

Outer Shelf Carbonate Pinnacles & Troughs on the Western Continental Shelf of India

By

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ABSTRACT

Outer shelf carbonate pinnacles and associated troughs were first separated off Bombay by Nair (1971a). Similar pinnacles and troughs have since been observed on the outer shelf and upper slope (depths about 70-180 meters) off Ratnagiri and Goa. Dredge hauls in the area indicate the presence of algal and/or oolitic limestone (beachrock) of Holocene age. Topographic and sedimentary data suggest that these small scale features may be erosional or constructional features originating on a surface topography consisting of now submerged Tertiary sand bars which have remained uncovered due to low rates of present day sedimentation on the outer shelf and upper slope.

INTRODUCTION

In recent years numerous instances have been documented of the occurrence of small scale topographic irregularities composed of algal and/or oolitic limestone on the outer continental shelf of many tropical coasts (Ludwick and Walton 1957, Nota 1958, Squires 1963, Macintyre and Milliman 1970, McMaster, Lachance and Ashraf 1970). Apparently similar features were observed during the course of a survey along a northwest-southeast traverse on the Fifty Fathom Flat off the coast of Bombay (Nair 1971 a, Fig. 3). In order to establish a) whether these features extend to the shelf edge and beyond and b) whether they extend southward along the shelf

edge, three transects one each off Bombay, Ratnagiri and Goa were surveyed on the I. N. S. DARHSAK in May 1971. Bottom profile from the nearshore region to the upper continental slope (about 200 metres depth) were obtained by a Kelvin Hughes MS 26 G echosounder recording at the rate of 200 soundings per minute (Fig. 1). Bottom sampling was restricted to the outer shelf and was carried out by a dredge, grab and scoopfish. Productive dredging was limited to two stations, one off Bombay and the other off Ratnagiri, the former yielding some molluscan shells while the latter resulted in about 2 kilograms of limestone. This report is an account of the interpretation of the echosounding data, petrography of the dredge samples and of the sediment distribution from the present and earlier cruise collections.

RESULTS

Topography and Sediments : The shelf width off Bombay is 300 kilometers wide of which the outer 130 kilometers with an average depth of 85 meters is composed of pinnacles with and without adjacent troughs. The pinnacles are commonly 1-2 meters in height, reaching a maximum of eight meters at places, whereas the troughs are usually 1-2 meters deep. A few troughs are as much as 10 meters deep with more than one pinnacle neither of which project over the top of the depression (Fig. 2a). The sediments in the area are invariably composed of oolites (white, greyish white and light brown superficial oolites) and skeletal debris consisting of molluscs, coralline algae, bryozoa, foraminifera and lithic fragments. Shells of the middle shelf (50-70 meters) are usually dull lusted, extensively bored and often blackened in sharp contrast to those on the outer shelf (70-100 meters)(').

Off Ratnagiri, the shelf narrows down to about 100 kilometers and the shelf break takes place at 130 meters. The pinnacles and troughs, restricted to depths between 95-100 meters, are poorly developed as compared to those off Bombay, the heights and depths being rarely greater than a meter (Fig. 2b). Most prominent in the Ratnagiri profile, but not equally well developed in the other two profiles, are well defined terraces at -92, -85, -75, and -55 meters. On the upper slope between 158-182 meters the irregularities reappear and a dredge haul between these depths yielded algal limestone. Sediment composition on the outer shelf is largely similar to that off Bombay with the difference that most of the oolites and some of the shells are dominantly brown or black. Most noticeable in the oolite colour was a gradation from white through tan to black and a combination of the above colours. Indication of a similar range of coloration was conspicuous in the accompanying foraminifera shells.

The progressive narrowing of the shelf is reflected in the 60 kilometer wide shelf off Goa, the shelf break being at a depth of 130 meters. A terrace at -90 meters is clearly observed. Pinnacles with relatively gentle depressions occur on a sloping shelf between sea-floor depths of 62-89 meters. (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 are assumed to have been obtained from the upper slope (158-182 meters) as the shelf break takes place at 130 metres. That the samples are freshly dislodged from outcrops and are not loose material lying on the sea-floor is indicated by the dirty brown colour, scoriaceous nature (cavities may be due to the action of boring organisms), abundant serpulid tubes on the exposed surface while the freshly broken surface is greyish white, devoid of serpulid tubes. Individual pieces of rock were examined under binocular microscope and no significant differences were noticed. One sub-sample assumed therefore to be representative of the entire dredge haul was thin sectioned for petrographic study. Thin section shows the rock to be composed of coralline algae, brayoza and foramanifera cemented together by greyish brown ferroan matrix, the latter may have been introduced into the diagenetic environment from the coastal formations most of which are heavily lateritise

In soluble residus obtained after treating another sub-sample with cold 8 percent HCL, constituted 4 percent of the rock. Bulk of the residus was composed of clay which was removed by dispersing the residue in water and decanting off the clay suspension. Material remaining after removal of clay is composed of angular to sub-angular grains of two different sizes, 0.025 - 0.037 mm and 0.012 - 0.015 mm. Among the minerals observed are quartz, plagioclase (partially altered) hornblende, augite, zircon, kyanite (?) and opaques.

