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Prodromus of vertebrate paleontology and geochronology of Bermuda

Storrs L. Olson
Smithsonian Institution

David B. Wingate

Paul J. Hearty
University of Wollongong, paulh@uow.edu.au

Frederick V. Grady

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Abstract

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Keywords

Prodromus, Vertebrate, Paleontology, Geochronology, Bermuda

Disciplines

Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

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PRODROMUS OF VERTEBRATE PALEONTOLOGY AND GEOCHRONOLOGY OF BERMUDA

Storrs L. OLSON, David B. WINGATE, Paul J. HEARTY & Frederick V. GRADY

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Resum

Les fluctuacions pleistocèniques del nivell de la mar han estat el primer determinant de la deposició geològica i l'evolució biòtica a Bermuda. L'illa està composta d'arenes carbonatades dipositades sobre el cim erosionat d'un volcà submarí durant el decurs de nivells de la mar elevats dels períodes interglacials. A partir de les arenisques interglaciars s'han obtingut unes poques restes de vertebrats, principalment d'edat pleistocènica mitja. Els intervals glacials estan marcats per sols vermells, derivats principalment de la pols atmosfèrica. Els vertebrats fòssils d'edat glacial no es troben preservats a la superfície i només es coneixen de coves i rebliments de fissures. A Bermuda es coneixen faunes fòssils dels darrers dos episodis glacials, però no dels anteriors. Es coneixen extincions certes o probables de vertebrats correlacionades amb, com a mínim, quatre pujades interglacials del nivell de la mar (estadis isotòpics marins, MIS, 11, 9, 5 i 1). Es revisa la història de la paleontologia de vertebrats a Bermuda i s'allisten i es descriuen breument les localitats de vertebrats fòssils.
Paraules clau: ocells fòssils, extinció pleistocènica, canvi del nivell de la mar.

Summary

Pleistocene sea-level fluctuations were the primary determinant of geological deposition and biotic evolution on Bermuda. The island is composed of carbonate sand deposited on the eroded summit of a submarine volcano during elevated sea-levels of interglacial periods. A few vertebrate remains have been recovered directly from interglacial sandstones, mainly of mid-Pleistocene age. Glacial intervals are marked by red soils derived mainly from atmospheric dust. Vertebrate fossils of glacial age are not preserved at the surface and are known only from caves and fissure fills. Fossil faunas are known on Bermuda from the last two glacial episodes but none of the earlier ones. Certain or probable extinctions of vertebrates are correlated with at least four interglacial rises in sea-level—-Marine Isotope Stages (MIS) 11, 9, 5, and 1. The history of vertebrate paleontology on Bermuda is reviewed and fossil vertebrate localities are listed and briefly described.
Keywords: fossil birds, Pleistocene extinction, sea-level change.

INTRODUCTION

Bermuda is an isolated oceanic island situated 1000 km ESE of Cape Hatteras, North Carolina (Fig. 1, inset). Its volcanic core, last active during the Oligocene (Reynolds & Aumento, 1974), was probably subaerial for some of its existence because rare basaltic pebbles and a small percentage of volcanic grains have been found in surface deposits. Apart from the initial volcanic origin of Bermuda, the most important factor affecting the geology of the island has been fluctuating sea-levels during the Pleistocene, with marine carbonate deposition on the platform during interglacial high sea stands. An excellent summary of the Quaternary history of Bermuda may be found in Vacher *et al.* (1995).

The exposed rocks on the island consist almost entirely of biogenic carbonate dunes or "eolianite" (a term coined by Sayles, 1931) formed from comminuted mollusk shells, coral, coralline algae, and foraminifera. These sediments are transported to the shore by waves and currents, and are subsequently blown onto land by strong winds. The eolianites form primarily during interglacial highstands when rises in sea-level flood the Bermuda platform (Bretz, 1960; Land *et al.*, 1967), and during early regression from the highstand position. Thus, eolianites are landward facies of shoreline deposits. During glacial periods of sufficient intensity to bring sea-level below the edge of the platform, the shelf is exposed and biogenic sediment formation ceases because the highest parts of the platform (present-day Bermuda islands) are essentially cut off from eolianite deposition.

During glacial lowstands, red soils develop from oxidation of the underlying limestone and deposition of wind-borne dust coming off of the Sahara Desert (Glaccum & Prospero, 1980; Muhs *et al.*, 1990). These soils redden with age, and become heavily leached while exposed to the elements over tens or hundreds of thousands of years. Thus, they seldom contain identifiable fossils. However, in caves and fissures fossils are protec-

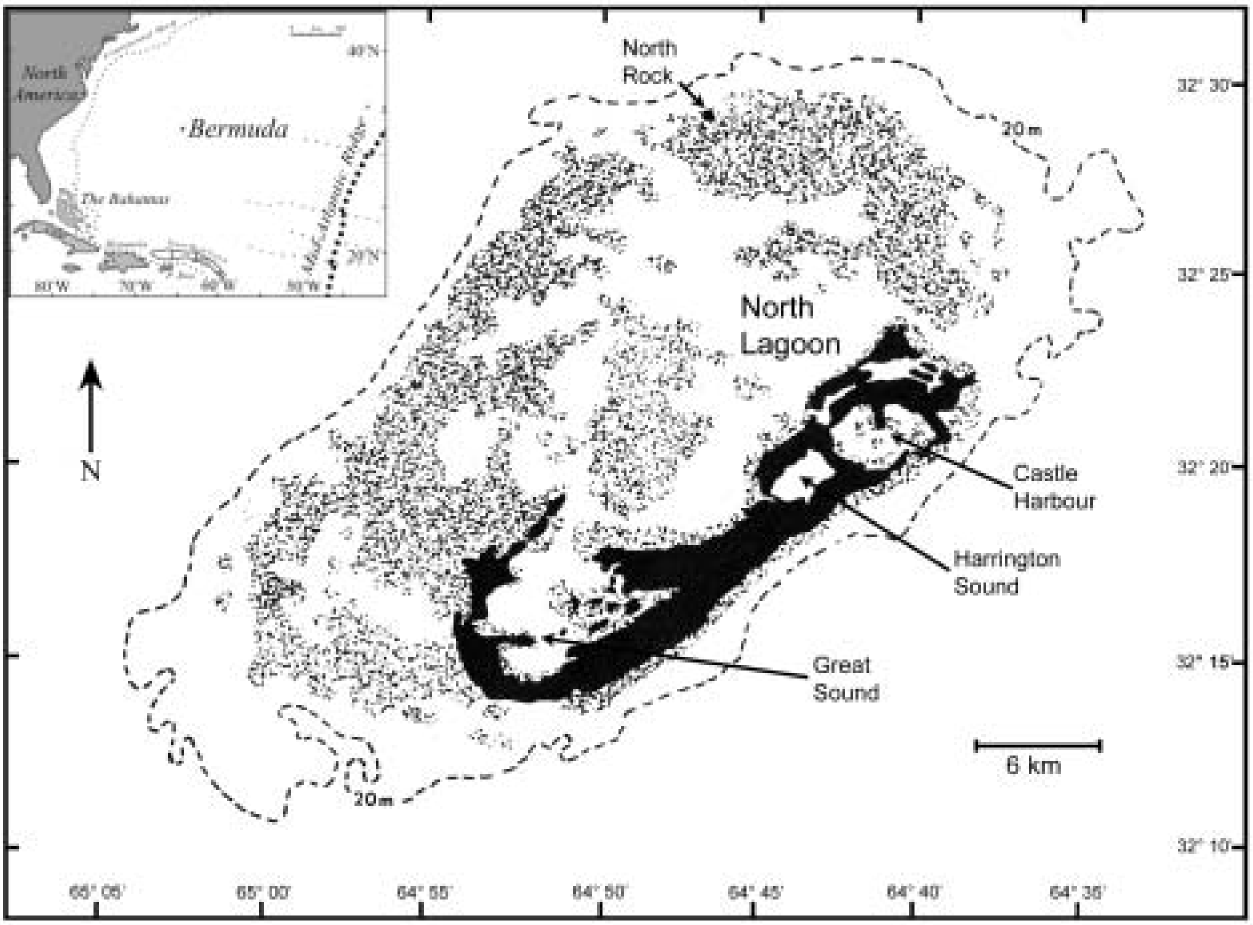


Fig. 1. Map showing present land area of Bermuda (in black) and the extent of reefs and the Bermuda platform (dashed line) that would have been exposed during major glacial episodes (modified from Logan, 1988: 33). Inset: Map showing position of Bermuda relative to the E coast of North America.

