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The chronology of occupation at Teouma, Vanuatu: Use of a modified chronometric hygiene protocol and Bayesian modeling to evaluate midden remains

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ABSTRACT

A number of radiocarbon dates, both published and unpublished have been obtained from archaeological deposits across the Teouma site on the island of Efate in Vanuatu. These are on a range of materials from the midden and associated cemetery including charcoal (13) and shell (7) as well as a number of less commonly dated ^{14}C sample types including bone from 2 terrestrial giant tortoises (?*Meiolania damelipi*), 8 pigs (*Sus scrofa*) and 2 chickens (*Gallus gallus*). Thirty-six human bone collagen dates and 5 *Conus* sp. shell ring artifacts from the cemetery context have been discussed in detail elsewhere (Petchey et al., 2014). In this paper, we evaluate the radiocarbon data according to observed contextual associations and established understandings of ^{14}C offsets, and collate all available information in a Bayesian framework to establish the age and duration of the settlement at Teouma. This analysis provides a maximum age range for the Lapita deposits of between 3000 and 2560 cal BP and a most likely start date of 2920–2870 cal BP and end date of 2870–2750 cal BP (68.2% prob.). This is slightly younger age for the deposits than previously reported, but is in keeping with evaluation of the burials themselves, the majority of which are dated to between 2940 and 2720 cal BP. This age range indicates that the site was in use at the same time as colonization events in Tonga (2850–2830 cal BP) and Fiji (3020–2860 cal BP), and supports the hypothesis that Vanuatu was at the center of a region-wide interaction sphere for several generations after initial settlement.

1. Introduction

The Teouma site is located on the south coast of Efate Island, Vanuatu, 800 m from Teouma Bay (Fig. 1).

Excavations took place between 2004 and 2010 (Bedford, 2006; Bedford et al., 2009, 2010) during which 68 burial features, concentrated in a band running northeast to southwest, parallel to the former beach, were uncovered. There are two key zones of the site that have been extensively dated; the Cemetery Zone and the Midden Zone located to the east of the Lapita cemetery (Fig. 2). The Lapita midden contained a number of domesticated species (i.e., *Sus scrofa*, *Gallus gallus* and the commensal *Rattus exulans*), as well as a large number of bones from indigenous birds and animals, many now extinct, including fruit bats (Pteropodidae), flying fox (*Pteropus* sp.), land tortoise (?*Meiolania damelipi*), and crocodile (*Mekosuchus kalpokasi*) (Bedford et al., 2009; Valentin et al., 2010:1826). Layer 3 of the Midden Zone (MZ3) deposit was considered to be contemporary with Layer 3 of the cemetery (CZ3) because it largely respected the cemetery boundary and contained substantial amounts of extinct fauna as well as obsidian from New Britain deposited on top of an orange/yellow tephra (Spriggs and Bedford, 2013). Layer 2 of the Midden Zone (MZ2) seems to have been contemporary with the cemetery but also likely associated with terminal Lapita midden dumping that extended on top of the cemetery (i.e., Cemetery Zone Layer 2/3 transition [CZ2/3]). These thin deposits are considered to immediately post-date the cemetery because the midden caps the burials but still contains ceramics of Lapita affiliation and substantial quantities of extinct fauna. A later midden deposit (Layer 2 Cemetery Zone [CZ2]), up to 50 cm thick, covered the cemetery and extended downslope over the former beach. This is associated with Arapus and Early Erueti ceramics currently dated to c. 2800–2500 BP[1] (Bedford et al., 2009:219–221). Layer 1 from both zones has not been dated. It represents natural post-occupation

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[1] Arapus ceramics are characterized as plain globular cooking pots with out-curving rims and notching on the lip, and are associated with immediately Post-Lapita settlements on Efate. Over time Arapus rims and associated lip form changed into very distinctive wide and flat forms that have been termed Early Erueti ceramics, a phase succeeded by Late Erueti ceramics at about 2500 BP (Bedford, 2006:161).

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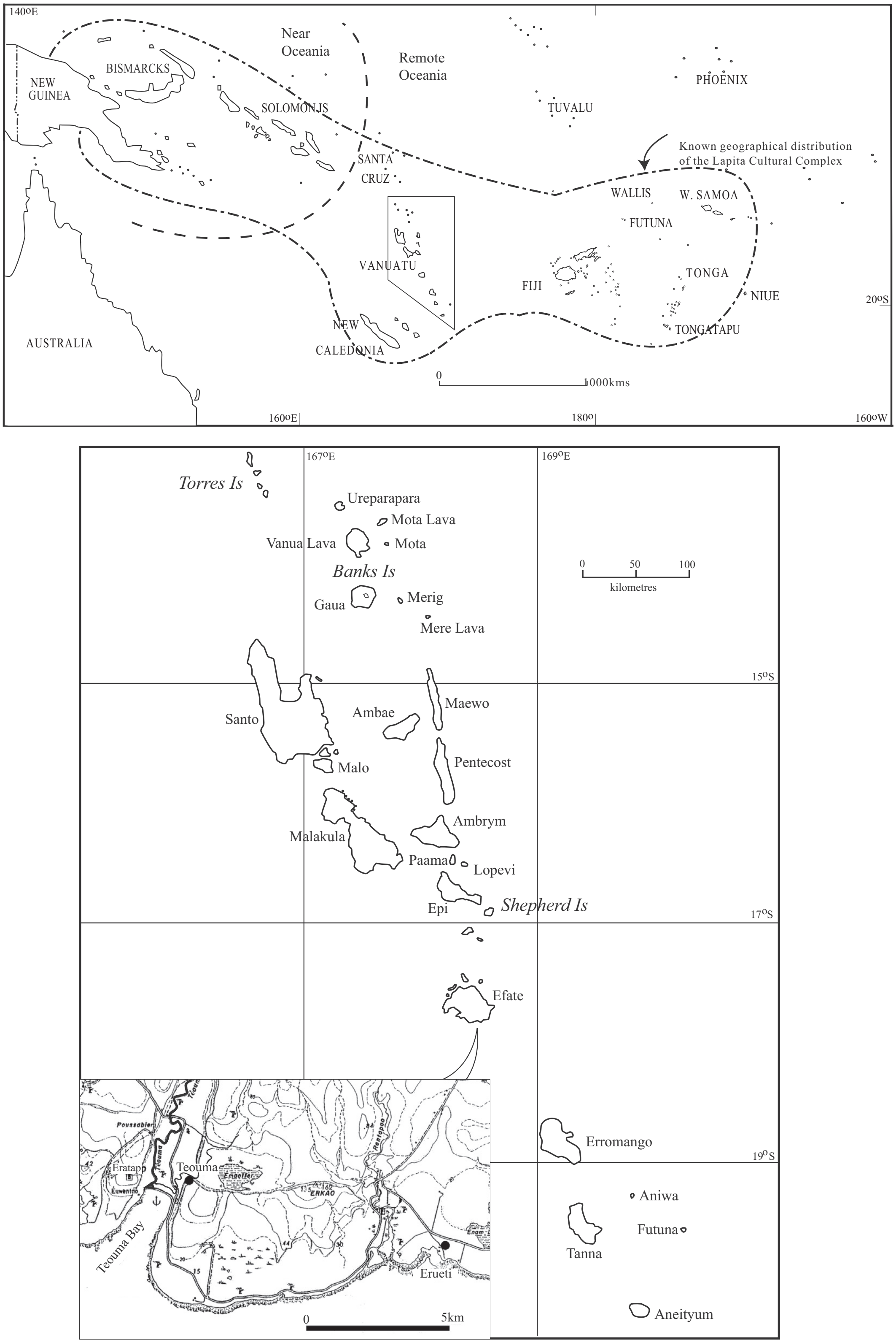

Fig. 1. Map of Remote Oceania showing location of Vanuatu. Insert: The Teouma archaeological site.

accumulation, rich in tephra, but also some earlier material brought up from lower levels of the site.

