

A rich Pleistocene–Holocene avifaunal sequence from Te Waka #1: terrestrial fossil vertebrate faunas from inland Hawke's Bay, North Island, New Zealand. Part 2

Trevor H. Worthy,[1] Richard N. Holdaway,[2] Brent V. Alloway,[3] Jenny Jones,[1] Jeanette Winn,[4] and Deborah Turner[5]

1 Palaeofaunal Surveys, 2a Willow Park Drive, Masterton, email twmoa@wise.net.nz.
2 Palaecol Research, PO Box 16569, Christchurch.
3 Institute of Geological and Nuclear Sciences, Wairakei Research Centre, Private Bag 2000, Taupo.
4 Tui, RD 2, Wakefield, Nelson.
5 'Glenore', RD 4, Napier.

Abstract: The results of 13 m^2 of new excavations in the rockshelter called Te Waka #1, 900 m above sea level in inland Hawke's Bay, North Island, New Zealand, are presented. The site is shown to have an unparalleled continuous faunal record in sediments about 3 m deep that spans the period from the Kawakawa eruption 22 600 ^{14}C yrs BP to the present. Good temporal control is afforded by clear stratigraphy, three obvious tephras (Taupo Ignimbrite, one unidentified, Kawakawa Tephra (Oruanui Ignimbrite)), seven AMS radiocarbon ages, and one uranium-series age. Three frog species, a tuatara, five lizards, 42 birds, and three bats are represented in the 2490 identified bones from the combined faunas from W. H. Hartree's late 1950s and our 1999–2000 excavations. The fauna is interpreted as being mainly derived from the prey remains of *Falco novaeseelandiae*; it includes the first fossil records of *Garrodia nereis* and *Charadrius bicinctus* from the North Island. The presence in the fossil avifauna of species that live only in shrubland or forest indicates that such vegetation was present on Te Waka between 22 600 ^{14}C yrs BP and the Late Glacial Maximum (LGM, 18 000 ^{14}C yrs BP). *Pterodroma cookii* ceased to breed on Te Waka over the LGM. The absence of this species (which nests solely under forest), the lack of forest passerines, and the presence of species characteristic of open vegetation indicate a substantial loss of vegetation around the site at that time. The sedimentary and faunal record indicate that the area was reafforested about 14 000 ^{14}C yrs BP.

Keywords: Fossil avifauna, palaeoenvironment, climate change, Quaternary, Te Waka, Hawke's Bay, New Zealand.

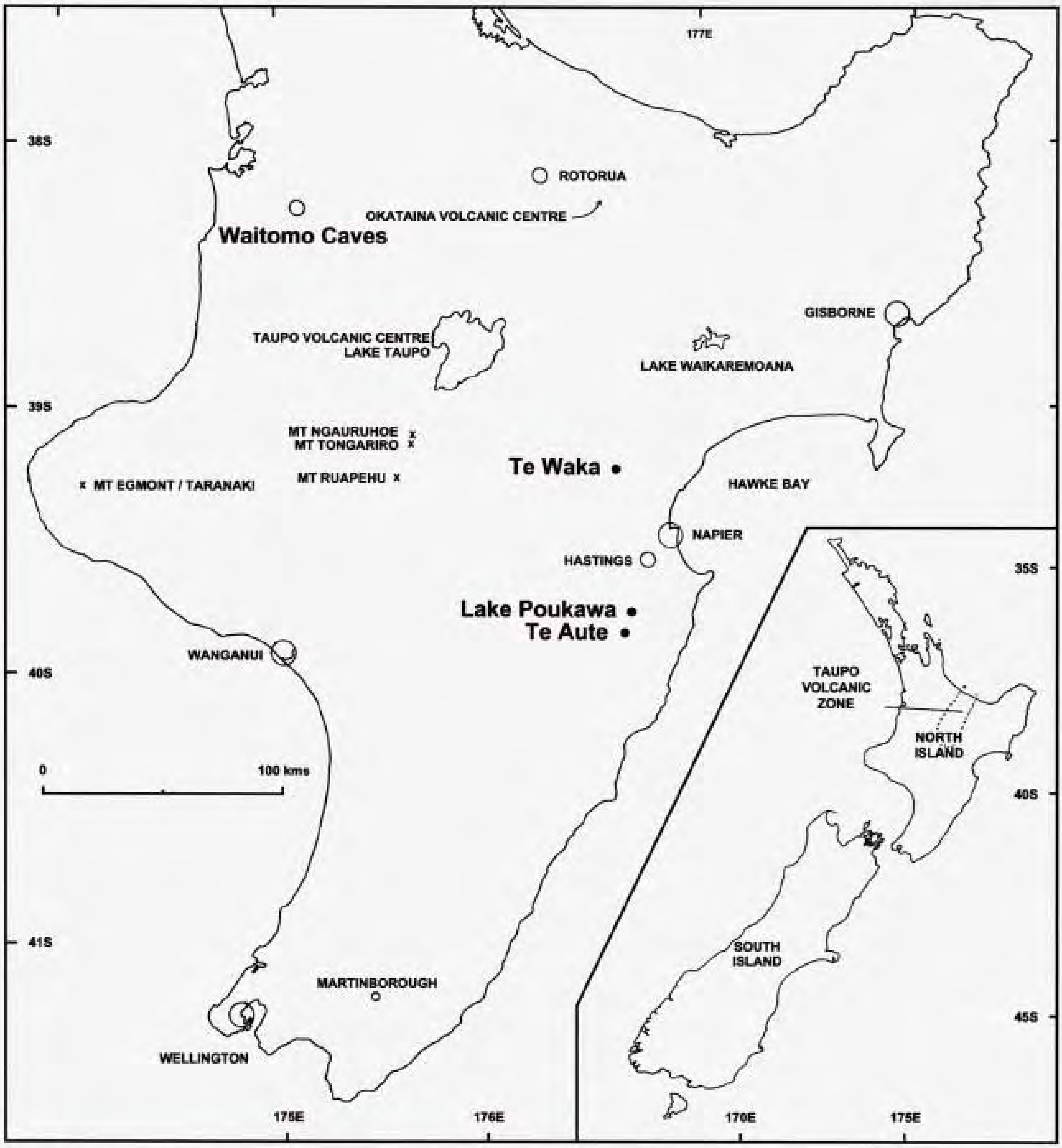

Fig 1. Map showing location of Te Waka #1 and various geographic features mentioned in the text.

Introduction

Mr W. H. (Bill) Hartree, jnr, farmed in the Puketitiri Valley in inland Hawke's Bay and was an enthusiastic excavator of rockshelter sites in the area. His collections during the period 1957 to 1961 are preserved in the Museum of New Zealand Te Papa Tongarewa, Canterbury Museum, and the Hawke's Bay Cultural Trust Museum in Napier. They formed the core of a regional analysis that primarily dealt with the Holocene fauna (Worthy & Holdaway 2000), the first in a planned series of papers on faunas of the inland Hawke's Bay region. Because of the species compositions in the deeper layers, the fauna in the site Te Waka #1 (Fossil Record Number [Geological Society of New Zealand] V20/f437) (Figs 1, 2) was identified by Worthy & Holdaway (2000) as having been accumulated from some time in the Pleistocene to the present.

Hartree located the site some time in 1957 and excavated it during several visits as follows: 28/6/58, 9/8/58, 2/4/59, 25/5/59, 11/7/59, 18/7/59 with R. J. Scarlett and others (W. H. Hartree's ms diary). The fauna from these excavations was summarised by Worthy & Holdaway (2000). Hartree's excavation notes, associated with the preserved specimens, indicate he excavated to a depth of 4 m (13 feet) in a trench on one side of the shelter. He encountered two tephra layers, which he identified with the bird bones as the Taupo and the Waimihia tephras.

The fossil sites in inland Hawke's Bay, especially in the Puketitiri – Te Pohue area (Fig 1), often include layers of tephra derived from eruptions from centres in the Taupo Volcanic Zone, some 70–80 km to the west. The main tephras encountered in fossil sites are the Taupo Ignimbrite (1850 ±10 yrs BP) and the Waimihia Tephra (Unit S of Wilson 1993, 3200 ^{14}C yrs BP) (Froggatt & Lowe 1990; Holdaway & Beavan 1999). Each forms distinct and, at times, thick layers, which provide good stratigraphical control for sites of Holocene age.

The fact that the species composition and the relative proportions of species within regional faunas varied considerably over time has been well documented by recent work in the South Island (Worthy 1994, 1998a, 1998b, 1999; Worthy & Holdaway 1993, 1994a, 1996a; Worthy & Mildenhall 1989). That such faunal changes over time also occurred in the North Island has been documented for the Hawke's Bay lowlands (Worthy 2000a) and Waitomo (Worthy & Swabey in press). The upland, inland site of Te Waka #1, as it has the recorded presence of tephras and deep stratigraphy, therefore afforded an excellent opportunity to extend this record further back in time in the North Island. Furthermore, the high frequency of small taxa found in the deposit, which is a result of the fauna having been accumulated primarily by a predator rather than there being mostly larger taxa as is normal in a cave pitfall or swamp, was believed to offer a unique insight into palaeofaunal composition of the region. Therefore, the site was re-excavated with the aim of obtaining adequate samples to describe the faunas from the various time periods represented and so map possible changes in the local fauna through time.

Methods

Excavation procedure

A metre grid was established over the site (Fig 3) with an origin at 4 cm below a bolt in the roof (860 mm above the floor at that point), on the northern side of the trench at the junction between squares B2 and B3. Bolts were drilled into the roof on the metre grid and weighted lines suspended from them to define the grid at floor level and below. A horizontal datum at –620 mm was established along the boundary of squares in rows B and C from an iron standard at the entrance side of square B1 to a bolt in the cave roof at the junction of squares C6 and C7 (Fig 4).

Fig 2. View of entrance in May 1959 showing Hartree excavating his 'entrance trench', photograph by J. C. Yaldwyn.

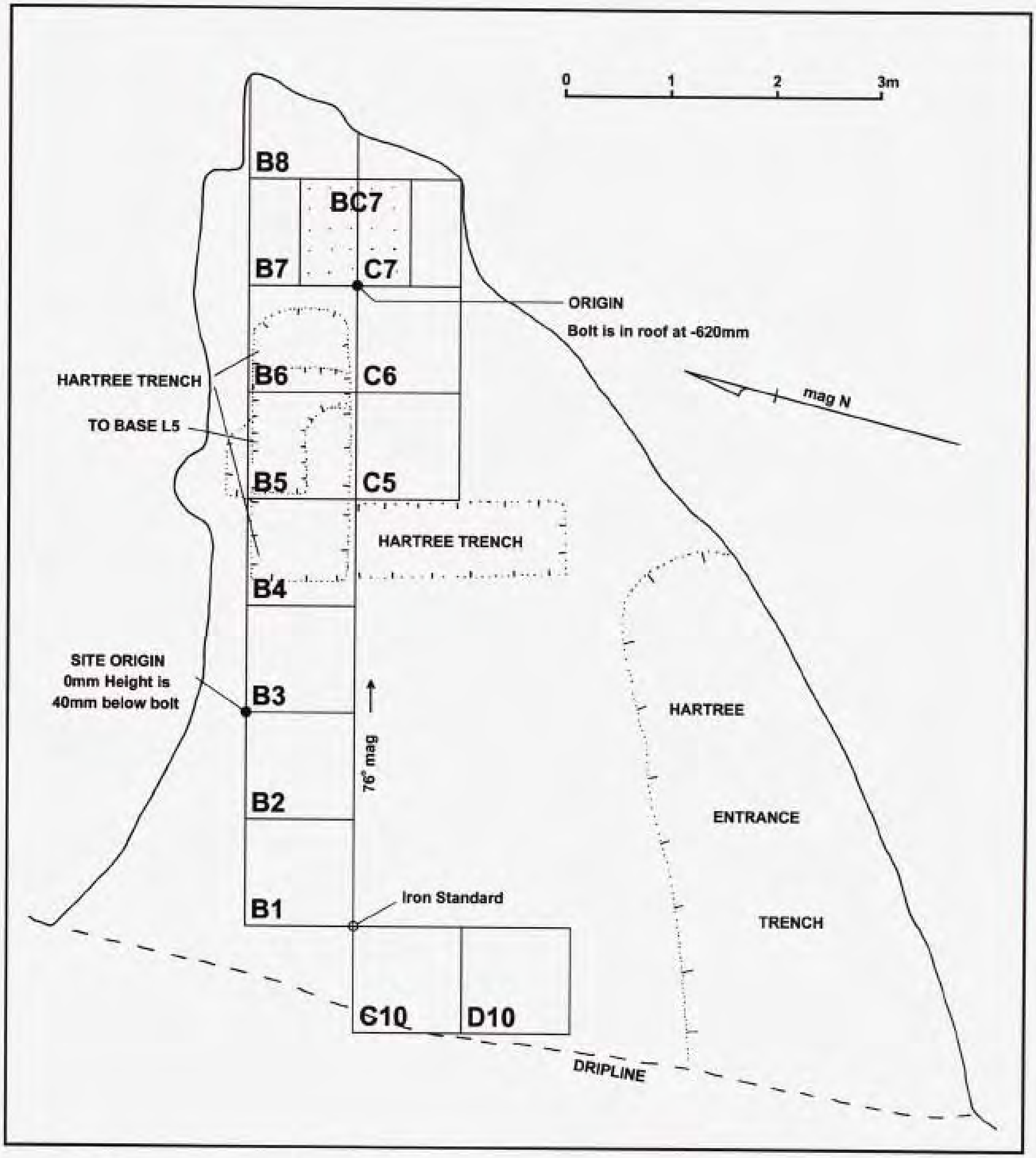

Fig 3. Plan of excavations in Te Waka #1. The 1999–2000 excavated squares are labelled B1–B8, C5–C7, C10, and D10. In part of squares B7–C7, the excavation was continued as square BC7 to the cave base. Three trenches made by Hartree were identified, of which 'Hartree Entrance Trench' was his main excavation. That which was encompassed by squares B4–B6 only penetrated the Taupo Ignimbrite in the smaller area labelled 'to base L5'. The original depth of the linking cross-wise trench is unknown, but it is unlikely to have penetrated the Taupo Ignimbrite. The 'Site Origin' for the excavation was taken as 40 mm below the bolt in the roof at B3, but a secondary origin in the roof at B7/C7 made a more practical point from which to run a string line to the iron standard in the southwest corner of B1.

The site was excavated in 1 m x 1 m squares by stratigraphic layer. Deeper layers were excavated in thinner units (spits). Larger bones were located with respect to the northwest corner of the square (eastings and southings) and their depths measured below the height datum. Depths were measured with a steel tape from a string line held level (as indicated by a spirit-bubble) between the square origin and a point above the bone. Plans of surface features at the interface between layers were drawn and profiles mapped for representative sections of the site. An extensive photographic record was kept of the excavations.

At all depths, but most especially in Layer 7, limestone slabs, some up to 2 m x 1 m x 0.5 m thick, were encountered. These were derived from slabs that had periodically spalled from the roof, following weathering that advanced preferentially along silty layers in the limestone. In squares C6 and C7, a buried layer of flowstone up to 40 cm thick and stalagmites up to 60 cm high (speleothems) were present. Rocks and flowstone were reduced to manageable units using sledgehammers and removed from the site. Otherwise, excavation was by trowel. All sediment was carried in buckets to the stream about 20 m away and wet-sieved through 6 and 2 mm meshes. Bones were hand-picked from the sieves. They were easily seen because the sediment was silty and generally washed cleanly though the mesh, leaving clean stones and bones behind. The exception was the sediments from Layers 2 and 5, which contained more clay. Washing the clay completely through fine mesh was very time-consuming, so in about half the squares the slurry retained on the fine mesh was collected and processed under laboratory conditions. After washing the clay out with a jet of water, the concentrate was dried and hand-picked for bones a few cubic centimetres at a time.

In all, 14 squares (B1–B8, C5–C8, C10, D10) were excavated to a depth of 2 m below the cave floor. A 1 m x 1 m excavation in square BC7 penetrated a further 1.5 m to reach the bedrock. In D10, a test pit was made from 2 to 2.5 m below ground level, where the Kawakawa Tephra (c. 26, 000 CAL yrs BP) was encountered and the excavation stopped.

Excavations were during the periods 10–16 December 1999, 2–9 April 2000, 9–18 October 2000, and 11–20 December 2000. Excavation design and control were by Worthy and Holdaway. All specimens were identified and catalogued into the fossil bird collection of the Museum of New Zealand Te Papa Tongarewa by Worthy.

Fig 4. Photograph of site in April 2000 viewed looking into cave along excavation trench squares B1–B8 with N. Field for scale.

In addition to the collection of fossil bones, samples were collected for micro-mollusc analysis and sent to F. Brook (Department of Conservation, Northland Conservancy) for separate analysis. A core was taken through Layers 4 and 5 for pollen analysis in square B7, but only badly corroded spores were present, with the tree fern types *Cyathea smithii* type and *Cyathea dealbata* type most strongly represented. Because of the strong corrosion only robust types can be expected, so a full analysis was not warranted (M. McGlone, Landcare Research, pers comm 11 Oct. 2001).

Radiocarbon dating

Bones were radiocarbon dated by the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand. The surfaces of all samples were ground with a Dremmel to remove surface coatings and dirt. The remaining sample was then crushed and sieved to <450 µm, then demineralised in 0.5 M HCl while stirred at room temperature for 1 h to extract the collagen. The collagen was then gelatinised in 0.01 M HCl under N_2 at 90° C for a minimum of 16 h. The gelatin fraction was made into a graphite target and dated using accelerator mass spectrometry (AMS). Ages are reported as conventional radiocarbon ages (CRA), based on the Libby T½ of 5568 yrs, uncorrected for secular variation, in years before present (^{14}C yrs BP), where present is AD 1950. Calibrated dates in calendar years before present (CAL BP) were determined for the eggshell and petrel specimens using Winscal, which is based on 1998 atmospheric data and radiocarbon ages from Stuiver *et al.* (1998). The terrestrial calibration was done using CalPal, the Cologne Radiocarbon Calibration & Palaeoclimate package.

Uranium-series dating

A speleothem (flowstone) sample was submitted to the Institute of Geological and Nuclear Sciences at Lower Hutt for uranium-series dating using alpha spectrometry. Counts of the uranium series isotopes ^{234}U, ^{238}U, ^{232}Th, and ^{230}Th were made. From the ratios $^{234}U/^{238}U$ and $^{230}Th/^{234}U$, age was determined by assuming half-lives of ^{234}U at 245 000 years and ^{230}Th at 75 380 years.

Flowstone is difficult to date using uranium-series dating because authigenic ^{230}Th derived from surrounding sediments is often deposited with the secondary calcite. The commonly used test for this detrital contamination is to examine the $^{230}Th/^{232}Th$ ratio (Schwarcz 1980). If the activity ratio is greater than 20, it is assumed that the ^{230}Th in the sample is derived solely from in situ radiogenic decay and the uranium-series age is accurate. $^{230}Th/^{232}Th$ values between 5 and 20 should be treated with some caution as they may indicate the presence of authigenic ^{230}Th, but it may be assumed that the uranium-series age is close to the true age, although possibly older. $^{230}Th/^{232}Th$ ratios of less than 5 indicate samples with a high level of authigenic (detrital) ^{230}Th and that the uranium-series ages are likely to be inaccurate and the true ages significantly younger.

