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Sonograph Patterns of the Central Western Continental Shelf of India

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ABSTRACT

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Side scan sonar and bathymetric surveys were conducted on the central western continental shelf of India. The sonographs portray a smooth, relatively featureless inner shelf, up to a depth less than 40-50 m, which is covered with fine grained sediments. The sonographs of the outer shelf, from beyond 60 m depth, to the shelf edge, exhibit bedforms such as reef outcrops (algal and oolitic ridges) and minor topographic undulations. Towards the shelf edge these give way to isolated colonies of algal knolls. A transition zone with tonal variations is present between 40 and 60 m water depth.

Ground-truth data from sediment and rock distribution maps indicate depositional (inner shelf), nondepositional or erosional (outer shelf) environments and a combination of both in the transition zone. These match well with the sonographs.

ADDITIONAL INDEX WORDS: *Sonograph, sediment texture, algal ridges and algal knolls.*

INTRODUCTION

The National Institute of Oceanography has carried out detailed Geological and Geophysical surveys on the western continental margin of India. These surveys include echosounding, side scan sonoar, sub-bottom profiling, gravity and magnetics and extensive sampling with grabs, corers and dredges. Based on the large volumes of data collected, various geological, geochemical and geophysical maps were prepared. NAIR *et al.* (1978) mapped the surface sediment distribution over the central western continental shelf using grab samples spaced at 10 km interval along the traverses separated by 20 km.

In this paper, the shelf physiography and facies distribution as indicated by means of side scan sonar records (sonographs) collected over the central western continental shelf of India (Figure 1) have been discussed with the help of previously published sedimentological data (Figure 2). The sonographs were collected within an area stretching about 325 km in length and about 150 km in width.

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OCEANOGRAPHIC CHARACTERS OF THE STUDY AREA

The central western continental shelf is bordered by the western ghats extending roughly in a N-S direction and consisting of Precambrian gneisses, schists and granites with extensive laterite cappings (KRISHNAN, 1968). The width of the shelf in this area is greater in the northern part (≃100 km) and becomes narrower towards the south with an average of 80 km. The shelf break is of the gentle type (WEAR, *et al.*, 1974) and varies between water depths 90 and 120 m. It has the characteristics of an open shelf, being nearly flat, with extremely low angle of slopes from the shore line to the break in slope. Similar shelves are present in the western north Atlantic, the eastern gulf of Mexico, the Yucatan and the Sahul (GINSBURG and JAMES, 1974).

The surface water circulation pattern in this area changes with seasonal variations in intensity and direction. The monsoon plays an important role in the general circulation pattern. During the monsoon period (May to September) the flow is towards the south at a velocity of about 1.5 knots, occasionally reaching up to 2 knots. During the non-monsoon period the flow

