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Phosphatic Sediments on the Eastern Australian Upper Continental Slope

by

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SUMMARY

Phosphatic pebbles, cobbles and platy slabs have been dredged from the upper continental slope off eastern Australia between latitudes 25° and 31°S, at depths of between 197 and 293 metres. They occur in areas which are at present non-depositional. The northern examples are believed to have been formed in shallow water as algal-growth nodules which were subsequently cemented by calcium carbonate. The southern examples appear to have originated as accretionary nodules on the Miocene continental shelf, or as concretions within the Miocene succession, which have been reworked and abraded during Quaternary low sea level stands. A single example of laminated phosphorite was also recovered. The phosphatic nodules have been subsequently cemented by calcium carbonate, and evidence is cited which suggests that this cementation process is still active.

In most of the rocks phosphate values are of the order of 4.0 to 6.5 percent P_2O_5, but one of the goethite-coated cobbles consists of laminated material containing up to 26 percent P_2O_5. The faunal assemblage indicates an original Miocene age for the nodules and rock fragments, and that redeposition and formation of the matrix occurred in the Pliocene or post-Pliocene.

INTRODUCTION

During the Bureau of Mineral Resources Marine Geology survey off eastern Australia in 1970, phosphatic material was dredged from six different localities on the upper continental slope between depths of 197 and 293 metres. One sample was recovered off Indian Head, Fraser Island, one from off Ballina, and three samples were recovered between Coffs Harbour and Port Macquarie. Von der Borch (1970) reported the occurrence of phosphatic concretions in deeper water (385 m) off Yamba, as well as nodular material from three localities between Coffs Harbour and Port Macquarie. The location of all these samples is shown in Figure 1.

The phosphatic material occurs where bedrock or gravel is quite common on the upper part of the slope, and little or no fine material is being deposited. This appears to be due to the removal of fine material by the East Australian Current, especially between latitudes 27°S and 32°S where it occurs on the upper continental slope as a narrow, swift southward flow (Boland and Hamon, 1970).

DESCRIPTION OF THE PHOSPHATIC MATERIAL

Station 1376, off Fraser Island

The dredge haul from the northernmost station included rocks with fresh surfaces suggesting that they were broken off an outcrop. Sparker records (Fig. 2a) show a wedge of younger sediments thinning towards the edge of the shelf, and at the edge of the shelf, in a water depth of approximately 260 metres, bedrock is exposed. The dredge recovered the rock at 293 metres on the steep upper part of the continental slope.

The rock is an oligomictic conglomerate consisting of angular and rounded ferruginous rock fragments set in a light-coloured calcareous matrix (Fig. 3a). The rock fragments are generally pebble- to cobble-size with diameters ranging from 8 to 70 mm.

In thin section the rock fragments show an overall colloform structure (Fig. 3b). They are dark reddish-brown in colour and this tends to mask any birefringence, but it can be discerned that some layers are isotropic, whereas others are anisotropic. X-ray diffraction analysis shows that the dominant minerals are goethite and calcite, but some phosphate minerals must be present, presumably collophane, as chemical analysis indicates that as much as 4 percent P_2O_5 is present in the rock fragments.

Remains of algae, ostracods, bryozoa, molluscs and foraminifera are present within the rock fragments, but they are not abundant. In some cases layers of clear calcite have formed on succeeding colloform layers. These are not continuous and they are thick in the middle and gradually thin towards the ends. The calcite has most probably been formed by encrusting organisms which have subsequently been enveloped by the next colloform layer.

The matrix consists of the tests of foraminifera and the remains of other organisms such as algae, bryozoa, molluscs and echinoids. The minerals present are quartz, glauconite, sparry calcite and collophane, set in a micrite cement (Fig. 4a). The foraminifera include shallow and deep water benthonic types as well as pelagic forms; these are described more fully in the section on Palaeontology. Quartz is a relatively minor constituent of the matrix and it usually occurs as angular grains 0.03 to 0.20 mm. in diameter. Glauconite is rare, usually occurring as pellets, although in places the micrite has a greenish tinge suggesting that glauconite is present in the cement. Some sparite occurs, usually as aggregates, suggesting that some recrystallization, presumably of skeletal material, has taken place. Collophane is presnet as thin layers about 0.015 mm thick, often running along grain boundaries (Fig. 4b). The collophane shows first order grey interference colours and has wavy extinction indicating that it is microcrystalline.

The micrite cement is brown to colourless and it makes up the majority of the matrix. The brown colour is due to the migration of iron oxide from the rock fragments into thesarrounding micrite.

<u>Phosphatic material from the southern stations</u>

The southern examples vary in size from granules to boulders; nodules were dredged from stations 1512, and 1516, and cobbles and boulders were dredged from station 1513[1]. Sparker profiles (Fig. 2b) show no indication of bedrock at the water-sediment interface and penetration is of the order of 0.2 seconds two-way travel time. However, the sea floor shows several undulations and step-like features which are probably patches of gravel. On the upper part of the slope between stations 1513 and 1516 the dredge hit hard rock twice, but did not recover a sample. The sparker section indicates that the gravel is a surface to near-surface feature, and does not continue to any great depth.

The nodules range in size from 1 to 3 centimetres in diameter and they have a polished goethite coating (Fig.5a). Although generally rounded, many give the appearance of having been fragments of larger rocks. The nodules from station 1516 are associated with softer goethite-coated clastic pebbles and cobbles, some of which appear similar to the nodules except that they tend to be flatter, less rounded, and less highly polished. Granules consisting of abraded nodules also occur, as well as a phosphatized shark's tooth and a rounded quartzite pebble.

