PRELIMINARY STUDY OF SEDIMENT AGES AND ACCUMULATION RATES IN JAKARTA BAY DERIVED FROM DEPTH PROFILES OF UNSUPPORTED ^{210}Pb

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ABSTRACT

Preliminary study of sediment ages and accumulation rates has been carried out in Jakarta Bay using unsupported ^{210}Pb. ^{210}Pb occurs naturally in sediments as one of the radioisotopes in the ^{238}U decay series. The total ^{210}Pb activity in sediments has two components, namely; supported and unsupported. The latter derives from dissociation of ^{210}Pb from ^{226}Ra through diffusion of the intermediate gaseous isotope ^{222}Rn which diffuse into the atmosphere and decay to ^{210}Pb. ^{210}Pb falling directly into seawater and deposit on the bed of the marine with sediments. ^{210}Pb has half-life of 22.26 years makes it well suited to dating and determining the accumulation rate of sediments laid down over the past 100 – 150 years. Two cores samples with diameter 7.5 cm were taken by scuba divers from Jakarta Bay and were analyzed of ^{210}Pb using α-spectrometer equipped with PIPS detector. The sediment ages and range of sediment accumulation rates of core I and II are up to 169 years and (0.25 – 1.93) kg/m^{2}y and up to 157 years and (0.15 – 2.68) kg/m^{2}y, respectively.

Keywords: *sediment ages, accumulation rates, marine sediment, ^{210}Pb.*

INTRODUCTION

In tracing of the history of man's effect on the environment it is evident in many places the period of greatest impact lies within the last 150 years. Lake and estuarine sediments provide a basis for reconstructing many aspects of this impact, for estimating rates of change and for establishing a baseline in environmental monitoring programs. In such studies the establishment of accurate dating of sedimentation as well as chronologies is of vital importance not only for dating events but also for determining sediment accumulation rates.

Several radionuclides can be used as tracers of various marine processes, including sedimentation. The natural radionuclide ^{210}Pb is one of the ^{238}U decay series (Fig 1), has physical half-life of 22.26 years and decays to ^{210}Bi by beta emission. It is present in the atmosphere as a result of the decaying series of events. ^{226}Ra in the earth's crust decays to the rare earth ^{222}Rn, which diffuse into atmosphere. ^{222}Rn decays via a series short half-lived daughters to ^{210}Pb. ^{210}Pb is removed from the atmosphere by precipitation and a range of residence times have been reported between 9.6 days and a few weeks[1,2].

^{210}Pb enters and is continuously introduced into the marine environment from, (i) the atmosphere, after decay from ^{222}Rn exhaled from the continental crust with short residence time in the atmosphere and is referred to as unsupported ^{210}Pb, and (ii) within the water column, mainly through the radioactive decay of dissolved ^{226}Ra, which is normally assumed to be in equilibrium with ^{226}Ra, is referred to as supported ^{210}Pb[2,3,4]. Because of its reactivity, it rapidly becomes associated with suspended matter and, therefore, subject to sedimentation. After deposited, it can be used as a tool for determination sedimentation rate over 100-150 years due to it half-life 22.26 years. The distribution of ^{210}Pb in the sediment profile reflects the depositional history, e.g., regular deposition, periods of non-deposition or erosion, mixing by bioturbation, changes in the deposition rate and change in the sediment source.

In this study, the ages and accumulation rate are determined from the depth profiles of unsupported ^{210}Pb of marine sediment. The samples from Jakarta Bay are analyzed in order to comprehend this technique. Moreover, this method in using natural radionuclide ^{210}Pb for determining of marine process is firstly developed in the Center for the Application of Isotopes and Radiation Technology, National Nuclear Energy Agency, Indonesia.

EXPERIMENTAL SECTION

In order to elucidate in determining of sediment ages and accumulation rates in marine sediment, two sediment cores were used which were collected by diver in May 2003 from eastern part of Jakarta Bay

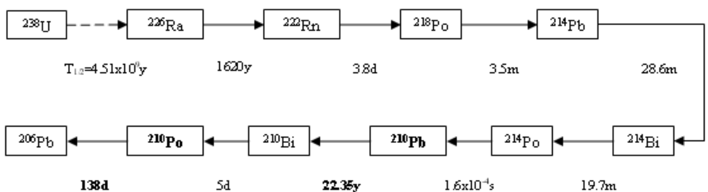

Fig 1. The generation of ^{210}Pb through the ^{238}U decay scheme.

