RADIOCHRONOLOGY OF SEDIMENTS FROM THE MEDITERRANEAN SEA USING NATURAL ^{210}Pb AND FALLOUT ^{137}Cs

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The ^{210}Pb and ^{137}Cs profiles of sediment cores from two locations in southern Spain, three locations in southern Turkey and two locations in northern Cyprus were determined by direct γ -ray spectroscopy. Sedimentation rates were derived for all locations using the ^{210}Pb data. The rates range from $1.39 \pm 0.12 \text{ cm} \cdot \text{y}^{-1}$ ($0.50 \pm 0.04 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$) to $0.08 \pm 0.01 \text{ cm} \cdot \text{y}^{-1}$ ($0.039 \pm 0.003 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$). Except for one core, the ^{137}Cs profiles were also used to compute sedimentation rates. The results are in good agreement with those of ^{210}Pb values. The results of the Constant Initial Concentration and Constant Rate of Supply dating models are in good agreement with each other. The flux of unsupported ^{210}Pb varies between 0.11 ± 0.03 to $0.74 \pm 0.01 \text{ pCi} \cdot \text{cm}^{-2}$. The average depositional flux was found to be considerably lower for cores from the Eastern Mediterranean.

Accurate dating techniques are important in the use of sediment records for reconstruction of recent environmental changes. The precision to which this can be accomplished has been greatly enhanced over the past 20 years by the development of a range of radiometric techniques that use radioisotopes both from natural and artificial sources. The principal isotope for dating in the time scale of the past 100–150 years is ^{210}Pb . ^{210}Pb with a half-life of 22.6 years is a member of the natural ^{238}U series. Using this isotope, lake and sea sediment can be dated with a precision of five to ten years. In this method the activity of the unsupported ^{210}Pb (i.e., total activity of ^{210}Pb in the sediment minus that supported by ^{226}Ra) is measured throughout the sediments. Artificial radioisotopes such as ^{137}Cs have been present in the environment only for the past 35 years, and can be used for dating only the most recent sediments. ^{137}Cs is produced during nuclear fission. Thus, its presence in the environment is due to nuclear testing or to releases from nuclear reactors. In these tests, ^{137}Cs was injected into the stratosphere where it circulates globally. ^{137}Cs moves from the stratosphere back to the troposphere and it is precipitated from the troposphere to the earth's surface. The use of this isotope does however provide a valuable check on the accuracy of the ^{210}Pb data. Most of the researchers measure the unsupported ^{210}Pb by measuring the α -emission of ^{210}Po or by measuring the β -emission of ^{210}Bi . Although these methods are highly sensitive, they are very complex and require radiochemical separation techniques. With the development of hyperpure germanium detectors, it is possible to measure ^{210}Pb in

environmental samples directly with a high precision. The advantage of ^{210}Pb assay by γ -counting lies in the non-destructive nature of the method and in the determination of a range of γ -emitting radioisotopes, such as ^{226}Ra and ^{137}Cs , besides ^{210}Pb .

Models of sediment accumulation

Assuming that the flux P ($\text{dpm} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$) of ^{210}Pb to the sediment-water interface has remained constant and no post-depositional migration of ^{210}Pb has occurred over the dating interval, the activity of ^{210}Pb in the sediment at any depth, z is given by the following expression:

$$A(z) = A_0 \cdot e^{-\lambda \cdot z/s} \quad (1)$$

where $A(z)$ – activity of ^{210}Pb in dpm/g at depth z ,
 A_0 – activity of ^{210}Pb in dpm/g at $z = 0$,
 z – depth of sediment in cm ,
 s – sedimentation rate in $\text{cm} \cdot \text{y}^{-1}$,
 λ – decay constant.