In thin section the nodules are seen to consist of quartz, glauconite, calcareous skeletal material (mainly foraminifera), rock fragments, goethite pellets, carbonate apatite, and a trace of feldspar (Fig. 6a). The quartz has an average grain size of 0.1 mm and it usually occurs as angular, subelongate grains. Some quartz grains are rimmed by

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[1] The term nodule is used throughout to indicate bodies which have formed by accretionary growth in an exposed or semi-exposed position on the sea-floor. The Wentworth size classification is used for clastic particles.

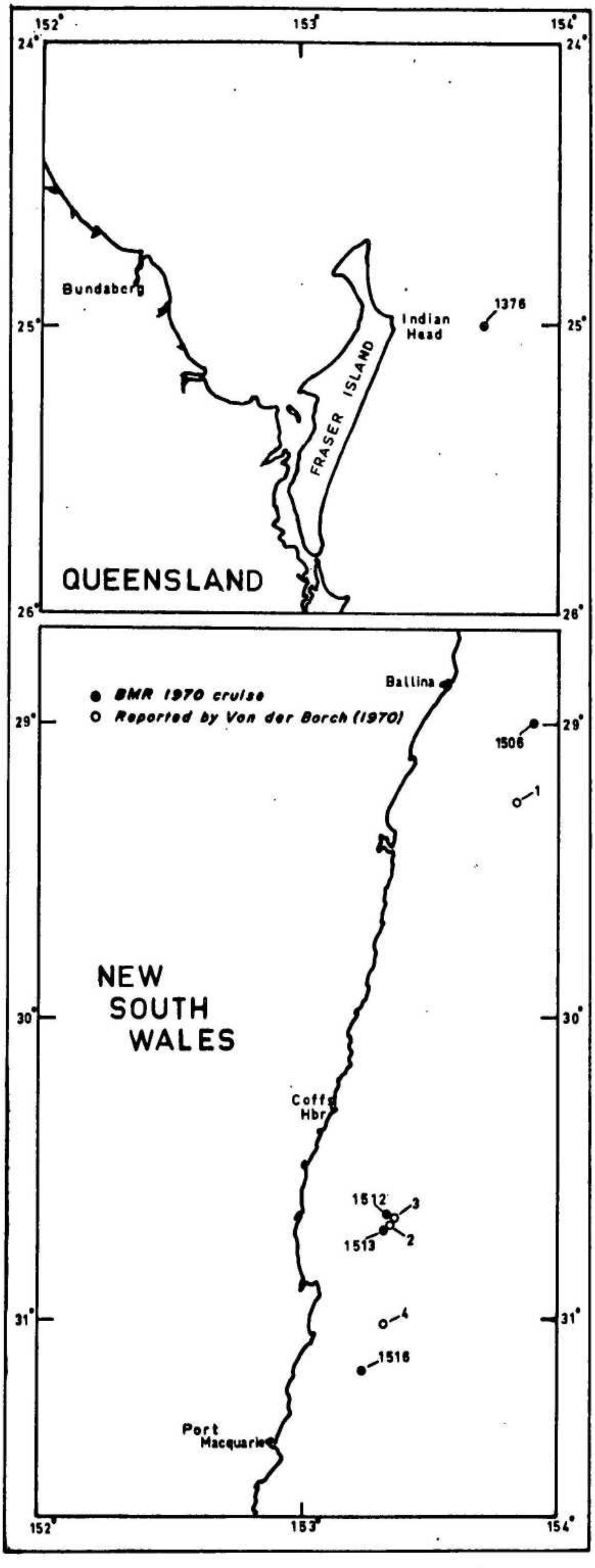

FIG I LOCATION OF SAMPLE STATIONS

To accompany Record 1970/59 Aus 2/178

glauconite and in other cases the glauconite appears to be replacing quartz. Glauconite also occurs as pellets and sometimes infills the tests of foraminifera. The glauconite pellets are rounded to elliptical in shape and have an average diameter of 0.3 mm. There is often partial replacement by goethite around rims and along cracks and in some cases there is complete replacement by goethite; both altered and unaltered types often exist side by side.

Rock fragments and pellets are not common in the nodules; both usually are dark brown in colour owing to the presence of goethite. One rock fragment, about 8 mm in diameter, consists of geothite pellets, quartz, glauconite, calcareous skeletal material, and carbonate apatite in a ferruginous matrix. This particular rock fragment was rimmed by carbonate apatite.

Carbonate apatite is visible under the microscope in veins and irregular aggregates. Its presence in veins and aggregates suggests that there must have been mobilization and concentration of the phosphate at some stage. In one case the skeleton of an unknown organism has been completely replaced by carbonate apatite (Fig. 6b). The chemical analyses indicate that as much as 20 percent carbonate apatite is present in the nodules, but as the amount present in veins, aggregates and skeletal material is only about 6 to 8 percent, then the majority of the carbonate apatite must be present as microcrystalline collophane within the matrix. The matrix consists of iron-stained silt and clay-size material set in a cement of goethite and subordinate micrite. Goethite also fills the interior of foraminiferal tests.

The largest dredge haul was from station 1513, where cobble- and boulder-size slabs and blocks were recovered (Fig. 5b). The slabs and blocks are encrusted with organisms, mainly corals, bryozoa, algae, and calcareous worm tubes. Some of the rocks are only encrusted on one side, the under surface having a glazed coating composed of a thin skin of dark brown goethite. Many have smoothed, glazed protuberances which are nodules cemented onto the rock, and fresh broken surfaces show nodules and fragments of nodules set in a dense fine-grained matrix. The ratio of matrix to nodules is fairly large, most of the nodules being completely separated from each other.

