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RADIOACTIVITY OF OCEAN SEDIMENTS
VII. RATE OF DEPOSITION OF DEEP-SEA SEDIMENTS

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INTRODUCTION

Many of the problems of past geological history and of present processes of sedimentation require a knowledge of the rate of accumulation of marine sediments. A very important step in the determination of the rate of deposition of a sediment is the measurement of a time interval. This is equally true whether use be made of the *stratigraphic* method with core samples or the *supply* method based upon the rate of supply of sedimentary material to the sea. The stratigraphic method gives rates for individual localities, whereas the supply method yields averages for large areas over long periods of geological history.

The methods previously employed to estimate the rates of deposition of ocean sediments are well summarized in the chapter on "Marine Sedimentation" in *The Oceans* (13). It is only necessary here to emphasize the subjectivity of these methods and their limitations. Schott (12) arrived at the mean rates of deposition of the three main types of ocean sediments by assuming that the pelagic foraminifera, *G. menardii*, began to accumulate in the deposits of the equatorial Atlantic 20,000 years ago. *G. menardii* were absent or nearly absent while the lower strata represented in the short cores collected by the METEOR were being deposited. The choice of such a time interval has no basis in fact, even though it may be guided by the estimates of various authors of the beginning of postglacial time over the land areas of the northern hemisphere. Further, Schott's estimates are likely to be in error because no correction was made for distortion of the sediment in the coring of the sample. This distortion was probably quite appreciable in view of the narrow liner employed and the fact that the boundary of particular interest was often close to the bottom of the core. But quite apart from the preliminary nature of such estimates, generally well recognized by investigators making use of the data, no analysis of the changes in the rate of deposition in the past is possible from such measurements, and application of such averages to dating specific vertical sections of the ocean bottom is certainly not advisable.

Average rates, based on supply methods, are dependent, among other things, on the accuracy with which the extent of erosion over a long period of geological time can be estimated and on the estimate of the area over which the chemical and detrital deposition occurs. For some purposes such averages obtained by Kuenen (4), Revelle and Shepard (11), and Lohmann (5) are useful, but these figures can never be more than averages for large areas and for long periods of time.

A series of measurements of the radium content of core samples of marine sediments by Piggot and Urry (8, 9, 10), Urry and Piggot (17) and Urry (16) has demonstrated that properties of the radioelements can be employed to date the events that have left their records in the ocean bottom. The radioactive method of dating possesses several advantages. It is free from any consideration of the water content or distortion in the core sample, or of the particular rate of deposition at the site of the sample or the temporal variations of this rate. Piggot and Urry (10) have discussed the application of this method to core samples from the North Atlantic, the Caribbean Sea, and the North Pacific.

It should be a simple matter to calculate the rate of deposition, and the changes in this rate with time, from measurements of intervals of time made in the manner indicated above. However, the length of the core is less than the depth of the original undisturbed sediment that was penetrated. A correction must be applied for this shortening which appears to increase regularly from top to bottom of the core. The term distortion is applied here to this shortening. The term compaction will be reserved for the natural phenomenon in the undisturbed sediment.

THE METHOD

The radioelements of the uranium-238 series are not incorporated in equilibrium amounts into the deep-ocean sediments[1] at the time of their deposition. Consequently, the radium content changes as time progresses and therefore as a particular layer becomes buried. The re-establishment of radioactive equilibrium, reflected in the changing

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[1] Radioelements are in equilibrium when the rate of growth of each member of a series is equal to its decay rate, and hence the amount present is independent of time. Disturbance of the equilibrium appears to be negligible in the shelf deposits. However, only one core of such a sediment has been studied, and alternative explanations of the constant radium content in this core may be found either in a very high rate of deposition or in the fact that shelf deposits consist of extensively reworked detrital material.

radium content, is the basis of a method of measuring time. The method has been adequately described previously (10) and will be discussed only briefly by reference to a typical curve of radium content as a function of depth from measurements in a core of red clay, plotted in Fig. 1.

