

HOLOCENE LIMESTONES OF PART OF THE WESTERN CONTINENTAL SHELF OF INDIA

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Abstract

Dredging on the western continental shelf of India has shown that the most common rock types outcropping on the irregular topography of the outer shelf (70–90 m) are algal limestones and shelly limestones containing superficial ooids and pelletoids, while those on the upper continental slope (130–180 m) are algal bryozoan limestones. The limestones have a radiocarbon age ranging between 9,000 and 11,000 years. Depositional environment on the continental shelf during the Holocene appears to be characterised by shallow waters in association with lagoon-barrier beach environment.

INTRODUCTION

During the course of geological sampling of the northern part of the western continental shelf of India, a number of rock samples were obtained by dredging. The dredge locations of the six samples described here are shown in Fig. 1. Out of the six samples, five are shelly limestones and one is a calcareous sandstone. The depthwise distribution of the samples are as follows: one sample from the inner shelf (depth 20 m), three from the outer shelf (depth 70–100 m) and two from the upper continental slope (150–180 m).

Previous work on the dredge samples from the western shelf was by Nair (1971), who reported the occurrence of oolitic limestones from a 90 m terrace (the fifty fathom flat) on the outer shelf off Bombay. He suggested that the oolitic limestones are akin to beach rocks and that they may have originated during a period of lower sea level. Nair (1974) also offered a preliminary reconstruction of the Holocene sea level changes based on radiocarbon dates of some of the samples described in this paper.

The purpose of this paper is to present information on the petrography, mineralogy, faunal content and radiocarbon age of the rock samples.

FIELD AND LABORATORY TECHNIQUES

All rock samples were obtained by using a pipe dredge with a chain bag. Dredge haul depths given in Table I, are averages of depths obtained from the echogram at the start and at the end of dredging.

Thin and polished sections were made of the rock samples, grain size of the ooids were measured with a micrometer ocular, insoluble residue was obtained by treating the rocks with acetic acid. Identifications of the skeletal fragments in the thin sections were made by comparison with photographs in Horowitz and Potter (1971) and Milliman (1974). Radiocarbon dates were determined at the Physical Research Laboratory, Ahmedabad. Carbonate mineralogy was identified by staining methods (Friedman, 1971). Rock colour is reported by comparison with the Rock Colour Chart.

SEDIMENT DISTRIBUTION AND BOTTOM TOPOGRAPHY

On the western continental shelf the beach sands extend to about 2–3 m depth. Succeeding this narrow sand zone are the inner shelf (down to 60 m), recent terrigenous silts and clays. These sediments grade into the relict, coarse, calcareous sands of the outer shelf (depth greater than 60 m). The depth of the shelf break is

variable. It ranges from 90 m off Bombay to 140 m off Saurashtra coast (Siddiquie and Rajamanickam, 1974). The study of the carbonate components of the coarse fraction (Hashimi and Nair, 1976) has shown that (a) foraminifera and molluscs dominate the inner shelf skeletal components, (b) the ooids and lithoclasts constitute the most abundant non-skeletal components of the outer shelf and (c) the outer shelf in contrast to the inner shelf is a region of non-accumulation of sediments.

