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Clay mineral distribution in the continental shelf sediments from Krishna to Ganges river mouth, east coast of India

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Ninety six sediment samples (< 2 μm fractions) of the eastern continental shelf of India between Ganges in the north and Krishna in the south have been studied by X-ray diffraction. On the basis of nature and abundance of different clay minerals and montmorillonite (M) to illite (I) ratio, 6 distinct clay mineral assemblages which reflect their sources are identified. Illite (80%) and chlorite-rich (20%) clay mineral suite, with less kaolinite (av. K/C = 0.3) and traces of montmorillonite is found in the estuarine sediments of the Ganges. The Brahmani-Mahanadi province is characterised by the increase of montmorillonite (M/I = 0.4), kaolinite (av. K/C = 1.5) and gibbsite. Mixed mineral assemblage in the offshore shelf regions off the Hooghly has resulted due to the mixing of clay mineral suite of Brahmani-Mahanadi with the Gangetic suite. A kaolinite-rich (up to 55%) assemblage with an average M/I ratio of 0.8 occurs in the eastern ghats coastal province. Variations in the abundance of clay minerals with sediment type have also been observed. The Godavari and Krishna assemblages are distinguished by highest concentrations of montmorillonite (up to 67%; M/I varies from 1 to 4.5) and kaolinite (28-36). Montmorillonite in this region is 12Å type in contrast to the 15Å montmorillonite in the remaining part of the shelf. It is found that the Godavari derived sediments extend northwards and deposit up to Visakhapatnam under the influence of southwest monsoon currents.

The earlier studies on clay mineralogy of sediments of the east coast shelf are limited and qualitative[1-6]. The only comprehensive study on the shelf is by Rao *et al.*[7] in the northern part of the east coast of India. The present study is an extension of the work by Rao *et al*[7]. The objective is to map the distribution of various clay minerals in the surface sediments and to determine the clay mineral assemblages in terms of their source rocks and sediment variability and to trace their dispersal in relation to the patterns of water circulation.

Materials and Methods

A total of 128 surficial sediment samples, collected during 76 and 77 cruises of *R V Gaveshani* in June 1980 were used (Fig. 1A). Textural distribution was carried out and clay minerals were investigated in 96 of the above samples. Clay mineralogy was carried out[7] on a Philips X-ray diffractometer using nickel filtered CuKα radiation. Representative X-ray diffractograms of montmorillonite and illite, and kaolinite plus chloride including the slow scan X-ray patterns for separating the kaolinite and chlorite were made. Crystallinity of montmorillonite (V/P)[8] was also measured.

Results and Discussion

Texture—Silty clay/clayey silts are predominant in the shelf off the Ganges, the Mahanadi, the Godavari and Krishna (Fig. 1B). However, lateral variations in sediment type have been observed between south of the river Devi and Chipurupalli. Sands and silty sands are the dominant sediments in the nearshore regions between north of Chilka lake and south of the Devi followed by clayey silts/silty clays in the offshore. The sediments between Chilka lake and Gopalpur are silty clays. The sediments between Gopalpur and Chipurupalli show gradation in sediment type with depth. The sediments in the nearshore are sands followed by silty sands and silty clays with increasing depth towards offshore. The sediments off Visakhapatnam are sands in the nearshore, clayey sands in the midshelf and silty clays in the upper slope.

Clay minerals—X-ray diffraction studies (Figs 2 and 3) have yielded 4 groups of clay minerals (illite, montmorillonite, kaolinite and chlorite). Illite and montmorillonite mineral phases show a strong antipathetic relationship so that areas of high montmorillonite content are areas of low illite content and *vice versa*. Illite constitutes 80% of the

