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HIGH-MAGNESIUM CALCITE OOIDS FROM THE GREAT BARRIER REEF

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ABSTRACT

Ooids are reported from the Great Barrier Reef Province for the first time. They occur over an area of 340 km^2 in the Capricorn Channel in water depths of 100–120 m, and are believed to have formed in the early Holocene. X-ray diffraction analysis shows the ooids to be composed of high-magnesium calcite. This is confirmed by electron probe studies, which also indicate that magnesium occurs in a non-carbonate phase within the chambers of foraminifera that acted as ooid nucleii. Petrographic and scanning electron microscopic studies show that the ooids exhibit well defined concentric, radial, and granular fabrics. All three fabric types occur in the cortex developed around polycrystalline nuclei. A well developed radial fabric occurs in optical continuity with echinoderm fragments that acted as nuclei. Diagenetic alteration of the ooids has resulted first in an overprint of a secondary radial fabric on the primary concentric and radial ones, and secondly in the progressive obliteration of these three fabrics by the growth of an equigranular mosaic, leading to the formation of a structureless ooid. During or after these changes ooid nuclei have been replaced by high-magnesium calcite.

Introduction

Ooids have been conspicuous by their absence in the Great Barrier Reef Province, both in recent sediments and in the Pleistocene record. This is surprising as the province is one of the largest areas of carbonate production in the world, and the physical/chemical conditions that many authors (eg. Newell, Purdy, & Imbrie, 1960; Bathurst, 1971) regard as conducive to ooid growth are likely to occur in many parts of it.

This paper describes the first reported occurrence of ooids in the Great Barrier Reef area. They were obtained by the Australian Bureau of Mineral Resources during a marine geological survey in 1970 from depths of 100 to 120 m in the Capricorn Channel, between the Capricorn and Swain Reefs, in the southern part of the Great Barrier Reef (Fig. 1). Dredge samples were obtained from many sites within an area of 340 km^2. High concentrations of ooids (46% of sample) were recovered from only one sample station (Lat. 22°45'S, Long. 152°21'E). At all other stations within the shaded area in Figure 1, ooids comprised about 10% of the total sample.

Petrography

The ooids are spherical, ellipsoidal, or discoidal (Fig. 2A). They range from 0.1–0.3 mm in diameter, are dark grey or light brown, and are mostly well polished; some are highly pitted (Figs. 2B, 3A, 3C). Their shapes are controlled largely by the shape of the nucleus. In thin section, many ooids show depressions on the external surface (Fig. 2B) similar to the 'bumps' described by Eardley (1938) on ooids from the Great Salt Lake. In the Great Barrier Reef ooids the surface depressions are almost certainly caused by algal borings (Fig. 3A, C). The ooids have finely laminated concentric and radial structures (Figs. 2B, C, D; 3B, C, D). Most show a symmetrical extinction cross (Fig. 2F).

The ooids may be divided into two groups: (a) Those with a polycrystalline nucleus, usually debris of foraminifera, corals, molluscs, or polyzoa; and (b) Those with a nucleus composed of one crystal of calcite, i.e. echinoderm debris. The former are the most abundant.

Group A. Four different fabrics may be present in the cortex of this group.

i. Concentric structure due to alternating laminations of carbonate and organic material. The organic layers are 2–10 μm thick (Fig. 3D).

ii. Primary radial structure formed by radially orientated crystals between consecutive concentric organic layers (Fig. 3C). The crystals are too small to allow determination of their crystallographic orientation.

iii. Secondary radial structure transecting the concentric structure. These radially orientated crystals may extend to the outer surface of the ooid (Figs. 2B, C & F), or may be limited to a zone in the middle of the ooid cortex. Traces of the concentric layering can be seen within the radially orientated crystals (Fig. 2C). The latter are length fast.

iv. A microgranular mosaic is seen in many ooids as patches of equigranular or irregularly shaped crystals, 2–10 μm in size. They form the total fabric visible in the structureless ooids. (Figs. 2C & E).