Tephra identification

Tephra samples were collected by THW and BVA for correlation and dating purposes. Tephra identification (especially Layer 11) required confirmation by ferromagnesian mineralogy and glass chemistry. Tephra samples were wet-sieved into >250, 250–125, 125–63, and <63 µm size fractions. For electron microprobe analysis, 50 mg of glass from the 250–125 µm fraction was separated using a Frantz Isodynamic Separator. Ferromagnesian minerals were examined using a polarising microscope. The major element compositions of glass shards were determined by using a JEOL JXA-733 electron microprobe housed at Victoria University of Wellington and a Cameca SX-50 wavelength dispersive microprobe housed at the University of Toronto (Table 1). The major element compositions of an internal glass standard (UA-5831) were routinely analysed to check and correct for machine drift.

Abbreviations and Terminology

Institutions: AU, Geology Department, University of Auckland, Auckland; CM, Canterbury Museum, Christchurch; WO, Waitomo Caves Museum, Waitomo Caves.

For bones in the following list, elements may be singular or plural: ad, adult; ant, anterior; cerv vert, cervical vertebrae; cmc, carpometacarpi; cor, coracoids; dent, side of mandible; fem, femora; fib, fibula; fur, furcula; frag/s, fragment/s; hum, humeri; innom, innominate (ilium and acetabular region of pelvis); juv, juvenile; mand, mandible; pal, palatines; pel, pelves; phal, phalanges; pmx, premaxilla; proc, process; pt, part; quad, quadrate; q-o-j, quadrateojugal; rad, radii; rami, articular end of mandible; scap, scapula; stern, sternum; thor vert, thoracic vertebrae; tmt, tarsometatarsi; tt, tibiotarsi. L left, R right; where p, s, or d precedes L or R, it refers to a proximal, shaft, or distal part respectively.

MNI is minimum number of individuals determined from the most frequently occurring element (maximum of left or right side only if relevant) in the sample.

Avian taxa reported here follow the taxonomy advocated by Holdaway *et al.* (2001) and Worthy *et al.* (in press) and thus differ from that of Turbott (1990), mainly by the recognition of some North Island taxa as full species, as they were originally described. *Euryanas finschi* is hereafter referred to *Chenonetta finschi* following Worthy & Olson (2002).

The Holocene is defined as beginning at 10 000 ^{14}C yrs BP, the time since the end of the most recent cold stage. The Otira Glaciation, the most recent New Zealand glaciation, lasted from about 70 000 to 15 000 ^{14}C yrs BP. It is broadly equivalent to the Wisconsinan–Weichselian or Marine Oxygen Isotope stages 4-2. The Last Glacial Maximum (LGM) is taken as the period from c. 25 000 to 15 000 ^{14}C yrs BP, and the Late Glacial (Termination 1) is the period of rapid climatic and vegetational change from 15 000 to 10 000 ^{14}C yrs BP (eg, Newnham *et al.* 1999). These divisions better reflect the major episodes of vegetation history than does use of the term Aranuian (Suggate 1978), which covers all the time from 14 000 years to the present.

Fossil Site Parameters

Regional setting

Te Waka #1 (39° 14' 43"S, 176° 37' 52"E, NZMS 260 V20/234115) is a small cave at 900 m a.s.l. (Fig 1). The relationship of Te Waka #1 to other caves in the Puketitiri – Te Pohue area is given as Figure 2 in Worthy & Holdaway (2000). The cave is formed in the Te Waka Limestone of Mangapanian, mid–late Pliocene ages, that caps the Te Waka Range. The crest of the range peaks at 1021 m to the northeast and is remarkably flat, being formed by the surface of the Te Waka Limestone. The western side of the range has steep slopes, with cliffs in the limestone facies, whereas the gentle eastern slopes reflect the dip of the strata to the southeast. The Pacific Ocean, in Hawke Bay, is about 25 km distant and visible from Te Waka Range.

The cave entrance (Fig 2) opens to the west c. 8 m above the stream in a shallow valley c. 1 km southeast of, and 150 m below, the main ridge. The afternoon sun penetrates to the back of the cave. The entrance, as marked by the drip-line, is about 8 m wide, and the cave extends inward for a maximum of 8.5 m. Prior to excavations, the roof was about 3 m above ground level at the entrance and sloped down towards the rear of the cave, intersecting the floor at 7 m from the entrance.

Tephras in soil profiles

Formed vehicle tracks at many points across the hillsides near Te Waka #1 expose soil profiles and their contained tephras. The cuttings show an A horizon that contains a discontinuous tephra deposit (100–200 mm thick) comprising coarse (up to 150 mm) pieces of pumice derived from the Taupo Ignimbrite. About 200–300 mm lower in the profiles, the Waimihia Tephra (Unit S) is clearly visible as a layer of orange-brown lapilli (3–8 mm) about 100 mm thick. Being loose and unconsolidated, it is easily eroded to form a notch in the profile. In some profiles, a discontinuous, centimetre-thick, dark-grey coloured, water-flushed fine ash bed is about 200–300 mm below the Waimihia Tephra. The identification of this tephra is unknown, but its macroscopic features are most like tephras sourced from the Tongariro Volcanic Centre (Alloway pers observ).

Vegetation

The late Holocene vegetation on Te Waka is represented by a 300 ha remnant between 740–960 m a.s.l. It consists mainly of tall red beech (*Nothofagus fusca*) with scattered podocarps. Above about 820 m, Hall's totara (*Podocarpus halli*) is the main podocarp, but below this altitude, prior to them having been milled, rimu (*Dacrydium cupressinum*) and matai (*Prumnopitys taxifolia*) became increasingly common (Parsons 1997: 14-17). The main understorey trees are broadleaf (*Griselinia littoralis*), kamahi (*Weinmannia racemosa*), and kaikomako (*Pennantia corymbosa*). Common understorey shrubs include tree fuchsia (*Fuchsia excorticata*), putaputaweta (*Carpodetus serratus*), ongaonga (*Urtica ferox*), and horopito (*Pseudowintera colorata*). At the start of the twentieth century, the area above about 900 m was in grassland with matagouri (*Discaria toumatou*) bushes, daisies (*Celmisia* spp.), spaniards (*Aciphylla* spp.), and some associated kanuka (*Kunzea ericoides*) forest (Parsons 1997). While most of the vegetation destroyed by volcanic events such as the Taupo Eruption recovered within 100—200 years (Wilmshurst & McGlone 1996), the crests of high ridges (>800 m) exposed to the extremes of weather, such as Te Waka, probably either did not carry tall forest or had its reestablishment much delayed. The open vegetation recorded on Te Waka at the start of the twentieth century is probably typical of the open vegetation that occurred along the higher ridges throughout the Holocene, and areas of such vegetation were doubtless temporarily expanded by the destruction of forest during volcanic events.

Stratigraphy of the fossil deposits

The stratigraphy of the site is illustrated by the north wall of squares B6–B8 (Figs 5, 6). The stratigraphy is clearer towards the rear of the cave, as soil mixing processes operating in the vegetated entrance zone and the absence of

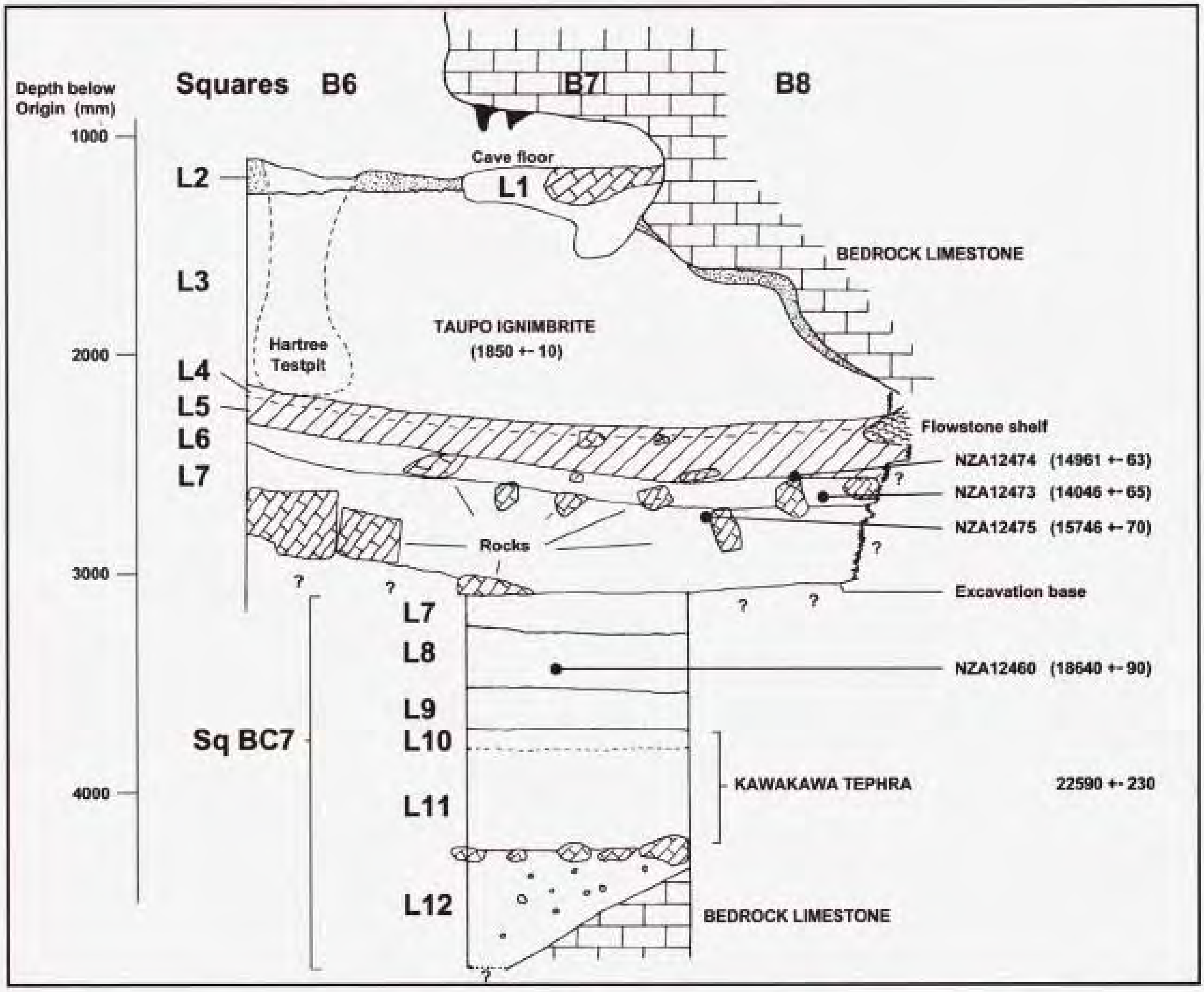

Fig 5. Stratigraphy of the deposits as shown by the section on the north wall of squares B6–B8 and square BC7. L1–L12 are the layers described in the text. Radiocarbon dates, shown after their identifying NZA numbers, are Conventional Radiocarbon Ages (^{14}C yrs BP). The ages of the two tephras are also given as comparable Conventional Radiocarbon Ages in ^{14}C yrs BP.

Fig 6. Photograph of north wall of section, squares B6–B8 on 18 October 2000. The set square is 300 x 200 mm.

Taupo Ignimbrite (Layer 3) near the entrance have resulted in Layer 2, Layer 4/5, and Layer 6 merging and having no clear boundaries. The stratigraphy is therefore described mainly from the B6–B8 section (Figs 5, 6), but with reference to the southern section in B1—B4 and C5–C7 (Fig 7). Hereafter, the alphanumerics B1, C5, etc can be taken as referring to the excavated squares.

Layer 1 was a friable, uncompacted, highly organic soil containing numerous goat (*Capra hircus*), rabbit (*Oryctolagus cuniculus*), and brush-tailed possum (*Trichosurus vulpecula*) bones. The sediment was derived mainly from decomposed goat droppings. It was thickest towards the back of the cave and had some admixture of Taupo Ignimbrite as a result of rabbit burrowing. Rabbit holes that had been excavated in only the upper parts of the Taupo Ignimbrite near the rear of the cave were infilled with this mixed material. The numerous mammal bones show that this layer was deposited after the area came under European influences in the late nineteenth century. Towards the centre and rear of the cave, fill derived from the Hartree excavations covered Layer 1 to a depth of up to 300 mm.

Layer 2 is a friable red-brown earth up to 150 mm deep that was compacted to a light red-brown loamy clay where humans and animals had access. It had a flat contact with the Taupo Ignimbrite, but its upper surface was uneven as a result of differential erosion by goat trampling or rabbit burrowing, and in places such activities had entirely removed it. At the rear of the cave, Layer 2 extended down as a wedge between the roof and the Taupo Ignimbrite, which had shrunk away from the roof/wall. The sediment contains small (10–20 mm) calcite clasts,

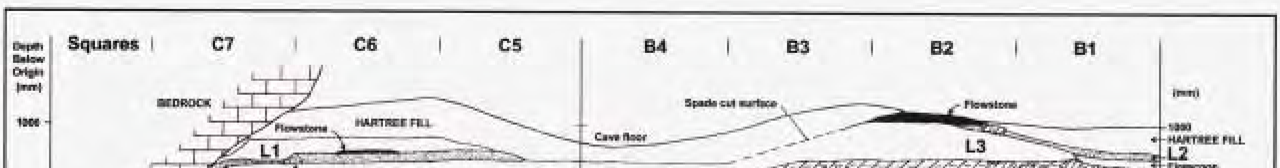

Fig 7. Stratigraphy of south wall compiled from squares B1–B4, C5–C7.

rare bones, and moa eggshell. Layer 2 is assumed to be a mixture of detritus from algae and bryophytes growing on the cave roof and the insoluble products of the weathering of the limestone itself. At scattered points over the cave floor, for example in C6 and B2, the boundary between Layer 2 and Layer 1 was separated by a thin sheet of flowstone, deposited below actively dripping stalactites.

Layer 3 is an unmistakable homogeneous layer of Taupo Ignimbrite. It forms a layer that reaches a maximum thickness of 1 m towards the back of the cave, where it filled a pre-existing hollow in the cave floor. In B2–B3, Layer 3 was up to 300 mm thick at the south wall, where it was capped with flowstone. The ignimbrite is whiter towards the top of the section and became greyer towards the base, where it had a greater moisture content. In the basal 100 mm of the ignimbrite, there are clasts of pumice up to 50 mm across, as well as carbonised twigs, leaves, and rare small branches. Occasionally, broken stalactites were found buried within the ignimbrite, for example one was lying horizontally in C6, 150 mm below the top of the ignimbrite. These must have fallen from the roof during the eruption. The Taupo Ignimbrite filled in the pre-existing cave hollows and so buried rocks lying on the previous silt floors in the cave rear. It also buried stalagmites up to 500 mm high in C5.

Layer 4 was defined arbitrarily as the first 30 mm of sediment below the Taupo Ignimbrite. It was a red-brown clay earth containing limestone blocks that were usually 50–150 mm in diameter and 20–50 mm thick, but occasionally up to 500 mm in diameter. The surface of Layer 4 represented the cave floor 1850 ^{14}C yrs BP, prior to the Taupo eruption. On that surface, scattered limestone rocks lay on a flat silt floor in B6–B8 and C6–C7. The cave floor over the area in C5 and B4–B3 rose 600–700 mm up a slope towards the entrance.

Layer 5 was defined as the remainder of the red-brown clay-loams below the Taupo Ignimbrite. In B7–B8, the combined Layers 4 and 5 was 250 mm thick. In C5, stalagmites up to 250 mm diameter and 500 mm high had been deposited within, and protruded above, combined Layers 4 and 5, beneath large stalactites. These stalagmites were formed at the same time as the red-brown clay-loams of Layer 5 were deposited. On the limestone wall, speleothem deposition was contemporaneous with the build-up of silt on the floor, which resulted in an upwardly widening wedge of flowstone. The sediment of Layer 5 was thinnest on the former slopes in the mid-reaches of the cave. For example, in C6 it was only 160 mm thick. Towards the entrance, over B1–B3, the combined Layers 4 and 5 were up to 400 mm thick, but these layers graded into Layer 6 without clear boundaries so that the combined Layers 4–6 were together about 700 mm thick. At the back of the cave, higher moisture levels facilitated weathering, which resulted in the sediments of Layers 4 and 5 being wetter and containing a higher clay fraction. Towards the entrance, the better-drained sediments were more friable, though still a red-brown clay. In areas near the cave wall in B1–B3, the sediment was greyer and soil voids contained white 'fungus'-like growths, reflecting alternate wetting and drying, and the deposition of calcite by percolating water from the wall. Throughout Layer 5 were small limestone clasts. Fossil bones and moa eggshell fragments were rare towards the cave entrance; the greatest concentrations were in the former hollow at the rear of the cave. Some 600 g of moa eggshell was recovered from B8 alone.

A tephra in Layer 5 was not visible during excavation or in the sections, but was identified during wet-sieving of sediment from 50 to 100 mm below the Taupo Ignimbrite (Layer 3). It appeared as reddish-brown lapilli up to 10 mm in diameter. The lapilli are consistent in colour, size, and stratigraphic position with the Waimihia Tephra (Unit S) in other sites in the Puketitiri – Te Waka area, and are assumed to represent it in this site.

In B6–B8, Layer 6 was marked by an abrupt change from the red-brown clay-rich sediment of Layer 5 to a very friable, grey, rubbly layer with c. 50% by volume of small (mainly 10–40 mm diameter) limestone clasts with rounded edges. The layer was 80–120 mm thick and rich in land snails and bones. The layer is interpreted as being the result of a hiatus in deposition of fine sediments, during which drips from the roof concentrated and rounded the small limestone clasts and land snails were concentrated on the cave floor. As mentioned above, Layer 6 was not clearly differentiated from Layer 5 near the entrance.

Layer 7 was a grey silty sand that was soft to the touch, as it lacked the small rough limestone clasts common in Layers 5 and 6. It lacked any clay component and washed through sieves easily. It also was homogeneous and lacked laminations that might have reflected variable water flows during deposition. However, this sand had been deposited around large boulders derived from a roof collapse. In B6—B8 and C6–C7, Layer 7 was 500–600 mm deep. We designated a thin concentration of reddish lapilli (2–5 mm diameter) as the lower boundary of Layer 7. Small amounts of similar lapilli were found floating on sieves from the sediment in B7 at all levels below 200 mm under Layer 5, but an obvious concentration, visible during excavation as smudged red-orange specks in a trowelled surface, was present 400–550 mm below the Taupo Ignimbrite. We terminated our excavation at this level in B1–B8 and C5–C7. The sandy sediment was interpreted as having been washed into the site by periodic sheet-flows of water, presumably during periods of heavy rain. The bones were all lying horizontally and, while none was articulated, occasional groups of bones obviously came from part of a single individual, implying a low energy depositional environment.

Layers below Layer 8 were examined only in BC7 and D10.

Layer 8 was marked by an increase in proportion of grit from small limestone clasts and an absence of the red lapilli. Layer 7 graded into it. In BC7 and in the south wall of C6, the upper boundary of Layer 8 was 600–700 mm below Layer 5. As seen in BC7 (Fig 3), Layer 8 was 250 mm thick. The base of the layer seemed to be the lower limit of petrel bones. No land snails were found in Layer 8: they were obvious in the layers above as they floated from the sediment during sieving.

Layer 9 was a 180 mm layer of grey, gritty sediment, lacking any pumice. A disarticulated parakeet skeleton from this layer provided perhaps the oldest bones found in our excavations.

Layer 10 was coarse, grey, gritty pumice sediment, with white vesicular clasts up to 20 mm in diameter. It commenced 1.1 m below Layer 5 and was 100 mm thick.

Layer 11 was a layer of compacted grey-white pumice sand 500 mm thick, whose laminar structure indicates that it was a secondary deposit. The interface between Layer 11 and Layer 10 was flat. Layers 10 and 11 are the secondarily deposited components of the Kawakawa Tephra (see section below). Layer 11 overlaid a cave floor formed on Layer 12 sediments and enclosed the prominent limestone rocks of that layer.

