calcareous nannoplankton as our source of paleontological information primarily because the success of our approach depends on analyses of large numbers of samples from many locations and, compared with other fossil groups, only the relative ease with which a census of nannoplankton is obtained makes this feasible.

A broad and uniform representation of the Pacific Late Miocene nannoplankton was our only sampling criterion. Our estimate of Late Miocene biogeography is based on averages of the calcareous nannoplankton compositions of 603 samples from 17 Pacific Deep Sea Drilling Project (DSDP) sites (figure 1, table 1). Our inferences about the oceanographic significance of the Late Miocene Pacific nannoflora are based on analyses of this average biogeography and on variations observed in the nannoplankton compositions about this average.

Data

Census data for each sample consist of the relative abundances of 15 nannoplankton taxa (table 2) among the first few hundred individuals encountered on a traverse of a smear slide. The total number of individuals counted for each sample was determined for each sample as the number that could be counted in a convenient period of time. The precision of the estimated abundances was evaluated later (Mosimann, 1965) and additional counts were made if necessary. This approach allowed us to optimize the trade off between the total number of samples counted and the precision of the census data for each sample. At two sites, 173 and 278, many samples were so poorly preserved that an accurate census could not be made in a reasonable period of time. For many of those samples only presence-absence data were collected.

Although the number of individuals counted in samples ranges from only a few to a few hundred, our first interest here is in the average composition of the Late Miocene nannoplankton at each site. Since about 35 samples were counted at each site, the total number of individuals that the average compositions are based on ranges from several hundred to several thousand.

Analysis

Paleobiogeographic data typically consist of large numbers of variables, whether a determination involves morphometric measures on one individual or a census of relative abundances of hundreds of individuals. This highly multivariate character gives paleobiogeographic data its potential to reflect and record many different aspects of complex paleo-oceanographic systems. It also complicates its description, interpretation and comparison with other kinds of data. One popular and productive solution to this problem has been applications of principal components analysis to various measures of covariation between the variables (or measures of similarity between the samples), or some elaboration of the technique such as factor analysis (Davis, 1973). This general method has several distinct advantages in the context of our paleobiogeographic data.

First, these highly multivariate, strongly intercorrelated data are reduced as principal components to a few, uncorrelated composite variables. This greatly simplifies its description.

Second, principal components describe the structure of these data in a manner which identifies its primary sources of compositional variation.

Finally, since principal components analysis and its variants are, as we use them, merely data transformations, once the essential variation in a body of data has been described

and interpreted in its reduced form, it can be "untransformed" and presented in terms of the original paleobiogeographic data (Haq and Lohmann, 1976). This is a useful feature for coworkers without an intuitive understanding of the biogeographic significance of eigenvalues and principal components, and it facilitates comparison of our results with their data.

In this study we used principal components analysis in a number of quite different ways:

1. The average nannoflora at each site was determined as the 1st Q-mode principal component of all samples at that site (Lohmann, 1978; Thunell and Lohmann, 1979). We chose this rather than a vector of means, partly because the associated higher order principal components summarize the variation at each site much more efficiently than a vector of variances, but mostly because the scaling and criteria involved in determining the 1st Q-mode principal component are more consistent with those in our subsequent analyses. The observed relative abundances are scaled so that each sample vector has unit length. This gives each sample equal weight in determining the composition of the 1st principal component. This component, by design, has a proportional composition that is most similar to the observed proportional compositions of the samples. The scaling procedure also enhances the influence that the relatively more abundant taxa, and therefore the more precisely estimated taxa, have on the outcome.

Our first step, then, was to determine the 1st Q-mode principal component of the samples at each of 17 different sites.

2. Variation among the average nannofloral compositions of the sites, the average biogeography itself, was determined by the first three Q-mode principal components of the 17 site averages (each average a previously determined principal component). Note that in step 1 we were primarily interested in a summary of the nannofloral compositions of all samples at a site, so we used the 1st Q-mode principal component for each site. In step 2 we are interested in biogeography, in the compositional variations among the sites. That variation is described by the 2nd and 3rd Q-mode principal components from a subsequent analysis, this time of the 17 previously determined 1st Q-mode principal components! The 2nd and 3rd components describe most of the variation exhibited among the site averages, and by examining their geographic distribution we get an indication of the environmental factors causing it.

3. In order to examine the variability in nannofloral compositions within each site in the context of its average biogeography and to evaluate it in terms of the environmental factors to which it is attributed, the composition of all the original samples described in terms of these three principal components was estimated by projecting each sample vector onto each of the three principal component axes ("estimated factor loadings" of Klován and Imbrie, 1971).

4. The pattern of variation in nannofloral compositions at each site, expressed in terms of the three Q-mode principal components of site averages, was summarized by constructing ellipses reflecting the covariation among the components (Sokal and Rohlf, 1969; Dagbert and David, 1974). Each covariation ellipse projected on a principal components plane is centered at the mean composition of the site. The orientation of the ellipse, reflecting the sources of variation, was determined by the "D-mode" principal components, the scaled eigenvectors of the variance-covariance matrix (D), of nannoplankton compositions as expressed in terms of the three Q-mode principal components of site averages. The eccentricity of each ellipse, reflecting the degree of covariation between the sources of variation, is determined by the variance (eigenvalue) associated with each D-mode principal component axis: the major and minor axes of each ellipse are scaled by the square root of their associated eigenvalues.

5. Records of oceanographic change may not be the same from place to place, either because there are different influences affecting different places or because different places respond differently to common influences. While examining the spatial distribution of records of different causal influences gives us some indication of their identity, identifying any spatial patterns or systematic differences among records of the ocean's response to a common influence gives us some insight into the way the ocean works. The

different modes of variability exhibited by the nanoplankton records and the spatial patterns of that variability were determined by the eigenvectors of a matrix of correlations between the nanoplankton time series, essentially an R-mode principal components analysis (Davis, 1976; Lohmann, 1981a).

Nanoplankton compositions of the site "averages" (1st Q-mode principal components of individual sites) and of the rotated principal components (varimax factor assemblages) describing variation among sites and the abundances of the varimax factor assemblages at each site are all presented as percent to facilitate comparison with census data.

All computer programs used for these analyses are listed and described in a Woods Hole Oceanographic Institution Technical Report (Lohmann, 1980). Programs used at each step are indicated in Appendix 2.

TAXONOMY

A taxonomy was designed specifically with the needs of this project in mind. Abundant, consistently recognizable taxa are identified at the specific level. Uncommon species are lumped into broader, usually generic, categories. Where genera are difficult to distinguish with light microscope, usually because of their small size, they are lumped into supergeneric, morphologic categories. Rare taxa, even if distinct, are ignored since, with the analytical techniques we use, they have a negligible influence on the result. This taxonomy is comprehensive in that it describes nearly the entire nannoflora. It is robust in that most categories can be recognized even in moderately dissolved assemblages. Since the abundant taxa recognized at species level tend to be stratigraphically long-ranging, and since the short-ranging taxa are either ignored because they are rare or lumped into longer ranging generic and supergeneric categories, evolution is effectively excluded as a major source of variation in our data. This taxonomy represents our attempt to balance consistency and taxonomic refinement against application to a wide variety of samples and the effort spent to collect the data.

The relative abundances of 15 categories of calcareous nanoplankton (table 2) were tabulated on the basis of the following taxonomy. Major taxa are illustrated in Plates 1 and 2. The census data are listed in Appendix 1.

A. Reticulofenestra group

Two species are recognized: R. haqii and R. pseudoumbilica. R. haqii is described by Backman (1978).

When Gartner (1967b) described R. pseudoumbilica, he noted great variability in the diameter of this form's central opening. Photographs 15 through 18 in Plate 2 illustrate this variability. Coccolithus gelidus was defined by Geitzenauer and Huddlestun (1972) as a species from the Late Pliocene. Backman (1978) revised this species which occurs throughout the Late Miocene and Early Pliocene and renamed it Reticulofenestra gelidus. To minimize taxonomic problems in our counts, R. pseudoumbilica is broadly interpreted to include R. gelidus.

B. Coccolithus minutulus, Cyclococcolithus neogammation, Rhabdosphaera, Discolithina, Oolithotus and Scyphosphaera

Since these are very rarely encountered in our samples, we did not include them in our analysis.

C. Cyclococcolithus macintyreii and Cyclococcolithus leptoporus

C. macintyreii is described by Bukry and Bramlette (1969). To avoid confusion between these two taxa we identify them in both natural and cross polarized light (Gartner, 1967a). When recrystallization occurs, it is often difficult to differentiate between the two.

D. Coccolithus pelagicus group

This taxon is broadly defined and includes all related species such as C. eopelagicus and C. miopelagicus. (Haq and Lohmann, 1976)

E. Sphenolithus spp., Helicopontosphaera spp., Discoaster spp., Ceratolithus spp. and Amaurolithus spp.

The species belonging to each of the above genera are not distinguished.

F. Cyclolithella rotula

C. rotula was often found in well-preserved samples. We used the species concept of Haq and Berggren (1978). As this is a somewhat difficult taxon to recognize after recrystallization or dissolution, it is possible that some C. rotula have been included in the small circular to subcircular placolith group.

G. Small elliptical placoliths

This group includes all elliptical placoliths smaller than R. haqii (approximately 5 microns). This group is probably made up of forms belonging to the genera Dictyococcites and Reticulofenestra.

H. Small circular to subcircular placoliths

This group includes all the circular placoliths smaller than C. rotula in size. Most of the forms in this group probably consist of the genera Coccolithus and Cyclococcolithus.

I. Dissolved and badly preserved coccoliths

Any coccolith which could not be readily identified because of poor preservation was assigned to this category.

J. Unidentified larger nannofossils

All large nannofossils which could not be identified with certainty.

K. Coccolithus pataecus, Coccolithus radiatus, and Umbilicosphaera jafari

To recognize and distinguish these taxa, phase contrast was used. C. pataecus is described by Gartner (1967b). All three taxa are illustrated and discussed by Haq and Berggren (1978).

STRATIGRAPHY

The importance of identifying time-correlatable horizons throughout the world ocean was recognized at the beginning of the CENOP project. The main requirement is that the error in time-correlation must be less than the time scales of biogeographic variability. Such a horizon has been identified and characterized isotopically for the Late Miocene and is a focus for CENOP biogeographic efforts (Keigwin, 1979; Bender and Keigwin, 1979; Haq et al., 1980).

The biogeographic results presented here represent a much longer interval of time, about six million years, the entire Late Miocene. At the outset our only stratigraphic requirement was that samples were Late Miocene. For this we usually found stratigraphies published in the DSDP Initial Reports adequate. Where possible, we selected stratigraphic sequences where both the Middle/Late Miocene and Late Miocene/Pliocene boundaries were recognized so that we could more evenly sample the entire time interval.

This minimal stratigraphy was satisfactory for us to achieve our initial objectives, determination of an average Late Miocene biogeography and an analysis of the variability about that average. It also allowed us to make a rough comparison of 11 complete Late Miocene time series and to analyze their spatial variability. Since this comparison is directly limited by the degree to which the time series can be intercorrelated, a detailed comparison must incorporate much more stratigraphic information (Lohmann, 1981b).

RESULTS

Average Biogeography

The composition of the 1st Q-mode principal component for each site, the "site average", is listed in table 3. The first three Q-mode principal components of these 17 site averages (1st Q-mode principal components) account for 93% of the variability observed in their nannofloral compositions (figure 2). The 1st component is approximately an average of the 17 sites. If the Late Miocene nannoflora of the Pacific were to be described by a single sample, its composition would be that of this 1st component. The 2nd and 3rd components describe the variability about this average, and their distributions reflect the average biogeography of Pacific Late Miocene nanoplankton.

The 2nd principal component describes the reciprocal variation between more small elliptical placoliths, sphenoliths, R. pseudoumbilica and C. pataecus in shallower sites and more discoasters, dissolved coccoliths, and C. leptoporus in deeper sites (figure 3). This component evidently describes the selective dissolution of the less resistant calcareous nanoplankton taxa as samples originate from deeper and deeper sites lying in more corrosive bottom waters and beneath areas of lower sedimentation of biogenic calcite. Although sphenoliths are usually more resistant to

dissolution, the species we encounter in the Late Miocene (S. abies and S. neoabies) are the smaller, more delicate forms that are apparently more susceptible to dissolution than the group as a whole.

The degree of selective dissolution implied by the magnitude of this 2nd component, if it is attributed to dissolution, is consistent with the general pattern of dissolution seen in the modern ocean. Sites 284, 207A, 208, 158, 281, 289, and 317B, all above 2700 m, show little indication of dissolution; below that depth the degree of dissolution indicated by the magnitude of the 2nd principal component changes predictably with location. Sites 71 and 77B exhibit relatively little dissolution for their great depth, below 4200 m, presumably due to their location in the eastern equatorial Pacific. Today the calcite compensation depth (CCD) is deepest in the eastern equatorial Pacific, being depressed by high production and accumulation of biogenic calcite. Site 319 lies at the same depth nearby but just outside the equatorial zone of high productivity. The magnitude of the 2nd principal component for Site 319 implies and its depth and location predict greater dissolution. Sites 292 and 55 exhibit relatively severe dissolution for their shallow depth, above 3000 m, presumably because they lie in the western equatorial Pacific. Today the CCD is shallow there due to lower productivity. Compared with all other sites dissolution, as indicated by the 2nd principal component, at higher latitude,

temperate sites 284, 281, 296, 173, 206, 278 and 310 is relatively greater at shallower sites and intermediate at depth. There is even some indication that, as it does today (Lisitzin, 1972), the Late Miocene lysocline sloped from shallower in the North Pacific (site 310) to deeper in the south (sites 206, 278).

