Géologie de Mayaguana, SE de l'archipel des Bahamas

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Extended abstract

The Bahamas archipelago is well known because its carbonate platforms have registered glacio-eustatic changes since the Cenozoic. The study of the northern Bahamian platforms (Great and Little Bahama Banks) has produced numerous data concerning the surface and subsurface geology at a regional scale. At a global scale, these studies led to reconstruct the sea-level history and to understand the dynamics of the polar ice-sheets. Indeed, detailed investigations of the fossil reefs, coastal deposits, and paleosols exposed on these islands bring direct information on past climate changes and sea-level fluctuations. By contrast, the southeastern Bahamian islands have up to now not been investigated in details and this work is one of the first attempts to bridge this gap.

We focused our study on the island of Mayaguana. Located near the NW-SE trending Bahama Escarpment, but about 250 km away from the zone of important earthquake activity and major interplate motion of the NCPBZ, the Mayaguana bank (53x12 km) rises within the same 2000 m depth contour as the Acklins-Crooked platform to the W, but is separated from the Inagua and Caicos banks to the SE by the deep Caicos Passage. The bank consists of a 4 km-thick cover of Mesozoic and Cenozoic carbonates underlain by stretched continental crust, or by a hot-spot track. The main tectonic features in the area include the NE extension of the seismically active, sinistral Cauto Fault, which runs through the Caicos Passage, and the N60°W trending Sunniland (or Bahamas) fracture zone, a long-lived feature related to Jurassic rifting. The only previous geological investigations of Mayaguana were focused on the fossil reefs broadly exposed along the coast and on dolomitic rocks of Miocene age found in several drill cores. Because these rocks occur at shallower depths (~10 m) than on neighbouring platforms, it was proposed that Mayaguana has subsided at a slower rate than other Bahamian banks.

Methods applied in the present study embrace geological mapping, sedimentological logging and paleontological investigations (corals, foraminifers). Over 500 samples were collected for petrographic and geochronological studies. The latter include amino-acid racemization and Sr-isotope analyses of bulk-rock samples, as well as U-series dating of fragments collected from *in-situ* corals and ^{14}C dating of whole-rock samples and laminar crusts.

Seven lithostratigraphic units, briefly described below, were identified on Mayaguana, four of which are new additions to the stratigraphic record of the Bahamas islands. They mostly comprise peritidal carbonates that formed during episodes of platform flooding, separated by karstic surfaces and paleosols corresponding to exposure intervals.

The Mayaguana Formation: This unit forms one small exposure at the western end of a km-sized rocky headland near Little Bay, a small embayment on the north coast of Mayaguana, at elevations between sea level and up to +1 m. It consists of fine-grained, hard limestone containing a rich assemblage of larger benthic foraminifers including *Miogypsina globulina* and *Miolepidocyclina burdigalensis*, indicative of a shallow, high-energy, peri-reefal environment. This limestone yielded $^{87}Sr/^{86}Sr$ ratios averaging at 0.708546 ± 0.00001, resulting in an early Miocene age (18.4-18.7 Ma), which corroborates the biostratigraphic age (Burdigalian) obtained from the foraminiferal asssemblage.

The Little Bay Formation: Exposed at both ends of the Little Bay headland, at elevations between sea level and up to +1.5 m, this unit consists of fine-grained, hard dolostone, displaying multidirectional cross-bedding and ripple laminations. Petrographic analysis reveals a dense microsucrosic dolomite, preserving no evidence for any primary rock fabric. Sedimentary structures suggest that this unit was deposited in a high-energy tidal environment. Sr-isotope analyses gave an average $^{87}Sr/^{86}Sr$ ratio of 0.708988 ± 0.000025, indicating a late Miocene age (5.59-6.81 Ma).

The Timber Bay Formation: This unit crops out at several locations along the north coast of Mayaguana at elevations between sea level and up to +3 m. It consists of hard, partly dolomitized, coral/algal boundstone and rudstone, with a bioclastic grainstone matrix. Allochems were mimically replaced by cryptocrystalline dolomite, whereas coarser dolomite precipitated in intra- and intergranular pores. The occurrence of coral/algal build-ups and its overall poorly stratified nature relate to a shallow and energetic reefal setting. The average $^{87}Sr/^{86}Sr$ ratio of collected samples is 0.709067 ± 0.000011 corresponding to a middle Pliocene age (2.12-4.09 Ma).

The Misery Point Formation: This unit is best exposed on a 1 km long, up to 15 m high, rocky shore segment, the Misery Point cliff, but also occurs at four other locations along the northern coast of the island. It includes three vertically stacked shallowing-up sequences corresponding to lithostratigraphic units of lower rank (members) and consisting of pervasively weathered carbonates, separated and capped by paleosols. Sedimentary structures and faunal content suggest these sequences were deposited by marine processes in reefal, peri-reefal and beach settings, respectively. $^{87}Sr/^{86}Sr$ ratios measured on these carbonates give a range between 0.709126 ± 0.00008 and 0.709138 ± 0.00015 corresponding to an early Pleistocene age (~1.00 and 1.19 Ma).

