ATOLL RESEARCH BULLETIN

NO. 420

QUATERNARY OOLITES IN THE INDIAN OCEAN

BY

C.J.R. BRAITHWAITE

ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
AUGUST 1994

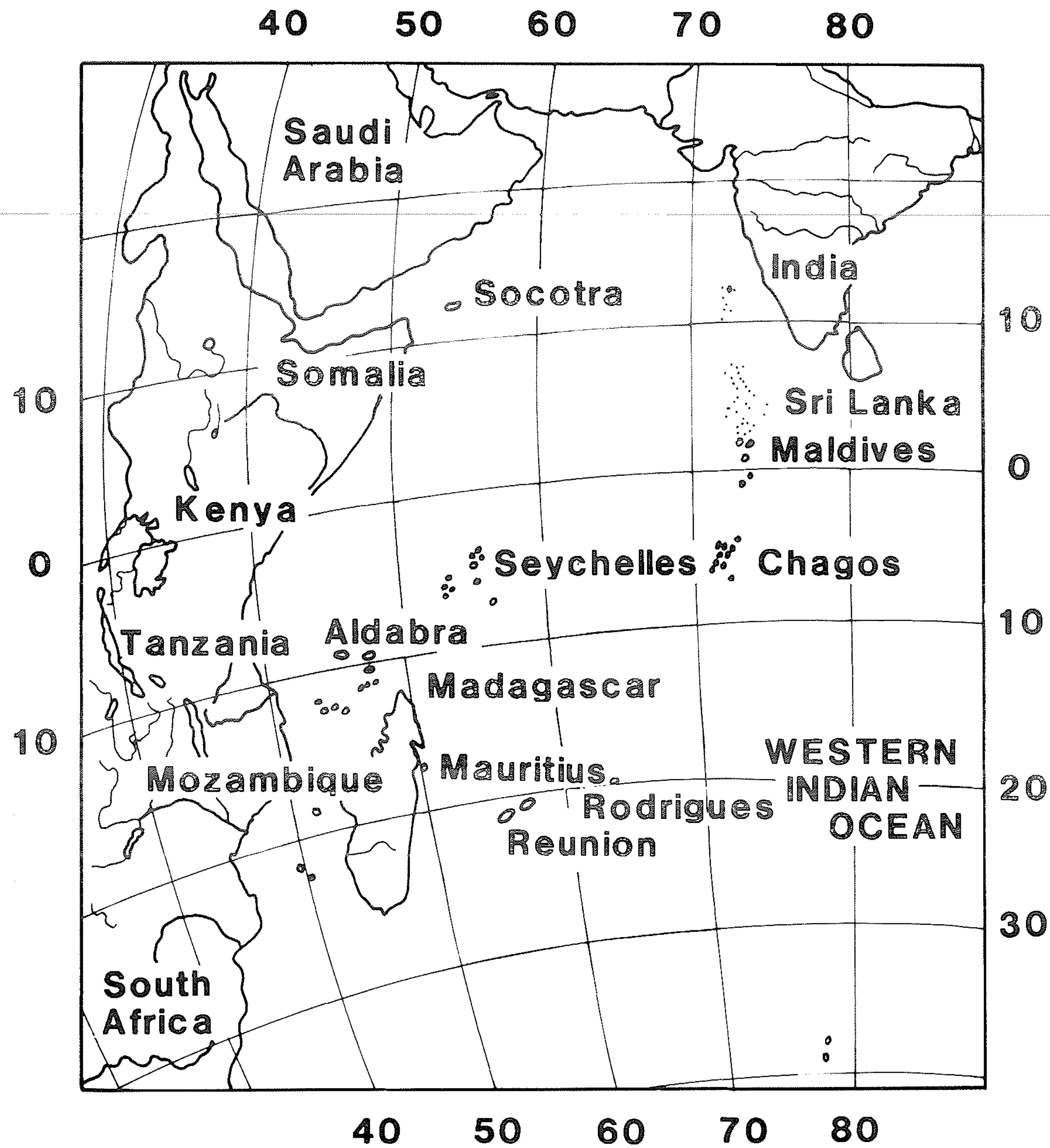

Fig. 1 General map of the Indian Ocean indicating positions of the principal locations referred to in the text.

