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Front Cover: Rice Bay Formation, looking southwest along Grotto Beach. Photograph by Sandy Voegeli.

Back Cover: Dr. John Milliman, The College of William and Mary. Keynote Speaker for the 13th Symposium. Photograph by Sandy Voegeli.

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CAVE AND KARST INVENTORY OF THE PRIMEVAL FOREST, NEW PROVIDENCE ISLAND, BAHAMAS: UNEXPECTED DISCOVERIES

John E. Mylroie, Joan R. Mylroie, Athena M. Owen, and Willapa J. Waterstrat
Department of Geosciences
Mississippi State University
Mississippi State, MS 39762
mylroie@geosci.msstate.edu

ABSTRACT

The Primeval Forest, a new Bahamian national park, is located on the west side of New Providence Island, Bahamas. The small site, 3.5 hectares (8.6 acres), contains a rare high-canopy forest that has escaped development. The park was named for the presence of old forest and plant life. The karst features of the park made the area impossible to use for agriculture, which preserved the older plant life. The relatively unspoiled nature of the site was instrumental in motivating the creation of the park by the Bahamas National Trust to preserve the landscape and its biological contents. The park trends from highest elevation in the northwest, on the side of an eolian ridge, dropping to a low plateau or bench to the southeast, which in turn becomes a flat lowland. The bench portion of the park is riddled with numerous pits, caves, natural bridges, sinkholes, and banana holes. The Trust commissioned a cave and karst inventory to document the extent of the physical resources within the park.

The initial strategy was to survey what was thought to be a series of independent karst features. As such, the survey began in a banana hole, but connections were found to nearby features, and 122 stations subsequently were set in this initial cave. A second team surveyed a surface baseline, from which stations were established at 102 prominent karst features for permanent identification. The karst feature density, one of the highest ever seen in the Bahamas, was unexpected, at approximately 19.4 karst features per acre or 49.7 per hectare. Also unexpected was the degree of connectivity of karst features. These features occurred at a variety of elevations as phreatic tubes, but followed the strike (NE-SW) of the low bench. The bench drops to the SE into a series of low karst valleys that are the result of the coalescing collapse of pits, caves and banana holes. The final unexpected discovery was the herringbone cross bedding, and the trace fossils *Ophiomorpha* sp. and *Conichnus conicus* in pit and cave walls. Based on current understanding, these sub-tidal indicators identify the rocks as the Cockburn Town Member of the Grotto Beach Formation, Late Pleistocene in age. The phreatic passages seen in the caves are syngenetic, as both the rock and the fresh-water lens position were produced by the last interglacial sea-level highstand, Oxygen Isotope Substage 5e, ~125 ka.

INTRODUCTION

On February 16, 2006, at the request of Mr. Eric Carey of the Bahamas National Trust, an initial reconnaissance of the Primeval Forest property in western New Providence Island (Figure 1) was completed. That investigation indicated that the Primeval Forest has an unusual array of cave and karst features that are unique in The Bahamas. It was recommended that because of the strong interaction between the cave and karst landscape, the flora and fauna, and the bedrock geology, that a full cave and karst resource inventory be undertaken.

SURVEY

The initial cave and karst resource inventory was conducted during March 11-18, 2006. The initial survey placed 125 underground survey stations, 102 karst features stations, and 38

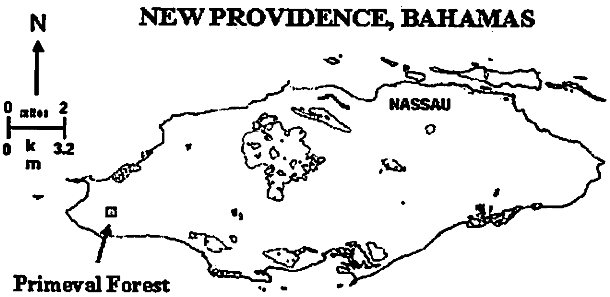

Figure 1. Map of New Providence Island, Bahamas, showing location of the Primeval Forest.

surface survey stations. The survey stations were placed at varying intervals to encompass the individual cave area, as well as facilitate shots into the next cave section (Figure 4). Permanent markers were placed on the karst features resulting from the karst survey, for future identification.

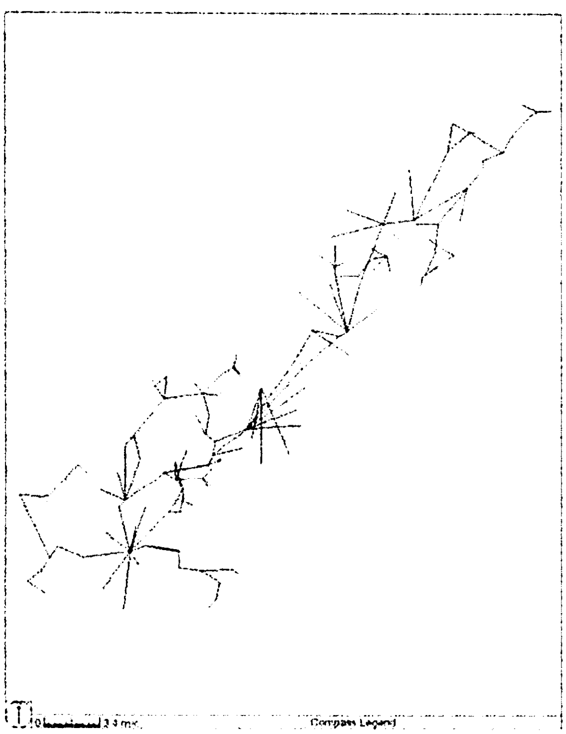

Figure 2. "A" survey showing line plots. North is to the top.

