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The Determination of Accretion Rate in Setiu Mangrove, Malaysia: Thorium-230 Versus Artificial Horizontal Marker Method

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ABSTRAK

Dalam kajian ini, penentuan kadar sedimentasi telah dibuat dengan menggunakan kaedah $^{230}Th_{excess}$ dan penanda tiruan mendatar. Dengan menggunakan kaedah $^{230}Th_{excess}$, purata sedimentasi sebanyak 0.62 cm thn^{-1} adalah diperolehi. Kadar sedimentasi ini adalah setanding dengan kaedah penanda tiruan mendatar yang memperolehi sebanyak 0.61 cm thn^{-1}. Kaedah $^{230}Th_{excess}$ adalah didapati lebih baik dan tepat bagi penentuan kadar sedimentasi. Penyediaan sampel adalah juga ringkas, malah prosedur penyediaannya adalah cepat dan mudah bagi penentuan kadar sedimentasi di hutan paya bakau. Sekiranya kadar sedimentasi melalui sampel teras diambil kira, kadar sedimentasi pada kedalaman 100 cm adalah dianggarkan termendap pada 163 tahun dahulu.

ABSTRACT

In this study, determination of sediment accretion rate using the ^{230}Th and the artificial horizon marker method in Setiu mangrove were done. Applying the $^{230}Th_{excess}$ method, an average accretion rate of 0.62 cm yr^{1} was obtained. This is comparable to that of an artificial horizon marker method giving an average of 0.61 cm yr^{1}. The $^{230}Th_{excess}$ method provides a rapid and simple method of evaluating $^{230}Th_{excess}$ accumulation histories in sediment cores. Sample preparation is also significantly simplified, thus providing a relatively quick and easy method for the determination of the accretion rate in mangrove areas. Assuming that the accretion rate values are accurate, this may imply that the sediments in the upper 100 cm were deposited during the last 163 years.

INTRODUCTION

Mangrove forests are a buffer zone between the coast and the ocean. One of their presumed important functions is to provide a mechanism for trapping sediment. In terms of their biological and chemical aspects, mangrove forests are a highly productive source of organic matter, from which there is a net outwelling of energy that supports the complex estuarine and nearshore food web. Geologists, on the other hand, view mangroves as sediment sinks, characterized by long-term import of sediments as indicated by the substantial accretion of recent sediments, which underlie mangrove forests and adjacent coastal plains (Wolanski *et al.* 1992). Physically, by virtue of being in the intertidal areas, they can act as recorders of environmental changes via sedimentological characteristics and in the preservation of spores and pollens.

Despite the acceptance that mangrove ecosystems are important sinks for sediments, few studies have addressed sediment accretion in this environment. Several authors (Goldberg and Koide 1962; Koide *et al.* 1972) have studied some aspects of the sedimentology of mangroves and quote different sedimentation rates, which is probably a reflection of the non-representative sampling techniques employed. Spenceley (1982) and Shahbuddin *et al.* (1998) have introduced a simple method for measuring accretion by simulating pneumatophores using rods and stakes and an artificial horizon marker method, respectively. Although long-term accretion rates using radionuclides have been well-documented (Sharma *et al.* 1987; Lynch *et al.* 1989; Anderson 1982) publications on the use of this approach have been few (Kamaruzzaman *et al.* 2000; Shahbuddin *et al.* 1998) and limited in the mangrove ecosystems. In the present study, we use thorium (^{230} Th) and an artificial horizon marker method to establish sediment accretion rates.

The measurement of ^{230}Th concentrations in sediments provides one method of developing accretion histories. ^{230}Th is formed at a constant rate in the water column from the decay of ^{238}U and is rapidly scavenged and incorporated into the underlying sediments. ^{230}Th is a valuable tracer of the processes whereby reactive elements are scavenged from seawater and produced at a constant rate throughout the oceans. Following its production in seawater, ^{230}Th is rapidly hydrolyzed and subsequently removed to sediments on a time scale of a few decades in the deep ocean and weeks to months in surface water. Their excess ^{230}Th (i.e., the amount in excess of that expected from secular equilibrium with ^{238}U present in mineral latices) has been widely used to date sediment horizons and estimate average accretion rates (Goldberg and Koide 1962; Ku 1976; Scholten *et al.* 1990). For the artificial horizon marker method, sediment accretion was based on the vertical basis only. Vertical sediment accretion refers to the vertical thickness of sediment gained in a certain area for a certain period and can either be positive, denoting accretion and growth, or negative, denoting erosion.