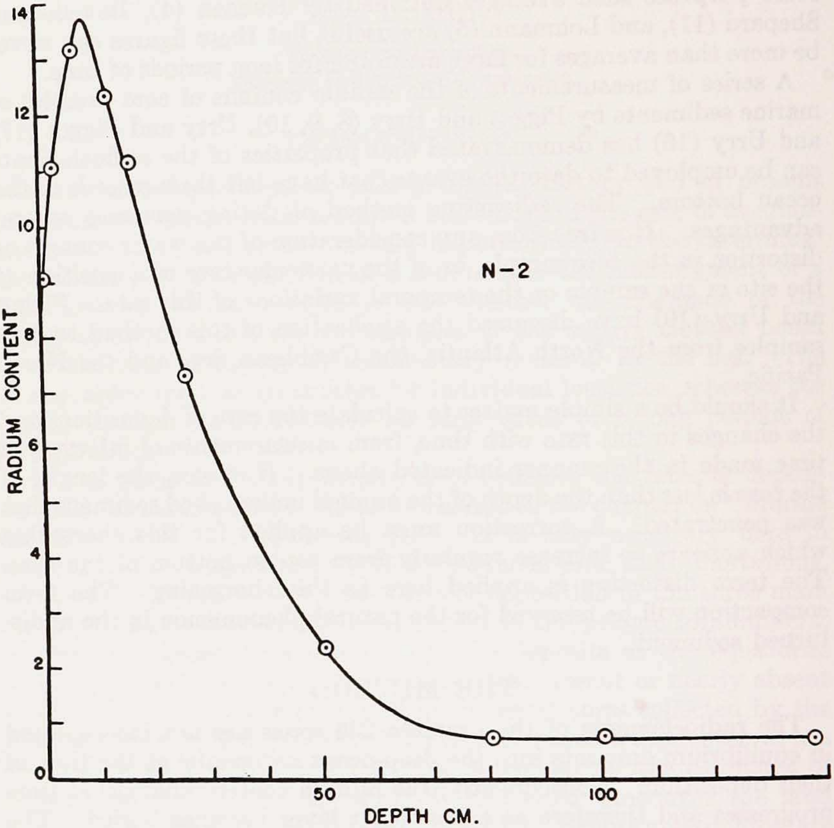

Figure 1. Typical curve of the radium content as a function of depth in a core of deep-sea sediment. The radium content is expressed in units of 10^{-12} g Ra per g of sediment dried at 110° C.

The immediate parent of radium is ionium, which is present in freshly-depositing sediment in excess of that necessary to replenish the radium. Hence the radium at first increases until equilibrium is established between these two elements. The concentration of uranium in deep-ocean sediments is very much less than that necessary to replenish the ionium; consequently the ionium, and with it the radium content, decreases until equilibrium is established between ionium and the small amount of uranium. No further detectable change occurs after this because of the extremely long half-life of uranium; complete equilibrium in the uranium family has been re-established. The half-life of ionium is 82,000 years. Equilibrium is practically re-established in six half-lifes, or roughly 500,000 years. This whole process can be followed by measuring only the radium content. In practice, the decrease in radium becomes so small beyond 450,000 years as to render the method very inaccurate.

In analyzing the data, such as are plotted in Fig. 1, to obtain the age of the sediment at any specific depth it is necessary to know the original ionium and uranium content. These contents can be obtained from the peak value and from the constant radium content in the bottom of the core if the sediment at the bottom is considerably older than 500,000 years, as in core N-2. Many cores, a number of which are much longer than core N-2, were deposited very much more rapidly than this red clay; they show no constant radium content in their lower reaches, but fortunately an accurate knowledge of the uranium content is unnecessary for the first 300,000 years. The uranium content can be measured independently if necessary (14). A general mathematical treatment of the variation of radium concentration with time in a system of radioelements originally present in any haphazard mixture has been published previously (15).

This method has been employed to date a variety of events, such as changes in the lithology and foraminiferal fauna, which have been observed to occur, often repeatedly, in a number of cores from both hemispheres. Such dates seem to constitute the only reliable basis for correlation of these events from place to place. The method will probably find its greatest usefulness in establishing this basis. Nevertheless, it is of value to inquire into the rates of deposition that can be calculated from the dating.

DISTORTION

In securing a core of unconsolidated sediment with a coring tube (3), the sediment is nearly always distorted; that is, the length of the core is less than the depth of sediment penetrated. Because of the thinning of any layer of sediment in the "bulb of compression" established below the bottom of the coring tube, the thickness of the new layers that are forced into the tube as it penetrates deeper into the sediments becomes an increasingly smaller fraction of the *original* thickness of the layers.

The amount of such distortion is not easy to determine, because it depends on a variety of factors such as the type of sediment, the water content, the diameter of the tube, and the velocity of penetration. In order to measure the degree of distortion, it is necessary to core a sediment exhibiting a series of distinctive boundaries which must be measurable in both the core sample and the original undisturbed sediment. Vertical sections of original undisturbed ocean sediments are naturally not readily accessible. Simulated sediments of similar constituency, prepared in tanks, might be used.

Piggot (7) made use of the varved clays of New England to determine the amount of distortion with his gun-coring apparatus (6). A number of the cores studied in the present program of research were secured with this apparatus. It seems correct to assume, for several reasons, that the distortion in coring the varved clay is somewhat greater than would be expected in coring many deep-sea sediments. Hence, application of Piggot's data possibly overcorrects the errors of distortion and thus givès the upper limit for the rates of deposition. With no allowance for distortion, one must obtain the lower limit for the rates. From the data obtained by Piggot, it appears that the distortion at a given depth is a nonlinear function of the fraction of the total core length. It can be seen from Fig. 2 that the effect of distortion is negligible, with respect to the errors in the other determinations, for the upper six-tenths of the total core length. In several cores, the present method of determining the rates of deposition is inapplicable in the lower four-tenths of the core length, because the

