Reports

Paleoclimatological Analysis of Late Quaternary Cores from the Northeastern Gulf of Mexico

Abstract. *Oxygen isotopic, radiocarbon, and micropaleontological analysis of deep-sea cores from the northeastern Gulf of Mexico identify an episode of rapid ice melting and sea-level rise at about 9600 years B.C. This age coincides, within the limits of all errors, with the age of the Valders ice readvance and with the age assigned by Plato to the flood he describes.*

περὶ δὴ τῶν ἐνακισχίλια γεγονότων ἔτη πολιτῶν σοι δηλώσω... *Plato*

The major trend of global environmental change during the past 700,000 years (the Brunhes normal magnetic epoch) has been reconstructed by oxygen isotopic analysis. The excellent correlation of the isotopic curves of the Atlantic-Caribbean cores (*1–4*) with that of a western equatorial Pacific core (*5*) has firmly established the worldwide significance of the isotopic record (*6*). According to the isotopic data, eight major periods of glaciation occurred during the Brunhes epoch, each separated by major interglacials.

The Laurentide ice sheet was the largest Pleistocene ice sheet in the Northern Hemisphere, surpassing the extent and volume of the modern Antarctic ice sheet. It is likely, therefore, that the Laurentide ice sheet had an important and perhaps dominant effect on the heat balance of the hydroatmosphere during anaglacial, pleniglacial, and cataglacial phases. In order to study the dynamics of this ice sheet during the last glacial age and the ensuing deglaciation, a suite of 11 piston cores was recovered in 1971 on a 400-km transect along the west Florida continental slope.

The continental slope off northwestern Florida is an area of particularly high sedimentation, partly because of abundant noncarbonate detritus from the Mississippi and other rivers to the north and partly because of the abundant fauna of pelagic foraminifera thriving in the area of upwelling along the edge of the Loop Current (*7*). Preliminary analysis of the coccolith stratigraphy showed that, as expected, accumulation rates decrease from north to south. The two northernmost cores, cores GS7102-5 and GS7102-9, from sites northwest and southeast, respectively, of the submarine feature known as the De Soto Canyon (*8*) (Fig. 1), were used for the present study. The continued presence of *Emiliania huxleyi* in both cores indicates that the oldest sediments cored are younger than about 260,000 years. In addition, the absence or near absence of the pelagic foraminiferal species *Globorotalia menardii* and *G. tumida* below about 150 cm in both cores indicates that subzone X1 of Kennett and Huddlestun (*9*) was not penetrated; thus the age of the oldest sediments cored is younger than about 75,000 years.

Continuity of the stratigraphic record and absolute dating. It has been emphasized by Emiliani (*3*) that any effort directed at the reconstruction of the behavior of any parameter through time requires, as a prerequisite, that the source material represent a time continuum. In the case of deep-sea cores, continuity through time is best established by close cross-correlation with the use of different parameters. Because of the lateral uniformity of ecological conditions over vast areas of the open seas and the unsorted character of the fossil record, extremely accurate intercore correlations are possible (*3, 10*). The deep-sea core from the western equatorial Pacific (*5*) has been correlated to within 10 cm with a Caribbean core (*6*), and this close correlation can be extended to equatorial Atlantic cores that are actually antipodal with respect to the western Pacific core. A close correlation involving two or more cores practically guarantees their respective stratigraphic continuity.

Cores GS7102-5 and GS7102-9 consist of brown to olive-gray silty clay, rich in calcareous faunas, and represent the time interval between the beginning of the last glacial age (the Wisconsin sensu lato) and the present. The two cores may be correlated closely with each other by means of the various micropaleontological abundance curves shown in Fig. 2 and the coiling direction curves for *Globorotalia truncatulinoides* shown in Fig. 3. It is apparent, from these comparisons, that core GS7102-9 is stratigraphically longer. The presence of *Pulleniatina obliquiloculata* near the bottom of the core, together with the absence of *Globorotalia menardii*, indicates that this core penetrates stage 4. Core GS7102-9 was chosen, therefore, for oxygen isotopic analysis (see below).

