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The Age of Rat Introduction in New Zealand: Further Evidence from Earthquakes #1, North Otago

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ABSTRACT

Holdaway *et al.* (2002), argue that two Optically Stimulated Luminescence (OSL) dates from the rock shelter site at Earthquakes #1, North Otago, New Zealand, support an inference drawn from the Rafter Laboratory's first series of radiocarbon ages on rat and bird bones, that *Rattus exulans* had reached the site early in the first millennium AD. We raise questions about the stratigraphic integrity of the site and the significance of the OSL dates. We also report four new radiocarbon ages from Earthquakes #1, two each on pigeon and *Rattus exulans* bone. The bird bone ages are effectively identical to results obtained in the first series, but the rat bone ages are much younger than in the first series. We conclude that no secure case for early rat introduction can be derived from the Earthquakes #1 data.

Keywords: NEW ZEALAND, *RATTUS EXULANS*, AMS BONE DATING, OSL DATING.

INTRODUCTION

The age of introduction of *Rattus exulans* (kiore, Pacific rat) to New Zealand has been debated vigorously since 1996 (e.g., Anderson 1996, 2000, 2002; Anderson *et al.* 2001; Beavan-Athfield and Sparks 2001; Beavan-Athfield *et al.* 1999, 2001; Brook 2000; Hedges 2000; Higham and Petchey 2000; Holdaway 1996, 1999; Holdaway and Beavan 1999; Petchey 1999; Smith and Anderson 1998; Yaldwyn 2002). It is an important issue on at least two counts. First, if rats flourished in New Zealand for a millennium or more before the establishment of human settlement and the introduction of additional plant and animal taxa, then the sequence of potential extinctions related to human influence is to some extent divisible analytically, with important consequences for understanding late Holocene ecology. Second, the arrival of people in New Zealand at 2000 BP or earlier, even if they did not survive or remain there, challenges orthodox constructions of Polynesian prehistory, the more so if it is conceded that introductions of rats at different early ages to both main islands and to Norfolk Island (Holdaway 1999) suggest multiple visits or settlement survival over a period of centuries.

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However, the critical and fundamental issue is whether the data which are held to demonstrate the introduction of *Rattus exulans* earlier than the second millennium AD are reliable. Establishing this point is also a matter of some urgency, because differing opinions about it are becoming embedded in the more general ecological and archaeological literature (e.g., Anderson 2003; Worthy and Holdaway 2002), and in the views of the archaeological community in New Zealand, where a recent poll shows a majority in favour of early rat introduction (Prickett 2003).

The most recent argument in favour of that opinion has been advanced by Holdaway *et al.* (2002), who report optical (Optically Stimulated Luminescence or OSL) ages on quartz grains from sedimentary samples obtained at Earthquakes #1. The ages are held to compare favourably with a series of earlier-published (Holdaway 1996, 1999; Worthy 1998) AMS ages on *Rattus exulans* and bird bone gelatin samples, and to validate the argument that *Rattus exulans* arrived in New Zealand about two millennia ago.

Our view is that there are unresolved problems in the stratigraphy of Earthquakes #1 that cast doubt on the rat bone ages and their association with the OSL dates. We have attempted to test part of this argument by obtaining four new AMS ages. These consist of rat and bird bone samples from the upper and lower faunal layers, as those were described by Worthy (1998). We discuss the results in the context of stratigraphic and sampling issues and conclude that neither the AMS ages nor the OSL dates provide the support for early rat introduction that is claimed of them.

STRATIGRAPHIC ISSUES

All the rat bone samples from the Earthquakes #1 rock shelter site were obtained in September 1995 during excavations by Trevor Worthy, Richard Holdaway and Gavin Udy. The excavations were unusually complex for such a small area (just over $1m^2$). The only detailed description (Worthy 1998: 438–443, and see his Fig. 6) recognises six separate units, as follows.

1. 'Test Pit', which was the first excavation of 0.3 x 0.8 m. This was taken out as a single unit and reached unfossiliferous silts at 25–30 cm depth.

2. 'South Excavation' of 0.4 x 0.6 m, which was excavated in spits that also attempted to follow observable stratigraphy. Material was retained in units 0–6 cm, 6–12 cm, and 12–20 cm, which constitute the 'upper faunal layer'. Units 20–33 cm and 33–40 cm constitute the 'lower faunal layer'. The upper faunal layer fell mainly within Layer 1, which extended to 13–18 cm deep. Beneath it was an unfossiliferous layer of silt extending to 24–26 cm (Layer 2), and below that was the reddish layer 3, with scarce faunal remains, continuing down to limestone clasts at 40 cm.

3. 'Baulk' 0.3 m wide between 1 and 2 above. This was excavated to 30 cm and the material added to the Test Pit sample (upper faunal layer).