QUATERNARY OOLITES IN THE INDIAN OCEAN

BY

C. J. R. BRAITHWAITE

ABSTRACT

Aeolian calcarenites from Rodrigues in the Western Indian Ocean include oolites. No recent oolites are recorded in the Indian Ocean and there is only one other Pleistocene record. The calcarenites are compared with deposits in the Seychelles, East Africa, India, and South Africa which consist of marine-derived bioclasts. In general they indicate critical water depths over generating shelves and thus particular stages in sea-level change. They are characteristic of both early phases of cooling and later stages of warming events. There seems to be no explanation for the restricted distribution of oolites in the Indian Ocean.

INTRODUCTION

Aeolianites are widespread in the Pleistocene deposits of the Western Indian Ocean. Those on Rodrigues are unusual in that those on the east coast consist of oolites with a relatively small bioclastic component. With the exception of deposits in Kathianar in India, described by Chapman (1900) and Evans (1900), these are the only oolitic deposits known from the Pleistocene or Holocene of the Western Indian Ocean.

FIELD DESCRIPTION

Rodrigues lies about 650 km east of Mauritius, Lat. 19° 42' S, Long. 63° 25' E (Fig. 1). It is approximately 18.3 km long and 6.3 km wide, consisting predominantly of young undersaturated basalts erupted between 1.5 and 1.5 million years ago (McDougall *et al.* 1965). The south-eastern and south-western margins of the island are blanketed by a discontinuous cover of cross-bedded calcarenites (Fig. 2). These were known a hundred years ago when they were described by Balfour (1879) and Slater (1879) who visited the island during the Transit of Venus expedition to make observations on the general geology. Their reports describe caves in these limestones in which the bones of the Solitaire and other flightless birds were found.

Although Rodrigues has a surface area of only about 120 km^2 the platform on which it rests is at least 1650 km^2. The island surface slopes gently outwards to about 100 m depth before plunging into deeper water. The island is bordered on its south-western coast by a fringing reef 4-8 km from the shore and Admiralty Charts show that the lagoon area within this is generally very shallow (McDougall *et al.* 1965). However, the shallow platform beneath extends a considerable distance both to the west and the east and, as will be shown, probably played a significant part in the formation of the calcarenites.

Most of the calcarenites are bioclastic and were originally marine, but those in

Department of Geology and Applied Geology,
The University, Glasgow G12 8QQ, Scotland, U.K

Manuscript received 23 April 1993; revised 28 June 1994

south-eastern localities (Pointe Coton, Trou d'Argent) are clean-washed oolites. In both south-eastern and south-western areas grains are well rounded and well sorted within individual laminae. Cliff sections show well-defined high-angle cross bedding in sets of up to 10 m, forming cosets locally of more than 20 m thickness (Figs. 3 and 4). Cross-laminae dip at angles up to 30-35° and set-bounding surfaces generally dip a few degrees in a seawards, (generally southerly) direction. In some areas the upper margins of dunes are full of casts of branching root systems which imply colonization by substantial trees. There are, however, no distinctive *terra rossa* or palaeosol deposits and plants must have grown in unconsolidated sand before and perhaps during cementation.

The thickness of the calcarenites is quite variable. In western localities they blanket a gently undulating ramp, while in the east they occupy an erosional bench cut into the underlying basalts. Significantly, in both areas basal surfaces appear to extend below present sea-level. McDougall *et al.* (1965) recorded these limestones as occurring at more than 60 m above present sea-level, while Snell and Tams (1920) claimed that they extend up to 500 ft (165 m). Present observations suggest that the lower figure is more realistic. The thickest sequences are found in the south-west of the island in the area of Caverne Patate where cave systems penetrate at least 30 m of limestone. Montaggioni (1973) suggested that typical thicknesses are 15-20 m).

