# RESPONSE OF SILICEOUS MICROPLANKTON FROM THE SANTA BARBARA BASIN TO THE 1997–98 EL NIÑO EVENT

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## ABSTRACT

We report on fluxes of siliceous microorganisms (diatoms, radiolarians, and silicoflagellates), organic carbon, calcium carbonate, biogenic silica, and lithogenic particles in the Santa Barbara Basin (SBB; 34°4'N, 120°02'W), offshore of California, in a sediment trap set 540 m deep. We describe changes in particle fluxes, emphasizing the period from 1996 to early 1998, and compare flux values and species composition for non–El Niño (1996) and El Niño (1997–98) conditions. The California coastal waters were strongly influenced by El Niño conditions beginning late in the summer of 1997. Terrigenous input to our sampling site, as measured by the lithogenic flux, was significantly higher during the El Niño period, presumably reflecting higher rainfall and runoff into the basin. Samples from December 1997 to February 1998 contained large amounts of detritus, Chrysophyte cysts, benthic diatoms, and estuarine benthic foraminifers, indicating that considerable material was flushed from the river mouths during large storms. Both opal and organic carbon fluxes mirrored the productivity cycle, with high fluxes during the spring-summer upwelling period and low fluxes during fall and winter. However, for the winter of 1998 organic carbon fluxes were unusually high, and coincided with a February peak in the carbonate flux and high abundance of arenaceous tintinnids. Opal fluxes decreased, and major changes in the contribution of siliceous microplankton assemblages to the biogenic opal flux were observed during El Niño conditions: (1) Diatom fluxes were an order of magnitude lower, and species richness was higher than in the 1996 non–El Niño period. (2) The flux of radiolarians was 20% lower in late 1997–early 1998 when compared to the 1993–96 period. (3) The fall-winter peak in silicoflagellate fluxes, seen annually from 1993 to 1996, was missing in 1997. In addition, major changes in species composition were observed, including a significant increase in the proportion of warm-water flora and fauna, and a decrease in the relative contribution of the siliceous microorganisms indicative of spring upwelling conditions in the SBB.

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## INTRODUCTION

The onset and decay of El Niño events have been difficult to predict locally, so data on the response of microorganisms to these phenomena are rare. We were fortunate to have a sediment trap mooring already deployed in the center of the Santa Barbara Basin (SBB), southern California (fig. 1), beginning in August 1993 (table 1; Lange et al. 1997; Thunell 1998), which allowed us to study the changes in the flux of particles associated with the 1997–98 El Niño event, considered to be the strongest El Niño of this century (Davey and Anderson 1998; Wolter and Timlin 1998).

Many of the physical observations in the California Current region during late 1996 and early 1997 were fairly close to the seasonal norms. El Niño conditions developed very rapidly in March 1997 in the western and central equatorial Pacific (Chavez et al. 1999), becoming the dominant forcing process in the summer of 1997 in the eastern Pacific (Lynn et al. 1998; Chavez et al. 1999) and reaching peak strength in January–March 1998 (fig. 2). In the SBB, temperatures of the upper water column were unusually high at the end of summer 1997 and remained elevated throughout the fall and winter (fig. 3A; Thunell et al. 1999). A dramatic return to non–El Niño conditions in the equatorial Pacific occurred in May 1998 (fig. 2; Chavez et al. 1999; Takayabu et al. 1999), and by early autumn 1998 a shift to strong southward wind stress had produced cooler than normal sea-surface temperatures (SST) in the California Current system (Hayward et al. 1999).

It is our intent to describe temporal changes in the particle fluxes of organic carbon, calcium carbonate, biogenic silica, and the lithogenic fraction, and to compare flux values as well as the species composition of planktonic siliceous microorganisms for non–El Niño (1996 through mid-1997) and El Niño (mid-1997 through spring 1998) conditions in the SBB. Previous studies have already reported on particle fluxes and calcareous and siliceous components for the period 1993–96 (Thunell et al. 1995; Lange et al. 1997; Thunell 1998; Kincaid et al. 2000). These studies demonstrated that the flux patterns of the various components of the plankton are a response to changes in upper ocean conditions in the SBB, and that the shifts in species composition

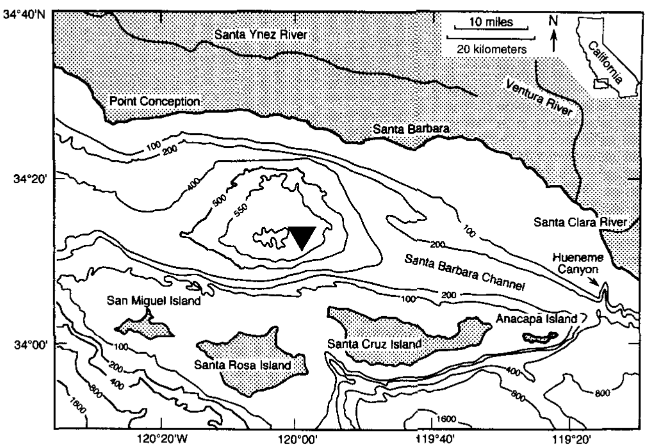


Figure 1. Bathymetry (in meters) of Santa Barbara Basin, and location of sediment trap mooring (black triangle).

