

Letter Section

CLAY SEDIMENT ACCUMULATION RATES ON THE MONSOON-DOMINATED WESTERN CONTINENTAL SHELF AND SLOPE REGION OF INDIA

D.V. BOROLE

National Institute of Oceanography, Dona Paula, Goa 403 004 (India)

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Abstract

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Clay accumulation rates shown in sediment cores from the nearshore to outer continental shelf and slope regions in water depths of 10-1246 m on the western continental margins of India were determined by the ^{210}Pb dating technique. The ^{210}Pb excess concentration encountered in these regions is about 3-5 dpm/g and is independent of water depth.

The range of clay accumulation rates is from 1.8 to 19 mm/yr for the shelf region and decreases southward from the Tapti and Narbada river confluence in the Gulf of Cambay. This pattern indicates sediment dispersal in the coastal region regulated by southwest monsoon-dominated littoral currents. The same trend is encountered all along the southwestern traverse. This suggests that suspended matter transport across the shelf is minimal since clay accumulation rates on the outer shelf are only 1.8-2.5 mm/yr.

The clay accumulation rate in the slope region is 3.8 mm/yr. The high accumulation rates encountered on the upper continental slope may be attributed to the terrigenous influx of Indus river sediment.

Introduction

The most suitable method for determining sediment accumulation rates is the ^{210}Pb excess dating technique (half life=22.2 yrs) which permits age determinations for the past 100 years (Krishnaswami et al., 1971; Koide et al., 1972, 1973). Comprehensive reviews of the technique have been given by Goldberg and Bruland (1974), Turekian et al. (1977), Turekian and Cochran (1978), Krishnaswami (1979) and Schell (1982). The potential of the ^{210}Pb technique as a tool for delineating trends

in modern accumulation rates and inferring processes on the Washington continental shelf has also been demonstrated (Nittrouer et al., 1979; Carpenter et al., 1981).

^{210}Pb geochronology of nearshore sediments is useful in reconstructing the recent sedimentary and climatic conditions, including flash floods and hurricanes; e.g., based on ^{210}Pb studies in Chesapeake Bay, Schubel and Hirshberg (1978) have identified two storm events and their contribution to sediment thickness. In addition to this, information on accumulation rates would be of particular use in tracing the influence of industrialisation, as Thomson et al.

(1975) have shown in their studies of Long Island Sound.

Although there are a few exceptions (Borole, 1980; Kalesha et al., 1980), little information is available on modern sediment accumulation in tropical coastal zones. Only two cores from the western continental shelf of India have been dated with ^{210}Pb (Borole et al., 1982b; Dilli, 1986). However, on the northwestern shelf Nair et al. (1982) and Nair (1984) have reported that sediment deposition from the Indus, although being hindered on the shelf by the tidal barrier off the Gulf of Kutch, is taking place in the deep waters of the continental shelf and this has been substantiated by Gupta and Hashimi (1985) who found typical Indus-borne clay minerals in cores from the slope.

Owing to the highly variable and strongly seasonal climatic conditions dominated by the monsoon regime prevailing over tropical India, sedimentary processes may differ markedly from those in temperate regions. Therefore, it is of interest to compare the accumulation rates from shelf regions which differ climatically. In this paper the ^{210}Pb results from seven cores from the western Indian margin are presented.

Study area

The western shelf, about 150 km wide near Karachi, widens to about 350 km off the Gulf of Cambay (Fig. 1), narrowing again to 60 km near the southwestern coast. Shallow seismic reflection studies by Siddiquie et al. (1985) reveal a 20–30 m of thick sequence of clay in this area, apparently a result of modern sediment deposition. Three rivers, the Indus, Narbada and Tapti, supply large amounts of sediment to this shelf. The Indus river alone contributes 0.44×10^9 t annually (Holeman, 1968) while the Narbada and Tapti together discharge about 0.6×10^8 t annually (Borole et al., 1982b). The general surface current direction is to the south and southeast during February to October with velocities ranging from 2 to 58 cm/s and during November to January it is reversed towards the

north and northwest, velocities ranging from 2 to 37 cm/s (Fig. 1).