In thin section the nodules are similar to those described earlier. The matrix is made up of goethite pellets, rock fragments, quartz, glauconite, sparry calcite and skeletal material set in a white to dark brown calcareous cement. The goethite pellets are dark reddish brown in colour and have an average size of 0.4 mm. Goethite is also present within the tests of foraminifera, as is glauconite. The rock fragments are basically the same type and they appear to be fragments of nodules. They range in size from 1.0 to 3.5 mm. One rock fragment contained the skeleton of an unknown organism about 2.5 mm long which had been completely replaced by carbonate apatite. Quartz is usually in the very fine sand-size range but in a few cases coarse sand-size grains are present. The quartz is nearly always replaced by calcite around rims and along cracks. Glauconite occurs as pellets and infilling tests of foraminifera.

One slab-like rock from the dredge haul at station 1513 differs from the rest in that it consists of bedded sedimentary rock and is not made up of cemented nodules. The rock has a thin goethite coating like the others, but internally shows regular laminations within a limonitic crust. In thin section the laminations are seen to consist of calcite and carbonate apatite with a small proportion of dark iron stained micrite (Fig. 7a). Small algal bodies, some brown coloured and others nearly colourless, occur quite frequently. The carbonate apatite is colourless to yellowish brown in ordinary light and it occurs as elongate crystals which are sometimes bent around other crystals. It gives anomalous biaxial interference figures and contains numerous ellipsoidal inclusions which are generally aligned parallel to the length of the crystal. These inclusions are light to dark brown in colour and have an average length of 0.03 mm.

Electron probe measurements show that the mineral is significantly poorer in phosphorous than normal igneous apatite. It contains 29 to 32 per cent P_2O_5 compared with 41 to 42 percent for igneous apatite. Incorporation of carbonate into the apatite lattice seems to be the only reasonable explanation for this. Presumably the mineral is the carbonate fluorapatite francolite which is common in marine phosphorites. In the central, layered part of the rock this mineral makes up about 60 percent of the constituents.

Calcitic and ferruginous filamentous rods about 0.06 to 0.20 mm in length occur individually or as intertwined masses throughout the rock (Fig. 7b). It would appear that these are the remains of some type of alga which probably played a part in cementing the rock.

PHOSPHATE ANALYSES

Nine separate samples were analysed colorimetrically by AMDEL for phosphate content; the results are shown in the Table. The P_2O_5 content varies from 4.0 to 26.2 percent, with the majority of samples assaying between 4.0 and 10.0 percent P_2O_5.

TABLE PHOSPHATE ANALYSES

Station number	Latitude	Longitude	Depth (m)	$\%P_2O_5$	description
1376	25°00'0S	153°42'4E	293	5.6	Oligomictic conglomerate
1506	29°01'0S	153°54'0E	229	4.8	Flat slab-like pebbles
1512	30°39'6S	153°19'8E	197	6.3	Nodule
1513(a)	30°43'4S	153°18'6E	200	26.2	Laminated rock
1513(b)	"	"	200	6.3	Matrix of cemented nodules
1516	30°10'6S	153°13'9E	241	9.5-10.0	Nodules

The phosphate content is variable within single samples. For example, a bulked sample from the conglomerate dredged at station 1376 assayed at 5.6 percent P_2O_5, but when the rock fragments were separated from the micrite cement and both analysed separately, the rock fragments contained 4.0 percent P_2O_5, whereas the cement contained only 0.6 percent. In thin section, the phosphate mineral in the rock fragments is obscured by the heavy ferruginous staining.

The phosphate content of rocks consisting of cemented nodules is lower than that of the individual nodules because of the lack of phosphate minerals in the matrix. However, fragments of nodules in the matrix tend to upgrade the phosphate values to about 6 percent P_2O_5. Analyses of two nodules give results of 9.5 and 10.0 percent P_2O_5, but von der Borch (1970) reports values as high as 20.7 percent P_2O_5 for material dredged from the same general area.

The highest P_2O_5 value of 26.2 percent was provided by the laminated rock from station 1513; up to 60 percent francolite was seen in thin sections of this material. Only one cobble of this type was dredged from this locality, suggesting that it is not particularly abundant. However, a more detailed sampling operation would be needed to confirm this.

DIAGENESIS

The cobbles and boulders dredged between Coffs Harbour and Port Macquarie appear to have undergone rather rapid diagenesis, in the form of cementation and replacement, largely as a result of biological activity.

As described previously, many cobbles and boulders are made up of nodules incorporated in a relatively fine-grained matrix. Microscopic examination of the matrix shows that it consists of fragments of nodules, goethite and glauconite pellets, quartz grains and the skeletal remains of organisms set in a micrite cement. This micrite cement is relatively free of iron when compared to the cementing material of the nodules. In some cases the micrite is layered, and sometimes there are brown rods and filaments within the micrite (Fig. 8a).

In the dredge haul from station 1516, which consists largely of uncemented nodules, two nodules were cemented by white, porous, somewhat fetid calcareous material incorporating smaller nodule and shell fragments. Under the microscope it can be seen that goethite pellets, angular quartz grains, glauconite pellets, and the remains of organisms such as foraminifera, molluscs, echinoids and bryozoa are also present. However, the most interesting feature of this rock is the way in which these grains, fragments and nodules are bound together. The grains are enmeshed by needles and rods of aragonite as well as filamentous algal material. The rods and filaments sometimes form an interlocking network binding the larger grains and nodules. This white, porous material from station 1516 can be correlated with the completely lithified matrix from station 1513. Exactly the same type of grains and fragments are present in both, and the micrite cement and brown filaments from station 1513 appear to represent a more advanced stage in the cementation process.