MATERIALS AND METHODS

Sampling

The Setiu mangrove of the study area is located on the South China Sea coast of Peninsular Malaysia and about 60 km northwest of Kuala Terengganu, the capital state of Terengganu (*Fig. 1*). The Setiu mangrove is a unique area as it covers many ecosystems such as estuaries, intertidal areas and lagoons. The lagoon's ecosystem is semi-enclosed with limited and poor tidal flushings and has a total water surface area of about 880 ha. This study area is of primary oceanographic interest since it is one of the largest estuaries of the Terengganu coast into which two river systems flow, i.e., the Setiu and Chalok rivers. These areas are areas of diverse ecosystems, with utilizable natural resources, a vast array of biological diversity and coastal and riverine fishing activities. The Setiu area lies in the wet tropics where high rainfall (averaging 400 mm) is recorded during the monsoon season. In this study, four transect lines (TR1, TR2, TR3 and TR4) were set up inside the mangrove (*Fig.* 1), where the total of 54 sampling stations were fixed along the transects. Two 150 cm sediment cores were also collected with a D-section core sampler from the mangrove forests. The cores were cut into segments of approximately 5 cm interval, labelled and stored frozen until analysis in the laboratory.

Determination of Sediment Accretion Using Artificial Horizon Marker Method

For the determination of the sediment accretion, the methodology applied in this work is based on measuring the thickness of a vertical sediment section divided by the time span necessary for its deposition. For the purpose of this study, a slab of perspex (9 cm x 9 cm x 1.5 mm) was planted at each sampling point and acts as a marker level. As a stabilization measure, the disturbed sediment above the markers were left for a month before initial readings of marker level depths were recorded. As another measure to aid stabilization of sediments above the marker levels, 5 holes were drilled in each perspex slab to enable water to pass through from the surface to the bottom. The thickness of sediments above the markers was then measured on a monthly basis for a 12 month period. The thickness of sediment at every sampling point was determined by taking the average of six readings per marker. Accuracy of reading is approximately ± 2 mm. The average thickness of the sediment for the month in study is then subtracted by the thickness of sediment obtained from the previous month. A positive value indicates accretion while a negative value indicates erosion.

Analytical Method for ^{232}Th and ^{230}Th

The sediment samples were digested and the analyses for total Th (^{232}Th) following the published methodologies with some modifications (Noriki *et al.* 1980; Sen Gupta and Bertrand 1995; Kamaruzzaman 1999). An inductively-coupled plasma mass spectrometer (ICP-MS) was used for the quick and precise determination of Th in the digested sediment. In brief, the digestion method involved heating of 50 mg of

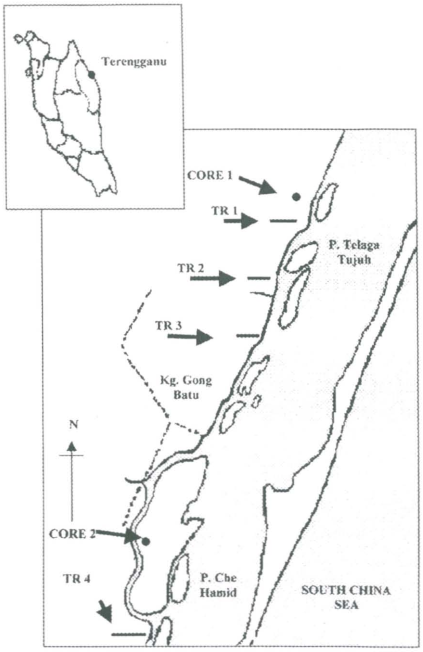

Fig. 1: Location of transects (TR1, TR2, TR3 and TR4) and cores (•) in the mangrove forests of Setiu mangrove, Terengganu, Malaysia

a finely powdered sample in a sealed teflon vessel in a mixture with a mixed acid solution (1.5 mL) of concentrated HF, HNO_3 and HCl. The Teflon vessel was kept at 150 ^{0}C for 3 – 5 h. After cooling, a mixed solution of boric acid and EDTA (3 mL) was added, and the vessel was again heated at 150 ^{0}C for at least 5 h. After cooling to room temperature, the content of the vessel was transferred into a 10 mL polypropylene test tube and was diluted to 10 mL with deionized water. A clear solution with no residue should be obtained at this stage. A laboratory standard material of mangrove sediment was also subjected to the same procedure. The relative 1 σ value of replicate determinations of a sample was less than 3% and the results obtained for HA, coincided with certified values within a difference of ± 3%.