If the initial activity A_0 is assumed to be constant, which implies that apart from the flux of the radionuclide, the sedimentation rate s is also constant, then a semilogarithmic plot of $A(z)$ versus z should give a straight line with an intercept of $\log A_0$ and a slope of $-\lambda/s$. From the slope, the sedimentation rate s can be determined. Since the initial activity A_0 is assumed to be constant, this model is referred to as the Constant Initial Concentration (C.I.C) model.¹ With increasing depth, sediments are subject to significant compaction even over the depth interval for which the ^{210}Pb method is useful. In order to correct for this compaction effect, mass depth $m(z)$ ($\text{g} \cdot \text{cm}^{-2}$) instead of linear depths z (cm) is used. Mass depth $m(z)$ can be computed from the porosity profiles. Since porosity changes with depth, each sediment section Δz should be corrected for compaction according to the equation:²

$$\Delta m = \Delta z (1 - \Phi_z) \bar{\rho}_s \quad (2)$$

where Δm – weight of the sediment section in $\text{g} \cdot \text{cm}^{-2}$,
 Δz – thickness of each section in cm ,
 Φ_z – porosity of sediment at depth z (the percentage of water content),
 $\bar{\rho}_s$ – mean density of sediment solid in $\text{g} \cdot \text{cm}^{-3}$.

An alternative way of taking compaction into account is to correct for linear depth z by using the porosity result of each sediment section Δz^3

$$\Delta z' = \Delta z \cdot \frac{\Phi_0 - \Phi_z}{1 - \Phi_0} + \Delta z \quad (3)$$

where $\Delta z'$ – corrected thickness of each section in cm,
 Φ_0 – porosity of sediment at depth $z = 0$.

If only a constant flux is assumed, the corresponding model is called Constant Rate of Supply (C.R.S.) model. The age of a sediment core at a mass depth $m(z)$ is given according to the Constant Rate of Supply model as:

$$t = \frac{1}{\lambda} \cdot \ln \left[\frac{\sum_{\text{all } m(z)} A_{210\text{Pb}_{\text{uns}}} }{\Sigma A_{210\text{Pb}_{\text{uns}}}(m)} \right] \quad (4)$$

Where $\sum_{\text{all } m(z)} A_{210\text{Pb}_{\text{uns}}}$ is the total unsupported ^{210}Pb in the entire sediment column in units of $\text{dpm} \cdot \text{cm}^{-2}$ and $\Sigma A_{210\text{Pb}_{\text{uns}}}(m)$ is the unsupported ^{210}Pb below a mass-depth $m(z)$.⁴

Experimental

Sediment cores were recovered using a gravity corer with transparent PVC tubes (inner diameter 6 cm), a technique which has been previously used in studying Lake Zurich and Lake Constance sediments by us.^{5,6} In those studies the recovery of the topmost sediment section was checked by measuring cosmic ray-produced ^7Be (53 d) in first sediment sample. Observation of ^7Be as in our case indicated no sediment loss. In our present study the time elapsed between core recovery and core analysis did not allow the observation of ^7Be .

The samples were stored vertically at 4 °C and later extruded and sampled at 0.5 or 1 cm intervals. Fixed volume sediment samples were dried at 110 °C for up to 48 hours prior to analysis and their dry weights were measured. These values, together with wet weights, were used to calculate the porosities. From the experimental porosities, correction for compaction of each sediment section was done according to Relation (3).

Table 1 shows core codes, sampling depth, location and sampling dates of the cores analyzed.

Gamma-ray spectra were observed with a Coaxial Hyperpure Ge Detector with an active area, diameter, and height of 9200 mm², 52 mm, and 42 mm, respectively, connected to a multichannel analyzer. The resolution was 790 eV for the 122 keV γ -ray.

