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A LATE QUATERNARY PALEOECOLOGICAL RECORD FROM CAVES OF SOUTHERN JAMAICA, WEST INDIES

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Studies of an unusual and diverse system of caves in coastal southern Jamaica have yielded a paleoclimatic record associated with a fossil vertebrate record that provides useful insights into the poorly documented paleoecology of latest Wisconsinan and Holocene Jamaica. Episodes of significantly increased precipitation during the Holocene have left characteristic deposits of speleothems, and have supported both faunal and archaeological communities that were dependent on these mesic conditions. Deposits of fossil bat guano preserved in the caves provide a $\delta^{13}C$ record of alternating mesic and xeric climatic episodes that supports the interpretation of the faunal and archaeological record.

A diverse assemblage of late Pleistocene and Holocene vertebrate remains (Table 1) have been recovered from the ~10 km Jacksons Bay cave system on the south coast of Portland Ridge, Clarendon, Jamaica (Fig. 1). Portions of this cave system have been known since at least 1897 (Duerden 1897), but difficult terrain meant that the full extent of the caves did not begin to be appreciated until the discovery of Drum Cave in 1976 (Wadge *et al.* 1979). Significant new cave discoveries continue to be made; Potoo Hole was first explored in 1993 as an adjunct to the paleontological work described here (Fincham 1997). Concurrent with the collection of vertebrate remains, collections of fossil bat guano and other materials were made. As well as providing the context for a unique record of vertebrate extinctions, these materials offer insights into the paleoclimate of the area during the latest Pleistocene and Holocene, of which relatively little is currently known.

Portland Ridge (77° 13' W, 17° 44' N) is a carbonate peninsula in the most southerly part of Jamaica. It consists of some 2200 m of Eocene-Miocene limestones resting on volcanic rocks (Wadge *et al.* 1979). As currently known, the Jacksons Bay system consists of some 9200 m of mapped passages, the inland ones running less than 40m below the modern karst surface. The much shallower coastal sections extend at a very gradual dip to an unknown depth below modern sea level and emerge in one of the offshore terraces; many of the (undived) coastal passages sump seaward in slightly brackish water. The caves (Fig. 2) are essentially an interconnecting phreatic system of trunk passages following two major joint systems now modified by several big collapses. Although the Portland Ridge Peninsula behaves geomorphologically as a carbonate island, it is of interest that these caves do not appear to follow the flank-margin model described by Mylroie and Carew (2000) for carbonate islands. The caves are equilibrated to a lower sea level than today: it is possible that, at low sea levels, allogenic groundwater may have reached the peninsula from further north.

Table 1. Birds and mammals from the fossil and subfossil record, Jacksons Bay Caves (domesticated species omitted)
@ = endemic # = extinct

Tyto alba (barn owl)
Leptotila jamaicensis (White Belly)
?Milvago sp (caracara) @#
Pelicanus occidentalis (brown pelican)
Cathartes aura (John crow)
Amazona cf. agilis (Amazon parrot)
Xenicibis xympithecus (flightless ibis) @#
Rattus rattus (black rat)
Geocapromys brownii (hutia) @
Oryzomys antillarum (Jamaican rice rat) @#
Undescribed rodent. @#
Xenothrix mcgregori (primate) @#
Homo sapiens (man)
Herpestes auropunctatus (mongoose)
Artibeus jamaicensis (Jamaican fruit bat)
Ariteus flavescens (naseberry bat) @
Erophylla sezekorni (buffy flower bat)
Monophyllus redmani (Redman's flower bat) @
Eptesicus lynni (Lynn's brown bat) @
Brachyphylla nana (brown flower bat) #
Macrotus waterhousii (leaf-nosed bat)

Some 14 nominally separate but developmentally interconnected caves can be divided into an "upper" cave group that developed well above the present water table, and a "lower" group developed at or below the modern water table. The lower caves contain standing water (but no active streams or flows) and have not proved to be of paleontological significance. The "upper" caves are older and drier, with a distinctive sequence of secondary deposits. They are frequently breached by collapse pits 10 - 20 m deep, most notably in Arrow, Somerville, Drum, and Lloyds Caves. These features provide

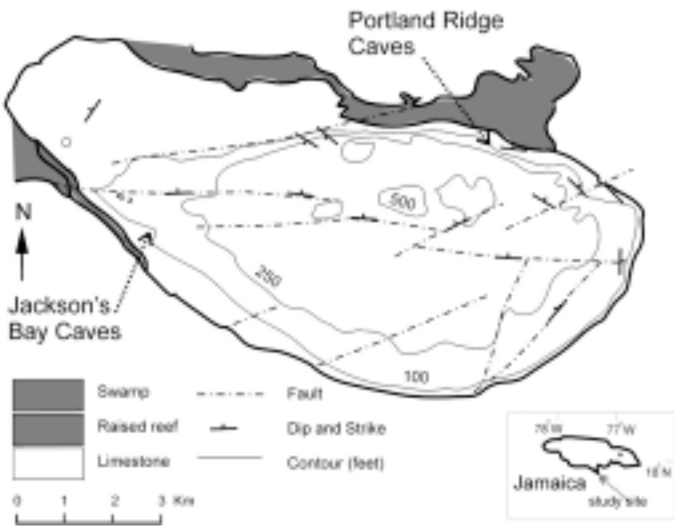

Figure 1. Location map of Portland Ridge Peninsula, the southernmost part of Jamaica, Jacksons Bay Cave site. Modified from Wadge *et al*. 1979. The Blue Mountains are shown on the inset (*).