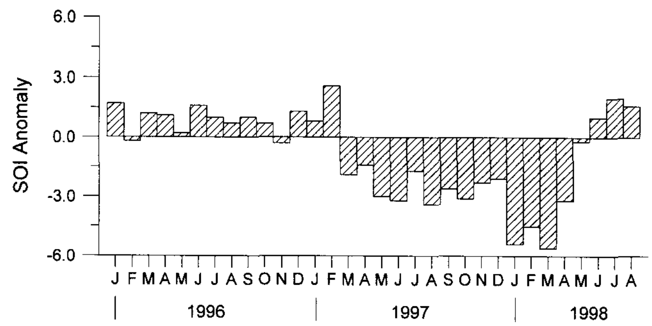


Figure 2. Southern Oscillation Index (SOI) anomaly from January 1996 through August 1998 (modified from Thunell et al. 1999). This index is based on atmospheric pressure difference between Tahiti and Darwin, Australia. Positive values indicate non–El Niño conditions, and negative values represent El Niño conditions. The 1997–98 El Niño began in March 1997 in the western and central equatorial Pacific and ended abruptly in mid-May 1998; a cold La Niña condition began in mid-1998 (e.g., Chavez et al. 1999). Data provided by the National Oceanic and Atmospheric Administration (NOAA).

do indeed reflect the circulation patterns in the area (Hendershott and Winant 1996). In addition, benthic diatoms advected from the shelf trace the influence of rainfall and river runoff.

This work is a continuation of the original plan to monitor biweekly changes in the flux of planktonic microorganisms over an exceptionally long time span in the SBB. The goal of this ongoing trapping program (being carried out by the University of South Carolina) is to monitor seasonal changes in sediment fluxes, to evaluate seasonal and interannual variability in response to El Niño (La Niña) events, and to appraise sediment formation and accumulation in the SBB. Results from sediment trap studies, in conjunction with measurements of climatic conditions, are relevant for identifying and calibrating climate proxies that can be applied to the sediment record in order to reconstruct and interpret climate signals contained in the well-preserved laminated sediments of the SBB (e.g., Soutar and Crill 1977; Kennett et al. 1995; Schimmelmann and Lange 1996).

## MATERIALS AND METHODS

The SBB is at the northern end of the Southern California Bight. A description of the study area and general hydrology of the SBB and the adjacent California Current can be found in Hendershott and Winant 1996, Lange et al. 1997, and Thunell 1998. The location of the sediment trap (34°14'N, 120°02'W; fig.1) as well as the type of trap used (cone-shaped with 13 cups; 0.5 $m^2$ collection area) has not changed over the five years of the experiment (August 1993–April 1998; Lange et al. 1997; Thunell 1998). The mooring was deployed at 590 m water depth, and the trap was positioned about 50 m off the bottom. Each trap sample represents a two-week period of collection except for the interval 22 May to 25 June 1997, when sampling resolution increased to 7 days (table 1). Samples were collected continuously and poisoned with $HgCl_2$.

Analysis of the siliceous microplankton, including diatoms, silicoflagellates, and radiolarians, was carried out on 1/64 splits of the total material in the original sample. The split was first washed with distilled water to remove salt and preservative and then acid-cleaned and prepared according to the method described in Wigley 1984. Samples were passed through a sieve so that all counts refer to cells ≥ 45µm. Thus the abundance of small diatoms such as *Chaetoceros* vegetative cells and resting spores (which range in size between 5 and 30 µm) is somewhat underestimated. This underestimation may not be that great because of the formation of sticky transparent exopolymer particles by *Chaetoceros* (Passow et al. 1994), which are very hard to disaggregate during the cleaning procedure, and are therefore retained in the sieve.

Two types of permanent slides were made: (1) Naphrax mounts for diatoms and silicoflagellates, which were analyzed quantitatively with an Olympus Provis AX 70 microscope with phase contrast illumination usually at 250× magnification and at 650× for resting spores and other small valves; and (2) Canada Balsam mounts for radiolarians, which were counted with a Zeiss Photomicroscope 1 at 100× magnification. The organisms were identified to the lowest taxonomic level possible.

Daily fluxes in each sample were estimated for the three taxonomic groups surveyed as well as for individual species, and are expressed in numbers $m^{-2}$ $d^{-1}$ (Sancetta and Calvert 1988). Relative contributions of selected diatom and radiolarian species, which represent upwelling conditions, warm oceanic waters, or littoral influence advected from the upper shelf (see Lange et al. 1997; Weinheimer and Cayan 1997, for definition of species groups) are given as percentages of total assemblages.

TABLE 1
**Fluxes of Siliceous Microorganisms in Santa Barbara Basin, August 1993 to April 1998**