McDougall *et al.* (1965) thought that the depositional morphology of the calcarenites had been obscured by recent erosion. In fact, low dune ridges can be seen in south-western areas and air photographs reveal a spectacular series of parallel dune crests facing north and north-east and having a wave length of from tens to hundreds of metres. These extend for several kilometres from the present shoreline (Fig. 5). Groups of steep foreset laminae are visible on air photographs and can be traced across outcrops. Interdune areas are less conspicuous and are characterized in limited outcrops by low angle lamination and shallow troughs.

PETROGRAPHY

The oolites have a mean diameter of about 300μm (medium sand), many nuclei are dark micritic peloids while others are bioclasts. Cortical layers have the tangential structure typical of recent aragonitic ooids and may be more than 100μm thick (Fig. 6). Bioclast calcarenites consist predominantly of foraminifera, including *Marginopora* and *Heterostegina*, together with echinoderm plates, calcareous algal fragments (cf. *Goniolithon* and *Halimeda*), mollusc shell and coral fragments. In the samples examined grains have a mean size of 400-800μm. The marked contrast in grain typebetween oolitic and bioclastic rocks are paralleled by differences in mineralogy and diagenetic history. The bioclastic limestones include both aragonite and calcite (identified by X-ray diffraction) but have only a sparse fine-grained blocky calcite cement. This is restricted to patches where it forms meniscus bridges between grains and occasional pendant drops, suggesting deposition in the vadose zone, although it lacks the fibrous or prismatic textures typical of such environments. By contrast, in oolites, the ooliths themselves consist of aragonite and they are commonly embedded in a coarse blocky calcite cement which may completely fill pores and locally extends inwards from grain surfaces as a neomorphic replacement of the original tangential structure.

INTERPRETATION

The distinctive high-angle lamination which characterizes the calcarenite deposits on Rodrigues, and the occurrence of calcarenites over such a range of altitude, seems to confirm an aeolian origin. Submarine sand-waves might be of similar size but would generally be expected to have lower angle cross-bedding and are unlikely to have accumulated over such a slope. They would, moreover, have had to be related to a sea-level more than 60 m higher than at present. Deposition of these rocks must have occurred at a time when sea-level stood **lower** than at present, perhaps by about 10 m. However, the sediments were of marine origin and reflect generation in shelf environments. Thus, sea-level must have been high enough to maintain a permanent water cover over a sufficiently large area. The large area of gently-sloping surface beneath present reefs would have ensured that a suitable shelf was present over a range of sealevels, although not during the glacial maximum. Grains generated within the shelf were swept onshore by storm waves and accumulated as beach and, ultimately, dune deposits, the latter probably migrating several kilometres from the shoreline. Correlation with a lower sea-level implies a general correlation with a cooler climate.

THE AGE OF THE DEPOSITS

Two different calcarenite types are present on Rodrigues and since lithological variations are paralleled by diagenetic differences the rocks are likely to be of at least two different ages. Montaggioni (1970) referred to **three** separate dune assemblies in the eastern area but these have not been identified here. The calcarenites have not been precisely dated but it is clear that they are not Recent. The active phase of accretion was followed by a passive phase of colonization by trees, and the whole assemblage has been dissected by a mature karst system which, judging from the included fauna, is at least late Pleistocene (see again Slater, 1879). However, the ages inferred for these deposits have been determined by reference to associated limestones. Montaggioni (1970) regarded them as of the same age as calcarenites on Mauritius. In this interpretation they should equate with high sealevel stand dates of $^{230}Th/^{234}U$ ages of 120 ±15-20 ka obtained by Battistini (1976) for Pleistocene limestones on Mauritius, which were compared in turn with dates of 160 ±40 ka and 110 ±40 ka given by Veeh (1966) and of 114 ±6-7 ka and 104 ±4-6 ka given by Elbez (1976). However, none of these ages was obtained from calcarenites and, for reasons of environment, it is unlikely that the aeolian calcarenites on Rodrigues were contemporary with the marine deposits from which the dates were obtained. There are no observations of rocks overlying the Rodrigues calcarenites and this contrasts with the relative positions of aeolianites in Kenya (Braithwaite, 1984) and on Aldabra (Braithwaite *et al.*, 1973) which are probably substantially older (see below).

