Theoretical and Applied Karstology, **13–14** (2000–2001), pp. 57–65

Karst genetic model for the French Bay Breccia deposits, San Salvador, Bahamas

Lee Florea[1*], John Mylroie[2], & Jim Carew[3]

[1] *Kentucky Cabinet for Natural Resources, Frankfort, KY 40601, USA*
[2] *Department of Geosciences, Mississippi State University, Mississippi State, MS 39762, USA*
[3] *Department of Geology, University of Charleston, Charleston, SC 29424, USA*

Abstract

On the Island of San Salvador in the Bahama archipelago 30 breccia deposits can be found along the French Bay sea cliffs on the southeastern coast of the island. Breccia deposits of this type have not been observed on any other location on the island. These deposits have traditionally been interpreted as paleo-talus deposits from an eroding sea cliff formed on a transgressive eolianite deposited at the start of the oxygen isotope substage 5e sea-level highstand (ca. 125,000 years before present). New evidence supports a karst genesis. A survey of several deposits revealed a vertical restriction of +2 to +7 meters above sea level consistent with flank margin caves developed during the substage 5e still-stand. The morphologies of the features were found to be globular and contain distinct caliche boundaries, overhung lips, and smooth undulating bases. Petrographic results support a model in which voids are created and then infilled with a soil breccia. It can be concluded from these results that the deposits reflect qualities of a lithified soil breccia filling in breached flank margin caves.

Keywords: karst breccia, paleokarst, San Salvador.

Modèle génétique karstique des dépôts de French Bay Breccia, San Salvador, Bahamas

Résumé

Sur l'île de San Salvador (archipel de Bahamas) on a trouvé 30 dépôts de brèches situés le long de la côte de French Bay, dans la partie sud de l'île. Ces dépôts ont été traditionnellement interprétés comme des dépôts de paléo-talus d'une ancienne falaise marine, formés sur des éolianites transgressives qui ont été déposées au début du stage isotopique 5-e (haute mer). Les nouvelles données indiquent une genèse karstique. L'étude de quelques dépôts a révélé une disposition verticale restreinte de +2 jusqu'à +7 m au-dessus du niveau de la mer, correspondant aux grottes de flanc marginal développées durant le stage 5-e. La morphologie des formations est globulaire et inclut des horizons de caliches et des bases légèrement ondulées. L'analyse pétrographique suggère que les cavités ont été remplies d'une brèche terrigène. On conclut que ces dépôts représentent une brèche terrigène lithifiée qui a rempli des cavités de flanc marginal.

Mots-clés*: brèche karstique, paléokarst, San Salvador.*

Introduction

San Salvador Island is located in the eastern portion of the 1000 km Bahamian Archipelago (Fig. 1). The size of the island is relatively small: roughly 12 km wide by 19 km long (Fig. 2). All rocks exposed on San Salvador are Pleistocene and Holocene carbonates. The geologic record is dominated by subtidal facies at low elevations, and eolianites at higher elevations; the result of cyclic changes in the glacio-eustatic sea level. This produced cycles of carbonate deposition, during sea level high stands, and erosion, during sea level lowstands. Several of these sequences are apparent on the island, but only the sea level associated with the oxygen isotope substage 5e still-stand (125,000 BP) was high enough for marine facies to remain subareal in modern sea level conditions (Carew & Mylroie, 1994; 1997).

