The discovery of a Dodo *Raphus cucullatus* Linn. (Aves, Columbiformes) in a highland Mauritian lava cave

***Gregory J. Middleton*[1] *& Julian P. Hume*[2]**

[1] P.O. Box 269, Sandy Bay, Tasmania 7006, Australia ozspeleo@iinet.net.au

[2] Bird Group, Dept. of Zoology, The Natural History Museum, Tring and London, UK. j.hume@nhm.ac.uk

Abstract

In September 2006, during a survey of Mauritian caves for cockroaches (Blattodea), a skeleton of a Dodo (*Raphus cucullatus* Linn. 1758) termed 'Dodo Fred' was serendipitously discovered in a highland lava cave. It was subsequently removed from the cave for curation. It is only the second individual associated skeleton to be found, the only one recorded in context and in modern times, and has been called 'the most scientifically important Dodo in the world'. This paper records the circumstances surrounding its discovery, and provides additional information concerning other Dodo subfossil deposits. The preservation of bone material in lava tubes is also discussed. The publication of this paper has unfortunately been considerably delayed, so some of the factual content is no longer novel.

Keywords: Dodo; subfossil; associated skeleton; Mauritius; lava cave

Mauritius and its caves

The isolated island of Mauritius is situated in the southwestern Indian Ocean, lying about 850 km east of Madagascar. It is 65 km long and 45 km wide and has a land surface area of 1,825 sq km. Mauritius, with its dependency Rodrigues, 560 km to the east, and the French island of Réunion, 160 km to the south-west, comprise the Mascarene Islands (Fig. 1).

The main island of Mauritius is almost entirely volcanic, having originated about 13 million years ago in seabed eruptions, emerging above sea level about 8 million years ago (Saddul 2002). The island is dominated by two spectacular mountain peaks, remnants of two large volcanic craters, and there are a number of smaller and more recent craters, including Trou aux Cerfs, Grand Bassin, Bassin Blanc and Trou Kanaka (Fig. 2). The main volcanoes have been extinct for at least 200,000 years though some lava flows may have occurred as recently as 26,000 years BP, particularly in the Plaine des Roches area in the north-east (Antoine 1983; Saddul 2002).

Lava tube caves are widely scattered across the island; Middleton (1998, 2005) has documented over 150 since 1992. There are also a few karst caves in aeolian calcarenite, mainly on the south and east coasts of the main island of Mauritius and in the south-west of Rodrigues Island.

History of the Dodo and its discovery

The Dodo (*Raphus cucullatus* Linn. 1758) was endemic to Mauritius, and disappeared soon after its discovery. It is the first species widely recognised as having become extinct due to the action of humans (either through direct hunting, habitat alteration or introduction of predators and competing species), and has become a true icon of extinction (Hume 2006). The exact date of extinction is unknown, but the best estimate, based on contemporary records, appears to be about 1693 (with a 95% confidence interval of 1688 to 1715) (Hume and others 2004). Therefore any bones found since 2000 would have to be at least 300 years old.

In the first half of the 17th century, Dodos were regarded as curiosities but surprisingly few were taken from Mauritius alive or dead. A stuffed specimen had been on display in the Ashmolean Museum, Oxford, England since at least 1656, but by 1755 it had deteriorated to the extent that only the head and one foot remained (Nowak-Kemp & Hume 2016). These unique skin specimens still reside in the University Museum of Zoology, Oxford (Fig. 3). A second foot existed in London until the late 19th century but its whereabouts is now unknown (Hume and others 2006). Together with a skull in Copenhagen and an upper mandible in Prague, these remnants constituted the world's inventory of Dodo material prior to 1865 (Fuller 2002).

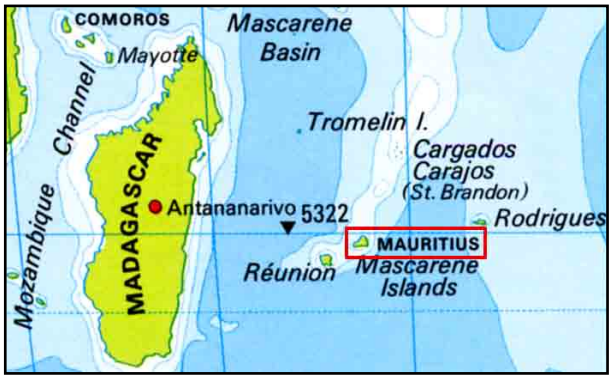

Figure 1. Location of Mauritius, in south-west Indian Ocean.

