Th-230 dating of ~30m long piston cores taken from two North Atlantic abyssal plains during the ESOPE Cruise

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Two sediment cores longer than 20 meters, obtained from two abyssal plains of the North Atlantic during the ESOPE cruise were analyzed for U and Th isotopes. In the Madeira Abyssal Plain sediment (ESOPE core 10), excess ^{230}Th data do not show a simple exponential decrease with depth, being reflected by complex depositional history of the sediments, and hence the Th isotope data can only weakly constrain the rate of sediment accumulation. Relatively low ^{230}Th concentration in the top 5 meters may be caused by rapid accumulation of turbiditic materials. That a significant excess ^{230}Th exists even at depths of ~20m in the core suggests that the average sedimentation rate is rapid, perhaps ~10 of centimeters per thousand years. This high rate of sediment accumulation has resulted largely from frequent turbidites, and not from pelagic clay sedimentation. In the Nares Abyssal Plain sediment (ESOPE core 48), excess ^{230}Th relative to ^{234}U has been found down to ~5m, showing its almost exponential decrease with depth. Based on the excess ^{230}Th distribution, an average sedimentation rate for the core is estimated to be 1.2 ± 0.3 cm/ 10^3 y.

INTRODUCTION

Sampling of long sediment cores in the deep sea is made either by piston coring or by drilling from ship. As long as 10m of sediment samples can be obtained with standard piston corers. In contrast, deep-sea drilling is capable to sample sediment materials down to several hundred meters but normally disturbs top several tens of meters of the core. Therefore, there have been few investigations on sediments lying between 10 and ~50m below the sediment-water interface.

In the framework of the international seabed programme concerning the concept assessment of disposal of high-level radioactive wastes into marine sediments, the ESOPE Cruise (Etude des Sédiments Océaniques par Pénétration) was sponsored by the Nuclear Energy Agency of OECD to obtain ~30m long undisturbed cores for scientific investigation from

the Madeira and Southern Nares abyssal plains in June–July, 1985. The purpose of this study was to determine the rates of sedimentation for two ESOPE long cores using the natural U/Th decay series nuclides. Obviously such information is beneficial to stratigraphers, paleontologists and pore water geochemists who are studying these cores.

The nuclide ^{230}Th is one of the most useful chronometer for these deep-sea cores because of its long half-life of 75,200 years and high abundance of ^{230}Th derived from the water column in the deep-sea sediments. One category of the currently proposed ^{230}Th dating methods is to use $^{230}\text{Th}/^{232}\text{Th}$ ratio on the assumption that the $^{230}\text{Th}/^{232}\text{Th}$ ratio at the time of deposition has remained constant over the depositional history (e.g., Goldberg and Koide, 1962). Another is to employ excess ^{230}Th relative to ^{234}U on the assumption that the specific activity of excess ^{230}Th in freshly depositing sediment

has been constant with time (Ku *et al.*, 1968). Advantages and disadvantages of these methods are critically described in recent reviews (e.g., Ku, 1976; Turekian and Cochran, 1978).

Here we report our results and their implications on the two long cores obtained from the Madeira Abyssal Plain and the Nares Abyssal Plain in the North Atlantic. Details of geochemical and geological investigations for these cores will be published elsewhere (Shuttenhelm *et al.* editors, in preparation). Some useful geochemical and geological information on the Madeira Abyssal Plain sediments may also be found in Kuijpers *et al.* (1984).

METHOD

Core sediments were sampled using a heavy, large diameter, stationary piston corer, the STACOR developed at the French Petroleum Institute, on board the M.S. Marion Dufresne on which modifications and special fittings for the handling of the new STACOR corer in the open

ocean were made. Five and eight long cores were obtained from the Great Meteor East study area and the Southern Nares Abyssal Plain, respectively (Fig. 1). Sediment samples (~50 – 100g wet weight) were subsampled from different depths in the STACOR long cores aboard ship and returned to the land-based laboratory for radiochemical analysis. The samples were dried at 110°C and homogenized with a mortar and a pestle.

