Journal of Coastal Research | 11 | 4 | 973-983 | Fort Lauderdale, Florida | Fall 1995

Vermetid Buildups from Grand Cayman, British West Indies

Brian Jones and Ian G. Hunter

Department of Geology
University of Alberta
Edmonton, Alberta T6G 2E3, Canada

ABSTRACT

JONES, B. and HUNTER, I.G., 1995. Vermetid buildups from Grand Cayman, British West Indies. *Journal of Coastal Research,* 11(4), 973–983. Fort Lauderdale (Florida), ISSN 0749-0208.

Vermetid buildups, formed primarily of *Dendropoma*, are found in the coastal areas near Bodden Town and Great Bluff Estates on Grand Cayman. These gastropods are commonly encrusted by foraminifera (*Homotrema rubum, Acervulina*? sp.), coralline algae, and cyanobacteria. Spaces between the gastropods are filled with silt- to sand-sized sediment derived from the nearby lagoon. Bioerosion by echinoids, bivalves, worms, algae, and fungi substantially modified these buildups. C^{14} dating of the gastropod shells suggests that the *in situ* buildups died during the period of 1625–1740 AD. The presence of vermetids at these localities on Grand Cayman is not consistent with the high-energy conditions in which these gastropods usually thrive. Today, there are no living vermetids at these localities and the active biological processes are bioerosion and encrustation. The demise of the *in situ* vermetid buildups during the period of 1625–1750 AD may have been related to changes triggered by the Little Ice Age. Alternatively, their demise may have been caused by a change in sea-level or a significant reduction in the wave energy that was impinging on the coastlines.

ADDITIONAL INDEX WORDS: *Algae ridge, sea-level stillstands, rocky substrates, Little Ice Age.*

INTRODUCTION

Vermetid buildups are generally found in marginal areas of the tropics (Safriel, 1975) such as Bermuda (Stephenson and Stephenson, 1954, 1972; Ginsburg *et al.*, 1971; Shinn, 1971; Schroeder, 1972; Ginsburg and Schroeder, 1973; Safriel, 1974, 1975), the Mediterranean (Pérès and Picard, 1952; Safriel, 1966, 1974, 1975; Tzur and Safriel, 1978; Ayal and Safriel, 1980; Barash and Zenziper, 1985), the Cape Verde Islands (Crossland, 1905), the Fernando de Noronha Islands and the Brazilian coast (Kempf and Laborel, 1968; Laborel, 1977, 1979; Jindrich, 1983), West Africa (Laborel and Delibrias, 1976; Laborel, 1977), and Florida (Stephenson and Stephenson, 1950; Warmke and Abbott, 1962; Shier, 1969). Vermetids are also common throughout the subtropical part of the Pacific (*e.g.*, Yonge, 1932; Cramwell and Moore, 1938; Hadfield *et al.*, 1972; Brattström, 1980; Hopper, 1981; Keen, 1983; Hughes, 1983; Colgan, 1985). Although present throughout the Caribbean (Table 1), buildups of vermetids have only been reported from Curaçao (Focke, 1977), Barbados (Lewis, 1960), and Grand Cayman (Jones and Hunter, 1988). Many Caribbean intertidal zones, where vermetids should be present, are characterized by algal ridges that include only a few of these gastropods (Glynn, 1973; Adey, 1975; Adey and Burke, 1975).

Buildups formed of vermetid gastropods are present at two localities on Grand Cayman (Figures 1, 2). This paper describes the biological components involved in the construction of these buildups and comments on their geological setting.

VERMETID BIOLITHITES OF GRAND CAYMAN

The buildups are formed of tightly coiled to loosely sinuous or almost straight vermetid shells that are at least 1.5 cm long with an average inside diameter of 1.3 mm and average shell thickness of 0.3 mm (Tongpenyai, 1989; Figures 3, 4, 5). Shells that initially had a tightly coiled shell tended to straighten out during ontogeny (Figure 4). These shells typically have weakly developed lamellar growth striae on their exterior (Figure 5A) and a dendropomatid operculum with a well-developed axial mammilla and flange (Figure 5B). The taenioglossate radula, found in the shells, have a squarish to rectangular transverse rachidian tooth with its posterior corners turned down to form distinct cusps (Figure 5C). The lateral

---

94072 received 13 April 1994; accepted in revision 28 September 1994.

Table 1. *Recorded distribution of vermetids in the Caribbean.*

Location	Species	Author
Bahamas	*Spiroglyphus irregularis*	Newell *et al.*, 1959
Bahamas	*Petaloconchus* aff. *nigricans*	Newell *et al.*, 1959
Barbados	*Spiroglyphus irregularis*	Lewis, 1960
Barbados	*Petaloconchus* cf. *varians*	Lewis, 1960
Bermuda	*Petaloconchus (Macrophragma) erectus*	Abbott, 1974
Bermuda	*Petaloconchus (Macrophragma) varians*	Abbott, 1974
Bermuda	*S. (S.) annulatus = D. corrodens*	Abbott, 1974
Bermuda	*Spiroglyphus (Novastoa) irregularis*	Abbott, 1974
Bermuda	*Dendropoma* sp.	Bromley, 1978
Brazil	*Serpulorbis decussatus*	Abbott, 1974
Caribbean	*Dendropoma (D.) nebulosum*	Keen, 1961
Caribbean	*Petaloconchus (Macrophragma) varians*	Keen, 1961
Caribbean	*Serpulorbis (S.) decussatus*	Keen, 1961
Cuba	*Dendropoma (D.) corrodens*	Keen, 1961
Florida	*Petaloconchus (Macrophragma) floridanus*	Keen, 1961
Florida	*Petaloconchus (Macrophragma) mcgintyi*	Keen, 1961
Florida	*Petaloconchus (Macrophragma) nigricans*	Morton, 1965
Florida Keys	*Dendropoma irregularis*	Stephenson and Stephenson, 1972
Florida Keys	*Spiroglyphus* sp.	Stephenson and Stephenson, 1972
Florida to Brazil	*Petaloconchus (Macrophragma) erectus*	Abbott, 1974
Florida to Brazil	*Petaloconchus (Macrophragma) varians*	Abbott, 1974
Grand Cayman	*Dendropoma (Novastoa) irregulare*	Abbott, 1958
Grand Cayman	*Dendropoma (Novastoa) irregulare*	This paper
Grand Cayman	*Spiroglyphus irregularis*	Logan, 1981
Jamaica	*Dendropoma (Novastoa) irregulare*	Morton, 1965
Little Cayman	Vermetids indet.	Potts, 1980
N Carolina to West Indies	*Serpulorbis decussatus*	Abbott, 1974
Panama	*Dendropoma (Novastoa) irregulare*	Glynn, 1973
Puerto Rico	*Petaloconchus (Macrophragma) varians*	Glynn, 1968
Puerto Rico	*Petaloconchus mcgintyi*	Warmke and Abbott, 1962
SE Florida to Brazil	*Spiroglyphus (Novastoa) irregularis*	Abbott, 1974
SE Florida to Lesser Antilles	*S. (S.) annulatus = D. corrodens*	Abbott, 1974
St. Croix	*Dendropoma* sp.	Adey, 1975
West Caribbean	*Stephopoma myrakeenae*	Abbott, 1974
West Indies	*Petaloconchus floridanus*	Warmke and Abbott, 1962
West Indies	*Serpulobis riisei*	Warmke and Abbott, 1962