Table 1
Core codes, sampling depth, location and sampling dates of the core analyzed

Core codes	Sampling depth, cm	Location	Sampling date
Core 2 (Turkey)	53	36 33 33 34 16 48	Sept/1984
Core 3 (Turkey)	83	36 32 18 34 18 30	Sept/1984
Core 35 (Turkey)	180	36 28 06 34 22 30	Oct/1984
Core BC-1 (Spain)	33	—	1986
Core BC-6A (Spain)	33	—	1986
Core KS-1A (Cyprus)	14	—	1991
Core KS-2A (Cyprus)	12	—	1991

The dried samples were stored in closed beakers for about one month to ensure equilibrium between ^{226}Ra and its daughters, which grow in with the 3.85 day half life of ^{222}Rn . Dried samples (1–10 g) were counted for a period of $2.5 \cdot 10^5$ seconds by placing the counting samples directly on the detector. In order to minimize background activity, the detector was shielded by a lead cylinder with a height of 420 mm, thickness of 90 mm and diameter of 210 mm. In all of the measurements, the effect of self-absorption was assumed to be negligible. The background activity was subtracted from each spectrum. The γ -rays of 46.5, 351.9 and 661.6 keV belonging to the decay of ^{210}Pb , ^{226}Ra and ^{137}Cs , respectively, were used for dating.

Results and discussion

A typical γ -ray spectrum of the sediment samples is shown in Fig. 1. The photopeaks belonging to ^{210}Pb and ^{226}Ra are well resolved. Unlike most other studies where the levels of supported ^{210}Pb is inferred from a few ^{210}Pb measurements on much deeper sections in the sediment core, we were able to determine the ^{226}Ra levels and thus supported ^{210}Pb in each section simultaneously. The efficiency calibration was carried out by using a standard solution. Five grams of an inactive matrix was mixed with a known activity of standard solution. The efficiencies at the counting geometry were found to be 15.6% and 4.45% for ^{210}Pb and ^{226}Ra , respectively.

Cores from the Western Mediterranean

The sediment cores were collected at two locations (BC-1 and BC-6A) on the eastern coast of Spain. The results of activity measurements for cores BC-1 and BC-6A are given in Table 2. The unsupported ^{210}Pb activity profiles of cores BC-1 and BC-6A

Fig. 1. Gamma-ray spectrum of the sediment samples prepared from the top section of core BC-1 from the eastern coast of Spain

are shown in Figs 2a to b. A weighted least-squares fit for core BC-1 leads to a sedimentation rate of $0.84 \pm 0.07 \text{ cm} \cdot \text{y}^{-1}$ or $0.21 \pm 0.02 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$. The ^{210}Pb profile for core BC-6A showed a nearly constant ^{210}Pb activity. No sedimentation rate could be evaluated using the C.I.C. model. ^{210}Pb chronology was done only by the C.R.S. model.

The ^{210}Pb inventories of cores BC-1 and BC-6A were computed by assuming the annual atmospheric flux of unsupported ^{210}Pb as $0.9 \text{ dpm} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$.⁷ They were found as 107% and 160%, respectively. Within the uncertainty of the assumed flux, all the ^{210}Pb in both cores seems to be recovered.

Figures 3a to b show the age-depth relation in cores BC-1 and BC-6A. The points represent ages using Constant Rate of Supply model and the line represents those using Constant Initial Concentration model. For the core BC-1 the results of the two dating models are in good agreement with each other. In core BC-6A, there seem to be two different regions, one between 0-20 cm having a high

Fig. 2. Unsupported ^{210}Pb activity profile. The solid line is the weighted least-squares fit to the data.
a) core BC-1, b) core BC-6A, c) core-2, d) core-3, e) core-35, f) core KS-1, g) core KS-2

sedimentation rate of $1.39 \pm 0.12 \text{ cm} \cdot \text{y}^{-1}$ ($0.50 \pm 0.04 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$) and the other below 20 cm, having a sedimentation rate of $0.23 \pm 0.12 \text{ cm} \cdot \text{y}^{-1}$ ($0.12 \pm 0.01 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$).