The analytical method of ^{230}Th for the determination of sedimentation rate in the sample was carried out according to the published method (Tsunogai and Yamada 1979; Harada and Tsunogai 1985; Kamaruzzaman 1999) with some modifications. The method involved heating 1 - 2 g of dried sediment and digesting it with a mixture of solution of concentrated HF, HNO_3 and HCl. The solution containing Th was heated to make the solution clear before being treated with anion and cation exchange resins for the separation and purification. The effluent containing Th was then heated to dryness and finally dissolved in 5% HNO_3. The concentration of ^{230}Th was then measured with a fast and sensitive ICP-MS. The precision assessed by the replicate analyses was less than 3%. The accuracy was also examined by analyzing in duplicate a Canadian Certified Reference Materials Project standard (DL-1a) and the results coincided with the certified values within a difference of ± 3%.

RESULTS AND DISCUSSION

Accretion Rates

This study spanned 11 times from January 2001 to January 2002 and a thickness at all sampling points along each transet was recorded during low tides. Sampling dates and times were predetermined based on the yearly predicted tidal data table produced by the Hydrographic Department of the Royal Malaysian Navy. *Fig. 2* shows that the summary of the average accretion rate obtained was 0.61 cm yr^{-1}. The highest average accretion rates are found in the period from March to July corresponding to the non-monsoon season (*Fig. 2*). There is a positive accretion rate for all months (Table 1). The

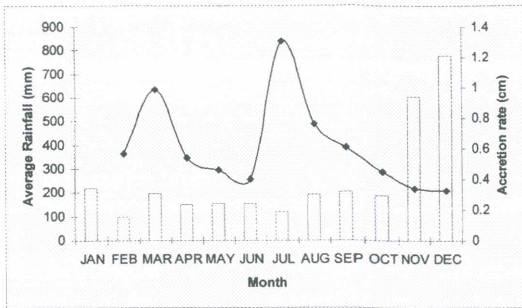

Fig. 2: Average of monthly mean rainfall (□) with average monthly accretion rate (▪) at Setiu mangrove

TABLE 1
Monthly accretion rate for TR1, TR2, TR3 and TR4 giving an averaged yearly accretion rate of 0.61 cm/yr

Month	Accretion Rate (cm)
February	0.62
March	0.99
April	0.57
May	0.46
June	0.40
July	1.31
August	0.89
September	0.65
October	0.55
November	0.45
December	0.36
Average cm/yr	0.61

highest accretion rate was observed in the month of July (1.31 cm month^{-1}) and lowest in December (0.36 cm month^{-1}). The much lower accretion rate during monsoon seasons (Nov – Jan) may be due to the higher energy of water movement from the upper stream, which may carry the fine sediment to the seas.

For the second method using thorium, $^{230}Th_{excess}$ was used to determine the accretion rates of the study areas (Scholten *et al.* 1994; Suman and Bacon 1989; Mangini and Stoffers 1990). The amounts of $^{230}Th_{excess}$ are calculated using the following equation:

$$^{230}Th_{excess} = {}^{230}Th_{total} - (0.8 \text{ X } {}^{232}Th_{total}) - {}^{234}U(1\text{-}\exp\{-l^{230}t\}) \qquad (1)$$

where $^{230}Th_{total}$ and $^{232}Th_{total}$ are the measured concentrations of ^{230}Th and ^{232}Th, respectively, and ^{234}U and l^{230} are the concentrations of ^{234}U (of which radioactivity is assumed to be 1.1 times the ^{238}U concentration) and the decay constant of ^{230}Th (9.24 x 10^{-6} yr), respectively. The second term on the right hand side of the equation ($^{232}Th_{total}$) is necessary in order to subtract the lithogenic fraction and the assumed coefficient, 0.8, which is a mean activity ratio of $^{230}Th/^{232}Th$ for the lithogenic fraction as reported by Anderson (1982). The third term ($^{234}U(1 - \exp\{- \lambda^{230}t\})$ is for the correction of ^{230}Th produced from ^{234}U in the sediments, which is necessary because ^{230}Th is produced from authigenic U contained in the sediment.