Preliminary dating of the site using charcoal suggested it was first used c. 3200–3000 cal BP (Bedford et al., 2006:818). Analysis of the Lapita ceramics indicated they were of Western or Middle Lapita style transitioning from Early or Far Western that had general similarities to ceramics from the Reef/Santa Cruz Group and New Caledonia, while in CZ2/3 there were some sherds with Late or Eastern style Lapita. The mix of older styles, exotic ceramics, simplified dentate-stamped designs and incised and shell impression wares all support the hypothesis that Teouma represents an early phase of expansion into Remote Oceania with some continued interaction with the wider region that was

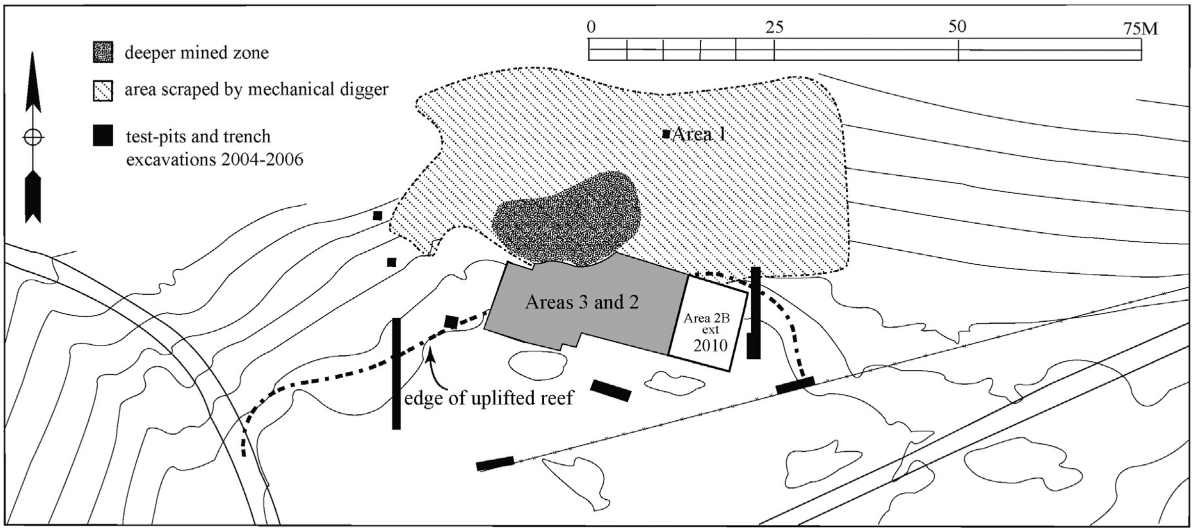

Fig. 2. Teouma excavations showing location of the Cemetery Zone (Areas 3 and 2) in relation to the Midden Zone (Area 2B extension and adjacent trench) as discussed in the text.

ongoing for a few hundred years (Bedford et al., 2009:225–6). An extensive dating program has since been undertaken at the site on a range of materials including charcoal and marine shell, as well as human, terrestrial native fauna and domesticate bones. This program includes samples from the Lapita cemetery (CZ3), the contemporary midden that abuts up against the cemetery boundary (MZ3 and MZ2), the immediately post-cemetery midden (CZ2/3 and CZ2), and burials found in shallow deposits 70 m to the south and southeast of the Lapita cemetery that are believed to be of Early Erueti age. Chronological evaluation of this information poses a number of challenges, including: the calibration of remains that have a mixed dietary ^{14}C input (domesticates and human bones); the establishment of suitable local marine reservoir offsets (commonly referred to as ΔR) for different shell species; the likelihood of inbuilt age[2] in wood charcoal that has not been identified as short-lived species, nuts or twigs; and heirloom effects for shell adornments associated with the burials.

This paper is a collation of both published and unpublished dates from various deposits across the site, both Lapita and immediately post-Lapita. All results are evaluated according to current understanding of natural ^{14}C parameters and observed contextual associations and evaluated in a Bayesian framework to establish the age and duration of site use.

1.1. Sample selection

A total of 47 radiocarbon dates have been obtained for the Lapita cemetery, including 37 human bone - one of which was a cremation burial; 5 *Conus* spp. arm band ornaments in direct association with burials 4, 11, 17, 58 and 59; a chicken associated with the fill of burial 50; 2 pig bones; a *Turbo argyrostomus* shell date and one charred nutshell date from the fill of burial 67. A further 10 dates have been obtained from the contemporary adjacent (Layer 3) midden deposits (MZ3). These include 6 nut charcoals, 2 unidentified wood charcoal, and 2 pig bone dates. From the Layer 2 midden (MZ2) there are 2 charred nut and one pig date. A further 11 dates are from the Layer 2/3 transition Cemetery Zone midden (CZ2/3). The samples include 2 unidentified wood charcoals, one chicken bone, 3 pig bones, 4 marine shell samples (3 *T. argyrostomus* and 1 *Trochus niloticus*) and 2 tortoise bones. A single *T. argyrostomus* shell date comes from the CZ2 deposits considered to belong to the Arapus phase. Seven burials from later deposits to the south and southeast were dated for comparison with the Lapita remains.

This wide range of material includes what are commonly termed "novel" ^{14}C sample types — that is samples that have not been thoroughly tested by the comparison with reliable short-lived materials from secure stratigraphic contexts in order to assess likely issues and offsets that may affect the calibrated radiocarbon ages. The evaluation of samples at the Teouma cemetery presented here does not constitute such a robust test. Instead, our evaluation implements various assumptions and results of current theories regarding different ^{14}C sample types within a real archaeological situation to demonstrate the potential shortcomings of our current knowledge, but at the same time show the value of different sample types to the evaluation of Pacific chronologies.

1.2. Radiocarbon preparation

Radiocarbon dates were prepared and analyzed at the University of Waikato Radiocarbon facility in New Zealand (Wk–),[3] the Australian National University Radiocarbon facility (SANU–) and the Rafter Radiocarbon laboratory (Geological and Nuclear Sciences, New Zealand; NZA–) following standard accelerator mass spectrometry (AMS) protocols, whereby the shells were washed in dilute HCl to remove surface contamination, and charcoal samples were treated with a series of dilute HCl, multiple NaOH and HCl washes prior to CO_2 collection (UCI, 2006). All Waikato shells were tested for recrystallization prior to dating using the Feigl staining technique (Friedman, 1959). Bone dates were prepared at Waikato following bone ultrafiltration methodologies outlined in Bronk Ramsey et al. (2004) and Petchey et al. (2011). Chicken bone (NZA-29,450) was prepared as per Beavan Athfield and Sparks (2001) and Beavan Athfield et al. (2008). Unmodeled (dietary and/or reservoir corrected, as per discussions below) calibrated radiocarbon dates are given in Table 2. Radiocarbon information is given in Table 1.

All ultrafiltered gelatin was assessed for purity prior to analysis using standard % gelatin yield, %N, %C and C:N quality assurance parameters (see Petchey et al., 2014). Waikato gelatin stable isotope measurements used for dietary reconstruction and quality assurance (QA) were

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[2] Radiocarbon results of wood charcoal samples may be influenced by inbuilt age if they originate from long-lived species (Allen and Wallace, 2007), or by "storage age" if the species selected is resistant to weathering and decay, or if stored wood is burned (Schiffer, 1987).

[3] Waikato AMS graphite targets were measured at the Keck Radiocarbon Laboratory, University of California, Irvine, United States and GNS Science, Wellington, New Zealand.

