NUKLEONIKA 2006;51(Supplement 2):S39–S44

Determination of the sediment deposition rates in the Kuwait Bay using ^{137}Cs and ^{210}Pb

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Abstract Five bottom sediment cores from the Kuwait Bay were dated using ^{210}Pb and ^{137}Cs radionuclides. For evaluating the sedimentation rate two methods were applied: geochronology with the constant rate of supply unsupported ^{210}Pb (CRS model) and the Weibull distribution of anthropogenic ^{137}Cs. The sedimentation rates in this region, calculated by the first method ranged from 0.24 to 0.39 cm/year, while the same rates obtained from ^{137}Cs distribution were slightly lower: from 0.1 to 0.25 cm/year. These relatively small differences can be explained by additional input of the Chernobyl accident to the ^{137}Cs inventory in the bottoms sediments of the Northern Hemisphere.

Key words bottom sediments • sedimentation rate • unsupported ^{210}Pb • ^{137}Cs radionuclide

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Received: 10 October 2005
Accepted: 15 December 2005

Introduction

Chemical compositions as well as radionuclide concentrations in the bottom sediment cores are the source of valuable information concerning the physicochemical processes occurring in water ecosystems. Particularly, the determination of concentration of some pollutants and specific activity of the natural radionuclide ^{210}Pb in profiles of bottom sediment cores allows tracing the history and sources of pollution in different aquifers.

The isotope ^{210}Pb ($T_{½}$ = 22.3 y), a decay product of gaseous ^{222}Rn escaping from the surface of soil to the atmosphere, returns to the surface soil or water reservoirs within a couple of weeks as solid fallout. Part of the ^{210}Pb activity coming from the fallout and adsorbed in the surface sediments is called unsupported and it is strictly connected with sedimentary processes on the contrary to the ^{210}Pb produced inside the sediment matrix. For old (>150 years) sediments, covered with later deposited layers, this radionuclide is basically in radioactive equilibrium with ^{226}Ra, its long-lived precursor. Therefore, the unsupported part of ^{210}Pb activity in the bottom sediment layers can be simply calculated as a difference between the specific activities of these two radionuclides. The different models connecting the ^{210}Pb specific activity profile of sediment cores with sediment deposition dates or the rate of sedimentation are described in the literature [8]. The most widely used method for the lakes, coastal zones or estuaries, where sedimentation processes are intensified by anthropogenic actions is the constant rate of supply (CRS) of unsupported ^{210}Pb, proposed by Appleby and Oldfield [5]. An alternative method, based on the Weibull distribution of anthropogenic ^{137}Cs, which originally was proposed for soil samples [9], has been later developed also for dating of the bottom sediments [10]. This method has been very recently applied by the authors for preliminary determination of the sediment rates for two bottom sediment cores from the Kuwait Bay [4].

The Kuwait Bay is an important part of the Euphrates–Tigris–Karun (Shatt Al-Arab) Delta, whose geology, morphology and sedimentation is up to now poorly known. The distribution of sediment facies over this area was investigated in terms of influence of the tidal deposits on the occurrence of the foraminifera, only [3]. However, beside the river and tidal deposits, frequent dust storms also make a significant contribution to the sediment budget in this region. Moreover, the whole Arabian Gulf area is subjected to continuous man-made pollution connected with the production and transportation almost onethird of the world crude oil. Additionally, northern part of the Arabian Gulf was a region of the ecological disaster during the 1991 Gulf War, when an estimated 11 million barrels of oil were deliberately spilled into the sea and its destruction products and solid fallout from the half-year lasting fires of over 700 oil wells in Kuwait were partially transported to the bottom sediments. This was the reason of an international scientific activity in the determination of total petroleum hydrocarbons and trace metals in the bottom sediments as indicators of the scale of this pollution [1, 11].