All gradations occur between concentric, markedly radial, and structureless fabrics. It is likely that the ooids have been undergoing progressive diagenetic alteration, stages of which can be detected within individual ooids. The ooids probably had an original structure consisting of a fine, concentrically laminated cortex, between which minute radially orientated crystals occurred. The first stage of diagenetic alteration results in the growth of large radially orientated crystals.

This process has not destroyed the concentric lamination. Either concurrently, or at a later stage, a recrystallization has occurred giving rise to a fine mosaic of equigranular or irregular shaped crystals, the growth of which destroys both the primary and secondary radial structure and the concentric structure. This process has proceeded to near completion in a few ooids. It is suggested therefore that the secondary radial structure is obliterating the concentric structure while the equigranular structure is obliterating both.

Group B. In this group, echinoderm fragments form the ooid nucleii (Fig. 2D). The ooid cortex is composed of radially orientated crystals in optical continuity with the nucleus. (Fig. 2D). The radial structure predominates over any concentric structure.

Chemical analysis

The result of X-ray diffraction analysis of several hand-picked ooids is given in Figure 4. Surprisingly this shows high-Mg calcite as the only mineral phase. A single sharp peak occurs at $29.86^{o}2\theta$ (0.299 nm) corresponding to a composition of $Ca_{85}Mg_{15}CO_3$. The X-ray trace showed no aragonite or low-Mg calcite. Several sample splits have since been re-run with the same result. This means that both ooid cortex and nucleus are now composed of the same mineral phase. Many oolitic nucleii consist of grains which were not originally composed of high -Mg calcite (e.g. polyzoans, coral fragments) indicating that the former mineral has been replaced by high-Mg calcite.

Microprobe analysis on individual ooids has been carried out to determine the position and relative distribution of Mg^{2+} and Ca^{2+}, and also to complement the diffraction results. One such analysis is shown in Figure 5. The ooid is composed of a nucleus, which is a foraminifer, enclosed in a wide zone of cortex (Fig; 5A). Figure 5B shows the distribution of Mg^{2+}.

It is abundant throughout the ooid, but is heavily concentrated in the chambers of the foraminfer. Figure 5C shows the distribution of Ca^{2+}, which is heavily concentrated in the ooid cortex and in the carbonate part of the foraminifer, i.e. the septa and walls. Little calcium occurs within the chambers of the foraminifer. These pictures show that Mg^{2+} occurs strongly as part of the calcium phase in the ooid cortex, thus confirming the X-ray diffraction results, but also show Mg^{2+} in abundance as part of a non-calcium phase in the foraminiferal chambers. Microprobe analysis also shows a high concentration or iron within the chambers, confirming our identification of glauconite during petrographic studies.

Discussion

There is no direct evidence on the age of the ooids whether relict or forming at the present time or on whether or not they have been derived. Jenkyns (1972) described Jurassic 'oolites' in Europe and attributed them to the effect of sediment-binding algae in water as deep as 125 m; i.e. the 'oolites' were in fact small oncolites forming in deep water. Those 'oolites' were characterized by a concentric structure, no radial structure, a micritic fabric, and mechanically bound nanno-organisms within the 'oolite' cortex. The ooids described in the present work resemble those described by Jenkyns only in the depth at which they have been found, and in the environmental setting postulated for the Jurassic material (Jenkyns, 1972, p. 24). The present writers consider it possible but highly unlikely that the ooids are forming in place at the present time.

Some circumstantial evidence points to an early Holocene age for the ooids. First, the samples were collected in 100–120 m of water; this is much deeper than the normal environment of ooid formation and suggests that they are a relict feature. While it is true that the ooids could be derived from a recent, much shallower source, it is difficult to postulate where this source could be, in view of the fact that ooids have never before been reported in the Great Barrier Reef Province.

Secondly, petrographic and scanning electron microscope studies reveal some degree of diagenetic alteration in the ooid structure; this also suggests that the ooids are not recent. If these ooids are relict then their present metastable mineralogy and their highly polished external surfaces testify to the fact that they have never been removed from the marine environment. Robinson (1967) describes how the chalky nature of ooids that have been subjected to subaerial weathering contrasts with the highly polished appearance of their recent counterparts. If the above reasoning is correct, then the ooids we have described are likely to be less than 15000 years old (i.e. they postdate the end-Pleistocene low sea level stand) and have always remained in a marine environment.