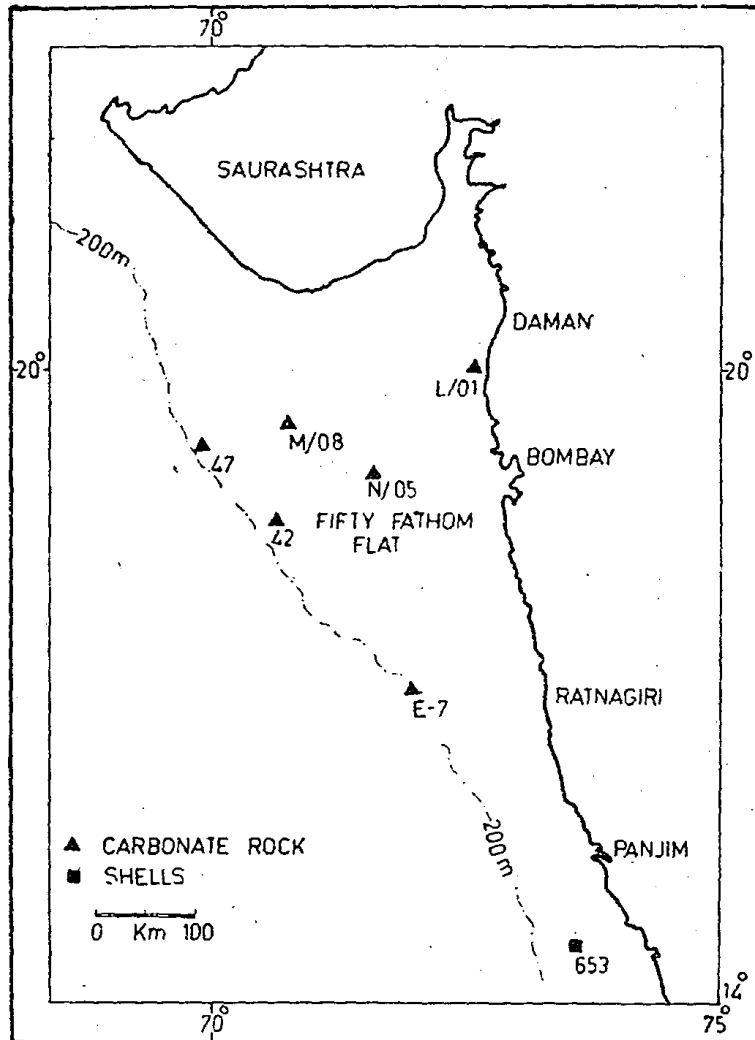


Figure 1. Sample location.

The bottom topography is smooth on the inner shelf and becomes progressively irregular in relief at the shelf edge. The irregular topography has a relief of the order of 1-10 m and consists of prominences with adjoining troughs and V-shaped depressions. These features originated during the Holocene transgression and owe their present configuration to erosional processes (Nair, 1975). The limestones described here are all obtained from the zone of irregular topography. It is known from echo-sounding data that large areas of the outer continental shelf, especially the northern portions (Siddiquie and Rajamanickam, 1974) have an uneven topography. This suggests that limestones may be a common rock type on the bottom of the western shelf.

DESCRIPTION OF DREDGE SAMPLES

The relevant information concerning the dredge samples are summarised in Table I. The details of petrography, insoluble residue, faunal content and radiocarbon age of the samples are discussed below :

Calcareous sandstone (L/01)

Calcareous sandstones were obtained from 20 m depth off the coast of Daman. They are moderate brown (5YR 3/4), well indurated and devoid of any perceptible laminations. A large number of cavities (solution ?) and borings give the sample a very porous appearance. Encrustations of bryozoans are common.

TABLE I. Summary of salient characteristics of the dredge samples

Sample No.	Nature of Sample	Depth (metres)	Skeletal Components	Non Skeletal components other than ooids	Insoluble Residue (per cent)	Radiocarbon age (years)	Remarks
L/01	Calcareous sandstone	20	Foraminifera, Molluscs	quartz, muscovite hornblende, biotite	37.01	Not dated	
42	Oolitic limestone	98	Foraminifera, Molluscs and algae	quartz, plagioclase	0.63	9,200 ± 135	
N/05	Oolitic limestone	70	Molluscs	quartz, pyroxene albite	7.44	Not dated	Probably Holocene 11,000 yrs.
M/08	Oolitic limestone	82	Molluscs	None	1.63	8,960 ± 200	
47	Algal-pellet limestone	150	Algae, foraminifera, molluscs	ooids (rare)	—	11,150 ± 130 11,035 ± 400	
E/7	Algal-Bryozoan limestone	180	Algae, bryozoa, foraminifera	hornblende, quartz, plagioclase	1.39	10,415 ± 250	
653	Composite shells	58	Molluscs, foraminifera	—	—	9,135 ± 130	Grab sample

In thin section, the rock consists of equigranular grains of quartz (66%), feldspar (6%), mica (2%), amphibole (0.6%), pyroxene (1%) and shells (12%). Garnet, rutile and apatite are seen but are very rare. The grains are cemented by sparry carbonate, probably aragonite.

The insoluble residue constitutes 37% by weight of the rock and is composed of essentially the same minerals noted in thin sections. Microfauna in the sample consists of only two species of foraminifera, *Ammonia beccarii* (60%) and *Poroepionides lateralis* (40%). Both are shallow water, cosmopolitan species frequently reported from beaches (Bhalla, 1968).

Oolitic limestones

The three samples of oolitic limestones obtained from the outer shelf in the depth range of 70–100 m show striking differences particularly in the size and structure of the ooids. They are, therefore, described below in detail.

Sample No. 42 is a very pale orange (10 YR 8/2) coloured rock with patches of dark yellowish orange (10 YR 6/6). It is well cemented, has numerous small and large holes and is encrusted with serpulids.

Thin section shows it to be an oobiomicrite with a high grain to micrite ratio. Most of the ooids are of the superficial type with a single lamina (cortex) enclosing a pelletoid nucleus. True ooids showing the concentric laminae are extremely rare. The nucleus is light brown cryptocrystalline carbonate containing black inorganic matter. The same material is concentrated at the periphery of the ooids giving them a distinct black rim.

