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THE RELATIONSHIP BETWEEN THE TOPOGRAPHY AND INTERNAL STRUCTURE OF AN OOID SHOAL SAND COMPLEX: THE UPPER PLEISTOCENE MIAMI LIMESTONE

Charles C. Evans
Laboratory of Comparative Sedimentology
University of Miami
Miami Beach, Florida

ABSTRACT

The use of cores from closely spaced borings in combination with both natural and man made outcrops allows refinement of interpretations of the depositional history of the Miami Limestone. The seaward thickening wadge of Miami Limestone is divided into three depositional facies: the bryozoan facies, the bedded facies, and the burrow-mottled facies. The bryozoan facies is restricted to the low-lying area west (landward) of the Coastal Ridge and does not extend eastward beneath the ooid rich bedded and burrow-mottled facies.

The distribution of the bedded and mottled facies on the coastal ridge reflects the morphological division (Halley et al., 1977) of this oil sand complex into a shoal and channel system and a barrier bar. In the shoal and channel system, cross- bedding is restricted to the flanks of individual shoals, where it may be vertically continuous throughout the section. The depositional scenario of these shoals of a stabilized interior with a surrounding fringe of active sands of consistent with their present topographic expression.

The barrier bar is a composite of discrete sediment successions which are not laterally correlatable. Each succession grades upward from the cross-bedded facies at the base to the mottled facies at the top, which is marked by a sharp contact of the upper burrowed surface with the basal cross- bedding of the succeeding unit. The cross-bed dip directions are sometimes east-west, perpendicular to the north-south axis of the barrier bar, and multidirectional within any one outcrop. Large scale through and channel fill deposits are also common features in the barrier bar.

These observations lead to the following conclusions: 1) contrary to implications of previous studies, the ooid sand shoal complex of the eastern part of the Miami Limestone was built up in place, and did not migrate backward over earlier platform interior deposits of the bryozoan facies, 2) the distribution of cross-bedding in the shoal and channel system confirms the bar and channel origin for this morphology, and 3) the seaward barrier bar is a more complex feature than suggested by its morphology, probably the result of coalescing tidal deltas.

INTRODUCTION

The upper Pleistocene Miami Limestone is Southeastern Florida serves as a link between the extensive oolitic limestones of the Phanerozoic and the Holocene examples of the Bahamas.

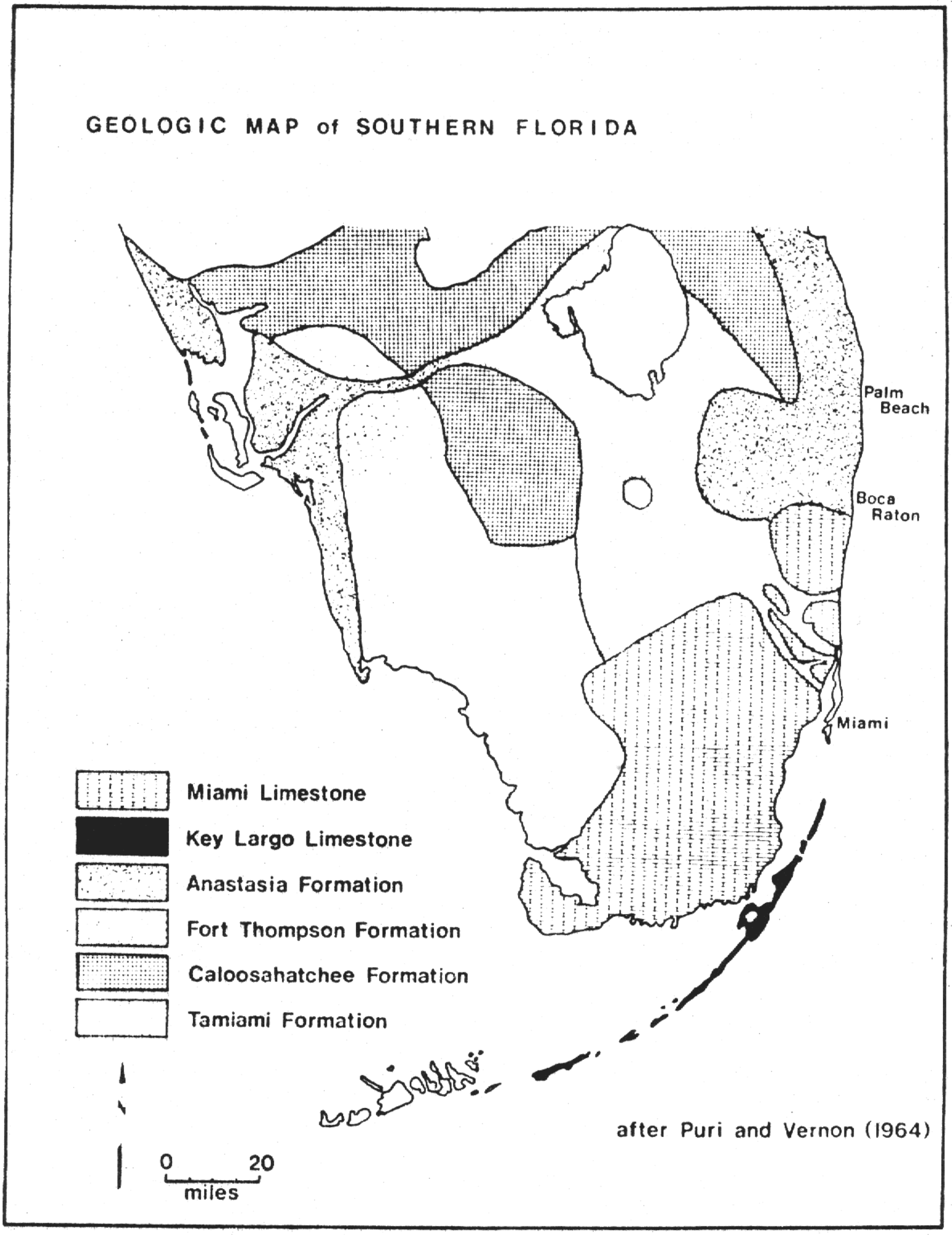


Figure 1. The geologic map of southern Florida (Puri and Vernon, 1964). The Miami Limestone (brick pattern) covers the entire southeastern tip of the Florida peninsula. It is laterally adjacent to the Miocene-Pliocene Tamiami Formation (fine speckled pattern), and the Pleistocene Ft. Thompson Formation (open circle pattern), Anastasia (flecked patterns) and Key Largo (black) Formations. The Miami Limestone unconformably overlies all of these formations.

Outcrops of the Miami Limestone provide a unique opportunity to study the relationship between still visible depositional topography and the facies anatomy. Previous studies of the Miami Limestone have been restricted to the upper few meters of the formation exposed in outcrops, providing a two-dimensional view of the Miami Limestone. A recent line of closely spaced borings coupled with further study of outcrops has allowed a three- dimensional reconstruction of the anatomy of the Miami Limestone and a revised interpretation of the depositional history of this unit.

PREVIOUS STUDIES

The general depositional history of the Miami Limestone is well known, as described by Parker et al., (1955), Hoffmeister et al., (1977). The Miami Limestone appears to have been the result of a mobile ooid sand belt and bankward Lagoon which was stranded by the Sangamon high sand of the sea and subsequently subaerially cementated. The Sangamon age was first suggested by Parker, et al., (1955) on the basis of its stratigraphic position, overlying the Ft. Thompson Formation. Subsequently, Broecker and Thurber (1965) and Osmond et al., 1965) dated oolitic samples of the Miami Limestone at 130,000 years by Uranium series. Halley and Evans (1983) have suggested the time equivalence of the Miami Limestone with other Limestones from the Lesser Antilles, Yucatan Peninsula, Bahamas, and South America, all though to have been deposited during the last (130,000 years B.P.) interglacial.

The Miami Limestone occupies the entire southeastern tip of the Florida peninsula, and area in excess of 5000 square kilometers. It is laterally adjacent to the Miocene-Pliocene Tamiami Formation and the Pleistocene Ft. Thompson, Anastasia, and Key Largo Formations, all of which are exposed on the surface (Fig. 1). The Miami Limestone itself is divisible into three facies: the bryozoan facies, first described by Hoffmeister et al., (1967), the bedded facies, and the mottled facies (Evans, 1983). The vast majority of the area covered by the Miami Limestone is represented by the bryozoan facies (Hoffmeister et al., 1967). The two ooid-rich facies are confined to the eastward (seaward) side of the formation where they form a belt, elongate north-south, covering approximately 500 sq. km. (Fig. 2). Th eastern belt of ooid-rich deposits, a bathymetric high during Miami Limestone time, is now the southern extension of the Atlantic Coastal Ridge.

Parker et al., (1955) provided the first cross-section of the Miami Limestone (Fig. 3) in which he established that the cross-sectional shape of the formation is a seaward-thickening wedge with the thick end of the wedge making the topographic high of the Atlantic Coastal Ridge.

Hoffmeister et al., (1967) mapped two distinct facies within the Miami Limestone: an ooid-rich facies forming the Atlantic Coastal Ridge, and a bryozoan-rich facies confined to the low lying region west of the Ridge. Based primarily on the surface geology, he also offered schematic cross-section of the Miami Limestone (Fig. 3) which inferred the stratigraphic relationship of the bedded oolitic facies and the bryozoan facies.

Subsequent topographic studies by White (1970) and Halley et al., (1977) further recognized that the Ridge is divisible into two morphologically distinct areas: 1) a system of shoals and intervening channels, the individual members of which show a pattern perpendicular to the coast and 2) a barrier bar which is a relatively continuous, elongate feature parallel to the coastline (Fig. 4). These two areas of predonimantly positive relief are separated by a back barrier channel .(Halley et al., 1977). Based on the orientation of the morphology of these two areas and the recognition of accretion ridges at the southern terminus of the barrier bar, Halley et al., (1977) interpreted the system of shoals and intervening channels as being the result of tidal flows on and off the shelf, whereas the elongate barrier bar was inferred to be the result of southerly longshore drift.