OTHER INDO-PACIFIC DEPOSITS

Within the western Indian Ocean aeolianites (calcarenites with characteristics similar to those described) have been identified in a number of areas. In northern Madagascar Battistini (1976) recorded dune-bedded carbonate rocks low in the Pleistocene. These overlie his Recif I but appear to be older than Recif II, dated at 160 ±10-15 ka. This dune assemblage is said to be more than 200 m thick but only about 15 m are shown on the published synthetic section extending for 25 km in the south. It is considerably thinner on the north and east coasts. Like the deposits on Rodrigues the top is marked by non-deposition, in this case resulting in a dissected erosion surface and what are described as "decalcified pockets".

In East Africa, calcarenites with high angle cross-bedding and consisting of marine-derived grains are exposed on the northern coast of Kenya, south of Malindi, and in the extreme south, near Shimoni and Wasini Island (Braithwaite, 1984). In both of these areas the deposits are believed to extend **below** present sea-level but are stratigraphically **above** coral-bearing marine limestones which were apparently the source of material dated by Battistini (1976) as 240 ±40-70 ka. They are overlain by younger limestones which have been described by Crame (1980, 1981) and which appear similar to the youngest coral-bearing limestones on Aldabra. Aldabra has a small area of calcarenites with high angle cross-bedding exposed on the south coast (Braithwaite *et al.,* 1973). These are overlain by two marine limestones, the youngest of which has been dated by Thomson and Walton (1972) as forming between 118-136 ±9 ka. It is this which is equivalent to the younger coral limestone in Kenya. These calcarenites, in which grains are entirely of marine bioclasts, formed when Aldabra was a shallow marine platform with only small sand cays accumulating along what is now the southern coast and in a relatively large area to the north-east.

The aeolian calcarenites of southern India have already been referred to (Chapman, 1900, and Evans, 1900). Knox (1977) described other calcareous aeolian dune deposits of supposed middle to late Pleistocene age from Saldanha Bay in South Africa. These average 30 m in thickness but are reported by Visser and Schoch (1973) to be as much as 88 m locally. Once more they consist predominantly of marine bioclasts.

DISCUSSION

The descriptions given reinforce the view that aeolian deposits are a common, even characteristic, feature of Pleistocene limestone successions in the Indian Ocean. They are of a variety of ages but have commonly (although not exclusively) formed in areas which do not have present day dunes. It might be argued that winds were stronger in the past and that the absence of present-day dunes is a reflection of the inadequacy of present day winds. However, this is unlikely, Bagnold (1941) and Wolman and Miller (1960) have indicated that in dune formation the net transport of sands is controlled more by prevailing winds above threshold velocity than by extreme wind events. In almost all of the Indian Ocean examples the sands were of medium to fine grade and therefore do not reflect excessive wind speeds. Elsewhere, in Bermuda (Mackenzie 1964), aeolianites show palaeowind vectors which are essentially the same as present directions while in the Turks and Caicos islands (Lloyd *et al.* 1987) palaeocurrents in both Pleistocene and recent aeolianites (which include oolites) can be related to south-easterly Trade Winds.

The presence of oolites remains enigmatic. Their formation, and that of the bioclasts, was probably critically dependent on water depths over the generating shelves. If sealevel is too high shelves are deeply flooded and unlikely to reach the necessary saturation conditions. If it is too low shelves are restricted (or dry) and again fail to generate sediment. Thus it seems that the oolites and the aeolianites generally are characteristic of early stages of cooling and later stages of warming events when sealevel was only marginally below its present position. Why they were not more widespread in the Indian Ocean, where there are several extensive shallow banks, is not known. Marine-deposited oolites may be present but if they are it is likely that all lie beneath present-day shelves.

