

Nature & Origin of Small Scale Topographic Prominences on the Western Continental Shelf of India

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Small prominences of the order of 1 to 8 m in height occur on the western shelf of India. These features are confined to the outer shelf (65-130 m water depth) and are largely composed of algal and oolitic limestone, radiocarbon dated to be of 9000-11000 yr, and their erosional derivatives. Echo-sounding and sedimentary data suggest that these prominences are the erosional remnants of now submerged relict bars that formed during the Holocene transgression. They have remained uncovered due to low rates of sedimentation and/or the presence of bottom currents on the outer shelf.

OCCURRENCE of small scale topographic prominences formed of algal and/or oolitic limestone on the outer continental shelf off many tropical coasts¹⁻⁵ was reported. Similar features were observed during the course of a survey along a northwest-southeast traverse on the 50 fm flat off the coast of Bombay⁶. Thus to establish (a) whether these features extend up to the shelf edge and beyond and (b) whether they extend southward along the shelf edge, 3 transects one each off Bombay, Ratnagiri and Goa were surveyed on the INS *Darshak* in May 1971. This paper presents interpretation of the echo-sounding data, petrography of the dredge samples and of the sediment distribution from the present and earlier INS *Darshak* cruise collections.

Methods

Bottom profile (Fig. 1) from the nearshore region up to the upper continental slope (about 200 m depth) was obtained by a Kelvin Hughes MS 26 G echosounder recording at the rate of 200 soundings/min. Bottom sampling was restricted to the outer shelf and was carried out by a dredge, grab and scoopfish. Productive dredging was limited to 2 stations, one off Bombay and the other off Ratnagiri, the former yielding some molluscan shells while the latter resulted in about 2 kg limestone.

Results

Topography and sediments — The shelf width off Bombay is about 300 km, of which the outer 225 km (which includes the 50 fm flat) between depths of 65 and 100 m are composed of pinnacles with and without adjacent troughs. Pinnacles (pinnacle-like appearance of the features is due to the vertical exaggeration of the scale of the echo-gram; on equal vertical and horizontal scale, these features would be transformed into gentle undulations) are commonly 1 to 2 m in height, reaching a maximum of 8 m at places. The troughs are usually 1 to 2 m deep. A few troughs are as much

as 10 m deep with more than one pinnacle neither of which projects over the top of the depression (Fig. 2A). A progressive increase in the relief is also observed as one proceeds from shallow to deeper waters. In addition to these features, there are a number of large (c. 2000 to 4000 m in width) mound-shaped protuberances with a relief of 6 to 8 m. These are found on the outer shelf at depths of 80 to 85 m. The shelf-break in this region occurs at about 95 m.

Sediments in this area are invariably composed of oolites (cream and tan-coloured) and skeletal debris consisting of molluscs, coralline algae, Bryozoa, Foraminifera and lithic fragments. Shells of the middle shelf (50-70 m) are usually dull lustrated, extensively bored and often blackened in sharp contrast to those found on the outer shelf (70-100 m).

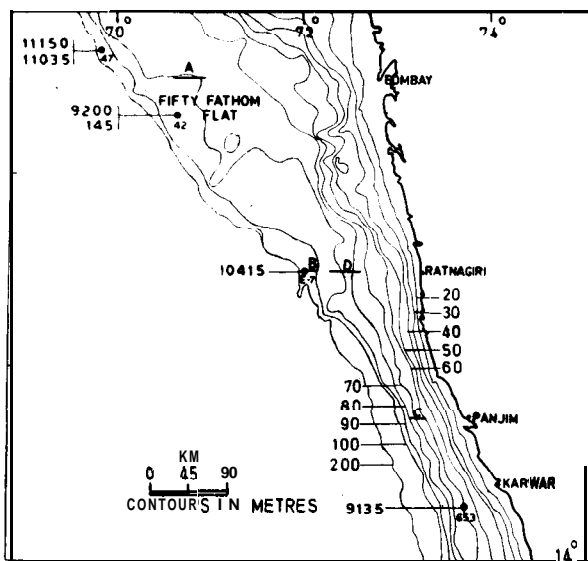


Fig. 1 -Location of bottom profiles (A, B, C and D) shown in Fig. 2 [Also shown are radiocarbon dates (after Nair, 1974)]