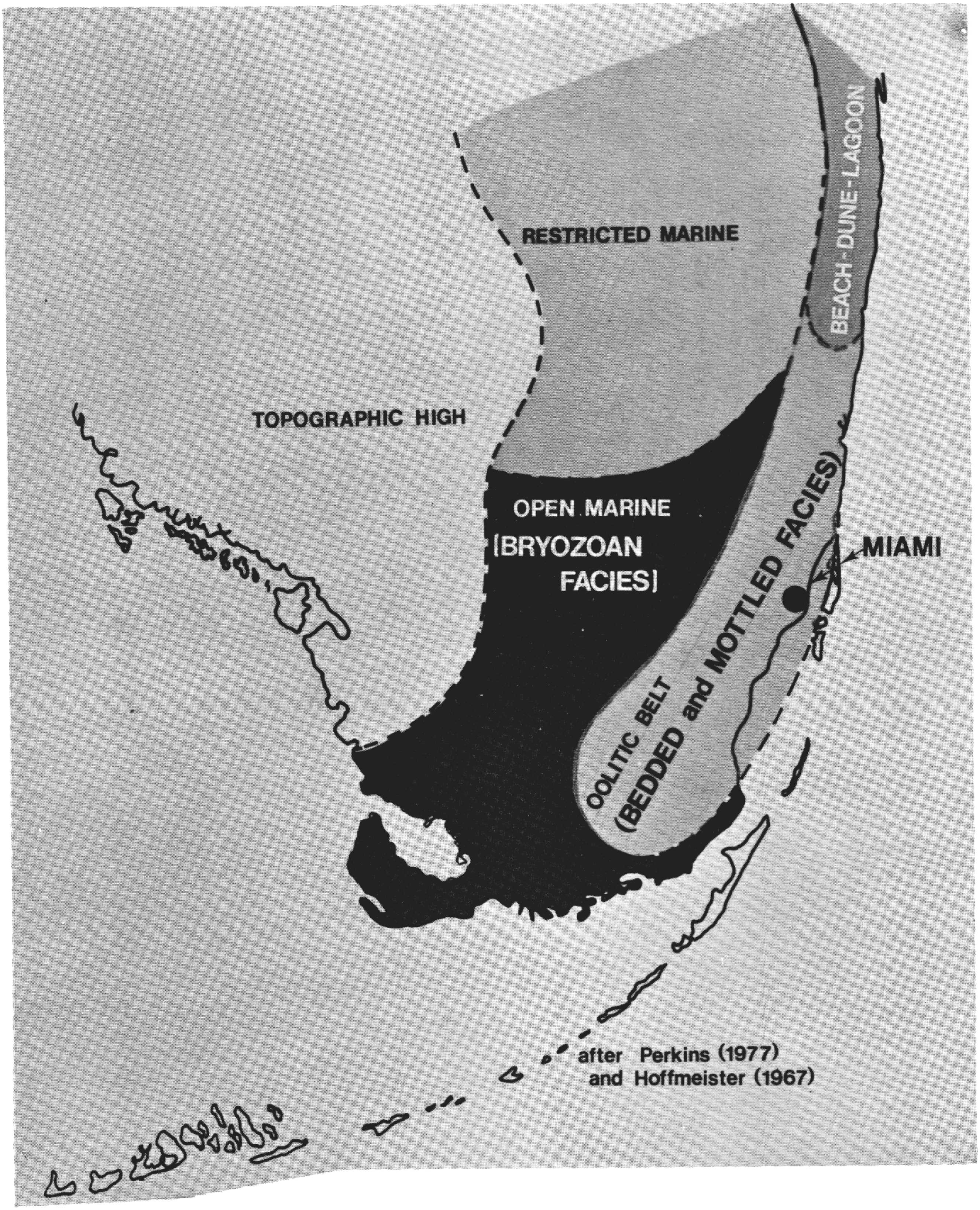


Figure 2. The depositional environments during Miami Limestone time lafter Perkins, 1977) and generalized facies distribution of the Miami Limestone (Hoffmeister et al., 1967 and this study). The mobile oolitic belt on the eastern side of the Miami Limestone is a topographic high which forms the southern extension of the Atlantic Coastal Ridge. The bryozoan facies of the low-lying area west of the Ridge was deposited under open marine platform conditions.

The present study complements the work of previous authors, by presenting new data and integrating information from both sedimentary structures and topography. It also shed further light on the depositional history of the Miami Limestone.

The oolitic belt of the Miami Limestone is divisible into barrier bar and a shoal and channel system on the basis of topography. As shown by a series of borings that penetrate the formation, the topographically defined areas have distinct and recognizable anatomies. The barrier bar records a characteristic succession of bedded and mottled facies indicating episodic sediment deposition and sediment inactivity. In the shoal and channel system the record is predominantly one of the sediment stability, with active sedimentation, limited to the flanks of the individual shoals. The facies pattern in the Miami Limestone is is directly comparable to the pattern of surface sediments in the Holocene ooid accumulation at Soulter's Lays, Bahamas. The borings, also reveal that the mobile oolitic belt was established and developed in place.

MATERIALS AND METHODS

The core materials used in this study are those obtained from a line of core borings taken for the engineering studies of the Metrorail rapid transit system. The cores were spaced at intervals of roughly 330 meters along the 14 km. section studied. Although not all of the borings were available for study, those obtained provided a relatively complete section of the Miami Limestone.

The main method used in the study of the cores consists of the logging of four inch diameter cores using a hand-lens and/or binocular microscope. The bulk of the work was carried out at the Law Engineering Testing Company warehouse in downtown Miami. When appropriate more detailed examination of samples was carried out at the University of Miami's Comparative Sedimentology Laboratory by impregnation with polyester resin and preparation of thin-sections.

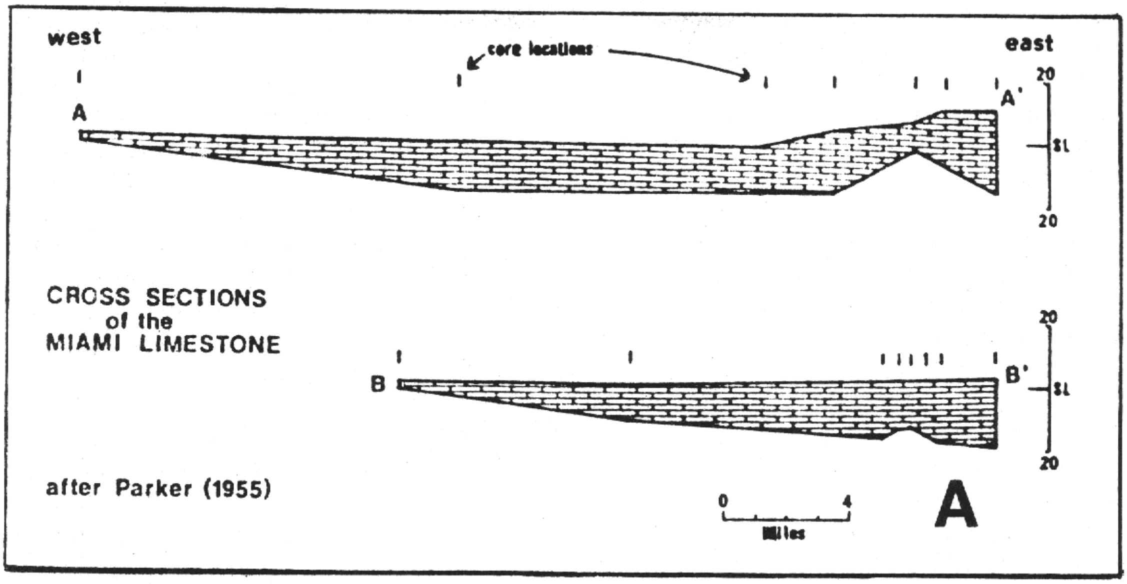
Where possible, the line of borings was supplemented with observation from outcrops. Outcrops provided paleocurrent data and determination of geometries of sedimentary structures. Paleocurrent directions were obtained by measuring dip angles and directions of foreset beds using a Brunton compass. Only those beds with dip angles of 20 or more are included in the results to insure that the measurements are from avalance foresets.

FACIES

The oolitic unit of Hoffmeister et al., (1967) can be subdivided into two distinct facies which are recognizable primarily on the basis of their fabric. These facies are here named the bedded facies and the mottled facies. The two facies are end members of a spectrum of variation that is typically observed as a vertical succession which grades upward from the bedded facies into the mottled facies.

BEDDED FACIES

The bedded facies is composed of oolitic grainstone characterized by well-defined cross-bedding. The cementation of the ooid sand preserved and even enhances the primary physical structures of the rock. As the rock surface weathers, the original white to cream color changes to grey and the bedding becomes more obvious as the hard, well-cemented layers stand out in relief against the weakly cemented friable layers.