* corresponding author. *E-mail address*: mr_chaos@hotmail.com

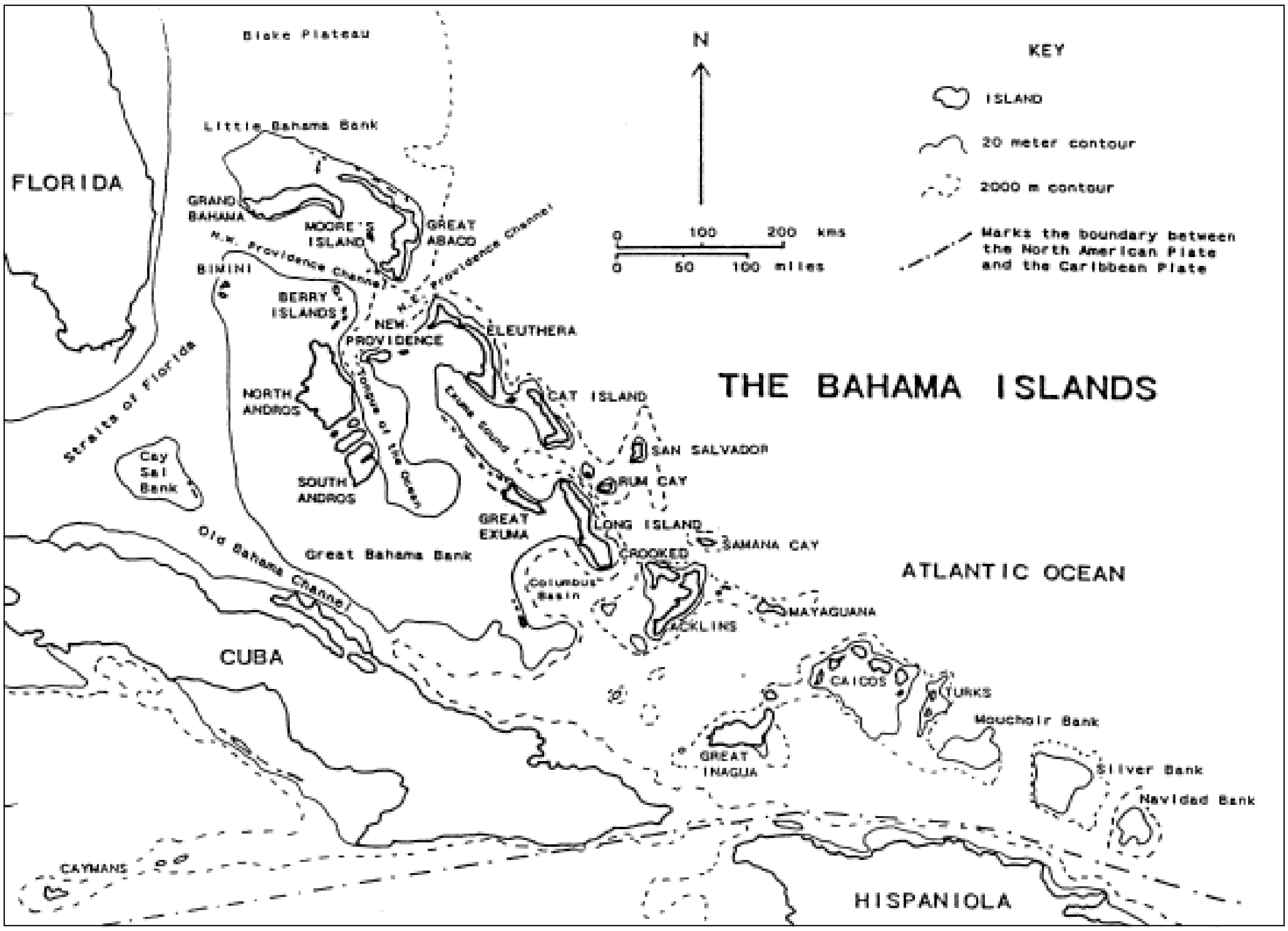

Fig. 1. The Bahama Islands (from Carew & Mylroie, 1994). *Les îles Bahamas (d'après Carew & Mylroie, 1994).*

The island is highly karstified with several morphologic manifestations of karst features. Inland pits, blue holes, karren of various forms, and caves are several types of karst features identified. Paleo-karst features are also present on the island in the form of infilled dissolution pockets, "palmetto stumps" (Carew & Mylroie, 1994), notches (Mylroie & Carew, 1991; Reece *et al.*, 2000), and breccia deposits (Marshall, *et al.*, 1984; Florea *et al.*, 2000).

On San Salvador, 30 breccia deposits can be found along more than 1km length of sea cliffs in French Bay (Fig. 2 and 3). Breccia deposits of this type have not been observed at any other location on the island. Similar breccia facies have been recognized within caves on other carbonate islands such as the Cayman Islands (Jones & Smith, 1988), Isla de Mona (Mylroie & Carew 1995), and New Providence Island in the Bahamas (Mylroie *et al.*, 1991). The deposits on San Salvador occur in Late Pleistocene carbonates of the French Bay Member of the Grotto Beach Formation.

The breccia deposits in French Bay consist of angular blocks of laminar-bedded oosparites ranging from 1 cm to more than 1 m in size within a red micritic matrix. This description indicates the deposits are soil breccias and distinguishes them from coastal breccias or back-beach rubble. Coastal breccia facies contain more rounded clasts as a result of continuous wave attack and contain a white sand matrix as opposed to a red (paleosol) matrix. The French Bay breccia deposits range from matrix to clast supported, and occur as promontories due to the more resistant nature of the paleosol matrix.

These deposits have traditionally been interpreted as paleotalus deposits from an eroding sea cliff of oxygen isotope substage 5e transgressive dune deposits ca. 125,000 years ago (French Bay Member of Carew & Mylroie, 1985). In this theory a substage 5e transgressive dune was eroded to produce sea cliffs during the substage 5e sea level maximum. When sea level fell at the end of the 5e substage, the sea cliff became an inland scarp; the resulting inland scarp underwent erosion and collapse producing cliff-base talus slope. Over time this talus lithified to produce a paleotalus associated with the surrounding solution pockets and paleosol. Recent rise in sea level has renewed coastal erosion on these paleotalus deposits producing the modern day distribution and location of this facies.

