RADIOACTIVITY OF OCEAN SEDIMENTS. VI. CONCENTRATIONS OF THE RADIO-ELEMENTS IN MARINE SEDIMENTS OF THE SOUTHERN HEMISPHERE

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ABSTRACT. It has been reported in previous publications of this series that the mode of variation of the radium concentration below the ocean bottom affords a method of determining time in ocean sediments. Hitherto, these researches were confined to the northern hemisphere. Similar studies in the southern hemisphere, combined with the necessary geological and biological investigations, should provide an answer to the question of the contemporaneity of glaciation in the northern and southern hemispheres. Measurements of the radium content as a function of depth in the sediment are presented here for ocean-bottom cores secured by the U.S. Navy Antarctic Expedition of 1946-47.

INTRODUCTION

MANY measurements of the radium content of deep-ocean sediments have been reported in previous publications of this series.[1-5] A number of determinations of the radium content of "grab samples" of bottom sediments were given by Piggot.[1] Among these were measurements on samples secured in the southern hemisphere, but until the present investigation was undertaken the variation of the radium content below the surface of the ocean bottom south of the equator had not been studied.

One might inquire why interest should be evinced in comparing the radioactive relations in the deposits of the southern hemisphere with those in the sediments of the northern hemisphere. Variation of the radium content has been studied in detail for a number of cores secured in the northern hemi-

[1] Piggot, C. S., 1933. The Radium Content of Ocean-Bottom Sediments. Am. Jour. Sci., 25, 229.

[2] Piggot, C. S., and Urry, Wm. D., 1939. The Radium Content of an Ocean-Bottom Core. J. Wash. Acad. Sci., 29, 405.

[3] Piggot, C. S., and Urry, Wm. D., 1941. Radioactivity of Ocean Sediments. III. Radioactive Relations in Ocean Water and Bottom Sediments. Am. Jour. Sci., 239, 81.

[4] Piggot, C. S., and Urry, Wm. D., 1942. Radioactivity of Ocean Sediments. IV. The Radium Content of Sediments of the Cayman Trough. Am. Jour. Sci., 240, 1.

[5] Urry, Wm. D., and Piggot, C. S., 1942. Radioactivity of Ocean Sediments. V. Concentrations of the Radioelements and their Significance in Red Clay. Am. Jour. Sci., 240, 93.

sphere;[6] and there is no reason to believe that the overall relations between the members of the uranium-238 series are simply dependent on the latitude and longitude. The present results fully bear out the universal nature of these radioactive relations in all marine sediments with the possible exception of inshore deposits.

Our main interest in studying many core-samples of deep-water sediments from all the oceans arises from the fact that the lack of radioactive equilibrium in the sediments, at the moment that they are deposited, provides a method of measureing time below the ocean floor for the order of the last half-million years.[7]

The concentration of uranium in the material being deposited on the ocean floor is insufficient to support its ionium content, and, therefore, the excess ionium decreases—by 50 per cent of the remainder every 82,000 years. For practical purposes, the excess ionium disappears in 400 to 500 thousand years. Thereafter, the ionium content is constant because the uranium content can be considered inexhaustible for periods of millions of years.

No reliable method is yet available for the rapid measurement of the minute amounts of ionium scattered universally throughout the Earth's crust, but fortunately the readily determined radium suffices to provide the necessary data concerning its parent ionium. With one exception[5] (which in the light of recent results may not actually be an exception), the material depositing on the ocean floor contains less radium than the ionium can support. Consequently, the following general picture for the variation of the radium content with time, and therefore, with the depth of the buried sediment, is obtained. The radium content increases below the surface rather rapidly, unless the rate of deposition is phenomenally high, until it is in equilibrium with the ionium content. Below the depth representing the time interval necessary to establish this equilibrium the radium content diminishes only so fast as the ionium content decreases. Finally, if the material at the bottom of the core be considerably older than 500,000 years, the curve of radium content against depth should exhibit a

[6] Piggot, C. S., and Urry, Wm. D., 1941. Time Relations in Ocean Sediments. Bull. Geol. Soc. Amer. **53**, 1187.

[7] Urry, Wm. D., 1942. The Radioelements in Non-equilibrium Systems. Am. Jour. Sci., **240**, 426.

flat tail and the constant radium content is then a measure of the uranium content as well as of the ionium content, all the elements in the uranium-238 series being in radioactive equilibrium. This general picture of the variation of the radium content with the depth of the sediment is found to be true, not for a few specific examples, but for all the cores of deep-ocean sediments that have been examined. Shelf deposits remain to be investigated. In a single long core of inshore sediment in the present suite, the radium content remained extremely constant from top to bottom in agreement with the results of Sanderman and Utterback[8] working with very short cores collected in the north Pacific.

All the above phenomena associated with the variation of radium content with time beneath the ocean floor can be given a complete quantitative description with the equations governing the growth and decay of the radioelements.[7] In this manner it is possible to analyze the experimental curve of radium content as a function of depth and to assign a date to the sediment at any desired depth.

