A 2000-YR-LONG RECORD OF CLIMATE FROM THE GULF OF CALIFORNIA

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Abstract

High resolution study (samples every ca. 37 yr) of the diatoms, silicoflagellates, and geochemistry of Kasten Core BAM80 E-17 yields a detailed record of climatic and paleoceanographic change for the past 2,000 years for the eastern Guaymas Basin, a region of very high diatom productivity within the central Gulf of California.

Roughly every 200 years, intervals enriched in diatoms alternate with intervals characterized by higher terrigenous material and total organic carbon (TOC), suggesting solar forcing. The record of percent biogenic silica is remarkably similar to the radiocarbon production curve, with increased diatom production occurring during sunspot minima. It is suggested that solar minima coincide with an increase in the strength an/or duration of late fall/winter northwest winds blowing down the Gulf due to atmospheric cooling above northwest Mexico.

A prolonged interval of dramatically warmer SST’s that is marked by a two-fold increase (above normal background fluctuations) in the relative abundance of the tropical diatom Azpeitia nodulifera occurs between ca. 910-1140 A.D., corresponding to the Medieval Warm Period. This interval is interrupted by a brief period (ca.1020-1100 A.D.) of reduced A. nodulifera and enhanced diatom production.
Introduction

The climate of the Gulf of California (referred to elsewhere as “the Gulf”) region is divided into a mid-latitude, winter phase and a subtropical, summer phase. During the winter, prevailing surface winds are northwesterly, along the mean pressure gradient, causing an overturn of the water column, upwelling of nutrients and enhanced phytoplankton production. This pattern is punctuated by brief southerly winds lasting a few days caused by an anticyclone that often resides over the southwestern United States (Bandon-Dangon and others, 1991). During the summer, winds blow steadily from the south, resulting in a monsoonal climate of increased rainfall.

Thunell’s (1998) sediment trap studies in the Guaymas Basin reveal that the peak flux in biogenic silica, which is overwhelmingly diatoms, occurs in November to December, coincident with the onset of northwest winds. A secondary peak occurs in early spring, coinciding with a period of coastal upwelling, that is stronger along the mainland coast than it is off the coast of Baja California (Santamaria-del-Angel and others, 1994). Such conditions produce anoxic bottom conditions and some of the most rapidly accumulating biogenic sediments in the world.

High resolution studies of the latest Holocene in the Guaymas Basin have focused on Kasten core BAM80 E-17, which was taken by the R/V Matamoros of Oregon State University in 1980 at 27.920°N and 111.610°W beneath 620 m of water. Over 450 cm of varved, diatom-rich sediment was recovered in this core. Murray (1982) used varve counting to estimate the sedimentation rate of BAM80 E-17 at 0.23 cm/yr; however, he noted that three radiocarbon dates on benthic foraminifers suggested a sedimentation rate of 0.13 cm/yr. Subsequent varve counting by Karlin (1984) yielded a sedimentation rate of 0.135 cm/yr that conforms more closely to the sedimentation rate suggested by radiocarbon dating.

Murray (1982) studied the downcore variability of silicoflagellate assemblages over the entire length of BAM80 E-17 at 5 cm intervals. He found major cycles in the relative percentages of *Octactis pulchra*, a silicoflagellate that he considered to be indicative of upwelling and high productivity, and *Dictyochoa messanensis*, a silicoflagellate that is more common outside of the Gulf on the Pacific coast of southern Baja California.
Schrader and Baumgartner (1983) estimated decadal variations of productivity levels during the past 500 years in a number of Kasten cores from the central Gulf of California. They used *O. pulchra* to estimate productivity with a chronology based on varve counts and silicoflagellate assemblage changes. Schrader and Baumgartner (1983) compared their results with a tree-ring record from the Sierra Madre Occidental and concluded that drier continental conditions showed a good match with intervals of increased productivity (higher upwelling).

Julliet-Leclerc and Schrader (1987) used oxygen isotopes from the biogenic silica of diatoms to infer sea surface temperature (SST) variations in the eastern Guaymas Basin over the past 3,000 years. Their data for Kasten core BAM80 E-13, which was dated by $^{137}$Cs isotopes and varve counting, suggested to them that SST’s warmed as much as 13°C during the past century. Subsequently, Julliet-Leclerc and others (1991) revised their SST estimates, calling for a ca. 8°C increase during the past century. Such a warming, however, seems rather extreme compared to the <3°C maximum warming in SST’s predicted for the past 300 yr in the Guaymas Basin by the alkenone studies of Goñi and others (2001).

