

Particle Flux During the Southwest Monsoon on the Western Margin of India

by

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With 3 Figures and 4 Tables

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Abstract

Three sediment traps on a mooring were deployed on the outer shelf at a depth of 115 m from May to September 1985 on the western continental margin of India to study the particle flux during the southwest monsoon.

The morphology and mineralogy of the collected particulate matter is reported here. The result suggests that present-day sedimentation on the outer shelf is dominated by large particle or particle aggregates, composed mainly of biogenic carbonates.

Clay minerals in the samples collected are dominated by illite and chlorite derived most probably from the Indus River while the inner shelf clays are mainly composed of montmorillonite and kaolinite. Compared to "cross shelf transport", "along shelf transport" of sediment appears to be the more dominant mechanism for sediment transport on the western continental shelf of India.

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1. Introduction

The study of flux, size distribution, composition and mineralogy of particulate matter is of prime importance in many fields of oceanography. Conventional techniques for collection of particulate matter include filtration of seawater collected by bottle samplers. The downward flux of particulate matter is dominated by large particles or particle aggregates (MCCAVE, 1975) which are not collected by bottle samplers. Large particles which settle rapidly can be collected adequately by large volume in situ filtration (BISHOP et al., 1978) or by sediment traps (GARDNER, 1977; HONJO, 1980; KNAUER et al., 1979). Sediment traps in spite of many limitations have recently emerged as an important technique for long-term collection of the rapidly settling downward flux of particles.

Most of the sediment trap studies have been made in the deep sea and very few studies have been made on the open continental shelves (LANDING & FEELY, 1981; DUCKLOW et al., 1985). There is a paucity of information on suspensates and sedimentary processes operating over the outer continental margin (PIERCE, 1975). To study the sedimentary processes on the outer shelf during the southwest monsoon three sediment traps were deployed on a single mooring at a depth of 115m approximately 65 km offshore. This paper describes the morphology and mineralogy of the particulate matter collected in the traps.

2. The Study Area

The western continental shelf of India has been described by NAIR et al., (1978, 1982a). The sediments in the area (Fig. 1) consist of modern fine-grained sediments on the inner shelf and relict carbonate sands on the outer shelf. The area receives more than 2500mm of rain during the southwest monsoon period from June to September. This constitutes more than 80 per cent of the total annual rainfall (NAIR & HASHIMI, 1980).

The major rivers (Indus, Narmada and Tapti) join the Arabian Sea in the northern part of the West Coast of India. The study area lies more than 500 km south of the Tapti which is the nearest major river, besides other seasonal rivers in between.

3. Experimental Procedures

3.1 Sampling Methods

Three sediment traps were deployed on a taut subsurface mooring at a depth of 115m on the outer continental shelf (Fig. 1). The sediment traps used for this study are a modification of those described by GARDNER (1977). It consists of a PVC cylinder with a diameter of 150mm and a height of 450mm. The closing mechanism is a butterfly valve which was held in an open position under tension by means of a rubber spring outside the cylinder. A Benthos precision timed release attached to the top of the mooring released a steel messenger which closed the trap. The sediment trap in turn released another messenger to close the traps below. No poison was added to the traps.

The sediment traps were deployed at the depths of 30, 70 and 103 m on a subsurface mooring. The bottom trap was set 12 m above the bottom to alleviate the effect of resuspension. The concrete anchor weight of 500 kg was released by means of an acoustic release transponder.

The sediment traps were deployed on 5th May 1985 prior to the onset of the monsoons. The timer was set to release the messenger on 1st September 1985.