4. 'Enlarged Test Pit.' Units 1 and 3 above were then excavated to 45 cm deep and the material kept separate.

5. 'North Excavation' of 0.3 x 0.8 m was excavated in spits and the stratigraphy recorded as three layers. Layer 1 was fossiliferous and extended to 25–30 cm; Layer 2 was unfossiliferous and 5–10 cm thick; Layer 3 was of reddish silts with scarce fossils which extended into limestone clasts at about 60 cm. Trowelling through Layer 2 disclosed a burrow filled with layer 1 material. This seems to have angled down to the north, ending in a chamber at about 50 cm depth.

6. 'Against Cliff' was excavated last, in units of 0–5, 5–15, 15–25 and 25–50 cm. The upper three were assigned to the upper faunal layer, which terminated at about 25 cm in the unfossiliferous silts of layer 2. Everything below that point was added to the material from the lower faunal layer in the Enlarged Test Pit (4 above).

Given the number of excavation areas, and the considerable variation in the units of sampling and assignment to layers in a "relatively complex depositional sequence" (Holdaway *et al.* 2002: 500), the disclosure of excavation sections would seem essential, yet none have been published. This is unfortunate because it is apparent from a diagram of spits and layers in the 0.5-m-wide east baulk of South Excavation (Worthy 1998: Figure 6) that the levels of the main layers varied considerably across the excavation, both north-south and east-west, and that they were in turn crossed in some fashion by the burrow. The base of layer 1, for example, varied from 13 cm deep in South Excavation to 30 cm deep in North Excavation, and layer 2 from 5 to 10 cm in thickness.

The burrow, of which much is made by Holdaway *et al.* (2002), was not noticed during excavation of the Test Pit, but it is assumed by the excavators to have existed there. Only the portion of it in North Excavation is recorded. There is no plan or section of the feature, excepting a curious device referred to in the caption of Figure 5 as "dashed lines [that] show approximate location of burrow fill" (Holdaway *et al.* 2002: 469). Here it appears as a stylised slot extending from Layer 1 into layer 3. Worthy's notes (pers. comm. 9 September 2003) refer to it as a tubular feature of 10 cm diameter, which was noticed in North Excavation as trending from the Test Pit at about 30 cm depth. This point is discussed further below.

The same Figure 5 purports to show the north face of North Excavation, but it is not a recorded section of stratigraphy, having no spits, layers, or levels marked on it, and the locations of the samples shown on it have been projected on to the same plane from different locations elsewhere in the excavation. The OSL sampling locations were on the north face, but as Holdaway *et al.* (2002: 472) remark, the early series of rat and bird bone samples was "collected from the north and south excavations and from beneath the test excavation." In other words, the actual locations of the radiocarbon samples, relative to a stratigraphy which varied across the excavation, have simply been collapsed to place everything on the same plane, the so-called 'Section X–X'.

The absence of published sections makes it impossible to map the precise relationship of sampling to excavation units in relation to the stratigraphy, yet potential problems loom in the given descriptions. In 'Against Cliff' for example, the excavation units assigned to the upper and lower faunal layers have no intervening unit, so small bones existing around 25 cm depth, the point to which layer 1 reached, may have ended up in either the upper faunal layer, 0–25 cm, or the lower faunal layer, 25–50 cm. There might be some significance in the fact that rat bones occur in the lower faunal layer only in the collection that includes 'Against Cliff'.

The absence of field-recorded sections in Holdaway *et al.* (2002) makes it difficult to evaluate the relationship between the excavation units and the layers into which they have been combined, and the possibility of mis-assignment of samples. A similar absence of data makes it impossible to understand the precise relationship of the burrow to the layers and excavation units through which it seems to have cut. This is especially important in considering the argument of Holdaway *et al.* (2002: 494) that the burrow was constructed about 1300 BP, because it implies that some of layer 1 had already accumulated and enclosed the older samples NZA-5922 and NZA-5923, near the base of layer 1, before burrowing began. How this could be known is not apparent in the absence of stratigraphic evidence to show from where the burrow was started, and that evidence could not exist if the anterior part of the burrow was destroyed unrecognised, as the authors concede, during excavation of the Test Pit. Is the stratigraphy implied here, then, merely an inference drawn from the age distribution of the dates?

