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# CONSTANT RATE OF SUPPLY (CRS) MODEL FOR DETERMINING THE SEDIMENT ACCUMULATION RATES IN THE COASTAL AREA USING $^{210}Pb$

*Ali Arman Lubis**

Marine and Environment Group
Center for the Application of Isotopes and Radiation Technology
National Nuclear Energy Agency, BATAN
Jl. Cinere Pasar Jumat, Jakarta, 12440, Indonesia

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## ABSTRACT

*A CRS model has been applied to determine the ages and accumulation rates of sediment. This model assumes a constant flux of unsupported $^{210}Pb$ to the sediment, allows the rate of sedimentation to vary over time. The applicable of CRS model was used to analysis of two bottom sediment cores (JB 17 and JB 11) from Jakarta Bay. The result show that sediment accumulation rates in JB 17 varied from 0.09 to 1.13 kg.m$^{-2}$.y$^{-1}$ and in JB 11 varied from 0.18 to 2.47 kg.m$^{-2}$.y$^{-1}$.*

**Keywords**: CRS model, $^{210}Pb$, dating sediment, accumulation rates, coastal.

***) Correspondence**: Phone: + 62-21-7690709, Fax: +62-21-7691607, email: alilubis@batan.go.id

## 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 (Gelen, et al, 2003).

The isotope $^{210}Pb$ (T½ = 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 excess 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 excess 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 (IAEA-TECDOC-298, 1983; Crickmore, et al, 1990).

The excess $^{210}Pb$ activity in each sediment layer declines with its age in accordance with the usual radioactive decay law. This law can be used to calculate the age of the sediment provided that the initial excess $^{210}Pb$ activity when laid down on the

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bed of the marine can be estimated in some way (Crickmore, et al, 1990; Ivanovich, et al, 1992).

If the erosive processes in the catchment are steady, and give rise to a constant rate of sediment accumulation, it is reasonable to suppose that every sediment layer will have the same initial excess $^{210}$Pb activity. In this case the excess $^{210}$Pb activity will decline exponentially with depth of sediment. And the sediment accumulation rate is constant in all sediment layers which can be simply determined from the slope of semi-logarithmic of excess $^{210}$Pb against depth or cumulative dry mass. This model refers to a constant flux-constant sedimentation rate (CF:CS) model (Crickmore, et al, 1990; Ballestra, et al, 1994).

In many cases it is clear that rates of erosion and sedimentation have varied significantly during the past 150 years. In this event the $^{210}$Pb profile may be expected to be non-linear. There are essentially two models which are mathematically practicable for calculating $^{210}$Pb dates under varying sediment accumulation rates, the constant initial concentration (CIC) model and the constant rate of supply (CRS) model (Ballestra, et al, 1994; Sanchez-Cabeza, et al, 1999; Hancock, et al, 1999). The CIC model assumes that an increased flux of sedimentary particles from water column will remove proportionally increased amounts of $^{210}$Pb from the water to the sediments. The excess $^{210}$Pb activity will vary with depth in accordance with the formula (Pennington et al) : $C = C(o)e^{-kr}$ where $C(o)$ is excess $^{210}$Pb concentration of sediments at the sediment water interface. The age (t) of a sediment layer with $^{210}$Pb concentration C is therefore : $t = \frac{1}{k}\ln\frac{C(o)}{C}$

