A NEW MODEL FOR CALCULATION OF FINE-GRAINED SEDIMENT ACCUMULATION RATE IN RAPID ACCRETION ZONES

Do Minh Duc[1] and Wim Boer[2]

[1]Faculty of Geology, University of Science, Vietnam National University, Hanoi

E-mail: ducdm@fpt.vn

[2]The Netherlands Institute for Sea Research (NIOZ)

ABSTRACT

Sediment accumulation rates in about 100 years have widely determined by radionuclide profiles of ^{210}Pb (half life=22.3y). Calculations of accumulation rate are made according to the constant initial concentration (CIC model) or constant rate of ^{210}Pb supply (CRS model). Generally, the CIC model is very popularly used. In this model, a constant initial concentration (supported value of ^{210}Pb activity) must be outlined. Because of high accumulation rates in rapid accretion zones, some gravity cores are not long enough to expose supported values and the accumulation rates can not be defined. The paper proposes a new model - apparent constant initial concentration (ACIC) that uses a numerical solution to determine supported values of cores in rapid accretion zones from adjacent cores with the defined supported values. During the joint project of Vietnam and the Netherlands in the Red River delta front, 12 gravity cores with lengths of 0.8-2.0 m were taken and analyze for ^{210}Pb activity. Results of using the model to analyze show that accumulation rates in the region can reach 3.96 cm/y.

1. INTRODUCTION

^{210}Pb method: The accumulation and erosion of sediment at the sea bottom are important in controlling morphological and biological processes. Rates of sediment accumulation can be determined by methods of natural radioisotopic analysis. ^{210}Pb is a radioisotope which is produced in the ^{238}U series. In the decay chain it leads to the production of stable ^{206}Pb. Marine sediments can receive ^{210}Pb from several sources: decay of ^{238}U dissolved in the seawater and ^{238}U in the sediment. Another pathway is that ^{238}U in the earth crust decays via a number of intermediates to ^{222}Rn and then escapes to the atmosphere. On its turn, ^{222}Rn decays via intermediates to ^{210}Pb, which is a solid. After a short stay in the atmosphere, ^{210}Pb falls out on land and ocean with rain and dust. The ^{210}Pb present in the ocean is adsorbed onto suspended particles in the seawater, part of which may sink and carrying ^{210}Pb down to the sea bottom.

Sediment accumulation rates in about 100 years have widely determined by radionuclide profiles of ^{210}Pb (half life=22.3y). On the sea bottom, the most recently deposited sediments in the water-sediment interface have the highest concentration of ^{210}Pb. At deeper depths, the concentration of ^{210}Pb decreases due to the decay. A typical profile of ^{210}Pb shows an exponential decrease with depth. However ^{210}Pb only decreases to a certain background value which caused by local production of ^{210}Pb from ^{238}U. Based on these characteristics, the calculation of accumulation rate from ^{210}Pb profile is made according to the constant initial concentration (CIC model). In this model, a constant initial concentration (supported value of ^{210}Pb activity) must be outlined. Because of high accumulation rates in rapid accretion zones, some gravity cores are not long enough to expose supported values and the accumulation rates cannot be defined. In the paper a new mathematical model has proposed to solve that problem and the Red River delta front is considered as an example.

Red River delta front at the Balat mouth – an example of rapid accretion zone: The Red River is the biggest river in the North Vietnam which runs from China to Vietnamese coast. Data of hydrological stations that the annual amount of suspended sediment transported by the Red River system into the Gulf of Tonkin is about 101 x 10^6 m^3 (Houwelingen, 2000). In the wet season (from June to January), about 90% of the whole sediment is transported (Nhuan et al., 1996) and 37.8% of the total amount of sediment supplied, through the Red River (Balat) mouth. Nowadays, despite sea level rise (1-2 mm/year) and rapid tectonic subsidence - 2 mm/year on average (Ngoi et al., 2000), the Balat mouth represents a very rapid accretion zone. The shoreline at the area is expanding at a rate of about 15-100 m/yr. The study area has a diurnal tidal regime with an average amplitude of 2.5-3.5 m. Waves usually have a dominant direction to the east, northeast in the dry season and to southeast, east in the wet season. The average and maximum wave heights are 0.7-1.3 m and 3.5-4.5 m, respectively, but in severe storms wave heights can reach over 5 m (Nhuan et al., 1996).

