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Refining the chronology for west polynesian colonization: New data from the Samoan archipelago

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ABSTRACT

The timing and unprecedented speed of the Lapita migration from the western edge of Oceania to western Polynesia in the Central Pacific have long been of interest to archaeologists. The eastern-most extent of that great human migration was the Samoan Archipelago in West Polynesia, although critical questions have remained about the timing and process of Samoan colonization. To investigate those questions, we carried out a Bayesian analysis of 19 radiocarbon dates on charcoal and 8 uranium-thorium (U-Th) series coral dates from four archaeological sites on Ofu Island in the eastern reaches of Samoa. The analysis indicates initial settlement of Ofu at 2717–2663 cal BP (68.2%) by people using Plainware rather than the diagnostic dentate-stamped Lapita pottery. This date range indicates that there is not a significant chronological gap between Lapita and Plainware sites in Samoa, which holds implications for modeling the settlement process in the Central Pacific.

1. Introduction

Studies of human migration and colonization are a hallmark of archaeological inquiry. The last, and arguably greatest, migration in world prehistory was the expansion of humans across the far-flung islands of Oceania. The process and timing of that migration have been debated since European explorers entered the region, and that interest has only intensified as archaeological evidence has accumulated. Of particular importance has been the migration of the Lapita peoples (cf. Kirch, 1997) identified, most notably, by a unique dentate-stamped pottery. However, the term Lapita has been expanded by some to encompass an entire cultural complex (Green, 1979).

Lapita cultural elements appear to have developed in the far western Pacific, with populations migrating into Remote Oceania (east and south of the Solomon Islands) over the course of a few centuries, and spreading into the Central Pacific (Fiji and West Polynesia). With the discovery of Lapita sherds at the Mulifanua site on ʻUpolu Island, the Samoan Archipelago marks the eastern extent of Lapita migrations. But, despite decades of searching by archaeologists, Mulifanua still stands as the only site in Samoa to yield dentate-stamped Lapita ceramics. Many other sites have been found, however, that have produced Plainware (i.e., undecorated) ceramics, some of which appeared to be contemporaneous with Mulifanua. In recent years, prior radiocarbon determinations have been re-evaluated based on the application of "chronometric hygiene" protocols, with many dates rejected as unreliable. If these dates are removed from consideration, then a chronological gap lies between Mulifanua (and other Lapita sites in Tonga and Fiji) and the Plainware sites of Samoa. Thus, these re-evaluations of chronology raise important questions about the significance of the Samoan Archipelago in Lapita-era migration.

To address these questions, we apply a Bayesian analysis to 27 pre-2000 cal BP radiocarbon and thorium-230 dates from four sites on Ofu Island, Manuʻa Group, American Samoa. We then interpret the results in the context of West Polynesian prehistory. Using Ofu Island as a proxy, we provide a chronology for the colonization of the Manuʻa Group on the eastern margin of the Samoan Archipelago.

2. Context

The Samoan Archipelago lies in West Polynesia and comprises eight major inhabited islands that, due to Western colonial intervention, are now separated into the Independent State of Samoa in the west (ʻUpolu, Savaiʻi, Manono, and Apolima islands) and the U.S. Territory of American Samoa in the east (Tutuila, Aunuʻu, Ofu, Olosega, Taʻu, Swains, and Rose Atoll) (Fig. 1). The Manuʻa Group, which is constituted by Ofu, Olosega, and Taʻu islands, forms the eastern extent of inhabited islands in the archipelago. Although the Manuʻa islands are small in

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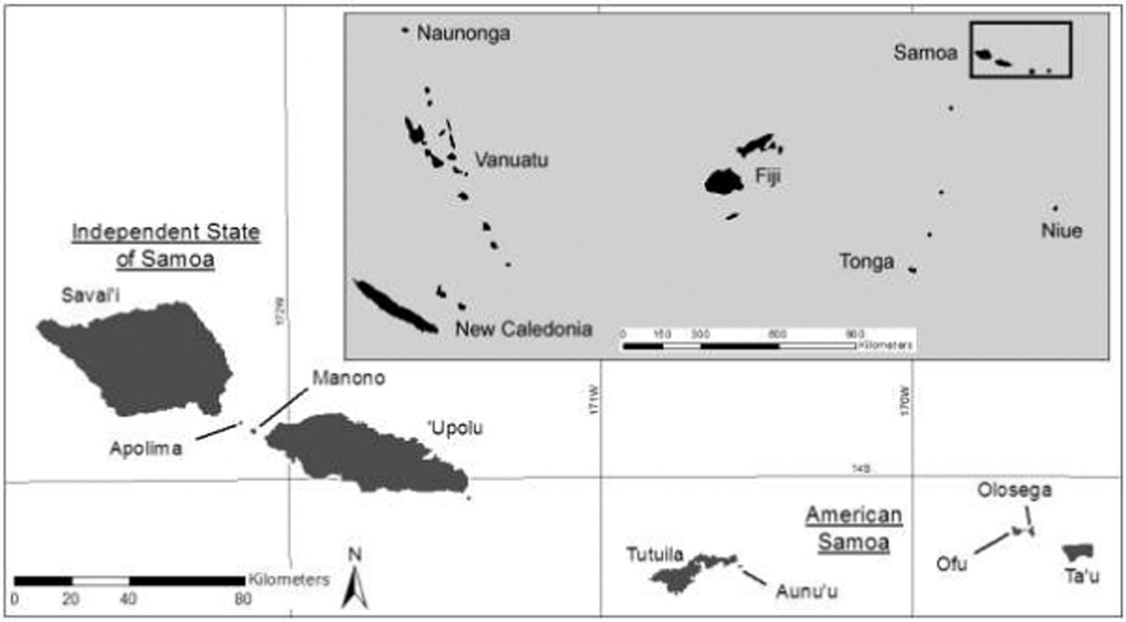

Fig. 1. Map of the Samoan Archipelago, with inset of the Central Pacific. Map data from ESRI, Inc.

area, they are classified as high volcanic islands. Ofu (7 km^2) and Olosega (5 km^2) are separated by less than 100 m while Ta'u (39 km^2) is only 14.5 km to the southeast, so there is inter-visibility and relatively easy travel between the islands. These are the youngest islands in the archipelago, and their coastlines have undergone considerable change over the last 3000 years due to tectonics, sea-level fluctuations, and local geomorphological processes (Kirch, 1993b; Quintus et al., 2015).

