Reports

Absolute Dating of Caribbean Cores P6304-8 and P6304-9

Abstract. *Two deep-sea cores from the central Caribbean have been dated by the thorium-230/protactinium-231 method. The ages obtained are in agreement with the ages previously obtained from other deep-sea cores from the same area. Because of their greater precision, the new dates provide a more accurate time scale for the past 170,000 years.*

Caribbean cores P6304-8 (14°59′N, 69°20′W, 3927 m deep, 1054 cm long) and P6304-9 (14°57′N, 68°55′W, 4126 m deep, 1429 cm long) have been analyzed in considerable detail both isotopically and micropaleontologically (*1*). These analyses demonstrated that the two cores contain continuous and undisturbed sections of globigerina ooze sediment, ranging in age from the present to an estimated 225,000 years ago for core P6304-8, and from the present to an estimated 425,000 years ago for core P6304-9.

These two cores have now been dated by the Th^{230}/Pa^{231} method (Tables 1 and 2, Fig. 1). The analytical technique has been described in detail (*2*). The ages are shown in Fig. 1 as are C^{14} ages from Ostlund. The errors assigned to the Th^{230}/Pa^{231} ages are the spread given by two or three repeat measurements.

The ages were calculated by the use of the following equation:

$$t = 8.26 \ln (0.106\, Th_u^{230}/Pa_u^{231}) \times 10^4 \text{ years}$$

where Th_u^{230} and Pa_u^{231} are the activities of the uranium-unsupported fractions of the two isotopes. This equation is similar to that given by Rosholt *et al.* (*3*, p. 171), but the constants are different, in part because of the newer values for the half-lives of Th^{230} (75,200 years) and of Pa^{231} (32,480 years), and in part because activity ratios are used.

For the time t = zero (the present), the above equation gives a Th^{230}/Pa^{231} ratio of 9.4. This ratio is 15 percent lower than that given by Sackett (*4*) because the latter includes a correction for the U^{234} excess in seawater. Table 3 shows the Th^{230}/Pa^{231} ratios for the topmost samples of all cores dated by the Th^{230}/Pa^{231} method. The resulting Th^{230}/Pa^{231} ages are compared with the C^{14} chronology. The two sets of figures are in good agreement for the Caribbean cores A240-M1, A179-4, A254-BR-C, P6304-8, and P6304-9 (*3*, *5*, present paper), whereas a large disagreement exists for Caribbean core V12-122 (*6*) and North Atlantic core 280 (*3*).

Table 1. Core P6304–8; analytical data.

Depth (cm)	U–238* (d/h/g)	U–234* (d/h/g)	Th–230*† (d/h/g)	Pa–231*† (d/h/g)	$\frac{Th^{230}}{Pa^{231}}$	Age (years)	$CaCO_3$ (%)
21 to 29	50.0	51.0	442.0	40.0	11.05	12,600 ± 1000	64.3
151 to 159	45.6	48.8	238.0	11.8	20.17	62,800 ± 2000	67.8
321 to 326	40.0	40.0	181.6	6.4	28.37	91,000 ± 3000	60.0
390 to 395	46.0	46.0	176.0	5.4	32.59	102,300 ± 3000	54.9
631 to 639	60.0	60.0	56.8	0.8	71.00	166,700 ± 7000	66.5

* Carbonate-free basis. † Corrected for uranium-supported nuclides.

Table 2. Core P6304–9; analytical data.

Depth (cm)	U–238* (d/h/g)	U–234* (d/h/g)	Th–230*† (d/h/g)	Pa–231*† (d/h/g)	$\frac{Th^{230}}{Pa^{231}}$	Age (years)	$CaCO_3$ (%)
82 to 86	50.0	51.0	294.0	22.6	13.00	26,600 ± 1000	56.2
192 to 196	44.0	48.0	340.0	16.0	21.25	67,000 ± 2000	47.3
321 to 326	42.0	42.0	218.0	7.4	29.46	94,100 ± 3000	57.0
396 to 401	58.0	58.0	206.0	6.4	32.19	101,300 ± 3000	54.0
531 to 536	47.6	47.6	112.0	2.0	56.00	147,200 ± 6000	52.0

* Carbonate-free basis. † Corrected for uranium-supported nuclides.