The unexpected result of this effort was the "A" survey--a complex cave system that was originally thought to be two small, interconnected banana holes. This survey was initiated in the first natural bridge cave on the main trail from the parking area into the Primeval Forest. What was originally thought to be the interconnected banana holes ended up being part of a single cave system that continued for 125 stations before all components were finally linked to the survey (Figures 2 and 3). Connectivity of this level is highly unusually and has not been described anywhere else in the Bahamas.

A second survey effort was mounted between May 24-31, 2006, during which an additional 65 surface karst features were linked to the surface survey that was extended by 39 stations (Figure 4). An additional 60 stations were placed in a series of small caves and pits, none of which showed the complex connections found in the "A" survey nor connected to the original "A" survey from March. The results of both surveys were shown in cave maps of the surface openings, the "A" survey cave, and the independent cavelets that were surveyed. A series of these finished maps are shown in Figures 5-9. The most significant of these is Bat Cave (Figure 5), which runs from Karst Station 152 southwest past Karst Station 136 (see Figure 4). A small bat colony of an unknown species exists in the southwest portion of the karst feature. This was the only feature in the park found to contain bats.

The inventory completed on May 31, 2006 is believed to have located and assessed the vast majority of the cave and karst features located in the Primeval Forest (Figure 4). The cave and karst features are concentrated in the northwestern half of the Forest, where the elevation is higher. Isolated features, mostly of small size, approximately a meter or less, were found in the southeastern half of the Forest. They were not surveyed individually or tied into the surface survey grid, due to a lack of time.

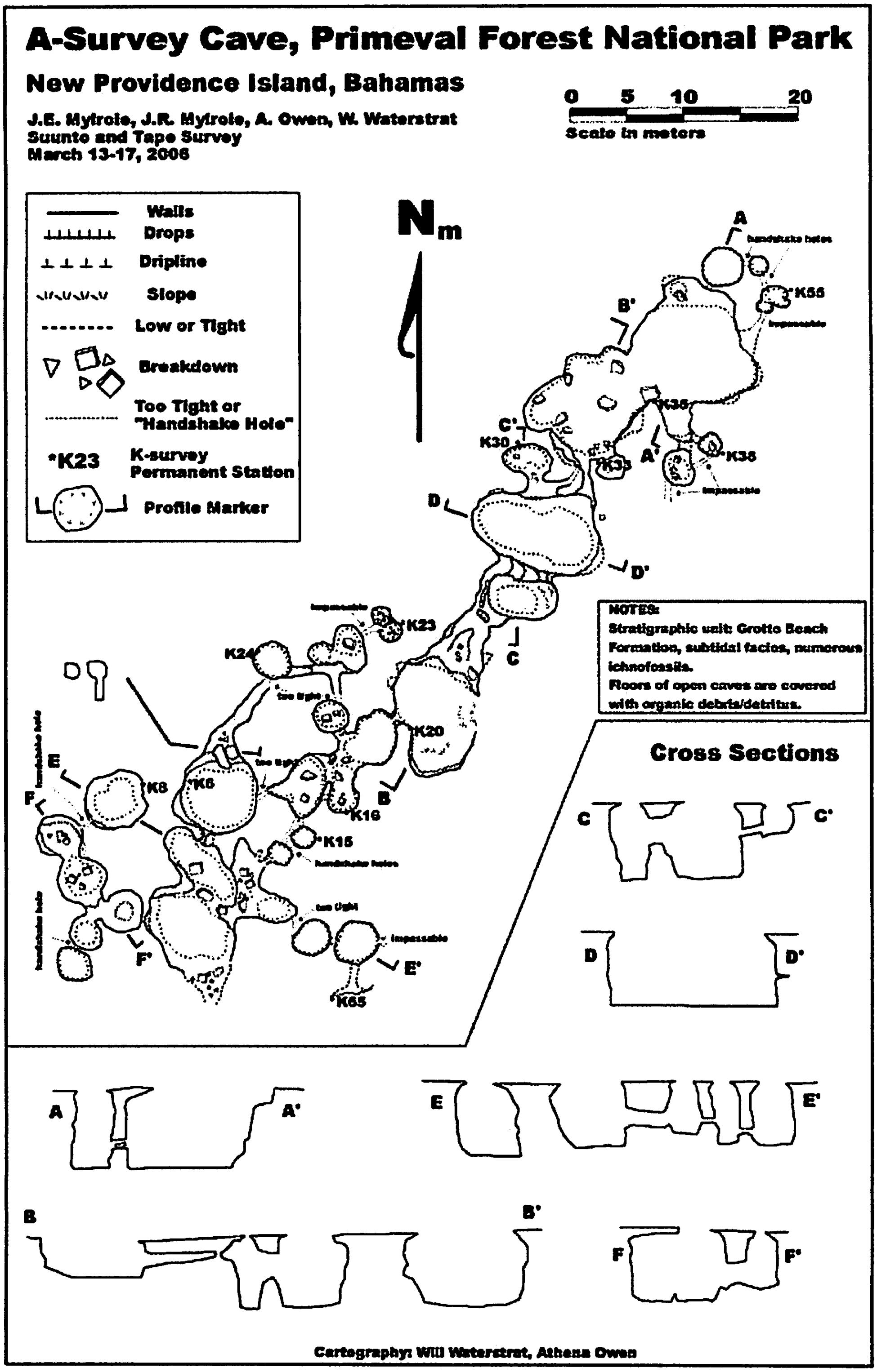

Figure 3. Final Map of the "A" Survey Cave.

