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MIOGYPSINIDS (LARGER BENTHIC FORAMINIFERS) FROM THE MAYAGUANA FORMATION (EARLY MIOCENE), MAYAGUANA ISLAND, SE BAHAMAS

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ABSTRACT. For the first time in the Bahamas, larger benthic foraminifers of the Miogypsinidae family have been collected from surface exposures between sea level and +2 m. Based on biometric and comparative analyses, two species of *Miogypsina* SACCO and one species of *Miolepidocyclina* SILVERSTRI have been identified in a limestone succession exposed on Mayaguana Island, in the southeastern part of the Bahamas archipelago. These species include *Miogypsina globulina* (MICHELOTTI), *Miogypsina* cf. *intermedia* (DROOGER), and *Miolepidocyclina* cf. *burdigalensis* (GÜMBEL), indicating a Burdigalian age (Early Miocene) for these limestones. Moreover, the association of the described miogypsinids with small porcelaneous and hyaline benthic foraminifers indicates a semi-protected to open environment. The obtained biostratigraphic age of this limestone unit is further confirmed by ages based on Sr-isotope measurments.

By contrast, no other larger benthic foraminifer such as *Miogypsinoides* YABE & HANZAWA, *Lepidocyclina* GÜMBEL, and *Nephrolepidina* DOUVILLÉ commonly associated with the described species of miogypsinids has been observed. This peculiar absence suggests that the Mayaguana Bank was a micro-province within the American province.

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INTRODUCTION

For the first time in the Bahamas archipelago, larger benthic foraminifers belonging to the genera *Miogypsina* SACCO, *Miolepidocyclina* SILVESTRI, and *Sphaerogypsina* GALLOWAY have been identified in rock samples collected from surface exposures of an ancient limestone unit called the Mayaguana Formation, on Mayaguana Island, SE Bahamas (Godefroid, 2012). In the studied samples, these three taxa are associated with small benthic foraminifers with a calcareous test and likely thrived in an open, peri-reefal environment on the northern margin of the Mayaguana Bank.

Rock exposures predating the Middle Pleistocene were hitherto unknown in the Bahamas islands (Carew and Mylroie, 1985, 1995, 1997; Hearty and Kindler, 1993, 1997; Kindler and Hearty, 1995, 1997; Hearty and Kaufman, 2000), whereas samples collected from cores retrieved during relatively recent drilling campaigns, such as on Great Bahama Bank ("Bahamian Drilling Project"; Kenter et al., 2001; Eberli et al., 2001) or on San Salvador Island (Supko, 1977; Vahrenkamp et al., 1991), are no older than the Miocene-Pliocene boundary. Exposed rock units range between the Middle Pleistocene and the Holocene. They mostly comprise eolian sediments (Kindler and Hearty, 1995; Carew and Mylroie, 2001) and, to a lesser extent, reefal to peri-reefal deposits mostly dating from the last interglacial period (Marine Isotope Stage 5e, around 120 ka BP; Chen et al. 1991; White and Curran, 1995; White et al. 1998; White et al. 2001). Recent geological investigations on Mayaguana Island revealed the existence of four new lithostratigraphic units, essentially formed in a marine environment and ranging in age from the Early Miocene to the Early Pleistocene (Kindler et al., 2011; Godefroid, 2012). The stratigraphic framework of the archipelago has thus been revised and the lithological units discovered on Mayaguana have expanded our knowledge on the variety of fossil faunal associations that thrived in the Bahamas region (Godefroid, 2012).

In the American-Caribbean province, the occurrence of larger benthic foraminifers

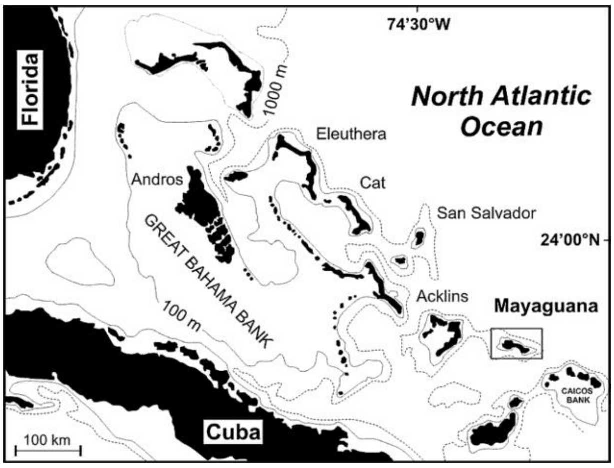

Figure 1. Geographical situation of the Bahamas and of Mayaguana Island in the southeastern part of the archipelago (modified from Godefroid, 2012).

(*Miogypsina* SACCO, *Miogypsinoides* YABE & HANZAWA, *Lepidocyclina* GÜMBEL, *Nephrolepidina* DOUVILLÉ, and *Amphistegina* d'ORBIGNY) is well known in the Lesser Antilles (Carriacou, Baumgartner et al., 2008), in Costa-Rica (Baumgartner et al., 2008), in the Dominican Republic (Serra-Kiel et al., 2007), in Jamaica (Robinson and Wright, 1993), and in Brasil (BouDagher-Fadel et al., 2010). The literature on the miogypsinids from this province is profuse (Barker and Grimsdale, 1936; Drooger, 1952; Cole, 1964, 1967), but sometimes puzzling due to the large number of identified species in a given locality. The difficulties inherent to species identification and the inconsistencies existing in the literature partly relate to the fact that the biological and environmental factors, which control foraminifer morphology, have often been disregarded with the use of biometric (Drooger, 1952, 1963; Raju, 1974) and statistic parameters (Cole, 1941, 1964, 1967) as strict criteria of determination. It follows that many newly identified species are actually morphological variants of a unique type-species.