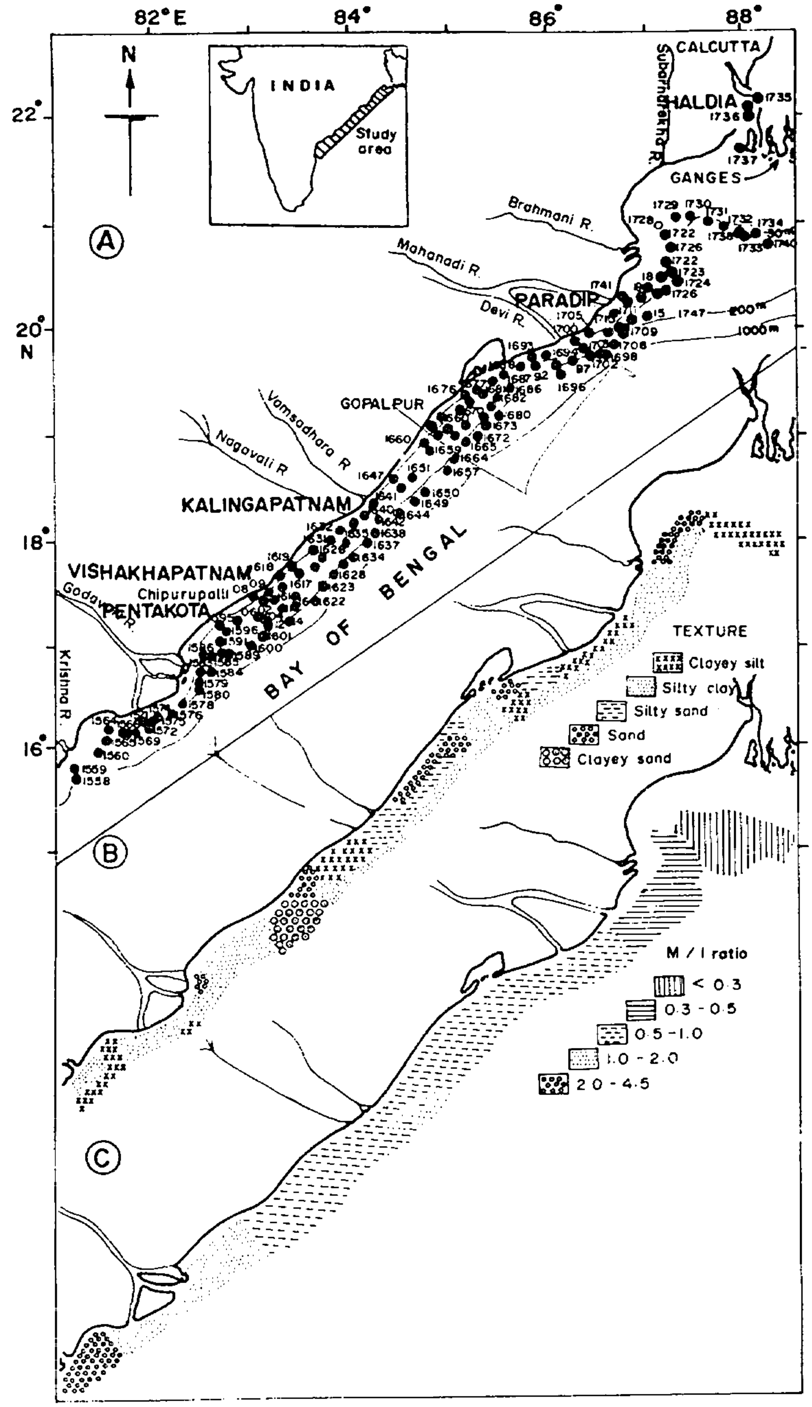

Fig. 1—Sample location (A); textural distribution of the sediments (B); and distribution of montmorillonite to illite (M/I) ratio in the sediments (C)

sediments off Ganges and progressively decreases southwards off the shelf of the peninsular rivers. It decreases from 60% in the sediments off Brahmani in the north to 15% in the sediments off Krishna with a value of about 44% off Visakhapatnam and about 20% in the samples off Godavari. On the other hand, montmorillonite occurs as traces in the sediments off Ganges and shows a progressive increase towards south. Montmorillonite increases from 14% in the samples off Brahmani to 67% in the sediments off Krishna with a value of 32% off Visakhapatnam and about 40% in the samples off Godavari. Kaolinite