The 3rd Q-mode principal component of the site averages describes the reciprocal variation between more sphenoliths, small elliptical placoliths and discoasters in low-latitude, tropical sites and more R. pseudumbilica, dissolved coccoliths, and C. pelagicus in high-latitude, temperate sites (figure 4). This component describes a distinct latitudinal differentiation of the Late Miocene nanoplankton, presumably in response to climate. For simplicity we will often in our discussion of this dichotomy refer to a cool, temperate and a warm, tropical nanoflora, although the nanoplankton could well reflect some other aspect of climate that varies latitudinally.

A varimax rotation of the principal components identifies the compositions of the three end-member assemblages that the two principal sources of variation produce (figure 5): (1) a cool, temperate assemblage characterized by R. pseudumbilica, dissolved coccoliths, and C. pelagicus; (2) a deep, dissolved, warm, tropical assemblage characterized by discoasters and C. leptoporus; and (3) a shallow, undissolved, warm, tropical assemblage characterized by sphenoliths, small elliptical placoliths and C. pataecus.

Variation in Biogeography

Projection of all 603 samples onto the planes of the principal components allows the variation in nannofloral compositions at each site to be evaluated in terms of the sources of variation that were identified by the analysis of the site averages (figure 6). There is a continuum of variation in the observed nannofloral compositions between the extreme compositions of the three end-member assemblages (figure 6A); the orientations of the major axes of the covariation ellipses in figure 6B summarize and point to the end-member sources of this compositional variation at each site. The mean composition of the samples from a site determines the center of its covariation ellipse and the size of the ellipse reflects the amplitude of the variation in compositions observed about that mean.

Compositions at most sites are due to variations between an undissolved, warm assemblage characteristic of shallow tropical sites (317B, 158, 289) and another assemblage characteristic of sites in temperate latitudes (206, 281, 278, 296, 173). This is the dominant source of variation at sites 317B, 158, 289, 71, 77B, 208, 284, 207A, 296, 281 and 206, as indicated by the orientations of the major axes of their covariation ellipses. The dominant source of variation at 173, 310 and 55 is between the high-latitude, temperate assemblage and a dissolved, warm one characteristic of deep, tropical sites (292, 55). Based on

the bathymetric and geographic distributions of the 2nd and 3rd Q-mode principal components of site averages shown in figures 3 and 4, both of these patterns of variation in the composition of nannofloras are interpreted to reflect primarily changes in climate. The differences between them are interpreted to reflect differences in dissolution environments among the sites at different depths.

Variation at sites 292 and 319 is mostly between the deep and shallow tropical nannofloras. Variation at site 278 is due to changes in the proportion of dissolved coccoliths to R. pseudoumbilica and C. pelagicus. Both patterns are attributed primarily to changes through time in the intensity of dissolution at each site.

These interpretations of the oceanographic significance of the Late Miocene calcareous nanoplankton are supported by the systematic changes in nanoplankton compositions, shown by their patterns of compositional variation, between adjacent sites.

As would be expected, nannofossil compositions of samples from adjacent sites 71 and 77B both show a similar range in composition attributable to climate (figure 7). However, the nannofloral compositions of most samples from deeper site 71 have been changed by selective dissolution: The proportion of discoasters, dissolved coccoliths and C. leptoporus has increased at the expense of small elliptical placoliths, R. pseudoumbilica, sphenoliths and C. pataecus.

Also as expected, sites 310 and 296, both from between 30° and 40°N, show a similar mean and range of compositions attributable to climate (figure 8). However, the warm component at site 296 is similar in composition to the warm, undissolved nannofloras at shallow, tropical sites 289 and 317B, while the warm component of most of the samples at deeper site 310 is similar to that at deep, tropical sites 292 and 55. A look at the locations of these sites convincingly shows that these differences cannot be attributed to any surface circulation pattern; one flora would have to be advected across the stream of the other. We attribute the differences to selective dissolution and removal of the less resistant taxa from the warm component of the nannoflora at deeper site 310. The wide range in compositions exhibited at site 310 is due to the wide range in effects of both climate and dissolution.

Selective dissolution apparently gives site 206 the coldest appearing Late Miocene nannoflora in the Pacific. Its nannofloral composition, before it was altered by dissolution, would have been expected to be between that at warmer sites 289 and 208 to the north and cooler sites 207A, 284 and 281 to the south (figure 9). Since it is a temperate site, the proportion of tropical nannoflora at 206 is small and the predominant effect of dissolution is to make its overall composition appear even cooler rather than dissolved.

Selective dissolution and climate are the two primary factors that determine the composition and distribution of Pacific Late Miocene calcareous nannoplankton. There is evidence for this both in their average biogeography and in the predictable ways their compositions vary through time. Although the dichotomy between temperate and tropical nannofloras still shows through, figure 6B shows that most of the geographic (between site) variations in nannofloral compositions are due to differences in depth of water at which the samples were taken. Nevertheless, temporal variations in composition recorded within a site are still mostly attributable to migrations of latitudinally differentiated nannoflora in response to climatic changes. The usual biogeographic approaches to paleoceanography are not suitable for studying these changes because water depth alone has such a strong effect on the compositions of nannoplankton assemblages. An analysis which examines spatial changes in the signature or shape of nannoplankton records, rather than changes in the geography of nannofloral compositions, is indicated.

Analysis of the Stratigraphic Record

Up to this point the only stratigraphic requirement has been that most samples analyzed were Late Miocene. Not even the relative stratigraphic order of samples at a site was considered, nor would it have affected the results. Even

minimal stratigraphic correlations among the sites, however, show a remarkably consistent Late Miocene dissolution and climatic history for the Pacific.

Late Miocene records at 11 of our DSDP sites are relatively complete and well-preserved (table 4). We examined their nanoplankton dissolution and climate histories and identified the fewest number of different modes of variation (eigenmodes) needed to represent them. This analysis focused on the shapes of the nanoplankton records, their signatures or differences through time, and is not at all sensitive to the differences in nanofloral compositions between the sites.

In order to compare records from different sites, ages of individual samples were estimated by linear interpolation between the Miocene/Pliocene and Late/Middle Miocene boundaries, assigned ages of 5 and 11 m.y., respectively (Berggren and Van Couvering, 1974). Then values for dissolution and climate were interpolated at 200,000-yr intervals between 4.6 and 11.4 m.y. ago using the rectangular integration method of Davis (1973). This interpolation method weights the contribution of each sample to the interpolated value in proportion to the stratigraphic interval it represents. The different, independent modes of variation (eigenmodes) displayed by the records are the R-mode principal components, the scaled eigenvectors of a matrix of correlations between the records. The principal component loadings, the correlation of the eigenmodes with the record at each site,

reflect the spatial distribution of the eigenmodes and the scores reflect their distribution through time.

Nannoplankton Dissolution Record

Nearly three-quarters of the variation exhibited by the 11 nannoplankton histories of calcite dissolution can be represented by three different modes of variation (figure 10).

Except for deep, North Pacific site 310, the 1st eigenmode of variation in the nannoplankton dissolution records predominates in shallower water sites (figures 11 and 12), in water depths above 3000 m. Although this may describe a real decrease in nannoplankton dissolution at those depths through the Late Miocene, it is most likely an artifact of our methods. There is a strong apparent correlation between dissolution and climate in shallow sites. This is seen in figure 6B as elongated ellipses describing the covariation between the 2nd and 3rd Q-mode principal components of site averages at individual shallow sites. These two components are part of a closed sum, since each sample is normalized to unit variance, and this has a tendency to induce artificial inverse covariation. This tendency should be particularly strong on the 2nd principal component, the dissolution indicator, in samples from shallow sites where we would expect little if any effects of dissolution. In fact, the 1st eigenmode of the dissolution records is similar, as will be shown, to the

nannoplankton records of climate, especially those from lower latitudes.

This explanation cannot be applied to deep site 310. Most of its overall variation in nannoplankton compositions can be attributed to differences in dissolution, and the amplitude of these variations is greater than at any other site (figures 6B and 8). Its apparent similarity to the other records correlated with the 1st eigenmode is caused by a clear shift, in the middle of the Late Miocene, in the affects of calcite dissolution. Dissolution of the calcareous nannoplankton drops sharply about 8 m.y. ago at this site (figure 13). Before that time the warm component of the nannoflora at site 310 was similar to that at deep tropical sites; assemblages tend to be dominated by solution-resistant discoasters and dissolved coccoliths at the expense of small elliptical placoliths, sphenoliths and R. pseudoumbilica.

After 8 m.y. ago the warm nannoflora at site 310 is similar to that at shallow undissolved tropical sites and the full range of variation in nannoplankton is almost identical to that at nearby shallower site 296.

The bathymetric and stratigraphic distributions of the 2nd and 3rd eigenmodes of the dissolution records is similar and they likely represent the same mode. Both eigenmodes predominate in deeper sites (figures 11 and 14) and their overall stratigraphic signature or shape is similar. Differences are largely stratigraphic and we attribute them to miscorrelations.

Based on this analysis we recognize two different histories of dissolution in the Late Miocene Pacific: (1) In the North Pacific there is a sharp decrease in the dissolution of calcareous nannoplankton in the middle of the Late Miocene. This is accurately recorded only at deep North Pacific site 310. At this site the interval of strongest dissolution begins in the earliest Late Miocene about 11 m.y. ago and ends about 8 m.y. ago. (2) Deeper equatorial and South Pacific sites record a decrease in nannoplankton dissolution after the Middle Miocene (figure 14). The period of less dissolution was from 8 to 10 m.y. ago. After that time dissolution increased irregularly in the deepest sites; this increase continued into the Pliocene.

Nannoplankton Climate Record

Three eigenmodes are needed to represent 74% of the variation displayed by the 11 nannoplankton climate records (figure 15). The first two modes distinguish between tropical and south temperate patterns of climate change (figure 16).

The 1st eigenmode represents most of the variation seen in the nannoplankton records of changes in tropical climate. These changes are uncorrelated with the changes seen in southern temperate climates and a 2nd eigenmode is needed to adequately describe them.

The 1st and 3rd eigenmodes are roughly similar. For now we attribute their differences to stratigraphic miscorrelations and consider them descriptions of the same climatic mode. The 3rd eigenmode predominates in sites 206 and 310. Equating it with the 1st eigenmode, which represents mostly tropical sites, results in essentially two different histories of climate change recorded by Pacific Late Miocene nannoplankton:

(1) Tropical and North Pacific sites are invariably cool during the late Middle Miocene (figure 17). The nannoflora is characterized by greater abundances of R. pseudoumbilica and C. pelagicus and lesser abundances of sphenoliths, discoasters, and small elliptical placoliths. In the earliest Late Miocene the tropics warm to a level greater than at any other time during the Late Miocene. This peak warming occurred about 10 m.y. ago. Tropical nannofloras were dominated by sphenoliths, discoasters, and small elliptical placoliths. After that time the tropics cool, but only temporarily, to a minimum about 7 m.y. ago. The tropics then warm again in the latest Miocene and remain warm into the Pliocene.

(2) Climate in the temperate South Pacific (figure 18) warmed much more gradually in the Late Miocene and did not warm appreciably until the latest Miocene, beginning about 7 to 9 m.y. ago and continuing into the Pliocene. Superimposed on this warming is some evidence for the same temporary cooling seen about 7 m.y. ago in the tropics.

DISCUSSION

Pacific Late Miocene calcareous nannoplankton reflect and record two different aspects of their environment, climate at the ocean's surface and intensity of calcite dissolution at depth. The nannoplankton records change both through time and geographically, reflecting not only the history of the Pacific Ocean but also how the Late Miocene Pacific Ocean works.

Throughout the Late Miocene Pacific nannoplankton were differentiated latitudinally into tropical and temperate nannofloras. These nannofloras migrated latitudinally, presumably in response to climatic change at the ocean's surface; however, these migrations record different histories of climatic change between the south temperate and tropical Pacific. After a cool late Middle Miocene the tropical Pacific warmed sharply. The abundance of the tropical nannoplankton increased at tropical and North Pacific sites. The south temperate Pacific not only did not warm in the early Late Miocene, but may have cooled slightly. Tropical nannoflora did not increase their abundance at south temperate sites until the latest Miocene. The result of this rapid warming in tropical latitudes and gradual warming farther south is a sharp temporary increase in the latitudinal climatic gradient across the southern Pacific Ocean (figure 19C). There is no evidence for this in the North Pacific and sites 296 and 310 are probably evidence to the contrary. The strong contrast between

the tropical and south temperate Pacific existed between 8 and 10.5 m.y. ago with greatest contrast at 10 m.y.