ACKNOWLEDGEMENTS

I wish to thank Prof. Gulam T. G. Mohammedbhai and Dr. André Chan Chim Yuk of the University of Mauritius for guidance during visits to the Rodrigues deposits as part of a programme financed by British Council. Work in Kenya was supported by the

Carnegie Trust for the Universities of Scotland and that on Aldabra by the Royal Society, and the Natural Environment Research Council, with logistical support and facilities provided by the Seychelle Islands Foundation.

REFERENCES

Bagnold, R. A. 1941. The Physics of blown sand and desert dunes. Methuen, London, 265pp.

Balfour, I. B. 1897. The Physical features of Rodrigues. An account of the petrological, botanical and zoological collections made in Kerguelen's Land and Rodrigues during the Transit of Venus Expeditions 1874-5. Philosophical Transactions of the Royal Society of London **168**:289-292.

Battistini, R. 1976. Application des methodes Th^{230}-Ur^{234} a la datation des depots marins anciens de Madagascar et des iles voisines. Association Sénégal Etudes Quaternaire Africain, Bulletin Liason Sénégal **49**:79-95.

Braithwaite, C. J. R. 1984. Depositional history of the Late Pleistocene limestones of the Kenya Coast. Journal of the Geological Society of London **141**:685-699.

Braithwaite, C. J. R., Taylor, J. D. and Kennedy, W. J. 1973. The evolution of an Atoll: the depositional and erosional history of Aldabra. Philosophical Transactions of the Royal Society of London, Series **B 266**:307-340.

Chapman, F. 1900. Notes on the consolidated sands of Kathiawar. Quarterly Journal of the Geological Society of London **56**:584-588.

Crame, A. 1980. Succession and diversity in the Pleistocene coral reefs of the Kenya Coast. Palaeontology **23**:1-37.

Crame, A. 1981. Ecological stratification in the Pleistocene coral reefs of the Kenya Coast. Palaeontology **24**:609-646.

Elbez, G 1976. Application de la methode de datation $^{230}Th/^{234}U$ a la determination des niveaux marins de Madagascar et des isles environmentes. Memoires Maitre (Geophysique) soutenu a l'Universite de Paris-Sud, Centre Orsay.

Evans, J. W. 1900. Mechanically formed limestones from Junagarh (Kathiawar) and other localities. Quarterly Journal of the Geological Society of London **56**:559-583 and 588-589.

Knox, G. J. 1977. Caliche profile formation, Saldanha Bay (South Africa). Sedimentology **24**:657-674.

Lloyd, R. M., Perkins, R. D. and Kerr, S. D. 1987. Beach and shoreface ooid deposition on shallow interior banks, Turks and Caicos islands, British West Indies. Journal of Sedimentary Petrology **57**:976-982.

Mackenzie, F. T. 1964. Bermuda Pleistocene eolianites and palaeowinds. Sedimentology **3**:52-64.

McDougall, I., Upton, B. G. J. and Wadsworth, W. J. 1965. A geological reconnaissance of Rodrigues Island, Indian Ocean. Nature **206**:26-27.

Montaggioni, L. 1970. Essai de reconstruction palaeogeographique de l'ile Rodrigue (Archipel des Mascareignes, Ocean Indien). Compte Rendu de la Academie Sciences de France, Paris **271**:1741-1744.

Slater, H. S. 1879. Observations on the bone caves of Rodrigues. An account of the petrological, botanical and zoological collections made in Kerguelen's Land and Rodrigues during the Transit of Venus Expedition 1874-5. Philosophical Transactions of the Royal Society of London **168**:420-422.

Snell, H. J. and Tams, W. H. T. 1920. The Natural History of the island of Rodrigues. Proceedings of the Cambridge Philosophical Society 1916-1919 **19**:420-422.