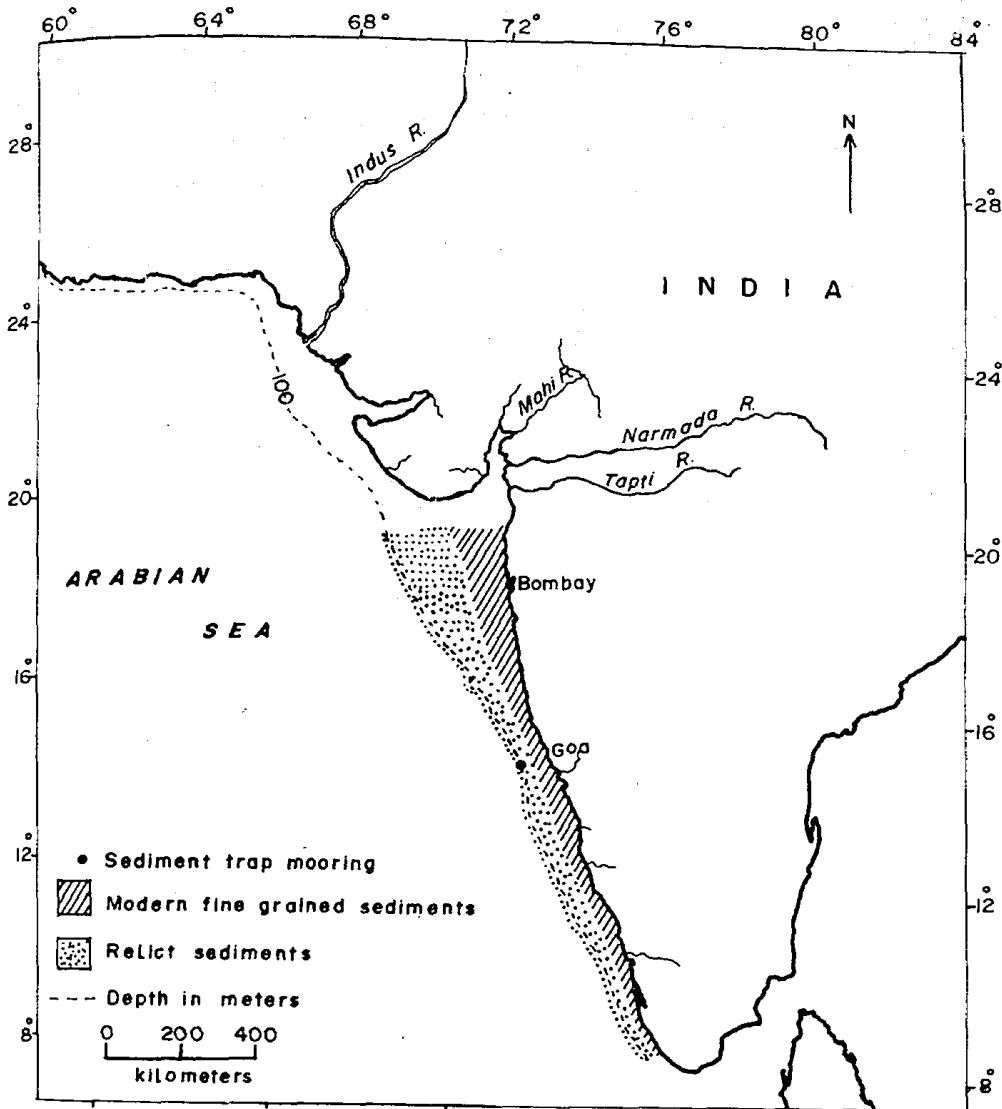


Fig. 1: Location of sediment trap station, major rivers and sediment distribution on the Western Margin of India.

The mooring was recovered on 1st October 1985. The bottom trap at 103m failed to close and an unknown quantity of sample was lost. As the bottom sediment in that area was coarse carbonate sands a Peterson Grab sample was taken.

3.2 Laboratory Methods

After recovery the traps were stored in a deep freeze. In the laboratory the entire content was put into a clean plastic bucket and about 5ml each were taken for scanning electron microscopy and for size analysis. The remaining part was split into two parts using a plankton splitter. One part was kept in a deep freeze as an archive. The other part was further split into two parts. One quarter of the sample was dried in an oven at 50 °C and weighed using an electronic microbalance (least count 1µg) after keeping the sample in the weighing room for at least 8 hours. About 6 mg of the sample was taken after thorough grinding and mixing of the sample for organic carbon analysis using a

Perkin-Elmer CHN analyser. The remaining portion was weighed and used for chemical analyses.

The other quarter of the sample was wet sieved using a 63 μm sieve. Both fractions were dried at 50°C, weighed and studied under a binocular microscope for identification of various components and aggregates. A 5 ml aliquot of the sample was filtered at low vacuum using 0.4 μm Nuclepore filters. The central portion was cut and mounted on aluminium studs and sputtered coated with gold for scanning electron microscope studies.

Calcium carbonate percentage was determined by weight loss method by adding 0.5 N HCl to a known weight of the sample. The residue was filtered on tared 0.2 μm Nuclepore filters, washed with prefiltered distilled water, dried and weighed.