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in collaborating with Research Center for Oceanography, Indonesian Institute of Sciences. Sediment cores were collected from the water depth of 10 m and 15 m and the length are 30 cm and 28 cm, respectively. In the laboratory, cores were sectioned at 1, 1.5 and 2 cm intervals from top to bottom and sections stored in sealed plastic bags. About half of each section was homogenized for ^{210}Pb analyses and the remaining was used for heavy metals analyses. Wet and dry masses were determined before and after drying samples at 60^{0}C, and dry bulk density were calculated. Sediment porosity was determined from water content, assuming a mineral density of 2.5 g.cm^{-3} [3,4,5]. ^{210}Pb analyses were performed according to the methodology described by Ballestra [6]. Briefly 3 g of dried homogenized sediment was spiked with ^{209}Po tracer for the determination of the chemical yield. A mixture of concentrated hydrogen chloride, nitric acid and aqua-regia was used to digest the sample. The remaining sample was filtered and ascorbic acid was added to complex any iron present. ^{209}Po and ^{210}Po in solution was plated onto a nickel disc for 3 hours at room temperature while stirring. Polonium isotopes (total) were counted with α-spectrometer equipped with PIPS detector (Canberra model A450-20AM) with the resolution 20 keV. ^{210}Pb was assumed to be in radioactive equilibrium with ^{210}Po in the sediment samples. Supported ^{210}Pb was determined from ^{226}Ra which is assumed in equilibrating between them, ^{226}Ra was analyzed using γ-spectrometer equipped with coaxial HPGe detector (Canberra model 2010) relative efficiency 10 % and resolution 2.3 keV in the energy ^{60}Co 1332 keV. Samples from top, middle and bottom cores were sealed for approximately 4 weeks to achieve equilibrium with it daughter of ^{210}Pb [3].

Table 1. Porosity and activity of unsupported ^{210}Pb in coring I from Jakarta Bay.

Depth (cm)	Porosity (ϕ) (%)	Unsupported ^{210}Pb (Bq/kg)
0-1	0.86	26.77
1-2	0.84	30.74
2-3	0.84	20.15
3-4	0.83	27.88
4-5	0.83	26.34
5-6	0.81	21.86
6-7.5	0.81	24.47
7.5-9	0.83	25.50
9-10.5	0.83	23.04
10.5-12	0.84	10.12
12-13.5	0.83	11.38
13.5-15	0.82	7.21
15-16.5	0.81	5.52
16.5-18	0.82	3.89
18-20	0.80	6.19
20-22	0.81	1.71
22-24	0.78	0.70
24-26	0.77	0.08
26-28	0.79	-
28-30	0.77	-

RESULT AND DISCUSSION

The sediment in both cores from Jakarta Bay comprised mainly fine grained silt and clay minerals with the silt + clay contents higher than 90%. The cores appeared homogeneous, with no visible stratification. The relationship between porosity (ϕ) and depth in core I and Core II are shown in Table 1 and Table 2, respectively. The value of ϕ in core I was 0.86% which found in the surface as indicated the highest value and decreased with depth to 0.77% at 28-30 cm. Similarly, core II has the value of ϕ was 0.88% in the surface and 0.77% at 26.5-28 cm. These trends indicated the increasing in compaction from the surface to the bottom along both sediment cores.

The activity of supported ^{210}Pb from top, middle and bottom of sediment cores which was assumed in equilibration with ^{226}Ra were relatively constant with depth. The activity of supported ^{210}Pb in core I and Core II was 11 Bq/kg and 16 Bq/kg, respectively. ^{226}Ra decays to form from the gaseous ^{222}Rn, which in turn decays via a series of short-lived daughters to form ^{210}Pb (Fig. 1) [7,8,9]. On the other hand, the activity of unsupported ^{210}Pb which was determined from the

Table 2. Porosity and activity of unsupported ^{210}Pb in coring II from Jakarta Bay.

Depth (cm)	Porosity (ϕ) (%)	Unsupported ^{210}Pb (Bq/kg)
0-1	0.88	23.45
1-2	0.86	21.80
2-3	0.86	27.04
3-4	0.85	21.69
4-5	0.87	18.35
5-6	0.86	24.95
6-7	0.87	26.20
7-8	0.86	18.69
8-9	0.85	20.35
9-10	0.83	25.74
10-11.5	0.81	19.10
11.5-13	0.80	16.10
13-14.5	0.82	16.84
14.5-16	0.81	22.88
16-17.5	0.8	24.42
17.5-19	0.78	13.34
19-20.5	0.80	13.18
20.5-22	0.78	8.17
22-23.5	0.78	1.94
23.5-25	0.80	1.32
25-26.5	0.77	-
26.5-28	0.77	-