The Th^{230}/Pa^{231} ratios obtained from the uppermost samples analyzed in the former five cores (Table 3) extrapolate to a ratio of 9.4 for t = 0, which is identical to that predicted by the equation given above. The two latter cores (V12-122 and 280) extrapolate to a ratio of about 13.5, giving an age of about 29,000 years for t = 0.

Koide and Goldberg (*7*) measured a 14 percent U^{234} excess in seawater at different depths and in different oceans, and Thurber (*8*) verified that this excess is preserved in marine carbonates. On the other hand, the clay phase in some cores, as implied by the 9.4 ratio mentioned above, appears to deposit Th^{230} and Pa^{231} in equilibrium with the U^{238} and U^{235} concentrations in the ocean.

Cores V12-122 and 280 give a Th^{230}/Pa^{231} ratio which is much too high not only at the top but throughout (*3*, *6*), indicating that Pa^{231} is depleted with respect to Th^{230} in both cores. The fact that the chronologies of cores V12-122 and 280 do not give zero years for the top of the cores, and do not correlate with the C^{14} chronology over the common range of the two methods, leads to a rejection of the Th^{230}/Pa^{231} ages obtained from these two cores.

A discordant suite of Th^{230}/Pa^{231} ages from a given core, apparently due to fractionation of Th^{230} or Pa^{231} during the process of adsorption and deposition, does not necessarily entail discordant Th^{230} or Pa^{231} chronologies. An example is offered by core V12-122 which, while giving a discordant Th^{230}/Pa^{231} chronology (*6*, Table 2, second column from right), it gives a largely concordant Th^{230} chronology (*9*). Of particular significance is the fact that, using the rate of sedimentation of 3.62 cm/1000 years given by the age of 147,200 years for the 533 cm level of core P6304-9, an age of 313,000 years is calculated for Ericson's U/V boundary (which occurs at 1135 cm in the core): this age is virtually identical to the Th^{230} age obtained for the same boundary in core V12-122 (*9*).

The ages of the temperature maxima and minima of stages 2 and 4 to 8 are shown in Table 4 for all concordant cores so far analyzed by the Th^{230}/Pa^{231} method. Stage 1 has been omitted because its chronology is more accurately known from C^{14} analysis of continental materials (see, for instance, *10*). The age of core stage 2 (Table 4) correlates with the time of known maximum advance of continental ice in both North America and Europe. No Th^{230}/Pa^{231} age measurements have been made for the temperature maximum of stage 3, which is not as high as that of interglacials. The ages of the temperature extremes of stages 4 to 8 appear well established and in good or excellent internal agreement. Table 4 also shows the ages of the insolation minima (as read from *11*, Fig. 14) which are believed to have triggered the successive glaciations (*12*). As expected, the insolation minima precede temperature minima, because of the time delay related to ice cap formation. The lag, however, does not appear to be constant, being 4000 to 5000 years for stages 2 and 4, 14,000 years for stage 6, and 9000 years for stage 8. The greater lag for the earlier glaciations may result from the fact that these glaciations were considerably larger than the latest ones (Early and Main Würm), a phenomenon for which there is ample field evidence in both Europe (*13*) and North America (*14*).

Littoral deposits of Pleistocene age occurring above present sea level were generally formed during interglacial ages (*15*). In fact, the Th/U ages of 85,000, 130,000, and 190,000 years ago for fossil coral and oolite from the Bahamas and the Florida Keys; of 75,000 to 90,000 and 115,000 to 140,000 years for raised beaches in Morocco and the Mediterranean; and of 25,000 to 50,000, 75,000 to 100,000, 172,500, and 217,500 for the Worozonfian, Pelukian, Kotzebuan, and Middletonian interglacial deposits of Alaska (*16*), indicate that these deposits were variously formed during deep-sea core warm stages 3, 5, 7, and 9.