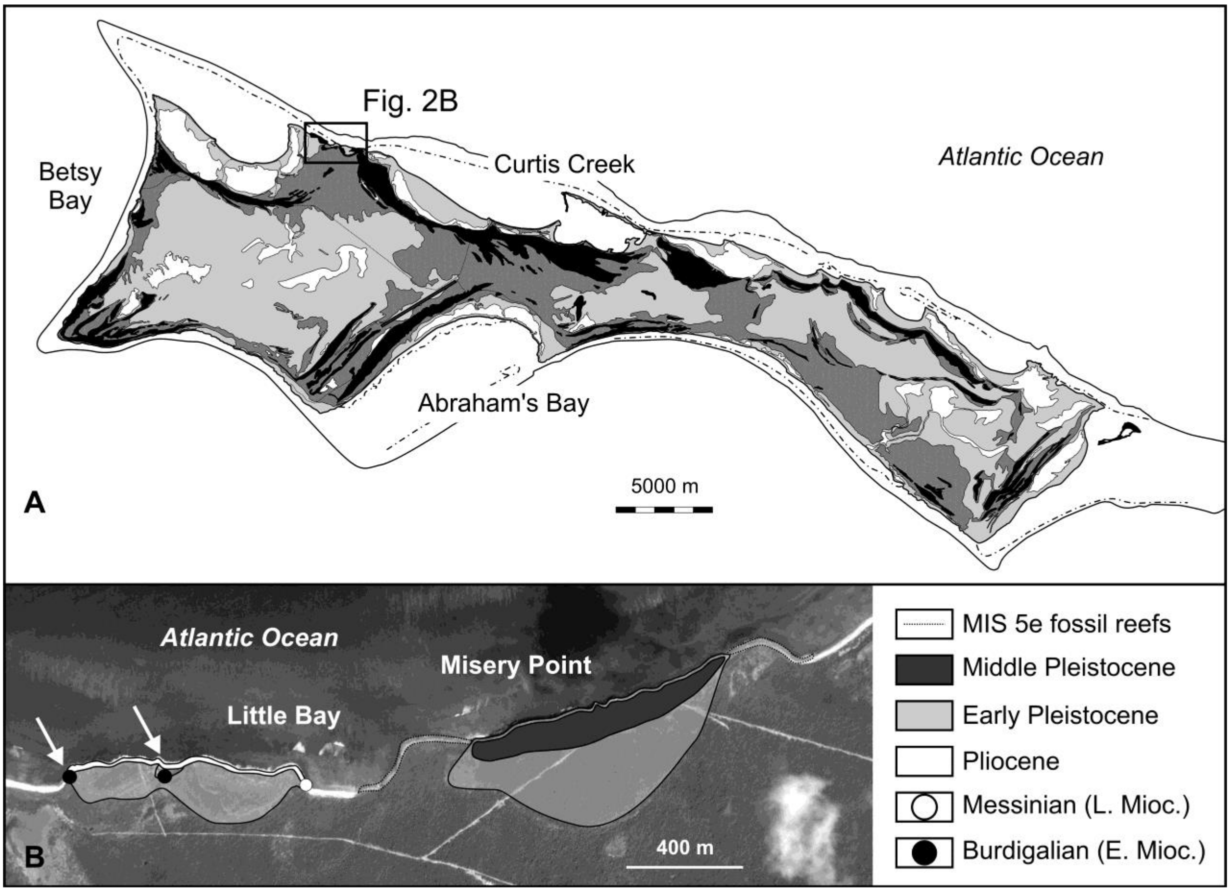

Figure 2. (A) Simplified topographic map of Mayaguana Island; black pattern = high ridges; dark grey pattern = low ridges; light grey pattern = lowlands; white pattern = lakes, ponds, and lagoons. (B) Geological map of the Little Bay - Misery Point area on the north coast of the island showing the location of the exposures of the Mayaguana Formation (full dots indicated by white arrows; modified from Godefroid, 2012).

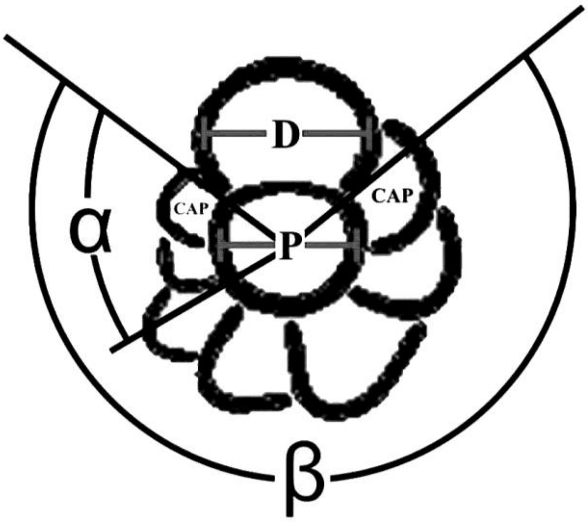

Figure 3. Sketch illustrating the ways of measuring the various structures forming the primitive stage of the nepiont that can be observed in equatorial sections (modified from Özcan et al., 2009). P: protoconch; D: deuteroconch; CAP: primary auxillary chambers; α: angle made by the smallest spire around the protoconch; β: angle made by both spires around the protoconch. Horizontal lines indicate the diameters of the protoconch and the deuteroconch, respectively.

This paper presents a detailed inventory of the larger benthic foraminifers found in the limestones of the Mayaguana Formation. Due to the scarcity of well-oriented sections in our preparations, species determinations are essentially based on the comparison of observed morphological criteria (size, test thickness, test shape, shape of equatorial chambers, size and number of pillars) with those recently described in the literature. Based on the observation of some good oblique equatorial sections, two species of *Miogypsina* were nonetheless identified and used for precisely dating the Mayaguana Formation. This biostratigraphic age was later corroborated by several ages derived from the measurement of Sr isotopes.

GEOLOGICAL SETTING

Mayaguana Island is located in the southeastern part of the Bahamas Archipelago (Figures 1 and 2A), and its geology has not been extensively studied until recently (Cant, 1977; Pierson, 1982; Godefroid, 2012). The Mayaguana Bank is a rectangular-shaped, isolated carbonate platform about 53 km long and 12 km wide. It stands within the same bathymetric contours as the Crooked-Acklins platform to the west, but is separated from the Inagua and Caicos banks to the east and south by the deep Caicos Passage (Figure 1). This bank comprises a ca. 4 km-thick Mesozoic to Cenozoic carbonate succession (Mullins and Lynts, 1977) that likely overlies stretched continental crust (Pindell and Kennan, 2009). The Mayaguana area is located in the vicinity of the Great Bahamian Escarpment and about 250 km away from the oblique subduction zone between the North American and the Caribbean plates. It includes the moderately active, sinistral, SW-NE trending Cauto Fault, which runs trough the Caicos Passage, and the N60W trending Sunniland Fracture Zone inherited from the Jurassic rifting phase related to the opening of the Atlantic Ocean (James, 2009). Early geological research on Mayaguana focused on the fossil coral reefs exposed all along the island shoreline (Cant, 1977) and on limestone and dolostone of Miocene to Pleistocene age obtained from core borings (Pierson, 1982; Vahrenkamp et al., 1991).

The present work is part of a larger study, which aimed at establishing the geological map of Mayaguana (Godefroid, 2012). This island comprises a total of eight lithostratigraphic units, four of which are not exposed elsewhere in the Bahamas (Kindler et al., 2011; Godefroid, 2012). These newly discovered units (Figure 2B; Godefroid, 2012) include moderately lithified grainstones and floatstones deposited in a peri-reefal setting (Misery Point Formation; Early Pleistocene), dolomitized coralgal framestone (Timber Bay Formation; Pliocene), hard microsucrosic dolostone (Little Bay Formation; Messinian), and foraminiferal grainstone-packstones (Mayaguana Formation; Burdigalian) which are further described below.

METHODS

Samples were collected with a hammer and chisel from the Mayaguana Formation.

