Laminated Diatomaceous Sediments from the Guaymas Basin Slope (Central Gulf of California): 250,000-Year Climate Record

Abstract. *During Deep Sea Drilling Project-International Program of Ocean Drilling leg 64, December 1978 to January 1979, the initial test of the Deep Sea Drilling Project's hydraulic piston corer obtained an almost undisturbed section from a 152-meter hole into the sediments of the oxygen minimum zone at a depth of 655 meters along the Guaymas slope in the central Gulf of California. The section records variations in climate, productivity, and circulation for more than 250,000 years of Late Pleistocene to Holocene history with recordings of seasonal variations in these parameters in the laminated sections.*

Rhythmically laminated marine sediments are rare, but they occur in areas where there is a seasonal sediment flux and the bottom waters are depleted in oxygen to an extent which prevents an infauna to churn the seasonal signal (*1, 2*). Such sediments record critical, high-resolution information on paleoclimatic and paleoceanographic variation (*2, 3*). Revelle (*4*), Byrne and Emery (*5*), and Calvert (*6*) have described short gravity cores from the slopes of the Guaymas Basin in the Gulf of California revealing the presence of varve-like rhythmites of muddy diatomaceous ooze. The varve mechanism in the central Gulf is still debated, but it involves the interaction of the seasonal deposition of terrigenous material and of the products of coastal upwelling phases. Leg 64 of the Deep Sea Drilling Project (DSDP) returned to this oxygen minimum area for site 480 (water depth, 655 m) (Fig. 1) to successfully test the newly developed Serocki-Storms-Cameron hydraulic piston corer (HPC) (*7*). The climatic record contained in this unique core collection will doubtlessly prompt further research. Our present description is intended as a guideline to the quality, extent, and limitations of the sediment record.

Two alternating sediment types, distinguished by primary sedimentary structure, occur. The section (Fig. 2) is divided almost equally between (i) zones comprising rhythmically laminated couplets of light, pale olive diatom ooze and darker, moderate olive brown muddy diatomaceous ooze and (ii) zones of homogeneous diatomaceous muds to ooze. In addition, there are sporadic sand layers, turbidites, phosphatic concretions, fish debris, an ash layer, and a dolomitic mudstone. The sediments contain signals from both marine productivity (diatoms, Radiolaria, nannofossils, benthic and planktic Foraminifera, dinoflagellates, fish scales and organic carbon) and continental influences (terrigenous clays, silts and sands, pollen, plant debris, and organic carbon). The water content decreases from 85 percent in the first core to about 65 percent by core 3 (10 m), which suggests that the top of the core is very near the sediment-water interface. Cores below the level of core 19 (90 m) are flaky and crumbly if thin slices are cut because of abundant fibrous diatom frustules (*Chaetoceros* bristles, *Thalassionema* and *Thalassiothrix* species).

Laminated zones (Fig. 2). Rhythmite couplets are mixtures of biogenic and terrigenous components. The pale olive, light lamina is generally a nearly pure diatom ooze with 70 to 80 percent diatoms and 15 to 25 percent terrigenous clay. The dark lamina is a moderate olive brown muddy diatomaceous ooze with 45 to 60 percent terrigenous clay and 15 to 45 percent diatom frustules. Some laminae have up to 10 percent nannofossils (in cores 3, 4, 14, 15, and 29) along with variable amounts of other marine microfossils. Laminae are of variable thicknesses, mostly submillimeter, and either the light or the dark lamina may be thicker (*8*).

Homogeneous zones (Fig. 2). Homogeneous zones consist of moderate olive gray diatomaceous mud to muddy ooze. The lack of sedimentary structure is characteristic, but the sediments also have fewer diatoms (10 to 40 percent) than the bulk laminites and more abundant benthic Foraminifera and calcareous nannofossils (10 to 15 percent). Terrigenous clay (40 to 60 percent) includes quartz (6 to 10 percent) and feldspars, mainly plagioclase (5 to 12 percent). Pyrite is a ubiquitous minor constituent, commonly as framboids within complete diatom frustules.