Broecker and co-workers (*6*) recognized a number of raised coral-reef terraces in Barbados, also presumed to have been formed during interglacial high-stands of sea level, and dated the lowermost three at about 82,000, 103,-

Table 3. Th^{230} and Pa^{231} data; Th^{230}/Pa^{231} ages; and comparable C^{14} ages (by direct measurement or by correlation with dated cores) for seven deep-sea cores from the Caribbean (top 6) and the North Atlantic (bottom one). Locations, lengths, and depths of the cores are given in (*1*), (*3*), (*5*) and (*6*). Subscript t = total; subscript u = uranium unsupported. All Th and Pa concentrations calculated on a carbonate-free basis.

Core No.	Below top (cm)	Th_t^{230} (dph)	Pa^{231} (dph)	Th_u^{231} (dph)	Pa_u^{231} (dph)	Th_u^{230}/Pa_u^{231}	Th_u^{230}/Pa_u^{231} (years)	Comparable C^{14} age (years)
A240–Ml	11–20	100.1	9.1	92.2	8.8	10.5	8600	8500
A179–4	10–17	98.3	8.6	82.0	7.9	10.4	7900	9000
A254–BR–C	31–40			31.4	2.7	11.6	17,100	15,500
P6304–8	21–29	493.0	42.3	442.0	40.0	11.0	12,600	9,500
P6304–9	82–86	345.0	24.9	294.0	22.6	13.0	26,600	23,800
V12–122	10–15			170.0	12.2	13.9	31,800	9,000
280	8–16	125.2	8.6	110.2	7.9	14.0	32,400	11,000

Table 4. Ages of the temperature maxima and minima of stages 2 to 8 in the five Caribbean cores [data partly from (*3*) and (*5*)] analyzed by the Th^{230}/Pa^{231} method. Ages bearing asterisks and daggers are interpolations or extrapolations necessary when the measurements were not made at the exact stratigraphic position of the temperature extremes. Stage 1 has been omitted because its chronology is more accurately known from C^{14} analysis of continental materials [see, for instance, (*10*)].

Core number	Stage number						
	2	3	4	5	6	7	8
A240–Ml			60,000*	93,000	106,000	140,000*	
A179–4				97,000			
A254–BR–C	19,000		60,000	98,000	105,000*	143,000	
P6304–8	16,000		79,000*	91,000	102,000		178,000†
P6304–9	17,000		70,000*	94,000	103,000	147,000	
Average	17,000		67,000	94,400	104,000	143,000	178,000
Insolation minima	22,000		71,000		117,000		187,000

* Interpolated. † Extrapolated.