2. MATERIALS AND METHODS

Sediment samples were collected and obtained during the Vietnam - Netherlands "Red River Delta" joint research project in 2000. During two successive fieldworks in the dry (March) and wet (August) season of the project, a grid of 20 shallow penetrating echosounder profiles was retrieved. Based on the interpretation of the acoustic, stations were selected for bottom sampling. A total of 44 gravity cores (up to 2 m long) were taken (Fig. 1). All the sampling stations were taken at depths of over 8m. Gravity cores were subsequently split into two halves lengthwise by a core cutter. These two halves were macro described. Then a split half was sub-sampled by pressing PVC tubes (maximum capacity of 5 ml) with piston into the sediment. Volumes of samples were determined by a volume scale on the tubes and their weights were measured by an electric balance with a sensibility of 0.1 mg. These samples were kept in small glass bottles for further study on ^{210}Pb. Undisturbed core halves were X-Ray photographed by a Hewlet Packard Faritron Series 43805N-X-Ray machine emitted X-Rays with a voltage of 60 kVp. Sub-samples weighted about 100 mg each were subsequently taken from these halves for granulometry by Coulter LS 230 analyzer. Sediments sample in small glass bottles were freeze-dried, reweighed to determine dry bulk density. ^{210}Pb activities were determined by measuring it's grand daughter ^{210}Po. A sample of about 0.3 g of freeze-dry sediments was spiked with ^{208}Po as a yield tracer. Sediments were subsequently put in a concentrated mixture of HNO_3:HCl (ratio 1:1). After that the sample was electroplated onto a silver plate by spontaneous deposition in a 70% $HClO_4$ environment. The activity of the internal standard ^{208}Po and ^{210}Po was determined by measuring the count rate of the samples with a Canbera A-600-23-AM alpha pips detector.

Calculations of accumulation rate were made according to the constant initial concentration (CIC) model (Ivanovich and Harmon, 1992). In this model, the ^{210}Pb excess must decline exponentially against depth and follows a formula:

$$\ln(A_z) = \ln(A_o) - \lambda/s * z \quad \text{or} \quad s = \frac{\lambda * z}{\ln\left(\frac{A_o}{A_z}\right)} \qquad (1)$$

where: s is accumulation rate (cm/y), λ is decay constant of $^{210}Pb = 0.03114y^{-1}$, A_o and A_z are the activities of excess ^{210}Pb (mBq/g) at the surface and a depth of z (cm), respectively. The equation (1) can be converted to

$$A'_z = A_o * e^{a*z} + A_c \qquad (2)$$

where: A'_z is the activities of total ^{210}Pb at a depth of z, A_o is like above, A_c is the constant initial concentration or supported value of ^{210}Pb activity (mBq/g), $a = - \lambda/s$ (cm^{-1}).

The equation (2) is solved by least-square fit method with “Solver” procedure (see http://www.frontsys.com for detail) of Microsoft Excel which permits to determine the most fitted exponential function of an available set of ^{210}Pb activities (A_z’) with A_c, A'_o and a values at once.