About 0.5g of the dried sediment was used for radiochemical analyses of the U and Th isotopes. The chemical procedure is similar to that described by Ku *et al.* (1968) and Yang *et al.* (1986a). The sample was treated with HNO₃ and HF successively in the presence of ~2dpm of yield tracers (²³²U–²²⁸Th) and dissolved in dilute HCl. The U and Th were co-precipitated with iron hydroxides and separated from the major elements in the solution. Further purification of the nuclides was performed by standard anion exchange procedures.

Fig. 1. Location of the North Atlantic study areas, Great Meteor East (GME) in the Madeira Abyssal Plain, and the Nares Abyssal Plain (NAP). Generalized depths in kilometers.

The isolated Th and U were extracted into ~1 ml of 0.4M TTA (Tenoyl-tri-fluoracetone) in benzene and plated on a stainless steel disk. The α -activity of the Th and U isotopes were measured by an α -spectrometer with silicon surface barrier detectors.

The sedimentation rate (S) is calculated on the basis of the equation,

$$A = A_0 \exp\left(-\frac{\lambda}{S} Z\right) \quad (1)$$

where A and A_0 is the specific activity of excess ^{230}Th at any depth (z) and at the surface, respectively, λ is the decay constant of ^{230}Th . The fundamental requirements to hold this relationship are that the sediment accumulation rate has been constant and that the production and removal rates of ^{230}Th per unit area of the ocean bottom have been constant for the time concerned. The effect of bioturbation is not considered here, because most of our radiochemical data have been obtained far below the bioturbation zone. The relationship indicates that the logarithmic plot of excess ^{230}Th versus depth should be linear and from the slope of the plot, the sedimentation rate can be derived. In many cases, however, the linear relationship does not hold satisfactorily for the entire length of the core owing to the fact that the combination of the above requirements is rarely found under the natural conditions. Even so, it seems possible to put some time constraints for the sediments as discussed below.

RESULTS AND DISCUSSION

ESOPE core 10

(position $31^\circ 16', 70^\circ N$, $25^\circ 23', 33^\circ W$: uncorrected water depth, 5,376 m)

Analytical data for U and Th isotopes are given in Table 1. The ^{230}Th activity is generally in excess relative to ^{234}U at almost all depths of the core. The only exceptions are sample numbers 17621 and 17698. The sample 17671 was repeatedly measured and its high concentrations of both ^{230}Th and ^{234}U were confirmed. The high excess ^{230}Th in the sample 17612 is

probably associated with the relatively low carbonate content which can be recognized visually. The excess ^{230}Th activity and its ratio to the ^{232}Th activity are plotted against depth in Fig. 2. The large scatter of the data suggests that these sediments have accumulated under variable depositional conditions. This view is supported by the lithology which shows a frequent occurrence of turbidite layers with a rather high carbonate content alternating with pelagic ooze to clamp the core (Kuijpers *et al.*, 1984; Shuttenhelm *et al.*, in preparation).

Fig. 2. Profiles of excess ^{230}Th and $^{230}\text{Th}_{\text{xs}}/^{232}\text{Th}$ ratio in the ESOPE core 10 from the GME study area in the Madeira Abyssal Plain. No excess ^{230}Th was found at depths indicated by arrows.

The interpretation of the ^{230}Th data in terms of a sediment accumulation rate is obviously complicated. Although there seems to be a decreasing trend in the excess ^{230}Th below 5m, it is difficult to estimate the sedimentation rate with equation (1). It has been demonstrated that in the case of variable carbonate contents (16–86%) as we have here, the normalized $^{230}\text{Th}_{\text{xs}}/^{232}\text{Th}$ method often provides a better decreasing trend (e.g. Goldberg and Koide,

Table 1. Results of U and Th isotopes (dpm g⁻¹) for the ESOPE core 10 from the GME study area in the Madeira abyssal plain