It appears that the algal filaments play an important role in the cementation process, and the fact that in the sample from station 1516 these filaments are still largely unmineralized suggests that the process is rapid and in operation on the present day sea floor. Foraminifera present in the lithified matrix include forms not older than Pliocene (Belford, pers. comm).

Apart from the development of the cement, a number of replacement processes, including phosphatization, calcitization, and ferruginization, can be recognized in thin section. There appear to be at least four stages of diagenetic replacement within the nodules and two within the matrix.

Two stages of phosphatization can be seen in the nodular material; the first stage involves the replacement of skeletal material by carbonate apatite (Fig. 6b) while the second stage involves the mobilization of the phosphate and the subsequent formation of cross-cutting veins and irregular patches of apatite.

Calcitization occurs in both the nodules and the matrix, but it is better developed within the latter. This process involves the replacement of quartz by calcite around rims and along cracks. In some cases this has led to the almost complete replacement of quartz.

Ferruginization occurs at a later stage than calcitization and extensive ferruginization of secondary calcite is evident. In the matrix large grains of quartz can be seen surrounded and invaded by calcite which in turn is enveloped and replaced by goethite (Fig. 8b). In the nodules goethite has replaced most of the calcite, leaving only minor amounts of calcite surviving around the quartz grains.

The replacement of glauconite by goethite occurs quite frequently, usually with only minor replacement around rims and along cracks, but in some examples goethite has completely replaced the glauconite.

As in the case of the introduction of cement, it seems likely that biological activity, particularly by algae, has been the dominating influence in the replacement of quartz by calcite. Although the regional environment is one of relatively high energy and the water masses must be well mixed, organic growth and decay processes can produce micro-environments at or close to the sediment water interface in which the chemical conditions are entirely different from those of the overlying waters. Thus absorption of CO_2 by algae could increase the pH to a point where silica is dissolved and carbonate precipitated. Cessation of biological activity would result in a decrease in pH, thus bringing about conditions whereby goethite could replace calcite.

PALAEONTOLOGICAL DATA

The micrite matrix of the conglomerate from station 1376 contains the remains of algae, bryozoa, molluscs, crinoids, echinoids, and foraminifera. The foraminifera have been identified by Dr V. Palmieri of the Geological Survey of Queensland on whose conclusions the following notes are based. Various types are present including shallow water, warm water pelagic, and deep water benthonic types. The clear micrite contains the planktonic foraminiferids Globorotalia cultrata, G. tumida, G. crassaformis, G. tosaensis?, Globigerinoides sacculifer, G. ruber, Globoquadrina altispira, Pulleniatina obliqueloculata, and Sphaeroidinellopsis seminulina which collectively range from Pliocene to Recent. The iron-stained micrite contains small indeterminable foraminifera of unknown age, but which could be Tertiary, suggesting that the micrite matrix has formed gradually over a long period of time.

The nodules which were dredged between Coffs Harbour and Port Macquarie have a possible middle Miocene age (Von der Borch, 1970). This has been based on the presence of the crab Ommatocarcinus corioensis (lower Miocene-lower Pliocene) and foraminifera such as Globoquadrina dehiscens and Globigerinoides bispherica. The matrix of the cemented nodules contains abundant planktonic foraminifera and some smaller benthonic types. The presence of Sphaeroidinella sp. would indicate that the matrix is not older than Pliocene (Belford, pers. comm.).

ORIGIN

The phosphatic rock fragments of the conglomerate from station 1376 have been formed by algal growth, probably in an estuarine or very shallow, low energy marine environment during the Miocene or earlier. The colloform structure consists of irregular sheets with cell structure enveloping shallow marine organisms such as ostracods and red algae (Corallinaceae). Ferruginization of the algal material occurred possibly simultaneously or soon after formation, as the goethite is uniformly developed throughout. Erosion followed and the material was broken up into angular, variable sized rock fragments. The erosion most probably occurred after a slight lowering of sea level. Submergence then took place and a gradual change from a shallow to a deeper marine environment is indicated by the presence of both shallow water and deep water benthonic foraminifera in the matrix.

It is not clear when enrichment with phosphorus occurred, but it certainly predates the matrix binding the ferriginous and phosphatic fragments which was formed during this later submergence. Most of the phosphorus content of the rock is held in the fragments, and what phosphate minerals are present in the matrix occur in vein form indicating that they result from secondary mobilization of apatite.

The nodular material dredged from the top of the continental slope between Coffs Harbour and Port Macquarie appears to have formed by accretionary growth on the continental shelf during middle Miocene times. It is not clear whether these nodules were subsequently buried by later sediments from which they have since been eroded, or whether the present day sea floor in this area has remained submerged and essentially non-depositional since the Miocene. Von der Borch (1970) concluded that the nodules formed as phosphatic concretions within Miocene host sediments and were subsequently eroded and coated with goethite.

Many of the nodules are broken and have clearly been abraded; in view of the strong evidence for a widespread low sea level stand at about - 200 metres during the Pleistocene (Dill, 1968; Jongsma, 1970), it is reasonable to assume that this abrasion took place in the Pleistocene when the continental shelf was exposed and the uppermost part of the slope was in the littoral zone. The seismic sections provide no evidence of extensive dissection of the near surface strata, and although minor erosion of the Miocene sediments, resulting in reworking and concentration of the phosphatic nodules, must have occurred when this zone was in very shallow water, it is none the less likely that their present resting place is at or close to the Miocene surface where they were formed.