Two features are unusual about the ooids that we have described: their composition and their dominantly radial structure. While a modern consensus indicates that ooids precipitate as aragonite orientated in tangential or random directions (Bathurst, 1971), Friedman et al. (1973) report aragonitic ooids in the Gulf of Aqaba possessing a radial orientation, and Frishman & Behrens (1969) report briefly on recent high-Mg calcite ooids with a radial structure in Baffin Bay, Texas. There are therefore two possible alternatives for the origin of the ooids we have described: either they were precipitated originally as aragonite and have been subsequently replaced by high-Mg calcite, or they were precipitated originally as high-Mg calcite.

The first alternative requires the replacement of a metastable phase by an even more metastable phase; this is unlikely, although it has been noted previously (Taylor & Illing 1969). Some evidence for this is seen in the total absence of aragonite or low-Mg calcite in the nuclei of the ooids, despite the fact that coral and polyzoal debris acts as nuclei. That this replacement is an internal feature of the ooids is indicated by the presence of abundant aragonite and low-Mg calcite in the sediment of which the ooids form a part. The exact mechanism of replacement is speculative, but may involve high concentrations of magnesium adsorbed on organic films in the manner described by Gebelein & Hoffman (1973) and Friedman et al. (1973). Shearmann et al. (1970) showed that a change in mineralogy from aragonite to low-Mg calcite can occur in ooids without effacing the laminated concentric structure; organic material acts as templates for the precipitation of calcite after aragonite. If the organic material was able to contribute magnesium, in the manner suggested by Gebelein & Hoffman (1973), as well as acting as a template, then high-Mg calcite could have been precipitated.

The second hypothesis of direct precipitation of high-Mg calcite requires clase scrutiny, especially in view of the report by Frishman & Behrens (1969) of high-Mg calcite ooids with a radial structure forming in Baffin Bay, Texas. Optical continuity of radially orientated crystals with echinoderm fragments acting as nuclei suggest a precipitational mechanism. As the boundaries of nuclei and cortex are sharp, little replacement has occurred. The composition of the ooids (15 mole % $MgCO_3$) may also indicate an inorganic precipitational origin from marine waters. This is suggested by Alexandersson's (1972) contention that Mg-calcites with a $MgCO_3$ content of 13-18 mole % are likely to have been precipitated from sea water.

It is apparent that we cannot yet advocate one hypothesis or the other for the formation of the ooids. However, it is equally apparent that ooids may undergo a complex diagenetic history while in the marine environment and while they remain as metastable carbonates.

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REFERENCES

ALEXANDERSSON, T., 1972 - Mediterranean beachrock cementation: marine precipitation of Mg-calcite: In, THE MEDITERRANEAN SEA, D.J. Stanley (ED), Strondsburg, Pa., Dowden, Hutchinson and Ross.

BATHURST, R.G.C., 1971 - Carbonate sediments and their diagenesis: DEVELOPMENTS IN SEDIMENTOLOGY, V. 12. Amsterdam, Elsevier.

EARDLEY, A.J., 1938 - Sediments of Great Salt Lake, Utah. Bull. Am. Assoc. petrol. Geol. V. 22, pp. 1305-1411.

FRIEDMAN, G.M., AMIEL, A.J., & BRAUN, M., 1973 - Generation of carbonate particles and laminites in algal mats - examples from sea-marginal hypersaline pool, Gulf of Aqaba, Red Sea. Bull. Am. Assoc. Pet. Geol. V. 57, pp. 551-7.

FRISHMAN, S.A., & BEHRENS, E.W., 1969 - Geochemistry of oolites, Baffin Bay, Texas (Abs.). Geol. Soc. Am. Abs. with programs. pl. 7, p. 71.