Lapita ceramics first appear in the Bismarck Archipelago of the Western Pacific possibly as early as 3470–3250 cal BP (Denham et al., 2012; Specht et al., 2014) and spread into Remote Oceania about 3000 cal BP (Petchey et al., 2014; Petchey et al., 2015; Sheppard et al., 2015). Lapita populations have been regarded as the first colonists of the Fiji-West Polynesia region and ancestral to all later Polynesians (e.g., Golson, 1961; Green, 1979). Based on recent chronological assessments, Lapita colonization of Fiji-West Polynesia occurred rapidly and probably no earlier than 3000 cal BP (Anderson and Clark, 1999; Burley et al., 2010; Nunn and Petchey, 2013). Subsequently, ceramic decoration was largely lost, as Lapita ceramics were replaced with Plainware. The claim that Samoa is part of the Lapita horizon is based on the discovery of a site at Mulifanua, on the western coast of 'Upolu Island. That site is now underwater – the result of Holocene subsidence (Dickinson and Green, 1998) – but was fortuitously discovered when dredging a ferry harbor. Archaeological investigation of in situ deposits has not taken place, but cultural remains from the site recovered from dredge piles include Lapita sherds in an Eastern Lapita decorative style characteristic of sites in Fiji and Tonga (Green, 1974; Petchey, 2001). Also recovered were shells and a turtle bone that provide the only dates for the site. Based on the critical evaluation of these dates, Petchey (2001:67) suggested that Mulifanua was settled around 2800 BP. However, there are still uncertainties with the dates: the association of the dated material with the cultural deposit; the stratigraphic position of dated samples; the reliability of the date on that turtle bone specimen; and large standard deviations of the shell dates. Consequently, chronometric dates of the colonization and abandonment of Mulifanua remain in question. Petchey's most compelling argument for 2800 BP is stylistic similarities of the Mulifanua Lapita decorative elements with those found at sites in Fiji and Tonga, and given what we now know of the chronologies of settlement in those archipelagos, a date of 2800 BP is reasonable (see below).

Numerous archaeological projects in Samoa over the last several decades have failed to locate additional archaeological deposits with Lapita ceramics. Sites dated to 3000–2800 BP, or earlier, and therefore contemporaneous with Mulifanua and other Central Pacific Lapita sites, have yielded only Plainware ceramics: 'Aoa (Clark and Michlovic, 1996), Aganoa, and Utumea (Moore and Kennedy, 1999) on Tutuila, and To'aga on Ofu (Kirch and Hunt, 1993). Other sites lacking dentate-stamped sherds that may date before 2500 cal BP were reported from Manono and elsewhere on 'Upolu (Jennings and Holmer, 1980). Many other Plainware sites have been documented in the archipelago, but typically date to the mid-to-late first millennium and later, thus post-dating the Lapita era.

In recent years the radiocarbon determinations from the Plainware sites have been re-evaluated based on chronometric hygiene protocols (Rieth, 2007; Rieth and Hunt, 2008; Rieth et al., 2008). Those studies rejected many dates, including the early (pre-2500) Plainware dates, based on large standard deviations, dates on unidentified wood charcoal, and/or stratigraphic inconsistencies. As a result, Rieth et al. (2008) report only 22 pre-2000 BP dates as reliable. Removing the questionable dates from consideration results in a gap in the sequence between Mulifanua and the settlement of the rest of the archipelago at 2400–2200 cal BP (Addison and Morrison, 2010) or 2500–2400 cal BP (Rieth and Hunt, 2008; Rieth et al., 2008). Addison and Morrison (2010) further propose that Samoa was settled twice, once by a Lapita group that reached Mulifanua and perhaps a small number of sites that are currently submerged, and again by a group carrying Plainware pottery that settled 'Upolu and all the other islands. Rieth and Cochrane (2012:338) argue for "a severely diminished or absent prehistoric population in Sāmoa after occupation of Mulifanua, until about 550–250 BCE," but additional exploratory archaeology focused on locating buried cultural deposits on coastal flats is warranted.

3. Methods and results

To build on the corpus of chronometric dates from Samoa, Clark and Quintus have carried out archaeological investigations at three sites on the island of Ofu: the Va'oto (AS-13-13) and Coconut Grove (AS-13-37) sites on the Va'oto Plain at the southern tip of the island, and the Ofu Village (AS-13-41) site on the west coast (Fig. 2). Additionally, we

Fig. 2. The location of the four sample locations on Ofu Island discussed in the text. Note that these sites are located near the widest stretches of fringing reef.

present eight new U-Th series dates of coral samples collected from those sites. These data are combined with a set of dates from the To'aga (AS-13-1) site on the south-central coast of Ofu reported by Kirch (1993a).

3.1. Radiocarbon dating

The combined dataset consists of 19 pre-2000 cal BP charcoal radiocarbon dates from four sites on Ofu: 11 from Va'oto, 2 from Coconut Grove, 2 from Ofu Village, and 4 from To'aga (Fig. 2; Table 1). The charcoal samples from Va'oto, Coconut Grove, and Ofu Village were dated at Beta Analytic using an accelerator mass spectrometer (AMS). Charcoal samples from these sites were taken in situ and point-plotted in 3D space. Three additional samples from charcoal residue on ceramic sherds, all from the Va'oto site, were taken and dated by Susan Eckert. Most charcoal samples were not identified prior to submission for analysis, but short-lived samples, specifically *Cocos nucifera* endocarp (coconut shell), have been dated from all three sites. All identified samples were examined by Jennifer Huebert at the University of Auckland. Five samples – 2 from Ofu Village, 1 from Coconut Grove,

Table 1
Description of radiocarbon dates from Ofu Island used in this analysis. To'aga dates are recalibrated based on data presented by Kirch (1993a).