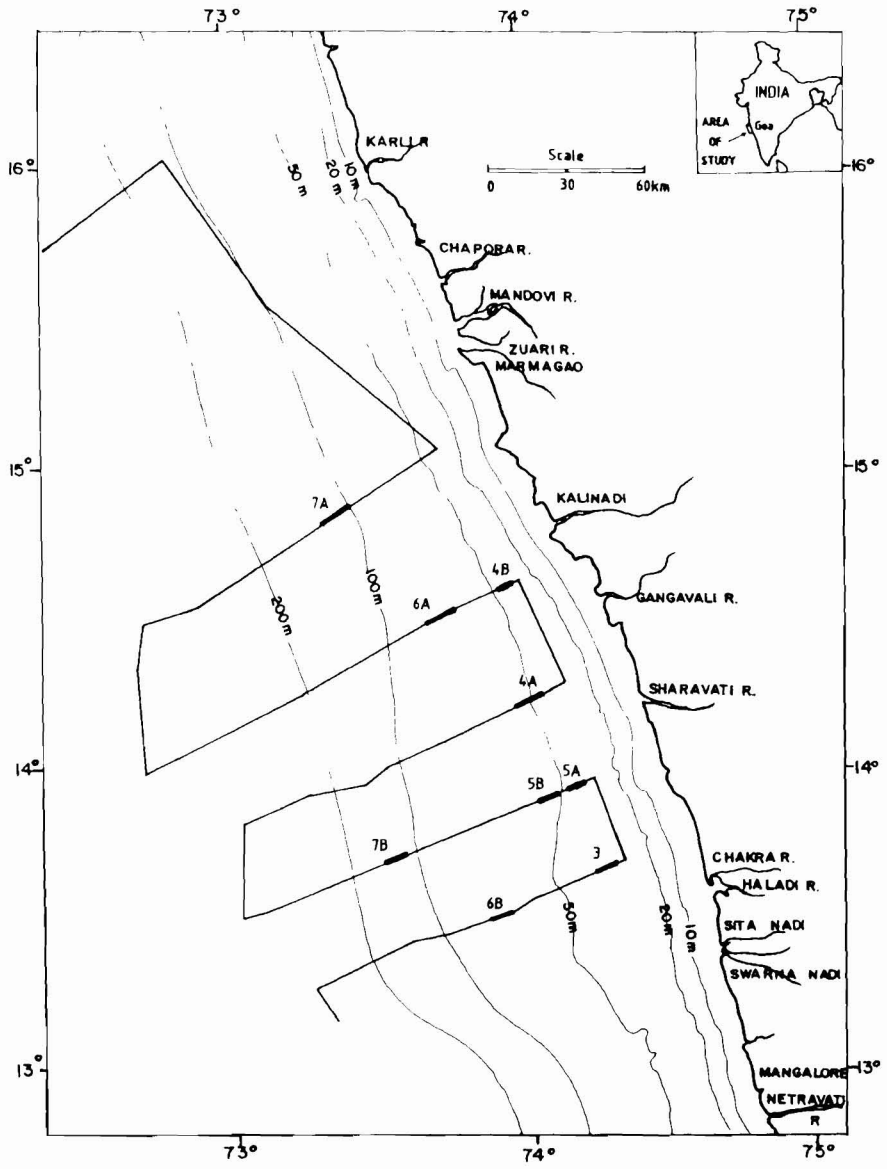


Figure 1. Map of the central western continental shelf of India showing side scan sonar tracks. Numbers on the track lines indicate the locations of sonographs shown in Figures 3-7.

is northwards at a velocity up to 1 knot. March to April is the transition period during which the surface currents are relatively weak.

SEDIMENT SUPPLY AND TRANSPORT

Several rivers discharge sediments from the western ghats into the Arabian Sea (Figure 1). Total annual discharge by the major rivers is approximately 23,500 million cubic meters, of which the Kalinadi contributes 6,537, the Gangavali 4,925, the Netravati 4,615, the Sharavati 4,545, the Mandovi and Zuari 1,920 and the remaining contribute 966 cubic members (RAO, 1979). Most of these rivers are estuarine in

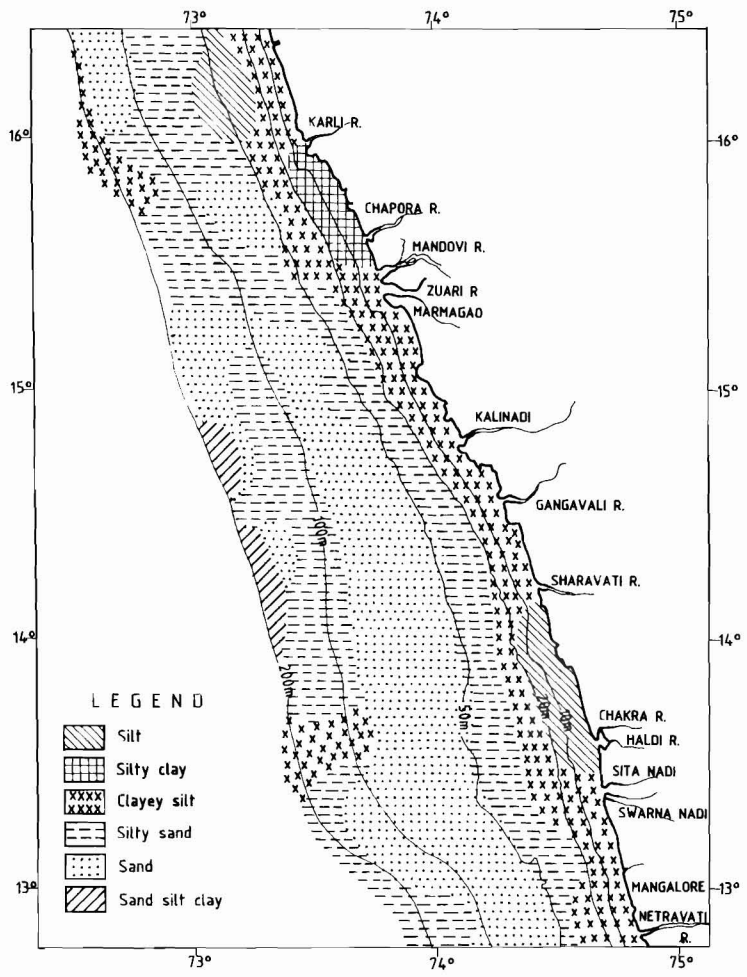


Figure 2. Map showing surface sediment distribution on the central western continental shelf of India (after Nair *et al.*, 1978).

nature. The Mandovi river is a typical example of the estuaries in this region and has been studied in detail. VARMA *et al.* (1975) reported that high precipitation during the monsoon season (May to September) causes a decrease in temperature (31.5°C pre monsoon and 25.5°C post monsoon), and salinity (29.5 to 36°/00 pre monsoon and 2 to 35°/00 during monsoon) and an increase in suspended load from <50 mg/l (pre monsoon) to >100 mg/l during monsoon. Increase in the suspended load suggests that much of the sediment is likely to be carried during the monsoon season. During post and pre monsoon periods the contribution of sediments is negligible.

METHODS

About 800 km of side scan sonar data were collected during the 7th oceanographic cruise of *ORV Sagar Kanya* and several hundreds of km of bathymetric data on *ORV Sagar Kanya, MV Skandi Surveyor* and *MV Farnella* during various cruises. The EG & G seafloor mapping system model SMS 960 recorder combined with model 272 transducer tow fish was used to collect the sonographs. The side scan sonar system was operated at a frequency of 110 KHz and scanned at 100 m range on either side of the track. The fish was towed along the starboard side of the *ORV Sagar Kanya* with a cable

length of approximately 300 m, its length reduced while traversing shallow depths. The system has an automatic speed correction and lateral image correction facility

A Honeywell Elac narrow beam echosounder was operated concurrently to obtain bathymetric profiles. Additional bathymetric data was obtained by Raytheon echosounder coupled to a line scan recorder. Both the echosounders were operated at 12 KHz frequency.

