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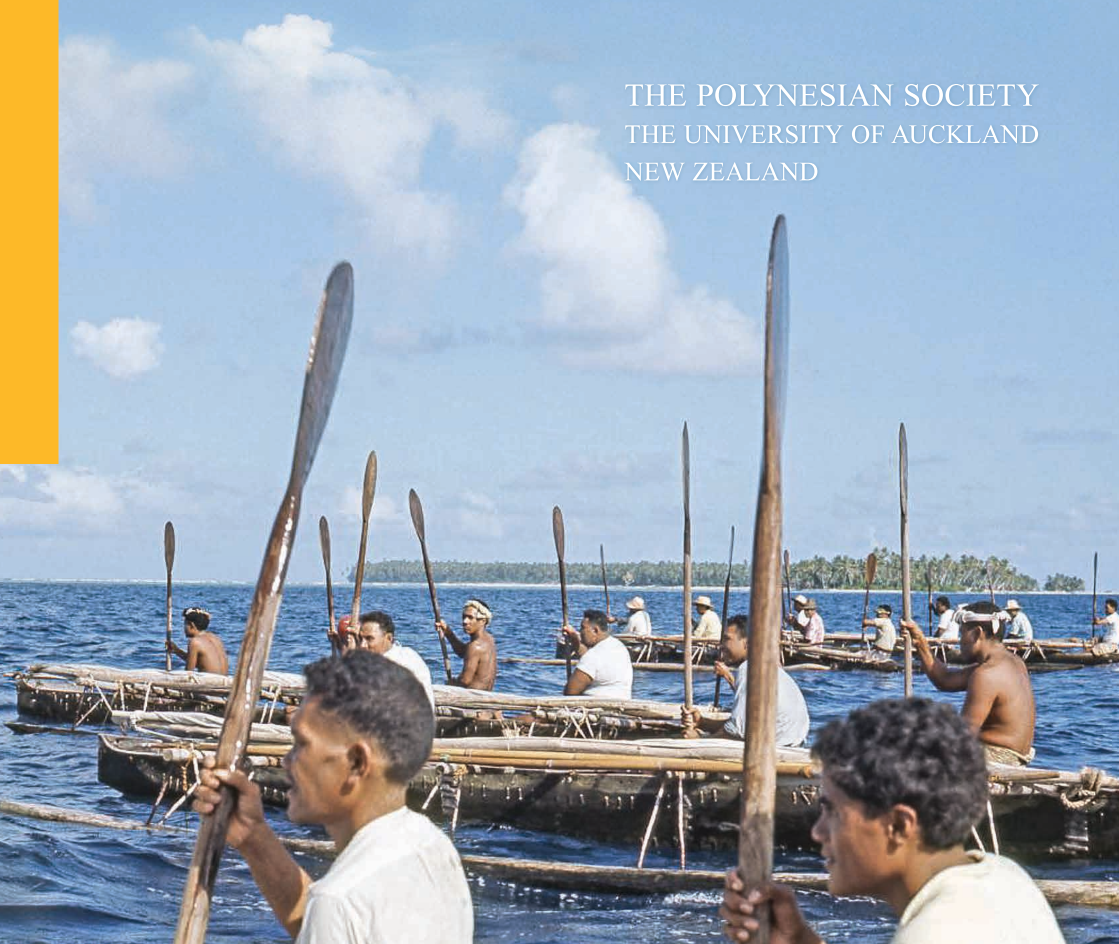

NEW AMS RADIOCARBON DATES AND A RE-EVALUATION OF THE CULTURAL SEQUENCE OF TIKOPIA ISLAND, SOUTHEAST SOLOMON ISLANDS

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The small volcanic island of Tikopia, situated at a geographically key intersection between the southeastern terminus of the Solomon Islands and the northern end of the Vanuatu archipelago, first gained anthropological fame through the extensive ethnographic field research and writings of Sir Raymond Firth (1936, 1939). Tikopia is a Polynesian Outlier, one of about 18 such islands lying within Melanesia and Micronesia whose populations speak Polynesian languages (Feinberg and Scaglion 2012). Based on Tikopia oral traditions, Firth (1961) opined that many of the Tikopia lineages traced their origins to islands in Western Polynesia, with ancestors arriving from Tonga, Sāmoa, Futuna, ʻUvea or Rotuma.