The aim of this study was to compare the sedimentation rates by two independent isotopic methods: CRS and Weibull distribution of ^{137}Cs in the Sulaibikhat Bay, which occupies the south-western part of the Kuwait Bay. The main source of the silty and muddy sediments of the bay is the submerged estuarine delta deposits of the Schatt Al-Arab. The previous, preliminary measurements for two cores, examined mainly in connection with the hypothetical contamination of this area with depleted uranium, gave the exact value for one core only [4]. There are no other sedimentation rate data in the literature for this important estuary.

Experimental

Sampling methodology

The location of the sampling sites (Fig. 1) was achieved by GPS and the dead reckoning method using local marine navigation aids. The core samples were collected in shallow subtidal areas using a 7.5 cm aluminium tube. The pipe was pushed from the boat into the muddy sediment to a depth of up to 120 cm below the sediment/water interface. The pipe was then filled in the top by seawater and sealed tightly by an expandable rubber stopper and pulled out by rope. The core samples were subdivided into 5 cm increments through the length of the core.

Before the radioactivity measurements, the samples were oven-dried for 12 h at 105°C, crushed to pass through 0.5 mm sieve and then pressed in a special vessel to get the dishes of 7.2 cm in diameter and

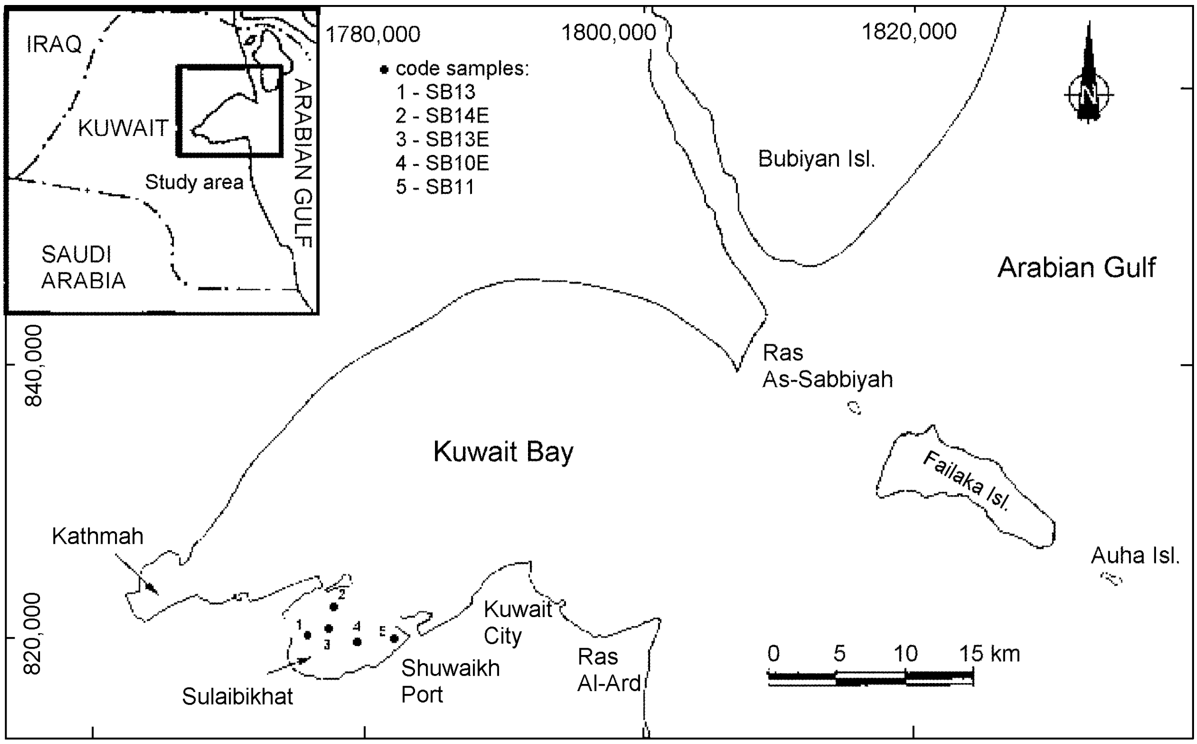

Fig. 1. Locations of the sampling sites on May 2004.