differences between total ^{210}Pb and supported ^{210}Pb indicate decreased from top to the bottom with the maximum activity at the layer 1-2 cm (30.74 Bq/kg) and 2-3 cm (27.04 Bq/kg) for core I and core II, respectively. The unsupported ^{210}Pb levels in core I varied from 30.74 Bq/kg to 0.08 Bq/kg and in core II ranged from 27.04 Bq/kg to 1.32 Bq/kg (Table 1 and Table 2). Moreover, the activity of unsupported ^{210}Pb on the surface of sediment is constant, and is usually interpreted as being caused by sediment mixing on time scales that are short compared with the ^{210}Pb half-life (Krisnaswami et. al. and Koide et. al.) [7,10]. Mixing in this layer may be due to disturbance from waves or currents, or to the activity of invertebrates such as heart urchins which plough through the surface layer of sediment mixing components to a depth of about 2 cm (Bird et al,) [7,8,11,12].

The activity of unsupported ^{210}Pb with depth in core I and core II are not decrease exponentially; as a result, the sedimentation rates are not constant with the time. Due to this circumstance, the sediment age and accumulation rate are determined by using Constant Rate of Supply (CRS) model [8,9,10,11]. Calculations were made by:

$$A_d = A_o e^{-\lambda t}$$

$$t = \frac{1}{\lambda} Ln\left[\frac{A_o}{A_d}\right]$$

$$\lambda = \frac{\ln 2}{T_{1/2}}$$

where A_d is the unsupported ^{210}Pb in the core below depth d, A_o is the entire unsupported ^{210}Pb below water interface, λ is decay constant of ^{210}Pb, $T_{1/2}$ = 22.26 years and t is time (date).

The varying sediment accumulation rate r can be calculated from

$$r = \frac{\lambda A_d}{C_d}$$

where C_d is the unsupported ^{210}Pb concentration.

The inventory of unsupported ^{210}Pb was calculated as the sum of activity of unsupported ^{210}Pb at all depths. These are useful to study sediment accumulation, as inventory is independent of model interpretation. Total Inventory along sediment cores for core I was 1508 Bq/m^2 and core II was 1927 Bq/m^2, these values will be discussed below in relating to the sediment accumulation rates [6,14,15].

Results of calculation of sediment age and accumulation rate using CRS model are shown in Table 3 and Table 4 and represented in Fig. 2 and Fig. 3. Bottom sediments of core I and core II are dated as year of 1834 and 1846, respectively. Moreover, these dates correspond to the past 169 years and 157 years. Accumulation rates of sediment in core I varied from 0.25 kg/m^2.y to 1.93 kg/m^2.y with the average 0.97 kg/m^2.y, the maximum value corresponded to the year of 1996. Meanwhile, the accumulation rates in core II ranged from 0.15 kg/m^2.y to 2.68 kg/m^2.y with the average 1.56 kg/m^2.y. The accumulation rates in core I was slightly constant from 1910 to 1950 with the average of 0.75 kg/m^2.y, and significant change was produced from 60's to present time when the sediment accumulation rates increased from 0.57 kg/m^2.y to 1.93 kg/m^2.y. Similarly, the accumulation rates in core II

Table 3. Sediment ages and accumulation rate of coring I.

Depth (cm)	Date (year)	Sediment accumulation rate (kg/m^2.y)
0-1	2001	1.71
1-2	1998	1.37
2-3	1996	1.93
3-4	1992	1.28
4-5	1988	1.21
5-6	1983	1.26
6-7.5	1976	0.93
7.5-9	1967	0.69
9-10.5	1956	0.57
10.5-12	1950	0.99
12-13.5	1940	0.68
13.5-15	1931	0.80
15-16.5	1922	0.80
16.5-18	1910	0.83
18-20	1873	0.25
20-22	1834	0.28

Table 4. Sediment ages and accumulation rate of coring II.

Depth (cm)	Date (year)	Sediment accumulation rate (kg/m^2.y)
0-1	2002	2.52
1-2	2000	2.60
2-3	1998	2.00
3-4	1997	2.37
4-5	1996	2.68
5-6	1994	1.88
6-7	1992	1.63
7-8	1990	2.23
8-9	1988	1.93
9-10	1983	1.36
10-11.5	1978	1.57
11.5-13	1974	1.62
13-14.5	1968	1.33
14.5-16	1959	0.78
16-17.5	1942	0.49
17.5-19	1928	0.55
19-20.5	1901	0.30
20.5-22	1846	0.15