Fig. 1. *Mapa on es mostra l'àrea terrestre actual de Bermuda (en negre) i l'extensió dels esculls i la plataforma de Bermuda (línia de punts) que hauria estat exposada durant els episodis glacials principals (modificat a partir de Logan, 1988: 33). Quadre inserit: Mapa on es mostra la posició de Bermuda respecte la costa E de Nord-Amèrica.*

ted from external elements such as sun, wind, and rain, increasing their potential for preservation. Additionally, cave flowstone may also periodically bury fossil deposits, affording even greater protection from degradation. Consequently, nearly all knowledge of faunas of glacial age is derived from subsurface "pitfall" deposits (Hearty *et al.*, 2004).

The majority of fossils from Bermuda that have been extracted from surface deposits are almost entirely of interglacial age, despite the fact that interglacial deposits represent only a fraction (some 10-15%) of the temporal record of Bermuda since the first surface rocks were deposited. By far the greater part of the temporal record of Bermuda is represented by red soils, which rarely contain fossils, thus highlighting the importance of cave and fissure deposits for filling out this important gap in the fossil record.

The land area of Bermuda fluctuates greatly between sea-level highstands and lowstands (±100-150 m) (Chappell & Shackleton, 1986). In our current interglacial period, the area of Bermuda is about 56 km^2. This land area would have been significantly reduced at the peak of the last interglacial (MIS 5e) highstand about 120 kya ago when sea level was 6-9 m higher than present (Hearty & Neumann, 2001; Hearty, 2002). During the maximum sea-level rise of the MIS 11 interglacial, ca. 400 kya ago, sea-level was more than 20 m above the present level, reducing the area of Bermuda to less than 20-30% of the island's current area (Olson & Hearty, 2003). In contrast, during maximum glacial lowstands, the entire Bermuda platform would have been exposed, becoming an extensive limestone plateau with an area of about 1000 km^2, nearly two orders of magnitude larger than at present (Fig. 1).

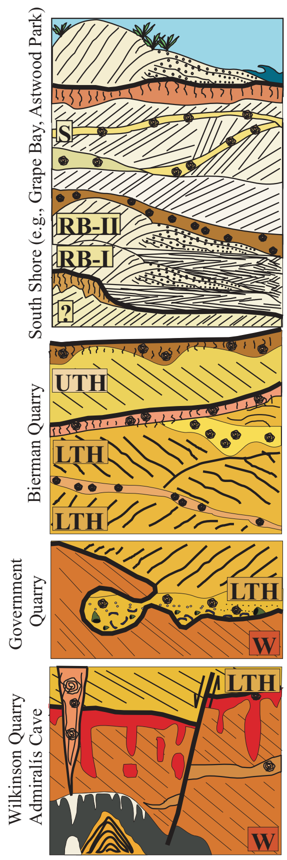
VERTEBRATE CHRONO-STRATIGRAPHY OF BERMUDA

The oldest exposed deposits on Bermuda consist of the highly recrystallized limestone of the Walsingham Formation, cropping out mainly on the SW side of Castle Harbour. The age of the Walsingham Formation has not been radiometrically determined, but it is presumed to be at least 800 kyr old (early Pleistocene) and could possibly be older, as indicated by reversed magnetic polarity and old amino acid racemization and electron spin resonance ages (Hearty & Vacher, 1994). The rocks are primarily eolianite with some weakly-developed intercalated protosols (weak interglacial soils, Vacher & Hearty, 1989), indicating that there was abundant dry land present at the time of deposition. The only terrestrial macrofossils known so far from the Walsingham are two shells of the pulmonate snail *Poecilozonites* (subgenus *Poecilozonites*) recovered from a protosol in Wilkinson Quarry.

Capping the Walsingham Fm is a massive terra rossa soil, referred to as the "Big Red Soil" or BRS (Hearty, 2002), that represents an extended period of island stability in Bermuda's history, when maximum sea-levels were depressed and much of the Bermuda platform emergent. Although sea levels fluctuated during this period, they never rose high enough to initiate carbonate deposition in the area of the present island. This span of almost a half million years (estimated to be from 800 kya to 450 kya—Olson and Wingate 2000) extended from MIS 13 back to MIS 21 (Hearty & Vacher, 1994) or even MIS 26 (Hearty, 2002). Weathering of the Walsingham and deposition of wind-borne dust from the Sahara over this long period of time resulted in the development of a deep karst surface (up to 5 m) mantled by the BRS (Fig. 3). From the available field evidence, it appears that Bermuda island was emergent from much of the early Pleistocene (Walsingham Fm) and early middle Pleistocene (BRS), perhaps for as long as 1 to 1.5 Mya. There can be no doubt that over this long period the biota that must have colonized and evolved would have been more diverse and distinctive than any of those that succeeded it. Unfortunately, because the BRS is heavily leached and no cave or fissure fills of this age have been found, we know nothing at all about the island fauna of this period beyond the assumption that the few terrestrial species known from the Lower Town Hill Formation are probably remnants of a BRS fauna. This extended period of island emergence came to a sudden end during MIS 11, when sea level rose to over 21 m above present (Hearty *et al.*, 1999; Kindler & Hearty, 2001), flooding most of the land area. Eolianites of the Lower Town Hill Formation were deposited during this interglacial.

The earliest fossil vertebrates from Bermuda are those in the Lower Town Hill Formation at Green Island (Olson & Hearty, 2003) that were deposited near present sea-level during interglacial MIS 11, about 400 kya ago. Sea-level continued to rise to more than 21 m above sea-

LOCATION/STRATIGRAPHY



FORMATION/MB	MIS	Estimated/ Absolute Age (ka)	DESCRIPTION	FOSSIL SITES
Holocene/Recent	1	0-10	Minor coastal deposits with small dunes, marsh sediments, interior soil formation	12; 16-18; 24-26
St. Georges Geosol	2-4	10-70	Reddish brown clayey silt, sparse/rare fossils continued development interior island	8; 9; 18
Southampton Fm	5a/5c	70-105	Extensive weakly-cemented dune complex with intercalated, bifurcating protosols containing abundant invertebrate fossils, primarily land snails; South shore only.	
Hungry Bay Fm*	5c	105	Thin, fine-grained local dunes on South shore	11
Harrington Mb (Rocky Bay Fm)	5d	105-118	Thin to locally thick, tan to orange silty soil with abundant land snails and marine fossils at base	
Devonshire Mb (Rocky Bay Fm)	5e	118-133	Marine and dune facies with fossil mollusks, corals; sea level +2.5 to +6-8 m; exposed along modern shore	
Grape Bay Mb* (Rocky Bay Fm)				
Geosol	6	133-195	Unnamed paleosol at base of last interglacial sequence	8-10; 11
Unnamed Unit*	7	195-235	Isolated, buried dunes of questionable age	
Ord Road Geosol	8	235-300	Reddish brown to orange paleosol	
Upper Town Hill Fm	9	300-330	Extensive eolianites forming core of Bermuda; marine deposits along North Street, Hamilton.	6
Harbour Road Geosol	10	330-370	Clayey red-orange soil with fossil snails	8
Lower Town Hill Fm	11	370-425	Extensive marine and eolian deposits with multiple subdivisions by unconformity and protosols. Fossiliferous marine deposits at +21 m (Government Quarry), +5 to +10 m (Front Street), and +1 to +3 m (Coopers and Green Islands). Multiple zones with abundant avian and land snail fossils.	1-5
Castle Harbour Geosol (aka Big Red Soil)	12-24?	425-900	Deep red clayey soil developed on extensively karstified surface with soil pits extending up to 5 m into host limestone. Fossils absent.	
Walsingham Fm	25-37?	900-1500?	Recrystallized eolianite and marine deposits (St. Georges West); cavernous with extensive speleogenesis and cave fillings with surface materials; faulted with minor displacement and fissures filled with sediments and fossils of various ***younger*** ages.	