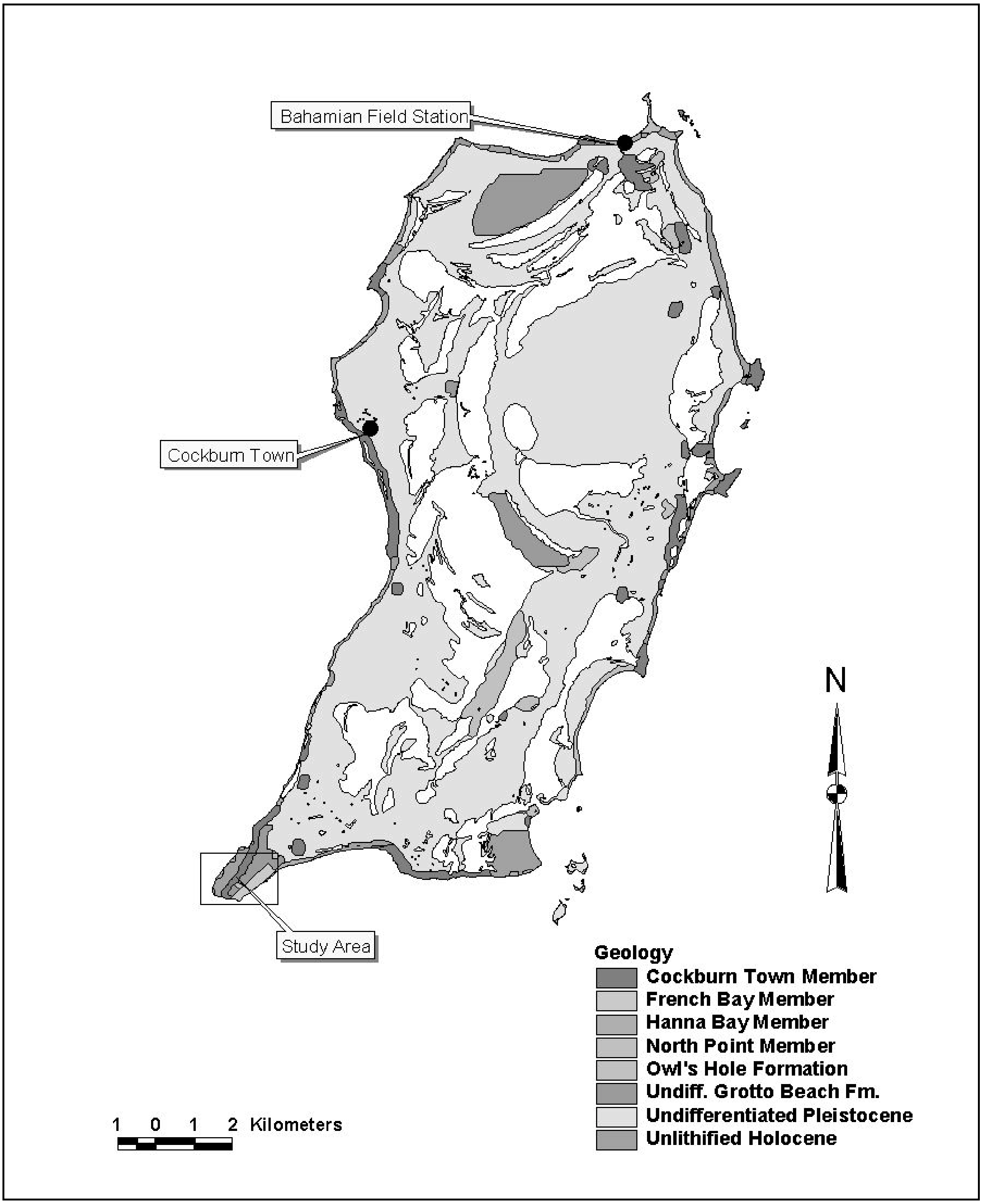

Fig. 2. Map of San Salvador with location of study area (data from Robinson & Davis, 1999).
Carte de San Salvador avec la situation de la zone étudiée (données extraites de Robinson & Davis, 1999).

Fig. 3. Breccia deposit on French Bay sea cliff.
Dépôts de brèche de la falaise de French Bay.

An alternative explanation for the development and distribution of the breccia deposits can be derived from the theory of flank margin cave development. Fresh water entering the groundwater system through precipitation floats on the saltwater as a lens thinnest near the discharge at the margins of the island and thickest where the recharge is maximum. Both the fresh and the saline water quickly become saturated with respect to calcite in a carbonate island environment. Mixing of fresh and saline water along the base of this lens produces a solution with renewed dissolution capabilities (PLUMMER, 1975). Thus, karst features tend to develop along this interface.

The thinning of the fresh-water lens near the discharge at the island margins increases the velocity of water due to a reduction in cross-sectional area. This increase in velocity combined with the intersection of the upper and lower mixing surfaces of the lens promote maximum dissolution potential (SANFORD & KONIKOW, 1989; MYLROIE & CAREW, 1988; 1990). In the Bahamas, the freshwater lens tends to be thickest in eolianite ridges and discharges along the flanks of these ridges. The caves associated with this dissolution process have been termed flank margin caves (MYLROIE & CAREW, 1990).

The morphology of flank margin caves reflects the manner in which they were formed. These caves are mixing chambers not conduits; therefore are formed independent of surface conditions, or hypogenic (PALMER, 1991). They contain large globular chambers with concave dissolution surfaces connected to others by narrow windows or not connected at all, have undulating ceilings and floors, and are vertically restricted. Because these voids form along the flanks of eolianite dunes, they tend to be clustered like "beads on a string" (VOGEL *et al.*, 1990).

If the French Bay breccia deposits were indeed the result of karst processes, several indicators would be present. The deposits would be distributed along a linear trend parallel to the paleocoastline. The deposit morphologies would reflect a void history by being globular with undulating bases and overhung lips. The deposits would appear as a sequence similar to "beads on a string." The boundary between the country rock and the breccia would be distinct and could include altered wall rock or stalagmitic material (flowstone).

The intent of this study was to characterize several of the deposits with field reconnaissance, accurate survey and morphology, photographic documentation, and petrographic analysis. From this, a conclusion of non-karstic or karstic genesis would be made. Finally, a new sequence of formation would be developed based on the results obtained.