The Owl's Hole Formation: It consists of bioclastic/peloidal/oolitic grainstone, rudstone, and framestone deposited in eolian, beach, and peri-reefal settings, respectively. It is exposed up to elevations of 25 m and occurs along the north coast (Curtis Hills, Cactus Hill, Misery Point), the eastern part of the platform (Booby Cay) and the center of the island (Abraham's Bay Hill). $^{87}Sr/^{86}Sr$ values average at 0.709155 ± 0.000009 corresponding to the middle Pleistocene (0.34-0.88 Ma). One sample from Abraham's Bay Hill gave one single alloisoleucine/isoleucine (or A/I) ratio of 0.637 ± 0.029. This value is assigned to aminozone G/H and also supports a middle Pleistocene age, possibly MIS 9 or 11. The peri-reefal facies at Booby Cay provided an average A/I ratio of 0.739 ± 0.020 and two poorly reliable U-Th dates (416 ± 30 and 510 ± 54 ka) suggesting a correlation with MIS 11 to MIS 15.

The Grotto Beach Formation: It is by far the most extensive stratigraphic unit found on Mayaguana. It comprises three members: a coral boundstone terrace of +1 to +3 m elevation that is exposed along most of the island's shorelines (Cockburn Town Mb.); extensive lowlands (up to +3 m) in the interior of the island (Big Cove Mb.), mostly consisting of grainstone to floatstone with *Halimeda*, mollusk and coral fragments; and oolitic ridges extending for several km and reaching up to +30 m apsl (French Bay Mb.). The ridges are characterized by high-angle cross-beds except for their basal part, where low-angle cross-beds, fenestral porosity, and bioturbations occur. The coral boundstone is interpreted as a fossil bank-barrier reef, exceeding in size coeval build-ups described from other Bahamian islands. The bioclastic floatstone from the island's interior was deposited in lagoonal to beach settings behind and above the reef. The oolitic ridges record an older shallowing-upward succession of facies from subtidal to eolian, the latter one being most extensively represented. U-Th ages measured from the coral terrace range between ~117 and 130 ka. These ages are similar to those gathered from other Bahamian fossil reefs and can be correlated with MIS 5e. A/I ratios obtained from the reef matrix, the lowlands and the oolitic ridges vary between ~0.301 and 0.472. These values span aminozones C, E1 and E2, suggesting a correlation with MIS 5a (aminozone C) and 5e (E1/E2), respectively.

The Whale Point Formation: It is only found in the NE corner of the Mayaguana bank where it forms hectometre-sized islets (Booby Rocks). About 10 m thick, this formation comprises friable bioclastic grainstone marked by large, landward-dipping, eolian crossbeds. Obtained A/I ratios range between 0.516 and 0.486 indicating a MIS 7 or an early MIS 5e age. However, its location on the platform, its relationship with other stratigraphic units, its petrography, and its low-grade diagenetic alteration, all suggest a correlation of the Whale Point Formation with MIS 5a.

The Rice Bay Formation: It is represented by low-elevation ridges at several coastal locations. These ridges overlie the paleosol and/or the calcrete capping the Grotto Beach Fm., but are not covered by similar features themselves. They consist of friable, mostly bioclastic grainstone, in which original grain mineralogy is always preserved. Constituent particles are usually bound by low-Mg calcite meniscus cement, but bladed rim cement also occurs in some samples collected at about +2 m apsl. High-angle foresets, with a landward dip, and low-angle, fenestrae-rich cross-beds occurring near sea level, characterize these ridges. Sedimentary structures indicate that formation was deposited in a beach-dune environment. This unit yielded one single whole-rock A/I ratio of 0.100 ± 0.001 corresponding to the middle to late Holocene which is corroborated by several ^{14}C dates ranging between 2'800 and 1'000 years BP.

The four oldest stratigraphic units (Mayaguana, Little Bay, Timber Bay and Misery Point Formations) occur exclusively along the north coast of Mayaguana. In the Little Bay area, they form a vertical succession less than 12 m thick, spanning a time interval of ca. 17 Ma, which translates to an accumulation rate of 0.6 m/Ma. The Plio-Pleistocene boundary, represented by the uppermost limestone-dolostone boundary, was observed at ca. +3 m apsl on the north coast exposures, but at depths between 6 and 10 m below sea level in cores drilled at more southerly locations. The youngest units (Owl's Hole, Grotto Beach, and Rice Bay Formations) are evenly distributed throughout the island.