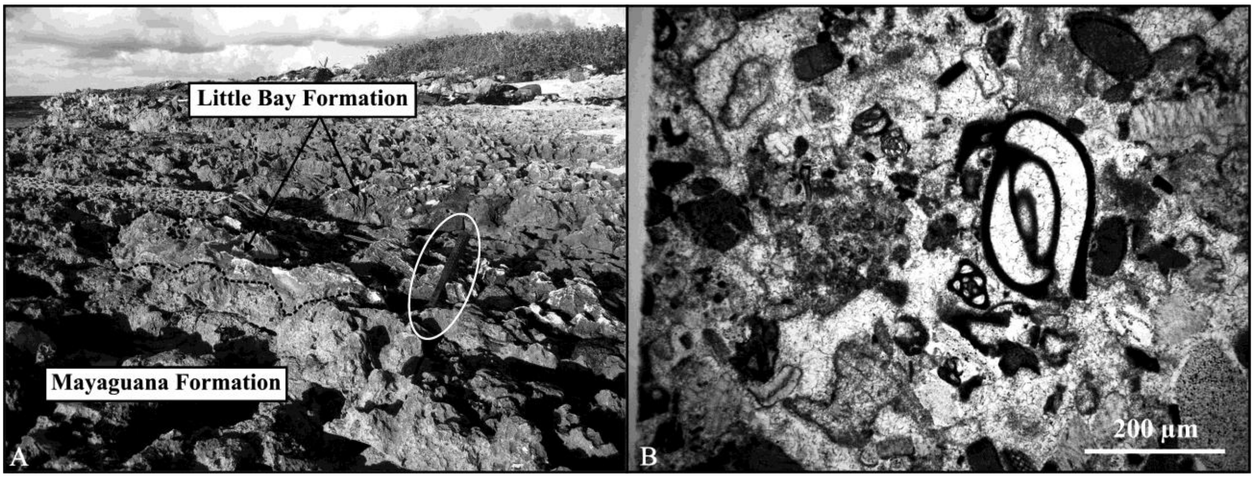

Figure 4. (A) Field view of the Little Bay headland showing the boundary between the Little Bay and the Mayaguana formations, dating respectively from the Messinian and the Burdigalian. Hammer (in white ellipse) for scale is 36 cm long. (B) Microfacies of the limestones of the Mayaguana Formation (Sample FAb 454).

Preliminary examination with a hand lens was performed in the field to select samples containing miogypsinids which present a typical three-layered structure. Several thin sections of standard (3 x 2 cm) and large (6.0 x 4.5 cm) size were produced for each sample. Rock fragments were cut into small cubes that were further ground down to reveal identifiable foraminifer sections, glued on a glass slide, and thin sectioned. Despite the large number of manufactured cubes (>50), no perfect equatorial section revealing the nepionic stage has been obtained.

The distinction between the different species of miogypsinids is essentially based on the morphology of the axial section and on the biometric parameters (Drooger, 1963) of oblique equatorial sections (Figure 3). Whenever possible the α and β angles were measured (Figure 3). The degree of symmetry of the two spirals around the protoconch and the deuteroconch, which is diagnostic of miogypsinid species, was calculated using the equation: $V = 200 \times \alpha/\beta$. The obtained V values were then compared with those reported in the literature. For the American-Caribbean province, species determination essentially relies on the studies of Drooger (1954) and Cole (1964, 1967), and, for comparative purposes, with the works of Brandano et al. (2007), BouDagher-Fadel (2008), Özcan et al. (2009a,b), and Sirel and Gedik (2011) achieved in the European and Indo-Pacific provinces.

RESULTS

The Mayaguana Formation

This heavily karstified unit is exposed along the north coast of Mayaguana Island, at several locations along the Little Bay headland (coordinates: western outcrop: N22°26.531’, W73°03.790’; eastern outcrop: N22°26.359’, W73°03.435’; central outcrop: N22°26.651’, W73°03.644’; Figures 2B and 4A). The formation is about 2 m thick and is readily identified by its calcareous nature and greyish alteration color. Its lower boundary likely occurs below sea level and has not been observed, but its upper boundary corresponds to a sharp karstic surface, infilled and overlain by the Messinian dolostones of the Little Bay Formation (Figure 4A). In thin section, the Mayaguana Formation reveals well-preserved packstones/grainstones with abundant hyaline and porcelaneous benthic foraminifers (Figure 4B). Other allochems include red-algae, mollusc and coral fragments. Constituent grains are bound by widespread low-Mg calcite cement, comprising an early generation of isopachous rims and a late phase of drusic spar. Alveolar septal structures of uncertain origin (microbial, pedogenic) can locally be observed. They are always associated with micritic zones.

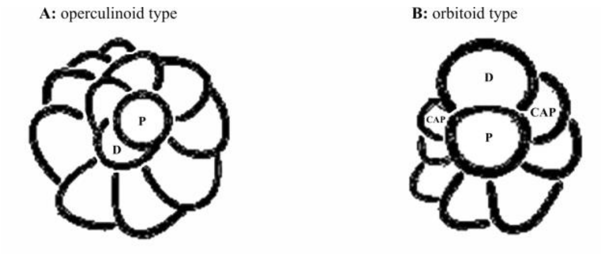

Figure 5. (A) Sketch of the coiling of peri-embryonic chambers in monospiraled forms of the genus Miogypsina*. Note that it surrounds totally, or almost totally, the protoconch (P) and the deuteroconch (D). (B) Sketch of the arrangement of primary auxillary chambers (CAP) around the protoconch and the deuteroconch in a bispiraled form of the genus* Miogypsina.

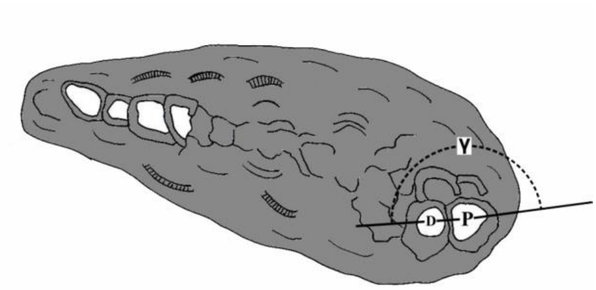

Figure 6. Sketch (not to scale) of an oblique equatorial section of Miogypsina cf. intermedia *(Pl. II, fig. C) showing part of the nepiont chambers and the non-significant position of the angle γ = 175°. P: protoconch; D = deuteroconch.*

Micropaleontological Determinations and Faunal Inventory

As mentioned above, the difficulties in determining miogypsinids at species level are linked to the quality of obtained sections. In our case, most acquired sections are axial, and exploitable equatorial sections are unfortunately rare. The latter are indeed necessary to determine the coiling of the nepiont and to mesure biometric parameters used for a precise determination.

Definition of the genera *Miogypsina* and *Miolepidocyclina*

From a biostratigraphic view point, the genera *Miogypsina* and *Miolepidocyclina* indicate the Early Miocene. However, to refine the dating of the Mayaguana Formation, it is essential to identify these taxa at species level.

The genus *Miogypsina* is characterized by the presence of lateral chambers, when compared to the genus *Miogypsinoides*, and by peripheral to subperipheral embryonic chambers that can be mono- or bispiraled (Cole, 1967). The first peri-embryonic chamber of monospiraled forms presents a stolon at its base (Figure 5A). The coiling of peri-embryonic chambers surrounds totally, or almost totally, the protoconch and the deuteroconch. Monospiraled forms usually have relatively thick embryonic walls. Bispiraled forms comprise two peri-embryonic chambers, each of which are located at the interstice between the protoconch and the deuteroconch. In these forms, the first peri-embryonic chambers totally surround the protoconch (Figure 5B).

The genus *Miolepidocyclina* is characterized by the position of the embryo which can be centered to subcentered. The embryo can be both micro- and megalospherical. In this study, no *Miolepidocyclina* species comprises a juvenarium. Therefore, species determination relies on the geometrical arrangement of equatorial chambers observed in axial sections.

Systematics

Order Foraminiferida EICHWALD, 1830
Family Miogypsinidae VAUGHAN, 1928
Genus *Miogypsina* SACCO, 1893

Type species: *Miogypsina intermedia* DROOGER, 1952

***Miogypsina* cf. *intermedia* DROOGER, 1952**
Fig. 6; Pl. I, figs. A-E

1967. *Miogypsina (Miogypsina) antillea* (CUSHMAN). - Cole, pl. 26, figs. 6,7, p. 335.
2010. *Miogypsina intermedia* (DROOGER).- BouDagher-Fadel and Price, pl. 3, figs. 23, 24, pl. 4, figs. 4-9.