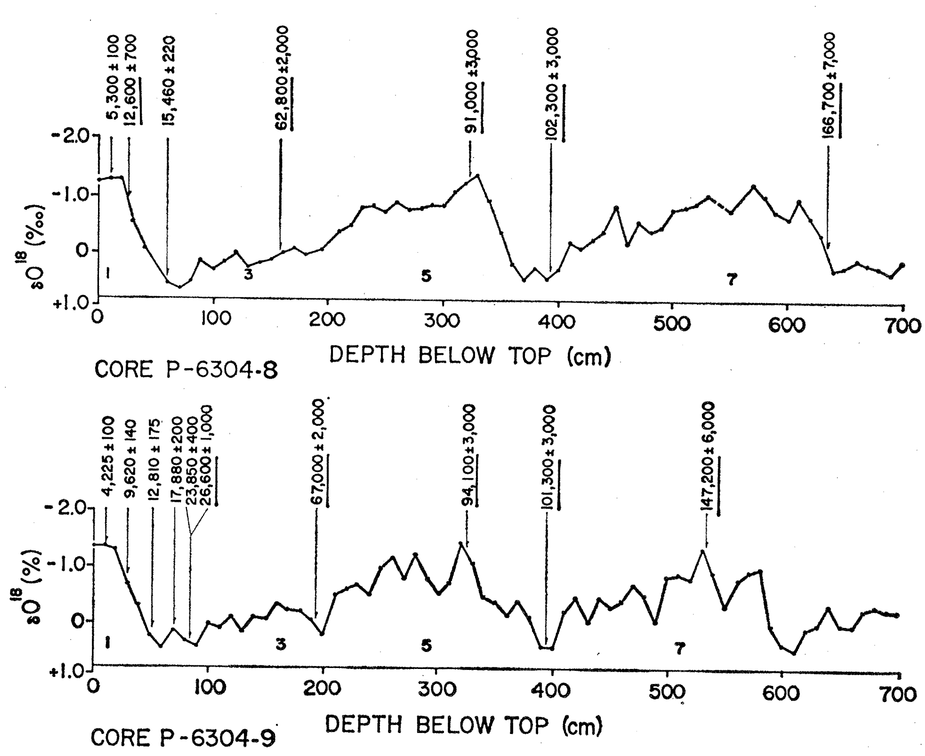

Fig. 1. The Th^{230}/Pa^{231} (underscored) and C^{14} ages of cores P6304-8 and P6304-9. Numbers below curves identify core stages.

000, and 122,000 years ago by the Th^{230}/U^{234} method. One of these figures does not agree with the deep-sea chronology as determined by Th^{230}/Pa^{231} measurements. In fact, while the age of 82,000 years corresponds to the interglacial stage 5, and the age of 122,000 years to the end of interglacial stage 7, the age of 103,000 years does not correspond to an interglacial but to a full glacial (temperature minimum of stage 6). The possibility that the 103,000-year-old terrace may not have been formed during an interglacial age should be investigated. In fact, supramarine littoral deposits formed during glacial rather than interglacial ages are not unknown. For instance, Emiliani (*17*) obtained definitely glacial isotopic values from the top of the falesia near Vila Nova de Milfontes, Portugal, and Emiliani and Mayeda (*15*) obtained similar values from a fossil beach at + 5 m in Sardinia, an island which should be much more stable than Barbados.

E. RONA
C. EMILIANI

Institute of Marine Sciences,
University of Miami,
Miami, Florida 33149

References and Notes

1. C. Emiliani, *J. Geol.* **74**, 109 (1966); L. Lidz, *Science* **154**, 1448 (1966).
2. E. Rona, L. K. Akers, J. E. Noakes, I. Supernaw, *Progr. Oceanogr.* **3**, 289 (1965).
3. J. N. Rosholt, C. Emiliani, J. Geiss, F. F. Koczy, P. J. Wangersky, *J. Geol.* **69**, 162 (1961).
4. W. M. Sackett, *Science* **154**, 646 (1966).
5. J. N. Rosholt, C. Emiliani, J. Geiss, F. F. Koczy, P. J. Wangersky, *J. Geophys. Res.* **67**, 2907 (1962).
6. W. S. Broecker, D. L. Turner, J. Goddard, T.-L. Ku, R. K. Matthews, K. J. Mesolella, *Science* **159**, 297 (1968).
7. M. Koide and E. D. Goldberg, *Progr. Oceanogr.* **3**, 173 (1965).
8. D. L. Thurber, *J. Geophys. Res.* **67**, 4518 (1962).
9. T.-L. Ku and W. S. Broecker, *Science* **151**, 448 (1965).
10. E. S. Deevey and R. F. Flint, *ibid.* **125**, 182 (1957).
11. C. Emiliani, *J. Geol.* **63**, 538 (1955).
12. ——— and J. Geiss, *Geol. Rundschau* **46**, 576 (1959).
13. F. E. Zeuner, *The Pleistocene Period* (Hutchinson, London, 1959).
14. R. F. Flint, *Glacial and Pleistocene Geology* (Wiley, New York, 1957).
15. C. Emiliani and T. Mayeda, *Amer. J. Sci.* **262**, 107 (1964).
16. W. S. Broecker and D. L. Thurber, *Science* **149**, 58 (1965): C. E. Stearns and D. L. Thurber, *Quaternaria* **7**, 29 (1965); R. L. Blanchard, "Uranium decay series disequilibrium in age determination of marine calcium carbonates," thesis, Washington University, St. Louis, Mo. (1963).
17. C. Emiliani, *Actes Congr. Int. Quaternaire 4th*, 831 (1956).
18. Supported by AEC contract AT-(40-1)-3622 and NSF grant GA-1311. We thank B. L. Brandau, C. C. Dorta, and G. Ostlund for portions of the analytical work. Contribution No. 983 from the Institute of Marine Sciences, University of Miami.