teeth appear to have one cusp on their inner edge whereas the marginal teeth are simple hooked cones with a broad rounded base. The apical region of the shell has one, two, or three columella laminae (Figure 5D). The aragonite shell is formed of up to 12 alternating prismatic and crossed-lamellar layers (Figure 5E, F).

Individual shells may be segregated from neighbouring shells, cross-cut neighbouring shells, or share a compromise margin with another shell (Figure 5F, G). Collectively, the shells form large honeycombed masses that encrust hard substrates.

Most Cayman vermetids are considered to be *Dendropoma* because their opercula are the same size as their apertures (*cf.* BARASH and ZENZIPER, 1985) and have well-developed axial mammilla comparable with those figured for *Dendropoma* by KEEN (1961, Figure 33), HADFIELD *et al.* (1972, Figures 3, 9), MORTON (1965, Figure 5D, E), HUGHES (1978, Figure 3), and BARASH and ZENZIPER (1985, Figure 4). The Cayman vermetids corrode the surrounding limestone and neighbouring shells in the manner reported for other *Dendropoma* (*cf.* KEEN, 1961; MORTON, 1965; BROMLEY, 1978; BARASH and ZENZIPER, 1985). Radula from the Cayman vermetids are similar to *Dendropoma* and *Petaloconchus* radulas described by MORTON (1965). According to the classification of KEEN (1961), the Cayman vermetids belong to the subgenus *Novastoa* because they form honeycombed sheets that encrust exposed rock surfaces.

Species of *Dendropoma* are identified by their colour, soft-part anatomy, shell morphology, operculum structure, and radula structure (*e.g.*,

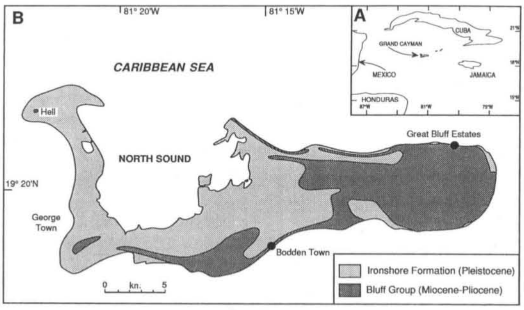

Figure 1. Map of Grand Cayman showing the localities at which vermetid buildups were found.

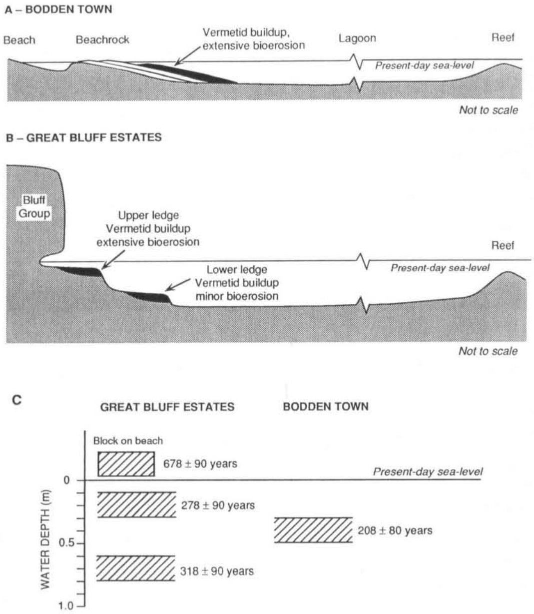

Figure 2. Schematic cross-sections of the coastal areas at Bodden Town (A) and Great Bluff Estates (B) showing the general setting of the vermetid buildups. (C) Summary diagram showing present-day positions of the vermetid buildups and their ages.

MORTON, 1955, 1965; HADFIELD, 1970; HADFIELD *et al.*, 1972). As a result, there is considerable confusion concerning species identification and it is "... hazardous to put a name on many specimens ..." (LABOREL, 1977, p. 234). This is especially true for the Cayman shells because their identification must rely solely on shell morphology and only rare radula and opercula. The general morphology of most shells, however, is comparable to *D.* (*Novastoa*) *irregulare* (ORBIGNY, 1842); a species that ABBOTT (1958) has previously identified from Grand Cayman. It should be noted, however, that *D. lamellosum* is similar and, like the Cayman shells, has a tendency to straighten out in its distal parts (*e.g.*, MORTON, 1965).

Bodden Town Buildup

The vermetid buildup (0.1 to 0.3 m thick) at Bodden Town (Figure 1), which encrusts seaward dipping sheets of beachrock, are covered by water that is 0.3 to 0.5 m deep. They extend laterally for about 30 m. Energy levels are low because an offshore reef protects the lagoon (Figure 2). The buildup is formed of densely packed, tightly coiled vermetid gastropods with sediment between the shells. Associated with the gastropods are the encrusting foraminifera *Homotrema rubrum* and *Acervulina*? sp. Living *H. rubrum* are common on cavity walls on the underside of the buildup. Extensive bioerosion by echinoids (*Echinometra*), sponges (*Cliona*), worms (sipunculids), bivalves, algae, and fungi has significantly modified the buildup (JONES and GOODBODY, 1984).

Samples of this vermetid buildup were originally mistaken for tubes associated with boring worms because many of "... the tubes are cut by later generations of worm tubes ... and penetrate and truncate the original grains of the rock" (JONES and GOODBODY, 1984, p. 204). Furthermore, such 'tubes' invariably contained nereid polychaete annelids that appeared responsible for their formation (JONES and GOODBODY, 1984, p. 204). Further analysis of samples from Bodden Town, however, showed that the 'tubes' are vacated vermetid shells that were later inhabited by the nereid worms. The 'boring' is not inconsistent with this identification because vermetids can erode rock and old shell material by using their radula (*e.g.*, HUGHES, 1979; BARASH and ZENZIPER, 1985).