Figure 2. The Jacksons Bay Cave System, plan view. Grid lines are at 500 m intervals. Drum Cave, which overlies Jacksons Bay Cave, is shown in lighter shading. Modified from Fincham (1997), which should be consulted for more detailed mapping. Important passage locations are Bone Hall (A), Brown Dust Passage (B), The Map Room (C), Mantrap Hole (D), Arawak Gallery (E) and Big Chamber (F).

points of ingress for secondary deposits including lateritic karst residuum (red cave fill), limestone breakdown clasts, and notable accumulations of owl (*Tyto alba*) vomitus. The very dry, powdery, indistinctly stratified, red paleosol-derived cave fill floors large areas of these caves, reaching a depth up to 1.5 m in places. Many of the vertebrate remains were in this material. These sediments are frequently capped by a thin (< 2 cm) but laterally extensive flowstone deposit that commonly forms the walls of rimstone pools (gours). Typically, these pools contain large numbers of cave pearls–speleothems formed by the concentric accretion of calcite from dripping water around crystallization nuclei. In the Jacksons Bay caves, gastropods commonly provide these nuclei (McFarlane 1987), although vertebrate bones also form cores. Largely inactive but very clean and uncorroded speleothems that are at least partially contemporaneous with the rimstone pools extensively ornament ceilings and walls. In some areas of the caves, 1-5 m deep accumulations of subfossil bat guano bury the floors. Archaeological remains are common in the caves, including Amerindian skeletal remains dated at 710 ±60 ^{14}C yrs BP (Mizutani *et al.* 1992), cassava griddles, pottery, petroglyphs and pictographs (Fincham & Fincham 1997). These remains are always superficial to the sediment and flowstone capping, and are either unmodified or occasionally thinly veneered with calcite (Wadge *et al.* 1979).

Portland Ridge is located in the rain shadow of the Blue Mountains (~2300 m) and supports a xerophyllic, sclerophyllous vegetation described by Asprey and Robbins (1953) as the arid coastal facies of dry limestone scrub forest, and more graphically by Seifriz (1943) "...as superb a picture of the eternal persistence of life under the most adverse conditions nature can produce". Annual precipitation averages 1014 mm with a pronounced dry season of 6-10 months having <100 mm-month (data from Amity Hall, 91 year averages; Anonymous 1950). The precipitation-evapotranspiration (PET) ratio is 1.58, placing the area in the "Dry Forest" Holdridge Life Zone (Holdridge 1967). These conditions are apparently too xeric to support major bat populations, with the ubiquitous *Pteronotus parnelli* and *Macrotus waterhousii* occurring in minimal populations of 10-100 individuals, in contrast to populations of 10^4-10^5 individuals commonly occurring in comparable caves elsewhere in the more mesic areas of the island (Goodwin 1970; McFarlane 1986). The presence of extensive deposits of subfossil bat guano in several of the Jacksons Bay caves, unrelated to modern populations, is therefore of considerable paleoecological import.

SAMPLING AND METHODS

In addition to a general study of all the caves of the area, four main field sites were studied: Brown Dust Passage in Drum Cave; Bone Hall Chamber in Drum Cave; Lloyds Cave; and Map Room in Skeleton Cave. Vertebrate remains were collected from the red cave fill, from the dry gour pools, from the owl vomitus, and occasionally from the fossil bat guano. Guano samples were collected from several layers exposed in the walls of excavated pits. Sample sites were documented *in situ* before removal of samples for lab analysis. Guano volumes were determined by survey of their lateral extent and measurement of thickness in test pits and by probing with a steel rod.