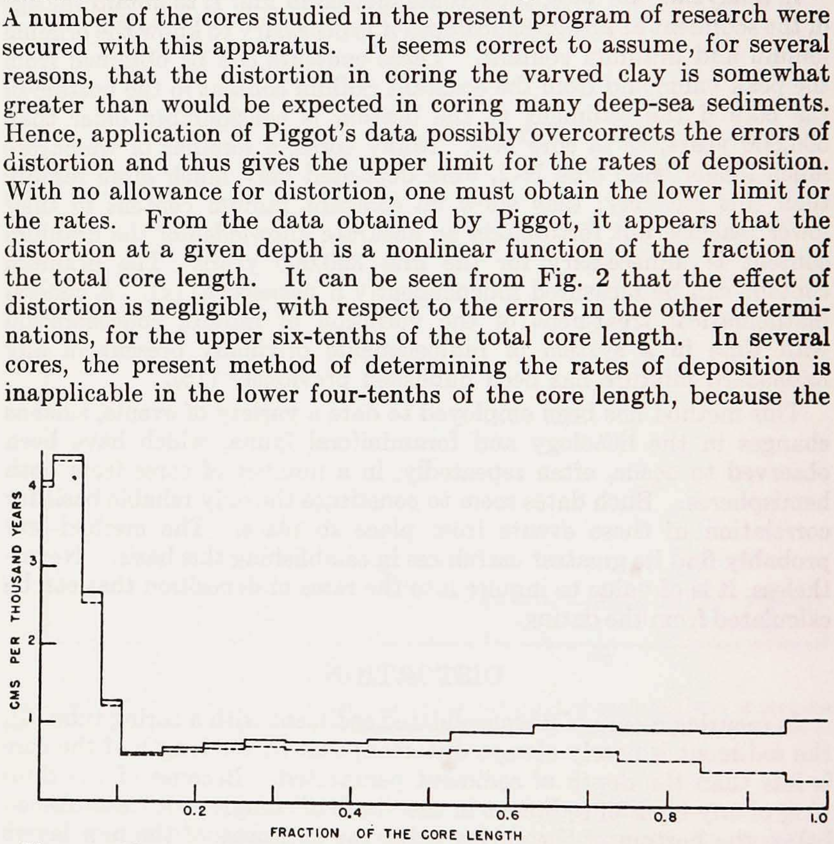

Figure 2. The rate of deposition of globigerina ooze in cm per 1,000 years as a function of the fraction of the core length, illustrating that the error involved in neglecting the distortion becomes appreciable below a depth of 0.6 of the core length. Solid lines—calculated with Piggot's distortion factors. Broken lines—neglecting distortion.

time exceeds 450,000 years; consequently, for such cores the amount of distortion is only in question as far as extrapolation to determine the total time of deposition of the whole core is concerned.

In calculating the following results, Piggot's factors to correct for distortion have been employed except where otherwise stated.

SOURCE AND LOCATION OF MATERIAL

Table I contains the data necessary to evaluate the significance of the rates of deposition. N-numbered cores were secured by Dr. J. L. Hough during the 1946–47 Navy Antarctic Expedition. Samples of core P-259 were provided by Dr. Roger Revelle of Scripps Institution of Oceanography. The remaining P-numbered cores were secured by Dr. C. S. Piggot with his core sampler.

TABLE I. Correlative Data for Cores of Ocean Sediments Studied for Rates of Deposition by Variation of the Radium Content

Core No.	*Type*	*Location*			*Depth*	*Core length*	*Total time of deposition*
		(° ′)	(° ′)		(m)	(cm)	(yrs)
N-3	Glacial marine	68 26 S	179 35 W	Antarctic	3280	228	1,130,000
N-4	Glacial marine	69 12 S	179 34 E	Antarctic	3720	260.5	172,000
N-5	Glacial marine	70 17 S	178 23 W	Antarctic	2980	242.5	460,000
N-2	Red clay	32 21 S	105 55 W	S. E. Pacific	3610	138	1,230,000
P-259	Red clay	30 41 N	121 46 W	N. E. Pacific	4080	246.5	1,080,000
N-1	Red clay-Glob. ooze	08 56 S	92 05 W	Equatorial Pacific	3920	194	990,000
P-135	Globig. ooze	19 18 N	76 48 W	Caribbean	4900	110	21,500
P-136	Globig. ooze	18 38 N	79 12 W	Caribbean	4650	190	111,000
P-137	Globig. ooze	19 14 N	80 20 W	Caribbean	4890	190	301,000
P-126	Foram. marl and	48 38 N	36 01 W	N. Atlantic	4820	282	72,000
P-130	Glacial marine	49 40 N	28 29 W	N. Atlantic	3740	277	24,000
P-124	Calc. blue mud	46 03 N	43 23 W	N. Atlantic	4700	281	12,000

RATES OF DEPOSITION

The rates of deposition for the past 450,000 years are shown in Figs. 3 and 4. Few general conclusions can be reached from the study of such a small number of cores. Red clay from the North and South Pacific and glacial marine deposits of the Antarctic Ocean show (Fig. 3) no immediately apparent change in the rate of deposition at the time of the last interglacial stage in the northern hemisphere. The rate of deposition was generally low at the time of the last glacial stage in the northern hemisphere. The only notable changes in the rates of deposition during the past 450,000 years appear to have occurred at the time of the middle interglacial stage, the Yarmouth of North America or the Mindel-Riss of Europe. During this middle interglacial stage some of the cores show an increased rate of deposition, occasionally almost as rapid as that at present.

Rates of deposition and their variation with the climatological conditions must be controlled by complex factors, often opposing in their effects. These factors have decided local characteristics, as is evident from the high rates in cores P-124 and P-130. These high rates, as previously discussed (10) and given here in Table II, are undoubtedly due to the locations of the sediments at the foot of the Continental Shelf off Newfoundland and at the foot of the east wall of the Faraday Hills of the mid-Atlantic Ridge. The high rate of deposition of the glacial marine sediment at the site of core N-4 at one end of a trough south of Scott Island Bank, compared with the rates at adjacent sites N-3 and N-5, is possibly due to a similar condition.