C^{14} dating of the gastropod shells from this buildup yielded an age of 208 ± 80 years BP.

Great Bluff Estates

The best examples of vermetid buildup are found near Great Bluff Estates (Figure 1) where energy levels are low because of an offshore reef (Figure 2). During periods of high winds and storms, however, there can be considerable wave activity in this area.

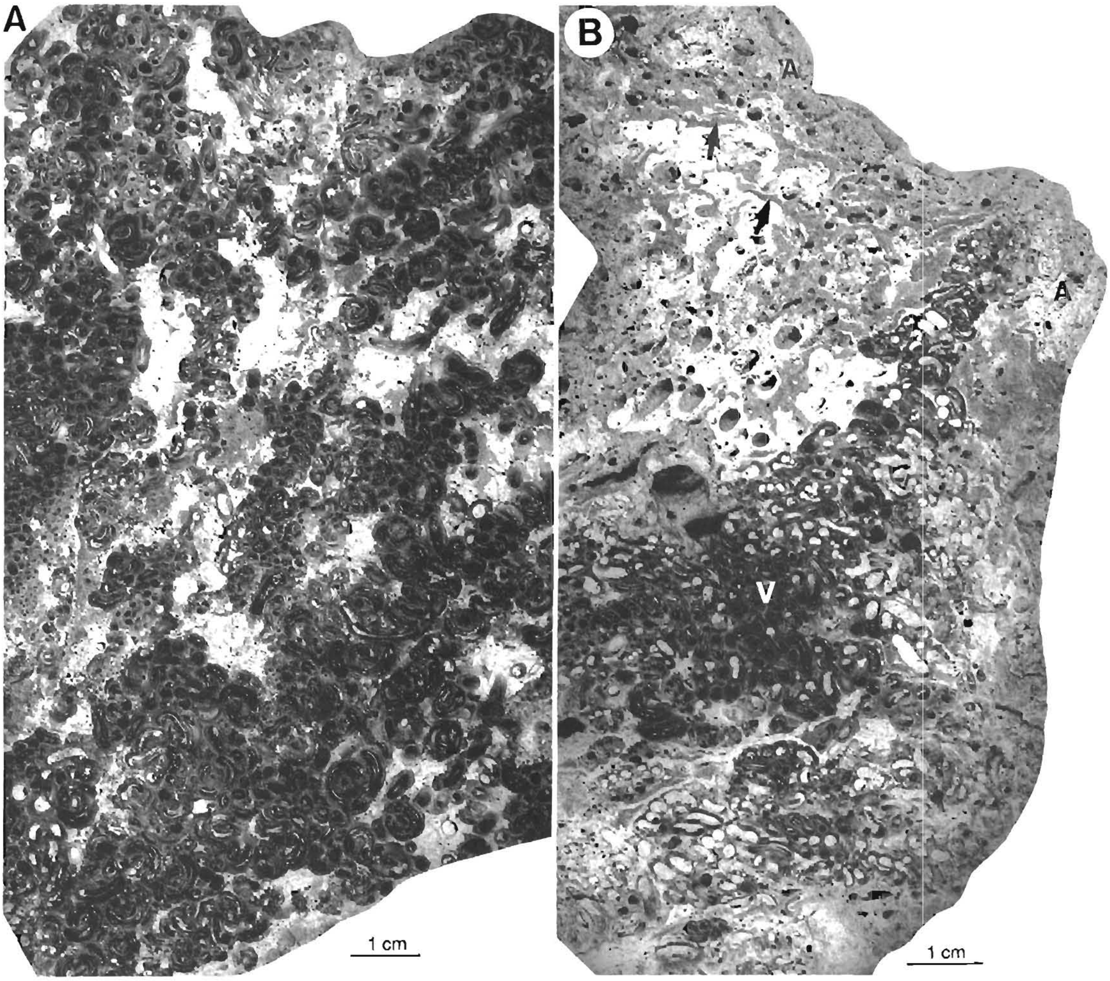

Figure 3. Hand samples of the vermetid buildups from the lower ledge at Great Bluff Estates (A) and the loose block at Great Bluff Estates (B) showing vermetid shells (v), sediment (white) and laminae formed of *Homotrema rubrum* (arrows).

The cliff near Great Bluff Estates, formed of dolostones that belong to the Miocene Cayman Formation, is characterized by a 'wave-cut notch' (up to 1.0 m deep and 0.3 m high). The vermetids form an upper ledge and a lower ledge (Figure 2). In addition, there is a large (2 m × 1.5 m × 0.75 m) block of vermetid buildup on the beach (Figures 3B, 4).

Upper Ledge

The buildup (Figure 3B) on the upper ledge, which can be traced along the coastline for 200–300 m, is presently covered by water that is 10 to 30 cm deep. Its top is just below the base of the 'wave-cut notch'. This buildup, formed of vermetids (Figure 5), coralline algae, and *H. rubrum* (Figure 6A, C, D, E), has been modified through bioerosion by *Echinometra,* sponges (*Cliona*) worms, bivalves, algae, and fungi. This buildup is presently encrusted by abundant green and fleshy algae.

C^{14} dating of the shells gave an age of 278 ± 90 years BP.

Lower Ledge

The vermetid buildup of the lower ledge, in water 0.6 to 0.8 m deep, is up to 1.5 m wide and extends along the coastline for 50 m. The buildup