Cores from the Eastern Mediterranean

Three sediment cores were recovered (Core-2, Core-3 and Core-35) from the southern coast of Turkey. The ^{210}Pb activity measurements are given in Table 3. Figures 2c to 2e show the distribution of unsupported ^{210}Pb in cores 2, 3 and 35. The

Fig. 3. Comparison of Constant Rate of Supply and Constant Initial Concentration dating models. The points correspond the Constant Rate of Supply model and the line represents the Constant Initial Concentration model. a) core BC-1, b) core BC-6A, c) core-2, d) core-3, e) core-35, f) core KS-1, g) core KS-2

Table 2
Results of activity measurements for cores BC-1 and BC-6A

Depth, cm	BC-1			BC-6A		
	$A_{210\text{PbTot.}}$ dpm/g	$A_{210\text{PbSupp.}}$ dpm/g	$A_{210\text{PbUnsupp.}}$ dpm/g	$A_{210\text{PbTot.}}$ dpm/g	$A_{210\text{PbSupp.}}$ dpm/g	$A_{210\text{PbUnsupp.}}$ dpm/g
1	11.33 ± 0.94	3.20 ± 0.32	8.13 ± 0.99	25.89 ± 2.43	3.25 ± 0.09	21.65 ± 2.52
2	9.72 ± 0.94	0.52 ± 0.09	9.20 ± 0.95	5.00 ± 0.58	4.02 ± 0.38	0.98 ± 0.71
3	7.06 ± 0.68	4.80 ± 0.51	2.26 ± 0.44	—	—	—
4	4.62 ± 0.50	0.77 ± 0.10	3.85 ± 0.51	4.09 ± 0.71	2.80 ± 0.47	1.28 ± 0.85
5	3.07 ± 0.32	2.97 ± 0.38	0.10 ± 0.49	5.91 ± 0.81	4.38 ± 0.32	1.53 ± 0.87
6	9.72 ± 0.88	2.04 ± 0.28	7.68 ± 0.93	5.23 ± 1.14	4.17 ± 0.56	1.06 ± 1.28
7	6.33 ± 0.77	3.72 ± 0.39	2.61 ± 0.86	4.39 ± 0.85	3.25 ± 0.33	1.14 ± 0.92
8	2.27 ± 0.25	2.06 ± 0.26	0.22 ± 0.36	4.88 ± 0.67	1.12 ± 0.34	3.76 ± 0.74
9	1.21 ± 0.12	1.32 ± 0.16	—	5.21 ± 1.11	1.32 ± 0.36	3.89 ± 1.15
10	3.11 ± 0.32	1.43 ± 0.31	1.68 ± 0.44	4.10 ± 0.72	2.66 ± 0.43	1.44 ± 0.84
11	1.59 ± 0.01	3.33 ± 0.38	—	5.94 ± 0.77	4.12 ± 0.31	1.82 ± 0.83
12	2.99 ± 0.28	—	—	6.72 ± 0.62	3.82 ± 0.23	2.90 ± 0.67
13	1.24 ± 0.14	0.80 ± 0.14	0.44 ± 0.14	2.00 ± 0.75	0.52 ± 0.30	1.48 ± 0.65
14	4.43 ± 0.52	0.60 ± 0.08	3.83 ± 0.52	8.06 ± 1.20	1.12 ± 0.22	6.87 ± 1.23
15	1.26 ± 0.14	2.17 ± 0.31	—	16.30 ± 0.99	3.70 ± 0.42	12.61 ± 1.07
16	1.95 ± 0.19	0.43 ± 0.06	1.51 ± 0.20	22.63 ± 1.68	5.70 ± 0.43	16.94 ± 1.73
17	4.40 ± 0.60	0.78 ± 0.11	3.61 ± 0.60	5.47 ± 0.91	5.23 ± 0.44	0.234 ± 1.04
18	—	—	—	3.63 ± 0.71	4.41 ± 0.46	—
19	3.37 ± 0.37	3.18 ± 0.34	0.19 ± 0.51	2.37 ± 0.72	1.95 ± 0.33	0.41 ± 0.79
20	3.58 ± 0.43	1.41 ± 0.19	2.18 ± 0.47	11.26 ± 1.26	4.24 ± 0.31	7.02 ± 1.36
21	2.39 ± 0.22	5.96 ± 0.59	—	10.22 ± 2.24	10.38 ± 0.97	—
22	0.76 ± 0.08	1.81 ± 0.22	—	7.67 ± 1.11	1.89 ± 0.45	5.78 ± 1.20