Sample number	Site	Unit	Layer	Depth	Material	Taxon	13c/12c	Conventional date	Calibrate date (95.4%)
Beta-35602	To'aga	Unit 23	IIIA	NA	Charcoal	Unidentified charcoal	−26.9	2630 ± 100	2958–2380 BP
Beta-26464	To'aga	Unit 10	IIb	70–80 BS	Charcoal	Unidentified charcoal (flecks)	−27.8	2620 ± 140	3057–2351 BP
Beta-35603	To'aga	Unit 23	IIIB	190–260 BS	Charcoal	Unidentified charcoal	−28.4	2600 ± 170	3156–2314 BP
Beta-35601	To'aga	Unit 28	II	290–300 BS	Charcoal	Unidentified charcoal (flecks)	−27.8	2900 ± 110	3177–2781 BP
Beta-249325	Va'oto	35E/16N	IIb, level 5	97 BD	Charcoal	Unidentified charcoal	−25.9	2200 ± 40	2330–2120 BP
Beta-128705	Va'oto	23E/6N	IIc, level 7	72–74 BD	Charcoal	Unidentified charcoal	−25.8	2230 ± 40	2337–2151 BP
Beta-297826	Va'oto	37E/9N	V, Feature 60	144 BD	Charcoal	Unidentified charcoal	−26.2	2280 ± 40	2354–2157 BP
Beta-366730	Va'oto	39E/9N	Feature 74	129 BD	Charcoal	*Cordyline* sp. Stem	−28.00	2350 ± 30	2464–2324 BP
Beta-366729	Va'oto	40E/9N	Vc	121 BD	Charcoal	*Cocos nucifera* endocarp	−25.30	2350 ± 30	2464–2324 BP
Beta-262551	Va'oto	35E/12N	IV, Feature 25	103–113 BD	Charcoal	Unidentified charcoal	−28.0	2320 ± 50	2652–2155 BP
Beta-120417	Va'oto	24E/2N	IIIc, Feature 12	114–117 BD	Charcoal	Unidentified charcoal	−27.20	2370 ± 50	2700–2312 BP
Beta-249326	Va'oto	28E/8N	IV, level 7, Feature 39	99 BD	Charcoal	Unidentified charcoal	−25.40	2430 ± 40	2702–2353 BP
Beta-297824	Va'oto	36E/7N	V, Feature 59	133 BD	Charcoal	Unidentified charcoal	−25.1	2520 ± 30	2744–2491 BP
Beta-249327	Va'oto	23E/10N	IVb, level 6	98–108 BD	Charcoal	Unidentified charcoal	−22.20	2520 ± 40	2747–2470 BP
Beta-128706	Va'oto	24E/18N	IVG, level 15	169 BD	Charcoal	Unidentified charcoal	−30.30	2460 ± 40	2710–2364 BP
Beta-308978	Coconut Grove	XU-2	II	56 BD	Charcoal	Unidentified charcoal	−27.7	2370 ± 30	2489–2337 BP
Beta-307473	Coconut Grove	XU-2	III	67 BD	Charcoal	*Cocos nucifera* endocarp	−24.9	2470 ± 30	2717–2380 BP
Beta-354137	Ofu Village	XU-4	VIc	301 BD	Charcoal	*Cocos nucifera* endocarp	−23.0	2490 ± 30	2730–2460 BP
Beta-383081	Ofu Village	XU-4	VIc	226 BD	Charcoal	*Cocos nucifera* endocarp	−23.40	2490 ± 30	2730–2460 BP

and 2 from Va'oto – were identified as short-lived taxa. All conventional radiocarbon dates were calibrated in Oxcal 4.2 (Bronk Ramsey, 2009) using the IntCal 2013 calibration curve (Reimer et al., 2013). Charcoal dates from prior investigation at To'aga (Kirch, 1993a), which were dated using standard radiocarbon techniques, were recalibrated for this analysis. As such, those samples from To'aga have significantly higher error ranges relative to samples from the other Ofu sites (> ± 100 compared to ± 30 or ± 40).

Shell dates from previous research at To'aga were not used in this analysis, which we restricted to charcoal for consistency. It should be noted, though, that preliminary checks have shown that the inclusion of the remaining pre-2000 cal BP shell dates would have little effect on the results of this analysis.

3.2. Uranium and thorium (U-Th) dating

Pristine, culturally unmodified branches and two coral abraders of *Acropora* spp. coral were collected: (1) in situ within cultural layers or (2) at the boundary of the lowest cultural layer and sterile sedimentary deposit (paleo beach). In the first instance, coral samples date the formation of the cultural layers as unmodified coral branches and abraders were added as part of the layer matrix, while in the latter, coral dates provide a *terminus post quem* for the formation of the earliest cultural layer (e.g., sample 2014-19). Branch samples were first examined to determine the general state of preservation. To exclude samples with diagenesis, coral branches with obvious water rounding were not considered further for U-series dating. Only coral branches that exhibited sharp and well preserved verrucae were selected. These pristine-appearing branches were subsampled for analysis of diagenetic alteration from deleterious products including marine aragonite and calcite cements, meteoric cements, and dissolution and extensive bioerosion using Scanning Electron Microscopy (SEM) (Hua et al., 2015; Nothdurft and Webb, 2009). Small representative pieces were cut with a diamond saw and analyzed with SEM for identifying pore filling cements. The lab numbers and provenance information for the U-series dated coral samples are presented in Table 2.

A subsample of material from each of the coral specimens was cut and the exterior corallites removed with a diamond edged circular saw. Material was crushed with bone cutters and an agate mortar and pestle to approximately 1 mm grain size. Cleaning procedures follow those described in Clark et al. (2014a, 2014b) and were performed in an ultra-clean lab. Coral fragments for analysis were examined under a microscope to select the cleanest coral pieces free from alteration and clay or infilled cement contamination. SEM indicates that the skeletal components of the majority of samples are unaltered with largely pristine skeletal aragonite. Samples are generally pristine and the internal core of the coral skeletons considered unaltered. In those samples that were affected by alteration, the diagenetic effects were minimal and primarily confined to the exterior portions of the coral skeleton. The removal of the external skeleton before crushing and microscopic vetting of the crushed coral fragments after undertaking the H_2O_2 cleaning procedure eliminated any sample fragments that may have contained altered material. For this reason, all samples were considered suitable for U-Th dating.