The discovery of the first subfossil Dodo material

The paucity of Dodo remains in the early 19th century led some authorities to doubt that the Dodo had ever existed, placing it among the make-believe creatures of myth and fantasy (Hume 2006; Nowak-Kemp & Hume 2016). This initiated a race to find the first subfossil remains, primarily led by the leading British scientists of the day (Hume and others 2009). Meanwhile, amateur natural historians based on Mauritius searched diligently for subfossil remains without success until a Dr Philip Ayres discovered a supposed Dodo bone in a cave in the Roches Noires district prior to 1860 (Cheke & Hume 2008), but its identification remains in doubt (JPH pers. obs). In 1865, George Clarke, a schoolteacher in Mauritius, who had also been searching for Dodo remains for many years, was informed by a railway engineer, Harry Higginson, about the retrieval of large numbers of bones of extinct tortoises from a marsh called Mare aux Songes in the south-east of the island (Hume and others 2009). A railway embankment had been constructed alongside the marsh, and labourers were stockpiling bones as they dug the marsh for peat. Clark sent some of the labourers into the centre of the marsh and a large number of Dodo bones were recovered (Clark 1866), though these were removed without contextual data. Such was the number of subfossil remains subsequently retrieved that almost all Dodo remains held in the world's museums today are derived from this one site (Hume and others 2009).

Although a number of 'complete' skeletons have been constructed from this material, the fossil deposit represents a composite of different Dodos; thus associated bones from a single individual are lacking. Tannins from decaying vegetation have stained the bones brown and black, though this has not affected preservation (Meijer and others 2012). Although these bones are relatively well preserved, determining how the individuals died and why so many Dodo remains have

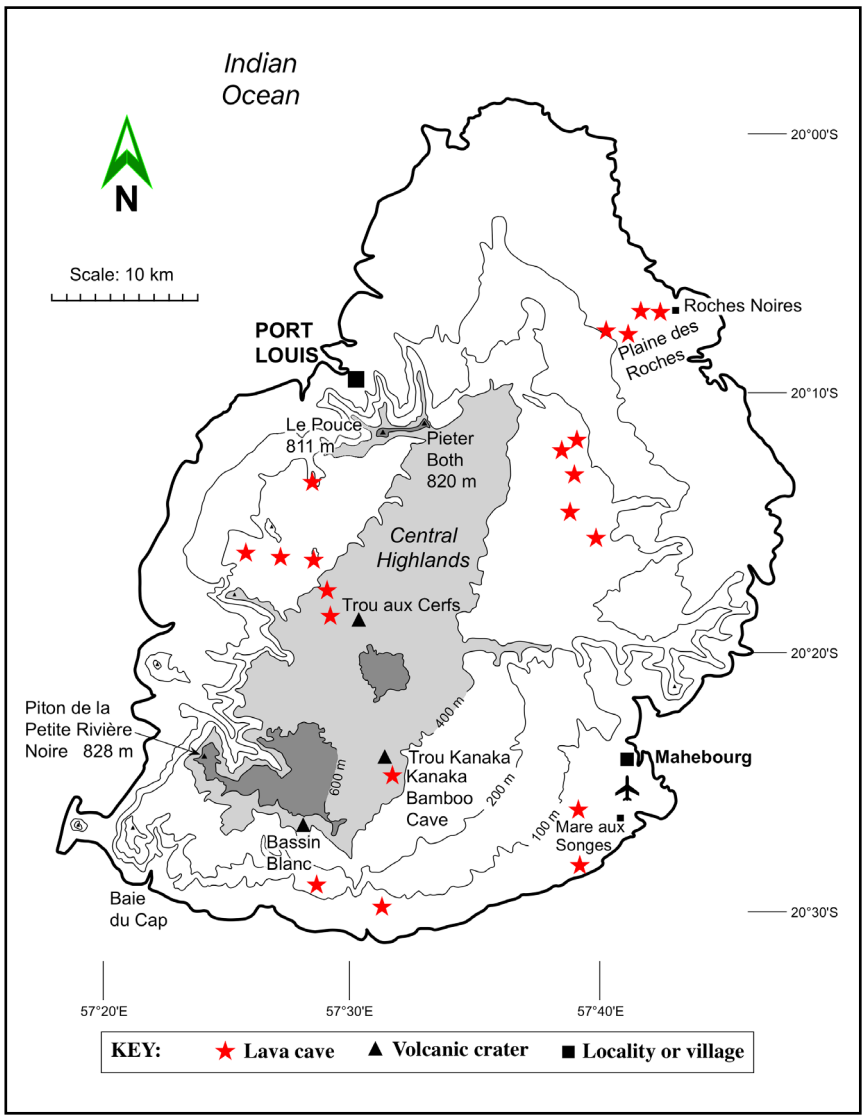

Figure 2. The island of Mauritius showing location of some lava caves and places mentioned in the text.