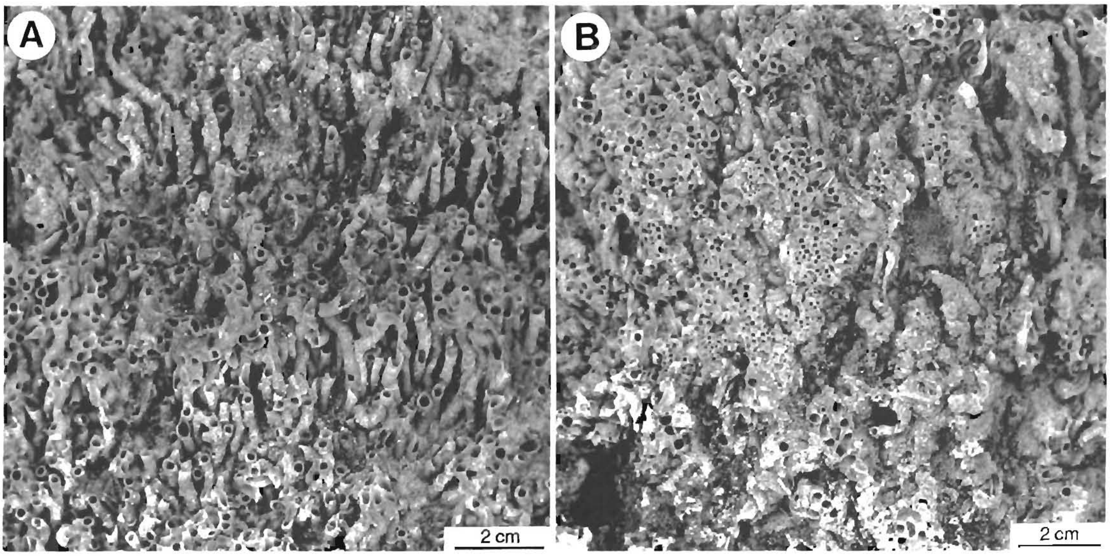

Figure 4. A and B, General views of part of block on beach at Great Bluff Estates showing the density of the vermetid shells which are either straight to slightly sinuous (A) or tightly coiled (B).

has a core of densely packed *Dendropoma* and an outer layer formed of *H. rubrum* and *Acervulina*? sp. (Figure 6B, F, G, H) with lesser numbers of coralline red algae and partly calcified cyanobacteria (Figure 3A). The *Dendropoma,* which colonized the rocky substrate, built up a honeycombed mass of tightly coiled shells. Although most shells are well preserved, others are partly replaced by fluorescent calcite. Areas between the shells are filled by encrusting organisms and sediment. The lower ledge has suffered little bioerosion and is therefore harder than the buildup of the upper ledge.

C^{14} dating of the shells gave an age of 318 ± 90 years BP.

Loose Block on Beach

This vermetid buildup is a complex intermixture of *Dendropoma, H. rubrum, Acervulina*? sp. and sediment (Figure 4A, B). The *H. rubrum* and *Acervulina*? sp. commonly form collars around the vermetid shells (Figure 7). The *H. rubrum* are conspicuous because their red colour contrasts sharply with the amber vermetid shells and the white to cream sediment (Figure 3A). The numbers of *H. rubrum* are variable even in the context of a small hand sample. In many cases the *H.*

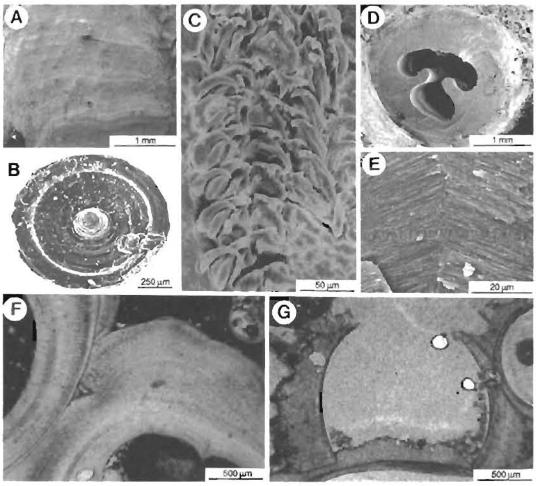

Figure 5. Morphology of *Dendropoma* (*Novastoa*) *irregulare*. A–E, SEM photomicrographs. F and G, thin section photomicrographs. (A) Shell exterior with transverse growth lines. (B) Operculum with well developed central mammilla and flange. (C) General view of radula. (D) Two columellar laminae in terminal region of shell. (E) Alternating cross-lamellar layers and prismatic layers of shell. (F and G) One shell cross-cutting a neighbouring shell; note that the part of the shell not affected by neighbouring shell continued to grow.