Table 1
Radiocarbon ages for bone, charcoal and shell from the Teouma archaeological site.

Sample ID	Context	Material	CRA (BP)	$\delta^{13}C$ (‰) ± 0.2 (IRMS)[a]	Unmodeled cal BP (68.2% prob.)	Unmodeled cal BP (95.4% prob.)
Cemetery Zone (Layer 3) burial associated						
Wk-21030	Burial 26 (cremation)	Human bone carbonate	2850 ± 24	−25.3	3000–2890	3060–2870
Wk-15729	Ornament associated with Buria1 11	Shell (*Conus* sp.)	3162 ± 34	3.0	2990–2820	3070–2750
Wk-16831	Ornament associated with Burial 4	Shell (*Conus* sp.)	3139 ± 36	1.9	2950–2790	3040–2740
Wk-37680	Ornament associated with Burial 17 in secondary context	Shell (*Conus* sp.)	3100 ± 23	3.1	2880–2750	2960–2720
Wk-37682	Ornament associated with Burial 58	Shell (*Conus* sp.)	3107 ± 23	3.8	2890–2760	2970–2730
Wk-37681	Ornament associated with Burial 59	Shell (*Conus* sp.)	2959 ± 22	2.7	2760–2610	2800–2510
Wk-25198	Associated with B50 fill	Chicken (*Gallus gallus*)	2944 ± 30	−18.5	3030–2870	3150–2830
SANU-22513	Layer 3 (fill in Burial 67 grave)	Charcoal (nut)	2780 ± 30	–	2950–2840	2960–2790
Cemetery zone (Layer 3) non-burial contexts						
Wk-16830	Midden	Wood charcoal (unidentified)	2961 ± 36	−25.5	3180–3060	3230–2990
SANU-12025	Layer 3	Shell (*Turbo argynostomus*)	3220 ± 25	–	3060–2890	3150–2830
Wk-28389	Layer 3, Spit 2	Pig bone (*Sus scrofa*)	2802 ± 30	−19.9	2960–2840	3070–2770
NZA-29450	Layer 3, atop Burial 50	Chicken (*Gallus gallus*)	2747 ± 30	−20.5	2870–2790	2930–2760
Cemetery Zone midden (Layer 2/3) caps the cemetery						
Wk-28386	Layer 3, Spit 1?	Pig bone (*Sus scrofa*)	2833 ± 30	−18.0	2850–2760	2930–2740
Wk-28387	Layer 2/3 interface	Pig bone (*Sus scrofa*)	3005 ± 30	−15.0	2930–2780	3010–2740
Wk-28388	Layer 2/3 interface	Pig bone (*Sus scrofa*)	2737 ± 30	−20.3	2850–2760	2930–2740
Wk-28393	Layer 3, Spit 1 depression feature	Pig bone (*Sus scrofa*)	2728 ± 30	−19.9	2850–2750	2920–2740
SANU-12024	Layer 2/3 interface	Shell (*Turbo argynostomus*)	3190 ± 25	–	3010–2850	3100–2780
SANU-12029	Layer 2/3 interface	Shell (*Turbo argynostomus*)	3140 ± 60	–	2960–2770	3090–2720
SANU-12027	Layer 2/3 interface	Shell (*Turbo argynostomus*)	3240 ± 35	–	3100–2910	3190–2840
SANU-12026	Layer 2/3 interface	Shell (*Trochus niloticus*)	3140 ± 35	–	2950–2790	3040–2740
SANU-12023	Layer 2/3	Shell (*Turbo argynostomus*)	3060 ± 25	–	2840–2730	2920–2700
Wk-15728	Layer 2/3 interface	Wood charcoal (unidentified)	2848 ± 35	−27.9	3010–2880	3080–2860
Wk-28391	Layer 3, Spit 1	Pig bone (*Sus scrofa*)	2748 ± 30	−19.8	2850–2760	2930–2740
Wk-28392	Layer 3, Spit 1	Pig bone (*Sus scrofa*)	2837 ± 30	−18.4	2920–2780	2960–2750
SANU-22509	Layer 3, Spit 1	Charcoal (nut)	2830 ± 30	–	2970–2870	3060–2850
SANU-22512	Layer 3, Spit 1	Charcoal (nut)	2785 ± 30	–	2930–2840	2960–2790
SANU-22507	Layer 3, Spit 1	Charcoal (nut)	2860 ± 30	–	3060–2920	3080–2870
SANU-22516	Layer 3	Wood charcoal (unidentified)	140 ± 30	–		
SANU-22514	Layer 3	Charcoal (nut)	2805 ± 30	–	2950–2870	3000–2800
SANU-22511	Layer 3	Charcoal (nut)	2810 ± 35	–	2960–2860	3010–2790
SANU-22517	Layer 2/3 interface	Charcoal (nut)	2800 ± 35	–	2950–2860	3000–2790
SANU-22505	Layer 2/3 interface	Wood charcoal (unidentified)	2760 ± 30	–	2920–2790	2950–2770
Wk-28390	Layer 1/2 interface	Pig bone (*Sus scrofa*)	2739 ± 30	−19.5	2850–2760	2930–2740
Wk-25601	Layer 2/3	Giant tortoise (?*Meiolania damelipi*)	2733 ± 30	−25.4	2860–2780	2920–2760
Wk-25602	Layer 2/3	Giant tortoise(?*Meiolania damelipi*)	2741 ± 30	−23.1	2860–2780	2930–2760
Midden Zone (Layer 2)						
SANU-22510	Layer 2, Spit 2	Charcoal (nut)	2675 ± 30	–	2840–2750	2850–2740
SANU-22506/22,525	Layer 2, Spit 2	Charcoal (nut)	2795 ± 30/2840 ± 30	–	2950–2850	2970–2790

[a] Isotope ratio mass spectrometer value measured directly on CO_2 collected during combustion of sample for dating. SANU $\delta^{13}C$ values were measured on accelerator and are not reported here because significant fractionation can occur.

measured at Iso-trace Research Department of Chemistry, University of Otago, on a Carlo Erba NA 1500 elemental analyzer (EA), coupled with either a Europa Scientific '20/20 Hydra' or a Thermo Finnigan Delta Plus Advantage. Bone isotope QA parameters (% gelatin yield, %N, %C and C:N) and stable isotope values ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$) are given in Tables 2 and 3.

Table 2
Quality assurance and stable isotope data for Post-Lapita burials from Teouma.

Sample ID	Burial no.	%N	%C	C:N	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{34}S$ (‰)	Gelatin yield (%)	% Marine carbon (−21/−12)
Wk-24,480	1	15.2	43.4	3.33	9.61	−19.82	13.60	1.4	13
Wk-24,481	2A	15.1	43.4	3.35	9.62	−20.25	13.23	1.2	8
Wk-24,482	2B	15.0	42.7	3.32	8.57	−20.38	12.90	1.3	7
Wk-24,483	3	14.2	41.5	3.41	8.67	−20.74	-	0.2	3
Wk-24,484	4	14.9	42.2	3.30	9.78	−19.59	13.88	1.6	16
Wk-30,871	Trench 3, B1	15.4	43.1	3.27	7.16	−20.13	13.17	1.0	10
Wk-30,872	Trench 3, B2	15.1	43.9	3.39	8.67	−19.16	14.15	0.6	20

Table 3
Quality assurance# and stable isotope data for animal bones from Teouma.