The cobble of laminated phosphorite recovered from station 1513 was the only one of this type found, and it would be unwise to place too much emphasis upon it. However, it does suggest that, in addition to accretionary nodules, the Miocene succession may also include bedded phosphorites.

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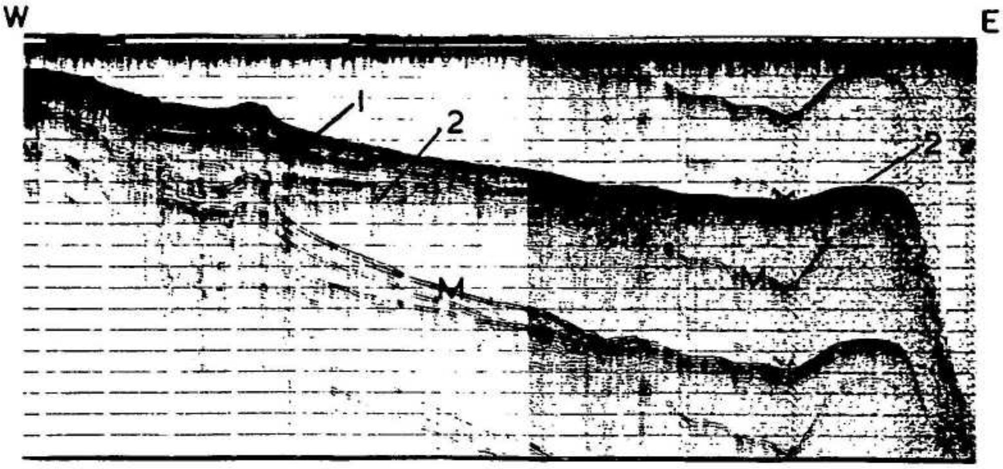

Fig. 2(a). Sparker profile off Indian Head showing unconsolidated sediment (1) thinning towards the edge of the shelf, and bedrock (2) exposed at the edge of the shelf. Horizontal scale lines are 50 milliseconds (2-way time) apart, and scale line breaks occur every 5 minutes (approximately 0.5 nautical miles). Multiple reflexions are indicated by M.

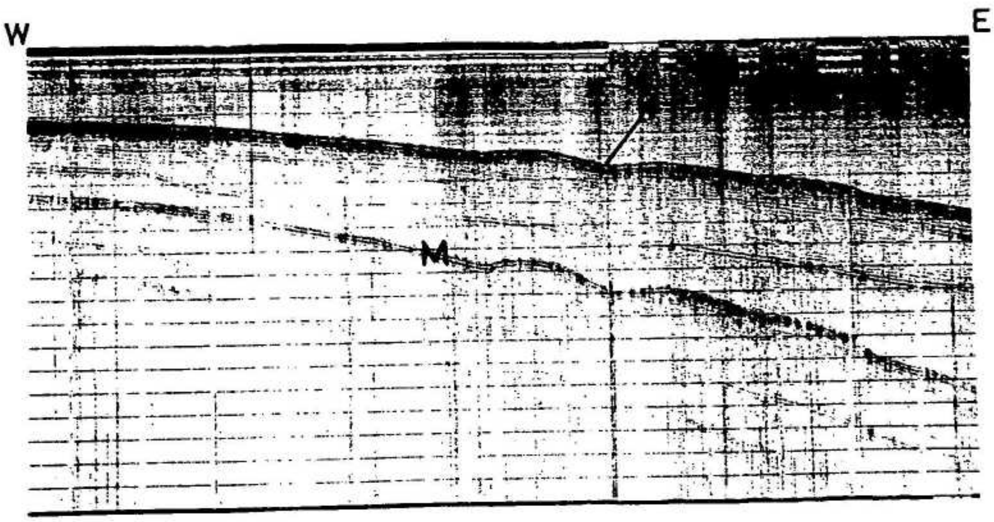

Fig. 2(b). Sparker profile off Nambucca Heads showing undulating character of sea-floor with reflecting horizons underneath. Phosphatic gravel was dredged from (1).

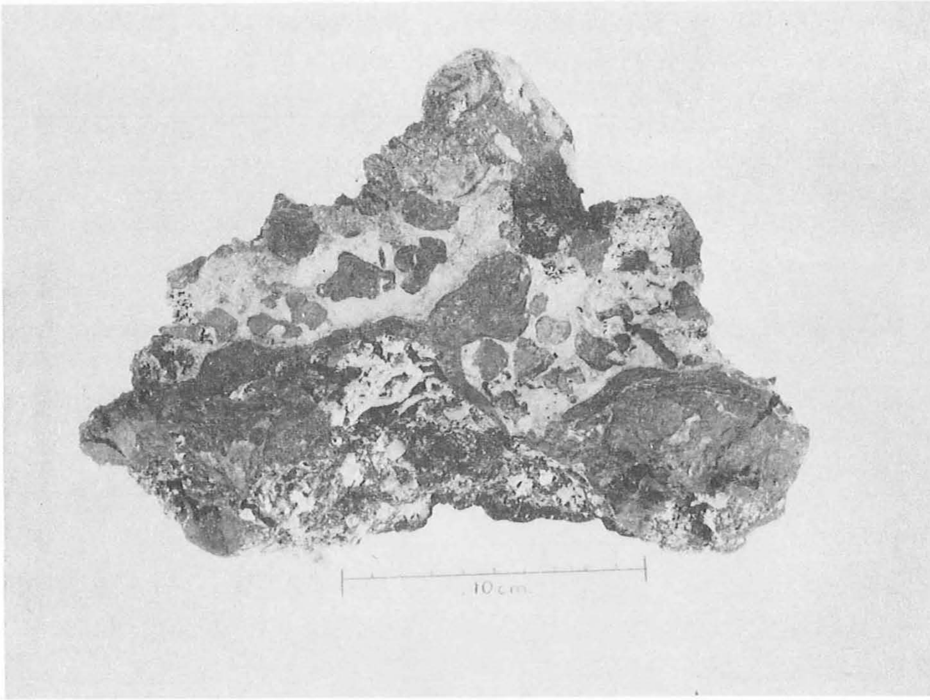

Fig. 3(a). Oligomictic conglomerate, station 1376

Fig. 3(b). Photomicrograph of rock fragment showing colloform structure and clear calcite layers. Ordinary light, x100