There is no evidence, such as basal sands or subtle grading, that homogeneous sections are redeposited sediments. We interpret these zones to reflect times with a less pronounced oxygen minimum zone in which the bottom conditions could support both an epifauna and a limited infauna. Typically, the lower contact of a thicker homogeneous section is gradational whereas the upper contact is frequently abrupt. Some zones could be variously interpreted as either layered or burrowed and disturbed. Fuzzily laminated patches were cross-cut discordantly with homogeneous brownish diatom muds. These muds do not appear to be injections from the coring process, because the transition to laminations is abrupt, without deformation or signs of fracture. Instead, we interpret these transition zones to be burrowing pathways from large animals such as crabs or mollusks. Typically

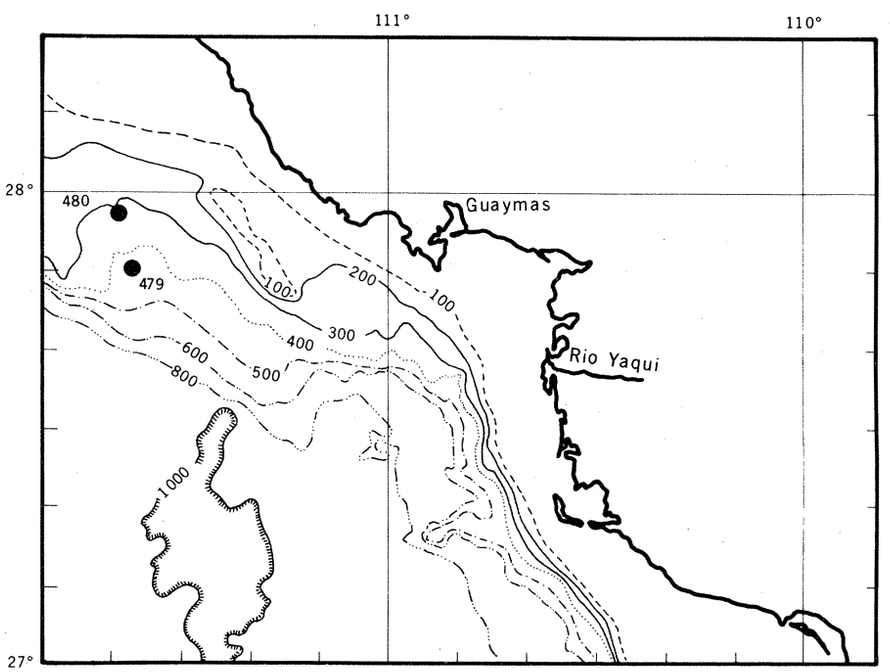

Fig. 1. Location of conventionally drilled site 479 and HPC site 480 in the central Gulf of California, Guaymas Basin. Depth contours are in fathoms (1 fathom = 6 feet).

0036-8075/80/0314-1207$00.50/0

they occur near the lower contact of a homogeneous zone which would be expected if an epifauna reappeared after more oxygenated conditions were restored on the sea floor. Such zones indicate that portions of the homogeneous sections may originally have been laminated and later bioturbated while other portions were continuously churned by infauna during sedimentation. A characteristic of the laminated zones which may have been later burrowed by larger animals is that they contain significantly fewer benthic Foraminifera.

Events. Interruptions within the rhythmically laminated portion are uncommon. Sands with minor wood and shell fragments occur at the base of scattered thin, graded turbidites. A few medium gray, well-sorted sand-to-silt intercalations occur in cores 13 (64 m) and 20 (97 m). Their composition is typical of the Sonora province (*9*). They do not show grading, and the upper and lower contacts are sharp. In core 21 (101 m) a 55-cm-thick multilayered series of 17 cyclic, thin (1 to 3 cm), graded beds (miniturbidites) occurs just below a hard dolomitic mudstone 10 cm thick; all are within a predominantly homogeneous zone. In core 24 (115 m) there was no recovery, but driller's records indicate a hard layer, thought to be another dolomitic bed. We suggest that those portions of hole 480 with sandy intercalations are related to minimum stands of sea level. We correlated these intervals to the dolomitic and sandy layers with similar intercalations in hole 479 (*7*), which was conventionally cored to a depth of 440 m subbottom only 6 km away (Fig. 1).