| Sample # | Date cup opened | Days after 1 Jan 1993 | Collection days | Flux diatoms | Flux silicoflag. | Flux radiolaria |
|---|---|---|---|---|---|---|
| 1 | 12 Aug 93 | 224 | 14 | 2.92E+04 | 0 | 5.40E+03 |
| 2 | 26 Aug | 238 | 14 | 1.19E+05 | 2.56E+02 | 6.31E+03 |
| 3 | 09 Sep | 252 | 14 | 7.31E+04 | 2.01E+02 | 5.93E+03 |
| 4 | 23 Sep | 266 | 14 | 7.06E+04 | 4.94E+02 | 7.93E+03 |
| 5 | 07 Oct | 280 | 14 | 1.06E+05 | 8.23E+02 | 1.21E+04 |
| 6 | 21 Oct | 294 | 14 | 7.08E+04 | 6.95E+02 | 1.44E+04 |
| 7 | 04 Nov | 308 | 14 | 1.18E+05 | 1.54E+03 | 1.65E+04 |
| 8 | 18 Nov | 322 | 14 | 7.99E+04 | 3.20E+03 | 9.00E+03 |
| 9 | 09 Dec | 343 | 14 | 2.72E+04 | 1.66E+03 | 5.08E+03 |
| 10 | 16 Dec | 350 | 14 | 3.42E+04 | 1.05E+04 | 5.34E+03 |
| 11 | 30 Dec | 364 | 14 | 4.79E+04 | 8.06E+03 | 5.36E+03 |
| 12 | 13 Jan 94 | 378 | 14 | 4.10E+04 | 2.27E+03 | 4.22E+03 |
| 13 | 27 Jan | 392 | 14 | 3.90E+04 | 6.77E+02 | 6.97E+03 |
| 14 | 11 Feb | 407 | 14 | 1.03E+06 | 5.49E+02 | 1.05E+04 |
| 15 | 25 Feb | 421 | 14 | 3.21E+04 | 1.65E+02 | 8.86E+03 |
| 16 | 11 Mar | 435 | 14 | 2.06E+04 | 1.10E+02 | 4.77E+03 |
| 17 | 25 Mar | 449 | 14 | 3.33E+04 | 8.23E+01 | 3.87E+03 |
| 18 | 08 Apr | 463 | 14 | 6.74E+05 | 0 | 4.99E+03 |
| 19 | 22 Apr | 477 | 14 | 6.81E+06 | 3.66E+01 | 5.19E+03 |
| 20 | 06 May | 491 | 14 | 2.90E+05 | 1.65E+02 | 5.80E+03 |
| 21 | 20 May | 505 | 14 | 7.30E+04 | 2.74E+02 | 4.00E+03 |
| 22 | 03 Jun | 519 | 14 | 7.79E+04 | 7.31E+01 | 2.58E+03 |
| 23 | 17 Jun | 533 | 14 | 7.42E+05 | 1.83E+02 | 5.12E+03 |
| 24 | 01 Jul | 547 | 14 | 2.32E+05 | 2.56E+02 | 4.83E+03 |
| 25 | 15 Jul | 561 | 14 | 1.91E+05 | 4.57E+02 | 5.96E+03 |
| 26 | 29 Jul | 575 | 13 | 2.42E+05 | 1.38E+02 | 6.18E+03 |
| 27 | 23 Aug | 600 | 14 | 1.20E+05 | 1.04E+03 | 5.32E+03 |
| 28 | 06 Sep | 614 | 14 | 1.61E+05 | 1.37E+03 | 6.80E+03 |
| 29 | 20 Sep | 628 | 14 | 8.51E+04 | 8.78E+02 | 1.09E+04 |
| 30 | 04 Oct | 642 | 14 | 8.92E+04 | 7.09E+03 | 1.03E+04 |
| 31 | 18 Oct | 656 | 13 | 5.90E+05 | 2.76E+03 | 8.68E+03 |
| 32 | 21 Feb 95 | 782 | 14 | 1.24E+04 | 3.40E+03 | 1.61E+04 |
| 33 | 07 Mar | 796 | 14 | 6.47E+03 | 7.31E+02 | 1.30E+04 |
| 34 | 21 Mar | 810 | 14 | 7.57E+03 | 2.30E+03 | 1.35E+04 |
| 35 | 04 Apr | 824 | 14 | 1.38E+05 | 1.57E+03 | 1.59E+04 |
| 36 | 18 Apr | 838 | 14 | 2.86E+05 | 6.22E+02 | 1.09E+04 |
| 37 | 02 May | 852 | 14 | 1.62E+06 | 7.31E+01 | 1.48E+04 |
| 38 | 26 Aug | 968 | 14 | 1.77E+05 | 4.61E+03 | 1.32E+04 |
| 39 | 09 Sep | 982 | 14 | 4.42E+05 | 1.82E+04 | 1.19E+04 |
| 40 | 23 Sep | 996 | 14 | 3.23E+05 | 1.06E+05 | 1.58E+04 |
| 41 | 07 Oct | 1010 | 14 | 7.95E+04 | 2.43E+04 | 1.57E+04 |
| 42 | 21 Oct | 1024 | 14 | 1.93E+05 | 2.36E+04 | 1.40E+04 |
| 43 | 04 Nov | 1038 | 14 | 2.06E+05 | 9.51E+03 | 2.44E+04 |
| 44 | 18 Nov | 1052 | 14 | 6.69E+04 | 7.02E+03 | 9.36E+03 |
| 45 | 02 Dec | 1066 | 14 | 3.88E+04 | 1.35E+04 | 8.48E+03 |
| 46 | 16 Dec | 1080 | 14 | 1.27E+05 | 2.34E+04 | 1.44E+04 |
| 47 | 30 Dec | 1094 | 14 | 1.27E+05 | 5.08E+04 | 9.51E+03 |
| 48 | 13 Jan 96 | 1108 | 14 | 1.17E+04 | 2.56E+03 | 4.17E+03 |
| 49 | 27 Jan | 1122 | 14 | 1.68E+05 | 1.17E+03 | 1.45E+04 |
| 50 | 10 Feb | 1136 | 13 | 2.77E+05 | 8.78E+02 | 1.17E+04 |
| 51 | 26 Mar | 1181 | 14 | 2.77E+05 | 7.31E+01 | 1.13E+04 |
| 52 | 09 Apr | 1195 | 14 | 1.97E+06 | 0 | 9.03E+03 |
| 53 | 23 Apr | 1209 | 14 | 1.02E+06 | 1.46E+02 | 1.27E+04 |
| 54 | 07 May | 1223 | 14 | 1.37E+06 | 5.12E+02 | 1.42E+04 |
| 55 | 21 May | 1237 | 14 | 1.30E+05 | 3.66E+01 | 5.38E+03 |
| 56 | 04 Jun | 1251 | 14 | 4.20E+05 | 2.93E+02 | 7.53E+03 |
| 57 | 18 Jun | 1265 | 14 | 2.19E+04 | 0 | 1.03E+04 |
| 58 | 02 Jul | 1279 | 14 | 8.91E+04 | 4.39E+02 | 9.62E+03 |
| 59 | 16 Jul | 1293 | 14 | 1.19E+05 | 6.58E+02 | 8.70E+03 |
| 60 | 30 Jul | 1307 | 14 | 2.09E+05 | 1.10E+03 | 1.52E+04 |
| 61 | 13 Aug | 1321 | 14 | 1.41E+05 | 5.49E+02 | 1.25E+04 |
| 62 | 27 Aug | 1335 | 14 | 3.05E+05 | 4.02E+02 | 8.70E+03 |
| 63 | 24 Sep | 1363 | 14 | 4.91E+05 | 6.36E+03 | 1.29E+04 |
| 64 | 08 Oct | 1377 | 14 | 1.97E+05 | 1.53E+04 | 1.66E+04 |
| 65 | 22 Oct | 1391 | 14 | 5.74E+05 | 1.48E+04 | 1.87E+04 |
| 66 | 05 Nov | 1405 | 14 | 2.70E+06 | 6.36E+03 | 8.89E+03 |