In most cores of deep-sea sediments there is a wealth of evidence of the changing geological, geophysical, climatological, and oceanographical conditions of the immediate past. Studies of the lithology and biology of cores of marine sediments have produced a record of the history of these changing conditions and this record appears to be preserved in a more complete and less disturbed state in many ways, than that revealed by studies of the continents.[9] For a satisfactory solution to many of the problems of the history of the immediate past it is essential to establish a basis for correlating the evidence for specific events, such evidence often being uncovered at widely separate localities, in very different types of sediments, and in deposits accumulating at very different rates. An outstanding example of this type of problem is the question of contemporaneity of glaciation in the northern and southern hemispheres. It was with a view to providing an answer to this question in the near future that the present work was undertaken. Obviously, there is only one sound basis for

[8] Sanderman, L. A., and Utterback, C. L., 1941. Radium Content of Ocean Bottom Sediments from the Arctic Ocean, etc. Sears Foundation: J. Mar. Res. 4, 132.

[9] Bradley, W. H., et al., 1940. Geology and Biology of North Atlantic Deep-Sea Cores. U.S.G.S. Prof. Paper 196-A.

the correlation of the evidence; it must be dated with respect to a fixed time, preferably the present.

Presentation of the time-depth analyses of the curves of radium content against depth for these cores from the southern hemisphere would serve no useful purpose here because the results of studies of the lithology, of the foraminifera, and of other properties of these sediments are not yet available. In view of the fact that the accumulation of these necessary data may require appreciable time, it seemed advisable to report here the radioactive measurements that will eventually form the basis for dating these sediments. Furthermore, a knowledge of the concentrations of the radioelements in deep-sea sediments of all the oceans is necessary to understand the relations existing between the radioelements in ocean water and in bottom sediments. These new results will form an important addition to the body of data necessary for a consideration of the principle of dynamic equilibrium in the ocean as applied to the radioelements. Attention was drawn to the complementary nature of the Ra/U ratios in water and sediment some years ago[3]; but the transiency of the radioelements complicates the problem, and little could be accomplished with the data in existence at that time. This problem will be taken up elsewhere following publication of new determinations of the radium and uranium content of river and ocean waters. Studies of this type are of interest because they promise to provide an insight into the operation of such mechanisms as co-precipitation, selective adsorption, and concentration in organic matter.

SOURCE OF THE MATERIAL

Dr. J. L. Hough, formerly of Woods Hole Oceanographic Institution,[10] accompanied the U. S. Navy Antarctic Expedition of 1946-47 on board the U.S.C.G.C. *Northwind*. He was successful in securing ten core samples of the ocean bottom varying in length from six inches to eight and one-half feet. Six of these cores, that is, all of those exceeding five feet in length, were chosen for determination of the radium content. The cores had been sealed and preserved in Lucite liners following withdrawal of the liners from the coring tube. The

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liners were split longitudinally and one-half was sampled at appropriate intervals of depth. Full details concerning the apparatus employed to secure these samples, and the procedures followed in treating the samples, will undoubtedly be described by a competent authority elsewhere.

An ambitious program of many studies was planned for these cores, and, therefore, a minimum amount of material could be spared for any given part of the program. There is a further limitation in the amount of material available because it is highly desirable to work with samples that represent no more than a depth of one cm. in the sediment. The quantities employed for the radioactive measurements varied from as little as 0.3 gram near the top to 2 to 3 grams near the bottom. These amounts proved to be just sufficient to measure the radium content with the required accuracy.

The titles used to describe the sediments in this paper are tentative. They are based on preliminary observations, chiefly of color and texture, and they certainly fail to describe all the less obvious changes in the type of sediment that occur within a given core, particularly in the case of those classed as glacial marine.

The locations of the sediments sampled by these cores are shown on the charts in figure 1.

EXPERIMENTAL

The apparatus and procedure for the determination of minute quantities of radium have been fully described elsewhere.[11] Most specimens of ocean sediments lose radon on standing. The determination involves the measurement of the gaseous radon in equilibrium with radium, and, therefore, in order to insure that all the radon was collected in the ionization chamber the present samples were heated as previously described[11] for 40 to 60 minutes at 550°C in a stream of nitrogen and sealed for at least 30 days prior to measurement. At the time of measurement the gas in the storage tube was collected and added to that derived from fusing the sample. The weight of sample necessary for expressing the result was determined after drying the specimens at 110°C for 24 hours and prior to heating to 550°C. Heating to the

[11] Urry, Wm. D., and Piggot, C. S., 1941. Apparatus for Determination of Small Quantities of Radium. Am. Jour. Sci., 239, 633.

