resenting differences in clock readings at the two sites provided a posteriori synchronization of the clocks. The corrections were of the order of 250 μsec in January and 10 μsec in October, with formal standard errors of a few nanoseconds or less. Thus, remote clock synchronization at the nanosecond level can be accomplished through VLBI. On a time scale of hours, each of the hydrogen maser standards was stable to at least a few parts in 10^{13} in these two experiments. Because of the discontinuities, little of use can be said about stabilities on longer time scales.

H. F. HINTEREGGER, I. I. SHAPIRO
D. S. ROBERTSON, C. A. KNIGHT
R. A. ERGAS
Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge 02139
A. R. WHITNEY
Department of Electrical Engineering, Massachusetts Institute of Technology
A. E. E. ROGERS
Haystack Observatory, Northeast Radio Observatory Corporation, Westford, Massachusetts 01886
J. M. MORAN
Smithsonian Astrophysical Observatory, Cambridge, Massachusetts 02138
T. A. CLARK
Goddard Space Flight Center, Greenbelt, Maryland 20771
B. F. BURKE
Research Laboratory of Electronics, Massachusetts Institute of Technology

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7. We intended to eliminate effects of charged particles on the delay and delay-rate measurements by taking observations simultaneously at L-band and at X-band. However, the necessary modifications to the configuration at Haystack could not be implemented for this experiment.
8. The set of relative frequencies chosen, [0,1,4, 6,24,36] Mhz, constitutes two overlapping Arsac arrays [J. Arsac, thesis, University of Paris (1966)]. One array has a unit spacing of 1 Mhz and the other a unit spacing of 6 Mhz; the arrays have two elements, 0 and 6 Mhz, in common. The Arsac array, [0,1,4,6] Mhz, uniformly samples all spacings from 1 to 6 Mhz.
9. The measurement errors are inversely related to the correlation amplitudes (and to the effective bandwidth). In the January experiment, for example, these varied from 0.3 to 1 percent and were quite constant for each source observed. The corresponding spread in differenced delay errors was from 1.5 to 0.5 nsec. The measurement errors in the October experiment at X-band were, on the average, not much larger, because the correlation amplitudes were about a factor of 2 higher, and thereby almost compensated for the decrease by a factor of 3 in the effective bandwidth.
10. The VLBI observations of extragalactic radio sources are sensitive to changes in both the length and the direction of each baseline, but not to a parallel displacement. Therefore, with no loss in generality, we can take the coordinates of one site as fixed.
11. The plane normal to the earth's rotation axis defines the declination origin, but there is no corresponding natural way to define the origin of right ascension for VLBI observations. We fixed the right ascension of at least one source at its a priori value for this analysis; for longer baselines, where the source coordinates play a relatively more important role, an a priori covariance matrix would be employed.
12. The neutral atmosphere was modeled in the manner described by H. Hopfield [*J. Geophys. Res.* **74**, 4487 (1969)]; the corrections to the observables were determined for the measured or extrapolated values of surface temperature, pressure, and humidity for each site. The ionospheric corrections involved a simple model that employed the values for the integrated electron content deduced by J. Klobuchar (personal communication) from observations of the Faraday rotation of radio signals transmitted from a satellite in synchronous orbit. The individual atmospheric corrections varied in magnitude from about 0.1 to 3 nsec for the differenced delay measurements, and from about 0.05 to 1 psec/sec for the corresponding delay-rate data. The ionospheric corrections varied in magnitude over approximately the same range for the L-band observations, and were about 20 times lower at X-band.
13. The hydrogen maser frequency standards in use at both sites were in a relatively poor state of repair at the time of this experiment. As a result, a number of discontinuities in clock offset occurred that required parametrization.
14. All source coordinates were estimated except those for 3C345 and CTA 102 (see Table 2) since their positions previously determined by radio and optical methods agreed to within 0.2 arc second (*20, 24*).
15. The coordinates for 3C273 and 3C147 were not held fixed at their initial values (*20, 23*) since we believed that they were the most likely to be in error. In the case of 3C273, our belief was confirmed after the completion of our analysis. The lunar occultation data on which the entry for 3C273 in Table 2 was based were re-reduced with more data added [C. Hazard, J. Sutton, A. N. Argue, S. M. Kenworthy, L. V. Morrison, C. A. Murray, *Nature* **233**, 89 (1971)] and yielded a revised position in close agreement with our result. There is no significant difference in declination; the difference in right ascension is 0.5 arc second with respect to the new occultation value, but only 0.15 arc second with respect to one of the two optical determinations presented by Hazard *et al.* There are no new determinations with which to compare the coordinates of 3C147, which is known to have a complex structure at least on the level of a few tenths of an arc second [W. Donaldson and H. Smith, *Mon. Not. Roy. Astron. Soc.* **151**, 253 (1971)].
16. The coordinates of 3C345 and 3C454.3 were held fixed at Wade's positions [see Table 2 and (*14*)]. A separate clock offset in epoch and in rate for each day's observations was used, yielding the total of 18 clock parameters.
17. Again in October, the hydrogen maser at Green Bank was not in good health (*13*); at Haystack a maser built by H. Peters was borrowed from Goddard Space Flight Center for the occasion. Since 1969 the masers permanently located at the two sites have been refurbished.
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29 February 1972; shortened 1 September 1972 ■