1.2 cm in height with the total mass of the sediment sample ~ 100 g. Such prepared samples were put into the polypropylene sealed dishes and kept at least 1 month before counting to achieve the radioactive equilibrium between ^{226}Ra and ^{222}Rn.

Radioactivity measurements

Radiometric analysis was carried out using a Canberra spectrometric system with a ReGe detector with a Be-window, described elsewhere [7]. The system was calibrated for the detection efficiency for the whole γ-energy region by preparing an identical bottom sediment samples with a ^{152}Eu standard (SREu-4, POLATOM, Poland). The activity concentration of ^{210}Pb and ^{137}Cs was determined directly from their basic γ-lines (46.3 and 661.3 keV, respectively), whereas the activity of ^{226}Ra was calculated from 295.1 and 351.9 keV of ^{214}Pb and 609.3 keV of ^{214}Bi γ-lines. The standard counting time of 1,600,000 s was applied to get the relative standard deviations in the activity concentrations below 10% for all radionuclides.

Quality assurance

The accuracy of the radiometric procedure was checked in independent experiments by determination of the measured radionuclides in three standard reference materials: IAEA-327 (Radionuclides in soil), IAEA-Soil-6 and IAEA-368 (Radionuclides in Pacific Ocean sediment). The obtained activity concentrations for all certified radionuclides were close to the reported values with deviations not exceeding 10%.

Results

Sedimentation rate determination from CRS model

Results of the determination of the radionuclides in five core profiles are given in Table 1.

At a constant rate of supply of the unsupported ^{210}Pb radionuclide model (CRS) the age of sediment – t in the layer at a distance of x from the sediment/water interface is given by the equation:

(1) $$t = 1/\lambda \ln(A_{0-\infty}/A_{x-\infty})$$

where: λ – decay constant of ^{210}Pb; $A_{0-\infty}$ – total inventory of the unsupported ^{210}Pb in the whole core; $A_{x-\infty}$ – cumulative inventory of the unsupported ^{210}Pb beneath sediment of depth x (Bq/kg dry weight).

Accordingly, the average sedimentation rate up the depth of x can be calculated from the formula:

(2) $$v = x/t$$

After introducing the Eq. (2) to Eq. (1), the following working expression is obtained:

(3) $$\ln(A_{0-\infty}/A_{x-\infty}) = \lambda(x/v)$$

Table 1. Activities of ^{137}Cs, ^{210}Pb and ^{226}Ra in core profile samples [Bq/kg d.w.]