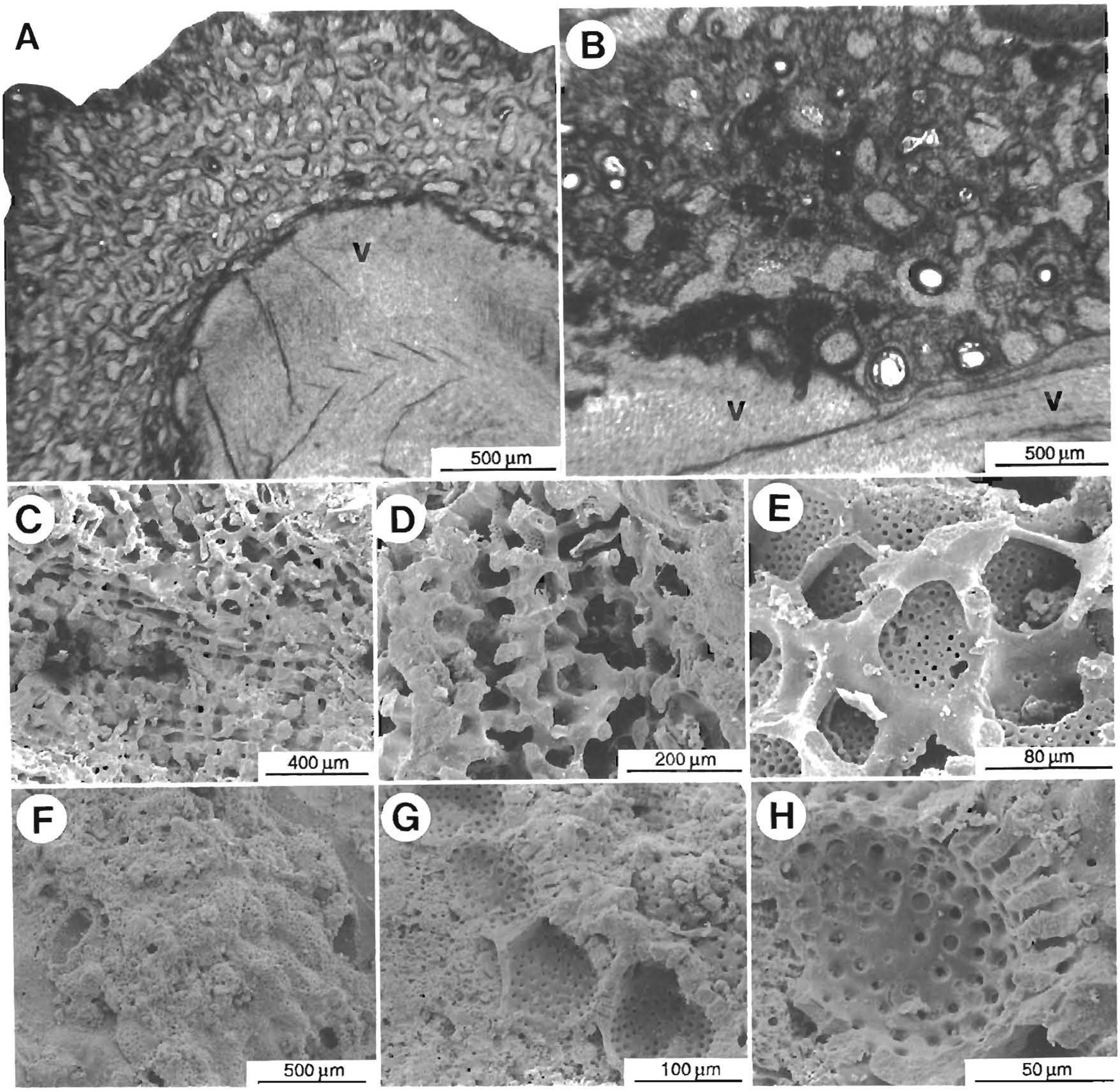

Figure 6. Encrusting foraminifera that occur around the vermetid shells (V). (A and B) thin section photomicrographs. (C to H) SEM photomicrographs. (A) Vermetid shell encrusted by *Homotrema rubrum*. (B) Vermetid shell encrusted by *Acervulina*? sp. (C) Concentric growth pattern of *H. rubrum* between two vermetid shells. (D) Interior of *H. rubrum* showing imperforate walls and isolated cribrate aerolae. (E) Outer surface of *Homotrema rubrum* showing cribrate aerolae between imperforate walls. (F) *Acervulina*? sp. encrusting a vermetid shell. (G) General morphology of *Acervulina*? sp. (H) Perforate walls of *Acervulina*? sp.

rubrum and/or *Acervulina* sp. fill the intra-shell spaces and bind the shells together (Figure 7).

Some vermetid shells are encased by a thin (< 0.5 mm) layer of dense, dark coloured, fluorescent micrite that formed by destructional and constructional processes. Destructional envelopes, less than 0.2 mm thick, are formed by the boring-filling-boring mechanism of micrite envelope formation (*cf.* BATHURST, 1966; KOBLUK and RISK, 1977a,b). In this case, boring algae and fungi appear to be responsible for the boring. Constructional envelopes, formed by the combination of microbe calcification in the body chambers of encrusting *H. rubrum*, and micritization of *H. rub-*

Figure 7. General view of thin section of vermetid buildup from the loose block, Great Bluff Estates, showing *Homotrema rubrum* (H) and sediment (S) that occurs between the vermetid shells (v) which form the framework.

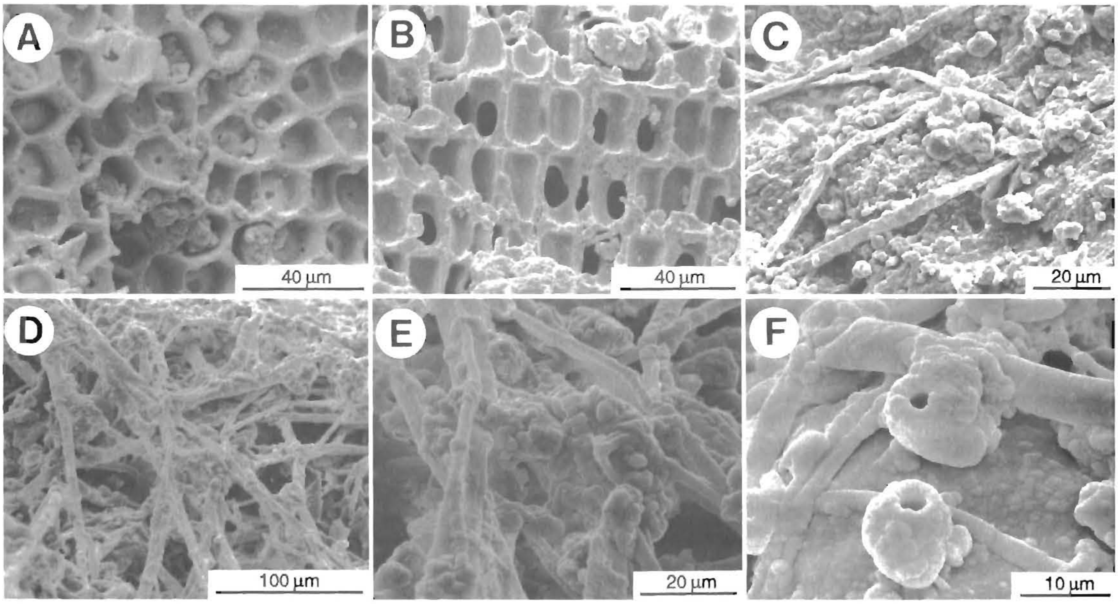

Figure 8. SEM photomicrographs showing components of the *Homotrema rubrum* crust that occurs on the lower ledge at Great Bluff Estates. (A and B) Coralline red algae. (C) Surface with partly calcified cyanobacteria. (D–F) Detailed views of calcified cyanobacteria.

Table 2. *Environmental setting of* Dendropoma *(*Novastoa*).*

Locality	Species	Zone	Location	Reference
South Africa	*D. corallinaceum*	1 m tidal height centered on M.W.M.	Exposed coastline	Hughes (1978, 1979)
Brazil	*Dendropoma* sp.	Just below H.W.M.		Sanlaville (1972)
Israel	*Dendropoma* sp.	At mean sea level	Exposed ledges	Safriel (1966, 1975)
Israel	*Dendropoma* sp.		Exposed wave swept areas	Tzur and Safriel (1978)
Curaçao	*Dendropoma* sp.	Surf zone	Exposed wave swept areas	Focke (1977)
Not specified	*Dendropoma* sp.	Upper infra-littoral	Hard substrate in strong wave action	Kempf and Laborel (1978)
Fernando de Noronha Islands	*Dendropoma irregulare*	Centered on M.W.M.	Exposed ledge in strong wave action	Jindrich (1983)

rum. The fluorescent micrite of these envelopes contrast sharply with the non-fluorescent aragonite of the vermetid shells.