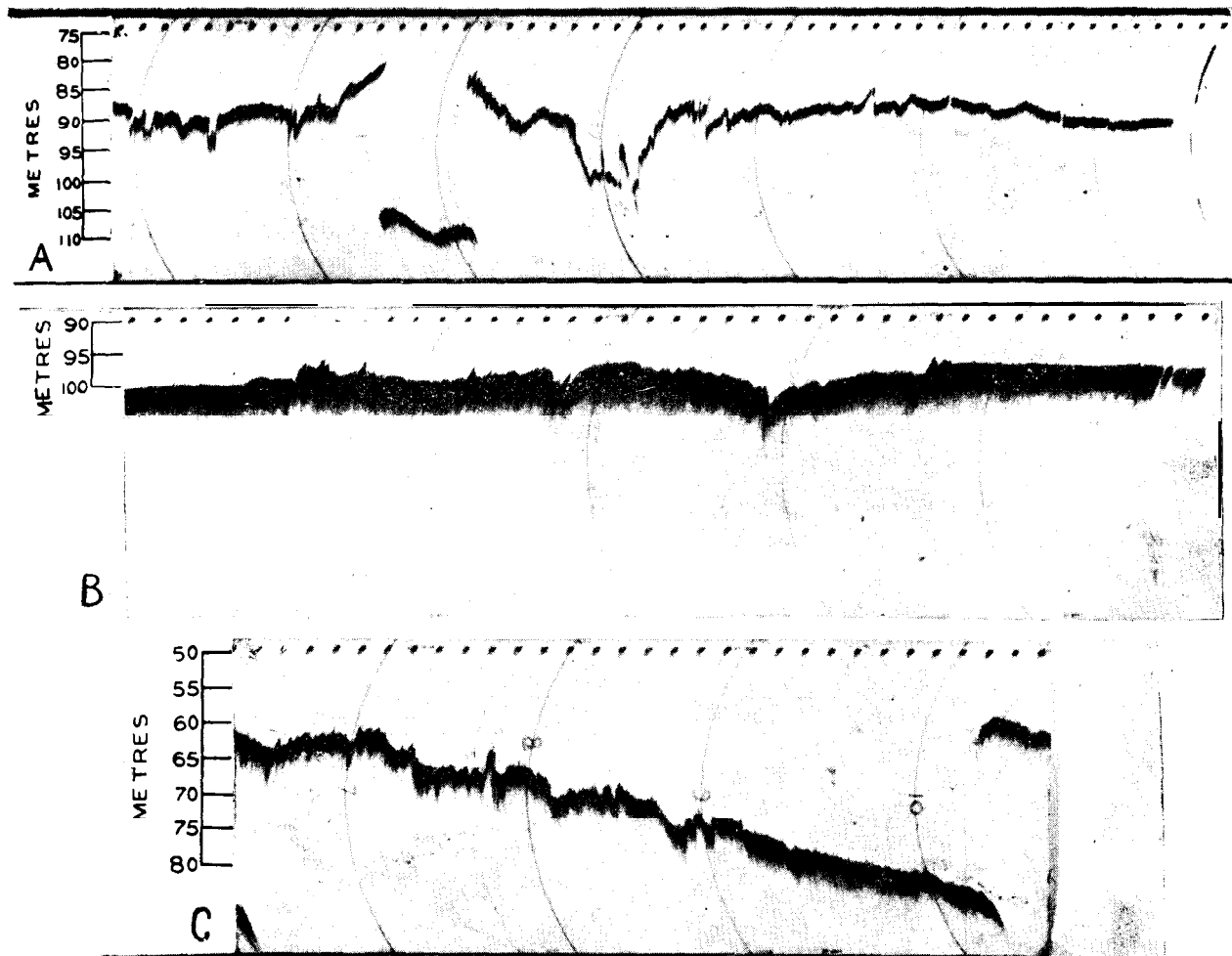


Fig. 2 -- Representative bottom profiles of the outer shelf (A) off Bombay, (R) off Ratnagiri and (C) off Goa [Horizontal distance between 15 min time mark is approximately 4500 m. Offsets in profiles A and C due to change in scale]

Off Ratnagiri, the shelf narrows down to about 100 km and the shelf-break takes place at 130 m. Pinnacles and troughs, restricted to depths between 95 and 100 m, are poorly developed as compared to those off Bombay. The heights and depths are rarely greater than 1 m (Fig. 2B). In the Ratnagiri profile there are well-defined terraces at -65, -75, -85 and -92 m (Fig. 3). On the upper slope, between 158 and 182 m, the irregularities reappear and a dredge haul between these depths yielded algal limestone. Sediment composition in the outer shelf is largely similar to that off Bombay. The major difference is that most of the oolites and some of the shells are dominantly brown or black. In the oolite colour the most noticeable feature is the gradation from white through tan to black and a combination of the above colours. A similar range of colouration is conspicuous in the accompanying Foraminifera shells.

