

A new genus and species of buteonine hawk from Quaternary deposits in Bermuda (Aves: Accipitridae)

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Abstract.—*Bermuteo avivorius*, new genus and species, is described from rare Quaternary fossils from the island of Bermuda. Although clearly referable to the Buteoninae, its relationships within that group are difficult to assess. Considerable size variation may be attributable to sexual dimorphism associated with bird-catching behavior. It is uncertain if the species survived into the historic period. Factors contributing to the rarity of hawk remains in the fossil record of Bermuda are discussed. One fragmentary ulna is from a larger hawk, possibly the Red-tailed Hawk *Buteo jamaicensis*.

The isolated North Atlantic island of Bermuda was once home to various species of endemic land birds, the number of which fluctuated between glacial periods of greatly increased land area and certain interglacial periods when high sea-levels caused extinctions through reduction in land area (Olson & Hearty 2003, Olson & Wingate 2000, 2001, 2006; Olson et al. 2005, 2006). The island also receives regular influxes of migrating birds from the American mainland. It would not be unexpected, therefore, that there may have been an endemic raptor on the island that fed upon this regular and probably abundant food source. Eight species of North American hawks (Accipitridae) have been reported as vagrants to Bermuda (Amos 1991) of which only *Circus cyaneus* and *Accipiter striatus* occur with any regularity. The others are *Elanoides forficatus*, *Haliaeetus leucocephalus*, *Accipiter gentilis*, *A. cooperii*, *Buteo jamaicensis*, and *B. lagopus*, as well as a vagrant of the Old World eagle *Hieraaetus pennatus*.

In 1603, Diego Ramirez mentioned that on Bermuda “There are many very

large dark herons, many very handsome sparrow-hawks, so stupid that we even clubbed them” (Wilkinson 1950:56). The tameness presumably refers to both the herons and the hawks and strongly suggests a resident species of hawk unaccustomed to humans or other predators, rather than some migratory species that would probably have been much less approachable.

In 1610, William Strachy wrote of “Hawkes of which in March wee found diuers [diverse] Ayres, Goshawkes and Tassels” (Lefroy 1981:35). “Ayres” could perhaps mean “eyries.” “Tassel” is a variant of “tercel” or “tiercel,” applied to the smaller male of any species of falcon, but often used to mean any small falcon. In this case, it could refer either to the Merlin *Falco columbarius* or to the American Kestrel *Falco sparverius*, both of which are regular transients and winterers on Bermuda (Amos 1991:119).

If Ramirez indeed encountered a endemic hawk, it must have disappeared soon thereafter, as one gathers from the comments of Captain John Smith that there was no longer a resident hawk on

the island in 1623: "Sometimes are also seene Falcons and Jar-falcon, Ospraies, a bird like a Hobby, but because they come seldome, they are held but as passengers" (Lefroy 1981:330).

The numerous fossil deposits on Bermuda (Olson et al. 2005) indicate a native hawk indeed existed on the island, yet remains of it are frustratingly few, even after 25 years of collecting. The sample consists of but 7 bones (3 complete) from 4 or 5 localities that represent a minimum of 6 individuals.

Comparative material examined (all USNM, M = male, F = female).—*Accipiter cooperii* 18855 F Maryland, 501627 M West Virginia, 614361 F New Mexico; *A. striatus* 554770 F North Carolina; *Busarellus nigricollis* 345772 F Brazil; *Buteo albicaudatus* 622367 F Guyana; *B. albonotatus* 621010 M Guyana; *B. b. buteo* 610637 M Sweden; *B. b. vulpinus* 558449 M South Africa; *B. brachyurus* 50938 unsexed partial Brazil, 291403 M partial Florida; *B. j. jamaicensis* 289619 F Haiti; *B. j. borealis* 561859 M Maryland; *B. l. lagopus* 610370 F Sweden; *B. l. sanctijohannis* 291309 M Kansas; *B. n. nitidus* 344055 M? Venezuela; *B. n. plagiatus* 288763 M Guatemala; *B. p. platypterus* 321823 F captive, 613957 F Panama; *B. p. brunnescens* 500678 unsexed partial Puerto Rico; *B. p. insulicola* 554967 M Antigua; *B. poecilochrous* 346398 M captive; *B. polyosoma* 319437 M Argentina; *B. regalis* 320771 M New Mexico; *B. ridgwayi* 318882 F Haiti; *B. solitarius* 610551 M, 622662 M, 622663 F all Hawaii; *B. swainsoni* 321986 M California, 614363 F Colorado; *B. ventralis* 400056 M partial Chile; *Buteogallus aequinoctialis* 621054 F Guyana; *B. anthracinus* 562529 F Panama; *B. gundlachii* 323421 M partial Cuba; *B. meridionalis* 622379 M Guyana; *Chondrohierax uncinatus* 611557 F Panama; *Circus cyaneus* 291684 M Maryland; *C. melanoleucus* 500257 M Russia; *Elanus leucurus* 19603 unsexed California; *Elanoides forficatus*

