SVENSKA GEOFYSISKA FÖRENINGEN

VOLUME 1, NUMBER 1 **Tellus** FEBRUARY 1949

A QUARTERLY JOURNAL OF GEOPHYSICS

The Geochronology of the Deep Ocean Bed

By HANS PETTERSSON, Oceanographic Institute, Gothenburg

(Manuscript received 2 Dec. 1948).

Abstract

In this article different lines of approach to a geochronology of the deep ocean bed, as revealed by sediment cores, are indicated.

One of the most difficult problems met with in the stratigraphy of the deep ocean bed is that of dating the different strata, i.e. the chronological problem. For continental rocks radioactive age-determinations from the ratio lead or/and helium to uranium or/and thorium have afforded the means of establishing an absolute chronology spanning over $2 \cdot 10^9$ years or more[1]; but the disintegration of the two immensely longlived parent elements is far too slow to be of any use in dealing with deep ocean sediments. Moreover, in deep sea deposits the content of uranium, and in still higher degree the content of thorium, are extremely small and the mechanical structure of these deposits is altogether unsuitable for either helium- or lead-determinations.

Fortunately there are other, more short-lived elements in the uranium series which lend themselves to age determinations. In order to explain the surprising scarcity of radium in sea water compared to its content of uranium [1] the author in 1936 [2] suggested that a precipitation occurs in sea water of its immediate parent element, ionium, together with ferric hydroxides, carrying down the ionium produced from dissolved uranium, or at least a considerable part of it, to the bottom sediment where it subsequently gives birth to radium. This process would, incidentally, also explain the remarkably high content of radium in certain abyssal sediments, especially in the Red Clay and the Radiolarian Ooze, discovered already by JOHN JOLY [3]. Radium determinations in some relatively long cores taken by the explosive core sampler of C. PIGGOT and published by PIGGOT and URRY [4] proved that there occurs a decrease in radium with "depth" below the sediment surface. Apart from the very uppermost 20 to 30 cms of the core, where an increase of ionium-supported (and possibly also a decrease in the excess of non-supported) radium complicates the trend, the curves published by the two authors show a pronounced exponential decline in radi-

[1] Other methods of age determinations, using rubidium or the ratio between lead isotopes etc., have not yet come into extensive use.

um content with "depth" i.e. with time. The rate of decrease, if ascribed to unsupported radium, is much too slow to be compatible with reasonable values for the rate of sedimentation, but if ionium is accepted as the dominant substance the figures become acceptable and afford plausible values for the rate of sedimentation [5]. This method gives promise of becoming useful for deep-sea sediments of a fairly high radium content, except in localities where an admixture of grains of active minerals with uranium-supported radium, say of volcanic origin, may give rise to errors [6]. Unfortunately, even under favourable circumstances, with sediments where the rate of sedimentation and of ionium precipitation have remained constant or at least in constant relation over a sufficiently long span of time, the method can hardly be used over more than 3 or 4 half-periods of ionium, i.e. 250 000 to 330 000 years, owing to the low residual content of radium after this time; 6 to 12 percent of the maximum value near the surface.

Another radioactive disintegration process which in certain cases may afford chronological evidence is that of radium itself, where this element has happened to become separated from its parent element ionium. This seems to be the case in the manganese concretions, owing to the pronounced affinity between radium and manganese. Working on manganese nodules from the central and the eastern Pacific, obtained from the Challenger and the Albatross collections, the author, from the rapid decrease in radium with "depth" beneath the nodule surface has found it possible to obtain values for the mean rate of radial growth averaging about 1 mm in 1 000 years [5]. It will be interesting to compare these values found from Pacific nodules with those for nodules obtained to the south east of Bermuda during the Swedish deep-sea expedition.

If we compare the very slow disintegration of uranium and of thorium to the hour hand of the radioactive clock, we may say that the ionium decay, as used with deep sea deposits, represents the minute hand, and that of the radium built into the manganese concretions the second hand.

Within the limitations, set out above, radioactive age-determinations from ionium-supported and unsupported radium in deposits and concretions may become useful in the establishment of a chronology of the latter half of Quaternary Age. In his dissertation on the utilization of the volcanic ash layers in Iceland as means of dating ancient sites, S. THORARINSSON has coined the term tephrochronological for the geochronological use of volcanic ash layers [7]. In a review of THORARINSSON's thesis the present author pointed out the use which submarine geology might derive from this means of investigation, which had, in fact, already been employed by Miss NEEB in her very able work on the sediments from the Sunda Seas raised by the Snellius expedition [8].