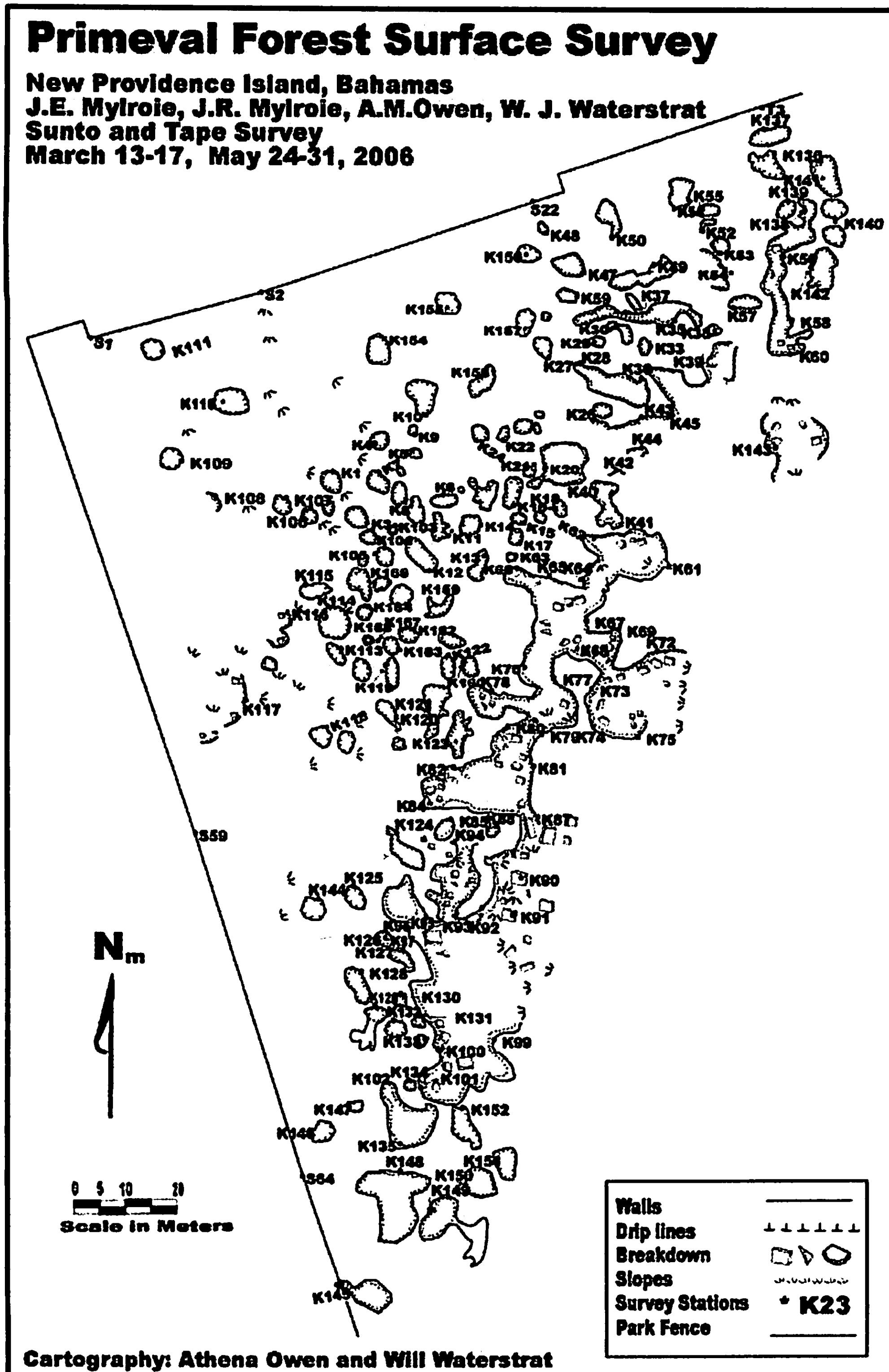

Figure 4. Surface Survey, showing all identified karst features, and portion of the boundary fence.