621940 F Guyana; *Geranospiza caerulescens* 345774 M Brazil; *Harpagus bidentatus* 612259 F Panama; *Hieraspiza superciliosa* 586298 F Guyana; *Ictinia plumbea* 613357 M Panama; *Leptodon cayanensis* 613953 M Panama; *Leucopternis a. albicollis* 344057 M Venezuela; *L. a. costaricensis* 611558 M Panama, 613956 M Panama; *L. melanops* 432181 F captive, 621942 F Guyana; *L. plumbea* 432154 M partial Panama; *L. princeps* 613281 M Panama; *L. semiplumbea* 613395 F Panama; *Parabuteo unicinctus* 630259 M Uruguay; *Rostrhamus sociabilis* 227376 M Argentina; *Rupornis magnirostris* 562526–8 MMM Panama, 630135 F Uruguay.

Systematics

Family Accipitridae

Accipiter differs from the Bermuda hawk in having the humerus with pectoral crest larger and more triangular, with the apex situated more distally, the shaft more sigmoid, and the distal end relatively wider; the femur has the trochanter in external view truncate, less pointed, and the rotular groove is narrower.

In *Circus*, the humerus differs from that of the Bermuda hawk in about the same way as *Accipiter*, although the shaft is less sigmoid; the femur is more elongate with the rotular groove narrower, as in *Accipiter*; the tibiotarsus is much more elongate and gracile.

The various New World "kites" (excepting *Rostrhamus* and *Helicolestes*) are a heterogeneous assemblage but all have the feet less specialized for strong grasping than typical hawks and the hindlimb elements are smaller in proportion to body size than in the Bermuda hawk.

The Bermuda hawk clearly belongs with the Buteoninae, which includes *Buteo*, *Geranoaetus*, *Buteogallus*, *Harpohaliaetus*, *Leucopternis*, and *Parabuteo* (Lerner & Mindell, 2005), with *Rupornis*

(*B. magnirostris*) and *Pernohierax* (*B. leucorrhous*) being split off from *Buteo* but with *Asturina* (*B. nitidus*) included in the genus (Riesing et al. 2003). Raposo et al. (2006) have shown that *Leucopternis* is polyphyletic, with some species being closer to *Buteo* and others to *Buteogallus*, but insufficient taxon sampling makes it uncertain just what generic nomenclature may emerge with further study.

On modern geographic grounds, the most likely progenitor of the Bermuda hawk would be a species of *Buteo*, the only genus of the subfamily occurring on adjacent mainland North America. It would not be unexpected, however, for almost any of the buteonine genera that are currently Neotropical in distribution, or nearly so, to have had a more northerly distribution in the Pleistocene: viz. *Parabuteo*, *Buteogallus*, *Rupornis*, *Leucopternis*. It has long been established in the fossil record that many taxa of vertebrates that are now restricted to the Neotropics once occurred in eastern North America. In connection with Bermuda, the endemic flightless rail *Porzana piercei* was a direct descendent of the Yellow-breasted Crake *P. flaviventer*, a species that now occurs no farther north than Cuba and Hispaniola, suggesting that this species probably once occurred on the mainland in eastern North America (Olson & Wingate 2000).

The species currently placed in *Buteogallus* (including *Heterospizias meridionalis*) all have the tibiotarsus more elongate and slender than in the Bermuda hawk (Olson 2006). *Parabuteo* differs in having the pectoral crest of the humerus much more triangular, the femur much more robust, and the tibiotarsus much more elongated. After *Buteogallus* and *Parabuteo* have been eliminated from consideration, it becomes more difficult to place the Bermuda hawk, which is something of a mosaic, although it has a few unique features in certain elements. Because the scant material cannot at this point be

assigned with confidence to any existing genus, a new genus becomes expedient until more specimens should indicate an alternative.