Depth code [cm]	SB13E			SB10E			SB13			SB14E		
	^{137}Cs	^{210}Pb	^{226}Ra	^{137}Cs	^{210}Pb	^{226}Ra	^{137}Cs	^{210}Pb	^{226}Ra	^{137}Cs	^{210}Pb	^{226}Ra
5	2.57 ± 0.10	33.2 ± 1.6	19.0 ± 0.4	2.37 ± 0.10	35.6 ± 1.6	19.3 ± 0.4	2.23 ± 0.4	30.2 ± 1.8	19.4 ± 0.5	2.56 ± 0.08	36.1 ± 1.2	18.9 ± 0.3
10	3.00 ± 0.11	29.9 ± 1.5	19.7 ± 0.4	2.83 ± 0.11	32.8 ± 1.6	19.3 ± 0.4	1.37 ± 0.09	24.5 ± 1.5	20.1 ± 0.5	2.24 ± 0.08	34.8 ± 1.2	17.0 ± 0.3
15	3.55 ± 0.11	28.0 ± 1.5	19.8 ± 0.4	1.86 ± 0.09	24.7 ± 1.5	19.0 ± 0.4	1.35 ± 0.10	23.9 ± 1.7	19.7 ± 0.5	1.23 ± 0.06	28.8 ± 1.1	17.9 ± 0.3
20	2.79 ± 0.11	24.71 ± 1.5	19.5 ± 0.4	2.29 ± 0.09	24.5 ± 1.4	19.6 ± 0.4	0.41 ± 0.02	21.3 ± 1.2	19.1 ± 0.4	0.11 ± 0.05	20.9 ± 1.4	17.5 ± 0.3
25	1.28 ± 0.07	19.2 ± 1.4	18.1 ± 0.4	1.90 ± 0.09	26.2 ± 1.5	19.4 ± 0.4	0.82 ± 0.04	17.8 ± 0.9	16.4 ± 0.4	0.16 ± 0.04	19.4 ± 1.5	17.5 ± 0.3
30	0.43 ± 0.04	18.8 ± 1.4	19.2 ± 0.4	0.34 ± 0.04	25.4 ± 1.4	19.8 ± 0.4	≤0.09	18.3 ± 1.0	18.3 ± 0.4	<0.09	20.3 ± 1.5	17.7 ± 0.3
35	0.18 ± 0.03	18.1 ± 1.4	19.8 ± 0.4	0.59 ± 0.05	18.4 ± 1.3	19.1 ± 0.4	–	–	–	–	18.6 ± 1.5	18.3 ± 0.3
40	0.27 ± 0.02	18.0 ± 1.2	19.8 ± 0.3	0.28 ± 0.03	18.6 ± 1.4	19.2 ± 0.4	–	–	–	–	17.2 ± 1.4	17.5 ± 0.3
45	<0.09	18.7 ± 1.5	19.6 ± 0.4	0.74 ± 0.05	18.1 ± 1.4	18.8 ± 0.4	–	–	–	–	17.8 ± 1.5	17.6 ± 0.3
50	<0.09	18.2 ± 1.2	19.1 ± 0.3	<0.09	17.0 ± 1.4	18.3 ± 0.4	–	–	–	–	18.4 ± 1.5	18.0 ± 0.3