During the experimental cruise to the western Mediterranean with the "Skagerak" in 1946 our expectations of finding in the sediment cores, layers of volcanic ash were amply fullfilled. In a preliminary study [6] of three cores taken from the Tyrrhenian Sea I have attempted to correlate some of the uppermost ash layers with historic eruptions of Mount Vesuvius and of its predecessor Monte Somma. A mineralogical study of samples from the same cores made by MELLIS [6], although not directly confirming the attempted dating, did not contradict it. Future work on these and other cores, some of which were taken during the recent Swedish Deep Sea expedition in the same locality, will confirm or refute this attempted dating. There is little doubt, however, that such a closer study, comprising also cores taken near the N African coast from the "Skagerak", and in the eastern Mediterranean from the "Albatross", will afford a unique register of the volcanic eruptions of the explosive, ash-producing type in the Mediterranean and possibly lead to results also of archeological interest as regards the last thirty to forty centuries. Already a cursory examination of the 1946 cores indicate a much greater volcanic activity below the — 6 meter level in the cores than in their upper parts. If it proves possible to correlate the ash layers from different cores taken in the same region, isochronic surfaces within the sediment may be constructed, leading to a relative chronology of the region considered.

In the open oceans such ash layers are relatively rare. Nevertheless in a number of long cores raised by means of the PIGGOT core sampler from the N Atlantic Ocean in 1936, American geologists have found two distinct layers containing volcanic ash which were recognisable from one core to another [9]. When the large material of deep sea cores brought back by the Swedish Deep Sea expedition have been subjected to a mineralogical analysis much more will be known about the role of volcanic ash layers and the chances they may offer of a relative chronology of the different strata from a region surrounding volcanic islands.

At present the most promising way of arriving at chronological results in deep-sea stratigraphy seems to be that of biological analysis, notably on the composition of the foraminiferal tests or shells in different levels of cores from calcareous ooze, especially, of course, the so called Globigerina Ooze. Already nearly forty years ago E. PHILIPPI, from his investigation of the biological components in bottom samples raised by the German South Polar Expedition 1901—03, pointed out that faunal changes have occurred affecting the composition of the bottom sediments [10]. In 1911 G. BRAUN [11] called attention to the opportunities afforded by the change in the composition of the sediments at a certain level below the surface, indicating the commencement of post-glacial time. Later authors have worked up the samples taken from different levels in deep-sea cores with regard to the relative composition of the foraminiferal shells of more or less thermophile species, as indicators of climatic changes. In this manner W. SCHOTT, working on cores raised by the "Meteor" from the equatorial Atlantic was able to fix the level corresponding to the end of the last glaciation, assumed to have occurred 20 000 years ago, and in this way estimate the rate of sedimentation in post-glacial time [12]. The same method was also applied by CUSHMAN and HENBEST [9] to the Northatlantic samples mentioned previously and by WISEMEN to cores raised from the Indian Ocean.

On my invitation Dr F. PHLEGER undertook to analyze a limited number of samples from three cores from the Tyrrhenian Sea with respect to their foraminifera. He found very pronounced variations with "depth" which he attributes to two cold and one warm period in the Mediterranean surface [13]. Dr PHLEGER, who accompanied the "Albatross" on her cruise between Martinique and Christo-