Methods

A January 2000 survey was conducted of seven breccia deposits along the northeast section of the French Bay sea cliffs using fiberglass tape and *Suunto* compass and inclinometer (Fig. 3). Several survey transects were run across each of these seven breccia deposits and all seven deposits were linked by survey. On larger deposits, profile transects were taken to help in the characterization. Solution pockets and other features of interest proximal to the deposits were tied in to the survey to aid in mapping and the interpretation. A cartographic quality map of the surveyed deposits was generated and tied in to the 1984 MARSHALL *et al.* survey of the deposit locations (portion of map displayed in Figure 4). This map was georeferenced on ArcView and overlaid onto the topographic map of the island (provided by ROBINSON & DAVIS, 1999).

To support the breccia survey, a field investigation was conducted of various locations of geologic or hydrologic significance on San Salvador Island. Several karst features were visited and explored including several of the well-known flank margin caves (CAREW & MYLROIE, 1994; MYLROIE & CAREW; 1994). Stops were made at locations containing coastal and soil breccia facies. In addition, stops were made at sites of active cave collapse in the island interior and talus slope development.

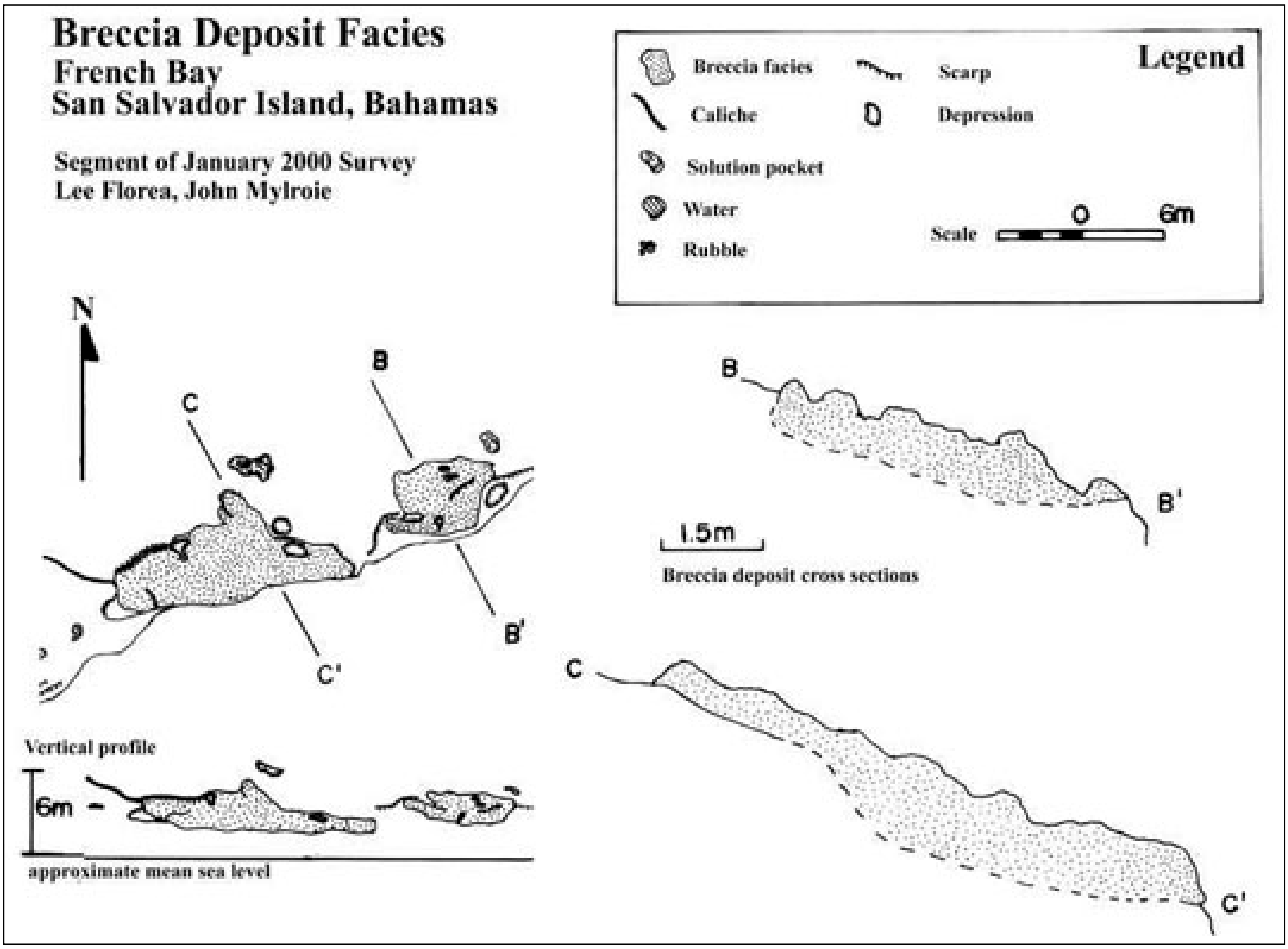

Fig. 4. Partial map of January 2000 breccia survey. *Carte partielle de la brèche relevée en Janvier 2000.*

Four samples were taken from one of the larger breccia deposits to use in petrographic analysis. These samples included: a sample from the country rock near the deposit, a sample from a clast contained within the deposit, a sample of the matrix, and a sample of the caliche boundary separating the deposit from the country rock. Thin sections were made from these samples at the University of Kentucky Department of Geology, and the analysis was performed using a petrographic microscope at the Kentucky Geological Survey.