Fig. 4(a). Matrix of oligomictic conglomerate showing quartz, sparry calcite and skeletal material set in a micrite cement. Note the darker micrite on the left and right hand side of the photograph. Ordinary light, x100.

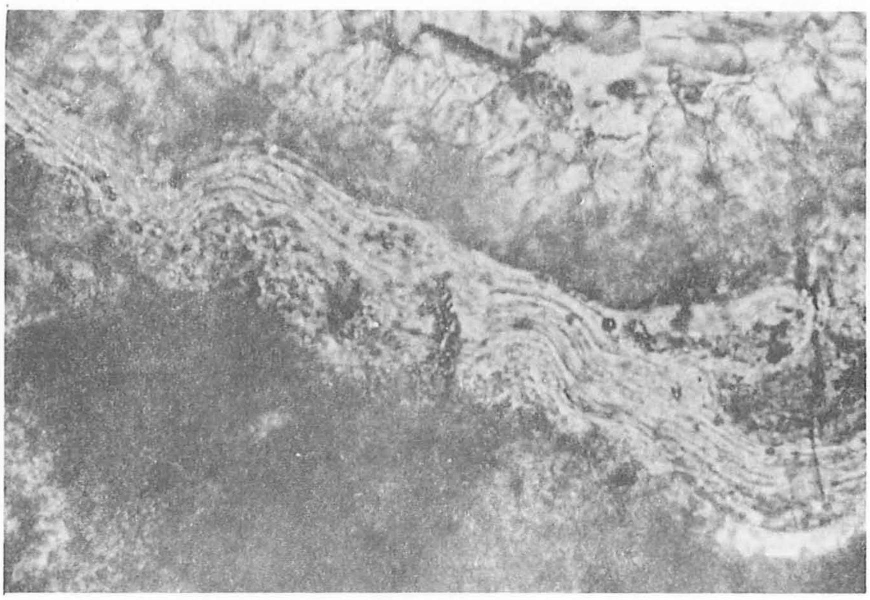

Fig. 4(b). Photomicrograph of colloform structured collophane in the matrix. Ordinary light, x600.

Fig. 5(a) Example of nodules dredged from station 1516 showing glazed goethite coating and some encrustation. Note coral fragment and phosphatized shark's tooth.

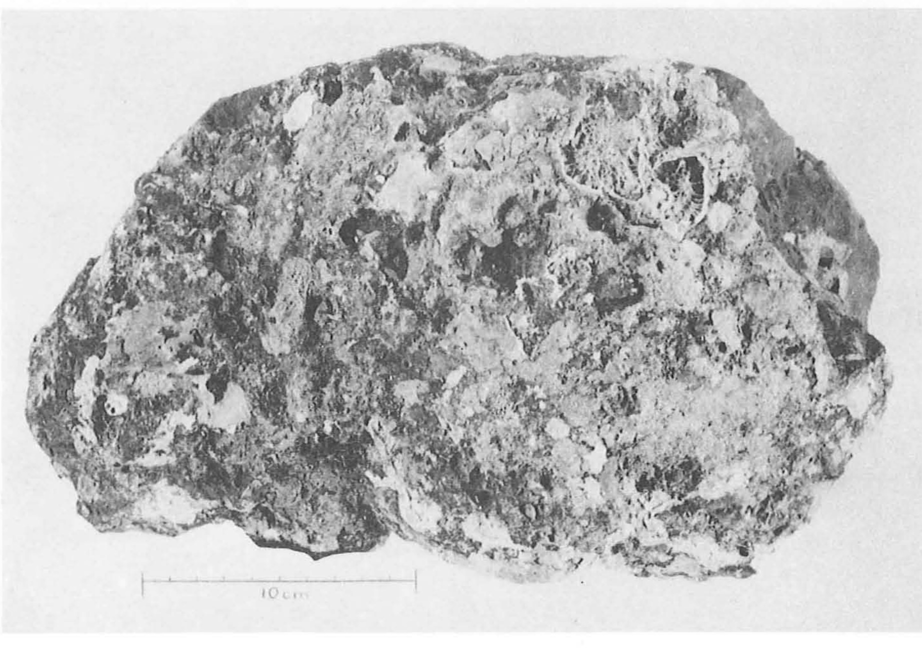

Fig. 5(b). Boulder consisting mainly of light matrix in which the darker nodules and fragments of nodules are not well defined, station 1513