Quaternary Paleotemperatures and the Duration of the High-Temperature Intervals

Abstract. *Oxygen isotopic analysis of Caribbean cores P6304-4 and P6304-7, and the close correlation of these cores with other Caribbean and Atlantic cores previously analyzed, make possible the reconstruction of a paleotemperature curve of considerable detail. This curve demonstrates again the unusualness of the present interval of high temperature within the framework of Quaternary climatic evolution, and the need for a close study of man's impact on climate.*

According to the classical picture, still adopted in some contemporary textbooks (*1*), the Quaternary consisted of four major glaciations each lasting approximately 100,000 years, separated by interglacials ranging in length from 100,000 to 300,000 years. The classical picture, as recorded in (*2*), is illustrated in Fig. 1.

Oxygen isotopic analyses of deep-sea cores, together with absolute dating by the ^{14}C and $^{230}Th/^{231}Pa$ methods, has revealed a completely different picture (*3–6*), with more numerous, shorter, and more regular glacial-interglacial cycles.

An early temperature curve (*3*, figure 15) was based largely on two piston cores, which were later found to represent an incomplete stratigraphic record (*4*). The necessity of basing paleotemperature reconstructions on complete stratigraphic sections was stressed, and means to test for continuity were discussed (*4*). Two Caribbean cores, numbers P6304-8 and P6304-9, were found to be continuous, and a generalized temperature curve largely based on these two cores was published (*4*, figure 6).

Two additional cores from the central Caribbean sea (cores P6304-4 and P6304-7) have now been analyzed. Core P6304-4, 1190 cm long, was collected at 15°27′N, 70°43′W, at a depth of 4136 m; core P6304-7, 1239 cm long, was collected at 15°06′N, 69°38′W, at 3929 m. The percentages

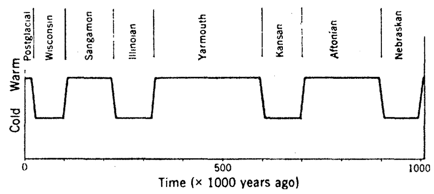

Fig. 1. The Quaternary as classically understood [data from (*2*)].

of the sediment fraction larger than 62 μm and the coiling directions of the pelagic foraminiferal species *Globorotalia crassaformis* and *G. truncatulinoides* (Fig. 2, curves B, C, and D) showed that the two cores correlate with each other as well as with cores P6304-8 and P6304-9 (*4*, figure 5). Thus, stratigraphic continuity is demonstrated. Oxygen isotopic analysis was done at stratigraphic intervals of 10 cm on the shells of the pelagic foraminiferal species *Globigerinoides sacculifera* (Table 1). The samples were treated in the same way as those of core P6304-9 (*4*).