Throughout the Late Miocene there has been, as expected, more dissolution of calcareous nannoplankton at depth; however, the water depth at which dissolution increases most changes geographically just as it does today. It is deeper in areas of higher productivity and biogenic calcite sedimentation, such as the eastern equatorial Pacific. In the North Pacific the depth at which calcite dissolution increases is regionally shallower than it is in the south. Today that difference reflects the more estuarine circulation of the Pacific and more lagoonal circulation of the Atlantic: new deep waters are produced and sink in the Atlantic and Southern Oceans and old deep waters upwell in the North Pacific (Berger, 1970). In the Late Miocene Pacific this pattern was most intense 8 to 10 m.y. ago. During that time deep tropical and south temperate sites record greater preservation of calcareous nannoplankton (figure 19D) while deep North Pacific site 310 records an equivalent period of intense dissolution.

That this geographic pattern of changes in dissolution reflects a deep oceanography similar to today's is consistent with the record of changes in the carbon isotopic composition of the Late Miocene Pacific deep water (figure 19E). As newly formed deep waters sink and spread through the oceans, dissolved oxygen is consumed and carbon dioxide released with combustion of the organic matter raining down from the

surface. Organic matter is greatly enriched in the lighter carbon isotope and its combustion continuously enriches old deep waters in carbon-12 (Kroopnick, 1974). During the period of greatest contrast in the preservation of calcareous nannoplankton between the North and South Pacific the carbon isotopic composition of the deep water is heaviest. This is consistent with the introduction of newly formed deep waters into the Pacific during that time. The shallowing of calcite dissolution to the North and deepening of preservation to the south indicates that these new deep waters entered the Pacific from the Southern Ocean.

The increase in the climatic gradient between the tropical and southern temperate Pacific that we find in the earliest Late Miocene implies a decrease in the latitudinal heat transport by the surface ocean and an increase at depth. We postulate that this increase was provided by an increase in the production of deep and bottom waters in the Southern Ocean beginning 10 m.y. ago. This new deep water entering the Pacific provided the heavier benthic carbon isotopic compositions recorded in the early half of the Late Miocene. It enhanced the estuarine circulation of the North Pacific and the lagoonal circulation of the South Pacific that is reflected by a northward increase in calcite dissolution. This period of increased deep Pacific circulation driven by increased deep water production in the Southern Ocean ended about 7.5 m.y. ago.

CONCLUSIONS

1. There are primarily two factors that determine the composition and distribution of Pacific Late Miocene calcareous nannoplankton. The first is attributable to climate and produces the latitudinal differentiation of Late Miocene nannofloras. The second, attributable to selective dissolution, superimposes an even stronger bathymetric differentiation of nannofloras on that due to climate.

2. These two factors together produce the three distinct Late Miocene nannofloral assemblages recognized in the Pacific. There is a high latitude assemblage characterized by R. pseudoumbilica and C. pelagicus. There are two tropical assemblages. One is a shallow water, undissolved assemblage characterized by sphenoliths, small elliptical placoliths, and C. pataecus. The other is a deep-water, dissolved assemblage characterized by discoasters.

3. Except for warmest-water assemblages, selective dissolution tends to give Late Miocene nannofloral assemblages a cooler-water aspect. Dissolution of warm-water nannoflora increases the abundance of discoasters at the expense of small elliptical placoliths, sphenoliths, and C. pataecus. Dissolution of cooler-water nannoflora increases the proportion of the cool-water component (R. pseudoumbilica, C. pelagicus and C. leptoporus) at the expense of the more soluble taxa in

the warm-water component. This gives the nannoflora a cooler-water aspect, and at the same time changes the composition of the warmer-water component towards more resistant taxa.

4. Variation in the composition of the Late Miocene nannoflora at most of the 17 sites can be primarily attributed to changes in climate, although the extent to which this is true depends on the oceanographic setting of the site.

5. Even at sites where most variation is attributable to climate change, the overall character of the nannoflora is often entirely altered by dissolution.

6. Late Miocene nannoplankton from equatorial and south temperate sites below 3000 m record a period of reduced calcite dissolution between 8 and 10 m.y. ago. Our only record from the North Pacific, site 310, indicates greatly increased dissolution during that same period.

7. Even with minimal stratigraphic control, the nannoplankton-recorded Late Miocene climatic histories appear strikingly similar at all tropical and North Pacific sites (except where nannoplankton assemblages have been too strongly dissolved). In the tropics the earliest Late Miocene invariably records a very sharp warming from a cold late Middle Miocene. Most sites record a temporary cooling in the middle Late Miocene about 7 m.y. ago.

8. Climatic histories recorded at southern temperate sites are distinctly different from those in the tropics. The warming from late Middle Miocene into the Late Miocene is much more gradual than in tropical latitudes. This difference increased the latitudinal climatic gradient during the early Late Miocene.

9. Nannoplankton oceanographic records indicate that during the early half of the Late Miocene about 8 to 10 m.y. ago an increase in the latitudinal climatic gradient between the tropical and south temperate Pacific Ocean is associated with a period of greatly increased calcite dissolution in the deep North Pacific and increased preservation in the south. To explain these records we postulate a temporary increase in the production of deep and bottom waters in the Southern Oceans during this period, an interpretation consistent with Late Miocene changes in the carbon isotopic composition in the deep Pacific.

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APPENDIX 1

Census data for Late Miocene calcareous nannoplankton at 17 Pacific Deep Sea Drilling Project (DSDP) sites. Data are given as raw counts of the 15 taxonomic categories listed in table 1. First column is sample number, 2nd is subbottom depth in meters, 3rd is total number of individuals counted. Remaining columns are the 15 counting categories. Note that for some samples in which nannoplankton were rare, either because of dissolution or dilution, only presence-absence data could be collected, especially in sites 173 and 278.

1	37.15	71	0	0	0	0	0	2	0	0	55	0	0	14	0	0	0
2	38.60	62	0	0	0	0	2	0	0	0	41	0	0	19	0	0	0
3	40.12	70	0	0	0	0	0	1	0	0	56	0	0	13	0	0	0
4	41.62	70	0	0	0	1	2	0	0	0	59	0	0	8	0	0	0
5	43.12	50	0	0	0	0	2	0	0	0	36	0	0	12	0	0	0
6	44.67	50	0	0	2	0	2	0	0	0	38	0	0	8	0	0	0
7	46.20	49	0	0	0	0	7	0	0	0	33	1	0	8	0	0	0
8	47.70	69	2	0	1	0	6	3	0	0	39	0	0	18	0	0	0
9	49.20	81	9	0	0	1	10	8	2	0	29	0	0	22	0	0	0
10	50.70	88	0	0	3	0	8	16	0	0	41	0	0	20	0	0	0
11	52.20	161	1	0	0	1	4	6	0	0	131	0	0	18	0	0	0
12	53.70	80	0	0	0	0	0	3	0	0	48	0	0	29	0	0	0

1	19.44	113	10	7	0	10	0	2	0	0	15	6	0	50	0	0	0
2	19.44	83	13	0	0	14	0	3	0	0	23	19	0	8	0	0	0
3	20.94	111	9	9	0	11	1	1	0	0	23	40	0	7	0	0	0
4	22.44	102	8	10	0	14	3	5	0	0	12	33	0	5	0	0	0
5	23.44	97	7	8	0	12	2	7	0	1	21	27	0	4	0	0	0
6	25.44	90	8	7	0	14	2	12	0	0	12	25	0	7	0	0	0
7	25.50	59	4	0	0	0	0	10	0	0	7	9	0	28	0	0	0
8	25.50	120	13	0	0	8	2	16	0	0	23	0	0	57	0	0	0
9	27.00	91	10	6	0	10	1	17	1	0	10	19	0	9	0	0	0
10	28.44	81	20	18	0	5	0	7	0	0	7	15	0	8	0	0	0
11	29.94	98	12	2	0	7	3	26	0	0	14	23	0	9	0	0	0
12	31.44	49	11	0	0	1	0	5	0	0	6	2	0	24	0	0	0
13	32.82	106	11	11	0	6	3	8	0	3	31	21	0	12	0	0	0
14	34.44	94	13	9	0	1	2	1	0	0	34	21	0	11	0	0	0
15	35.50	89	16	0	1	4	6	33	0	0	2	14	0	13	0	0	0
16	39.44	95	32	1	0	1	6	7	0	0	7	9	0	31	0	0	0
17	39.44	94	32	3	0	2	4	8	0	0	6	20	0	17	0	0	0
18	41.44	91	1	25	0	5	8	12	0	0	5	26	0	4	0	0	0
19	41.44	86	1	9	0	4	9	20	0	0	13	28	0	2	0	0	0
20	42.94	139	2	0	0	9	6	21	1	0	8	44	0	45	2	1	0
21	44.44	91	1	14	0	4	8	25	0	0	4	21	0	9	0	0	0
22	47.44	86	0	1	0	4	9	26	0	0	3	34	0	2	0	0	0
23	48.94	105	0	1	0	2	20	27	0	2	16	26	0	4	0	0	0
24	50.35	110	0	0	0	15	8	63	0	0	4	18	0	2	0	0	0
25	53.44	77	2	2	0	7	4	15	0	0	24	13	0	3	0	0	0
26	54.94	59	10	0	0	4	5	1	0	0	19	2	0	18	0	0	0
27	56.44	100	15	0	0	9	10	10	0	1	43	2	0	10	0	0	0
28	57.94	108	36	0	0	1	1	9	0	0	25	14	0	21	0	0	0
29	59.44	109	0	2	0	9	7	23	0	1	12	45	0	1	0	0	0
30	60.94	97	33	0	0	8	2	3	0	0	15	3	0	33	0	0	0

1	82.70	253	36	0	0	5	0	20	0	0	3	140	0	49	0	0	0
2	84.16	111	25	4	0	7	1	14	0	2	0	58	0	0	0	0	0
3	87.20	193	20	0	0	3	2	0	1	0	2	124	1	40	0	0	0
4	90.23	112	9	10	0	2	2	37	0	0	4	43	0	3	0	0	0
5	94.00	97	23	6	0	10	2	8	0	2	12	19	0	12	0	0	0
6	97.00	102	18	4	0	10	6	9	0	2	4	48	0	1	0	0	0
7	100.00	112	23	17	0	6	5	4	0	2	5	25	0	23	0	0	0
8	110.75	118	26	10	0	4	7	10	0	1	2	49	0	8	0	0	0
9	113.62	115	14	3	0	6	19	16	0	1	3	43	0	7	0	0	0
10	116.62	103	33	0	0	5	7	7	0	3	5	24	0	17	0	0	0
11	120.81	108	5	21	0	8	0	3	1	4	20	35	0	10	0	0	0
12	123.82	95	12	25	0	3	3	3	0	2	2	30	0	10	0	0	0
13	126.80	99	1	33	0	1	2	16	0	0	2	37	0	3	0	0	0
14	130.50	124	1	29	0	3	3	9	0	0	9	67	0	0	0	0	0
15	133.45	150	29	8	0	5	3	18	0	0	0	54	0	27	0	0	0
16	136.51	117	0	13	0	10	10	16	0	0	9	45	0	3	0	0	0
17	139.60	110	0	29	0	8	4	15	0	0	1	47	0	2	0	0	0
18	144.11	87	0	10	0	8	17	8	0	0	12	27	0	3	0	0	0
19	147.22	105	0	11	0	5	6	32	0	2	0	39	0	4	0	0	0
20	151.19	121	0	0	0	0	11	32	1	0	17	54	0	0	0	0	0
21	154.21	102	0	0	0	5	7	21	0	0	21	41	0	1	0	0	0
22	157.26	101	19	1	0	0	2	41	0	0	1	7	0	29	0	0	0
23	161.96	82	38	1	0	3	3	4	0	0	3	7	0	23	0	0	0
24	162.62	110	36	0	0	10	6	2	0	0	8	9	0	39	0	0	0
25	165.55	100	29	1	0	10	4	3	0	0	12	4	0	37	0	0	0
26	166.60	203	17	0	0	3	1	7	3	0	8	108	0	56	0	0	0
27	168.60	215	22	0	4	4	0	5	0	0	11	102	0	66	0	0	0