The inner shelf and slope sediments are mostly clays and silty clays (fig. 1a, Nair and Hashimi, 1980) with low carbonate contents (5–25%) while the outer shelf sediments are rich in CaCO_3 (90–95%) (Rao, 1978). The predominant clay mineral is montmorillonite, followed by kaolinite, illite, chlorite and gibbsite (Nair et al., 1982).

Materials and methods

Five piston cores (5 cm diameter) were collected from the nearshore, inner shelf and outer shelf on R.V. *Gaveshani* in 1982 and gravity cores were taken from the slope region off Bombay on I.N.S. *Darshak* in 1969 in depths of 348–1246 m. The radiocarbon dates and chemical composition of these cores have already been published (Borole, 1980; Borole et al., 1982a,b,c). The core locations are shown in Fig. 1.

Measurement of ^{210}Pb in the sediments was carried out using the standard procedure described by Krishnaswami et al. (1971). The radon emanation method was used to measure ^{226}Ra (Bhat et al., 1974).

Results and discussion

The ^{210}Pb excess activity extrapolated to surface sediments for all the cores irrespective of water depth (10–800 m) is nearly constant, being about 3–5 dpm/g of sediment (Table 2).

Accumulation rates

Accumulation rates are controlled by redistribution and “bottom focusing”, or by preferential deposition of sediment by bottom currents as shown by ^{230}Th excess dating of sediments (Bacon, 1984; Bacon and Rosholt, 1982). Similar processes are applicable to dynamic coastal environments.

In terms of Pb isotope studies, the observed

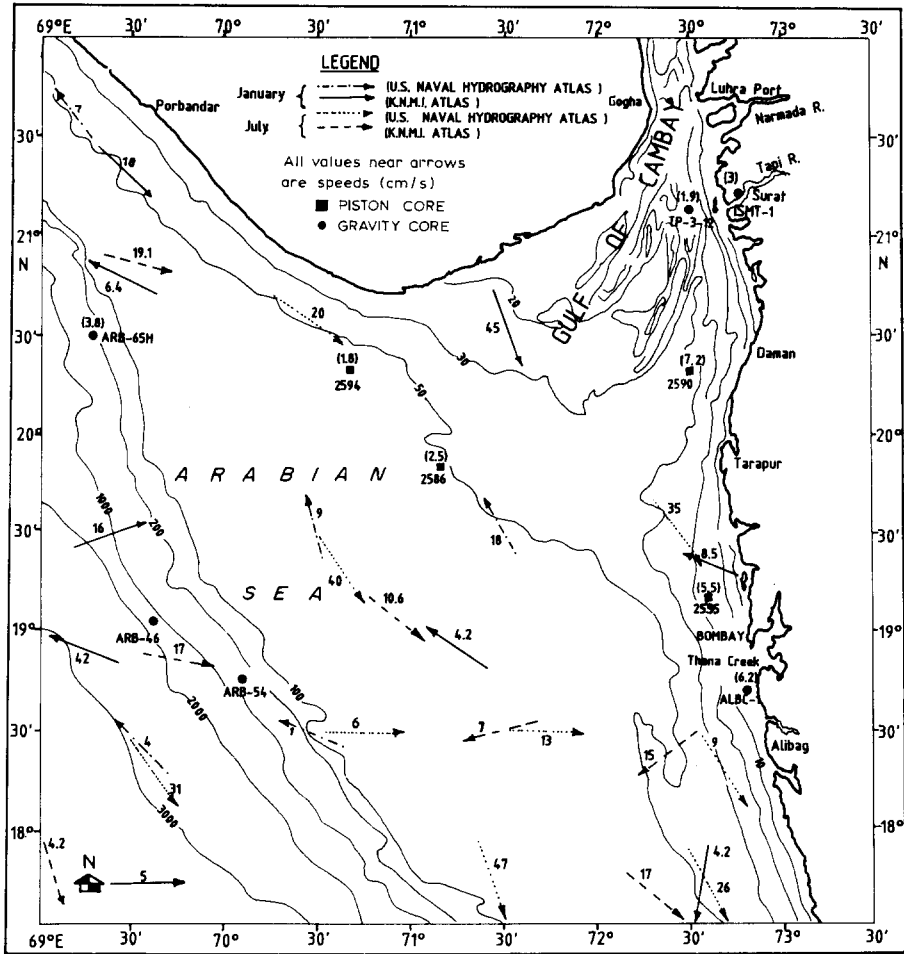


Fig. 1. Sampling location and bathymetry. Distribution of accumulation rates (mm/yr, numbers in parentheses) are also shown. Surface current patterns from K.N.M.I. (1952) and N.H.O.U.S. (1970).