corresponding sedimentation rates are $0.16 \pm 0.01 \text{ cm} \cdot \text{y}^{-1}$ ($0.08 \pm 0.01 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$), $0.31 \pm 0.05 \text{ cm} \cdot \text{y}^{-1}$ ($0.13 \pm 0.02 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$) and $0.085 \text{ cm} \cdot \text{y}^{-1}$ ($0.040 \pm 0.003 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$) for cores 2, 3 and 35, respectively. The atmospheric fluxes of ^{210}Pb for these cores are evaluated as $0.15 \pm 0.01 \text{ pCi} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$, $0.12 \pm 0.03 \text{ pCi} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$ and $0.14 \pm 0.02 \text{ pCi} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$, respectively.

The results of the C.I.C. and C.R.S. models for cores 2, 3 and 35 are in good agreement with each other, as shown in Figs. 3c to e. The ^{210}Pb inventories in cores 2, 3 and 35 were computed by assuming an annual atmospheric flux of $0.9 \text{ dpm} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$. The results were 27.5, 23.3 and 34%, respectively. Such low inventories may be due to the possible loss of ^{210}Pb activity or more probably due to the high value of atmospheric flux assumed. Indeed the average flux of ^{210}Pb computed in this region was around $0.14 \text{ pCi} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$, which is by a factor of three less than the reported value.

Table 3
Results of the activity measurements for cores 2, 3 and 35

Depth, cm	Core-2				Core-3				Core-35			
	Tot. ^{210}Pb , dpm/g	Supp. ^{210}Pb , dpm/g	Unsupp. ^{210}Pb , dpm/g	Tot. ^{210}Pb , dpm/g	Supp. ^{210}Pb , dpm/g	Unsupp. ^{210}Pb , dpm/g	Tot. ^{210}Pb , dpm/g	Supp. ^{210}Pb , dpm/g	Unsupp. ^{210}Pb , dpm/g	Supp. ^{210}Pb , dpm/g	Unsupp. ^{210}Pb , dpm/g	
1	4.79 ± 0.42	0.33 ± 0.07	4.46 ± 0.43	2.57 ± 0.28	0.33 ± 0.09	2.24 ± 0.29	8.54 ± 0.46	1.05 ± 0.13	7.49 ± 0.47	1.05 ± 0.13	7.49 ± 0.47	
2	4.38 ± 0.39	1.18 ± 0.08	3.20 ± 0.40	1.43 ± 0.15	0.12 ± 0.08	1.31 ± 0.17	6.66 ± 0.38	1.58 ± 0.11	5.08 ± 0.40	1.58 ± 0.11	5.08 ± 0.40	
3	2.19 ± 0.18	0.62 ± 0.04	1.57 ± 0.19	-	0.51 ± 0.05	-	3.89 ± 0.22	0.97 ± 0.07	2.93 ± 0.23	0.97 ± 0.07	2.93 ± 0.23	
4	0.64 ± 0.18	0.36 ± 0.06	0.28 ± 0.19	1.17 ± 0.22	0.46 ± 0.10	0.71 ± 0.24	1.87 ± 0.26	1.71 ± 0.11	0.15 ± 0.28	1.71 ± 0.11	0.15 ± 0.28	
5	0.86 ± 0.15	0.16 ± 0.07	0.70 ± 0.17	0.39 ± 0.13	0.64 ± 0.06	-	1.69 ± 0.26	0.85 ± 0.10	0.84 ± 0.28	0.85 ± 0.10	0.84 ± 0.28	
6	1.22 ± 0.11	0.31 ± 0.06	0.91 ± 0.13	1.31 ± 0.13	0.52 ± 0.05	0.79 ± 0.14	-	1.67 ± 0.11	-	1.67 ± 0.11	-	
7	0.54 ± 0.12	0.44 ± 0.04	0.11 ± 0.12	0.25 ± 0.10	0.52 ± 0.08	-	1.29 ± 0.16	1.16 ± 0.09	0.13 ± 0.18	1.16 ± 0.09	0.13 ± 0.18	
8	1.63 ± 0.14	0.63 ± 0.08	1.01 ± 0.16	0.24 ± 0.12	0.48 ± 0.06	-	1.70 ± 0.15	1.30 ± 0.08	0.40 ± 0.17	1.30 ± 0.08	0.40 ± 0.17	
9	0.46 ± 0.18	0.83 ± 0.09	-	0.93 ± 0.11	0.35 ± 0.04	0.57 ± 0.12	-	1.39 ± 0.13	-	1.39 ± 0.13	-	
10	0.45 ± 0.07	0.11 ± 0.04	0.33 ± 0.08	-	-	-	1.55 ± 0.17	1.33 ± 0.08	0.22 ± 0.19	1.33 ± 0.08	0.22 ± 0.19	
11	0.89 ± 0.14	0.28 ± 0.04	0.61 ± 0.15	0.60 ± 0.01	1.02 ± 0.04	-	-	1.51 ± 0.14	-	1.51 ± 0.14	-	
12	0.23 ± 0.12	0.57 ± 0.05	-	0.61 ± 0.34	1.13 ± 0.09	-	-	-	-	-	-	
14	0.76 ± 0.15	0.49 ± 0.04	0.28 ± 0.16	-	-	-	-	-	-	-	-	