5 August 1968

East Pacific Rise Crest: A Near-Bottom Geophysical Profile

Abstract. *A deep-towed magnetometer profile made across the East Pacific Rise crest shows many anomalies with about 1000-gamma amplitudes and 500-meter wavelengths and has larger amplitude changes corresponding to magnetic field reversals. This profile across contacts between normal and reversely magnetized crustal blocks is interpreted to place an upper limit of 4700 years on the time required for field reversals and an upper limit of 280 meters on the width of the intrusion center at the rise crest. This intrusion center may occasionally shift several kilometers laterally with respect to the rise axis. The magnetometer records are compatible with the hypothesis that the magnetic field has undergone many fluctuations of short period and small intensity in the past 2 million years. Sediment accumulation increases from less than 2 meters at the rise crest axis to about 20 meters at the western end and 10 meters at the eastern end of the profile. This increase in accumulation appears to be the result of ocean-floor spreading.*

The segment of the East Pacific Rise that extends into the mouth of the Gulf of California is a continuous swell 350 km long in the ocean floor. This portion of the rise has been the subject of a magnetic survey by Larson *et al.* (*1*) who, along with Moore and Buffington (*2*), concluded that the area is an active site of ocean-floor spreading. They suggest that this spreading at a half-rate of 3.0 cm/year produced the Gulf of California during the past 4 million years.

In May 1968, TIP-TOW expedition surveyed an area (15 by 20 km) at the East Pacific Rise crest in this region with the Marine Physical Laboratory's deep-towed instrument package, generally referred to as the Fish (*3*). In the course of this survey a profile 65 km long was collected in three segments through the area across the crest. The profile includes the first three transitions on the western flank of the rise and terminates in the vicinity of the eastern edge of the central anomaly (*1*) (Fig. 1).

The instrumentation used in our study consisted of (i) a high-resolution, up-looking, down-looking, echo-sounding combination, (ii) a sea-floor penetration sounder operating at 3.5 khz, and (iii) a proton-precession magnetometer. The instrument package was towed behind the surface ship close to the ocean floor on several kilometers of armored coaxial cable. Conventional bathymetric and magnetic observations were also obtained from the towing ship.

The profile was made by towing the Fish at a generally constant height of 80 m from the ocean floor (Fig. 2). This strategy allowed us to obtain optimum bathymetric resolution and sediment penetration to the basement reflector while keeping the magnetometer at an approximately constant distance from the ocean floor.

The profile provides a bathymetric cross section of abyssal hills at the East Pacific Rise crest. These abyssal hills are typical of this segment of the rise (*1*) and also appear to be the characteristic bathymetric feature on the East Pacific Rise at other locations (*4*). Their average relief in this area is about 200 m, and they are several kilometers wide. They are lineated parallel to the trend of the rise and perpendicular to this profile (*1*).

The 3.5-khz system for acoustic penetration of sediment has a limit of resolution of about 2 m. This instrumentation detected no sediment over the central 22 km of the rise crest. A thin sediment cover containing no internal reflectors and overlying a distinct "basement" reflector appears on both sides of the rise-crest center. The western side of the profile (extending farther from the rise crest) shows sediment cover thickening away from the rise-crest center. The sediment penetration increases gradually from 0 to 0.025 second of two-way travel time. The bottoms of three gravity cores taken in the area all yield the same sediment velocity of 1480 m/sec (*5*). This is the velocity corrected for conditions in situ, and can be used for determining the true thicknesses of the profiled sediment (Fig. 2).

The sediment generally thickens away from the crest, but it appears to be preferentially ponded in local lows.