GEBELEIN, C.D., & HOFFMAN, R., 1973 - Algal origin of dolomite laminations in stromatolitic limestone. J. Sedim. Petrol., V. 43, pp. 603-12.

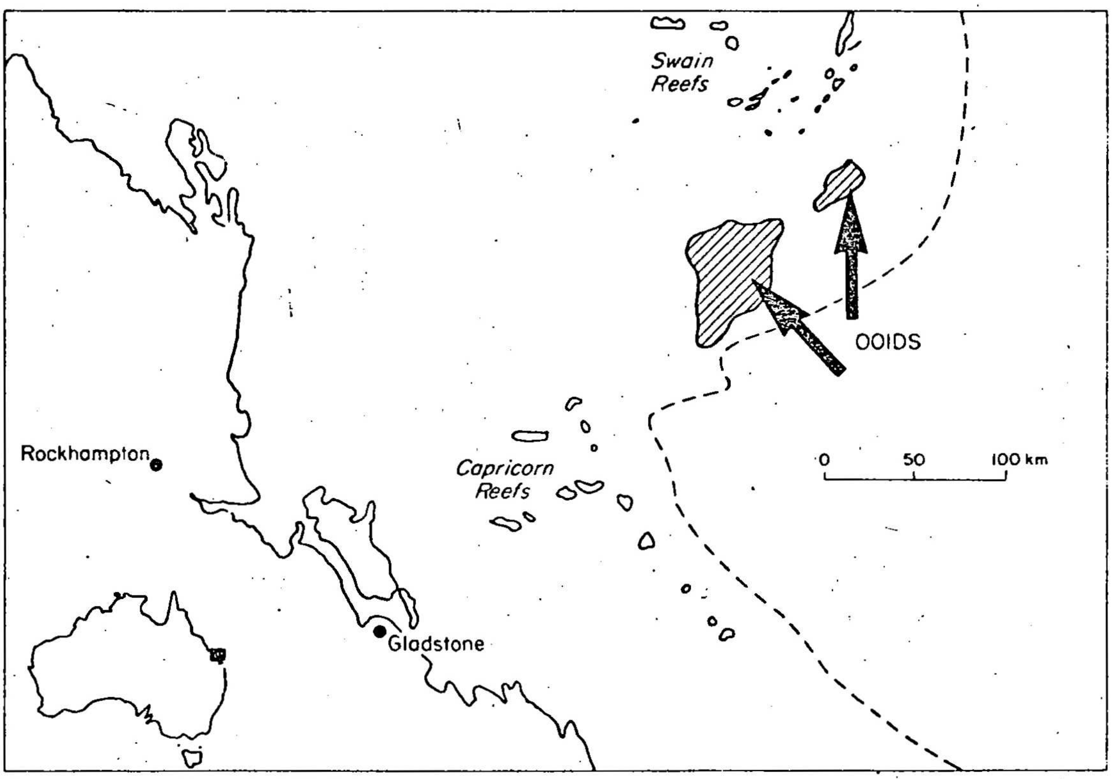
JENKYNS, H.C., 1972 - Pelagic "oolites" from the Tethyan Jurassic. J. Geol. V. 80, pp. 21-33.

NEWELL, N.D., PURDY, E.G., & IMBRIE, J., 1960 - Bahamian oolitic sand. J. Geol., V. 68, pp. 481-97.

ROBINSON, R.B., 1967 - Diagenesis and porosity development in recent and Pleistocene oolites from southern Florida and the Bahamas. J. Sedim. Petrol. V. 37, pp. 355-64.