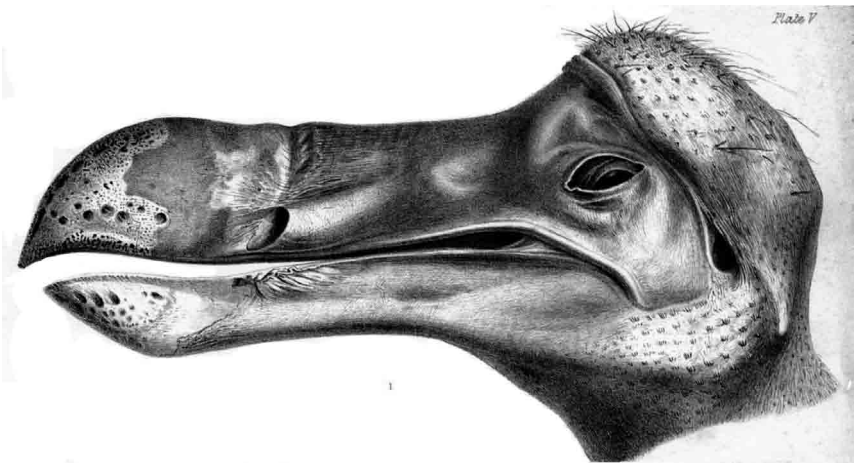

Figure 3. The only surviving head of a Dodo – the "Oxford skull" – from Fuller (2002, p. 114) as reproduced from Strickland & Melville (1848).

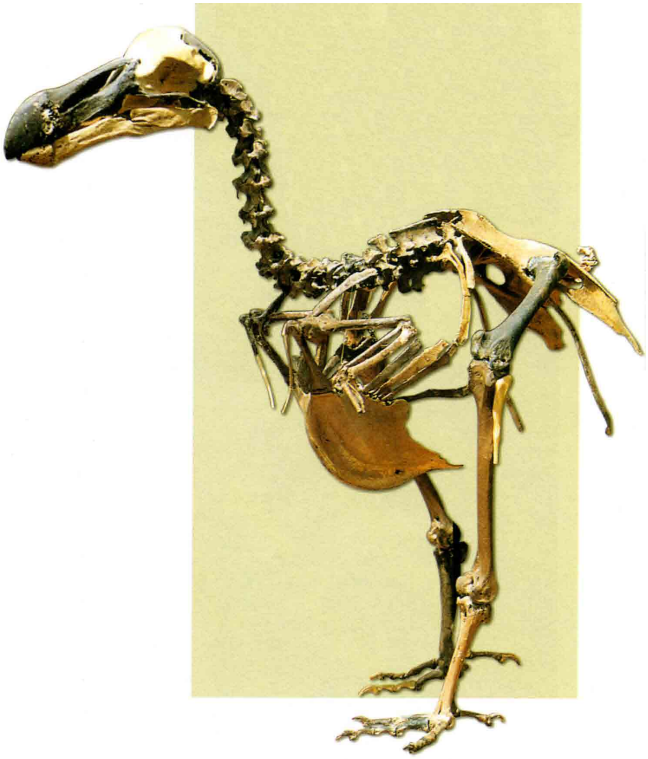

Figure 4. The only (nearly) single-individual Dodo skeleton – about 75 cm tall. (A few elements were provided from Mare aux Songes material.)