Ship speed was maintained at approximately 5 knots throughout the side scan sonar surveys, with navigation by Magnavox dual channel satellite navigator. Positional accuracy was ± 50 m.

RESULTS

Based on the features recorded, the sonographs are divided into the following types.

Type 1: Featureless sonographs (Figure 3) were collected over much of the inner shelf area. These records have light tonality and gradually changed to moderate tonality towards the outer shelf (Figure 4A). This type of featureless record is restricted to water depth less than 40 to 50 m. Acoustic return from the sea bed in this area is weaker resulting in light tonality. The bottom topography is smooth as characterised by the sonographs. Some of the sonographs (Figure 4B) collected at a depth of 50 m recorded a boundary marking areas of distinct tonal difference. This represents a variation in the composition of the sea bed.

Type 2: Tonal patches (Figure 5) were recorded in most of the area between the depths 40 and 60 m. The sea bed in this area is depicted as a mosaic of light and dark patches. The dark patches have irregular shapes and sharp boundaries and at certain places appear at regular spacing. The width of these patches range from few meters to more than 100 m.

Type 3: Well defined parallel lineations (Figure 6) dominate the side scan imagery on the outer shelf from a depth of 60 m, to the shelf break. These parallel acoustically strong features have barrier like appearance. Undulations with <5 m relief are seen on echograms from this area. These features are parallel to the shore line and confined to the area seawards of the tonal patches, and continue as far as shelf edge. They are more abundant in the northern part of the study area and the frequency of their occurrence is progressively lower towards the south.

Type 4: Numerous dark spots (Figure 7) were recorded on the sonographs collected over the shelf break and upper slope region. These spots

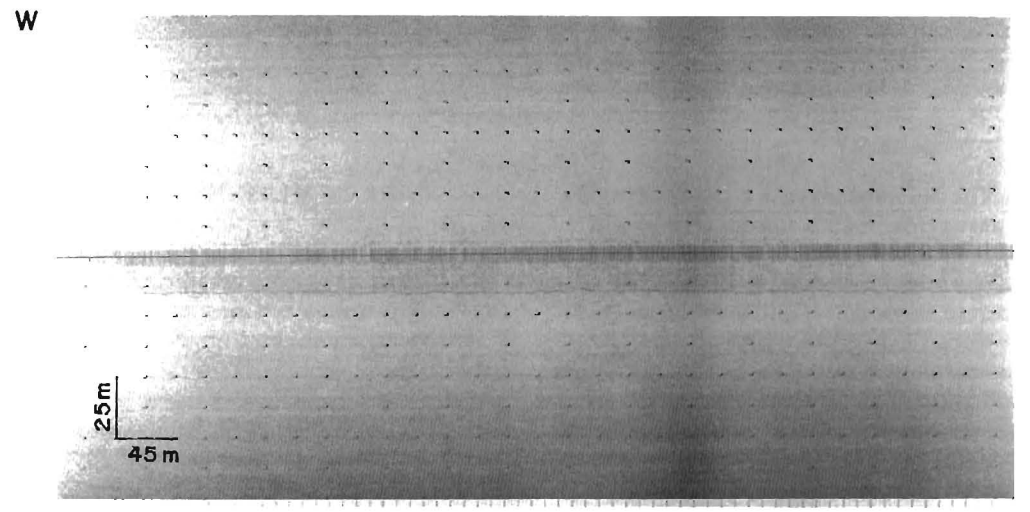


Figure 3. Sonograph showing featureless pattern due to the smooth topography on the inner shelf which is covered with fine grained sediments.