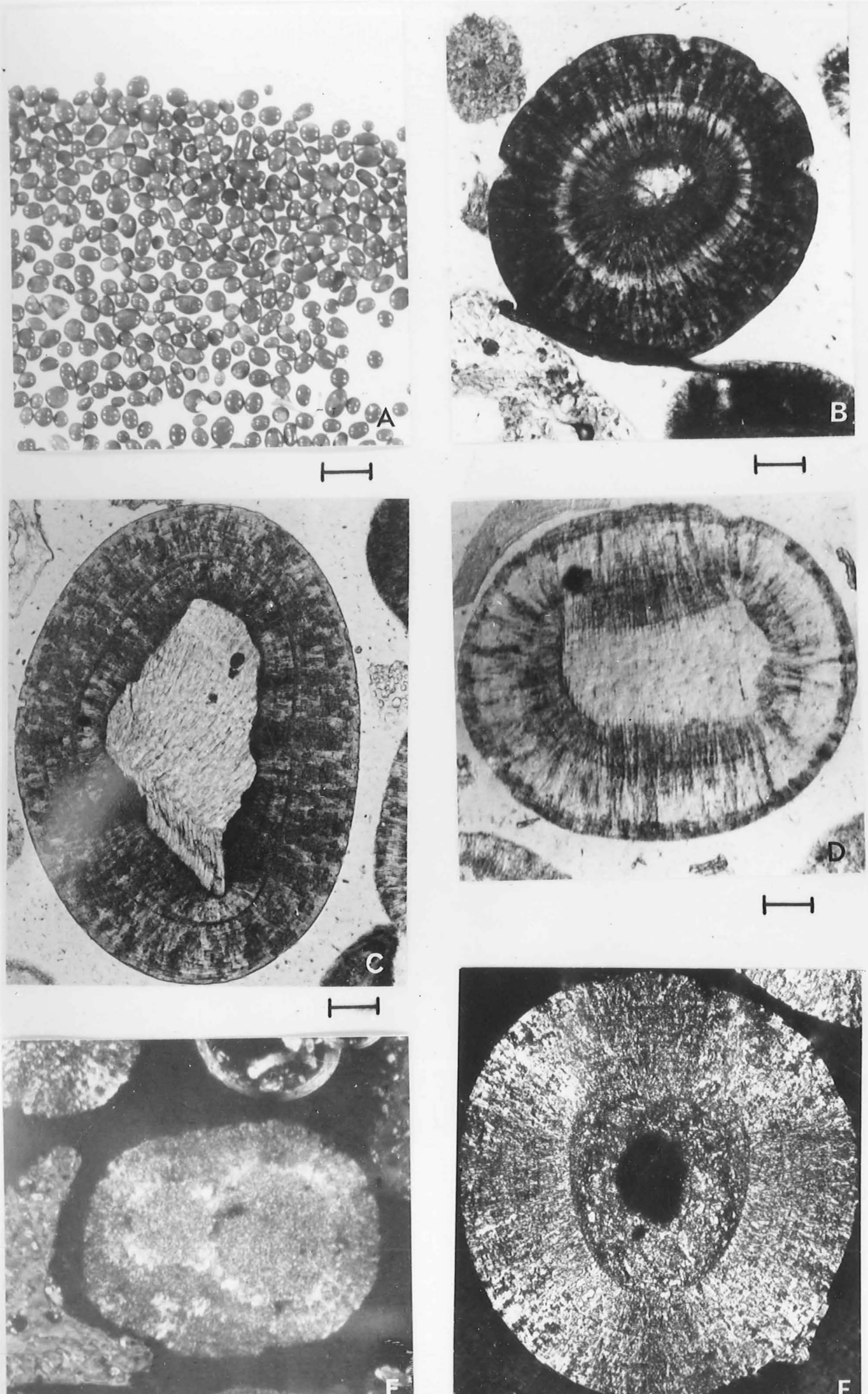
SHEARMAN, D.J., TWYMAN, J., & KARIMI, M.Z., 1970 - The genesis and diagenesis of oolites. Proc. Geologists' Assoc. (Engl.), V. 81, pp. 561-75.

TAYLOR, J.C.M., & ILLING, L.V., 1969 - Holocene intertidal calcium carbonate cementation, Qatar, Persian Gulf. Sedimentology, V. 12, pp. 69-107.