Collected by Thirioux in the early 20th Cent. and still on display in the Mauritius Institute.
(from Grihault 2005)

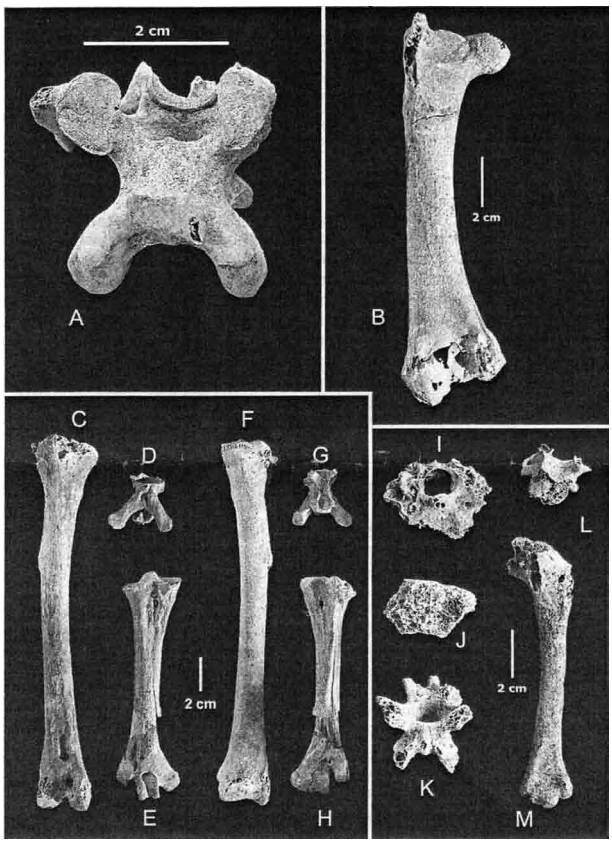

Figure 5. A-H Dodo bones from "small cave shelters" at Baie du Cap in southern coastal Mauritius; I-M from Plaine des Roches lava tunnels – as figured by Janoo (2005).

been preserved in the deposit has proved difficult. The thermal and chemical conditions in the swamp have also destroyed all DNA (Beth Shapiro pers. comm. 2007).

Around the late 19th/early 20th century, a barber and amateur natural historian, Etienne Thirioux, discovered a unique associated individual Dodo in an unspecified 'cave' location on Le Pouce, the third highest mountain of Mauritius (Hume 2007; Claessens & Hume 2015). This almost complete skeleton is extremely well preserved, and remains on display in the Mauritius Institute, Port Louis (Fig. 4). Unfortunately, Thirioux left no documentation as to the whereabouts of his discovery or any contextual data about its retrieval (Claessens & Hume 2015). However, recent examination of Le Pouce by the authors and zoologist, Owen Griffiths, revealed no lava tube caves but did identify a previously excavated boulder scree cave, which may represent one of Thirioux's collecting localities (Hume 2011).

Two other small collections of Dodo bones from lava caves have been reported (Janoo 2005). Five bones from lava rockshelters at Baie du Cap (Fig. 5 A-H) may have been deposited during the period of Dutch occupation after consumption by escaped slaves as they bear knife cut marks (Chowdhury 2003), and two bones and three fragments from a lava tube at Plaine des Roches (Fig. 5 I-M) are probably from natural accumulation. Up to 2006, the discovery of an associated individual Dodo with contextual data still eluded science.

The finding of subfossil Dodo Fred

In September 2006, while Middleton was assisting Dr Fred Stone and Deborah Ward, cave biologists from Hawaii, to search for cave cockroaches (Blattodea) in Mauritian caves, Ward happened upon some bones in a lower breakdown chamber in Kanaka Bamboo Cave, K1, in the south of the island (Middleton 2008) (Fig. 6). As they appeared to be old and fragile, Ward suspected they might be bones of the Dodo. Both biologists had previous experience with bird palaeontologists recovering subfossil bones from lava caves in Hawaii, and so were certain they were bird bones of great age. *In-situ* photos of the specimens were taken by Ward and these were forwarded by Griffiths to a colleague at the Natural History Museum, London, (JPH), who has made a long term study of the extinct fauna of the Mascarene Islands. Hume did not hesitate in pronouncing these bones as Dodo and excitingly responded to Griffiths: "This is only the second associated Dodo skeleton and the first with context" (Hume pers. comm. – e-mail to Owen Griffiths 15 Oct. 2006).

Subsequently the original party members took Griffiths to see the bones and to photographically record

the site (Figs 7, 8, 9, 10) after which it was agreed that the discovery should not be publicised until a professional team could be organised to collect it.

Some of the original photos of the bones had been captioned by Ward as "Dodo – Fred", referring to photos by Fred Stone of the dodo bones. After receiving the images, Hume casually called the skeleton Dodo Fred as a means of identification, thus the wrong 'affectionate' name, Fred, was applied to the specimen. The name has now become ingrained in the literature.