*Continued on next page*

TABLE 1 (*continued*)
**Fluxes of Siliceous Microorganisms in Santa Barbara Basin, August 1993 to April 1998**

| Sample # | Date cup opened | Days after 1 Jan 1993 | Collection days | Flux diatoms | Flux silicoflag. | Flux radiolaria |
|---|---|---|---|---|---|---|
| 67 | 19 Nov | 1419 | 14 | 3.08E+06 | 3.88E+03 | 1.37E+04 |
| 68 | 03 Dec | 1433 | 14 | 1.79E+05 | 3.99E+03 | 1.43E+04 |
| 69 | 17 Dec | 1447 | 14 | 2.89E+05 | 1.13E+04 | 2.50E+04 |
| 70 | 31 Dec | 1461 | 14 | 5.30E+04 | 3.66E+02 | 7.86E+03 |
| 71 | 14 Jan 97 | 1475 | 14 | 4.45E+05 | 6.58E+02 | 8.81E+03 |
| 72 | 28 Jan | 1489 | 14 | 1.54E+05 | 1.83E+02 | 1.09E+04 |
| 73 | 11 Feb | 1503 | 14 | 1.26E+05 | 1.10E+02 | 9.51E+03 |
| 74 | 25 Feb | 1517 | 14 | 2.17E+05 | 3.66E+02 | 1.96E+04 |
| 75 | 11 Mar | 1531 | 13 | 8.45E+05 | 8.78E+02 | 1.77E+04 |
| 76 | 22 May | 1603 | 7 | 4.65E+05 | 2.49E+03 | 2.93E+04 |
| 77 | 29 May | 1610 | 7 | 2.72E+05 | 3.95E+03 | 1.74E+04 |
| 78 | 05 Jun | 1617 | 7 | 1.18E+04 | 4.02E+02 | no data |
| 79 | 12 Jun | 1624 | 7 | 7.38E+04 | 3.29E+02 | no data |
| 80 | 19 Jun | 1631 | 7 | 5.22E+04 | 2.19E+02 | no data |
| 81 | 26 Jun | 1638 | 14 | 4.79E+04 | 2.82E+03 | no data |
| 82 | 10 Jul | 1652 | 14 | 3.17E+05 | 3.07E+03 | no data |
| 83 | 24 Jul | 1666 | 14 | 5.15E+04 | 1.68E+03 | no data |
| 84 | 07 Aug | 1680 | 14 | 4.27E+04 | 1.28E+03 | no data |
| 85 | 21 Aug | 1694 | 14 | 2.18E+04 | 5.49E+02 | no data |
| 86 | 04 Sep | 1708 | 14 | 3.42E+04 | 8.05E+02 | no data |
| 87 | 18 Sep | 1722 | 14 | 5.51E+04 | 1.32E+03 | no data |
| 88 | 02 Oct | 1736 | 14 | 3.32E+04 | 2.56E+02 | no data |
| 89 | 17 Oct | 1751 | 14 | 1.13E+04 | 9.87E+02 | 4.53E+03 |
| 90 | 31 Oct | 1765 | 14 | 1.18E+04 | 3.29E+02 | 2.89E+03 |
| 91 | 14 Nov | 1779 | 14 | 8.67E+03 | 7.31E+01 | 3.22E+03 |
| 92 | 28 Nov | 1793 | 14 | 2.72E+04 | 6.58E+02 | 6.18E+03 |
| 93 | 12 Dec | 1807 | 14 | 3.04E+04 | 1.46E+02 | 1.12E+04 |
| 94 | 26 Dec | 1821 | 14 | 4.15E+04 | 4.39E+02 | 5.45E+03 |
| 95 | 09 Jan 98 | 1835 | 14 | 2.52E+04 | 1.17E+03 | 5.49E+03 |
| 96 | 23 Jan | 1849 | 14 | 6.40E+03 | 1.32E+03 | 3.22E+03 |
| 97 | 06 Feb | 1863 | 14 | 2.60E+03 | 7.31E+01 | 5.05E+03 |
| 98 | 20 Feb | 1877 | 14 | 4.46E+03 | 1.43E+03 | 3.11E+03 |
| 99 | 06 Mar | 1891 | 14 | 3.75E+04 | 2.45E+03 | 3.33E+03 |
| 100 | 20 Mar | 1905 | 14 | 8.01E+04 | 1.83E+03 | 3.44E+03 |
| 101 | 03 Apr | 1919 | 19 | 6.08E+04 | 0 | 3.10E+03 |