For the 450 cm-long record of BAM80 E-17, Julliet-Leclerc and Schrader (1987) appear to have used a sedimentation rate of ca. 0.15 cm/yr in plotting their SST record for the past 3,000 years. They observed a total temperature amplitude of ca. 8°C over the 3,000 yr-long record with highest SST’s (17°C) occurring at the core top and approximately 3,000 years ago. Julliet-Leclerc and Schrader (1987) suggested that northwesterly winds (=upwelling and low SST’s) were at their maximum between 2,000 and 1,500 yr B.P., which would presumably correspond to ca. 2,200 to 1,660 yr B.P., if Karlin’s (1984) sedimentation rate of 0.135 cm/yr was used.

A high resolution study of diatoms, silicoflagellates, and geochemistry on the same samples would reveal much about the interrelationships between these various proxies. At the same time, a paleoclimatic record of the past 2,000 yr from BAM80 E-17 should be very valuable both for synthesizing the late Holocene paleoceanographic history of the Gulf of California and for comparisons with high resolution records from the Pacific coasts of Baja and Alta California.
Materials and Methods

Samples were taken at 5 cm-intervals from the upper 250 cm of BAM80 E-17, corresponding to a sampling interval of ca. 37 yr, according to Karlin’s (1984) sedimentation rate of 0.135 cm/yr. The approximate 1 cm-thickness of each sample and the varved nature of the sediments means that each sample represents on the order of seven years of deposition. Samples were taken vertically across the varves and homogeneous splits were used for siliceous microfossil and geochemical studies.

Geochemistry

Bulk ICP-AES geochemical analyses were performed on these samples following total sample dissolution after metaborate fusion. The following elements were analyzed: Na, Mg, Al, Si, P, K, Ca, Ti, Cr, Mn, Fe, Sr, Y, Zr, Nb, and Ba. Weight percent biogenic silica was estimated from the analyses by using the Si/Al ratio to factor out the terrigenous (non biogenic) silica. Our data indicate that the average sea floor terrigenous sediment in the central Gulf of California is very similar to the average for Pacific pelagic clay which has a Si/Al ratio of 3.30. Silica in excess of this ratio is deemed biogenic. Calcium carbonate percent was determined for the same samples by acidification and measurement of evolved CO2 by coulomtery. Total carbon was determined on a separate aliquot by combustion at 1000°C and coulometric measurement of evolved CO2. Organic carbon was calculated as the difference between total carbon and CaCO3 carbon.

Diatoms

Following Sancetta (1995), counts of diatoms were made at 500X, ignoring small diatoms that strongly dominate the sediment assemblages and mask subtle changes, such as Chaetoceros spores and Thalassionema nitzschioides. In addition, small and delicate taxa (Fragilariopsis, Rhizosolenia, Thalassiosira) were not counted in order to reduce bias caused by differential dissolution. Rather, larger centric diatoms demonstrating clear environmental preferences according to the sediment trap studies of Sancetta (1995), and sediment fabric studies of Pike and Kemp (1997) and Kemp and others (2000) were counted, including Actinocyclus curvatulus, A. octonarius, Actinoptychus spp., Azpeitia nodulifera,
Cosinodiscus radiatus, Cosinodiscus spp. (mainly large-diameter forms such as C. asteromphalus, C. granii, and C. oculus-iridis), Cyclotella spp. (mainly C. littoralis), Roperia tesselata, and Stephanopyxis palmeriana. At least 200 diatoms per sample were counted while making random traverses across the microscope slide at 500X.

Silicoflagellates

Silicoflagellate slides were systematically tracked across an upper, middle and lower area to obtain a representative count of 200 specimens for the samples. Counts were typically made at magnification 250X, with 500X used in checking questionable identifications. All whole specimens and half specimens with apical structures intact, were counted. Lesser fragments were not counted.

Results

For the purposes of this report, only selected geochemical, diatom and silicoflagellate data are displayed. Complete tables of the data collected are available on request from the authors.