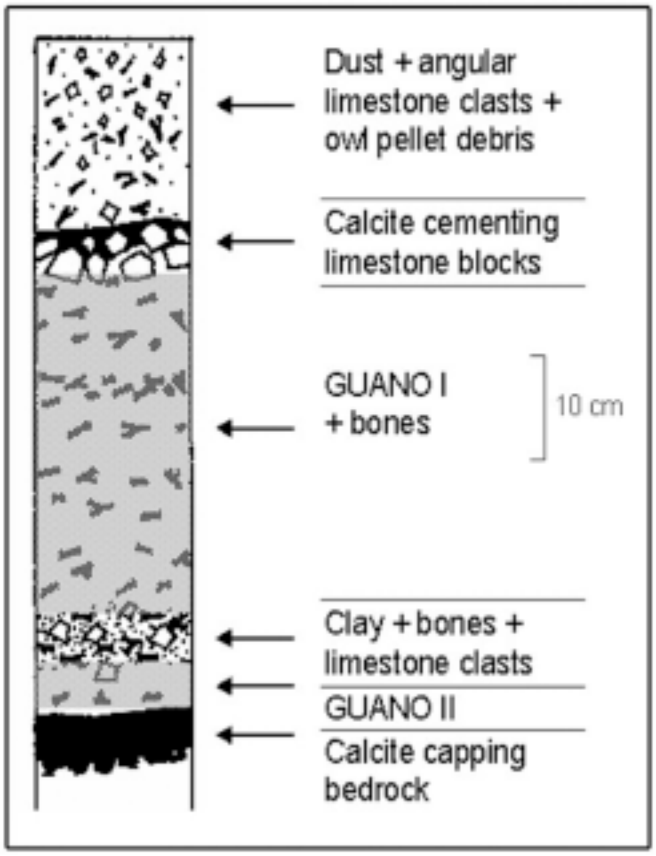

Figure 3 Diagrammatic profile of Brown Dust Passage Excavation Pit.

Vertebrate specimens were dated directly by ^{14}C dating of their bone collagen, or indirectly by ^{14}C dating on the associated guano (acid insoluble chitin residue) or gastropods (inorganic shell carbonate). Gastropods were radiocarbon dated following manual removal of calcite as necessary, and acid etching. Because gastropods can acquire some of their carbon from old, radiogenically dead carbonate bedrock, the measured dates were then corrected for the 'limestone effect' (Goodfriend & Stipp 1983) by subtracting a pseudo-age of 320 ±60 yrs BP obtained from modern (dead) *Pluerodonte* collected in the forest above Birthday Cave. Although we cannot establish the relative contribution of post-bomb radiocarbon (if any) in our modern sample, this 320 year correction factor is in general concordance with that published for other Jamaican specimens and based on modern, pre-bomb *Pluerodonte* (Goodfriend & Stipp 1983). Bone dates are based on collagen fractions prepared by decalcification in excess 1M HCl and alkali washes in 5% NaOH. Fossil guanos were treated with excess 6M HCl at 90° C for 24 hrs, then repeatedly washed in de-ionized water to remove soluble organics and secondary carbonates. Stable isotope mass spectrometry was performed by Beta Analytic (Miami, Florida).

All the original radiocarbon dates reported in this work are obtained by beta counting or accelerator mass spectrometry by Beta Analytic; they are corrected for fractionation using $\delta^{13}C$ values, but are not corrected for ^{14}C flux to facilitate comparison with older published dates. Dates are therefore quoted in radiocarbon years before present (^{14}C yrs BP), not calendar years. All quoted errors are 1σ. Radiocarbon data are summarized in Appendix 1.

Results

Excavation of the Brown Dust Passage sediments in Drum Cave began in January 1995, and was further extended and deepened in July 1995 and September 1996. Stratigraphy is clear and distinctive (Fig. 3). A 20 cm surface deposit of light-colored dust, angular fragments of limestone breakdown, and modern owl-pellet debris overlies a thin (<2 cm) calcite floor, which cements larger limestone breakdown blocks. This unit caps a rather uniform, 34 cm thick layer of dark brown, subfossil bat guano (36% acid-insoluble organics by ignition), hereafter designated 'Guano I'. This is underlain by a 6 cm thick layer of limestone fragments, clay and finely comminuted bone, and then the 3 cm thick 'Guano II'. Below, more clay and degraded bone fragments continue to a solid calcite floor at -125 cm, presumed to be developed directly on the bedrock. Bone occurs throughout the section, often in concentrations so thick as to warrant the description 'bone cake'. Numerous 'hardgrounds' formed by calcite induration of the sediments are scattered throughout the section. Guano II was deposited 11,980 ±80 ^{14}C yr BP, followed by a short hiatus and the deposition of Guano I beginning at 11,260 ±80 ^{14}C yr BP and terminating at 10,250 ±80 ^{14}C yr BP. The Guano I deposit is laterally extensive, forming a deep, 250+ m^3 accumulation. It is deepest in Brown Dust Passage and extends laterally to the Bone Hall chamber (below).

Bone Hall, Drum Cave, is a large, flat-floored chamber receiving vertebrate remains from the same collapse pit as Brown Dust Passage. Accumulation rates have been lower than in Brown Dust Passage (BDP), but the stratigraphy is quite similar. The Guano I stratum of BDP appears in Bone Hall as three thin guano layers: G1a, G1b, and G1c. The latter dates to 11,220 ±100 ^{14}C yrs BP, statistically indistinguishable from the initiation of Guano 1 in Brown Dust Passage. Guano II is not present in Bone Hall. The Bone Hall pit was terminated at -30 cm where solid calcite overlies the presumed bedrock floor. A gastropod date from this basal calcite yielded 13,220 ±150 ^{14}C yrs BP.

Mantrap site, an 8 m deep pit entrance to Lloyds Cave, yielded several vertebrate remains, the most interesting of which was an uncalcited skull of the endemic primate, *Xenothrix mcgregori*, (unfortunately undateable due to the uniqueness of the specimen) recovered from the surface of the cave fill. The 100+ cm deep guano deposit from the Guano Crawl, further south in Lloyds Cave, gave a basal date of 16,400 ±110 yrs BP, a date of 10,440 ±100 ^{14}C yrs BP at 30-40 cm depth, and a date of 1750 ±80 ^{14}C yrs BP at the surface.