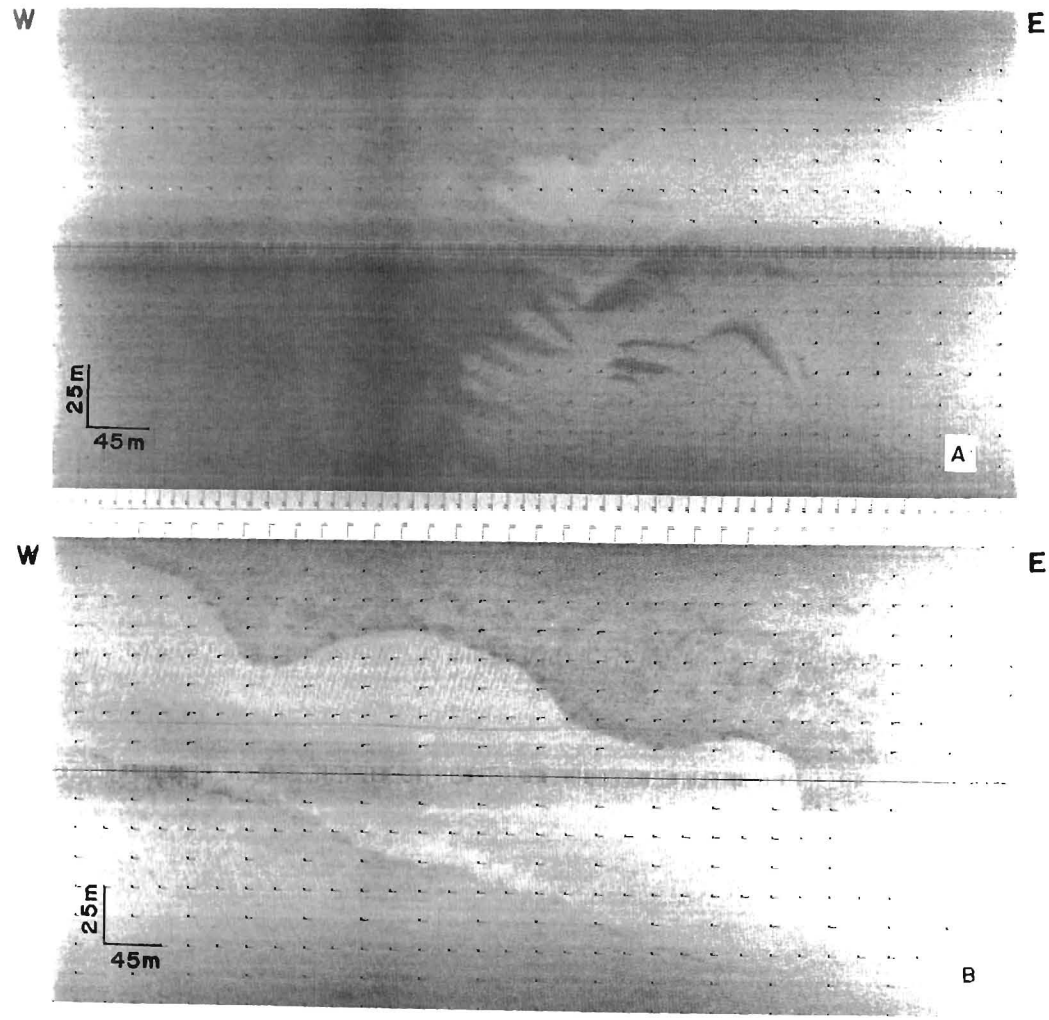


Figure 4. Sonographs showing (A) light tone towards the inner shelf and moderate tone towards the outer shelf; and (B) distinct tonal difference reflecting variations in the surface sediments (*i.e.* coarse—dark tone, finer—light tone).

are circular in shape and occur in isolated groups that follow the trend of the parallel lineations.

Echograms

The results of the several hundreds of kms of bathymetric data collected during the cruises are in agreement with the conclusions of NAIR *et al.* (1978) and will not be discussed in detail. However a summary is given below.

The topography of the inner shelf is smooth and featureless as evidenced by the echograms (Figure 8A), which also recorded sub-bottom reflections. These sub-bottom reflections gradually surfaced in the echograms (Figure 8B) collected on the shelf between the depths of 40 and 60 m. Topography in this region is uneven, dipping very gently towards the outer shelf. Echograms on the outer shelf (Figure 8C) recorded undulations of 2 to 3 m relief. Pinnacles of 4 to 5 m high (FIgure 8D) were noticed

