PHOSPHATIZED OOLITES ON THE WESTERN CONTINENTAL SHELF OF INDIA

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Phosphatized oolites are distributed at the shelf edge in the relict calcareous sand facies occurring between 40 and 66 fathoms. The presence of a wave-cut terrace at 50 fathoms lends support to the conclusion that the oolite formation took place during Pleistocene low stands of sea level. Physico-chemical conditions for phosphate mineralization in the present-day waters being suitable, a mechanism whereby the selective replacement of carbonate of the shells by phosphate in the waters is found to be most suitable.

INTRODUCTION

During the course of the investigation of the size distribution and carbonate content of the sediments of the western continental shelf of India, an examination of the coarse fraction of the sediments had indicated the presence of oolites in some of the samples (Nair and Pylee 1968). Oolites are sand-sized spherical to ovoid grains consisting of a nucleus of quartz, calcite or other mineral with a shell of calcium carbonate, commonly aragonite, which may or may not exhibit a concentric or radial structure.

The importance of oolites lies in their providing evidence of a highly specialized environment, viz. shallow water, high energy zone, with physico-chemical conditions favourable for carbonate precipitation, and as such they have been investigated extensively around the continental shelves of the world (Newell *et al.* 1960; Subba Rao 1964; Ginsburg *et al.* 1963; Pilkey *et al.* 1966). The purpose of this study is to investigate the areal distribution of the oolites on the continental shelf of western India and provide some idea of the environmental conditions necessary for their formation, particularly in view of their phosphatized nature. This information may in turn lead to an understanding of the genesis of marine phosphorites in general, the economic importance of which cannot be overemphasized.

METHODS

Coarse fractions of the samples obtained after wet sieving were split into further size grades by mechanical sieving and the quantity (by wt) of oolites in each size fraction was estimated. Size of the oolites was measured with a micrometerocular. Thin sections were made for mineralogical studies.

Selected thin sections were etched with dilute hydrochloric acid to differentiate the nucleus from the shell. The total phosphorous content of some of the oolites was also determined.

Regional setting—The sedimentary facies on the continental shelf of western India has been reported by Nair and Pylee (1968) to be as follows.