The Map Room, Skeleton Cave, has red paleosol-derived sediments 1.5 m deep, with no identifiable stratification, filling the back of the chamber to the roof, where it intercalates with small stalactites on the roof. The top surface of this deposit against the roof is marked by a distinct layer of uncalcited gastropods dating to 3910 ±70 ^{14}C yrs BP. An excavation dug one meter from the wall yielded a bone (*Geocapromys*) from the top 0 – 30 cm layer dating to 1870 ±50 ^{14}C yrs BP. Gastropods from a depth of ~30 cm date to 6410 ±110 ^{14}C yrs BP. This level also yielded a hemi-mandible of *Xenothrix*. Gastropods from 1.5 m date to 3420 ±60 ^{14}C yrs BP.

Potoo Hole has extensive deposits of bat guano in the Arawak Gallery and the Big Chamber. The thickest part of the deposit forms a guano "mountain," rising some 6 m in height above the general guano floor covering; is at least a meter deep, but was not excavated. Samples taken from the top of the "mountain" date to 950 ± 50 ^{14}C yrs BP but the date of the start of deposition is not known.

High Dome Cave, located on the northeastern side of the Portland Ridge, (Portland Ridge Caves group; Fig. 1) also preserves extensive deposits of stratified fossil guano; a sample from 115 cm depth exposed by guano mining yielded a date of 10,850 ±100 ^{14}C yrs BP.

Chronology and paleoenvironmental significance of the cave deposits

The origin of the Jacksons Bay caves is poorly understood. The caves formed within the Miocene host rock. The oldest dated cave calcite, a U-Th date on flowstone from Shamrock Passage, a lower level passage in the Jacksons Bay New Cave, gave an age of 278 +57,-37 ka. The weighted mean of four samples (Wadge *et al.* 1979) from the same flowstone is 202 ±16 ka, so that section of the cave must have been already formed before that date. The 'upper' caves pre-date the New Cave, and may have their origins in the earliest Pleistocene or late Pliocene as did comparable caves on Isla de Mona, Puerto Rico (Panuska *et al.* 1998). Regardless of the timing of speleogenesis, the caves did not become paleontologically important until the opening of the collapse pit entrances, which admit vertebrate remains. The radiocarbon date of 13,220 ±150 ^{14}C yrs BP on the calcited gastropod cemented to the bedrock floor of the Bone Hall Excavation, Drum Cave, pre-dates all fossil and sediment deposits in this cave and probably marks the opening of the Drum Cave #3 collapse pit.

The late Pleistocene and Holocene was marked in these caves by the progressive emplacement of the red cave fill, vertebrate deposits, and calcite floors. These extensive deposits provide *prima facie* evidence that these caves were much wetter at intervals in the recent past. In many cases, the characteristics of the deposits and the relationships between dated materials give additional information about the environmental conditions of formation.

Evidence for wet phases

In Lloyds Cave, bat guano deposition began at least as early as 16,400 ±110 ^{14}C yrs BP and continued until at least 1750 ±120. In Brown Dust Passage, Drum Cave, guano deposition began more than 11,980 ±80 ^{14}C yrs BP but terminated around 10,350 ±70 ^{14}C yrs BP. The thickest guano deposits are Late Holocene; e.g., deposition of the very large guano deposits in Potoo Hole (~ 4000 m³) terminated around 950 ±50 BP. The preservation of laminations (seasonal?) in the 10,850 ±100 ^{14}C yrs BP guano deposit of High Dome Cave (north side of Portland Ridge) evidences that the relatively thin late Pleistocene deposits in the Jacksons Bay caves are not simply the result of decomposition deflation. This suggests that conditions were more favorable for bats in the Jacksons Bay caves during the late Holocene.

A U-Th date on the top of an inactive stalagmite from the Coliseum, Jacksons Bay Great Cave, of 1.9 +2.9,-2.8 ka and a basal date of 27.9 +12,-11 ka (Wadge *et al.* 1979) is consistent with Late Pleistocene to Holocene wet intervals. The solid calcite beneath the guano in Brown Dust Passage, Drum Cave, and the numerous calcite-indurated layers scattered throughout the section indicate wetter conditions than now pertain in the cave; these wet conditions began an unknown time before ~13 ka and continued (perhaps intermittently) until some time after 10 ka. In Bone Hall, Drum Cave, the gastropod core of a cave pearl dated to 3700 ±120 yrs BP. From this we infer that conditions were at least seasonally wet enough to account for the extensive development (~1500 m² in Drum Cave alone) of gour pools that have never been observed to fill in 25 years of speleological investigations in the cave.

At present water levels, crocodiles are not found in any of the Jacksons Bay Caves: discoveries of undated, but superficial, crocodile remains, *Crocodylus acutus*, on top of the cave fill in Mantrap Hole, Lloyds Cave, indicate wetter conditions in the middle to late Holocene when the cave supported extensive bodies of standing water.