The top of the Kawakawa Tephra was found on the east side of D10 at a depth of –3740 mm below site datum, which was only 10 mm higher than in BC7 (upper surface at –3730 mm). However, 500 mm towards the west side of D10 (ie, towards the entrance) the upper surface of the tephra was 250 mm higher, which suggests that the tephra layer sloped down into the cave to a flat floor from D10 to the cave rear at that time.

Layer 12 was stream-laid sediment of coarse sand and grit with limestone clasts, and contained pebbles reworked from the Te Waka Limestone. In BC7, this layer was up to 500 mm deep, but its base was the sloping surface of bedrock of the cave floor. Layer 12 was barren.

Ages of the deposits

^{14}C AMS ages

Seven radiocarbon ages were obtained from material (6 bones, 1 eggshell) excavated from Te Waka #1 (Appendix 1). The ^{14}C ages were generally stratigraphically consistent both with each other and with the age of the tephras (Fig 5). The exception was NZA12474 (14 961 ± 65 ^{14}C yrs BP; 17 619–17 103 CAL BP), which came from the boundary between Layers 5 and 6. Because the age is determined from a bone of a species common in Layer 6, it is assumed that the bone came from Layer 6 and may have been brought higher in the sequence by the nesting activity of moa in the site. This is probable as Layer 6 is only about 100 mm thick and probably represents about 2000 years of deposition. The age from a piece of moa eggshell from within Layer 6 (14 046 ± 65 ^{14}C yrs BP, 17 092–16 601 CAL BP; NZA 12473) suggests that the maximum age for the base of Layer 5 is not older than c. 14 000 ^{14}C yrs BP.

Three dates were obtained on bones of *Chenonetta (=Euryanas) finschi* collected by Hartree. The stratigraphic data recorded with the Hartree specimens cannot be directly related to that shown in Figures 5 or 7 as there is considerable variation of layer depth both into and across the cave and we do not know where Hartree's depth origin was in relation to ours. The bones were chosen at random from the collection, using such data as was available, to increase the likelihood that all came from strata below the equivalent of our Layer 7 and so to date the deeper parts of Hartree's excavation. The purpose was to determine whether his excavation had the same temporal range as ours. The dates ranged from 17 499 to 20 450 ^{14}C yrs BP (20 779 ± 441 to 23 914 ± 284 CAL BP), which supported the conclusion that the layers he sampled were contemporary with our Layers 8 to 10.

The collagen yields, N and C contents, and C:N ratio for the bones (Appendix 1) are well within the acceptable range for AMS ages of bones without enhanced treatment protocols (Holdaway & Beavan 1999). The ancillary isotopic data also support the reliability of the AMS ages. The $\delta^{13}C$ values for the three samples of bone from mottled petrels (*Pterodroma inexpectata*) are, at -15.1 to -15.7, similar to that of -16.1 for a bone of the same species from the late Holocene of North Canterbury (NZA6967; CRA 1115 ± 70 ^{14}C years BP) (RNH, unpubl. data). These values are in the usual range for marine birds (Schoeninger & DeNiro 1984). For the Finsch's duck, the values are as would be expected for a vegetarian bird foraging on C3 plants in an open environment. For example, they are comparable to the $\delta^{13}C$ of 22.1 measured on a bone (from Bohemia Cave) of the same species that foraged above the tree line on Mt Owen (NZA12766, 1262 ± 45 ^{14}C years BP). Finsch's duck was neither an aquatic nor a riparian grazer, unlike most *Anas* species. However, individual Finsch's ducks from sites within former areas of forest, such as that from Cave F1c near Waitomo Caves (NZA12768, 2024 ± 50 ^{14}C years BP; $\delta^{13}C$ = -27.2; RNH unpubl. data), exhibit a depleted level of $\delta^{13}C$ that is consistent with the bird having fed on vegetation growing beneath a dense canopy (Lajtha & Marshall 1994).

Reported values of $\delta^{13}C$ for moa eggshell are mostly between –9.2 and –15.4 (Higham 1994; Holdaway & Beavan 1999), although a piece of shell from dunes in Northland yielded a markedly enriched value of –4.2, which was attributed to one of several possible sources of error (Higham 1994). The eggshell $\delta^{13}C$ from Te Waka, with a value of –8.4, was at the enriched end of the range, but markedly less so than the obvious outlier in the present data.

The level of enrichment in ^{15}N ($\delta^{15}N$) for the three bones of *P. inexpectata* was consistent with that for bone protein of carnivores at the top of the marine food chain (Schoeninger & DeNiro 1984). Mottled petrels eat mainly lantern fish, with some crustacea and squid (Heather & Robertson 1996). The values for the three bones of different geological age were also extremely similar. The $\delta^{15}N$ for the three Finsch's duck bones is typical for bones from areas with relatively high rainfall, such as near Waitomo Caves (eg, NZA12768, 2024 ± 50 ^{14}C years BP; $\delta^{15}N$ = 3.9; RNH unpubl. data).

There is nothing in these isotopic data to indicate that the obtained radiocarbon ages would be affected in any way, and there is no source of ancient carbon in the system to be incorporated in the food chain as was shown to occur in, for example, Lake Taupo (Beavan-Athfield *et al.* 2001).

Speleothem age

A single uranium-series age (GNS R25433) was obtained from a speleothem in Te Waka #1; the sample was taken from the base of a stalagmite in C5 on its southern profile. The stalagmite was deposited coevally with Layer 5, resulting in its base being surrounded by the sediments of that layer. It was then completely buried by the Taupo Ignimbrite. It yielded an age of 29 600 CAL yrs BP (+1400, -1500 yrs) (Table 1). However, the very low activity ($^{230}Th/^{232}Th$) ratio (1.92) for this sample indicates the measured age is older than the true age (see Methods, and Schwarcz 1980) and so this age is discounted.

Table 1. Uranium-series results for the analysis of a calcite speleothem (GNS R25433) from the base of Layer 5, Te Waka #1 (see text regarding $^{230}Th/^{232}Th$ ratio).

	Bq/kg	SD
^{238}U	0.692	0.015
^{235}U	0.03187	0.00068
^{234}U	0.750	0.016
$^{234}U/^{238}U$	1.083	0.026
^{232}Th	0.0934	0.0047
^{230}Th	0.1790	0.0065
$^{230}Th/^{232}Th$	1.92	0.11
$^{230}Th/^{234}U$	0.239	0.010
AGE	29.6 ka	+ 1.4 , - 1.5 ka

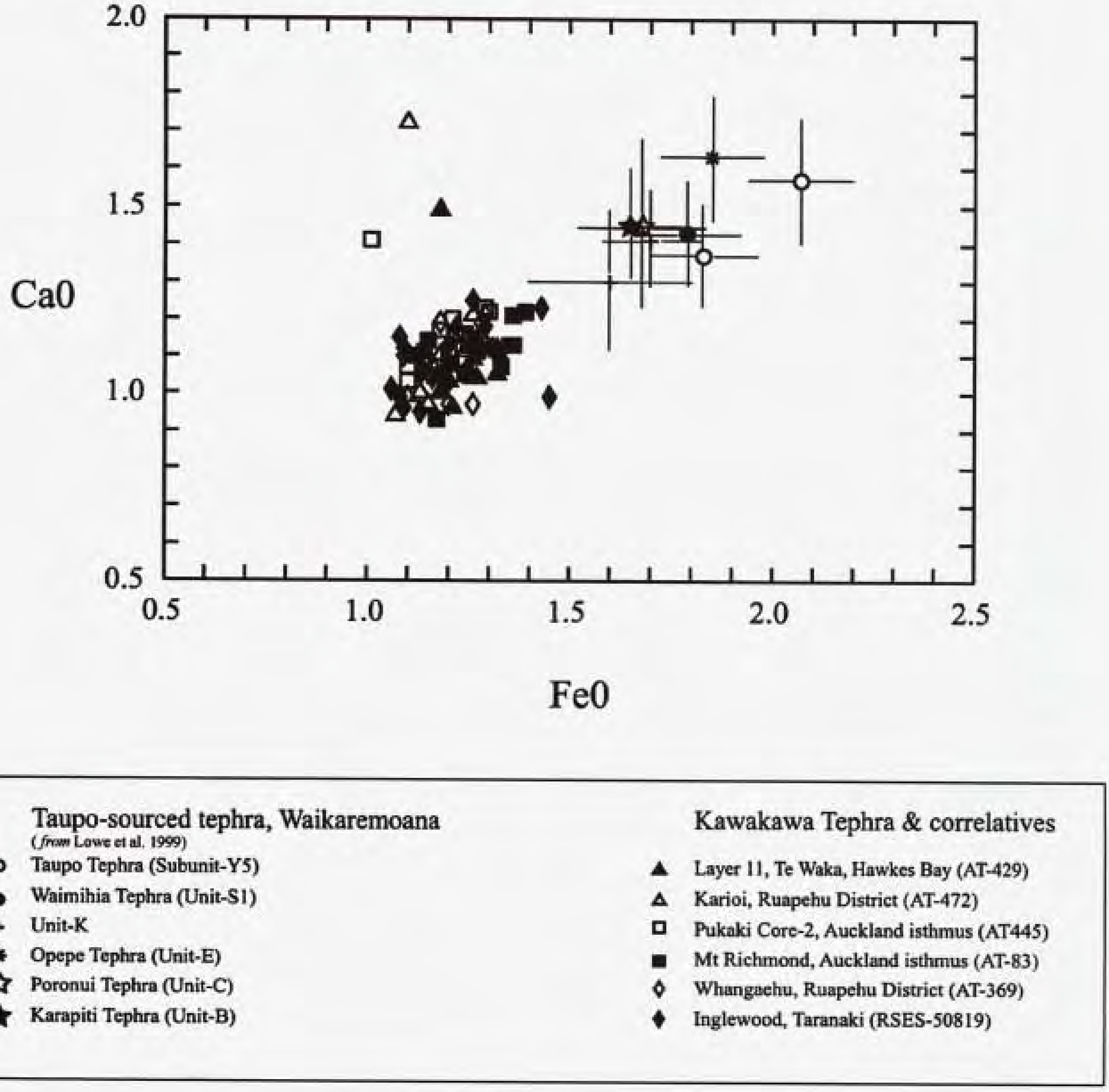

Fig 8. FeO versus CaO for glass shards (determined by EMP) of Kawakawa Tephra correlatives and younger distal tephras similarly derived from the Taupo Volcanic Centre.

Tephrochronology

Widespread distal tephras can provide key stratigraphic marker horizons for defining the temporal relationships of cover-bed sequences at sites where the stratigraphies and ages are not well known. Three macroscopic rhyolitic tephras were observed at the excavation site – though only the lowest tephra was geochemically analysed to verify its identity. The two uppermost tephras at an adjacent site have previously been identified as Taupo Ignimbrite and Waimihia Tephra (Unit S) (Holdaway & Beavan 1999). Both were erupted from the Taupo Volcanic Centre (Wilson 1993) and have been extensively recorded in near surface cover-bed successions throughout Hawke's Bay and adjacent regions. These tephras have conventional radiocarbon ages of 1850 ± 10 (n = 41) and 3230 ± 20 yrs BP (n = 17), respectively (Lowe *et al.* 1999).

The lowermost tephra, Layer 11, is here correlated with Kawakawa Tephra (Oruanui Ignimbrite) on the basis of stratigraphic position and associated radiocarbon chronology, mineralogy, and major element composition of glass shards. The most voluminous and widespread late Pleistocene silicic tephra, Kawakawa Tephra was erupted from the Taupo Volcanic Centre at approximately 26 500 calibrated years ago (Vucetich & Howorth 1976; Wilson *et al.* 1988; Froggatt & Lowe 1990; Pillans *et al.* 1993; Wilson 2001). This tephra has proven to be extremely useful in regional studies because it defines an isochronous horizon for correlation and age control of early LGM deposits, geomorphic surfaces, and associated soils. It is found extensively within North Island cover-bed successions (eg, Auckland, Sandiford *et al.* 2001; East Cape, Vucetich & Pullar 1969; Taranaki–Wanganui, Alloway *et al.* 1995, Pillans *et al.* 1993; Wairarapa, Palmer 1982), as well as South Island successions (eg, Canterbury, Kohn 1979, Nicol *et al.* 1994; West Coast, Campbell 1986, Mew *et al.* 1986, Almond 1996) and offshore marine environment (eg, Pillans & Wright 1992, Carter *et al.* 1995).

Mineralogically, Layer 11 is typically composed of vesicular and chunky glass shards (70–90%) with subordinate plagioclase and quartz (<10–15%). Layer 11 is also characterised by the presence of hornblende and hypersthene with subordinate augite and rare Fe-Ti oxides. The major element compositions of glass shards of Layer 11 were determined by electron microprobe (EMP) analysis (Table 2). Major element composition of glass shards from Layer 11 (AT-429) supports a Taupo Volcanic Centre origin and are indistinguishable from Kawakawa Tephra correlatives analysed from the Ruapehu District (AT-369 & AT-472), Taranaki (RSES-50819), and Auckland isthmus (AT-83 & AT-445). Despite Layer 11 being a secondarily reworked deposit, EMP analysis indicates that the glass constituents are homogeneous, as indicated by the generally low standard deviations (Table 2). Kawakawa Tephra and its correlatives can also be clearly distinguished from other distal tephras derived from the Taupo Volcanic Centre (Fig 8).

Summary of depositional history

The Te Waka #1 cave was undercut below harder limestone by the erosion of softer, more muddy limestone, initially along the intersection of two major joints. Subsequent roof collapse and stream erosion of the limestone slabs led to the formation of the cave before 22 590 ^{14}C yrs BP (26 500 CAL BP). Stream sediments (Layer 12) formed the lower layer in the cave 4.25 m below site datum (which was on the cave roof at the present entrance). The Kawakawa Tephra was erupted about 26 500 CAL BP (Froggatt & Lowe 1990), and the associated ignimbrite (Oruanui Ignimbrite) was deposited in the stream catchment and redeposited into the cave shortly after to form Layers 10 and 11 to a total thickness of 600 mm. The slope of the tephra surface down into the cave at the entrance suggests the cave had already been abandoned by the stream by that time and a debris pile had already formed at the entrance, on to which the tephra was deposited. From this time on no stream entered the cave.

Layers 8 and 9 were relatively gritty sands, which were probably deposited by sheet-flows of water flowing downslope from the entrance during rainstorms. The closely associated, though disarticulated, remains of a single parakeet skeleton indicate that flow energies were not great in Layer 9. A date of 18 640 ^{14}C yrs BP (NZA12460; 21 940–21 246 CAL BP) on a bone about 280 mm above the Kawakawa Tephra indicates a relatively slow period of deposition, or that perhaps dripping water was sufficient to erode fine sediment from the cave. From the layout of the cave, it is apparent that water flowed towards the back of the cave and then along the south-eastern wall towards the entrance (Fig 2). Deposition of Layer 8 ended at the same time as an unidentified eruption deposited fine red lapilli in the catchment. This tephra is stratigraphically consistent with its being the Okareka Tephra, erupted about 18 000–19 000 ^{14}C yrs BP from the Okataina Volcanic Centre (Froggatt & Lowe 1990; Sandiford *et al.* 2001). The tephra was washed into the cave, presumably from the area about the entrance or off the overlying hillside, to form the thin layer visible in our excavation. In Hartree's excavation in the south-eastern (downhill and downstream) part of the site, the layer was 100–150 mm thick, as is shown in J. C. Yaldwyn's photographs taken in 1959 (Fig 9), when it was mistaken for the Waimihia Tephra.

After that, until about 16 000 ^{14}C yrs BP, as shown by NZA12475 (18 550-17 982 CAL BP), fine sands (Layer 7) were deposited, accumulating to a depth of about 600 mm in about 2000 years. There was a major roof collapse in the cave at some point in this period; at least two rock layers, about 1 m thick in total, spalled from much of the cave roof. The sands of Layer 7 were worked around these blocks by intermittent, low-energy sheet-flows of water. The pile of rocks was particularly attractive to avian predators, which used the site as a roost or feeding station and left many bones to accumulate in the sands. Some moa nested in the cave at this time as well.

From about 18 000 to about 16 800 CAL BP, as shown by NZA12473, the deposition of fine sands ceased and dripping water from the roof created a lag deposit of small limestone clasts and concentrated bones, eggshell, and land snails in the 100 mm thickness of Layer 6.

About 14 046 ^{14}C yrs BP, as shown by NZA12473 (17 092-16 601 CAL BP), a further change in the hydrology of the catchment was marked by the onset of speleothem deposition and the contemporaneous deposition of red-brown clay-rich sediments. Deposition of similar clayey sediments on cave floors without water transport has been the norm in most lowland caves in humid sites in New Zealand throughout the Holocene (THW pers. observ). It is assumed that the result of higher temperatures and greater availability of water caused increased weathering of the cave walls and roof, providing a steady 'rain' of the non-soluble weathering products. The combination of higher temperatures and increased water availability, and the simultaneous establishment of dense shrubland or forest vegetation on the land above Te Waka #1 (as the onset of forest growth nearby at that time (McGlone 1988; Newnham *et al.* 1999) shows is likely), would have facilitated the biogenic supersaturation of groundwaters with the CO_2 necessary for speleothem growth.

Fig 9. Photograph of stratigraphy in Hartree's entrance trench taken in 1959 by John Yaldwyn. It is interpreted following the stratigraphy observed in Figures 5–7, as follows: the thin upper layer is Layer 2; a thick layer of Taupo Ignimbrite (Layer 3); the middle series of light, slightly darker, and light bands are Layers 4 and 5 and 6 in the drier form seen nearer the entrance. These are followed by a layer of grey sands (Layer 7). The next layer is a lens of reddish lapilli, which Hartree erroneously referred to the 'Waimihia Tephra' and which is possibly the Okareka Tephra. It is the thicker, downslope accumulation of the unidentified tephra we found in the base of Layer 7. Below that are more sands of Layers 7 and 8.

Table 2. Mean major element composition of glass shards from Layer 11, Te Waka and Kawakawa Tephra correlatives

		SiO_2	TiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	Cl	H_2O	n
AT-429*[1]	Layer 11, Te Waka	77.74	0.14	12.56	1.20	0.12	1.14	4.08	2.92	0.19	5.68	11
		(0.51)	(0.04)	(0.35)	(0.04)	(0.01)	(0.19)	(0.16)	(0.14)	(0.02)	(0.07)	
AT-472*[1]	Karioi,	77.99	0.12	12.49	1.25	0.12	1.10	3.80	2.92	0.19	7.15	13
	Ruapehu District	(0.31)	(0.04)	(0.22)	(0.05)	(0.01)	(0.13)	(0.12)	(0.10)	(0.02)	(0.58)	
	(S20/242918)											
AT-445*[1]	Pukaki Core-2	77.68	0.15	12.41	1.19	0.14	1.17	3.90	3.21	0.15	4.85	15
	Auckland	(0.38)	(0.04)	(0.30)	(0.08)	(0.01)	(0.10)	(0.20)	(0.23)	(0.02)	(1.25)	
	(R11/715674)											
AT-83*[1]	Mt Richmond,	78.08	0.12	12.29	1.26	0.11	1.11	3.77	3.13	0.14	7.95	11
	Auckland	(0.27)	(0.07)	(0.10)	(0.10)	(0.02)	(0.07)	(0.22)	(0.15)	(0.02)	(0.55)	
	(R11/742729)											
50819‡[2]	Inglewood, Taranaki	79.35	0.12	12.40	1.19	0.12	1.07	2.47	3.08	0.18	7.14	15
	(Q19/147267)	(0.30)	(0.03)	(0.12)	(0.11)	(0.01)	(0.09)	(0.37)	(0.10)	(0.02)	(0.98)	
Waipara	Omihi Stream,	77.55	0.15	12.65	1.20	0.15	1.08	3.87	3.12	0.23	6.10	19
Site-A‡[3]	North Canterbury	(0.43)	(0.05)	(0.26)	(0.13)	(0.03)	(0.09)	(0.19)	(0.17)	(0.03)	(1.04)	
	(N34/915943)											
50334-40‡[2]	Whangamata Road	79.01	0.13	12.15	1.15	0.12	1.05	3.31	3.07	—	5.65	74
	Type Section	(0.38)	(0.03)	(0.30)	(0.10)	(0.02)	(0.19)	(0.21)	(0.25)		(1.62)	
	(T17/619830)											

Note: ‡Analyses made using a JEOL JXA-733 electron microprobe housed at Victoria University of Wellington. A beam current of 80nA and a 20 µm beam diameter were used for all analyses. * Analyses made using a Cameca SX-50 wavelength dispersive microprobe operating at 15 keV accelerating voltage and housed at University of Toronto. Beam current of 15 nA and a 10-20 mm beam diameter were used for all analyses. All elements calculated on a water-free basis, with H_2O by difference from 100%. All Fe expressed as FeO. Mean and ± 1 SD (in parentheses) based on *n* analyses. [1]Analyst – B. V. Alloway, [2]Analyst – P.C. Froggatt, [3]Analyst – D. Manning.