1	82.00	264	0	0	2	0	1	43	0	0	2	131	3	82	0	0	0
2	85.00	223	1	0	3	0	0	64	1	0	2	98	2	51	1	0	0
3	86.50	217	3	0	2	0	1	48	3	0	4	113	3	39	1	0	0
4	89.00	105	3	9	0	2	0	50	3	0	2	34	0	2	0	0	0
5	92.93	116	0	17	0	6	1	30	0	1	0	61	0	0	0	0	0
6	97.27	110	6	16	0	0	0	47	0	0	0	37	0	4	0	0	0
7	102.11	108	5	11	0	1	0	50	0	0	0	35	0	6	0	0	0
8	105.60	106	4	12	0	0	1	38	0	0	2	40	0	9	0	0	0
9	109.80	111	0	15	0	1	1	37	0	0	0	57	0	0	0	0	0
10	114.25	125	1	7	0	1	0	49	1	6	0	57	0	3	0	0	0
11	118.37	123	8	15	0	0	4	38	0	1	1	38	0	18	0	0	0
12	122.52	114	12	11	0	2	2	36	1	3	2	39	0	0	0	0	0
13	126.40	93	15	4	0	2	4	23	0	0	4	41	0	0	0	0	0
14	130.80	102	9	16	0	7	2	24	0	1	1	41	0	1	0	0	0
15	139.40	109	13	14	0	1	3	21	0	0	2	45	0	6	0	0	0
16	143.80	99	7	12	0	2	0	27	0	1	2	44	0	2	0	0	0
17	147.63	98	10	7	0	1	4	34	0	0	0	40	0	2	0	0	0
18	152.61	92	1	5	0	1	0	38	0	0	2	30	0	12	0	0	0
19	155.92	84	1	37	0	1	2	14	1	0	2	23	0	3	0	0	0
20	160.38	127	1	29	0	4	0	18	0	0	3	72	0	0	0	0	0
21	164.42	96	0	17	0	5	5	28	2	0	0	33	0	3	0	0	0
22	168.63	96	0	12	0	2	1	41	0	0	0	39	0	1	0	0	0
23	172.52	94	0	8	0	3	4	34	0	0	2	43	0	0	0	0	0
24	177.21	92	0	10	0	2	1	39	0	0	1	30	0	3	0	0	0
25	181.26	96	0	0	0	2	8	42	0	0	4	38	0	1	0	0	0
26	185.52	90	1	0	0	3	10	28	1	1	9	37	0	0	0	0	0
27	191.92	84	3	10	0	3	0	33	0	2	8	21	0	4	0	0	0
28	196.42	83	6	7	0	3	1	36	1	0	4	21	0	1	0	0	0
29	200.43	103	40	5	0	0	5	19	0	0	3	10	0	21	0	0	0
30	202.00	118	47	0	1	1	0	13	0	0	3	13	3	35	0	0	2
31	205.01	162	73	0	0	0	10	16	1	0	0	0	0	62	0	0	0
32	208.00	77	22	0	1	0	0	3	0	0	9	20	0	22	0	0	0
33	211.00	59	10	0	0	0	0	0	0	0	10	0	0	37	0	0	2

1	119.75	3	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0
2	120.50	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
3	121.25	4	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
4	122.00	4	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
5	122.75	2	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
6	124.00	6	1	0	0	0	1	1	0	0	1	1	0	1	0	0	0
7	131.50	3	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0
8	132.25	6	1	1	0	0	1	1	0	0	0	1	0	1	0	0	0
9	133.01	2	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
10	133.64	3	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0
11	134.17	2	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
12	134.79	3	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
13	139.01	2	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
14	139.64	4	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0
15	140.33	3	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
16	140.93	3	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
17	141.43	2	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
18	141.94	2	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
19	142.63	3	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
20	148.99	3	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
21	149.81	3	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
22	150.21	3	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0
23	150.83	2	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
24	151.30	5	1	0	0	1	1	0	0	0	1	1	0	0	0	0	0
25	151.94	4	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0
26	152.41	4	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0
27	159.13	4	1	0	0	1	1	0	0	0	0	1	0	0	0	0	0
28	159.77	4	1	0	0	0	1	0	0	0	0	1	0	0	0	0	1
29	160.42	5	1	0	0	1	1	0	0	0	1	1	0	0	0	0	0
30	160.94	4	1	0	0	1	1	0	0	0	0	1	0	0	0	0	0
31	161.52	5	1	0	0	1	1	0	0	0	1	1	0	0	0	0	0
32	162.25	4	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0
33	162.76	3	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0
34	163.41	4	1	0	0	0	1	0	0	0	1	1	0	0	0	0	0
35	163.89	3	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0
36	164.52	3	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0
37	168.75	5	0	0	0	1	0	1	0	0	1	1	0	1	0	0	0
38	169.50	6	1	1	0	0	0	1	0	0	1	1	0	1	0	0	0
39	169.51	3	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
40	171.05	29	0	0	0	0	1	1	0	0	0	0	0	27	0	0	0
41	172.51	3	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0
42	173.00	6	1	0	0	0	1	1	0	0	1	1	0	1	0	0	0
43	178.26	3	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0
44	179.76	5	1	0	0	0	1	0	0	0	1	1	0	1	0	0	0
45	181.30	5	1	0	0	0	0	1	0	0	1	1	0	1	0	0	0
46	187.76	113	14	0	0	0	2	4	0	0	8	40	0	45	0	0	0
47	189.26	48	6	0	0	0	0	0	0	0	6	5	0	31	0	0	0
48	190.76	4	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0
49	192.30	99	6	0	0	0	0	2	0	0	12	39	0	40	0	0	0
50	196.51	37	2	0	0	0	0	2	0	0	6	10	1	16	0	0	0
51	198.01	79	7	0	0	0	0	7	1	0	6	35	0	23	0	0	0
52	199.51	4	1	0	0	0	0	1	0	0	0	1	0	1	0	0	0
53	201.01	59	5	0	0	0	0	2	0	0	5	30	0	17	0	0	0

1	188.01	85	1	0	2	6	5	1	2	0	4	58	0	0	3	0	2
2	189.51	222	1	0	1	10	6	4	5	0	8	122	2	57	3	2	0
3	191.01	293	1	3	1	10	3	16	5	0	7	161	3	69	5	3	2
4	191.90	80	33	0	0	3	13	3	0	0	2	10	0	15	0	0	0
5	192.61	98	46	2	0	6	8	2	0	1	4	9	0	19	0	0	0
6	193.24	95	58	0	0	4	7	2	0	2	2	9	0	11	0	0	0
7	194.57	83	23	4	0	9	7	2	1	0	6	1	0	28	0	0	0
8	195.35	101	41	0	0	11	20	4	0	2	2	7	0	10	0	0	0
9	197.90	72	31	0	0	5	7	6	0	0	5	7	0	11	0	0	0
10	199.06	71	28	3	0	7	8	1	0	0	6	2	0	14	0	0	0
11	199.97	77	43	0	0	5	17	2	0	1	1	0	0	8	0	0	0
12	201.00	61	21	1	0	8	15	4	2	0	0	3	0	7	0	0	0
13	202.40	115	43	0	0	9	21	0	0	0	1	12	0	26	0	0	0
14	203.00	101	40	0	0	11	10	4	0	0	3	8	0	25	0	0	0
15	210.62	49	0	0	0	0	0	0	0	0	0	39	0	10	0	0	0
16	211.06	82	33	10	0	4	12	2	2	0	1	8	0	10	0	0	0
17	212.56	118	63	2	0	2	18	3	1	1	3	13	0	9	0	0	0
18	213.64	89	41	0	0	8	8	0	0	0	0	9	0	23	0	0	0
19	215.92	90	42	9	3	3	7	1	2	0	0	7	0	16	0	0	0
20	216.99	120	68	2	0	5	10	5	1	0	1	11	0	17	0	0	0
21	217.98	71	46	0	0	1	10	1	0	0	0	0	0	13	0	0	0
22	219.00	91	42	0	0	1	13	1	0	0	3	16	0	15	0	0	0
23	219.50	109	44	0	1	3	18	2	0	0	4	24	0	13	0	0	0
24	230.06	167	40	0	3	2	12	3	2	0	0	49	5	35	0	6	7
25	230.51	163	48	0	0	10	14	3	0	0	2	27	1	55	0	0	0

1	75.00	185	9	0	6	0	5	4	4	2	2	81	2	53	6	0	11
2	75.75	342	9	0	2	5	2	5	3	0	2	206	1	86	5	0	16
3	76.50	215	18	0	0	14	5	10	4	3	1	116	1	25	0	0	15
4	77.50	218	15	0	0	14	9	3	4	0	3	138	3	4	0	4	19
5	78.00	257	22	0	0	15	5	6	8	0	6	176	2	0	0	2	12
6	79.00	226	21	0	0	20	5	7	5	0	0	159	2	1	1	0	4
7	79.50	237	25	0	0	20	4	13	6	0	0	152	3	0	3	1	8
8	80.50	286	28	0	0	17	4	8	3	0	1	188	9	1	1	5	18
9	81.00	264	35	0	0	6	0	5	8	0	1	183	4	4	4	0	12
10	82.50	173	31	0	0	17	12	4	2	1	1	97	1	3	0	0	2
11	83.04	116	28	9	0	4	10	6	4	3	1	46	0	5	0	0	0
12	84.00	133	21	8	0	4	10	7	2	3	0	68	0	10	0	0	0
13	84.50	92	21	7	1	3	9	7	4	1	0	28	0	11	0	0	0
14	85.08	194	46	0	0	16	12	14	7	4	1	83	1	4	0	2	2
15	85.50	225	48	0	0	8	14	20	5	0	2	109	0	6	2	1	2
16	85.68	241	47	0	0	9	20	20	9	3	4	108	0	14	1	1	4
17	85.98	113	35	5	0	2	6	9	2	1	1	48	0	4	0	0	0
18	86.58	156	31	0	0	5	9	6	6	1	0	89	0	2	2	0	4
19	86.58	218	22	0	3	0	7	6	3	0	2	135	1	32	0	1	5
20	87.00	274	50	0	0	10	13	31	9	3	4	128	1	11	6	1	5
21	87.18	139	32	0	0	3	3	4	3	2	0	81	1	5	1	1	3
22	87.50	97	30	11	0	7	7	4	3	1	1	29	0	3	0	0	0
23	87.78	220	91	0	0	12	14	6	5	4	1	76	2	6	1	0	2
24	88.08	159	49	0	0	5	8	5	2	2	0	79	0	4	1	1	3
25	88.50	109	36	2	0	4	7	4	3	2	0	46	0	5	0	0	0
26	88.68	261	84	0	0	13	27	8	1	0	3	114	1	2	2	1	4
27	89.00	110	32	20	0	2	7	3	0	2	0	35	0	9	0	0	0
28	89.28	206	30	0	0	5	13	2	3	2	0	139	2	2	1	1	5
29	89.58	143	21	0	0	8	13	6	5	0	1	77	3	4	0	2	2
30	90.00	111	53	3	0	2	6	6	0	0	1	32	0	8	0	0	0
31	90.16	235	33	0	0	15	4	12	0	2	0	152	3	10	1	1	2
32	90.50	155	25	9	0	5	3	13	3	2	0	84	0	11	0	0	0
33	90.78	186	40	0	0	7	10	10	1	2	1	104	0	11	0	0	0
34	92.68	168	34	0	0	9	4	8	5	2	0	88	0	9	0	1	3
35	93.28	217	60	0	0	8	12	8	0	0	3	108	0	14	3	1	0
36	94.50	218	10	7	0	4	8	4	1	2	0	96	2	77	7	0	0
37	96.00	150	4	6	0	3	11	4	1	0	2	53	0	59	6	0	0
38	97.50	182	12	7	0	8	24	5	3	0	8	55	1	55	4	0	0
39	99.00	133	1	1	2	9	27	4	8	0	1	33	1	41	4	0	0
40	100.50	110	11	2	2	9	22	1	4	0	2	12	1	39	0	0	5
41	102.00	99	9	1	1	5	11	1	3	0	4	11	0	43	9	0	1
42	103.50	87	4	0	3	6	16	4	3	0	1	6	0	34	7	0	3
43	105.00	80	14	0	2	6	4	1	3	2	6	7	0	26	5	0	3
44	106.50	91	40	0	2	2	10	1	0	0	4	1	0	28	3	0	0
45	109.50	102	30	2	2	4	6	10	2	0	1	7	0	32	6	0	0
46	112.50	85	27	0	2	5	11	2	1	0	1	7	2	23	4	0	0
47	115.50	68	23	0	0	0	6	3	1	0	0	9	0	20	2	1	3
48	118.50	101	39	0	4	0	3	1	1	0	0	11	0	36	5	1	0
49	120.00	115	31	0	0	2	29	0	0	0	2	1	2	46	2	0	0

62	202.51	168	0	0	3	6	18	13	6	1	5	62	1	45	5	0	3
63	223.01	70	26	0	3	0	8	0	4	1	3	4	0	20	0	0	1
64	224.04	240	74	0	5	3	22	14	9	0	15	48	3	35	8	0	3
65	225.30	125	59	1	1	2	11	2	5	1	20	2	0	17	3	0	1
66	232.01	144	35	0	17	4	10	5	4	0	12	32	2	18	4	0	1
67	233.51	146	50	0	8	6	8	3	4	0	3	33	2	22	6	0	1
68	235.01	208	63	0	19	4	16	8	5	0	14	37	1	31	7	0	3
69	236.51	191	59	0	20	6	14	2	5	0	2	38	6	25	12	1	1
70	238.01	186	74	0	10	4	11	3	3	0	5	37	2	28	5	1	3
71	239.51	174	58	0	11	5	6	5	4	0	2	38	6	27	5	0	7