Varve formation. The Guaymas Basin at present is noted for high organic productivity (*4, 10*), particularly by diatoms associated with coastal upwelling triggered by northwesterly winds during the dry season (January through May). A pale olive lamina with an excellently preserved upwelling (*11*) diatom assemblage is thus produced. Upwelling along the Guaymas slope ceases during the rainy season (July through September) when winds come from the southeast (*12*) and terrigenous material is washed into the area from the Yaqui or other Sonoran rivers to form a dark lamina with a moderately well preserved oceanic (*11*) diatom assemblage. This mode of dark and light laminae formation has been discussed by earlier investigators (*4-6*). However, the simple couplet composition pattern derived from this model (*13*), namely, upwelling diatom species (*11*) dominant in light laminae and robust oceanic diatom species in dark laminae, although prevalent in the first few cores, is contradicted in other parts of the section at site 480. In cores 16 (78 m) and 29 (142 m), for example, some light laminae contain monospecific diatom assemblages of *Coscinodiscus asteromphalus* and *C. nodulifer*, which are oceanic forms, and dark laminae are dominated by a bloom-type upwelling flora. Such shifts will allow us to resolve major climatic pattern changes in wind and precipitation over the Gulf region.

Chronology. The age structure of the sedimentary section is not yet well defined. We estimated a minimum age of about 250,000 years by averaging varve counts (*8*), assuming that the accumulation rates are uniform over the entire core length; we know, however, that the homogeneous zones were deposited at a lower rate and thus the core may be significantly older.

Another approach was to correlate the homogeneous zones with cold cycles on the oxygen isotope stratigraphy (*14*), which suggests ranges of 300,000 to 400,000 years for the base of hole 480. Distinctly cold diatom assemblages with *C. marginatus* were found in several homogeneous sections. We predict oxygen isotopic stage 5e between core 11 and core 13.

Several pitfalls are inherent in the varve counts. "Rhythms" may not strictly represent 1-year periods as we may not be able to differentiate the very fine laminae deposited during periods of drought. At present, we have no absolute estimate of the actual accumulation rates of the homogeneous sections; these will be forthcoming shortly from pollen, magnetic, and isotope stratigraphy.

The importance of the long laminated section (*13*) in the central Gulf for regional and more extensive paleoclimatic and paleoceanographic studies lies in the fact that the exchange of surface water between the Gulf and the open Pacific is subject to climatic-oceanographic fluctuations between the California Current water and equatorial Pacific water (*15*). Variations in the properties of surface water masses inside the Gulf reflect Pacific-wide effects of such phenomena as the southern oscillation (*16*) and resulting El Niño versus anti-El Niño condition (*17*).

Because this set of cores is so unique and potentially so valuable for the study

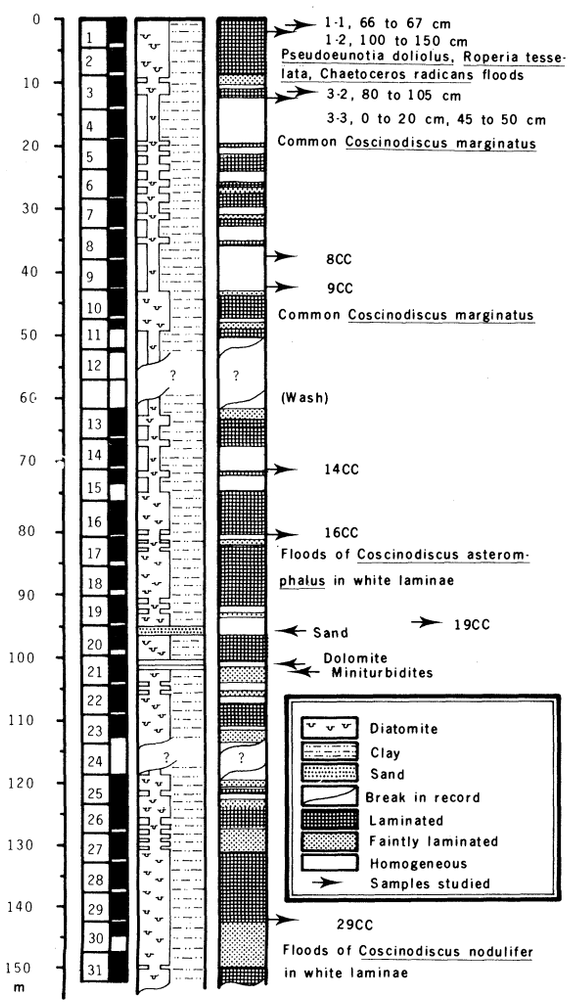

Fig. 2. Site log of HPC site 480. Column 1, depth in meters; column 2, core numbers; column 3, recovery record (black intervals, recovered material; white intervals, not recovered material); column 4, simplified lithology, DSDP standard symbols; column 5, simplified textural interpretation; column 6, arrows indicate positions of samples used in diatom pilot studies with major floral trends. *CC*, core catcher.