Lab no. (sample no.)	%N	%C	C:N	δ^{15}N^ (‰)	δ^{13}C^ (‰)	δ^{34}S^ (‰)	Gelatin yield	Percent marine carbon (–21/–12)	Percent marine carbon (–20/–10)
Chicken (*Gallus gallus*)									
NZA–29450 (VUTTEO003)	13.5	39.7	3.4	12.4	–20.5	–	–	1	0
Wk–25198 (VUTTEO006)**	11.4	33	3.4	9.9	–18.2	–	0.6	31	18
Giant tortoise (?*Meiolania damelipi*)									
Wk–25601 (8.631 3A4.9)	15.0	43.4	3.4	3.0	–23.2	11.8	0.4	0	0
Wk–25602 (8.1215 3A5.7)	15.0	42.2	3.3	3.3	–22.8	12.6	0.4	0	0
Pig (*Sus scrofa*)									
Wk–28391 (6.886)	15.2	43.6	3.3	11.1	–20.2	13.8	0.6	9	0
Wk–28392 (6.891)	15.9	44.6	3.3	8.2	–18.9	12.9	1.7	23	11
Wk–28393 (6.914)	15.7	45.3	3.4	9.8	–20.2	13.0	1.2	9	0
Wk–28386 (6.124)	15.3	44.4	3.4	8.9	–18.0	13.5	1.4	33	20
Wk–28389 (6.1042)	–	–	–	–	–19.9++	–	0.4	2	1
Wk–28390 (6.6)	15.5	44.4	3.3	9.4	–20.4	14.7	0.8	7	0
Wk–28387 (6.1354)	15.7	45.4	3.4	14.4	–15.1	14.0	1.0	66	49
Wk–28388 (6.1093)	15.3	44.0	3.4	6.8	–20.4	12.9	0.6	7	0

Most well-preserved archaeological bone protein has a %N value that ranges between 11 and 16, a %C value between 30 and 45, and a C:N ratio range of 3.1–3.5, while the % gelatin yield should be ≥0.5% (van Klinken, 1999; Brock et al., 2007; Petchey et al., 2014). Three samples had low yields (highlighted in gray) but acceptable isotopic values. These should be treated with caution.

++ δ^{13}C value measured using a Europa Scientific Penta 20–20 isotope ratio mass spectrometer on gas split taken during preparation of ^{14}C samples at the University of Waikato. Measured relative to VPDB with precision of ±0.2‰.

^ $^1\delta^{13}$C measured relative to VPDB with precision of ±0.1‰. δ^{15}N measured relative to AIR and with precision of ±0.2‰. δ^{34}S measured relative to IA-R061, IA-R042 and IA-R027 (Iso-Analytical) or IAEA-S-1, IAEA-S-2 and NBS123 (Isoprime) with precision of ±0.3‰.

**Gelatin isotope values not measured by Waikato. Values as reported by Storey et al. (2010: Table 4).

1.3. Chronological model building

A number of issues need to be considered when evaluating ^{14}C results on the range of materials sampled at Teouma; post-depositional disturbance, heirloom effects, inbuilt age, local marine reservoir offsets, and diet. Some of these are well-recognized archaeological interpretive issues; others are natural ^{14}C variation issues that are rarely taken into consideration by researchers because these offsets are often not statistically significant except in the highest precision chronologies (i.e., high precision [better than ±25 years] dates with well-constrained, multi-date sequences). Despite these apparent interpretive issues, dates on these novel ^{14}C sample types often have greater potential to refine and focus ^{14}C chronologies that deal with specific research questions, such as faunal extinction and cemetery use. The range of material dated from Teouma has potential to address these questions, but the analysis requires a holistic evaluation of the dates based on established understanding of radiocarbon variation in nature. For this paper we have used an approach that identifies and eliminates all known unreliable results from further analysis (cf. modified chronometric hygiene or manual rejection) based on a set of previously established parameters for charcoal, shell, and bone, combined with a Bayesian approach that weights samples according to how likely they are to be correct based on assumptions that compose the model. It relies on a model-averaging approach to arrive at an acceptable hypothesis (cf. Bronk Ramsey, 2009a; b).

1.3.1. Charcoal

The dataset of Teouma charcoal dates includes one nut charcoal sample from CZ3 and 2 unidentified wood charcoals from CZ2/3. From the Midden Zone deposits there are 2 unidentified wood charcoal and 6 nut charcoal samples from Layer 3 and a further 2 nut charcoal results from Layer 2.

Short-lived nut charcoal samples with only 1 year of growth are considered to be one of the most reliable dating materials assuming minimum stratigraphic displacement. It is also well established that most wood charcoal determinations will date earlier than the event by an unknown amount. This could be by a few years, or several hundred years (Spriggs and Anderson, 1993; Allen and Wallace, 2007). It is possible to build a sliding outlier correction for charcoal into any Bayesian model to correct for this variable inbuilt-age (see for example Bronk Ramsey, 2009a; b; Nunn and Petchey, 2013), but in this instance we have opted to remove the 4 unidentified charcoals from further analysis because of the large number of short-lived nut charcoal results (n = 9), the possible displacement of small charcoal samples through a porous midden matrix, and because it will avoid unnecessary complications to our Bayesian model.

1.3.2. Bone protein

Pig, chicken (both omnivorous animals) and fully terrestrial giant tortoise (herbivorous) have been dated from the Teouma midden. These provide a unique comparison to dates on human remains from both the Lapita and post-Lapita deposits, and by dating human and faunal remains the chronological relationship between sample and target event is brought into congruence. Moreover, inbuilt age is minimal because of the fairly rapid rate of collagen turnover and the short-lived nature of most animals. The interpretation of these ^{14}C results is, however, linked to diet. Generally it is assumed that natural variations in δ^{13}C values among plants and animals are maintained within the consumer bone collagen and that offsets between diet and consumer isotopic ratios, caused by metabolic fractionation, are relatively predictable. Ultimately, this is an area of research that is complicated by numerous assumptions that make it difficult to assign actual proportions to different foods (see Hedges and Reynard, 2007; Schulting and Richards, 2002). Despite these problems, it is essential prior to age calibration that the marine ^{14}C contribution to bone protein is evaluated because of the c. 400 ^{14}C year offset of the marine reservoir compared to the terrestrial reservoir (Stuiver et al., 1986). One methodology to counteract the effect of ^{14}C coming from the marine environment is the use of linear extrapolation between terrestrial and marine δ^{13}C endpoints. This overly simplifies the evaluation of diet, but has demonstrably been successful for the evaluation of radiocarbon results on human bone from the Teouma Lapita cemetery (Petchey et al., 2014) and elsewhere (Petchey et al., 2011). Possible errors were only noted in instances where C$_4$ plants may have been eaten, but a larger scale isotopic evaluation of diet undertaken by Kinaston et al. (2014:14) suggests this is limited at Teouma. Petchey et al. (2014) concluded that collagen δ^{13}C values for Pacific humans that consumed terrestrial C$_3$ pathway plants, or the flesh of animals that fed on those plants, fell around −21‰, while a δ^{13}C value of c. −12‰ indicated a diet that is high in marine protein. Moreover, humans from temperate regions who get most of their protein from marine food typically have δ^{15}N values above +12‰, while those that consume predominantly terrestrial protein have δ^{15}N values below this. Typically, the introduction of domesticates and dietary diversification increases the interpretive difficulties (e.g., Field et al., 2009; Jones and Quinn, 2009; Petchey et al., 2011:37).

The isotope values for post-Lapita individuals are given in Table 2. δ^{13}C values of between −20.7‰ and −19.2‰ and δ^{15}N values between 7.2 and 9.8 are depleted and more homogeneous than the Lapita individuals (δ^{13}C = −18.2‰ to −13.0‰; δ^{15}N 10.6‰ to 15.2‰ [Petchey et al., 2014]). Valentin et al. (2014:391) attributed this isotopic shift to a diet consisting of greater quantities of herbivore and C$_3$ derived foods. This predominantly homogenous and terrestrial diet provides us with greater confidence in the calibration of these remains because the percent marine carbon correction (%MC) and associated errors are small.