Throughout the Holocene, autochthonous deposition was slow; only 250 mm was deposited in the period 14 000 to 1850 ^{14}C yrs BP, and this included some reworked Waimihia Tephra in its upper part. Then, at 1850 ^{14}C yrs BP (c. AD 200, 1750 CAL BP) the rear parts of the cave received a primary deposit of at least 1 m of Taupo Ignimbrite. This tephra arrived with sufficient violence to knock stalactites from the roof and carry branches into the cave, and it was hot enough to have carbonised all leaves and branches. The environment surrounding the cave must have been severely impacted. However, in a relatively short time, moa were back in the area and nesting in the cave. Only 100 mm of sediment was deposited on top of the Taupo Ignimbrite before European influences began in the 1870s.

Site taphonomy

Taphonomic processes are the processes by which the fossils in a site are accumulated and preserved. The identification of these processes is essential to an understanding of the composition of the fossil fauna and its relationships to the living faunas from which it was drawn. Several different taphonomic processes operated in Te Waka #1 sequentially and simultaneously.

The site was used by moa for shelter and nesting, which provided a primary source of fossils in the form of eggshell fragments and bones from the rare random death of individuals sheltering in the cave. Moa eggshell was abundant in all non-tephra post-Kawakawa levels and, judging by the presence of two classes of thickness, represented at least two species of moa. Some moa died in the site, including individuals of *Euryapteryx curtus* and *E. geranoides* in the Pleistocene levels, and *Anomalopteryx didiformis* and *Dinornis struthoides* in the Holocene levels. The nesting and other activities of these large birds resulted in much trampling and disturbance of the sediments and associated damage to bones on the surface at the time. Bones that lay on the surface for any length of time in the humid Holocene became weathered and were also often coated in calcite speleothems, as were, for example, those of an *Aptornis* that died in the early Holocene. The inward slope of the cave floor and the trampling of moa resulted in most bones accumulating against the wall, where overhangs gave them some protection.

The second, and most important, source of fossils was the activity of predatory birds. The abundance of bones with greenstick fractures and digestion features is evidence of dismemberment, if not actual killing, of prey, and ingestion of their bones (Andrews 1990). In New Zealand, the only predators were birds, with the laughing owl (*Sceloglaux albifacies*) responsible for most deposits (Worthy & Holdaway 1994b, 1996b; Worthy 1997, 2001). The New Zealand falcon (*Falco novaeseelandiae*) and Eyles's harrier (*Circus eylesi*) also accumulated several deposits (Worthy 1997; Worthy & Holdaway 2002).

The identity of the predator is indicated by a combination of the species composition of the fauna and the representation of, and damage to, the skeletal elements. Falcons primarily hunt diurnal prey. Smaller taxa such as quail and parakeet are their favoured prey size, though pigeons are also taken occasionally. Falcon prey remains usually consist of very digested bones, with few complete elements. Similarly, the faunas attributed to Eyles's harrier from Hukanui 7A (Worthy & Holdaway 2002) include mainly diurnal species, but the bones found in the deposits are mostly the distal wing and leg elements and part of the sternum, the parts of the body that were not ingested. A few very heavily digested bone fragments were also present. The large harrier took mainly larger species; pigeons (*Hemiphaga novaeseelandiae*) and kokako (*Callaeas wilsoni*) were very common in its diet. In contrast, the laughing owl took mainly nocturnal prey, usually weighing 100–200 g. Among the diurnal species that were taken, parakeets and similar-sized birds were common, but larger species, including pigeons, young kiwi, and weka, were taken occasionally. The bone remains in laughing owl accumulations often show some digestion features, but few elements are heavily digested and most elements are represented, some of which are complete. The actual damage observed depends on the prey species and the relative robustness of its bones (Worthy & Holdaway 1994b, 1996b; Holdaway & Worthy 1996).

Element survival in prey species

As the mottled petrel (*Pterodroma inexpectata*) was one of the main prey species at Te Waka #1, we compared the survival patterns of its elements there with those of petrels in Hermits Cave (West Coast, South Island), where the predators were laughing owls (Worthy & Holdaway 1994b), and with those observed at falcon feeding stations in the Auckland Islands (Table 3). The petrel remains at Te Waka #1 were dominated by pectoral girdle (coracoid, sternum,

Table 3. Element representation for *Pterodroma inexpectata* from the 1999–2000 excavations at Te Waka #1 compared to similar data from *Pachyptila turtur* from Hermits Cave (Worthy & Holdaway 1994b) and *Pachyptila* spp. from falcon roosts on Auckland Islands (Worthy & Hyde, unpubl. data). The elements listed from Te Waka #1 were derived from all squares and levels below Layer 5 and represent a minimum of 19 individuals, as determined from ulnae. The analysed sample of 305 bones is less than the total sample of 346 bones as shafts and other fragments were not counted. The column headed %E shows the proportion that N represents for the minimum number of individuals (MNI) represented by the sample (assuming that bilateral elements number potentially 2xMNI and that an individual has 18 presacral vertebrae and 15 phalanges in a foot, including the metatarsal). Where elements have (pt) appended, it means either whole or incomplete bones were included.

Element	N, Te Waka	% E MNI=19 Te Waka	N, Hermits	%E MNI=28 Hermits	N, Akd Is.	%E MNI=8 Akd Is.
Crania (pt)	2	10.5	7	25.0	0	0
Sterna (pt)	13	68.4	13	46.4	3	37.5
Pelvis synsacra (pt)	1	5.3	8	28.6	0	0
Mandible rami	5	13.2	2	3.6	0	0
Premaxillae	7	36.8	2	7.1	0	0
Furculae (pt)	9	47.4	11	39.3	2	25.0
Vertebrae (presacral)	17	5.0	230	45.6	11	7.6
Coracoids (pt)	28	73.7	450	89.3	6	37.5
Scapulae (pt)	18	47.4	28	50.0	4	25.0
Humeri	20	52.6	8	14.3	13	81.2
Humeri proximal	3	7.9	8	14.3	0	0
Humeri distal	3	7.9	5	8.9	0	0
Ulnae	19	50.0	35	62.5	14	87.5
Ulnae proximal	3	7.9	10	17.8	0	0
Ulnae distal	10	26.3	5	8.9	0	0
Radii	14	36.8	9	16.1	14	87.5
Radii proximal	9	23.7	44	78.6	0	0
Radii distal	12	31.6	42	75.0	1	6.2
Carpometacarpi (pt)	28	73.7	27	48.2	12	75.0
Manual phalanges 1.1, 2.1, 2.2	28	24.6	95	56.5	33	68.3
Femora	1	2.6	17	30.3	1	6.2
Femora proximal	4	10.5	7	12.5	3	18.7
Femora distal	1	2.6	10	17.8	2	12.5
Tibiotarsi	2	5.3	8	14.3	0	0
Tibiotarsi proximal	2	5.3	22	39.3	2	12.5
Tibiotarsi distal	6	15.8	12	21.4	2	12.5
Tarsometatarsi	10	26.3	23	41.1	3	18.7
Tarsometatarsi proximal	2	5.3	10	17.8	0	0
Tarsometatarsi distal	2	5.3	10	17.8	1	6.2
Pedal phalanges	26	4.6		NA	19	7.9
	305		1158		146	

Table 4. List of vertebrates known as fossils from Te Waka #1, derived from identification of 2093 bones excavated in 1999–2000 and those of Hartree's excavations listed in Worthy & Holdaway (2000).

Layer	2	2	4&5	4&5	6	6	7	7	8	8	9&10	9&10	Hartree
Species	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	NISP	MNI	X/y
Anomalopteryx didiformis			32	1									3/1
Euryapteryx curtus							9	1					4/1
Euryapteryx geranoides													1/1
Pachyornis mappini													1/1
Indet emeid sp.			3				2				1	1	
Dinornis struthoides			12	1									
Apteryx mantelli			6	1	2	1	10	2			1	1	12/1
Apteryx owenii							2	1					
Apteryx sp.							4	1					
Pterodroma inexpectata	4	2	18	3	98	8	346	19	4	2	7	1	266/27
Pterodroma cookii							1	1					256/16
Garrodia nereis							2	1					
Cnemiornis gracilis													31/1
Chenonetta finschi					7	2	8	1					54/3
Falco novaeseelandiae													
Coturnix novaezelandiae	10	1	1	1	2	1	9	1					5/2
Aptornis otidiformis			64	1									
Fulica prisca									2	1			
Gallirallus australis	9	1	6	1	2	1	1	1					10/2
Capellirallus karamu			2	1									
Gallinula hodgenorum													11/3
Charadrius bicinctus							2	1					
Coenocorypha barrierensis			2	1			11	1			2	1	1/1
Hemiphaga novaeseelandiae			14	3									14/1
Strigops habroptilus			9	1	4	1							5/1
Nestor meridionalis			9	1	2	1							6/2
Cyanoramphus spp.	28	3	84	6	17	3	32	2	16	1			36/8
Ninox novaeseelandiae	12	1											
Aegotheles novaezealandiae	1	1	40	3	3	1	4	1					20/5
Acanthisitta chloris	3	1	62	5	4	2	11	3					2/2
Xenicus spp.	1	1	33	4	7	2	9	2					9/4
Pachyplichas jagmi			6	2	4	1	6	2					1/1
Traversia lyalli													1/1
Anthus novaeseelandiae			3	1	2	1	14	2					6/3
Mohoua albicilla	5	2	46	3	1	1	1	1					4/1
Petroica longipes	2	1	141	9	5	2	12	2					57/5
Petroica toitoi	19	1	3	2									3/2
Notiomystis cincta			1	1									1/1
Anthornis melanura	30	2	6	2	1	1							
Prosthemadera novaeseelandiae	8	1											1/1
Callaeas wilsoni	3	1	10	3	2	1							32/2
Philesturnus rufusater	3	1	4	2									6/1
Turnagra tanagra	1	1											17/3
Heteralocha acutirostris			1	1									
Totals	139	21	618	60	163	30	496	46	22	4	11	4	
Chalinolobus tuberculatus			1	1									
Mystacina robusta			11	1	3	1	2	1					
Mystacina tuberculata			5	2									3/1
Rattus exulans	353		4										
Gecko 2 spp	1		68		4		12						
Skink 2 small spp	7		101		4		40		3		4		
Cyclodina alani			3	1									
Leiopelma hochstetteri			2	1									
Leiopelma hamiltoni			2	1									
Leiopelma markhami	3	1	5	1									
Leiopelma hamiltoni/hochstetteri			6										
Sphenodon sp.													4/1
Total vertebrates	503	22	826	68	174	31	550	47	25	4	15	4	
Total bones 1999-2000	2093												

scapula, furcula) and wing (humerus, ulna, carpometacarpus, manus phalanges 1.1, 2.1, 2.2) elements, with few cranial, vertebrae, pelvis, or leg elements. Distal leg elements outnumbered proximal ones. Most of these prey remains had not been digested, indicating that they had not been ingested, but greenstick fractures and extensive notching of the sterna indicate they were prey items. A few elements, particularly the femora, were heavily digested and fragmentary. The bones were mainly those of the body parts that were not ingested, such as the defleshed paired wings and pectoral girdle, and the feet.

In comparison, the pattern of representation of fairy prion (*Pachyptila turtur*) bones in Hermits Cave, in which remains were accumulated following breakdown of pellets ejected by laughing owls at a roost (Worthy & Holdaway 1994b), was markedly different. The Hermits Cave material included far more cranial and axial elements (vertebrae, pelves), and there were more complete bones (especially of the legs) and a better representation of elements overall, as indicated by addition of whole plus either distal or proximal portions. One apparent anomaly in this trend was the preservation of fewer premaxillae, but this probably relates to the markedly smaller size of the prion bones compared to those of *Pterodroma inexpectata*. Another anomaly is that there were relatively fewer humeri in the owl-accumulated sample. This might be explained by the non-ingestion of these big and robust elements, which therefore could not be incorporated in the pellets that gave rise to material in the site.

The element representation in the sample of *Pachyptila* bones collected from *Falco novaeseelandiae* feeding stations on Auckland Islands by Noel Hyde (Hyde & Worthy unpubl. data; material in MNZ) differed markedly from the Hermits Cave assemblage of the same genus. Some of the remains were derived from pellets and were extensively digested and fragmented, but most were the uneaten wings and pectoral girdle elements. We determined the MNI of 8 for the total sample in the same manner as for the fossil assemblages. Despite the small sample, the over-all survival pattern of bones in the Auckland Island sample was very similar to that from Te Waka #1. The only discrepancy was the relatively enhanced survival of the smaller manual phalanges in the Auckland Island sample because they were within articulated wings. In the fossil sample, these small bones are more likely to be lost following disarticulation of the wings during decomposition and deposition. The similarity of element preservation and representation of the Te Waka #1 petrel material to the sample from the Auckland Islands, and the differences between both and the Hermits Cave collections suggest that petrel bones at Te Waka #1 were accumulated by falcons rather than laughing owls.

Faunal composition

Because the Holocene (Layers 2–5) and the Pleistocene (Layers 6–9) were markedly different in faunal composition, they were analysed separately. The percentage of nocturnal birds of MNI in each of these categories was calculated at 14.8% and 50.0%, respectively. In Hartree's collection, which has no clear time control but which is (judging from the site descriptions, sections, and the three dates reported herein) mainly of Pleistocene age, 48.1% of the total avian MNI represented were nocturnal. Vertebrates other than birds (Table 4) appear to have been dominated by nocturnal animals, but few individuals are represented. However, skink bones outnumber gecko bones (Table 4), and although MNIs for these lizards were not determined, they far exceeded the other non-avian taxa. The high frequency of petrel remains biased the overall proportion of nocturnal birds, so when petrels were absent, as in the Holocene deposit, the proportion of nocturnal birds was relatively low. In sites attributed to laughing owls, nocturnal prey account for 73% at Hermits Cave, which had petrels (Worthy & Holdaway 1994b), and 50–60% at Predator Cave, where there were no petrels (Holdaway & Worthy 1996). The low frequency of nocturnal prey exclusive of petrels at Te Waka #1 contrasts with the collections from these sites.

Petrels excluded, the relatively low frequency of nocturnal animals in the prey assemblage from Te Waka #1 and the domination of the lizard fauna by skinks were similar to those features recorded for other falcon sites, such as Falcon Sites 1 and 2 on Mt Cookson (Worthy & Holdaway 1995) and the Island Cliff Falcon Site (Worthy 1998a).

The diurnal birds at Te Waka #1 included relatively few large birds such as New Zealand pigeon, kokako, Finsch's duck (*Chenonetta finschi*), and weka (*Gallirallus australis*), unlike the faunas in the Hukanui 7a or Hukanui Pool sites (Worthy & Holdaway 2002), which are some 7–8 km from, but at about the same altitude as, Te Waka #1. The faunas in those sites were probably accumulated by the activities of Eyles's harrier, so the dissimilar faunal assemblage from Te Waka #1 suggests that it was accumulated by a different diurnal predator.

The physical characteristics of the site are more like those typical of falcon than those of laughing owl. Laughing owl sites are crevices in cliffs or, if they are within larger cave entrances, they are in crevices within which nests might be made (Worthy & Holdaway 1994b, 1996a, b, 2002; Worthy 1997, 1998a). Most falcon sites have been located on more exposed ledges or in open rockshelters, and they are often in elevated sites (Worthy & Holdaway 1995, Worthy 1998a). Te Waka #1 is an open rockshelter and probably lacked the narrower crevices at its rear that were normally sought by laughing owls. Hence, while Te Waka #1 is not in a very elevated situation in the landscape, it is more like a site used by falcons than by laughing owls.

The taphonomic features of the damaged bones and the site location therefore indicate that falcons were the main factor responsible for accumulating the kill assemblage.

Systematic Palaeontology

Introductory notes for each species can be found in Worthy & Holdaway (1993; 1994a). We follow the nomenclature advocated by Holdaway *et al.* (2001), Worthy & Holdaway (2002), and Worthy *et al.* (in press). Several taxa listed as subspecies in Turbott (1990) are now accepted as species, for example in *Anas*, *Cyanoramphus*, *Porphyrio*, *Philesturnus*, and *Callaeas*. Specimen catalogue numbers and number of bones over MNI (x/y) are given for all species. Data are presented by layer in the format: catalogue number, elements, and square.

Phylum Chordata
Subphylum Vertebrata
Class Amphibia, Order Anura
Family Leiopelmatidae

Genus *Leiopelma* Fitzinger

***Leiopelma markhami* Worthy, 1987 (Markham's Frog)**
Material: Layer 2 – MNZ S39617, ischium, pt tibialefibulare, B7/B8/A8; MNZ S39327, prearticular, C10, total 3 bones; Layer 4 – MNZ S39514, 1 pt tibiofibula, B6, total 1 bone; Layer 5 – MNZ S39329, L hum, B5; MNZ S39602, L articular, 1 urostyle, R ilium, B7; total 4 bones.

***Leiopelma waitomoensis* Worthy, 1987**
(North Island Giant Frog)
Note: No material of this, the largest of the endemic frogs, was found, yet this species has been found at lower elevations in the nearby Puketitiri Valley.

***Leiopelma hamiltoni* McCulloch, 1919**
(Hamilton's Frog)
Material: Layer 5 – MNZ S39330, R hum (length = 9.0 mm, proximal width = 1.3 mm, shaft width = 0.8 mm, distal width = 2.4 mm), B5; MNZ S39567, R ilium, B8; (total 2 bones).

***Leiopelma hochstetteri* Fitzinger, 1861**
(Hochstetter's Frog)
Material: Layer 5 – MNZ S38892, R hum, prox fem, B4; (total 2 bones).

***Leiopelma hamiltoni* McCulloch, 1919 (Hamilton's Frog) or *Leiopelma hochstetteri* Fitzinger, 1861 (Hochstetter's Frog)**
Material: Layer 5 – MNZ S39366, 1 bone, C6; MNZ S39408, 5 bones, C7; (total 6 bones).

Class Reptilia, Order Squamata
Family Scincidae

Genus *Cyclodina* Girard

***Cyclodina* cf. C. *alani* (Robb, 1970) (Robust Skink)**
Material: Layer 5 – MNZ S38893, R max, vert., B4; MNZ S39595, R dentary, B7, (total 3/1).

Note: These bones are referred to this species because of their large size (bigger than other taxa except *Cyclodina northlandi*) and because the number of teeth is the same as for *C. alani* (Worthy 1987).