Nota Bene: Stratigraphy: Vacher et al. (1989; 1995); Stratigraphy and geochronology: Hearty et al. (1992). Revision of South Shore stratigraphy after Hearty (2002); Isotope ages: Imbrie et al. (1984).

Fig. 2. Composite stratigraphy, nomenclature, correlation with marine isotope stages (MIS), estimated or known ages, description, and source of known fossil deposits from Bermuda. Site numbers refer to the numbering system used in the text. LTH = Lower Town Hill Formation, RB = Rocky Bay Formation, S = Southhampton Formation, UTH = Upper Town Hill Formation, W = Walsingham Formation. * = see Hearty (2002).

Fig. 2. *Estratigrafia composta, nomenclatura, correlació amb els estadis isotòpics marins (MIS), edats estimades o conegudes, descripció, i font dels depòsits fossilífers coneguts de Bermuda. Els nombres de les localitats corresponen al sistema de numeració emprat al text. LTH = Formació Lower Town Hill, RB = Formació Rocky Bay, S = Formació Southhampton, UTH = Formació Upper Town Hill, W = Formació Walsingham. * = vegeu Hearty (2002).*

Fig. 3. NE corner of Wilkinson Quarry showing the Big Red Soil (BRS) overlying and filling karstic cavities in the recrystallized limestone of the Walsingham Formation. These two units represent more than two-thirds of Bermuda's history, as known from surface rocks, for which there is no vertebrate fossil record. The BRS is capped here by eolianites of the Lower Town Hill Formation (Marine Isotope Stage 11).

Fig. 3. *Cantó NE de la Pedrera de Wilkinson on es mostra la "gran terra vermella" (BRS) que cobreix i reompl les cavitats càrstiques a les calcàries recristal·litzades de la Formació Walsingham. Aquestes dues unitats representen més de dos terços de la història de Bermuda, com se sap a partir de les roques superficials, pels quals no hi ha registre fòssil de vertebrats. La BRS està aquí coberta per eolianites de la Formació Lower Town Hill (estadi isotòpic marí 11).*

level and the small vertebrate faunule known from Calonectris Quarry dates from this inundation (Olson & Hearty, 2003).

We know nothing about the fauna of the succeeding glacial period MIS 10, which would be of extreme interest for determining what vertebrates may have colonized the island during its first expansion following the great MIS 11 inundation.

We know almost as little about the vertebrates of interglacial MIS 9, represented by the Upper Town Hill Fm eolianites. Although snails of this age are known, the only knowledge of vertebrates has come about through the extraordinary discovery of a single fossil tortoise in rocks of this age (see Tortoise Site below). MIS 11 was certainly an extinction event on Bermuda through reduction of land area and alteration of habitat by radical sea-level rise. MIS 9 also probably represents an extinction event if the tortoise is any example.

Following this were two glacial cycles MIS 8 and MIS 6 separated by a less important interglacial MIS 7 that, according to the revised stratigraphy of Hearty (2002), deposited little or no carbonate sand on the present land surface of the island. Thus there may have been a relatively long interval from about 250 kya to 120 kya during which land area may have been sufficiently stable such that the Bermudan biota was not adversely affected. We now know that the so-called "crane fauna" (Olson & Wingate, 2000) dates to glacial period MIS 6 (Hearty *et al.*, 2004) and this fauna may have started to develop as early as MIS 8, though we do not know for certain of any cave or fissure fills dating back to MIS 7 or 8. Deposits of "crane fauna" in association with the large snail *Poecilozonites nelsoni* are known only from fissures in Government and Wilkinson's quarries and possibly Fern Sink and Jane's caves.

The onset of the last interglacial MIS 5e is represented by extensive carbonate deposition and an abundance of the snail *Poecilozonites bermudensis zonatus*. A few fissure fills date to this period, for example Gould's (1969: 511) "Graveyard Fissure" (see Hearty *et al.*, 2004) and a remnant in Convolvulus Cave, but the only deposit of this age with vertebrate remains is the massive talus cone in Admirals Cave (Hearty *et al.*, 2004). MIS 5 was also an extinction event on Bermuda that terminated the "crane fauna," as those species are absent in Admirals Cave with the exception of a few bones of *Rallus ibycus* at the very beginning of the sequence at the onset of MIS 5e.

The last glacial period MIS 4-2, characterized by the "re-appearance" of *P. nelsoni* and the appearance of a large flightless rail *Rallus recessus* (Olson & Wingate, 2001) is well represented in fissure fills in quarries and in Admirals and other caves.

The Holocene interglacial period MIS 1 appears to have caused the disappearance of *Rallus recessus* and at this time *P. nelsoni* was succeeded by *P. bermudensis bermudensis*. Holocene deposits with vertebrates occur in several caves, often as a thin veneer unconformably overlying older sediments. Holocene vertebrates are abundantly represented in the lacustrine sediments dredged from Spittal Pond and sparsely in near-surface deposits on Cockroach Island, Harrington Sound.

Thus although Bermuda has relatively a very good and highly interesting record of fossil vertebrates, there are many gaps and much that we do not know. There is nothing known about glacial age faunas older than MIS 8 and it is not certain that deposits of such age even exist. If they do they will probably only be found by additional quarrying or by underwater exploration.

HISTORY OF VERTEBRATE PALEONTOLOGY ON BERMUDA

The first mention of vertebrate fossils from Bermuda appears to be that of Nelson (1837: 113), who mentioned "birds' bones" found in a cave on Ireland Island (the northern tip of the west end of Bermuda), bones and eggs of birds "in the limestone on the coast of Harrington Sound," and an egg "found in a block of limestone near Hamilton". "Turtle bones," presumably sea turtle "were also procured from the North Bastion [Ireland Island] coral rag, and from the sands at Elbow Bay."

The next mention of vertebrate fossils concerns remains reputed to be of what was then the mysterious "cahow" of early settlers. Until the living bird (*Pterodroma cahow*) was "rediscovered" in 1906 (Nichols & Mowbray, 1916), the identity of this bird was very much in doubt and a considerable amount of speculative literature was devoted to the subject. Verrill (1908) reported on bones and even feathers embedded in a stalactite found in a cave by Louis L. Mowbray, who reported that the bones could be easily distinguished from those of the shearwater *Puffinus obscurus* (= *P. lherminieri*) and must therefore belong to the "Cahow", even though the generic affinity of the latter remained at that point undetermined. The location of the cave, said to have been discovered only a few months before Mowbray's communication of 15 March 1908, was undisclosed. Shufeldt (1916: 626) later reported that Mowbray had collected this material in Crystal Cave in 1907. He also said that Mowbray had collected in Bassett's Cave (see below) a "perfect skull and beak of Strickland's Shearwater (*P. stricklandi*), the specimen being covered with calcite."

Shufeldt (1916, 1922) reported extensively on seabird bones recovered in various Bermuda caves by Edward McGall and Anthony Tall about 1915. No mention is made of the location of these caves apart from the fact that some of them were sea caves in cliffs that had to be reached using ropes—-a description that would perfectly fit caves exposed in the Great Head cliffs of St. David's Island. Most of this material is now in the Carnegie Museum, Pittsburgh, and has been restudied in connection with a revision of Shufeldt's taxonomy (Olson, in press).

Considerable interest once attached to multiple discoveries of fossilized bird eggshell in eolianite deposits of Bermuda (Wood, 1923; Lewis, 1928), although no specific localities were given for any of these. Most of these eggs were about 63 x 38 mm in size (Wood, 1923: 207) and it was speculated that they might be eggs of White-tailed Tropicbird *Phaethon lepturus*. Because of the cliff-nesting habits of tropicbirds, their bones are very rarely preserved in Bermuda or elsewhere (e.g. St. Helena, Olson, 1975), and it would be even more unlikely for their eggs to be preserved. It is far more likely that these were eggs of Cahow *Pterodroma cahow*, formerly the most abundant bird in Bermuda, which nested in burrows and cavities throughout the island. Eggs of the Cahow range from about 56-62 mm long by 41-44 mm in diameter (Wingate in Palmer, 1962, and unpublished data), whereas eggs of Bermuda *Phaethon lepturus* average smaller—-49-58 x 36-41 mm (Lee & Walsch-McGehee, 1998).