Less is known about the isotopic offsets for other omnivorous animals, or where dietary extremes occur (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). Variations in diet-tissue enrichment may be responsible for the calculated −20/−10 δ^{13}C endpoints reported by Clark et al. (2013) for pigs from Hanamiai (French Polynesia), where the marine endpoint (−10‰) may reflect an artificially high marine diet through controlled feeding practices (Richards et al., 2009:36). Clark et al. (2013) reported δ^{15}N values for pigs eating only terrestrial protein as measuring between +7.0 and +10.3‰, while those assumed to have a predominantly marine diet return values that fell between +14.4 and +18.3‰.

Ultimately, the effect of using δ^{13}C endpoints of −20‰ and −10‰ instead of −21‰/−12‰ results in relatively little change to the dietary %MC for the Teouma animals (Table 2), except in those cases where the %MC input is already high (i.e., chicken Wk-25198, and pigs Wk-28392, Wk-28386 and Wk-28387), therefore resulting in a smaller marine correction. This is most extreme for Wk-28387 (pig from CZ2/3) whereby −20/−10 δ^{13}C endpoints results in a shift from 66%MC to 49%MC (Table 2). Comparison with the short-lived nut charcoal results from CZ2/3 (combined in a single phase model in OxCal – see model building discussion below) reveals that both endpoint models give results at an acceptable level of agreement (−21/−12: A_{model} = 142; − 20/−10: A_{model} = 104.8), but the individual agreement index for Wk-28,387 in the −20/−10 model is poor (A = 51.8%). Although data are limited we have opted to use the −21/−12 correction model for the subsequent Bayesian analysis in keeping with Petchey et al. (2014).

1.3.2.1. Tortoise. Stable δ^{13}C and δ^{15}N isotope values for the two giant tortoise bones from CZ2/3 are given in Table 3. The δ^{13}C values (−22.8‰ and −23.2‰) reflect the terrestrial environment, and are comparable to average values recorded by Kinaston et al. (2014:Table 2; −23.4 ± 0.5‰) for tortoise at the site. They interpreted these as reflecting either a canopy (i.e., recycling of ^{13}C-depleted CO$_2$ from decomposing forest floor litter resulting in δ^{13}C values that were lower than other terrestrial mammals such as fruit bats), or a physiological effect. Our δ^{15}N values (3.0‰ and 3.3‰) fall at the lower end of the Kinaston et al. (2014:12–13) range (δ^{15}N = 4.9 ± 2.8‰, n = 17), which they suggest may be the result of foraging in the mangrove environment because of a similarity to mangrove shellfish and crabs (−δ^{13}C = 26.1‰; δ^{15}N = −2.0‰ and δ^{13}C = −24.1‰; δ^{15}N = 2.5‰ respectively). If tortoise are feeding on shellfish from the mangrove environment it could have an effect on the ^{14}C content, but this does not appear to be significant since the results are comparable to a chicken bone; NZA-29450 from the same deposit considered to be fully terrestrial in origin (see below). We have, therefore, assumed a terrestrial calibration for both terrestrial giant tortoise results.

1.3.2.2. Pig. Pacific pigs are generally considered to have an opportunistic and omnivorous diet. The δ^{13}C and δ^{15}N values of the Teouma pigs (Table 3) suggest that most (Wk-28388, Wk-28390, Wk-28391, Wk-28392, and Wk-28393) have eaten predominantly terrestrial foods, but three consumed various mixes of both marine and terrestrial foods (Wk-28386, Wk-28387 and Wk-28392). The more depleted (terrestrial) values are comparable to those reported by Kinaston et al. (2014:Table 2; δ^{13}C = −19.6 ± 0.7‰; δ^{15}N = 9.6 ± 1.1‰; n = 20) who interpreted the results as representing a diet largely composed of C$_3$ plant and animal foods. The enriched δ^{13}C value of −15.1‰ for Wk-28387 may be indicative of a controlled feeding environment where higher proportions of marine foods were fed to this animal (cf., Richards et al., 2009). It is unlikely that this value reflects feeding on C$_4$ foods (e.g., grasses, sea-grass and seaweeds), which could also result in an enriched δ^{13}C value, because the δ^{15}N value (14.4‰) reflects a diet dominated by higher trophic level foods. A mixed terrestrial/marine calibration (Table 3) has been applied to the pig bones based on the dietary correction between δ^{13}C endpoints of −21‰ and −12‰.

1.3.2.3. Chicken. The two chicken results give very different results; the isotopes for NZA-29450 (δ^{13}C = −20.5‰ and δ^{15}N = 12.4‰) suggest that this particular chicken may have acquired a protein rich terrestrial diet, though the high δ^{15}N value could be indicative of hot/dry conditions (cf., Valentin et al., 2014). Kinaston et al. (2014:Table 2) report values of δ^{13}C = − 19.7 ± 1.1‰ and δ^{15}N = 11.1 ± 1.2‰ for chickens (n = 7). The chicken bone associated with Burial 50 fill (Wk-25198) on the other hand had a slightly more enriched carbon signature (δ^{13}C = −18.2‰ and δ^{15}N = 9.9‰) suggesting that this chicken may have derived some of its diet from C$_4$ plants and/or marine foods.

1.3.3. Shell

Theoretically, marine shells that are gathered for food should provide very robust age estimates for human activity because they will give radiocarbon dates close to the timing of the gathering event. Various issues need, however, to be considered before dating any shell. In particular, shells may give apparently erroneous ^{14}C results depending on genera and even species selected, as well as local ocean conditions unless appropriate corrections are applied. Research in the Pacific (Petchey et al., 2008) has demonstrated that the marine reservoir in the southern gyre region is fairly uniform and that the Vanuatu specific reservoir correction (ΔR) of 40 ± 44 ^{14}C years is suitable for most open ocean suspension feeding shellfish and coral species. Location-specific issues such as hardwaters[4] and/or the potential ingestion of carbonate from the uplifted limestone cliffs that border Teouma on the east and southeast (Dickinson et al., 2013) make it likely that ancient ^{14}C from this limestone will have influenced most dates of deposit feeding, herbivorous and suspension feeding shellfish that occupy the local estuarine environment (Petchey and Clark, 2011; Petchey et al., 2013). Even in such problematic locations informed corrections can be made based on observed oceanographic conditions, local geology and understanding of shellfish habitat and dietary preferences.

There is a single *T. argyrostomus* result from the CZ3 (SANU-12025); three from CZ2/3 (SANU-12024, SANU-12029, SANU-12027) and one from CZ2 (SANU-12023). One *T. niloticus* (SANU-12026) shell comes from CZ2/3. Both these genera are potentially problematic for dating; *Turbo* spp. are herbivorous gastropods with a preference for calcium carbonate strata (Beesley et al., 1998:675, 768), while *T. niloticus* is an algal grazing gastropod that prefers rock and reef environments (Beesley et al., 1998:683). Consequently, both can ingest terrestrial sediment while feeding. Studies into herbivorous shellfish have clearly demonstrated large ^{14}C offsets for herbivores collected from along limestone coastlines (Dye, 1994; Anderson et al., 2001:37–9; Petchey et al., 2012). To estimate the possible offset for these two species it is necessary to calculate a reservoir correction (ΔR). This can be done using contemporaneous terrestrial material (i.e., a terrestrial/marine pair), but there are no ideal sample pairs from Teouma since both the Cemetery Zone and Midden Zones could have been deposited over some time span (see below and Petchey et al., 2014) and the majority of terrestrial samples from CZ2/3 are novel materials (i.e., previously untested ^{14}C sample types) or materials with a mixed marine/terrestrial diet (i.e., chicken and pig bone) which add uncertainty to the evaluation. One short-lived nut charcoal sample (SANU-22513) was found in the midden deposits in the Cemetery Zone and when compared to SANU-12025 we get a ΔR of 105 ± 39 ^{14}C years (see Petchey et al., 2013 for methodology). Similar ΔR results are obtained by using a systematic offset methodology in OxCal (Bronk Ramsey, 2009a; b) whereby we used the following command Delta_R("local",U(−200, 200)) for *Trochus* and *Turbo* shells grouped into CZ3 and CZ2/3 phases within the OxCal sequence model b as outlined below. This methodology gave us a ΔR of 118 ± 40 ^{14}C years for Layer 3 *T. argyrostomus* and 121 ± 27 ^{14}C years for the Layer 2/3 *Turbo* and *Trochus* shells.