Progressive narrowing of the shelf is reflected in the 60 km wide shelf off Goa, the shelf-break occurring at a depth of 130 m. Terraces are observed at depths of 62, 74, 85 and 90 m, but these are far less distinct than those off Ratnagiri.

Pinnacles with relatively gentle depressions occur on a sloping shelf between the sea-floor depths of 62 and 84 m (Fig. 2C). Unlike off Ratnagiri, the shelf slopes smoothly to the upper continental slope. Sediments in composition, texture and colour are similar to those off Ratnagiri.

Dredge samples — As mentioned in the preceding section dredging resulted in limestone off Ratnagiri and some molluscan shells off Bombay. The Ratnagiri samples were probably obtained from the upper slope (158-182 m) as the shelf-break occurs at about 130 m. That the samples are freshly dislodged from the outcrops and are not loose material lying on the sea-floor is indicated by the dirty brown colour, scoriaceous nature (cavities are probably due to the action of boring organisms), abundant serpulid tubes on the exposed surface while the freshly broken surface is greyish white and devoid of serpulid tubes. Individual pieces of rock were examined under binocular microscope and no significant differences were noticed. One sub-sample was taken as the representative of the entire dredge haul and was thin-sectioned for petrographic study. It showed that the rock is

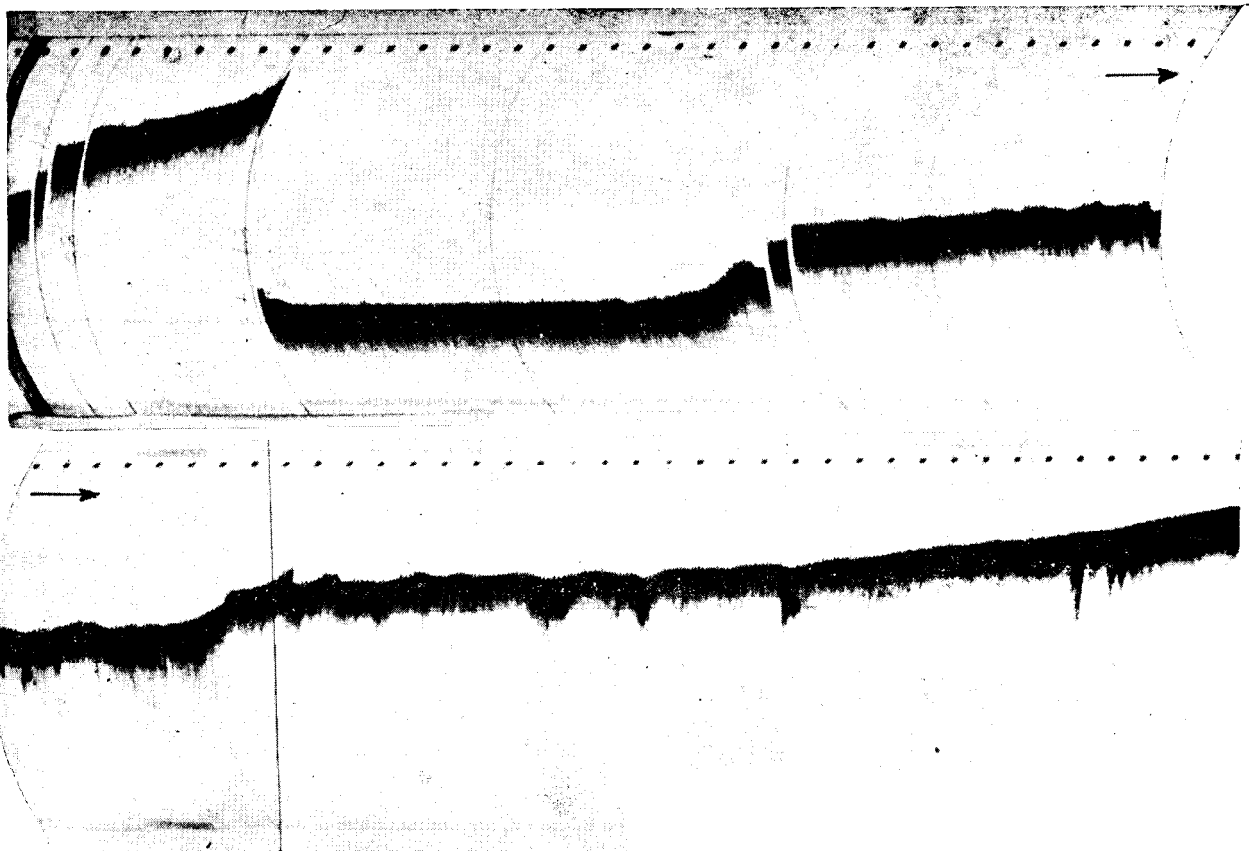


Fig. 3 — Submerged terraces on the outer shelf off Katnagiri (location D in Fig. 1) [Terrace depths from right (landward) to left (seaward) are 65, 71, 86 and 92 m]

largely composed of coralline algae, with some amount of Bryozoa and Foraminifera cemented together by greyish brown ferroan matrix, the latter might have been introduced by the river runoff into the diagenetic environment from the coastal formations most of which is heavily lateritized.

Insoluble residue obtained after treating another sub-sample of the algal limestone with cold 8% HCl constituted 4% rock. The bulk of the residue was composed of clay which was removed by dispersing the residue in water and decanting off the clay suspension. The material remaining after the removal of clay was composed of angular to sub-angular grains of 2 different sizes (0.025-0.037 and 0.012-0.015 mm). Among the minerals observed were quartz, plagioclase (partially altered), hornblende, augite, zircon, kyanite (?) and opaques.

A 3rd sub-sample was dated by the radiocarbon method which gave an age of 10415 ± 260 yr (NIO No. E/7, TIFR No. TF 1200).