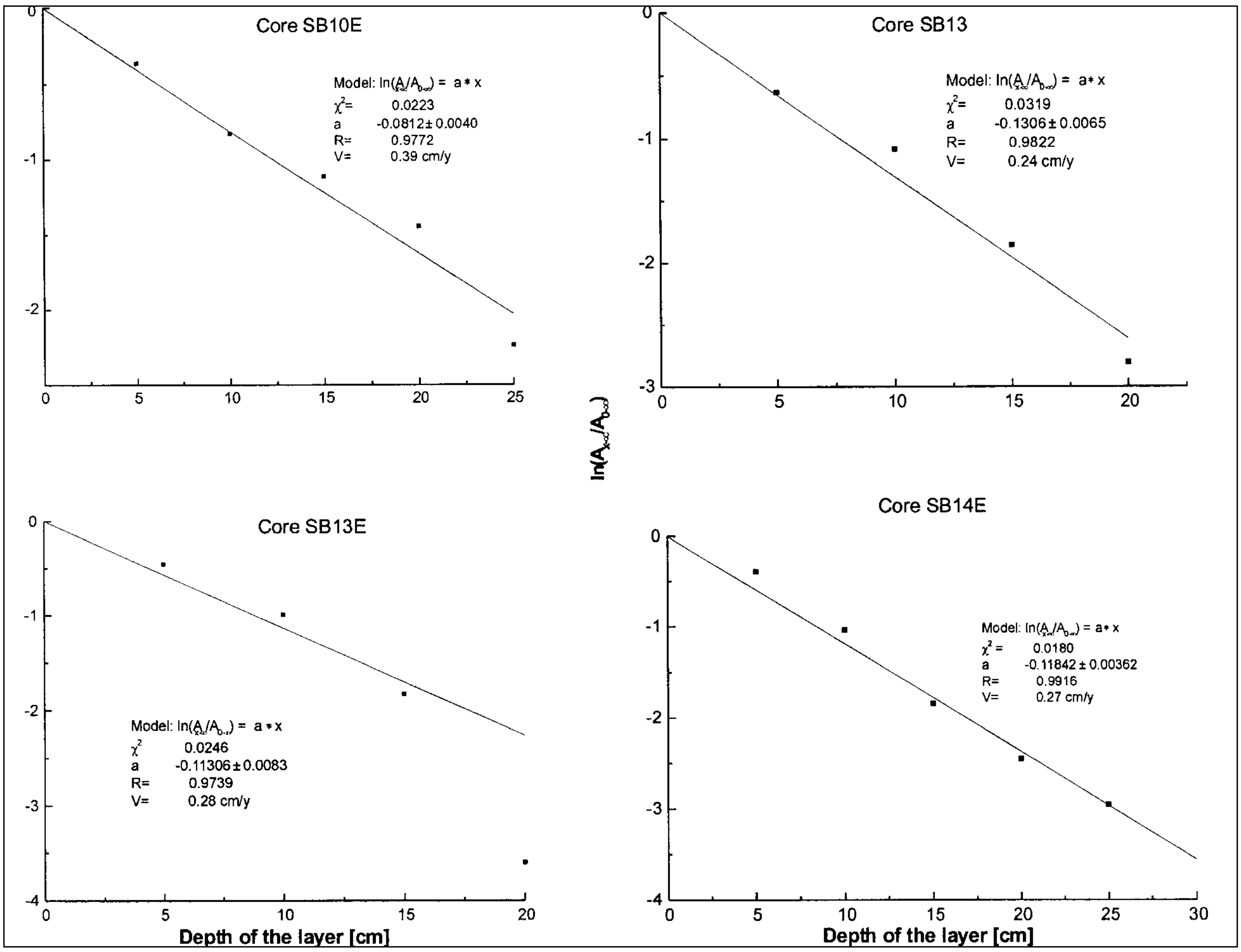

Fig. 2. Application of the CRS model for bottom sediment cores.

In Fig. 2, the application of Eq. (3) for calculation of the sedimentation rates for four cores is shown. The calculated values from the slope of linear relationship values of the sedimentation rates ranged from 0.24 to 0.37 cm/year.

The variation of ^{137}Cs activity with the depth of the profile for all examined cores is shown in Fig. 3. For one core (SB11), a strong mixing of the sediment layers was observed. It was probably caused by bioturbation frequently occurring in this hot water aquifer [2].