The greater than 63 μm and less than 63 μm fractions were ground in an agate mortar separately, made into a slurry by adding filtered distilled water and pipetted onto glass slides and run on a Philips X-ray diffractometer for X-ray diffraction analysis. The scanning was carried on the whole sample as well as carbonate and organic matter free fractions (treatment with 0.5 N HCl and 30% H_2O_2). The samples were scanned from 4° to 30° at 2°20 min^{-1} using Ni filtered Cu $\text{K}\alpha$ radiation. Standard test for confirmation of montmorillonite was carried out by glycolating the sample at 110°C for 1 hour. Semi-quantitative analysis for clay mineral percentages was done by measuring the peak areas and following the method of BISCAVE (1965).

4. Results and Discussions

4.1 Total Particle Flux

The total particle flux (TPF) as well as flux of the greater than 63 μm and less than 63 μm fractions are given in Table 1. Compared to the particle flux in other nearshore environments (between 2–200 $\text{mg} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$, LARRANCE et al., 1979; LANDING & FEELY, 1981) the TPF on the outer shelf is very low. It is only marginally higher than the TPF values reported for the deep sea, (between 12.95 to 69.4 $\text{mg} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$, HONJO, 1980; between 10 to 120 $\text{mg} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$, DEUSER, 1986). The high carbonate and low silicate percentage in the trap samples indicate a low terrigenous contribution to the particle flux on the outer shelf. This may be due to the lack of major rivers on the west coast near the study area.

Table 1: Total particle flux-measured on the outer shelf.

Sample No.	Depth (m)	Total particulate flux $\text{mg}/\text{m}^2 \cdot \text{day}^{-1}$			No. of days collected.
			(mg)	(%)	
Sediment Trap No. S 1	30	+ 63 μm	270.48	67.6	117
		- 63 μm	129.68	32.4	
		Total:	400.17	100.0	
Sediment Trap No. S. 2	70	+ 63 μm	98.88	55.5	117
		- 63 μm	79.16	44.5	
		Total:	178.04	100.0	
Sediment Trap No. S 3*	103	+ 63 μm	46.48	66.5	147
		- 63 μm	23.44	33.5	
		Total:	69.92	100.0	

* The trap at 103 m failed to close and an unknown amount of sample was lost.

4.2 Major Components

The distribution of major biogenic components is shown in Table 2. Most of the large particles greater than 63 μm consisted of mollusc and foraminiferal aggregates bound by sticky greenish colored organic material (Fig. 2 A & B). These aggregates ranged from 0.5 to 4.0 cm long. These aggregates were more dominant in the uppermost (S1) trap and decreased in number towards the bottom. The aggregates became more compact and denser towards the bottom.

Table 2: Distribution of major biogenic components.

Sample Description	Sediment Trap No. 1 depth 30 m	Sediment Trap No. 2 depth 70 m	Sediment Trap No. 3 depth 103 m	In one gram of bottom sediment depth 115 m
Foraminifera				
Planktonic	370	152	47	75
Benthic	-	-	-	15
Pteropods				
Straight	311	160	76	30
Coiled	370	146	40	45
Bivalves	656	167	5	2
Radiolarians	-	-	4	-
Fish Bones	-	52	6	-
Spines	244	-	-	-
Fish scales	12	6	1	-
Ostracods	-	-	-	4
Ooids, Peloids & Fecal pellets	-	-	6	175
Micro Pellets 63-80 μm	-	-	-	~500

Well-formed red fecal pellets (Fig. 2 C) ranging in size up to 1.2 cm were found only in the bottommost (S 3) trap. Pteropods both coiled and straight varieties were the dominant component in all the traps as well as the bottom sediment. Planktonic foraminifera mostly *Globigerinoides* sp and *Globirotalia* sp were more numerous in the upper traps and decreased towards the bottom.

Bivalves (Fig. 2 D) with both valves attached and ranging in size up to 750 μm were found in all the traps. Their frequency decreased rapidly towards the bottom and only two bivalves could be found in the bottom sediment. The reason for the rapid decrease is not known. They may have been transported away, due to their lighter weight or may have been selectively grazed by other predators.

Fish scales (Fig. 2 E) were found in all the traps but are more numerous and well preserved in the uppermost (S1) trap. Moults of crustaceans were more numerous in the bottommost (S3) trap. Radiolarians (*Orospheroid* sp) with well preserved spines and diameter up to 1300 μm were found in the bottommost (S3) trap. 'Y' shaped fish bones were found in the S2 and S3 traps but not in the bottom sediment (Fig. 2 F).