In 1977–78, as part of the second phase of the Southeast Solomon Islands Culture History Program organised by the Bernice P. Bishop Museum and funded by the U.S. National Science Foundation, the senior author and Douglas E. Yen carried out two seasons of archaeological and ethnobotanical investigations on Tikopia (Kirch and Yen 1982). Excavations totalling more than 271 m^3 at 26 different localities around the island revealed well-stratified archaeological deposits, yielding large assemblages of artefacts (5,650 objects) and faunal remains (>35,000 NISP vertebrate remains; 1.03 metric tons of mollusc remains). The cultural sequence of Tikopia proved to be complex, with three discrete prehistoric cultural phases recognised on the basis of changes in the material cultural assemblages. The initial Kiki Phase, estimated to have commenced c. 900 BC, was marked by the presence of sand-tempered pottery related to the early Lapita Cultural Complex (Green 1979). This was followed by the Sinapupu Phase during which incised Mangaasi-style ceramics (Garanger 1971, 1972) were imported into Tikopia from one or more localities in the Vanuatu archipelago. The final Tuakamali Phase lacked ceramics altogether but contained distinctly Polynesian-style adzes and fishing gear indicative of the arrival of voyagers from Western Polynesia (as the oral traditions suggested). It was therefore during the Tuakamali Phase that Tikopia took on its cultural and linguistic characteristics as a Polynesian

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Outlier. The Tikopia cultural sequence, as defined by Kirch and Yen (1982: 311-34; see also Kirch 1984, 1986, 1997) remains one of the best-defined archaeological sequences for any Polynesian Outlier, and is of considerable importance for our understanding of the prehistory of the southwestern Pacific.

Kirch and Yen (1982: 311-17, Table 50) submitted 20 samples from their Tikopia excavations, primarily of wood charcoal or carbonised coconut shell, to the radiocarbon laboratories of Teledyne Isotopes, University of California at Riverside, Beta Analytic, and the Australian National University. Based on the ^{14}C results received from these laboratories, the three-phase Tikopia cultural sequence was pegged to a chronological sequence as follows: Kiki Phase, 900–100 BC; Sinapupu Phase, 100 BC–AD 1200; and Tuakamali Phase, AD 1200–1800.

From the perspective of the many advances that have been made in sample selection, preparation and ^{14}C dating methods, more than three decades after these initial radiocarbon dates were run, it is apparent that the initial programme of dating the Tikopia sequence suffered from several shortcomings. First, although it was recognised that some samples contained carbonised coconut (*Cocos nucifera*) shell (endocarp), the wood charcoal samples were not botanically identified, leaving open the possibility that some samples could have included charcoal from old-growth trees or even driftwood, a problem that later became apparent in the dating of archaeological sites in Eastern Polynesia (Spriggs and Anderson 1993). Second, δ^{13}C values were not determined for the dated samples and the reported ages were based on an assumed δ^{13}C value of -25.0‰. For most samples this assumption was probably reasonably accurate, although for one sample of human bone and another of *Thalassia*, a genus of seagrass with C_4-like carbon stable isotope ratios, this is more questionable. In addition, radiocarbon laboratories at the beginning of the 1980s were still using the liquid scintillation method of beta-particle decay counting, with standard errors (1σ) for the Tikopia samples ranging from ± 75 yr at best, and up to ± 165 yr in the case of two samples. Finally, the calibration of radiocarbon samples using calibration curves derived from dendrochronologically dated bristlecone pines was then in its infancy. Kirch and Yen (1982: 312, Table 50) used the early calibration tables of Michael and Ralph (1972) and of Damon *et al*. (1972) to derive "corrected dates" for the Tikopia samples. Table 1 lists the original 20 radiocarbon dates, given here with new calibrated age ranges, calibrated using OxCal v4.2.4 with the SHCal13 atmospheric calibration curve (Bronk Ramsey 2009a; Hogg *et al.* 2013).