SAMPLING LOCATIONS AND PAIRING

The precise locations of the radiocarbon dating samples reported by Holdaway *et al.* (2002; see also Worthy 1998), are clear in some cases but not in others. The rat bone sample NZA-5920 is reported as from 12 cm depth in an undisturbed part of the site (Holdaway *et al.* 2002: 493), but which part is not disclosed. The pigeon (*Hemiphaga novaeseelandiae*) bone (NZA-5923) came from 25 cm depth in North Excavation, therefore in layer 1, and the rat bone sample NZA-5922 is from the same area and depth. Both are said to be in undisturbed sediments some 5 cm above the burrow and in "a part of the site that has not been disturbed by burrowing" (Holdaway *et al.* 2002: 493). There might have been no evidence of burrowing but NZA-5922 came from a disturbance, represented by the vertical line in Figure 5 (Holdaway *et al.* 2002: 469), extending from about 16 to 24 cm in depth (Worthy 1998: 443). NZA-5923 was located about 40 cm to the west at 25 cm depth (Worthy 1998: 441; Holdaway pers. comm. 15 April 1996) and is therefore not from the same location as NZA-5922.

The kokako (*Callaeas cinerea*) bone (NZA-5927) is shown as located within the burrow in the north face in Figure 5 (Holdaway *et al.* 2002: 469) and Holdaway *et al.* (2002: 493) propose that it might have come from a section of the burrow in Test Pit which was not recognised during excavation. In fact, it came from 50 cm depth in the middle of the Enlarged Test Excavation, near the base of layer 3. It was excavated by Worthy (pers. comm. 9 September 2003), who regards it as having been in a position of original deposition, which was well below the level of the burrow at that point.

A second series of three additional AMS radiocarbon dates (NZA-9619 to 9621) on rat bone samples was obtained by Holdaway *et al.* (2002: 494). These returned much younger ages than those in the first series, all less than 700 BP on calibrated medians (Table 1). Except to say that the samples came from "nearer the cliff" no details of area or depth are given. The authors note that bioturbation was obvious in the locality of the samples, which raises the question of why they selected them for dating. If they were convinced that undisturbed strata existed in the site — the rationale for using OSL dating — then why not take new samples of rat bone for dating from the same place? It is difficult to see the point of obtaining a new series of radiocarbon ages on rat bone from contexts which were believed to be disturbed.

TABLE 1

Results of AMS dating on *Rattus exulans* and bird bone samples from Earthquakes #1 up to 2002.

See text for discussion and Worthy (1998), Holdaway (1996), Holdaway *et al.* (2002) for further details.

Rafter Lab No.	**Taxon**	**CRA**	**δ^{13}C ‰**
NZA-5920	*Rattus exulans*	1130 ± 32	-20.8
NZA-5921	*Rattus exulans*	1405 ± 66	-20.4
NZA-5922	*Rattus exulans*	1747 ± 69	-20.8
NZA-5923	*Hemiphaga novaeseelandiae*	1699 ± 77	-20.4
NZA-5927	*Callaeas cinerea*	1462 ± 71	-21.4
NZA-9619	*Rattus exulans*	516 ± 58	-19.4
NZA-9620	*Rattus exulans*	683 ± 58	-19.3
NZA-9621	*Rattus exulans*	663 ± 66	-19.6

In the light of stratigraphic differences and uncertainties, the argument for pairing the first four rat and bird bone dates (NZA-5921 and NZA-5927; NZA-5922 and NZA-5923) is clearly insecure. The bones were not adjacent in either case, nor in the same features, which is why Figure 5 is quite misleading. The extent of the disturbance that enclosed NZA-5922 is unknown, but the sample could have come from at least as high as 16 cm depth. NZA-5927 has to be assigned to layer 3, whereas the rat bone in the burrow (NZA-5921) is almost certainly from layer 1. Holdaway *et al.* (2002: 494) seek to overcome this difficulty by arguing a stratigraphic case *a posteriori* from the dates.

> The AMS ages of the kokako (TW 96/2 [NZA-5927]) and rat (E1/3 [NZA-5921]) bones are consistent with the bones being emplaced in the burrow fill after deposition of the sediments that comprise OSL sample EQ1-25 and enclose AMS samples E1/4 [NZA-5922] and E1/5 [NZA-5923], and before deposition of the sediments that contain rat bone E1/2 [NZA-5920].

Reconstructing stratigraphic sequences that were not recorded in the field by subsequent appeal to chronology is a dubious procedure at best and the similarity in dates within the two 'pairs' cannot validate stratigraphic integrity or chronometric reliability.

FAUNAL DISTRIBUTION

Holdaway *et al.* (2002: 500) say that an important aspect of their project results is

> ...confirmation of the stratigraphic evidence for no significant bioturbation or major reworking of the part of the deposit that yielded "old" rat bones. The close agreement between the optical and ^{14}C ages provides strong supporting evidence that both dating systems are measuring the true ages of the "target" events at the site, namely the time of burial of faunal remains in primary depositional context.

We have noted already some evidence of disturbance in areas from which the "old" rat bone samples were collected, including the burrow in North Excavation which might have extended into the Test Excavation. There are further data in the faunal evidence, although not all of this is available. Worthy (1998) notes that faunal data from North Excavation were to be produced by Holdaway, but they have not yet appeared, nor are the samples deposited with the other material from Earthquakes #1 in the Otago Museum.