The CRS model assumes that there is a constant fallout of $^{210}$Pb from the atmosphere to the marine water resulting in a constant rate of supply of $^{210}$Pb to the sediments irrespective of any variations which may have occurred in the sediment accumulation rate. This model was proposed by Krishnaswamy et al. The cumulative residual excess $^{210}$Pb, $A$, beneath sediments of age t varies according to the formula:

$$A = A(o)e^{-kt}$$

where $A(o)$ is the total residual excess $^{210}$Pb in the sediment column and k is the $^{210}$Pb radioactive decay constant. k = ln(2)/$T_{1/2}$. $A$ and $A(o)$ are calculated by direct numerical integration of the $^{210}$Pb profile. The age of sediments of depth x is then given by:

$$t = \frac{1}{k}\ln\frac{A(o)}{A}$$

The sedimentation rates can be shown to be given directly by the formula:

$$r = \frac{kA}{C}$$

The different models connecting the $^{210}$Pb specific activity profile of sediment cores with sediment deposition dates or the rate of sedimentation are described above. 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 excess $^{210}$Pb. The constant rate of supply model (CRS) and models close to it take into consideration that there is always a variable sedimentation, i.e. sedimentation rates vary with depth. Modelling by CRS requires a thorough knowledge of the bulk density variation with depth. This model therefore keeps track of compaction and changes of compaction with core depth and is used widely in $^{210}$Pb dating.

The aim of this study is to use a CRS model in determining the age and sediment accumulation rates in relating to the many cases that the sedimentation have varied significantly with time and depth. The sediment cores from Jakarta Bay were used to discuss in detail the applicability of this model.

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# MATERIALS AND METHODS

### *Core sampling*

Two sediment cores were taken with a gravity corer with diameter 4 cm and the length of 50 cm from Jakarta Bay (Fig. 1). One core (JB 17) was collected from the deep part of the bay (30 m) and another one (JB 11) was collected from shallow water (10 m). Sediment cores were collected in 2004. Prior to the analytical procedures the cores were split in 2 cm slices for both cores. The outer of the sliced cores were discarded to avoid the mixing between layers. Wet and dry masses were determined before and after drying samples at 60$^{0}$C, and dry bulk density and porosity were calculated.

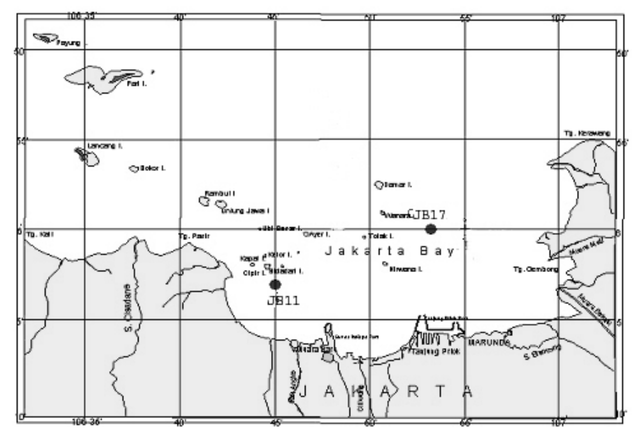


**Fig. 1**. Map of sampling location in Jakarta Bay

### *Analytical procedures*

Dating of sediments by $^{210}$Pb (22 years half-life) covers the time interval of about the past 150 years, i.e. it covers the start of the industrial age at the end of the 19th century. The dating includes estimation of radioisotope activities and modelling the activities with depth in a sediment core. $^{210}$Pb analyses were performed according to the methodology which can be found elsewhere (e.g., Madsen & Sørensen, 1979; Erlenkeuser & Pederstad, 1984) (Theng, et al, 2003; Carroll, et al, 1999). Briefly 3 g of dried homogenized sediment was spiked with $^{209}$Po tracer for the determination of the chemical yield. A mixture of HCl, $HNO_3$, $H_2O_2$ and $H_2O$ 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 stainless steel disc for 3 hours at room temperature while stirring to produce a thin film. Polonium isotope (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

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top, middle and bottom cores were sealed for approximately 4 weeks to achieve equilibrium with it daughter of $^{210}$Pb (IAEA-TECDOC-1360, 2003). The excess $^{210}$Pb, therefore, was determined from the subtraction of total $^{210}$Pb and supported $^{210}$Pb.