Results

The survey of the breccia deposits revealed a vertical restriction in development of +2 to +7 meters above sea level (Fig. 4). Nearby solution features such as infilled solution pockets, "palmetto stumps" (Carew & Mylroie, 1994), and stalagmitic material (flowstone) in open phreatic pockets range from approximately +5 to +10 meters above sea level.

The deposit morphologies are globular, with undulating bases (Fig. 4). These boundaries are distinct and in some locations present a thick caliche layer separating them from the country rock and cross cutting structure (Fig. 5). The inland boundaries of the deposits have detectable overhung lips in locations. The distribution of the deposits themselves is random, yet do follow a "bead on a string" description typically associated with flank margin caves (Vogel *et al*., 1990).

Petrographic analysis of the deposits revealed that the breccia clasts and the country rock are indistinguishable and are laminar-bedded oosparites, confirming previous results (Marshall *et al*., 1984). Both country rock and clasts display evidence of dissolution activity such as partially dissolved ooids and vug development. Both also contain sparry cements of two generations: a first generation equant isopachous calcite and a calcite meniscus druse (Fig. 6).

Petrography of the matrix shows it to be unstructured and contain copious amounts of fine particulate detritus of Saharan origin (Muhs *et al.,* 1990) within a micritic calcite cement. The matrix also contains a large number of modified ooids weathered out of the original rock and occasional

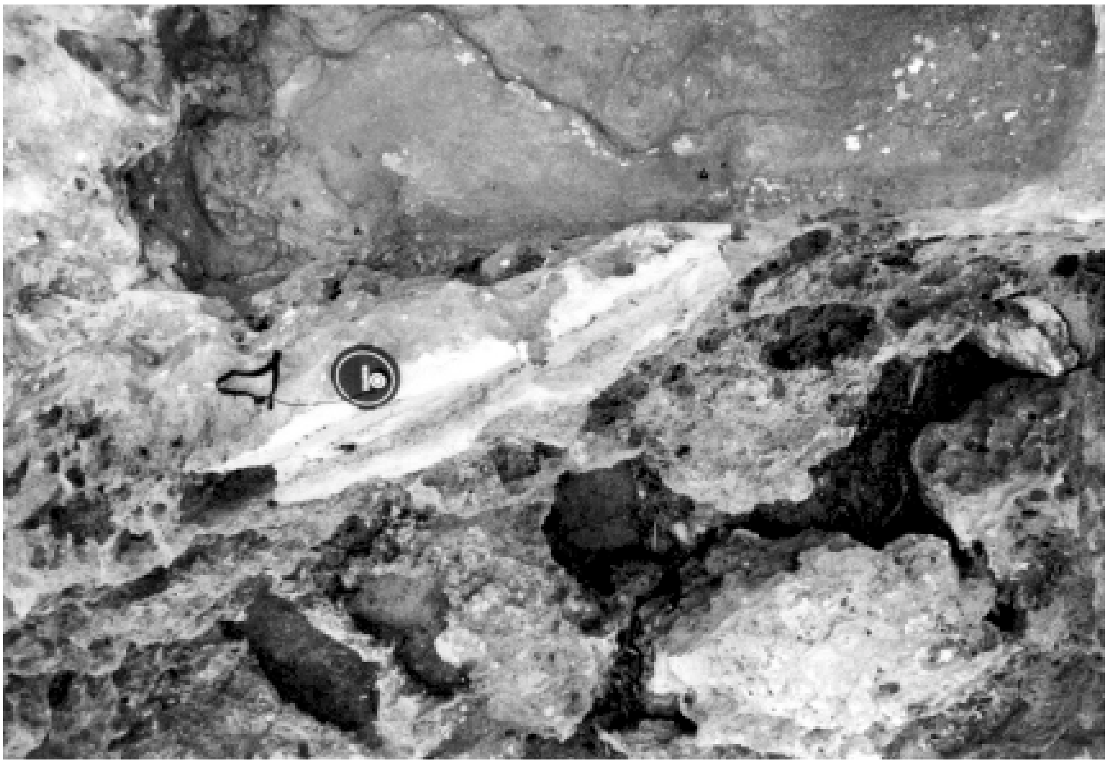

Fig. 5. Photograph of caliche boundary separating country rock (top) from breccia (bottom).
Limite de caliche séparant la roche calcaire en haut de la brèche en bas.