On the present data, there is a difference in faunal representation between the upper (essentially layer 1) and lower (essentially layer 3) faunal layers. This might be due in part to the small sample sizes involved (Worthy 1998), but the lower layer contains some taxa which became extinct on the mainland in pre-European times as the result of *Rattus exulans* predation, and others which cannot survive in the presence of *Rattus exulans*. These data "support the pre-kiore age advocated for the lower layer" (Worthy 1998: 441).

Thirty-two fragments of *Rattus exulans* bone, representing a Minimum Number of 1 Individual, were assigned to the lower layer (Worthy 1998: 516), but these occur only in a collection which includes Against Cliff, an area of notable bioturbation. It seems a reasonable possibility, therefore, that no rat bone was originally deposited in layer 3. Rather, a small quantity may have been taken down to that level by bioturbation, or it has been accidentally incorporated in the lower layer material as a result of the sampling process.

The upper layer contains bones of introduced species — mouse, skylark and blackbird. In both of the excavation units for which data are available, and where material was excavated by spits, remains of introduced taxa occurred deep in layer 1. Skylark (*Alauda arvensis*) occurs to 12 cm in South Excavation, blackbird (*Turdus merula*) to 15 cm in Against Cliff, and mouse (*Mus musculus*) to 25 cm in Against Cliff, i.e., to the bottom of Layer 1 (Worthy 1998: 515–518).

The distribution of *Rattus exulans* bone in the site is similarly interesting. In South Excavation it did not extend below 12 cm, the same depth as the skylark bone. In the Test Excavation it is necessarily (because of the excavation method) recorded as extending to 30 cm, but whether it actually occurred to that depth is unknown. In Against Cliff, where it was most abundant, it occurred frequently down to 25 cm, the same depth as mouse bone.

Disturbance, then, was widespread in the site. Layer 1 material was very probably carried down into layer 3 in the large North Excavation burrow, which had extended unrecognised into the Test Excavation area. Layer 3 material excavated from the burrow is presumably incorporated in layer 1, but at unknown levels, because that at which the burrowing started is not recorded stratigraphically. The burrow was first noticed only at the point at which it crossed the light-coloured silts of layer 2. Consequently, additional disturbance within the relatively dark, organically rich silts of layer 1 could probably not have been distinguished during excavation. Some layer 1 material may have been carried down into layer 3 in Against Cliff. In South Excavation the bones of taxa which were introduced after AD 1850 extend to the same depth as the *Rattus exulans* bones, indicating disturbance over the full depth range of rat bone occurrence. Since there are no data for North Excavation, and the Test Excavation was not recorded by spit, only South Excavation and Against Cliff provide some comparative data within the site. Given that the latter was substantially disturbed, the data from the former might suggest that rat bone was initially deposited only in the upper levels of layer 1 and that all other occurrences of it in the site result from disturbance. Worthy (pers. comm. 8 September 2003) comments that the site, "exhibits obvious and substantial bioturbation" and that is why he confined his faunal analysis to the two main units, upper and lower.

OSL DATES

If, as Holdaway *et al.* (2002) say, the OSL samples were taken from finely-laminated and therefore undisturbed strata, then the results probably indicate the natural age-sequence of the sedimentary deposition. At face value, they suggest that deposition at 25 cm depth (EQ1-25: 1530 ± 170 BP) was occurring around 1500 BP, and at 50 cm depth (EQ1-50: 1980 ± 150 BP) about 2000 BP. These results are held to "broadly confirm the ^{14}C ages for the deposit" (Holdaway *et al.* 2002: 491). It is concluded that:

> ...the bracketing of two "old" ^{14}C ages on Pacific rat bones from the Earthquakes #1 site by optical ages on the enclosing sediments, in combination with concordant AMS ^{14}C ages on two other (herbivorous) species, strongly supports the reliability of AMS ^{14}C ages on Pacific rat bone gelatin and, hence, the presence of Pacific rats in the South Island nearly 1000 years before Polynesian settlement (Holdaway *et al.* 2002: 500).

The meaning of 'bracketing' here is somewhat obscure. Only one of the dating 'pairs' (rat bone NZA-5922 and pigeon bone NZA-5923) is bracketed by the OSL ages which Holdaway *et al.* (1999) prefer. The lower rat bone sample, NZA-5921, is younger even than the upper OSL age, and the kokako bone sample has an AMS age which barely touches the younger limit of the very wide error margin of the upper OSL date. However, Holdaway *et al.* (2002: 491) also suggest that if the soil moisture was higher prior to the removal of forest in the district, then better estimates of the OSL ages might be 1820 ± 220 BP for EQ1-25 and 2350 ± 200 for EQ1-50. If those values were adopted, then only one date, NZA-5922, would overlap at more than a few years with an OSL age.