There are also five *Conus* sp. rings associated with the burials (Wk-15729 [Burial 11]; Wk-16830 [Burial 4]; Wk-37680 [Burial 17]; Wk-37682 [Burial 58] and Wk-37681 [Burial 59]). *Conus* are carnivorous reef dwelling animals (Beesley et al., 1998:852–3) and therefore should more closely reflect ocean reservoir offsets. However, shells associated with burials may also have heirloom offsets while larger animals may have some inbuilt age,[5] though this is mitigated somewhat by sampling procedures that select material from as near to the growth edge of the shell as possible. Moreover it is possible to assess the level of offset by comparison with paired radiocarbon data, such as the associated burial dates. This is discussed in some depth in Petchey et al. (2014) where it was demonstrated that the regional reservoir value (40 ± 44 ^{14}C years) produces *Conus* sp. ring ^{14}C results that are in keeping with the associated calibrated burial results.

1.3.4. Cremated bone

Burial 26 is a collection of cremated bones[6] (see Scott et al., 2010:901–2). This gives an uncalibrated result (Wk-21030) of 2850 ± 24 ^{14}C years and has a δ^{13}C of −25.3‰, which suggests alteration to the carbonate fraction has occurred; bone carbonate δ^{13}C value is a function of the bulk diet and is offset by around +12‰ to +14‰ (Ambrose and Norr, 1993; Tieszen and Fagre, 1993), consequently any human bone carbonate δ^{13}C values should be significantly more enriched than this (Teouma human tooth carbonate values range between c. −10‰ and −14‰ see Petchey et al., 2014:237). The absolute dating of calcined bone fragments is a recent development in radiocarbon dating (Lanting and van der Plicht, 2001; Naysmith et al., 2007). The technique, although successful in many inter-comparison studies, remains largely experimental, and recent tests (van Strydonck et al., 2010; Hüls et al., 2010) have demonstrated that during the burning process, exchange of carbon from firewood and other organic remains can occur, resulting in a possible transmission of the 'old wood' effect (i.e., inbuilt age). Therefore, the δ^{13}C value does not represent a dietary signal and there is no indication of dietary difference between this individual and other individuals from Teouma (contra to Scott et al., 2010:907). When calibrated with the terrestrial calibration curve (IntCal13) this sample gives an age of 3010–2880 cal BP. Even though this overlaps with the human bone dates from the cemetery (2940–2880 cal BP) reported in Petchey et al. (2014), we have not included this result in our analysis because the unusual nature of the burial and the absence of any other associated dating evidence.

2. Radiocarbon calibration and model building

All radiocarbon dates were calibrated in OxCal v4.2 (Bronk Ramsey, 2014) using the Marine13 and Intcal13[7] curves (Reimer et al., 2013). Mixtures between these curves were determined from dietary terrestrial/marine δ^{13}C endpoints (−21‰/−12‰) given in Tables 2 and 3. Given the limitations of the dietary evaluation we have used an uncertainty of ±10 following the recommendations of Ambrose (1993:112). A location-specific reservoir correction value (ΔR) of 40 ± 44 ^{14}C years has been applied to calibrations of the *Conus* sp. shells and 105 ± 39 ^{14}C years to the *Trochus* and *Turbo* shell calibrations to adjust for regional oceanic variation in ^{14}C. All dates discussed in the text are reported at 68.2% probability unless otherwise noted.

To refine the chronological interpretation of Teouma we have utilized Bayesian statistical methods whereby ^{14}C ages are constrained by prior information such as stratigraphic sequence and archaeological provenance. The overall model is assessed by the calculation of an agreement index (A_{model}) that tells us how well the model agrees with the observations. If "A" falls below 60% (equivalent to the 5% level of a χ^2 test), the model should be re-evaluated (Bronk Ramsey, 1995). The radiocarbon dates from the midden and cemetery zones are modeled as separate overlapping sequences. Within each of these sequences the various layer designations are grouped in phases that are arranged in a contiguous sequence. Between each phase is a boundary that provides an estimate for the date of transition between each phase. The boundaries between the different CZ and MZ phases are

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[4] Hardwaters contain large amounts of bicarbonate ions, which are generated by seepage through calcareous strata and can make radiocarbon ages anomalously old.

[5] The limited data available for reef gastropods suggests that most live >5 years and some may reach 20 years of age (Frank, 1969:247). This is unlikely to be truly reflective of animals collected from locations previously uninhabited by humans.

[6] Cremated or calcined bones (those with a white coloration rather than those that are charred) have been exposed to temperatures greater than 600 °C (van Strydonck et al., 2010).

[7] The ^{14}C division between the Northern and Southern Hemispheres is considered to lie along the Inter-tropical Convergence Zone (ITCZ). This creates additional uncertainty when calibrating terrestrial samples from Pacific locales because many island groups, including Vanuatu, straddle the South Pacific Convergence Zone, which merges with the ITCZ to the west. Because the Southern Hemisphere calibration curve (Hogg et al. 2013; McCormac et al. 2004) was developed from trees younger than 1000 cal BP collected above 25°S (South Africa [25° S], New Zealand [40° S] and Southern Chile [55° S]) we have opted to use the Northern Hemisphere calibration curve (IntCal13: Reimer et al., 2013) for terrestrial calibrations from central Vanuatu [~16° S].

also cross-linked in accordance with archaeological interpretation of the relationship between the two areas. After running the model an agreement index is calculated for individual dates, and any with an individual agreement index $<60\%$ were assigned a prior outlier probability of 5% within the General t-Type outlier model – which allows outliers to be either too young or too old (Bronk Ramsey, 2009b); therefore accounting for both potential inbuilt age and context displacement. The following dates are excluded from the model: Wk-21,030 (cremation burial) and SANU-22,516 (modern wood charcoal). Following initial modeling runs the prior outlier probability is revised and a date's influence on the model is readdressed and reweighted according to the posterior probability.

3. Results

The initial run of this model (a) produced an acceptable agreement index (A_{model}) of 70.8 (Table 4). Although several samples had individual agreement indexes less than 60 (Wk-37681 [A = 6.3], Wk-28391 [A = 47.2], SANU-22507 [A = 44.5], S ANU-22506/22525 pair [A = 54.8]), only one sample was found to have a much greater posterior probability of being an outlier than expected (i.e., had a posterior value of >10): Wk-37681/Burial 59 *Conus* shell armband (O:73/5). Model (a) gives a start date for the Cemetery Zone of 2930–2870 cal BP and an end date of 2830–2700 cal BP, with transitions between Layer 3 and Layer 2/3 at c. 2870–2820 cal BP and a transition between Layer 2/3 and Layer 2 at 2840–2770 cal BP. The start of the Midden Zone activity has been cross-linked to the beginning of activity in the CZ and has an end date of 2870–2750 cal BP.