The determination of average sedimentation rate is based on the assumption that the $^{230}Th_{excess}$ is incorporated into the sediments with a constant rate (Ku and Broecker 1966; Osmond 1979). The values of $^{230}Th_{excess}$ derived from Equation 1, are as in Table 2. If this assumption is correct, the radioactivity of $^{230}Th_{excess}$ in sediment core which decreases exponentially with depth, and the sedimentation rates can be calculated from the following equation:

$$S=-\lambda^{230}/b \qquad (2)$$

TABLE 2
The values $^{230}Th_{excess}$ from both cores derived from the ICP-MS determination for samples from Setiu mangrove, Terengganu, Malaysia

Depth (cm)	CORE 1 $^{230}Th_{excess}$ (dpm)	CORE 2 $^{230}Th_{excess}$ (dpm)
5	0.9212354	0.0999891
15	n.d	n.d
25	n.d	0.175643256
35	0.81126842	0.17549332
45	0.80461206	n.d
55	1.0091255316	0.05433326
65	0.84016584	0.154021403
75	0.79115462	n.d
85	0.81121136	0.097565956
95	0.64565212	0.087338325

(n.d: not detectable)

where b is a gradient of the 'best-fit' curve in the plot of logarithmic concentrations of $^{230}Th_{excess}$ against depth (cm). As shown in *Fig. 3*, accretion rates for both cores were calculated to be 0.61 cm yr^{-1} and 0.62 cm yr^{-1}, respectively.

Our results for both methods, i.e. ^{230}Th and the artificial horizon marker method, are quite consistent giving an average accretion rate of about 0.61 cm yr^{-1}. However, the $^{230}Th_{excess}$ method provides a rapid and simple method of evaluating $^{230}Th_{excess}$ accumulation histories in sediment cores. Sample preparation is also significantly simplified, thus providing a relatively quick and easy method for the determination of the aceretion rate in mangrove areas. Even though our values for both the methods are somewhat higher, it is comparable to accretion rates reported at other intertidal areas (Bird 1971; Spenceley 1982; Shahbuddin *et al.* 1998).

Our higher values can be explained by the geographical position of our study area, where their location is located inside the estuary, close to the mouth, providing it with 2 sediment sources, fluvial and tidal. Greater water discharge from the river also brings much more suspended sediment to be trapped by the mangrove roots. Assuming that the sedimentation rate values are accurate, this may imply that the sediments in the upper 100 cm were deposited during the last 163 years. The high average accretion rates in the Setiu mangroves indicate that this mangrove is still prograding and in an immature stage.

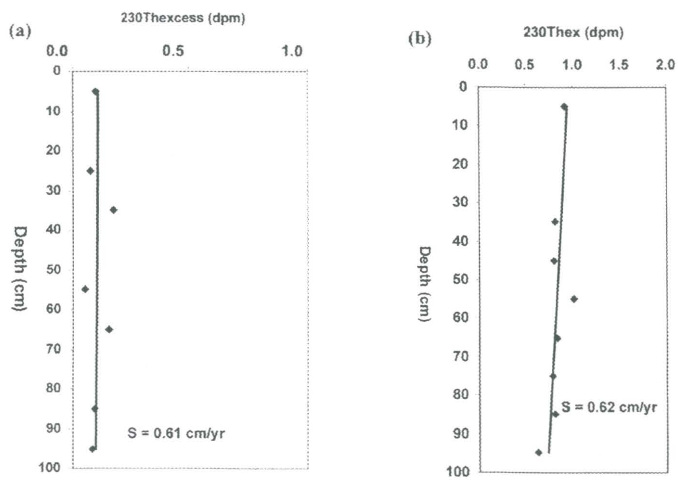

Fig. 3: (a) $^{230}TH_{excess}$ versus depth for core 1 and (b) $^{230}THexcess$ versus depth for core 2 with sedimentation rate, S = 0.61 cm/yr and 0.62 cm/yr, respectively

This finding suggests that the mangrove forests are not just passive colonizers of mud banks, but actively capture mud to create their own environments. Mangroves are thus an important sink for the fine sediment from rivers and coastal waters. Sediment supplied to the mangrove area might undergo the common process where they are suspended and carried back and forth, deposited and eroded before they finally settle either permanently or for a certain time period. The opportunity for sediment to settle or be deposited is greatly influenced by the frequency and duration of flooding (Cahoon and Reed 1995).

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