The isotopic curves for the two cores (Fig. 2, curves A) correlate closely with each other as well as with the curves obtained from other Caribbean cores previously analyzed (*3*–*7*). By using all the isotopic curves obtained so far from Caribbean and Atlantic cores, it is now possible to average stage by stage the information provided by each core and to reconstruct a paleotemperature curve of greater detail than the one previously published (*4*, figure 6). The new curve (Fig. 3) exhibits a number of major maxima and minima, together with many smaller peaks and valleys. The amplitude of the major cycles is similar to that of the previous curves (*3*, figure 15; *4*, figure 6) and is in accordance with a wealth of nonisotopic evidence (*7*). It represents, therefore, true temperatures. The deep minimum of stage 4 is based, as

Table 1. Caribbean cores P6304-4 and P6304-7: Oxygen isotopic analysis of shells of *Globigerinoides sacculifera*. The results are expressed as per mil deviations from the Chicago standard PDB-1.

Depth (cm)	P6304-4	P6304-7
0	− 1.22	− 1.35
	− 1.38	− 1.40
	− 0.68	− 1.16
	− 0.21	− 0.64
	+ 0.33	− 0.27
50	+ 0.27	+ 0.28
	+ 0.07	+ 0.29
	+ 0.14	+ 0.20
	+ 0.28	+ 0.23
	+ 0.31	+ 0.15
100	+ 0.09	+ 0.04
	+ 0.23	+ 0.11
	− 0.01	+ 0.10
	− 0.17	+ 0.13
	− 0.02	− 0.06
150	− 0.09	+ 0.11
	+ 0.19	− 0.07
	+ 0.15	− 0.06
	+ 0.17	+ 0.14
	− 0.21	− 0.28
200	− 0.37	− 0.20
	− 0.52	− 0.28
	− 0.48	− 0.70
	− 0.56	− 0.66
	− 0.40	− 0.70
250	− 0.46	− 0.67
	− 0.58	− 0.83
	− 0.63	− 0.89
	− 0.52	− 0.97
	− 0.70	− 0.94
300	− 1.05	− 0.88
	− 1.05	− 0.80
	− 0.69	− 1.28
	− 0.17	− 1.35
	+ 0.54	− 1.13
350	+ 0.59	− 0.96
	+ 0.42	− 0.33
	+ 0.32	+ 0.25
	+ 0.19	+ 0.17
	0.00	+ 0.17
400	+ 0.20	+ 0.39
	+ 0.23	+ 0.21
	− 0.10	+ 0.03
	+ 0.25	− 0.30
	− 0.28	− 0.01
450	− 0.35	− 0.45
	− 0.52	− 0.40
	− 0.65	+ 0.03
	− 0.64	− 0.44
	− 0.65	− 0.56
500	− 0.63	− 1.06
	− 0.66	− 0.99
	− 0.67	− 0.91
	− 0.50	− 1.06
	− 0.37	− 1.13
550	− 0.60	
	− 0.68	− 1.06
	− 0.03	− 1.17
	+ 0.33	− 0.71
	+ 0.17	− 0.68
600	− 0.03	− 1.01
	− 0.23	− 1.03
	− 0.03	− 0.77
	− 0.25	− 1.09
	− 0.56	+ 0.09
650	− 0.54	− 0.02
	− 0.42	− 0.03
	− 0.49	+ 0.24
	− 0.59	− 0.02
	− 0.75	− 0.20
700	− 0.44	− 0.26
	− 0.78	− 0.36
	− 0.84	− 0.91
	− 0.37	− 0.46
	+ 0.09	− 0.38
750	+ 0.05	− 0.64
	− 0.28	− 1.50
	− 0.38	− 1.21
	+ 0.05	− 1.31
	− 0.18	− 1.35
800	− 0.39	− 1.36
	− 0.35	− 1.48
	− 0.91	− 1.20
		− 0.24
		+ 0.26
850		+ 0.16
	− 0.99	− 0.19
	− 0.51	− 0.10
	− 0.02	− 0.18
	+ 0.49	− 0.46
900	− 0.05	− 0.44
	− 0.10	− 0.50
	− 0.38	− 0.89
	− 0.24	− 0.74
	− 0.17	− 1.25
950		− 1.02
	− 0.75	− 0.72
	− 0.68	− 0.65
	− 0.35	− 0.94
	− 0.50	− 0.78
1000	− 0.63	− 0.69
	− 0.43	− 0.44
	− 0.44	+ 0.40
	− 0.59	+ 0.42
	− 0.49	− 0.24
1050	− 0.97	− 0.38
	− 0.50	− 0.56
	− 0.67	− 0.44
	− 0.62	− 0.24
	− 0.77	− 0.34
1100	− 1.00	− 0.63
	− 0.75	− 0.51
	+ 0.05	− 0.96
	+ 0.15	− 1.21
	+ 0.39	− 0.39
1150	+ 0.29	− 0.75
	+ 0.43	− 0.73
	0.00	− 0.34
	− 0.03	+ 0.05
	+ 0.22	− 0.22
1200		− 1.02
		− 1.22
		− 0.96
		− 1.16
		− 0.48