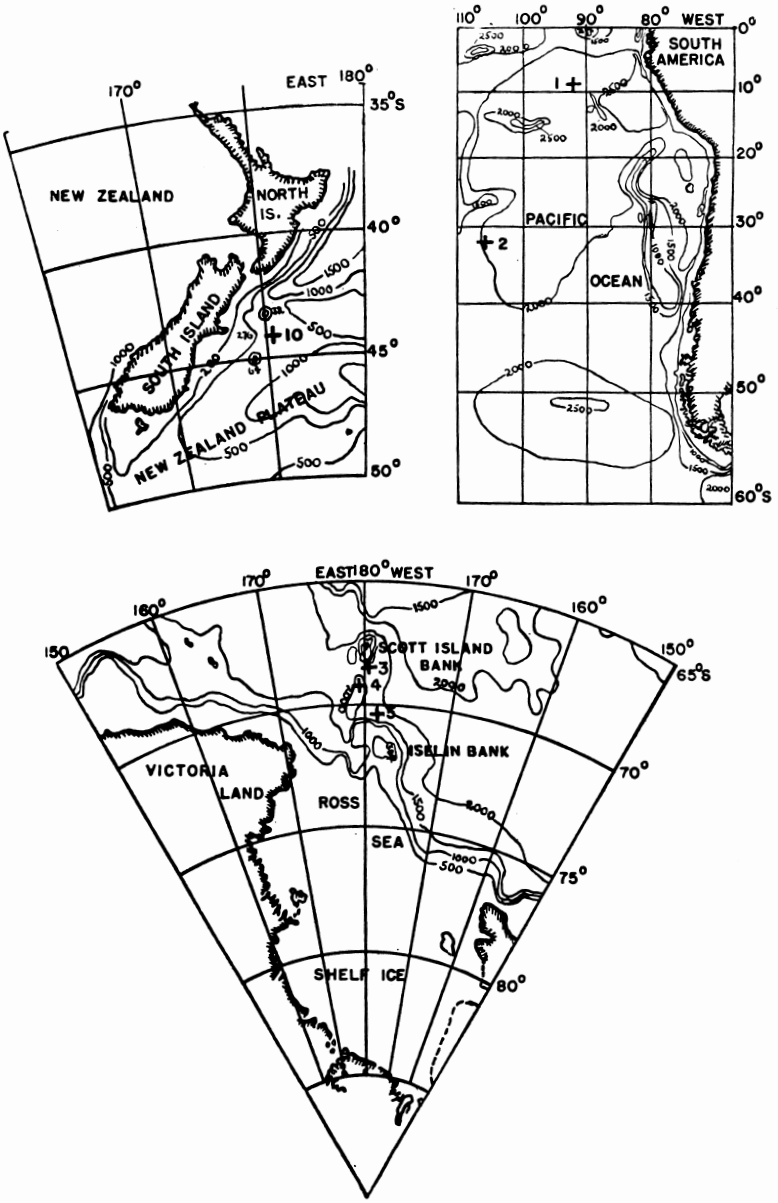

Figure 1. Partial tracings of charts of the U. S. Navy Hydrographic Office showing the location of the sites where core samples of ocean-bottom sediments were secured by the U. S. Navy Antarctic Expedition of 1946-1947. Only those cores studied for radioactivity are indicated. All depths are given in fathoms.

higher temperature avoids certain difficulties otherwise encountered in fusing the sample to liberate the radon.[11]

The root mean square probable error, insofar as the statistical fluctuations of the ion current and errors in measuring the records and setting calibration voltages are concerned, is about 1.5 per cent for most of the determinations. In a few cases where only very small samples were available the probable error was 3 per cent. Periods of observation varied from 5 to 20 hours depending upon the total amount of radium to be measured.

The absolute accuracy of the determinations is another matter. For the determination of time in ocean sediments it is only necessary to know the relative values of the radium content in any given core. However, for other purposes, such as have been indicated above, the absolute values are of interest. Radium solutions containing 10×10^{-12} g. radium, prepared by the National Bureau of Standards, were employed to calibrate the apparatus. From 1941 to 1948 repeated calibrations have always yielded the same calibration constant to within 2 per cent. This, however, affords no complete check on the agreement between various laboratories and various methods, and to provide for such checks the National Bureau of Standards prepared in 1939 a suite of rocks to serve as a means of intercalibration. With the exception of a few inhomogeneous granites, the agreement between the radium determinations at the Massachusetts Institute of Technology, the National Bureau of Standards, and the Geophysical Laboratory was satisfactory and the standard rock samples have been certified to have a given radium content within appropriate limits.[12]

In order to intercheck the apparatus used for the ocean sediments, which measures the total ion current, with another apparatus in use at the Geophysical Laboratory which determines radium by counting alpha particles,[13] one of the suite of rock samples used as standards of radioactivity has been

[11] National Research Council, 1938- . Minutes of the Committee on Standards of Radioactivity. R. D. Evans, Chairman. (The work of this committee is now the responsibility of the Sub-committee on Radiogeology of the N.R.C. Committee on Nuclear Science.)

[12] Davis, G. L., 1947. Radium Content of Ultramafic Igneous Rocks. I. Laboratory Investigation. Am. Jour. Sci., 245, 677.

measured at frequent intervals with the results shown in Table I.