Thomson, J. and Walton, A. 1972. Redetermination of Chronology of Aldabra by $^{230}Th/^{243}U$ dating. Nature **240**:145-146.

Veeh, H. H. 1966 Th^{230}/U^{238} and U^{234}/U^{238} ages of Pleistocene high sea-level stand. Journal of Geophysical Research **71**:3379-3386.

Visser, N. H. and Schoch, A. E. 1973. The geology and mineral resources of the Saldanha Bay area. Republic of South Africa, Department of Mines, Geological Survey Mememoir **63**:150pp.

Wolman, M. G. and Miller, J. P. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology **68**:54-73.

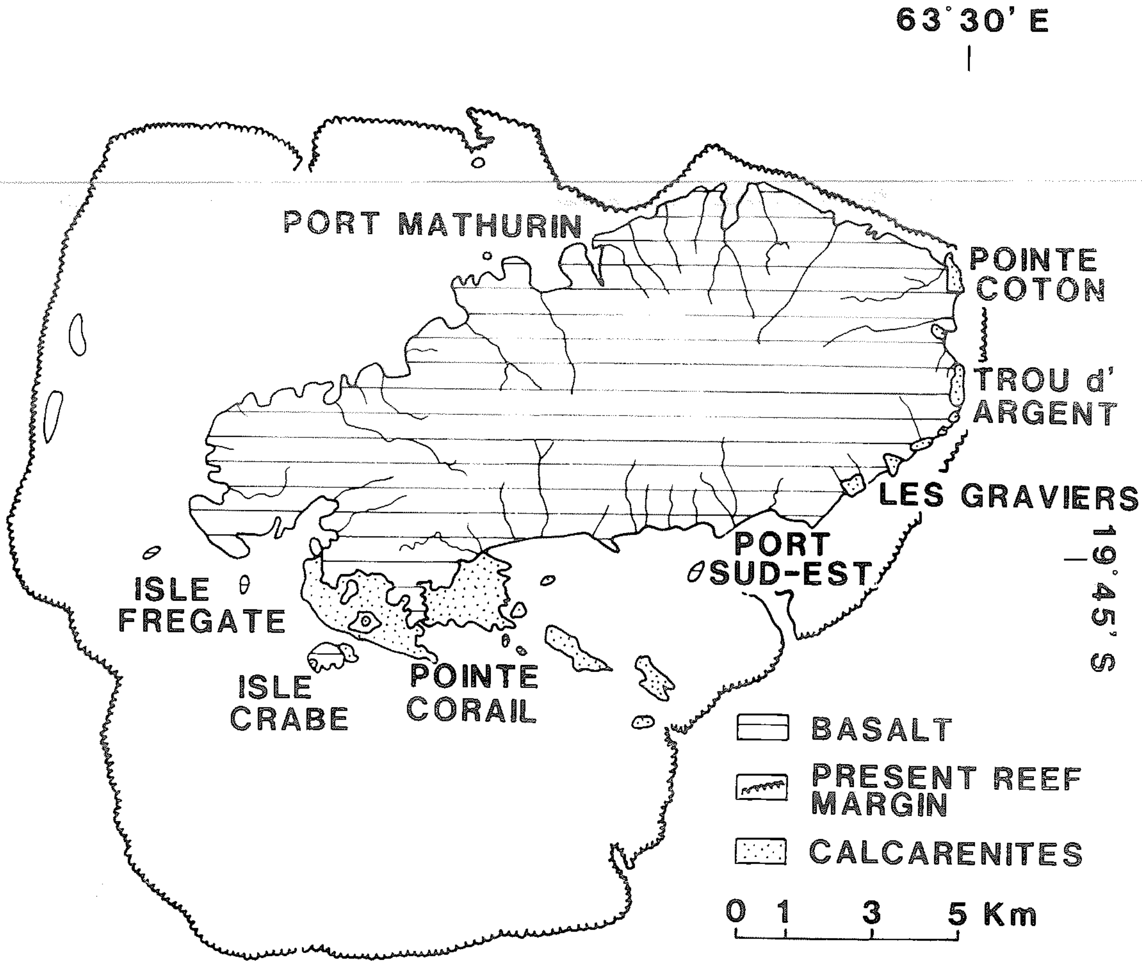

Fig. 2 General map of Rodrigues showing distribution of main areas of calcarenites. Based on air photographs and Montaggioni (1973).