The fraction less than 63 μm was studied under a polarizing and scanning electron microscope. Even in this fraction most of the particles were in the form of small aggregates (Fig. 2 G). The aggregates were mostly composed of diatom frustules and clay particles (Fig. 2 H). Radiolarians, silicoflagellates and calcareous nannoplankton remains were also found though they were relatively rare.

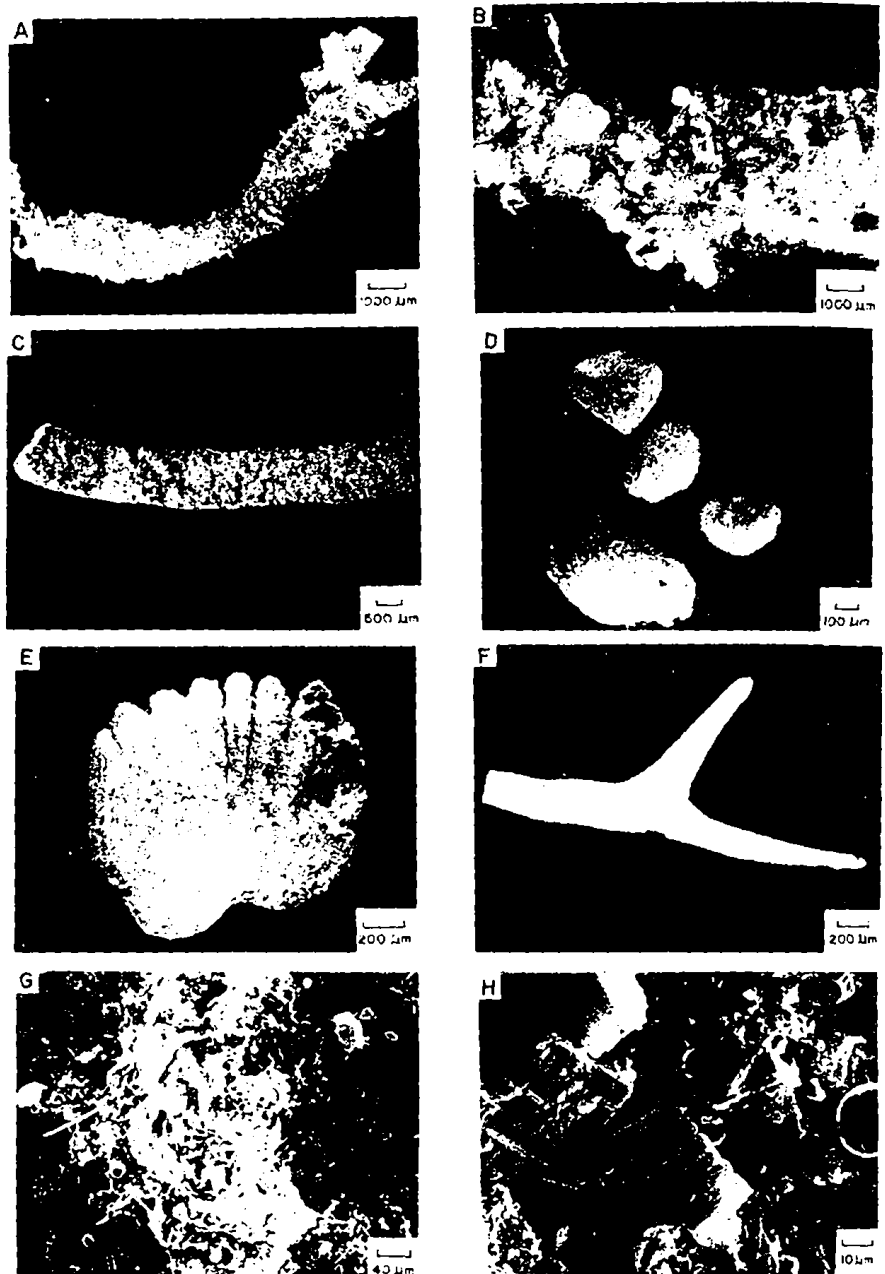


Fig. 2: Microphotographs and scanning electron micrographs showing biogenic and mineral particles in the trap samples.

- A. Biogenic aggregates composed of pteropod, foraminifera and bivalve shells. S1
- B. Same as A with large size shells. S1
- C. Red fecal pellet. S3
- D. Bivalves. S1
- E. Fish scale. S1
- F. Fish bones. S2
- G. SEM photograph showing an aggregate composed of biogenic fragments and clay particles. S2
- H. Enlarged view of G showing numerous diatoms, pteropods and clay fragments. S2

4.3 Organic Carbon and Calcium Carbonate

Organic carbon and calcium carbonate percentages are shown in Table 3. High organic carbon (6–12%) in all the traps compared to the bottom sediment (1.1%) indicate that though the supply of organic matter is high it is not preserved in the bottom sediment. A significant percentage of the organic matter is oxidized or consumed by organisms near the sediment water interface.