TABLE I

Standard Rock Kimberlite in 10^{-12} g. radium per g.
Measurements of the Radium Content of the

NBS value		0.59 ± .04	some sealed, some not sealed
Geophysical Laboratory			
ion current	1940	0.64 ± .01	sealed
	1942	0.65 .02	sealed
	1947	0.64 .02	not sealed
counting	1941	0.67 ± .01	not sealed
	1941	0.64 .01	not sealed
	1941	0.68 .01	sealed

On the basis of the measurements of the kimberlite, it might appear that determinations by both methods at the Geophysical Laboratory are slightly too high, but this is not the case when one considers the results from the three laboratories for all the standard rocks. The kimberlite has a very convenient radium content but is not to be highly recommended as the most suitable of the standards because of a tendency to spatter in the fusion furnace whether pre-heated or not. Had no allowance been made for the amount of spattered material, the values in Table I would have been in good agreement with the value assigned by the National Bureau of Standards. It can be stated with assurance that the radium contents of the sediments reported here are accurate to 10 per cent on an absolute basis.

In the analysis of the radioactive data for the purpose of finding the time-depth relations, it is important in some cases to express the radium content on a volume basis. This can be done with a knowledge of the original water content. Those samples in which water was to be determined were weighed within thirty minutes after opening a core liner and later heated at 110 to 120°C and re-weighed. It appears from the results in Table II that the ends of the core liner were not always well sealed. However, there was little evidence of shrinkage, indicating appreciable loss of water, except at the ends of one or two cores.

TABLE II

The Radium Content of Ocean-Bottom Cores;
U.S.C.G.C. *Northwind*, U.S. Navy Antarctic Expedition 1946-47.

(Collected by Dr. J. L. Hough)

Core N–1, Lat 08°56′S, Long 92°05′W, 2150 fathoms, alternating red clay and globigerina ooze.

Specimen	Depth from top of the core (cm.)		Water content per cent by weight	Radium content in 10^{-12} g. per g.
		(red clay)		
N-1- 0	0.0 to	0.3	54.1 (65.5)[a]	18.95
N-1-10	2.0	2.5	—	19.81
N-1-11	4.0	4.5	—	22.39
N-1-14	12.0	12.5	—	23.07
N-1- 4	15.0	15.5	65.9	29.11
N-1-18	25.5	26.0	—	29.67
N-1- 5	30.0	30.8	63.9	26.36
N-1- 7	192.7	194.2	71.5	0.53
		(mixture — predominantly red clay)		
N-1- 2	6.0	6.5	57.3	20.38
N-1-13	9.0	9.5	—	20.43
N-1-17	22.0	23.0	—	20.38
		(mixture — about equal amounts of each type)		
N-1-12	6.6	7.2	—	16.90
N-1-15	18.0	18.5	—	15.86
		(Globigerina ooze)		
N-1-16	20.5	21.5	—	7.01
N-1-19	28.0	29.0	—	6.45
N-1- 3	32.5	33.0	64.3	6.18
N-1-21	40.5	41.5	—	4.75
N-1-23	59.0	60.0	—	4.71
N-1-24	80.0	81.0	—	2.85
N-1-25	100.0	102.0	—	1.40
N-1- 6	124.5	125.7	51.6	0.57
N-1-27	166.5	167.5	—	0.61

[a] Value corrected for observed shrinkage arising from loss of water while in storage in the Lucite liner.

TABLE II (Continued)

Core N-2, Lat. 32°21′S, Long. 105°55′W. 1980 fathoms.
Red clay

Specimen	Depth from top of the core (cm.)		Water content per cent by weight	Radium content in 10^{-12} g. per g.
N-2- 0	0.0 to	0.3	45.8	9.08
N-2- 1	2.0	2.5	46.4	11.09
N-2- 2	6.0	6.5	47.0	13.19
N-2- 3	11.8	12.5	47.0	12.33
N-2-11	16.0	16.5	—	11.16
N-2- 4	25.0	26.0	50.1	7.30
N-2-14	50.0	51.0	—	2.35
N-2-16	80.0	81.0	—	0.72
N-2- 5	100.0	101.0	43.4	0.76
N-2- 6	137.3	138.3	41.5	0.69

Core N-3, Lat. 68°26′S, Long. 179°35′W. 1800± fathoms.
Glacial marine

Specimen	Depth from top of the core (cm.)		Water content per cent by weight	Radium content in 10^{-12} g. per g.
N-3- 0	0.0 to	1.0	—	3.62
N-3- 1	2.0	2.5	38.6	3.49
N-3- 2	8.0	8.5	44.7	4.30
N-3-10	15.0	16.0	—	5.68
N-3- 3	24.0	24.5	47.0	5.07
N-3-12	33.0	34.0	—	4.85
N-3- 4	50.0	51.0	48.4	3.92
N-3-15	80.0	81.0	—	2.41
N-3- 5	100.0	101.0	47.0	1.77
N-3-16	125.0	126.0	—	0.97
N-3- 6	169.0	170.0	47.5	0.62
N-3- 7	227.0	228.0	41.6	0.62