Genus *Bermuteo*, new genus

Type species.—*Bermuteo avivorus*, new species.

Diagnosis.—Differs from all other genera of hawks examined in the head of the femur, which is relatively smaller and not spherical and ball-like in all views but somewhat flattened proximo-distally, in posterior view with the distal margin nearly continuous with the posterior crest of the neck (Fig. 1). The distinct wing-like process of the external condyle of the femur in most Accipitridae is reduced in *Bermuteo* (also in *Circus* and *Rostrhamus*). The available tibiotarsi are extremely robust by comparison with those in other buteonine hawks (Fig. 2).

Etymology.—An amalgamation of Bermuda with the genus *Buteo*, from the Latin word *buteo*, a hawk, used for the European Buzzard *Buteo buteo*, and like that genus treated here as masculine in gender.

Bermuteo avivorus, new species

Figs. 1–3, Table 1

Holotype.—Complete left femur USNM 531932 (Fig. 1B, D). Collected 15 October 2000 by S. L. Olson and P. J. Hearty.

Type locality.—Bermuda, Hamilton Parish, Admirals Cave, 32°21'05.6"N; 64°42'48.6"W (see Olson et al. 2005:227).

Stratigraphy and age.—Level *r* of test pit in large talus cone. Late Pleistocene, Marine Isotope Stage (MIS) 5e (=last interglacial), ca. 120,000 YBP (see Hearty et al. 2004:1158).

Measurements of holotype (mm).—Total length 55.4, proximal width 9.2, proximal depth 6.4, depth of head 3.9, width and depth of shaft at midpoint 4.8 × 4.6, least circumference of shaft 15.0, distal width 10.4, distal depth 7.9.



Fig. 1. Left femur of *Bermuteo avivorus*. Holotype USNM 531932 (B, D), compared with a robust male *Rupornis magnirostris* USNM 562528 (A) and a more gracile male *Rupornis magnirostris* USNM 562527 (C, E). A–C, upper row anterior view, lower row posterior view. D, E, enlarged views of proximal end to show the peculiarities of the head of the femur of *Bermuteo avivorus*; upper row anterior view, middle row posterior view, lower row medial view. Scales = 2 cm.

Paratypes.—Complete right humerus USNM 531933 (Fig. 3A, C); proximal end of right tibiotarsus USNM 531934; lower pockets of Sibley’s Cave (see Olson et al. 2005), collected 12 February 2004 by F. V. Grady and S. L. Olson. Possibly Pleistocene (Wisconsinan glacial MIS 2–4) based on degree of flowstone encrustation.

Proximal third of right tibiotarsus USNM 531935 (Fig. 2D), collected 24 February 1979 by David B. Wingate; Fern Sink Cave (see Olson et al. 2005). Both Holocene and last glacial age deposits occur in Fern Sink Cave. This specimen was found at the surface and is thus probably Holocene (Hearty et al. 2004).



Fig. 2. Paratypical tibiotarsi of *Bermuteo avivorus*. (B, D, E), compared with *Buteo lineatus* (A, USNM 16634) and *B. polyosoma* (C, USNM 319437). B, complete left BAMZ 2004 228 003; D, proximal end of right USNM 531935; distal end of left USNM 264674. The two living species are considerably larger than indicated by the other bones of *Bermuteo*, yet, although the complete fossil tibiotarsus is shorter, it is more robust than in either of the living birds. Scale = 2 cm.

Distal third of left tibiotarsus USNM 264674 (Fig 2E), collected by Paul Cooper in "Walsingham Caves," probably either Walsingham Cave or Walsingham Sink Cave (see Olson et al. 2005). Of uncertain Quaternary age, but perhaps Holocene as it is not encrusted and is little stained.