Sediment between the vermetid shells is formed of poorly sorted silt- to sand-sized skeletal grains embedded in a dense, dark-coloured, fluorescent micrite (Figure 7). Recognizable skeletal grains include *Halimeda* plates, red algae, fragments of vermetid gastropods, bivalves, and foraminifera. All grains show evidence of boring by algae and/or fungi and most are micritized to the extent that identification is impossible. Peloids are present locally. Although most chambers in the vermetids contain fine-grained sediments, some contain coarse-grained sediment like that around the gastropods. Some chambers in the vermetid shells are lined with high-Mg calcite cement.

C^{14} dating of shells from this block yielded an age of 678 ± 90 years BP suggesting that it was not derived from the lower or upper ledges. Despite extensive searches in the surrounding area, the place of origin of this block is not known.

HOMOTREMA RUBRUM CRUST ON LOWER VERMETID BIOLITHITE, GREAT BLUFF ESTATES

The upper and seaward surfaces of the vermetid buildup in the lower ledge at Great Bluff Estates are coated by a layer, up to 2 cm thick, formed of *H. rubrum* (50–90%) with lesser numbers of coralline red algae and partly calcified cyanobacteria (Figure 3B). Vague laminations are defined by the colour contrast between the red *H. rubrum* and the thin white laminae of coralline algae and micrite (Figure 3B). The coralline red algae forms thin layers (Figure 8A, B), generally less than 2 mm thick, that directly overlie the *H. rubrum.* The red algae skeletons are not altered and have no sediment or cements in their cells.

Exposed surfaces of the buildup are green because they are covered with a mat formed of cyanobacteria and coralline red algae (Figure 8). This combination was probably responsible for the other white laminae that are present between the *H. rubrum* laminae (Figure 3B). Many cyanobacteria filaments in the surface mats are partly or totally calcified (Figure 8C, D, E) by irregularly shaped calcite crystals up to 4 μm long. Associated with the filaments are hemispherical spores (Figure 8F) that are akin to those described by Jones (1987, Figure 6C, D). There is no evidence of filaments trapping grains. Locally, the laminae appear to be formed mostly of micrite and it is difficult to detect the presence of filaments even at high magnifications on the SEM. Extensive calcification may have disguised the original filaments (*cf.* JONES and MOTYKA, 1987).

DISCUSSION

Significance has been given to the positions of fossil vermetids because they may record sea-level standstills over the last 5,000 years (*e.g.,* VAN ANDEL and LABOREL, 1964; KEMPF and LABOREL, 1968; DELIBRAS and LABOREL, 1971; SANLAVILLE, 1972; LABOREL and DELIBRAS, 1976; LABOREL, 1977). KEMPF and LABOREL (1968) and LABOREL (1977, 1979) also drew attention to the fact that vermetids seem to be disappearing from the coastlines of Brazil and West Africa. Although the reason for such a decrease is not known, LABOREL (1977) suggested that it might be related to increased turbidity of coastal waters, oil pollution, or some unknown biological phenomenon. Grand Cayman appears to follow a similar pattern because there are fossil, but few living, vermetids.

Modern *Dendropoma* typically thrive in a narrow zone (< 1 m) centered on mean sea level where there is a rocky substrate and exposure to strong onshore waves (Table 2). Depending upon the viewpoint taken, this ecological niche offers

Table 3. *Comparison of supposed disadvantages (from Hughes, 1979) and advantages (from Barash and Zenziper, 1985) of food supply, reproduction, environmental conditions and competition brought about by the attached mode of life of vermetids.*

Property	Hughes (1979) Disadvantages	Barash and Zenziper (1985) Advantages
Food supply	Must be brought to animal by waves	Better exploitation of food gathering by numerous individuals
Breeding	Males release sperm into water and rely on currents to take it to the females	Fertilization ensured since sermatophores have more chance of reaching females
Fixed life style	Cannot move if conditions change	—
Competition	May be smothered by other sedentary animals or plants	Dense aggregations leads to exclusion of other animals competing for space

distinct disadvantages or advantages to the vermetids (Table 3). From a global perspective, their ecological niche appears hostile because of the problems associated with feeding, reproduction, and competition in such high energy conditions (*cf.* HUGHES, 1979—Table 3). Nevertheless, vermetids are successful in this niche and their adaptation to the so-called hostile conditions are actually to their advantage (*cf.* BARASH and ZENZIPER, 1985–Table 3). Despite their ability to take advantage of this niche, their sedentary, attached mode of life means that they cannot overcome adverse environmental conditions caused by external factors (*cf.* HUGHES, 1979—Table 3). A change in sea level or energy levels, for example, usually leads to their demise.

The vermetids at Bodden Town and Great Bluff Estates are not alive today. Indeed, these buildups are currently the sites of other biological activity. Bioerosion is evident at both localities. At Great Bluff Estates maximum bioerosion is found in the buildup of the upper ledge where the water is shallow and more active. The vermetid buildup located on the lower ledge shows significantly less bioerosion. At Bodden Town, the vermetid buildup has suffered considerable bioerosion (*cf.* JONES and GOODBODY, 1984) with the chief agents of bioerosion being echinoids, sponges (*Cliona*), worms (sipunculids and sphionids), bivalves (*Lithophaga*), *Lithotrya*, algae, and fungi. The exposed surfaces of the vermetid buildups commonly provide ideal substrates on which other organisms can colonize. At Great Bluff Estates, for example, the surfaces of the lower vermetid biolithite are covered with a crust formed of *Homotrema rubrum* and cyanobacteria filaments.

The reason(s) for the demise of the *in situ* vermetid buildups at Great Bluff Estates and Bodden Town are not really apparent. Today, the coastal areas at Great Bluff Estates and Bodden Town are characterized by relatively calm waters because they are separated from the open ocean by off-shore reefs (Figure 2). Such settings are not normally conducive to vermetid growth. If the C^{14} dates are taken at face value, then the death of the vermetid buildups would correspond to a date of 1625 to 1750 AD, an age that would coincide with the height of the Little Ice Age (1675–1800 AD—GLYNN *et al.*, 1983). If this correlation is correct, the demise of the vermetids could be attributed to temperature changes or circulation changes caused by the Little Ice Age. Such an hypothesis would parallel the explanation that GLYNN *et al.* (1983) offered for the demise of the corals found in a Central America reef that died between 1650–1800 AD. An alternate explanation for the demise of the Cayman vermetids, which may or may not be related to the Little Ice Age, would involve a reduction in energy conditions. There are two ways in which such changes could have been triggered. First, a slight change in sea level may have led to the demise of the vermetids as in other settings. A simple change in sea-level, however, would not necessarily cause a reduction in the energy levels of the waves that reach the coastline. Thus, a second possibility involves significant changes in energy conditions rather than a simple change in sea-level. For example, the vermetids may have grown at Bodden Town and Great Bluff Estates before the off-shore reef had completely separated the lagoons from the open ocean. At that time, onshore waves would have created high-energy conditions along the coast. Increase in coral growth may have led to the development of an off-shore barrier reef that prevented wave energy from reaching the coast. That reduction in energy levels may have caused the demise of the vermetids.