Geochemistry

As indicated by earlier studies by Karlin and Levy (1985), the dominant sediment components of BAM80 E-17 are biogenic silica (mainly diatoms) alternating in cycles with intervals with greater amounts of terrigenous components (e.g., Fe, Ti, Mg, Al) and organic carbon. These cycles mirror yearly varves, with diatoms enriched during the late fall-early spring phase of strong northwest winds (November-May) and detritus enriched during the summer phase (June-September) of monsoonal rainfall and decreased diatom production. Weight percent CaCO₃ is very low (<0.5%) except in the topmost 20 cm of BAM80 E-17, where it ranges between 2 and 6%. This suggests that substantial pore water dissolution of CaCO₃, possibly due to oxidative decomposition of organic matter, occurs below the 20 cm depth (Karlin and Levy, 1985).

Biogenic Silica Production

The record of weight percent biogenic silica for the past 2,000 yr. in BAM80 E-17 is shown on Figure 1, where it is compared with
the $\Delta^{14}C$ radiocarbon production curve (Stuiver and others, 1998). Intervals of increased $\Delta^{14}C$ are thought to coincide with the sunspot minima, because an increase in solar activity (more sunspots) is accompanied by an increase in the “solar wind,” which reflects cosmic rays and reduces $^{14}C$ production. These cycles in $^{14}C$ production and, by inference, in solar activity, have periodicities of about 200 years, which are termed Suess Cycles by Damon and Sonnett (1991).

The biogenic silica record of the past 2,000 years in the eastern Guaymas Basin appears to bear remarkable resemblance to $\Delta^{14}C$ radiocarbon production curve, with peaks in biogenic silica coinciding with sunspot minima (Figure 1). This correlation seems to be especially good between ca. 450 and 1350 A.D.; however, after ca. 1400 A.D, the peaks in wt.% biogenic silica appear to be 60-80 yr younger than those in the radiocarbon production curve. Such an offset implies a possible acceleration in sedimentation rates in the topmost 85 cm of BAM80 E-17, which might be expected from reduced compaction and increased water content near the top of the core. If such a correlation is correct, it is possible that some surface

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**Figure 1.** Record of weight percent biogenic silica in BAM80 E-17 and possible correlation (dashed lines) with radiocarbon production rate (Stuiver et al., 1998). Shaded intervals show selected sunspot minima.
sediments may not have been recovered by BAM80 E-17, a suggestion made by Julliet-Leclerc and Schrader (1987).

We hypothesize that during periods of reduced solar activity (sunspot minima), increased winter cooling of the North American continent leads to intensification of northwest winds down the axis of the Gulf, leading to increased upwelling and enhanced diatom production. Recently, Shindell and others (2001) used a general circulation model (GCM) to predict a 1 to 2 °C cooling of winter temperature for the North American continent during the Maunder Minimum (ca. 1680). Citing the effect of a dimmer Sun on the Arctic Oscillation/North Atlantic Oscillation, they argued that reduced solar activity reduced the strength of the westerly winds, which resulted in lower continental winter temperatures. Increased winter cooling of northwest Mexico would likely deepen the atmospheric low there, resulting in an enhanced pressure gradient down the Gulf and an increase in resulting northwest winds.

Support for this hypothesis comes from Thunell’s (1998) report of the biweekly averages of biogenic silica accumulating in a sediment trap in the eastern Guaymas Basin between the summer of 1990 and the end of 1996. His data reveal greatly enhanced opal production in the period from 1994 through 1996 compared to period between late 1990 and late 1993. Thunell (1998) infers that the 1994-1996 increase in opal production was due to a decrease in ENSO strength during these years. However, this period displays better correlation with an interval of decreased solar activity (see http://science.nasa.gov/ssl/pad/solar/sunspots.htm) rather than reduced ENSO as measured by the NINO3 index (http://rainbow.ldgo.columbia.edu/ees/data/elnino3.htm).

Dean (2000) demonstrated that Ti concentrations in sediment samples from a box core collected in the Gulf of California off the west coast of Mexico between the mouths of the Rio Yaqui and Rio Mayo, two of the largest rivers draining the west slope of the Sierra Madre Occidental, exhibit striking cycles over the last 200 years with an average period of about 10 years, coinciding almost exactly with 10- to 12-year cycles of precipitation as reconstructed from tree rings (Frittz, 1991). Dean (2000) concluded that these cycles reflect rainfall cycles, as Ti is concentrated in the detrital sediments deposited during the summer monsoonal rains rather than in the biogenic silica-rich sediments deposited during the winter. However, the strong negative correlation between weight percent Ti
and biogenic silica in BAM80 E17 ($r^2 = -0.752$) suggests that Dean’s (2000) Ti cycles may actually be biogenic silica cycles operating to dilute a constant terrigenous supply, if variations in seasonal biogenic silica production are greater than variations in terrigenous input, as is implied by Thunell’s (1998) sediment trap data.