Of much greater interest is an egg, deposited in the British Museum (A841a), that Wood (1923: 207) considered likely to be "chelonian" that measured 79 X 48 mm (converted from inches). Data with the specimen indicate that it was presented by W. Young on 14 Oct 1903 and was said to be from the"?Paget limestones" in a "consolidated beach about 40 feet above sea level." Wood (1923: 207) reported that the fossil was "found several feet beneath the deep red, clayey soil that covered the limestone rock in which it was imbedded." What used to be called the Paget Formation is equivalent to aeolianites of the last interglacial (MIS 5). Wood's photograph of the specimen (plate IX, figure 5) shows fairly large pieces of limestone still attached so that analyses of lithology and amino acid racemization should make a more accurate determination of age possible.

Wood's speculation as to the origin of this egg is surely wrong given that sea-turtle eggs are spherical and soft-shelled. The egg is much too small for the Short-tailed Albatross *Phoebastria albatrus*, fossilized eggs of which have been found in Bermuda (Olson and Hearty 2003), but is otherwise much too large for any other seabird known from Bermuda or for the endemic night-heron *Nyctanassa* sp., which was not significantly different in size from the Yellow-crowned Night-heron *N. violacea* (average egg size 51 X 37 mm—-Watts, 1995). Another possibility is that this might be the egg of the endemic crane *Grus latipes* (Wetmore 1960) which is known only from fissure fills that are now thought to date back to two glacial periods ago (MIS 6, Hearty et al. 2004). The measurements of the fossil egg would barely fall within those of the Sandhill Crane *Grus canadensis*, the minimum dimensions of which are 77.4 and 44 mm (Bent 1926: 235). How the egg of a crane would have been incorporated into interglacial eolianites is rather problematic, as sufficient suitable habitat for cranes would probably only have been available during glacial episodes. If the egg is truly that of a crane it would probably date from earliest stages of the last interglacial episode.

Beebe (1935: 190) mentioned and illustrated fossil and "semi-fossil" bones of Cahow from unspecified caves and roadcuts.

In 1956, a fissure that had been opened in Wilkinson Quarry was found to contain bones of extinct birds. More material was collected here in 1958 by Wingate and subsequently an extinct species of duck *Anas pachysceles* and a crane *Baeopteryx* (=*Grus*) *latipes* were described by Wetmore (1960), who also mentioned the presence of undescribed species of rails (Rallidae). Practically simultaneously, several fossiliferous fissures were encountered in Government Quarry and abundant material was recovered here in 1960 by Wingate along with avian paleontologist Pierce Brodkorb of the University of Florida. Brodkorb kept this material, which included excellent representation of 3 new species of rails, in his private collection but despite considerable prodding (e.g. Olson, 1977: 353-354) he never published on any fossils from Bermuda. After his death, the material was incorporated into the paleontological collections of the Florida Museum of Natural History. Information on the morphology and relationships of the largest of the rails was incorporated into a systematic revision (Olson, 1997) prior to the naming of the species as *Rallus recessus* (Olson & Wingate, 2001). Two smaller, and older, species of rails *Rallus ibycus* and *Porzana piercei* (Olson & Wingate, 2000) were also named from the former Brodkorb material.

Meanwhile, Wingate had been accumulating specimens and knowledge of new and potential fossil localities around the island. Olson and Robert F. Baird collected specimens from several of these sites in Jul and Aug 1981. In Aug 1984, Olson and Grady continued collecting, particularly at Green Island and Calonectris Quarry. Olson made additional collections in 1985. Publication on the fossils collected was delayed, however, because of considerable uncertainty regarding the ages of the various fossil deposits. Problems with stratigraphy and chronology of Bermudan vertebrates began to be resolved when Olson and Hearty started collaborative fieldwork with Wingate in Feb and Jul 1999. Olson and Hearty's excavation of Admirals Cave in Oct 2000 provided the Rosetta Stone for understanding the last 120 kya of Bermuda's biotic history (Hearty *et al.*, 2004). They continued to make further refinements and collections, emphasizing the chronology of *Poecilozonites* land snails in Feb 2002. In Nov 2003 Olson, Hearty, and Grady continued fieldwork, making more extensive excavations in Admirals Cave. In Feb 2004, Olson, Grady, and Wingate surveyed almost all the caves and quarries known to have produced fossil vertebrates and in most recovered as much additional material as possible. Olson revisited Fern Sink Cave in April 2004.

The fieldwork and publications to date (Wetmore, 1960; 1962; Olson & Wingate, 2000; 2001; Olson & Hearty, 2003; Hearty *et al.*, 2004; Olson, 2004a,b) have set the stage for a full exposition of the known history of Bermuda's vertebrate biota, including the descriptions of new species. To facilitate future publications we briefly summarize below the general information for all of the fossil vertebrate localities found so far in Bermuda.

Fossil Vertebrate Localities of Bermuda

Geographical coordinates for most sites, to tenths of a second, were determined by Olson and Grady using a global positioning system (GPS) in Feb 2004. Others are from the United States Board of Geographical Names gazetteer for Bermuda (USBGN 1955). By far the majority of the sites containing significant specimens of fossil vertebrates come from the strip of land forming the northeastern edge of the main island of Bermuda, along the SW shore of Castle Harbour (Figure 4). All sites listed below are in Hamilton Parish unless otherwise indicated. Cave names are from the unpublished Bermuda Cave Survey (1st edition, 22 February 1983) by Thomas M. Iliffe, copies of which have been deposited with the Bermuda Aquarium, Museum and Zoo (BAMZ) and the Bermuda Biological Station for Research.

a) Deposits in Interglacial Eolianites

1. *Green Island*.—-N32°20' W64°39' (USBGN). Also known as Green Rock. Situated just SE of Nonsuch Island at the mouth of Castle Harbour. Many bones of Short-tailed Albatross *Phoebastria albatrus* occur here in rocks of the Lower Town Hill Formation (MIS 11, ca. 400 kya). These represent the remains of a breeding colony and include individuals of all ages from near embryos to adults. The fossils were buried in a back beach storm deposit. The site has been fully described by Olson & Hearty (2003). Most of the specimens were collected in 1984 by Olson and Grady, using a gas-powered rock saw. The only other vertebrate remains found here were a few fish bones (Olson & Hearty, 2003), several bones of the endemic skink *Eumeces longirostris*, and the tip of a rostrum of a Great Auk *Pinguinus impennis* (Olson, 2004a). Recent bones of *Puffinus lherminieri*, which nested here until the mid 20th century but is now extirpated on Bermuda, were collected here by Wingate in 1967.

2. *Cooper's Island*.—- N32°21' W64°39' (USBGN). Fossilized eggs of Short-tailed Albatross *Phoebastria albatrus* have been found on both the north and south sides of the island in a continuation of the same deposits with albatross bones on Green Island (Olson & Hearty, 2003).

3. *Tucker's Bay*.—- N32°19'34.3" W64°44'23.7". Fossil eggs of Short-tailed Albatross *Phoebastria albatrus* were collected in the vicinity of Tucker's Bay (specimens labelled Vesey's Bay), referring to the extreme SW corner of Harrington Sound, by Charles Lloyd Tucker in 1936 and subsequently. Three of them are in the collections of BAMZ. Olson and Wingate visited the property in 2004 and took the above GPS reading but very little rock is still exposed. Limestones here are mapped as the Lower Town Hill Formation (Vacher *et al.*, 1989), which would correspond to the age of the albatross deposits in which other eggs were found (Olson & Hearty, 2003). Wingate interviewed Tucker on 27 Oct 1960 at his property on the day after he had found another egg. He related that he had found about 30 eggs there in less than an acre (0.4 hectare) over his lifetime. Wingate's diary records a measurement for one of them as 4 3/8 X 2 7/8 inches (= 111 X 72 mm), a value very close to the mean reported for Short-tailed Albatross by Olson & Hearty (2003).