Archaeological remains are extensive in both the upper and lower Jacksons Bay caves, but are always superficial to the paleosols and calcite floors. Broken water jars in Water Jar Cave have been taken as evidence that Amerindians collected fresh water from now-dry gour pools (Fincham & Fincham 1997). A date on Amerindian bone intimately associated with these ceramics indicate that this practice continued until at least 710 ±80 ^{14}C yrs BP.

These data suggest intermittently wetter-than-today conditions in the interval from at least 28 ka, isotope stage 2, the Late Glacial Maximum, until about AD 1300, the Medieval Warm Period of Northern Europe (Lamb 1995). The wettest, or longest, wet interval was probably coincidental with the thickest guano deposits, which terminated at ~950 ^{14}C yrs BP.

Table 2. Stable carbon isotope record of the Jacksons Bay Cave guanos.

Sample ID	Age (^{14}C kyr BP)	d $^{13}C_{PDB}$
95-24, 95-25, **	0	-21.6, -22.8, -21.6
85-02	0.70 +/- 0.05	-25.0
95-16	0.95 +/- 0.05	-26.8
93-03	1.75 +/- 0.08	-27.7
95-21	10.25 +/- 0.08	-21.7
95-04	10.35 +/- 0.07	-16.6
95-07	10.44 +/- 0.10	-20.7
96-15	10.85 +/- 0.1	-20.6
95-03	11.05 +/- 0.07	-17.5
96-16	11.22 +/- 0.1	-21.3
95-22	11.26 +/- 0.08	-18.6
95-23	11.98 +/- 0.08	-20.9
95-08	16.40 +/- 0.11	-22.4

** indicates a replicate analysis

Evidence for flood activity

The dates from the uncalcited gastropods and bone in the red sediment of the Map Room, Skeleton Cave, need to be examined: the top layer beside the cave wall dates to 3910 ±70 ^{14}C yrs BP, while the 0–30 cm layer of the excavation dates to 1870 ±50 ^{14}C yrs BP; the 30 cm level dates to 6410 ±110 ^{14}C yrs BP, but the 150 cm level dates to 3420 ±60 ^{14}C yrs BP. From this chronological jumble, we conclude that the Skeleton Cave fill and its contents were catastrophically emplaced, probably by severe flooding, sometime after ~3600 ^{14}C yrs BP and most probably after 1870 ^{14}C yrs BP during the same Late Holocene wet phase responsible for massive guano deposition in Potoo Hole and Amerindian water collection in Water Jar Cave.

Paleoecological significance of stable isotopic records of guano deposits

The utility of subfossil bat guano deposits as a source of a ^{13}C/^{12}C stable isotope proxy record of climate has been demonstrated by Mizutani *et al.* (1992). Insectivorous bat guano consists of finely commutated insect exoskeletons, of which some 25-40% by dry weight may be chitin (polymerized N-acetylglucosamine) (Jeuniaux 1971). Chitin is highly resistant to chemical and physical degradation, although it is readily digested by fungal and bacterial chitinases under aerobic and anaerobic conditions respectively (Miller *et al.* 1993; Koval & Kharkevich 1983). However, under conditions of low pH (Logan *et al.* 1991) or desiccation, decomposition is extremely slow. Last Interglacial insect remains from Nova Scotian sediments contain as much as 28% dry weight of chitin (Miller *et al.* 1993). We have found subfossil guano from a dry site in Bat Cave, Grand Canyon (Arizona, USA) radiocarbon dated at 12,400 ±90 yrs BP (DAM 96-03) that preserves 31.9% dry weight of chitin (unpublished data).

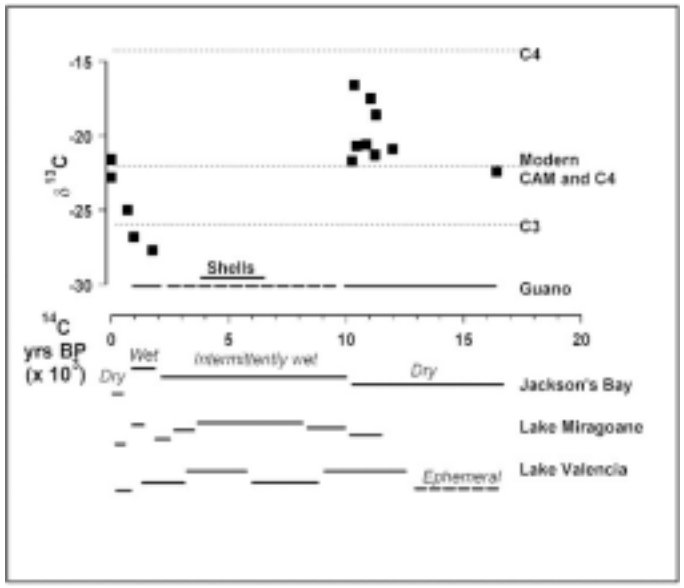

Figure 4 δ^{13}C values for fossil bat guano samples are graphed against time; the horizontal line just above the x-axis indicates the span of guano deposition, the unbroken part showing dated continuous deposition and the dashed part showing probable continuous deposition. The line marked "Shell" marks the cluster of cave pearl dates. A summary of inferred climatic conditions for Jacksons Bay and lake levels for Lake Mirogoane and Valencia, are shown below the x-axis.