The presence of oolitic and/or algal limestones on the outer continental shelf and upper slope was reported by Nair⁶ (Fig. 2). Subsequently, a radiocarbon date was determined on a sample of algal limestone (*Darshak* cruise No. 4, sample No. 47; depth 150 m, TIFR No. TF 970) which gave an age of 11150 ± 130 yr. This agrees well with the age of the Ratnagiri samples obtained at a similar depth. It may be mentioned here that algal lime-

stones have a limited use as sea-level indicators because of the variable depth range in which the algae have been found to live⁷. Therefore, the sea levels based on the ages of such rocks generally indicate a lower stand as compared to the ages obtained, for example, from oolitic limestones.

Discussion

Shelf edge pinnacles and troughs have been postulated by MacIntyre and Milliman⁴, to originate in two possible ways: (i) Organic capping of pre-existing structures which may be constructional or erosional. Constructional features such as barrier beaches and sand bars have been suggested for the origin of prominences off Venezuela³ and a combination of constructional and erosional features capped by coralline algae off the southeast coast of the USA by MacIntyre and Milliman⁴, who further attribute the associated oolitic ridges and mounds to deposition and subsequent lithification during the Holocene transgressions. (ii) An organic reef (bio-herm) origin has been suggested for the prominence off Florida and a submerged reef formed during a lower stand of sea level for those off the Gulf of Mexico and on the north Australian shelf, quoted in MacIntyre and Milliman⁴.

From the available data it is not possible to arrive at a positive conclusion about the origin of the features reported in the present study. The

data nevertheless permit some qualified inferences. A critical examination of the echogram shows that the bottom profile consists of minor relief forms superimposed on the main structure composed of undulating topography. These undulations are commonly about 500-700 m in wavelength and exceptionally 1000 m or more. When traced landward they become progressively smaller in wavelength. The general relief of the crests represented by the height of the pinnacles is, as mentioned earlier, of the order of 1-2 m. Thus a possible geomorphic feature comparable in morphology and dimension are barrier beaches, while the minor relief forms may be submarine bars and their smaller equivalents could be ridges and runnels. The formation of the latter two is favoured where the overall gradient is flat and where the supply of sediment is abundant⁸. It has been stated by King⁹ that in many areas, the extra beach material can be associated with deposition of much glacial or fluvioglacial sand and other material in the areas which now form the shallow waters of the offshore zone as a result of the post-glacial rise in sea level.