**Diatoms and Environment**

Figure 2 shows the relative percentage contribution of selected diatom groups during the past 2,000 yr. in BAM80 E-17. Sancetta’s (1995) sediment trap data in the eastern Guaymas Basin reveal the environmental and seasonal preferences of these diatom taxa. *Azpeitia nodulifera*, a tropical species, is only present in the modern eastern Guaymas Basin during ENSO-like conditions. On the other hand, *Roperia tesselata* is a late winter-early spring taxon indicative of waters that are well mixed by northwest winds. Sancetta (1995) concludes that *Coscinodiscus radiatus* is more common in the mixed waters of the winter, whereas the mostly large-diameter taxa

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![Diatoms and Environment](image-url)
tabulated as *Coscinodiscus* spp. (*C. asteromphalus*, *C. grani*, and *C. oculus-iridis*) are associated with the stratified, low nutrient waters of the summer-early fall that are deposited in the late fall when the thermocline breaks down after the onset of northwest winds (Kemp and others, 2000). *Cyclotella* spp. (mostly *C. littoralis*) are coastal taxa that are thought to be indicative of low production in warm, stratified, and nutrient limited waters of the summer and early fall.

The relative abundances of most of these diatom groups appear to fluctuate within generally well-constrained limits (horizontal dashed lines on Figure 2). An exception is the tropical diatom, *Azpeitia nodulifera*, which rises to 36 to 57% of the diatom assemblage, maximum values for the 2000 yr-long BAM80 E-17 record, between ca. 920 and 1020 A.D. This interval, centered on 1000 A.D., recalls the Medieval Warm Period (MWP). In their recent, detailed compilation of Northern Hemisphere tree ring records for the past 1,200 years, Esper and others (2002) report that "the warmest period" of the Medieval Warm Period covers the interval 950-1045 A.D., a period that closely matches this *A. nodulifera* abundance peak in BAM80 E-17. Closer to the Gulf of California, Baumgartner and others (1992) report a major peak in the numbers of Pacific sardine, which is indicative of warmer SST’s, in the Santa Barbara Basin during the interval from *ca.* 960 to 1040 A.D. It is therefore possible that the peak *A. nodulifera* abundances between *ca.* 920 and 1020 A.D. in the BAM80 E-17 record represent a regional, anomalously warm event, possibly associated with the Medieval Warm Period.

This event is followed by reduced numbers of *A. nodulifera* between ca. 1050 and 1090 A.D., an interval that coincides with a peak in biogenic silica production (Figure 1). Baumgartner and others (1992) report greatly reduced numbers of Pacific sardine in the Santa Barbara Basin between *ca.* 1060 and 1130 A.D., suggesting possible region wide cooling of SST’s.

Shortly thereafter, between ca. 1100 and 1140 A.D., *A. nodulifera* again increases to >25% of the diatom assemblage of BAM80 E-17, while percent biogenic silica falls by >15% (Figure 1), indicating a return to warmer SST’s. This second return to warmer SST’s in the Guaymas Basin is matched by only moderate increases in the Pacific sardine biomass in the Santa Barbara Basin (Baumgartner and others, 1992), suggesting that this warm event was more limited in extent or expression.
Cyclotella spp. display reduced abundances during the broader part (920-1150 A.D.) of this Medieval Warm Period, compared to the periods immediately proceeding or following it (Figure 2). Although Sancetta (1995) concludes that Cyclotella spp. are indicative of low diatom production in warm-stratified, nutrient-limited waters, it is also likely that these small, relatively delicate diatoms might be selectively removed from sediments characterized by reduced diatom production and increased dissolution of biogenic silica.

Increased occurrences of Roperia tesselata, a late winter-early spring diatom indicative of waters that are well mixed by northwest winds, characterize the interval between ca. 1550 and 1800 A.D. (Figure 2), a period that closely matches the Little Ice Age according to Grove (1988) (1550-1850 A.D.). This same interval is marked by sustained higher percentages of biogenic silica (>30%) (Figure 1), suggesting increased diatom production, presumably due to strengthened northwest winds during the winter. Other diatom groups do not appear to show any unusual change in relative abundance during this period.