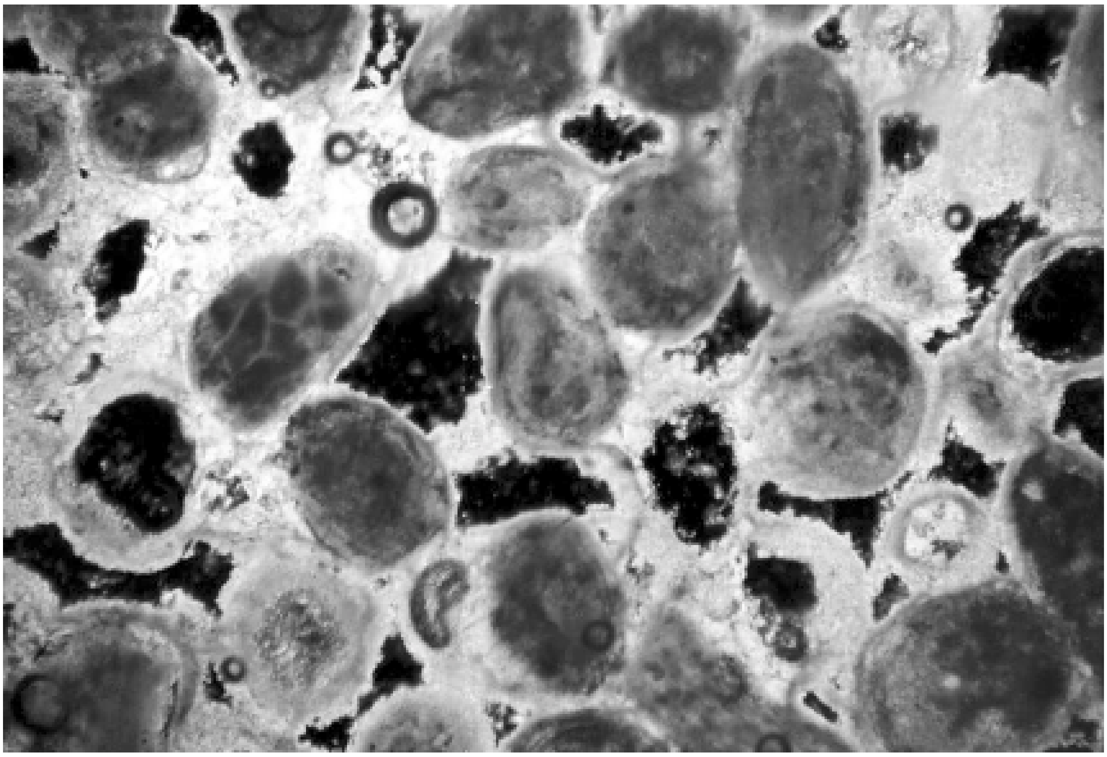

Fig. 6. Petrographic slide of clast material from breccia. Note dissolved ooids and two generations of calcite cement.
Photographie du matériel clastique de la brèche en lame mince. A noter les ooïdes dissous et les deux générations de ciment calcitique.

biolithic fragments. Voids within the matrix contain aragonite fibers. The caliche boundary is structured, displaying prominent layering and consisting primarily of layered micritic calcite with some fine particulate Saharan detritus (Fig. 7). Voids within the caliche contain a calcite meniscus druse of vadose origin and whisker calcite cement commonly found in Bahamian cave walls (Vogel *et al.*, 1990).

Discussion

The vertical restriction of the deposits supports a karstic genesis. In the flank margin theory of cave development, the highest rates of dissolution are proximal to the shore at the intersection of the halocline and the water table. The elevations of the breccia deposits, +2 to +7 meters above sea level (Fig.4), are consistent with other flank margin caves on in the Bahamas that formed in response to the substage 5e sea level still-stand (Mylroie & Carew, 1990).

The presence of nearby paleosol features and stalagmitic material indicates dissolution activity at approximately the same time as the breccia formation. The elevations of these nearby solution features, +5 to +10 meters above sea level, indicate the presence of a paleo land surface at the breccia deposit elevation to a few meters above the breccia deposits (Fig. 4).

Petrography of the country rock and clasts show dissolution has occurred (Fig. 6). The first generation equant isopachous calcite is consistent with a fresh phreatic cementation zone (Harris *et al.*, 1985) that would have been deposited during void formation. The second-generation calcite meniscus druse would have been deposited in a vadose groundwater environment after sea level had fallen. The presence and structure of the caliche boundary layer supports a two-phase origin for the breccia deposits (Fig. 7): a void development phase in which the caliche is deposited as a secondary calcite deposit such as stalagmitic material or through biologically enhanced micritization (Bathurst, 1975), and a second collapse phase in which the void is filled with a proto-breccia.

What this evidence suggests is that the French Bay breccia deposits were formed through karstic processes. This does not eliminate talus from being a component of their formation. In fact, it is likely that talus generated from slope retreat processes is a portion of the material that filled these breached flank margin caves. This process can be observed today occurring on the other side of Sandy Point at Altar Cave (Carew & Mylroie, 1994).

Conclusions

The survey results as well as comparisons to morphologies of present day flank margin caves and sites of active talus formation show that the breccia deposits reflect qualities of a soil breccia filling in breached flank margin caves. These results combined with the petrography suggest the following sequence of events (Fig. 8):