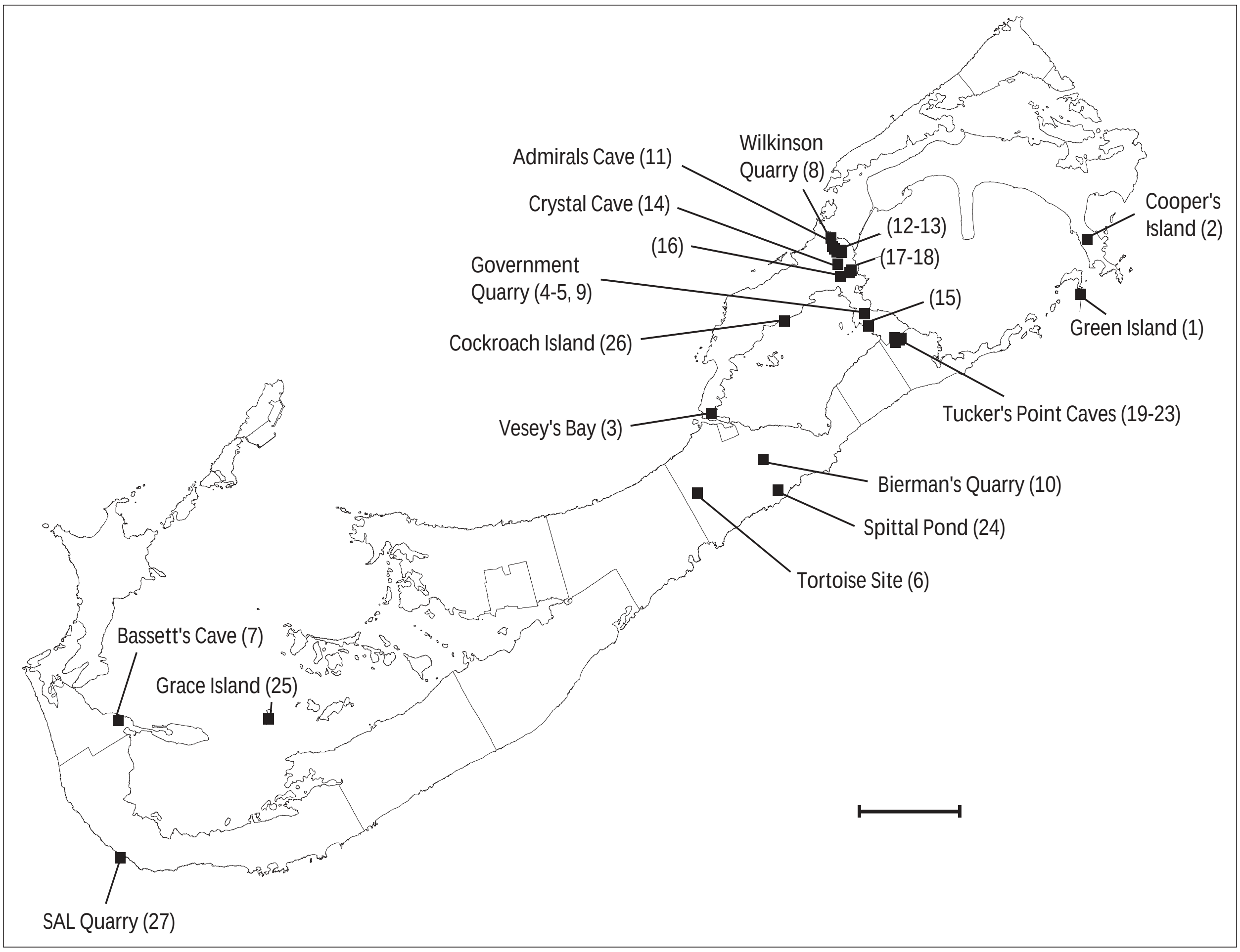


Fig. 4. Map of Bermuda showing known fossil localities. Numbers correspond to the site numbers used in the text. Scale = 2 km.

Fig. 4. *Mapa de Bermuda on es mostren les localitats fòssils conegudes. Els nombres corresponen als nombres de les localitats emprats al text.*

4. *Calonectris Quarry*.—-N32°20'28.3" W64°42'27.4". Located at the NW extreme of Government Quarry (q.v.), this important site consisted of a beach deposit that formed in a horizontal unconformity between the Walsingham Formation and the overlying Lower Town Hill Formation (Fig. 5). Fossils here consisted mainly of bones of the shearwater *Calonectris diomedea diomedea*, but also included skink, other seabirds, at least 2 species of passerines, and a bat. These were deposited at an elevation of 21.3 m above present sea-level in the maximum rise of interglacial MIS 11, about 400 kya ago (Hearty *et al.*, 1999; Olson & Hearty, 2003), when the land area of Bermuda was at its all-time minimum. Wingate first collected here in Nov 1967, followed by some combination of Olson, Wingate, Grady, and R. Baird in Aug 1981, Aug 1984, and Feb 1985. This site and its fauna will be the subject of a more detailed future publication.

5. *Dead End Cave*.—-This is on the SW wall of the northwesternmost extent of Government Quarry probably no more than 10 m directly through the limestone from Calonectris Quarry. It is a sea-cave with deposits of the same age and elevation as Calonectris Quarry (Hearty *et al.*, 1999). It was discovered by Wingate and first investigated by Hearty in 1997 and by Hearty and Olson in Feb 1999. The only vertebrate remains were a few heavily encrusted bones of seabirds.

6. *Tortoise Site*.—- N32°18'40.3" W64°44'36.2". Smiths Parish, 3 Verdmont Valley Close off Verdmont Valley Drive. The holotype of the fossil tortoise *Hesperotestudo bermudae* was collected here in Aug 1991 from a foundation wall that had been excavated in deposits of the Upper Town Hill Formation (Meylan & Sterrer, 2000). This is the only vertebrate fossil yet known from the Upper Town Hill (MIS 9, ca. 310 kya old).

b) Caves and Fissure Fills

7. *Bassett's Cave*.—- Ca. 1 km slightly N of W of the former Tucker's Island (N32°16' W64° 51' U. S Board on Geographic Names [USBGN]) in Sandy's Parish in far western Bermuda. The cave is shown on Vacher *et al.*, (1989) as being in rocks of the Lower Town Hill Formation (MIS 11). Shufeldt (1916: 626) reported that Mowbray had collected in Bassett's Cave a "perfect skull and beak of Strickland's Shearwater (*P. stricklandi*), the specimen being covered with calcite." *Puffinus stricklandi* is a synonym of *P. griseus*, a species unlikely to be found in a cave deposit in Bermuda. The only species of Procellariidae close to this size that has been found as a fossil on Bermuda is *Calonectris diomedea*, known only from Calonectris Quarry in deposits of Lower Town Hill age. Because Bassett's Cave itself would have to be

Fig. 5. The Calonectris Quarry site (at the level of Olson's shoulders) as it appeared in 1981 (it has since been quarried away). Sea level rose to this height (21.3 m above present) during MIS 11. Inset: close-up of the two pockets of Calonectris Quarry excavated in 1981. In both photographs notice the unconformity between the homogeneous limestone of the Walsingham Fm (extending higher on the right) and the overlying, distinctly cross-bedded eolianite of the Lower Town Hill Fm. Dead End Cave is at the same level directly through the wall of the quarry shown here.

Fig. 5. *La localitat de la Pedrera Calonectris (al nivell de les espatlles d'Olson) com es trobava el 1981 (des de llavors la pedrera s'ha continuat explotant). El nivell de la mar va arribar a aquesta altària (21,3 m per damunt de l'actual) durant l'estadi isotòpic marí 11. Quadre inserit: visió de prop de dues borses de la Pedrera Calonectris excavades el 1981. A les dues fotografies es nota la disconformitat entre les calcàries homogènies de la Formació Walsingham (que s'estenen més adalt a la dreta) i la clara laminació encreuada de les eolianites de la Formació Lower Town Hill que s'hi sobreposa. La cova Dead End es troba al mateix nivell directament a través de la paret de la pedrera que es mostra aquí.*

younger than this, the identity of the procellariid skull that Mowbray found here becomes highly problematic. Most likely it was the skull of a Cahow made to seem larger by its encrustation of flowstone. Bassett's Cave was massively polluted with aviation fuel and heavy metals from a U. S. military installation prior to 1995 (Kent, 2004) and we made no attempt to explore it for fossils.