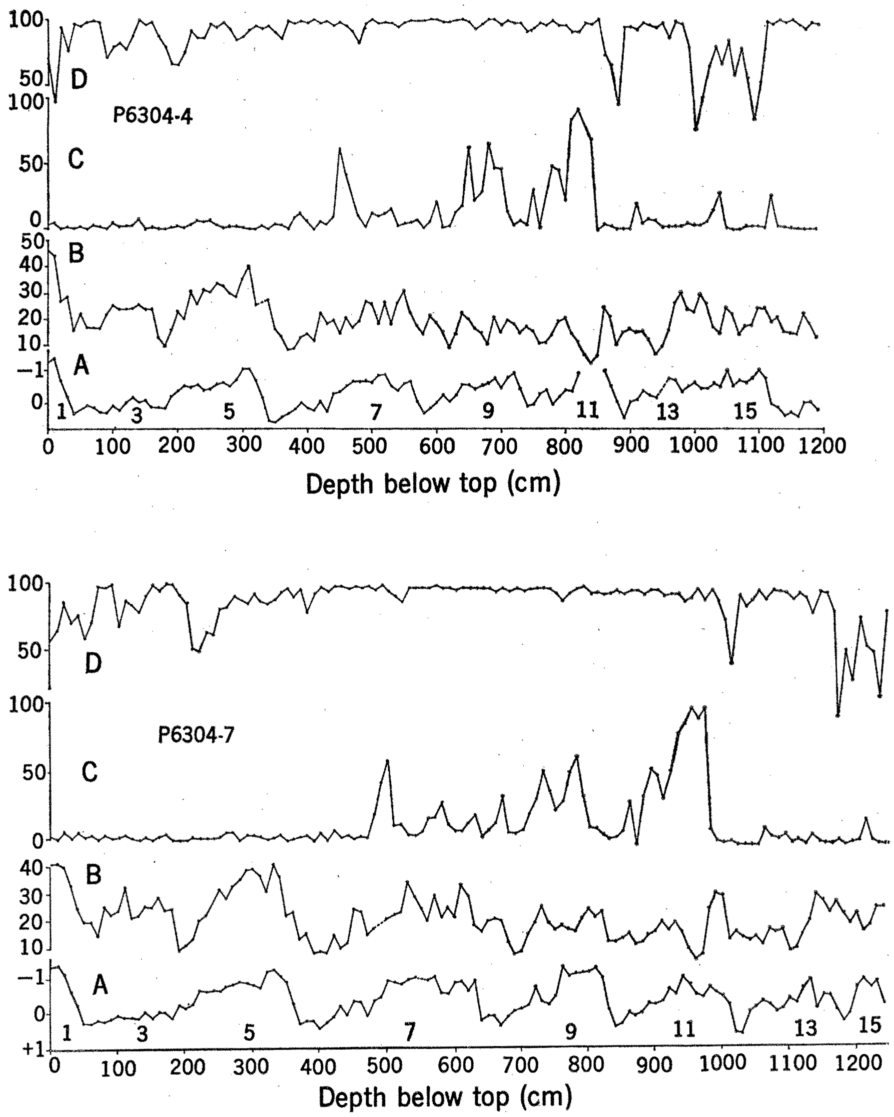

Fig. 2. Caribbean cores P6304-4 and P6304-7. (Curves A) $^{18}O/^{16}O$ ratios in the shells of *Globigerinoides sacculifera* (per mil deviation with respect to the Chicago standard PDB-1). (Curves B) Weight percentage of the sediment fraction larger than 62 μm. (Curves C) Percentage of the right-coiled specimens of *Globorotalia crassaformis*. (Curves D) Percentage of the right-coiled specimens of *Globorotalia truncatulinoides*. The numbers above the horizontal axis refer to stages.