To accompany Record 1974/24 AUS 6/170

Fig. 1.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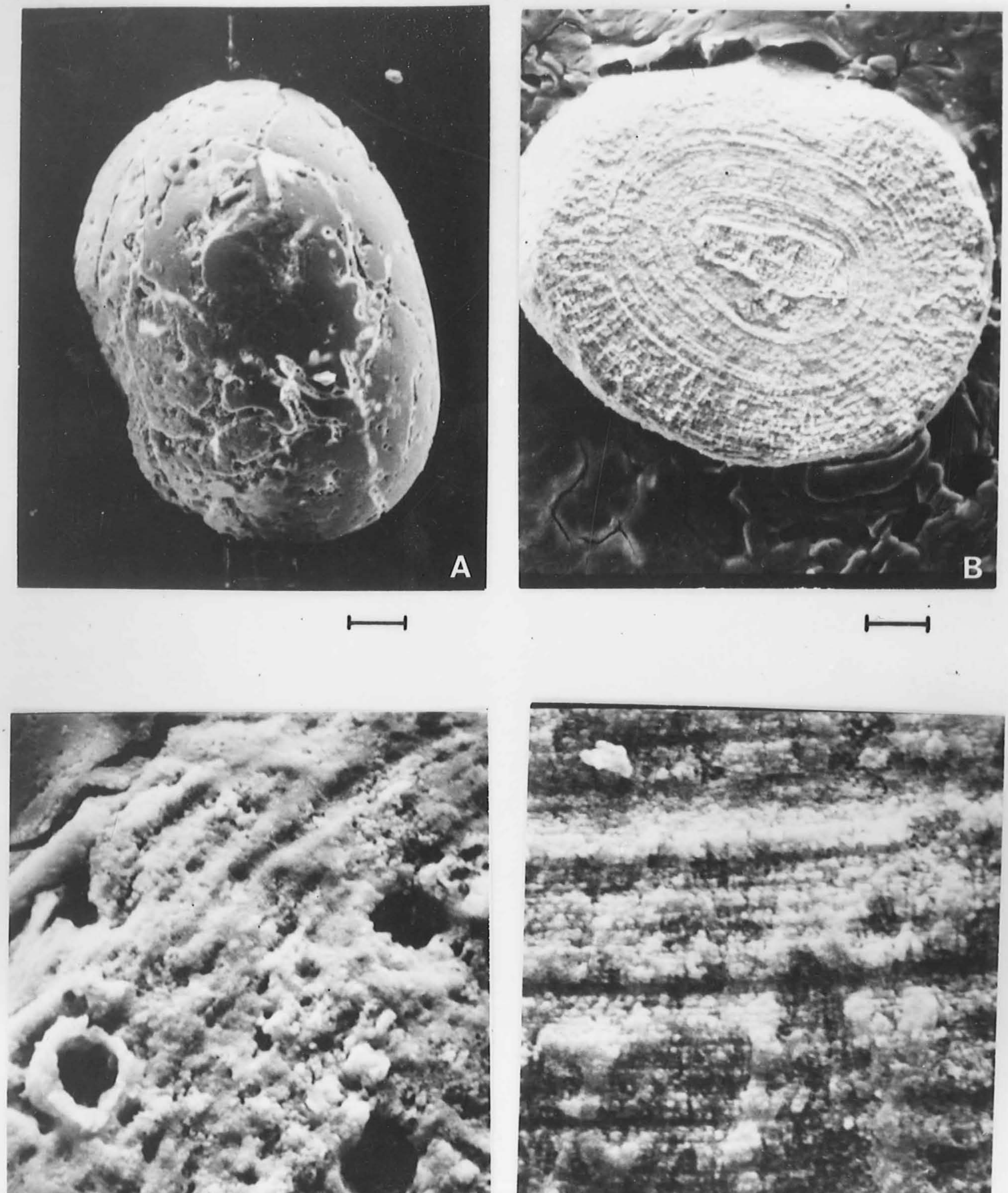
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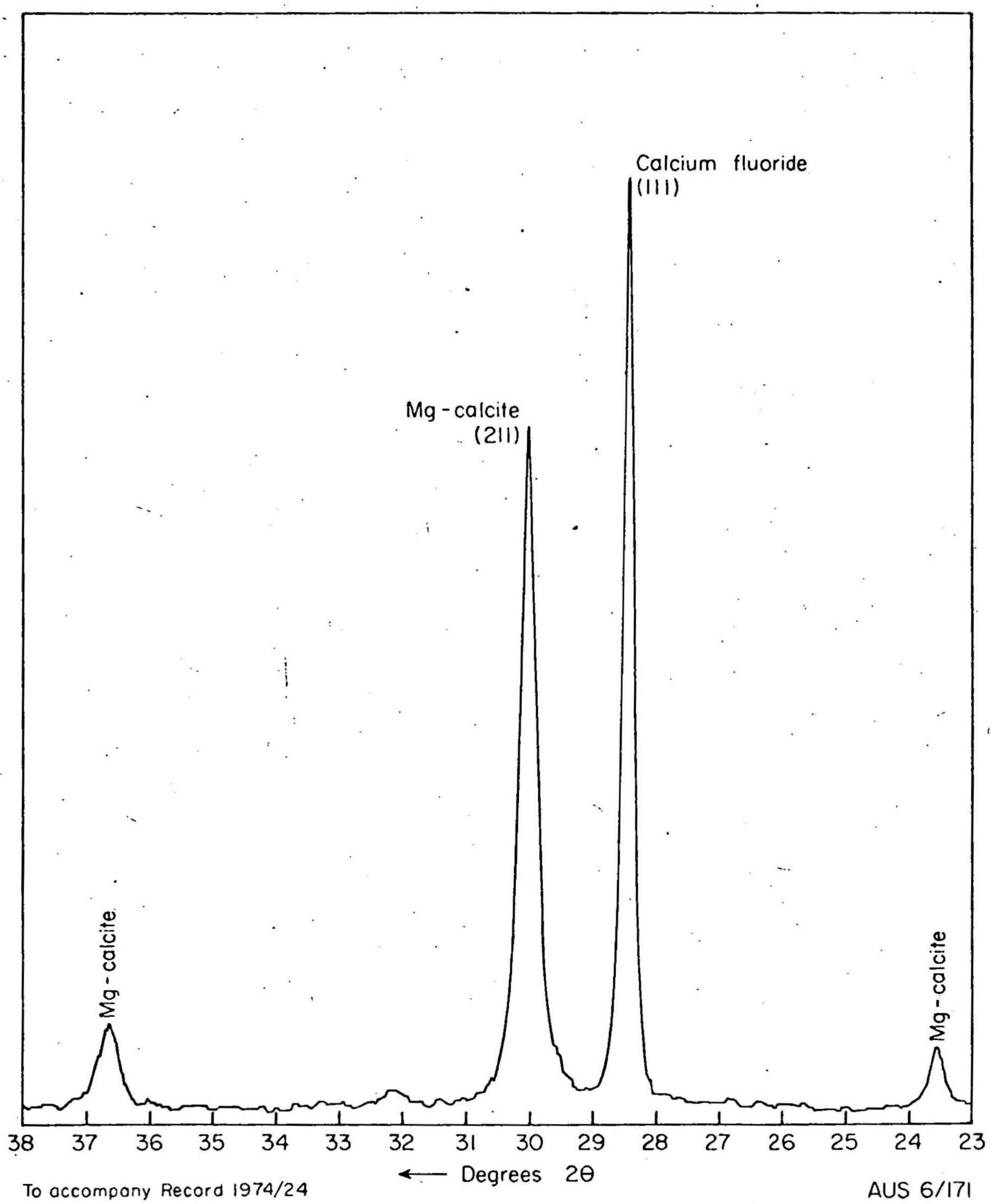