Sample. No.	Depth (m)*	²³² Th	²³⁰ Th	²³⁸ U	²³⁴ U
17596	0.96	0.93 ± 0.16	2.43 ± 0.32	0.73 ± 0.06	0.71 ± 0.05
17600	1.88	0.72 ± 0.21	2.07 ± 0.46	0.75 ± 0.05	0.71 ± 0.05
17608	4.29	1.42 ± 0.33	3.48 ± 0.69	1.78 ± 0.07	1.77 ± 0.07
17612	5.29	1.21 ± 0.34	9.38 ± 2.22	1.01 ± 0.08	0.97 ± 0.08
17620	6.85	1.07 ± 0.20	3.26 ± 0.48	1.25 ± 0.08	1.29 ± 0.08
17621	7.09	1.22 ± 0.14	5.81 ± 0.61	5.81 ± 0.21	6.03 ± 0.22
17626	8.49	0.96 ± 0.16	3.15 ± 0.42	1.90 ± 0.09	1.88 ± 0.09
17630	9.38	0.96 ± 0.14	3.01 ± 0.35	1.75 ± 0.09	1.91 ± 0.09
17633	10.20	1.32 ± 0.23	4.10 ± 0.59	1.52 ± 0.16	1.49 ± 0.15
17639	11.65	1.67 ± 0.25	4.25 ± 0.55	1.70 ± 0.07	1.66 ± 0.06
17642	11.94	0.86 ± 0.15	1.85 ± 0.26	1.69 ± 0.06	1.74 ± 0.07
17644	13.31	1.82 ± 0.25	3.83 ± 0.47	2.65 ± 0.09	2.72 ± 0.09
17649	14.61	1.33 ± 0.09	2.89 ± 0.16	1.22 ± 0.05	1.16 ± 0.04
17660	17.46	1.22 ± 0.10	1.89 ± 0.14	1.56 ± 0.06	1.68 ± 0.06
17668	19.35	0.72 ± 0.26	1.30 ± 0.40	0.55 ± 0.09	0.59 ± 0.09
17677	21.63	1.23 ± 0.13	1.56 ± 0.15	1.16 ± 0.10	1.08 ± 0.09
17683	23.36	1.07 ± 0.29	1.35 ± 0.34	0.75 ± 0.07	0.66 ± 0.07
17698	27.38	0.55 ± 0.06	0.37 ± 0.05	0.50 ± 0.14	0.47 ± 0.13

* Sampling depth intervals are less than 5 cm.

1962). Yet the ²³⁰Th_{xs}/²³²Th versus depth plot in Fig. 2 is also not striking. Therefore our ²³⁰Th data can only weakly constrain the sediment accumulation rate. There is a significant excess ²³⁰Th even at depths around 20m suggesting that these deposits are younger than ~300,000 years. This gives a crude estimate of average sedimentation rate of greater than 7 cm/10³ y. For the top 5m, excess ²³⁰Th values are lower than those expected from the general trend of the data for lower depths. This could only be derived by dilution of ²³⁰Th content with rapidly deposited materials like turbidites, if ²³⁰Th flux from the overlying water column to the sediment remained constant. Assuming that all ²³⁰Th produced in the water column is removed and deposited in the underlying sediments, we obtain the surface excess ²³⁰Th activity (A₀, dpm/g dry sediment) as follows,

$$A_0 = \frac{\lambda C_u L}{\rho S} \quad (2)$$

Where λ is the decay constant of ²³⁰Th (9.22 × 10⁻⁶ y⁻¹), C_u is the concentration of the parent

²³⁴U in seawater (2.8 × 10⁻³ dpm/cm³), L is the depth of overlying water (537,600 cm), ρ is the dry bulk sediment density and S is the sedimentation rate. Taking $\rho = \sim 0.5$ g/cm³ (Lyle and Dymond, 1976) and A₀ = 1.8 dpm/g, we calculate S to be 15 cm/10³ years. On the other hand, if we apply equation (2) to the sample at 5.29m with $\rho = \sim 1$ g/cm³ which is relatively high in pelagic clay content and excess ²³⁰Th (8.4 dpm/g), the upper limit of sedimentation rate can be calculated to be 1.5 cm/10³ y. The actual clay sedimentation rate must be much lower than this value, because the decay of ²³⁰Th after deposition and loss of ²³⁰Th from the overlying water column by lateral transport (Anderson *et al.* 1983) are not taken into account in the calculation. These results are consistent with recent detailed sedimentological studies on the Madeira Abyssal Plain (Kuijpers *et al.*, 1984).