Table 4
Results of the activity measurements for cores KS-1 and KS-2

Depth, cm	KS-1			KS-2		
	$A_{210\text{PbTot.}}$ dpm/10 g	$A_{210\text{PbSupp.}}$ dpm/10 g	$A_{210\text{PbUnsupp.}}$ dpm/10 g	$A_{210\text{PbTot.}}$ dpm/10 g	$A_{210\text{PbSupp.}}$ dpm/10 g	$A_{210\text{PbUnsupp.}}$ dpm/10 g
0.5	46.85 ± 2.66	5.66 ± 0.63	41.19 ± 2.73	24.19 ± 1.70	13.73 ± 0.79	10.46 ± 1.88
1.0	6.37 ± 1.61	5.91 ± 0.53	0.46 ± 1.70	12.39 ± 2.98	11.42 ± 0.65	0.98 ± 3.05
1.5	6.79 ± 1.08	2.24 ± 0.29	4.55 ± 1.11	41.68 ± 3.50	7.92 ± 1.35	33.93 ± 3.76
2.0	3.95 ± 0.86	6.66 ± 0.52	—	8.86 ± 2.33	12.18 ± 0.97	—
2.5	9.16 ± 1.43	7.93 ± 0.51	1.23 ± 1.52	22.68 ± 2.71	8.63 ± 0.98	14.05 ± 2.88
3.0	6.49 ± 1.04	3.93 ± 0.56	2.56 ± 1.18	18.42 ± 1.43	15.44 ± 0.58	2.97 ± 1.54
3.5	7.89 ± 1.21	6.95 ± 0.50	0.94 ± 1.72	8.97 ± 1.18	12.15 ± 0.67	—
4.0	11.45 ± 1.00	11.46 ± 0.64	—	16.05 ± 2.34	23.46 ± 1.02	—
4.5	15.00 ± 1.72	4.61 ± 0.45	10.39 ± 1.77	15.37 ± 2.76	8.93 ± 1.16	6.43 ± 2.99
5.0	20.84 ± 1.41	7.43 ± 0.44	13.41 ± 1.48	3.22 ± 1.33	13.43 ± 0.56	—
5.5	20.62 ± 2.40	7.48 ± 0.78	13.14 ± 2.52	—	17.68 ± 1.21	—
6.0	25.26 ± 3.05	10.88 ± 0.10	14.38 ± 3.05	—	13.67 ± 0.69	—
6.5	26.55 ± 3.27	9.76 ± 0.96	16.79 ± 3.41	9.17 ± 1.94	10.77 ± 0.92	—
7.0	28.78 ± 3.62	10.78 ± 1.20	18.00 ± 3.81	16.08 ± 1.59	13.66 ± 0.49	2.42 ± 1.66
7.5	25.63 ± 2.77	10.39 ± 0.87	15.24 ± 2.90	—	13.53 ± 1.07	—
8.0	16.33 ± 3.06	8.68 ± 0.84	7.65 ± 3.18	14.96 ± 2.17	11.39 ± 0.95	3.56 ± 2.37
8.5	15.69 ± 2.98	9.35 ± 0.89	6.34 ± 3.11	9.77 ± 2.70	8.62 ± 0.79	1.15 ± 2.81
9.0	3.95 ± 2.42	14.87 ± 0.72	—	—	—	—
9.5	—	12.75 ± 1.89	—	—	—	—
13.5	8.28 ± 1.00	2.91 ± 0.49	5.37 ± 1.11	—	—	—
14.0	5.31 ± 1.43	0.73 ± 0.35	4.58 ± 1.47	—	—	—

