

Letter Section

## Microbial Origin of the Phosphorites of the Western Continental Shelf of India

V. PURNACHANDRA RAO and R.R. NAIR

*National Institute of Oceanography, Dona Paula, Goa 403 004 (India)*

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### Abstract

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Phosphatised algal nodules were recovered by dredging from the western continental shelf off Goa at depths ranging from 70 to 150 m. Energy dispersive X-ray analysis indicates that the phosphorus present in the algal nodules is confined to brownish grains and occurs as cavity fillings. Phosphate grains are predominantly distributed in the outer layers and become less abundant towards the centre of the nodule.  $P_2O_5$  and fluorine contents are higher (9.5 and 1.25%, respectively) in the outer laminations while they are lower (5.4 and 0.78%) in the inner layers. SEM studies have revealed that the phosphate grains comprise endolithic filamentous fungi. Phosphatised cellular structures resembling bacteria are also present. It is thus envisaged that the direct role of upwelling compared to the microbial influence is probably of less significance in the phosphatisation of these limestones.

### Introduction

Nair (1985) studied seventeen rock samples consisting of oolitic limestones and algal nodules dredged from the outer western continental shelf of India which extends from off Saurashtra in the north to Kerala in the south. Several workers (Burnett, 1977, Bremmer, 1980, Baturin, 1982) have suggested that the phosphorites on the western margins of continents are genetically related to coastal upwelling phenomena. Upwelling also occurs on the western continental margin of India especially during the southwest monsoon (June–September). Although all the samples studied by Nair (1985) are in the upwelling region (some are

from the intense upwelling region between Ratnagiri and Mangalore), only the algal nodules showed the presence of apatite. It appears, therefore, that processes other than upwelling (bacterial activity was speculated by Nair (1985)) may be important for phosphatisation of the algal nodules. Rao et al. (1987) studied the  $P_2O_5$  content in continental margin sediments and reported the highest  $P_2O_5$  concentrations (up to 2.17% and (varying from 0.2 to 2.17%) in the slope sediments. The  $P_2O_5$  content in the inner shelf sediments is low, varying from 0.25 to 0.75%, while on the outer shelf, it ranges from 0.09 to 1.53%. Paropkari et al. (1985) reported low organic matter contents (average 0.9%) in the outer shelf sands which are associated with algal nodules. The purpose

of this paper is to demonstrate evidence of microbial activity in the algal nodules.

## Results

The studied algal nodules are 5–10 cm in size and occur at a depth of 70–150 m on the outer continental shelf off Goa (Fig.1). The age of

the nodules determined by radiocarbon methods is 11,040 yrs and these nodules are associated with relict carbonate sediments. Polished sections exhibit distinct concentric laminations (Fig.2A) and the nodules are similar in appearance to rhodoliths. Brown-coloured phosphate grains are present as infillings in cavities probably formed by fungal and algal