Fig. 3 High angle dips in cross-laminae of calcarenites. Sante François, Rodrigues. Metre rule gives scale.

Fig. 4 Two sets of high angle cross-laminae in calcarenites. Trou d'Argent, Rodrigues. Sets about 10 m high. Note on the right hand side the abutment against the sloping surface of the underlying volcanics.

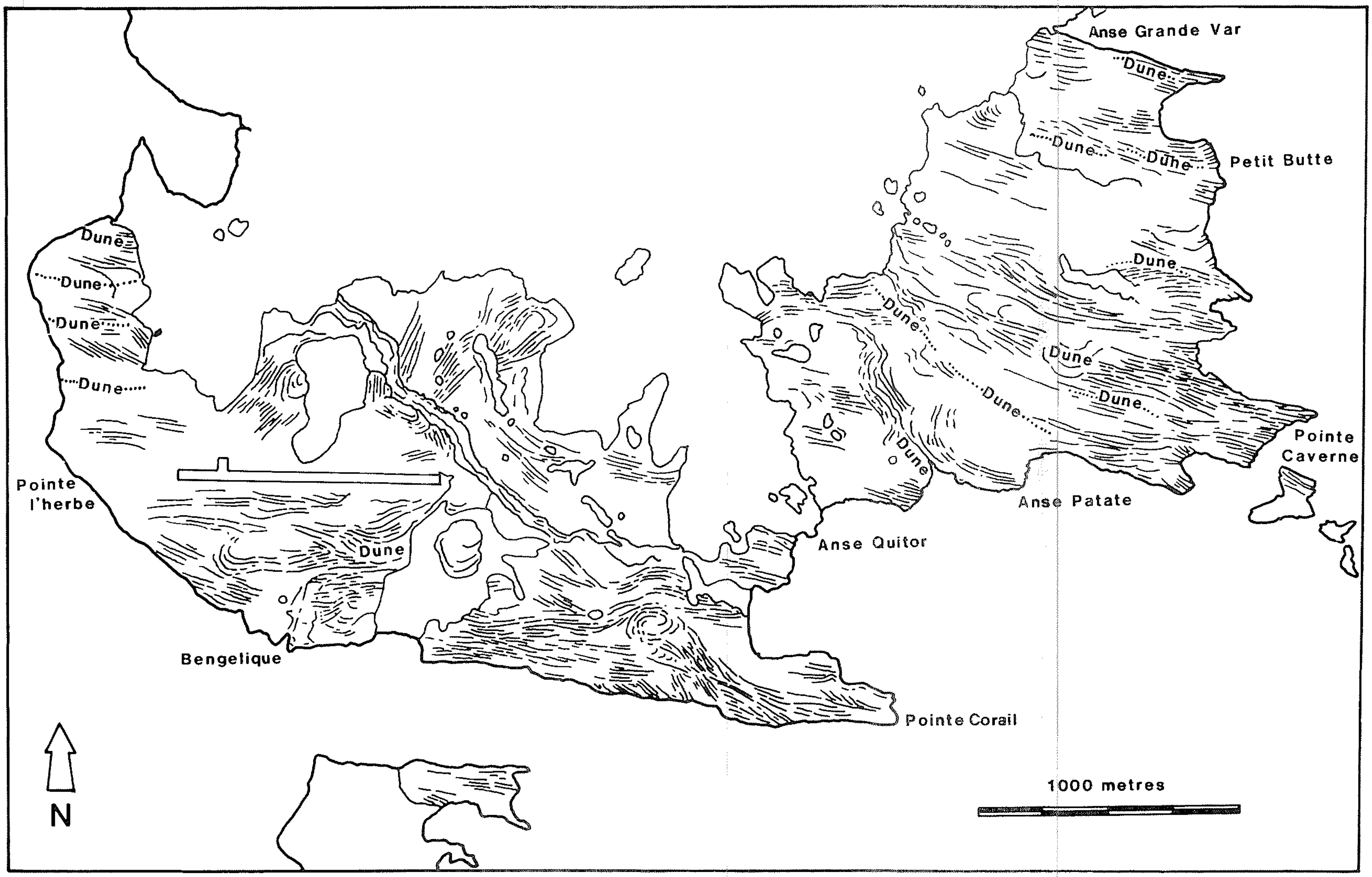