Table 3: Percentage of calcium carbonate and organic carbon in the trap samples and bottom sediment.

Sample No.:	Calcium carbonate percentage determined by weight loss due to acidification.	Percentage of organic carbon
S1 Total sample	66.36	6.44
+ 63 μ m	75.93	5.24
- 63 μ m	42.46	9.34
S2 Total sample	44.44	10.96
+ 63 μ m	63.23	9.33
- 63 μ m	28.62	12.28
S3 Total sample	58.93	7.83
+ 63 μ m	62.02	6.73
- 63 μ m	53.59	9.22
Bottom sediment	90.66	1.1*

* From PAROPKARI et al. (1985)

Calcium carbonate percentages ranged from 44.4 to 66.4 per cent in the trap samples compared to 90.6 per cent in the bottom sediment. This may be due to the higher percentage of organic matter in the trap samples. The higher percentage of calcium carbonate in the greater than 63 μ m fraction reflects the higher abundance of molluscs and pteropods in this fraction.

4.4 Mineralogy

The non clay minerals in the trap samples are quartz, feldspar and the carbonate minerals calcite and aragonite. The carbonate minerals as expected were found to be dominant in the greater than 63 μ m fraction. Aragonite content was found to be higher in the larger size fraction. This may be due to the fact that pteropods tests which are found mostly in the greater than 63 μ m fraction are composed of aragonite (BERNER & HONJO, 1981).

Clay minerals observed in the trap samples are illite, chlorite, kaolinite and montmorillonite in the order of abundance. The relative percentages of clay minerals in the trap samples as well as in the bottom sediment are shown in Table 4.

Table 4: Relative percentages of clay minerals in the trap samples and bottom sediment.

Clay Mineral	S1	S2	S3	Bottom sediment
Illite	56.8	60.5	47.8	56.9
Chlorite + Kaolinite	39.5	35.87	44.5	35.1
Montmorillonite	3.7	3.7	7.7	8.0

Clay minerals in the trap samples and bottom sediment show similar mineralogy as well as similar clay mineral percentages (Fig. 3). However, the relative clay mineral percentages of the samples collected are different from those of the inner shelf. The inner shelf is dominated by montmorillonite (> 70%) followed by kaolinite (~ 20%). Illite and chlorite together constitute less