Hume and Dr Lorna Steel, a bone histology expert from the Natural History Museum, London, went to Mauritius in June 2007 to assist Mauritian authorities to recover the bones of 'Fred'. This occurred on 29 June, in the presence of the Mauritian Minister for Foreign Affairs, officials of the National Heritage Trust and TV camera crews. All contextual data was retrieved and the bones were chemically hardened to prevent damage (Figs 11, 12), before being transported to the Mauritius Institute, Port Louis, where they are now stored.

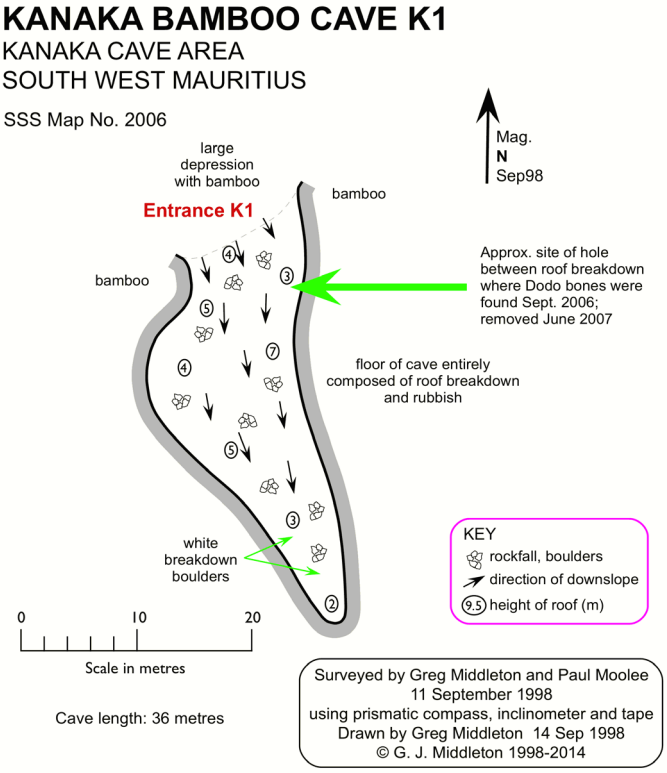

Figure 6. Plan of Kanaka Bamboo Cave.
The general area of the lower chamber in breakdown where Deborah Ward found the Dodo bones is indicated.

Figure 7. Dr Fred Stone and Deborah Ward at the entrance to Kanaka Bamboo Cave.

Figure 8. Deborah points to the depression in the floor where the skeletal material lies.

Figure 9. Large leg bones of the Dodo.

Figure 10. The main mass of skeletal remains – in an advanced state of decomposition.

Figure 12 (above). The bones of one foot were able to be recovered virtually complete. Photo (and preparation): Lorna Steel.

Figure 11 (left). Some of the bones immediately after removal from the cave. Photo: Lorna Steel.

The significance of Dodo Fred

After Dodo Fred's discovery, a number of reports were made about the importance of the find, but without realising the poor state of bone preservation, and before the presence of DNA could be established. On 3 July 2006 the *National Geographic News* reported:

Adventurers exploring a cave on an island in the Indian Ocean have discovered the most complete and well-preserved dodo skeleton ever found, scientists reported yesterday.

Very little has been known about the dodo—from what exactly it looked like to what it ate—since it became extinct in the 1600s.

The new skeleton is thought to be complete and was likely preserved by its cave setting.

Nicknamed Fred after the caver who found the bones, the bird was kept under guard while the recovery took place, according to press reports.

... the location of the new skeleton makes it much more likely to yield DNA, said Beth Shapiro, a geneticist from Oxford University who studies dodo remains. Most other dodo bones have come from a swampy region of Mauritius known as Mare aux Songes, she said.

"We have found tons of bones there, but the hot, wet, acidic environment has meant that the DNA survival has been terrible," Shapiro said.

The cave site of the new skeleton is likely to provide the best hope of a decent DNA sample because the bones will not have been exposed to sunlight and the temperature was fairly constant, she added. (Ravilious 2007).