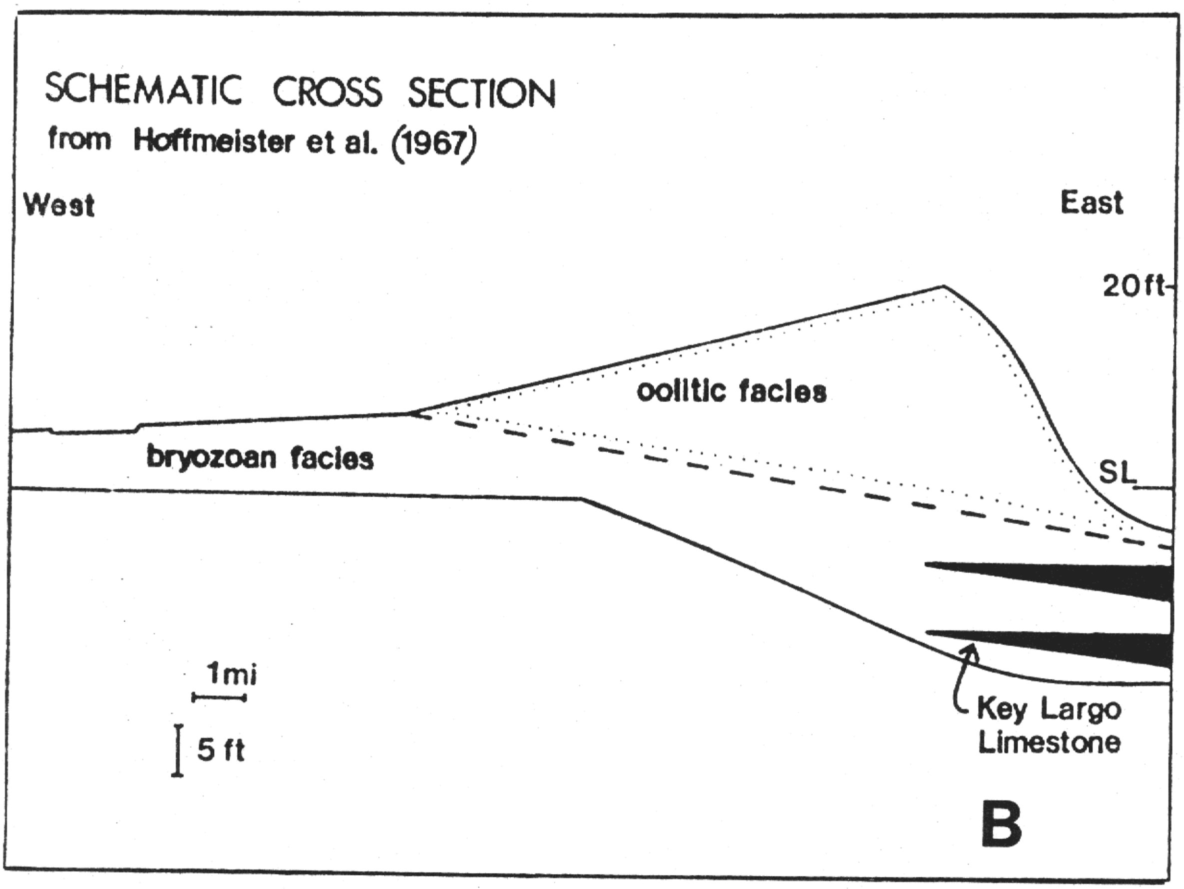


Figure 3. Cross-section of the Miami Limestone. A. Section drawn by Parker (1955) based on well cuttings. Parker delineated the general seaward thickening wedge shap of the formation. B. Schematic section drawn by Hoffmeister et al. (1967) incorporating his division of the formation into two facies into the general outline of Parker (1955). The vertical relationship of the bryozoan and oolitic facies is deduced from surface exposures (see fig. 2) and use of Walther's Law.

Individual foresets in the bedded facies of the Miami Limestone exhibit the following characteristics: They typically dip at or near the angle of repose; they are of constant thickness within any one set, and are defined by a variation of grain size which has influenced the cementation pattern. Individual cross-beds fine upward (perpendicular to the foreset slope) typically from grains on the order of 500 microns in diameter at the base of the bed to 250 microns at the top of the bed. The finer portions of the beds are preferentially cemented thus each bed consists of the couplet of a coarse, friable layer and a finer, well-cemented layers. The thickness of the individual beds is remarkably uniform, varying between 1.5 and 3 cm in thickness, the only variation in any one set being a reactivation surfaces, which are marked by a slight change in the dip angle of the foreset and/or a small concentration of skeletal material on the foreset slope. Measured dips of cross-bed in the Miami Limestone range from 7 to 25; with no measurements showing ìan average of 19.7, and 23 of them 20 or higher. The contact between the toe of the foresets and the lower bounding surface (bottomset bed) is typically tangential.

The individual foresets are found in wedge-sets, which represent the migration of a single sand wave, and tabular cosets, which represent the migration of large scale, composite bedforms. Tabular cosets of cross-beds are defined by horizontal first-order bounding surfaces which are frequently marked by a coarse skeletal lag. The cosets range in thickness from a maximum of slightly greater than 2 meters to 10 cms. The cosets are typically about 1 meter thick and are laterally continuous within a given outcrop (40 scale). Individual cross-bed sets, defined by second order bounding surfaces which show as thin horizontal beds, are between 10 cm and 1 meter, with a typical thickness of about 30 cms. The individual sets may thicken in the downcurrent direction, as one set of overtaken by a second set forming a single set of their combined thicknesses. Individual sets are discontinuous.

As suggested by the preceding discussion the bedded facies records periods of active sedimentation as was produced by migrating sand waves of overall amplitude between 10 cm and 1 m. The cross- bedding is the result of avalanching down the face of these sand waves, resulting in foresets which dip at or close to the 20 angle of repose reported for ooid sand (Christopher Schenk, pers. comm.). The consistent internal organization and constant thickness of the beds in any one set suggest that the beds were deposited under relatively uniform flow conditions such as would be expected of tidal currents.

MOTTLED FACIES

The mottled facies is a peloid-ooid grainstone which forms a sponge-like meswork or distorted honeycomb of regularly shaped intersecting or discontinuous rods, tubes and passages, most closely resembled by the outer surface of a loufa sponge. A planar or two dimensional exposure shows that the overall mottled appearance of this rock is a result of the cementation pattern. Cemented patches form distinct mottles which float in the uncemented background sediment. These mottles are typically elongate, but irregular or even ameoboid in form, 1-3 cm wide and up to 10 cm long. The intervening patches of uncemented material of pores are of equal or greater dimension than the cemented mottles. The uncemented sediment is often physically washed away or has been dissolved, leaving only the cemented framework whose loufa-like texture is then visible in three dimensions.

The individual structures recognized in the mottled facies include rodlike and two types of tubular trace fossils; large diameter tubes of unknown origin. All three of these trace fossil types are clearly visible in the mottled facies of the Miami Limestone because of selective cementation of these features with respect to the matrix. Weathering further enhanced the rods which appear in positive relief against the weakly ìcemented matrix.

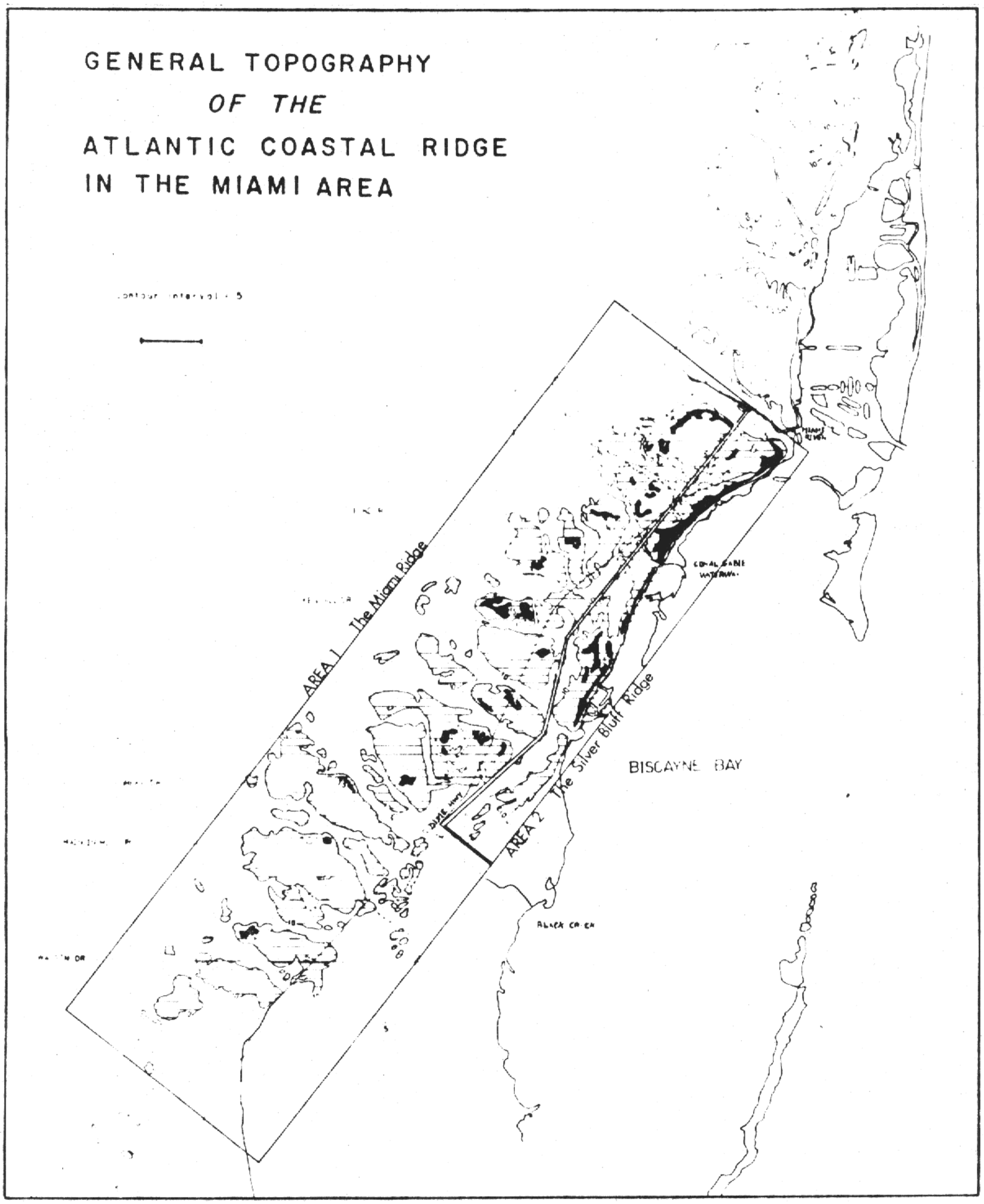


Figure 4. The topography of the Atlantic Coastal Ridge in the Miami area. The striped pattern represents elevations between 10 and 15 feet above sea level, the black represents areas greater than 15 feet above sea level. Redrawn from base map of Metropolitan Dade County Planning Dept. (1963). White (1970) and Halley (1977) divided the Ridge into two areas, Area 1 (the Miami Ridge), is a system of shals and channels with the individual members of the system showing a coast- perpendicular orientation. Area 2 (the Silver Bluff Ridge), interpreted as a seaward barrier bar (Halley, et al., 1977), is a relatively continuous feature which is elongate parallel to the coastline.