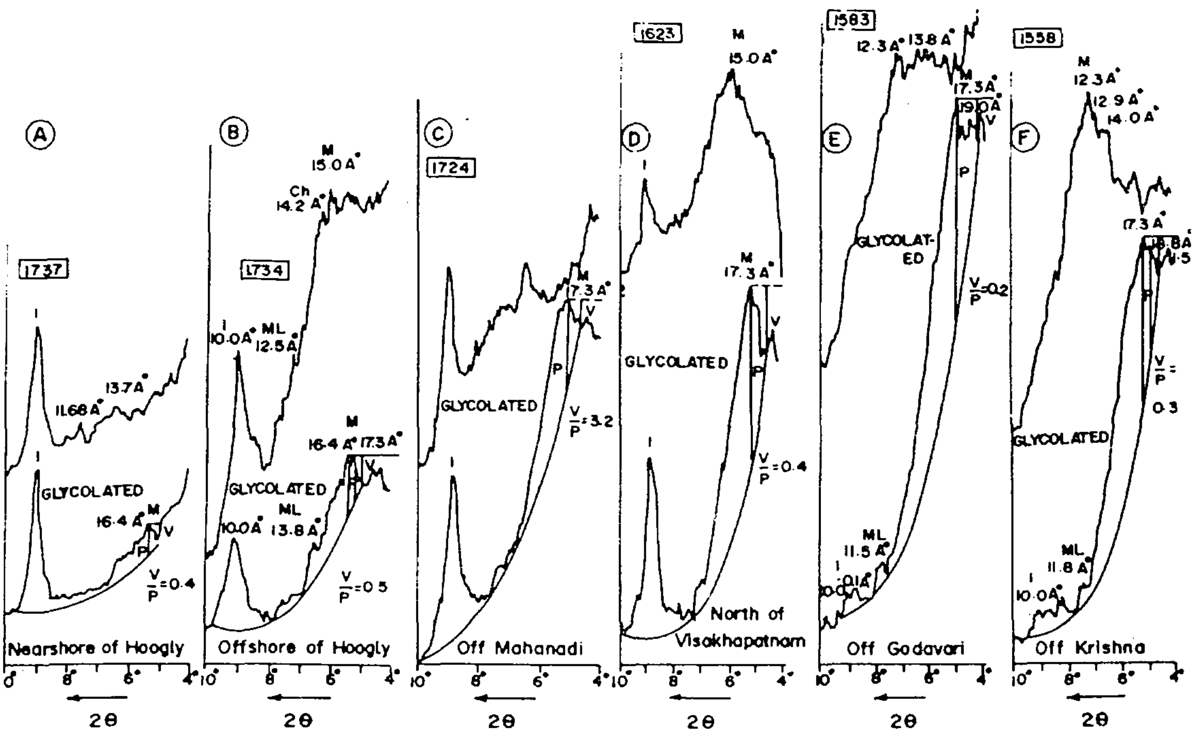

Fig. 2—(A to F) Characteristic X-ray patterns (unglycolated and glycolated) showing montmorillonite (M) and illite (I) variations in the study area

plus chlorite content is highest (Fig. 3) in the sediments where there is no major river influx and varies from 55 to 18%.

Distinct differences in the montmorillonite have been observed. For example, montmorillonite in the sediments of the northern part of the study area has 'd' spacings at 15Å and upon glycolation shitted to 17.3Å (Fig. 2). Whereas the montmorillonite in the sediments off Krishna and Godavari rivers has characteristic 'd' spacings at 12.3Å in unglycolated X-ray patterns and expands to 17.3Å after glycolation (Fig. 2). This montmorillonite has similar characteristic X-ray patterns of 12Å montmorillonite reported by Thorez[9].

On the basis of the distribution of various clay minerals and montmorillonite to illite ratio, it is possible to divide the study area into 6 mineralogical provinces, each is characterised by distinct clay mineral assemblages and source area. The boundaries between the 6 regions are not strictly defined and provinces overlap.

Ganges province—Clay mineral assemblage of the Hooghly (a distributory of Ganges) estuary is characterised by highest concentrations of illite (70-80%) and Fe-poor chlorite/kaolinite (20-30%; av. K/C = 0.3) and traces (up to 2%) of montmorillonite (Figs 2 and 3). This assemblage essentially reflects the glacial weathering products carried by the Ganges from the Himalayas and thus the mineral phases from the Gangetic province appears to be the major source to this part of the shelf. Clay mineralogy of the suspended[10] and bed loads[11] of the river Ganges and the adjacent shelf sediments are in agreement with the above observations.