Complete left tibiotarsus BAMZ 2004 228 003 (Fig. 2B). From a lot of bones

originally numbered 0434 in a catalog at BAMZ that cannot now be found, so no collection data are now available for this specimen. The lot also contains about 20 complete or fragmentary humeri and ulnae of Cahow *Pterodroma cahow*, and one pachyostotic bone fragment of uncertain identity but definitely not avian. The hawk bone and others in the same lot



Fig. 3. Paratypical right humerus of *Bermuteo avivorus*. (A, C) USNM 531933) in anconal (A) and palmar (C) views, compared with a large individual of *Buteo platypterus* (B, D, USNM 321823). E, F, distal end of left ulna of fossil *Buteo* cf. *jamaicensis* (E, USNM 531936) compared with *Buteo jamaicensis* (F, USNM 17945). Scale = 2 cm.

were covered with calcareous encrustations containing tubes of serpulid marine worms, indicating that the bones had at one time been in seawater. Therefore, it is probably safe to assume that this lot was recovered from a cave that is currently under water, as I am not aware of dry caves on Bermuda showing evidence of inundation during the last interglacial. The most frequent reason for bird bones being found in caves in Bermuda is that the birds entered the cave under their own power and died there and if this were the case, then the hawk tibiotarsus was

deposited during a glacial period when sea level was lower than at present. The encrustations on the bone are too old to have formed during the present interglacial and hence can be no younger than the last interglacial period (Marine Isotope Stage 5—see Appendix). Therefore, the minimum age for the tibiotarsus would appear to be the penultimate glacial age (MIS 6) or early in the last interglacial (MIS 5).

*Measurements of paratypes (mm).—*Humerus: total length 84.8, proximal width 17.0, head to distal end of pectoral

Table 1.—Measurements (mm) of paratypical tibiotarsi of *Bermuteo avivorus*.

Measurement	BAMZ 2004 228 003	USNM 531935	USNM 531934	USNM 264674
Total length from proximal margin of inner cnemial crest	89.6	—	—	—
Total length from proximal articular surface	87.2	—	—	—
Length from proximal articular surface to distal end of fibular crest	28.9	31.8	—	—
Proximal width	10.6	9.8	10.5	—
Proximal depth	13.8	12.6	—	—
Width and depth of shaft at midpoint	6.0 × 5.2	—	—	—
Width and depth of shaft below distal fibular insertion	6.7 × 4.6	—	—	5.7 × 4.2
Distal width	11.2	—	—	10.7
Distal depth	7.0	—	—	7.4

crest 32.2, width and depth of shaft at midpoint 6.4×6.1 , distal width 15.0, distal depth 8.0.

Tibiotarsi: see Table 1. BAMZ 2004 228 003 least circumference of shaft 17.7.

Etymology.—Bird-eating, from Latin, *avis*, bird, and *voro*, eat greedily, devour, from the presumed ornithophagous habits of any diurnal raptor inhabiting Bermuda.

Diagnosis.—As for the genus. A small to medium-sized buteonine varying in size from that of small males of *Rupornis magnirostris* probably to that of *Buteo lineatus*.

Description.—The humerus is slightly larger and decidedly more robust than in the largest females of *Buteo platypterus* (Fig. 3). From that species it differs in having the proximal and distal edges of the pectoral crest more incised, resulting in a more pointed apex, and in having the ectepicondylar prominence smaller and situated more proximally. In these respects, the Bermuda bird is more similar to the much larger species *Leucopternis albicollis*. The humerus in *L. semiplumbus* and *L. melanops* (Clade 3 within *Leucopternis*—Raposo et al. 2006) is very different from that of *L. albicollis* or *Bermuteo* in being proportionately shorter with a much more sigmoid shaft. The shaft in *Rupornis* and in *B. (Asturina)*

nitidus is also more sigmoid than in the Bermuda bird.

The femur is from a small individual, presumably male, and is quite comparable in length with males of *Rupornis magnirostris* from Panama, and intermediate in robustness between gracile and robust individuals of that species (Fig. 1). The peculiarities of the head of the femur are noted in the generic diagnosis. There is a single relatively large ovoid pneumatic foramen on the anterior face below the trochanter. Pneumaticity in this area is characteristic of the Accipitridae in general, though the number and position of foramina may be quite variable among species and individuals.

The tibiotarsus is extremely robust, the shaft width being equal to that in hawks of much larger size, such as *Buteo lagopus*. I did not examine any buteonine (or any other genus of Accipitridae for that matter) with a comparably robust tibiotarsus. The inner cnemial crest is longer and deeper and the fibular crest is proportionately longer than in related hawks.