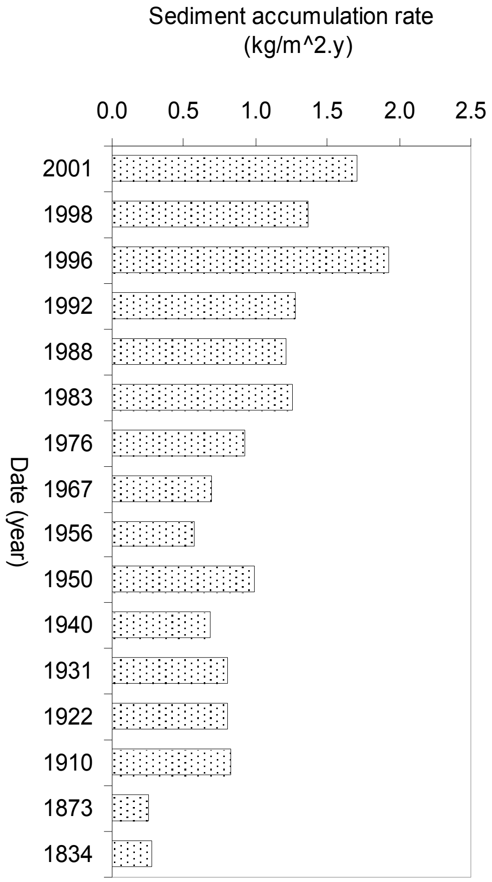

Fig 2. Sediment ages and accumulation rates of coring I of Jakarta Bay.

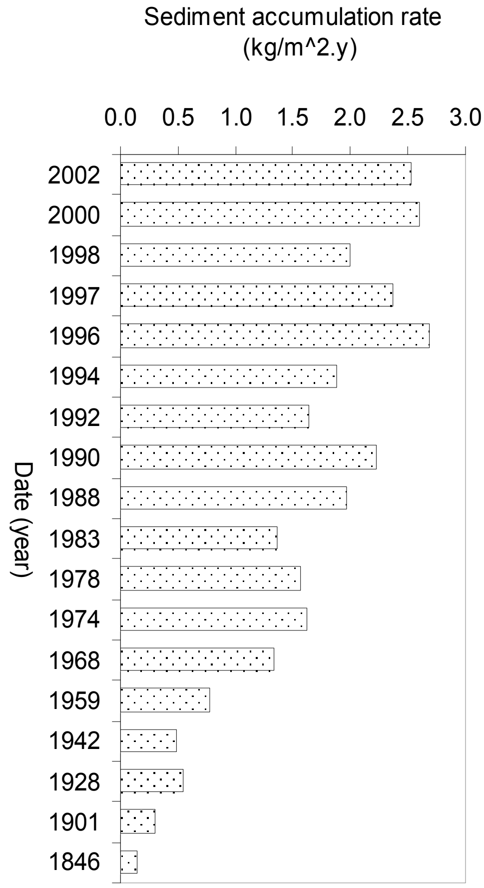

Fig. 3. Sediment ages and accumulation rates of coring II of Jakarta Bay.

was slightly constant from 1901 to 1950 and thereafter it increased significantly from 0.78 kg/m^2.y to 2.68 kg/m^2.y. The significant change in accumulation rates in both cores was caused by the change in the upper catchment of Jakarta Metropolitan area and its vicinity due to urban expansion and land clearing. Moreover, the fluctuation during the last century seems to have some correlations with major floods in recent history. These occurred in every 5 years approximately (in 2001, 1996, 1989) which can be identified in core II (Fig. 2), corresponding to time intervals during which increases in sediment accumulation rates took place [18,19].

Even though the fluctuation of accumulation rates in both cores are quite similar, but the sediment accumulation rates between two sediment cores was different. The average of sediment accumulation rates in core II approximately twice of core I. Non unexpectedly, the inventory in core II was found higher than in core I which related to the highly deposited sediment in the area of core II [6,17].

CONCLUSION

Unsupported ^{210}Pb can be used for determining the ages and accumulation rates of marine sediment. Example from Jakarta Bay was analyzed using CRS model and shows that the sediment ages in two cores are up to 169 years and 157 years on the bottom and the sediment accumulation rates range from 0.25 kg/m^{2}y to 1.93 kg/m^{2}y and 0.15 kg/m^{2}y to 2.68 kg/m^{2}y with the average 0.97 kg/m^2.y and 1.56 kg/m^2.y, for core I and core II, respectively. Moreover, the sediment accumulation rate on last 50 years increase significantly which may caused by the change on the upper land for construction and housing.

It is suggested to complement this method using artificial isotope ^{137}Cs and other conventional techniques for lacking errors of determination and interpretation.

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