8. *Wilkinson Quarry*.—- Located on the S shore of the NW corner of Castle Harbour, the quarry now extends landward nearly as far as Admirals Cave. Several fissures of different ages exposed in this quarry have yielded important fossils of vertebrates and snails.

Original fissure.—- This is the site of the original fossil material studied by Wetmore (1960) from which he named *Baeopteryx* (=*Grus*) *latipes* and *Anas pachysceles*. This fauna also contained the rails *Rallus ibycus* and *Porzana piercei* that were described later (Olson & Wingate, 2000). The first fossil birds collected here were obtained by David Nicol in 1956, and more extensive material was obtained in 1958 by Wingate, all of which is now in the National Museum of Natural History, Smithsonian Institution, Washington (USNM). This early material came from a fissure in the NE part of the quarry in the vicinity of site UWQ 8 (see below).

Site UWQ 1. N32°21'08.9" W64°42'52.2". On 15 Feb 1999, Olson and Hearty found that a large fissure in Lower Town Hill (MIS 11) limestone about 6-8 m deep and ca. 0.5 m wide at the widest point had been exposed in the middle of the E side of the quarry (Fig. 6). This was filled with reddish-brown (5-7.5YR 3.5/4 Munsell, 1994) soil and contained abundant shells of *Poecilozonites nelsoni* and bones of *Rallus recessus*, as well as those of other species of birds. On 17 Feb Olson and Wingate removed about 0.5 m^3 of sediment from this fissure that was later processed to recover small bones and snails. This fissure was determined to be of last glacial age: 29,510 ±210 ^{14}C yr BP (Hearty *et al.*, 2004).

Site UWQ 8. N32°21'13.9" W64°42'53.2". This smaller fissure (Fig. 7), in the Walsingham Formation, was found on the N side of the quarry by Olson and Hearty on 10 Nov 2003 and collected by them and Grady on several subsequent days. It was mostly open at the top and was then blocked by a slanting piece of flowstone. Beneath this was a column of red soil the main portion of which was about 95 cm high by 45 cm wide, with a narrow pocket extending about 65 cm higher on one side. Rock rubble and flowstone effectively divided the main sediment accumulation into upper and lower units. This sediment contained heavily mineralized shells of land snails and a few bones of a rail and passerine birds. Beneath the sediment was an opening ca. 40 cm high completely rimmed with flowstone and with small stalactites pendant from the ceiling. These had a U/Th date of 55.2 ± 0.9 ka. The bottom of this opening was a thick layer of pure yellowish calcite flowstone at the same level as the present floor of the quarry. This had a U/Th date of 62.9 ± 1.5 ka. We were able to break through this to reach a small amount of additional red soil with remains of snails. Thus this deposit appears to have formed during the last glacial period MIS 4 but is considerably older than UWQ 1.

9. *Government Quarry*.—-Bermuda's largest quarry occupies much of the SE portion of the isthmus between Harrington Sound and Castle Harbor. The main part of the quarry is just to the E of Calonectris Quarry, which was in the westernmost portion of the larger quarry. Over the years many caves and fissures were opened here, most of which have since been quarried away, although their approximate location has been determined by reference to the 1960 topographical survey map. With the exception of Calonectris Quarry and Dead End Cave, these contain deposits dating from the last glacial (MIS 4), the last interglacial (MIS 5), and the preceding glacial period (MIS 6 or possibly MIS 8-6). Specimens from these deposits have been given the following 6 label designations.

Crane Crevice.—-SE face of Government Quarry. Material collected in 1960 by Wingate and Pierce Brodkorb in USNM and Florida Museum of Natural History (UF). The presence of *Anas pachyscelus*, *Grus latipes*, and *Rallus ibycus* indicate deposition no younger than glacial MIS 6, although this fauna could possibly have existed from MIS 8 through 6. Material in USNM collected by Howard Wilson labeled "South Face fissure fill" is probably the same as Crane Crevice. This includes bones of seabirds, a dove, a small rail, and passerines but no certain index species to suggest the age of deposition.

Rail Cave.—-W face of S half of quarry. Material collected in 1960 by Wingate and Pierce Brodkorb in USNM and UF. The presence of *Rallus recessus* indicates deposition during the last glacial period MIS 4. Specimens are marked as coming from "lowest level" and "upper shelf". The lowest level was very clearly an original solution tube created by a former underground stream, the only such feature found so far during subaerial cave exploration on Bermuda, as secondary roof collapse has destroyed or buried the original solution features in other caves. All of the bones were found in mud-filled swirl pits on the floor of the cave and one fully articulated skeleton of *Rallus recessus* was found here cemented in place by a patina of flowstone (Fig. 8).

Finch Cave.—-S face of S half of Government Quarry about 100 m W of Crane Crevice. Material in USNM collected by Wingate. Named for the presence of abundant remains of an as yet undescribed endemic species of towhee *Pipilo*, many of which are heavily encrusted with calcite. The presence of some bones apparently referable to *Rallus ibycus* suggests that this deposit was contemporaneous with the "Crane Fauna" of Olson & Wingate (2000).

Wilson's Cave.—-Material at UF is so labeled. Additional specimens in USNM collected by Howard Wilson and labeled "Southeast Face fissure fill" indicating the SE face of Government Quarry is believed to be from the same site. This includes bones of passerines and a bat.

Fissure fill, upper level, Government Quarry.—-Material in USNM was collected in August 1981 by Robert Baird, with a second batch dated 19 August. Estimated to be 12 to 15 ka, based on calibrated amino acid ratios from *Poecilozonites nelsoni*. Contains skink, seabirds, rail, dove, and passerines.

1985 Fissure, Government Quarry.—-E end of S working face. Vertical fissure with red soil and snails and bones. Material in USNM was collected by Olson 15 Feb 1985. Estimated to be 12 to 15 ka, based on calibrated amino acid ratios from *Poecilozonites nelsoni*, which is corroborated by a humerus of *Rallus recessus*. There are also two bones of a small heron, possibly *Butorides*.

10. *Biermans Quarry*.—- N32°19'00.5" W64°43'45.3". Located in Smiths Parish, south of Harrington Sound, this quarry is in rocks of the Upper Town Hill and Lower Town Hill formations (MIS 9 and 11, respectively), rather than in the older Walsingham Formation being mined at Wilkinson and Government quarries. On the currently disused NE wall of the quarry (coordinates above) there is a well-developed red soil between the two formations that probably represents the MIS 10 glacial period, but unfortunately this contains no identifiable fossils. We have not seen any crevices or fissures in this quarry, and although it has produced important collections of land snails, only one collection of vertebrate remains has so far been found. A small lot of bird bones at USNM collected by Patricia Corrado for a school project and later obtained by Wingate was defintely collected in Biermans Quarry, where Corrado's father worked, but the exact locality was never determined. This collection consists of bones of *Anas pachysceles* and *Rallus ibycus*, species that occurred during glacial period MIS 6 (and perhaps in MIS 7-8).

11. *Admirals Cave*.—-Entrance N32°21'07.4" W64°42'50.6"; the current opening in the area of the talus cone is at N32°21'05.6" W64°42'48.6", which as calculated by GPS would be 80 m SE (137°) of the entrance. This is the most important fossil site in Bermuda (Hearty et al., 2004), containing a massive talus cone of beautifully stratified sediment and fossils with nearly continuous deposition over the past 120 kya (Fig. 9). The position of the talus cone in the cave has been well mapped by Iliffe (2003) and the stratigraphy and chronology documented

Fig. 6. E wall of Wilkinson Quarry, site UWQ 1. The red soil of the fissure fill dates back to the height of the last glaciation and contains abundant shells of *Poecilozonites nelsoni* and bones of the extinct flightless rail *Rallus recessus*, as well as other birds.