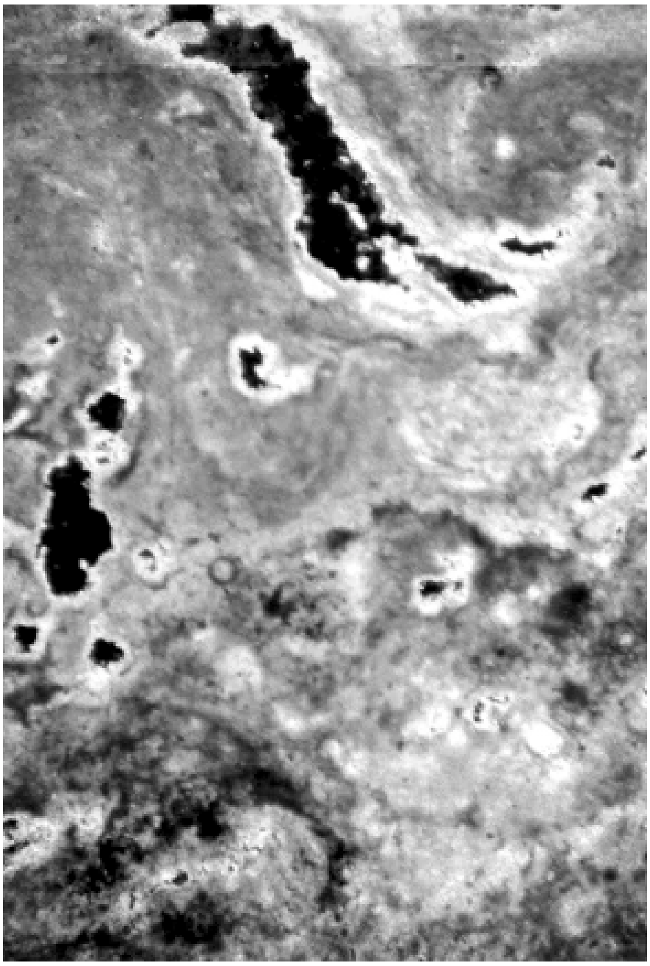

Fig. 7. Petrographic slide of caliche material (country rock direction is toward bottom). Note layered micritic calcite. *Photographie de la bordure de caliche en lame mince (la roche calcaire vers le bas). A noter la calcite micritique stratifiée.*

1. A transgressive oolitic eolianite is deposited during the transgression of an oxygen isotope substage 5e highstand (Carew & Mylroie, 1985), approximately 130,000 years ago.

2. A raise in sea level during the substage 5e maximum cemented the eolianite and initiated dissolution along the halocline/water table interface, approximately 125,000 years ago.

3. Voids of significant size were produced in a short time span along the flank margin of this deposit (Mylroie & Carew, 1990).

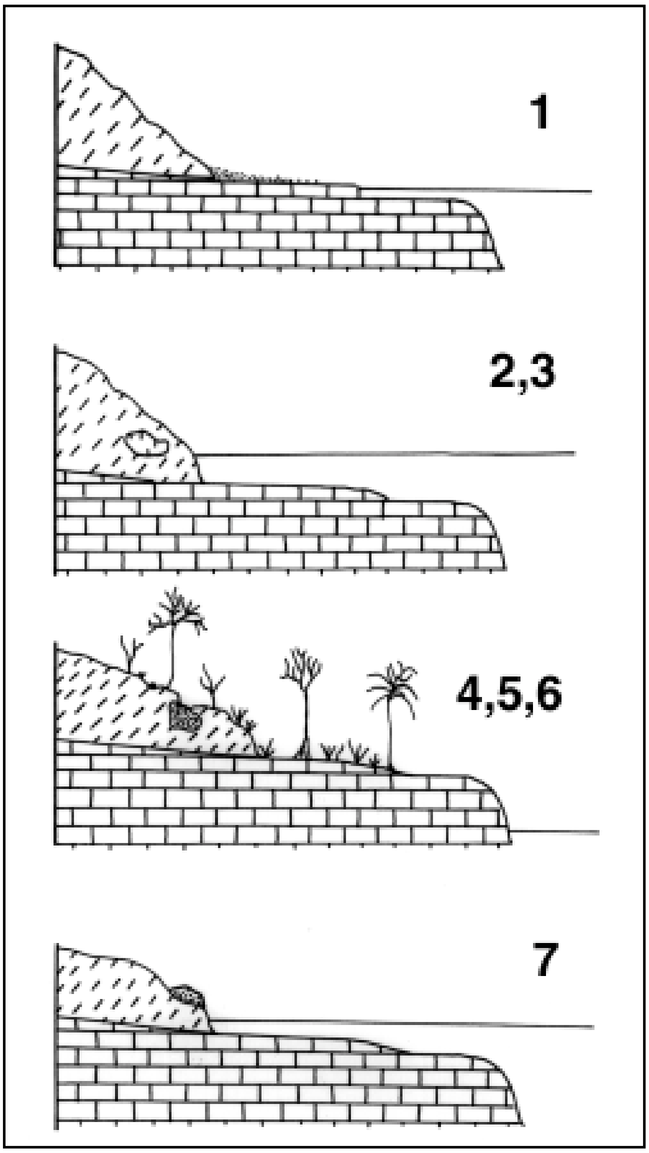

Fig. 8. Modified sequence of breccia development.
Phases de développement de la brèche.

4. After sea level withdraw at the end of substage 5e 120,000 years ago, these voids were exposed to vadose conditions and secondary modification occurred. Precipitation of calcite on the void wall developed a layer of stalagmitic material, and biologic activity enhanced micritization of the wall rock.

5. Denudation of the land surface eventually intersected the voids. Soil and ceiling collapse collected on the floor of the voids creating a thick layer of proto-breccia.