Deposition of globigerina ooze in the Caribbean Sea was also slowest during the last glacial stage in the northern hemisphere, as shown in Fig. 4 (cores P-135, 136, 137). There appears to be some evidence that the increase to the present high rates of deposition of globigerina ooze was delayed by several thousand years as compared with the red clay of the Pacific and with the glacial marine deposits of the Antarctic. In fact, there was little or no increase in the rate of deposition of globigerina ooze in the Caribbean Sea until the beginning of the climatic optimum of postglacial time about 7,000 years ago. This delay had been noted previously in the foraminiferal marls of the North Atlantic (10) and is attributed to the fact that considerable time is necessary to re-establish the abundance of organic life following a prolonged period of cold surface waters.

An interesting phenomenon is observed in cores P-135 and P-136 from the Caribbean Sea. At the site of both of these cores there was comparatively instantaneous deposition of 70 to 80 cm of sediment, as shown in Fig. 4; and in each case, this rapidly-deposited globigerina ooze was characterized by a 2 cm thick zone of practically pure, uncemented foraminiferal shells at a depth of about 66 cm in both cores. Instantaneous deposition of any such depth as 70 to 80 cm of sediment is immediately apparent from the curves of radium content. Thus, the typical curve of Fig. 1 will be sharply broken, with the lower portion displaced to greater depths, the two parts being joined by a horizontal straight line (9). The break occurs at 21,500 years in core P-135 and at 21,000 years in core P-136, which is close enough to be considered contemporaneous. In view of the probable error of the

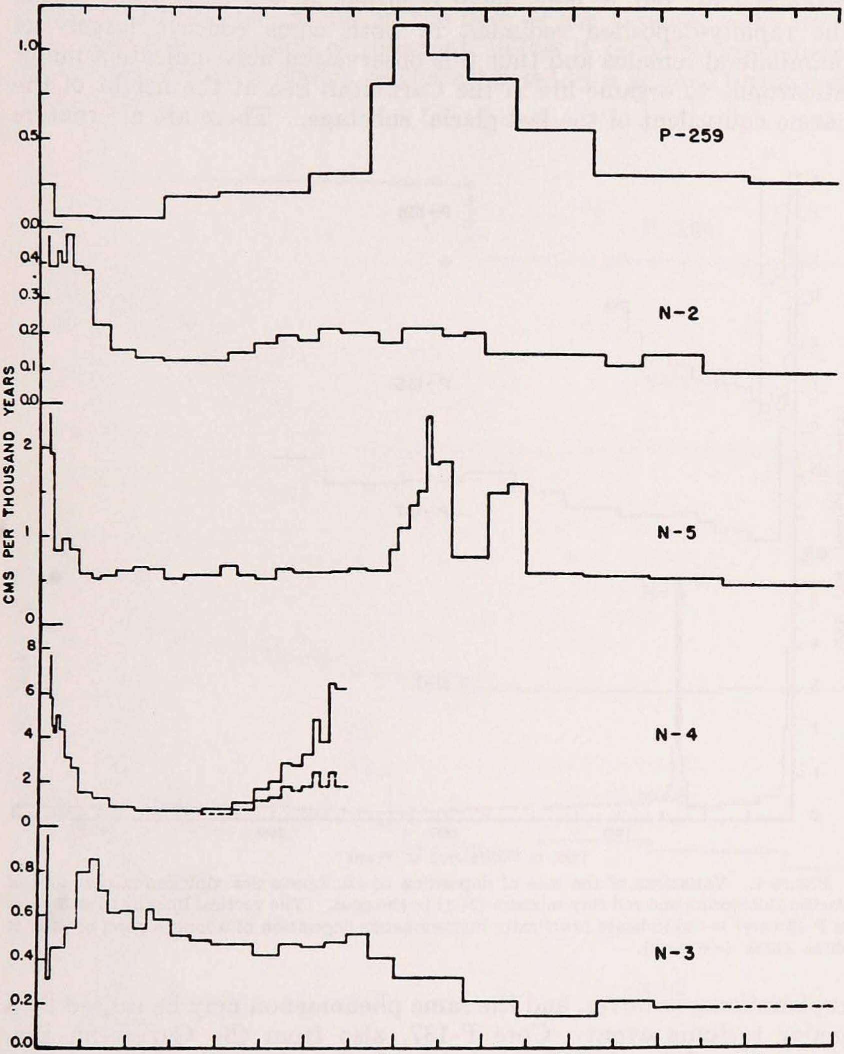

Figure 3. Variations of the rate of deposition of Pacific red clay and Antarctic glacial marine sediments in the past. Red clay—P-259 and N-2. Glacial marine sediments—N-3, N-4 and N-5. N-4—broken lines—no correction for distortion; the distortion factors very probably overcorrect the rate of deposition at the bottom of this core.

measurements, it cannot be stated that the deposition was truly instantaneous, but it must have occurred in less than 1,000 years. The rapidly-deposited sediment in both cores consists largely of foraminiferal remains and thus this observation may indicate a major catastrophe to organic life in the Caribbean Sea at the height of the marine equivalent of the last glacial substage. There are alternative explanations, however, and the same phenomenon may be caused by a major tectonic event. Core P-137, also from the Caribbean Sea, shows no such break in the deposition. Core P-136 was secured from the center of an extensive plateau forming the bottom of the Cayman Trough south of the Bartlett Deep. Core P-135 was secured from the same plateau at the eastern end of the Cayman Trough just south of the Oriente Deep. Core P-137 was obtained at 4,890 meters from the steep slope of the Bartlett Deep between Little Cayman Island and the