CONCLUSIONS

Vermetid colonies once flourished near Great Bluff Estates and Bodden Town on Grand Cayman. These gastropods, along with encrusting foraminifera, red algae, and cyanobacteria, produced buildups that covered rocky substrates. Comparison with modern vermetids suggests that they must have flourished when those coastlines were characterized by higher energy conditions. The fact that those localities are now characterized by quiet-water conditions and include different biological communities suggests that coastal conditions must have changed. C^{14} dating of the *in-situ* vermetids suggests that such changes may have taken place in the period of 1625–1750 AD, possibly because of temperature changes brought about by the Little Ice Age. An alternative cause, which may or may not be related to the Little Ice Age, would be related to reduced energy levels along these coastal areas.

ACKNOWLEDGEMENTS

This study was made possible by a grant from the Natural Science and Engineering Research Council of Canada to Jones (No. A6090) and some logistical help made available by Mr. Richard Beswick (Director, The Water Authority, Grand Cayman). We are also indebted to Dr. L.D. Arnold (Alberta Environment Centre, Environmental Isotopes Section) who provided us with the C^{14} dating of the shell material, Dr. Noel James who discussed some aspects of these problems with us while on Grand Cayman, Boonrasri Tongpenyai who helped collect samples on Grand Cayman, Elsie Tsang who assisted in the preparation of the manuscript, George Braybrook who assisted us with some of the SEM work and the journal reviewers who offered critical comments that helped in the revision of this paper.

LITERATURE CITED

ABBOTT, R.T., 1958. The marine mollusks of Grand Cayman Island, British West Indies. *Monographs of the Academy of Natural Sciences of Philadelphia*, No. 11, 138p.

ABBOTT, R.T., 1974. *American Seashells*. New York: Van Nostrand Reinhold, Second Edition, 663p.

ADEY, W.H., 1975. The algal ridges and coral reefs of St. Croix. *Atoll Research Bulletin*, 187, 1–67.

ADEY, W.H. and BURKE, R., 1975. Holocene algal ridges and barrier reef systems of the eastern Caribbean. *Geological Society of America Bulletin*, 87, 95–109.

AYAL, Y. and SAFRIEL, U., 1980. Intertidal zonation and key-species associations of the flat rocky shores of Sinai. *Israel Journal of Zoology*, 29, 110–124.

BARASH, A. and ZENZIPER, Z., 1985. Structural and biological adaptations of Vermetidae (Gastropoda). *Il Bollettino Malacologico*, 21, 145–176.

BATHURST, R.G.C., 1966. Boring algae, micrite envelopes and lithification of molluscan biosparites. *Geological Journal*, 5, 15–32.

BRATTSTRÖM, H., 1980. Rocky-shore zonation in the Santa Marta area, Columbia. *Sarcia*, 65, 163–226.

BROMLEY, R.G., 1978. Bioerosion of Bermuda reefs. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 23, 169–197.

COLGAN, M.W., 1985. Growth-rate reduction and modification of a coral colony by a vermetid mollusc, *Dendropoma maxima*. *Proceedings of the Fifth International Coral Reef Congress*, Tahiti, 6, 205–210.

CRAWELL, L.M. and MOORE, L.B., 1938. Intertidal communities of the Poor Knights Islands, New Zealand. *Transactions of the Royal Society of New Zealand*, 67, 375–403.

CROSSLAND, C., 1905. The ecology and deposits of the Cape Verde marine fauna. *Proceedings of the Zoological Society of London*, 1, 170–186.

DELIBRAS, C. and LABOREL, J., 1971. Recent variations of the sea level along the Brazilian coast. *Quaternaria*, 14, 45–49.

FOCKE, J.W., 1977. The effect of a potentially reef-building vermetid-coralline algal community on an eroding limestone coast, Curaçao, Netherlands Antilles. *Proceedings of the Third International Coral Reef Symposium*, Miami, 1, 239–245.

GINSBURG, R.N.; MARSZALEK, D.S., and SCHNEIDERMANN, N., 1971. Ultrastructure of carbonate cements in a Holocene algal reef of Bermuda. *Journal of Sedimentary Petrology*, 41, 472–482.

GINSBURG, R.N. and SCHROEDER, J.H. 1973. Growth and submarine fossilization of algal cup reefs, Bermuda. *Sedimentology*, 20, 575–614.

GLYNN, P.W., 1968. Mass mortality of echinoids and other reef flat organisms coincident with midday low water exposure in Puerto Rico. *Marine Biology*, 1, 226–243.

GLYNN, P.W., 1973. Aspects of the ecology of coral reefs in the western Atlantic Region. *In:* JONES, O. A. and ENDEAN, R., (eds.), *Biology and Geology of Coral Reefs*. New York: Academic Press, Biology 1, 2, 271–324.

GLYNN, P.W.; DRUFFEL, E.M., and DUNBAR, R.B. 1983. A dead Central American coral reef tract: Possible link with the Little Ice Age. *Journal of Marine Research*, 41, 605–637.

HADFIELD, M.G., 1970. Observations on the anatomy and biology of two California vermetid gastropods. *Veliger*, 12, 301–309.

HADFIELD, M.G.; KAY, E.A.; GILLETTE, M.U., and LLOYD, M.C., 1972. The Vermetidae (Mollusca: Gastropoda) of the Hawaiian Islands. *Marine Biology*, 12, 81–98.

HOPPER, C.N., 1981. Reproductive biology of Hawaiian vermetid gastropods. *American Zoologist*, 20, 927.

HUGHES, R.N., 1978. The biology of *Dendropoma corallinacean* and *Serpuloris natalensis*, two South African vermetid gastropods. *Zoological Journal of the Linnean Society*, 64, 111–127.

HUGHES, R.N., 1979. Coloniality in Vermetidae (Gastropoda). Biology and Systematics of Colonial Organisms. *Systematics Association Special Volume* 11, 243–253.

HUGHES, R.N., 1983. The vermetid gastropods of Hong Kong. *In:* MORTON, B. and DUDGEON, D., (eds.), *Proceedings of the Second International Workshop on* *the Malacofauna of Hong Kong and southern China.* Hong Kong: Hong Kong University Press, p. 127–183.