Brahmani and Mahanadi province—In contrast to the Gangetic province, the clay mineral assemblages of these rivers are characterised by relatively high content of kaolinite plus chlorite (av. 28%; range 16-41%) and montmorillonite (av. 15%; 8-25%) and the presence of gibbsite (Figs 2 and 3) with a corresponding decrease in illite (av. 60%; 41-71%) and chlorite (av. K/C = 1.5) contents. The crystallinity of montmorillonite is about 0.3. Chlorite is an Fe-rich variety. M/I ratio varies from 0.3 to 0.5 (Fig. 1C). This change in clay minerals suite is due to the fact that these rivers drain sediment terrains under humid tropical conditions. Further, the drainage basin of Brahmani consists mostly of Quaternary sediments and the large part of the drainage basin of Mahanadi consists of metamorphic rocks including gneisses and schists with local acid and basic igneous bodies[12]. Hence the chemical weathering products such as kaolinite and montmorillonite have relatively increased in the clay mineral suite.

Mixed mineral province—The offshore samples off the Hooghly consists of relatively low contents of

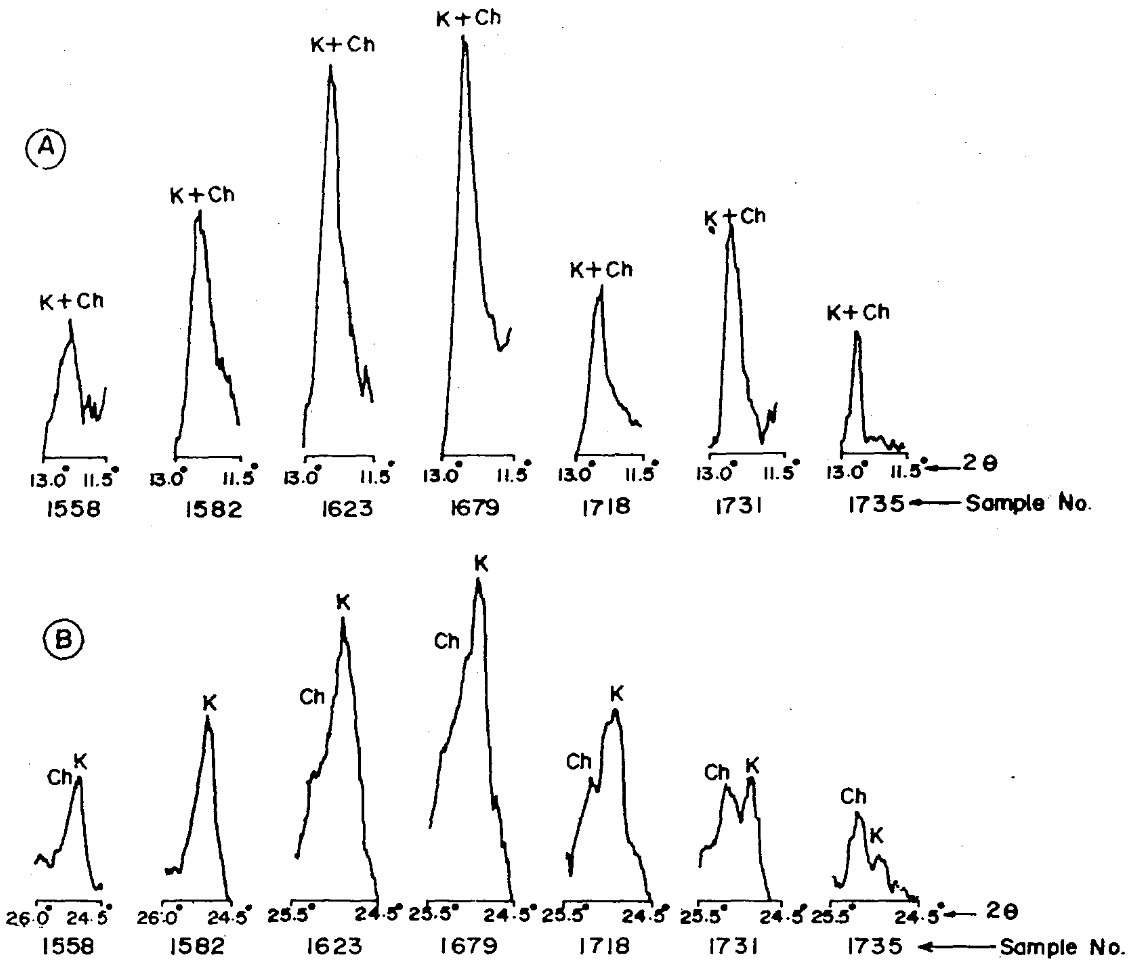

Fig. 3-Characteristic X-ray patterns in the variation of kaolinite plus chlorite reflection (7Å peak) (A), and variations in the slow scan X-ray patterns of kaolinite and chlorite reflection (3.54Å) (B)