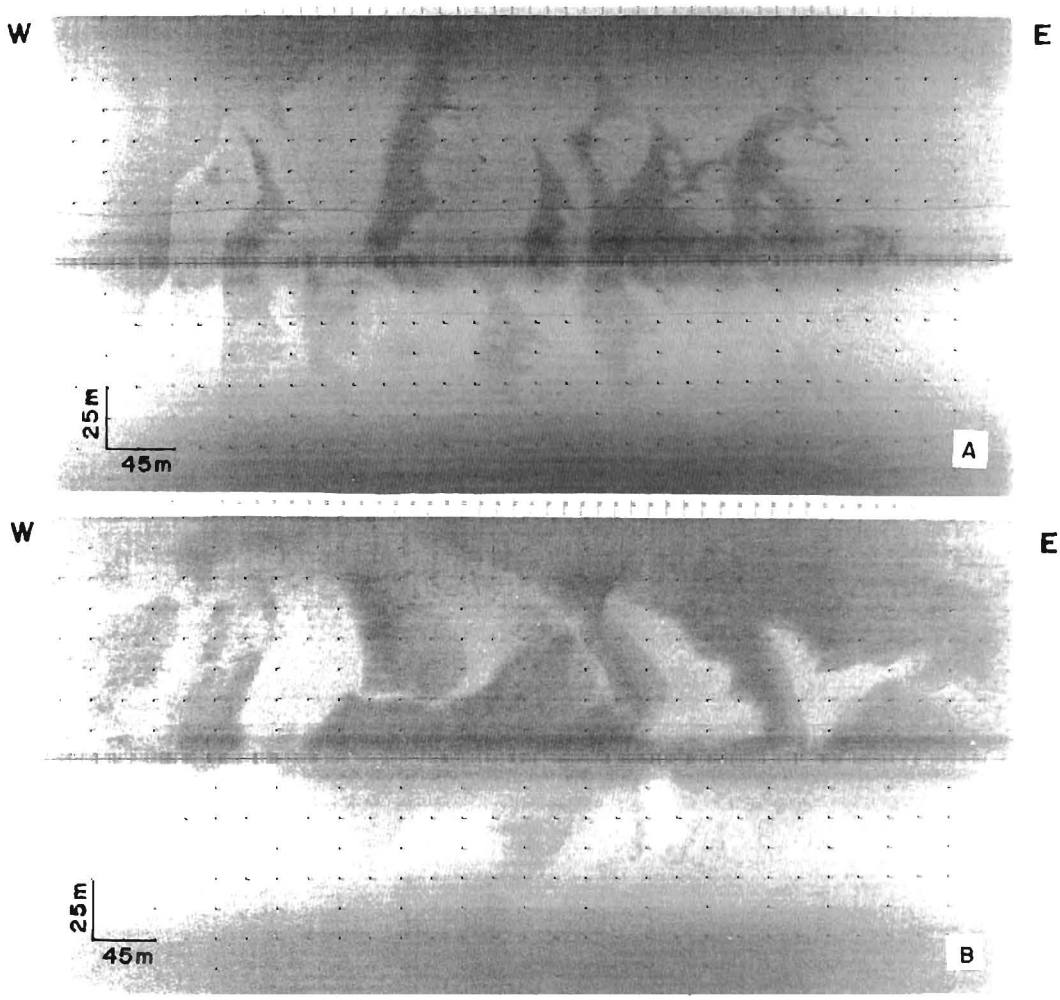


Figure 5. Sonographs showing tonal patches produced by textural differences in the sediments. Dark patches are the reflections from coarse grained sediments. (A) Abundance of the patches is less towards the inner shelf; and (B) more towards the outer shelf.

over the upper continental slope. The shelf break in this area is gentle and the depth beyond the shelf break increases sharply.

DISCUSSION

Areas of Blanket Sedimentation

The sediment distribution map (Figure 2) shows that silt, silty clay, and clayey silt cover the inner shelf. This is represented by the featureless patterns (Type 1) on the sonographs (Figure 3). These sonographs apparently indicate areas of fine grained sediment accumulation. The fine grained sediments form a relatively narrow band confined to <50 m water depth and within a distance of 25 to 35 km from the coast. The boundary between coarse and fine grained sediments (Figure 4) is noticed at this depth. This may be due to the fact that the sediment laden estuarine waters are influenced by the currents and spread parallel to the coast. NAIR *et al.* (1978) explained that during the monsoon, the estaurine waters have salinities as low as 2°/00 and when these low salinity sed-

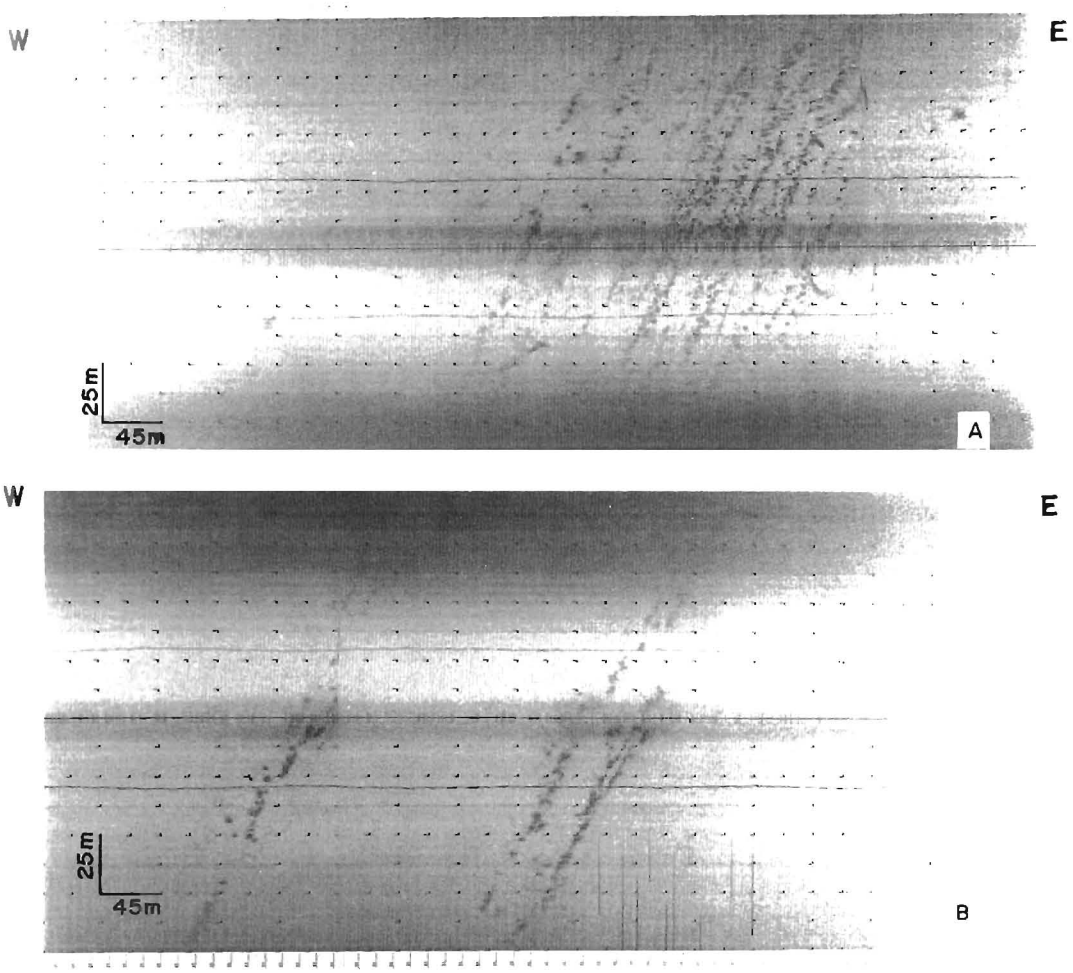


Figure 6. Sonographs showing lineations produced by algal and oolitic ridges. (A) Ridges are more in number and closely spaced towards the north; and (B) widely spaced and less in number towards the south.

iment laden waters are discharged into relatively high salinity waters of the inner shelf, the sediment flocculates and deposits.