Core N-4, Lat. 69°12′S, Long. 179°34′E. 2040 fathoms.
Glacial marine

Specimen	Depth from top of the core (cm.)		Radium content in 10^{-12} g. per g
N-4- 0	0.0 to	0.5	2.62
N-4- 3	10.0	10.5	3.37
N-4- 5	20.0	21.0	3.70
N-4- 6	30.0	31.0	4.08
N-4- 7	49.8	51.0	4.26
N-4- 8	80.0	81.0	2.65
N-4- 9	120.0	121.0	3.46
N-4-10	160.0	161.0	2.21
N-4-12	225.0	226.0	1.64
N-4-13	259.5	260.5	1.53

No measurements of water content were made in this core.

TABLE II (Continued)

Core N-5, Lat. 70°17′S, Long. 178°23′W. 1635 fathoms.
Glacial marine

Specimen	Depth from top of the core (cm.)		Water content per cent by weight	Radium content in 10^{-13} g. per g.
N-5- 0	0.0 to	1.0	32.1	1.70
N-5- 1	4.0	4.7	40.2	1.79
N-5- 2	9.0	9.6	46.8	2.13
N-5- 3	16.0	17.0	44.2	2.67
N-5- 4	25.0	26.1	43.4	3.03
N-5- 5	55.0	56.0	43.4	2.58
N-5-16	105.0	106.1	—	0.95
N-5- 6	130.0	131.0	45.7	1.29
N-5-17	165.0	166.1	—	1.12
N-5- 7	200.0	201.1	36.6	1.01
N-5- 8	241.3	242.5	40.2	0.77

Core N-10, Lat. 44°14′S, Long. 175°15′E. 300 fathoms.
Greenish gray mud

Specimen	Depth from top of the core (cm.)		Water content per cent by weight	Radium content in 10^{-13} g. per g.
N-10-0	0.0 to	1.0	28.9	1.17
N-10-4	50.0	51.0	35.0	1.14
N-10-6	100.0	101.0	32.5	1.18
N-10-7	140.0	141.0	33.3	1.11
N-10-8	175.0	176.0	29.3	1.18

RESULTS

All determinations of the radium content of the cores from the southern hemisphere are to be found in Table II. The variation of the radium content with the depth in each core is shown in figures 2, 3, and 4. The number of determinations necessary to define a curve varies appreciably for several reasons. In general, the samples must be more closely spaced near the top where the radium content is changing most rapidly, but extreme variations in the type of sediment and sudden changes in the rate of deposition will also require a more detailed survey than would otherwise be the case.

With the exception of the inshore deposit (core N-10), the maximum radium content in all deep-sea cores is to be found at some distance below the surface of the ocean bottom. One can gain a general idea of the recent rate of deposition from the depth at which such maxima occur. The time required