6. Vadose recharge lithified the proto-breccia into the present day deposit.

7. Continued erosion has stripped the remaining overlying country rock and has left the deposits standing in positive relief along the French Bay sea cliffs.

References

Bathurst, R. G. C. (1975) *Carbonate sediments and their diagenesis: Developments in sedimentology*, **12**, Elsevier, New York, 658 p.

Carew, J. L., & 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: *Pleistocene and Holocene carbonate environments on San Salvador Island, Bahamas* (Curran, H. A., *Ed.*), Guidebook for Geological Society of America, Orlando annual meeting field trip, pp. 11-61.

Carew, J. L., & Mylroie, J. E. (1994) *Geology and Karst of San Salvador Island, Bahamas: A Field Trip Guidebook*, Bahamian Field Station, 32 p.

Florea, L. J., Mylroie, J. E., & Carew, J. L. (2000) French Bay Breccia Deposits. San Salvador, Bahamas: Evidence for Karst Genesis In: *Karst Studies and Problems: 2000 and Beyond*, Proc. Joint meeting of Friends of Karst, Theor. & Applied Karstology, and IGCP 448, Presa Universitara Clujeană, pp. 44–48.

Harris, P. M., Kendall, C. G. St. C., & Lerche, I. (1985) Carbonate cementation – A brief review. In: *Carbonate cements* (Schneidermann, N., & Harris, P. M., *Eds*.), Soc. of Economic Paleontologists and Mineraloligists Sp. Publ. **36**, 379 p.

Jones, B., & Smith, D. S. (1988) Open and filled karst features on the Cayman Islands: Implications for the recognition of paleokarst. *Canadian Journal of Earth Sciences*, **25**, p. 1277–1291.

Marshall, P. E., Rasor, D., Lawson, C., Dechene, J. L., Carew, G., Schorr, C., & Mylroie, J. (1984) Investigation of Breccia Facies, San Salvador, Bahamas (*abstract*), *Bull. of the South Carolina Academy of Science*, **46**, p. 109.

Muhs, D. R., Bush, C. A., Stewart, K. C., Rowland, T. R., & Crittenden, R. C. (1990) Geochemical evidence of Saharan dust parent material for soils developed on Quaternary limestones of Caribbean and western Atlantic islands. *Quaternary Research*, **33**, pp. 157–177.

Mylroie, J. E., & Carew, J. L. (1988) Solution Conduits as Indicators of Late Quaternary Sea Level Position. *Quaternary Science Reviews*, **7**, pp. 55–64.

Mylroie, J. E., & Carew, J. L. (1990) The Flank Margin Model for Dissolution Cave Development in Carbonate Platforms. *Earth Surface Processes and Landforms*, **15**, pp. 413–424.

Mylroie, J. E., & Carew, J. L. (1991) Erosional notches in Bahamian carbonates: Bioerosion or groundwater dissolution? In: Proc. Fifth Symposium on the Geology of the Bahamas (Bain, R. J., *Ed.*), Port Charlotte, Florida, Bahamian Field Station, pp. 185–191.

Mylroie, J. E., & Carew, J. L. (1994) *A Field Trip GuideBook of Lighthouse Cave, San Salvador Island, Bahamas*. Bahamian Field Station, 10 p.

Mylroie, J. E., & Carew, J. L. (1995) Karst Development on Carbonate Islands in Unconformities and Porosity in Carbonate Strata. *AAPG Memoir*, **653**, pp. 55–76.

MYLROIE, J. E., & CAREW, J. L. (1997) Geology of the Bahamas. In: *Geology and hydrogeology of carbonate islands* (VACHER, H. L., & QUINN, T. M., *Eds*.), Elsevier, pp. 91–139.

MYLROIE, J. E., CAREW, J. L., SEALEY, N. E., & MYLROIE, J. R. (1991) Cave Development on New Providence Island and Long Island, Bahamas. *Cave Science*, **18**, *3*, pp. 139–151.

PALMER, A. N. (1991) Origin and Morphology of Limestone Caves.*GSA Bulletin*, *103*, pp. 1–25.

PLUMMER, L. N. (1975) Mixing of sea water with calcium carbonate ground water. In: *Quantitative studies in geological sciences* (WHITTEN, E., H., T., *Ed*.), *GSA Memoir*, **142**, p. 219–236.

REECE, M., MYLROIE, J. E., & JENSON, J. W. (2000) *Cave and Karst Development of Guam: Implications for aquifer history*. Program Guide, NSS Conv. 2000, Elkins, WV, p. A-15.

ROBINSON, M. C., & DAVIS, R. L. (1999) Preliminary Geographical Information System Analysis and Maps of Physical, Hydrological, Archaeological, and Biological Resources, San Salvador Island, Bahamas. In: *Proc. Ninth Symposium on the Geology of the Bahamas and Other Carbonate Regions* (CURRAN, H., A. & MYLROIE, J., E., *Eds*.), Bahamian Field Station, San Salvador, Bahamas, p. 101–109.

SANFORD, W. E., & KONIKOW, L. F. (1989) Porosity development in coastal carbonate aquifers. *Geology*, **49**, pp. 249–252.

VOGEL, P. N., MYLROIE, J. E., & CAREW, J. L. (1990) Limestone petrology and cave morphology on San Salvador Island, Bahamas. *Cave Science*, **17**, pp. 19–30.