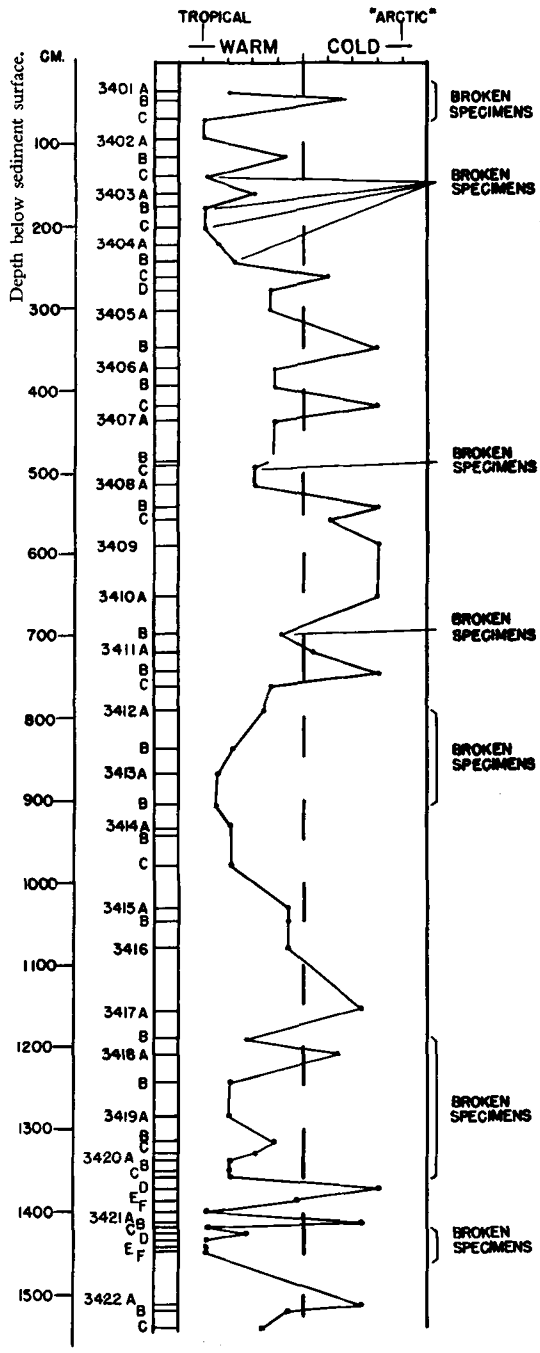

Fig. 1. Approximate relative water temperatures indicated by the faunas of Foraminifera from Core 34 taken at ALBATROSS Station 30.

bal in August 1947, sampled a long core taken in calcareous ooze near the centre of the Caribbean Sea, from a depth of 4 900 metres. The diagram in fig. 1 is reproduced from his paper, which has just been published [14], and displays an intricate pattern of changes from cold to warm and back, affecting the plankton community in the surface waters of that region during a past which may well extend back beyond the antepenultimate glaciation. An analysis of a second core taken during our return voyage a year later near St Coix, which is at present being investigated, by Dr PHLEGER, will shed more light on these highly interesting climatic variations.

In the autumn of 1947 Dr W. SCHOTT, on my invitation, took up work in my institute on the foraminifera sampled from cores taken in the open Atlantic in July of 1947 on our cruise from Madeira to Martinique. Dr SCHOTT finds here, especially in one of the cores, 1.7 metres long, evidence of pronounced climatic variations, which he is inclined to correlate with the well known radiation curve of MILANKOVICZ. It is to be hoped that when Dr SCHOTT resumes his work here next year he will also be able to study cores from our second Atlantic crossing in June—August 1948 taken nearer the equator.

The scope of the foraminiferal analysis is necessarily limited to cores fairly rich in calcareous tests, whereas with cores of Red Clay, extending back into a much more remote past, the shells are in general too scarce and to affected by the dissolving power of sea-water to lend themselves to a biological analysis. In addition to his, pronounced climatic variations like those characterizing the glaciations during the Quaternary Age are not believed to have occurred during the Tertiary, except towards its final phase with deteriorating climatic conditions.

Another line of attack on the chronological problem by investigating biogenic components in the sediment is that of pollen analysis. Samples from the three Tyrrhenian cores mentioned above were submitted to a cursory pollen analysis by Mr C. LARSSON of the Swedish Geological Survey [6]. A surprisingly high number of pollen grains, largely from *Pinus* species were counted in different levels with considerable variations both in total number and in composition during the span of time corresponding to the deposition of the cores. The lack of a dependable pollen-analytical key for the western Mediterranean region makes it at present difficult to carry the analysis further but the results, as they are, seem to promise that the pollenanalytical methods, which have given such magnificent results on terra firma in Sweden and other countries, may also prove of use for submarine chronology. In the open oceans the chances of finding identifiable pollen grains in sufficient numbers for an analysis are obviously not great. Still in the vicinity of ocean islands or near coasts with dense vegetation one may expect to find a fair amount of pollen grains in the sediments also in considerable depths, where the prevailing winds have carried them out over the sea surface. The establishment of a dependable pollen-analytical key is an obvious prerequisite if the analysis is to be of lasting chronological value. Thanks to the recently published investigation by O. H. SELLING [15] on the pollen grains found in borings on the Hawaiian islands an advance towards this goal has been made. On Professor SKOTTSBERGS instigation, borings were made in a peat bog on the Tovii Plateau of Nukuhiva by a landing party from the "Albatross" during our stay at that island, which may be hoped to give another contribution to the same purpose.

A highly speculative possiblity of a different geochronological method seems to be offered by the cosmic spherules, described by Sir JOHN MURRAY and RENNARD as rare components of deep-sea deposits with a very slow rate of sedimentation. The number of these tiny pellets of fused meteoritic iron may reach about one score in a quart of Red Clay and much less in Globigerina Ooze. An investigation on the frequency of such cosmic spherules in the different levels of deep-sea cores may yield results of considerable interest. Apart from fortuitous variations in the distribution of meteorites over the planets surface, which will become equalized over a long span of time, one may expect variations in the frequency of meteoric showers per annum to have occurred as the sun with attending planets passes in and out of clouds of cosmic dust on her path through the universe. According to a hypothesis propounded by Swinne meteorites should be a relatively recent occurence, limited to the last 25 000 years and have been absent during preceding millions of years, If this were true, cosmic spherules should also be limited to the uppermost centimeters (or decimeters) of slowly accumulating deposits and should be absent in deeper and older strata. Anyhow, a variation with "depth" in the number of the cosmic spherules would afford interesting information on the frequency of iron meteors in the past. It is conceivable, that in case such variations are found to be reproduced from one core to another, the frequency curves representing the variations might afford independent means of constructing isochronic surfaces in the sediments.