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1	102.25	378	5	0	8	0	5	65	3	16	4	102	0	122	23	0	25
2	103.75	199	5	0	0	1	2	23	1	0	3	64	10	64	11	0	15
3	104.50	324	4	0	5	0	1	49	3	0	2	120	15	84	19	0	21
4	105.54	499	65	0	6	8	3	48	7	0	1	240	14	59	10	0	37
5	105.96	331	33	0	6	7	1	54	3	0	6	142	8	34	13	0	24
6	106.40	369	44	0	9	6	4	45	0	0	0	154	16	41	16	0	33
7	107.03	481	54	0	11	11	5	101	7	0	15	148	12	79	16	0	19
8	107.90	384	32	3	4	0	0	39	2	0	4	187	21	67	9	0	15
9	108.54	362	18	0	12	3	10	40	3	0	8	128	8	110	7	3	11
10	109.40	426	15	0	8	2	2	56	5	0	4	185	18	89	10	0	32
11	110.00	468	8	0	4	3	4	97	7	0	10	176	14	88	23	1	31
12	110.90	433	10	0	4	1	1	78	3	0	3	220	12	86	7	0	6
13	121.00	516	10	0	12	2	5	33	7	0	8	311	19	63	22	1	23
14	121.31	287	2	0	4	1	0	15	4	0	6	181	7	40	13	0	14
15	122.46	431	14	0	16	0	2	42	9	0	6	245	12	45	22	0	18
16	122.90	277	5	0	3	0	0	15	4	0	2	190	4	40	8	1	5
17	123.57	398	2	0	0	1	0	20	3	0	1	306	6	41	2	0	15
18	124.40	336	5	0	2	0	2	20	6	0	3	229	7	42	7	0	12
19	125.04	379	7	0	8	1	4	33	5	0	10	235	11	46	6	0	9
20	125.46	290	2	0	0	1	3	17	3	0	4	189	6	37	10	1	15
21	126.54	466	14	0	7	0	5	60	9	0	4	256	9	62	27	1	12
22	127.00	610	10	0	11	1	5	119	11	0	5	319	20	71	25	0	12
23	127.40	352	5	0	5	2	3	50	7	0	4	203	6	40	18	0	7
24	127.71	279	8	0	6	0	0	34	5	0	0	125	5	42	27	0	25
25	128.46	384	19	0	6	2	1	63	4	0	8	202	5	41	19	0	14
26	128.90	190	4	0	0	0	1	23	4	0	1	111	0	25	14	0	7
27	129.00	427	30	0	14	4	7	45	6	0	18	203	12	72	9	1	5
28	139.54	538	21	0	7	1	7	19	4	0	5	383	6	59	14	0	10
29	140.01	381	7	0	7	0	2	13	3	0	5	274	5	47	8	0	9
30	140.40	579	8	0	4	1	0	27	1	0	3	434	9	69	11	0	12
31	141.51	516	23	0	12	0	3	54	3	0	10	332	11	59	3	0	6
32	141.90	584	28	0	10	1	3	57	2	0	7	355	11	76	18	0	15
33	142.57	414	24	0	7	1	3	31	2	0	4	251	7	68	8	0	8
34	143.40	476	28	0	8	2	8	19	3	0	9	302	13	63	6	0	14
35	144.07	546	89	0	12	2	9	36	8	0	15	265	9	79	11	0	10
36	144.51	500	70	0	22	7	12	27	12	0	8	246	8	63	15	0	10
37	145.57	612	102	0	17	10	11	44	8	0	8	285	14	82	18	0	12
38	146.01	312	60	0	7	1	16	26	6	0	4	115	7	45	17	0	6
39	146.40	489	57	0	6	2	12	36	9	0	0	263	10	66	21	0	7
40	147.51	454	59	0	4	1	8	37	5	0	2	240	10	58	18	0	10
41	147.90	516	65	0	8	7	11	41	5	0	1	274	11	59	16	0	17
42	157.57	410	45	0	0	2	2	31	2	0	1	228	9	65	13	0	12
43	158.01	233	25	0	0	1	6	1	3	0	3	142	1	49	2	0	0
44	161.01	315	39	0	3	0	5	19	4	0	4	163	6	62	5	0	5
45	162.51	240	6	1	0	0	2	19	1	0	0	151	1	48	8	0	3
46	163.96	370	36	0	7	3	1	17	2	0	0	212	5	69	8	0	10
47	164.73	229	21	0	0	8	2	12	3	0	0	145	2	24	3	1	6
48	165.28	274	14	0	0	4	1	20	2	0	0	200	3	18	7	0	5
49	165.68	205	31	0	1	3	1	13	0	0	2	128	1	14	3	1	6
50	166.00	153	3	0	0	0	3	51	1	0	40	3	2	44	1	0	0
51	176.08	316	18	0	3	0	11	32	5	0	6	151	12	58	8	0	12
52	176.68	439	28	0	1	7	5	37	6	0	2	288	7	37	5	1	15
53	177.28	445	22	0	0	9	4	46	3	0	4	262	11	60	12	0	12
54	177.58	393	27	0	3	5	12	56	5	0	7	182	10	58	14	0	14
55	180.01	407	15	0	2	7	18	30	6	0	3	222	3	91	4	1	5
56	183.01	304	10	18	2	2	13	30	4	0	11	121	5	71	11	0	6
57	184.51	251	6	0	2	4	10	27	2	0	6	87	4	87	13	0	3
58	195.01	152	0	6	4	4	11	9	7	0	9	60	2	38	1	0	1
59	196.51	148	0	4	2	3	8	9	7	0	2	74	2	23	3	1	9
60	198.01	201	1	0	1	4	7	23	7	0	10	79	1	61	2	0	5
61	201.01	277	0	0	2	10	20	33	14	0	24	83	4	76	1	0	10

1	168.51	81	9	0	0	0	6	0	1	0	0	17	0	48	0	0	0
2	171.51	70	10	0	0	0	1	2	0	0	0	11	0	46	0	0	0
3	174.51	67	22	0	0	0	4	0	0	0	1	0	0	40	0	0	0
4	178.01	83	19	0	0	0	0	0	0	0	0	6	0	58	0	0	0
5	181.05	83	27	0	0	0	0	0	2	0	0	0	0	54	0	0	0
6	184.05	2	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
7	186.30	73	19	0	0	0	0	0	0	0	0	15	0	39	0	0	0
8	187.04	4	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0
9	190.04	5	1	0	0	0	1	1	0	0	0	1	0	1	0	0	0
10	193.08	3	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
11	195.40	4	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0
12	196.34	4	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0
13	196.80	274	197	19	0	0	0	5	0	0	0	0	0	0	0	0	0
14	196.80	77	19	0	0	0	5	0	0	0	0	0	0	53	0	0	0
15	199.56	4	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0
16	202.44	5	1	0	0	1	0	0	0	0	0	1	0	1	0	0	0
17	205.25	4	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0
18	206.92	3	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
19	209.06	3	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
20	212.08	3	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
21	214.25	4	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0
22	215.54	3	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
23	218.21	131	16	0	0	0	1	0	0	0	0	53	0	61	0	0	0
24	221.51	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
25	224.25	3	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
26	225.26	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
27	233.80	65	12	0	0	0	0	0	0	0	0	0	0	53	0	0	0
28	238.01	42	5	0	0	0	4	0	0	0	0	0	0	33	0	0	0
29	241.05	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
30	243.30	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0

1	22.47	161	0	0	0	12	19	0	0	0	0	121	0	3	1	3	1
2	24.01	184	0	0	0	5	20	0	0	0	0	158	1	0	0	0	0
3	25.51	121	1	0	0	13	16	0	7	0	0	66	2	0	1	1	9
4	26.25	121	1	0	0	14	10	0	1	0	1	88	2	2	2	0	0
5	36.26	168	51	0	0	10	0	0	2	0	0	86	0	18	1	0	0
6	37.76	161	53	0	0	11	3	0	0	0	0	69	0	21	1	0	2
7	46.49	114	29	0	0	9	24	0	0	0	0	40	0	9	1	0	0
8	48.01	114	40	0	0	2	34	1	1	0	0	15	0	19	2	0	0
9	49.51	127	30	0	0	4	55	0	1	0	0	17	0	19	0	1	0
10	51.01	109	37	0	0	1	42	0	0	0	0	16	0	13	0	0	0
11	52.56	170	53	0	0	0	39	0	0	0	1	41	0	36	0	0	0
12	54.01	117	33	0	0	2	39	0	0	0	0	14	0	29	0	0	0
13	54.75	110	42	0	0	4	24	0	1	0	1	21	0	17	0	0	0
14	55.26	125	43	0	0	6	48	0	0	0	1	16	0	11	0	0	0
15	56.74	111	42	0	0	2	31	3	0	0	0	13	0	20	0	0	0
16	58.26	135	56	0	0	3	21	0	0	0	0	12	0	43	0	0	0
17	59.74	122	56	0	1	0	15	13	0	0	0	7	0	30	0	0	0
18	61.26	138	64	0	0	3	14	5	0	0	0	21	0	29	2	0	0
19	75.00	123	49	0	0	0	11	7	0	0	0	24	0	32	0	0	0
20	76.50	131	52	0	0	9	12	0	0	0	0	0	0	55	3	0	0
21	78.00	127	61	1	1	5	12	3	0	0	0	0	0	40	4	0	0
22	79.51	117	44	0	0	8	31	3	0	0	0	5	2	22	0	0	1
23	81.00	115	47	0	0	4	19	12	0	0	0	14	0	15	4	0	0
24	82.49	142	28	0	0	5	54	6	0	0	0	24	0	16	3	0	5
25	83.25	134	26	0	1	11	47	3	0	0	0	18	0	23	3	0	2

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1	123.50	320	2	0	2	4	2	2	1	0	0	188	4	106	3	0	6
2	126.50	144	0	0	1	4	2	2	0	0	0	51	3	80	1	0	0
3	129.51	221	13	0	1	10	14	1	7	0	1	101	0	71	0	1	1
4	133.01	289	13	0	1	4	1	8	5	0	0	177	1	72	3	0	4
5	134.54	261	8	8	13	2	8	6	4	0	0	131	9	52	2	1	17
6	136.04	420	18	0	18	5	9	16	4	0	1	245	5	81	3	2	12
7	137.51	212	11	0	0	8	1	2	2	0	0	115	5	54	5	2	5
8	139.04	340	15	9	4	1	3	8	8	0	2	193	8	61	6	0	19
9	140.54	331	14	0	11	0	12	7	6	0	1	171	8	72	11	0	17
10	142.01	243	3	0	4	0	1	1	1	0	0	177	2	37	9	0	8
11	142.51	317	17	0	8	0	3	2	4	0	0	213	5	56	0	0	8
12	142.90	370	9	0	8	0	7	1	3	0	0	258	3	64	2	0	14
13	143.52	191	20	0	6	0	0	0	1	0	0	99	3	50	2	0	9
14	144.02	250	30	0	14	0	3	4	5	0	0	141	2	47	4	0	0
15	144.40	150	8	0	5	0	0	1	3	0	0	99	0	30	2	0	2
16	145.51	374	9	0	6	0	0	8	4	0	0	287	3	46	4	0	6
17	145.52	287	7	0	1	2	0	5	2	0	0	201	2	41	4	0	22
18	147.02	316	14	0	5	2	2	3	7	0	0	221	1	53	2	0	6
19	148.51	434	27	0	0	12	0	3	2	0	1	304	0	75	1	1	7
20	151.51	503	53	0	19	3	0	4	3	0	0	307	7	75	13	0	17
21	152.02	307	13	0	6	0	1	1	0	0	0	194	5	51	8	0	28
22	153.52	385	31	0	11	0	7	2	5	0	7	207	1	65	17	0	30
23	153.90	304	8	0	4	0	1	7	3	0	0	206	6	42	6	0	21
24	155.04	284	20	0	17	0	0	4	5	0	0	173	6	45	9	0	5
25	155.40	345	20	0	9	0	1	7	4	0	3	219	4	59	9	0	10
26	156.54	513	16	0	14	0	0	3	2	0	0	368	4	80	14	0	12
27	156.90	287	13	0	8	0	0	2	0	0	0	220	4	29	8	0	3
28	158.04	503	17	0	23	0	1	7	4	0	0	361	8	67	12	0	3
29	159.01	441	6	0	5	0	0	1	0	0	0	346	3	61	9	0	10
30	159.54	300	11	0	9	0	0	7	1	0	0	187	8	57	8	0	11
31	159.90	354	19	0	6	0	0	5	0	0	0	231	5	78	8	0	2
32	161.01	296	8	0	0	0	0	1	0	0	0	188	0	83	6	0	9
33	161.51	291	8	0	2	0	0	0	0	0	0	198	2	64	8	0	9
34	161.90	366	26	0	5	3	4	10	5	0	2	208	7	84	7	1	4
35	162.51	297	14	0	13	0	2	3	3	0	1	182	4	58	4	0	12
36	163.02	324	10	0	5	0	0	4	1	0	0	213	3	76	4	0	8
37	163.40	380	25	0	5	0	3	13	1	0	3	230	0	90	4	0	6
38	164.01	253	19	0	7	2	2	5	0	0	0	146	4	55	9	1	3
39	164.57	240	13	0	10	0	3	0	0	0	1	156	5	49	1	0	2
40	164.90	270	24	0	12	1	0	0	4	0	0	167	0	59	1	1	1
41	165.51	366	17	0	11	0	7	0	1	0	0	254	6	61	2	0	7
42	166.04	348	15	0	9	0	3	3	1	0	0	231	3	70	6	0	7
43	166.40	351	9	0	2	0	3	0	0	0	0	248	4	78	0	0	7
44	167.01	428	34	0	13	0	4	8	2	0	2	263	5	81	4	3	9
45	167.54	256	22	0	9	0	1	1	2	0	0	145	3	64	1	1	7
46	167.90	455	38	0	15	0	8	6	2	0	2	274	4	88	4	2	12
47	168.51	481	69	0	13	0	14	6	1	0	3	274	5	88	0	0	8
48	169.04	377	32	0	6	0	3	0	6	0	0	236	6	72	7	0	9
49	169.41	395	40	0	11	0	9	7	5	0	2	239	2	71	5	0	4
50	171.01	183	24	0	0	4	11	3	0	0	1	80	1	57	0	1	1
51	174.01	187	28	0	0	2	15	7	0	0	0	60	4	66	2	2	0
52	177.01	266	17	0	0	2	15	4	6	0	0	183	1	31	5	0	2
53	180.51	244	39	7	1	6	16	1	3	0	2	78	2	81	8	0	0
54	183.51	272	13	12	0	0	9	1	2	0	0	160	2	65	7	0	1
55	185.01	178	21	14	0	0	13	0	1	0	0	73	0	53	3	0	0
56	188.01	169	33	0	0	7	18	3	2	0	2	55	0	48	1	0	0
57	190.01	231	32	18	0	1	7	5	1	0	0	115	1	44	3	4	0
58	193.01	257	45	7	1	9	7	4	1	0	1	129	3	50	0	0	0
59	196.01	274	39	6	0	5	18	5	2	0	1	139	0	53	3	3	0
60	199.51	246	30	8	1	11	8	11	0	0	1	112	1	57	5	1	0
61	202.51	159	12	1	1	4	5	3	4	0	1	94	0	30	3	1	0