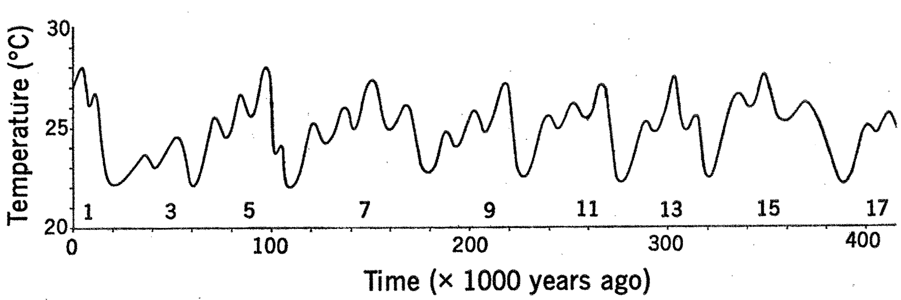

Fig. 3. Generalized temperature curve for the surface water of the central Caribbean sea. The numbers above the horizontal axis refer to stages.

Table 2. Sediment thickness in increments of 100,000 years in four Caribbean cores.

Core	Thickness (cm)			
	0 to 100,000 years ago	100,000 to 200,000 years ago	200,000 to 300,000 years ago	300,000 to 400,000 years ago
P6304-4	330	330	330	
P6304-7	360	360	390	
P6304-8	360	370		
P6304-9	340	340	340	330

before, on the evidence provided by core 280 (*5*), which shows a particularly high rate of sedimentation and therefore provides more detailed information for the pertinent stratigraphic interval. The time scale adopted is based on measurements of ^{14}C and $^{230}Th/^{231}Pa$ (*3, 7*) for the time interval 0 to 150,000 years ago; beyond this interval it is based on the ages of the northern summer insolation minima as read from figure 14 in (*3*). On the basis of this chronology, the duration of the temperature cycles varies from 40,000 (stage 3) to 70,000 years (stage 7), but the rate of sedimentation, averaged over intervals of 100,000 years, remains almost constant in all undisturbed Caribbean cores (Table 2). This supports the chronology adopted here and in previous papers (*3–8*) (*9*).

The impact of oxygen isotopic analysis of deep-sea cores on our understanding of the Quaternary period can be appreciated by comparing Fig. 3 with Fig. 1. Of particular interest is the fact that intervals of temperatures as high as the present ones, far from lasting 100,000 years or more, now appear to be short, wholly exceptional episodes in the environmental evolution of the Quaternary (*10*). New evidence from land deposits supports this view (*11*), strengthening the warning from the deep sea that the present episode of amiable climate is coming to an end. In this context, man's interference with climate through deforestation, urban development, and pollution must be viewed with alarm (*12*). If the present climatic balance is not maintained, we may soon be confronted with either a runaway glaciation or a runaway deglaciation, both of which would generate unacceptable environmental stresses. A clear, quantitative understanding of man's effect on climate must be obtained.

CESARE EMILIANI

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

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13. Supported by NSF grant GA-15226. Contribution No. 1555 from the Rosenstiel School of Marine and Atmospheric Science, University of Miami.