U and Th isotope ratios were measured on a Nu Plasma multi-collector inductively coupled plasma mass-spectrometer (MC-ICP-MS) with a DSN-100 nebulizing system and a modified CETAC ASX-110FR autosampler, at the Radiogenic Isotope Facility, University of Queensland following procedures described in Clark et al. (2014a, 2014b). U-Th data in Table 3 shows ^{232}Th concentrations similar to values of other Pacific island corals of a similar age (e.g. Burley et al., 2012, Cobb et al., 2003, Weisler et al., 2006, Weisler et al., 2009). ^{232}Th values range between 0.019 ppb and 1.39 ppb, with an average concentration of 0.44 ppb. These values are relatively low and indicate that initial ^{230}Th component from detrital ^{232}Th is minimal or negligible, resulting in excellent age precision. All the samples fulfill the criteria, outlined in Scholz and Mangini (2007), to identify diagenetic factors that affect both age precision and accuracy. These include calcite content of less than 2%, ^{232}Th concentrations less than 2 ppb, U concentrations that fall within modern coral values (i.e. 2.5–3.5 ppm), and δ^{234}U that fall within modern seawater and coral values (i.e. 147 ± 5‰). Thus, the Samoan samples are considered reliable for U-Th dating.

3.3. Single phase Bayesian modeling

The use of Bayesian analysis to determine precise chronologies for island colonization and depositional sequences is becoming widespread in Oceania (Allen and Morrison, 2013; Burley and Edinborough, 2014; Burley et al., 2015; Cochrane et al., 2013; Denham et al., 2012; Nunn and Petchey, 2013; Petchey et al., 2015; Sheppard et al., 2015). Simply, Bayesian statistics allow one to integrate prior information into the calculation of probability distributions for individual dates; that prior information may be stratigraphic evidence or more general chronological controls. Based on information included in the model, the program provides a quantitative assessment of the accuracy of the model, i.e., the agreement index. The conventional recommendation is that the agreement index should be above 60% for all samples and the model as a whole. If the agreement index of an individual sample is less than 60%, it may mean the sample is an outlier; if the model agreement index is less than 60%, the model could be invalid.

We integrate charcoal and coral dates into a single Bayesian model, facilitated by the use of OxCal, to model the start date for the colonization of Ofu Island. For simplicity, we model island colonization as a single uniform phase using the standard boundary command. This model assumes no prior ordering of dates – all determinations are a random scatter of events in no particular order – but evaluates all dates within a shared group to determine, for instance, the probability that the statistical tails of some dates are the product of plateaus in the calibration curve. This is particularly important for this time period, which is significantly affected by the Iron-Age calibration plateau. The integration of coral dates with AMS radiocarbon dates in the model may allow us to overcome the deficiencies of wood charcoal dates within that time range. Furthermore, it allows us to quantitatively assess the internal

Table 2
Lab numbers and provenance for U-series dated *Acropora* spp. corals from Va'oto, Ofu, American Samoa. All lab numbers are preceded by 2014.

Lab no.	Site	Unit	Layer	Level	Depth (cmbd)	Weight (g)	Condition	Calibrated date (BP)
15	Coconut Grove	11	III	6	64	8.5	Unmodified	2814–2778
16	Va'oto	24E/18N	IVb	15	161–171	382.9	Abrader	2486–2454
17	Va'oto	37E/11N	III	5	82	55.1	Unmodified	2363–2323
18	Va'oto	T1	V	–	130–150	9.2	Unmodified	3147–3103
19	Coconut Grove	12	III	8	59	3.0	Unmodified	2692–2640
20	Va'oto	40E/9N	Vb	10	106	4.6	Unmodified	2392–2356
21	Va'oto	40E/9N	Vb	10	102	11.6	Unmodified	2395–2359
22	Va'oto	39E/9N	VI	–	134–187	12.2	Unmodified	2397–2356
23	Va'oto	39E/9N	VI	–	134–187	26.1	Unmodified	2517–2489
24	Va'oto	32E/8N	IVb	7	90–100	3.3	Abrader	2385–2345

Table 3
U–Th isotope data and ages for *Acropora* spp. branch coral analyzed in 2014. Samples 15 and 19 are from Coconut Grove and all others are from Va'oto. Samples 16 and 24 are abrader artifacts, all others are unmodified.