1	156.72	194	7	0	0	6	0	66	0	0	1	68	7	13	14	0	12
2	160.01	130	0	0	1	3	0	32	1	0	1	62	4	18	7	1	0
3	162.39	190	4	0	0	7	0	58	2	3	5	88	6	2	9	0	5
4	162.54	348	7	0	2	1	0	148	0	0	1	139	2	41	1	0	6
5	167.04	204	10	1	0	2	0	65	1	0	4	102	3	3	5	0	8
6	173.90	255	6	2	0	1	1	101	2	0	2	109	3	8	13	0	6
7	181.92	317	5	0	0	5	0	85	3	3	8	178	5	9	6	0	8
8	186.85	387	17	0	0	13	0	154	3	8	11	144	8	17	2	0	10
9	192.03	273	45	0	0	9	8	93	2	4	19	59	5	20	7	2	0
10	204.51	167	28	1	0	11	2	30	4	3	10	52	2	18	6	0	0
11	212.51	461	21	0	0	3	4	173	0	0	0	197	7	48	1	0	7
12	217.72	276	51	0	0	8	3	105	0	2	0	63	1	23	10	1	8
13	222.92	217	32	0	0	8	5	63	1	0	1	76	0	15	11	1	4
14	227.75	212	16	0	0	3	6	65	1	0	4	84	1	21	10	1	0
15	232.91	223	15	0	0	4	7	48	2	3	7	88	0	19	19	0	11
16	239.22	267	5	0	0	1	2	97	2	0	1	132	0	11	4	3	9
17	244.52	266	0	3	2	15	8	90	2	2	2	111	0	12	14	2	2
18	249.53	208	3	3	0	10	5	69	1	1	3	85	2	6	15	0	4
19	254.42	222	7	1	0	6	0	89	0	1	5	76	0	12	14	2	9
20	258.35	292	1	5	2	12	5	82	2	2	12	134	4	13	17	0	1
21	264.46	240	0	2	0	9	6	72	2	2	3	116	2	5	14	1	6
22	269.38	319	0	0	2	11	7	209	2	0	4	47	0	13	15	0	9
23	279.52	266	0	0	4	8	13	154	5	2	4	47	2	20	4	2	1
24	289.42	113	0	0	0	3	6	58	1	0	14	11	2	10	2	0	6
25	294.25	163	0	0	6	10	7	100	0	0	10	7	0	15	2	1	5
26	299.92	268	21	0	2	3	4	186	3	1	3	5	1	20	13	2	4
27	299.92	166	12	0	0	2	4	109	0	0	3	0	0	27	9	0	0
28	306.53	161	56	0	0	2	12	58	0	0	8	0	0	20	2	1	2
29	310.51	154	21	0	1	2	13	37	0	0	8	28	0	36	3	5	0
30	316.01	146	29	0	3	6	4	38	0	0	7	9	0	41	3	4	2
31	325.51	181	39	0	1	14	8	22	0	0	6	20	0	64	4	2	0
32	339.01	140	37	0	3	1	10	21	1	0	1	14	0	39	12	0	1
33	344.51	7	1	0	0	0	1	0	0	0	1	1	0	1	2	0	0
34	348.51	8	1	0	1	0	1	1	0	0	0	1	0	1	2	0	0

1	45.20	56	0	0	0	11	0	13	0	0	27	4	0	0	0	0
2	45.43	69	0	0	0	9	0	31	0	0	14	0	0	12	0	0
3	45.93	102	1	0	0	14	1	1	0	0	80	1	0	1	0	0
4	46.20	70	1	0	0	8	0	5	0	1	42	1	0	6	0	0
5	46.43	92	1	0	0	4	0	1	0	0	71	0	0	4	0	0
6	46.72	106	1	0	0	12	0	9	0	0	64	6	0	4	0	0
7	46.93	57	0	0	0	8	1	7	0	0	38	1	0	2	0	0
8	47.22	66	0	0	0	10	0	7	0	1	44	4	0	0	0	0
9	47.43	59	1	0	0	10	1	3	0	0	40	1	0	0	0	0
10	47.70	37	0	0	0	17	1	1	0	0	11	4	0	2	0	0
11	47.93	77	0	0	0	8	3	3	0	0	54	0	0	3	0	0
12	48.20	68	0	0	0	5	0	12	0	0	45	4	0	1	0	0
13	48.51	219	0	0	0	9	2	4	0	0	192	2	0	4	0	0
14	48.73	90	1	0	0	10	0	4	0	0	71	1	0	0	0	0
15	48.93	66	0	0	0	9	0	5	0	0	40	2	0	5	0	0
16	49.20	96	1	0	0	9	0	1	0	1	81	0	0	3	0	0
17	49.44	74	0	0	0	6	1	2	0	0	63	0	0	0	0	0
18	49.70	104	1	0	0	4	1	3	0	0	92	0	0	2	0	0
19	49.93	114	0	0	0	3	0	1	0	0	110	0	0	0	0	0
20	50.23	51	1	0	0	2	0	2	0	0	43	1	0	0	0	0
21	50.43	57	0	0	0	5	0	0	0	0	51	0	0	1	0	0
22	50.70	122	1	0	0	3	1	2	0	0	103	0	0	9	0	0
23	50.93	95	2	0	0	9	0	7	0	2	66	3	0	4	0	0
24	51.21	135	1	0	0	16	1	6	0	0	104	0	0	1	0	0
25	51.43	123	0	0	0	15	0	3	0	0	101	0	0	1	0	0
26	51.73	64	0	0	0	6	0	2	0	0	54	0	0	1	0	0
27	51.93	104	0	0	0	7	0	1	0	0	94	0	0	2	0	0
28	52.36	181	1	0	0	16	1	2	0	0	153	0	0	6	1	0
29	53.26	154	2	0	0	14	2	7	0	0	118	0	0	11	0	0
30	54.42	161	0	0	0	0	7	5	0	0	126	0	0	23	0	0
31	55.30	166	0	0	12	0	4	37	0	0	76	8	4	24	0	1
32	55.92	185	5	0	9	0	3	27	0	0	118	0	0	23	0	0
33	56.78	117	0	0	7	0	6	14	0	0	79	0	1	10	0	0
34	57.42	161	1	0	7	1	5	13	0	0	109	0	1	23	0	0
35	58.30	145	1	0	3	2	1	19	0	0	96	4	0	18	0	0
36	58.92	141	0	0	6	5	2	8	0	0	103	0	2	14	0	0
37	59.80	201	0	0	7	0	5	29	0	0	148	0	0	12	0	0
38	60.42	199	0	0	8	4	1	40	0	0	120	0	4	22	0	0
39	61.30	95	0	0	3	1	3	4	0	0	73	0	0	11	0	0
40	61.92	191	0	0	3	0	2	15	0	0	155	0	1	15	0	0
41	62.80	180	0	0	1	2	3	0	0	0	164	0	0	10	0	0
42	66.50	69	0	0	0	4	1	8	0	0	53	0	0	3	0	0
43	68.00	136	0	0	3	1	0	12	0	0	110	0	1	9	0	0
44	70.00	111	0	0	0	0	0	12	0	0	82	1	0	12	1	3
45	72.00	82	0	0	0	0	0	5	0	0	64	0	1	12	0	0
46	72.75	162	0	0	0	0	0	30	0	0	117	0	0	15	0	0
47	75.00	82	0	0	0	1	0	0	0	0	79	0	0	2	0	0
48	77.00	55	0	0	0	0	0	2	0	0	51	0	0	2	0	0
49	79.00	77	0	0	2	0	1	6	0	0	63	0	0	5	0	0
50	81.00	116	0	0	0	1	4	10	0	0	87	0	0	14	0	0

1	150.12	240	6	1	1	3	8	2	0	0	6	124	10	78	0	0	1
2	150.93	188	5	5	9	1	8	1	0	0	6	59	2	92	0	0	0
3	151.82	388	13	0	14	0	5	9	3	0	10	249	9	74	0	0	2
4	152.37	427	0	0	1	0	1	2	0	0	2	342	3	76	0	0	0
5	153.32	571	20	0	3	0	5	7	2	0	6	385	10	133	0	0	0
6	153.93	419	11	0	5	0	7	6	3	0	14	260	10	103	0	0	0
7	154.82	317	19	0	3	2	10	5	2	0	14	81	14	167	0	0	0
8	155.43	272	33	0	3	0	10	6	0	0	18	98	11	93	0	0	0
9	156.32	290	13	0	8	0	9	14	1	0	15	122	9	97	1	0	1
10	158.93	305	41	2	6	0	4	6	1	0	31	79	7	128	0	0	0
11	160.41	314	67	9	13	2	27	4	1	0	27	107	6	51	0	0	0
12	161.75	92	31	0	0	9	8	5	0	0	7	16	4	12	0	0	0
13	170.51	109	16	0	0	7	15	2	0	0	11	24	4	30	0	0	0
14	173.51	174	33	0	0	5	9	2	1	0	24	50	2	48	0	0	0
15	176.51	147	27	0	0	2	15	0	0	0	18	50	1	34	0	0	0
16	181.51	172	16	4	0	4	21	0	0	0	7	79	0	41	0	0	0
17	188.01	162	2	6	0	3	14	2	0	0	15	80	0	40	0	0	0
18	191.01	167	5	0	0	2	8	1	0	0	21	99	1	30	0	0	0
19	194.01	199	0	7	0	1	19	1	1	0	9	117	0	41	1	1	1
20	197.51	142	0	0	0	6	13	12	3	0	16	72	1	18	0	0	1
21	200.01	176	0	1	0	5	13	7	4	0	15	108	2	18	0	0	3
22	203.51	157	0	0	0	3	20	9	3	0	17	73	3	28	0	0	1
23	207.93	132	9	4	4	1	15	5	5	0	22	36	2	26	0	0	3
24	208.82	99	18	0	5	0	14	6	5	0	17	0	5	25	0	0	4
25	209.43	171	74	0	3	0	3	4	3	0	48	0	3	31	1	0	1
26	210.32	114	43	0	0	1	9	1	1	0	26	0	1	31	0	1	0
27	215.93	180	71	0	10	3	13	4	0	0	33	0	3	42	0	0	1
28	216.82	127	55	0	10	0	5	2	0	0	18	0	1	35	0	0	1
29	217.38	154	70	0	6	0	15	2	0	0	21	0	2	37	0	0	1
30	218.18	170	52	0	2	0	6	2	1	0	40	14	6	47	0	0	0
31	218.93	191	72	0	6	1	7	1	1	0	26	26	1	49	0	1	0
32	219.82	205	68	0	5	1	14	3	0	0	36	22	3	52	0	0	1
33	221.01	151	56	11	0	4	8	3	1	0	6	10	0	52	0	0	0