Skink sp. indet
Material: Layer 2 – MNZ S39373, MNZ S39324, total 7 bones; Layer 4 – MNZ S39437, 1 frontal; Layer 5 – MNZ S39409, MNZ S39520, MNZ S39593, MNZ S39331, MNZ S39566, total 100 bones; Layer 6 – MNZ S39583, 4 bones; Layer 7 – MNZ S39446, MNZ S39643, MNZ S39298, MNZ S39540, MNZ S39351, MNZ S39653, MNZ S39307, total 40 bones; Layer 8 – MNZ S39543, 3 bones; Layer 9 – MNZ S39659, total 4 bones. Grand total 159 bones.

Family Gekkonidae

Genus *Hoplodactylus* Fitzinger

***Hoplodactylus* sp. indet. cf. *H. maculatus* (Boulenger, 1885) (Common Gecko)**

Material: Layer 2 – MNZ S38834, 1 bone; Layer 4 – MNZ S39513, MNZ S39620, 23 bones; Layer 5 – MNZ S39410, MNZ S38894, MNZ S39521, MNZ S39594, MNZ S39332, 45 bones; Layer 6 – MNZ S39460, MNZ S39627, 4 bones; Layer 7 – MNZ S39644, MNZ S39299, MNZ S39539, MNZ S39350, 12 bones.

Note: Most of these bones are of appropriate size to be from the common gecko *Hoplodactylus maculatus* (Boulenger, 1885), which has long been considered to be a common and widespread species. However, recent work has shown that it is a "super-species" complex, including at least 13 cryptic species that generally have allopatric distributions (Daugherty *et al.* 1994).

Class Aves, Order Dinornithiformes
Family Emeidae

Genus *Anomalopteryx* Reichenbach

***Anomalopteryx didiformis* (Owen, 1844) (Little Bush Moa)**

Material: Layer 5 – MNZ S39367, R side mandible, rib, vert, pubis frag, C6; MNZ S39592, 4 cerv vert, 3 caudal vert, R fib, pubis, sternal rib, 3 ribs, 2 uncinate processes, 1 phal, 1 phalanx 1.1, hyoid, 5 tracheal rings, 2 frags, B7; MNZ S39546, 3 vert, 1 uncinate proc, 1 rib, frags, 5, B8; (total 34/1).

Genus *Pachyornis* Lydekker

***Pachyornis mappini* Archey, 1941 (Mappin's Moa)**

Material: No bones of this species were found in our excavation, although one bone was attributed to this species from Hartree's excavations (Worthy & Holdaway 2000).

Genus *Euryapteryx* Haast

***Euryapteryx geranoides* (Owen, 1848) (Stout-legged Moa)**

Material: No material of this species found in excavation, although Hartree excavated a sternum of one individual (Worthy & Holdaway 2000).

***Euryapteryx curtus* (Owen, 1846) (Coastal Moa)**

Material: Layer 7 – MNZ S39584, juv R tmt, phal 2.1, B8; MNZ S38877, mand tip and right ramus, B3; MNZ S38884, pmx, tracheal ring, phal, B3; (total 7/1). The following is also probably *Euryapteryx curtus*: MNZ S39634, juv, sesamoid, phal 1.2, B7.

Emeid species indeterminate

Material: Layer 4&5 – MNZ S39488, uncinate proc., tracheal ring, C5; MNZ S39506, thor vert, C5; MNZ S39355, 12 tracheal rings, C6; MNZ S39419, 1L fib, C7; Layer 7 – MNZ S39495, juv phal 2.1, C5; MNZ S39386, sesamoid, C6; Layer 9 – MNZ S39657, phal 1.2 (ungual), BC7.

Family Dinornithidae

Genus *Dinornis* Owen

***Dinornis struthoides* Owen, 1844 (Slender Moa)**

Material: Layer 5 – MNZ S39394, thoracic rib, LR metatarsals, 1 phal I.1, LR phal I.2, 1 ungual, 1 cervical vert, 1 caudal vert, C7; MNZ S39590, cervical vert, phal, B7; MNZ S39547, 1 cervical vert, B8; (total 11/1).

Moa eggshell

Moa eggshell specimens listed here are coloured white and include at least two thickness classes.

Material: Layer 2 – MNZ S38829, 3 pieces eggshell, B1; MNZ S38830, 2 pieces, B1; MNZ S39484, 25 pieces, C5; MNZ S39368, 4 pieces, C6/B6; MNZ S39370, 39 pieces, C6; MNZ S39430, 16 pieces, C7; MNZ S39509, 6 pieces, B6; MNZ S39303, 7 pieces, D10.

Layer 4&5 – MNZ S38846, 30 pieces, B2; MNZ S39377, 15 pieces, C6; MNZ S38886, 14 pieces, B4; MNZ S39432, 17 pieces, C7; MNZ S39512, 39 pieces, B6; MNZ S39618, 44 pieces, B7; MNZ S39579, uncounted, B8; MNZ S38847, 3 pieces, B2; MNZ S39489, 3 pieces, C5; MNZ S39354, 106 pieces, C6; MNZ S38865, 15 pieces, B3; MNZ S39413, 54 pieces, C7; MNZ S39524, 102 pieces, B6; MNZ S39589, 250 g, 2+ thicknesses, B7; MNZ S39337, 4 pieces, B5; MNZ S39544, 600 g, B8; MNZ S39311, 2 pieces, C10.

Layer 6 – MNZ S39382, 9 pieces, C6; MNZ S39450, 7 pieces, C7; MNZ S39451, 127 pieces (1 egg), C7; MNZ S39528, 8 pieces, B6; MNZ S39625, 14 pieces, B7; MNZ S39572, uncounted, B8; MNZ S39568, uncounted, B8; MNZ S38850, 1 piece, B2.

Layer 7 – MNZ S39496, 1 piece, C5; MNZ S39387, 4 pieces, C6; MNZ S39439, 7 pieces, C7; MNZ S39534, 2 pieces, B6; MNZ S39633, 23 pieces, B7; MNZ S39585, uncounted, B8; MNZ S39352, 3 pieces, B5; MNZ S39392, 1 piece, C6.

Order Apterygiformes
Family Apterygidae

Genus *Apteryx* Shaw & Nodder

To date, only *Apteryx owenii* can be reliably identified from its bones, which are smaller than those of other species. Bones of other *Apteryx* species cannot be reliably separated using shape or size characters (pers. obs.). Adult bones of the two brown kiwis *A. mantelli* (North Island brown kiwi) and A. australis (South Island brown kiwi), and the great-spotted kiwi A. *haastii* overlap markedly in length (Worthy 1997). The largest *A. mantelli* is as big as any *A. australis*. The fossils discussed here are referred to *A. mantelli* as this is the only large kiwi known from the North Island.

***Apteryx mantelli* Bartlett, 1852**
(North Island Brown Kiwi)

Material: Layer 5 – MNZ S38837, rib, L hum, B1; MNZ S39335, synsacrum, B5; MNZ S39548, 3 vert, B8, (total 6/1); Layer 6 – MNZ S39576, 2 vert, B8, (total 2/1); Layer 7 – MNZ S38848, L side pelvis, B2; MNZ S38862, vert, rib, B2; MNZ S39492, L tt, C5; MNZ S39494, R innom, thor vert, 2L quad, Sq, C5; MNZ S39438, skull, C7; MNZ S39328, L fib, C5/B4/B5 (total 10/2); Layer 9 – MNZ S39655, L astragalus, BC7, (total 1/1).

***Apteryx owenii* Gould, 1847 (Little Spotted Kiwi)**

Material: Layer 7 – MNZ S39635, 1 cerv vert, 1 ungual phal, B7, (total 2/1).

Note: This is the first record of this species for the site. The bones are attributed to *A. owenii* because of their small size.

***Apteryx* sp. juv (Kiwi species)**

Material: Layer 7 – MNZ S38856, rib, B2; MNZ S39507, L coracoidscapula, C5; MNZ S39345, R tmt, R astragalus, B5 (total 4/1).

Order Procellariiformes
Family Procellariidae

Genus *Pterodroma* Bonaparte

Note: Worthy & Holdaway (2000) did a morphometric analysis of the *Pterodroma* bones from Te Waka and nearby sites and referred them to the species *P. cookii* and *P. inexpectata*. However, for both taxa, the long bones averaged 4–5% shorter than those from modern populations. This difference was explained as temporal variation.

***Pterodroma inexpectata* (Forster, 1844) (Mottled Petrel)**
Material: Layer 2 – MNZ S38835, sL ulna, B1; MNZ S39322, synsacrum of juv, rad, pR tt, C10; (total 4/2).

Layer 4&5 – MNZ S38838, juv sL hum, R scap, ant stern, sL ulna, 3 frags, B1; MNZ S38887, R tt, R fib, R scap, B4; MNZ S38836, L cmc, B1; MNZ S39416, dL ulna, L M2.1, C7; MNZ S39552, L cor, 2pL hum, 1dL hum, 2 frags fur, 1 p rad, 1 M2.2, B8; (total 18+/3).

Layer 6 – NZA12474 (boundary layers 5 and 6), R cmc), B8; MNZ S39378, L ulna, C6; MNZ S39379, dL tmt, C6; MNZ S39447, 2pL1pR1dL hum, 1R cor, 1L1R scap, 2pt fur, 1M 2.2, 2pR1sL1dR ulna, 2L3R cmc, 2L3pL1dL1R1dR rad, L ramus, pt stern, 1 vert, 1L M2.1, 1pR1dR tt, C7; MNZ S39448, L hum, C7; MNZ S39465, L cmc, L tmt, dR cmc, 1p rad, dL hum, pterygoid, 1 q-o-j, 1R M2.1, 1 M3.1, pt fur, 1 lacrymal, C7; MNZ S39461, L ulna, C7; MNZ S39529, dL fem, B6; MNZ S39573, pts 2 fur, dR ulna, s ulna, R scap, pt mand, B8; MNZ S39569, 2L tmt, R cmc, 2R scap, pL hum, 1dL 1p rad, pt fur, R quad, B8; (total 67/5).

Layer 6&7 – MNZ S38839, 2sL1sR hum, 1dR1pR2pL3dL rad, 1L M2.1, pt R dent, R cor, dR cor, dR ulna, L quad, B1; MNZ S38841, frag R hum, 2 vert, juv pR hum, B1; MNZ S38843, L hum, RsR ulna, L cmc, pt fur, R cor, L M2.1, 1 manus phal, vert, pR rad, B1; MNZ S38849, pL fem, B2; (total 31/3).

Layer 7 – MNZ S38844, sL hum, dR ulna, stern, L cor, fur, B1; MNZ S38851, R hum, B2; MNZ S38852, L cmc, B2; MNZ S38855, 1L1d+sL hum, L scap, B2; MNZ S38857, LR hum, L ulna, 2L cmc, LR scap, pL fem, ant stern, 5 phal, 1L1dR rad, B2; MNZ S38861, 1L1d+sL ulna, 2L M2.1, 2L cmc, fur, 3L1pR rad, LR tmt, sL tt, L cor, B2; MNZ S39491, L ulna, C5; MNZ S39493, cran, pmx, C5; MNZ S39498, 2L hum, LR ulna, 3R cmc, 1 pmx, 2L2R cor, 5 ant stern, 2L1R M2.1, LR rami, 3 frags dent, 1R1dR1dL2p rad, 8 pedal phal, 2L2R scap, 5 vert, 1 syn, 1L1pL1dR tt, 1dL1pL tmt, 5 manus phal, 1 pal, 2 fur frags, C5; MNZ S39385, R hum, dL hum, pR cmc, L scap, manus phal, pt dent, LR M2.1, dLdRpL rad, pL tt, dL ulna, C6; MNZ S39393, 2L2sR ulna, 2R cmc, 1 pt stern, L quad, 1L1dR1s rad, 1 pt pmx, LR scap, L tmt, C6; MNZ S38878, LR cor, fur, L M2.1, LR cmc, stern, pL hum, L tmt, L rad (juv), B3; MNZ S38897, R ramus, R cmc, 2 phal, pR fem, L scap, dR rad, B4; MNZ S39444, 1R2L hum, LR cor, LR scap, 2 phal, 2 pts fur, R tmt, L cmc, R ulna, s rad, dL tt, C7; MNZ S39532, 2L M2.1, 1R cor, 1pR tt, 1 vert, B6; MNZ S39629, pL hum, B7; MNZ S39630, L tmt, B7; MNZ S39631, L cmc, B7; MNZ S39632, juv L ad R hum, LR cmc, pL ulna, 2L1R cor, 2 pmx, 1 ant stern, 1 cran frag, 2 tips pmx, 3 frags fur, LR M2.1, L tt, 7 vert, 1 pterygoid, 1dL tmt, 2 phal, 1 rib, 1dL1p rad, 1 juv R ulna, B7; NZA12475, L ulna, B8; MNZ S39291, R hum, B4; MNZ S39292, pR ulna, B4; MNZ S39293, 1L juv 1 ad R 2sR hum, 1 ant stern, 1pL2dL ulna, 1L cmc, 2L1R cor, 2dL2s rad, 1L1R rami, 1dL1dR tt, 3 vert, 2 dent, 1L M2.1, 1 ulnare, B4; MNZ S39538, 2L cor, L M2.1, ulnare, 1L M2.2, s ulna, B6; MNZ S39349, 2L1R1dR cmc, 1L M2.1, ant stern, pt fur, R scap, 1 pedal phal, LdL ulna, 5 frags rad, L cor, B5; MNZ S39645, LR cor, R cmc, 2L tmt, R scap, 1pL1pR1dL fem, 1s ulna, 3 pts fur, BC7; NZA12460, R hum, BC7; MNZ S39588, 1dR tt, 2 vert, 2 manus phal, 1 pedal phal, 1p rad, B8; MNZ S39304, L cmc, D10; MNZ S39306, dL hum, pt stern, pt L cor, C10, D10; MNZ S38870, RL hum, B3; MNZ S38872, juv R rad, B3; MNZ S38873, ad L rad, B3; MNZ S38874, R ulna fledgling, B3; MNZ S38875, R rad, B3; MNZ S38876, L hum, B3; MNZ S38881, L hum, L ulna, L rad juv, B3; MNZ S38882, R hum, 2R ulna, R rad, R cor, L cmc, fur, B3; MNZ S38885, 2L2d+sL1dL1pL 1pR1dR ulna, 1R2sR 1p+sR hum, 2L2R cor, 5 pedal phal, 1L2R cmc, 1L1pR tmt, 1R2dL2pL1pR rad, 3R scap, 1dR tt, 2L M2.1, 2 M2.2, 1R fem, B3; (total 346/19).

Layer 8 – NZA12460, R hum (76.3 mm), BC7; MNZ S39654, L cmc, BC7; MNZ S39308, L cor, juv ulna, frags, C10; (total 4/2).

Layer 9 – MNZ S39656, LR M2.1, ant stern, L scap, pL tt, dL ulna, BC7; (total 6/1).

Layer 10 – MNZ S39661, M1.1, BC7; (total 1/1).

***Pterodroma cookii* (Gray, 1843) (Cook's Petrel)**

Material: Layer 7 – MNZ S39646, 1dR tmt, BC7.

Note: This bone was from near the base of Layer 7 in Square BC7. This 1 m^2 excavation was the only part inside the cave where we excavated to this depth. The fauna excavated by Bill Hartree in the 1950s and 60s includes 257 bones of this species. The associated excavation notes indicate that most were from his entrance trench and all were from below what he termed the 'Waimihia Tephra'. In our excavations, this red lapilli was noticed throughout much of Layer 7, but it was concentrated in a narrow band where we stopped excavating over most of the site. Therefore, except in Square 7BC and D10, we did not excavate the layers where Hartree recovered most, if not all, of his *Pterodroma cookii* material.

Family Oceanitidae

Genus *Garrodia* Forbes

***Garrodia nereis* (Gould, 1841)**
(Grey-backed Storm Petrel)

Material: Layer 7 – MNZ S39648, phal M2.1, L rad, BC7 (total 2/1).

Note: This is the first fossil record of this species for the North Island. *Garrodia* nests on the surface of the ground, rather than in burrows, and generally does so in tussock *Chionochloa* or *Poa* grassland under low vegetation like bases of flax *Phormium* spp. or tussock plants (Marchant & Higgins 1990: 689).

Order Anseriformes

Family Anatidae

Genus *Cnemiornis* Latham

***Cnemiornis gracilis* Forbes, 1892 (North Island Goose)**

Material: One part skeleton of this species was excavated by Hartree from deep in his 'entrance trench' (Worthy & Holdaway 2000), but we found no material in our excavations. This individual died in the site, either from being trapped between the blocks of rocks or from other causes, which we cannot now ascertain, but it was not falcon prey.

Genus *Chenonetta* Brandt

***Chenonetta finschi* (Van Beneden, 1875) (Finsch's Duck)**

Material: Layer 6&7 – MNZ S39462, juv R tt, C7; MNZ S38840, juv stern, ad R fem, vert, phal, rib, B1; MNZ S38842, juv syn, B1; (total 7/2); Layer 7 – MNZ S38845, L ramus mand, B1; MNZ S38860, R juv tmt, B2/B3; MNZ S38863, R fib, B2; MNZ S39652, pmx, 4 pedal phal, BC7; (total 8/1).

Order Falconiformes
Family Falconidae

Genus *Falco* Linnaeus

***Falco novaeseelandiae* Gmelin, 1788 (New Zealand Falcon)**

No bones of this species were found although we attribute most of the predated fauna to falcon predator activity.

Order Galliformes
Family Phasianidae

Genus *Coturnix* Bonnaterre

***Coturnix novaezelandiae* Quoy & Gaimard, 1830 (New Zealand Quail)**

Material: Layer 2 – MNZ S38828, L scap, dL hum, B1; MNZ S38831, stern, dLpL fem, pL hum, pR ulna, L cor, B1; MNZ S39316, L tmt, L rad, C10; (total 10/1); Layer 5 – MNZ S39399, L scap, C7, (total 1/1); Layer 6 – MNZ S39453, 1pR rad, C7; MNZ S39578, pL fem, B8, (total 2/1); Layer 7 – MNZ S38879, pR hum, R scap, R cmc, B3; MNZ S39636, 1dL cor, B7; MNZ S39294, dR hum, dR tt, B4; MNZ S38871, R rad, B3; MNZ S38883, LR ulna, B3; (total 9/1).

Order Gruiformes
Family Aptornithidae

Genus *Aptornis* Mantell

***Aptornis otidiformis* Owen, 1844 (North Island Adzebill)**

Material: Layer 4&5 – MNZ S39486, pL cor, pedal phal 3.3, C5; MNZ S39353, 3 caud vert, pedal phal R2.1, R2.2, R2.3; R4.2, C6; MNZ S39395, 3 phal, 1 pterygoid, 2 ribs, 4 ossified tendons 1 frag, C7; MNZ S39418, ?L pedal phal 3.1, C7; MNZ S39525, R hum, B6; MNZ S39591, stern, 4 vert, 9 rings, R lachrymal, pt pubis, L rad, L ulna, caudal vert, L metatarsal, 5 phal + 3 unguals, 6 ossified tendons, B7; MNZ S39545, 3 vert, 2 pedal phal, pt 3 ribs, B8; (total 64/1).

Note: The presence of a patina of calcite covering many of these bones indicates they lay on the cave floor exposed to the air for some time before burial. These bones indicate that a single bird died in the site, and the distribution of the bones suggests the skeleton initially lay in the unexcavated area of A6–A7.

Family Rallidae

Genus *Gallirallus* Lafresnaye

***Gallirallus australis* (Sparrman, 1786) (Weka)**

Material: Layer 2 – MNZ S39371, cerv vert #3, pedal phalanges 3.3, 4.1, 2.1, 4.2, 4.3, 4.4, C6; MNZ S39426, fur, dL tmt, C7, (total 9/1); Layer 4&5 – MNZ S39487, cerv vert #3, C5; MNZ S39412, mand, L hum, C7; MNZ S39551, pLdL fem, stern, B8; (total 6/1); Layer 6 – MNZ S39463, mand, pterygoid, C7; (total 2/1); Layer 7 – MNZ S39443, L cor, C7; (total 1/1).