## RESULTS AND DISCUSSION

The accuracy of the radiometric procedure was evaluated in an independent experiment by checking the activity of determined radionuclide $^{210}$Pb in two standard reference materials produced by International Atomic Energy Agency: IAEA-368 and IAEA 300 marine sediments. The obtained activity concentrations for certified radionuclide $^{210}$Pb were close to the reported values with deviations of < 10 %. The result is tabulated in **Table 1**.

**Table 1.** Comparison of $^{210}$Pb concentration between present work and certified values for the standard reference materials IAEA-368 (Pacific ocean sediment) and IAEA-300 (Baltic sea sediment).

| Reference materials | Certified (Bq.kg$^{-1}$) | Present work (Bq.kg$^{-1}$) | Different (%) |
|---|---|---|---|
| **IAEA-368** | 23.2 | 24.9 | 7.3 |
| **IAEA-300** | 360 | 326 | 9.4 |

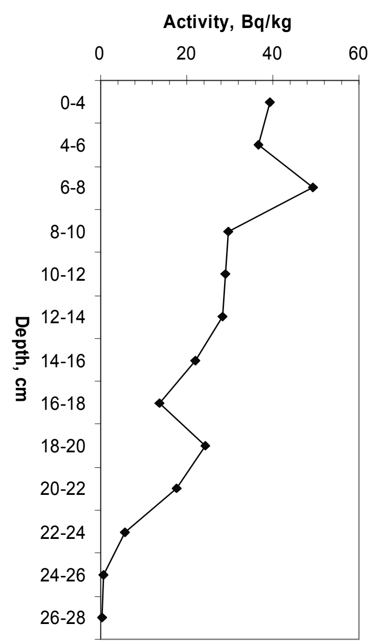


**Fig. 2a**. Depth profile of excess $^{210}$Pb in sediment samples of JB 17.

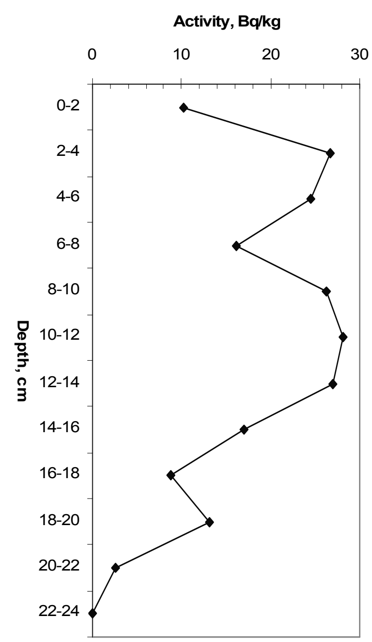


**Fig. 2b**. Depth profile of excess $^{210}$Pb in sediment samples of JB 11.

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The supported $^{210}$Pb of JB 17 and JB 11, has little or no variation with depth. Therefore, it was determined from the average of the three layers (top, middle and bottom), was 7 Bq.kg$^{-1}$ and 8 Bq.kg$^{-1}$, respectively. The profiles of excess $^{210}$Pb of JB 17 and JB 11 , on the other hand, significantly changed with depth, are graphically shown in Fig. 2a and Fig. 2b, respectively. They are both not decreasing exponentially; as a result, the sedimentation rates are not constant with time. Due to this circumstance, the sediment age and accumulation rates are determined by the most widely used a CRS model (Sanchez-Cabeza, et al, 1999). The CIC model could not be applied because of the non-exponential form and the behavior of $^{210}$Pb profile at both measurement points is non-monotonous decreasing. The Excess $^{210}$Pb activity profile in JB 17 and JB 11 has maximum value in a few layer beneath the surface sediment, indicate that on the top layer may be due to disturbance from waves or current, or to the activity of invertebrates such as heart urchins which plough through the surface layer of sediment (Hancock, et al, 1999).

The results obtained from calculation using CRS model for the ages and accumulation rates in JB 17 and JB 11 are tabulated in Tables 2 and Table 3, and the dating sediments are shown in Fig. 3a and Fig. 3b, and the accumulation rates in different time (date) are depicted in Fig. 4a and Fig 4b for JB 17 and JB 11, respectively.