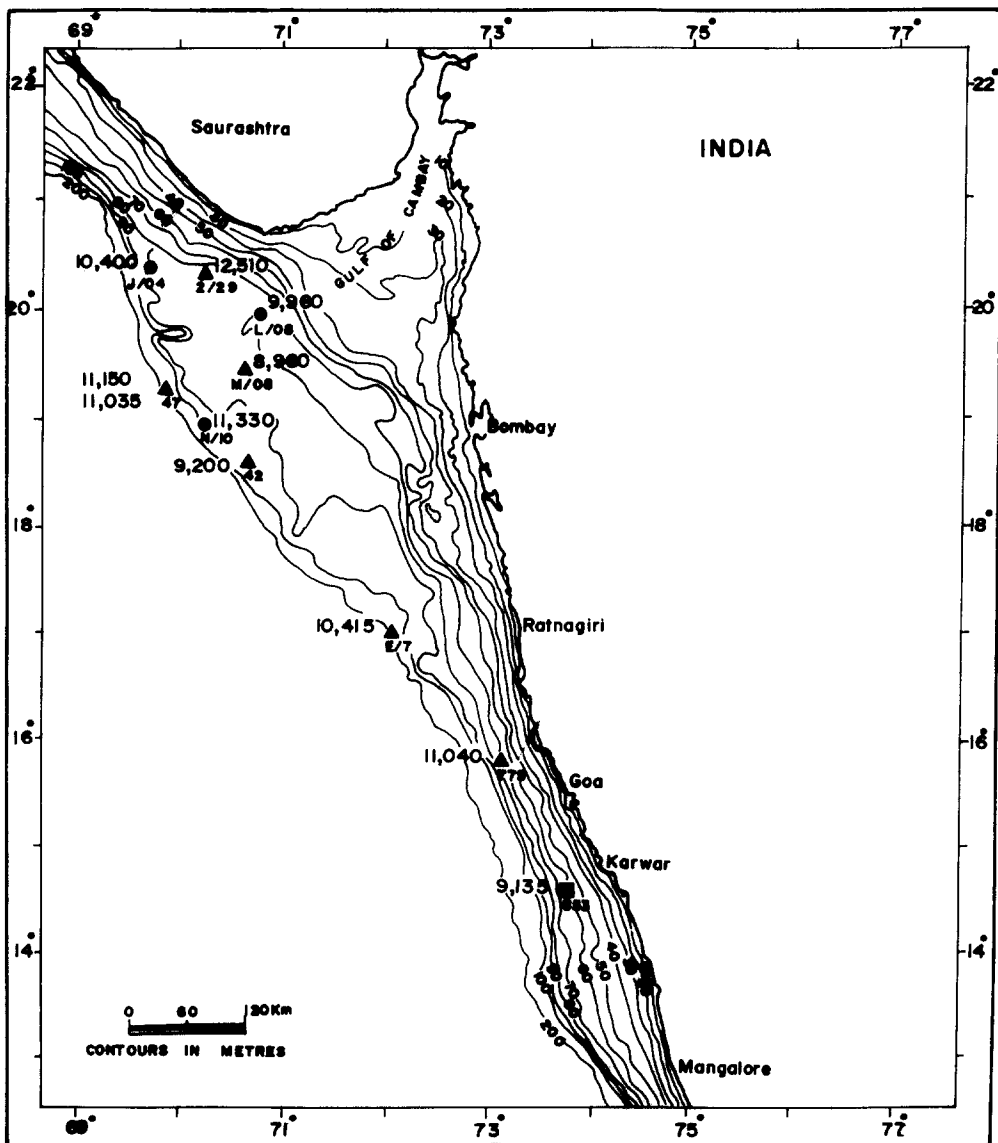
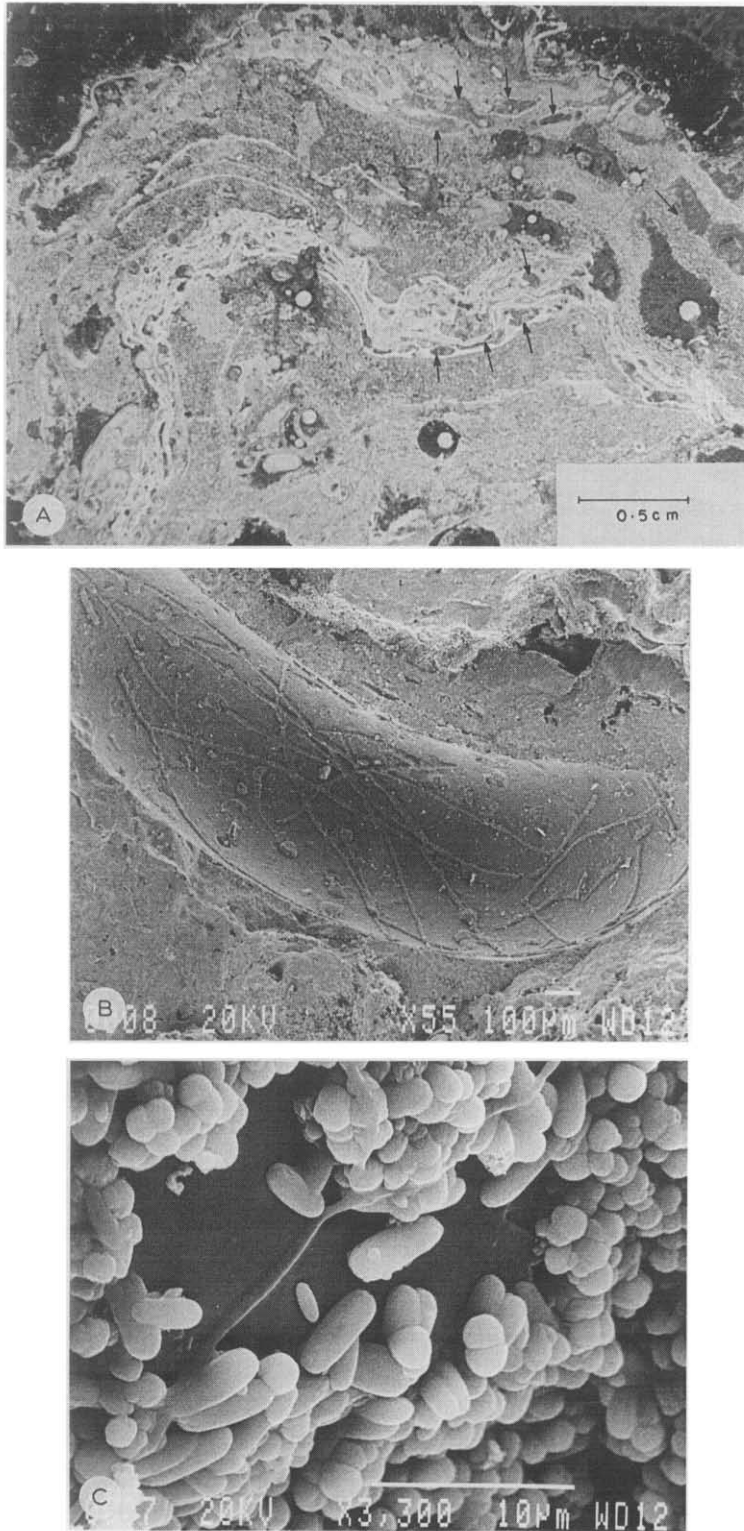


Fig. 1. Sample location, bathymetry and radiocarbon dates (yrs B.P.) (Nair, 1985). Samples from station 775 are discussed in this paper. Sediments to the depth of 60 m are modern muds and those from 60 to 110 m are relict carbonate sediments.