Remarks.—None of the few remains thus far found of the Bermuda hawk can be identified with any known species of New World Accipitridae and the more diagnostic elements cannot certainly be assigned to an existing genus either. If

these bones are all from a single species, then this species was extremely variable in size, probably reflecting an exaggerated sexual dimorphism. Species of hawks that feed principally on birds tend to exhibit greater sexual dimorphism (Snyder & Wiley 1976). The Bermuda hawk would have had little else to feed on than birds, apart, probably, from the occasional bat (Grady & Olson 2006) and perhaps lizard. Among the buteonines, the continental Short-tailed Hawk *Buteo brachyurus* feeds mainly on birds (Miller & Meyer 2002) and the Hawaiian Hawk *B. solitarius* would of necessity have fed mainly on birds prior to the introduction of rodents to the islands (Clarkson & Laniawe 2000).

The holotypical femur came from a bird the size of small males of *Rupornis magnirostris* with a mass of 244–268 g ($n = 3$, USNM specimen data). The humerus indicates a bird somewhat larger than females of *Buteo platypterus* and would thus probably have had a mass in excess of 459 g (Mosher & Matray 1974). The tibiotarsi, especially the extremely robust complete specimen, probably indicate birds with an even greater mass, as the least circumference of the shaft of the tibiotarsus is supposed to be a good indicator of body mass (Campbell & Marcus 1992). It is probably not prudent to extrapolate too far from such limited data, but if all the bones here referred to *Bermuteo avivorus* are indeed from a single species, then it seems quite possible that some females could have had a body mass more than twice that of some males.

The scarcity of fossils of this hawk on Bermuda deserves discussion. Predators are always less abundant than prey so it would be expected that with fewer individuals there would be fewer opportunities for fossilization, all other conditions being equal. In the Galapagos, hawks (*Buteo galapagoensis*) are absent all deposits in lava tube caves (Steadman 1986). In the Hawaiian Islands, remains of *Buteo*

are almost never found in caves, most of the exceptions involving human transport (Olson & James 1982, 1991). On the other hand, for whatever reason, hawk fossils are comparatively common in lacustrine deposits on Oahu (James 1987) and Kauai (Burney et al. 2001). Thus, the absence of hawk fossils from the late Holocene sediments of Spittal Pond on Bermuda (Olson et al. 2005), part of which accumulated during the historic period, is noteworthy and suggests that *Bermuteo avivorus* may have become extinct naturally prior to the late Holocene.

Buteo cf. *jamaicensis*

Referred specimen.—Distal portion of left ulna USNM 531936 (Fig. 3E), Admirals Cave, Bermuda, collected 12 October 2000 by Storrs L. Olson and Paul J. Hearty; level $v^?$, in spoil by stalagmite in test pit of large talus cone. Level v dates to the last (Wisconsinan) glacial (MIS 2–4) (see Hearty et al. 2004:1158).

Measurements (mm).—Distal width 8.6, distal depth 8.8, width and depth of shaft at break 5.5×5.6 .

Remarks.—This specimen appears to be much too large for *Bermuteo avivorus*, being about the same size as a males of either Red-tailed Hawk *Buteo jamaicensis* or the North American Rough-legged Hawk *B. lagopus sanctijohannis*, the only two species of *Buteo* ever recorded from Bermuda. Whereas the *B. lagopus* occurs more frequently as a vagrant winterer, there is strong evidence that the rarer *B. jamaicensis* may at times have become a breeding resident, though probably not before the introduction of rodents in the 17th century. Wingate (2005) reviewed the several 19th century records, which included a report of nesting, and noted recent records of a pair, the first of which appeared in 2001, that built a nest in 2006 and perhaps the year before, although it was not known if young were produced (Wingate in litt. 29 May 2006).

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Appendix

Amino acid age constraints on a fossil hawk bone from Bermuda

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A tibiotarsus that is a paratype of the fossil hawk *Bermuteo avivorus* Olson was found without data in the collections of the Bermuda Aquarium, Museum and Zoo (BAMZ 2004 228 003). Grains of calcareous sand incorporated in marine encrustations, including tubes of serpulid worms on this fossil were analyzed to attempt to determine an approximate minimum age for the bone.