## RESULTS

### Temperature

Upper ocean temperatures at the sediment trap location were derived from conductivity-temperature-density (CTD) casts conducted between 1 July 1993 and 22 July 1998. These data are used to evaluate overall changes in the thermal structure of the upper 100 m during the study period. Data from the CTD casts were transformed into a 15-day by 2-meter matrix which underwent two smoothing passes and was then contoured. Figure 3A is a visual representation of the temperature profile for the study period presented here, January 1996 to April 1998. Daily SSTs are shown in figure 4 (top panel).

Throughout 1996, which is considered to be a normal non–El Niño period, SSTs in the SBB ranged from a low of ~10.5°C in April at the onset of upwelling to a high of ~17.5° in September and October (fig. 4). The most noticeable change in response to El Niño occurred in late summer 1997, when SSTs reached almost 20°, which is nearly 3° warmer than for the same period the previous year (fig. 4); temperatures did not drop in late fall when cooling typically begins. In fact, temperatures remained elevated throughout fall and winter, and thermocline depth reached a maximum between December and January (fig. 3A). In winter 1998, temperatures in the SBB were 1°–2° higher than during the two previous winters (figs. 3A and 4).

### Chlorophyll Concentrations

Chlorophyll a concentrations for CalCOFI station 82.47 (see inside back cover for basic station plan) of cruises 9602, 9604, 9608, 9610, 9702, 9704, 9707, 9709, 9802, and 9804 were used to construct figure 3B. Routine CalCOFI procedures include measurements at discrete depths of 0, 1 or 2, 10, 20, 30, 40, 50, 60, 70, 75, 85, 99, 100, 118 or 119, 125, 138 or 139, and 150 m. The original data can be found at *www-mlrg.ucsd.edu/calcofi.html*. We generated a 45-day by 5-meter data matrix from the original CalCOFI data set by using a linear interpolation algorithm that was chosen to preserve the true data points. The resulting unsmoothed matrix was then contoured, representing the seasonal cycle (fig. 3B).

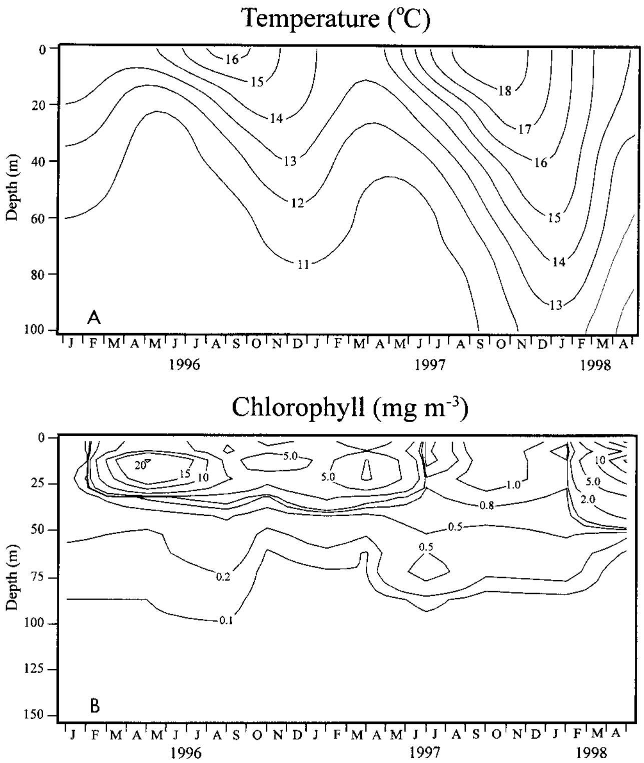


Figure 3. January 1996 to April 1998. *A*, Upper ocean (0–100 m) temperature at sediment trap location generated from conductivity-temperature-density (CTD) casts. The data set from the CTD casts was then reduced by averaging depth bins of 2 meters and transformed into a 15-day by 2-meter data matrix. The resulting matrix underwent two smoothing passes and was then contoured. *B*, Time/depth plot of chlorophyll a concentration (measured quarterly) at CalCOFI station 82.47 in Santa Barbara Basin. A 45-day by 5-meter data matrix was generated from the original CalCOFI data set with a linear interpolation algorithm, and the resulting unsmoothed matrix was then contoured.