With this purpose in view, but also for other investigations where larger quantities of material are required. I had one piston core-sampler provided with extra wide tubes: 4" bore instead of the ordinary calibre of 2", intending to use this wider sampler which yields 4 times more material per unit of length (the total length is limited to 6 metres), especially in the Red Clay area of the Central Pacific Ocean, which MURRAY found to be particularly rich in cosmic spherules. Incidentally, the frequency of these spherules might, apart from fortuitous variations, serve as an inverse measure of the rate of sedimentation[1].

Unfortunately the wide-bore sampler was lost at the first attempt to use it, owing to an accidental breaking of the steel wire rope, already in the eastern Pacific. In Honolulu it was replaced by others, which were used occasionally during our continued cruise, especially during our last Atlantic crossing. It was found that the shorter and wider sampler was more easily worked than the longer samplers immediately after trawling experiments, since these experiments produced a marked after-effect on the wire rope, making it rotate the suspended core sampler.

The different approaches to the chronology of the deep-sea deposits reviewed above will be tried out during the working up of the great material, 1 640 metres of deep sea cores, collected by the Swedish Deep-Sea Expedition.

[1] Dr KULLENBERG has called my attention to the opportunities offered to oceanographers of a remote future of identifying our own "coal age" by the cinders scattered over wide areas of the deep ocean bed specially along the transoceanic steamer routes.

REFERENCES

1. PETTERSSON, H., a. o., 1939: The Radioactivity of Seawater. *Medd. Ocean. Inst. Göteborg.* **1** No. 12.
2. PETTERSSON, H., 1937: Über das Verhältniss U/Th in den Gesteinen und im. Meer *Mitt. Radium Inst. Wien.* No 400 a.
3. JOLG, J., 1908: On the Content of Radium and Thorium in Deep Sea Deposits. *Phil. Mag.* **6**, p. 190.
4. PIGGOT, C. S., and URRY, W. D., 1939: The Radium content of an Ocean Bottom Core. *Wash. Acad. Sc.*, No 29, p. 405. [See also *Amer. J. Sc.* 1939—43.]
5. PETTERSSON, H., 1943: Manganese Nodules and the Chronology of the Deep Ocean Floor. *Medd. Ocean Inst. Göteborg.* **2** p. 9.
6. PETTERSSON, H., a. o., 1948: Three Sediment Cores from the Thyrrenian Sea. *Medd. Ocean Inst. Göteborg.* **2** No 15.
7. THORARINSSON, S., 1944: Tefrokronologiska studier på Island. *Geogr. Ann.* **26**, p. 1.
8. NEEB, GERDA A., 1943: The Snellius Expedition. Vol. V, pp. 3 and 55.
9. BRADLEY, W. H. a. o., 1939: Geology and Biology of N. Atlantic Deep Sea Cores. *U. S. Geol. Survey, Profess. Papers* No 196. p XIII.
10. PHILIPPI, E., 1908: Die Grundproben der Deutschen Südpolarexpedition 1901—03. *Deutsche Südpolar-exp. Vol. II, Geogr. und Geologi.*
11. BRAUN, G., 1913: Über die Marine Sedimente und ihre Benutzung zu Zeitbestimmung. *Meereskunde* No 79.
12. SCHOTT, W., 1935: Die Foraminiferen in dem äquatoriellen Teil des Atlantischen Ozeans, *Ergebn. d. Deutschen Atlant. Exp. »Meteor».* **3** p. 120.
13. PHLEGER, Jr., FRED B., 1947: Foraminifera of three Submarine Cores from the Thyrrenian Sea. *Medd. Ocean. Inst. Göteborg,* **2** No 13.
14. PHLEGER, Jr., FRED B., 1948: Foraminifera of a Submarine Core from the Caribbean Sea. *Medd. Ocean. Inst. Göteborg,* **2** No 16.
15. SELLING, O. H., 1948: On the Late Quaternary History of the Hawaiian Vegetation. *B. P. Bishops Museum Sp. Publ.* 39.
16. PETTERSSON, H., 1945: Oceanbottnens problem. *Ymer* **65** p. 161.