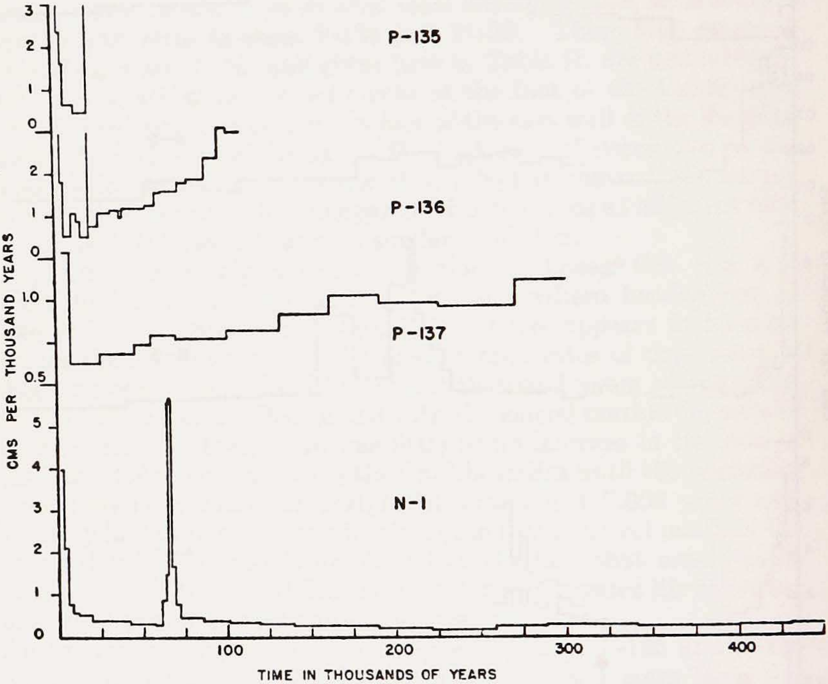

Figure 4. Variations of the rate of deposition of Caribbean Sea globigerina ooze and of Pacific globigerina and red clay mixture (N-1) in the past. The vertical lines at 21,000 years in P-135 and P-136 indicate practically instantaneous deposition of a long section of each of these cores (see text).

bottom of the Deep at 7,000 meters. However, there is no evidence in core P-137 that the steep walls of the Trough exhibit the counterpart of instantaneous deposition on the floor of the Trough. The loss of any appreciable section of sediment, unless it occurred immediately following deposition, should be characterized by a vertical break in the curve of Fig. 1.

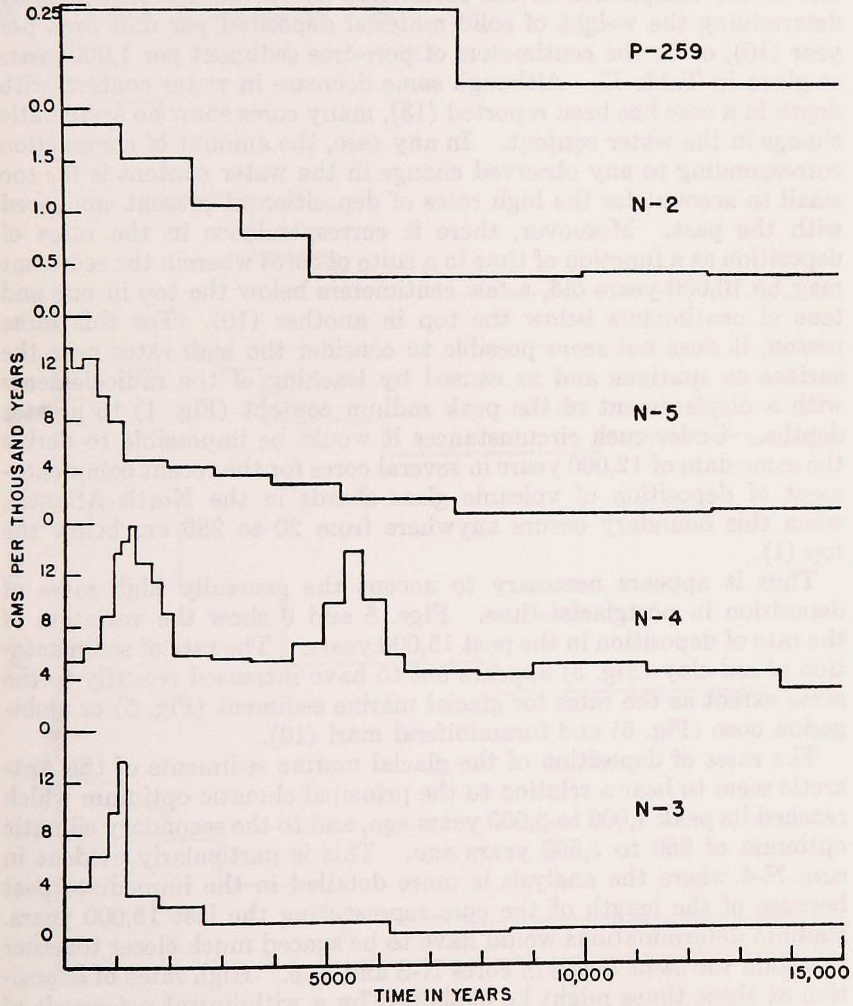

Figure 5. Showing the detail of Fig. 3 for the past 15,000 years.