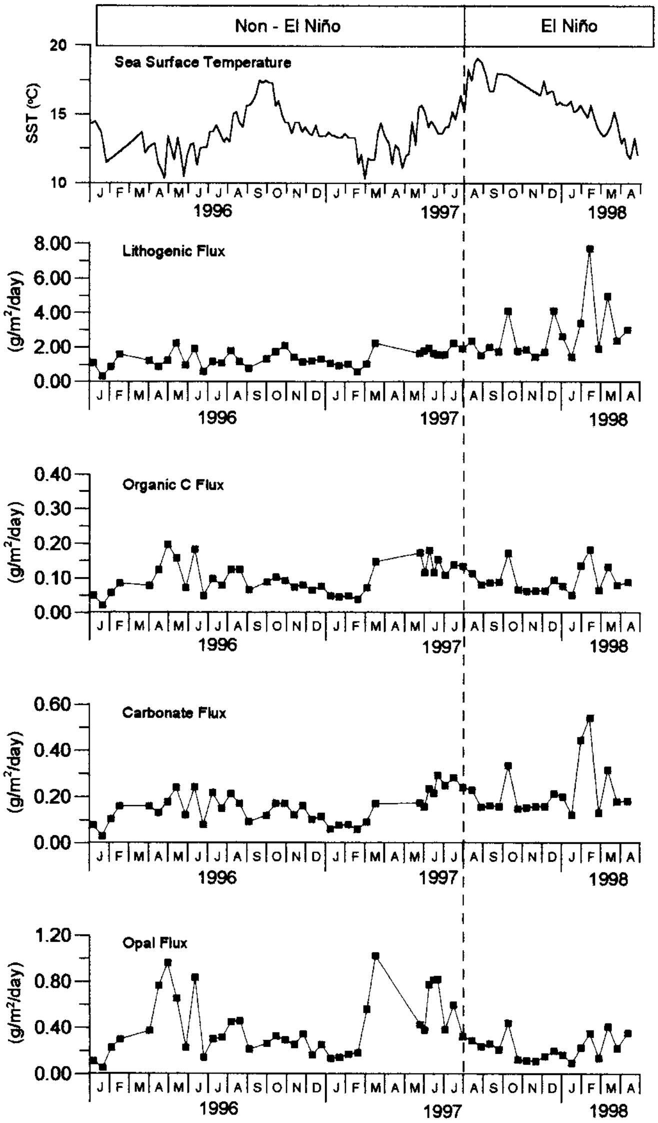


Figure 4. Daily sea-surface temperature records from a NOAA buoy (U.S. marine buoy #46054) located close to the sediment trap mooring, and fluxes of lithogenic particles, organic carbon, carbonate and biogenic silica (opal) measured in two-week-long samples from Santa Barbara Basin, from January 1996 to April 1998, emphasizing non–El Niño (1996 through mid-1997) and El Niño (mid-1997 through spring 1998) conditions. All fluxes are in $g/m^2/day$.

Chlorophyll a concentrations typically indicate the seasonal cycle in the SBB, with high values in spring and early summer (strong winds-upwelling-high productivity) and low concentrations in fall and winter (weak winds-diminished upwelling-decreased productivity). This general pattern was also observed during the study period (1996–98) except for fall 1996, when chlorophyll a concentrations were particularly high in the basin (fig. 3B) and in the coastal region near Point Conception (Schwing et al. 1997). These high levels may have been related to a pattern of relatively high mesoscale activity in the California Current, and elevated upwelling north of Point Conception in October (Schwing et al. 1997). Despite the strong 1997–98 El Niño, the concentration and spatial distribution of chlorophyll in spring 1998 was similar to that observed in previous springs (fig. 3B; Venrick 1998).

## Bulk-Sediment Flux

Bulk-sediment flux data at the SBB mooring are summarized in figure 4, and include daily fluxes of organic carbon, calcium carbonate, biogenic silica, and lithogenic particles, as determined by the methods of Thunell et al. (1995). Lithogenic material is the single largest contributor to the total mass flux, typically accounting for 50%–80% of the total. Terrigenous input to our sampling site, as measured by the lithogenic flux, was much higher during the El Niño period (up to 8 g $m^{-2}$ $d^{-1}$ vs. 1–2 g $m^{-2}$ $d^{-1}$ for the non–El Niño period), presumably reflecting higher rainfall, runoff, and downslope transport into the SBB (fig. 4). In fact, December 1997 to February 1998 was a period of exceptionally intense winter storm activity along the West Coast, especially during February (Lynn et al. 1998). Samples from this period contained large amounts of detritus, clay minerals, pollen grains, plant debris, Chrysophyte cysts, littoral shelf diatoms, and estuarine benthic foraminifers, indicating that a considerable amount of terrigenous material was flushed into the SBB during large storms.

Both biogenic opal and organic carbon fluxes (fig. 4) mirror the normal productivity cycle in that fluxes are high during the spring-summer upwelling period and low during fall and winter. Opaline silica is by far the dominant biogenic sediment produced in SBB, periodically accounting for up to 35% of the total flux (Thunell 1998). Interestingly, when comparing the magnitudes of the opal fluxes measured during the spring upwelling periods, we observe similar values for 1996 and 1997 (> 0.8 g $m^{-2}$ $d^{-1}$) and lower values for 1998 (< 0.4 g $m^{-2}$ $d^{-1}$). This would suggest reduced export of silica-bearing organisms as a response to El Niño conditions, as is also evidenced in the fluxes of radiolarians, diatoms, and—to a lesser extent, silicoflagellates (see below; fig. 5).