**Fig. 2.** A. Polished section of an algal nodule showing laminations. Arrows show the location of phosphate grains. B. SEM photograph showing a phosphate grain with endolithic filamentous fungi. C. SEM photograph showing phosphatised bacterial cells.

boring. The grains are more concentrated in the outer laminations and become significantly less abundant towards the centre of the nodule. SEM examination of freshly broken surfaces together with an energy dispersive X-ray analyser revealed that the brown-coloured grains consist of phosphatised endolithic filamentous structures most probably of fungal origin (Fig.2B). It has also been observed that appreciable concentrations of phosphorus, morphologically resembling bacteria, are located within the cellular structures. Rod-shaped and spherical bacterial forms, ranging from 1.0 to 4.0  $\mu\text{m}$  in size are present either together or separately (Fig.2C). Identification of the bacterial types has not been carried out as these are phosphatised and their morphology is difficult to recognise due to overgrowth. Duplicate chemical analyses of the different nodule layers showed that the average  $\text{P}_2\text{O}_5$  and fluorine contents are 9.5 and 1.25% and 5.4 and 0.78% in the outer and inner layers, respectively. These observations confirm that phosphate is present in the form of grains which consists of bacteria and fungi, and the abundance of the grains can be used to determine the phosphate content in the nodule. Since the grains are many in the outer layers, higher concentrations of phosphate are found accordingly.

## Discussion

Phosphate grains consisting of fungal filaments as infillings in the cavities of the algal nodules suggest that the nodules were bored and subsequently became the points of colonisation for bacteria and fungi. As fungi can bore and thrive at great depths, boring and colonisation may either have occurred at depths where the nodules presently occur or alternatively these processes may have taken place during times of lowered sea levels in the Pleistocene when the algal nodules were within the euphotic zone. It is well established that the outer continental shelf sediments and limestones of the western margin of India were formed in the Late Pleis-

tocene (Fig.1) (Nair, 1971, 1974, Nair et al., 1979). Because the algal nodules have been found in these relict carbonate sediments, and bacteria also colonised these nodules, we assume that the colonisation of fungi and bacteria had taken place at shallower depths during sea-level lowstands. It is also known that bacteria are very efficient concentrators of phosphorus whereby they assimilate large amounts of the element from the sea water in shallow water locations and during low sedimentation rates (Porter, 1946). The sediments on the outer shelf reflect low terrestrial run off and warmer climates (Nair and Hashimi, 1980) that existed during the Late Pleistocene and thus may represent the above-mentioned conditions for phosphorus assimilation.

The phosphate in our samples is well crystallised as shown by the sharp peaks on X-ray diffractograms and furthermore is restricted to grains consisting of fungi and bacteria while the surrounding carbonate material is not affected by phosphatisation. Therefore, phosphatisation of bacterial cells is a direct diagenetic process rather than the conventional one of calcification and then replacement of carbonate by phosphate. The investigations of Kobluk and Risk (1977), Krumbein (1968) and Klappa (1979) into calcareous deposits suggest that cyanobacteria are not directly involved in calcification but that precipitation of carbonate takes place mostly on dead filaments. Phosphatisation in our samples may be analogous to the process described by Kobluk and Risk (1977), Krumbein (1968) and Klappa (1979): it took place during bacterial and fungal decay in the early stages of diagenesis and the associated bacteria may be responsible for creating a suitable microenvironment for the precipitation of carbonate fluorapatite. The microbial role in phosphogenesis has been reported in the Tertiary Negev Desert phosphorites of Israel by Soudry and Champetier (1983), in the Cambrian phosphorites of Australia by Southgate (1986) and in seamount phosphorites of the Central Pacific by Rao and Burnett (in press).

Furthermore, phosphate within the bacterial structures has been reported by O'Brien et al. (1981), Riggs (1982), Zanin et al. (1985), Lamboy (1987) and Lamboy and Monty (1987), suggesting that the bacteria were in some way related to phosphogenesis. Thus, it is concluded that phosphatisation of algal nodules on the western continental shelf of India is a biochemical process mediated by fungi and bacteria rather than an inorganic replacement process which is genetically related to upwelling waters. Evidence against upwelling can be seen in the fact that the uranium content in the phosphate fraction is less than in the associated carbonate material (sample 775, Borole et al. (1987)). Had upwelling been the principle cause, the reverse distribution of uranium would be expected. Phosphorites hitherto reported as being formed by bacterial processes are either from ancient deposits or from weak upwelling areas such as those off eastern Australia (O'Brien et al., 1981). This paper documents yet another instance where microbial processes play an important role in weak upwelling areas on the western margins of continents. Hence, upwelling occurring on the western continental margins may not be taken for granted as the only process of phosphogenesis and the over-emphasis given to upwelling phenomena may be reviewed in the light of the significance of microbial processes.

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