illite and chlorite (av. K/C = 0.6) and high contents of montmorillonite (up to 19%) kaolinite and gibbsite compared to the Gangetic province (Figs 2 and 3) M/I ratio is < 0.3. V/P ratio of montmorillonite is about 0.5. There are 2 possible explanations: (1) it may be due to the early flocculation of illite in the estuarine sediments and differential settling of montmorillonite because of its smaller size as compared to the other clay minerals. This resulted in the distinct clay mineral assemblages in estuarine and shelf sediments of the Hooghly river; (2) alternatively, clay mineral suite of the peninsular rivers is mixing with the clay mineral suite of the Hooghly river. Increase of kaolinite, montmorillonite and gibbsite has been observed and the latter explanation[7] appears to be the likely mechanism. This further suggests that the Ganges derived sediments do not reach the shelf off the peninsular rivers.

Siddiquie[13] reported illite as the predominant clay mineral in the Bay of Bengal together with kaolinite and montmorillonite. Goldberg and Griffin[14] recorded abundant illite, chlorite and montmorillonite in the eastern part of the Bay of Bengal sediments and attributed this due to the influence of the Ganges and Brahmaputra. Kolla and Biscaye[15], Kolla and Rao[16] and Rao and Rao[17] suggested that the Bengal Fan contain abundant illite and chlorite which are dispersed by turbidity currents from Ganges and Brahmaputra.

Eastern ghats coastal province—The clay mineral assemblage in the region between Paradip in the north to Visakhapatnam in the south is characterised by the highest concentrations of kaolinite plus chlorite (av. 35%; 14-55%) followed by illite (av. 42%; 31-53%) and montmorillonite (av. 22%; 9-43%) (Figs 2 and 3). M/I ratio varies from 0.5 to 1.0 (Fig. 1C). Crystallinity index of montmorillonite is 0.4 (Fig. 2). In this region coastal rocks are formed by Archaen granulite facies including khondalites, charnockites and calc-silicates with associated acidic and basic suites. There are no major rivers present and the short rivers such as Devi, Vamsadhara and Nagavali are only of seasonal nature. Hence, tropical weathering on acidic and basic suite of rocks under poor drainage conditions resulted in near equal concetrations of kaolinite and illite and less content of montmorillonite in this region as compared to the Mahanadi province.

Spatial variations in the distribution of clay minerals with sediment type on the shelf have been observed. Illite and kaolinite plus chlorite are higher in the sandy zones that occur nearshore and on the outershelf and lower in clayey zones on the innershelf and on the continental slope. On the other hand montmorillonite concentrations are greater in clayey zones and lower in sandy zones.

The relation between sand percentage and illite and montmorillonite contents (Fig. 4A) indicates that montmorillonite admixes with illite if the sand percentage is < 30% and montmorillonite is always lower than illite if sand percentage increases to > 50%. The relation between clay percentage and illite and montmorillonite abundance (Fig. 4B) indicates that montmorillonite and illite percentages come closer and intermix at higher percentage of clay. They are distinctly separate with higher illite content if the clay content decreases to < 30%.

It has been explained[18] that the abundance of individual clay minerals in the sediments depends on the energy conditions of depositional environment and the organic matter content in the overlying waters. The same explanation applies in this region also. The plots (Figs 4A and B) between montmorillonite and illite with sand percentage and clay percentage of the sample further indicate that if the clay content is < 30% or if sand percentage is > 50%, clay minerals in the sediments may not reflect the provenance but may reflect the energy conditions of the environment.