Bottom sediments of core JB 17 (22-24 cm depth) and core JB 11 (18-20 cm depth) were dated as year of 1822 and 1873, respectively. There are two distinct correlations between depth and sediment date in JB17; i.e., 1) from top to the depth of (16-18) cm and 2) from (18-20) cm to the bottom. Similarly to JB 11; i.e., 1) from top to (14-16) cm and 2) from (16-18) cm to the bottom. These differences are affected by the concentration of unsupported $^{210}$Pb along the core. As can be seen from the profile of unsupported $^{210}$Pb in Fig 2a and Fig. 2b, there are shifts in the concentration in the depth of (18-20) cm and (16-18) cm for JB 17 and JB 11, respectively. Therefore, sediment accumulation rates were slightly constant in the lower part and afterward it changed to the surface.

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**Table 2**. Analysis data using CRS model to calculate the age and accumulation rates of sediment each layer of JB 17.

| Depth (cm) | Porosity (%) | Total $^{210}Pb$ ($Bq.kg^{-1}$) | Supported $^{210}Pb$ ($Bq.kg^{-1}$) | Excess $^{210}Pb$ ($Bq.kg^{-1}$) | Mass flux ($kg.m^{-2}$) | Inventory Excess $^{210}Pb$ ($Bq.m^{-2}$) | Excess $^{210}Pb$ (sum) ($Bq.m^{-2}$) | Estima-ted year | Date (year) | Accumulation rates ($kg.m^{-2}.y^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-4 | 74.59 | 46.37 | 7 | 39.37 | 7.67 | 302.19 | 302.19 | 6.8 | 1997 | 1.13 |
| 4-6 | 67.39 | 43.50 | | 36.51 | 4.32 | 157.81 | 460.01 | 11.0 | 1993 | 1.04 |
| 6-8 | 65.21 | 56.40 | | 49.40 | 4.85 | 239.69 | 699.70 | 18.7 | 1985 | 0.63 |
| 8-10 | 66.10 | 36.66 | | 29.66 | 4.94 | 146.52 | 846.23 | 24.5 | 1979 | 0.85 |
| 10-12 | 69.27 | 36.15 | | 29.15 | 4.32 | 126.02 | 972.25 | 30.5 | 1973 | 0.72 |
| 12-14 | 68.01 | 35.37 | | 28.37 | 5.02 | 142.67 | 1114.93 | 39.1 | 1965 | 0.59 |
| 14-16 | 65.37 | 29.10 | | 22.11 | 5.82 | 128.73 | 1243.66 | 49.3 | 1955 | 0.57 |
| 16-18 | 65.27 | 20.50 | | 13.51 | 5.55 | 75.08 | 1318.74 | 57.3 | 1947 | 0.70 |
| 18-20 | 66.84 | 31.16 | | 24.17 | 5.38 | 130.05 | 1448.80 | 78.7 | 1925 | 0.25 |
| 20-22 | 63.46 | 24.58 | | 17.58 | 5.73 | 100.83 | 1549.64 | 121.4 | 1883 | 0.13 |
| 22-24 | 63.48 | 12.81 | | 5.82 | 5.29 | 30.79 | 1580.43 | 181.6 | 1822 | 0.09 |
| 24-26 | 64.82 | 7.69 | | 0.69 | 5.55 | 3.83 | 1584.27 | | | |
| 26-28 | 63.02 | 7.27 | | 0.28 | 6.35 | 1.76 | 1586.04 | | | |
| 28-30 | 64.61 | 7.05 | | 0.06 | 6.17 | 0.35 | | | | |