Jindrich, V., 1983. Structure and diagenesis of recent algal-foraminifera reefs, Fernando de Noronha, Brazil. *Journal of Sedimentary Petrology,* 53, 449–459.

Jones, B., 1987. The alteration of sparry calcite crystals in a vadose setting, Grand Cayman Island. *Canadian Journal of Earth Sciences,* 24, 2292–2304.

Jones, B. and Goodbody, Q.H., 1984. Biological alteration of beachrock on Grand Cayman Island, British West Indies. *Bulletin of Canadian Petroleum Geology,* 32, 201–215.

Jones, B. and Hunter, I.G., 1988. Vermetid gastropod buildups from Grand Cayman, British West Indies. *Canadian Paleontology and Biostratigraphy Seminar,* Winnipeg, Program and Abstracts, p. 4.

Jones, B. and Motyka, A., 1987. Biogenic structures and micrite in stalactites from Grand Cayman Island, British West Indies. *Canadian Journal of Earth Sciences,* 24, 1402–1411.

Keen, A.M., 1961. A proposed reclassification of the gastropod family Vermetidae. *Bulletin of the British Museum (Natural History) Zoology,* 7, 181–213.

Keen, A.M., 1983. Vermetidae of the tropical eastern Pacific. *In:* Kellogg, M., (ed.), *Fifteenth Annual Meeting of the Western Society of Malacologists,* Titles and Abstracts, p. 10.

Kempf, M., and Laborel, J., 1968. Formations de vermets et d'algues calcaires sur les cotes du Brésil. *Recueil des travaux de la Station Marine d'Endoume,* 59, 9–23.

Kobluk, D.R. and Risk, M.J., 1977a. Calcification of exposed filaments of endolithic algae, micrite envelope formation, ahd sediment production. *Journal of Sedimentary Petrology,* 47, 517–528.

Kobluk, D.R. and Risk, M.J., 1977b. Micritization and carbonate grain binding by endolithic algae. *American Association of Petroleum Geologists Bulletin,* 61, 1069–1082.

Laborel, J., 1977. Are reef-building vermetids disappearing in the south Atlantic? *Proceedings of the Third International Coral Reef Symposium* (Miami) 1, pp. 233–237.

Laborel, J., 1979. Fixed marine organisms as biological indicators for the study of recent sea level and climatic variations along the Brazilian tropical coast. *Proceedings of the 1978 International Symposium on Coastal Evolution in the Quaternary* (São Paulo, Brazil), pp. 193–211.

Laborel, J. and Delibras, G., 1976. Niveaux marins recents à Vermetidae de littoral ouest Africain. *Association sénégalaise l'Etude pour Quaternaire de l'Ouest Africain, Bulletin de Liaison, Sénégal,* 47, 97–110.

Lewis, J.B., 1960. The faunas of rocky shores of Barbados, West Indies. *Canadian Journal of Zoology,* 38, 391–435.

Logan, A., 1981. Sessile invertebrate coelobite communities from shallow reef tunnels, Grand Cayman, B. W. I. *Proceedings of the Fourth International Coral Reef Symposium* (Manila), 2, 735–744.

Morton, J.E., 1955. The evolution of vermetid gastropods. *Pacific Science,* 9, 3–15.

Morton, J.E., 1965. Form and function in the evolution of the Vermetidae. *Bulletin of the British Museum (Natural History) Zoology,* 11, 585–630.

Newell, N.D.; Imbrie, J.; Purdy, E.G., and Thurber, D.L., 1959. Organism communities and bottom facies, Great Bahama Bank. *Bulletin of the American Museum of Natural History,* 117, 177–228.

Pérès, J.M. and Picard, J., 1952. Les corniches calcaires d'origine biologique en Méditerranée occidentale. *Recueil des Travaux de la Station Marine d'Endoume,* 1, 2–33.

Potts, L.W., 1980. The zonation of rocky littoral areas around Little Cayman. *Atoll Research Bulletin,* 241, 34–42.

Safriel, U.N., 1966. Recent vermetid formation on the Mediterranean shore of Israel. *Proceedings of the Malacological Society of London,* 37, 27–34.

Safriel, U.N., 1974. Vermetid gastropods and intertidal reefs in Israel and Bermuda. *Science,* 186, 1113–1115.

Safriel, U.N., 1975. The role of vermetid gastropods in the formation of Mediterranean and Atlantic reefs. *Oecologia,* 20, 85–101.

Sanlaville, P., 1972. *Vermetus* dating of changes in sea level, underwater archaeology—A nascent discipline. *UNESCO,* Paris, p. 185–191.

Schroeder, J.H., 1972. Fabrics and sequences of submarine carbonate cements in Holocene Bermuda cup reefs. *Geologische Rundschau,* 61, 708–730.

Shier, D.E., 1969. Vermetid reefs and coastal development in the Ten Thousand Islands, southwest Florida. *Geological Society of America Bulletin,* 80, 485–508.

Shinn, E.A., 1971. Aspects of diagenesis of algal cup reefs in Bermuda. *Gulf Coast Association of Geological Societies Transactions,* 20, 387–394.

Stephenson, T.A. and Stephenson, A., 1950. Life between tide-marks in North America. I. The Florida Keys. *Journal of Ecology,* 38, 354–402.

Stephenson, T.A. and Stephenson, A., 1954. The Bermuda Islands. *Endeavour,* 13, 72–80.

Stephenson, T.A. and Stephenson, A., 1972. *Life Between Tidemarks on Rocky Shores.* San Francisco: W. H. Freeman and Co., 425p.

Tongpenyai, B., 1989. An Assessment of the Use of Image Analysis in Carbonate Sedimentology. Unpublished Ph.D. dissertation, University of Alberta, Edmonton, 211p.

Tzur, Y. and Safriel, U.N., 1978. Vermetid platforms as indicators of coastal movements. *Israel Journal of Earth Sciences,* 27, 124–127.

Van Andel, T. and Laborel, J., 1964. Recent high relative sea level stand near Recife (Brazil). *Science,* 145, 580–581.

Warmke, G.L. and Abbott, R.T., 1962. *Caribbean seashells.* Wynnewood, Pennsylvania: Livingston Publishing Company, 348p.

Yonge, C.M., 1932. Notes on feeding and digestion in *Pterocera* and *Vermetus,* with a discussion of the crystalline style in the Gastropoda. *Scientific Reports, Great Barrier Reef Expedition, 1928-1929,* 1, 259–281.