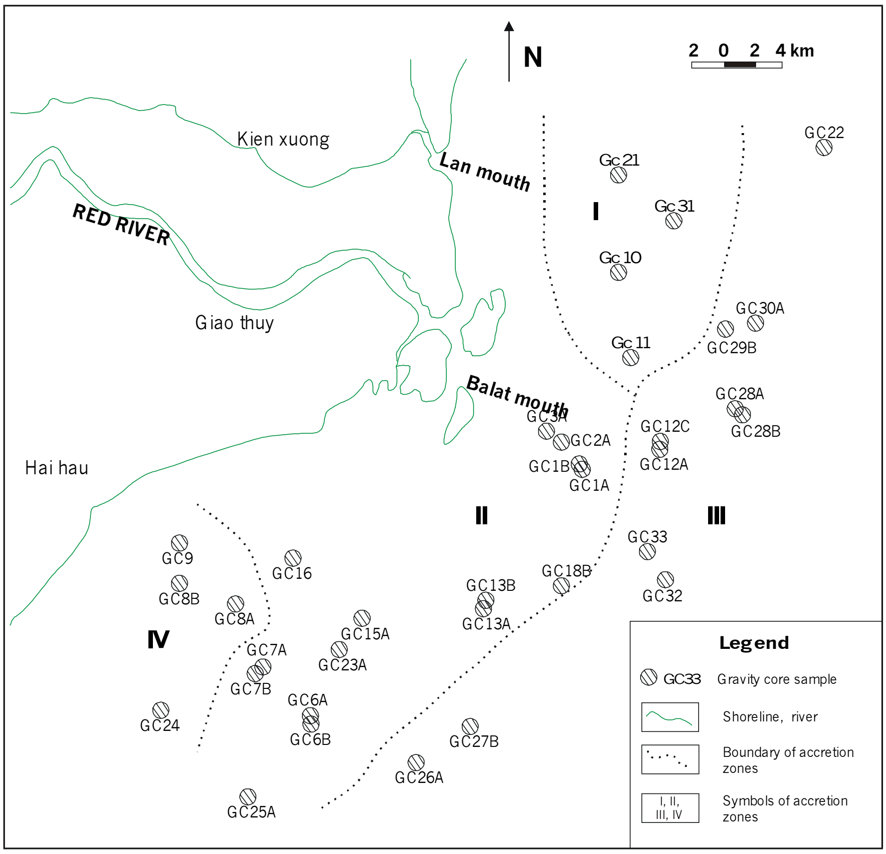


Figure 1. Gravity-coring stations and accretion zones in the Balat mouth

Because of high accumulation rate in the study area, some gravity cores were not long enough to expose a supported value of ^{210}Pb and the accumulation rates could not defined. In this paper, we propose a new model - apparent constant initial concentration (ACIC) that can use a determined supported value of a gravity core as a supported value of an adjacent core with high accumulation rate. For example G_0 is assumed to have a accumulation rate = s_o (cm/y) and a supported value = A_{co} (mBq/g) is defined at a depth of z_o (cm). G_1 is another core that cannot be determined a reliable supported value. A procedure of calculation is carried out in some steps as follows:

1. Test of compatibility: G_o and G_1 are quite close to each other, the cores were not taken at distinct depths and have same sedimentary characteristics (origin, colour, grain size and no bioturbidation being recognized in X-Ray photographs). A_{co} is met at the depth of z_o is equivalent to a time of about 100 years of sediment accumulation ($z_o/s_o \approx 100$).

2. Determination of accumulation rate of $G_1 - s_1$: assuming A_{co} is an apparent supported value of G_1 and the accumulation rate at G_1 is "n" times higher than G_o. So the supported value will be met at a depth of $z_1 = n * z_o$ (cm). Solving equation (2) for s_1 (in this case A_c in equation (2) is kept constant = A_{co} during "Solver" procedure).

3. Iteration: comparison of s_1 and $n * s_o$ if the different is higher a pre-defined value, change "n" and turn back to step 2. In the paper the pre-defined value is 0.01 cm.

The accumulation rate in a unit of g/cm^2/y is also calculated from equation (2) or by ACIC model with a change of z value to a cumulative dry mass value (g/cm^2).

3. RESULTS

So far 377 sub-samples of 15 gravity cores were analyzed for grain sizes . All gravity cores were X-Ray photographed for recognizing microstructures and bioturbidation. Twelve gravity cores were determined ^{210}Pb activities. Based on accumulation and deposition characteristics, the study area can be divided into 4 zones (Fig. 1).