Description: monospiraled species. One single, oblique equatorial section (Figure 6) allowed a more precise determination. In the studied assemblage, the tests are biconvex to plano-convex in axial sections, and measure between 1 and 2.8 mm in length, and between 0.5 and 1.0 mm in thickness. The tests may sometimes be inequally biconvex as the thickest portion is shifted towards the periphery. The regulary spaced pustules have a surface diameter between 32 and 112 µm. The nepionic stage is composed of about 6 to 7 chambers. The chambers of the neanic stage are subrounded to spatulate and comprise small stolons at their base. In axial sections, the chambers of the equatorial layer, numbering between 8 and 14, have a subrectangular shape in the center, with a diameter of ca. 60 µm, and are spatulate to ogive-shaped in the periphery, with a maximum diameter of 115 µm. Lateral layers comprise between 3 and 5 chamber intervals, depending upon the specimens.

The specimen sketched in Figure 6 is the most representative one. It measures 1’470 µm in length, and its maximum thickness reaches 580 µm. The thickness of the nepiont walls indicates the occurrence of one single whorl around the protoconch. The respective diameters of P and D are 94 and 109 µm, with a D/P ratio equalling 1.25. These biometric values as well as these morphologic descriptions can be matched with those of Drooger (1952) and identify this species as *M.* cf. *intermedia*.

Type species: *Nummulina globulina* MICHELOTTI, 1841

Miogypsina globulina (MICHELOTTI), 1959

Fig. 7 A; Fig. 8; Pl. I, figs. F-H; Pl. II, figs. A, B

1959. *Miogypsina globulina* (MICHELOTTI).- Drooger and Socin, pl. 1, figs 5, 6.
2005. *Miogypsina globulina* (MICHELOTTI).- Boudagher-Fadel and Lockier, pl. 3, fig. 2.
2007. *Miogypsina globulina* (MICHELOTTI).- Daneshian and Dana, p. 851, fig 6, n° 6-7.
2010. *Miogypsina globulina* (MICHELOTTI).- Matsumaru et al. p. 455, pl. 4, fig 5.

Description: **bispiraled species.** The determination of *M. globulina* exclusively relies on the observation of axial to oblique equatorial sections. Observed specimens are of moderate to

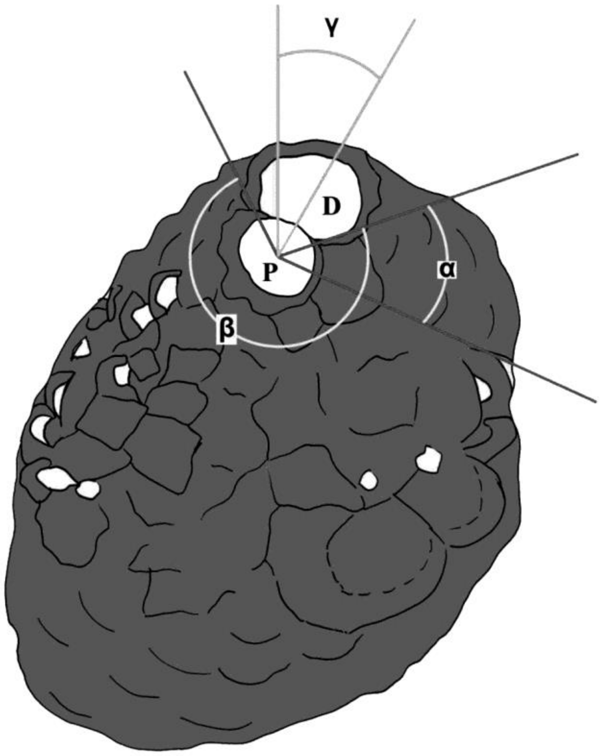

Figure 7. Sketch (not to scale) of an oblique equatorial section of Miogypsina globulina *showing the various biometric parameters: the respective diameters of P and D amount to 127 and 170 µm, with D/P = 1.34; β = 265°, α = 45°, and γ = +28°. The obtained value of V = 34.*

large size and measure between 770 and 1’650 µm in length from the apical line to the line on the opposite side of the section. Characterized by relatively thick walls, the protoconch appears to be spherical in shape, whereas the deuteroconch is larger and slightly subspherical. The test shape in oblique equatorial sections is rounded to subtriangular. In axial section, lateral layers contain 5 to 6 chamber intervals. Pillars are well marked, regularly spaced, and present thicknesses between 42 and 161 µm. The number of chambers in the equatorial layer of this species (viewed in axial section) is larger than 14, i.e. greater than in the case of *Miogypsina* cf. *intermedia*. The wall of the various chambers shows a relatively pronounced thickening. Angle values (Figures 7 and 8) correspond to those measured on the species *M. globulina*, according to the data of Drooger and Socin (1959), Brandano et al. (2007; Tab. 2, p. 125), and Özcan et al. (2009a).

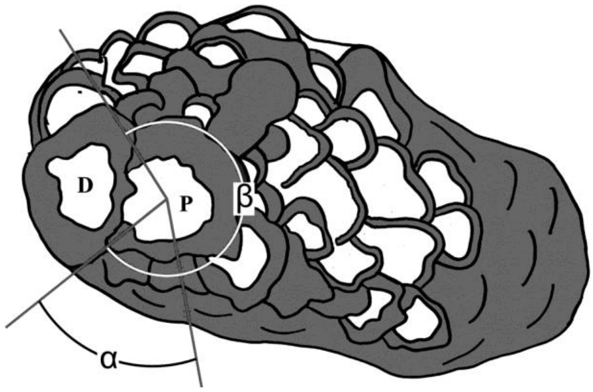

Figure 8: Sketch (not to scale) of another slightly oblique equatorial section of Miogypsina globulina *showing the various biometric parameters: the respective diameters of P and D amount to 127 and 159 µm, with D/P = 1.25; α = 62° and β = 263°, giving a value for V of 47.*

***Miogypsina* sp. indet. 1**
Pl. II, figs. C, D

Description: In axial sections, tests are ovoid, robust, and biconvex. They range between 1.5 and 2.5 mm in length, and between 0.968 and 0.594 mm in maximum width. Lateral layers are composed of 4 to 5 series of chambers characterized by very thick walls. Chambers of the equatorial layer, which measures about 62.5 µm in thickness, are sub-square to square in shape. Their morphology changes to spatulate in the test periphery. The position of the juvenarium could not be identified on these specimens. Some barely visible pillars have been observed.

***Miogypsina* sp. indet. 2**
Pl. II, fig. E

Description: In axial sections, the test is sub-rectangular to ovoid, 1.3 mm long, and 0.7 mm wide. Three layers of lateral chambers have been observed. These are rectangular-shaped and stacked on the top of each other. The equatorial layer shows a constant thickness of about 100 µm. Associated chambers are equidimensional and rectangular to square in shape. The lateral layers are crosscut by numerous, regularly spaced pillars. The position of the juvenarium could not be identified on these specimens.

***Miogypsina* sp. indet. 3**
Pl. II, fig. F

Description: This specimen is relatively small, robust, and biconvex to plano-convex. It measures about 800 µm in length and 400 µm in width. The length/width ratio is always close to 2. It comprises two series of lateral chambers with thick walls that are crosscut by some robust pillars with a superficial diameter of 33 µm. The thickness of the equatorial layer measures 50 µm, and equatorial chambers are spatulate.