Rods

Rods are solid sticks of well cemented ooid or peloid-ooid grainstone. In most instances they range from 1 to 1.5 cm in diameter and in good exposures can be traced over distances of little more than 10 cms. The rods are mildly tortuous along their length, almost invariably horizontally oriented, and may either lie on top of or intersect one another. In three outcrops along the barrier bar these rods and the uncemented matrix make up the sole components of the rock in sections of up to one meter thick. Elsewhere rods are commonly found to comprise less than an estimated 10 percent of the total volume. These rod-like structures are believed to be coprolites, formed by passing sand through the digestive tract of sandy bottom dwellers such as annelid worms of holothurians.

Large Tubes

The larger tubes are circular in cross-section, 2-3 cm in external diameter, and the diameter remains constant along the length of the tube which may be traced in outcrop for up to 40 cms. The tubes are frequently hollow, but occasionally filled with coarse skeletal material, are straight or gently curved, and may branch in several directions at nodal points. The tubes typically have have well developed micritic inner walls with a knobby exterior. The micritic walls may also include sparsely distributed molds of ooids. The sediments associated with these features sometimes contains distinctive rodshaped (1 mm in diameter) pellets with internal canals. The large tubes are found throughout the mottled facies of the Miami Limestone, and in many cases are estimated to comprise up to 30 percent of the rock by volume.

Tubular structures that are circular in cross-section and have a knobby exterior and/or a micritic lining are referred to the ichnogenus *Ophiomorpha*. These tubes are comparable to both Pleistocene examples (Howard and Frey 1973) and modern examples (Shinn, 1968, and Howard and Frey 1973) of burrows which are attributed to the burrowing crustacean *Calianassa* sp., also known as the ghost shrimp. Identification of these tubular burrows is based on the following criteria, as defined by Shinn (1968): 1) concentrically laminated mud lining, 2) knobby or nodose exterior, 3) general burrow morphology, and 4) association with distinctive fecal pellets.

These tubular structure from the Miami Limestone have been recently discussed by White (1970) and Perkins (1977). White (1970) attributed them to mangrove roots and used this contention in his subsequent interpretation of the shoal morphology as that of mangrove islands. The present study rather supports the interpretation of these structures to be the results of burrows produced by a marine crustacean, as previously suggested by Perkins (1977). The evidence of a burrowing origin for the tubular structure is further supported by the fact that the tubes are of constant diameter along their length. Molds left by decayed roots would taper towards their ends, and possibly change diameter at branching points. None of the shapes observed in the tubular structures suggests tapering of thinning tubes in the mottled facies of the Miami Limestone. Thus their vegetal origin cam be safely ruled out.

Small Tubes

The smaller tubes are also circular in cross-section with a constant external diameter of 1 to 2 centimeters. Individual specimens have been traced for about 50 cms. The outer wall is thick relative to the overall size of the tube and made of well cemented grainstone surrounding a central tube of relatively small (.5 cm) diameter. The central tube may be hollow or infilled with poorly cemented ooid sand. These tubes, when exposed in the bedding plane, commonly bifurcate forming an acute angle between the two branches. These small tubes are only a minor component of the rock by volume, they never comprise more than 10 percent of the total volume. The precise origin of the smaller tubes is unknown, although their tubular bifurcating form suggests that they may have been a dwelling structure for a very small animal, possibly a worm.

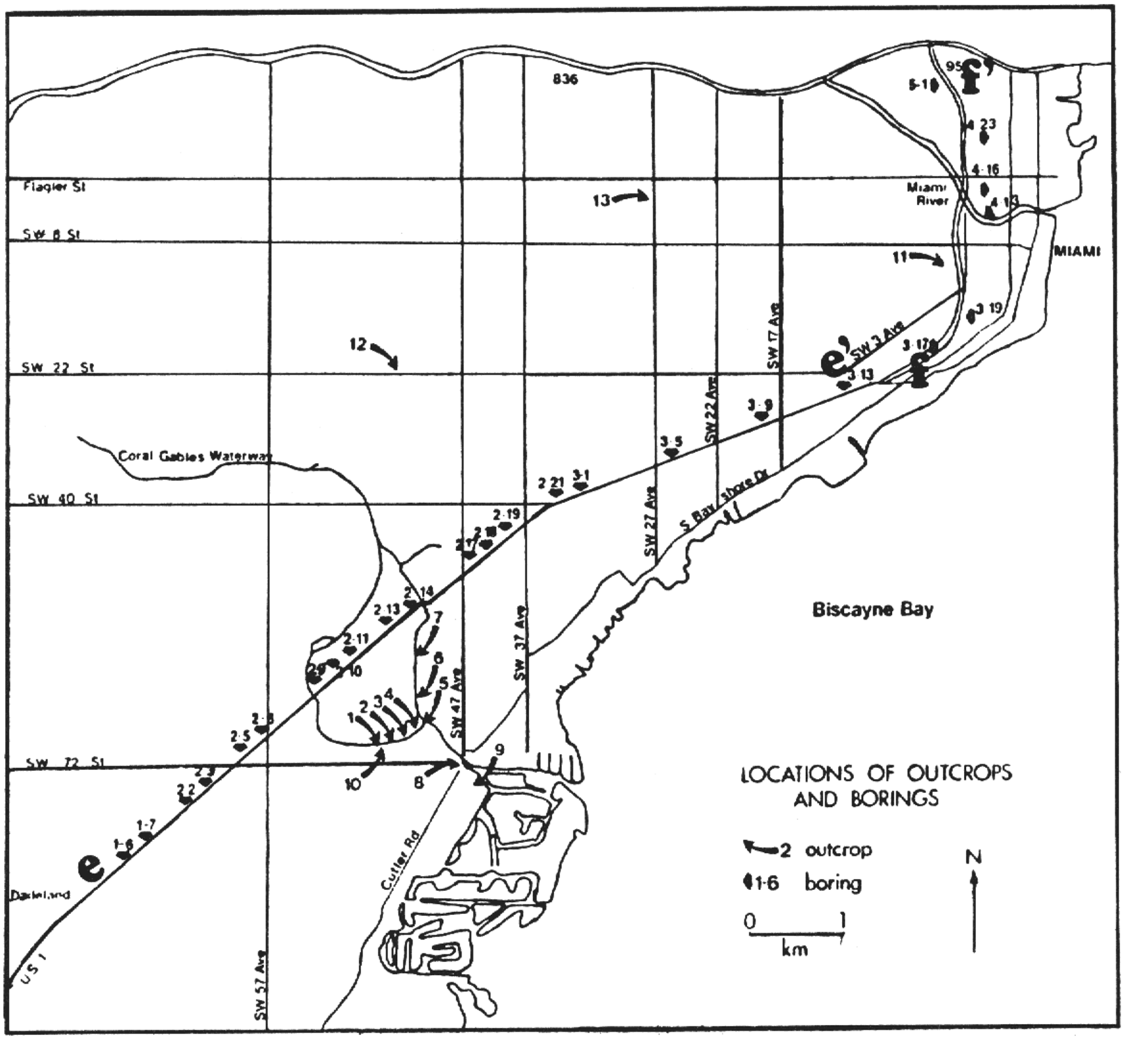


Figure 5. A map of the study area showing the locations of samples sites (outcrops, cores, and spoil) in relation to the topography. Outcrops referred to in the text are indicated by numbers. The two sections of borings in the text are marked as e-e' and F-F'.