The ooids range in diameter from a minimum of 0.08 mm to a maximum of 0.25 mm. The laminations, where present, are 0.05 mm to 0.125 mm in width. Ooids sorting is moderate to poor. Intraclasts are grapestones and pelletoids. The skeletal components consist of whole and fragmented gastropods, brachiopods, pelecypods and foraminifera. Some gastropods enclose ooids, foraminifera and other unidentified shell fragments. The cementing material identified by staining and X-ray diffraction is aragonite (Nair, 1971). *Amphistegina* is the dominant (35–40%) benthic foraminifera. Other species present are *Peneroplis proteus*, *P. pertusus*, *Calcarina hispida*, *Operculina ammonoides*, *Planorbulina* sp., *Elphidium crispum*, *E. advena*, *Quinqueloculina sulcata*, *Quinqueloculina* sp., *Spiroloculina nitida* and *Alveolina* sp. The dominance of *Amphistegina* is usually indicative of a clear, warm and shallow water environment (Poag, 1972; Guptha, 1973). In addition to the benthic foraminifera, indicators of shallow water conditions are the shells of thick walled *Chama*, a shallow water mollusc present in the dredge haul from the same location.

The sample has 0.6% insoluble residue and a radiocarbon age of $9,200 \pm 135$ years.

Sample No. N/05 obtained from a depth of 70 m (Table I) is a light grey coloured (N 7), firmly cemented, extensively bored rock. Encrustations of serpulid tubes and coralline algae are present. In thin section the rock is an oobiomicrite having a low grain to micrite ratio. The ooids are similar to those described as pelletoids by Milliman (1974). Ooid diameters range from 0.06 to 0.125 mm. Encircling laminae are rare in most cases and if present are poorly developed. Intergranular cement is sparry aragonite. Unlike sample No. 42, this sample contains some quartz, hornblende and pyroxene grains. The insoluble residue constitutes 7.5% by weight of the rock.

No radiocarbon analysis was made on this sample. A Holocene age of about 11,000 years may reasonably be assumed because an ooid concentrate from the same region and comparable depth has an age of $11,330 \pm 380$ years.

N/05 sample is very rich in benthic foraminifera. About 50 species are present, of which 50% are constituted by miliolids, 20% *Ammonia*, 18% agglutinated forms such as *Textularia* sp., *Bigenerina* sp., *Quinqueloculina agglutinans*. The remaining 12% of benthic foraminifera include the species of *Cibicides*, *Discorbis*, *Anomolina*, *Nonion*, *Bolivina*, *Lagena*, *Fissurina* and *Amphistegina*.

Sample No. M/08 was dredged from a depth of 82 m and is generally similar in hand specimen to the others described earlier. It is an oobiomicrite with a high grain to micrite ratio, and has grapestones and skeletal fragments. Differences in respect to the other oolitic limestones are (1) the large (0.4 mm to 1.1 mm) size of the ooids, (2) the presence of acicular aragonite cement and (3) the absence of non-carbonate minerals such as quartz, amphiboles and pyroxenes.

An interesting aspect in some of the ooids is the presence of what are apparently two distinct but different types of laminae. The outer lamina consists of the classical tangentially oriented aragonite crystals which is continuous around the

nucleus. The inner lamina is made of radially arranged crystals. This particular lamina is usually discontinuous around the nucleus. Shearman, *et al.*, (1970) in their studies of the ooids from the Trucial coast, noted that a change takes place in the arrangement of the crystals of the cortex in recent and old ooids. They found that the recent ooids have laminae with the crystals arranged tangentially, but with increasing age the arrangement of the crystals becomes radial. The co-existence of both radial and tangential crystals in the cortex of some of the ooids of the western shelf suggests that perhaps these ooids are in a stage of development which is intermediate between the recent and the ancient.

Foraminifera are absent in the sample. A coral *Echinopora* sp., and shell of the gastropod *Xenophora* sp., (a littoral form) were found in the dredge haul from the same location.

The insoluble residue constitutes 1.6%. The rock has a radiocarbon age of $8,960 \pm 200$ years.

Algal limestones

Two varieties of algal limestone were found, one from the upper slope off Bombay (sample No. 47), from a depth of about 150 m and the other from the upper slope off Ratnagiri (Sample No. E/7), from a depth of about 180 m.

Sample No. 47 is moderately compact, yellowish grey (5y 8/1) with numerous cavities. No encrusting organism is present. A faint banding is seen in hand specimen but is more prominent in thin section and is due to the presence of yellowish brown limonitic material.

In thin section the rock appears as an opaque brown mass due to micritisation of the algal fragments. In addition to coralline algae, foraminifera and molluscs, echinoid spines are also present. A few ooids are found in the sample and these were probably displaced from the outer shelf and incorporated into the rock by the binding action of the algae. Its radiocarbon age is $11,150 \pm 130$ years.