Given these issues, as well as the continued importance of the Tikopia cultural sequence for our understanding of southwestern Pacific prehistory, additional re-dating of archaeological samples from Tikopia seemed desirable. The opportunity to carry out such a re-dating program arose in 2015 in conjunction with Swift's dissertation research on bone collagen stable isotope analysis of Pacific rat (*Rattus exulans*) remains recovered from several Pacific archaeological assemblages, including Tikopia. Drawing upon the Kirch and Yen 1977–78 collections that have been curated in the Bishop Museum, samples of rat bone, pig (*Sus scrofa*) teeth, and previously undated charcoal samples were selected for AMS radiocarbon dating. In this paper we present the results of 13 new AMS dates, along with a Bayesian calibration model that combines the new AMS dates with the previously dated samples in order to reassess the Tikopia cultural chronology.

MATERIALS AND METHODS

Rat and pig elements were subsampled for stable isotope analysis prior to submission for AMS radiocarbon dating; specifically bone collagen and tooth dentin were analysed for carbon and nitrogen, and tooth enamel for carbon and oxygen. Rat bone elements were sonicated in ultrapure water for four hours, dried and abraded to remove surface contaminants. Samples were then crushed into chunks (~1 mm) with the aid of an agate mortar and pestle. Approximately half of each sample was reserved for future stable isotope analysis by Swift. Pig teeth were sampled for enamel and dentin just above the cemento-enamel junction using a Foredom SR-series motor and diamond-tipped drill bit, and the remainder of each tooth was submitted for AMS dating.

Curated charcoal samples from several stratigraphic contexts excavated in 1977–78 were examined in the laboratory by PVK, and carbonised fragments of coconut (*Cocos nucifera*) endocarp were extracted whenever these were present. Coconut endocarp (the hard "shell" of the nut) burns with a hot fire and is a preferred fuel for igniting earth ovens on Tikopia and elsewhere in Polynesia. The carbonised endocarp, with its two parallel surfaces and hard, shiny texture, is readily identifiable.

All samples for radiocarbon dating were submitted to the W.M. Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory at the University of California, Irvine. When sample sizes permitted, submitted bone and tooth dentin collagen samples were also analysed separately for $\delta^{13}C$ and $\delta^{15}N$. The samples were radiocarbon dated using a 500 kV compact AMS unit from the National Electrostatics Corporation (Southon *et al.* 2004). $\delta^{13}C$ values were measured to a precision of <0.1‰ relative to standards traceable to Pee Dee Belemnite (PDB), using a Thermo Finnigan Delta Plus stable isotope ratio mass spectrometer (IRMS) with gas bench input. Aliquots of ultra filtered bone and tooth dentin collagen were analysed for $\delta^{13}C$ and $\delta^{15}N$ to a precision of <0.1‰ and <0.2‰, respectively, using a Fisons NA1500NC elemental analyser/Finnigan Delta Plus IRMS (J. Southon, pers. comm., 2015). All results have been corrected for isotopic fractionation according to the conventions of Stuiver and Polach (1977), with $\delta^{13}C$ values measured on prepared graphite using the AMS spectrometer.

Table 1. Original radiocarbon dates for Tikopia reported by Kirch and Yen (1982), with new calibrations.