Although decomposition undoubtedly proceeds much faster in moist tropical environments, the low pH of fresh deposits (~pH 3.8) can preserve chitinous residues for extended periods of time. Subfossil bat guanos of a degraded nature can be conclusively identified by deacetylation of the chitin to chitosan followed by colorimetric assay using the van Wisselingh test (Muzzarelli 1977), or following enzymatic digestion using chitosanases and assay of the N-acetylamino sugars by the method of Reissig *et al.* (1955). Degradation of chitin progresses by depolymerization, but does not introduce significant shifts in the ^{13}C/^{12}C ratio (Schimmelmann & DeNiro 1986).

Modern insectivorous bat (*Pteronotus* and *Macrotus*) guano accumulating in small quantities in the Jacksons Bay caves has a mean δ^{13}C signature of -21.7, consistent with its origin in a food chain based on xerophyllic C4 and CAM plant taxa (Des Marais 1980). The Late Holocene fossil bat guanos from these caves have divergent δ^{13}C signatures that are independent of diagenesis or age (Table 2), which we interpret as resulting from an increased C3 plant component in the food chain during more mesic climatic excursions (indicated by δ^{13}C values around -26). Figure 4 shows the changes in δ^{13}C against time. These data suggest a xerophytic period similar to today at around 16,000 ^{14}C yrs BP and again at around 12,000–10,000 ^{14}C yrs BP with perhaps more C4 vegetation. The shift to C3 signatures at around 1,750-700 ^{14}C yrs BP (250

- 1300 AD) indicate wetter conditions, followed by an obvious trend up to modern CAM values showing increased aridity.

BIOGEOGRAPHIC SIGNIFICANCE OF THE PALEONTOLOGICAL REMAINS

A perennial and unresolved debate that has long been central to Caribbean biogeography addresses the manner in which terrestrial vertebrate colonists first reached the islands (Williams 1989). In the specific case of Jamaica, putative land bridges have been decisively eliminated on geologic grounds (Buskirk 1985); but see recalcitrant opinions in MacPhee and Iturralde-Vinent (1999). For several West Indian mammals, humans are thought to be the vectors. For this to be true, the dates on the oldest remains must be consistent with the earliest dates of human colonization. The Jacksons Bay Caves record throws some light on the origin of one endemic species of mammal, *Oryzomys antillarum*, the extinct Jamaican Rice Rat.

Although it has been shown that the Jamaican rice rat is apparently distinct from other *Oryzomys* (Morgan 1993), it has not previously been demonstrated that *O. antillarum* was present in the Pleistocene of Jamaica. The BDP excavation in Drum Cave yielded several mandibles of *O. antillarum* from above, and more importantly from within, the undisturbed Guano I horizon, which is tightly constrained to have been deposited between 11,260 ±80 ^{14}C yrs BP and 10,250 ±80 ^{14}C yrs BP. The bone bears the characteristic staining seen in all Guano I material, and the interface between Guano I and the overlying sediments is so distinct as to preclude any reasonable possibility that *Oryzomys* could be intrusive. *Oryzomys* is, thus, established as a *bona fide* member of the latest Pleistocene fauna of Jamaica. It has long been established that *O. antillarum* is little differentiated from its mainland sister taxon and, therefore, of relatively recent tenure on Jamaica (Morgan 1993). This Pleistocene record, therefore, also eliminates any possibility that *O. antillarum* was an accidental traveler on an Amerindian canoe, and adds it to the roster of native Antillean mammals whose arrival in the Antilles can be definitively ascribed to over-water disperal. Eustatic sea level between the Late Glacial Maximum (~20 ka) and 11-10 ka would have been between ~-120 and ~-40 m (Bard *et al.* 1990), considerably shortening the distance to be covered by exposing the Mosquito, Rosalind and Pedro Banks.

PALEOCLIMATIC RECONSTRUCTION

These records suggest that the paleoenvironment of Portland Ridge was significantly different from today during the latest Pleistocene and most of the Holocene. Wetter periods throughout the record (~16.5 ka to ~0.7 ka) are suggested by:

- extensive deposits of now largely inactive calcite
- extensive deposits of sub-fossil bat guano, no longer being deposited in such quantities
- archaeological remains indicating water collection in now dry caves
- crocodile remains in now dry caves
- evidence for mid- to Late Holocene flood activity
- Late Holocene guano δ^{13}C values indicating formerly more mesic conditions

The presence of guano in Lloyds Cave at 16.4 – 10.44 ^{14}C kyrs BP, and the layers of calcite of unknown depth overlying bedrock in BDP and Bone Hall suggest wetter conditions at least periodically from ~16–10 ^{14}C kyrs BP. Guano from 11.98 –11.44 ^{14}C kyrs BP, the cluster of guano dates 10.26–10.25 ^{14}C kyrs BP, and the calcite plus breakdown capping on the 10.25 ^{14}C kyrs BP guano suggest periodic interruptions. Guano deposition continued throughout this period until ~1.7 ^{14}C kyrs BP in Lloyds and ~0.95 ^{14}C kyrs BP in Potoo Hole, in combination with the possible flood event after 1.8 ^{14}C kyrs BP in Skeleton Cave, and the scattering of shell dates between 4 and 3.4 ^{14}C kyrs BP. These data suggest only periodic interruptions rather than a prolonged dry spell.