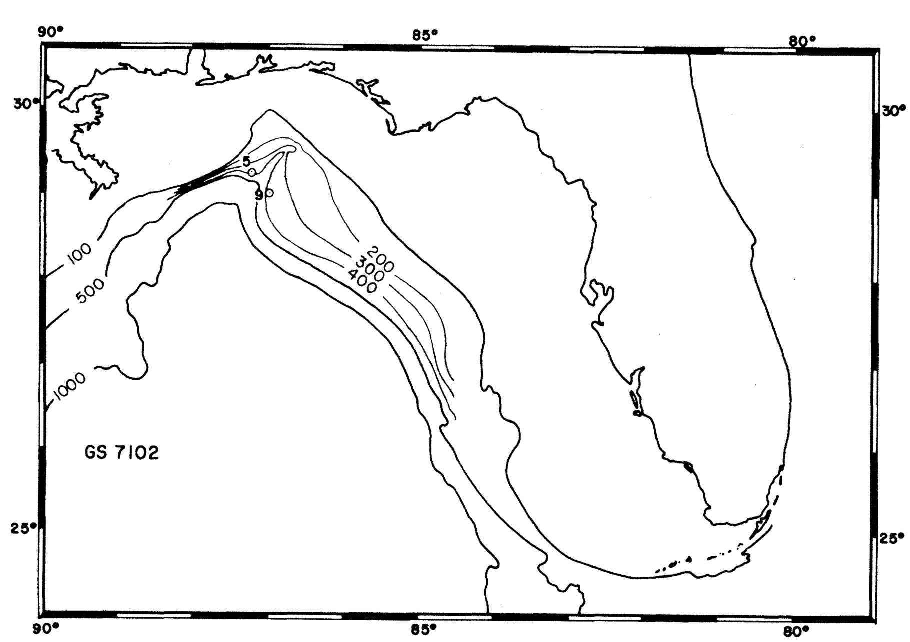


Fig. 1. Map of the De Soto Canyon area showing core locations; contours are in fathoms (1 fathom = 1.8 m). Core GS7102-5 (29°17′N, 87°15′W) was taken from a depth of 747 m and has a length of 980 cm. Core GS7102-9 (29°00′N, 87°00′W) was taken from a depth of 695 m and has a length of 1070 cm.

Radiocarbon ages were determined for 5 levels in core GS7102-5 (Table 1) and for 13 levels in core GS7102-9 (Table 2). All analyses were made on bulk core material. Bulk core material may contain some reworked carbonate and, therefore, may yield ^{14}C ages older than the true ages (*11*). In the present case, the dates obtained from core GS7102-5 are approximately 5000 years older than the equivalent ages from core GS7102-9, an indication of the presence of an appreciable amount of reworked carbonate. The site of core GS7102-9 is south of the De Soto Canyon and is, therefore, not only farther from detrital sources than that of core GS7102-5 but is also protected from them by the canyon itself. The Y/Z boundary of Ericson *et al.*, dated at 11,000 years before the present (B.P.) (*12*), occurs at 120 cm below the top in core GS7102-9, 10 cm above a layer ^{14}C-dated by us at 12,220 years B.P. and 10 cm below a layer dated at 10,865 years B.P. by the same method. The indication is that the ^{14}C ages of core GS7102-9 are accurate, at least down to 350 cm below the top. Between 360 and 500 cm the ^{14}C ages, which include an inversion, indicate very high sedimentation rates (see below). The observed inversion coincides with a sediment layer where *Globorotalia inflata* is anomalously absent and *Globigerinoides sacculifera-triloba* unusually abundant.

Table 1. Radiocarbon age measurements of core GS7102-5, based on total carbonate (*30*); σ, standard deviation.

Laboratory No.	Depth below top of core (cm)	Apparent ^{14}C age ($\pm 1\sigma$) (years)
UM 61	32 to 69	12,925 ± 200
UM 60	132 to 169	18,390 ± 205
UM 59	235 to 265	23,135 ± 410
UM 58	385 to 415	30,145 + 1930 − 2550
UM 57	485 to 515	>42,500

Micropaleontological paleoclimatology. Because of the relative proximity of core GS7102-9 to the mouth of the Mississippi River, the oxygen isotopic composition of the pelagic foraminiferal shells is expected to reflect mainly the isotopic composition of the seawater as it is variously diluted by the Mississippi discharge (see below).

In order to determine, therefore, the trend of changing temperatures of the surface water during the time of sediment deposition, we made counts of warm-, temperate-, and cold-water species of pelagic foraminifera, using those taxa noted by Kennett and Huddlestun (*9*) as being the most sensitive to temperature variations in the Gulf of Mexico. The counts were conducted at 10-cm intervals on aliquots of 520 polyspecific specimens (*13, 14*) from the sediment size fraction larger than 250 μ. An effective method of amplifying the signal obtained from the abundance variations of temperature-sensitive species is to calculate ratios of warm to temperate or cold species (*14, 15*), for those species that are most restricted to the temperature extremes and yet maintain an abundance sufficient for adequate statistics throughout the cores.

The species most restricted to warm waters, *Sphaeroidinella dehiscens*, *Pulleniatina obliquiloculata*, *Globorotalia menardii*, and *G. tumida*, are scarce in the top 150 cm of the two cores under study and almost or totally absent below (Fig. 2). These species, therefore, cannot be used to compute ratios. Their percentages were determined whenever possible, however, for their bearing on the determination of absolute temperatures. The temperate-warm species *Globigerinoides sacculifera-triloba* and *Globoquadrina eggeri* and the temperate-cold species *Globorotalia inflata* occur with varying abundance throughout the cores (Fig. 2). The ratio of *Globigerinoides sacculifera-triloba* + *Globoquadrina eggeri* to *Globorotalia inflata* was calculated from the abundance data. This ratio exhibits significant variations throughout the two cores (Fig. 4, A and B), variations that are believed to reflect closely the climatic changes that have occurred in the northeastern Gulf of Mexico during the past 75,000 years. As may be seen from Fig. 4, A and B, the ratio in core GS7102-5 parallels that in core GS7102-9 very closely.