Silicoflagellates and Environment

Murray and Schrader (1983) studied plankton and surface samples from the Gulf of California in order to determine the present-day geographic distribution of silicoflagellate taxa and to relate assemblages to various water masses. Taken with the earlier studies of Poelchau (1976), the studies of Murray and Schrader (1983) reveal the environmental preferences of silicoflagellate taxa. Tropical silicoflagellates include Dictyocha calida, D. ampliata, (grouped with D. calida by Poelchau, 1976), and D. perlaevis (D. sp. A and D. sp. B of Murray and Schrader, 1983). Dictyocha stapedia, (D. messanensis of Murray and Schrader, 1983), is a cosmopolitan form that dominates the silicoflagellate assemblage of Pacific stations west of the Baja California peninsula. Dictyocha sp. aff. D. aculeata appears to be an endemic Gulf variant of a taxon that is associated with the modern California Current. Octactis pulchra is associated with high levels of primary productivity in surface waters, supporting the observations of Schrader and Baumgartner (1983). The sediment trap data of Sancetta (written comm., 2001) confirm that O. pulchra is most abundant during the late fall to winter period of high primary productivity.
The relative percentage contributions of these environmental-indicator silicoflagellates in the BAM80 E17 record of the past 2000 yr are plotted on Figure 3. Because it may be argued that smaller, more delicate forms of *O. pulchra* are more likely to be preserved during periods of higher biosilica production, these small forms have been differentiated from the main *O. pulchra* populations. Similarly, in intervals where small *O. pulchra* are reduced, the largest silicoflagellates, *D*. sp. aff. *D. aculeata* and large *O. pulchra* (four times the size of the small form), are most abundant and give another index for reduced upwelling conditions.

The intervals between *ca*. 920-1020 A.D and 1100-1140 A.D., that are suggested by the diatom data (Figure 2) to be an expression of the Medieval Warm Period, are not marked by increases in the tropical silicoflagellates *Dictyocha calida*, *D. ampliata*, and *D. perlaevis* (Figure 3). Rather, these intervals are characterized by two peaks (>10%) of *D*. sp. aff. *D. aculeata* along with distinct
reductions in the abundance of the small form of *O. pulchra*. A similar coincidence of increased *D. sp. aff. D. aculeata* and reduced number of the small form of *O. pulchra* marks the topmost part of BAM80 E-17, identified here as the post-1880 A.D. interval. This same interval is marked by reduced biogenic silica (Figure 1) and may be representative of a modern interval of reduced productivity in the Gulf of California that has been suggested by the silica oxygen isotope studies of Julliet-Leclerc and Schrader (1987). Thus, silicoflagellates suggest that the interval indicated by diatoms to be an expression of the Medieval Warm Period was not marked by increased incursions of tropical silicoflagellates into the central Gulf of California, but rather was characterized by greatly reduced productivity, similar to that of the past century.

The interval of the Little Ice Age (ca. 1550-1800 A.D.), on the other hand, coincides with increased abundances of the small form of *O. pulchra* and generally reduced abundances of *D. sp. aff. D. aculeata* (Figure 3), suggesting increased productivity. As with the biogenic silica data (Figure 1) and the diatom (*R. tesselata*) (Figure 2) data, however, this interval does not really stand out as being different from other intervals of increased biogenic silica production during the past 2,000 years.

**Conclusions**

- During the past 2,000 yr, the record of percent biogenic silica in eastern Guaymas Basin core BAM80 E-17 bears a striking resemblance to the radiocarbon production curve, suggesting that diatom production increases during sunspot minima.
- In support of this conclusion, the sediment trap data of Thunell (1998) for the years 1990-1996 appear to show a stronger correlation of years of increased biogenic silica flux with years of decreased solar activity rather than with years of reduced ENSO strength.
- Increased abundance of the tropical diatom *Azpeitia nodulifera* between ca. 920 and 1020 A.D. and again between ca. 1100 and 1140 A.D. is suggested to be a representation of the Medieval Warm Period. Although tropical silicoflagellates do not increase in relative numbers during these intervals, greatly increased numbers of the large silicoflagellate *Dictyocha* sp. aff. *D. aculeata*
and reduced numbers of the small form of *Octactis pulchra* are evidence of reduced productivity.

- Increases in the relative abundance of the late winter-early spring diatom *Roperia tesselata* occur between ca. 1550 and 1800 A.D., an interval associated with the Little Ice Age. Percent biogenic silica is relatively high (>40%) during this entire period, suggesting enhanced winter time siliceous phytoplankton production associated with strengthened northwest winds. Silicoflagellate data also supports increased productivity during this period.

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**References**