Fig. 6. *Paret E de la Pedrera Wilkinson, localitat UWQ 1. La terra vermella del reblit del crull data del punt alt de la darrera glaciació i conté escopinyes abundants de* Poecilozonites nelsoni *i ossos del rascló avolador extingit* Rallus recessus, *i d'altres ocells.*

in detail by Hearty et al., (2004). Fossils were collected here desultorily in the 1980s. Serious excavation of a test trench and small bulk samples of sediment was undertaken by Olson and Hearty in Oct 2000. Olson, Hearty, and Grady extended this trench in Nov 2003, taking out larger bulk samples for screening elsewhere amounting to perhaps a little over one cubic meter. Olson and Grady obtained additional fossils here in Feb 2004.

West wall red talus, Admirals Cave.—-High up on the west wall of the main chamber in Admirals Cave is a thick talus slope of red soil ca. 4.5 m from top to bottom and 4.7 m wide at the base. It is 30-40 cm deep at the sides and deeper toward the middle. On the map in Iliffe (2003: 219) it is in the small chamber just north of the one labelled "Chamber of Innocence." Excavations made 14 and 16 Nov 2003 by Olson and Grady yielded abundant remains of land crab, some charcoal, and very few bones. Shells of *Poecilozonites bermudensis* were uncommon in the upper portions, those of *P. nelsoni* were occasional at mid-level and more common at the bottom. Thus it appears, despite the absence of any distinct strata in the soil, that deposition here probably represents mid- to late Holocene unconformably overlying sediments of the last glacial maximum such as observed in Walsingham Sink Cave.

Fig. 7. N wall of Wilkinson Quarry, site UWQ 8. This fissure contains shells of *Poecilozonites* that must be older than MIS 6 and may be the oldest fissure filling yet found on the island. A few bones of an extinct rail similar to *Rallus ibycus* and passerine birds were collected here in 2003.

Fig. 7. *Paret N de la Pedrera Wilkinson, localitat UWQ 8. Aquest crull conté copinyes de* Poecilozonites *que indiquen que ha de ser més primerenc que l'estadi isotòpic marí 6, i pot ser el reompliment més primerenc trobat a l'illa. El 2003 es varen recollir aquí uns pocs ossos d'un rascló similar a* Rallus ibycus.

12. *Convolvulus Cave*.—-Entrance N32°21'06.5" W64°42'45.8"; position approximately over SE talus slope N32°21'05.4" W64°42'45.0". By GPS calculation the SE talus slope would be 40 m approximately SSE (148°) of the entrance. This cave is near the entrance to the present Grotto Bay Hotel and has also been known as Bourne's Quarry Cave and Grotto Cave (Hearty et al., 2004: fig. 2) but the name Convolvulus Cave has been in use at least since 1873 when visited and photographed by scientists of the Challenger Expedition (Wyville Thompson, 1878: 302). There are two or three perimeter entrances that all eventually open into a large sinkhole formed by complete collapse of the former cave roof. On the SE wall of this sink may be seen a patch of thick veneer of indurated red soil packed with myriad shells of *Poecilozonites bermudensis zonatus* indicative of a soil accumulation during the last interglacial (MIS 5) that has now mostly been removed, presumably by roof collapse and erosion. The cave system continues off to the SE ending in a chamber with a long sloping cone of red soil talus.

Bones were collected from this cave by Wingate in 1961, and from the surface of the lower part of the SE red talus slope on 29 Aug 1981 by Olson, Wingate, and Robert Baird. Olson and Grady sampled extensively here on 10 Feb (with Wingate) and on 11 and 14 Feb 2004. Bones came from 3 areas: a small cave chamber (Toad Pocket) off the shallow sink at the entrance to the cave; a deposit of red soil encountered just before emerging into the large sink opening at mid-cave; and the SE talus cone.

The SE talus of red soil is a triangular slope about 4 m long and fanning out to about 4 m wide at the bottom, the soil having come in through another small entrance that now appears to be blocked. The cone was well stratified at least in the upper portions. A section ca. 1.5 m from the apex consisted of 3 cm of granular, almost pebbly, soil the bottom 1 cm of which was paler in color. Beneath this was 4-5 cm of similar soil, also lighter in color at the bottom. Beneath this was a 5-6 cm layer of darker soil with masses of large pieces of charcoal and abundant shells of land snails, including *P. b. bermudensis*. This overlay 2 cm of fine soil of lighter color, which in turn lay above 10 cm of very granular red soil with abundant snail shells and fragments but much less charcoal. Below this was a thick layer of undetermined depth of sterile granular red soil. Bird bones were scarce in the two levels with abundant snail shells. Taxa of birds recovered from Convolvulus Cave include seabirds, *Aegolius* sp., Picidae, and various passerines.

13. *Sibley's Cave*.—-N32°21'06.7" W64°42'46.4". Shown as Old Muddy Cave in Hearty et al. (2004: fig. 2). This is a high, relatively narrow passageway that descends rather steeply but ends in rubble without going to the water table. It contained only small patches of dry sediment here and there. Loose soil in the uppermost one of these, in a bowl-like depression about a meter across, was nearly entirely removed by Olson and Grady and washed elsewhere in an unsuccessful attempt to find more bone that might go with a complete cranium of the endemic night-heron *Nyctanassa* found here. Two

Fig. 8. Associated incomplete skeleton of *Rallus recessus* (BAMZ 2000 190 001) covered with flowstone, from Rail Cave, Government Quarry.

***Fig. 8.** Esquelet incomplet associat de* Rallus recessus *(BAMZ 2000 190 001) cobert per una colada, provinent de la cova Rail, Pedrera Government.*

bones of a hawk were found in the lower sediments. Material in USNM was collected by surface picking by Olson, Wingate, T. Illife and R. Baird on 19 Aug 1981; sediments were excavated and more bones collected by Olson and Grady on 12-14 Feb 2004.

14. *Crystal Cave*.—-Entrance N32°20'58.1" W64°42'48.1". Now a highly commercialized cave system that we have not investigated, this is where L. L. Mowbray obtained a number of the seabird bones studied later by Shufeldt (1916; 1922). In the USNM collections there is a complete mandible of *Aegolius* sp. labelled "Crystal Cave bone deposits" that was collected by the naturalist William Beebe in 1930. In 1935, the specimen was forwarded by Robert Cushman Murphy to Alexander Wetmore who decided he could not distinguish it from *Aegolius acadicus*.

15. *Devil's Sinkhole*.—-N32°20'20.9" W64°42'24.5". Located less than 10 m from Harrington Sound Road, just W of Government Quarry, the entrance is a relatively small opening in the Lower Town Hill Formation that drops precipitously over 12 m, so that access was only by means of two extension ladders lashed together, leading to a large cavern with large boulders of roof fall. Very well-preserved bird bones, often partial or nearly complete associated skeletons, occurred here in the interstices of boulders, usually in deep pockets of yellowish-white disintegrated limestone. Specimens were collected in August 1981 by Robert Baird, assisted later by Olson and Wingate; and again by Baird in January 1982 The avifauna consisted almost entirely of many individuals of *Pterodroma cahow* and *Puffinus parvus*, but also included one partial associated skeleton of the endemic night heron *Nyctanassa* sp.

16. *Fern Sink Cave*.—-Also known as Grand Canyon Cave (Hearty et al., 2004: fig. 5). Ca. 200 m NE of N32°20'50.9" W64°42'46.0". This cave system is entered through a great fault cleft in the Walsingham limestone that extends to the water table. In the subterranean part, on the SW side there is an extensive, steeply inclined, deposit of red soil talus. Parts of this have experienced sheetwash that has created occasional erosional cavities in places. The deposits consist of a thin surface veneer of Holocene sediments and fossils, as evidenced by shells typical of modern-type *Poecilozonites bermudensis* along with bird bones, overlying a glacial soil as indicated by the presence of shells of *P. nelsoni*. Most of the bird bones from here appear to belong to an undescribed species of small gallinule (*Gallinula*). These fossils occur below a zone about 5 cm thick of sterile, apparently leached sediment. The above-mentioned erosional cavities are in the glacial-age soil but may be lined with well-embedded shells of *P. bermudensis* from the overlying Holocene. Because of the sheetwash, the unconformity here is probably an erosional one that has removed the early Holocene, although the deposits in Walsingham Sink Cave and the W wall red talus of Admirals Cave suggest that the glacial/Holocene transition may have been a period of little deposition anyway. Charcoal from the lower level containing gallinule bones gave a radiocarbon date of 20,080 ± 110 ybp (Beta 192239).