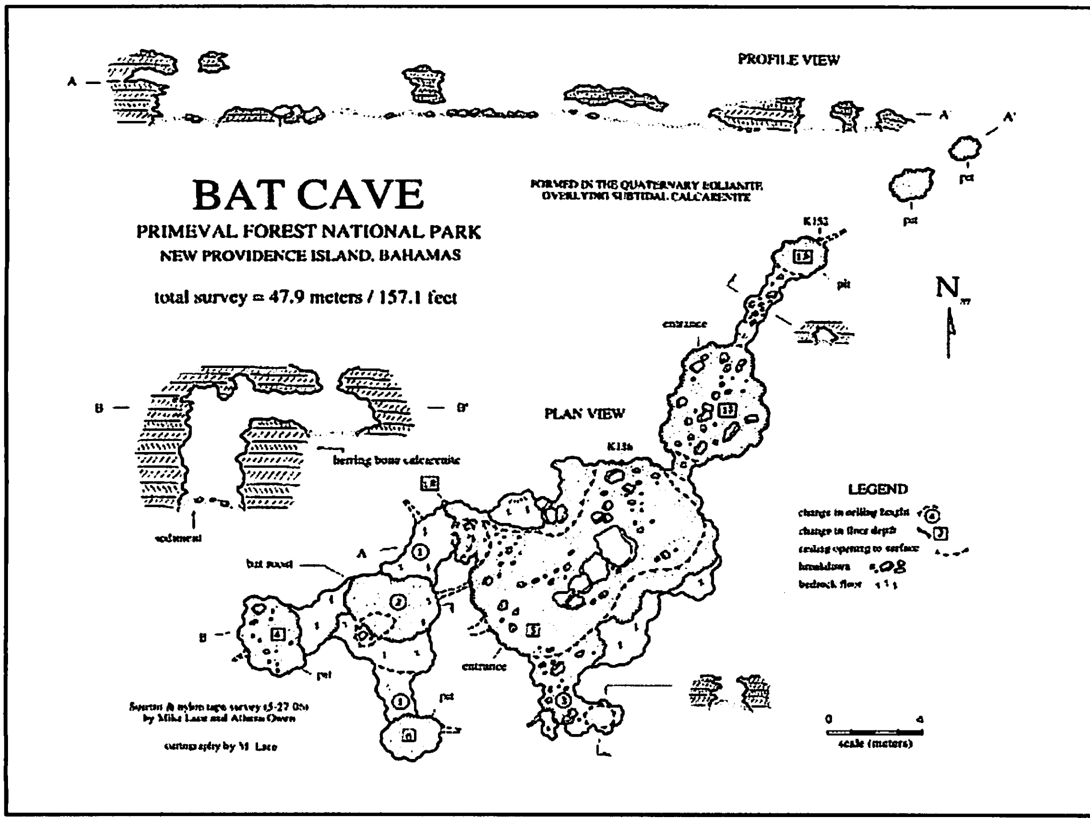

Figure 5. Karst feature 136 and 152 showing the karst location of the only known bat population in the park.

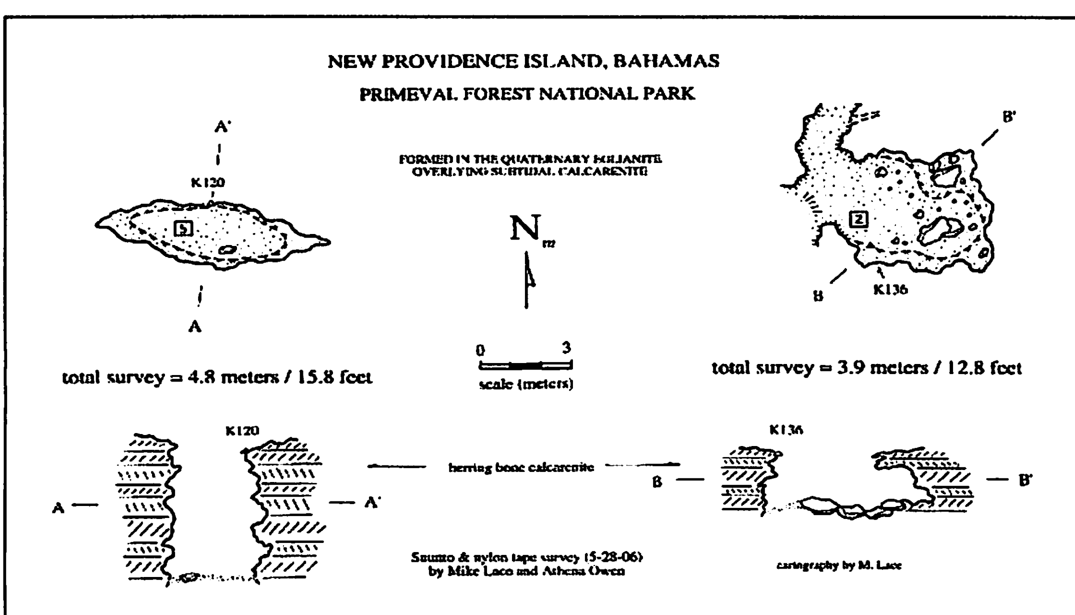

Figure 6. Karst features K120 and K136.