21 July 1972

Lead Aerosol Baseline: Concentration at White Mountain and Laguna Mountain, California

Abstract. *The lead aerosol concentration at White Mountain, California, may be regarded as the present baseline concentration for atmospheric lead for the continental United States. The seasonal trend of lead aerosols at White Mountain and Laguna Mountain shows a summer maximum and a winter minimum. This is because both mountain sampling sites are well above the thermal (radiation) inversion, which normally occurs in the winter, trapping pollutants below the inversion boundary.*

For evaluating the extent of lead aerosol contamination, it is desirable to know the continental lead aerosol baseline concentration. The natural lead concentration of the pristine atmosphere has been estimated from geochemical data (*1*) to be 0.0006 μg per cubic meter of air. Measurements of lead aerosols in the marine and arctic atmospheres show the following concentrations: north central Pacific Ocean, 0.0010 (*2*); windward Oahu, 0.0017 (*3*); south Indian Ocean, 0.0010 (*4*); north Indian Ocean, 0.0040 (*4*); Novaya Zemlya, 0.0002 (*4*); and Greenland, 0.0005 $\mu g/m^3$ (*5*).

Most lead aerosol concentrations over land areas were monitored in populous regions where the atmospheric lead concentration is usually in the range of several micrograms per cubic meter (*6*). The lowest lead aerosol concentration thus far reported on the continental United States was 0.022 $\mu g/m^3$ (*7*). We have determined the seasonal trend of lead aerosol concentrations at two mountainous locations which are virtually uninhabited and far above the thermal (radiation) inversion; their lead aerosol content may approach the continental baseline concentration.

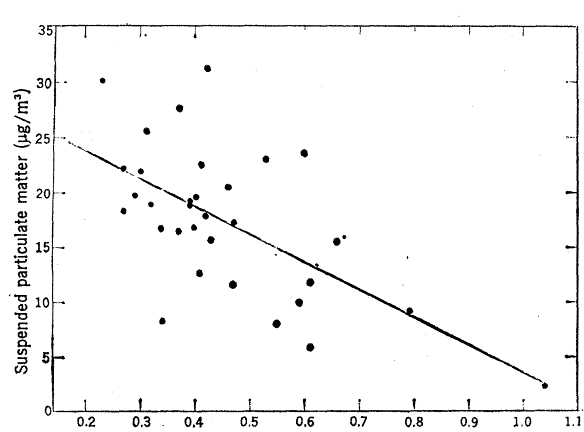

Fig. 1. Negative regression correlation between the percentage of lead aerosols and the concentration of suspended particulate matter at Laguna Mountain, California.

Barcroft Laboratory, a research station of the University of California, is located at 37°35′N, 118°15′W in the White Mountains, at an elevation of 3800 m; it is approximately 35 km north-northeast of and some 2530 m above Bishop, California. The laboratory is situated at the end of a seldom-used private road, with a locked gate about 3 km from the sampling site. The primary method of transportation to the laboratory is by helicopter from the university's Owens Valley Laboratory near Bishop.

Because of its high altitude and unusual geographic location, Barcroft Laboratory experiences extremes in meteorological conditions. The lowest temperature recorded at the laboratory was −37°C. Temperatures below freezing occur during any month of the year. The Sierra Nevada Mountains are between the White Mountains and the Pacific Ocean. The average annual precipitation at the laboratory is 48 cm, most of which falls as snow, which occurs even during the summer months. Snow usually covers the ground except during the three summer months. The average maximum wind from 1953 to 1969 (the mean of daily maximum 1-hour wind velocities) was about 43 km/hour, and the maximum wind (the highest 1-hour wind velocity) was 152 km/hour. About 60 percent of the wind is from the west or southwest. The average barometric pressure is 640 mb.

The Laguna Mountain sampling site is at the astronomical observatory of San Diego State University on the crest of the Peninsular Ranges; it is located at 32°51′N, 116°25′W, at an elevation of 1850 m. The San Diego metropolitan area is approximately 72 km west of this location. Automotive traffic is probably less than a dozen cars per week within 1 km of this location. Two kilometers west of the site is a mountain road with a daily traffic of 200 to 300 cars. The average barometric pressure is 815 mb.

The sampling, chemical, and mass spectrometric procedures have already been described (*8*). The samples consist of Millipore filters (type AAWP, 0.8-μm mean pore size) through which air is drawn by vacuum pumps. Each sample generally represents continuous filtration of air for 1 month. The two air samplers at the White Mountain research station have daily pumping rates of 17 and 25 m^3 of air, and the sampler at the Laguna Mountain site has a rate of 25 m^3/day. The lead contents were