ESOPE piston core 48

(position 22°54,89'N, 63°26,69'W: uncorrected water depth, 5,760m)

and

ESOPE box core 51

(position 23°21,32'N, 63°01,00'W: uncorrected water depth, 5,805m)

In the Nares Abyssal Plain area, the sediments consist of pelagic and turbiditic materials which are difficult to date owing to a lack of microfossils (Kuijpers *et al.*, 1987). Hence the radiochemical dating method is worthwhile to be applied to the core sediment. Data for U and Th isotopes are given in Table 2. Since we could not obtain samples shallower than 2m because of problems during the coring operations resulting in a poor-quality core top, ESOPE box core 51 from another location in the southern Nares Abyssal Plain was analyzed and the results

are given in Table 3. As plotted in Fig. 3, excess ^{230}Th is found down to ~5m of the ESOPE core 48. Based on the data between 2–5m, the sedimentation rate has been derived to be $1.2 \pm 0.3 \text{ cm}/10^3 \text{ y}$. Extrapolation of the regression line fitted the data toward the surface is congruent with the data obtained from the box core. This suggests that an average sedimentation rate may have been on the order of $1 \text{ cm}/10^3 \text{ y}$ for the last 300,000 years.

The box core data (Fig. 4) also reveal that excess ^{230}Th concentration decreases exponentially in the top 27cm of the core. The slope corresponds to a sedimentation rate of $0.2 \text{ cm}/10^3 \text{ y}$ which is five times lower than the average rate given above. This slow rate, however, is suspect, because of the following reasons. The standing crop of excess ^{230}Th in the ESOPE core 48 corresponds to the decay flux of $\sim 13 \times$

Table 2. Results of U and Th isotopes (dpm g^{-1} for dry sediment) for the ESOPE core 48

Sample. No.	Depth(m)*	^{232}Th	^{230}Th	^{238}U	^{234}U
18010	2.12	2.45 ± 0.19	4.07 ± 0.30	1.52 ± 0.13	1.42 ± 0.12
18011	2.49	3.72 ± 0.54	3.85 ± 0.55	1.59 ± 0.15	1.33 ± 0.14
18012	2.81	2.81 ± 0.29	2.44 ± 0.26	1.48 ± 0.13	1.40 ± 0.12
18013	3.14	2.23 ± 0.19	2.14 ± 0.18	1.64 ± 0.10	1.45 ± 0.09
18014	3.45	2.83 ± 0.24	2.02 ± 0.18	1.45 ± 0.11	1.52 ± 0.12
17956	4.17	1.96 ± 0.20	1.68 ± 0.18	1.00 ± 0.19	1.28 ± 0.23
17957	4.45	2.14 ± 0.16	1.53 ± 0.12	1.18 ± 0.09	1.19 ± 0.09
17958	4.79	1.93 ± 0.16	1.38 ± 0.12	1.45 ± 0.10	1.23 ± 0.09
17961	5.80	1.82 ± 0.18	0.96 ± 0.11	1.03 ± 0.14	0.94 ± 0.13
17964	6.81	2.49 ± 0.35	1.42 ± 0.21	1.41 ± 0.12	1.59 ± 0.13
17966	7.50	2.51 ± 0.29	1.36 ± 0.18	1.54 ± 0.12	1.38 ± 0.11
17969	8.49	2.74 ± 0.45	1.11 ± 0.21	1.22 ± 0.12	1.22 ± 0.12
17972	9.41	2.54 ± 0.34	1.00 ± 0.16	1.49 ± 0.16	1.25 ± 0.14
17975	10.36	2.53 ± 0.39	1.28 ± 0.20	1.48 ± 0.11	1.13 ± 0.09
17981	12.45	2.76 ± 0.30	1.39 ± 0.17	1.29 ± 0.10	1.22 ± 0.09
17985	13.75	3.13 ± 0.36	2.25 ± 0.27	1.61 ± 0.15	2.03 ± 0.17
17986	14.09	2.46 ± 0.41	1.44 ± 0.16	1.77 ± 0.11	1.68 ± 0.11
17991	15.85	2.55 ± 0.37	1.29 ± 0.21	1.48 ± 0.08	1.67 ± 0.08
17994	16.78	3.02 ± 0.32	1.76 ± 0.20	1.69 ± 0.15	1.59 ± 0.15
17997	17.76	4.46 ± 0.50	1.72 ± 0.21	1.37 ± 0.16	1.69 ± 0.18
17998	18.03	2.30 ± 0.31	1.30 ± 0.19	1.67 ± 0.21	1.42 ± 0.19
18003	19.79	2.62 ± 0.75	1.45 ± 0.45	1.78 ± 0.15	1.79 ± 0.15
18006	20.79	3.66 ± 0.80	1.79 ± 0.42	1.86 ± 0.13	1.67 ± 0.12
18009	21.78	3.31 ± 0.58	2.04 ± 0.37	1.81 ± 0.16	1.85 ± 0.17