of environmental changes in this area, the shipboard scientific party has refrained from sampling any more than the core catcher samples in order to preserve the cores for varve studies onshore, which require intact working halves of the cores. We proposed to the DSDP and the National Science Foundation that these cores be curated and samples distributed in a special way. A HPC varved core working group has been established within the Joint Oceanographic Institutions for Deep Earth Sampling, which will coordinate feasible ways to subsample the working half cores for subsequent shore-based studies.

HANS SCHRADER
School of Oceanography, Oregon State University, Corvallis 97331
KERRY KELTS, JOSEPH CURRAY
DAVID MOORE
Scripps Institution of Oceanography, La Jolla, California 92037
EDUARDO AGUAYO
Instituto Mexicano del Petroleo, México 14, D.F.
MARIE-PIERRE AUBRY
Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543
GERHARDT EINSELE
Geologisches Institut, 74 Tubingen, Federal Republic of Germany
DANIEL FORNARI
Lamont-Doherty Geological Observatory, Palisades, New York 10964
JORIS GIESKES
Scripps Institution of Oceanography
JOSE GUERRERO
Universidad Nacional Autónoma de México, México 20, D.F.
MIRIAM KASTNER
Scripps Institution of Oceanography
MITCHELL LYLE
School of Oceanography, Oregon State University
YASUMOCHI MATOBA
Department of Geology, Stanford University, Stanford, California 94305
ADOLFO MOLINA-CRUZ
Centro de Investigación Cientifica y de Educación Superior de Ensenada, Oceanografia, Ensenada, Baja California, México
JEFFREY NIEMITZ
Department of Geology, Dickinson College, Carlisle, Pennsylvania 17013
JAIME RUEDA
Instituto Mexicano del Petroleo
ANDREW SAUNDERS
Department of Geology, Bedford College, London NW1 4NS, England
BERND SIMONEIT
University of California, Los Angeles 90024
VICTOR VAQUIER
Scripps Institution of Oceanography

References and Notes

1. E. Seibold, *Geol. Rundsch.* **47**, 100 (1958); M. G. Gross, S. M. Gucluer, J. S. Creager, W. A. Dawson, *Science* **141**, 918 (1963).
2. A. Soutar and P. Crill, *Geol. Soc. Am. Bull.* **88**, 1161 (1977).
3. GARP (U.S. Committee for the Global Atmospheric Research Program, National Research Council), *Understanding Climatic Change: A Program for Action* (National Academy of Sciences, Washington, D.C., 1975).
4. R. Revelle, *Geol. Soc. Am. Mem. 43* (1950), p. 6.
5. J. Byrne and K. Emery, *Geol. Soc. Am. Bull.* **71**, 983 (1960).
6. S. Calvert, *ibid.* **77**, 569 (1966); *J. Geol.* **76**, 546 (1966).
7. The HPC operates on the principle of a 4.45-m core barrel which is lowered inside the drill string, hydraulically ejected into the sediment, and retrieved. The pipe is then lowered those 4.45 m to the next interval, and the procedure is repeated. At site 480 we pulled 31 cores (Fig. 2) and obtained about 118 m or 80 percent of the 152-m section with two cores empty and one core washed. Because of a misconception, the drill string was lowered one-half stand for each core or 4.75 m rather than the 4.45 m; this procedure produced even greater gaps in the record, although the recovery success of the HCP then increases to over 86 percent. The top and bottom approximately 20 cm of a core generally showed some sediment disturbance, but most of the sections survived undisturbed with more than 76 m consisting of finely laminated oozes. The ocean was becalmed at site 480, so there is no uncertainty in a core's exact depth position resulting from the ship's heave, although tidal effects are not compensated. The site is located at 27°54'N, 111°39.3'W in 655 m of water [J. Curray *et al.*, *Geotimes* **24**, 18 (1979)].
8. The number of dark-light couplets per centimeter is uniform within error throughout the section. Random counts of laminae reveal 12 to 15 couplets per centimeter in the top four cores and 12 to 29 couplets per centimeter in the bottom four cores. This slight increase in the frequency as well as a slight thinning of laminae suggests compaction of the sediment rather than an increase in the number of couplets deposited per unit time.
9. T. van Andel, *Mem. Am. Assoc. Pet. Geol.* **3**, 216 (1964).
10. B. Zeitzschel, *Mar. Biol.* **3**, 201 (1969).
11. For a definition of coastal upwelling and oceanic diatom assemblages, see G. Schuette and H. Schrader, *Nova Hedwigia* **64** (1979).
12. G. Roden, *Mem. Am. Assoc. Pet. Geol.* **3**, 216 (1964).
13. T. Baumgartner, A. Soutar, H. Schrader, paper presented at the California Cooperative Oceanic Fisheries Investigations meeting, Idyllwild, Calif., 1978.
14. N. Shackleton and N. Opdyke, *Geol. Soc. Am. Mem.* **145**, 449 (1976).
15. M. R. Stevenson, *Inter.-Am. Trop. Tuna Comm. Bull.* **14**, 389 (1970); K. Wyrtki, *Int. J. Oceanol. Limnol.* **1**, 114 (1967).
16. P. R. Julian and R. M. Chervin, *Mon. Weather Rev.* **106**, 1433 (1978).
17. K. Wyrtki, *J. Phys. Oceanogr.* **5**, 572 (1975); *ibid.* **7**, 779 (1977).
18. This research was sponsored by the National Science Foundation (NSF) through the Deep Sea Drilling Project. We are indebted to the engineering staff at DSDP for timely development of the HPC, to officers and drilling crew on board leg 64 of the R.V. *Glomar Challenger* and particularly to D. Cameron for his efforts at sea. H.S. was supported by NSF grant OCE 77-20624.