The high peaks at 330 cm below the top in core GS7102-5 and at 360 cm below the top in core GS7102-9 (Fig. 4, A and B), are due to a temporary, drastic decrease in the abundance of *Globorotalia inflata*. Al-

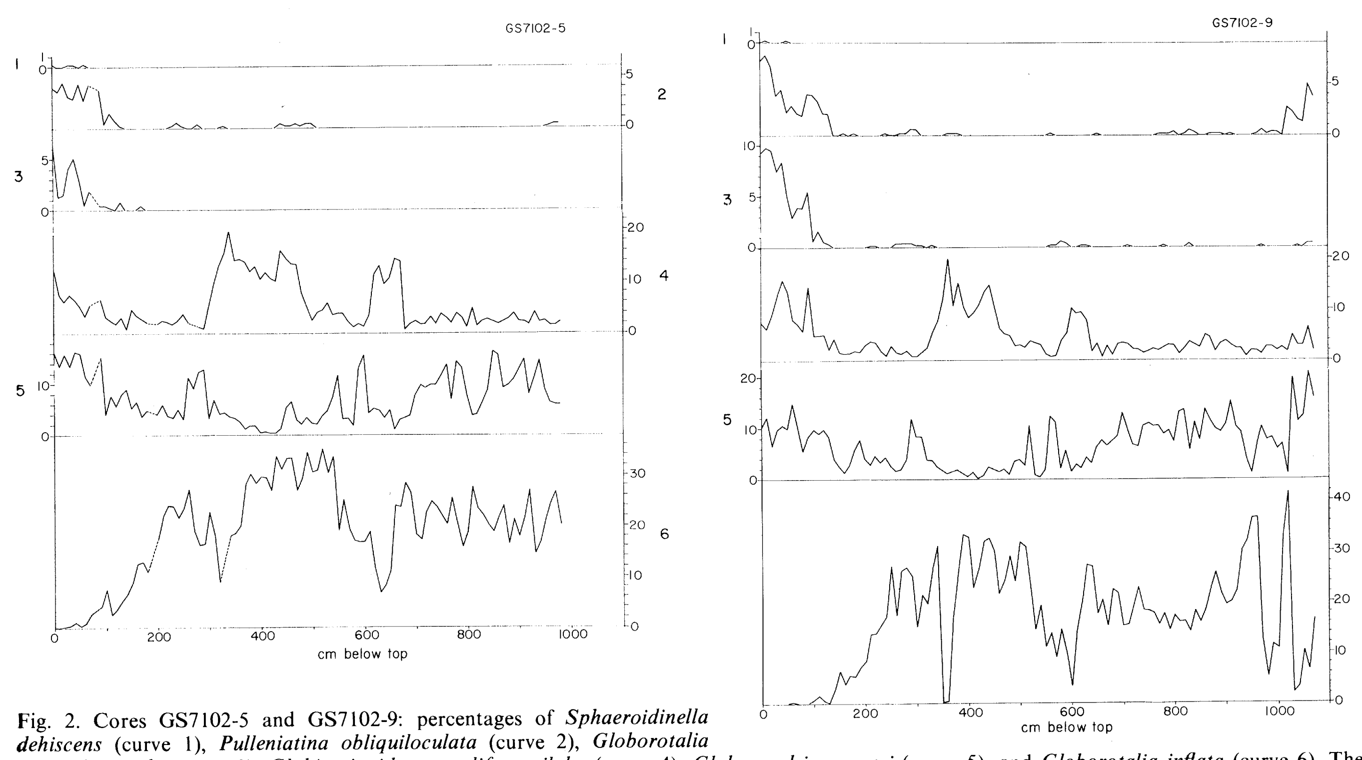


Fig. 2. Cores GS7102-5 and GS7102-9: percentages of *Sphaeroidinella dehiscens* (curve 1), *Pulleniatina obliquiloculata* (curve 2), *Globorotalia menardiitumida* (curve 3), *Globigerinoides sacculifera-triloba* (curve 4), *Globoquadrina eggeri* (curve 5), and *Globorotalia inflata* (curve 6). These curves are based on counts of at least 520 polyspecific specimens of planktonic foraminifera in the > 250-μ size fraction.

though this could be due to a very short episode of high temperature, we are more inclined to assign it to a temporary nonlinear behavior of the species in question. Examples of such behavior are known and will be discussed below. Altogether, the curves of Fig. 4, A and B, show that the last glacial age, the Wisconsin sensu lato, was not a period of uniformly low temperatures.