Through recent advances in amino acid racemization (AAR) geochronology using high performance liquid chromatography (HPLC), it is now possible to confirm the biological genesis and to provide age constraints from the encrustations. The worm tubes and sediment attached to the hawk bone were analyzed with reverse-phase HPLC (RPC) technique (Kaufman & Manley 1998) and conventional ion exchange (IE) AAR techniques, respectively. The RPC method is capable of analyzing minute sample sizes as small as single foraminiferan test (see Hearty et al. 2004a, for background and methods) weighing less than 0.1 mg. Five fragments of the encrustations, each weighing less than 1.0 mg, were analyzed by this method (Table 1). RPC yields

D/L for several amino acids but here we emphasize only D/L aspartic acid (Asp) and D/L glutamic acid (Glu).

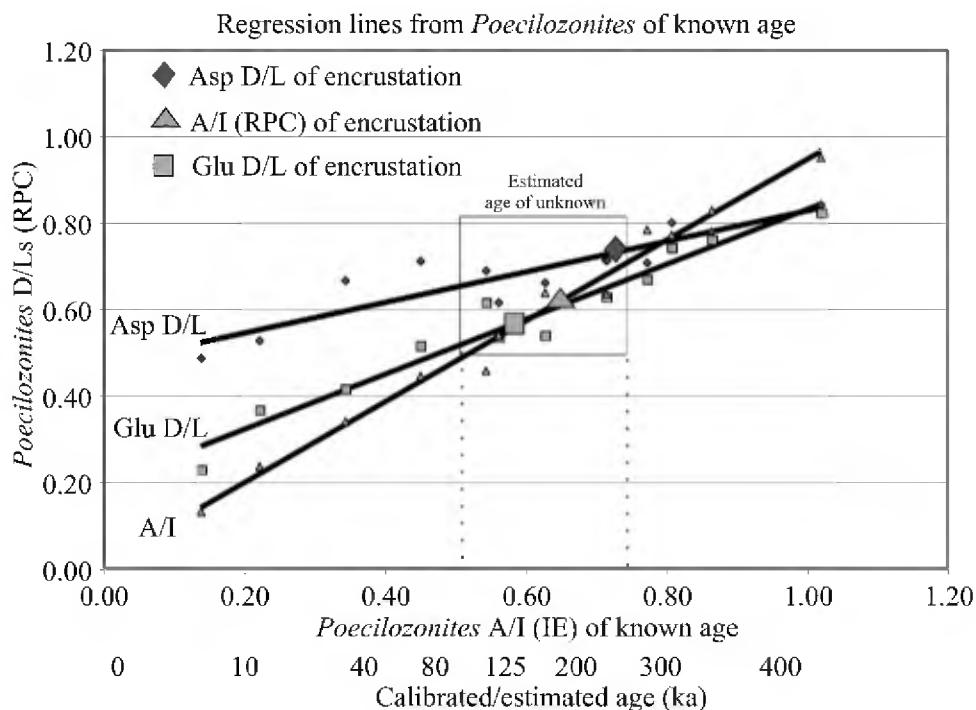
Carbonate sand grains such as those attached to the hawk bone are the dominant sediment type on Bermuda. The bulk sediment or whole-rock grains attached to the hawk bones were analyzed by IE yielding mainly A/I. These results are considered in light of an extensive whole-rock IE A/I database for Bermuda (Hearty 2002, Hearty et al. 1992, 2004b).

The high levels of several amino acids typical of marine shells confirm that the encrustations are of biological origin, in agreement with the observation that they contained serpulid worm tubes (Ian Macintyre, USNM, pers. comm. to Olson). The five fragments yielded average D/L Asp of 0.74 ± 0.07 , D/L Glu 0.58 ± 0.04 . A mean A/I of 0.61 ± 0.10 was determined on the same RPC solutions (Table 1). Because no data exist for serpulid worm tubes, comparisons of their D/Ls were made with the D/L Asp and Glu values from *Poecilozonites* land snails for which there is an extensive calibrated database of hundreds of samples (Hearty et al. 1992,

Appendix Table 1.—Results of RPC and IE analyzes of encrustations and incorporated carbonate sand grains on tibiotarsus of *Bermuteo avivorus* BAMZ 2004 228 003.