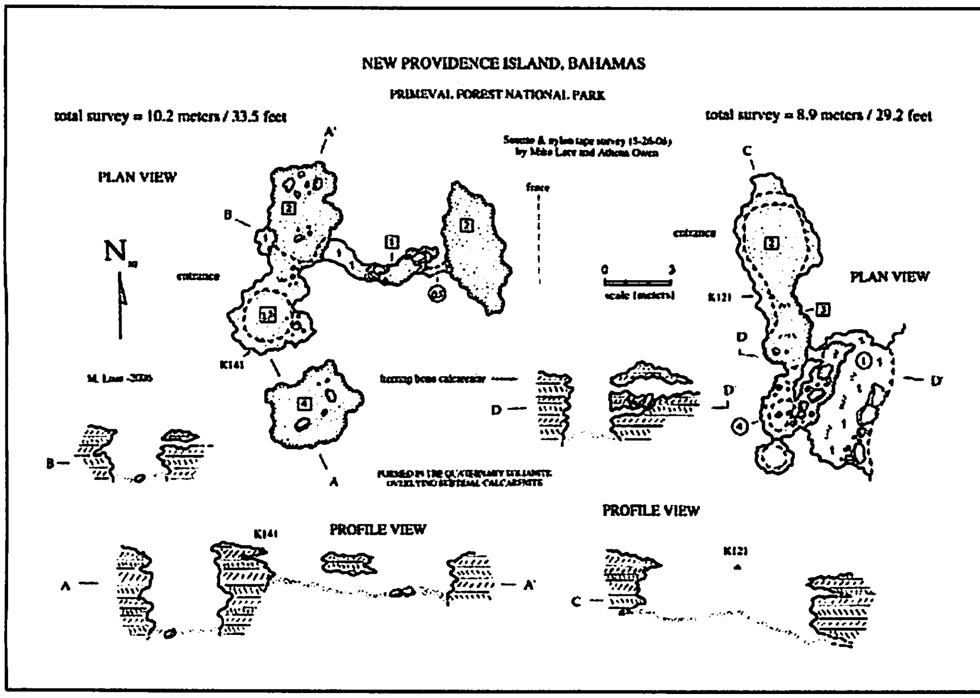

Figure 7. Karst features K141 and K121.

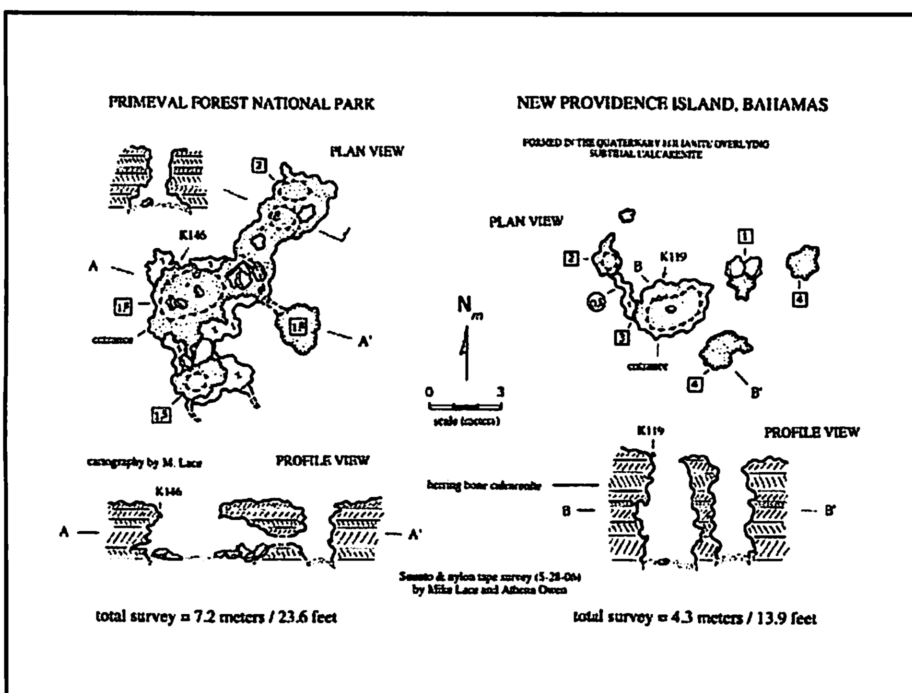

Figure 8. Karst features K146 and 119.

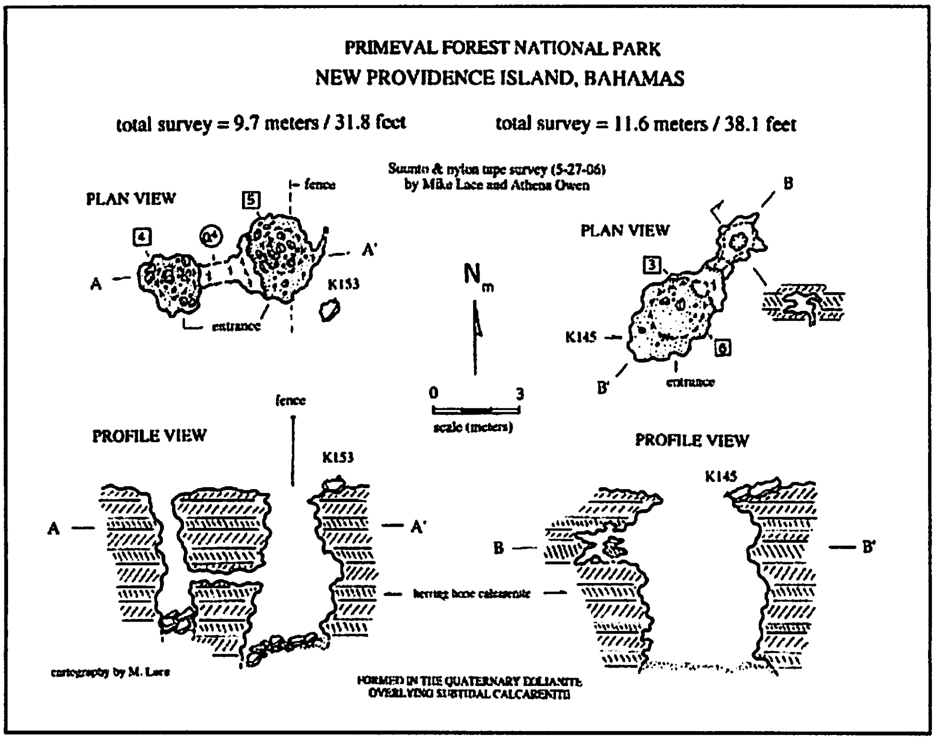

Figure 9. Karst features K153 and K146.