Lab No.	SORC-*	Site/ Locality	Stratigraphic Provenience	Tikopia Sequence Phase	Material	Reported ^{14}C Age BP†	Calibrated Age Range (2σ)**
UCR-964	101	TK-4	Unit U17, Layer II, 55–75 cm	Kiki	Charcoal	2680 ± 90	1012–488 cal BC
UCR-965	104	TP-52	Layer IV, 110–145 cm	pre-Kiki	Charcoal and coconut	3360 ± 130	1943–1291 cal BC
UCR-966	105	TK-36	Layer III, Zone C2	Kiki	Charcoal and coconut	2695 ± 90	1041–517 cal BC
Beta-1227	102	TP-48	Layer III, Zone C1	Kiki	Charcoal	2110 ± 95	361 cal BC–cal AD115
I-10702	30	TP-20	Layer IV, 127–145 cm, Zone B2	Early Sinapupu	Charcoal	1955 ± 165	363 cal BC–cal AD 431
Beta-1224	31	TP-20	Layer V, 208 cm, Zone B2	Early Sinapupu	Charcoal	1760 ± 85	cal AD 120–530
I-10700	26	TK-1	Unit J8, Layer VII, 120–125 cm, Zone B1	Late Sinapupu	Charcoal	850 ± 75	cal AD 1040–1305 cal AD 1362–1378
I-10699	24/25	TK-1	Unit J8-J9, Layer III, Zone A2	Early Tuakamali	Charcoal	1165 ± 85	cal AD 683–743 cal AD 760–1046 cal AD 1089–1110 cal AD 1119–1131
I-10722	55	TK-1	Unit J7-J8, Layer II, Zone A1 (Fe 1)	Late Tuakamali	Human bone	310 ± 75	cal AD 1451–1707 cal AD 1721–1811 cal AD 1837–1846 cal AD 1859–1879 cal AD 1931
Beta-1225	42	TP-2	Layer II, 80–110 cm	Early Sinapupu	Charcoal	1990 ± 100	335–329 cal BC 206 cal BC–cal AD 225 cal AD 290–337

Lab No.	SORC-*	Site/ Locality	Stratigraphic Provenience	Tikopia Sequence Phase	Material	Reported ^{14}C Age BP†	Calibrated Age Range (2σ)**
I-10720	49	TP-19	Layer IV, 120–126 cm	Late Sinapupu	Charcoal	840 ± 75	cal AD 1045–1098 cal AD 1106–1316 cal AD 1356–1382
I-10719	47	TP-16	Layer V, 150–160 cm	Early Tuakamali	Charcoal	660 ± 125	cal AD 1150–1508 cal AD 1583–1620
I-10724	57	Rakisu	Trench B1, Layer III	—	Charcoal	1220 ± 160	cal AD 576–1189
Beta-1228	114	Rakisu	Trench D1, Layer III	—	Charcoal	1130 ± 130	cal AD 678–1190
I-10723	56	Rakisu	Trench C2, Layer IIB	—	Charcoal	600 ± 165	cal AD 1047–1086 cal AD 1134–1670 cal AD 1749–1754 cal AD 1784–1795
I-10754	58a	Muripera	Trench F2, Layer VI/VII	—	Seagrass	490 ± 75	cal AD 1325–1342 cal AD 1390–1630
ANU-2942	58b	Muripera	Trench F2, Layer VI/VII	—	Coconut husk (noncarbonised)	200	cal AD 1670–1686 cal AD 1727–1748 cal AD 1756–1781 cal AD 1796–1805
I-10721	51	TP-25	Layer III, 90–95 cm	Late Tuakamali	Charcoal and coconut	490 ± 75	cal AD 1325–1342 cal AD 1390–1630
Beta-1226	54	TP-39	Layer II	Historic	Charcoal	<90	—
I-10717	38	TK-6	Pit A, 60–70 cm	Late Tuakamali	Charcoal	480 ± 75	cal AD 1330–1333 cal AD 1391–1636

* SORC=Solomon Islands Radiocarbon; the SORC numbers were assigned by the Bishop Museum.

** Calibrated with OxCal v4.2.4 using the SHCal13 atmospheric calibration curve.

† Note that reported ages were not corrected for $\delta^{13}C$.

AMS RADIOCARBON DATING RESULTS

Twenty-four samples were submitted to the University of California, Irvine W.M. Keck Carbon Cycle AMS facility for dating: eleven consisting of Pacific rat bones, six of pig teeth and seven of carbonised coconut endocarp. Unfortunately, only four rat bone and two pig tooth samples yielded sufficient collagen for AMS dating. All of the submitted carbonised coconut endocarp samples were dated. The results of AMS dating on these 13 samples are presented in Table 2. Age ranges shown in Table 2 were calibrated using OxCal v4.2.4 with the SHCal13 atmospheric calibration curve (Bronk Ramsey 2009b; Hogg *et al.* 2013), and are given at 2σ ranges (95.4% confidence intervals).