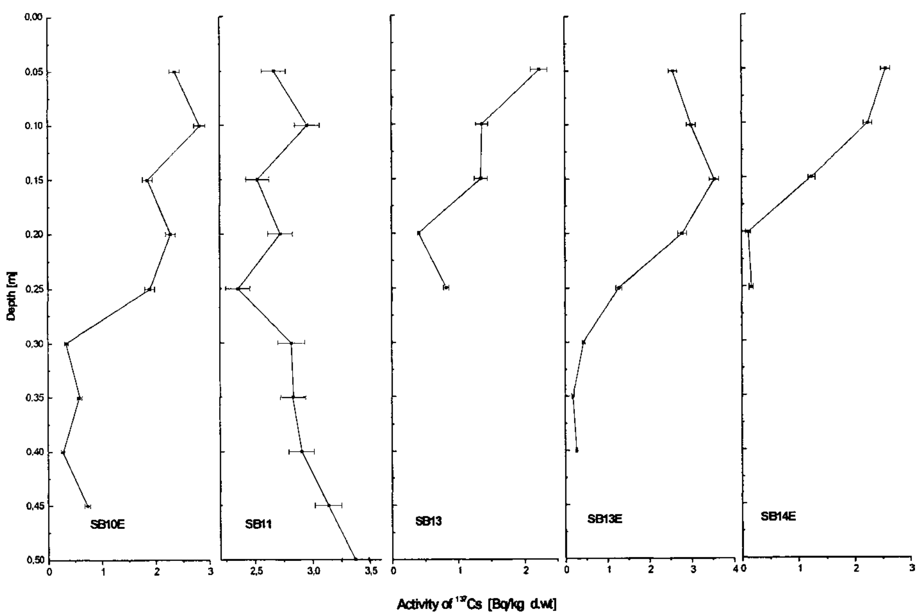

Fig. 3. Profiles of ^{137}Cs activity in bottom sediments.

Therefore, the results for this sample were excluded from calculation of the sedimentation rate by both the CRS and the Weibull distribution methods.

The ^{137}Cs profile data have been used for checking the validity of the Weibull exponential distribution for its description. According to this distribution, the vertical distribution of this radionuclide can be approximated by the following equation:

$$M_{0-x} = M_{0-\infty}[1 - \exp(\alpha x^n)] \tag{4}$$

where: M_{0-x} – cumulative specific inventory of ^{137}Cs in the core depth $(0-x)$ in Bq/m^2; $M_{0-\infty}$ – cumulative specific inventory of ^{137}Cs in the core depth $(0 - \infty)$ in Bq/m^2.

The unknown distribution parameters: $M_{0-\infty}$, α and n can be parameterised by the Genfit algorithm within MathCAD software, using the observed profile. After that, the concentration distribution of ^{137}Cs can be expressed as

$$C(x) = M_{0-\infty}\alpha n\, x^{n-1}\exp(\alpha x^n) \tag{5}$$

and after differentiation of Eq. (5), the depth, for which the maximum concentration of ^{137}Cs occurs –x_m, can be calculated from the following formula:

$$x_m = \exp\{1/n \cdot \ln[(n-1)/\alpha n]\} \tag{6}$$

The application of the Weibull approximation for this four undisturbed cores with the calculated parameters of this distribution and values of x_m, is presented in Fig. 4.

It is evident from this figure the cumulative specific inventories well fit into this distribution. However, the concentration distribution data are generally dispersed around the theoretical curve. If one regards the values of x_m as the peak of the year 1963, when maximum ^{137}Cs global fallout occurred, therefore, the sedimentation rate can be calculated by dividing the values of x_m by time which elapsed from 1963 to the sample collection. Such calculated values of the sedimentation rates – v are also given in Fig. 4. Generally, they are lower than those determined by the CRS model.

Conclusions

Simultaneous determination of ^{137}Cs, ^{210}Pb and ^{226}Ra activity in the sediment core profiles allows the determination of the sedimentation rates by two independent methods. In general, the rates obtained for the top <50 cm of the sediments from the Sulaibikhat Bay are in the range of 0.09–0.39 cm/year. These are in good agreement with our previous data [4] and the scarce values reported for the other part of the Arabian Gulf [2] and adjacent coastal area [12]. However, the application of the Weibull distribution model generally gives lower values in comparison to the CRS model. It can be caused by composed phenomena and some irregularities of the ^{137}Cs fallout. Beside the global