A possible sediment loss at the topmost section should not affect the sedimentation rate determined by the ^{210}Pb method. It will however, seriously affect the rate determined by the ^{137}Cs method. In our case the sedimentation rates obtained by both methods agree quite well. We take this as an indication of no loss in the uppermost sections of the sediment core samples.

Two sediment cores were recovered from northern Cyprus (KS-1 and KS-2). The activity measurements are summarized in Table 4. Figures 2f to g show the unsupported ^{210}Pb activity profile for KS-1 and KS-2. The sedimentation rates were evaluated as $0.28 \pm 0.01 \text{ cm} \cdot \text{y}^{-1}$ ($0.22 \pm 0.01 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$) and $0.16 \pm 0.04 \text{ cm} \cdot \text{y}^{-1}$ ($0.13 \pm 0.03 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$), respectively. The corresponding atmospheric fluxes of ^{210}Pb were $0.44 \pm 0.02 \text{ pCi} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$ and $0.17 \pm 0.04 \text{ pCi} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$. The ^{210}Pb inventories based on a flux of $0.9 \text{ dpm} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$ were in 58% and 32%, respectively. The average atmospheric flux computed for this region of about $0.30 \text{ pCi} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$ is probably a

better representation of the atmospheric ^{210}Pb flux. The results of C.R.S. and C.I.C. models are shown in Figs 3f to g.

Fallout ^{137}Cs measurements

Figure 4a shows the distribution of ^{137}Cs along the BC-1 core. The first peak located at a depth of about 0.6 cm is thought to be a marker of nuclear weapons and testing restarted in 1963, whereas the second peak at about 8 cm may be a marker of the first high-yield thermonuclear tests which took place in 1954. According to the positions of these ^{137}Cs peaks, the sedimentation rate was computed as $0.81 \text{ cm} \cdot \text{y}^{-1}$ ($0.13 \pm 0.02 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$). The sedimentation rate

Fig. 4. Distribution of ^{137}Cs activity. a) core BC-1, b) core BC-6A, c) core KS-1, d) core KS-2

obtained from ^{137}Cs profile is in good agreement with the value obtained by the ^{210}Pb method. The position of the 1963 peak indicates a possible loss of the sediment material from the upper part of the core during sampling. Another reason could be the upward migration of ^{137}Cs from the deeper sections. The ^{137}Cs profile did not reveal a clear distribution pattern that could lead to dating for the BC-6A core.