^{210}Pb concentration gradient profile as a function of depth in a sediment core may be due to two processes: (1) the sources of ^{210}Pb particles accumulating in a given region could vary with time, resulting in a ^{210}Pb excess profile resembling that of a decay profile, or (2) the observed profile could be a real decay profile with depths for which a time frame can be obtained. In order to confirm either of these two processes $^{210}\text{Pb}/\text{Al}$ ratios are plotted (Fig. 2; see also Table 1) as a function of depth (Koide et al., 1973; Goldberg and Bruland, 1974). The nature of the profile remains unchanged no matter which process occurs. Normalisation of the ^{210}Pb con-

centration to the Al content of the sediment also overcomes the problem of porosity changes with depth in the sediment column and the clay accumulation rates could therefore be estimated based on the observed distribution of the $^{210}\text{Pb}/\text{Al}$ ratio in the profile (Fig. 2) assuming a constant flux of ^{210}Pb and sediment accumulation. The average accumulation rates estimated from the slopes of the best-fit lines are given in Table 2. However, in the case of core 2594, the ^{210}Pb activity is restricted to a thickness of 4 cm, below which there is no unambiguous signal of ^{210}Pb . This is because at these depths in the core the sediment largely consists of relict calcar-

TABLE 1
²¹⁰Pb concentration in shelf and slope cores

Core	Depth interval (cm)	Al* (%)	²¹⁰ Pb total (dpm/g)	²¹⁰ Pb excess** (dpm/g)
ALBC-1	0-2.5	8.1	3.61 ± 0.07	2.95 ± 0.11
	4.5-7.5	7.8	3.53 ± 0.05	2.87 ± 0.10
	22.5-26.5	7.9	1.64 ± 0.03	0.98 ± 0.09
	34.5-38.5	7.8	1.17 ± 0.02	0.51 ± 0.08
	46.5-50.5	8.1	0.91 ± 0.01	0.25 ± 0.08
2595	66.5-70.5	7.6	0.78 ± 0.02	0.12 ± 0.08
	0-2	7.8	4.57 ± 0.06	3.60 ± 0.07
	4-6	8.8	4.34 ± 0.04	3.37 ± 0.05
	10-12	8.8	3.48 ± 0.08	2.51 ± 0.09
	18-20	7.9	3.51 ± 0.10	2.54 ± 0.11
	24-26	7.4	2.38 ± 0.15	1.41 ± 0.16
	34-36	7.6	1.70 ± 0.06	0.73 ± 0.07
	58-60	8.0	1.13 ± 0.07	0.16 ± 0.08
	78-80	7.8	1.10 ± 0.11	-
80-82	7.0	1.01 ± 0.13	-	
2590	0-2	8.4	4.35 ± 0.08	3.20 ± 0.10
	6-8	8.0	4.20 ± 0.10	3.05 ± 0.12
	10-12	8.5	4.10 ± 0.09	2.95 ± 0.11
	20-22	7.9	3.06 ± 0.05	1.91 ± 0.08
	22-24	8.2	2.40 ± 0.07	1.25 ± 0.09
	32-34	7.9	1.96 ± 0.10	0.81 ± 0.12
	34-36	8.0	1.73 ± 0.05	0.78 ± 0.08
	60-62	8.2	1.31 ± 0.13	0.16 ± 0.14
	82-84	7.9	1.20 ± 0.15	-
90-92	8.0	1.10 ± 0.09	-	
2594	0-2	6.8	4.30 ± 0.10	3.42 ± 0.11
	2-4	7.6	3.57 ± 0.06	2.70 ± 0.08
	14-16	7.0	1.90 ± 0.11	1.02 ± 0.12
ARB-65H	0-5	4.2	3.03 ± 0.06	2.33 ± 0.09
	5-10	4.1	2.25 ± 0.04	1.55 ± 0.08
	10-15	4.6	1.73 ± 0.08	1.03 ± 0.11
	30-35	4.2	0.70 ± 0.02	-
	50-55	4.3	0.66 ± 0.05	-
ARB-54	96-98	1.2	0.75 ± 0.10	-
	0-5	2.6	2.76 ± 0.14	1.53 ± 0.17
ARB-54	5-10	2.6	2.50 ± 0.10	1.29 ± 0.13
	10-15	2.3	1.65 ± 0.06	0.42 ± 0.11
	30-35	2.1	1.21 ± 0.06	-
	50-55	1.6	1.24 ± 0.07	-
	70-72	5.6	2.24 ± 0.10	-
ARB-46G	0-5	3.2	3.21 ± 0.12	1.68 ± 0.19
	50-55	2.0	1.71 ± 0.13	-
	70-72	1.4	1.24 ± 0.10	-
	82-84	1.4	1.65 ± 0.11	-