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**Table 3**. Analysis data using CRS model to calculate the age and accumulation rates of sediment in each layer of JB 11

| Depth (cm) | Porosity (%) | Total $^{210}$Pb (Bq.kg$^{-1}$) | Supported $^{210}$Pb (Bq.kg$^{-1}$) | Excess $^{210}$Pb (Bq.kg$^{-1}$) | Mass flux (kg.m$^{-2}$) | Inventory Excess $^{210}$Pb (Bq.m$^{-2}$) | Excess $^{210}$Pb (sum) (Bq.m$^{-2}$) | Estima-ted year | Date (year) | Accumulation rates (kg.m$^{-2}$.y$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-2 | 69.53 | 18.29 | 8 | 10.29 | 6.51 | 67.01 | 67.01 | 1.2 | 2003 | 2.47 |
| 2-4 | 67.61 | 34.70 | | 26.71 | 6.79 | 181.45 | 248.46 | 4.6 | 1999 | 1.96 |
| 4-6 | 68.97 | 32.53 | | 24.54 | 7.78 | 191.02 | 439.49 | 8.7 | 1995 | 1.90 |
| 6-8 | 63.35 | 24.17 | | 16.17 | 9.76 | 157.93 | 597.43 | 12.5 | 1991 | 2.55 |
| 8-10 | 62.05 | 34.24 | | 26.24 | 9.20 | 241.44 | 838.87 | 19.5 | 1984 | 1.33 |
| 10-12 | 60.70 | 36.09 | | 28.10 | 11.32 | 318.14 | 1157.01 | 31.7 | 1972 | 0.93 |
| 12-14 | 64.33 | 34.91 | | 26.91 | 10.61 | 285.71 | 1442.72 | 48.9 | 1955 | 0.62 |
| 14-16 | 61.23 | 25.06 | | 17.07 | 9.76 | 166.68 | 1609.41 | 66.2 | 1938 | 0.57 |
| 16-18 | 61.00 | 16.86 | | 8.87 | 8.77 | 77.81 | 1687.23 | 79.0 | 1925 | 0.68 |
| 18-20 | 61.14 | 21.15 | | 13.15 | 9.62 | 126.56 | 1813.79 | 131.1 | 1873 | 0.18 |
| 20-22 | 59.02 | 10.57 | | 2.58 | 11.88 | 30.61 | 1844.41 | | | |
| 22-24 | 57.39 | 8.05 | | 0.06 | 12.31 | 0.70 | 1845.11 | | | |
| 24-26 | 53.22 | 8.4 | | 0.40 | 14.86 | 5.94 | | | | |

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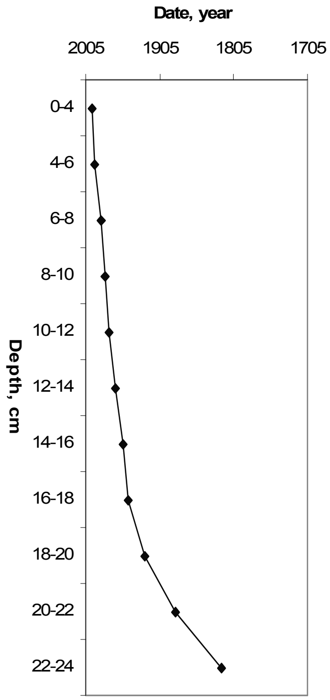