27 September 1979; revised 11 December 1979.

Fluorescent Light Induces Malignant Transformation in Mouse Embryo Cell Cultures

Abstract. *Fluorescent light induced a dose-dependent malignant transformation in mouse C3H10T$^1/_2$ cells. A plateau in the dose-response curve for transformation was correlated with that observed with ultraviolet light exposure. The similarity in the two dose-response patterns suggests that similar molecular processes may be involved in the induction of malignant transformation by the two types of radiation.*

Light from standard fluorescent bulbs is toxic and mutagenic to bacteria (*1*) and to mammalian cells in vitro (*2-5*). Fluorescent light also induces breaks in DNA strands (*6*), cross-links, and chromosomal aberrations (*7*) in cultured cells, as well as sites sensitive to *Micrococcus luteus* endonuclease (*8*). These sites are thought to represent pyrimidine dimers, a DNA lesion previously implicated in cancer induction (*9, 10*) and in vitro malignant transformation (*11*). We report here that fluorescent light is capable of transforming cells in vitro and that the frequency of malignant transformation induced is related to dose.

We used a cell line derived from mouse embryo (C3H10T$^1/_2$, clone 8) isolated and characterized by Reznikoff *et al.* (*12, 13*) and adapted for studies of radiation transformation in our laboratory (*14*). The cells were passaged and maintained as previously described (*14, 15*). Cultures containing about 2×10^6 cells in uncovered 100-mm petri dishes were irradiated with six fluorescent bulbs (GE F15-T8 Cool White) at a distance of 6 inches. The exposure rate was 27.3 J m^{-2} sec^{-1}, measured with a thermopile (Eppley). This was equivalent to 910 foot-candles (1 foot-candle = 10.76 lux) (International Light IL700 meter). All irradiated and control (exposed only to dark) dishes were maintained at 0° to 4°C in Hanks balanced salt solution (HBSS) containing 25 m*M* Hepes buffer (*p*H 7.1, HBSS) (*16*), during exposure periods ranging from 0 to 7 hours. The plates were then subcultured to 250 to 400 viable cells per plate and maintained for radiation transformation (*14*). Types II and III foci were scored separately as transformants; their morphology was similar to that previously observed for ultraviolet light (*11*), x-irradiation (*14*), and chemical carcinogen (*12, 13*) treatments. There was no spontaneous transformation in control cultures (no treatment) or in cultures maintained at 37°C throughout but incubated for 7 hours in HBSS.

Figure 1 (upper curves) presents survival data for 0 to 7 hours (0 to 6.9×10^5 J m^{-2}) exposure to fluorescent light, as well as for cultures kept in the dark at 0°

0036-8075/80/0314-1209$00.50/0