The algal limestones from the upper slope off Ratnagiri show significant differences from those off Bombay. In hand specimen the samples strongly resemble algal nodules and are encrusted with barnacles and serpulid tubes. Thin section of the sample shows it to consist of coralline algae and abundant bryozoans. The bryozoan cavities have recrystallised wall structure and in most cases are filled with cryptocrystalline carbonate. Interstitial cementing material is aragonite. Present in minor amounts are gastropods, pelecypods and foraminifera. Polished rock chips of both the algal limestones were stained with a solution of equal volumes of Alizarin Red S and 30% sodium hydroxide. The resulting colour was purple indicating the presence of high magnesium calcite. The ooids contained in sample No. 47, however, remained unstained because of their aragonite mineralogy. Unlike the algal limestones off Bombay, the algal bryozoan limestones contain large unaltered grains of hornblende and some grains of quartz and plagioclase. The radiocarbon age of the sample is $10,415 \pm 250$ years.

DEPOSITIONAL ENVIRONMENT

Evidences of lowered sea level in the past on the western shelf are the presence of ooids, the dominance of *Amphistegina*, a shallow water benthic foraminifera in the oolitic limestone and the occurrence of shallow water molluscs, at present, at a depth of 98 m. Further evidence of old shorelines are the linear distribution parallel to the coastline of fragmented shells, black skeletal fragments and black benthic foraminifera.

The nature and origin of the ooids help in deciphering, in a limited manner, the depositional environment. There is no general agreement however, about the exact origin of these shallow water grains. They are the end products of imperfectly understood processes which have been reviewed, for example, by Bathurst (1971) and Milliman (1974). It is generally agreed that algal, microbial and inorganic precipitation in shallow water are factors which give rise to ooids. What is not agreed to is whether a given ooid is the result of one or more than one of the above factors acting in combination. Donahue (1965) from the study of cave ooids (cave pearls) suggested that the requirements for their formation are four: (1) super saturation of CaCO_3 solution, (2) available detrital nuclei, (3) agitation of grains and (4) a splash cup. Bathurst (1971) elaborating Donahue's requirement states that, 'The super-saturation is necessary for crystal growth. The detrital nuclei provides a surface, which may or may not contain aragonite crystals, on which aragonite can grow. Agitation prevents the cave pearl from becoming a stalagmite, and ensures generally that the whole surface is presented, on suitably frequent occasions, to the super-saturated solutions. The splash cup keeps the ooid from staying out of the growth-promoting environment; its marine equivalent is the system of topographic and hydraulic controls that keep the ooid on the oolite shoal'.

The role of agitation in the formation of ooids has particular relevance to those on the western shelf. It has been found that the greater the agitation, the larger the number of ooid laminae that enclose the nucleus, and greater the degree of surface polish. In an environment of low turbulence, the ooids have a single lamina and have a dull luster (Bathurst, 1967).

The ooids of the western shelf, as emphasised earlier, are superficial ooids. Therefore, it would appear that they have formed in an environment of low agitation though not necessarily accompanied by low turbulence. Such an environment that immediately comes to one's mind is a lagoon or a coastal embayment. Lagoons and coastal embayments result from the development of barrier beaches and bars. It has been tentatively suggested that the ridges present on the outer continental shelf are ancient beaches and bars that formed during the Holocene (Flandrian) transgression (Nair, 1975).

In reconstructing the depositional environment, the algal limestones have limited use as compared to oolitic limestones. A major draw back hindering the reconstruction of the environment is the large depth range over which coralline algae are capable of surviving. Living corallines, for example, have been dredged from as much as 300 m depth in the tropics, while in temperate latitudes the maximum depth of growth is 50 to 100 m (Milliman, 1974). Coralline algae are important sediment contributors to the western shelf sediments. Hashimi and Nair (1976) found that algal fragments and lithoclasts (algal limestones) contribute as much as 68% of the skeletal component on the outer shelf. The most important role of calcareous algae is their binding activity. This is accomplished by the process of encrustation and cementation. It was probably this role that led to the incorporation of the quartz, hornblende and pyroxene grains in the algal limestones from the upper slope off Ratnagiri, and the few ooids, probably displaced from the outer shelf, cemented in the samples from the upper slope off Bombay.

ACKNOWLEDGEMENTS

We are grateful to Dr. S. Z. Qasim and Shri H. N. Siddiquie for suggesting improvements in the manuscript. Dr. D. P. Agrawal, Physical Research Laboratory, Ahmedabad is thanked for providing the radiocarbon dates.

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Note added in proof

Additional dredging on the continental shelf during the 18th cruise of R. V. Gaveshani between Vengurla and Mangalore has resulted in the recovery of Holocene algal limestones and calcareous sandstones. It would appear that Holocene submarine (?) cementation by carbonate precipitation was an extensive feature on the western continental shelf of India.

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(Received: Nov. 11, 1977)