**Fig. 3a**. Dating sediment, the depth versus date in JB 17 using CRS model.

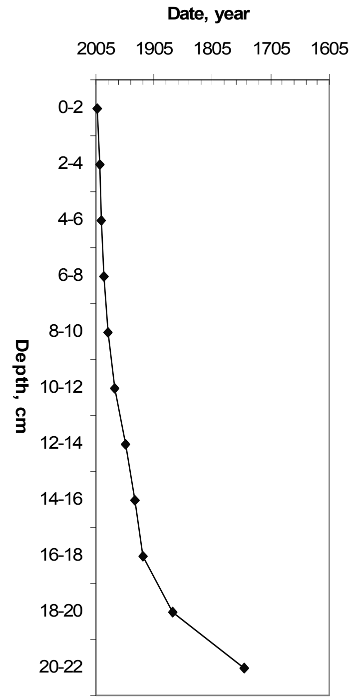


**Fig. 3b**. Dating sediment, the depth versus date in JB 11 using CRS model.

The sedimentation rate has experienced an increase along the time, from the minimum values for 150 years ago to the maximum values at the present time (Fig. 4a and Fig. 4b). The accumulation rate increases from 0.09 to 1.13 $kg.m^{-2}.y^{-1}$, approximately, at JB 17 and from 0.18 to 2.47 $kg.m^{-2}.y^{-1}$ in JB 11. This result is comparable to the previous result in 2003 with the accumulation rates 0.78 to 2.68 $kg.m^{-2}.y^{-1}$ which the sample was collected by scuba divers (Lubis, et al, 2006). Apparently, the accumulation rates in JB 11 seems twice of in JB 17 because core JB 11 was collected from onshore, whilst JB 17 was taken from offshore (deepwater of the bay). There will be a strong dependence on the contributions for the rivers basin in times of spates, being the area of the greatest sedimentation rate in the bay due to the fluvial confluence and tidal regime. As a result, the contribution of sediment loads from the rivers which ending up in Jakarta Bay was higher in JB 11 than in JB 17. Around the 70's the sedimentation rate had an important change which increased significantly up to present time in both points. These changes could be related to the starting of the increasing population in Jakarta and vicinity, and the heavy industries as well. As a result, land use changes, including urban expansion and land clearing in the Jakarta area, particularly in the upper catchments (Lubis, et al, 2006; Lubis, et al, 2004; Soehoed, 2002; Soehoed, 2003).

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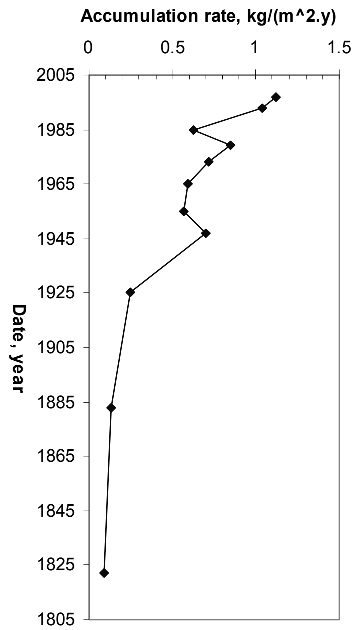


**Fig. 4a**. Accumulation rates versus year of formation for JB 17.

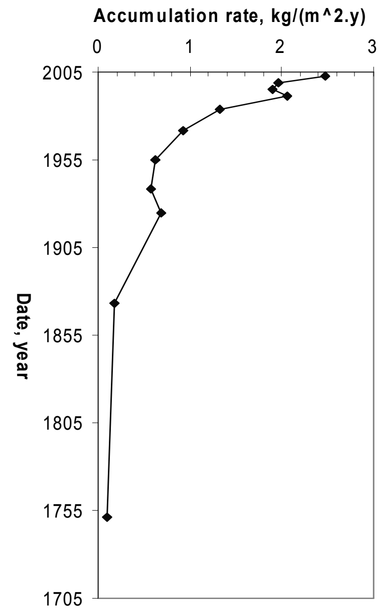


**Fig. 4b**. Accumulation rates versus year of formation for JB 11.

# Conclusion

It is clear that the CRS model can be used for analysis the concentration of unsupported $^{210}$Pb in sediment cores for determining the age and accumulation rates of sediment. Moreover, this model can determine the accumulation rates which vary with depth as well as time (year). The calculation sediment accumulation rates using CRS model of samples from Jakarta Bay are from 0.09 to 1.13 kg.m$^{-2}$.y$^{-1}$, at JB 17 and from 0.18 to 2.47 kg.m$^{-2}$.y$^{-1}$ in JB 11.

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