We tentatively divide the paleoclimate into four phases:

~16.5 – 10	^{14}C kyrs BP: Dry
~10 – 2	^{14}C kyrs BP: Intermittently wet
~2 – 0.7	^{14}C kyrs BP: Wet, humid
~0.7 – 0	^{14}C kyrs BP: Dry

COMPARISON WITH OTHER RECORDS OF CARIBBEAN CLIMATE CHANGE

Paleoclimatic records from the Caribbean are not abundant. One of the best-studied sites is Lake Miragoane, southern Haiti. Pollen and stable isotope records since ~10.3 ^{14}C kyrs BP are reported in Hodell *et al.* (1991) and Higuera-Grundy *et al.* (1999). This site is in a similar south-coastal, leeward-of-highlands setting as the Jacksons Bay site. Lake levels are complicated by rising Holocene sea level but the climatic interpretations take this into account. Low lake levels indicating a dry climate at ~10.5–10 ^{14}C kyrs BP are coincidental with the Younger Dryas period of Europe and North America. Higher lake levels at ~10–7 ^{14}C kyrs BP coincide with the end of Termination II and the early Holocene in the marine isotopic records although some discrepancy exists between lake level data and vegetation data. The pollen record continued to show dry conditions until ~8.2 ^{14}C kyrs BP. The highest lake levels between ~7 and 3.2 ^{14}C kyrs BP are matched by mesic forest in the pollen record. Decline of lake levels at ~3.2–2.4 ^{14}C kyrs BP indicate dry conditions, becoming very dry at 2.4–1.5 ^{14}C kyrs BP. A brief return to wet conditions at ~1.5–0.9 ^{14}C kyrs BP interrupted the drying trend to the present very dry conditions. These changes, summarized in Figure 4, are broadly comparable with the record from Jacksons Bay, although of higher resolution. The indication of higher water levels starting at ~10 ^{14}C kyrs BP in the Jacksons Bay sediments coincides with the lake levels rather than with vegetation indices. The short-lived wet episode of ~1.5–0. 9 ^{14}C kyrs BP is matched by the 0.7–2.0 ^{14}C kyrs BP wet event and the postulated <~1.8 ^{14}C kyrs BP flood event in Jacksons Bay Caves, and the recent return to dry conditions coincides in both records.

Little information is available on comparable sites in southern Jamaica. Digerfeldt and Enell (1984) report that levee deposits and silt/clay deposits in the peat of Black River Morass (on the southern coast west of Portland Ridge) indicates increased flooding and wetness between 1.5 and 1.0 ^{14}C kyrs BP. The other somewhat relevant Jamaican site is from the northern coast but of low resolution: Goodfriend and Mitterer (1988) present evidence of Pleistocene coolness and aridity from land snail amino acid epimerization data, moist conditions in the Late Holocene, and drier conditions beginning sometime during the last millennium. This pattern conforms to the Jacksons Bay record. Street-Perrott *et al.* (1993) report a lake core from Wallywash Great Pond, southern Jamaica, that records a cool, dry climate in the Late Pleistocene at 9.5–9.3 kyrs BP followed by three cycles of alternating wet and dry conditions during the Holocene, regrettably not directly datable.

Another lake site reported by Martin *et al.* (1997): Lake Valencia, just west of Caracas on the Venezuelan coast, is open to the NE trades at all seasons. It is not on the leeward side of highlands and, thus, has a somewhat different climatic regime, as is apparent from the differing climatic history. The lake was ephemeral before ~12.4 ka with savanna-chaparral vegetation; high during the period 12.4–8.8 ka with a shift to forest vegetation; low at ~8.88 to ~5.5 ka, high at ~5.5–3.0 ka, low at ~3.0–1.0 ka, and desiccated in historical times. These changes are summarized in Figure 4.

Higuera-Grundy *et al.* (1999) reviewed the published evidence of climatic change from the Caribbean region. All records agree that the Late Pleistocene was cool and dry with savanna vegetation and low lake levels, remaining dry until at least ~10.5 ^{14}C kyrs BP when forest taxa appeared in Guatemala. After ~10 ^{14}C kyrs BP the trade winds weakened, upwelling diminished and lake levels started to rise as a consequence of the higher precipitation. Early Holocene dryness apparently persisted in north coast of Jamaica, Florida, and the Yucatan; Jamaica continued to show a cool, dry climate until ~9.5 ^{14}C kyrs BP; Florida vegetation did not show a change to mesic conditions until ~7 ^{14}C kyrs BP. All the Caribbean records show a similar drying phase since ~1 ^{14}C kyrs BP, which is assumed to have caused the collapse of prehistoric and early historic agriculture (Leyden *et al.* 1998).