A third sub-sample was dated by radiocarbon method and gave an age of 10120+250 years B.P. (N.I.O.No. 71, TIFR No. TF 1200).

The presence of Oolitic and or algal limestones on the outer continental shelf and upper slope has already been reported by Nair (1971 a). Subsequently a radiocarbon age was determined on a sample of algal limestone (DARSHAK Curise No. 4, Sample No. 47, depth 150 metres, TIFR No. TF 970) and gave an age of 10725—400 years B. P. which agrees closely with the age of the Ratnagiri samples obtained at a comparable depth. It may be mentioned here that algal limestones have limited use as sea-level indicators because of the variable depth range in which the algae have been found to live (Milliman and Emery 1968) and therefore sealevels based on the ages of such rocks generally indicate a lower stand as compared to ages obtained from oolitic limestones, for example.

DISCUSSION

Shelf edge pinnacles and troughs have been postulated to originate in two possible ways (MacIntyre and Milliman 1970), a) 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 Venezuela (Squires 1963) and combination of constructional and erosional features capped by coralline algae off the southeast coast of the U. S.A by MacIntyre and Milliman (1970), who further attribute the associated oolitic ridges and mounds to deposition and subsequent lithification during the Holocene transgression. b) an organic reef (bioherm) origin has been suggested for the prominence off Florida and a submerged reef constructed during a lower stand of sea level for those off the Gulf of Mexico and on the north Australian shelf (quoted in MacIntyre and Milliman 1970).

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 meters in wave length and exceptionally 1000 meters or more. The general relief of the crests represented by the height of the pinnacles is, as mentioned earlier, of the order of 1-2 meters. Thus a possible geomorphic feature compared in morphology and dimension are the ridge and runnel topography formed on the foreshore zone of the beaches. According to King (1966) ridge and runnel topography develop best where the overall gradient is flat and where the supply of sand is abundant. King (1966) p. 342 further states that "In many areas the extra beach material can be associated with the deposition of much glacial or fluvio-glacial 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".

A significant observation is the fact that the pinnacles and troughs are most prominent off Bombay where the shelf is flat (gradient to minutes or less) and widest and becomes relatively subdued in profile towards the south where the shelf is generally half or less in width. A possible partial explanation for this may 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 meters depth) leaving the middle and outer shelf free from sedimentation and resulting in the 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 upto the middle and outer shelf giving rise to a general smoothening 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 percent) for the oolitic limestone off Bombay (Nair 1971 b) when compared to the 4 percent of the limestone off Ratnagiri.

The presence of brown and black shells between 55 and 90 meters depth has already been mentioned. Siddorenko (1901 in Zenkovich 1967), Pilkey (1969) and

Milliman, Fileky, Blackwelder (1968) have shown that blackening of shells is due to the content of organic matter and iron (in the form of iron - sulphide) and that blackening results due to burial in a reducing environment. Such reducing environment in the sediment and in the sediment water interface is usually present in regions where fine-grained sediment with organic matter accumulate, as in the nearshore regions. In the depth range of 55-90 meters however, sand sized material constitutes 60 percent or more of the bottom sediment (Nair 1968) while the organic matter ranges from 0.88 - 0.95 percent, as against 1.92-3.8 percent for the inner shelf (Murty 1968). Shell blackening cannot have taken place under the present conditions but may have resulted in the past during the Holocene transgression when the middle and outer shelf were subject to greater sedimentation. From the foregoing arguments it is inferred that the middle and outer shelf are zones of low sedimentation at the present but that in the past, probably during the Holocene, it was under the influence of higher sedimentation rates corresponding to the nearshore regions.

During periods of glacially lowered sea levels, rivers and streams will have deposited their sediment loads progressively further off over the continental shelf (Emery 1968, pg. 456) and upto the shelf edge during periods of maximum lowering. Former still stands of sea level are indicated by the submerged terrace at -92, -85, -75, -55 metres. Radiocarbon age of the rocks indicate a Holocene age, period during which the sea was in a transgressive phase throughout the world (Milliman and Emery 1968 and references therein). It is, therefore, possible that the oolitic and other sediments after deposition were transformed under the influence of the transgressive sea into ridges and bars, being in turn modified at places by cappings of algal limestones. The present topography being a result of the erosion of these constructional features. Evidence of erosion is indicated by the extensive deposits of oolites, algal debris broken shells and lithic fragments.

Except for the fact that the coastal Tertiaries underlain by the Deccan Traps extend to the continental slope off Bombay (Hinz & Closs, 1966), no data are available at present for the pre-Holocene surface over which the algal and/or oolitic limestone originated. Seismic reflection studies are needed which will aid in substantiating and/or modifying the above inferences regarding the origin of the pinnacle and trough topography.

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