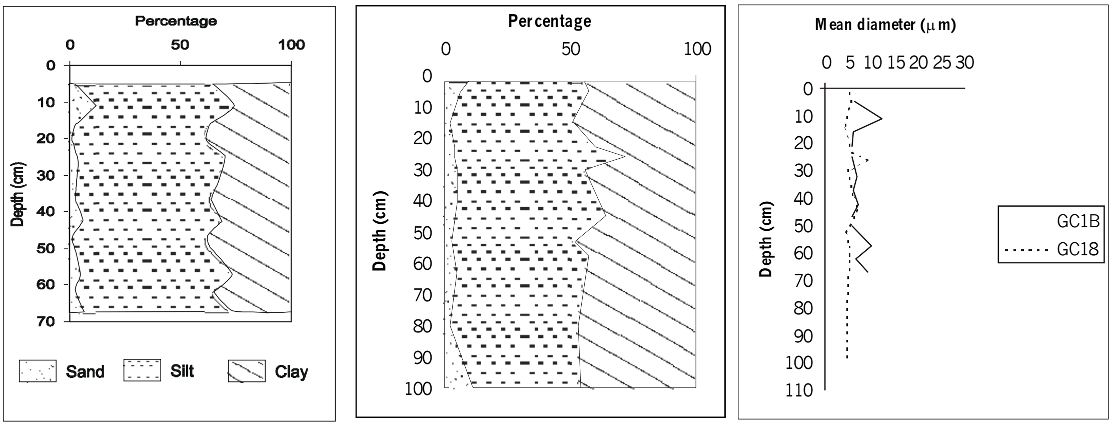
Zone 1 is in the north of the study area, includes cores GC10, 11, 21 and 31. The zone is specified as a low accretion zone. Two ^{210}Pb profiles were solved by the CIC model show that accumulation rate (S) varies from 0 to 1.17 cm/y and mass accumulation rate (ω) from 0 to 1.06 g/cm^2/y. The supported value (Ac) is quite stable and large in comparison to the other zones exceeds 46-47 mBq/g.

Zone 2 is from the middle to the south, includes 11 gravity coring stations. This is the main accumulation area in front of the Balat mouth. However two distinct sub-zones can be distinguished. The first is far from the river mouth (core 18) and further to the south (6B, 7A and 25). Herein the accumulation rates at the cores 18, 6B, 7A and 25 determined by the CIC models are from 0.69 to 1.68 cm/y and ω = 0.54-1.40 g/cm^2/y. Ac of the core 18 is 34.3 mBq/g. It is much higher at the other cores and reaches to 47-51 mBq/g. The second sub-zone is nearby the river mouth, includes 3 analyzed cores (1B, 2B and 15). The lengths of the cores are 70, 125 and 137 cm, respectively. Due to high accumulation rate, the cores are not long enough to expose the supported values. In order to solve the problem, 210Pb profiles of the cores were analyzed by ACIC model. Apparent supported value for cores 1B, 2B is taken from the core 18 and the one from the core 7A is used for the core 15. The similarity of grain-sizes of cores 1B and 18 (Fig. 2) permits a suitable use of ACIC model. The results of the model (Fig. 3) show that the accumulation rate at the core 1B is 1.83cm/y and ω is 1.41 g/cm^2/y. The core 2B has high, very small change in ^{210}Pb value and cannot be used for calculation of accumulation rate. One of the main reasons is that the location of the core is influenced by both accretion and erosion, among that accretion is dominant.

With the same procedure the accumulation rate was determined to be 3.96cm/y and 3.18g/cm^2/y at the core 15 (Fig. 4).

Zone 3 is the area of deeper than 25 m, includes 09 gravity-coring stations. The accumulation rate is very small. Three ^{210}Pb profiles were successful analyzed by CIC model that S is 0.15-0.18 cm/y and ω is 0.13-0.15 g/cm^2/y. However the supported value exposes in a quite large range from 37.6 to 47.1 mBq/g. It can be explained that this zone stretches in a large area from further north to south of the study area.

Zone 4 is at the southwest, includes GC8, 8B, 9 and 24. These cores were almost empty that shows surface sediments in zone 4 are sandy. Therefore sediment accumulation and deposition in this zone cannot be defined by ^{210}Pb.



a) b) c)