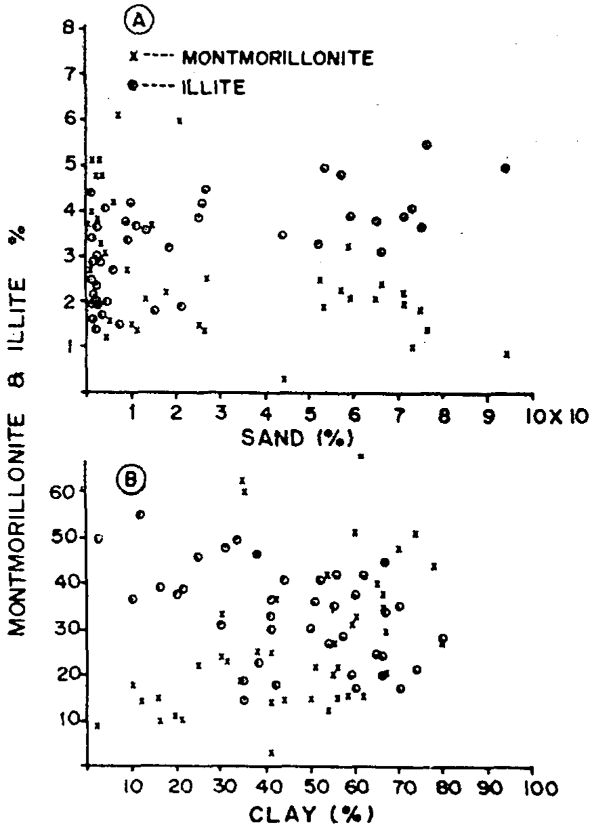

Fig. 4—Plot showing variations in abundance of montmorillonite and illite with sand percentage (A); and with clay percentage (B)

Godavari province—The clay mineral assemblage of this region (Figs 2 and 3) comprises about 38% (range 30-45%) of kaolinite and chlorite, 35% (22-51%) of montmorillonite, and about 27% (16-35%) of illite. M/I ratio in this region varies from 1 to 2 (Fig. 1C).

Krishna province—Clay mineral suite of this region consists of highest percentage (av. 52%; 33-67%) of montmorillonite followed by kaolinite plus chlorite (av. 27.6%; 18-39%) and illite (av. 22%; 15-38%). M/I ratio ranges from 2 to 4.5. The 12Å montmorillonite is characteristic type of both Krishna and Godavari sediments (Fig. 2). Montmorillonite in this region has lowest crystallinity (V/P = 0.2).

Highest concentrations of montmorillonite are found in the samples off Krishna followed by the Godavari. This is because the rivers rise in the western ghats consisting of Deccan traps. These Deccan traps are covered by black cotton soils which contain a large percentage of montmorillonite. Therefore, the drainage area in the upper reaches is a montmorillonite-rich zone but in the lower reaches, these rivers drain through Precambrian formations, hence kaolinite is the second in order of abundance and accordingly observed in the neighbouring shelf sediments. The relative variations in the kaolinite content of the sediments of the Godavari and Krishna rivers may be related to the size of drainage basins in their lower reaches.

Montmorillonite in the shelf sediments of Krishna and Godavari is poorly crystalline (V/P = 0.2-0.3) and is 12Å type in contrast to the montmorillonite, which is 15Å from the remaining part of the shelf. The poor crystallinity and change in montmorillonite type may possibly indicate that the basic volcanic rocks, the major supplier of montmorillonite-rich solids to the Krishna and Godavari rivers, weather under prevailing conditions to produce the 12Å montmorillonite. Alternately they might have undergone changes in the character when they transport from basic volcanic region to oceanic region *via* Precambrian metamorphics. Naidu[19] and Swamy *et al.*[20] studied the clay minerals of the deltaic sediments of the Godavari and Krishna and reported Na-montmorillonite along with minor amount of kaolinite.

Clayey silt/silty clays are dominant in the sediments off Krishna and Godavari and these sediments extend northwards up to Chipurupalli (Fig. 1B). Furthermore 12Å montmorillonite is characteristic clay mineral in these sediments between Krishna and Visakhapatnam. North of Visakhapatnam, 15Å montmorillonite is present. These differences in montmorillonite indicates that the Godavari derived sediments transport northwards under the influence of NE flowing currents associated with SW monsoon winds[21] and continue to deposite their sediments in the northern part of the shelf. Therefore the probable current direction inferred from the clay minerals is towards north. Heavy mineral study in the sediments of Krishna and Godavari indicated a northerly sea current in this region[22].

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