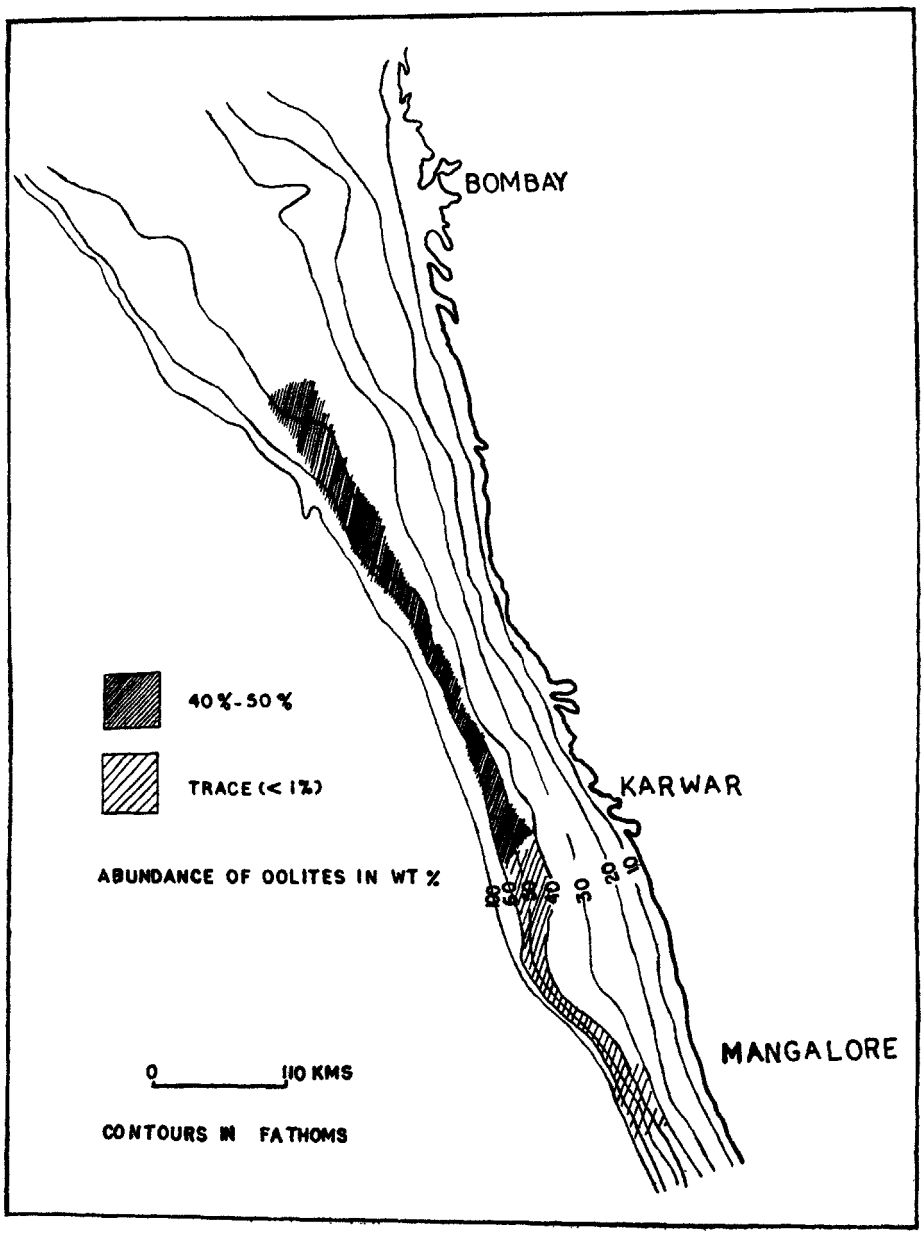


FIG. 1.

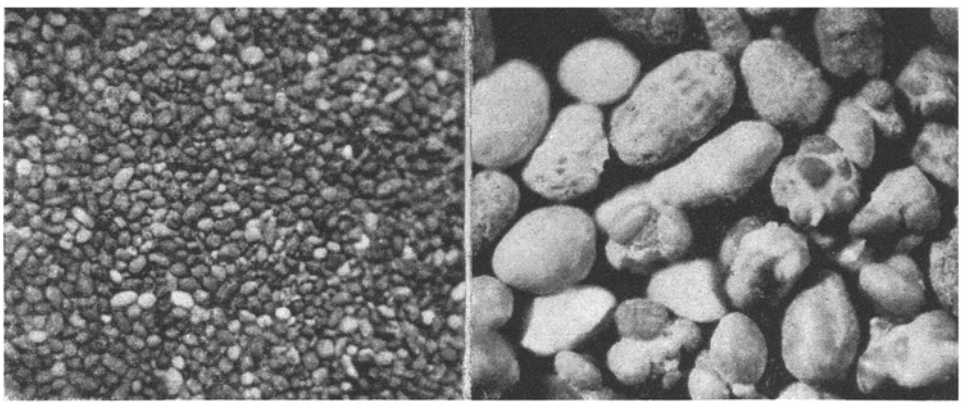
Up to a depth of 70 fathoms off Bombay, gradually shallowing to 20 fathoms to the south off Cochin, the shelf is covered by silty clays with low carbonate content (< 20%). This facies grade seaward into fine and medium sands with occasional coarse patches having relatively higher carbonate values (up to 60%). At slope depths, the sediments are dominantly foraminiferal sands. The outer shelf high carbonate sand zone has been concluded to be relict in origin. Shelf widths range as much as over 100 miles off Bombay tapering to as little as 30 miles off Cochin. The areal distribution of oolites in these shelf sediments is shown in Fig. 1.

Results

The oolites are confined to depths between 40 and 65 fathoms and rapidly decrease or are absent seaward or shoreward of these depths. The maximum depth of occurrence was at 108 fathoms and here they are found only in trace quantities, probably representing material washed down from the outer shelf. A distinct decreasing trend towards the south is also observed. As much as 58 per cent of the total sample is comprised of oolites off Bombay, whereas in samples off Mangalore, they are virtually absent being less than 1 per cent. There is a strong regional preference in other physical characteristics also. In the north, colour is yellowish brown to buff-heavily pitted and rough, and surface structure while in the south, they are black and greyish black with a highly polished surface devoid of any pits. Local preferences in colour have been mentioned by Mero (1964) as being one of the frequent aspects of oolitic phosphates. Differences in the size of oolites were also noticeable. Mean diameters ranged from 0·3 mm off Bombay, 0·08 mm off Karwar and 0·06 mm off Mangalore. Apart from their occurrence as individual oolites, at places, particularly in the south, they occur in aggregates of grape-like clusters ranging in size from 1·0 mm to 1·25 mm in diameter (Fig. 2).