GEOLOGY

A complete review of Bahamian geology can be found in Carew and Mylroie 1995; and 1997 (and references therein) with specific publications relating to New Providence Island in Carew et al., 1992; 1996. The Islands are made of up carbonate rocks that fall into three major stratigraphic units: the Holocene Rice Bay Formation, less than 6,000 years in age; the Upper Pleistocene Grotto Beach Formation, approximately 119,000 to 131,000 years in age; and the Mid-Pleistocene Owls Hole Formation, that consists of numerous units extending from 200,000 years in age to at least 500,000 years in age.

The Rice Bay Formation and Owls Hole Formation are made completely of eolianites (fossilized carbonate sand dunes). The Grotto Beach Formation contains fossil reefs and other sub-tidal units as well as eolianites. The Owls Hole and Grotto Beach formations have well-developed *terra rossa* paleosols, a hard, red to brown crust, on their top surfaces. The Rice Bay Formation, because it is so young, lacks a *terra rossa* paleosol. The Bahamas are tectonically stable, and are slowly subsiding at the rate of 1 to 2 meters per 100,000 years. As a result, the fossil reefs and other sub-tidal units of the Grotto Beach Formation are found above sea level today only because sea level was higher at the time those units were deposited. This past higher sea level was the result of ice sheets melting back a bit more than today. The geologic column for the Bahamas is presented in Figure 10.

The rocks in the Primeval Forest appear to be made entirely of the Grotto Beach Formation, based on the herringbone cross bedding on the cave and pit walls (Figure 11). In addition, there are several ichnofossils from organisms that only live in sub-tidal conditions. Given that these rocks show sub-tidal features above modern sea level, the rocks must be part of the Grotto Beach Formation. Eolianites exist higher up in a smooth transition, indicating that they too are part of the Grotto Beach Formation.

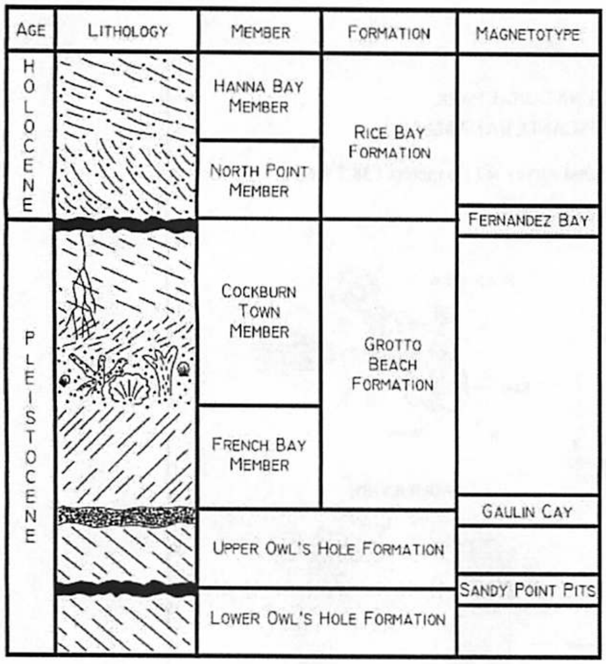

Figure 10. Geologic column for the Bahamas. The Owls Hole Formation contains more units than are shown here.

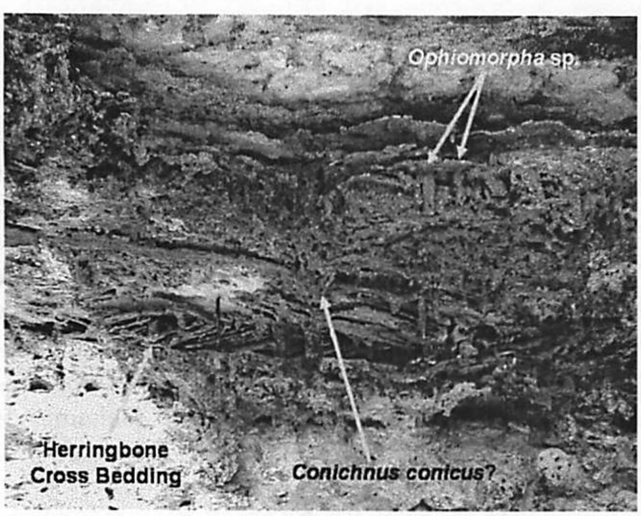

Figure 11. Pit outcrop at the Primeval Forest, at K49 of Figure 4, showing herringbone cross bedding and sub-tidal trace fossils.