Fig. 5 Air photograph interpretation of the south-eastern coast of Rodrigues showing the extent of calcarenite outcrops, their boundary with the underlying basalts, structural lines which are principally cross-bedding laminae, and the location of major fossil dunes.

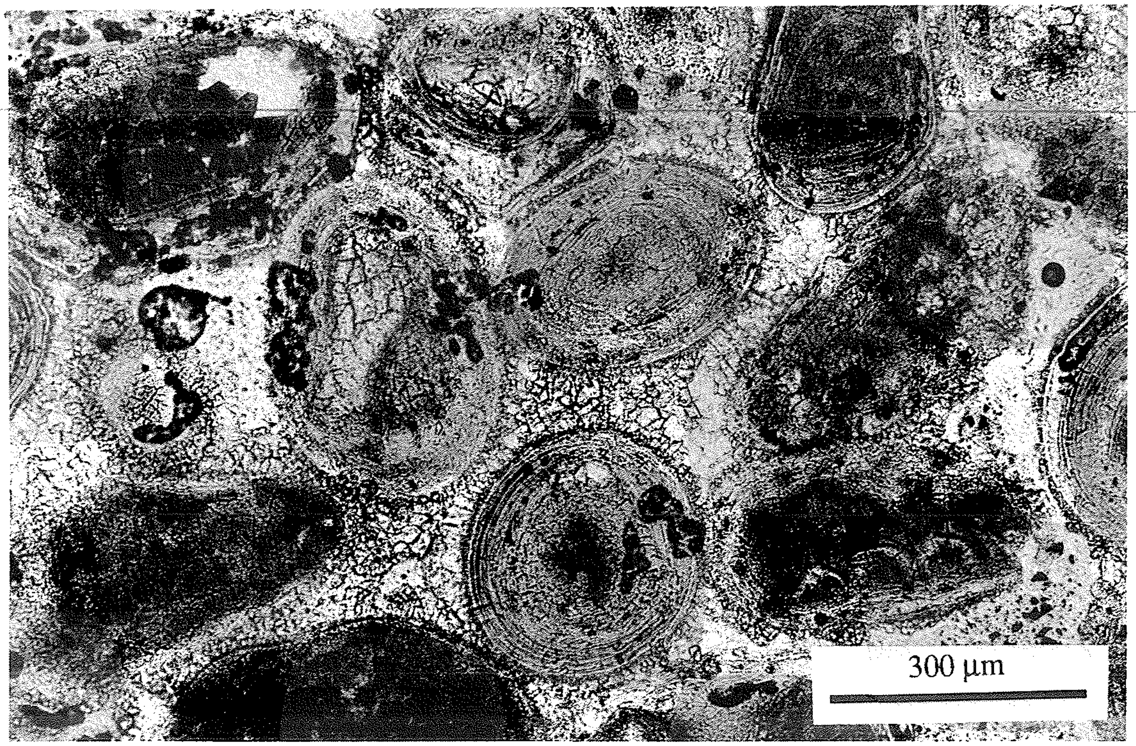

Fig. 6 Thin section showing tangential structure of aragonitic ooliths. Note that ooliths are about 300μm in diameter.