Sample name	Sample wt. (g)	U (ppm)	±2 s	^{232}Th (ppb)	±2 s	(^{230}Th/^{232}Th)	±2 s	(^{230}Th/^{238}U)	±2 s	(^{234}U/^{238}U)	±2 s	Uncorr. age (ka)	±2 s	Corr. age (ka)	±2 s	Corr. initial (^{234}U/^{238}U)	±2 s	Corr. age (BP)	±2 s	Corr. age (CE/BCE)	±2 s
2014-15	0.15146	2.7962	0.0017	0.159	0.000	1584.3	6.5	0.02971	0.00009	1.1461	0.0010	2.862	0.009	2.861	0.009	1.1473	0.0010	2796	9	−847	9
2014-16	0.15568	2.8451	0.0019	0.018	0.000	12,285	158	0.02628	0.00008	1.1430	0.0009	2.535	0.008	2.535	0.008	1.1440	0.0009	2470	8	−520	8
2014-17	0.15402	2.9673	0.0020	0.292	0.000	772.0	3.3	0.02508	0.00010	1.1468	0.0011	2.410	0.010	2.408	0.010	1.1478	0.0011	2343	10	−395	10
2014-18	0.15470	2.8213	0.0012	1.390	0.002	204.2	0.6	0.03316	0.00009	1.1452	0.0010	3.203	0.010	3.190	0.011	1.1466	0.0011	3125	11	−1188	11
2014-19	0.09423	3.0348	0.0014	0.942	0.001	278.1	1.2	0.02845	0.00012	1.1465	0.0013	2.739	0.012	2.731	0.013	1.1476	0.0013	2666	13	−724	13
2014-20	0.11255	2.8358	0.0017	0.525	0.001	416.1	1.6	0.02537	0.00009	1.1443	0.0008	2.444	0.009	2.439	0.009	1.1453	0.0008	2374	9	−429	9
2014-21	0.15502	2.8261	0.0011	0.224	0.000	971.6	3.8	0.02540	0.00009	1.1458	0.0011	2.444	0.009	2.442	0.009	1.1468	0.0011	2377	9	−429	9
2014-22	0.11300	2.8019	0.0020	0.614	0.001	351.6	1.4	0.02538	0.00010	1.1440	0.0017	2.446	0.010	2.440	0.011	1.1450	0.0017	2375	11	−431	11
2014-23	0.16029	3.1791	0.0020	0.123	0.000	2086.8	7.7	0.02667	0.00007	1.1451	0.0010	2.569	0.007	2.568	0.007	1.1461	0.0011	2503	7	−554	7
2014-24	0.15702	2.8203	0.0014	0.142	0.000	1516.4	7.1	0.02525	0.00010	1.1444	0.0012	2.431	0.010	2.430	0.010	1.1454	0.0012	2365	10	−417	10

consistency of both coral and radiocarbon dates. The single group analyzed is defined as all pre-2000 cal BP charcoal and coral dates from Ofu.

Three iterations of a Bayesian model were run to determine the timing of initial colonization of Ofu Island. Two of the coral dates (2014-15 and 2014-18) were excluded from analysis as they stem from pre-colonization contexts based on stratigraphic evidence. They were dated to address questions regarding landscape formation processes. All other samples are interpreted to date human activity, either by association or because the fresh coral finger was modified into an artifact (2014-16 and 2014-24). Sample 2014-19, an unmodified fresh coral finger, is of particular importance given that it is located at the interface of sterile beach sand and the basal cultural deposit at Coconut Grove.

The first iteration consisted of all coral and charcoal dates deemed to be associated with human activity (n = 27). The initial run of the model resulted in a modelled start date of 2875–2649 cal BP (95.4%) (Fig. 3). All but one determination returned agreement indices above 60%, and the model had an overall agreement of 75%. The lone radiocarbon date with an index below the threshold is the earliest charcoal date from To'aga (Beta-35601, A = 14%). Such a low agreement index, along with visual inspection, suggests that the sample is an outlier, perhaps because it was wood with in-built age. The outlier was removed from the phase and a second iteration of the model was run (Fig. 4). This resulted in a higher overall model agreement (A = 91.3%), and all dates have individual agreement indices above 60%. This iteration resulted in a shorter modelled start date of 2763–2645 cal BP (95.4%). To ensure reliable results, a third iteration of the model was run that included only determinations derived from either short-lived charcoal (n = 5) or coral from cultural deposits, as defined above (n = 8) (Fig. 5). Again, the model returned a high overall agreement index (A = 99.3), and all individual agreement indices were over 95%. The modelled start date was very similar to that modelled in the second iteration, with a 95.4% HPD range of 2774–2647 cal BP and a 68.2% range of 2717–2663 cal BP.

4. Discussion

Our Bayesian analysis of charcoal and coral dates from Ofu Island indicates colonization no later than 2650 cal BP. We favor the modelled range of 2717–2663 cal BP (68.2%) as the most precise period bracketing colonization. This range is influenced by four dates on short-lived material: one on coral and one on coconut endocarp charcoal from Coconut Grove, and two on coconut endocarp charcoal from Ofu Village. The three charcoal dates have large ranges associated with the Iron-Age calibration plateau and the coral age is interpreted as marking the first settlement of Coconut Grove based on stratigraphic context and consistency with the short-lived charcoal date from the same deposit. We add that the four sites covered in this analysis represent the areas of coastal lowlands most likely to have been available for early occupation, and it seems unlikely to us that significantly earlier colonization (before the 95.4% range of 2774–2647 cal BP) took place at any other location on the island.

Based on these data, Ofu Island appears to have been settled after Lapita colonization of 'Upolu, although the dates from Ofu overlap with those from Mulifanua when using the 95.4% HPD range (see Petchey, 2001). If one rejects or sets aside the earliest dates on Tutuila from 'Aoa, Aganoa, and Utumea (Clark and Michlovic, 1996; Moore and Kennedy, 1999) due to unidentified wood and questions of context as argued by some (Rieth, 2007; Rieth and Hunt, 2008; Rieth et al., 2008), then Ofu would appear to have been colonized prior to Tutuila. More importantly, the modelled colonization date for Ofu presented here, taken in conjunction with all pre-2000 cal BP determinations for Samoa, does not support a significant gap in the Samoan sequence between Lapita colonization on 'Upolu and the later Plainware occupation in the archipelago as previously suggested (e.g., Addison and Morrison, 2010; Rieth, 2007; Rieth and Hunt, 2008; Rieth et al., 2008). The date of