Areas of Textural Differences

Sonographs that show tonal patches (Type 2) are recorded at depths of 40-60 m. This region consists of silts and clays with varying proportions of sand (Figure 2) and may be termed a transition zone from fine to course sediments. The sub-bottom reflection from the coarse sediments seen in echograms of the inner shelf, gradually surfaced in this area (Figure 8B), which indicates the presence of coarser sediments at the surface. Surface samples in this area comprise of mainly calcarious sands with little fine grained sediments (Figure 2). It is therefore apparent that changes in sediment texture have produced the light and dark patches on the sonographs (Figure 5). The dark areas represent coarser sediments, while the light areas may be due to the presence of discontinuous fine grained sediments. The origin of this pattern is, however, not very clear. One reason could be that uneven topography and undulations recorded at this depth, may obstruct sediment movement resulting in the

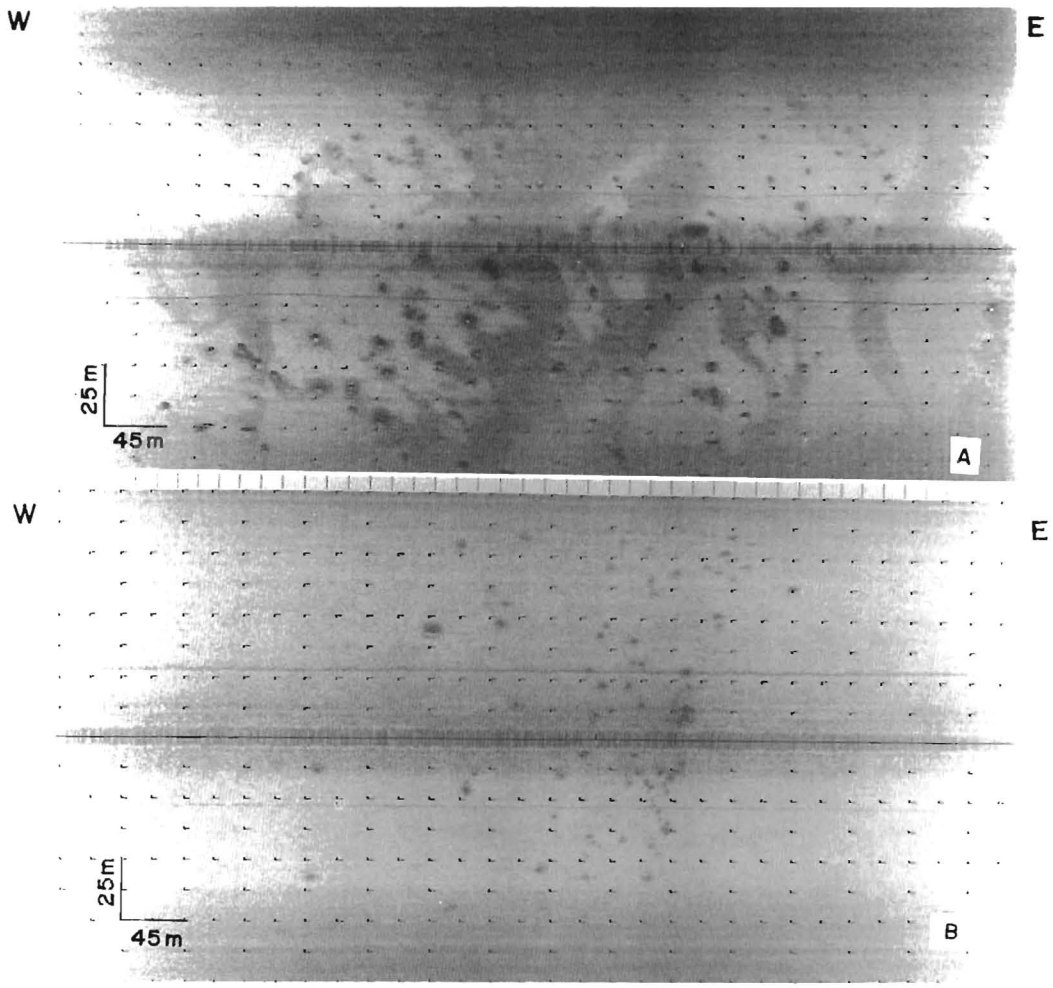


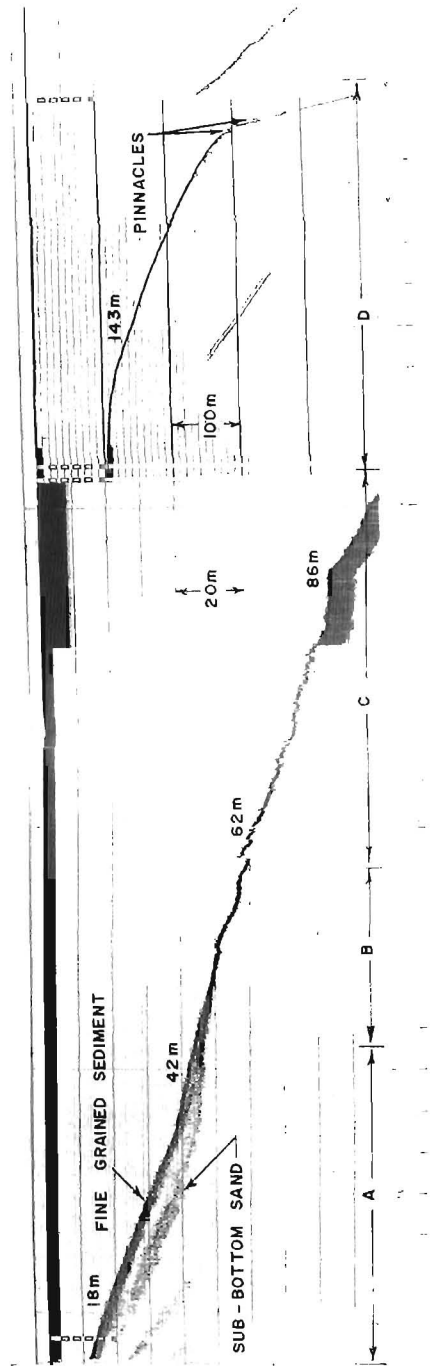
Figure 7 Sonographs showing spot phenomenon produced by algal knolls. (A) Algal knolls are densely distributed in the north; and (B) less towards the south.