Thin sections of the oolites reveal a nucleus consisting of an abraded shell fragment, heavily pigmented with iron oxide. Optical characteristics are generally masked by this body colour. The carbonate nucleus is surrounded by a thin coating of collophane which is greyish white in colour and remains isotropic under crossed nicols. Collophane is a collective term for a complex mixture of phosphate minerals usually dominated by francolite, a carbonate-apatite with the formula $Ca_5(PO_4, CO_3, OH)_3F$. Apart from its occurrence as coatings around individual oolites, it also forms the cementing agent for the oolite aggregates noted above. In the absence of any radial or concentric structure and the thinness of the coating in relation to the radius of the nucleus, it would seem more appropriate to refer to these oolites as superficial oolites (Leighton and Pendexter 1962). Etching of the thin section with dilute hydrochloric acid for approximately one minute also helped to differentiate the collophane by removal of the carbonate nucleus. Spot tests indi-

cated the presence of phosphorus in all the oolites under study. The determination of total phosphorus content was limited to selected samples. Values of 700 $\mu g/g$ and 1096 $\mu g/g$ in samples off Bombay and off Karwar respectively were obtained. These values confirm the suggestion of Pilkey *et al.* (1966) that variation in colour of the oolites represents various stages of phosphatization.



(A) (B)

FIG. 2. (A) oolites concentrated from a single sample. (B) shows mode of occurrence in the form of individual and composite grains. × 22.

DISCUSSION

The environmental conditions governing the formation of oolites in the field have been found to be one of high energy, warm, shallow waters saturated with calcium carbonate. Water depth of 6 ft has been considered optimum for oolite formation (Newell *et al.* 1960). Therefore, the presence of oolites in association with the relict sands of the outer shelf indicates that these are ancient deposits formed under environmental conditions, different from those now prevailing, but have remained uncovered by recent sedimentation. Supporting this conclusion is the fact that Sheperd (1964) has reported the presence of a wave-cut terrace on the western continental shelf at approximately the same depth as the oolite occurrence, viz. 50 fathoms. Summarizing briefly, some time during the Pleistocene, the sea level stood some 50 fathoms below the present for a sufficiently long period to give rise to a wave-cut terrace. Over this terrace, parts of which would have successively represented the migrating shore line, were deposited the sands and shells, the latter being covered over with a thin coat of carbonate precipitated from the overlying waters.

A feature of the oolites described here is the presence of a shell of collophane coating around the nucleus. The presence of phosphorus in oolites

has also been reported by Stetson (Pilkey *et al.* 1966). Collophane also forms the bulk of the marine phosphorite whether in the form of oolites, nodules or slags (Mero 1964). Amongst the mechanisms postulated for the phosphatization of oolites, the one most favoured is the gradual replacement of the carbonate ion by the phosphate ion (Ames 1959). The physico-chemical conditions favourable for phosphatization have been summarized by Degens (1965): (*a*) a *p*H in the waters greater than 7, (*b*) presence of calcareous materials, (*c*) PO_4 concentration greater than 0·1 parts per million, (*d*) a non-depositional environment. The redox potential of the system apparently does not affect replacement reaction (Arrhenius 1963). Another factor which plays an important part is upwelling. The upwelled waters rich in phosphates and nitrates help sustain a high level of organic productivity in the overlying waters. Upon the death and decay of organisms of the enphotic zone the phosphorus contained in them, either in the organic form or as skeletal apatite, is released into the surrounding waters and becomes available for phosphate mineralization (McMelvey, *see* Arrhenius 1963).

In the light of the above-mentioned requirements, it becomes evident that conditions prevailing on the western continental shelf of India provide an ideal environment for phosphatization. A calcareous sand zone with little or no present-day deposition has been reported by Nair and Pylee (1968). The presence of upwelling in the waters has been established by numerous workers, references to which are given in Banse (1968), and the prevalence of inorganic phosphate between 0·4 and 1·8 μg atoms per litre in the shelf waters even during periods of no upwelling (March) have been reported by Reddy *et al.* (1968).

It may, therefore, be reasonably concluded from laboratory and field data that the incipient phosphatization of the oolites, observed in the present study, results from the preferential replacement of the carbonate in the pre-existing calcareous materials by the phosphate derived from the present-day waters. Furthermore, the replacement mechanism seems to have proceeded to different stages in different places as is evidenced by the variable phosphate content which in turn is reflected in variations of colour.

The conclusions reached here are admittedly based on a relatively sparse distribution of samples. Considerably more samples are required and future investigations can profitably be made, particularly on the continental shelf between Bombay and Mangalore.

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