CAVE AND KARST DEVELOPMENT

The caves and karst features of the Primeval Forest are similar to what is found throughout the Bahamas, but the high density of the features, their complexity and interconnectivity, are unique. There are three main features present: banana holes, pit caves, and sinkholes. A review of Bahamian karst processes can be found in Mylroie and Carew, 1995, and Mylroie et al., 1995. Sinkholes (Figure 12) are conical depressions found in karst landscapes around the world, produced by dissolution excavating a basin in the rock. This dissolution excavation can be by removal of rock from the surface, or by removal of rock in the subsurface with collapse of surface rock and soil into the underlying void. The sinkholes in the Primeval Forest have formed mostly by collapse. Pit caves are vertical pathways dissolved out of the rock by water descending from the surface into the subsurface (Figure 13). In the Bahamas, they are commonly 2 to 10 m deep (6 to 30 feet). Banana holes are the surface expression of voids dissolved beneath the water table and later expressed at the surface by collapse (Figure 14). In that regard, they are a special case of sinkhole, in that their vertical bedrock walls and overhanging

Figure 12. A simple sinkhole in the Primeval Forest, at K143 of Figure 4, with bedrock ledges and sloping sides.

ledges reveal their origin as an underground void. Banana holes are considered phreatic in origin, that is, they developed below the water table. Pit caves are considered vadose in origin as they develop above the water table. The phreatic voids

Figure 13 a. A pit cave of the Primeval Forest. A view looking down at K16 of Figure 4.

Figure 13 b. A pit cave of the Primeval Forest. A view in the pit cave at K49 of Figure 4.

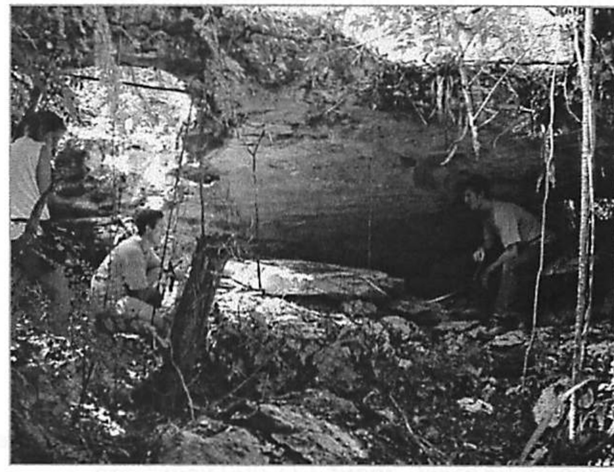

Figure 14. A banana hole in the Primeval Forest, at K8 of Figure 4. Note the natural bridge and low, wide shape of the chamber.

of the banana holes have been revealed by roof collapse, and are dry today because they formed approximately 125,000 years ago, when sea level and the water table was higher.

GEOLOGIC HISTORY

The history of the formation of the rocks and karst features at the Primeval Forest is an example of compression of geologic events, where the karst features formed at or near the same time as the rock formations, instead of long afterwards. The rock units were deposited when sea level was about 6 m (20 feet) higher than present, about 125,000 years ago (Figure 15). A broad shallow lagoon existed at this site, with waves creating the oscillation ripple marks that later became herringbone cross bedding. Organisms living in this shallow lagoon left the trace fossils seen in Figure 11. The lagoon was gradually filled in by beach sands and eolianites that allowed the water table, or fresh-water lens, to invade the entire rock sequence (Figure 16).

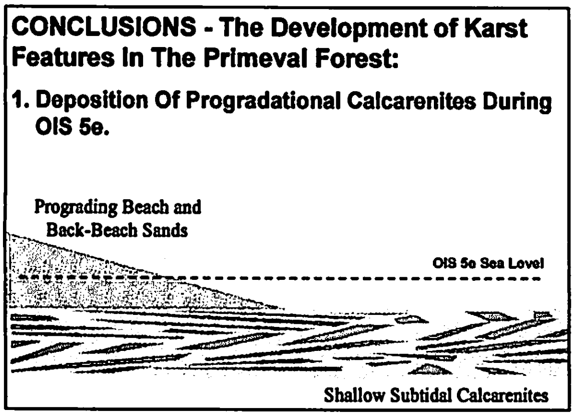

Figure 15. Initial condition of the lagoon at the Primeval Forest, about 125,000 years ago.

Once the fresh-water lens was in place, dissolution could take place in the phreatic zone below the water table. Dissolution is favored at the top of the lens, where vadose and phreatic waters mix (see Mylroie and Carew, 1995, for further discussion). The voids formed near the top of the bedrock body, and the roofs are thin. When sea level fell about 119,000 years ago, the banana holes were drained. They began to undergo collapse due to their thin roofs. Pit caves began to form, and the intersection of these caves helped collapse more of the banana holes (Figure 17).

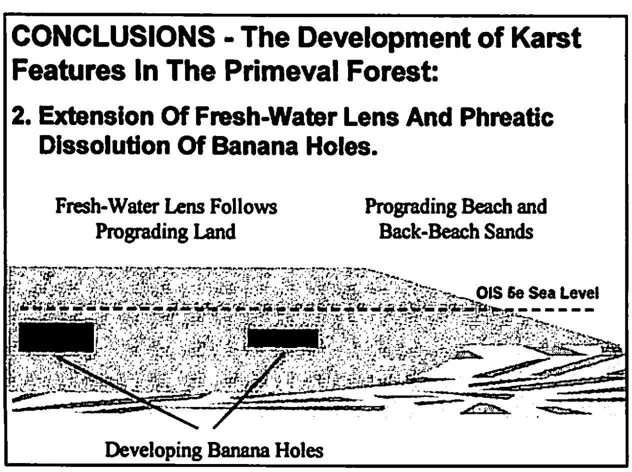

Figure 16. As sands prograde over the lagoon to make new land, the fresh-water lens extends into what was once a lagoon. Dissolution can now take place to make banana holes.