A further consideration is that if there was no rat bone originally deposited in layer 3, then EQ1-50, which dates that unit, becomes essentially immaterial to the argument about rat bone ages. The only pertinent result would be EQ1-25 from the base of layer 1. However, one date is always a problem, whatever method is used, and it is difficult to understand why no sample was taken from higher in the layer, given that so much is argued to hang on the internal chronology of this unit, including the crucial argument about the level within layer 1 from which the burrow began.

That aside, it is apparent that there is no correspondence of the single OSL date from layer 1 with the enlarged set of rat bone AMS ages from the same layer. These are highly variable (Table 1), and as nearly all of them are from disturbed contexts, there can be no confidence in a depth-age relationship or a comparison with the OSL sequence. In effect, these are two different records; one of undisturbed sediment accumulation on the northwest edge of North Excavation, where it is measured chronologically by OSL dates, and another of samples taken from disturbed layer 1 sediments in at least North Excavation, South Excavation and Against Cliff. Consequently, no stratigraphic measure of chronology is available for them.

NEW AMS RADIOCARBON DATES

Four new samples of bone from Earthquakes #1 were obtained from the Otago Museum and prepared for AMS ^{14}C dating at the Oxford Radiocarbon Accelerator Unit (ORAU). Routine extraction procedures were applied to extract collagen from the bones (Bronk Ramsey *et al.* 2000; Law and Hedges 1989). An ultrafiltration pre-treatment protocol was also applied to purify the bone gelatin further and retain only the >30kD molecular weight fraction for radiocarbon assay (Brown *et al.* 1988; Bronk Ramsey *et al.* 2000). The <30 kD particles may include degraded collagen fragments, salts, sediment particulates and contaminants sometimes of different radiocarbon age. These are removed during ultrafiltration.

We determined the preservation state of the bone by measurement of the atomic ratios of carbon to nitrogen (C:N ratio) and the percentage of extracted collagen from the bones, as well as their stable isotope ratios. C/N ratios were within the 2.9–3.6 range of acceptability for bone collagen used at ORAU (Table 2). Yields of ultrafiltered gelatin which are below 10 mg/g (1% weight collagen) are not dated routinely at ORAU because they indicate poor levels of collagen preservation. All of the ultrafiltered samples were above this threshold (Table 2). Taken together, the bone samples we analysed reflected adequately preserved bone ('transitional' on the scale of Hedges and van Klinken [1992]) with the exception of OxA-10882, and therefore the expectation is for reliable AMS results for these samples. OxA-10882 was of 'poor' preservation but not below our threshold for acceptability; in addition, the C/N ratio was normal and the % carbon as expected for collagen, therefore the sample was dated.

TABLE 2

Analytical data and radiocarbon ages for additional samples from Earthquakes #1 site. pyield = absolute collagen yield and see text for discussion; % Coll = Percent by weight of collagen; % C = Percent carbon combusion.

OxA No.	CRA	C/N	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰	Wgt mg	pyield	% Col	% C
10882	840 ± 45	3.2	-20.0	9.194	68.45	1.74	2.54	39.9
10878	1739 ± 33	3.3	-20.3	5.313	256.00	25.97	10.1	41.8
10879	1089 ± 33	3.1	-19.7	8.728	60.78	7.26	11.9	39.7
11546	1749 ± 29	3.2	-19.8	3.895	248.39	35.9	14.4	43.3

Sample catalogue reference and material: OxA-10882 VT774, (1, 0–300 mm) Test Trench, *Rattus exulans* shaft of femur. OxA-10878 AV8058, (1, 0–300 mm) Test Trench, *Hemiphaga novaeseelandiae* proximal coracoid. OxA-10879 VT811, (3, 250–600 mm) Against Cliff, *Rattus exulans* shaft of femur. OxA-11546 AV8128, (3, 250–600 mm) Against Cliff, *Hemiphaga novaeseelandiae* proximal carpometacarpus.

The >30kD fraction was lyophilised and mass spectrometrically analysed using a Europa Scientific ANCA-MS system consisting of a 20-20 IR mass spectrometer interfaced to a Roboprep CHN sample converter unit operating in continuous flow mode. CO_2 from the combustion was cryogenically distilled and graphite was prepared by reduction of CO_2 over iron within an excess H_2 atmosphere. Graphite targets were then AMS radiocarbon dated (Bronk Ramsey and Hedges 1997). Small samples of CO_2 (<1.6 mg C) were dated directly as CO_2 using the ORAU gas ion source (Bronk Ramsey and Hedges 1997). Values of $\delta^{13}C$ in this paper are reported in per mille (‰) with reference to VPDB and $\delta^{15}N$ results are reported with reference to AIR (Coplen 1994). Table 2 shows the sample details and results for four AMS radiocarbon ages from the University of Oxford Radiocarbon Accelerator Unit.