settling of fine grained sediment in between the undulations, giving rise to localized textural variations. Sediment displacement caused by wave induced bottom currents may also be one of the contributing factors. Calculations of NAIR and HASHIMI (1987) suggest that long period waves (13/14 seconds) that occur during monsoon period appear to be responsible for sediment redistribution.

Figure 8. Echosounder profile across the shelf (A) Inner shelf represented by smooth topography and covered with acoustically transparent fine grained sediments with sub-bottom reflections from coarse sediments (zone of sedimentation); (B) transition zone with uneven topography; (C) outer shelf exhibiting undulations of 2 to 3 m relief and absence of fine grained sediments (zone of algal and oolitic ridges); and (D) shelf edge and upper slope showing pinnacles (zone of algal knolls). Please note change in scale *(Facing page)*.

Areas of Reef Exposure

The parallel lineations (Type 3) observed on the sonographs (Figure 6) from the outer shelf region are produced by reef exposures. The undulations recorded on the echograms (Figure 8C) and sub-bottom reflections of shallow seismic profiles (SIDDIQUIE *et al.*, 1977) con-


PINNACLES
143m
100m
20m
86m
62m
42m
18m
FINE GRAINED SEDIMENT
SUB-BOTTOM SAND
A
B
C
D

firm the above observation. Sub-bottom profiles show that these relict features extended onto the inner shelf beneath the fine grained sediments. They are late Pleistocene algal and oolitic ridges (NAIR, 1975) built as long structures parallel to the shelf and occur as groups spaced at less than a km to few kms (Figure 6). The ridges seem to originate by organic capping of pre-existing structures which may be constructional or erosional; or by organic reef (bioherm) formation during lower stand of sea level (MACINTYRE and MILLIMAN, 1970). The sediments deposited on the continental shelf during lowered sea levels are later transformed under the influence of the transgressive sea into ridges and bars being in turn modified at places by cappings of algal limestones (NAIR, 1975). Width of the ridges varies from about 5 to 25 m. The groups of algal and oolitic ridges are more common in the north (Figure 6A) than in the south of the area (Figure 6B). A direct relationship exists between $CaCO_3$ content in the sediments (50 – 90% in the north and < 65% in the south (RAO, 1983)) and the frequency of reef occurrences. Algal reefs develop in clear waters. The shelf is narrow towards the south and terrigenous sediments, may reach as far as the outer shelf as evidenced by low carbonate content and distribution of iron stained quartz (NAIR *et al.*, 1978). The resulting turbidity in the water may thus restrict algal growth.

Coral algal reefs and algal hard grounds are characteristic of shelf margins in tropical seas (GINSBURG and JAMES, 1974). Algal ridges similar to those of the western shelf of India are present on the continental margin off Hatteras, southeastern United States (ZARUDZKI and UCHUPI, 1968; MACINTYRE and MILLIMAN, 1970). FOCKE (1978) reported the reef accumulation and reef growth that followed the Holocene transgression near Curacao. Radio carbon dating of algal limestones and reefs on the western shelf of India by NAIR (1975) indicated an age of ~ 11,000 yrs BP. Systematic mapping and dating of the reef samples collected sequentially in a traverse perpendicular to the shelf may yield results related to Holocene sea level fluctuations.

Areas of Algal Knolls

At the shelf break and on the upper slope at water depths beyond 100 m, the ridges give way to isolated colonies of algal knolls. Echograms over this area recorded pinnacle like features less than 5 m high (Figure 8D), while sonographs (Figure 7) show spot like phenomenon (Type 4). WILSON (1979) reported numerous dark spots on sonographs collected on upper continental slope of the Bay of Biscay, between water depths 165 and 444 m. These patches are interpreted as reflections produced by the coral *Lophelia Pertusa* (WILSON, 1979). Dredge haul from the upper continental slope of India between water depths 158 and 182 m, however, yielded algal limestone. Petrographic study of thin sectioned samples showed that the rock is largely composed of corralline algae, cemented together with some amount of Bryozoa and foraminifera (NAIR, 1975). Radio carbon dating of algal limestones gave an age of 1,1150 ± 130 years (NAIR, 1975). Therefore, it is suggested that the pinnacles are composed of algal knolls and remnants of reefs submerged during the Holocene transgression. Algal knolls, as with algal ridge occurrences, are more abundant in the north (Figure 7A) compared to the southern part of the area (Figure 7B). The same reasons may account for the similar variation in their distribution.