Reverse-phase HPLC (RPC)									
Lab ID	Catalog no.	Material	DL Asp	DL Glu	DL Ser	DL Ala	DL Val	DL Phe	A/I
4456 A	BAMZ 2004 228 003	encrustation	0.753	0.635	0.153	0.986	0.786	0.677	0.717
4456 B	BAMZ 2004 228 003	encrustation	0.715	0.592	0.095	0.915	0.780	0.535	0.576
4456 C	BAMZ 2004 228 003	encrustation	0.690	0.582	0.102	0.893	1.593	0.553	0.573
4456 D	BAMZ 2004 228 003	encrustation	0.859	0.547	0.110	1.022	1.236	0.708	0.707
4456 E	BAMZ 2004 228 003	encrustation	0.691	0.530	0.069	0.820	1.412	0.473	0.488
		Mean	0.742	0.577	0.106	0.927	1.161	0.589	0.612
		± 1σ	0.070	0.041	0.031	0.079	0.368	0.099	0.098

Ion Exchange HPLC (IE)									
			Run 1	Run 2	A/I	±1σ	CV		
4457 A	BAMZ 2004 228 003	sediment	0.201	0.208	0.205	0.005	2.420		
4457 B	BAMZ 2004 228 003	sediment	0.212	0.216	0.214	0.003	1.322		



Appendix Fig. 1. Linear regression lines from *Poecilozonites* land snail of calibrated ages of 10–400 ka were constructed for the three amino acid racemization products of interest (D/L Asp, D/L Glu, and A/I) against which the ratios from the encrustations on tibiotarsus of *Bermuteo avivorus* BAMZ 2004 228 003 (=“unknown”—represented by larger symbols) were compared. D/L Glu of 0.58 ± 0.04 ($n = 5$) provides the most precise constraints, yielding an estimated age range from about 100–150 ka. From the geochronological data, we infer that the hawk most likely entered a dry cave during the glacial lowstand of MIS 6 and was subsequently inundated and encrusted with sediment and serpulid tubes sometime during the MIS 5e highstand.

2004b). Prepared solutions of *Poecilozonites* from a broad range of ages (10–400 ka) were analyzed by both IE and RPC techniques. Regression lines from the *Poecilozonites* of known age (Fig. 1) were constructed for the three amino acid racemization products of interest (D/L Asp and Glu, and A/I) against which the ratios from the serpulid tubes were compared (Fig. 1). Because it is unlikely that rates are half as fast, or twice as fast as those of *Poecilozonites*, it is a reasonable first approximation for this exercise that the serpulids racemize at rates roughly comparable to *Poecilozonites*. D/L Asp of 0.74 ± 0.07 from the encrustation, when considered in the *Poecilozonites* age framework, provide an estimate of age between 100 and 300 ka (Fig. 1). But because D/L Asp is known to diminish asymptotically in racemization rate (and thus time resolution) as it approaches 0.8 (Hearty, unpublished data), these data are of little value. Nevertheless, when compared with the curves of *Poecilozonites*, the D/L Glu of 0.58 ± 0.04 from the encrustations equates with an estimated age range between the mid to last interglacial period and the late penultimate glacial (MIS 5c and late MIS 6), or from about 100–150 ka. The average A/I from the tubes of 0.61 ± 0.10 is similar to A/I of *Poecilozonites* that are closely associated with a TIMS U/Th age of 126 ± 3 ka from Admirals Cave (Hearty et al. 2004). The large error (16%) extends the age estimate across much of the last interglacial MIS 5 interval and into late MIS 6, in general agreement with D/L Glu results. The mean WR sediment A/I of 0.21 ± 0.01 requires no independent scheme for comparison, as a calibrated WR bioclastic limestone database is well established for Bermuda (Hearty 2002, Hearty et al. 1992). Within this framework, the value of 0.21 equates with a mid MIS 5 age estimate between about 85 and 115 ka.

In summary, D/L Glu values from marine encrustations on a hawk bone probably found in a submarine cave suggest a correlation with late MIS 6 or the early half of MIS 5. A/I results on encrusting bioclastic sediment indicate a similar correlation, although the presence of the serpulid

tubes on the bone indicates marine inundation and thus a probable highstand of sea level. Both MIS 5a and 5e highstands were at or above present sea level in Bermuda (Vacher & Hearty 1989, Hearty 2002), with MIS 5c being significantly lower. As the dating appears to point more toward early MIS 5 than late, we conclude the hawk bone was deposited in the cave sometime during MIS 6 and was subsequently inundated and encrusted marine with sediment and worm tubes most likely during the MIS 5e highstand.

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