A few records having a time resolution similar to that of the cores under study have been published. These records (Fig. 4) are (i) the palynological curve from the Sabana de Bogotá (*16*); (ii) the oxygen isotopic curves for Greenland (*17*) and Antarctic ice (*18*); (iii) the micropaleontological curve of Kennett and Huddlestun for the western Gulf of Mexico (*9*); and (iv) the micropaleontological curve obtained by Vergnaud-Grazzini from a Mediterranean core (*19*). These records and the micropaleontological records of our cores exhibit a gross similarity, showing the general trend of climate evolution between approximately 70,000 years B.P. and the present.

Nonlinear behavior and the limitations of paleoecology. In any paleoecological study, the assumption is made that the response of a population or an assemblage to the environment is stationary. That this is indeed grossly so, at least as far as assemblages including many different taxa are concerned, allows paleoecology to exist as a viable discipline, and to provide valuable, qualitative data on past environments. If, however, an attempt is made to extract detailed, quantitative data from restricted fossil assemblages, the validity of the basic assumption must be scrutinized. Such scrutiny leads immediately to the realization that the basic assumption is too often so invalid that paleoecology cannot hold any hope of ever providing the fine, quantitative data that are needed. Basically, a species may disappear, or its abundance be drastically altered, by biological changes unrelated to the physical environment. The coconut palm tree, for instance, is presently disappearing from Florida because of "blight": a future paleoecologist would be ill-advised to assume that the climate had deteriorated. In another case the warm-water foraminiferal species *Globorotalia menardii* sensu lato failed to materialize in the Atlantic and the Caribbean during warm stages 15 and 13, a time span totaling more than 100,000 years during which other, even warmer species (*Sphaeroidinella dehiscens* and *Pulleniatina obliquiloculata*) remained abundant.

We suspect *Globorotalia inflata* of nonlinear behavior at 330 cm in core GS7102-5 and at 360 cm in core GS7102-9, as noted above. Such nonlinear behavior is particularly critical in paleoecological studies involving planktonic foraminifera because the sample is very restricted in terms of the number of species, so that nonlinear behavior by one or two species is likely to make the entire effort inoperative or at least to increase noise so much as to render vain any attempt to quantify (*20, 21*). Studies on such parameters as pore size (*22*), shell morphology (*23*), shell growth characteristics, apertural morphology, and megalospheric to microspheric ratios (*24*) seem to us more likely to lead to a quantification of physical environmental parameters than studies based upon species distributions. Direct quantification is, of course, possible with the use of the $^{18}O/^{16}O$ ratio, because the laws of equilibrium isotopic fractionation do not change with time and are not affected by "blight." Still, critical evaluation is necessary to elevate the isotopic data to regional or global significance, for any given measurement refers strictly to the isotopic environment at a single point in space and time.

Table 2. Radiocarbon age measurements of core GS7102-9, based on total carbonate, and rates of sedimentation (*30*); σ, standard deviation.

Laboratory No.	Depth below top of core (cm)	Midpoint (cm)	Apparent Age ($\pm$ 1 σ) (years)	Interval (cm)	Rate of sedimentation (cm per 1000 years)
UM 257	35 to 65	50	5,735 ± 75	0 to 50	8.72
UM 258	65 to 100	82.5	8,640 ± 190	50 to 82.5	11.19
UM 259	100 to 120	110	10,865 ± 145	82.5 to 110	12.36
UM 260	120 to 140	130	12,220 ± 140	110 to 130	14.76
UM 261	183 to 200	191.5	16,310 ± 200	130 to 191.5	15.04
UM 262	200 to 220	210	17,280 ± 195	191.5 to 210	19.07
UM 263	230 to 250	240	17,885 ± 170	210 to 240	49.59
UM 265	290 to 310	300	20,625 + 610 − 660	290 to 310	21.90
UM 315	310 to 330	320	21,640 + 390 − 410	300 to 320	19.70
UM 311	350 to 370	360	25,040 + 545 − 585	320 to 360	11.76
UM 312	370 to 390	380	23,260 + 590 − 640	360 to 380	?
UM 313	490 to 510	500	25,035 + 550 − 590	380 to 500	?
UM 314	510 to 530	520	27,560 + 860 − 965	500 to 520	?

Table 3. Oxygen isotopic analysis of shells of *Globigerinoides rubra* in Gulf of Mexico core GS7102-9. The results are expressed as per mil deviations from the Chicago standard PDB-1.

Depth (cm)	$\delta^{18}O$	Depth (cm)	$\delta^{18}O$	Depth (cm)	$\delta^{18}O$	Depth (cm)	$\delta^{18}O$
0	−1.53		−0.62	500	−0.12		−1.51
	−1.57		−1.08		−0.28		−1.21
	−1.64		—		−0.60		−1.16
	−1.86	300	−0.44		−0.38	800	−1.28
	−1.13		—		−0.17		−1.43
50	−1.84		−0.87	550	−0.01		−1.28
	−1.87		−0.86		−0.51		−1.13
	−1.68		−0.04		−0.79		−0.92
	−1.68	350	—		−0.89	850	−0.79
	−1.66		−0.48		−1.06		−0.94
100	−1.98		−0.26	600	−1.00		−1.56
	−1.91		—		−1.39		−1.47
	−2.17		−0.10		−0.27		−1.47
	−2.15	400	−0.15		−0.62	900	−1.37
	−1.79		−0.23		−0.44		−1.61
150	−1.15		−0.30	650	−1.26		−1.35
	−0.41		+0.50		−1.16		−1.28
	−0.46		+0.21		−1.20		−1.14
	−0.48	450	+0.47		−0.93	950	−0.05
	−0.21		—		−1.24		−0.65
200	−0.15		—	700	−1.16		−0.45
	−0.09		−0.14		−1.38		−0.90
	−0.32		−0.81		−1.29		−0.86
	−0.44				−1.02	1000	−1.30
	−0.36				−1.27		−0.51
250	−0.04			750	−1.33		−0.21
	−0.45				−0.90		−0.65