Genus *Miolepidocyclina* SILVESTRI, 1907

Type species: *Orbitoides burdigalensis* GÜMBEL, 1870

***Miolepidocyclina* cf. *burdigalensis* (GÜMBEL) 1870**
(Pl. II, fig. G)

1952. *Miogypsina (Miolepidocyclina) burdigalensis* (GÜMBEL), Drooger, p. 66, 67.
1954. *Miogypsina (Miolepidocyclina) burdigalensis* (GÜMBEL), Drooger, p. 236.
2007. *Miolepidocyclina burdigalensis* (GÜMBEL), Daneshian and Dana, fig. 6, n° 14.
2009. *Miolepidocyclina burdigalensis* (GÜMBEL), Özcan and Less, Pl. 1, figs. 30, 31.

Description: The determination was made on an off-centered axial section, based on the test dimensions and the arrangement of the equatorial chambers. This is a very large (4.5 mm in diameter), biconvex specimen with slightly pinched edges. The equatorial layer presents a relatively constant thickness of about 100 µm. The chambers of this layer are circular in the center, and become largely spatulate and ogive-shaped in the periphery. The lateral layers are composed of 5 to 6 series of chambers, which are crosscut by numerous, irregularly spaced pillars. The superficial thickness of the pillars varies between 50 and 160 µm.

Descriptions provided by Drooger (1954) show specimens characterized by a juvenile stage in both a normally central and an occasionally

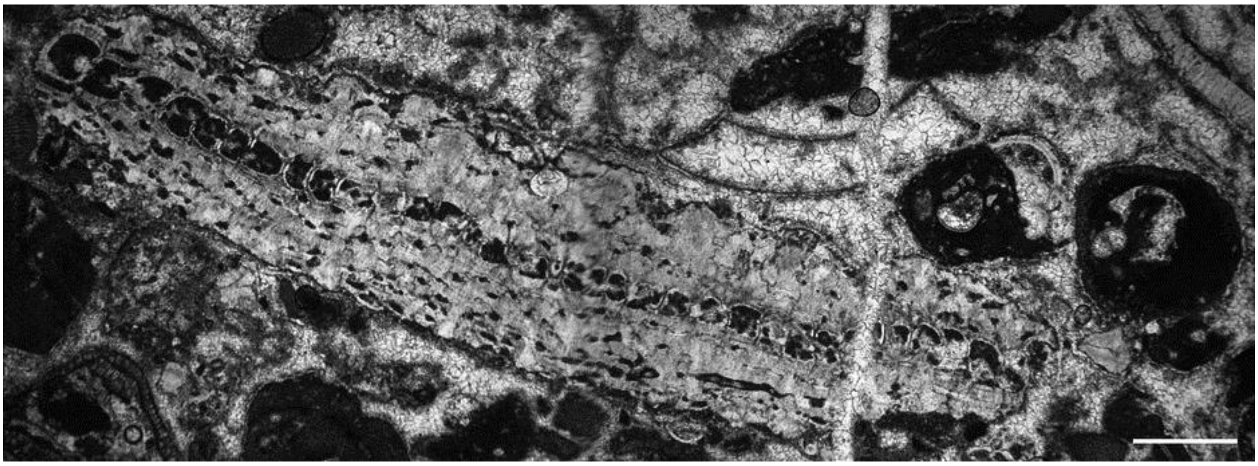

Figure 9. Axial section of Miolepidocyclina sp. *Sample FAb 454 collected from the western end of the Little Bay headland at the elevation of +0.5 m. Scale bar is 500 µm.*

peripheral position. The symmetry of equatorial chambers, with respect to the center of the equatorial layer, indicates the genus *Miolepidocyclina*. The morphological characteristics of our specimen compare well with specimens illustrated in the literature (refer to synonymy) as *M.* cf. *burdigalensis*.

***Miolepidocyclina* sp. indet.**

Fig. 9

Description: The test (Figure 9) is very long (5.2 mm) and slightly biconvex. Its width reaches 1 mm. The lateral layers include 5 to 6 series of curved chambers that are up to 400 µm wide. The thickness of the equatorial layer varies laterally. It is 100 µm thick in the middle of the test and 266 µm thick in the periphery. The chambers of this layer are rectangular in the middle of the test and spatulate to sub-spherical on the apical and actinal edges. Pillars are well expressed, and the thickest ones have a superficial diameter of 100 µm. The equatorial layer is slightly deformed in the middle of the test at the probable position of the juvenarium. This morphological characteristic is typical of the genus *Miolepidocyclina*.

DISCUSSION

Depositional Environment of the Mayaguana Formation

The limestones of the Mayaguana Formation were very likely deposited in a reefal to lagoonal environment, as indicated by the presence of numerous branched red-algal fragments and benthic foraminifers in thin sections. The identified species of miogypsinids essentially characterized peri-reefal settings (e.g., fore-reef or back-reef; Boudagher-Fadel and Price, 2013), whereas branched coralline algae thrive on lagoon floors. The larger benthic foraminifers have thus been reworked in a more proximal (internal) position with respect to their life habitat. The local occurrence of micrite in thin sections, and the lack of sedimentary structures on the exposed rocks, further indicate a moderate- to low-energy hydrodynamic setting for the Mayaguana Formation.

Age and Provincialism

The occurrence of the species *Miogypsina globulina*, *M.* cf. *intermedia,* and *Miolepidocyclina* cf. *burdigalensis* indicates a Burdigalian age (Early Miocene) for the samples. This age is consistent with Sr-isotope data obtained by Godefroid (2012) that gave an age between 18.4 and 18.7 Ma for the Mayaguana Formation (mean $^{87}Sr/^{86}Sr$ ratio = 0.708546±0.000007). Using a different method (foraminiferal biostratigraphy), our study confirms that this formation is, by far, the oldest stratigraphic unit uncovered so far on Mayaguana Island, and for that matter in the entire Bahamas Archipelago.

From a micropaleontological viewpoint, the absence of *Miogypsina cushmani*, *M. mexicana*, and of species belonging to the genera *Miogypsinoides*, *Nephrolepidina* and *Eulepidina*, which are usually associated with the species described in this paper (Boudagher-Fadel and Price, 2013), suggests that the Mayaguana Bank was an isolated faunal sub-province. The aforementioned association of larger benthic foraminifers is indeed well known in Jamaica, Cuba, Panama, and Brasil, but also in the Mediterranean and Indo-Pacific provinces (Boudagher-Fadel and Price, 2013). Their absence on the Mayaguana Bank emphasizes the lack of faunal mixing between the North and South American continents and this platform in the Burdigalian, despite their geographic proximity. The peculiar foraminiferal association observed in the Mayaguana Formation identifies this platform as a micro-province where only a limited number of species of larger benthic foraminifers were able to thrive.

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REFERENCES

Barker, R.W., and Grimsdale, T.F., 1936, A contribution to the phylogeny of the orbitoidal foraminifera, with descriptions of new forms from the Eocene of Mexico: Journal of Paleontology, v. 10, p. 231-247.