1	53.51	258	3	0	2	20	1	2	1	0	8	198	2	21	0	0	0
2	55.01	59	2	0	1	4	0	0	0	0	2	41	0	9	0	0	0
3	55.64	126	31	0	0	12	1	1	0	0	12	64	0	1	0	0	0
4	56.27	163	4	27	0	13	2	0	0	1	4	110	0	2	0	0	0
5	56.83	108	17	22	0	20	2	1	0	0	9	25	0	5	0	0	0
6	57.67	99	13	10	0	3	3	0	0	0	23	35	0	8	0	0	0
7	58.33	105	10	31	0	10	0	0	0	0	13	20	0	11	0	0	0
8	59.07	91	13	8	0	5	0	0	0	2	20	24	0	11	0	0	0
9	59.76	96	3	26	0	12	1	0	0	1	10	38	0	5	0	0	0
10	62.57	113	38	0	0	19	3	0	0	0	8	8	0	37	0	0	0
11	63.42	86	25	0	0	1	6	0	0	0	19	14	0	20	0	0	0
12	64.10	89	39	1	0	0	6	0	0	0	10	1	0	24	0	0	0
13	65.53	93	15	2	0	5	3	0	0	1	36	6	0	24	0	0	0
14	66.13	93	26	0	2	5	6	0	0	1	17	23	0	10	0	0	0
15	66.83	83	16	0	0	5	1	0	0	0	30	10	0	21	0	0	0
16	67.57	100	21	0	0	6	8	1	0	0	28	1	0	29	0	0	0
17	68.23	104	14	1	0	12	7	5	0	0	11	26	0	21	0	0	0
18	68.64	65	1	0	0	8	3	1	0	0	41	0	0	8	0	0	0
19	68.92	104	11	0	1	0	5	0	0	0	52	31	0	4	0	0	0
20	70.30	59	0	0	0	29	1	0	0	0	23	1	0	4	0	0	0
21	72.25	67	0	0	0	1	7	0	0	1	46	0	0	12	0	0	0
22	72.88	69	0	0	0	5	6	1	0	0	44	1	0	12	0	0	0
23	73.57	89	0	0	0	8	6	0	0	0	46	4	0	24	0	0	0
24	74.28	104	0	0	0	9	6	0	0	0	56	2	0	20	0	0	0
25	75.75	35	1	0	0	0	1	0	0	0	13	0	0	20	0	0	0
26	77.25	70	7	0	0	2	0	0	0	0	14	0	0	47	0	0	0
27	78.75	68	6	0	1	5	1	2	0	0	12	0	1	40	0	0	0
28	79.50	36	0	0	0	0	0	1	0	0	11	0	0	24	0	0	0

1	54.49	86	3	0	0	3	2	23	0	0	0	27	1	16	9	1	0
2	57.49	136	3	0	1	1	0	20	0	0	2	76	0	17	12	4	0
3	58.99	130	2	0	1	3	0	32	0	0	1	51	1	21	17	0	1
4	60.51	139	0	0	0	5	0	34	0	0	1	64	0	18	17	0	0
5	64.51	87	8	0	0	3	0	33	2	0	6	14	1	15	4	0	0
6	65.49	110	24	0	0	2	0	22	1	0	15	13	3	17	8	2	1
7	66.99	122	9	0	1	5	1	35	0	0	3	40	3	9	14	0	1
8	68.48	101	6	0	2	3	1	38	2	0	6	19	8	8	4	2	2
9	69.99	192	17	0	0	9	13	66	1	0	1	56	2	15	4	2	0
10	71.49	82	3	0	0	3	1	30	0	0	1	36	3	1	3	1	0
11	73.49	228	26	0	2	6	2	107	4	1	2	38	1	15	22	0	0
12	74.99	110	18	0	2	7	2	33	1	0	1	28	0	4	13	0	1
13	76.49	160	36	0	0	2	4	65	0	1	1	26	1	7	14	1	1
14	77.98	129	0	0	0	5	0	59	2	0	0	25	0	28	6	1	2
15	79.47	116	3	1	0	4	4	47	1	0	1	32	0	12	9	0	0
16	80.99	96	0	0	1	2	0	40	2	2	2	23	1	13	8	0	0
17	82.99	121	1	0	2	3	0	66	1	0	2	26	1	10	9	0	0
18	84.47	128	0	0	3	4	3	74	2	0	3	28	4	2	4	0	0
19	86.03	185	0	0	0	5	3	116	4	1	0	27	4	7	17	1	0
20	87.53	136	0	1	0	0	0	55	0	2	0	10	10	3	52	1	1
21	89.98	68	0	1	1	1	2	39	0	0	0	12	3	3	2	0	0
22	90.48	88	0	0	0	7	1	45	0	0	1	20	4	2	7	0	0
23	93.98	91	2	0	0	1	0	58	1	0	1	14	2	2	8	0	0
24	95.48	122	0	0	1	5	4	70	0	0	1	8	13	1	18	0	0
25	97.76	109	1	0	1	1	2	52	1	0	1	36	5	3	6	0	0

1	5.51	104	0	0	0	0	2	0	0	0	47	30	0	6	0	0	0
2	7.01	138	0	0	0	1	8	24	0	0	36	56	0	3	2	2	1
3	10.07	124	0	0	0	11	4	7	0	0	34	58	0	2	1	1	1
4	11.26	117	0	0	0	13	22	19	0	0	47	8	0	8	0	0	0
5	12.76	135	0	0	0	17	11	5	0	0	85	7	0	7	3	0	0
6	14.26	112	0	0	0	6	7	15	0	0	66	8	0	9	1	0	0
7	20.75	121	0	0	0	12	9	1	0	0	86	5	0	7	1	0	0
8	23.75	133	21	0	0	4	3	5	0	0	17	29	0	51	3	0	0
9	29.50	136	12	0	0	1	8	11	0	0	58	20	0	26	0	0	0
10	31.00	124	2	0	0	1	4	6	0	0	59	28	0	24	0	0	0
11	32.49	116	0	0	0	1	8	6	0	0	44	26	0	31	0	0	0
12	33.99	157	0	0	0	5	7	2	0	0	78	24	0	40	1	0	0
13	35.49	189	0	0	0	0	6	1	0	0	93	48	0	41	0	0	0
14	36.99	149	0	0	0	6	8	25	0	0	33	33	0	41	3	0	0
15	37.75	156	16	0	0	3	4	16	0	0	53	36	0	28	0	0	0
16	42.26	105	2	0	0	3	6	4	0	0	52	20	0	18	0	0	0

APPENDIX 2.

Computer programs used in this study;
all are listed in Lohmann (1980)

1. Determine "average" nannoflora at each site.

NANNO - archive nanoplankton census data for each site
QPCA - compute 1st Q-mode principal component of all
samples at each of 17 sites.

2. Determine the average biogeography, the variation among the average nannofloral compositions of the sites.

QPCA - compute first three Q-mode principal components of the 17 site averages, the 17 1st Q-mode principal components.

3. Express the nannofloral compositions of all original samples in terms of the average biogeography.

QPCA - estimate loadings of 603 original samples on the first three Q-mode principal components of the site averages.

4. Examine the pattern of variation in nannofloral compositions at each site in the context of their average biogeography.

ELLIPSE - compute and plot covariation ellipses for each site describing mean composition and pattern of covariation in their compositions expressed in terms of the average biogeography, the estimated principal components of site averages.

5. Summarize nanoplankton oceanographic records and search for similarities and systematic differences among them.

TIMER - given stratigraphic levels of known age, estimate ages of individual samples
RECTERP - interpolate sample compositions at 200,000-yr. intervals
SLICER - pick synchronous values from 11 interpolated time series
RPCA - compute correlations between time series and their eigenmodes (R-mode principal components)
BARPLOT - plot time series

Table 1. Present location and water depth for each Deep Sea Drilling Project (DSDP) site studied.

<u>Site</u>	<u>Location</u>		<u>Depth</u>
55	09°18.1'N	142°32.9'E	2850 m
71	04°28.3'N	140°18.9'W	4419 m
77B	00°28.9'N	133°13.7'W	4291 m
158	06°37.4'N	85°14.2'W	1953 m
173	39°57.7'N	125°27.1'W	2927 m
206	32°00.8'S	165°27.2'E	3196 m
207A	36°57.8'S	165°26.1'E	1389 m
208	26°06.6'W	161°13.3'E	1545 m
278	56°33.4'S	160°04.3'E	3675 m
281	47°59.8'S	147°45.8'E	1591 m
284	40°30.5'S	167°40.8'E	1066 m
289	00°29.9'S	158°30.7'E	2206 m
292	15°49.1'N	124°39.0'E	2943 m
296	29°20.4'N	133°31.5'E	2920 m
310	36°52.1'N	176°54.1'E	3516 m
317B	11°00.1'S	162°15.8'W	2622 m
319	13°01.0'S	101°31.5'W	4296 m

Table 2

CENSUS CATEGORIES FOR CENOP NANNOPLANKTON (LATE MIOCENE)

1. Reticulofenestra pseudumbilica (Gartner) Gartner
Reticulofenestra gelidus (Geitzenauer) Backman
2. Reticulofenestra haqii Backman
3. Cyclococcolithus macintyreii Bukry and Branlette
4. Cyclococcolithus leptoporus (Murray and Blackman) Kamptner
5. Coccolithus pelagicus (Wallich) Schiller
Coccolithus miopelagicus Bukry
6. Sphenolithus spp.
7. Helicopontosphaera spp.
8. Cyclolithella rotula (Kamptner) Haq and Berggren
9. Discoaster spp.
10. Small elliptical placoliths
(Dictyococcites and Cyclococcolithus affinities)
11. Small circular to subcircular placoliths
(Coccolithus and Cyclococcolithus affinities)
12. Dissolved, badly preserved coccoliths
13. Coccolithus pataecus Gartner
14. Coccolithus radiatus Kamptner
15. Umbilicosphaera jafari Muller

Table 3. Nannofloral compositions of site averages. Each site average is the 1st Q-mode principal component of all samples at that site. Compositions are Q-mode principal factor scores expressed as percent; the percent of the variation in compositions observed at each site that is accounted for by each component is indicated.

1	55	2	0	1	0	6	4	0	0	65	0	0	22	0	0	0	96%
2	71	12	6	0	8	5	15	0	0	17	22	0	15	0	0	0	66%
3	77B	13	9	0	5	5	12	0	1	6	37	0	12	0	0	0	73%
4	158	7	10	0	2	2	31	0	1	2	38	0	7	0	0	0	79%
5	173	23	1	0	5	11	4	0	0	13	28	0	14	0	0	0	64%
6	206	41	2	0	6	13	3	1	0	3	13	0	18	0	0	0	79%
7	207A	20	2	0	4	7	4	2	1	1	42	0	13	1	0	2	76%
8	208	9	0	2	1	2	9	2	0	2	47	2	17	3	0	3	85%
9	278	24	0	0	1	9	1	0	0	0	20	0	45	0	0	0	77%
10	281	32	0	0	4	22	2	0	0	0	20	0	18	1	0	1	74%
11	284	7	1	2	1	2	1	1	0	0	59	1	21	2	0	2	96%
12	289	8	0	1	3	3	34	1	0	3	30	1	10	5	0	2	77%
13	292	0	0	1	7	1	8	0	0	74	1	0	6	0	0	0	95%
14	296	16	1	2	2	7	2	1	0	10	31	2	26	0	0	0	72%
15	310	14	5	0	8	4	1	0	0	28	18	0	22	0	0	0	60%
16	317B	5	0	1	3	1	41	1	0	2	25	2	9	9	0	0	86%
17	319	3	0	0	4	6	7	0	0	42	21	0	16	1	0	0	84%

Table 4.

Stratigraphies for 11 Late Miocene nannoplankton
dissolution and climate records.

DSDP Sites	Mioc./Plioc.	Mid/Late Mioc.	Reference
71	18 m	59 m	Tracey <u>et al.</u> , 1971
77B	83.7 m	165.9 m	Hays <u>et al.</u> , 1972
158	82.3 m	207 m	van Andel, Heath <u>et al.</u> , 1973
206	191.4	220 m	Burns, Andrews <u>et al.</u> , 1973
207A	77 m	119 m	Burns, Andrews <u>et al.</u> , 1973
208	106 m	222 m	Burns, Andrews <u>et al.</u> , 1973
278	177 m	224.5 m	Kennett, Houtz <u>et al.</u> , 1974
281	36 m	78.5 m	Kennett, Houtz <u>et al.</u> , 1974
289	160.5	310 m	Andrews, Packham <u>et al.</u> , 1975
296	158.5 m	209 m	Karig, Ingle <u>et al.</u> , 1975
310	56 m	75 m	Larson, Moberly <u>et al.</u> , 1975

Ages assigned the Miocene/Pliocene and Middle/Late Miocene
boundaries are 5.0 and 11.0 m.y., respectively (Berggren and
Van Couvering, 1974).

FIGURE CAPTIONS

Figure 1. Locations of Pacific DSDP sites studied.

Figure 2. Distribution of site averages (2A) and nannoplankton taxa (2B) on the first three Q-mode principal components of the "average" Late Miocene Pacific nannoflora, the site averages. Each site average is the first Q-mode principal component of all Late Miocene samples from that site. Associations of sites and nannoplankton with deep or shallow waters and with temperate or tropical latitudes are indicated, based on the bathymetric and geographic patterns shown in figures 3 and 4. Coordinates of site averages (2A) are principal component loadings. Coordinates of nannoplankton taxa (2B) are scores.

Figure 3. Bathymetric distribution of the 2nd Q-mode principal component of the "average" Late Miocene nannoflora. This component differentiates a shallow, undissolved assemblage characterized by small elliptical placoliths, sphenoliths and R. pseudoumbilica from a deeper, dissolved assemblage characterized by discoasters, dissolved coccoliths, and C. leptoporus. Sites are grouped as temperate or tropical on the basis of differences in nannofloral composition shown in figure 4.

Figure 4. Geographic distribution of the 3rd Q-mode principal component of the "average" Late Miocene nannoflora. This component differentiates a low-latitude, tropical nannoflora characterized by sphenoliths, small elliptical placoliths and discoasters from a high-latitude, temperate nannoflora consisting of R. pseudoumbilica, dissolved coccoliths and C. pelagicus. Values plotted are component loadings. Dashed contour is the present day 20°C winter isotherm (after Sverdrup and others, 1942); it roughly bounds the tropics.