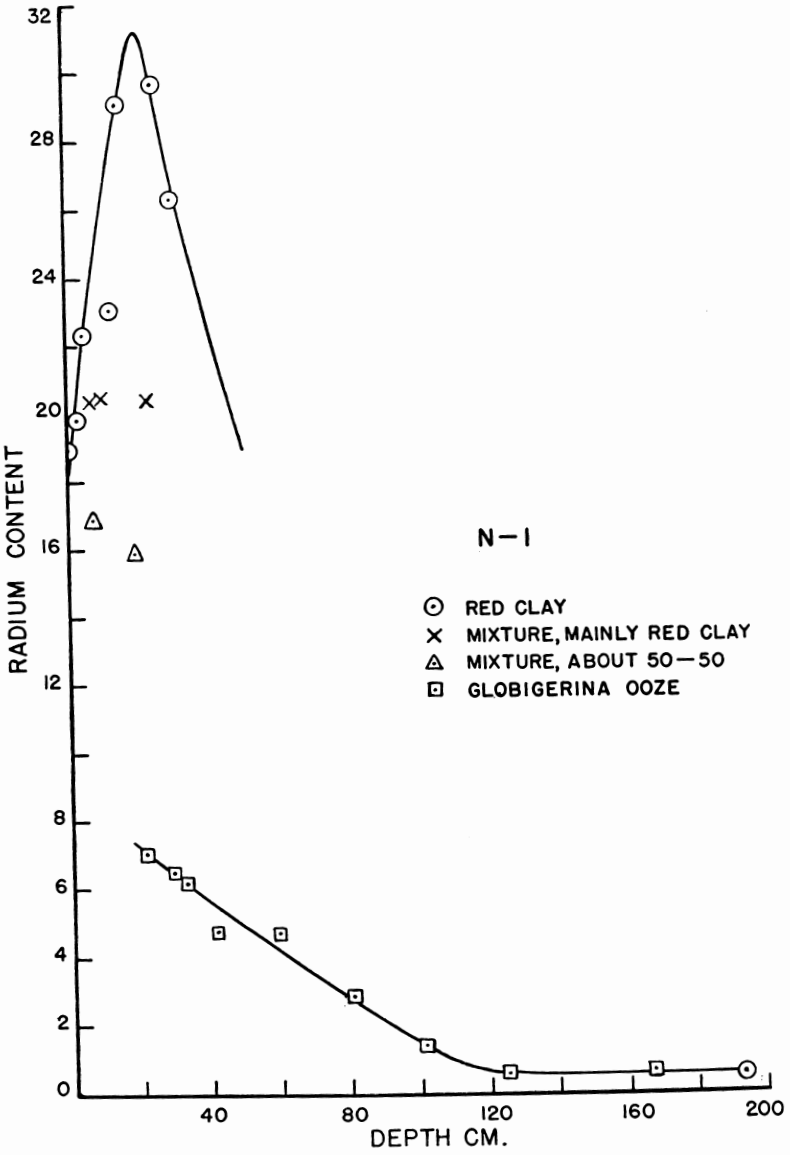

Figure 2. The variation of radium content with depth in a core of alternating red clay and globigerina ooze. The radium content is given in units of 10^{-13} g. radium per g. of sediment dried at 110°C.

to establish the maximum radium content is a function of the initial relation between radium and ionium, but it is not greatly dependent on this parameter and will be between 7000 and 9000 years.[7] A second obvious point on the time scale is where the radium content becomes independent of the depth in the core. This will occur in between 400 and 500 thousand years. Thereafter, this method of dating becomes inapplicable, but reasonable dates can be assigned below such depths if one assumes that the rate of deposition prior to 500 thousand years ago was not greatly different from the rate 400 thousand years ago, and if the distortion in securing the core sample is taken into account.[14]

INDIVIDUAL CORES

Core N-1. (*fig. 2*) Red clay and globigerina ooze have been alternately deposited at this site. It was hoped that two curves could be obtained, one for each type of sediment, and that these curves could be independently analyzed for time. If good agreement resulted, such a procedure would offer strong evidence in support of the basic principles underlying the measurement of time in ocean sediments. Unfortunately, red clay predominates in the top 30 cms., and insufficient globigerina ooze of the required purity is to be found above 20 cms. Below 30 cms., red clay of sufficient purity is unavailable except right at the bottom of the core. Thus, it is only possible to make the desired comparison between the depths of 20 and 30 cms.

It is interesting to note that the radium content, following establishment of complete equilibrium between radium, ionium, and uranium, is independent of the type of sediment. This means that the uranium content, which does not change with time, is the same for both types of sediment in this core and that the striking differences near the top and particularly in the middle are due to very different initial ionium contents.

The maximum recorded radium content in this core occurs at 25.8 cms. (n-1-18). There are very few samples of red clay that show as high a radium content as 29.67×10^{-12} g.

[14] Piggot, C. S., 1941. Factors Involved in Submarine Core Sampling. Bull. Geol. Soc. Amer. 52, 1513.

per g. and there is not one from the "Carnegie" collection of grab samples.[15]

This core sample must be representative of the sediment of more than half of all Pleistocene time at this location.

Core N-2. (fig. 3) This core sample, according to color and texture, is a red clay of very uniform character from top to

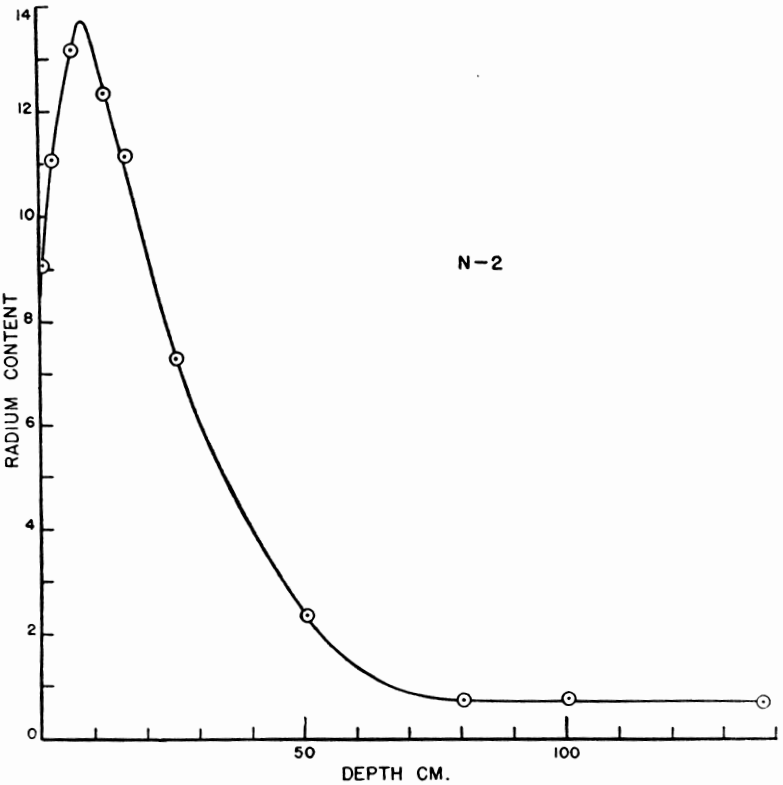

Figure 3. The variation of radium content with depth in a core of red clay. The radium content is given in units of 10^{-12} g. radium per g. of sediment dried at 110°C.