The ultrafiltration pretreatment applied to bone at ORAU has recently been found to add a small amount of contamination derived from the manufacturing process of the filters.

Bronk Ramsey *et al.* (n.d.) identified this as glycerin, used as a humectant to maintain the regenerated cellulose filter membranes. The amount of extractable carbon measured from the membrane averaged 40 μg C and was determined to be of infinite radiocarbon age, which means that it will be insignificant in its effect on very old bones and on bones of more recent age whose collagen yield is higher (>25–30 mg collagen). However, bones which are of Holocene age and which produce low amounts of collagen (-10 mg collagen) can be significantly affected. A new protocol for cleaning the filters has been developed to overcome this problem. It results in very reproducible dates, but bones dated previously at ORAU incorporate some error due to old carbon. The extent of the error is dependent upon the size of the pretreated yield of collagen.

Two of the samples in Table 1 are almost certainly affected by humectant carbon. OxA-10882 and 10879 are both likely to be too old by between one and four centuries, a range based on our experience of this error in other samples of comparable size and age which we have been able to re-date. The rat ages in Table 2, therefore, are maximum possible ages. Actual ages are certainly not older and, in fact, are likely to be significantly younger than those given.

DISCUSSION AND CONCLUSIONS

It is apparent that there are severe impediments to accepting the arguments advanced by Holdaway *et al.* (2002), and our additional data make acceptance no easier. If OxA-10879 is on material which was deposited originally in layer 3, then it is younger than the only other probable layer 3 AMS date (NZA-5927), and much younger than the OSL date EQ1-50. If it is from material that originated in the base of layer 1, then it is still significantly younger than the upper OSL age EQ1-25 and all the original series of bird and rat bone AMS dates. On the other hand, the new rat bone AMS dates reported here fall towards the younger ages represented in the second series (Table 1: NZA-9619–9621) obtained by Holdaway *et al.* (2002), rather than the first series from the site (Holdaway 1996). This raises again the much-debated issue of whether the "old" rat bone ages measured in 1995–1996 by the Rafter Laboratory are in some way flawed (Anderson 2000).

The correspondence between AMS ages on bird bone in the first date series and our results is intriguing in several ways. It is relevant to the question of whether variation in rat bone AMS ages has some basis in dietary variation (Anderson 1996; Beavan-Athfield *et al.* 2001; Holdaway *et al.* 2002) which is not expressed in results from obligate herbivores, such as pigeon. It also complicates the chronology of the Earthquakes #1 site. If, on the face of the pigeon bone dates, the age of all the original stratigraphy up to at least the lower levels of layer 1 was around 1400–1700 cal BP, then a very rapid rate of sediment accumulation is implied, which is inconsistent with the variation in fauna between the upper and lower layers (Worthy 1998). The alternative propositions may be that all three pigeon bone samples (possibly from the same individual) were originally from layer 3 and two of them were moved into layer 1, or that all three were originally in layer 1 and one has been moved into layer 3. Either way, there is poor agreement with the kokako bone date (NZA-5927), the rat bone AMS dates or the lower OSL date. Perhaps this demonstrates nothing more than that the Earthquakes #1 data are not capable of resolving the issues to which they have been applied.

We suggest that one possible model which would accommodate all the current data is as follows. The basic sedimentary accumulation in Earthquakes #1 occurred according to the

OSL chronology, and layer 3 is wholly of pre-rat age, as originally argued by Worthy (1998) on the basis of the presence of snipe (*Coenocorypha* sp. cf. *aucklandica*), saddleback (*Philesturnus carunculatus*) and owlet-nightjar (*Aegotheles novaezealandiae*) in that layer, and the declining numbers of tuatara (*Sphenodon* sp.) and Duvaucel's gecko (*Hoplodactylus* sp. cf. *duvaucelii*) from the lower to the upper layers generally. During the accumulation of layer 1, at some point which was probably within the second millennium AD, rat bones began to be deposited, possibly at the 12 cm level as indicated by South Excavation. Subsequent bioturbation distributed rat bone through layer 1, down into the burrow and possibly through layer 2 at other points. The same process brought older bird bone from layer 3 into layer 1. Continuing bioturbation after AD 1850 began distributing remains of modern taxa through layer 1. The rat bone dates of the first series are too old, as has been argued (Anderson 2000) of nearly all that were produced by the Rafter Laboratory at that time. Dates obtained later, which are reported by Holdaway *et al.* (2002) and in this paper, provide an approximate age for early rat introduction, although we suspect that OxA-10879 and OxA-10882 are somewhat too old, for a reason described above and elaborated in Bronk *et al.* (n.d.). We emphasise that this scenario is merely conjecture, but it will serve to indicate that the current data need not be taken as consistent with only one explanation. We conclude as follows.