Figure 5. Geographic distribution of three Q-mode varimax factors. A high-latitude, temperate factor assemblage is characterized by R. pseudoumbilica, dissolved coccoliths, small elliptical placoliths and C. pelagicus (5A). There are two low-latitude, tropical factor assemblages, their compositions depending on water depth: a shallow one characterized by small elliptical placoliths, sphenoliths, and C. pataecus (5B) and a deep one characterized by discoasters, dissolved coccoliths and C. leptoporus (5C). Compositions are factor scores expressed as percent. Values plotted are factor loadings expressed as percent. Dashed contour is the present day 20°C winter isotherm, roughly delineating the tropics.

Figure 6. Distribution of all 603 samples on the first 3 Q-mode principal components of the 17 site averages. 6A shows individual samples. 6B summarizes covariation in sample compositions for each site: +'s indicate the mean compositions, orientations of the ellipses indicate sources of variation in composition, and their eccentricities indicate strengths of covariation. If sample compositions were multi-normally distributed about their means (which they are not) then ellipses would be equal frequency ellipses. Major axes are scaled so that approximately 2/3 of the samples would lie within their ellipse.

Figure 7. Nannofossil composition of samples from adjacent sites 71 (dots) and 77B (diamonds). Both show a similar mean and range in composition attributable to climate. However, the nannofloral compositions of most samples from deeper site 71 have been changed by selective dissolution. The proportion of discoasters, dissolved coccoliths, and C. leptoporus has increased at the expense of small elliptical placoliths, sphenoliths and C. pataecus.

Figure 8. Nannofloral compositions of samples at sites 310 (dots) and 296 (diamonds), both from between 30 and 40°N. Both show a similar mean and range of composition attributable to climate. The warm component at shallower site 296 is similar in composition to the warm, undissolved nannofloras at shallow, tropical sites 289, 158, and 317B. The warm component in a number of samples at deeper site 310 is similar to that at deep, tropical sites 292 and 55.

Figure 9. Nannofloral compositions of samples at sites 289, 208, 206, 284, 207A and 281. These form a transect from the equator to 40°S. The composition of samples from deepest site 206, which should lie between those of sites 289, 208, and 207A, 284, 281, has been changed by selective dissolution to one with a much cooler water aspect.

Figure 10. Different modes of variation in the nannoplankton histories of calcite dissolution (2nd Q-mode principal component of site averages estimated in original samples). These three eigenmodes describe 74% of the variation observed at the 11 Pacific DSDP sites with most complete Late Miocene records. Values plotted are R-mode principal component scores and scales are in units of standard deviation from a zero mean. Dissolution increases to the left. Variance accounted for by each mode is indicated. Dashed lines are the Miocene/Pliocene and Middle/Late Miocene boundaries.

Figure 11. Bathymetric distribution of the first three eigenmodes of 11 Late Miocene records of nanoplankton dissolution in the Pacific. The 1st eigenmode tends to describe more of the variation observed in shallower sites and in deep North Pacific site 310. The 2nd and 3rd eigenmodes (dots and open circles) tend to describe variations in dissolution in deeper sites. Values plotted are the fraction of the variation of the record at each site attributable to each eigenmode (squared R-mode principal component loading).

Figure 12. Comparison of the 1st eigenmode of the nanoplankton dissolution histories with the records of dissolution at the sites it best describes. Except for site 310, these sites tend to lie in shallower water, above 3000 m. Correlations of each site record with this eigenmode is indicated (R-mode principal component loading). Dissolution increases to the left. Values for the eigenmodes are R-mode principal component scores. Values for nanoplankton dissolution are estimated loadings of samples on the 2nd Q-mode principal component of site averages, interpolated at 200,000-year intervals. Values for original samples are also indicated (dots). Dashed lines are stratigraphic levels bounding the Late Miocene that were used to correlate the records.

Figure 13. Nannofossil compositions of two separate groups of samples from site 310, above and below 65 m (about 8 m.y. ago). Variation among the older samples (dots) is between a cool, temperate nannoflora and a dissolved warm, tropical nannoflora. Variation among younger samples is between the same cool nannoflora, but their warm, tropical nannoflora is undissolved. These tendencies are summarized by covariation ellipses.

Figure 14. Comparison of the 2nd (13A) and 3rd (13B) eigenmodes of nanoplankton dissolution histories with the records of dissolution they best represent. These sites tend to lie in water deeper than 3000 m. Correlations of the site records with the eigenmodes is indicated. Dissolution increases to the left. Values for the eigenmodes are R-mode principal component scores. Values for nanoplankton dissolution are estimated loadings of samples on the 2nd Q-mode principal component of site averages, interpolated at 200,000-year intervals. Values for original samples are indicated (dots). Dashed lines are stratigraphic levels bounding the Late Miocene that were used to correlate the records.

Figure 15. Different modes of variation in the nannoplankton record of climate (3rd Q-mode principal component of site averages). Climate warms to the right. These three eigenmodes describe 74% of the variation observed at the 11 DSDP sites; the proportion represented by each is indicated. Values plotted are R-mode principal component scores. Dashed lines bound the Late Miocene.

Figure 16. Geographic distribution of the 1st and 2nd eigenmode of 11 Late Miocene records of the nannoplankton response to climate. Sites used to determine the average biogeography of Late Miocene nannoplankton but without complete Late Miocene records (open circles), were not included in this analysis. Values plotted are the fraction of the variance of the climate records attributable to each eigenmode. Values greater than .35 are delineated. Variations described by the 1st eigenmode (15A) are found most at tropical sites; those described by the 2nd eigenmode (15B) tend to be at south temperate sites. Dashed lines are present 20°C winter isotherms and approximately bound the tropics.

Figure 17. Comparison of the 1st (16A) and 3rd (16B)

eigenmodes of the 11 nanoplankton records of Late Miocene Pacific climate with the records of climate at the sites they best describe. Climate warms to the right. Correlations of the climate records with their associated eigenmodes are indicated. These sites tend to lie in tropical and north temperate waters. Values plotted for the eigenmodes are R-mode principal component scores. Values for nanoplankton climate are estimated loadings of samples on the 3rd Q-mode principal component of site averages interpolated at 200,000-year intervals. Values for original samples are also indicated (dots). Dashed lines are stratigraphic levels bounding the Late Miocene that were used to correlate the records.

Figure 18. Comparison of the 2nd eigenmode of the

nanoplankton records of Late Miocene Pacific climate with records of climate at the sites it best represents. Climate warms to the right. These sites all tend to be in southern temperate regions. Values plotted for the eigenmode are R-mode principal component scores. Values plotted for nanoplankton climate are estimated loadings of samples on the 3rd Q-mode principal component of site averages interpolated at 200,000-year intervals. Values for original samples are indicated (dots). Dashed lines are stratigraphic levels bounding the Late Miocene that were used to correlate the records.

Figure 19. Stratigraphic comparison of Pacific Late Miocene nannoplankton oceanographic records with variations in carbon isotopic composition of the deep water. Latitudinal contrast in climate was determined as the simple difference between tropical and south temperate climate, the 1st and 2nd eigenmodes of the 3rd Q-mode principal component of site averages estimated in original samples from 11 sites. The record of dissolution in the deep Pacific is the 2nd eigenmode of the 2nd Q-mode principal component of site averages. The carbon isotopic record is from benthic foraminifera at DSDP Site 289 (Woodruff et al., in press).

LOCATION OF CENOP DSDP SITES

Fig.3

3rd Q-MODE PRINCIPAL COMPONENT

TEMPERATE ASSEMBLAGE

SHALLOW, TROPICAL ASSEMBLAGE

Fig.6A

Fig. 6B

Fig.7

Fig.8

Fig.10

Fig.12

Fig.13

Fig.14

Fig.15

1st EIGENMODE (TROPICAL MODE)

2nd EIGENMODE (SOUTH TEMPERATE MODE)

Fig.17

Fig.18

PLATE 1

Scale in each photograph is 2 microns long.

- 1a,b. Cyclococcolithus macintyreii Bukry and Bramlette, 1969
distal view
a. DSDP 21/208/16/5 100-101 Natural Light
Pacific Ocean Late Miocene
b. DSDP 21/208/16/5 100-101 Cross Polarized Light
Pacific Ocean Late Miocene
- 2a,b. Cyclococcolithus leptoporus (Murray and Blackman)
Kampter 1956 distal view
a. DSDP 29/284/14/5 100-101 Natural Light
Pacific Ocean Lower Pliocene
b. DSDP 29/284/14/5 100-101 Cross Polarized Light
Pacific Ocean Lower Pliocene
- 3a,b. Reticulofenestra haqii Backman, 1978
distal view
a. DSDP 16/158/11/2 143-144 Natural Light
Pacific Ocean Late Miocene
b. DSDP 15/158/11/2 143-144 Cross Polarized Light
Pacific Ocean Late Miocene
4. Discoaster hamatus Martini and Bramlette, 1963
distal view
DSDP 21/208/16/5 100-101 Natural Light
Pacific Ocean Late Miocene
- 5a,b. Small elliptical placoliths (Dictyococcites and
Reticulofenestra affinities) Black, 1967/Hay, Mohler
and Wade, 1966
a. DSDP 31/296/17/4 42-43 Natural Light
Pacific Ocean Late Miocene
b. DSDP 31/296/17/4 42-43 Cross Polarized Light
Pacific Ocean Late Miocene

PLATE 2

Scale in each photograph is 2 microns long.

- 6a,b. Helicopontosphaera kamptneri Hay and Mohler, 1967
proximal view
a. DSDP 21/208/12/1 100-101 Natural Light
Pacific Ocean Late Miocene
b. DSDP 21/208/12/1 100-101 Cross Polarized Light
Pacific Ocean Late Miocene
- 7a,b. Coccolithus pelagicus (Wallich) Schiller, 1930
distal view
a. DSDP 21/208/16/5 100-101 Natural Light
Pacific Ocean Late Miocene
b. DSDP 21/208/16/5 100-101 Cross Polarized Light
Pacific Ocean Late Miocene
- 8,9. Sphenolithus abies Deflandre, 1954
axial view
8. DSDP 21/208/16/5 100-101 Cross Polarized Light
Pacific Ocean Late Miocene
9. DSDP 21/208/16/5 100-101 Cross Polarized Light
Pacific Ocean Late Miocene
transverse view
- 10a,b. Cyclolithella rotula (Kamptner) Haq and Berggren, 1978
distal view
a. DSDP 21/208/11/5 140-141 Natural Light
Pacific Ocean Late Miocene
b. DSDP 21/208/11/5 140-141 Cross Polarized Light
Pacific Ocean Late Miocene
11. Coccolithus radiatus Kamptner, 1955
distal view
DSDP 29/284/15/3 103-104 Phase Contrast
Pacific Ocean Lower Pliocene

PLATE 2 (continued)

12. Umbilicosphaera jafari Muller, 1974
distal view
DSDP 21/208/11/3 96-97 Phase Contrast
Pacific Ocean Late Miocene
- 13,14. Coccolithus pataecus Gartner, 1967
distal view
13. DSDP 21/208/11/3 96-97 Phase Contrast
Pacific Ocean Late Miocene
14. DSDP 29/284/15/6 103-104 Phase Contrast
Pacific Ocean Lower Miocene
- 15a,b. Reticulofenestra pseudoumbilica (Gartner) Gartner, 1967
distal view
a. DSDP 16/158/13/5 25-26 Natural Light
Pacific Ocean Late Miocene
b. DSDP 16/158/13/5 25-26 Cross Polarized Light
Pacific Ocean Late Miocene
- 16a,b. Reticulofenestra pseudoumbilica (Gartner) Gartner, 1967
distal view
a. DSDP 16/158/11/2 143-144 Natural Light
Pacific Ocean Late Miocene
b. DSDP 16/148/11/2 143-144 Cross Polarized Light
Pacific Ocean Late iocene
- 17,18. Reticulofenestra aff. R. pseudoumbilica (Gartner),
Perkner, 1967
both distal views
DSDP 18/158/23/3 100-101 Cross Polarized Light
Pacific Ocean Late Miocene

Plate 1

REPORT DOCUMENTATION PAGE		1. REPORT NO. WHOI-80-78	2.	3. Recipient's Accession No.
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<p>16. Abstract (Limit: 200 words) An analysis of the <u>variability</u> in the composition and distribution of Pacific Late Miocene calcareous nannoplankton about their <u>average biogeography</u> shows that there are primarily two environmental factors causing that <u>variability</u>, climate and dissolution. Climate produces a latitudinal, biogeographic differentiation of the Late Miocene nannoflora, while selective dissolution superimposes a bathymetric differentiation of the nannoflora on that due to climate. Together, these two factors produce three distinct Late Miocene nannofloral assemblages: a high-latitude assemblage and two tropical assemblages, their differences in composition depending on water depth and surface-water productivity.</p> <p>Selective dissolution produces most of the apparent biogeographic variation in Pacific Late Miocene nannoplankton compositions. Based on nannoplankton oceanographic records, we postulate that beginning 10 m.y. ago the production of deep and bottom waters in the Southern Ocean increased. This produced an northward decrease in calcite preservation, an increase in benthic $\delta C-13$, and a strong climatic gradient across southern latitudes. This period of increased deep Pacific circulation ended 7.5 m.y. ago.</p>				
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