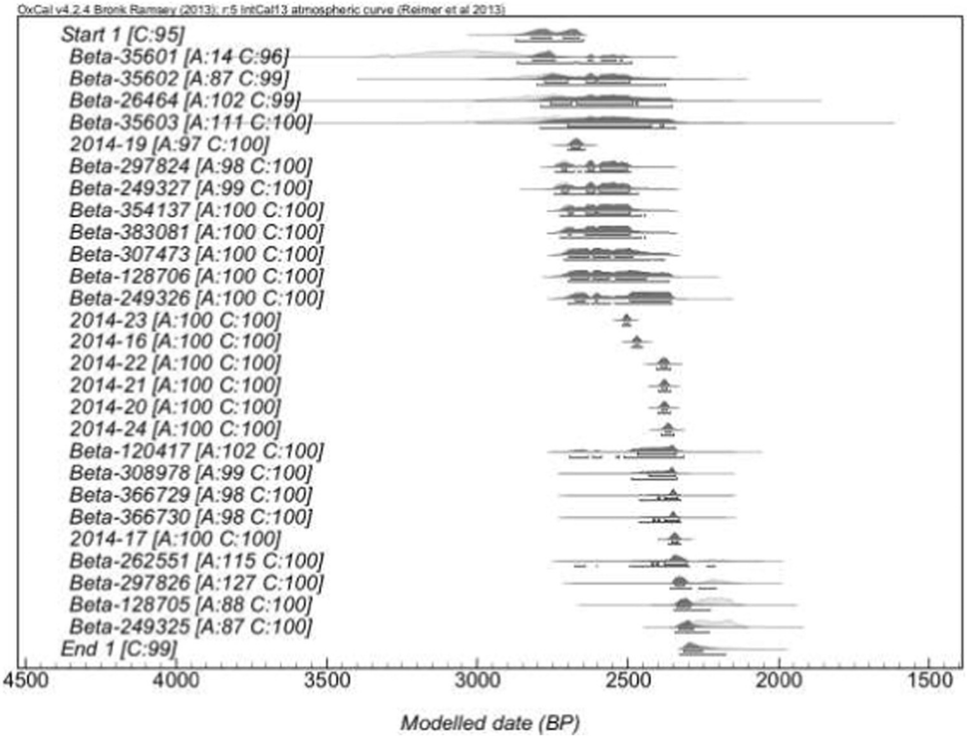

Fig. 3. Single phase Bayesian analysis of all culturally-associated pre-2000 BP coral and charcoal dates from Ofu Island. Note the agreement index of Beta-35601.

colonization of Ofu allows us to quantify the period of migration through the Central Pacific and place Manu'a more confidently within that span.

Recent reassessment of dates from the Bismarck Archipelago by Denham et al. (2012) provides an initial date for the appearance of Lapita ceramics at 3470–3250 cal BP (68.2%), although those dates may reflect, to some degree, an in-built age due to old-wood effect. Lapita populations expanded further into the Pacific to colonize islands in Remote Oceania. Denham et al. (2012:44) put the colonization of Vanuatu at 3250–3100 cal BP (68.2%) and Fiji at 3130–3010 cal BP (68.2%), but dates used to construct that chronology are either on unidentified wood with possible in-built age, from problematic context, or are anomalous relative to sites in proximity (Nunn and Petchey, 2013; Sheppard et al., 2015:34–35). Sheppard et al. (2015), therefore,

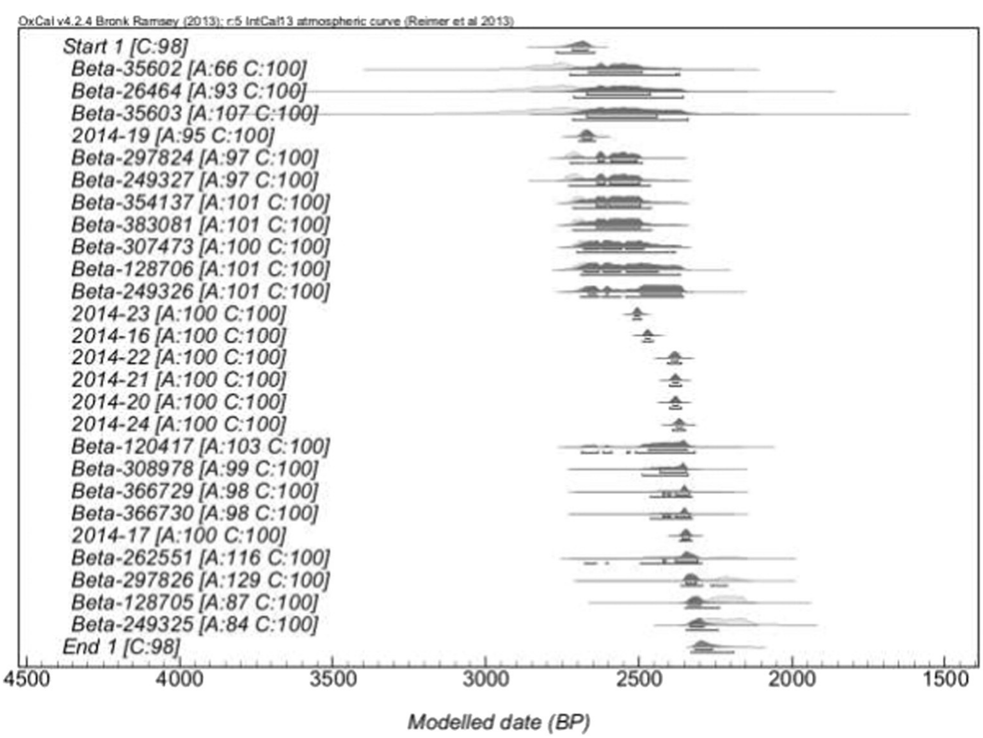

Fig. 4. Single phase Bayesian model of all culturally-associated pre-2000 cal BP dates from Ofu Island excluding the interpreted outlier Beta-35601.