The young age (unmodeled = 2760–2650 cal BP) for the *Conus* sp. arm band associated with burial 59 (Wk-37681) relative to the rest of the CZ3 dates may indicate a problem with the reservoir (ΔR) offset, or it may come from a slightly later phase of cemetery activity, possibly a later Arapus/Early Erueti phase. This sample was taken from the burial goods associated with Burial 59 – comparison of Wk-37681 with the ultrafiltered bone gelatin burial result (Wk-26342: 2790–2680 cal BP, reported in full in Petchey et al., 2014), suggests the shell result is not erroneous. However, this interpretation does not fit with archaeological observations and associated artifacts that place it firmly within an early Lapita context. A number of dates on the skeletons themselves (Burials 3, 41, 43, 48, 54, 55, 56, 58, 59 and 60; Petchey et al., 2014) also fall within this younger age range and it is possible that we are not dealing with a single-phase Lapita cemetery. In future, detailed analysis of finds and contextual information will be undertaken to examine this issue further.

Removing the Burial 59 *Conus* sp. date from the model improved the agreement index (A_{model} = 105.9), but makes little difference to the calibrated ages for each layer (Table 4). This model (b) gives a start date for the Cemetery Zone and associated midden of 2920–2870 cal BP and an end date of 2830–2710 cal BP, with transitions between Layer 3 and Layer 2/3 at c. 2870–2820 cal BP and a transition between Layer 2/3 and Layer 2 at 2840–2780 cal BP, covering a period of between 60 and 200 years. Activity in the Midden Zone ends c. 2870–2750 cal BP. The similarity between models (a) and (b) is to be expected because of the model averaging nature of the Bayesian analysis. Overlap between start and end dates for the Midden Zone indicate a very rapid midden build up (span) which is consistent between both model (a) and (b) (0–150 years) (Table 4). It should be noted that the endpoint for CZ2 is based on dates primarily collected to date the start and early development of this midden deposit. A more substantial and stratigraphically refined dating of the entire CZ2 deposit is required to assess the actual duration and influence of possible disturbance.

Table 4
OxCal modeled calibrated ages for the Teouma Cemetery and Midden Zone radiocarbon samples.

	Model a (with B59/Wk-37681)	Model b (with B59/Wk-37681 removed)
A_{model} (agreement index)	70.8	105.9
Start Teouma	3000–2870 cal BP	3000–2870 cal BP
Start CZ3 (Lapita)	2930–2870 cal BP	2920–2870 cal BP
Start CZ2/3 (Lapita)	2870–2820 cal BP	2870–2820 cal BP
Start CZ2 (Arapus)	2840–2770 cal BP	2840–2780 cal BP
End CZ2	2830–2700 cal BP	2830–2710 cal BP
Span CZ	60–210 yrs	60–200 yrs
Start MZ3 = Start CZ3	2930–2870 cal BP	2920–2870 cal BP
Start MZ2	2900–2850 cal BP	2890–2850 cal BP
End MZ2	2870–2750 cal BP	2870–2750 cal BP
Span MZ	0–10 20–150 yrs	0–10 20–150 yrs
End Teouma	2880–2580 cal BP	2880–2560 cal BP

Previous analysis of the cemetery zone using bone dates on the burials themselves suggested the burial ground was in regular use by c. 2940–2880 cal BP with the last interments occurring c. 2770–2710 cal BP though possible earlier use was indicated by Burial 57 (c. 3110–2930 cal BP) and later use was possible up until 2680 cal BP. Our multiphase cemetery/midden zone results agree with this evaluation. Moreover, because the midden respected the boundary of the cemetery, it is possible that the cemetery may have already been in place before deposition of the MZ3 material.

Continued use of the area is clearly indicated by the presence of a number of burials (Table 5) approximately 70 m south and southeast from the Lapita cemetery that date to between 2440 and 2350 cal BP (assuming a single phase relationship, −21/−12 endpoints and ΔR of 40 ± 44 ^{14}C years), and represent a *terminus post quem* for site use. These burials were expected to date to the Early Erueti phase on the basis that there is no cultural material later than this phase in the CZ2 midden or elsewhere in the site area. Worn Early Erueti pottery was found in the vicinity, albeit not in firm association with the burials. Our calibrated results for these burials fall slightly later than the current orthodox dates for this archaeological phase (2800–2500 BP). Before any firm conclusions are made regarding the association of these burials we recommend that a full evaluation of extant Early Erueti dates, within a Bayesian chronometric framework, is made to refine this post-Lapita chronology.

4. Discussion

From this evaluation of radiocarbon dates from the Teouma midden deposits it is apparent that there are a number of additional uncertainties associated with the dating of different sample types that complicate the chronological evaluation of this site. More importantly, our conclusions are based on prior information (stratigraphy and associated contextual information) that constrains the radiocarbon dates accordingly. Change in this prior information will have an influence on the model outcomes. We stress, therefore that the evaluation of the Teouma chronology presented in this paper is a model only. We can, however, conclude from this evaluation that:

1. Short-lived nuts provide a robust test of site age assuming no mixing of the deposit. Unfortunately, displacement can occur both up and down through a deposit. Our use of the General t-Type outlier model is designed to counteract this in combination with prior site information such as stratigraphy.

2. *Turbo* and *Trochus* species shells are affected by ingesting carbonate material while feeding. Therefore, in areas with limestone, where precise chronologies are required, they should be avoided unless a program of offset evaluation is undertaken (cf., Caution Bay [Petchey et al., 2013]). Although many researchers would exclude radiocarbon results on these animals from further evaluation, once a reservoir offset had been ascertained and applied the results are as accurate as most other sample types, and their value is clearly evident in the Bayesian model outlined here.

Table 5
Post-Lapita burial radiocarbon dates (? Late Erueti).

Sample ID	Context	Material	CRA (BP)	$\delta^{13}C$ (‰)	Unmodeled cal BP (68% prob.)
Wk-24480	Burial 1	Human bone gelatin	2423 ± 30	−19.3	2440–2360
Wk-24481	Burial 2A	Human bone gelatin	2455 ± 30	−19.6	2440–2360
Wk-24482	Burial 2B	Human bone gelatin	2465 ± 30	−19.3	2440–2360
Wk-24483	Burial 3	Human bone gelatin	2423 ± 30	−19.8	2440–2360
Wk-24484	Burial 4	Human bone gelatin	2452 ± 30	−18.8	2440–2360
Wk-30871	Trench 3, B1	Human bone gelatin	2501 ± 27	−19.1	2440–2360
Wk-30872	Trench 3, B2	Human bone gelatin	2422 ± 27	−19.1	2440–2350