Oxygen isotopic analysis. Core GS7102-9 was selected for oxygen isotopic analysis, not only because it is physically and stratigraphically longer than core GS7102-5 but also because, as shown by the ^{14}C results, it is free from reworked carbonate material. Because this core is located on the lee of the Mississippi River discharge, it was expected that oxygen isotopic analysis might produce information more relevant to the dynamics of the Laurentide ice sheet during the last major ice age and subsequent deglaciation than to temperature change. This is indeed the case. The oxygen isotopic results, based on *Globigerinoides rubra*, are given in Table 3 and shown in Fig. 5. The species *G. rubra* was used because it was sufficiently abundant in most samples. The samples were washed in an ultrasonic cleaner and directly reacted with 100 percent H_3PO_4 without further treatment.

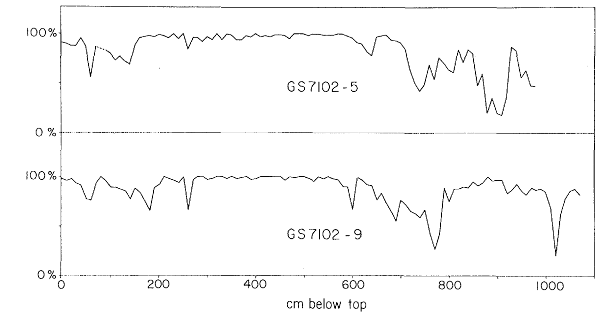
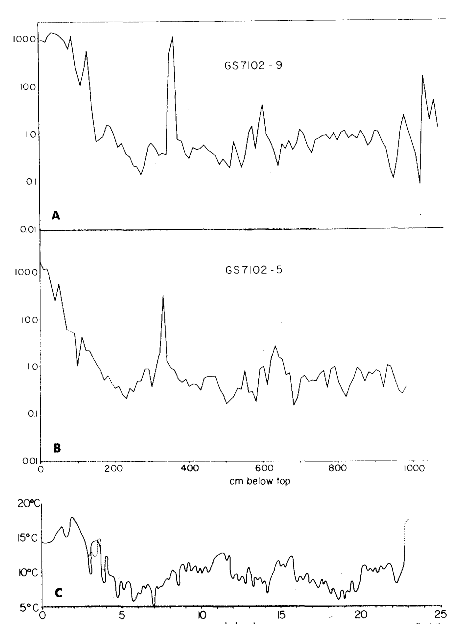


Fig. 3. Coiling direction of *Globorotalia truncatulinoides* in cores GS7102-5 and GS7102-9: percentages were determined on counts of a maximum of 100 monospecific specimens (as available) per sample in the > 250-μ size fraction.



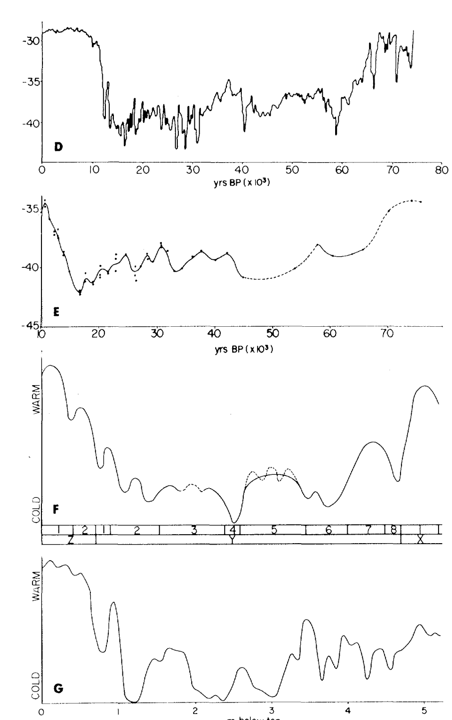


Fig. 4. Comparison among different environmental records over the past 75,000 years with the original authors' time scales or zonations. Curve A, ratio of *Globigerinoides sacculifera-triloba* + *Globoquadrina eggeri* to *Globorotalia inflata*, core GS7102-9 (this study); curve B, ratio of *Globigerinoides sacculifera-triloba* + *Globoquadrina eggeri* to *Globorotalia inflata*, core GS7102-5 (this study); curve C, palynological record, Sabana de Bogotá, Colombia (*16*); curve D, $^{18}O/^{16}O$ ratio in Greenland ice (*17*); curve E, $^{18}O/^{16}O$ ratio in Antarctic ice (*18*); curve F, micropaleontological record, western Gulf of Mexico (*9*); and curve G, micropaleontological record, Mediterranean Sea (*19*).