Figures 4c to d show the distribution of the fallout ^{137}Cs along the KS-1 and KS-2 cores. The high ^{137}Cs levels in the top sections of both cores are striking and can be attributed to the fallout from Chernobyl in May 1986. The origin of the ^{137}Cs is confirmed by the associated presence of the short-lived ^{134}Cs isotope. The activities of ^{137}Cs and ^{134}Cs at the top section of the sediment cores were corrected to May 1986. The ratios of ^{137}Cs to ^{134}Cs activity were computed as 3.13 and 2.68, respectively. These ratios are in good agreement with those reported.⁸ Sedimentation rates were derived as $0.30 \pm 0.04 \text{ cm} \cdot \text{y}^{-1}$ ($0.20 \pm 0.02 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$) and $0.21 \pm 0.03 \text{ cm} \cdot \text{y}^{-1}$ ($0.17 \pm 0.02 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$) for KS-1 and KS-2, respectively, in good agreement with those from ^{210}Pb dating. The observed fallout ^{137}Cs activities for cores 2, 3 and 35 were quite low to allow any dating.

Conclusion

Table 5 summarizes the results of sedimentation rates for sediments from the Western and Eastern Mediterranean, using ^{210}Pb and ^{137}Cs methods. The sedimentation rates in the Mediterranean Sea seem to be higher than those reported for the Marmara Sea ($0.11 \text{ cm} \cdot \text{y}^{-1}$ ($0.087 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$)).⁹ The high sedimentation rates of the cores BC-1 and BC-6A are in the same range as those of rivers ($0.37\text{--}4.00 \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$).¹⁰ These high sedimentation rates are probably due to the fact that most of the cores of this work were recovered very near the shore.

Table 5
Summary of results of the sedimentation rate determinations from cores of the Western and Eastern Mediterranean using ^{210}Pb and ^{137}Cs

Core code	Sedimentation rate				
	^{210}Pb			^{137}Cs	
	$s, \text{ cm} \cdot \text{y}^{-1}$	$r, \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$	$P, \text{ pCi} \cdot \text{cm}^{-2}$	$s, \text{ cm} \cdot \text{y}^{-1}$	$r, \text{ g} \cdot \text{cm}^{-2} \cdot \text{y}^{-1}$
BC-1	0.84 ± 0.07	0.21 ± 0.02	0.74 ± 0.01	0.81 ± 0.09	0.13 ± 0.02
BC-6A	1.39 ± 0.12	0.50 ± 0.04	—	—	—
	and	and	—	—	—
	0.23 ± 0.20	0.12 ± 0.01	—	—	—
2	0.16 ± 0.01	0.08 ± 0.01	0.15 ± 0.01	—	—
3	0.31 ± 0.05	0.13 ± 0.02	0.12 ± 0.03	—	—
35	0.08 ± 0.01	0.04 ± 0.003	0.14 ± 0.02	—	—
KS-1	0.28 ± 0.010	0.22 ± 0.010	0.44 ± 0.020	0.30 ± 0.04	0.20 ± 0.02
KS-2	0.16 ± 0.04	0.13 ± 0.030	0.17 ± 0.04	0.21 ± 0.03	0.17 ± 0.02

Every radioactive nuclide present in the sediments may, in principal, serve as the basis for a particular method of age determination. The sole knowledge of the concentration of radionuclides in sediment does not suffice and further information is in fact necessary. In the case of deep-sea sediments, ^{14}C , ^{10}Be , ^{230}Th , ^{231}Pa , ^{230}Th – ^{232}Th , ^{231}Pa – ^{230}Th measurements¹¹ are used in chronological studies.

The ^{210}Pb and ^{137}Cs radionuclides may also be considered useful in the chronology of sea sediments, where the average depth of the region is of the order of those of lakes. The distribution of ^{210}Pb and ^{137}Cs radioisotopes in the inshore regions may be affected by physical mixing and/or erosion process.

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