To accompany Record 1974/24

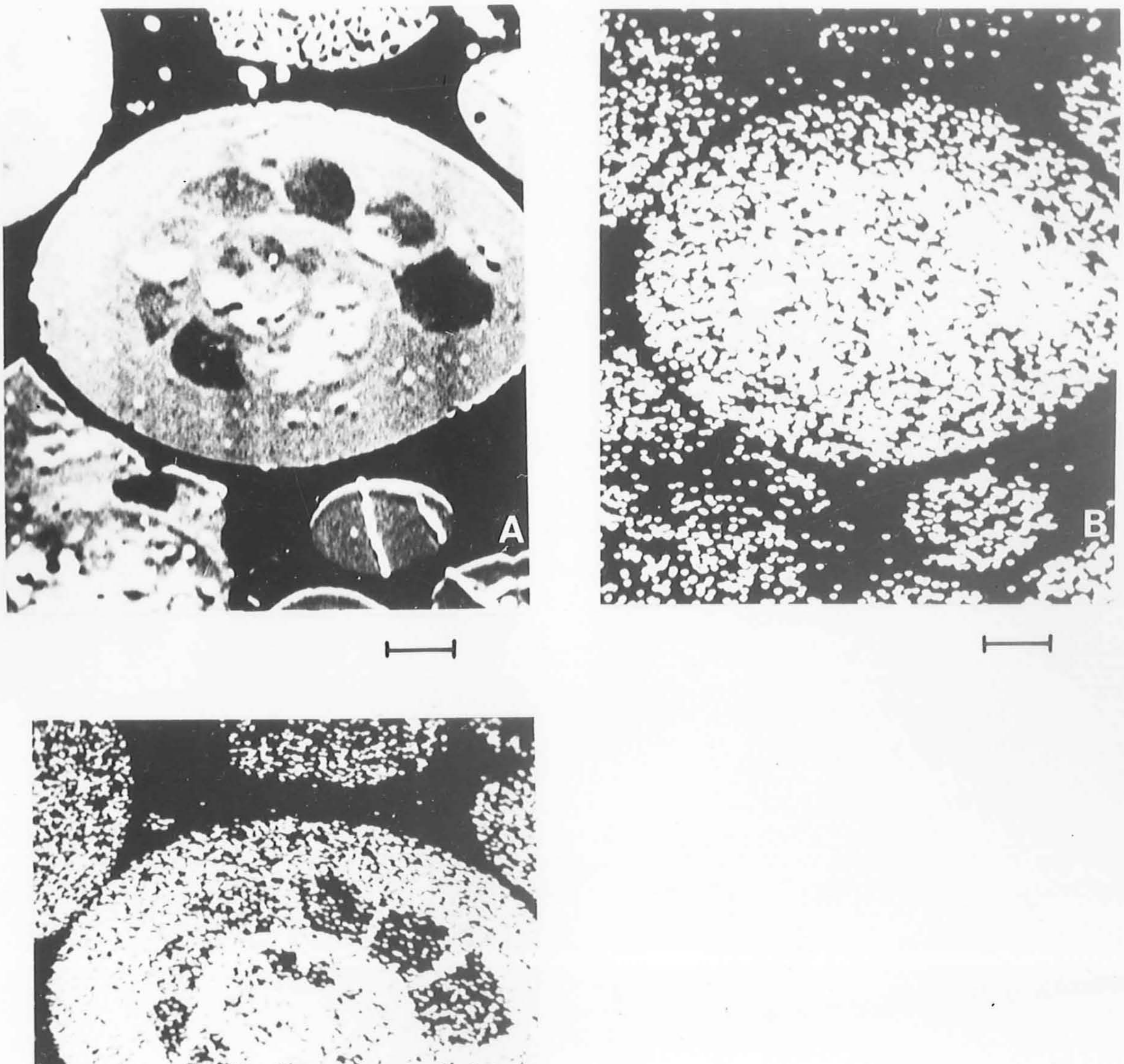
AUS 6/171

Fig. 4.

Fig. 5. A. Electron microprobe image of ooid in polished thin section. The foraminifer forming the nucleus, and the wide cortex are easily identifiable. Scale Bar = 50 µm.

B. Normal backscattered electron image showing the distribution of magnesium within the ooid cortex and nucleus. Scale Bar = 50 µm.

C. Normal backscattered electron image showing the distribution of calçium within the ooid cortex and nucleus. Scale Bar = 50 µm.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