1. Data published on the Earthquakes #1 excavation remain inadequate to enable evaluation of the site stratigraphy, the sampling protocol or the provenance of the bone samples dated by Holdaway (1996; Holdaway *et al.* 2002).

2. There is no clear evidence to indicate that *Rattus exulans* bone was deposited originally in layer 3. It was more probably confined to layer 1. Faunal data from North Excavation, when they are made available, may indicate the validity or otherwise of this conclusion.

3. Layer 1 has undergone substantial disturbance, probably by bioturbation. This is not confined to areas against the cliff face. Remains of animals introduced after about AD 1850 occur in several excavation units reaching deep into layer 1. In addition, there is a major disturbance in North Excavation represented by the burrow, which may have been more extensive. Rat remains might have been moved down to layer 3 in Against Cliff or to beneath the Test Excavation, and bird bones from layer 3 may have been re-deposited in layer 1 (Worthy 1998) in North Excavation and Against Cliff. As one of the original excavators, Worthy was of the view that the site was substantially disturbed.

4. It is impossible, on the available evidence, to determine the original depths within layer 1 at which any of the AMS rat bone samples were deposited. This information is not available for OxA-10879, OxA-10882, NZA-9619, NZA-9620 or NZA-9621. NZA-5921, in the burrow, has been shifted from its original position, NZA-5922 is from a disturbance of unreported extent, and NZA-5920 is from within the depth at which remains of all three introduced animals occur. There is, in addition, no apparent age-depth association amongst the AMS ages on rat bone. A correlation was argued for the first series of dates but it depended solely upon an assumption about the depth from which the burrow was cut.

5. The alleged pairing of rat and bird bone AMS ages, crucial to the argument of Holdaway *et al.* (2002) about the validity of the results, has not been demonstrated in the stratigraphy and excavation areas of the site and is inconsistent with various stratigraphic data. The association is actually one of excavation depth which, collapsed into a single plane, ignores the spatial variation in sample occurrence.

6. The relationship of the paired AMS dates to the excavation of the burrow, as concluded by Holdaway *et al.* (2002), appears to have been made *ex post facto*, by reviewing the radiocarbon results. In any event, the critical argument concerning these data is circular: the AMS dates are used to propose a stratigraphic sequence involving the burrow which is then adopted to validate the acceptability of the AMS dates.

7. As in other cases (Anderson 2000), the three rat bone samples from layer 1 which were dated in the first series from the site provided AMS results which were not duplicated by three later AMS dates from the same layer by the same laboratory, nor by AMS dates on rat bone from layers 1 and 3 by a different laboratory.

8. The upper OSL date refers to undisturbed stratigraphy, the relationship of which to the disturbed stratigraphy of much of layer 1, in which the rat bone occurred, is unknown. The date bears no particular relationship to any of the eight AMS ages for layer 1. The lower OSL date is effectively irrelevant.

9. Given that numerous problems are evident in stratigraphy and chronology of Earthquakes #1, and as other explanations for the current data are possible, there is no need to accept the hypothesis advanced by Holdaway *et al.* (2002). Their conclusion that "the series of ages from Earthquakes #1 shows that bones older than Polynesian settlement exist in New Zealand…" (Holdaway *et al.* 2002: 500) is not demonstrated by their data and arguments, nor is it supported by the critique and new data presented here.

10. It remains the case, therefore, that the only evidence to suggest an early introduction of rats to New Zealand is the first series of radiocarbon dates on rat bone produced by the Rafter laboratory in 1994–1996. Some of these were of archaeological provenance, and numerous samples dated subsequently from the same contexts indicate that the early results are wrong (Anderson 2000). Almost no attempt has been made to test the reproducibility of natural site results from the first series. Earthquakes #1 is now the exception, and the relatively late ages on rat bone samples submitted by us and by Holdaway *et al.* (2002) conform with the archaeological experience that the Rafter Laboratory's first series of rat bone AMS ages cannot be duplicated.

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REFERENCES

Anderson, A.J. 1996. Was *Rattus exulans* in New Zealand 2000 years ago? AMS radiocarbon ages from Shag River Mouth. *Archaeology in Oceania* 31: 178–184.

Anderson, A.J. 2000. Differential reliability of ^{14}C AMS ages of *Rattus exulans* bone gelatin in south Pacific prehistory. *Journal of the Royal Society of New Zealand* 30: 243–261.

Anderson, A.J. 2002. Rat bone, recollection and record. *Archaeology in New Zealand* 45: 216–219.