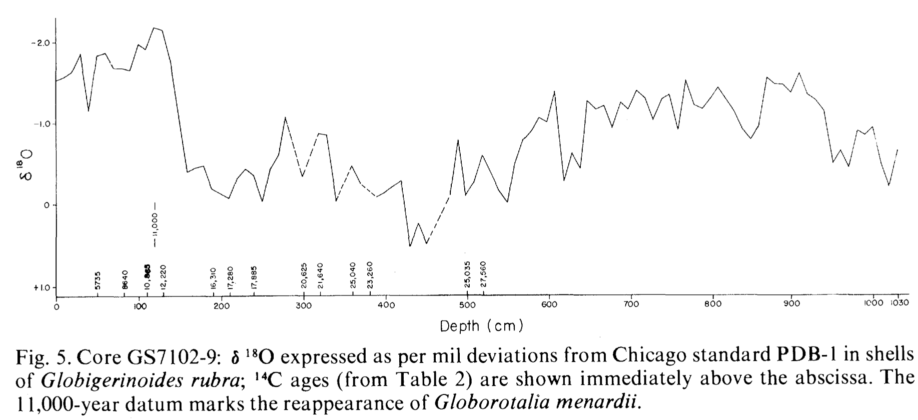


Fig. 5. Core GS7102-9: δ ^{18}O expressed as per mil deviations from Chicago standard PDB-1 in shells of *Globigerinoides rubra*; ^{14}C ages (from Table 2) are shown immediately above the abscissa. The 11,000-year datum marks the reappearance of *Globorotalia menardii.*

The modern oxygen isotopic composition of the surface water of the open Gulf of Mexico may be taken to be similar to that of the central Caribbean Sea, or + 0.92 per mil (*25*). From this value and the measured value of − 1.53 per mil for the modern *Globigerinoides rubra* in core GS7102-9, one obtains an absolute temperature value of 27.8°C. This figure is close to the surface summer temperature of 28° to 29°C which obtains in the area [*G. rubra* shells are predominantly of the red, summer variety; see (*26*)].

Between 12,200 and 11,000 years ago, that is, about 11,600 years ago, the isotopic composition of *G. rubra* was − 2.17 per mil, or 0.64 per mil lighter than today. If the temperature had been the same as today, a salinity decrease to about 33 per mil would be indicated. But, because the temperature was probably 3°C lower, a salinity decrease to about 31 per mil is indicated. The effect of ice meltwater is clear, as also found in the western Gulf of Mexico (*27*).

The time of 11,600 years B.P., when the influx of Laurentide ice meltwater into the Gulf of Mexico was highest, coincides in age with the Valders readvance. This 150-km readvance was, therefore, a surge [see (*28*)] which led to strong ablation and the observed high concentration of ice meltwater in the Gulf of Mexico. The concomitant, accelerated rise in sea level, of the order of decimeters per year, must have caused widespread flooding of low-lying areas, many of which were inhabited by man. We submit that this event, in spite of its great antiquity in cultural terms, could be an explanation for the deluge stories common to many Eurasian, Australasian, and American traditions. Plato (*Timaeus*, 23E; *Critias*, 108E, 111B) set the date of the flood at 9000 years before Solon, equal to 9600 years B.C. or 11,600 years B.P.: this date coincides, within all limits of error, with the age of both the highest concentration of ice meltwater in the Gulf of Mexico and the Valders readvance.

From about 14,000 to about 28,000 years ago, the concentration of ^{18}O in the foraminiferal shells was considerably greater, reflecting the lower temperatures of the last glacial age as well as the increased ^{18}O concentration in seawater associated with it. The maximum, + 0.50 per mil, is 2.03 per mil above the modern value of − 1.53 per mil. This is 0.73 per mil heavier than in Caribbean core A179-4 (*1*, table 24) and may represent an excess of evaporation in the Gulf of Mexico (which was closer to the Laurentide ice sheet).

The broad isotopic rise between 560 cm and 1000 cm below the top is believed to represent deep-sea core stage 3. It is, in fact, older than about 30,000 years; it does not include any appreciable amounts of *Globorotalia menardii* (Fig. 2, GS7102-9, curve 3); and it is preceded by a rise in the concentration of *Pulleniatina obliquiloculata* (Fig. 2, GS7102-9, curve 2), characteristic of the end of stage 4, and by an isotopic low (1000 to 1030 cm below the top). The isotopic peaks of stage 3 (770, 810, and 870 to 910 cm below the top) have values similar to the modern one (top of the core). In all Caribbean–equatorial Atlantic cores stage 3 is represented by only a minor rise in the concentration of ^{16}O, although it is more conspicuous in the more northern core 280 (*1–4*). In addition, all micropaleontological evidence presently available, including that shown in Fig. 4, A and B, indicates that stage 3 was "cool" with temperatures closer to those of a glacial age than those of an interglacial one. Finally, sea level during stage 3 apparently stood not much below the present. These diverse and apparently contradictory lines of evidence can be explained concurrently if a large but thin ice cap had persisted over northern North America during stage 3, with an unusually rapid rate of accumulation and ablation. Continued, rapid ablation under equilibrium conditions would supply the Gulf of Mexico with a continued, abundant influx of ice meltwater while low temperatures would be maintained.