bottom. Consequently, it is to be expected that the variation of the radium content can be expressed by a very smooth

[15] With the aid of figures 2 and 3 it can readily be realized that the radium content of a grab sample has little significance because it depends upon a number of arbitrary factors—the depth of penetration of the grab, and, therefore, the kind of grab employed; whether or not the sample was homogenized; and, if not, the location of the sub-sample for the radium measurement.

curve. This curve exhibits the maximum below the top characteristic of all the other cores. Prior to these determinations, measurements in red clay had been made for only one core of any significant length.[5] The samples for these earlier determinations were undesirably long; and, hence, it was difficult to establish the shape of the curve near the top. For various reasons it was concluded that there was no maximum radium content below the surface; and, thus, the single curve for red clay constituted an exception to the general rule. In view of the curve obtained for the present core of red clay and for the red-clay portion of core N-1 in figure 2, this previous exception may be in doubt.

Core N-2 must be representative of the sediment of most of Pleistocene time.

Cores N-3, N-4, and N-5, (fig. 4) These cores were all secured from the relatively small area lying between Scott Island Bank and Iselin Bank in the Ross Sea, as shown in figure 1. Upon superficial examination they all look quite similar, but at certain depths the sediment is completely free of pebbles and small angular fragments and at other depths such glacial marine debris is abundant. The sediments of all three are tentatively classified as glacial marine. Bearing in mind the two particularly significant positions on the time scale—the maximum value of the radium content and the position where the radium content reaches an essentially constant value—a glance at figure 4 shows that the rate of deposition of the sediment was very different at the site of each one of these cores. It would be interesting to look for the reason for this behavior in continuous ocean-bottom profiles of the area if these were available. The sediment is deposited most rapidly at the site of core N-4 in a small trough south of Scott Island Bank. Events that are characteristic of a given time should have left their records at very different depths in these three cores.

A pronounced dip in the curve is noticeable at the bottom of core N-5. This is to be expected[3] in all cases where the sediment at the bottom is less than 400 thousand years old because of the distortion occurring when the sediment is cored.[14] The distortion causes a shortening of the core sample compared to the original sediment, the amount of the short-

ening being negligible near the top but increasing rapidly near the bottom. A similar effect is present in the curve for core N-4, but it is less noticeable in this region of the curve. Naturally, no such dip is to be seen when the constant equilibrium value of the radium content is attained at some distance above the bottom of a core. The distortion will have no influence on the dating of a specific event, but it is a factor of no slight significance when rates of deposition are to be determined.[6]

One point for each of the cores N-4 and N-5 lies considerably below the curve. Insofar as was possible, pebbles and fragments of rock were removed from the sample whenever they were found in the course of reducing the sample to powder. Such material was considered foreign to the sediment carrying the pertinent radium but some coarse detrital material may have escaped detection. Since such material is almost certainly of much lower radium content than that indicated by the curve, particularly if basic in character, the discrepancy is in the right direction.

Core N-10. (*fig. 4*) As shown in figure 1 this core was secured from the New Zealand plateau in 300 fathoms of water. There is no consistent trend in the radium content, in fact the radium content is most remarkably uniform. It is very doubtful that five samples spaced in like manner over 176 cms. in any non-marine formation would exhibit such a constant radium content.

One might assume that the rate of deposition on the shelf off New Zealand is extremely rapid. The expected increase in radium content might then be hidden in the errors of the measurements, but the age of the sediment at the bottom of core N-10 could hardly exceed 500 years if we employ the greatest spread in the results given in Table II. With due consideration for the distortion in the core sample this would imply a rate of deposition of at least 5 meters per thousand years.

It appears more likely that the sediments of the continental shelf consist largely of detrital material and that the operation of the mechanism that destroys the state of equilibrium between radium and ionium in deep-sea deposition is con-