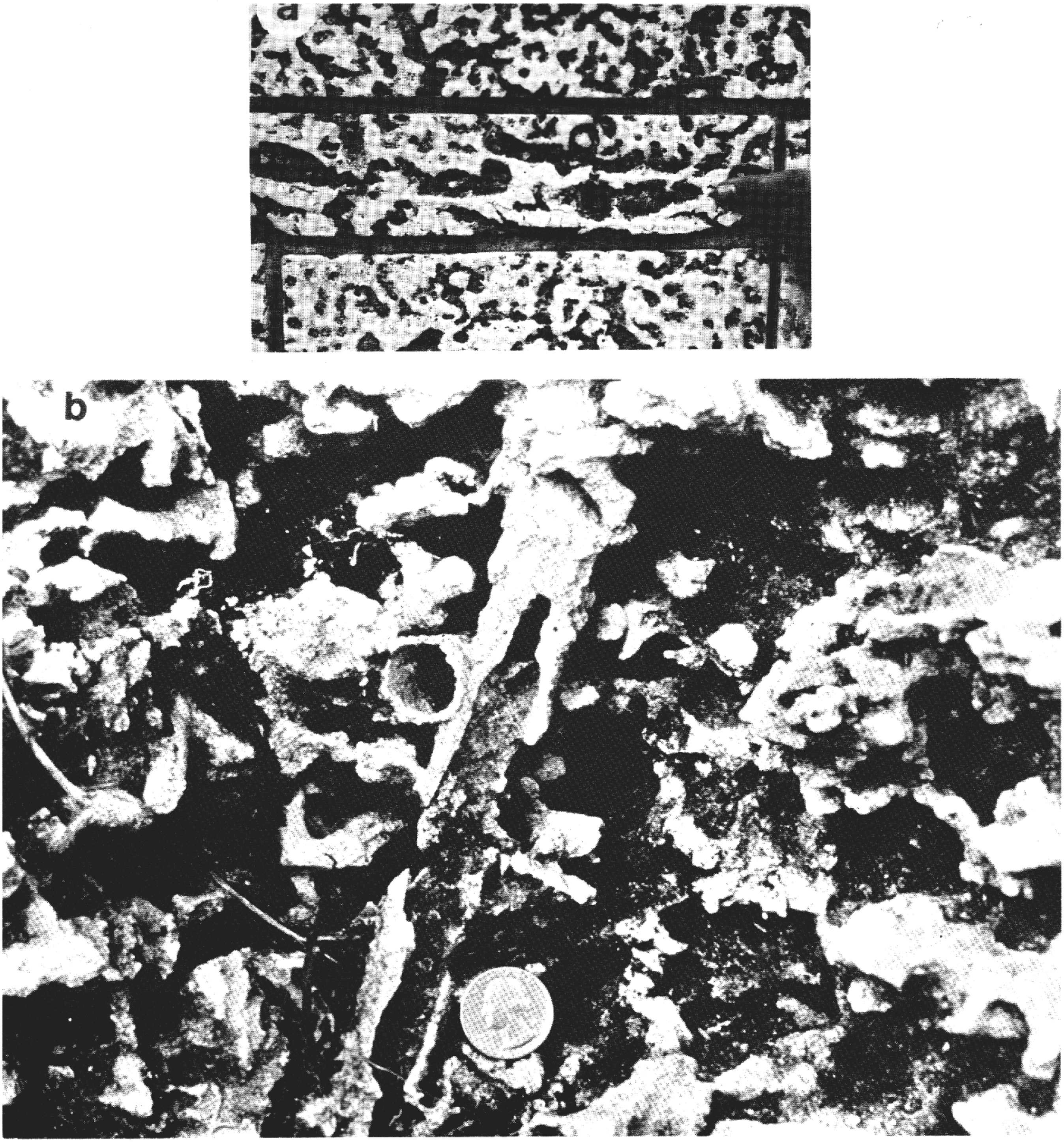


Figure 6. A. The mottled facies of the Miami Limestone showing the irregular fabric with occasional recognizable or regularly shaped features. B. Tabular traces produced by the burrowing shrimp Calianassa sp., quarter for scale. The photograph shows both a transverse section (upper center) and longitudinal view. At left center, with its axis oriented in and out of the paper, is a transverse view of the rod type trace.

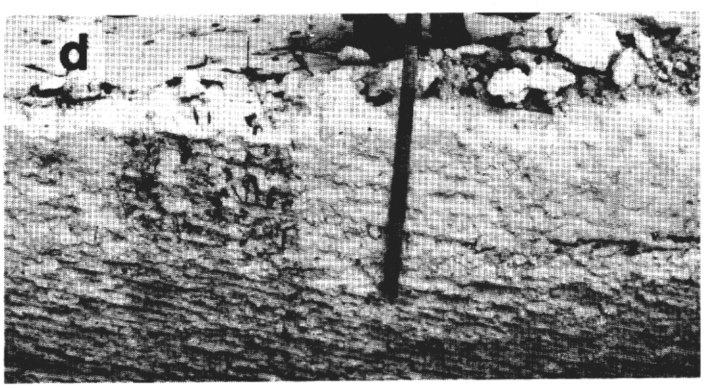


Figure 6. C. Rod type traces viewed in a bedding plane exposure. The rods are horizontally oriented, overlie one another (upper right) and intersect each other (lower left). The picture includes a pen for scale. D. The cross-bedded facies of the Miami Limestone. The large scale beds dip at about 24°. Individual beds are 2-3 cm thick and consist of a well cemented layer and a poorly cemented layer, causing the individual beds to weather out in relief. The scale is marked inalternating light and dark bands of 10 cm each.

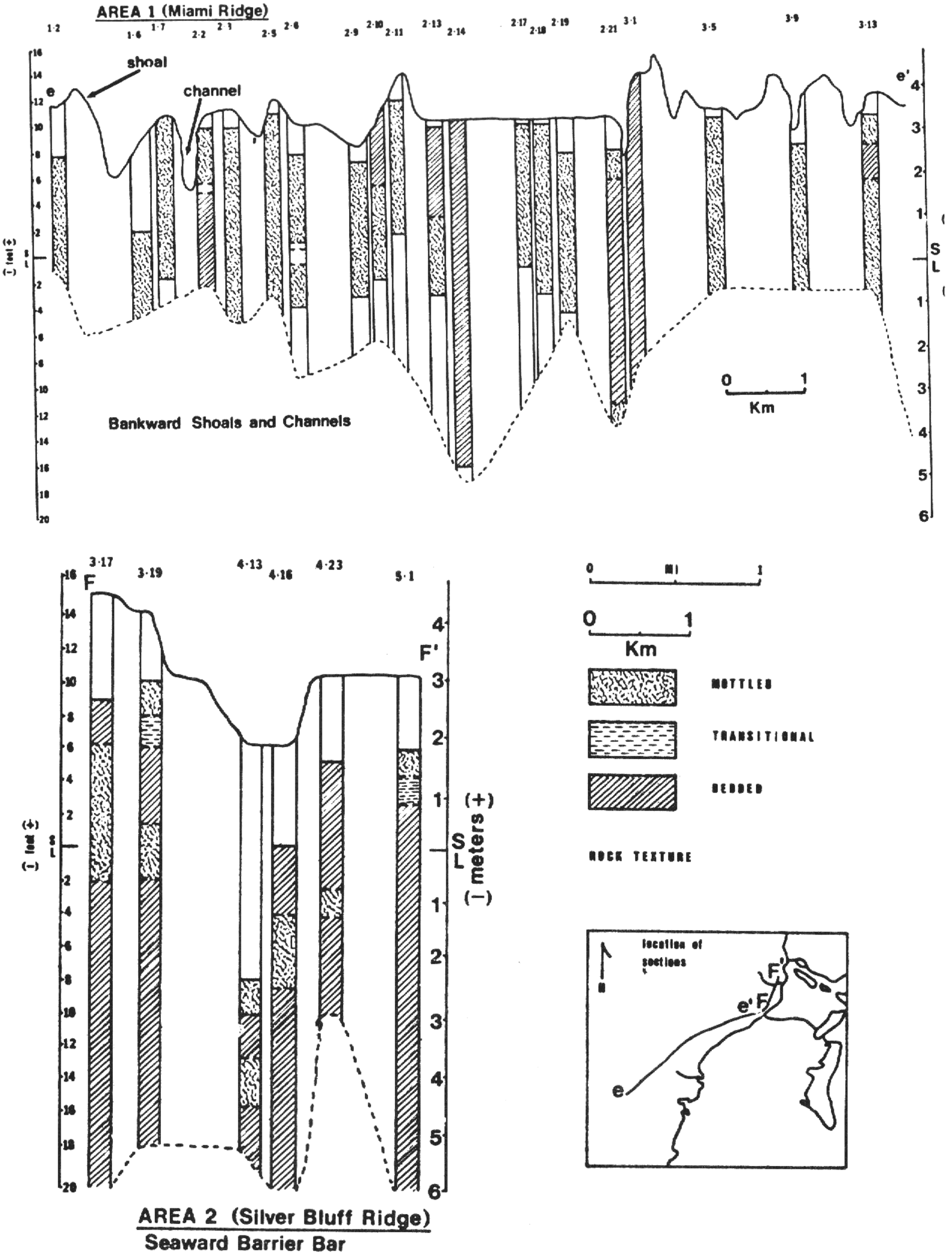


Figure 7. The distribution of the bedded (striped pattern) and mottled (squiggly pattern) facies in sections e-e' (top) and F-F' (bottom) of the Miami Limestone. Section e-e' is in the shoal and channel system, section F-F' is in the seaward barrier bar. The shoal and channel system is predominantly mottled with bedding restricted to the flanks of the individual shoals. The broad flat area between cores 2-13 and 2- 21 is an artifact of the section; it parallels a contour line on the flank of a shoal. The seaward barrier bar is predominantly bedded, intercalated with thin mettled zones.

The presence of well defined traces within the mottled facies, and the regular structure of the mottled fabric indicate that this facies is an ichnofabric produced by syndepositional burrowing. This is of significance sedimentologically because such an ichnofabric could only be produced under quiet conditions in which the sediment remained stable enough to allow infestation by the burrowing fauna. The intensity of burrowing which produced the mottled fabric also indicates that stable conditions persisted for a substantial period of time. It is noteworthy that virtually all of the cemented walls interconnect and do not randomly terminate in open channels as would be expected in a solution fabric. The well defined ordering of the fabric suggests biological processes for its origin and may be important in the retention of structural integrity of this rock, which commonly develops porosities in excess of 50 percent.