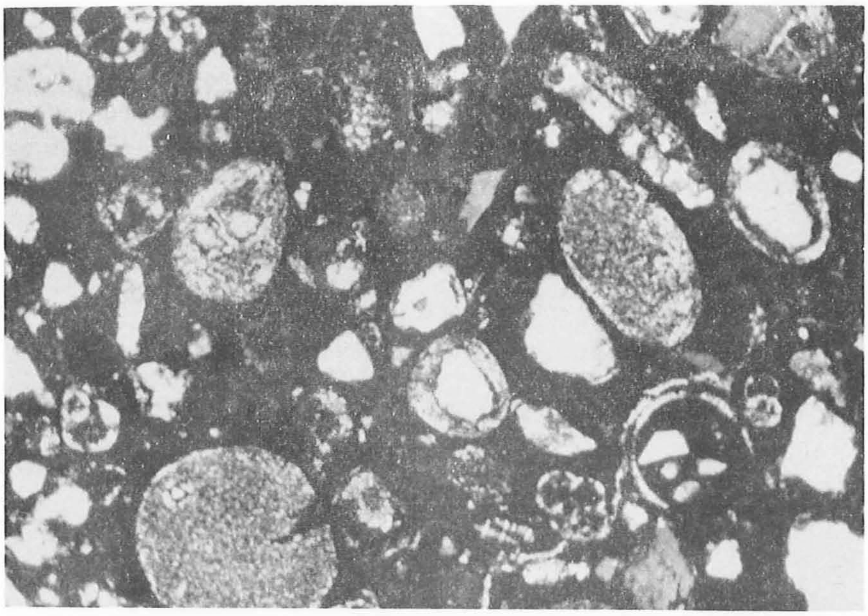

Fig. 6(a). Photomicrograph of nodule showing quartz glauconite clasts and skeletal material in a dark fine-grained matrix. Note glauconite rims around some of the quartz grains. Crossed nicols, x100.

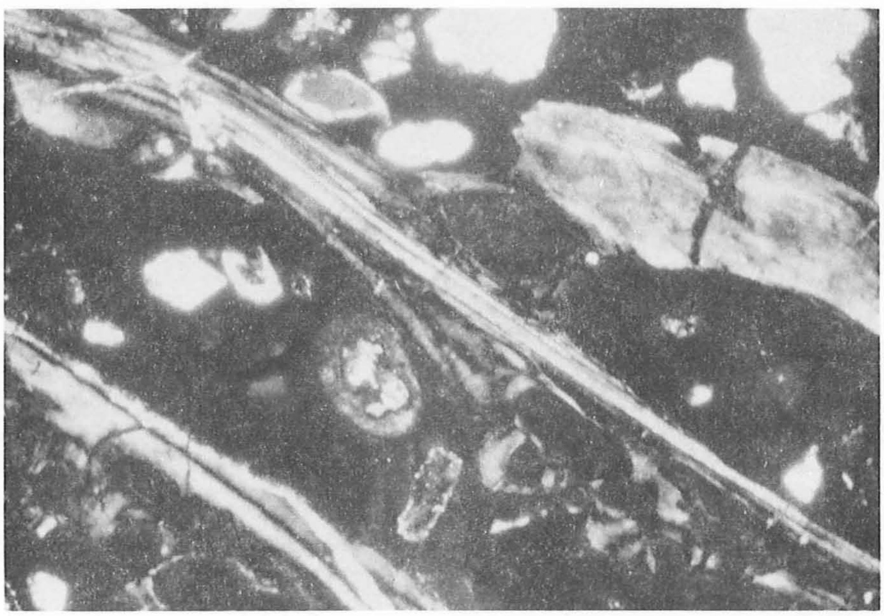

Fig. 6(b). Photomicrograph of nodule showing skeleton of an unknown organism which has been completely replaced by carbonate apatite. Crossed nicols, x100

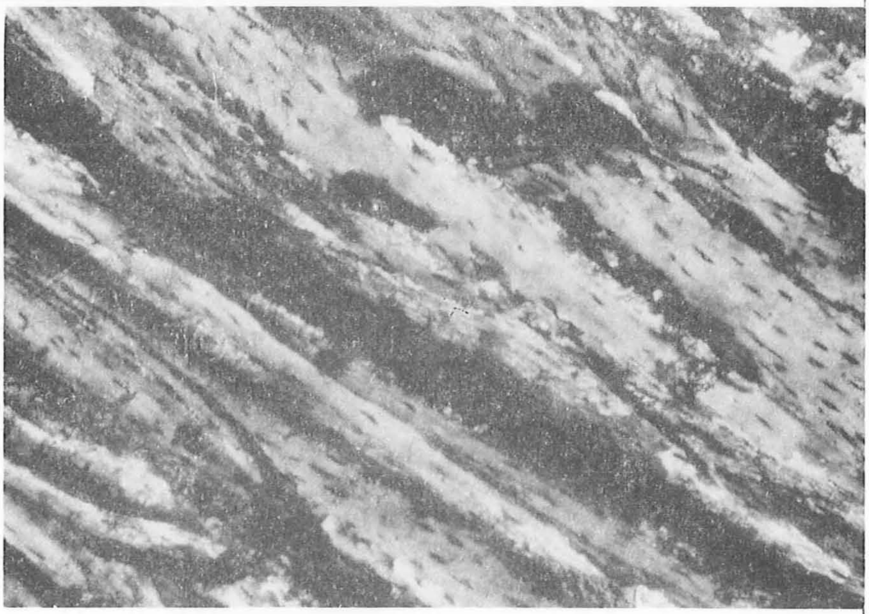

Fig. 7(a). Photomicrograph of laminated rock from station 1513 showing layers of carbonate apatite (francolite) and calcite. Note inclusions in the carbonate apatite which are aligned parallel to the length of the crystal. Crossed nicols, x100.