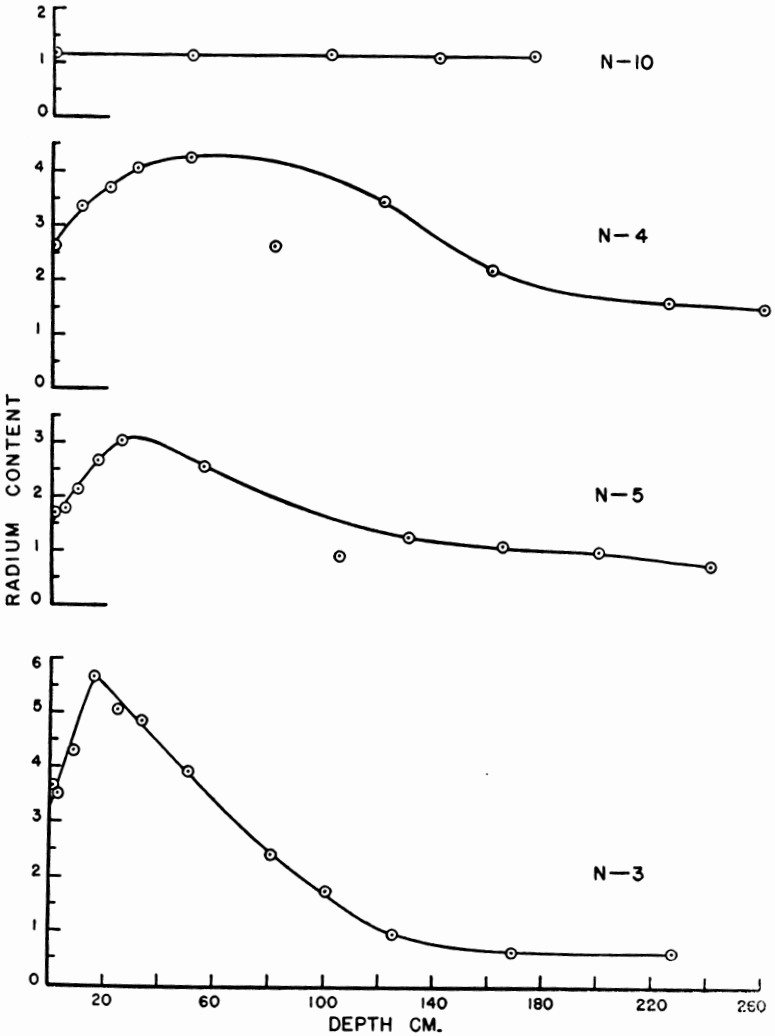

Figure 4. N-3, N-4, N-5 — The variation of radium content with depth in cores of glacial marine deposits of the Ross Sea, arranged in order of increasing rapidity of deposition reading upwards. N-10 — The variation of radium content with depth in a core of greenish gray mud from the New Zealand Plateau. The radium content is given in units of 10^{-12} g. radium per g. of sediment dried at 110°C.

fined to the deep-ocean basins.[16] If this is true, we are deprived of our method of measuring time on the continental shelf, but on the other hand we have a valuable clue to the nature of the mechanism by which the radioactive equilibrium is disturbed in that it requires deep water and the presence of only minor amounts of detrital material for its operation. From this, it follows that the deep-ocean sediments consist almost entirely of chemical and biochemical products. Such a conclusion seems obvious with respect to the calcium carbonate portion of a globigerina ooze, or to the silica of the diatoms or radialaria in these types of ooze; but there has been difference of opinion as to the formation of deep-sea clays devoid of organic skeletons, and as to the nature of the material that binds the organic skeletons together in those oozes consisting largely of organic remains.

ANALYSIS OF RESULTS

The purpose of this investigation was threefold.

Firstly, the results are being analyzed to determine the dates of important events in the Earth's recent history in the southern hemisphere. These events should be indicated by studies, now in progress, of the lithology and of the foraminifera of these cores. It is hoped that at least a tentative answer to the question of contemporaneous glaciation in the two hemispheres can be given by comparing this history with that derived from an earlier and similar co-operative endeavor on cores from the northern hemisphere.

Secondly, the rates of deposition of the sediments at the location of the cores from the southern hemisphere are in the course of evaluation both with respect to the type of sediment and to time in the past.

Thirdly, another analysis of the data is in progress which will add to the available information on the relations between the radioactive elements present in sea water and in ocean bottom sediments. A study of the initial concentrations of the radioelements in the surface of ocean sediments at the location of fourteen cores, including those described here, has revealed

[16] It is not possible to state that the mechanism causing a deficiency of uranium with respect to radium and ionium is also inoperative on the shelf. In order to demonstrate this it would be necessary to examine a very much greater depth of shelf-sediment than is represented by core N-10.

interesting correlations between the concentrations of the radioelements, the rate of their deposition, as distinct from the rate of deposition of the sediment itself, and the fineness of the sediment.

SUMMARY

Seventy determinations of the radium content of ocean sediments are reported here for a number of depths in each of six cores secured from the southern hemisphere. Curves of the radium content as a function of depth below the ocean bottom are similar in all qualitative respects to the curves previously obtained for cores from the North Atlantic and Caribbean Sea.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the cooperation of the Hydrographic Office of the U.S. Navy in placing the necessary material at the author's disposal through the good offices of Dr. R. H. Fleming. Dr. J. L. Hough contributed greatly to the success of the investigation, primarily in securing the core samples with the aid of his shipmates on the U.S.C.G.C. *Northwind*, and later by collaborating with the author in sampling the cores and assembling the necessary correlative data. The author herewith expresses his sincere thanks to Dr. Hough.

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