FACIAL SUCCESSION

In outcrops and cores the peloid-ooid grainstone of the mottled facies and the ooid grainstone of the bedded facies are observed in a characteristic vertical succession (Evans, 1982). The bottom of the succession is crossbedded ooid grainstone which grades upward first into a zone with identifiable trace fossils (*Ophiomorpha* and rods) against a bedded background, and then into the mottled fabric. The top of the successional unit displays a sharp boundary between the uppermost mottled material and the basal cross-bedding of the next succession. The contact is typically smooth, but at least in one outcrop it shows small scale (1 meter across) cut and fill structures (outcrop # 9) and in another outcrop (outcrop # 8) it is marked by a thin (2 cm thick) micritic layer. Where complete successions are exposed in outcrop, they are typically 3-4 meters thick. Such dimension, however, is largely an artifact due to the limited vertical exposure in the study area. In cores, the succession range in thickness from less than 2 meters up to 8 meters. The large variation in the thickness of the successions is apparently controlled by the range of thicknesses displayed by the bedded portion of the succession which may range between 0.5 m and 6 meters. The thickness of the mottled portion of these successions has nowhere been observed to exceed 3 meters, and is most commonly found to be about 2 meters thick.

These successions are uncommon in the shoal and channel system, where they appear in only three cores (# 2-2, 2-6, 3-13, Fig. 7). At one outcrop (#13) recognizable trace fossils against a background of bedded sediment which graded upward into mottled sediment was observed. This is interpreted as the uppermost portion of the previously described succession. In contrast to the shoal and channel system, succession are typical of the barrier bar. Complete or partial succession are seen in virtually all outcrops. In cores, where the successions appear as a simple alternation of bedded and mottled limestone (fig. 7), the successions can be identified in all six cores from the barrier bar. The lack of the transitional facies characterized by isolated fossils against a bedded background is attributed to the limited sample size recovered in a four inch diameter boring.

The successions are known to be laterally discontinuous between two outcrops less than 100 meters apart, as in the case in the Coral Gables Waterway, between the Lejeune Rd. Bridge (site #8) and a private home in the Cocoplum development just east of the bridge (site # 9).

The regular vertical succession of bedded oolitic limestone, bedded oolitic limestone with recognizable trace fossils, and mottled oolitic limestone illustrates the transformation of the bedded facies into the mottled facies by downward burrowing into an uncemented deposit which was temporarily inactive. Each succession records the change in prevailing conditions from active and rapid deposition of sediment to sediment stability.

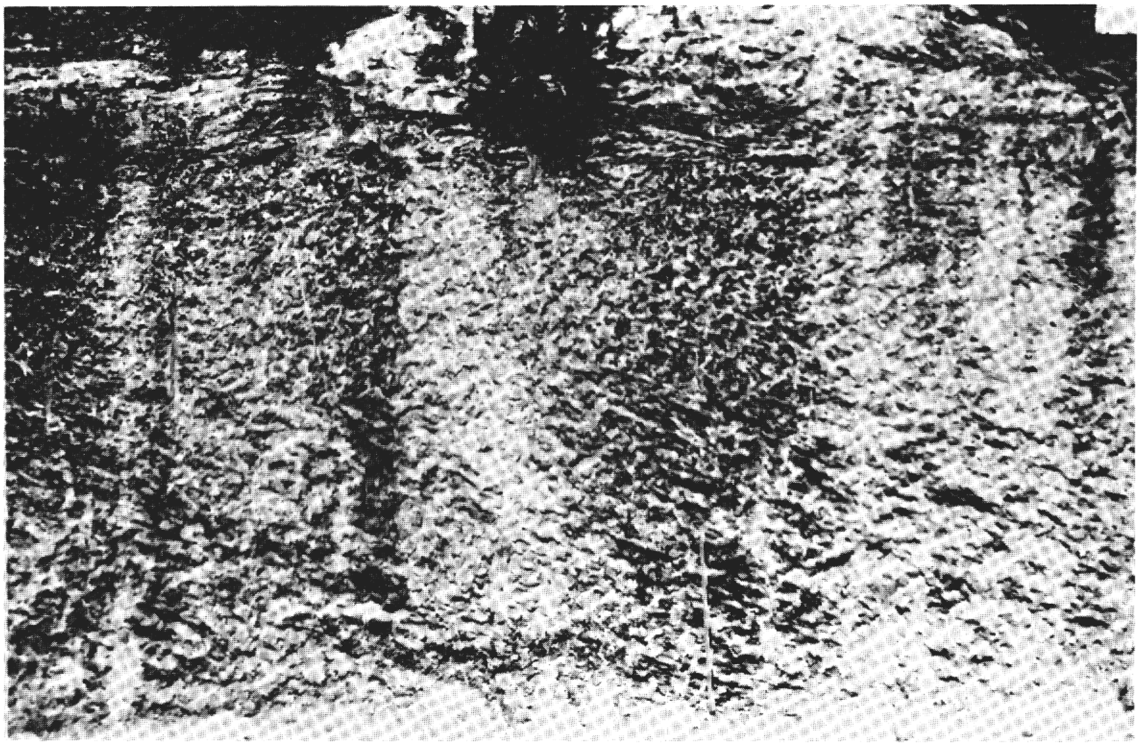


Figure 8. A unit of accumulation, or succession which grades upwards from Large scale (at least 2 meter foresets) cross-bedding through a zone of disturbed bedding with recognizable traces, into the mottled zone at the top. The top of the unit is marked by a sharp contact and overlain by the basal cross-bedding of the succeeding unit. the exposure is on the north wall of the foundation excavation at 1643 Brickell Ave., the scale at lower right center is 1 meter blocked off in 10 cm segments.

Figure 9. A medium scale trough, as indicated by truncation of bedding over a vertical expanse of about 2 meters. Outcrops is on the east wall of the first branch of the Coral Gables Waterway, the outcrop is nearly 2 m high.

DISTRIBUTION OF FACIES

The distribution of the bedded and mottled oolitic facies in relation to the topography of the present Atlantic Coastal Ridge provides the basis for interpretation of the depositional history of the Miami Limestone. It can be observed that deposits from the barrier bar and the bankward shoal and channel system contain the same bedded and mottled oolitic facies, but they differ in the relative abundance and distribution pattern of the two facies, as well as the overall thickness of the Miami Limestone in these two areas (Fig. 7).

BARRIER BAR

The section of Miami Limestone which developed over the barrier bar is thicker, (it reaches both higher elevations above and greater depths below sea level), contains a higher percentage of bedded limestone, and shows a different arrangement of the bedded and mottled oolitic facies than the section in the shoal and channel system. The Miami Limestone deposited on the seaward barrier bar is up to 11 meter thick, with a maximum extent below sea level of greater than 6 meters, and an average of 5.3 meters (fig. 7). The bedded oolitic facies, which comprises over 60 percent of the six cores examined (fig. 7) is laterally extensive. It is found in each of the six cores, but in vertical section it is invariably interrupted by thin (2.5 meters maximum) horizons of the mottled oolitic facies which are not laterally correlatable between cores. The general pattern shows an alternation of the bedded and mottled facies. There are at most two of these alternations within any one core (cores # 3-19 and 4-13, fig. 7) but outcrops located within 400 meters of the borings indicate the presence of a third succession which should have extended on top of the two core sites. The bryozoan-rich Limestone has not been recovered from the seaward barrier bar.

Outcrops along the seaward barrier bar (site 10, fig. 9) commonly display large scale through or cut and fill structures 5 meters across with as much as 2 meters of relief (as shown by truncated bedding). The axes of these channels are oriented perpendicular to the barrier. Halley and Evans (1983) have also reported channel fill deposits 3 meters thick and of undetermined horizontal dimensions from the seaward barrier bar in the northern part of the study area (site 11 on S.W. 10 St. just East of 2nd Ave.).

Sediment transport perpendicular to the main axis of the barrier bar is inferred by the paleocurrent directions measured on the seaward barrier bar as well by the orientation of the channel axes. The 23 measurements shown in figure 10 clearly indicate the bimodal distribution with the primary mode indicating south-eastward (off bank) transport, and the secondary mode indicating west-northwest (bankward) transport. Site 7 in figure 10, which shows northerly and southerly transport, is just bankward of the barrier bar in the back-barrier channel. The north-south transport at this locality is parallel to the main axis of the back barrier channel.

SHOAL AND CHANNEL SYSTEM

In contrast to the barrier bar, the oolitic Limestone in the shoal and channel system is predominantly mottled, it is much thinner and shows a considerably different distribution of the bedded and mottled facies. The mottled facies comprises more than 60 percent of the 20 cores examined from the shoal and channel system (fig. 7). The section thickness of the shoal and channel system is from about 5 to 8 meters, with the maximum extent below sea level about 5 meters, and the average depth below sea level about 5 meters, and the average depth below sea level 2.25 meters. The mottled facies is laterally extensive and may be vertically continuous throughout the recovered section. The bedded facies is laterally restricted, it occurs in no more than two adjacent cores, and is restricted to the flanks of the individual shoals (cores # 2-2, 2-6, 2-