An unpublished study of the temporal correlation of the relative abundance of the foraminiferal types in these three cores, as determined by Cushman (2), verifies the extraneous nature of the rapidly-deposited sediment on the plateau of the Trough, in the stratigraphic column.

An outstanding feature of the deposition of nearly all deep-sea sediments is the high rate in postglacial time, particularly since the beginning of the first climatic optimum about 7,000 years ago. This is not due to the compaction of the sediments, as can be demonstrated by determining the weight of solid material deposited per unit area per year (10), or by the centimeters of pore-free sediment per 1,000 years as given in Table II. Although some decrease in water content with depth in a core has been reported (13), many cores show no systematic change in the water content. In any case, the amount of compaction corresponding to any observed change in the water content is far too small to account for the high rates of deposition at present compared with the past. Moreover, there is correspondence in the rates of deposition as a function of time in a suite of cores wherein the sediment may be 10,000 years old, a few centimeters below the top in one and tens of centimeters below the top in another (10). For this same reason, it does not seem possible to consider the high rates near the surface as spurious and as caused by leaching of the radioelements with a displacement of the peak radium content (Fig. 1) to greater depths. Under such circumstances it would be impossible to derive the same date of 12,000 years in several cores for the recent commencement of deposition of volcanic glass shards in the North Atlantic, when this boundary occurs anywhere from 20 to 280 cm below the top (1).

Thus it appears necessary to accept the generally high rates of deposition in postglacial time. Figs. 5 and 6 show the variation of the rate of deposition in the past 15,000 years. The rate of sedimentation of red clay (Fig. 5) appears not to have increased recently to the same extent as the rates for glacial marine sediment (Fig. 5) or globigerina ooze (Fig. 6) and foraminiferal marl (10).

The rates of deposition of the glacial marine sediments of the Antarctic seem to bear a relation to the principal climatic optimum which reached its peak 4,000 to 6,000 years ago, and to the secondary climatic optimum of 950 to 1,550 years ago. This is particularly evident in core N-4 where the analysis is more detailed in the immediate past because of the length of the core representing the last 15,000 years. Radium determinations would have to be spaced much closer together to obtain the same detail in cores N-3 and N-5. High rates of deposition at these times might be explained by a withdrawal polewards of the limits of the drift ice. These limits at present are appreciably north of the location of these sediments. Glacial debris should be most abundant near the limits of the drift ice. Extending this hypothesis to glacial stages, it might be supposed that the very low rates of deposition of the glacial marine sediments during these stages are due to a permanently frozen Antarctic Ocean reaching north at least to Scott Island Bank at about Lat. 67° S. During these stages the sediment should be relatively free of glacial pebbles and fragments and there is some evidence from preliminary studies that this was the case at the height of the glacial stages.

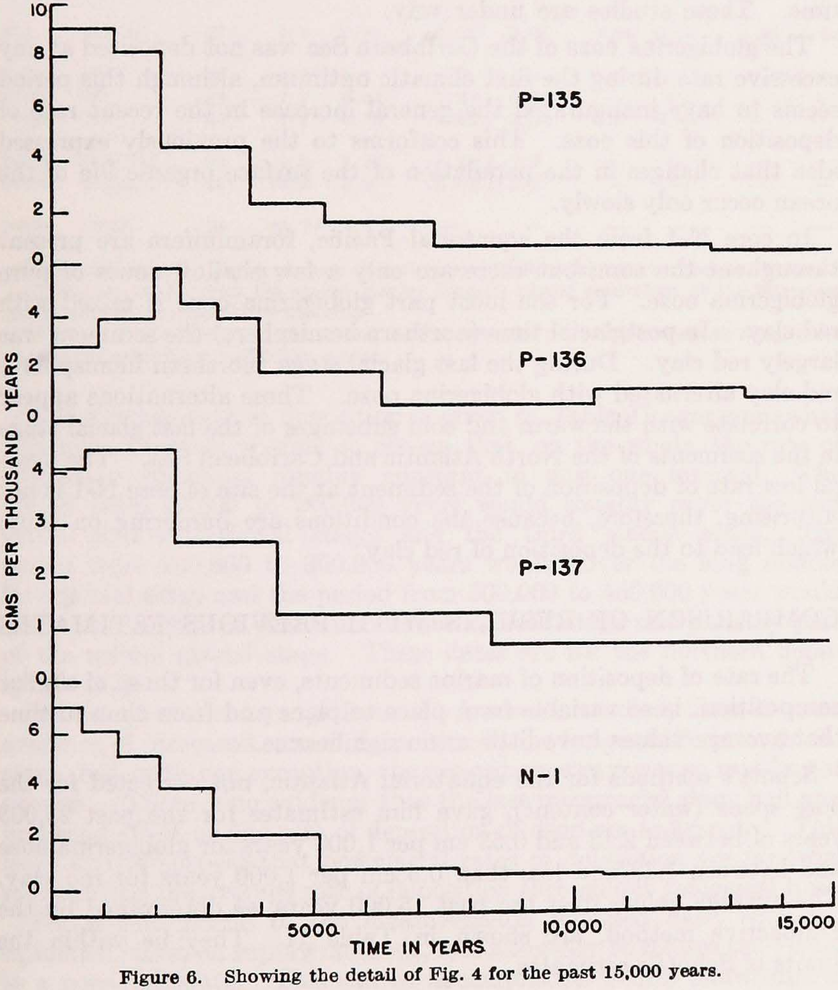

Figure 6. Showing the detail of Fig. 4 for the past 15,000 years.