Genus *Gallinula* Brisson

***Gallinula hodgenorum* (Scarlett, 1955) (Hodgens' Rail)**

Material: No material of this species was obtained during the present excavations, but Hartree recovered 11 bones representing 3 individuals (Worthy & Holdaway 2000). That material includes the holotype and paratypes of *Gallirallus hartreei* Scarlett.

Genus *Capellirallus* Falla

***Capellirallus karamu* Falla, 1954 (NZ Snipe Rail)**

Material: Layer 5 – MNZ S39565, dR tt, R fem, B8; (total 2/1).

Note: This is the first record of this species for the site.

Genus *Fulica* Linnaeus

***Fulica prisca* Hamilton, 1893 (New Zealand Coot)**

Material: Layer 8 – MNZ S39309, phalanx 2.1, ungual, C10, at -3100 to -3300 mm below datum.

Note: This is the first record of this species for the site.

Order Charadriiformes
Family Charadriidae

Genus *Charadrius* Linnaeus

***Charadrius bicinctus* Jardine and Selby, 1827 (Banded Dotterel)**

Material: Layer 7 – MNZ S39389, L scap, R cor, C6, (total 2/1).

Note: This is the first fossil record from the North Island. The bones were compared with specimens in MNZ and, apart from being substantially smaller than *Coenocorypha*, the coracoid differs markedly from that taxon in that it lacks a procoracoidal foramen.

Family Scolopacidae

Genus *Coenocorypha* G.R. Gray

***Coenocorypha barrierensis* Oliver, 1955 (North Island Snipe)**

Material: Layer 4&5 – MNZ S38888, L cor, B4; MNZ S39516, 1L M2.1, B6; (total 2/1); Layer 7 – MNZ S39637, R ramus mand, mand tip, B7; MNZ S39297, dR fem, B4; MNZ S39647, dR hum, L scap, BC7; MNZ S39390, sL cmc, pt fur, dL fem dL hum, pLdL tmt, C6; (total 11/1); Layer 9 – MNZ S39658, R cor, ant stern, BC7 (total 2/1).

Note: Bones of *Coenocorypha* found in the North Island are significantly smaller than those in the South Island and have been referred to *C. barrierensis* (Holdaway *et al.* 2001; Worthy *et al.* submitted).

Order Columbiformes
Family Columbidae

Genus *Hemiphaga* Bonaparte

***Hemiphaga novaeseelandiae* (Gmelin, 1789) (New Zealand Pigeon)**

Material: Layer 4&5 – MNZ S39619, R hum, frag L hum, B7; MNZ S39396, 2pL hum, 1dL1pL rad, C7; MNZ S38866, sR tmt, B3; MNZ S38890, L cor, R cmc, B4; MNZ S39601, L cmc, dR cor, pL hum, B7; MNZ S39549, pL ulna, pt notarium, B8; (total 14/3).

Order Psittaciformes
Family Psittacidae

Genus *Strigops* Gray

***Strigops habroptilus* Gray, 1845 (Kakapo)**

Material: Layer 4&5 – MNZ S39621, 5 phal, 1 metatarsal, B7; MNZ S39417, symphysis of mand, C7; MNZ S39336, L ulna, B5; MNZ S39550, pt cran, B8; (total 9/1); Layer 6 – MNZ S39490, pmx, 2 pal frags, C5; MNZ S39574, frag cran, B8; (total 4/1).

Genus *Nestor* Lesson

***Nestor meridionalis* (Gmelin, 1788) (Kaka)**

Material: Layer 4&5 – MNZ S39359, dR ulna, dR hum, C6; MNZ S39400, L pal, sR tt, C7; MNZ S39518, R fem, B6; MNZ S39598, R cmc, L fib, B7; MNZ S39334, pel, phal, B5; (total 9/1); Layer 6 – MNZ S39369, L ulna, B6; MNZ S39530, R tmt, B6; (total 2/1).

Genus *Cyanoramphus* Bonaparte

***Cyanoramphus* spp. indet**

Bones of parakeet species are indistinguishable morphologically, and their size ranges overlap broadly (Worthy & Holdaway 1994a), so species are not determined here.

Material: Layer 2 – MNZ S39485, pR ulna, C5; MNZ S39372, dR hum, mand frag, ant stern, C6; MNZ S39428, 2 pmx, R hum, L fem, L rad, C7; MNZ S39508, L tt, 1L1sL cor, 1R ulna, 1 R M2.1, B6; MNZ S39616, pel, dR cor, L hum, palatine, dL ulna, B7/B8/A8; MNZ S39301, pL cmc, D10; MNZ S39315, dRdL tt, dLpL tmt, ant stern, pR ulna, pR fem, R rad, C10; (total 28/3).

Layer 4&5 – MNZ S39582, cran, mand, stern, R ulna, LR cmc, R M2.1, L rad, L scap, pygostyle, pLpRdR fem, dL tt, LR tmt, pal, B8; MNZ S39357, R tmt, pL tmt, pL cor, R scap, R cmc, R M2.1, dR ulna, dL rad, C6; MNZ S39397, 1R1L1dL hum, 1R2pR1pL cor, 1pL fem, 1R1dL cmc, 1 cran frag, 1pR ulna, 1dR1R tt, 1R rad, 1R M2.1, 1 pmx, 1 pal frag, C7; MNZ S38868, pR tmt, B3; MNZ S38895, L cor, mand frag, B4; MNZ S39414, R hum, L ulna, LR cor, L fem, stern, L tt, pal, C7; MNZ S39519, 1sL hum, 1sR cor, 1p rad, 1dR cmc, 1dL tt, B6; MNZ S39603, 1 pel, pt mand, 2 ant stern, L quad, 2 pal, 2L tmt, 1L1dR fem, 1pR hum, 1dR ulna, 1dR rad, 1L1dL cor, B7; MNZ S39340, R quad, B5; MNZ S39553, 1L1dR cor, 1L ulna, 1R tt, 1dR rad, 2 pmx, 1 pt mand, 1L quad, B8; (total 84/6).

Layer 6 – MNZ S39449, R fem, R scap, R cor, LpR cmc, R M2.1, C7; MNZ S39464, R ulna, C7; MNZ S39526, 1pR1dR hum, 1dL tmt, 1pR ulna, 2dR fem, 1 L scap, B6; MNZ S39626, R cmc, dR ulna, B7; (total 17/3).

Layer 7 – MNZ S39505, dR ulna, C5; MNZ S39441, R cmc, C7; MNZ S39642, pel, stern, ant mand, L hum, LdR ulna, LR cor, pLpRdL fem, R tmt, dL tt, R scap, 1 pal, 1L2R M2.1, B7; MNZ S39296, L tmt, B4; MNZ S39537, mand tip, dR fem, R scap, B6; MNZ S39344, R hum, B5; MNZ S39649, L ulna, pL cor, L cmc, R tmt, BC7; MNZ S39391, L tmt, pt cran, R cmc, C6; (total 32/2).

Layer 8&9 – MNZ S39542, R quad, pt palatine, BC6; MNZ S39660, LR hum, LR cor, pLdL tt, L rad, L scap, LR tmt, pel, dL fem, LpR cmc, BC7; (total 16/1).

Order Strigiformes
Family Strigidae

Genus *Ninox* Hodgson

***Ninox novaeseelandiae* (Gmelin, 1788) (Morepork)**
Material: Layer 2 – MNZ S39613, LR ulna, 4 vert, 2 phal, L tt, L fem, R cor, L quad, B7/B8/A8, (total 12/1).

Note: This is the first record of this species from the site. The remains had been predated.

Order Caprimulgiformes
Family Aegothelidae

Genus *Aegotheles* Vigors & Horsfield

***Aegotheles novaezealandiae* (Scarlett, 1968)**
(New Zealand Owlet-nightjar)
Material: Layer 2 – MNZ S39614, pelvis, B7/B8/A8, (total 1/1); Layer 4&5 – MNZ S39431, pel, stern, 2R tt, 1R tmt, LR rad, C7; MNZ S39580, dL tmt, dL tt, L hum, L M2.1, LR palatine, B8; MNZ S39358, L tmt, R ramus, C6; MNZ S39398, R hum, dR cor, C7; MNZ S39597, L ulna, pt stern, R cmc, sR hum, pR cor, L scap, 2 pts mand, B7; MNZ S39338, R cmc, B5; MNZ S39556, 1pL1pR1dR tt, 2R1L ulna, 1R scap, 1L cmc, LR quad, LR pterygoid, R hum, pt mand, B8; (total 40/3); Layer 6 – MNZ S39628, dL tt, R hum, R ulna, B7; (total 3/1); Layer 7 – MNZ S39504, dL ulna, C5; MNZ S39638, L cor, dR tmt, B7; MNZ S39586, L tmt, B8; (total 4/1).

Note: Several of the bones of this species excavated by W. H. Hartree from Te Waka #1 are included in the paratypic series of this species.

Order Passeriformes
Family Acanthisittidae

Genus *Acanthisitta* Lafresnaye

***Acanthisitta chloris* (Sparrman, 1787) (Rifleman)**
Material: Layer 2 – MNZ S39374, R ulna, C6; MNZ S39321, R fem, dR tmt, C10; (total 3/1).

Layer 4&5 – MNZ S39622, 1dR tt, 1R tmt, 1L ulna, B7; MNZ S39361, pR tmt, C6; MNZ S39405, 1L1dL hum, 2pL1pR 1dL1dR tt, 1L1pL ulna, 1L1R scap, 1R fem, 1syn, 1L cor, 1pR tmt, 1R ramus, C7; MNZ S38869, pL tmt, B3; MNZ S39421, dL tt, R hum, R ulna, C7; MNZ S39604, 1L2dL2R hum, 2pL1pR2dL2dR tt, 1dR1pR tmt, 1L1pL ulna, 1L cmc, 1dL fem, 1L cor, LR acet, B7; MNZ S39563, 2R fem, 1L1R1pR tt, 2pL1pR tmt, 2R cmc, 1dR cor, LR ramus, R scap, stern, dR ulna, L M2.1, B8; (total 62/5).

Layer 6 – MNZ S39456, 2dL1pL tt, C7; MNZ S39570, R tt, B8; (total 4/2).

Layer 7 – MNZ S38859, R hum, B2; MNZ S39500, dL ulna, C5; MNZ S39640, R hum, dL cor, LdR ulna, B7; MNZ S39348, dR tt, phal 1.1, B5; MNZ S39650, dR tt, BC7; MNZ S39541, dR tt, dR ulna, B6; (total 11/3).

Genus *Pachyplichas* Millener

***Pachyplichas jagmi* Millener, 1988**
(North Island Stout-legged Wren)
Material: Layer 5 – MNZ S39406, 1pL tt, C7; MNZ S39424, L hum, R fem, L tt, L tmt, C7; MNZ S39562, pL tmt, B8; (total 6/2).

Layer 6 – MNZ S39458, 1pL tt, 1L tmt, 1dL fem, 1L cor, C7; (total 4/1).

Layer 7 – MNZ S39503, dL tt, C5; MNZ S39440, R hum, C7; MNZ S39535, LR hum, L cmc, ungual, B6; (total 6/2).

Genus *Traversia* Rothschild

***Traversia lyalli* Rothschild, 1894**
(Stephens Island Wren)
Material: No material was found during the current excavation, but a single bone was identified from Hartree's excavations (Worthy & Holdaway 2000).

Genus *Xenicus* G. R. Gray

***Xenicus* sp. indet**
Note: Osteological differences between the two species *Xenicus gilviventris* (rock wren) and *X. longipes* (bush wren) have not been described. Only two partial modern skeletons of *Xenicus gilviventris* are known and few of *X. longipes* (Millener 1988). As the lengths of the limb bones in these specimens are very similar and occupy only a small part of the range seen in fossil material, no attempt is made to identify the taxa pending an osteological study of the genus.

Material: Layer 2 – MNZ S39323, pL fem, C10; (total 1/1).

Layer 4&5 – MNZ S39433, R cor, C7; MNZ S39515, 1dR tmt, B6; MNZ S39623, 1pR ulna, B7; MNZ S39362, dR tt, L cmc, C6; MNZ S39404, 1L1dR ulna, 1R ramus mand, 1L scap, 1pL1pR cor, 1 pmx, C7; MNZ

S38864, 1R tmt, 1dL tt, B3; MNZ S39422, 1L hum, 1L ulna, 1L cor, 1L ramus mand, C7; MNZ S39517, 1R1pL1dL tmt, 1pL fem, 1R cor, 1 syn, 1R cmc, B6; MNZ S39600, 1pL tt, 1dL tmt, 1L ulna, B7; MNZ S39561, 1L1R hum, 1L1R ramus mand, 1L ulna, B8; (total 33/4).

Layer 6 – MNZ S39384, R rad, pR ulna, L cmc, pel, C6; MNZ S39457, 1R hum, 1L cor, 1R ulna, C7; (total 7/2).

Layer 7 – MNZ S38854, pL tt, B2; MNZ S39501, dR ulna, pL cor, C5; MNZ S39388, L ulna, C6; MNZ S38880, dR tt, B3; MNZ S39290, pL tmt, B4; MNZ S39445, L cor, C7; MNZ S39639, R hum, dR tt, B7; (total 9/2).

Family Motacillidae

Genus *Anthus* Bechstein

***Anthus novaeseelandiae* (Gmelin, 1789) (New Zealand Pipit)**

Material: Layer 5 – MNZ S39558, pR ulna, pR hum, L cor, B8; (total 3/1);

Layer 6 – MNZ S39455, 1dR cor, C7; MNZ S39575, L scap, B8; (total 2/1);

Layer 7 – MNZ S38853, L cmc, B2; MNZ S38858, R hum, B2; MNZ S39442, 1dR1L ulna, 1pL hum, C7; MNZ S39641, R hum, R cmc, ant stern, dL tt, B7; MNZ S39295, R fem, B4; MNZ S39346, L cor, dL fem, dL ulna, B5; MNZ S39651, R cor, BC7; (total 14/2).

Family Pachycephalidae

Genus *Mohoua* Lesson

***Mohoua albicilla* (Lesson, 1830) (Whitehead)**

Material: Layer 2 – MNZ S39610, 2dR tt, B7/B8/A8; MNZ S39320, L tmt, L cmc, L fem, C10; (total 5/2).

Layer 4&5 – MNZ S39434, L ramus mand, pel, C7; MNZ S39364, R fem, pL ulna, C6; MNZ S39403, L tmt, 1dL1pR tt, syn, 1R1pL rad, 1L1pR cmc, 1R scap, 1 pmx, 1pR cor, 1R1dL ulna, C7; MNZ S39423, L ulna, LR cor, C7; MNZ S39605, R tmt, 1L1pL1pR fem, 3R ramus mand, 1L cmc, 1L cor, 1dL ulna, B7; MNZ S39341, R cor, mand tip, dL tt, B5; MNZ S39559, 1L1pR1dR tmt, 1L1R 1pR hum, 1 pmx, 1 stern, 1L1R cor, 1R ulna, 1R scap, 1L rad, B8; (total 46/3).

Layer 6 – MNZ S39454, 1L hum, C7; (total 1/1);

Layer 7 – MNZ S39502, pL ulna, C5; (total 1/1).

Family Petroicidae

Genus *Petroica* Swainson

***Petroica toitoi* (Lesson, 1828) (North Island Tomtit)**

Material: Layer 2 – MNZ S39427, pR tt, C7; MNZ S39314, LR tmt, R fem, L tt, LR scap, fur, LR ramus mand, stern, LR hum, L ulna, LR rad, LR cor, R cmc, C10; (total 19/1).

Layer 5 – MNZ S39342, L hum, B5; MNZ S39310, 2 pL hum, C10; (total 3/2).

***Petroica longipes* (Garnot, 1827) (North Island Robin)**

Material: Layer 2 – MNZ S39611, R fem, R tt, B7/B8/A8; (total 2/1).

Layer 4&5 – MNZ S39343, L cor, B5; MNZ S39436, L tmt, stern, C7; MNZ S39624, LR ulna, 1dR1pR tmt, LR cmc, R scap, LR cor, R hum, pR tt, pel, LR M2.1, B7; MNZ S39581, L tmt, L scap, L fem, L cor, R ulna, dR tt, sternum, B8; MNZ S39363, 2pR tmt, C6; MNZ S39402, L tmt, pR hum, dR tt, C7; MNZ S39420, R ulna, C7; MNZ S39606, 1L2pL1dL1pR1dR hum, 1R1dL1pL tmt, 1L1pL2dL1dR3pR tt, 1R fem, 3R2dL1pL ulna, 2R quad, pel, 2R1dR cmc, 2R1L scap, 1 ant stern, 1L2R cor, 1L1R mand rami, mand tip, 1 p radius, B7; MNZ S39339, dL ulna, B5; MNZ S39557, 2R1dR1pR 4dL3pL tt, 2 pel, 1R2pR1dR 1pL tmt, 2L1pL1R fem, 2L2R hum, 6 ant stern, 2L2R cmc, 2R2L scap, 2dR1R1L2pL1dL cor, 4 pmx, 1 mand tip, 3R2L quad, 2R1L rami, 1L2R M2.1, 1dR tmt, 1dL1pL2pR ulna, 1 fur, B8; (total 141/9).

Layer 6 – MNZ S39380, R tmt, C6; MNZ S39459, L hum, dR tmt, C7; MNZ S39577, L cmc, dR tt, B8; (total 5/2).

Layer 7 – MNZ S39499, R hum, L scap, pt stern, C5; MNZ S39533, L tmt, R tt, LR fem, R cor, B6; MNZ S39536, R tt, L tmt, ant stern , B6; MNZ S39347, dL hum, B5; (total 12/2).

Family Meliphagidae

Genus *Notiomystis* Richmond

***Notiomystis cincta* (Du Bus, 1839) (Stitchbird)**

Material: Layer 5 – MNZ S38896, pL hum, B4; (total 1/1).

Note: This is the first record for the site.

Genus *Anthornis* Gray

Anthornis melanura **(Sparrman, 1786) (New Zealand Bellbird)**

Material: Layer 2 – MNZ S39609, 27/1 juv, B7/B8/A8; MNZ S39615, dR tmt, R hum, R ulna (3/1 juv), B7/B8/A8; (total 30/2).

Layer 5 – MNZ S39360, pR hum, pR tt, dL tmt, C6; MNZ S39401, ant stern, C7; MNZ S39560, dL tmt, R scap, B8; (total 6/2).

Layer 6 – MNZ S39381, dR tmt, C6; (total 1/1).

Genus *Prosthemadera* Gray

Prosthemadera novaeseelandiae **(Gmelin, 1788) (Tui)**

Material: Layer 2 – MNZ S39302, pL scap, D10; MNZ S39319, dLdR tmt, dR tt, pR cor, R scap, pL cmc, phal, C10; (total 8/1).

Family Callaeidae

Genus *Heteralocha* Cabanis

Heteralocha acutirostris **(Gould, 1837) (Huia)**

Material: Layer 5 – MNZ S39554, L tt, B8; (total 1/1).

Note: This is the first record for the site.

Genus *Callaeas* J. R. Forster

Callaeas wilsoni **(Bonaparte, 1851) (North Island Kokako)**

Material: Layer 2 – MNZ S39425, pR tmt, C7; MNZ S39318, pL fem, pL ulna, C10; (total 3/1).

Layer 5 – MNZ S38867, pL fem, sR tt, B3; MNZ S38891, pmx, pR tt, B4; MNZ S39415, syn, mand, R scap, C7; MNZ S39599, mand, L ramus, sR tmt, B7; (total 10/3).