Reflecting on the discovery in the initial stages, Hume wrote:

Not only did the bones turn out to be Dodo, they also belonged to a single individual in its position of death, a unique discovery [Fig. 13]. *The Dodo skeleton - affectionately called 'Dodo Fred' – was carefully removed, but many elements had already crumbled. However, these fragments are potentially suitable for DNA studies (unlike the material recovered from the Mare aux Songes), making Fred the most scientifically important Dodo in the World* (Cheke & Hume 2008).

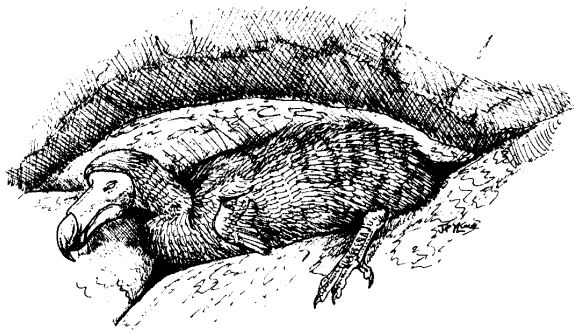

Figure 13. "Trapped in a cave and too weak to move, Dodo Fred died and his body collapsed into a small crevice, leaving part of the bill and one foot on the surface." Graphical interpretation of Fred's death by Julian Pender Hume (Cheke & Hume 2008).

Unfortunately, subsequent reports from the Natural History Museum indicated that tests on the Kanaka Bamboo Cave subfossils showed that collagen has not survived, in which case the DNA has also been lost (Lorna Steel pers. comm.).

Nevertheless, these bones are certainly important because they are from a single individual (only the second known) and they extend the known range of the species into the cool, damp highlands of Mauritius. While they are not destined to contribute to ongoing investigations into the phylogeny of the genus *Raphus*, the find has sparked renewed interest in this iconic species.

Preservation of bones in lava caves

In general, volcanic islands are notorious for the poor preservation and long-term survival of fossils in montane environments, primarily due to chemical decomposition and for topographical reasons, e.g. steep slopes leading to rapid run-off and lack of depositional basins (Hume 2005). Therefore the discovery of "Dodo Fred" in the highlands was unexpected. In the damp, humid cave environment where the specimen was discovered and coupled with an acidic environment – pH is always low unless carbonates are present – conditions are not conducive to bone preservation. The bones get leached very quickly of their organic content, leaving only the mineral structure, and become brittle (Hume 2005). This has resulted in a relative scarcity of subfossil bone material in lava caves on Mauritius. Furthermore, in Caverne de la Tortue, a lava tube cave in vesicular basaltic lava on Réunion, the cave atmosphere is extremely humid and the preservation of bone material is generally very poor. Recent remains of Hare (*Lepus* sp.), although dating from no earlier than c. 1850 (when hares were first introduced), were extremely fragile and disintegrated when being handled. Scanning electron microscopy of the hare bone surface indicated that not only was chemical degradation in process, but fungal hyphae and bacterial micro-biodegradation also played a major part in structural breakdown (Hume 2005). Large numbers of remains have been collected from calcarenite caves, such as those on Rodrigues (Cowles 1987, Hume 2013), but calcarenite caves are rare on Mauritius. In these limestone caves, subfossil bones can be found at depth or on the surface, and are not subject to the same chemical erosion as in acidic caves. Scavenging and disarticulation by vertebrates (mammals, birds, reptiles and amphibians), invertebrates (insects, snails, crabs) is prevalent but the bones themselves remain comparatively intact. Micro-biodegradation also occurs on exposed specimens but again significant loss of the bone structure is infrequent.

In complete contrast, bones collected from the Mare aux Songes are comparatively well preserved. Recent work by a Dutch-Anglo team (Rijsdijk and others 2009) has shown that the marsh, which otherwise would have a low pH, has a neutral to slightly alkaline pH value, therefore producing a stable chemical environment in which bone is perfectly preserved. The pH neutrality has been achieved by wind-blown carbonate sand entering the marsh, buffering the effects of an otherwise acidic environment. This factor and presumably rapid burial, which would reduce the effects of bioerosion and scavenging, provided an ideal environment for bone preservation.