Such an explanation supposes that climatic changes were roughly contemporaneous over the whole world. It is hoped that the still-unsolved question of simultaneous or alternating climatic changes and glaciations in the two hemispheres can be answered by studies of these cores, but it is certainly not possible to draw any conclusion from the rates of deposition. An answer to this question should be obtainable by studying the lithology and foraminifera of the cores from the southern hemisphere and correlating such studies with those already performed for sediments of the northern hemisphere on the basis of time. These studies are under way.

The globigerina ooze of the Caribbean Sea was not deposited at any excessive rate during the first climatic optimum, although this period seems to have inaugurated the general increase in the recent rate of deposition of this ooze. This conforms to the previously expressed idea that changes in the population of the surface organic life of the ocean occur only slowly.

In core N-1 from the equatorial Pacific, foraminifera are present throughout the core, but there are only a few shallow zones of pure globigerina ooze. For the most part globigerina ooze is mixed with red clay. In postglacial time (northern hemisphere) the sediment was largely red clay. During the last glacial stage (northern hemisphere) red clay alternated with globigerina ooze. These alternations appear to correlate with the warm and cold substages of the last glacial stage in the sediments of the North Atlantic and Caribbean Sea. The overall low rate of deposition of the sediment at the site of core N-1 is not surprising, therefore, because the conditions are bordering on those which lead to the deposition of red clay.

COMPARISON OF RESULTS WITH PREVIOUS ESTIMATES

The rate of deposition of marine sediments, even for those of similar composition, is so variable from place to place and from time to time that average values have little or no significance.

Schott's methods for the equatorial Atlantic, not corrected for the pore space (water content), gave him estimates for the past 20,000 years of between 2.13 and 0.53 cm per 1,000 years for globigerina ooze and between 1.33 and less than 0.5 cm per 1,000 years for red clay. The average values over the past 15,000 years, as determined by the radioactive method, are shown in Table II. They lie within the limits of Schott's estimates.

TABLE II. AVERAGE RATES OF DEPOSITION OF DEEP-SEA SEDIMENTS IN CM PER 1,000 YEARS FOR THE SEDIMENT IN THE ORIGINAL STATE (COLUMN A) AND FOR THE SEDIMENT IN A PORE-FREE STATE (COLUMN B)

Core No.	*Type*	*Per cent solid by volume**	*Time interval in thousands of years*							
			0 to 15		15 to 200		200 to 300		300 to 450	
			A	B	A	B	A	B	A	B
N-3	GM	30	1.3	0.39	0.50	0.15	0.23	0.07	0.22	0.07
N-4	GM	31	5.9	1.8	1.9†	0.59	—	—	—	—
N-5	GM	33	2.5	0.83	0.61	0.20	1.1	0.36	0.50	0.17
N-2	RC	31	0.68	0.21	0.18	0.06	0.16	0.05	0.12	0.04
P-259	RC	24	0.16	0.04	0.21	0.05	0.81	0.19	0.27	0.06
N-1	RC-GO	17	1.8	0.31	0.38	0.06	0.21	0.04	0.25	0.04
P-135	GO	42	2.5	1.1	—	—	—	—	—	—
P-136	GO	36	1.7	0.61	1.6†	0.58	—	—	—	—
P-137	GO	44	1.7	0.75	0.82	0.36	1.0	0.44	—	—
P-126	FM-GM	33	1.8	0.59	6.7† ‡	2.2	—	—	—	—
P-130	FM-GM	26	15.0	3.9	20.0† ‡	5.2	—	—	—	—
P-124	CBM	25	33.7†	8.4	—	—	—	—	—	—

† The bottom of the core is younger than the upper limit of the time bracket (see Table I).

‡ This interval includes the glacial marine deposits of the equivalent of the Wisconsin glacial substages in the North Atlantic.

* The per cent of solid by volume was determined from the water content by weight and an assumed grain density of 2.6 gr. per cc.

The average rate of deposition is given in Table II over somewhat arbitrary intervals of time so chosen that, on the whole, the rate of deposition remained roughly constant in any one interval. The period from 15,000 to 200,000 years would roughly cover the last glacial and interglacial stages and the third glacial stage. The period from 200,000 to 300,000 years would cover the long middle interglacial stage and the period from 300,000 to 450,000 years would cover the early part of the middle interglacial stage and possibly part of the second glacial stage. These dates are for the northern hemisphere (10).

Insofar as one can judge from the few cores studied, there is some evidence of increased rate of deposition in the long middle interglacial stage, but, with one exception, the deposition was never so rapid as at present. There is no evidence that the last interglacial stage had any profound effect on the rate of deposition of deep-sea sediments. This leads one to suspect that postglacial rates of deposition are far from representing the average rate of deposition throughout geological time.

For a comparison of the measurements reported here, with the estimates based on supply methods, it is necessary to reduce the values to a pore-free state. This can be accomplished with a knowledge of the water content by volume which was determined for each sample. The average per cent of solid material by volume is shown in Table II for each core.