Relative sea level (rsl) during deposition of the described units can be estimated from (1) the occurrence of sedimentological indicators of paleo-depth, the precision of which varies between 1 and 5 m, and (2) the elevation of these features apsl. For instance, the Little Bay Formation consists of shoal sediments located up to +1.5 m apsl. Given that such deposits are usually exposed to the atmosphere at low tide, rsl during the formation of this unit (late Miocene) must have been close to the present level. According to the same approach, the following rsl elevations can be estimated: <+10 m during the early Miocene (depth inferred from the foraminiferal assemblage of the Mayaguana Formation); +3 m during the middle Pliocene (reef flat of the Timber Bay Formation); +5 m, >+8 m, and +9 m during the early Pleistocene (distinctive reefal, lagoonal, and beach facies of the Misery Point Formation); >+3 m during MIS 5e (reefs of the Cockburn Town Member); and possibly +2 m during the Holocene (beach beds cemented by a phreatic cement at NW Point). Interestingly, these marine deposits of various ages (Miocene to Holocene) occur at about the same elevation, and were all deposited at a similar rsl (between +1 to +10 m apsl), which is surprising considering the difference in elevation between Mio-Pliocene and Quaternary sea-level stands. Indeed, global and regional charts, oxygen isotope-curves and some field evidence clearly suggest that sea level was higher than present during those time intervals because of significantly smaller continental ice volumes.

The following points of discussion can addressed on the basis of the aforementioned data.

Carbonate production on Mayaguana: Derived from the combined thickness of the Mayaguana to the Misery Point Formations, the sediment accumulation rate on the Mayaguana bank for the corresponding period (early Miocene to early Pleistocene) is much lower (0.6 m/Ma) than estimates calculated for carbonate platform tops of similar age (11 to 26 m/Ma). This particularity is best explained by a very slow subsidence that limited accommodation, and by the probable high elevation of the Mayaguana platform that permitted bank top flooding and associated carbonate deposition only during the highest sea-level stands of this time interval. During moderate sea-level highstands and lowstands, the bank top was emergent and subjected to karstification and pedogenesis. These two attributes (slow subsidence and raised position) could be linked to the ongoing transpression between the Bahamas and Hispaniola, or to the location of Mayaguana on a restraining bend of the Cauto fault system, that would have maintained the bank at a higher elevation than neighbouring platforms.

Tectonic tilting or antecedent bank topography: The peculiar distribution of "old" (Miocene to lower Pleistocene) stratigraphic units along the north coast, the changing elevation of the Plio-Pleistocene boundary, and the geometrical relationship between "old" and "young" (middle Pleistocene to Holocene) formations can be explained in two ways : (1) the island has been tilted towards the South, or (2) the Mayaguana bank was not flat-topped during the Neogene, but comprised a shallow area in the North and a deeper zone in the South. The tilting of the Mayaguana bank could have originated from repeated coseismic episodes along the Cauto fault system, the NE extension of which runs through the Caicos Passage, or from fault reactivation and upward propagation in the Sunniland fracture zone, that borders the northern edge of the Mayaguana platform. Alternatively, it may have been a response to lithospheric plate bending caused by the oblique underthrusting of the Bahamas beneath the Caribbean plate. Antecedent topography could be related to higher energy levels along the northern margin of the bank. The resolution of this dilemma (i.e. tectonics vs. topography) will have to wait until samples from Miocene to lower Pleistocene units can be retrieved from the subsurface in the southern part of Mayaguana and compared to the lithologies exposed along the north coast.

Sea-level history during the late Pleistocene (MIS 5e) and the Holocene: The extensive exposures of coastal and reefal deposits dating from the late Pleistocene and the Holocene on Mayaguana provide new and original data about the sea-level fluctuations during these time periods. Most previous reconstructions of MIS 5e sea level comprise two highstands, exceeding modern ordnance datum by a few meters, separated by a lowstand phase about 123 ka ago, and followed by a rapid drop of sea level at the end of MIS 5e, about 117 ka ago. No trace of such a lowstand episode was identified on Mayaguana. In contrast, the coral assemblages exposed in the reefal terraces indicate a marked deepening of the sea at about that time. Moreover, the broad seaward progradation of the Big Cove Mb. (late MIS 5e) suggests a slow regression after the mid-MIS 5e sea-level maximum. Contrary to most regions worldwide, the Holocene stratigraphic record from the Bahamas islands has, up to now, not yielded indications of a higher than present sea level during this time interval. However, the occurrence of phreatic cements at about +2 m in 2’000 years-old beach sediments at North West Point (NW Mayaguana) represent a solid piece of evidence that sea level might indeed have been higher at that time.

In conclusion, Mayaguana is unique among Bahamian islands in that it comprises four stratigraphic units predating the middle Pleistocene, including Pliocene and upper Miocene dolostone, and foraminiferal limestone from the early Miocene. The subsidence history of this bank is thus radically different from that of other Bahamian platforms where Neogene rocks occur at depths of 10’s to 100’s of meters. This limited vertical aggradation of the Mayaguana bank since the early Miocene and the lack of pelagic deposits in the stratigraphic record suggest that the platform may have remained more or less stable for the past 20 Ma, implying that Neogene sea levels never exceeded modern datum by more than 10 m. Alternatively, due to its tectonic setting, it could have stood higher than other banks and would have been only flooded by the most important Neogene transgressions. Further drilling will resolve whether the asymmetry in the distribution of the ancient lithostratigraphic units is due to tectonic tilting or antecedent topography. Last but not least, the pristine and complete sediment successions from both this and the previous interglacial periods provide new and original data that complement, albeit contradict, earlier sea-level reconstructions for these time periods.