In other fossil localities, significant and well preserved subfossil vertebrate deposits have been found in lava caves. For example in Hawaii, James and others (1987) were able to date bones weighing as little as 450 mg recovered from sediment in Puu Naio Cave on Maui which ^{14}C showed to be up to 7750 years old. In Haystack Cave, a small lava tube cave in Colorado, USA, a large collection of vertebrate remains were recovered dated at between 14,935 and 12,154 yrs BP (Emslie 1986). Steadman (1981) collected subfossil vertebrate remains from lava tube caves on the larger Galapagos Islands (Santa Cruz, Floreana and Isabela) where he noted that recent specimens were 'fresh and unmineralised' while older bones were 'dark and mineralised'. In none of the above examples which included bird material were the bones reported to be decomposing or even fragile, despite some being thousands of years old. However, bones of several individuals of two species of flightless rails (*Porzana* sp.) and much of the skeleton of a flightless ibis (*Apteribis* sp.) were collected from a lava tube in East Maui, Hawaiian Islands. Commenting on this discovery, Olson & James (1982, p. 15) noted that "The specimens were quite friable and deteriorated. They are probably of late Holocene age, as in the humid environment of a lava tube such as this one, exposed bone eventually disintegrates completely." Further, Steadman and Pregill (2004) reported "Samoan lava tubes are poorly suited for bone deposition and preservation because of flowing water, wet soils and stagnant air saturated with humidity." When they did find a bone deposit, they noted that the site was dry.

Why, then, were many of the bones of Dodo Fred reduced to fragments, or at least to fragile, weakened structures, when they might only be 300 years old?

It appears that a combination of factors is responsible. The depositional conditions of dry caves, even with high humidity, appear to have less effect on bone than those permanently wet, in which bone decomposition is comparatively rapid. Immediate burial is also important as it reduces the action of micro-bioerosion, but it is not essential as Rodrigues cave material will testify. Neither is altitude a pre-requisite for good preservation, as cave fossil deposits from montane regions have been perfectly preserved. Compared to marsh environments, cave deposits provide better opportunities for associated and articulated specimens, particularly if access is difficult, by reducing the effects of scavenging. Therefore high humidity coupled with permanent damp conditions as typified by Kanaka Bamboo Cave in which Dodo Fred

was discovered, facilitates the detrimental actions of chemical and biological agents. In the case of Dodo Fred, the organic component of the bones has been leached out leaving only the fragile mineral structure behind. How long the remains of this bird were lying in the cave cannot be determined, but in such an environment it is extraordinary that the bones of Dodo Fred survived at all.

REFERENCES

Antoine, R. 1983. La derniere coulée de laves à l'île Maurice. *Revue Agricole et Sucriere* 62(2): 91-92.

Cheke, A. & Hume, J. 2008. *Lost land of the Dodo: an ecological history of Mauritius, Réunion & Rodrigues.* T & AD Poyser: London.

Chowdhury, A. 2003. 'Maroon slave archaeological investigation project in the Republic of Mauritius.' Unpub. report, University of Mauritius.

Claessens, L., & Hume, J.P. 2015. Provenance and history of the Thirioux dodos. *Journal of Vertebrate Paleontology*. Memoir 15. Supplement to Number 6.

Clark, G. 1866. Account of the late discovery of Dodos' remains in the island of Mauritius. *Ibis,* 8(2): 141-146.

Cowles, Graham S. 1987. The fossil record [in] Diamond, A.W. (Ed.) *Studies of Mascarene Island birds*. Cambridge University Press: Cambridge UK. pp. 90-100.

Emslie, S.D. 1986. Late Pleistocene vertebrates from Gunnison County, Colorado. *Journal of Palaeontology* 60(1): 170-176.

Fuller, Errol 2002. *Dodo: A brief history.* Universe Publishing: New York. 180 pp.

Grihault, Alan 2005. *Dodo: the bird behind the legend.* IPC Ltd: Cassis, Mauritius.

Hume, J.P. 2005. Contrasting taphofacies in ocean island settings: the fossil record of Mascarene vertebrates [in] Alcover, J.A. & Bover, P. (eds) *Proceedings of the international symposium "Insular Vertebrate Evolution: the Palaeontological Approach". Monographies de la Societat d'Història Natural de les Balears,* 12: 129-144.

Hume, J.P. 2006. The history of the dodo *Raphus cucullatus* and the penguin of Mauritius. *Historical Biology* 18(2): 65-89.

Hume, J.P. 2007. Reappraisal of the parrots (Aves: Psittacidae) from the Mascarene Islands, with comments on their ecology, morphology, and affinities. *Zootaxa* 1513: 1-77.