Fossils were collected from the surface on 24 Feb 1979 by Wingate and T. Iliffe and mainly from the surface on 13 Feb 2002 by Olson, Hearty, and Wingate. On 11 Feb 2004 Olson and Grady collected surface samples and dug into the underlying glacial-age level in which fossils were rather heavily encrusted with calcite, as opposed to the Holocene bones, which were relatively clean. Olson collected additional samples here on 30 Apr and 3 May 2004. In addition to bones of seabirds, passerines, and the presumed gallinule, were two bones of the endemic night heron *Nyctanassa* sp., a tarsometatarus of *Aegolius*, and a partial tibiotarsus of a hawk.

17. *Walsingham Cave*.—-Main entrance N32°20'54.7" W64°42'37.7". This was once a popular recreational cave, with a relatively deep pool of blue water open to the light at the entrance with concrete steps for bathers. By leaving the path by the pool and going NE over a boulder field one passes another entrance called Bee Pit Cave on the cave survey although it is completely continuous with Walsingham Cave. This leads to a separate chamber leading back down to water. On the map in Richards (2003: 215) this is the slope indicated above the isolated pool shown in the passageway going off to the SW of the main chamber. Here on 17 Feb 2004 Olson and Grady excavated bones, mainly of seabirds, from a talus cone of red soil containing shells of *Poecilozonites bermudensis* but no *P. nelsoni,* hence the whole deposit is probably of Holocene age. A few bones labeled Walsingham Cave were collected by surface picking on 14 Aug 1981 by Robert Baird and Paul Cooper. We are not certain that this is the same cave as called Walsingham here and as this small sample contained one bone each of a hawk (Accipitridae) and a crow (*Corvus*), neither of which taxa were encountered by Olson and Grady, it seems quite possible that a different cave is involved.

18. *Walsingham Sink Cave*: N32°20'53.3" W64°42'39.0". The entrance is approximately 50-60 m NE of Walsingham Cave. This is a high, narrow cleft in a limestone escarpment that shortly beyond the entrance bends sharply to the right (NE), descends steeply to the water table, and continues on to open into a sinkhole to the NE. Olson and Grady collected here on 15 Feb 2004. Fossils occurred in two discrete deposits of red soil. The first was at the entrance, still in the light zone. The second was a talus cone deep in the cave about 2 m above the water table, and appeared to have come in through a separate small entrance. Both deposits contained shells of *Poecilozonites bermudensis* and *P. nelsoni*, and in the lower one it was clear that the *P. bermudensis* occurred only in a thin surface veneer of loose soil lying above a deeper, more consolidated, darker sediment with well-encrusted shells of *P. nelsoni* and at least one bone of *Rallus recessus*. So, as with the sediments in the W wall red talus in Admirals Cave, there appears to have been an unconformity here perhaps equivalent to units "w" through "z" in Admirals Cave (Hearty *et al.*, 2004). Apparent lack of deposition during that period resulted in late Holocene sediments being laid down directly on those probably dating back to near the last glacial maximum. It appears that the interval between deposition of abundant *P. nelsoni* at glacial maximum and deposition of abundant *P. bermudensis* in the latter part of the Holocene may have been a time when sedimentation ceased in many caves.

c) Tuckers Point Caves

The following 5 sites are all located near the SW shore of Castle Harbour on the grounds of the present Tuckers Point golf club.

19. *Church Cave*.—-N32°20'13.4" W64°41'59.1". A large, high-ceilinged cavern containing a substantial lake and with large boulders of roof-fall at the entrance among which Wingate obtained a few bones of seabirds and the rostrum of a crow *Corvus* sp. in May 1974. The latter may be modern. Olson, Hearty, and Wingate entered here briefly on 13 Feb 2002 but found nothing more of interest.

20. *Jane's Cave*.—-N32°20'11.1W64°42'04.0". On the S side of Paynter's Hill. A steep cave with two major chambers near the entrance. On 17 Feb 2004 Grady and Olson encountered a very few bones in a patch of thin sediment between the two chambers. In another chamber off to the N, not visited by Olson and Grady, Wingate obtained various bird bones in January 1975. These were labelled "Prettybone Cave" but Wingate's notes indicate that this is the same as Jane's Cave. The bones include a confusing assortment of rails suggesting perhaps that deposits here may be diachronic.

21. *Zephyr Cave*.—-N32°20'12.7" W64°42'00.5". A small, shallow opening practically in the fairway of the golf course. Grady and Olson excavated a few bones on 17 Feb 2004.

22. *Terrapin Cave*.—-N32°20'14.0" W64°42'04.3". Apparently not named on the cave inventory. Terrapin Cave is Wingate's designation because of finding remains of an individual of the possibly introduced (see Davenport *et al.*, in press) terrapin *Malaclemmys* here. The cave is located at the base of a limestone escarpment on the S side of Paynter's Hill. A few bones of *Puffinus parvus* were collected here by Wingate on 23 Jan 1974. Olson and Wingate visited the cave on 12 Feb 2004 and found that the entrance led to a steep drop requiring climbing gear or a ladder and no more bones were encountered.

23. *Tropicbird Cave*.—-Wingate's designation. The labels with specimens indicate that this cave was also on Paynter's Hill and Wingate's diary entry for 23 Jun 1974 includes a map showing that it is on the north slope of the hill close adjacent to the south side of the golf course fairway. Bones include those of *Pterodroma cahow, Puffinus parvus*, an associated skeleton of *Phaethon lepturus*, various rails, and passerines.

d) Miscellaneous Sites

24. *Spittal Pond*.—- N32°18' W64°43' (USBGN). This relatively large pond, located on the south shore in Smiths Parish, would only have begun to fill when sea level approached its present level about 5000 years ago. It is the focal point of Bermuda's largest nature reserve, as the pond is an important resting and feeding area for transient waterbirds. In Jun/Jul 1979, the pond was dredged to improve waterfowl habitat and the spoil from this dredging was dumped along the S side of the pond. Vertebrate remains, mostly those of non-resident waterbirds, were collected from this spoil by Wingate in Jul/Aug 1979 and throughout the subsequent year. More were collected by R. F. Baird in 1981. There was also evi-

dence of a midden accumulation, probably a European camp site just prior to, or after British settlement because of the discovery of a human femur belonging to a male Caucasian, as well as bones of pigs and cattle, fish bones, West Indian Top Shell *Cittarium pica*, and other edible mollusks. The spoil is now entirely vegetated, precluding the recovery of further fossil material.

25. *Grace Island*.——N32°16’ W64°49’ (USBGN) in Great Sound. Bones of *Pterodroma cahow*, and *Phaethon lepturus* were collected by Wingate, Jun 1972, from two small sink holes in Walsingham Formation.

26. *Cockroach Island*.—-N32°20’ W64°43’ (USBGN for Abbots Cliff) In Harrington Sound, base of Abbott’s Cliff. Bones of *Pterodroma cahow, Puffinus lherminieri/ parvus*, and *Phaethon lepturus* were collected by Wingate in Nov 1958. These remains were identified by Wetmore (1962: 15) who reported that they “were dug from about 4 cubic feet of sandy soil and rubble, some of them from near the surface where they were among roots of plants.” The bones were thought to be Recent in age. They were collected with shells of *Poecilozonites bermudensis*, which we now know to indicate Holocene age.

25. *SAL Quarry*.—-Southampton Parish, a sand quarry in the Southampton Formation on the coastline south of “Landmark”, ca. 300-400 m SE of West Whale Bay (N32°15’ W64°52’ USBGN). Various lots of bones of *Pterodroma cahow* found embedded in the sand along with abundant charcoal. Collected by Wingate 9 April 1979, Olson and R. F. Baird on 30 Aug 1981, and by Baird in Jan 1982.

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Fig. 9. Excavation at the base of the immense talus cone inside Admirals Cave. Nearly 120,000 years of continuous deposition is preserved here.

Fig. 9. *Excavació a la base del talús immens a l'interior de la cova Admirals. Aquí es conserven prop de 120.000 anys de deposició contínua.*

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