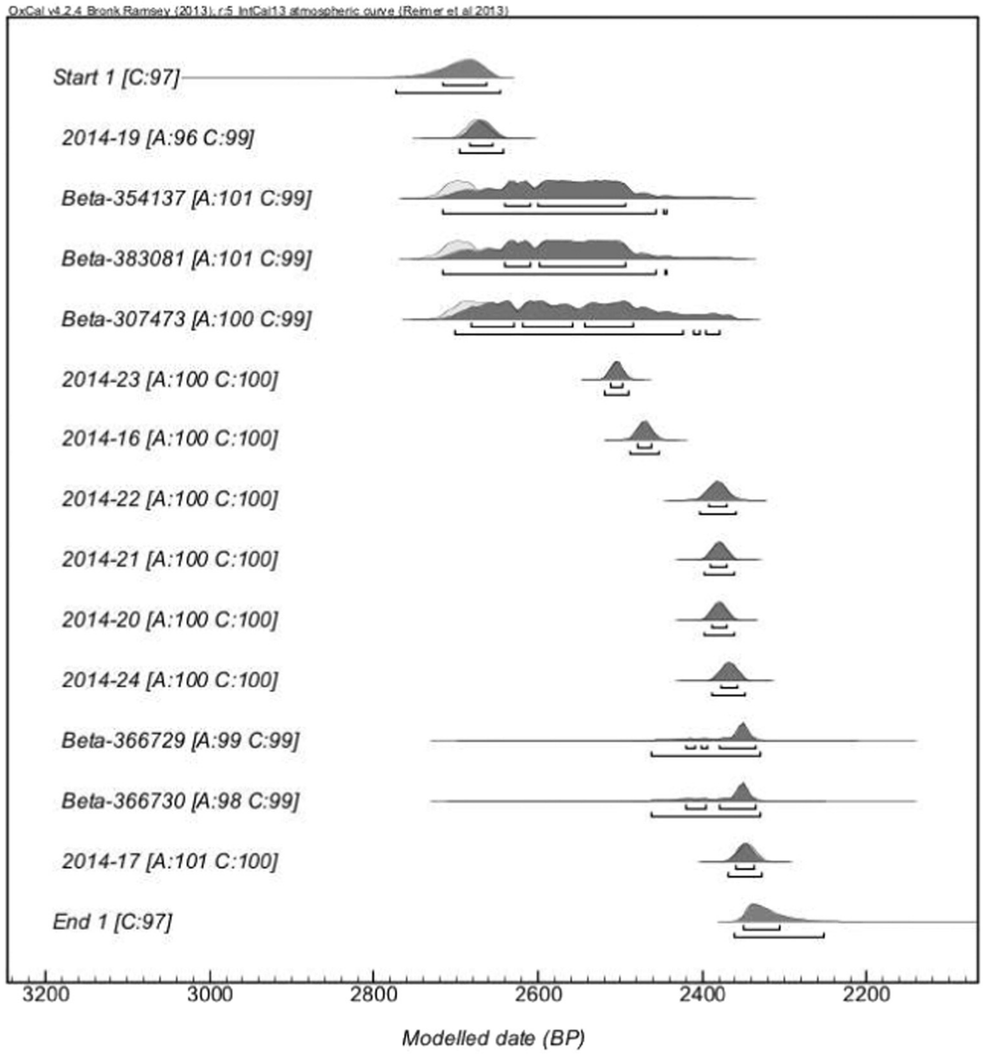

Fig. 5. Single phase Bayesian model of all culturally-associated coral and short-lived charcoal samples. This model had the highest overall agreement index of any iteration.

suggest that Remote Oceania was not colonized until 3000 cal BP or shortly thereafter, although one site in Vanuatu (Mauké on Aore Island Espiritu Santo), and one in the Loyalty Islands (Kurin on Maré) may be slightly earlier. The earliest sites in Fiji now appear to be Bourewa on Viti Levu Island and Matanamuani on Naigani Island. Nunn and Petchey (2013) critically reassessed the early dates for Bourewa using a Bayesian analysis, putting the site colonization at 2866–2771 cal BP (95.4%). Dates for Matanamuani were recently reanalyzed by Sheppard et al. (2015) through a Bayesian model, which revealed an outlier that Irwin et al. (2011) had initially identified as inconsistently old, possibly reflecting old-wood effect. When that date is removed from consideration, the Bayesian analysis indicates "an upper boundary for the site of 3001–2790 cal BP (95% HPD)" (Sheppard et al., 2015:32).

In West Polynesia, Burley and colleagues have proposed that in Tonga, the Nukuleka site, on Tongatapu, constitutes the founding Lapita colony of Tonga. Radiocarbon dates for Nukuleka document initial occupation at 2900–2850 cal BP, but subsequent Bayesian analysis pairing AMS and U-Th dates of Nukuleka (Burley et al., 2012), particularly a U-Th date on a coral file, further refined the colonizing date to 2846–2830 cal BP. Recently, those analytical techniques were applied to other Lapita sites in the Tongan Archipelago with the results showing subsequent settlement of the islands to the north 70–90 years later, with several islands colonized instantaneously in the Ha'apai Group, in the Vava'u Group, and possibly as far away as Niuatoputapu (Burley et al., 2015). The age of Mulifanua at ca. 2800 BP proposed by Petchey (2001) falls within the Lapita sequence of Tonga, and there is marked temporal proximity of Ofu to Mulifanua.

Taking 3000 cal BP as the beginning of the colonization of Remote Oceania and the colonization of Ofu as the end provides a timespan of the migration of 280–340 years (calculated based on 68.2% range). Lapita colonization of western Remote Oceania may have been completed within 14 generations (at 20 years each). Sheppard and colleagues (Sheppard, 2011; Sheppard et al., 2015; Sheppard and Walter, 2006) have argued that the speed of the Lapita colonization from the Bismarck Archipelago in the far west out to the Reef/Santa Cruz group in Remote Oceania was so fast that it can only be explained by invoking a leap-frog movement. Once in Remote Oceania, migration farther east continued in "an almost continuous expansion, possibly through a series of leap-frogs" (Sheppard et al., 2015:35). Similarly, because some of the pottery at the Nukuleka site came from an island to the west of Fiji, Burley and colleagues (Burley and Connaughton, 2007; Burley et al., 2010; Burley and Dickinson, 2010) view the Tonga colony as also suggesting a leap-frog settlement process. Sheppard et al. (2015:35) further argued that given this speed of expansion, there is now no evidence of population growth as a driver for the migration from the western Pacific out to Fiji. We conclude that the short timespan documented here for the migration beyond Fiji to Tonga and the eastern-most islands of Samoa also strongly argues against a demographically driven explanation for the colonization of West Polynesia, whether by Lapita or Plainware populations. This argument applies regardless of whether the colonization process was one of leap-frogging or direct, down-the-line movement; but if the latter took place, the time between each movement would have been short.