Layer 6 – MNZ S39383, R fem, C6; MNZ S39531, R acet pel, B6; (total 2/1).

Genus *Philesturnus* Geoffroy St.-Hilaire

Philesturnus rufusater **(Lesson, 1828) (North Island Saddleback)**

Material: Layer 2 – MNZ S39511, 1pL tmt, B6; MNZ S39317, mand tip, pR tt, C10; (total 3/1).

Layer 4&5 – MNZ S39435, R tt, C7; MNZ S39596, pmx, mand tip, B7; MNZ S39555, mand tip, B8; (total 4/2).

Family Turnagridae

Genus *Turnagra* Lesson

Turnagra tanagra **(Schlegel, 1865) (North Island Piopio)**

Recent studies of the mtDNA of *Turnagra* suggest it is basal to, or the sister group of, the bowerbird and catbird lineage, and not related to the birds of paradise or the pachycephalines (Christidis *et al.* 1996). We follow these authors' suggestion that *Turnagra* be retained in its own family.

Material: Layer 2 – MNZ S39510, 1dR tmt, B6; (total 1/1).

Class Mammalia

Order Chiroptera

Family Mystacinidae

As in many other parts of New Zealand, two species of *Mystacina* are present, distinguished by non-overlapping size ranges (Worthy & Holdaway 1994a, 1995; Worthy *et al.* 1996).

Genus *Mystacina* Gray

Mystacina robusta **Dwyer, 1962 (Greater Short-tailed Bat)**

Material: Layer 5 – MNZ S39356, 2R side mand, pR fem, C6; MNZ S39407, scap, d frag hum, C7; MNZ S39522, R side mand, pt cor, B6; MNZ S39607, L fem, mand, LM1, B7; MNZ S39333, R side mand, B5; MNZ S39564, R fem, B8, (total 11/1); Layer 6 – MNZ S39452, snout of skull, C7; MNZ S39571, 2 manus phalanges, B8; (total 3/1); Layer 7 – MNZ S39497, L hum, C5; MNZ S39587, coracoid, B8, (total 2/1).

Mystacina tuberculata **Gray, 1843 (Lesser Short-tailed Bat)**

Material: Layer 5 – MNZ S39608, 2L side mand, 1frag R side mand with M2-M3, 1dL hum, 1 phal, B7; (total 5/2).

Family Vespertilionidae

Genus *Chalinolobus* Peters

Chalinolobus tuberculatus **(J.R. Forster, 1844) (New Zealand Long-tailed Bat)**

Material: Layer 5 – MNZ S39523, 1pL hum, B6; (total 1/1).

Order Rodentia
Family Muridae

Genus *Rattus* Linnaeus

***Rattus exulans* (Peale, 1848) (Kiore)**

Material: Layer 2 – MNZ S38832, 12 bones, 1 individual, B1; MNZ S39375, 11 bones, C6; MNZ S39429, L mand, rib, caud vert, incisor, C7; MNZ S39612, 20/1 partial skeleton, B7/B8/A8; MNZ S39300, 90 bones, D10; MNZ S39325, 216 bones (10L5R dentaries), C10; (total 353 bones).

Layer 4&5 – MNZ S39305, L mand, L fem, C10; MNZ S39313, 2 bones, C10; (total 4/1).

Note: As C10 and D10 are at the entrance, there was no clear distinction between Layers 2 and 4&5 as Layer 3 (Taupo Ignimbrite) was missing from this part of the site. Layer 1, the organic soil accumulated by stock in the rear of the cave since European farming started, is absent at the entrance. Moreover, the large rocks in this part of the site had crevices around them and *Rattus rattus* had burrowed down around them, as indicated by a collapsed burrow (see below). Therefore, the *R. exulans* bones catalogued as from Layer 4&5 are probably bioturbated from higher layers and not of equivalent age to other components of the fauna from this 'layer'.

Rattus* sp. cf. *R. rattus

Material: C10 in collapsed burrow within Layer 5 – MNZ S39312, several bones from 5 individuals (pups).

Note: The burrow was marked by its unconsolidated, more organic fill than the surrounding sediment. The fill included, apart from the bones, chewed pieces of red plastic tape.

Mus musculus

Material: Upper layer in C10 – MNZ S39326, R dent.

Note: As per the notes under *R. exulans*, the upper layer in C10 probably equates to Layer 2 elsewhere in the site, though the cracks around the rocks and the rat burrow have allowed some 'European period' material to intrude into sediments of primarily older age.

Summary of fauna

The total species diversity among the fossils from Te Waka #1 includes three frogs, one tuatara, at least five lizards (skinks and geckos), 42 birds, and three bats (Table 4). To these can be added falcon as the inferred predator responsible for much of the faunal accumulation. The Te Waka #1 excavations provide information on the adequate sample size necessary to determine the total diversity in a predator site derived from a New Zealand fauna. In a study of the Pyramid Valley fauna, Holdaway & Worthy (1997) used diversity indices and rarefaction curves to suggest that a sample required more than 300 individuals to adequately estimate species richness. Even for the single small predator site of Earthquakes #1 in Otago, Worthy (1998a) showed that total species richness was not ascertained until the sample size exceeded 300 bones. In Te Waka #1, despite the relatively large size of the 1999–2000 excavations (13 m^2, c. 30% of the site area), several taxa recorded in Hartree's excavation were not recovered. These included two moa (*Euryapteryx geranoides, Pachyornis mappini*), the extinct North Island goose (*Cnemiornis gracilis*), Hodgens's waterhen (*Gallinula hodgenorum*), and Stephens Island wren (*Traversia lyalli*). All of these were derived from below our Layer 7, in the zone we sampled least. Conversely, the recent excavations added eight species of birds not recorded in Hartree's excavation.

The total numbers of bones found in each square of the recent excavations for Layers 1–7 (Table 5) show that bones were generally sparse, with a maximum of 369 bones in 1 m^2, and most were towards the back of the cave. The 1999–2000 excavations yielded 1614 bird bones referred to 37 species, or a mean of 43.6 bones per species.

Table 5. Total number of bones from each square for 2017 bones identified from within squares in the 1999–2000 excavations. Squares prefixed with B and C were excavated to and including Layer 7; only BC6, BC7, and D10 penetrated below Layer 7.

Square	B1	B2	B3	B4	B5	B6	B7	B8	C5	C6	C7	C10	D10	BC 6	BC 7
Number of bones	71	46	87	63	67	100	369	274	91	114	291	277	97	5	6

Table 6. Comparison of avian faunas by layers from Te Waka #1 1999–2000 excavations using proportions (rounded to two decimal points) of number of specimens (NISP) and minimum numbers of individuals (MNI).

Species	2 NISP%	4&5 NISP%	6 NISP%	7 NISP%	2 MNI%	4&5 MNI%	6 MNI%	7 MNI%
Anomalopteryx didiformis		5.18				1.67		
Euryapteryx curtus				1.81				2.17
Indet emeid sp.		0.49		0.40				
Dinornis struthoides		1.94				1.67		
Apteryx mantelli		0.97	1.23	2.02		1.67	3.33	4.35
Apteryx owenii				0.40				2.17
Apteryx sp.				0.81				2.17
Pterodroma inexpectata	2.88	2.91	60.12	69.76	9.52	5.00	26.67	41.30
Pterodroma cookii				0.20				2.17
Garrodia nereis				0.40				2.17
Chenonetta finschi			4.29	1.61			6.67	2.17
Coturnix novaezelandiae	7.19	0.16	1.23	1.81	4.76	1.67	3.33	2.17
Aptornis otidiformis		10.36				1.67		
Gallirallus australis	6.47	0.97	1.23	0.20	4.76	1.67	3.33	2.17
Capellirallus karamu		0.32				1.67		
Charadrius bicinctus				0.40				2.17
Coenocorypha barrierensis		0.32		2.22		1.67		2.17
Hemiphaga novaeseelandiae		2.27				5.00		
Strigops habroptilus		1.46	2.45			1.67	3.33	
Nestor meridionalis		1.46	1.23			1.67	3.33	
Cyanoramphus spp.	20.14	13.59	10.43	6.45	14.29	10.00	10.00	4.35
Ninox novaeseelandiae	8.63				4.76			
Aegotheles novaezealandiae	0.72	6.47	1.84	0.81	4.76	5.00	3.33	2.17
Acanthisitta chloris	2.16	10.03	2.45	2.22	4.76	8.33	6.67	6.52
Xenicus spp.	0.72	5.34	4.29	1.81	4.76	6.67	6.67	4.35
Pachyplichas jagmi		0.97	2.45	1.21		3.33	3.33	4.35
Anthus novaeseelandiae		0.49	1.23	2.82		1.67	3.33	4.35
Mohoua albicilla	3.60	7.44	0.61	0.20	9.52	5.00	3.33	2.17
Petroica longipes	1.44	22.82	3.07	2.42	4.76	15.00	6.67	4.35
Petroica toitoi	13.67	0.49			4.76	3.33		
Notiomystis cincta		0.16				1.67		
Anthornis melanura	21.58	0.97	0.61		9.52	3.33	3.33	
Prosthemadera novaeseelandiae	5.76				4.76			
Callaeas wilsoni	2.16	1.62	1.23		4.76	5.00	3.33	
Philesturnus rufusater	2.16	0.65			4.76	3.33		
Turnagra tanagra	0.72				4.76			
Heteralocha acutirostris		0.16				1.67		
Totals	100	100	100	100	100	100	100	100

Hartree's excavations yielded 876 identified bird bones from 31 species, or 28.2 bones per species. Neither collection by itself was sufficient to document the diversity of birds in the site. But it seems that the combined total of 2490 bones for 42 species (59.3 bones per species) is probably not sufficient either. A graph of diversity against sample size for the three faunas does not yield an asymptotic curve. These observations show that, where the living fauna was relatively diverse and predators were responsible for the accumulation of most of the fossil fauna, and where the density of bones in a deposit is low, many square metres may need to be excavated to obtain data that adequately reflect the diversity of the fossil fauna. It may be that, where the potential fauna approaches 50 species, a sample containing an average of more than 60 bones per species must be obtained before the diversity in the site can be estimated. The sample from Earthquakes #1 (Worthy 1998a), with only 329 identified bird bones from 27 species (12.18 bones per individual), thus probably still underestimated the actual diversity in the site.

Faunal composition by species

A notable feature of the total fauna is that several species are represented by the bones, or in some instances a single bone, of an individual. Most such species are large taxa such as the moa (*Anomalopteryx didiformis*, *Euryapteryx curtus*, *Dinornis struthoides*), or *Aptornis otidiformis* and *Cnemiornis gracilis*, and their presence results from the death of an individual in the site. However, *Apteryx owenii*, *Garrodia nereis*, *Fulica prisca*, *Capellirallus karamu*, *Charadrius bicinctus*, *Notiomystis cincta*, *Turnagra tanagra*, and *Heteralocha acutirostris* were each represented in the whole 1999–2000 excavations (some 26 m^3) by one or two bones of a single individual. Large samples are necessary to detect species that are rare in the fossil faunas. In predator-accumulated faunas, however, where only a part of an animal may be brought to the site at any one time, the number of such uncommon species may be more than in pitfall faunas. Most of these taxa are rare in fossil faunas generally, though *Fulica prisca* was common in the riparian sites at Lake Poukawa (Horn 1983) and in the riparian pitfall deposit of Waikari Cave in North Canterbury (Worthy & Holdaway 1996a). The records for *Garrodia nereis* and *Charadrius bicinctus* are the first for the North Island. The record of '*Garrodia nereis*' from Cave 5 at Martinborough, interpreted as a falcon deposit (Yaldwyn 1956), is now referred to *Oceanites maorianus* (Holdaway *et al.* 2001). Both records are significant indicators of palaeovegetation because they indicate that the relatively open habitats that those species prefer, such as tussock, must have been present near the cave in the late Pleistocene.

Faunal composition by layer (Table 6)

Layer 2 was preserved in only a limited area at the rear of the cave, where a low roof protected it from stock trampling. As a consequence, only a relatively small sample of fossil birds was obtained. All the bones were fragmented or digested prey remains, and were typically of forest species. Significantly, there were some bones of *Coturnix novaezelandiae*, which indicate the presence of at least some open, unforested habitat. More open habitats would have been available after the anthropogenic deforestation began about 485–490 CAL yrs BP (Wilmshurst 1997). It is perhaps significant that the *Coturnix* and *Pterodroma* bones recovered from Layer 2 were close to a small (0.5 m wide) hearth that protruded into the southwestern part of B1. This hearth provided evidence that people had used the site for shelter at least once. The presence of moa eggshell in Layer 2 shows that, despite the absence of moa bones, the cave continued to be frequented by moa after the Taupo eruption.

The fauna from Layers 4 and 5 was more diverse (26 taxa of birds) than that from Layer 2, as expected for the much larger sample, but there was a similar assemblage of species typical of forested habitats. Species such as the pigeon (*Hemiphaga novaeseelandiae*), parrots (*Strigops habroptilus*, *Nestor meridionalis*, and *Cyanoramphus* sp.), and most of the passerines are typical of either taller shrubland or forest. *Coturnix* is notably absent from this layer, except for the single bone from the base of Layer 5, which may be derived from Layer 6. However, three bones of one individual pipit (*Anthus novaeseelandiae*) were also found in this layer, which raises the possibility of forest clearings being present nearby.

The fauna from Layers 6 and 7 had a similar diversity to that of Layers 4 and 5, with 23 avian taxa, but differed in the composition and relative abundance of taxa. Most notably, *Pterodroma inexpectata* was the most abundant species, contributing 41% of the fauna in Layer 7 but less than 10% in the Holocene layers. Several taxa make their only appearance in the layers of glacial age (*Apteryx owenii*, *Euryapteryx curtus*, *Pterodroma cookii*, *Garrodia* *nereis, Chenonetta finschi, Charadrius bicinctus*) and to these can be added *Cnemiornis gracilis* and *Gallinula hodgenorum*, both of which were recorded by Hartree from the older layers. Offsetting these additions, several species of passerine are absent from this earlier part of the record, notably *Petroica toitoi, Notiomystis cincta, Prosthemadera novaeseelandiae, Philesturnus rufusater, Turnagra tanagra*, and *Heteralocha acutirostris*, although *Anthornis melanura* and *Callaeas wilsoni* were both present only in Layer 6 and not earlier, which probably indicates they were absent from the area at the glacial maximum.

Discussion

The diet of falcons in prehuman New Zealand

New Zealand falcons are opportunistic hunters of small mammals, birds, and insects (Oliver 1955; Heather & Robertson 1996), but there is little numerical information on their diet (Fitzgerald 1965; Lawrence & Gay 1991; Marchant & Higgins 1993: 282–3; Barea *et al.* 1999). Falcons do hunt at night (Harrow 1976; Noel Hyde, pers. comm. to THW), and they still occasionally prey on petrels on mainland New Zealand (Lawrence & Gay 1991; Marchant & Higgins 1993: 282–3). However, petrel colonies are now rare on the two mainland islands of New Zealand. The only significant colony of smaller petrels is that of Hutton's shearwater (*Puffinus huttoni*) in the Seaward Kaikoura Ranges. But Harrow (1976: 282) recorded there that 'a New Zealand Falcon's feeding station was found in the middle Kowhai Gorge, littered with dismembered parts of *P. huttoni*'. Furthermore, he observed a falcon pursue a departing shearwater in a late-setting full moon near dawn (Harrow 1976). Wilson (1959) recorded that falcons preyed on Cook's petrel (*Pterodroma cookii*) on Codfish Island, off Stewart Island. On the Auckland Islands, falcons regularly catch petrels (Noel Hyde, pers comm. to THW) and can probably hunt during the day over the sea and bring prey back to inland feeding stations, as did peregrines (*Falco peregrinus*) at Suva and Joske's Thumb in Vitilevu, Fiji (Clunie 1972, 1976; Worthy 2000b).

Fossil bones of *Pterodroma inexpectata* and *P. cookii* are widespread on the North and South Islands of New Zealand (Millener 1981; Worthy & Holdaway 2002, and references therein). As petrels provide a seasonally abundant food supply in the area of colonies, it is therefore not surprising that a fossil site resulting from the feeding activities of falcons should be found on the mainland with an accumulation of petrels. Here, we recognise the rich fossil site of Te Waka #1 as one such site. The taphonomic signature on the petrel bones, including the greenstick fractures, digestion features, and element representation described above, clearly indicate the New Zealand falcon as the predator and not the laughing owl or Eyles's harrier. On Te Waka, the sea is too distant for falcons to make diurnal catches over it, so the petrels were necessarily caught en route to or from their colonies at dawn or dusk. That petrels were the main prey implies a seasonal component to the accumulation for most of the fossils in Te Waka #1, because *Pterodroma inexpectata* comes ashore for breeding from December to June and all the birds migrate to the north Pacific for winter (Marchant & Higgins 1990). The seasonality is confirmed by a high proportion of the bones being of fledglings, which would have been only available in autumn.

Faunal Change and the disappearance of *P. cookii*

Pterodroma cookii is present in the Te Waka #1 site only in Layers 7 to 9, from after the deposition of the Kawakawa Tephra about 22 600 ^{14}C yr BP to about 18 000 ^{14}C yrs BP. In contrast, *Pterodroma inexpectata* was present from the earliest period of deposition shortly after 22 600 ^{14}C yr BP, through the LGM, right up until the area was reafforested in the Late Glacial, about 14 000 ^{14}C yrs BP. An explanation may be the different breeding habitats preferred by these species on islands today.

Pterodroma cookii and *P. inexpectata* nest in burrows in very different habitats on Codfish Island, where both species occur (Graeme Taylor, pers comm. 2 June 2001). Without exception, *Pterodroma cookii* nests under closed forest and mainly in relatively sheltered locations, whereas *Pterodroma inexpectata* nests in exposed situations, mainly on southern slopes under shrubs. Marchant & Higgins (1990) recorded the breeding habitat of *P. inexpectata* as usually being on rocky terrain such as cliff tops, rock faces, and steep coastal slopes, as well as on mountain spurs where nests are placed under tussock grass, shrubs, or forest, though it was noted that, on The Snares, closed-canopy *Olearia-Senecio* forest was avoided. Miskelly *et al.* (2001)

noted that, on The Snares, *P. inexpectata* burrows were confined almost exclusively to shallow soil in rocky areas in coastal tussock and under *Hebe elliptica* scrub. On Little Barrier Island, *P. cookii* nests under tall forest (Marchant & Higgins 1990). The difference in nesting habitat may explain why *P. cookii* was present on Te Waka from 22 600 ^{14}C yr BP for at least 3000 years but then disappeared from the record altogether, while *P. inexpectata*, also present in the early record, persisted to the end of the Pleistocene.

The New Zealand temperature record is perhaps best shown by the detailed oxygen isotope studies of speleothems in Nettlebed Cave on Mt Arthur by Hellstrom *et al.* (1998). Their data indicate that the period between the Kawakawa eruption and the LGM saw the $\delta^{18}O$ values change by about 71% of the total variance between those of the present day and the LGM. Assuming that the LGM saw a temperature depression of 4–5°C over most of New Zealand (McGlone 1988; Newnham *et al.* 1999), this suggests that temperatures at the time of the Kawakawa eruption were perhaps about 1–2°C below those of the present. The resulting climate could have been associated with shrubland-forest vegetation on Te Waka. Taken together for the whole period of 22 600–14 000 ^{14}C yr BP, the bird fauna indicates that a complex shrubland-grassland mosaic was present. Habitats for shrub or forest species such as robin, kokako, whitehead, and rifleman were available. At the same time, grassland habitats for taxa such as quail and pipit were also available. The presence of *P. cookii* before the LGM suggests that closed forest or tall shrubland existed in at least some of the valleys around Te Waka #1 then. But the absence of *P. cookii* thereafter suggests that over the LGM the vegetation was reduced to more open shrubland, which was too exposed for *P. cookii*. While there is no evidence that kokako or whitehead were present around the site over the LGM, the presence of robins and rifleman indicates the continued presence of some shrubland. It is noteworthy, however, that both *Garrodia nereis* and *Charadrius bicinctus* were present in the site at the LGM, when vegetation was in its most open state.