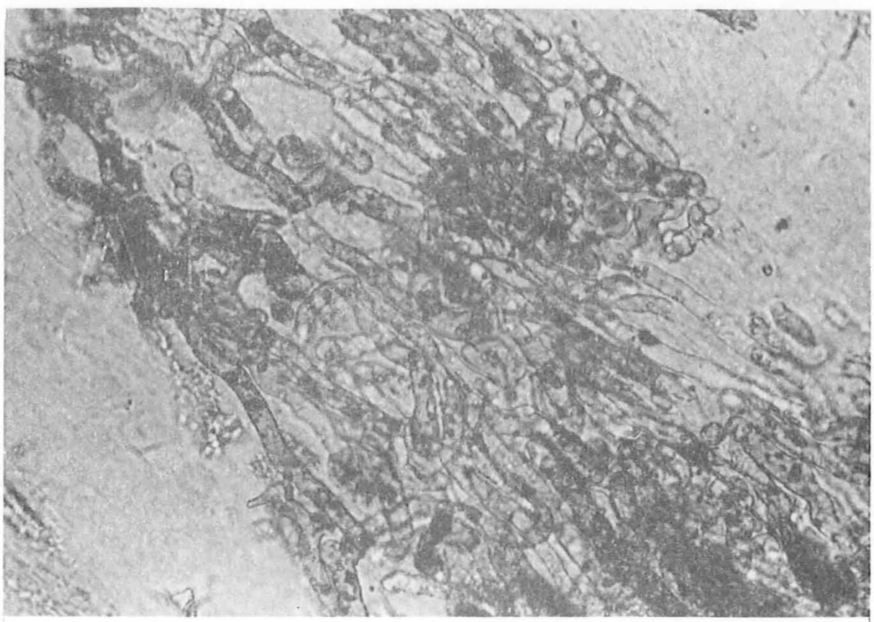

Fig. 7(b). Photomicrograph of laminated rock showing a mass of intertwined algal bodies within the carbonate apatite. Ordinary light, x600.

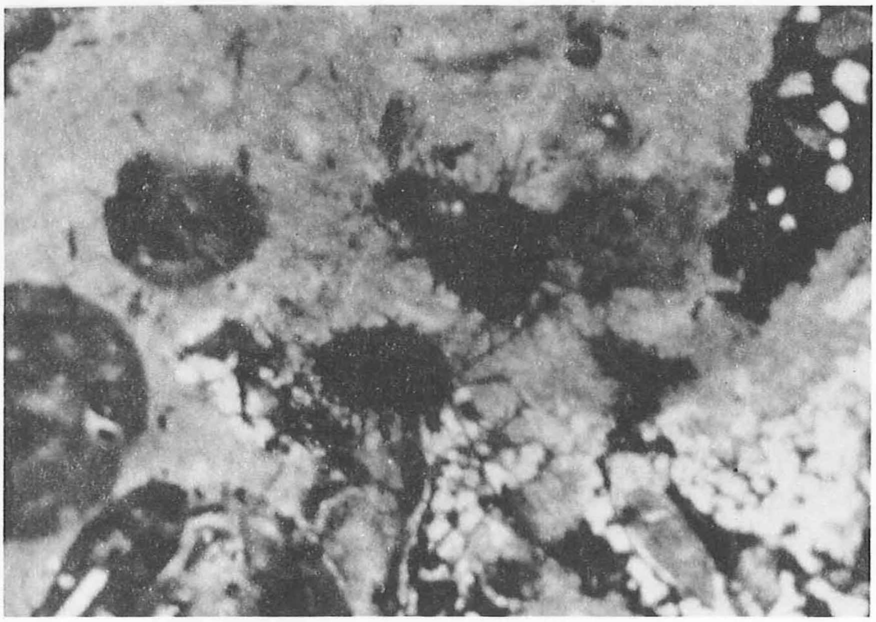

Fig. 8(a). Photomicrograph of lithified matrix showing algal bodies with radiating filaments. Ordinary light, x100.

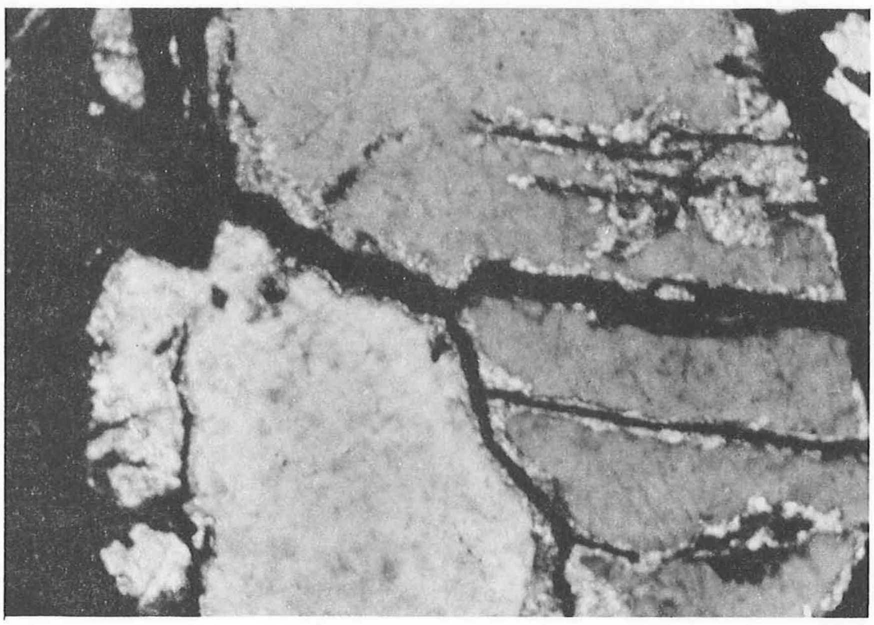

Fig. 8(b). Photomicrograph of quartz grain showing partial replacement by calcite which in turn has been partially replaced by goethite. Crossed nicols, x100.