The landscape underwent a progressive erosional evolution. As banana holes began to undergo collapse, pit caves formed and the land surface was degraded. As a result, broad open areas and depressions formed, making large sinkholes, called karst valleys (Figure 18). The karst valleys trend northeast to southwest on Figure 4, with karst features, numbered from the karst survey as, K41, K61, K76, K77, K81, K82, K93 and K101 as point locations (Figure 19). There has been over 100,000 years since the banana hole formation began, and time has allowed an erosional continuum to form, as seen in Figure 18.

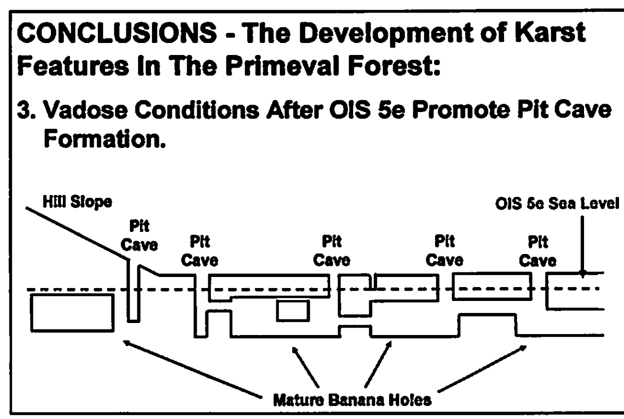

Figure 17. After sea level fell about 119,000 years ago, erosion began to truncate and expose the banana holes, while pit caves penetrated the land surface and opened some of the banana holes.

Few cave or karst features remain to the southeast, where the land is a low, undulating plain. The karst valleys with remnant caves are found toward the northwest. Farther to the northwest, intact and interconnected pit caves and banana holes appear. A few isolated pit caves are found still farther northwest and upslope onto the eolianites. Banana hole voids, if they exist, have not yet collapsed in this area. Two kilometers south (1.25 miles) of the park, at Clifton, the cliffs show the same sequence of herringbone cross bedding and trace fossils seen at the Primeval Forest, but over a greater vertical extent, showing the presence of deeper water in that location.

The caves and karst produced in the Primeval Forest are syngenetic, forming almost concurrently with the host lithology. This is a very rapid geologic process. Once these features formed, they underwent slow erosional decay that degraded them into the landscape we see today at the Forest.

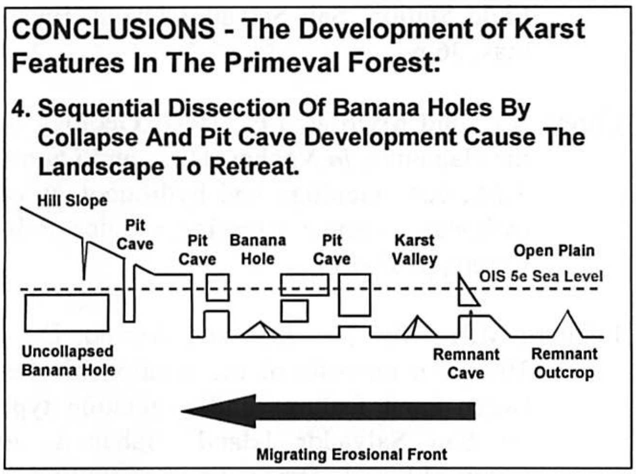

Figure 18. The continued dissection of the Primeval Forest over time by erosion created a sequence of open plain to the southeast, karst valleys in the central areas, banana holes and pit caves to the northwest, to isolated pit caves on the hill slope.

BIOLOGICAL IMPACTS

The flora and fauna of the Primeval Forest are preserved today in part because the chaotic nature of the landscape made the land less desirable for agriculture or development. Other creatures, such as bats, find the caves an ideal location for nesting. The wide variety of pits and banana holes, and the sheltered karst valleys, has created a whole sequence of micro-environments that have helped increase plant and animal diversity. Such karst-specific plant diversity has been reported from San Salvador Island (Lehnert et al., 1997).

CONCLUSIONS

The Primeval Forest is a unique landscape that expresses the full natural history of the Bahamas: the bedrock that forms the archipelago's

a.

b.

c.

Figure 19 a, b, and c. The karst valleys of the Primeval Forest. a) the broad, open expanse of the valleys; b,c) two examples of remnant caves in the karst valley.

foundation, the karst processes that sculpt that foundation, and the biota that make the landscape their home. The property has one of the most unique karst systems in the world. The rapid formation of the karst features and the connectivity of these features are very unusual and should be preserved.

The Bahamas National Trust, by obtaining this property, has made a significant contribution to science and the public. The quick action to fence the property, and to initiate an inventory of the Primeval Forest's contents, will allow the park to become a research, teaching, and recreational tool for The Bahamas. The scenic beauty of the park is outstanding (Figure 19) and will be a great asset to tourism on New Providence.

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