Kuenen (4), from a consideration of the extent of erosion since the Cambrian (500 million years), estimated 0.1 cm per 1,000 years for red clay and 0.2 cm per 1,000 years for globigerina ooze. The values in Table II for the warm periods of the middle interglacial stage and postglacial time give an average of 0.11 cm per 1,000 years for red clay. If the average over geological time is nearer to the mean over the whole of the last half-a-million years, a figure of 0.07 cm per 1,000 years would be more appropriate. Kuenen's estimate for globigerina ooze appears to be low on the basis of the present measurements in the Caribbean Sea, but this is hardly a fair comparison. However, it is definitely low for the foraminiferal marl of the North Atlantic (P-126).

Other estimates based on the supply methods are compared with Kuenen's values in *The Oceans* (13) and need not be discussed here.

SUMMARY

A study of the variation of the radium content during the period of re-establishment of radioactive equilibrium in the buried deposits of deep-sea sediments provides a method of dating the record of past events in the ocean bottom. The results of such studies can be readily applied to determinations of the rate of deposition provided that a knowledge of the distortion in securing core samples of the deep-sea sediments is available.

Application of the method of discerning rates of deposition is not limited, as was the application of earlier methods, to sediments deposited during postglacial time; it is possible to study the variation of the rate of deposition in the past as far back as the method of dating is applicable, *i. e.*, for about half a million years. Rates of deposition as a function of time are reported here for red clay, globigerina ooze, foraminiferal marl, glacial marine deposit, and calcareous blue mud, from the Antarctic Ocean to the North Atlantic.

Outstanding features of these determinations are as follows: Deposition of practically all of the sediments is more rapid at present than during the past half million years. The repeated climatological changes of the ice age did not have a particularly noticeable effect on the rate of deposition in general. Only during the long middle interglacial stage did the rates tend to be somewhat higher than the low rates generally prevailing in the past half million years. The lowest rates of deposition are associated with the last glacial stage and the early period of the middle interglacial stage or possibly the end of the second glacial stage. Locally, there are often interesting short-period changes in the rate of deposition which appear to be caused by climatological changes.

However, the amount of detail in an analysis of the rates of deposition varies greatly: in cores of equal length, far more detail can be obtained in one where the sediment was deposited in 100,000 years than in one where the sediment required a million years for deposition.

Average rates of deposition, insofar as they are comparable, are in good agreement with previous estimates by the *stratigraphic* and *supply* methods.

REFERENCES

1. Bradley, W. H., *et al.*
   1940. Geology and biology of North Atlantic deep-sea cores. Prof. Pap. U. S. geol. Surv., 196-A: I–XV + 1–50.
2. Cushman, J. A.
   1941. A study of the Foraminifera contained in cores from the Bartlett Deep. Amer. J. Sci., *239:* 128–147.
3. Hough, J. L.
   1939. Bottom-sampling apparatus; In, Recent Marine Sediments, A Symposium. Amer. Ass. Petrol. Geol. (pp. 631–664). 736 pp.
4. Kuenen, Ph. H.
   1941. Geochemical calculations concerning the total mass of sediments in the earth. Amer. J. Sci., *239:* 161–190.
5. Lohmann, H.
   1909. Plankton-Ablagerungen am Boden der Tiefsee. Schr. naturw. Ver. Schl.-Holst., *14:* 399–402.
6. Piggot, C. S.
   1936. Apparatus to secure core samples from the ocean-bottom. Bull. geol. Soc. Amer., *47:* 675–684.
7. 1941. Factors involved in submarine core sampling. Bull. geol. Soc. Amer., *52:* 1513–1523.
8. Piggot, C. S. and W. D. Urry
   1941. Radioactivity of ocean sediments. III. Radioactive relations in ocean water and bottom sediment. Amer. J. Sci., *239:* 81–91.
9. 1942. Radioactivity of ocean sediments. IV. The radium content of sediments of the Cayman Trough. Amer. J. Sci., *240:* 1–12.
10. 1942. Time relations in ocean sediments. Bull. geol. Soc. Amer., *53:* 1187–1210.
11. Revelle, Roger and F. P. Shepard
    1939. Sediments off the California coast; In, Recent Marine Sediments, A Symposium. Amer. Ass. Petrol. Geol. (pp. 245–282). 736 pp.
12. Schott, Wolfgang
    1935. Die Sedimente des äquatorialen Atlantischen Ozeans. B. Die Foraminiferen in dem äquatorialen Teil des Atlantischen Ozeans. Wiss. Ergebn. dtsch. Atlant. Exped. *Meteor,* 1925–27, Bd. 3, Teil 3, Lief. 1B: 43–134.

13. SVERDRUP, H. U., M. W. JOHNSON AND R. H. FLEMING
1942. The Oceans. Prentice Hall, Inc., New York. 1087 pp.

14. URRY, W. D.
1941. The radioactive determination of small amounts of uranium. Amer. J. Sci., *239:* 191–203.

15. 1942. The radio-elements in non-equilibrium systems. Amer. J. Sci., *240:* 426–436.

16. Radioactivity of ocean sediments. VI. Concentrations of the radio-elements in marine sediments of the southern hemisphere. Amer. J. Sci. (In Press.)

17. URRY, W. D. AND C. S. PIGGOT
1942. Radioactivity of ocean sediments. V. Concentrations of the radio-elements and their significance in red clay. Amer. J. Sci., *240:* 93–103.