*Standard deviation on Al is ± 3%.

**²²⁶Ra concentration (dpm/g) in surface sections of cores ALBC-1, 2595, 2590 and 2594 are 0.66 ± 0.08, 0.97 ± 0.03, 1.15 ± 0.06 and 0.88 ± 0.05, respectively. The surface ²²⁶Ra concentration for each core is subtracted from all the ²¹⁰Pb total concentrations to obtain the ²¹⁰Pb excess. For core ARB-65H, the average of the ²¹⁰Pb total activity of the lowermost three sections (0.70 ± 0.08 dpm/g) is assumed to be the ²²⁶Ra-supported value.

eous sands, which do not scavenge ²¹⁰Pb. The approximate sedimentation rate for the top 4 cm of this core has been calculated to be 1.8 mm/yr.

The range of integrated ²¹⁰Pb excess activity in the western continental shelf is 12.0-66.9 dpm/cm² (Table 2). The expected atmospheric ²¹⁰Pb excess value for this area calculated from its precipitation via rainfall is 40-50 dpm/cm² (Krishnaswami, 1973). Considering the uncertainties in the estimate the ²¹⁰Pb excess values in the shelf sediments (except for core 2586) are comparable to the atmospheric values of the ²¹⁰Pb excess.

Clay accumulation

The clay accumulation rates in the nearshore regions are in the range of 5-7 mm/yr (Fig. 1) and previously, Borole et al. (1982b) have reported a high clay accumulation rate of 1.9 cm/yr at the mouth of the Narbada and Tapti rivers in the Gulf of Cambay. From Fig. 1 one can see that the clay accumulation rates tend to decrease from 1.9 cm/yr at the Narbada and Tapti river mouths (the main source of terrigenous material to the study area), to 1.8 mm/yr towards the deeper water regions of the shelf. A similar decreasing pattern is encountered in the shallow-water samples (TP3-12, 2590, 2595 and ALBC-1).

The sediment distribution along the coast is apparently regulated by the prevailing surface currents (Fig. 1) which exhibit seasonal reversal. During the monsoon (June-September) the currents are directed to the south and southeast with velocities of 10-47 cm/s, and during November-January they are directed to the west and northwest with velocities of 4-9 cm/s. Thus, the southwest monsoon drift appears to be largely responsible for the sediment transport, with the result that the down-current sample locations (TP3-12, 2590, 2595 and ALBC-1) show greater accumulation rates while the locations represented by cores 2586 and 2594 show lesser rates.