Hume, J.P. 2011. Systematics, morphology, and ecology of pigeons and doves (Aves: Columbidae) of the Mascarene Islands, with three new species. *Zootaxa* 3124: 1-62.

Hume, J.P. 2013. A synopsis of the pre-human avifauna of the Mascarene Islands [in] Göhlich, U.B. & Kroh, A. (eds) *Proceedings of the 8th International Meeting of the Society of Avian Paleontology and Evolution*. pp. 195-237. Naturhistorisches Museum: Wien, Austria.

Hume, J.P., Cheke, A.S., & McOran-Campbell, A. 2009. How Owen 'stole' the Dodo: academic rivalry and disputed rights to a newly-discovered subfossil deposit in nineteenth century Mauritius. *Historical Biology* 21(1–2):33-49.

Hume, J.P., Datta, A. & Martill, D.M. 2006. Unpublished drawings of the Dodo *Raphus cucullatus* and a note on Dodo skin relics. *Bulletin of the British Ornithologists' Club* 126A: 49-54.

Hume, J.P., Martill, D.M. & Dewdney, C. 2004. Palaeobiology: Dutch diaries and the demise of the dodo. *Nature* 429 (10 June 2004).

James, H.F., Stafford, T.W., Steadman, D.W., Olson, S.L., Martin, P.S., Jull, A.J. & McCoy, P.C. 1987. Radiocarbon dates on bones of extinct birds from Hawaii. *Proceedings National Academy of Science USA* 84: 2350-2354.

Janoo, A. 2005. Discovery of isolated dodo bones [*Raphus cucullatus* (L.), Aves, Columbiformes] from Mauritius cave shelters highlights human predation, with a comment on the status of the family Raphidae Wetmore, 1930. *Annales de Paléontologie* 91: 167-180.

Meijer, H.J.M., Gill, G., Louw, P.G.B.D., Hoek Ostende, L.W.V.D., Hume, J.P., & Rijsdijk, K.F. 2012. Dodo remains from an in situ context from Mare aux Songes, Mauritius. *Naturwissenschaften* 99(3): 177-84.

Middleton, G.J. 1998. Lava caves of the Republic of Mauritius, Indian Ocean. *International Journal of Speleology* 27B (1/4): 87-93.

Middleton, G.J. 2005. Conserving the lava caves of Mauritius: the Caves of Mauritius Project 1998 [in] Barone, N. and others (Ed.) *Inside Volcanoes: Proceedings IX International Symposium on Vulcanospeleology* (Sep. 1999). Centro Speleologico Etneo: Catania.

Middleton, G.J. 2008. Mauritius 2006/07 – The finding of Dodo "Fred" and its recovery. *Journal of the Sydney Speleological Society* 52(10): 285-294.

Nowak-Kemp, M. & Hume, J.P. 2016. The Oxford Dodo. Part 1: the museum history of the Tradescant dodo: ownership, displays and audience. *Historical Biology* DOI: 10.1080/08912963.2016.1152471.

Olson, S.L. & James, H.F. 1982. Prodromus of fossil avifauna of the Hawaiian Islands. *Smithsonian Contributions to Zoology* No. 365 pp. 1-59.

RAVILIOUS, Kate 2007. Dodo skeleton found on Island, may yield extinct bird's DNA. National Geographic News, 3 July 2007 online at: http://news.nationalgeographic.com/news/2007/07/070703-dodo.html.

RIJSDIJK K.F, HUME, J.P. and 18 others. 2009. Mid-Holocene vertebrate bone Concentration-Lagerstätte on oceanic island Mauritius provides a window into the ecosystem of the Dodo (*Raphus cucullatus)*. Quaternary Science Reviews 28: 14-24.

SADDUL, P. 2002. *Mauritius: A geomorphological analysis* (rev. edn.) Geography of Mauritius Series; Mahatma Gandhi Institute: Moka.

STEADMAN, D.W. 1981. Vertebrate fossils in lava tubes in the Galápagos Islands [in] Beck, B.F. (ed.) *Proceedings 8th International Congress of Speleology, Western Kentucky, USA* 1981 pp. 549-550.

STEADMAN, D.W. & PREGILL, G.K. 2004. A prehistoric, noncultural vertebrate assemblage from Tutuila, American Samoa. *Pacific Science* 58(4): 615-624.

STRICKLAND, H.E. & MELVILLE, A.G. 1848. *The Dodo and its kindred.* Reeve, Benham & Reeve: London.