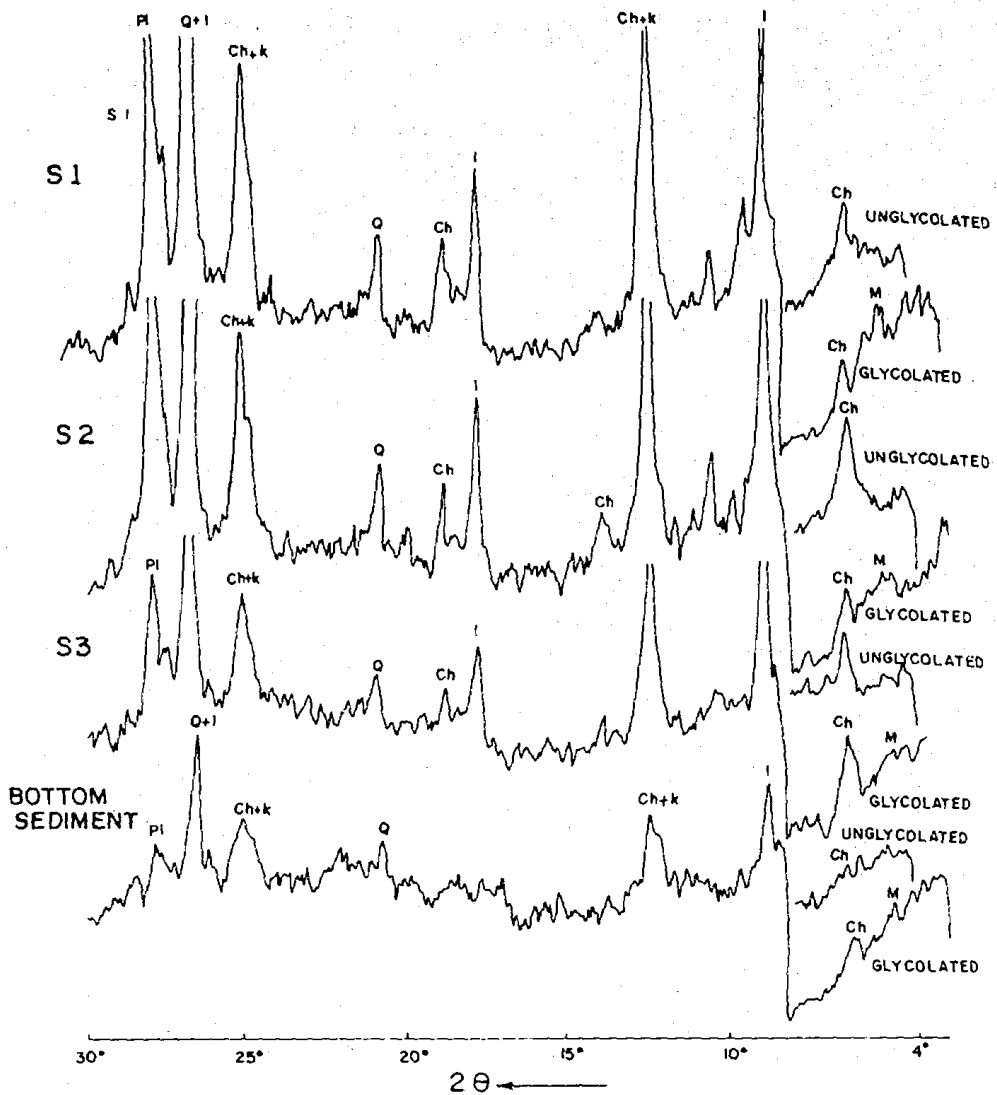


Fig. 3: X-ray diffractograms of the treated trap samples (S1, S2 and S3) and bottom sediments.

M = Montmorillonite	Ch = Chlorite
I = Illite	Q = Quartz
Pl = Plagioclase, Feldspar	K = Kaolinite

than 10% (NAIR et al., 1982b). The difference in clay mineral percentages indicates different sources for the inner and outer shelf sediments (KOLLA et al., 1976).

Montmorillonite is the most abundant clay mineral on the inner shelf on the West Coast of India. GOLDBERG & GRIFFIN (1970) reported a band of montmorillonite around the coast of India. The Deccan Traps are the principal source of montmorillonite. Based on 'd' spacing PURNACHANDRA RAO et al. (1983) reported montmorillonite derived from the Deccan Traps on the Kerala Coast (9° N to 10° N) which may have been transported due to the action of the southwest monsoon drift. The low percentage of montmorillonite in the trap samples as well as in bottom sediment of the outer shelf, indicates that while the

bulk of the clay minerals may have been deposited or transported along the inner shelf only a minimal quantity reaches the outer shelf. Based on satellite photographs WAGLE (1985) reported the presence of a turbid layer along the west coast of India confined within the 20m isobath while waters on the outer shelf were clear.

Chlorite is considered uncommon in tropical marine sediments and is indicative of cold or high altitude environment where mechanical weathering predominates (GRIFFIN et al., 1968). The source of chlorite as well as illite is most probably from the Indus River which drains the Himalayan Mountain (GOLDBERG & GRIFFIN, 1970; VENKATARATHNAM et al., 1981). The chlorite and illite is transported along the shelf, due to the action of the southwest monsoon drift.

5. Conclusions

The outer shelf off Goa is an area of low sedimentation. The particle flux in the study area has a sedimentation rate far lower than other coastal environments and is only marginally higher than the deep sea. The present-day flux is dominated by biogenic material of which biogenic carbonates in the form of mollusc and foraminifera shells are the major contributors. High organic matter percentages in all the traps compared to the bottom sediment indicate that a major portion of the organic matter is oxidized or consumed near the sediment-water interface.

The non-biogenic fraction is dominated by the clay minerals, quartz and feldspar. Clay mineral percentages in the trap samples and bottom sediment on the outer shelf are different from those on the inner shelf. The higher percentage of illite and chlorite in the trap samples indicate that the outer shelf off Goa receives a significant portion of its sediment from the Indus River. A very low contribution from the adjacent coast and inner shelf indicates that alongshelf transport, due to monsoon-driven currents, is a significant mode of sediment transport on the western continental shelf of India. Cross shelf transport appears to be minimal.

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