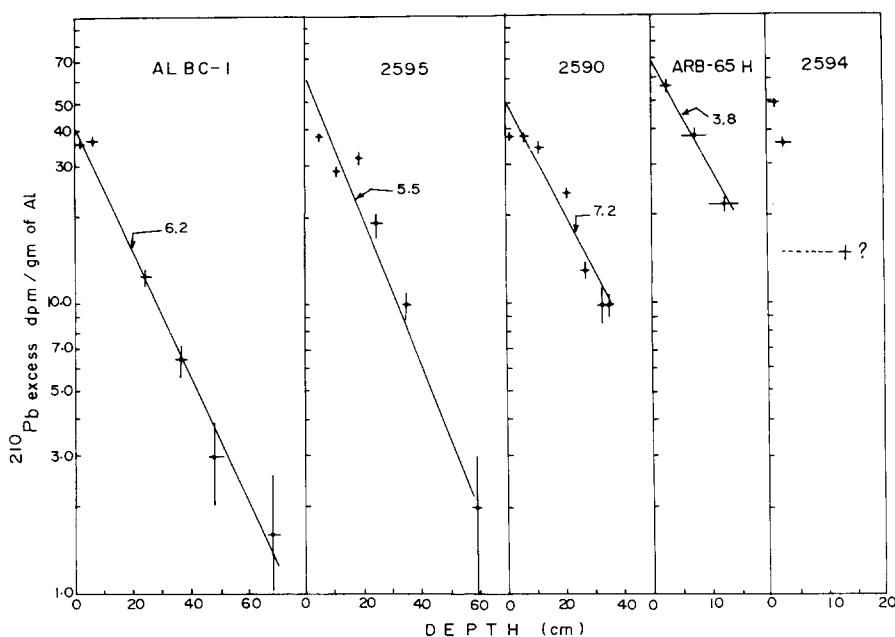


Fig. 2. ^{210}Pb excess activity (dpm/gm of Al) versus depth for five cores. The cumulative errors on the measurements of ^{210}Pb and Al are also indicated. The figures on the best-fit lines are the accumulation rates (mm/yr).

TABLE 2

Summary of sediment accumulation rates of ^{210}Pb and integrated fluxes in western continental shelf sediments

Core	Extrapolated to surface ^{210}Pb excess activity (dpm/g) (A_0)	Accumulation rate (mm/yr) (S)	^{210}Pb excess inventory in sediments* (Σ dpm/cm 2)	Reference
ALBC-1	3.4	6.2	33.8	This paper
2595	4.8	5.5	42.3	
2590	4.1	7.2	47.3	
2594	3.6	1.8	-	
2586	3.0	2.5	12.0	Dilli (1986)
TP3-12	2.2	19.0	66.9	Borole et al. (1982b)
ISMT-1	1.2	3.0	5.8	Rengarajan et al. (1983)
ARB-65H	3.2**	3.8 (90)***	19.5	Borole et al. (1982a,b,c)
ARB-54	3.0**	- (9.8)***	-	
ARB-46G	2.1**	- (16)***	-	

* ($\Sigma\text{dpm/cm}^2$) = $A_0 \cdot \rho \cdot S / \lambda$ where A_0 = the extrapolated activity at the surface, S = the accumulation rate (cm/yr), λ = the decay constant of ^{210}Pb (0.031/yr) and ρ = density (0.5 g/cm^3).

**Decay corrected to the date of collection.

*** ^{14}C accumulation rates (cm/ 10^3 yrs) reported by Borole et al., 1982 (a,b,c).

Based on clay mineralogical data from the continental shelf, Ramswamy and Nair (1988) have inferred that the cross-shelf transport of sediment is very insignificant on the western

shelf. In view of this, the present-day clay accumulation rate of 3.8 mm/yr at a water depth of 343 m (ARB 65H) cannot be attributed to terrigenous influx from the Narbada and Tapti

rivers alone. Another possible source could be the Indus river.

Accumulation rates on other shelves with major rivers influxes, such as the Amazon, Washington, Mississippi and Eastern Indian shelves vary from 1 to 20 mm/yr (Nittrouer et al., 1979; Kalesha et al., 1980; Kuehl et al., 1982; Schell, 1982). In marked contrast, the western shelf of India shows a very narrow range of 1.8–6.0 mm/yr and this is probably the result of a tidal barrier at the mouth of the Gulf of Kutch which restricts the transport of Indus sediments to the western Indian shelf (Nair et al., 1982; Nair, 1984).

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