CONCLUSIONS

The distribution of sonograph facies is shown in Figure 9. The sonographs and echograms over the central western continental shelf of India indicate that the inner shelf is plain, featureless, covered by modern fine grained sediments and receives a major portion of the sediment input from rivers.

The transition zone that lies between depths of 40 and 60 m exhibits textural differences due to redistribution or discontinuity in deposition of sediments.

The outer shelf exhibits varied bedforms such as reef exposures, oolitic limestones and algal ridges developed parallel to the coast. The northern part of the study area is more favourable for the development of algal and oolitic ridges compared to the south. At the shelf break and upper slope ridges give way to colonies of algal knolls.

Though existing data is insufficient to determine the chronology of these reef structures, sequential sampling and dating may indicate

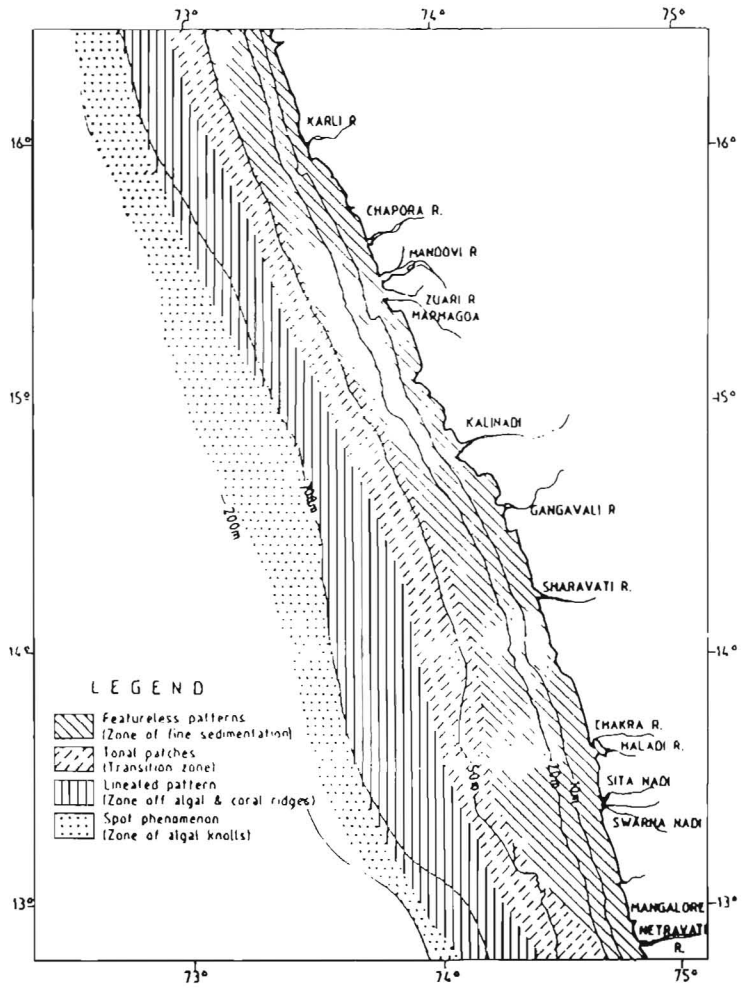


Figure 9. Schematic diagram showing sonograph facies distribution on the central part of the western continental shelf of India.

varying ages for these reef structures, with perhaps the younger ones being towards the coast.

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RESUMEN

Se ha realizado un seguimiento batimétrico y geológico con Side Scan Sonal de la plataforma continental del Oeste de La India. Los gráficos de sonar muestran una plataforma interior suave, sin apenas variaciones importantes, hasta una profundidad de 40-50 m, cubierta con sedimentos granulares finos. Los registros de sonar de la plataforma exterior, desde alrededor de la −60 m hasta el borde del talud continental, exhiben formas de lecho tales como crecimientos recifales (algas y crestas ooliticas) y otras ondulaciones topográficas menores. Hacia el borde de la plataforma éstas dan paso a bajos aislados con colonias de algas. Entre la −40m y −60 m existe una zona de transición con variaciones tonales.

Los datos de tipologia de fondos obtenidos de los mapas de distribución de roca y sedimento indican una situación sedimentaria (plataforma interior), no sedimentaria o en erosión (plataforma exterior) y una combinación de ambos en la zona de transición.

Estos datos se ajustan bein con los obtenidos con los gráficos de sonar.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

RÉSUMÉ

Des campagnes sonarlatéral et bathymétriques ont été menées sur la partie centre ouest du plateau continental indien. Les profils sonar montrent un proche plateau continental lisse et assez uniforme jusqu'aux profondeurs de 40-50 m, recouvert de sédiments fins. Les profils de la partie externe du plateau continental au dela de 60m de profoundeur, jusqu'à son rebord présente des formes comme des affleurements coralliens (algues ou oolithes) et des ondulations mineures. Vers la bordure du plateau continental, ces affleurements donnent lieu à des buttes algales isolées. Une zone de transition, avec des variations de ton est présente entre 40 et 60m de fond. Des données de référence terrain (cartes des sédiments et de répartition des roches) indiquent des environnements de dépôt (bordure du plateu), sans dépôt ou en érosion (plateau externe) et mixte (zone de transition), ce qui s'accorde avec les données du sonar.—*Catherine Bressolier, Laboratoire de Géomorphologie EPHE, Montrouge, France.*