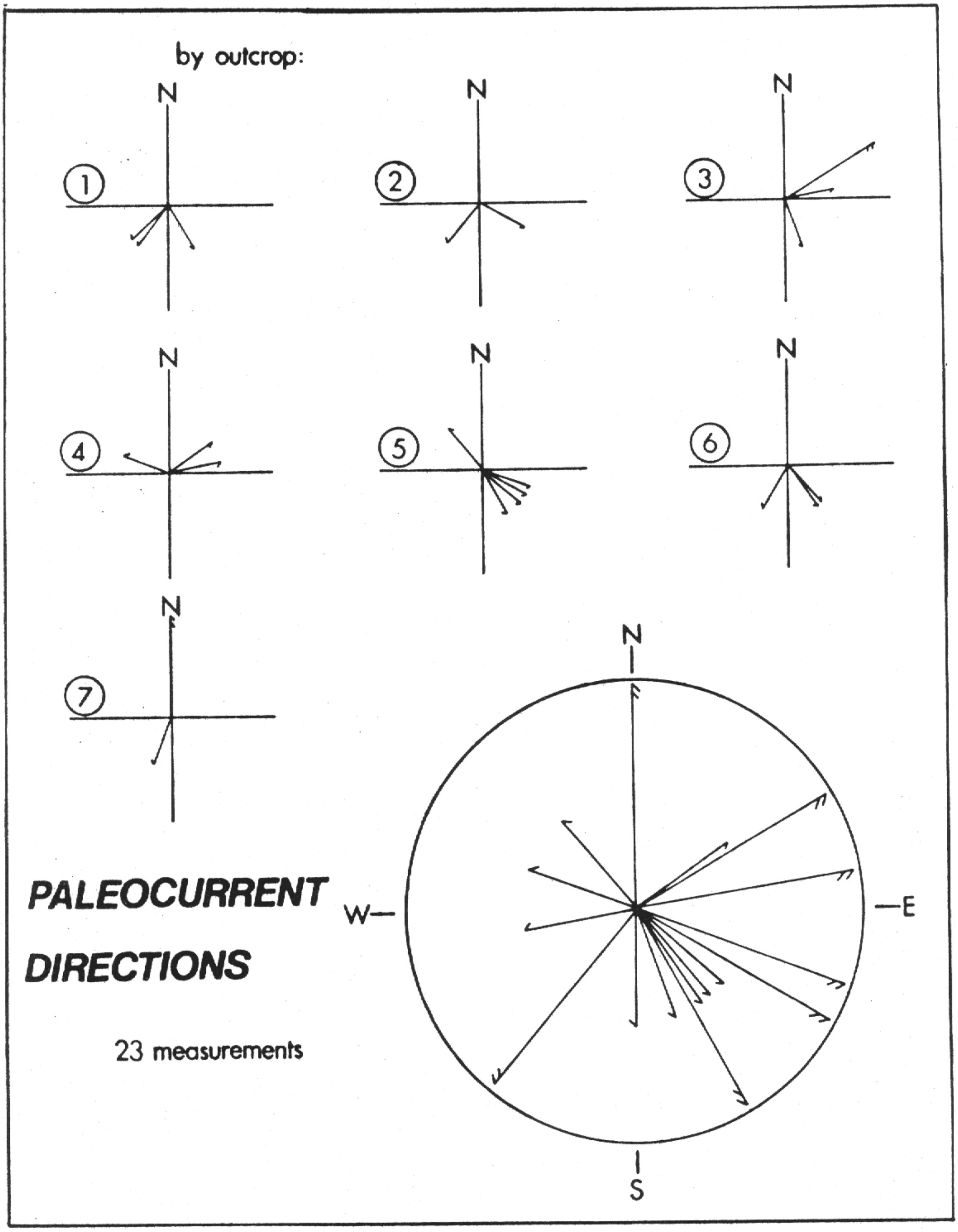


Figure 10. Paleocurrent measurements by outcrops, measured in the Coral Gables Waterway. The primary mode is southeast with a secondary mode at about 1800 to the primary mode, roughly northwest. Outcrop 7, which gives odd date in relation to the other 6 localities is the only one located off the barrier bar in the back barrier channel.

13, 2-14, 2-21, 3-1 fig. 7). The bedded facies is observed on the flanks of four of the five shoals crossed by section e-e (fig. 7) and may be vertically continuous throughout the formation (cores #2-14 and 3-1, fig. 7). The bryozoan facies has not been recovered in any of the 20 borings examined from the shoal and channel system.

Of the three excavations examined in the shoal and channel system at Coral Way between LeJeune and Red Roads, site 12, and 27 Ave. and n.W. 2nd St., site 13, and the upper reaches of the Coral Gables Waterway only one shows beddings. The bedding in this case was less than one meter of disturbed low-angle bedding, the rest of the material examined being entirely mottled.

DISCUSSION

The predominance of the bedded oolitic facies in the barrier bar attests to the mobility of the sand in this area, the vertical alternation of the bedded oolitic facies with mottled oolitic horizons however, reveals periodic inactivity. The fact that the mottled horizons are not laterally correlatable indicates that the successions are produced in localized rather than system-wide events. This localization of sediment deposition and sediment inactivity reveals the barrier bar to be a composite feature, may be the result of energy shadows produced by the shifting of local topography (Evans, 1982).

The bimodal paleocurrent direction distribution showing both modes perpendicular to the axis of the barrier bar, and the regularity of the avalanche foresets within any one set, indicate a strong and consistent current which periodically reverses itself as should be the case on a tidal current. The predominance of ebb-tidal flow in the study area is consistent with the seaward location of these deposits where they would have been deposited by waning ebb-tidal currents. Halley and Evans (1983) reported convex-upward beds from the Lejeune Rd. Bridge on the barrier bar which, according to Kaldi (1983, personal communication) produced under decelerating flow conditions in flume experiments. The presence of large troughs with axes perpendicular to the trend of the barrier bar also supports the proposed tidal flow across the bar.

The features of the barrier bar described above such a localized episodic deposition, medium scale channel features, and a bimodal paleocurrent distribution with both modes perpendicular to the axis of the bar, indicate that this feature is far more complex than is indicated by its morphology. It is a composite feature, dissected by infilled channels oriented perpendicular to its crest, and records predominantly off-bank transport. On the basis of these observations it is suggested that at least the northern portion of the barrier bar did not develop by longshore ìdrift, but instead built up in repose to tidal currents, probably as coalescing ebb-tidal deltas.

The interpretation of the mottled oolitic facies as representative of sediment stability implies that the interiors of the shoals in the shoal and channel system were inactive for long period of time. The close association of the bedded facies with the flank of the individual shoals confirms the tidal bar and channel origin proposed by Halley et al., (1977) on the basis to topography. Active sedimentation was largely confined to those portions of the shoals proximal to active tidal channels, a system which leads to the speculation that these may consist of a fringe of bedded san surrounding a mottled interior. The vertical continuity of the bedded facies in cores 2-14 and 3-1 suggests that at least some of the channels must have been long lived features, remaining active throughout the history of the ooid system.

The absence of the bryozoan facies beneath the ooid-rich bedded and mottled facies indicates that the mobile oolitic belt of the Miami Limestone was established and developed in place and did not migrate bankward over the platform interior deposits of the bryozoan facies as

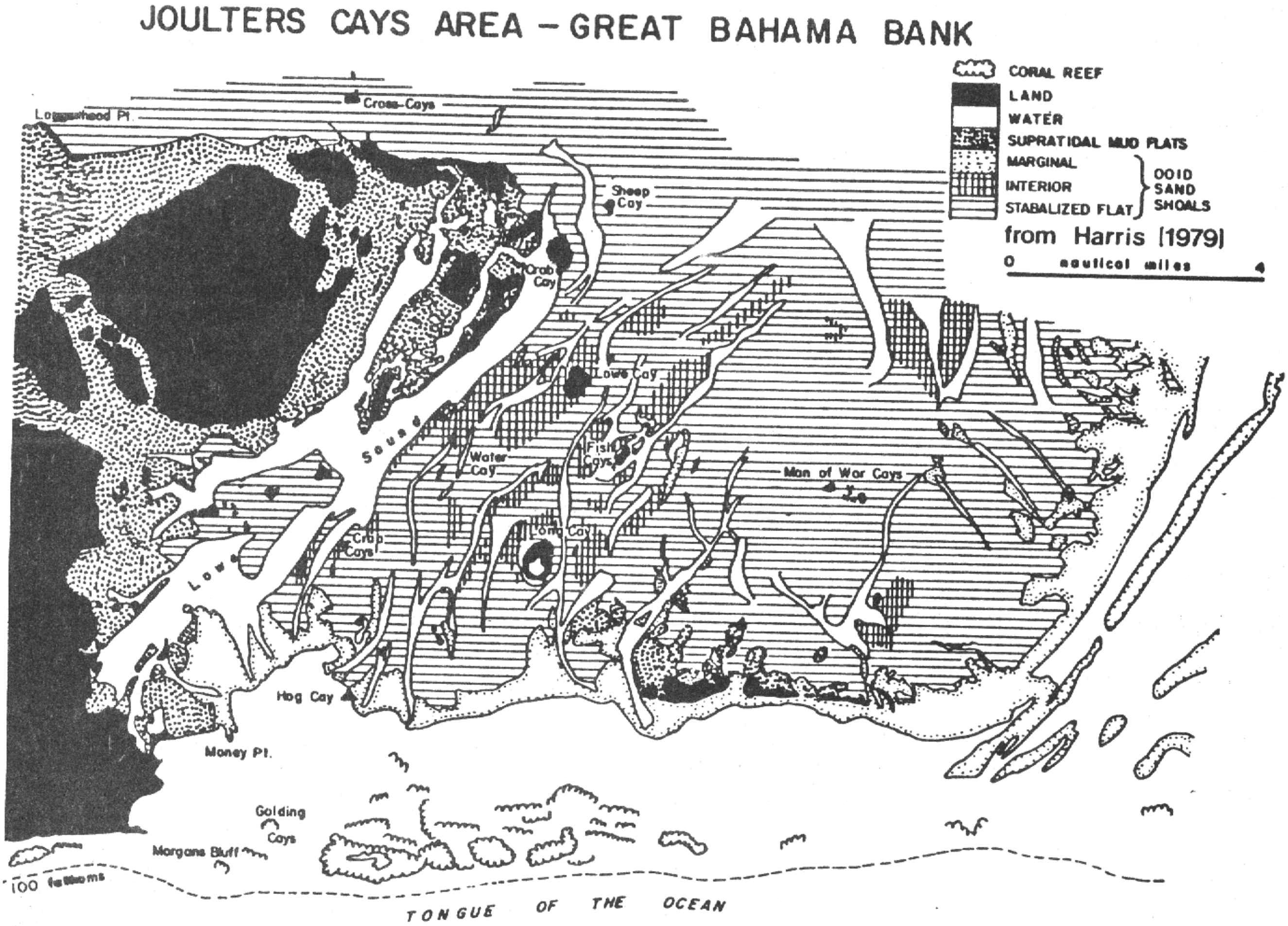


Figure 11. Surface sediments of the Joulter's Cays area, Greater Bahama Bank. The marginal sand shoal is comparable to the seaward barrier bar of the Miami Limestone and the stabilized sand flat is comparable to the bankward shoals of Miami. The interior shoals of Joulter's (Cross-hatched pattern) are located along the tidal channels, a relationship very similar to that suggested for the Miami Limestone where cross-bedding in the shoal and channel system is confined to the flanks of the shoals.

suggested by the schematic cross-section of Hoffmeister et al., (1967 and Fig. 3). It is perhaps more reasonable to suggest that there is some interfingering of the bedded and mottled oolitic facies with the bryozoan facies, and that the bryozoan facies developed behind the energy barrier provided by the bathymetric high established by the bedded and mottled facies.