Controls on climate

The ocean-atmosphere system strongly influences Jamaica's climate and, thus, in many ways is very simple. Martin *et al.* (1997), in a discussion of climate controls for the Amazon basin, note that the migration of the Intertropical Convergence Zone (ITCZ) governs seasonality in the Caribbean, when it shifts south in austral summer as the continent of South America warms. While the ITCZ is in its southerly position the Caribbean climate is governed by the North Atlantic sub-tropical high. Holocene shifts displayed in climatic records from southeastern Amazonia and Bolivian Altiplano demonstrate that during the period 15.5–8.8 ka, the ITCZ did not reach as far south into the Amazon basin during the austral summer as it does today. Martin *et al.* (1997) relate this shift to the difference in orbital parameters around 11 ka compared to today. Today's situation of perihelion in December, the austral summer, causes strong seasonal differences in the southern hemisphere. The shift to perihelion in June during the period 15.5–8.8 ka reduces southern hemisphere seasonal differences at this time. Since it is the warming of the continental mass that controls excursions of the ITCZ, the climatic controls on the southern hemisphere are, therefore, significant for the Caribbean climate. Associated with the shift northwards of the ITCZ is an increase in Caribbean precipitation and a weakening of the trade winds.

Hodell *et al.* (1991) note the general agreement between Holocene climatic changes in the Caribbean and in northern Africa, and suggest that the common controlling mechanism is provided by orbital changes. However, they point out that more abrupt changes, such as the sudden change to drier conditions at ~3200 ^{14}C yr BP in Lake Miragoane, related to ocean-atmosphere interactions, are superimposed on the simple, smooth orbital trends. The general trend of increased wetness and flood activity in the Jacksons Bay caves is probably related to the insolation high centered over 7 ka, but the sudden shift in the guano $\delta^{13}C$ from forest to xeric vegetation from ~2000 ^{14}C yrs BP to present must relate to non-orbital effects.

Jacksons Bay, almost exactly southwest of the Blue Mountains, the highest part of Jamaica, is particularly sensitive to trade wind direction. It is in a rain shadow position for NE winds but open to higher rainfall if the wind shifts to a more easterly origin. We suggest that the general pattern of mid-Holocene wetness is explicable by orbital changes controlling the position of the ITCZ. However, the frequent, rapid shifts of the last two millennia may relate more to local changes in prevailing wind direction.

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Appendix 1. Summary of radiocarbon dates from the Jacksons Bay Caves

ID	Site	Material	Age
95-04 (81354)	BDP, Drum cave. Surface guano	Bat Guano	10,350 ± 70
95-21 (83967)	BDP excavation, Drum Cave. Top of Guano I	Bat Guano	10,250 ± 80
95-22 (83968)	BDP excavation, Drum Cave. Base of Guano I	Bat Guano	11,260 ±80
95-23 (86687)	BDP excavation, Drum Cave, Base of Guano II	Bat Guano	11,980 ±80
95-17 (82655)	Surface gours, Drum cave, near Entrance #3. Cave pearl.	Shell	4,020 ±120 (3,700 ±120*)
95-03 (82221)	Bone Hall, Drum cave. 'Guano I'	Bat Guano	11,050 ± 70
96-16 (98640)	Bone Hall excavation, Drum Cave. 'G1c' layer.	Bat Guano	11,220 ±100
96-22 (98642)	Bone Hall, Drum Cave. –30 cm, bottom of pit	Shell	13,540 ±150 (13,220 ±150*)
95-07 (83966)	Guano Crawl, Lloyds Cave. -30 to -40 cm	Bat Guano	10,440 ±100
95-08 (82689)	Guano Crawl, Lloyds Cave. - 95 to -100 cm.	Bat Guano	16,400 ± 110
96-18 (98641)	Map Room, Skeleton Cave. 'surface' against roof.	Shell	4230 ±70 (3910 ±70*)
95-12 (81716)	Map Room, Skeleton Cave, mixed layer, 0 to -30 cm.	Bone	1870 ±50 (AMS)
95-14 (81718)	Map Room, Skeleton Cave. - 150 to -160 cm	Shell	3740 ± 60 (3420 ±60*)
95-32 (83970)	Map Room, Skeleton Cave. Xenothrix level.	Shell	6,730 ±110 (6,410 ±110*)
95-16 (82222)	'Guano Mountain', Potoo Hole. -5 to -10 cm.	Bat Guano	950 ± 50
93-03 (67572)	Guano Crawl, Lloyds Cave. Surface 1 cm.	Bat Guano	1750 ± 80
85-02	Queen's Series, Jacksons Bay Old Cave, -1 to –3 cm	Bat Guano	0.70 ±0.05
96-15 (98639)	High Dome Upper. Guano deposit at -115 cm.	Bat Guano	10,850 ±100

* indicates shell dates corrected for the 320 year "limestone effect"
ID numbers are field numbers, with Beta Analytic laboratory codes in parentheses.