* Sampling depth intervals are less than 5 cm.

Table 3. Results of U and Th isotopes (dpm g⁻¹) for the ESOPE core 51 (23°21'N, 63°01'W; 5,805m)

Depth (cm)	²³² Th	²³⁰ Th	²³⁸ U	²³⁴ U
0 – 2.4	3.45 ± 0.55	12.36 ± 1.84	1.40 ± 0.14	1.97 ± 0.18
6.7 – 8.9	3.14 ± 0.36	9.69 ± 1.05	1.29 ± 0.13	1.58 ± 0.15
13 – 15	3.07 ± 0.40	7.81 ± 0.98	1.05 ± 0.13	1.37 ± 0.15
19 – 21	3.11 ± 0.41	6.31 ± 0.79	1.57 ± 0.17	1.66 ± 0.18
24 – 27	2.30 ± 0.26	5.07 ± 0.54	1.48 ± 0.18	1.53 ± 0.18
31 – 33	2.61 ± 0.23	8.97 ± 0.71	1.56 ± 0.14	1.72 ± 0.15
37 – 38	2.60 ± 0.22	9.11 ± 0.69	0.95 ± 0.12	1.28 ± 0.15
44 – 46	1.94 ± 0.16	8.69 ± 0.64	1.37 ± 0.13	1.35 ± 0.13

Fig. 3. Profiles of excess ²³⁰Th and ²³⁰Th_{xs}/²³²Th ratio in the ESOPE core 48 from the southern Nares Abyssal Plain. The ESOPE core 51 data are also plotted.

10⁻³ dpm cm⁻² y⁻¹ on the assumption of the bulk sediment density, 1g/cm³ which is approximately equal to the production rate in the water column (14.7 × 10⁻³ dpm cm⁻² y⁻¹). If the excess ²³⁰Th flux remained unchanged, then the five times lower sediment accumulation rate should result in a five times higher excess ²³⁰Th concentration in the surface sediment.

Fig. 4. Profiles of excess ²³⁰Th and ²³⁰Th_{xs}/²³²Th ratio in the ESOPE core 51.

Certainly this is not observed. Recent sediment trap experiments (Anderson *et al.*, 1983) reveal that the vertical flux is somewhat lower than the production rate in the water column of open ocean low particle flux regimes. However, there is a clear general trend that the slower the sediment accumulation, the higher the surface excess ²³⁰Th concentration (Yang *et al.*, 1986b). Therefore, the likely explanation is that the decrease of ²³⁰Th concentration around 15–20 cm may have resulted from episodic dilution of ²³⁰Th with other sediment materials.

Since there is no significant excess ²³⁰Th below 5 μm of the ESOPE core 48, it is impossible to put any time-constraints on the sediment accumulation. If we assume the sedimentation rate of 1cm/10³ y for the entire length

of the core, the bottom age becomes as old as 2 m.y. This is a suitable range of the dating method using ^{10}Be with a half-life of 1.5 m.y. This determination remains for the future.

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