COMPARISON WITH JOULTER'S CAYS, BAHAMAS

The area occupied by the Miami Limestone is divisible into three distinct which from bankward to seaward (west to east) are: the platform interior, a shoal and channel system, and a barrier bar. These three topographic and sedimentologist subdivision of the Miami Limestone are directly comparable to the three major surface environments from the Holocene ooid sand complex at Joulter's Cays, Bahamas (Fig. 11). Harris (1979) described from bankward to seaward: platform interior sands, and sand flat, and a mobile fringe.

The mobile fringe, 0.5-2 km. wide, borders the sand flat on its seaward side. It is characteristically a clean ooid sand with bedforms characteristic of mobile sediments. The sediment section is thick in the Joulter's ooid sand complex. The mobile fringe is very similar in character to the barrier bar of the Miami Limestone.

The sand flat is bankward of the mobile fringe and is between 12-15 km. wide. Toward the west (bankward) the flat grades into platform interior deposits. Sediments from the sand flat are a mixture of peloids and ooids, and the accumulation is riddled by burrows. The sand flat is cut by numerous tidal channels which show the only evidence of traction transport in the sand system: channel spill over lobes, sand waves, and poorly developed levees. The sand flat environment of Jourler's Cays is similar in character to the shoal and channels system of the Miami Limestone.

The bryozoan facies of Hoffmeister et al., (1967) represents open platform deposits bankward of the mobile oolitic belt, and has not immediate counterpart of the Holocene Joulter's Cays system. It has some attributes of both Lowe Sound and the platform interior deposits. The thickness of the sediment, about 4 meters, and the abundance of burrows is similar to what Harris (1979) described from the platform interior at Jouler's Cays. The Lark accumulation of bryozoan Limestone in the Miami Limestone is suggestive of the sediment starved setting of the Lowe Sound.

SCHEMATIC CROSS SECTION

Based on the previous description of discussion of the three topography/sedimentologic subdivision of the Miami Limestone it is possible to draw an idealized cross-section of the formation which illustrates in some detail the rock types and facies anatomy of the Miami Limestone (Fig. 12).

The barrier bar, 3 km wide, comprises the thickest portion of the seaward thickening wedge of Miami Limestone. It is also where the oolitic limestone reaches both its maximum elevation above sea level here (7 meter) and its maximum depth below sea level. The bedded facies predominates (greater than 60 percent of the section) and in vertical section alternates with the thin (less than 2 meters) horizons of the mottled facies.

The shoal and channel system is about 10 km wide and predominantly mottled. A few lenses of bedded material may be scattered within the section, but in general, the cross-bedded facies is restricted to a vertically continuous occurrence where the section intersects the flank of a shoal. Sediment thickness at the shoal and channel system is typically less than that on the barrier bar, it averages about 8 meters. Both the maximum elevation above sea level (5 meters)

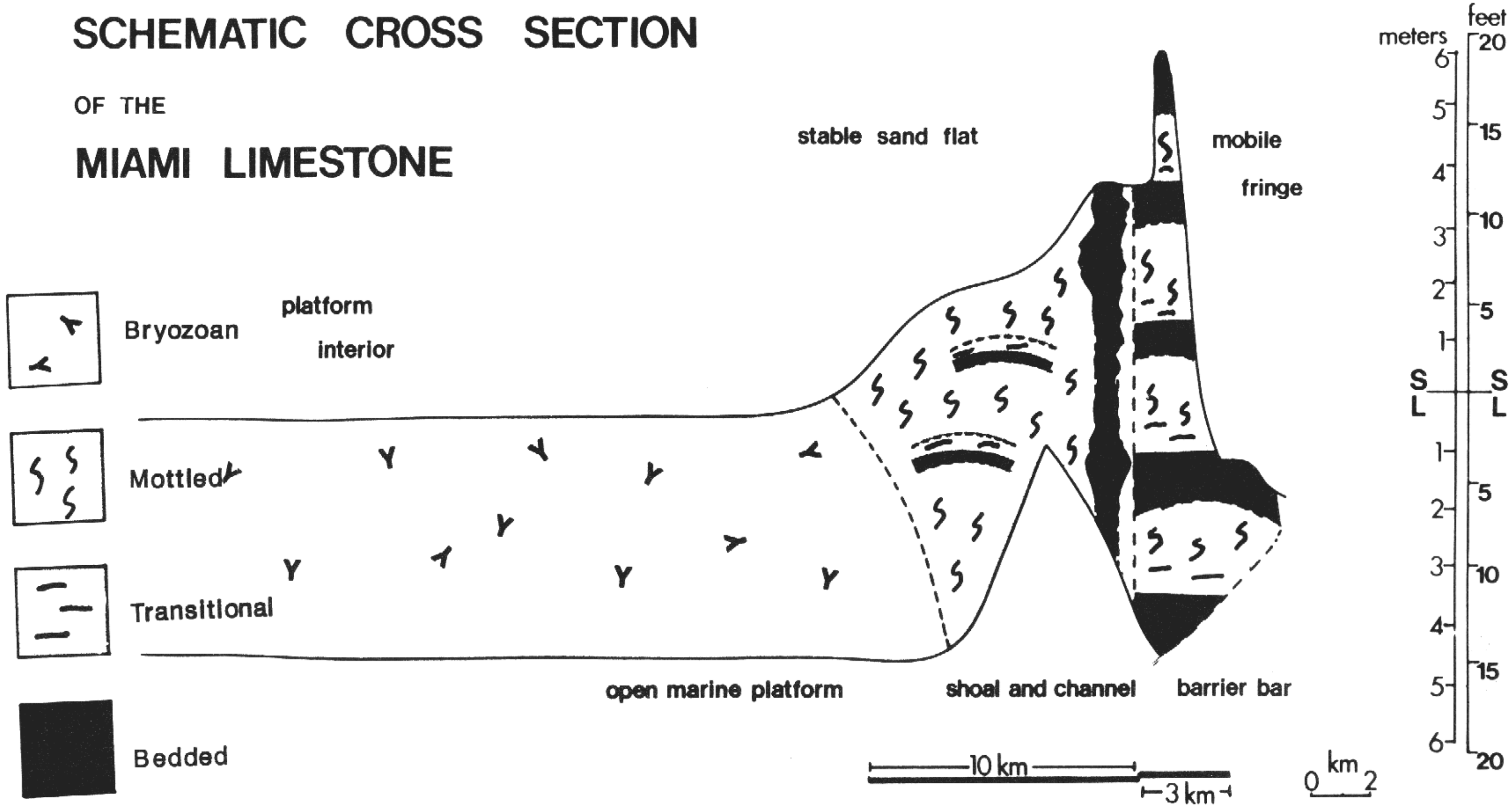


Figure 12. A schematic cross-section of the Miami Limestone. The topography and depth to the base of the section are measured from maps and cores. The internal anatomy is schematic. The seaward barrier bar is 3 km wide, has the thickest section of limestone (11 m) predominantly cross-bedded, and the cross-bedding is intercalated with burrowed horizons. The shoal and channel system is 10 km wide, but no more than 9 meters thick. The section here is predominantly mottled, with isolated outlying lenses of bedded facies, and, where the section intersects a channel, a vertically continuous section of cross-bedding. The open marine platform has the thinnest section of Miami Limestone, 6 meters or less, is laterally extensive, covering an area of about 500 sq.km., and characterized by peloidal sand and bryozoans. The names above the section refer to comparable environments from Joulter's Cays, Bahamas.

and the maximum elevation below sea level (5 meters) are also less than those found in the barrier bar.

The open marine platform contains the thinnest section of Miami Limestone (5-6 meters) and the least surface relief. The deposits of the open marine platform are readily distinguishable from those of the mobile oolitic belt both by the abundance of bryozoans and the lack of ooids.

CONCLUSIONS

1. The mobile oolitic belt of the Miami Limestone is divisible into two distinct facies on the basis of fabric and composition: a mottled facies and a bedded facies.

2. The distribution of the two oolitic facies in the shoal and channel system confirms the bar and channel origin of this morphology.

3. The distribution of the two oolitic facies in the barrier bar shows the bar to be a more complex feature than previously envisioned. The barrier bar is a composite feature which probably has its origin in coalescing ebbtidal deltas.

4. The mobile oolitic belt is not underlain by the open marine platform deposits of the bryozoan facies and must have grown in place rather than migrating bankward over open marine platform deposits as suggested by the previous model.

5. The three environments recognizable in the Miami Limestone on the basis of topography and facies patterns are directly comparable to those identified by Harris (1979) at Joulter's Cays, Bahamas.

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