It is apparent, therefore, that the isotopic curve of Fig. 5 should be viewed more as representing the dynamics of the Laurentide ice sheet than changing surface temperature at the location of the core.

Absolute temperatures. Our micropaleontological curves show that the minima of the ratio of *Globigerinoides sacculifera-triloba* + *Globoquadrina eggeri* to *Globorotalia inflata* (Fig. 4, A and B) range around 0.2 from the bottom of core GS7102-5, and from the correlative 970 cm below the top level in core GS7102-9, to the onset of the temperature rise leading into the post-glacial. Values of 100 to 150 are reached during the present interglacial (0 to 30 cm in core GS7102-5 and 0 to 90 cm in core GS7102-9). The relationship between the above ratio and absolute temperatures can be calculated from tables 2 and 13 in Imbrie and Kipp (*21*). In spite of the considerable noise, the data show that values of 0.2 relate to winter temperatures of 16°C and summer temperatures of 22°C. We conclude that this is the seasonal temperature range of the surface water of the northeastern Gulf of Mexico during the glacial ages. Modern winter and summer temperatures are, respectively, 22°C and 29°C, showing that both winter and summer temperatures during glacial ages were about 6° to 7°C lower than today. This value compares favorably with the estimate of 7° to 8°C for the glacial-interglacial temperature amplitude in the adjacent Caribbean Sea (*29*, table 1).

Sedimentation rates. The excellent set of ^{14}C dates obtained from core GS7102-9 allows us to calculate the sedimentation rates across short stratigraphic intervals. The data (Table 3) show that a sedimentation rate of 11.8 cm per 1000 years prevailed between 370 and 350 cm below the top. This rate increased to 49.6 cm per 1000 years around the temperature minimum of 270 cm below the top, a minimum which dates from about 18,000 years B.P. and represents the peak of the last glacial age. From this unusually high value, the rate then declined progressively to the modern value of 8.7 cm per 1000 years, an amount still three to four times greater than the rate of sedimentation of normal *Globigerina* ooze. Below 370 cm, an inversion in the ^{14}C ages occurs (Table 3), which precludes the calculation of sedimentation rates between 370 and 530 cm. A close inspection of core GS7102-9 has failed to reveal any evidence of sedimentary disturbance, including turbidite deposition. Furthermore, core GS7102-9 closely correlates with core GS7102-5 across this interval. We conclude that the observed inversion may result from a small amount of contamination with modern carbon introduced during the coring operation.

Conclusions. Oxygen isotopic and micropaleontological analysis of deep-sea cores from the northeastern Gulf of Mexico, together with ^{14}C dating at close stratigraphic intervals, has shown that, although the temperature remained low during stage 3, a considerable amount of ice meltwater was being continuously introduced into the Gulf of Mexico. It is apparent that a broad but thin ice sheet persisted over northern North America during this time. After the last glaciation (stage 2), the concentration of ice meltwater in the Gulf of Mexico increased, reaching a maximum at about 11,600 years B.P. This age coincides with that of the Valders readvance; because this readvance was accompanied by a rapid rise in sea level, it was apparently a surge, which brought ice to lower latitudes and caused rapid melting. We postulate that ensuing flooding of low-lying coastal areas, many of which were inhabited by man, gave rise to the deluge stories common to many traditions. Plato set the age of the flood at precisely 11,600 years B.P.

CESARE EMILIANI
Department of Geology, University of Miami, Miami, Florida 33124

STEFAN GARTNER
BARBARA LIDZ
Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida 33149

KONETA ELDRIDGE
DWIGHT K. ELVEY
Department of Geology, University of Miami

TING CHANG HUANG
Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida 33149

JERRY J. STIPP
MARY F. SWANSON
Department of Geology, University of Miami

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Spatial Scales of Current Speed and Phytoplankton Biomass Fluctuations in Lake Tahoe

Abstract. *Spectral analysis of current speed and chlorophyll a measurements in Lake Tahoe, California and Nevada, indicates that considerably more variance exists at longer length scales in chlorophyll than in the current speeds. Increasingly, above scales of approximately 100 meters, chlorophyll does not behave as a simple passive contaminant distributed by turbulence, which indicates that biological processes contribute significantly to the observed variance at these large length scales.*

Phytoplankton are small and usually immotile, floating freely in an aquatic habitat. Their growth rates are determined by light, temperature, nutrient concentration, and turbulence—environmental conditions to which they are subjected by physical transport processes. Any spatial patterns of phytoplankton abundance are thus a result of the interactions between transport processes and the differential rates of growth of algal populations under different physical, chemical, and biological conditions. Only limited direct control of physical location can be exercised by algal cells through flagellar locomotion and control of buoyancy.