3. Radiocarbon determinations on animal bones have the advantage that they date the hunting/gathering event. They can, however, be hard to interpret because of dietary offsets. At Teouma, terrestrial giant tortoise bones give results that are in excellent agreement with the other midden materials. This sample type has additional value as it provides a date for hunting and consumption of tortoise, and additional dates may reveal a chronological pattern to the exploitation of this native fauna. Similarly, chronological evaluation of other indigenous animals and birds in the Teouma midden may be of interest, including the flying fox (*Pteropus* sp.), other fruit bats (Pteropodidae), and terrestrial birds and crocodile (Valentin et al., 2010:1826).
4. Pig and chicken bone conventional radiocarbon ages are more varied due to their omnivorous diets. A diet correction using linear extrapolation between terrestrial and marine $\delta^{13}C$ endpoints of −21‰ and −12‰ has given calibrated radiocarbon results in keeping with other materials at Teouma. These animals are human commensals and therefore the ability to achieve reliable calibrated radiocarbon ages on them also has immense value to research in this region.
5. Cremated bone remains largely an unknown quantity. Recent experiments have demonstrated that during the burning process, exchange of carbon from firewood and other organic remains can occur, resulting in a possible transmission of the 'old wood' effect (i.e., inbuilt age). Although this effect is often relatively small, without paired, or closely associated samples against which we can compare, the offset remains unknown. The context and un-calibrated radiocarbon result of cremation (Burial 26) is within that expected for a Lapita-age burial.
6. The dietary model used for Teouma appears to work well, but our knowledge of endpoint values for human and other omnivorous animals from Pacific locales is poor. It is likely that this linear interpolation methodology may underestimate the intake of marine protein at the 0% endpoint and overestimate at the 100% endpoint. More complex evaluations of ^{14}C-diet corrections using complex stable isotope mixture models and large datasets of location specific faunal isotope data generally do not provide age evaluations that fit well with other dates for reasons that are not well understood (cf. Dewar and Pfeiffer, 2010); this may be because of the numerous assumptions about the magnitude of fractionation between trophic levels. Regardless of the shortcomings, leaving the dates uncalibrated is not an option because this would result in greater error.
7. The recent use of a third isotope ($\delta^{34}S$) in Pacific examples has met with varying success because of possible sea spray and/or limestone effects (Beavan Athfield et al., 2008; Kinaston et al., 2014; Petchey et al., 2014), explaining the apparent success of this methodology in some locations (e.g., Kinaston et al., 2013) but not at Teouma. Here similarity in $\delta^{34}S$ between tortoise bone and bone from animals with a mixed marine/terrestrial diet (Table 2) could be caused both by proximity to the ocean and by the limestone cliffs that surround the site.
8. Information on the diversity of freshwater fish and their consumption is limited in Vanuatu. It is, however, likely that they were exploited for food, particularly as Teouma is adjacent to a freshwater stream (Bedford et al., 2006; Bedford et al., 2009). Although freshwater fish are typically depleted in $\delta^{13}C$ and enriched in $\delta^{15}N$ values compared to animals in dry-land terrestrial systems (Privat et al., 2007; Richards et al., 2001), this is not always the case (Cook et al., 2001; Olsen et al., 2010) and depends on local conditions. There is currently no way to correct for this in the ^{14}C values except by comparison with other sample types. Based on charcoal ^{14}C determinations there does not appear to be any significant freshwater (specifically hardwater) influence on any other sample type except for the *Turbo* and *Trochus* shells as discussed above.

5. Teouma: the bigger picture

This analysis places the start date of the Lapita deposits at 2920–2870 cal BP with a possible use as early as 3000 cal BP, and an end date of 2870–2750 cal BP. These results are in keeping with evaluation of the burials, which places earliest use of the cemetery at c. 2970 cal BP with regular use underway by c. 2940–2880 cal BP and the last interment occurring c. 2770–2710 cal BP. Continued use of the area is evident by later burials dating to the end of the Erueti phase and by the CZ2 midden deposits which must predominantly be of post-Lapita age.

This Bayesian analysis of the midden deposits provides further confirmation of the chronological age of Teouma. Teouma has numerous indicators of being an initial colonization site for Efate, including extinct faunal remains, early ceramic forms and decoration, and New Britain obsidian, and is therefore of high interest to those investigating colonization in this region. The most recent chronological assessments have been by Summerhayes (2009) who divided Lapita in the Bismarck Archipelago into three generalized phases; 3300–3000 BP for Early Lapita, 3000–2800 BP for Middle Lapita and 2700-c.2200 BP for Late Lapita. This has subsequently been re-evaluated by Denham et al. (2012) using Bayesian techniques. They suggested the earliest possible date for Lapita appearance in the Bismarck region was 3360–3240 cal BP, which was followed by a" Bismarck formative phase" of c. 130–290 years before spread into Remote Oceania. In their model, Lapita reached Vanuatu c. 3250–3100 cal BP and Fiji c. 3130–3010 cal BP. Unfortunately, by limiting their analysis to charcoals, many of which were not identified to short-lived species, Denham et al. (2012) over-estimated the antiquity of these events.

A more robust chronometric evaluation has been achieved using site-based Bayesian evaluations that utilize a modified chronometric hygiene protocol in combination with stratigraphic information and evidence of early faunal and artifactual assemblages, such as that by Petchey et al. (2014) for Teouma, Nunn and Petchey (2013) for Bourewa (Fiji), Sheppard et al. (2015) for Nanngu (Santa Cruz, Solomon Islands) and Burley et al. (2015) for Tonga. These works indicate that at around 3000 BP the culture spread through the Solomon Islands chain, perhaps by leapfrogging to the Reefs-Santa Cruz Group (Sheppard and Walter, 2006), and on to Vanuatu. Unfortunately, dates from the earliest New Caledonian sites are influenced by inbuilt age in the charcoal (Sand, 2010). Bayesian evaluation of acceptable dates by Sheppard et al. (2015:33–34) placed occupation of Vatcha (Isle des Pins) shortly after 3000 cal BP. They noted that both artifacts and faunal evidence from the sites of Lapita (New Caledonia) and Kurin (Loyalty Islands) indicated a slightly earlier date for these deposits was likely despite an absence of secure chronometric data to support this. The earliest data from Fiji come from Bourewa (2838–2787 cal BP) and Matanamuani (VL 21/5) on Naigani Island (3019–2863 cal BP) (Irwin et al., 2011; Nunn and Petchey, 2013; Sheppard et al., 2015). Recent work using a combination of ^{14}C and U/Th dates by Burley et al. (2015) has refined the date of first Lapita landfall in Tonga to 2846–2839 cal BP (95.4% prob.), with ceramic transition to later Plainware forms beginning around 2728–2716 cal BP (95.4% prob.). The current chronological model for deposits at Teouma therefore spans the entire period of Lapita settlement across Remote Oceania.

This new regional chronology has highlighted a number of temporal problems within Vanuatu, not the least being a discrepancy between the oldest Teouma layers and the earliest Lapita assemblages at Makué; c. 3192–2945 cal BP (Galipaud et al., 2014). Although clearly early in the Vanuatu sequence, based on the quantities of Bismarck obsidian, fine dentate stamped ceramics and turtle bone remains, Sheppard et al. (2015:34–35) suggest these determinations may be too old. Moreover, dates for the disappearance of Lapita across Vanuatu have not been subjected to any Bayesian/modified chronometric evaluation. Previous research indicated that Lapita disappeared c. 2800 BP — at least in central and southern Vanuatu (Bedford, 2006; Bedford et al., 2009). This chronometric picture requires refinement to align with that of the Lapita cemetery at Teouma. Similarly, the transition to Arapus and Erueti phases has not been subject to rigorous Bayesian modeling.

6. Conclusions

The multi-phased midden deposits at Teouma have enabled us to further refine the chronology of this important Lapita site. Our analysis indicates that midden deposition started at the same time, or shortly after, the first burial deposits between 2920 and 2870 cal BP, and spanned a period of up to 200 years. Post-Lapita use of the area as a place for occasional burials continued until c. 2440–2350 cal BP.

This analysis has helped clarify the duration of site use at Teouma but has also raised some issues requiring further analysis. As noted by Petchey et al. (2014) in the analysis of the burial remains, a single-phase cemetery with rigid start and end Erlenkeuser, H. dates does not fit the Teouma ^{14}C data well. It is possible that a 2 or 3 phase Lapita cemetery is more appropriate, though there is no obvious archaeological evidence for this. Similarly, the chronometric definition of Arapus and Erueti phases needs refinement. Any further dating program at Teouma will require questioning of both archaeological and dating assumptions made, and renewed analyses of burial-associated material assemblages. This should be possible through detailed analysis of diagnostic artifact distributions in relation to particular burial contexts.

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