Figure 2. Grain size of cores 1B and 18

a) Core 1B b) Core 18 c) Comparison of mean diameter of 2 cores

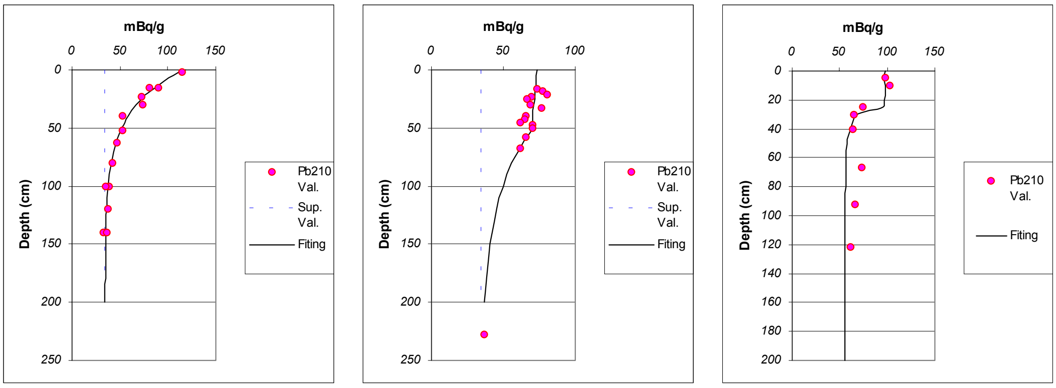


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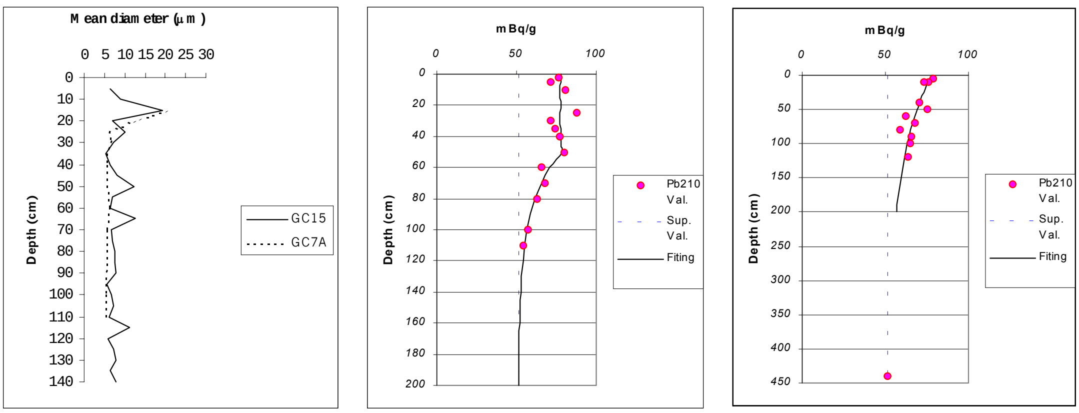
Figure 3. Results of CIC and ACIC models applied for cores 1B, 18 and 2B

a) Core 18 b) Core 1B c) Core 2B



a) b) c)

Figure 4. Results of CIC and ACIC models applied for cores 7A and 15

a) Comparison of grain-sizes b) Core 7A c) Core 15

4. DISCUSSIONS

A large amount of sediment transported through river mouths of the Red River system has made its delta front as a rapid accretion zone, especially in front of the Balat mouth. However the main accretion area is at the southeast and south of the mouth. Sediments are rarely transported to the southwest that causes a deficit of sediments in the Haihau nearshore zone and contributes to strengthen the shoreline erosion. High accumulation rates require long cores to expose the supported value of ^{210}Pb. In the Red River Delta project, the achieved gravity cores are between 0.8 to about 2m and in some cases the supported value cannot be defined. The establishment of the ACIC model provides a mathematical solution for this matter.

The ACIC model is developed from the CIC model and can use as the origin model if a supported value is defined from the available ^{210}Pb profile. In the case of using apparent supported value, the cores must be quite close to each other, the cores were not taken at distinct depths and have similar sedimentary characteristics (origin, colour, grain size and no bioturbidation being recognized in X-Ray photographs). These requirements make the new model a good reliability. The detail researches of microstructures, grain sizes and ^{210}Pb of cores in the Red River project have permitted a successful use of ACIC model.

The ACIC model derives a higher R2 value for the fitting curve and therefore represents a better reliability of the results. The ACIC can be applied in various zones with rapid accumulation rates. In the model, the influence of increasing of sediment dry mass when it is used to calculate mass accumulation rate.

5. CONCLUSION

The CIC model is very commonly used in practice of analyzing ^{210}Pb profiles. In rapid accretion zones, some gravity cores are not long enough to expose supported values for calculating the accumulation rates. The new model - apparent constant initial concentration (ACIC) assumes supported values of cores in rapid accretion zones from an adjacent core with the defined supported values. The procedure of calculation includes: 1) Test of compatibility of the cores; 2) Assume an accumulation rate in rapid accretion zone (S’) that can outline the exposing depth of supported value, then solve the equation for real accumulation rate (S) with “Solver” procedure of M.S. Excel; 3) Iterate step 2 until S-S’ is smaller than a pre-defined value.

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6. REFERENCES

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