Summary

Hartree's excavations of the late 1950s and our more recent ones in 1999–2000 are the largest from a New Zealand cave to date. They have revealed that Te Waka #1 has the most diverse fossil fauna known for a North Island cave site, with three species of frogs, a tuatara, five lizards, 42 birds, and three bats. The fauna is significant as it contains type material for several fossil species, and also represents the first North Island records in some cases. The fossils are inferred to be mostly the prey remains of New Zealand falcons, but some are the result of occasional birds dying in the site. Moa nested in the site throughout the period of deposition. The site has an unparalleled continuous record of faunal deposition for the last 22 000 ^{14}C yrs with stratigraphy controlled by obvious tephras. The fauna indicates the presence of substantial vegetation cover between 22 000 ^{14}C yrs BP and the LGM, sufficient for birds that require tall shrubland or forest to live in. This record therefore reveals faunal changes that are related to a sequence of reduced vegetation cover over the LGM and then reafforestation after 14 000 ^{14}C yrs BP.

Acknowledgements

The excavation in Te Waka #1 could not have occurred without the unstinting help of many people. Foremost are the owners, Perry and Kate King, who facilitated access and helped with a number of logistical matters. We thank the following people for help in the actual excavations: Tony Atkinson, Joanne Cooper, Travis Cross, Nigel Field, Ruth Fulford, Rob MacDonald, Alison Robertson, Dan Smith, Helena Struthers, Alan Tennyson, and Wayne and Margaret Twidle.

We are indebted to John Yaldwyn for giving us his slides from the 1959–60 period of excavation. We also thank Bob Ditchburn (Institute of Geological and Nuclear Sciences, Rafter Laboratory) for discussions about the uranium-series date on the speleothem. We also thank Alan Tennyson, Museum of New Zealand Te Papa Tongarewa, for his help in curating the material. We are indebted to three referees for their comments, which improved the text, and for drawing our attention to some pertinent references.

The study was funded by the Public Good Science Fund of the New Zealand Foundation for Research, Science and Technology, under contracts TWO601, PLC501.

References

Alloway, B.V., Neall, V.E., and Vucetich, C.G. 1995. Late Quaternary tephrostratigraphy of northeast and central Taranaki, New Zealand. *Journal of the Royal Society of New Zealand* 25: 385–458.

Almond, P.C. 1996. Loess, Soil Stratigraphy and Aokautere Ash on Late Pleistocene Surfaces in South Westland, New Zealand: Interpretation and Correlation with the Glacial Stratigraphy. *Quaternary International* 34–36: 163–176.

Andrews, P. 1990. *Owls, Caves and Fossils. Predation, preservation, and accumulation of small mammal bones in caves, with an analysis of the Pleistocene cave faunas from Westbury – sub-Mendip, Somerset,* UK. The University of Chicago Press. 231 pp.

Barea, L.P., Waas, J.R., Thompson, K., and Hyde, N.H. 1999. Diet provided for chicks by New Zealand falcons (*Falco novaeseelandiae*) nesting in forested habitat. *Notornis* 46: 257–267.

Beavan-Athfield, N.R., McFadgen, B.G., and Sparks, R.J. 2001. Environmental influences on dietary carbon and ^{14}C ages in modern rats and other species. *Radiocarbon* 43: 7–14.

Campbell, I.B. 1986. New occurrences and distribution of Kawakawa Tephra in South Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 29: 425–439.

Carter, L., Nelson, C.S., Neil, H.L., and Froggatt, P.C. 1995. Correlation, dispersal, and preservation of the Kawakawa Tephra and other late Quaternary tephra layers in the southwest pacific Ocean. *New Zealand Journal of Geology and Geophysics* 38: 29–46.

Clunie, F. 1972. A contribution to the natural history of the Fiji peregrine. *Notornis* 19: 302–322.

Clunie, F. 1976. A Fiji peregrine (*Falco peregrinus*) in an urban-marine environment. *Notornis* 23: 8–28.

Daugherty, C.H., Patterson, G.B., and Hitchmough, R.A. 1994. Taxonomic and conservation review of the New Zealand herpetofauna. *New Zealand Journal of Zoology* 21: 317–323.

Fitzgerald, B.M. 1965. Prey of a family of New Zealand falcons. *Notornis* 12: 181–184.

Froggatt, P.C. and Lowe, D.J. 1990. A review of late Quaternary silicic and some other tephra formations from New Zealand: their stratigraphy, nomenclature, distribution, volume, and age. *New Zealand Journal of Geology and Geophysics* 33: 89–109.

Harrow, G. 1976. Some observations of Hutton's shearwater. *Notornis* 23: 269–288.

Heather, B.D. and Robertson, H.A. 1996. *The field guide to the birds of New Zealand.* Auckland, Viking. 432 p.

Hellstrom, J., McCulloch, M., and Stone, J. 1998. A detailed 31,000-year record of climate and vegetation change, from the isotope geochemistry of two New Zealand speleothems. *Quaternary Research* 50: 167–178.

Higham, T. 1994. Radiocarbon dating New Zealand prehistory with moa eggshell: some preliminary results. *Quaternary Geochronology* 13: 163–169.

Holdaway, R.N. and Beavan, N.R. 1999. Reliable ^{14}C AMS dates on bird and Pacific rat *Rattus exulans* bone gelatin, from a $CaCO_3$-rich deposit. *Journal of the Royal Society of New Zealand* 29: 185–211.

Holdaway, R.N. and Worthy, T.H. 1996. Diet and biology of the laughing owl *Sceloglaux albifacies* (Aves: Strigidae) on Takaka Hill, Nelson, New Zealand. *Journal of Zoology London* 239: 545–572.

Holdaway, R.N. and Worthy, T.H. 1997. A reappraisal of the Late Quaternary fossil vertebrates of Pyramid Valley Swamp, North Canterbury, New Zealand. *New Zealand Journal of Zoology* 24: 69–121.

Holdaway, R.N., Worthy, T.H., and Tennyson, A.J.T. 2001. A working list of breeding bird species of the New Zealand region at first human contact. *New Zealand Journal of Zoology* 28: 119–187.

Horn, P.L. 1983. Subfossil avian remains from Poukawa, Hawke's Bay, and the first record of *Oxyura australis* (Blue-billed duck) from New Zealand. *Journal of the Royal Society of New Zealand* 13: 67–78.

Kohn, B.P. 1979. Identification and significance of a late Pleistocene tephra in Canterbury district, South Island, New Zealand. *Quaternary Research* 11: 78–92

Lajtha, K. and Marshall, J.D. 1994. Sources of variation in the stable isotopic composition of plants. Pp. 1–21 *In:* Lajtha, K. and Michener, R.H. (*eds.*) *Stable Isotopes in Ecology and Environmental Science.* Oxford, Blackwell Scientific.

Lawrence, S.B. and Gay, C.G. 1991. Behaviour of fledgling New Zealand falcons (*Falco novaeseelandiae*). *Notornis* 38: 173–182.

Lowe, D.J., Newnham, R.M., and Ward, C.M. 1999. Stratigraphy and chronology of a 15 ka sequence of multi-sourced silicic tephras in a montane peat bog, eastern North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 42: 565–579.

Marchant, S. and Higgins, P.J. (co-ordinators) 1990. *Handbook of Australian, New Zealand and Antarctic birds, vol. 1 – Ratites to Ducks.* Melbourne, Oxford University Press.

Marchant, S. and Higgins, P.J. (editors) 1993. *Handbook of Australian, New Zealand and Antarctic birds, vol. 2 – Raptors to Lapwings.* Melbourne, Oxford University Press.

McGlone, M.S. 1988. New Zealand. pp. 557–599. *in:* Huntley, B. and Webb, T. (*eds.*) *Vegetation history.* Dordrecht: Kluwer Academic.

Mew, G., Hunt, J.L., Froggatt, P.C., Eden, D., and Jackson, R.J. 1986. An occurrence of Kawakawa Tephra from the Grey River valley, South Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 29: 315–322.

Millener, P.R. 1988. Contributions to New Zealand's Late Quaternary avifauna. I: *Pachyplichas*, a new genus of wren (Aves: Acanthisittidae), with two new species. *Journal of the Royal Society of New Zealand* 18: 383–406.

Miskelly, C.M., Sagar, P.M., Tennyson, A.J.D., and Scofield, R.P. 2001. Birds of the Snares Islands, New Zealand. *Notornis* 48: 1–40.

Newnham, R.M., Lowe, D.J., and Williams, P.W. 1999. Quaternary environmental change in New Zealand: a review. *Progress in Physical Geography* 23: 567–610.

Nicol, A., Alloway, B.V., and Tonkin, P.J. 1994. Active folding in the Waipara Region of North Canterbury, New Zealand: Implications for Quaternary deformation and Landscape Evolution. *Tectonics* 13: 1327–1344.

Oliver, W.R.B. 1955. *New Zealand birds*. A. H. & A. W. Reed, Wellington. 661 p.

Palmer, A.S. 1982. Kawakawa Tephra in Wairarapa, New Zealand, and its use for correlating Ohakea Loess. *New Zealand Journal of Geology and Geophysics* 25: 305–315.

Parsons, P. 1997. *In the shadow of Te Waka. The history of the Te Pohue district*. CHB Print.

Pillans, B. and Wright, I. 1992. Late Quaternary tephrostratigraphy from the southern Havre Trough – Bay of Plenty, northeast New Zealand. *New Zealand Journal of Geology and Geophysics* 35: 129–143.

Pillans, B., McGlone, M., Palmer, A., Mildenhall, D., Alloway, B., and Berger, G. 1993. The Last Glacial Maxima in central and southern North Island, New Zealand: a paleoenvironmental reconstruction using the Kawakawa Tephra Formation as a chronostratigraphic marker. *Paleogeography, Paleoclimatology, Paleoecology* 101: 283–304.

Sandiford, A., Alloway, B., and Shane, P. 2001. A 28,000 – 6,600 cal.yr record of local and distal volcanism preserved in a paleolake, Auckland, New Zealand. *New Zealand Journal of Geology and Geophysics* 44: 323–336.

Schoeninger, M.J. and DeNiro, M.J. 1984. Nitrogen and carbon isotopc composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48: 625–639.

Schwarcz, H.P. 1980. Absolute age determinations of archaeological sites by uranium dating of travertines. *Archaeometry* 22: 3–24.

Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, F.G., van der Plicht, J., and Spurk, M. 1998. INTCAL98 Radiocarbon Age Calibration, 24,000–0 cal BP. *Radiocarbon* 40(3): 1041–1083.

Suggate, R.P. (editor) 1978. *The geology of New Zealand*. Government Printer, Wellington, New Zealand.

Turbott, E.G. (convener) 1990. *Checklist of the birds of New Zealand and Ross Dependency, Antarctica*. 3rd. ed. Auckland, Ornithological Society of New Zealand and Random Century.

Vucetich, C.G. and Howorth, R. 1976. Proposed definition of the Kawakawa Tephra, the c. 20,000 years-BP marker horizon in the New Zealand Region. *New Zealand Journal of Geology and Geophysics* 19: 43–50.

Vucetich, C.G. and Pullar, W.A. 1969. Stratigraphy and chronology of late Pleistocene volcanic ash beds in central North Island, New Zealand. *New Zealand Journal of Geology and Geophysics* 12: 784–837.

Wilmshurst, J.M. 1997. The impact of human settlement on vegetation and soil stability in Hawke's Bay, New Zealand. *New Zealand Journal of Botany* 35: 97–111.

Wilmshurst, J.M. and McGlone, M.S. 1996. Forest disturbance in the central North Island, New Zealand, following the 1850 BP Taupo eruption, *The Holocene* 6: 399–411.

Wilson, C.J.N. 1993. Stratigraphy, chronology, styles and dynamics of late Quaternary eruptions from Taupo Volcano, New Zealand. *Philosophical Transactions of the Royal Society London A* 343: 205–306.

Wilson, C.J.N. 2001. The 26.5 ka Oruanui eruption, New Zealand: an introduction and overview. *Journal of Volcanology and Geothermal Research* 112: 113–174.

Wilson, C.J.N., Switsur, V.R., and Ward, A.P. 1988. A new ^{14}C age for the Oruanui (Wairakei) eruption, New Zealand. *Geological Magazine* 125: 296–300.

Wilson, R. 1959. *Bird islands of New Zealand*. Whitcomb and Tombs, Christchurch, N.Z.

Worthy, T.H. 1987. Osteological observations of the larger species of skink *Cyclodina* and the subfossil occurrence of these and the gecko *Hoplodactylus duvaucelii* in the North Island, New Zealand. *New Zealand Journal of Zoology* 14: 219–229.

Worthy, T.H. 1994. Late Quaternary changes in the moa fauna on the West Coast of the South Island, New Zealand. Conference on Australasian Vertebrate Evolution, Palaeontology and Systematics, Adelaide, April 1993. *Records of the South Australian Museum* 27: 125–134.

Worthy, T.H. 1997. The Quaternary fossil fauna of South Canterbury, South Island, New Zealand. *Journal of the Royal Society of New Zealand*. 27: 67–162.

Worthy, T.H. 1998a. Quaternary fossil faunas of Otago, South Island, New Zealand. *Journal of the Royal Society of New Zealand* 28: 421–521.

Worthy, T.H. 1998b. The Quaternary fossil avifauna of Southland, South Island, New Zealand. *Journal of the Royal Society of New Zealand* 28: 537–589.

Worthy, T.H. 1999. Changes induced in the New Zealand avifauna by climate during the last glacial – interglacial period. Proceedings of the 4th International meeting of the Society of Avian Paleontology and Evolution. Washington, USA, June 1996. *Smithsonian Contributions to Paleobiology* 89: 111–123.

Worthy, T.H. 2000a. Two late-Glacial avifaunas from eastern North Island, New Zealand – Te Aute Swamp and Wheturau Quarry. *Journal of the Royal Society of New Zealand* 30: 1–26.

Worthy, T.H. 2000b. The prey of peregrine falcons *Falco peregrinus* as determined by skeletal remains from Joske's Thumb, Viti Levu. *Domodomo* 12 [1999]: 44–48.

Worthy, T.H. 2001. A fossil vertebrate fauna accumulated by laughing owls (*Sceloglaux albifacies*) on the Gouland Downs, northwest Nelson, South Island. *Notornis* 48: 225–233.

Worthy, T.H., Daniel, M.J., and Hill, J.E. 1996. An analysis of skeletal size variation in *Mystacina robusta* Dwyer, 1962 (Chiroptera: Mystacinidae). *New Zealand Journal of Zoology* 23: 99–110.

Worthy, T.H. and Holdaway, R.N. 1993. Quaternary fossil faunas from caves in the Punakaiki area, West Coast, South Island, New Zealand. *Journal of the Royal Society of New Zealand* 23: 147–254.

Worthy, T.H. and Holdaway, R.N. 1994a. Quaternary fossil faunas from caves in Takaka Valley and on Takaka Hill, northwest Nelson, South Island, New Zealand. *Journal of the Royal Society of New Zealand* 24: 297–391.

Worthy, T.H. and Holdaway, R.N. 1994b. Scraps from an owl's table – predator activity as a significant taphonomic process newly recognised from New Zealand Quaternary deposits. *Alcheringa* 18: 229–245.

Worthy, T.H. and Holdaway, R.N. 1995. Quaternary fossil faunas from caves on Mt Cookson, North Canterbury, South Island, New Zealand. *Journal of the Royal Society of New Zealand* 25: 333–370.

Worthy, T.H. and Holdaway, R.N. 1996a. Quaternary fossil faunas, overlapping taphonomies, and palaeofaunal reconstruction in North Canterbury, South Island, New Zealand. *Journal of the Royal Society of New Zealand* 26: 275–361.

Worthy, T.H. and Holdaway, R.N. 1996b. Taphonomy of two Holocene microvertebrate deposits, Takaka Hill, Nelson, New Zealand, and identification of the avian predator responsible. *Historical Biology* 12: 1–24.

Worthy, T.H. and Holdaway, R.N. 2000. Terrestrial fossil vertebrate faunas from inland Hawke's Bay, North Island New Zealand. Part 1. *Records of the Canterbury Museum* 14: 89–154.

Worthy, T.H. and Holdaway, R.N. 2002. *The lost world of the moa: Prehistoric life of New Zealand.* Indiana University Press, Indiana.

Worthy, T.H., Holdaway, R.N., Tennyson A.J.D., and Bartle, J.A. in press. First contact to the present, documenting changes in diversity in birds (Class Aves). *The New Zealand Inventory of Biodiversity: A Species 2000 Symposium Review.* Canterbury University Press.

Worthy, T.H. and Mildenhall, D.C. 1989. A late Otiran-Holocene paleoenvironmental reconstruction based on cave excavations in northwest Nelson, New Zealand. *New Zealand Journal of Geology and Geophysics* 32: 243–253.

Worthy, T.H. and Olson S.L. 2002. Relationships, adaptations, and habits of the extinct duck *'Euryanas' finschi. Notornis* 49: 1–17.

Worthy, T.H. and Swabey, S.E.J. in press. Avifaunal changes revealed in Pleistocene–Holocene deposits near Waitomo Caves, North Island, New Zealand. *Journal of the Royal Society of New Zealand.*

Yaldwyn, J.C. 1956. A preliminary account of the sub-fossil avifauna of the Martinborough Caves. *Records of the Dominion Museum* 3: 1–7.

Manuscript submitted December 2001, accepted February 2002.

Appendix 1

Results of radiocarbon analyses. Conventional radiocarbon ages (CRA) in ^{14}C yrs BP for samples from fossil site Te Waka #1. CAL BP is the 1 sigma calibrated calender age in years BP. % collagen is the yield following acid demineralisation of the powdered bone of the sample. Under Locality, Sq = square, L = layer, and -xxxxD is depth below site datum. The locality data given for the Hartree specimens (*Chenonetta finschi*) is all that was recorded for their specimen lots in the Canterbury Museum catalogue.

NZA	CRA	Error	CAL BP	^{13}C	%Coll	%N	^{15}N	C:N	Species	Locality	Notes
12473	14 046	65	17 092–16 601	-8.4	NA	NA	NA	NA	Moa species	Sq B8, L6 (50–100 mm), -2650-2700D	eggshell
12460	18 640	90	21 940–21 246	-15.1	10.9	13.3	20.2	3.2	*Pterodroma inexpectata*	Sq 7BC, L8, -3430D	humerus
12474	14 961	65	17 619–17 103	-15.6	12.9	13.4	20.1	3.3	*Pterodroma inexpectata*	Sq B8, L5-6, -2620D	R cmc
12475	15 746	70	18 550–17 982	-15.7	12.9	14.2	20	3.3	*Pterodroma inexpectata*	Sq B8, L7, -2730D	L ulna
13052	18 755	95	22 180 ±307	-23.6		19.77	3.63	3.01	*Chenonetta finschi*	Hartree Entrance trench	Pt CM Av18468
12962	20 450	100	23 914 ±284	-22.6		16.22	3.86	3.02	*Chenonetta finschi*	'3.0–3.3 m', in Hartree Entrance trench	Pt CM Av26685
12961	17 499	75	20 779 ±441	-23.2		14.79	0.275	3.03	*Chenonetta finschi*	800 mm below red pumice, Hartree Entrance trench	Pt CM Av18479