Baumgartner-Mora, C., Baumgartner, P.O., and Tschudin, P., 2008, Late Oligocene larger foraminifera from Nosara (Nicoya Peninsula, Costa Rica) and Windward (Carriacou, Lesser Antilles) calibrated by ^{87}Sr/^{86}Sr isotope stratigraphy: Revista Geológica de América Central, v. 38, p. 33-52.

BouDagher-Fadel, M.K, 2008, Evolution and geological significance of larger benthic foraminifera: Developments in Paleontology and Stratigraphy, v. 21, Elsevier, Amsterdam, 544 p.

BouDagher-Fadel, M.K., and Lokier, S.W., 2005, Significant Miocene larger foraminifera from South Central Java: Revue de Paléobiologie, v. 24, p. 291-309.

BouDagher-Fadel, M.K., and Price, G.D., 2010, American Miogypsinidae: an analysis of their phylogeny and biostratigraphy: Micropaleontology, v. 56, p. 567-586.

Boudagher-Fadel, M. K., and Price, G. D., 2013, The phylogenetic and palaeogeographic evolution of the miogypsinid larger benthic foraminifera: Journal of the Geological Society, v. 170, p. 185-208.

BouDagher-Fadel, M.K., Price, G.D., and Koutsoukos, E.A.M., 2010, Foraminiferal biostratigraphy and paleoenvironments of the Oligocene-Miocene carbonate succession in the Campos Basin, southeastern Brazil: Stratigraphy, v. 7, p. 283-299.

Brandano, M., Giannini, E., Schiavinotto, F., and Verrubbi, V., 2007, *Miogypsina globulina* (Michelotti) from the lower Miocene Villa S. Lucia Section (Mte Cairo - Central Apennines): Geologica Romana, v. 40, p. 119-127.

Cant, R.V., 1977, Role of coral deposits in building the margins of the Bahama banks, *in* Taylor, D.L., ed., Proceedings of the Third International Coral Reef Symposium, Miami, Florida, v. 2, p. 9-13.

Carew, J.L., and Mylroie, J.E., 1985, The Pleistocene and Holocene stratigraphy of San Salvador Island, Bahamas, with reference to marine and terrestrial lithofacies at French Bay, *in* Curran, H.A., ed., Pleistocene and Holocene carbonate environments on San Salvador Island, Bahamas: Geological Society of America, Orlando Annual Meeting Field Trip #2, Ft. Lauderdale, FL, CCFL Bahamian Field Station, p. 11-61.

Carew, J.L., and Mylroie, J.E., 1995, Depositional model and stratigraphy for the Quaternary geology of the Bahama Islands, *in* Curran, H.A., and White, B., eds, Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda: Geological Society of America Special Paper, v. 300, p. 5-32.

Carew, J.L., and Mylroie, J.E., 1997, Geology of the Bahamas, *in* Vacher, H.L., and Quinn, T.M., eds, Geology and hydrogeology of carbonate islands: Developments in Sedimentology, v. 54, p. 91-139.

Carew, J.L., and Mylroie, J.E., 2001, Quaternary carbonate eolianites of the Bahamas: useful analogs for the interpretation of ancient rocks?, *in* Abegg, E.F., Loope, D.B., and Harris P.M., eds., Modern and Ancient Carbonate Eolianites: Sedimentology, Sequence Stratigraphy and Diagenesis: SEPM Special Publication, v. 71, p. 33-45.

Chen, J.H., Curran, H.A., White, B., and Wasserburg, G.J., 1991, Precise chronology of the last interglacial period: ^{234}U-^{230}Th data from fossil coral reefs in the Bahamas: Geological Society of America Bulletin, v. 103, p. 82-97.

Cole, W. S., 1941, Stratigraphic and paleontologic studies of wells in Florida: Florida Geological Survey Bulletin, v. 19, p. 1-53.

Cole, W. S., 1964, Problems of the geographic and stratigraphic distribution of American middle Eocene larger foraminifera: Bulletin of American Paleontology, v. 47, p. 5-36.

Cole, W. S., 1967, A review of American species of Miogypsinids (Larger Foraminifera): Contributions from the Cushman Foundation for Foraminiferal Research, v. 18, p. 99-117.

Daneshian, J., and Dana, L.R., 2007, Early Miocene benthic foraminifera and biostratigraphy of the Qom Formation, Deh Namak, Central Iran: Journal of Asian Earth Sciences, v. 29, p. 844-858.

Drooger, C.W., 1952, Study of American Miogypsinidae: Unpublished Ph.D. dissertation, University of Utrecht, 80 pp.

Drooger, C.W., 1954, *Miogypsina* in Northern Italy: Proceedings of the Koninkijke Nederlandse akademie van Wetenschappen, v. 57, p. 227-249.

Drooger, C.W., 1963, Evolutionary trends in the Miogypsinidae, *in* Elsevier, ed., Evolutionary Trends in Foraminifera: A collection of papers dedicated to I.M. van der Vlerk on the occasion of his 70th birthday, p. 315-349.

Drooger, C.W., and Socin, C., 1959, Miocene Foraminifera from Rosignano, Northern Italy: Micropaleontology, v. 5, p. 415-426.

Eberli, G.P., Anselmetti, F.S., Kenter, J.A.M., McNeil, D.F., and Melim, L.A., 2001, Calibration of seismic sequence stratigraphy with cores and logs, *in* Ginsburg, R.N., ed, Subsurface geology of a prograding carbonate platform margin, Great Bahama Bank: results of the Bahamas Drilling Project: SEPM Special Publication, v. 70, p. 241-266.

Godefroid, F., 2012, Géologie de Mayaguana, SE de l'archipel des Bahamas: Terre & Environnement, v. 108, 230 p.

Gümbel, C.W., 1870, Beiträge zur Foraminiferenfauna der nordalpinen Eozängebilde oder der kressenberger Nummuliten Schisten: Abhandlungen der Matematisch-Physikalischen Classe der Königlich Bayerischen Akademie der Wissenschaften, v. 10, p. 581-720.

Hearty, P.J., and Kaufman, D.S., 2000, Whole-rock aminostratigraphy and Quaternary sea-level history of the Bahamas: Quaternary Research, v. 54, p. 163-173.

Hearty, P.J., and Kindler, P., 1993, New perspectives on Bahamian geology: San Salvador Island, Bahamas: Journal of Coastal Research, v. 9, p. 577-594.

Hearty, P.J., and Kindler, P., 1997, The stratigraphy and surficial geology of New Providence and surrounding islands, Bahamas: Journal of Coastal Research, v. 13, p. 798-812.

James, K.H., 2009, Evolution of Middle America and the in situ Caribbean Plate Model, *in* James, K.H., Lorente, M.A., and Pindell, J.L, eds., The origin and evolution of the Caribbean Plate: Geological Society, London, Special Publications, v. 328, p. 127-138.

Kenter, J.A.M., Ginsburg, R.N., and Troelstra, S.R., 2001, Sea-level-driven sedimentation patterns on the slope and margin, *in* Ginsburg, R.N., ed., Subsurface geology of a prograding carbonate platform margin, Great Bahama Bank: results of the Bahamas Drilling Project: SEPM Special Publication, v. 70, p. 61-100.

Kindler, P., Godefroid, F., Chiaradia, M., Ehlert, C., Eisenhauer, A., Frank, M., Hasler, C.-A., and Samankassou, E., 2011, Discovery of Miocene to lower Pleistocene deposits on Mayaguana, Bahamas: evidence for recent active tectonism on the North American margin: Geology, v. 39, p. 523-526.