Organic carbon fluxes almost always account for less than 5% of the total flux (Thunell 1998). However, in the winter of 1998 organic carbon fluxes were unusually high for that time of year (up to 0.15 g $m^{-2}$ $d^{-1}$ compared to values of 0.05 g $m^{-2}$ $d^{-1}$ for the previous winters) and coincided with a February peak in the carbonate flux (mainly derived from foraminifers and coccolithophores) and high abundances of tintinnids of the genus *Stenosemella*.

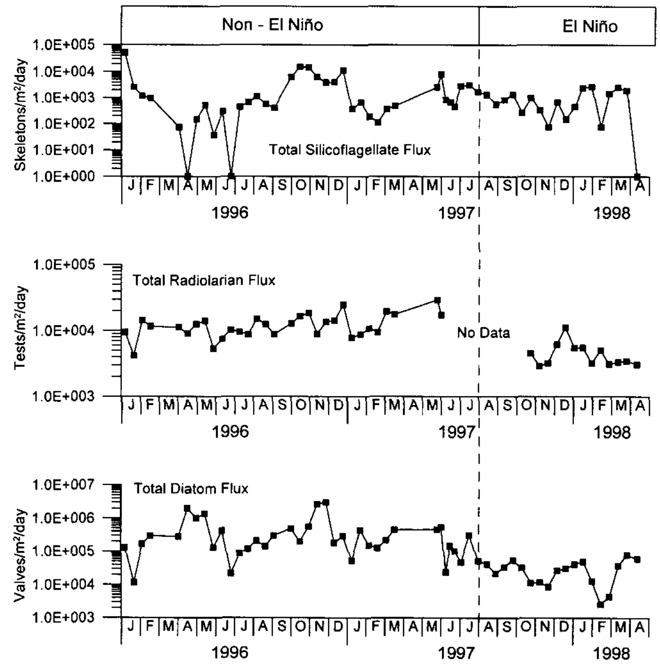


Figure 5. Fluxes of silicoflagellates, radiolarians, and diatoms (in numbers of individuals/m²/day) from January 1996 to April 1998, emphasizing non–El Niño (1996 through mid-1997) and El Niño (mid-1997 through spring 1998) conditions.

### Siliceous Microfossil Flux

We observed definite changes in the timing and magnitude of total flux for each siliceous microplankton group, as well as shifts in species composition of the assemblages (figs. 5 and 6). Changes include (1) a 20% drop in the flux of radiolarians for the period late 1997–early 1998 with respect to the 1993–96 average; (2) a substantial drop of an order of magnitude in the flux of diatoms (from $\geq 10^5$ valves $m^{-2}$ $d^{-1}$ in 1996–early 1997 to ca. $10^4$ valves $m^{-2}$ $d^{-1}$ in 1998) and an increase in species richness (from 5.4 to 6.5, Margalef [1958] Index) during El Niño conditions; and (3) a lack of the fall-winter peak in silicoflagellate fluxes seen annually from 1993 to 1996 (Lange et al. 1997; Kincaid et al. 2000). Instead, silicoflagellates peaked very briefly in late spring 1997 and then again in January 1998 (with *Dictyocha fibula* dominating the assemblage).

Diatom and radiolarian species groups associated with El Niño show unusually high percentages of warm-water taxa in coincidence with maximum temperatures in the water column (figs. 3A and 6). The average percentage of warm-water radiolarians was 2.5 times higher during this period when compared to 1996. Additionally, there was an unusually high contribution (>20%) in late summer and fall 1997 of diatom taxa representative of warm offshore waters (e.g., *Asterolampra marylandica*, *Bacteriastrum comosum*, *Hemiaulus hauckii*) and an atypical presence during fall 1997 and winter 1998 of warm-water radiolarian species *Pterocorys hertwigii*, *Didymocyrtis tetrathalamus*, and *Dictyocoryne truncatum*. This further reflects the effects of the 1997–98 El Niño on the coastal ecosystem of the SBB (fig. 6).

In contrast to the increase in warm-water indicators, there was nearly a 50% drop in the relative contribution of the siliceous microorganisms indicative of spring upwelling conditions in the SBB (Lange et al. 1997); for example, the diatom *Chaetoceros radicans* (resting spores and vegetative cells) and the radiolarians *Lithomelissa setosa* and *Spongopyle osculosa* (fig. 6).

Finally, the contribution of littoral, non-planktonic diatoms such as *Amphitetras antediluviana*, *Aulacodiscus kittonii*, and *Biddulphia biddulphiana* increased dramatically in November 1997 and February 1998 (fig. 6), probably reflecting the intense storm activity, high precipitation, runoff, and lateral advection into the central basin during the El Niño period.

## DISCUSSION AND CONCLUSIONS

The complicated hydrography of the SBB and the seasonal changes that occur as a result of the strong