Population size may have played another role, however, which is in ending Lapita-era (i.e., Lapita or Plainware) migration. As others have argued, settlement of Samoa may have stretched colonizers to their limit (Addison and Morrison, 2010), and this may have caused the initial populations inhabiting the archipelago to remain small and somewhat isolated (Cochrane et al., 2013). The suggestion that the migration may have been running out of steam, so to speak, is highlighted by the difference between the length of time from the beginning of the colonization of Remote Oceania to the settlement of Tonga ($\approx$154–170 years), as modelled by Burley et al. (2012) (2846–2830 cal BP), and the length of time from settlement of Tonga to the colonization of Ofu ($\approx$129–183 years), a considerably shorter distance.

The dates proposed here for Ofu also hold implications for understanding other aspects of West Polynesian colonization. At the 95.4% confidence level, the Ofu (Plainware) date range (2774–2647 cal BP) closely approaches, and possibly overlaps with, the occupation of Mulifanua (Lapita). At the very least, then, the time frame for a gradual transformation of Samoan Lapita to a Polynesian Plainware narrows considerably (Green, 1974:253). In Tonga, Burley and colleagues propose that the cessation of Lapita dentate stamping and the transition to Plainware ceramics took place over periods of "129 to158 years on Tongatapu, 32 to 49 years in Ha'apai, and 51 to 82 years in Vava'u" (Burley et al., 2015:11). Such a transition in Samoa may also have been fairly rapid. But, while there is evidence of a transition in Tonga, none of the first millennium BCE sites in Samoa have presented evidence of a decorated-to-plain transition. It is important to note that the modelled colonization date for Ofu of 2717–2663 cal BP at 68.2% overlaps with the Burley et al. (2015) dates of Lapita ceramic loss in Tonga (at 68.2%, cal BP) of 2709–2680 on Tongatapu, 2728–2716 for Ha'apai, and 2703–2683 for Vava'u. If the Ofu colonizers originated somewhere in Tonga (which is still uncertain), they may have embarked after, or in the dying stage of, decorative ceramic applications. Thus, this temporal correlation supports a migration scenario in which Ofu was settled soon after the loss of Lapita ceramics from Tonga.

Alternatively, it is conceivably that sites with Lapita pottery or showing such a transition to Plainware may lie submerged along the coasts of 'Upolu and Savai'i, but submergence of sites is not indicated for Tutuila or Manu'a in either the geomorphological model of Dickinson and Green (1998) or the documented locations of early sites (Clark and Michlovic, 1996; Kirch and Hunt, 1993; Moore and Kennedy, 1999; Quintus et al., 2015). On those islands, sites may yet be found buried under talus and colluvium back from the modern shoreline (Kirch, 1993b), but where such areas have been explored thus far, only Plainware has been found. Another proposed explanation for the apparent absence of sites with Lapita or transitional ceramics – and scarcity of pre-2500 BP settlements of any type – is limited occurrence of suitable coastal plains at that time (Rieth et al., 2008; Cochrane et al., 2015). But, the founding populations are likely to have been quite small (e.g., Addison and Morrison, 2010), and therefore would not require much in the way of a coastal flat. That certainly is the case with the Ofu sites and is overwhelmingly the case with early colonization of low coral atolls that typify settlement of the smallest of island landscapes (Weisler et al., 2012). Moreover, two non-culturally affiliated coral dates from Ofu, samples 2014-15 and 2014-18, indicate that the coastal landscape of Ofu onto which humans settled was available by the end of the 2nd millennium BCE. Certainly the conditions on each island in the archipelago were unique due to differing geological forces and geomorphological configurations, but while limited suitable land constrained colonization opportunities in Samoa, it did not prohibit settlement.

It is now clear that while some islands in the Samoan archipelago, notably 'Upolu, were colonized by Lapita people with dentate-stamped pottery, other islands, i.e., Ofu, were first settled by people making only Plainware pottery. Whether these conditions reflect colonization of Samoa by one group or two groups remains unresolved. The single-group model gains some support in closing the time gap between decorated and plain assemblages. At the same time, the same gap closure, in conjunction with the absence of stylistic transition, may be regarded as still indicating two distinct groups, one Lapita and one Plainware. The debate as to the number of colonization events and peoples for Samoa will require analysis of a range of data including detailed comparisons of ceramic assemblages amongst sites in Samoa and Tonga, and petrographic and/or geochemical analysis of ceramic constituents to identify exotic or locally made pottery. Detailed analyses of the ceramic assemblages from the Va'oto, Coconut Grove, and Ofu Village sites have not been completed, but we can say that the assemblages are broadly comparable with one another and with the assemblages from To'aga described by Hunt and Erklens (1993). How those assemblages compare with the Plainware assemblages from other sites in Samoa and Tonga remains to be determined.

5. Conclusions

The presence of a single site with Lapita ceramics in the Samoan Archipelago together with reevaluations of previously published dates has raised questions as to the continuity between Lapita and Plainware sites in Samoa, and about the precise age of that colonization(s). Our results provide preliminary answers to these questions. First, data from Ofu fills a gap in the chronological sequence of the archipelago created by previous chronometric hygiene protocols. While this still leaves open the possibility that multiple groups were involved in the human settlement of Samoa, it does refute the proposal that there was a substantial amount of time between these possible different settlement events. Second, our model indicates that Ofu was colonized sometime within 2774–2647 cal BP (95.4%) or perhaps more narrowly, 2717–2663 cal BP (68.2%). That such a date overlaps with modelled dates of the loss of dentate-stamped decoration in Tonga may explain the absence of Lapita pottery on Ofu, although other explanations are also possible. Thus, the data presented here contribute to the continuing efforts to understand the colonization of the Pacific. The precision allowed by the U-Th dating of coral, especially when input into a Bayesian model, creates opportunities for more robust models of colonization. In particular, they provide a precise duration of Lapita-era migration and the changing pace of island colonization. The Samoan Archipelago, and more specifically the Manu'a Group of American Samoa, inhabits an important place as the eastern Oceanic extent of arguably the most rapid maritime human migration in world prehistory.

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