Kindler, P., and Hearty, P.J., 1995, Pre-Sangamonian eolianites in the Bahamas? New evidence from Eleuthera Island: Marine Geology, v. 127, p. 73-86.

Kindler, P., and Hearty, P.J., 1997, Geology of the Bahamas: architecture of Bahamian islands, *in* Vacher, H.L., and Quinn, T.M., eds, Geology and hydrogeology of carbonate islands: Developments in Sedimentology, v. 54, p. 141-160.

Matsumaru, K., Sari, B., and Özer, S., 2010, Larger foraminiferal biostratigraphy of the middle Tertiary of Bey Daglari Autochton, Menderes-Taurus Platform, Turkey: Micropaleontology, v. 56, p. 439-463.

Michelotti, G., 1841, Saggio storico dei Rizopodi caratteristici dei terreni sopracretacei: Memorie di matematica e di Fisica della Società Italiana delle Scienze, v. 22, p. 253-302.

Mullins, H.T., and Lynts, G.W., 1977, Origin of the northeastern Bahama Platform: review and reinterpretation: Geological Society of America Bulletin, v. 88, p. 1447-1461.

Özcan, E., and Less, G., 2009, First record of the co-occurrence of Western Tethyan and Indo-Pacific larger foraminifera in the Burdigalian of the Mediterranean province: Journal of Foraminiferal Research, v. 39, p. 23-39.

Özcan, E., Less, G., and Baydogan, E., 2009a, Biometric analysis of lower Miocene larger foraminifera (Family Miogypsinidae, Lepidocyclinidae and Nummulitidae) from central Turkey: implications on regional geology: Micropaleontology, v. 55, p. 559-588.

Özcan, E., Less, G., Baldi-Beke, M., Kollanyi, K., and Acar, F., 2009b, Oligo-Miocene foraminiferal record (Miogypsinidae, Lepidocyclinidae and Nummulitidae) from the Western Taurides (SW Turkey): Biometry and implications for the regional geology: Journal of Asian Earth Sciences, v. 34, p. 740-760.

Pierson, B.J., 1982, Cyclic sedimentation, limestone diagenesis and dolomitization in upper Cenozoic carbonates of the southeastern Bahamas: Unpublished Ph.D. thesis, University of Miami, Miami, Florida, USA, 286 p.

Pindell, J.L., and Kennan, L., 2009, Tectonic evolution of the Gulf of Mexico, Caribbean and northern South America in the mantle reference frame: an update, *in* James, K.H., Lorente, M.A., and Pindell, J.L, eds., The origin and evolution of the Caribbean Plate: Geological Society, London, Special Publications, v. 328, p. 1-55.

Raju, D.S.N., 1974, Study of Indian Miogypsinidae: Utrech Micropaleontological Bulletin, v. 9, p. 1-148.

Robinson, E., and Wright, R.M., 1993, Jamaican Paleogene larger foraminifera, *in* Wright, R.M., and Robinson, E., eds., Biostratigraphy of Jamaica: Geological Society of America Memoir, n° 182, p. 283-345.

Serra-Kiel, J., Ferrandez-Canadell, C., Garcia-Senz, J., and Hernaiz Huerta, P.P., 2007, Cainozoic larger foraminifers from Dominican Republic: Boletin Geologico y Minero, v. 118, p. 359-384.

Sirel, E., and Gedik, F., 2011, Postmiogypsinella, a new Miogypsinidae (Foraminifera) from the Late Oligocene in Malatya Basin, Turkey: Revue de Paléobiologie, v. 30, p. 591-603.

Supko, P.R., 1977, Subsurface dolomites, San Salvador, Bahamas: Journal of Sedimentary Petrology, v. 47, p. 1063-1077.

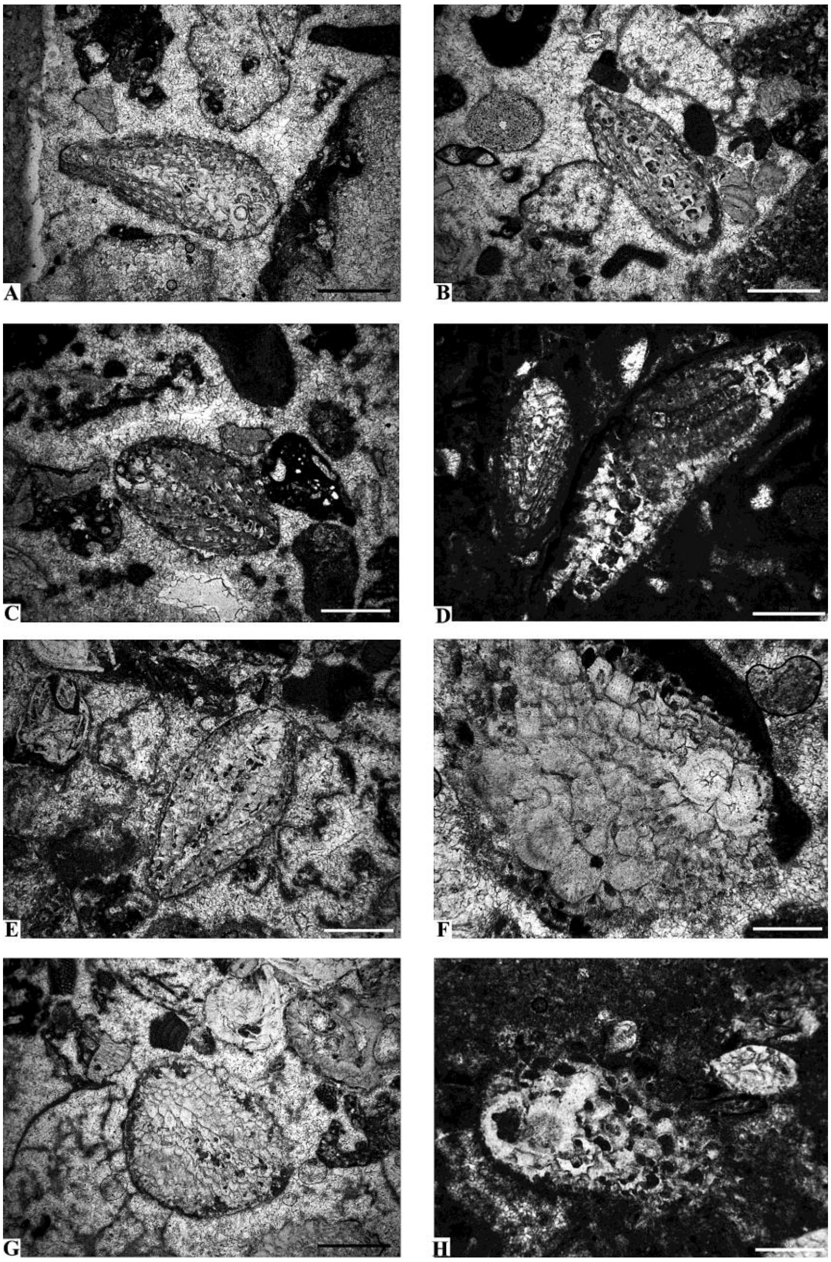
Vahrenkamp, V.C., Swart, P.K., and Ruiz, J., 1991, Episodic dolomitization of Late Cenozoic carbonates in The Bahamas: evidence from strontium isotopes: Journal of Sedimentary Petrology, v. 61, p. 1002-1014.