Anderson, A.J. 2003. Uncharted waters: colonization of remote Oceania. *In* M. Rockman and J. Steele (eds), *Colonization of Unfamiliar Landscapes,* pp. 169–189. Routledge, London.

Anderson, A.J., Higham, T.G. and Wallace, R. 2001. The radiocarbon chronology of the Norfolk Island archaeological sites. *In* A.J. Anderson and J.P. White (eds), *The Prehistoric Archaeology of Norfolk Island, Southwest Pacific,* pp. 33–42. Supplement 27, *Records of the Australian Museum*, Sydney.

Beavan-Athfield, N.R.B., McFadgen, B. and Sparks, R. 1999. Reliability of bone gelatin AMS dating: *Rattus exulans* and marine shell radiocarbon dates from Pauatahanui midden sites in Wellington, New Zealand. *Radiocarbon* 41: 119–126.

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

Beavan-Athfield, N.R.B. and Sparks, R. 2001. Dating of *Rattus exulans* bone from Pleasant River (Otago, New Zealand): testing the effect of burial contamination. *Journal of the Royal Society of New Zealand* 31: 795–800.

Bronk Ramsey, C. and Hedges, R.E.M. 1997. Hybrid ion sources: Radiocarbon measurements from microgram to milligram. *Nuclear Instruments and Methods in Physics Research B* 123: 539–545.

Bronk Ramsey, C., Higham, T.F.G. and Hedges, R.E.M. n.d. Improvements to the pre-treatment of bones for AMS radiocarbon dating at Oxford. *Radiocarbon* (forthcoming).

Bronk Ramsey, C., Pettitt, P.B., Hedges, R.E.M., Hodgins, G.W.L. and Owen, D.C. 2000. Radiocarbon dates from the Oxford AMS system: Archaeometry Datelist 30. *Archaeometry* 42: 459–479.

Brook, F.J. 2000. Prehistoric predation of the landsnail *Placostylus ambagiosus* Suter (Stylommatophora: Bulimulidae), and evidence for the timing of establishment of rats in northernmost New Zealand. *Journal of the Royal Society of New Zealand* 30: 227–241.

Brown, T.A., Nelson, D.E., Vogel, J.S and Southon, J.R. 1988. Improved collagen extraction by modified Longin method. *Radiocarbon* 30: 171–177.

Coplen, T.B. 1994. Reporting of stable hydrogen, carbon and oxygen isotopic abundances. *Pure and Applied Chemistry* 66: 273–276.

Hedges, R.E.M. 2000. Appraisal of radiocarbon dating of kiore bones (Pacific rat, *Rattus exulans*), in New Zealand. *Journal of the Royal Society of New Zealand* 30: 385–398.

Hedges, R.E.M. and van Klinken, G.J. 1992. A review of current approaches in the pretreatment of bone for radiocarbon dating by AMS. *Radiocarbon* 34: 279–291.

Higham, T.G. and Petchey, F.J. 2000. On the reliability of archaeological rat bone for radiocarbon dating in New Zealand. *Journal of the Royal Society of New Zealand* 30: 399–409.

Holdaway, R.N. 1996. The arrival of rats in New Zealand. *Nature* 384: 225–226.

Holdaway, R.N. 1999. A spatio-temporal model for the invasion of the New Zealand archipelago by the Pacific rat *Rattus exulans*. *Journal of the Royal Society of New Zealand* 29: 91–105.

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., Roberts, R.G., Beavan-Athfield, N.R., Olley, J.M. and Worthy, T.H. 2002. Optical dating of quartz sediments and accelerator mass spectrometry ^{14}C dating of bone gelatin and moa eggshell: a comparison of age estimates for non-archaeological deposits in New Zealand. *Journal of the Royal Society of New Zealand* 32: 463–505.

Law, I.A. and Hedges, R.E.M. 1989. A semi-automated bone pretreatment system and the pretreatment of older and contaminated samples. *Radiocarbon* 31: 247–253.

Petchey, F.J. 1999. New Zealand bone dating revisited: a radiocarbon discard protocol for bone. *New Zealand Journal of Archaeology* 19: 81–124.

Prickett, N.J. 2003. First settlement date and early rats: an opinion poll. *Archaeology in New Zealand* 45: 288–292.

Smith, I.W.G. and Anderson, A.J. 1998. Radiocarbon dates from archaeological rat bone: the Pleasant River case. *Archaeology in Oceania* 33: 88–91.

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

Worthy, T.H. and Holdaway, R.N. 2002. *The Lost World of the Moa: Prehistoric Life of New Zealand.* Canterbury University Press, Christchurch.

Yaldwyn, J.C. 2002. The match box — the rat bone — the Hukanui #7b excavations 1959. *Archaeology in New Zealand* 45: 118–127.

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