In the context of the above statement, a notable feature is that pinnacles and troughs are most prominent off Bombay where the shelf is flat and widest and becomes relatively subdued in profile towards the south where the shelf is generally half or less than half in width. A possible explanation for this appears to be that the terrigenous silt and clay sediment load is confined to a very limited distance from the coast. In a region where the shelf is very wide, as off Bombay, this distance would be represented by the outer limit of the inner shelf (60 m depth) leaving the middle and outer shelf free from sedimentation and resulting in pinnacles and troughs remaining uncovered, whereas in the case of the narrower parts of the shelf, i.e. Ratnagiri and southwards, terrigenous sediments may reach up to the middle and outer shelf giving rise to a general smoothing of the bottom profile. Evidence in support of the above argument is provided by the amount of insoluble residue, taken as a qualitative measure of the terrigenous sediment influx, which is considerably lower (0.9%) for the oolitic limestone off Bombay⁹, compared to the value of 4% for the limestone off Ratnagiri.

The presence of brown and black shells and oolites showing similar colouration between 55 and 90 m depth has already been mentioned. Blackening of shells is due to the content of organic matter and iron (in the form of iron sulphide) and their burial in a reducing environment¹⁰⁻¹². Such a reducing environment in the sediment and in the sediment-water interface is usually present in regions where fine-grained sediment with organic matter accumulate, such as in the nearshore regions. In the depth range of 55-90 m, however, sand-sized material constitutes 60% or more of the surficial bottom sediment¹³, while the organic matter ranges from 0.88-0.95% as against 1.92-3.9% for the inner shelf¹⁴. Blackening of Foraminifera tests and oolites, therefore, takes place not on the surface where they are now found but on burial beneath the sediment wherein the requisite reducing conditions

are available. Their relative abundance in the middle shelf, as compared to the outer shelf, suggests that the organic matter rich, terrigenous clastics may also aid in the process of blackening by giving rise to reducing conditions in the middle shelf.

During the periods of glacially lowered sea levels, rivers and streams would have deposited their sediment load progressively further over the continental shelf¹⁵, and up to the shelf edge during the periods of maximum lowering. The former still stands of sea level are indicated by the submerged terrace at -92, -85, -75, -55 m. Radiocarbon age (9000-11000 yr) of the rocks indicate a Holocene age¹⁶, a period during which the sea was in a transgressive phase throughout the world. It is, therefore, possible that the oolitic and other sediments after deposition are transformed under the influence of the transgressive sea into ridges and bars, being in turn modified at places by cappings of algal limestones.

The algal limestones overlie the oolitic limestones because, as pointed out by MacIntyre and Milliman⁴, coralline algae are capable of surviving over a wide depth range even to the lower limits of the photic zone and usually give rise to the last organic structures on the sea-floor during a transgressive sea level. It is for these reasons and also the fact that oolites are strictly of shallow water origin — that one finds on the outer shelf oolitic and algal limestones, whereas in deeper waters of the slope solely algal limestones occur.

The present topography of the outer shelf is a result of the erosion of these constructional features. Evidence of erosion is the presence of extensive deposits of oolites, algal debris, broken shells and lithic fragments. The extensively bored nature of the limestones point to the prominent role of boring organisms (sponges, algae, molluscs) in their breakdown into smaller fragments. The presence of bottom currents on the outer shelf which may redistribute the sediments and also winnow away what little sediment is deposited on the outer shelf can also be inferred. An indirect evidence in support of the above inference is the fact that the small troughs are maintained free of sediment-fill.

Except for the fact that the coastal Tertiaries underlain by the Deccan Traps extend to the continental slope off Bombay, no data are available at present for the pre-Holocene surface over which the algal and/or oolitic limestone originated. Seismic reflection studies of the western shelf^{18,19} indicate seaward dipping reflectors but no details of the upper few hundred metres of the sediment are available. High resolution, shallow penetration reflection profiles of the shelf should provide the appropriate data needed to substantiate and/or modify the above inferences regarding the origin of such small scale prominences.

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