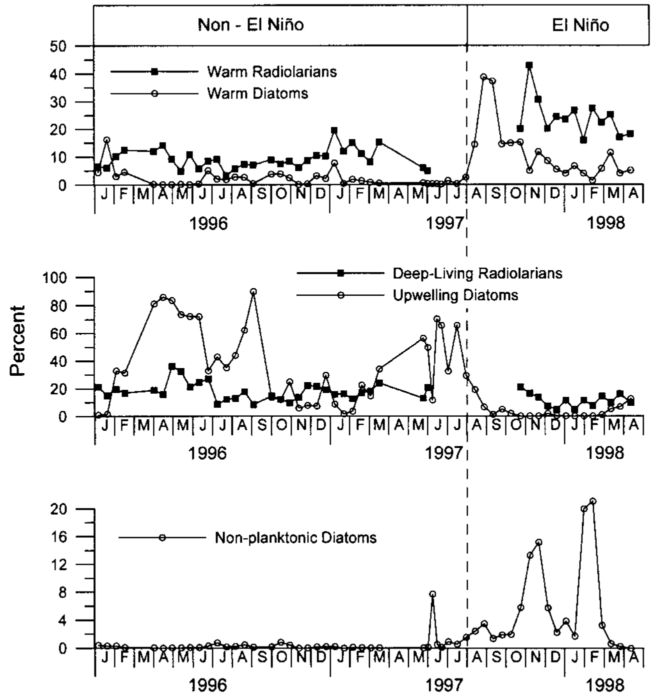


Figure 6. Relative contribution (in percentage of total assemblage) of selected diatom and radiolarian species representative of upwelling conditions, warm oceanic waters, and littoral influence advected from the shelf, from January 1996 to April 1998, emphasizing non–El Niño and El Niño conditions.

spring–early summer winds and the weak, variable winter winds make it a region of high climatic variability. The production and flux of biogenic material, and the diverse species composition of the microplankton reflect this seasonal variability, which has been studied in a few time-series experiments (Thunell et al. 1995; Lange et al. 1997; Thunell 1998; Kincaid et al. 2000). Added to this is the rainfall regime of the southern California coast, which accounts for terrigenous components carried by river runoff in the winter months and subsequent downslope movement and transport at depth of detrital material to the center of the basin. Overlying this repeatable seasonal pattern, the intermittent El Niño condition, which occurs at intervals of 3 to 7 years, disrupts the annual cycle. In 1997 a major El Niño developed in the western and central Pacific (see Chavez et al. 1999, and references therein), and by summer 1997 the coastal waters of California were strongly influenced by El Niño conditions (Lynn et al. 1998). The year 1998 was marked by a dramatic transition from El Niño conditions in early 1998 to cool-water La Niña conditions by late 1998 (e.g., Chavez et al. 1999; Hayward et al. 1999).

Since 1993 we have been carrying out a sediment-trapping experiment in the Santa Barbara Basin, offshore of California, which enabled us to document the dramatic biogeochemical perturbations associated with the 1997–98 El Niño event. Lange et al. (1997) showed that fluxes of diatoms, radiolarians, and silicoflagellates in the SBB exhibit a distinct seasonal pattern, with marked production maxima at different times of the year reflecting a succession of these microplankton groups: radiolarians in late summer and fall, silicoflagellates in winter, and diatoms in spring (table 1). This "normal" scenario was altered during the 1997–98 El Niño event. In the nearly 5 years of sediment trap data, from August 1993 to April 1998, the lowest diatom fluxes ever measured (2.6 and 4.5 x $10^3$ valves $m^{-2}$ $d^{-1}$) occurred at the height of El Niño in February 1998 (table 1). The flux of radiolarians dropped by 20% compared to the 1993–96 mean, and overall biogenic silica fluxes of non–El Niño conditions in 1996 and early 1997 (average = 0.42 g $m^{-2}$ $d^{-1}$) were much reduced compared to El Niño conditions of late 1997–early 1998 (average = 0.23 g $m^{-2}$ $d^{-1}$).

In addition to lowered total group fluxes (fig. 5), major changes in species composition coincided with the El Niño event (fig. 6). There was an increase in the relative abundance of eastern tropical Pacific and central gyre species, and a decrease in the deep-living radiolarians and in diatoms representative of upwelling conditions (Lange 1988; Lange et al. 1997; Weinheimer and Cayan 1997). These changes reflect warm-water incursions into the SBB and diminished upwelling associated with El Niño conditions. The excessive runoff from heavy rains brought high terrestrial discharges (Shipe et al. 2000) and unusually high abundances of benthic diatoms into the basin (fig. 6). Although these diatoms are a normal component of the trapped winter assemblage, their relative contribution never exceeded 7% in previous years (Lange et al. 1997).

The presence of the tintinnid *Stenosemella* sp. in high numbers in February 1998 is noteworthy. It has been demonstrated that members of the genus *Stenosemella* produce arenaceous loricae composed principally of mineral particles of nonbiological origin (with quartz as the principal grain type; Gold and Morales 1976). Our findings can be compared with a similar occurrence in February 1983 during an El Niño period (Reid and Stewart 1989). This was noted within 2–3 km of the coast in the San Diego area. Water temperature in 1983 was also higher than normal, and there was a decrease in total phytoplankton and a higher abundance of warm-water species along the coast. Precipitation was unusually high, and continental runoff, with associated sediment load, increased. It was suggested that this situation enhanced the availability of lithogenic silica particles necessary for the lorica building of these neritic tintinnids (Reid and Stewart 1989). This could also have been the situation in our case, with *Stenosemella* using particles resulting from terrestrial runoff.

Our findings point to reduced biogenic opal export production in the region and increased siliceous microplankton diversity consistent with the prevailing El Niño conditions, as suggested earlier by Lange et al. (1987, 1990) and Weinheimer and Cayan (1997) after studying the sedimentary imprint of previous El Niño events in the SBB. This reduced export production may be a consequence of lowered biogenic opal productivity in the upper waters. Previous observations on the biological consequences of the 1958 and 1983 El Niño events in the California Current region included substantial declines in phyto- and zooplankton biomass (McGowan et al. 1998), as well as anomalous occurrences of tropical species in the Southern California Bight (see articles in Eppley 1986).

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