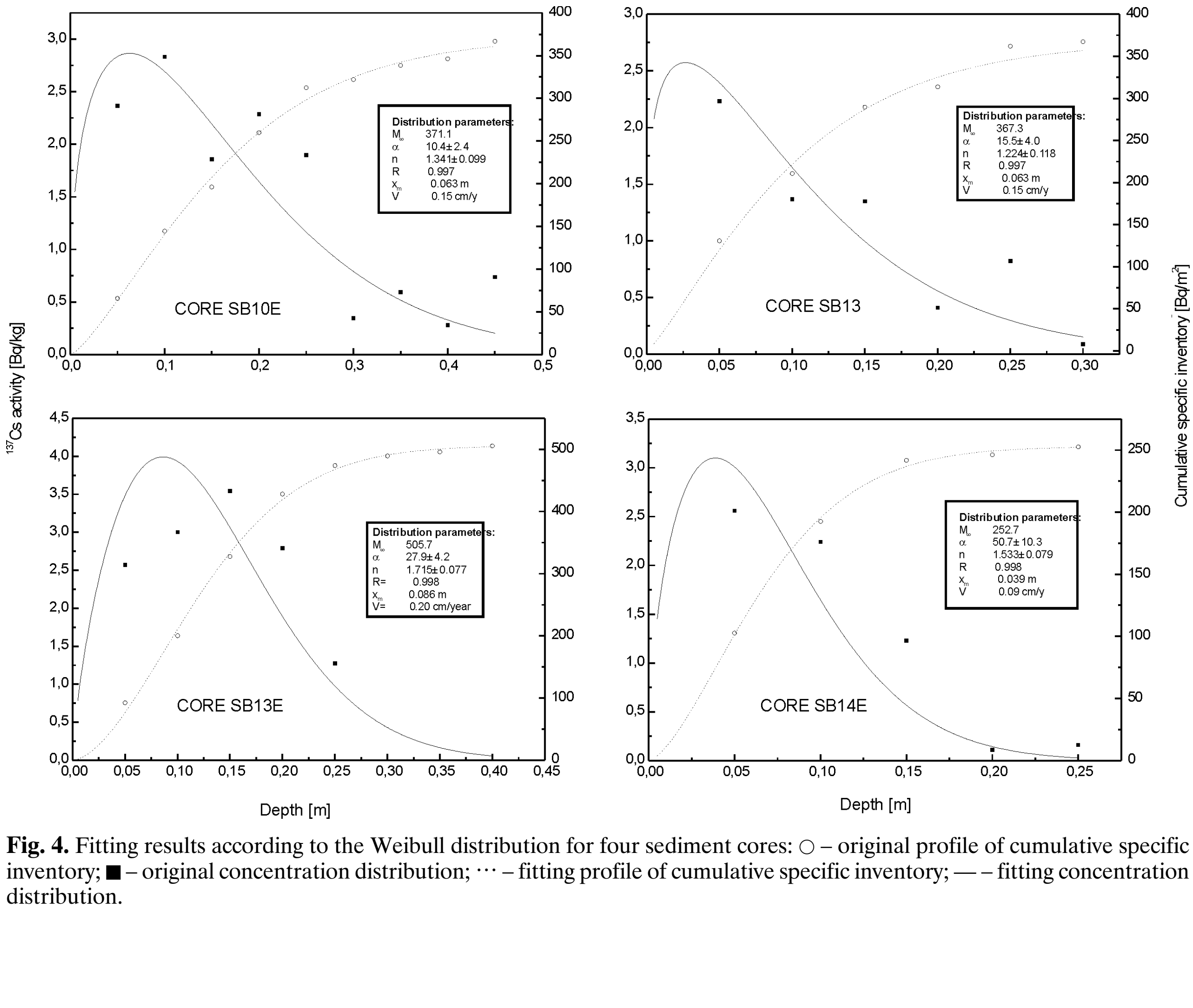

Fig. 4. Fitting results according to the Weibull distribution for four sediment cores: ○ – original profile of cumulative specific inventory; ■ – original concentration distribution; ⋯ – fitting profile of cumulative specific inventory; — – fitting concentration distribution.

fallout from nuclear atmospheric tests, the sediment inventory of this radionuclide was greatly influenced by the later Chernobyl accident in 1986. The higher ^{137}Cs fallout in this region was also observed later in 1996 and 1999 [6]. Therefore, this experimentally relatively simple method should be used as an auxiliary one, only. However, measuring anthropogenic ^{137}Cs activity in the sediment core profiles supply useful information concerning bioturbation and mixing in the cores and allow elimination of such samples from geochronology determinations.

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