White, B., and Curran, H.A., 1995, Entombment and preservation of Sangamonian coral reefs during glacioeustatic sea-level fall, Great Inagua Island, Bahamas, *in* Curran, H.A., and White, B., eds., Terrestrial and Shallow Marine Geology of the Bahamas and Bermuda: Geological Society of America Special Paper, v. 300, p. 51-61.

White, B., Curran, H.A., and Wilson, M.A., 1998, Bahamian coral reefs yield evidence of a brief sea-level lowstand during the Last Interglacial: Carbonates and Evaporites, v. 13, p. 10-22.

White, B., Curran, H.A., and Wilson, M.A., 2001, A sea-level lowstand (Devil's Point Event) recorded in Bahamian reefs: comparison with other last interglacial climate proxies, *in* Greenstein, B.J., and Carney, C.K., eds., Proceedings of the Tenth Symposium on the Geology of the Bahamas and Other Carbonate Regions: Gerace Research Center, p. 111-131.

PLATE 1



A: Oblique axial section of *Miogypsina intermedia* (DROOGER). Sample FAb 509 coming from the West of Little Bay at an elevation of +1 m. Scale bar is 500 µm.

B: Axial section of *M. intermedia* (DROOGER). Sample FAb 509 coming from the West of Little Bay at an elevation of +1 m. Scale bar is 500 µm.

C: Axial section of *M. intermedia* (DROOGER). Sample FAb 509 coming from the West of Little Bay at an elevation of +1 m. Scale bar is 500 µm.

D: Two specimens of *M. intermedia* (DROOGER). On the left, oblique axial section of a slighty biconvex form, and, on the right right, a plano-convex form viewed in off-centered axial section. Sample FAb 454 coming from the West of Little Bay at an elevation of +0.5 m. Scale bar is 500 µm.

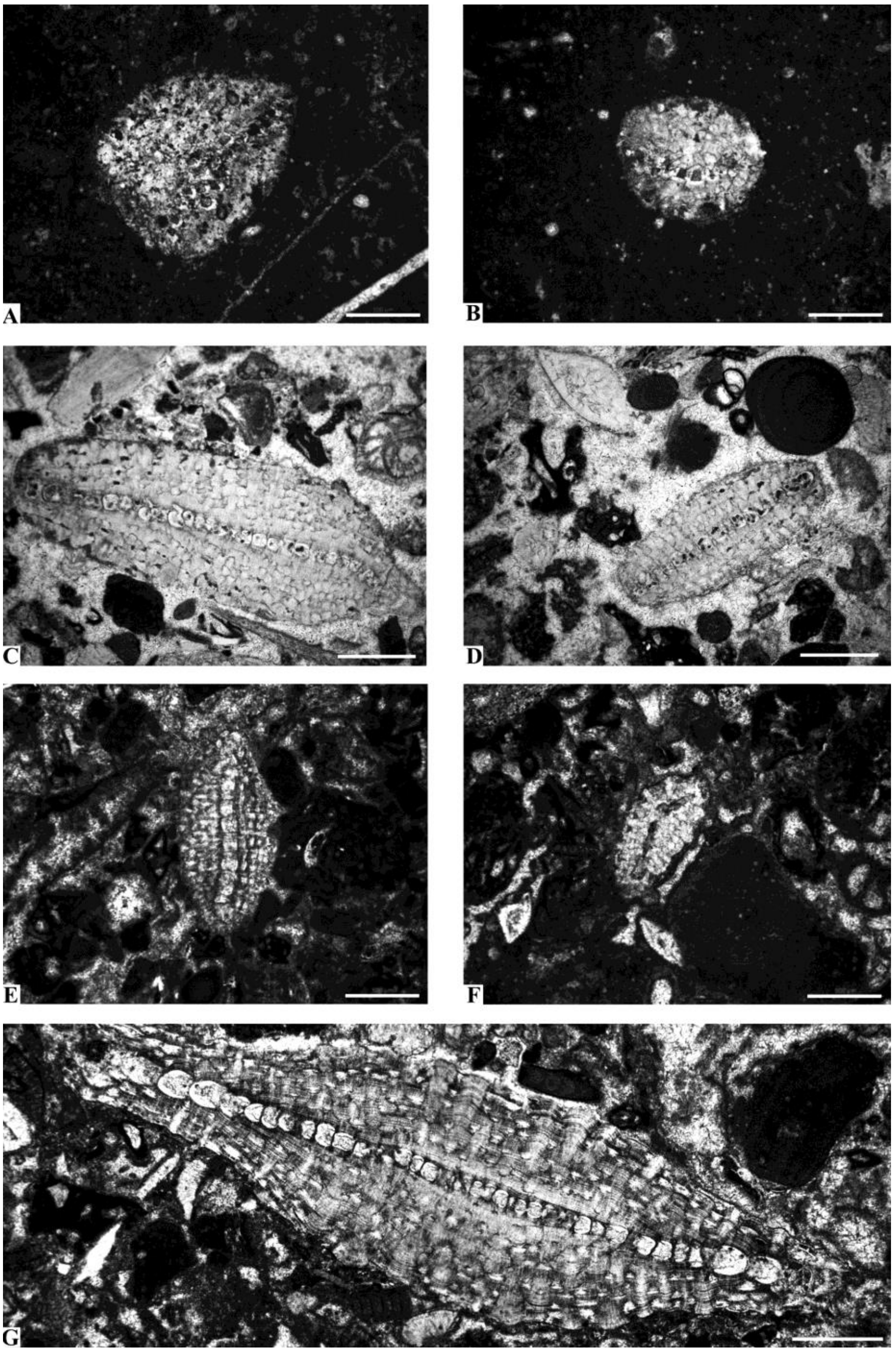
E: Oblique axial section of *M. intermedia* (DROOGER). Sample FAb 454 coming from the West of Little Bay at an elevation of +0.5 m. Scale bar is 500 µm.

F: Slighty oblique equatorial section of *Miogypsina globulina* (MICHELOTTI). Sample FAb 509 coming from the West of Little Bay at an elevation of +1 m. Scale bar is 200 µm.

G: Slighty oblique equatorial section of *M. globulina* (MICHELOTTI). Sample FAb 509 coming from the West of Little Bay at an elevation of +1 m. Scale bar is 500 µm.

H: Slighty oblique equatorial section of *M. globulina* (MICHELOTTI). Sample FAb 454 coming from the West of

PLATE 2



Scale bar is 500 µm for all figures.

A: Oblique and off-centered equatorial section of *M. globulina* (MICHELOTTI). Sample FAb 454 coming from the West of Little Bay at an elevation of +0.5 m.

B: Off-centered equatorial section of *M. globulina* (MICHELOTTI). Sample FAb 454 coming from the West of Little Bay at an elevation of +0.5 m.

C and D: Axial sections of *Miogypsina* sp. indet. 1. Sample FAb 509 coming from the West of Little Bay at an elevation of +1 m.

E: Axial section of *Miogypsina* sp. indet. 2. Sample FAb 454 coming from the West of Little Bay at an elevation of +0.5 m.

F: Slighty off-centered axial section of *Miogypsina* sp. indet. 3. Sample FAb 454 coming from the West of Little Bay at an elevation of +0.5 m.

G: Axial section of *Miolepidocyclina* cf. *burdigalensis* (GÜMBEL). Sample FAb 454 coming from the West of Little Bay at an elevation of +0.5 m.