Theoretical studies of general ecological processes (*1, 2*) and measurements from a variety of habitats (*3*) imply that spatial heterogeneity may be critically important in regulating community and population behavior. Since the epilimnia of lakes are extremely isotropic compared to benthic or terrestrial habitats, and since the organisms are largely unable to control their own location by active means, a demonstration that spatial heterogeneity is important in phytoplankton associations would strongly support the generality of this dimension of ecosystem structure.

Previous workers have sought to account for the complex phytoplankton associations observed even in the well-mixed layer of pelagic systems. Hutchinson (*4*) characterized the existence of multispecific assemblages in such seemingly uniform habitats as the "paradox of the plankton" and proposed that the temporal variability of the physical environment produces diversity. Subsequent investigators have emphasized the importance of spatial heterogeneity in well-mixed turbulent environments (*2, 5, 6*). Phytoplankton populations actually are distributed in nonrandom or patchy fashion on moderate scales (*7*), and theoretical relations between patch persistence, growth rates, intensity of turbulent transports, nutrient uptake rates, and so forth have been investigated (*6, 8*). In situ estimates of phytoplankton biomass can now be obtained by continuous flow fluorometric analysis of chlorophyll concentration, and this permits a direct comparison of the biological and physical structure of pelagic systems (*9*).

During the last 2 years we have made a detailed survey of various physical and biological parameters in Lake Tahoe, California and Nevada, a large (499-km^2), deep (maximum depth, 501 m), extremely oligotrophic lake (*10*) of considerable interest for both basic scientific and management research (*11*). Parameters measured include water currents at three depths, temperature, chlorophyll content, and algal species counts. We present some relations between the spatial spectra of chlorophyll a concentrations measured from a moving boat and the spectra of current fluctuations measured at a stationary meter mounted beneath a subsurface buoy. The spectra show that the direct effects of turbulent diffusion dominate biological processes at relatively small scales (less than approximately 100 m), but that biological processes have greater control of spatial distribution at larger scales.

The interpretation of time series data by power spectrum analysis is common in the physical (*12*) and social (*13*) sciences, but is less familiar to aquatic ecologists (*9*). In considering the spectrum of audible noise, for example, one might wish to know what portion of the sound energy was in a particular frequency band, say 2000 to 4000 hertz. Spectral analysis (*14*) gives a statistically acceptable answer to such questions for stationary time series. In other examples, it might be used to discover how much of the energy in turbulent velocity fluctuations is found at low frequencies (*12*), or how much of the variance in records of a certain economic indicator is due to long-term (low-frequency) fluctuations (*13*).

The chlorophyll data were gathered by pumping lake water from a depth of 18 m through a hose into a fluorometer (G. K. Turner Associates) mounted on a research vessel; the hose assembly was towed behind the vessel at 1.3 m/sec for a distance of approximately 3 km. This in situ method measures both chlorophyll and pheophytin, the concentration of pheophytin in Tahoe having been reported to be about 15 to 25 percent that of chlorophyll a (*15*). During these measurements the phytoplankton association in Lake Tahoe was dominated by a small, nonmotile diatom, *Cyclotella stelligera*. The chlorophyll signal was digitized, stored on magnetic tape, and analyzed for its spectral content with a fast fourier transform algorithm (*16*).

The current meter, a savonius rotor with eight magnetic reed switch pickups, was mounted at a depth of 17 m in Lake Tahoe's well-mixed epilimnion. Each revolution of the turning rotor produces eight pulses, and the time between pulses gives a measure of the low-frequency fluctuations in the magnitude of the horizontal velocity field. The current records discussed here were taken in midafternoon, when daily winds from the southwest of up to 15 m/sec, a standard feature of the Tahoe basin summer climate, drive the surface waters at average speeds of up to 10 to 15 cm/sec. At these speeds we estimate that one can measure fluctuations of the order of 0.5 cm/sec with a length constant of approximately 2 m. The current spectra were also calculated with the fast Fourier transform algorithm.

Since the fluctuations in current speed ($\simeq$1.5 to 2 cm/sec) are small compared to the average speed ($\simeq$10 to 15 cm/sec), the chlorophyll and current records can be spectrally analyzed using Taylor's "frozen turbulence" hypothesis (*17*) and the spectra presented in terms of a wavelength (λ) or wave number ($1/\lambda$). The records discussed here are a current record from 27 September 1973 and a chlorophyll tow from 28 September 1973, although virtually all of our records show the same major characteristics as these. (With time series of chlorophyll concentration and current speed taken at the same time and place correlations and coherence spectra between the records could be analyzed, but other experimental requirements and limits on the data acquisition system did not allow simultaneous measurement.) The thermocline was at 28 m, so both records