Carbon stable isotope ratios of pig and rat samples were evaluated for potential marine dietary contributions, as intake of marine reservoir ^{14}C can influence calendar age radiocarbon results by several hundred years. Assuming an entirely terrestrial C_3 diet would produce bone collagen $\delta^{13}C$ values of around -20 ± 1‰ (Clark *et al.* 2013), the $\delta^{13}C$ value of only one sample in this study (SORC-133, $\delta^{13}C$ = -17.0) suggests a marine dietary contribution (though this value may also be produced by consumption of C_4 plants such as sugarcane and other tropical grasses). The proportion of potential marine dietary carbon in the SORC-133 sample may offset the date produced by up to around 100 years (Petchey *et al.* 2014); however, this would not substantially alter the model produced here.

The cultural associations of the 13 new AMS dates are provided in Table 3. Two samples (UCIAMS-163474 and -163477) are from Kiki Phase contexts from sites TK-4 and TK-36 respectively. Site TK-4 is regarded as the oldest cultural deposit on Tikopia, containing a number of exotic (i.e., non-local) artefacts (metavolcanic adzes, obsidian from an Admiralty Islands source, chert from a probable Solomon Islands source). Kirch and Yen (1982: 111-25, 312-14) regarded TK-4 as the most likely locus of the island's founding settlement. TK-36 is part of the long Sinapupu transect (Kirch and Yen 1982, Fig. 30); the deeper layers there contain calcareous-tempered ceramics very similar to those from site TK-4. As indicated in Table 2, the two new dates from these sites yielded nearly identical ages. While these dates are consistent with two dates obtained previously for these sites (UCR-964 and -966; see Table 1), their much tighter error ranges provide greater precision in estimating the date of initial human colonisation of Tikopia.

Three of the new dates (UCIAMS-163457, -163475 and -163476) are assigned to the Early Sinapupu Phase. UCIAMS-163457 came from a deep stratigraphic context in site TK-1 where it was associated with incised pottery of exotic origin (likely from Vanuatu) and *Trochus* shell armbands. The date provides a good estimate for the later part of the Early Sinapupu Phase.

Table 2. New AMS dates on Tikopia samples.

Lab No. UCIAMS-	SORC-*	Site/ Locality	Stratigraphic Provenience	Material	$\delta^{13}C$ (‰)	^{14}C Age BP	Calibrated Age Range (2σ)**
163474	133	TK-4	Unit R16II, Layer II	*Rattus exulans* bone	-17.0	2625 ± 15	811–755 cal BC (92.5%) 680–671 cal BC (1.5%) 606–595 cal BC (1.4%)
163475†	136	TK-35	Unit A1, Level 2	*Rattus exulans* bone		1505 ± 20	cal AD 572–645 (95.4%)
163476	137	TK-35	Unit A2, Level 3	*Rattus exulans* bone	-19.2	1540 ± 15	cal AD 536–630 (95.4%)
163477†	140	TK-36	Unit A2, Layer II	*Rattus exulans* bone		2590 ± 15	800–745 cal BC (55.6%) 686–666 cal BC (9.8%)
163478	148	TK-1	Unit J5, 20–40 cm	*Sus scrofa* tooth	-19.9	825 ± 15	cal AD 1221–1275 (95.4%)
163479	149	TK-1	Unit J5, 40–55 cm	*Sus scrofa* tooth	-19.1	870 ± 15	cal AD 1181–1235 (80.0%) cal AD 1240–1266 (15.4%)
163456	23	TK-1	Unit J5, 40–60 cm (Fe 1)	*Cocos nucifera* endocarp	-23.3	970 ± 15	cal AD 1039–1160 (95.4%)
163457	28	TK-1	Unit J9, 140–160 cm	*Cocos nucifera* endocarp	-23.6	1600 ± 15	cal AD 430–548 (92.5%) cal AD 560–570 (2.9%)
163458	33	TK-4	Unit T28II, 75–95 cm	*Cocos nucifera*? endocarp	-25.9	215 ± 15	cal AD 1665–1682 (14.7%) cal AD 1730–1803 (80.7%)
163459	37	TK-5	Pit A, 42–48 cm	*Cocos nucifera* endocarp	-23.8	250 ± 15	cal AD 1648–1674 (43.8%) cal AD 1741–1772 (24.9%) cal AD 1778–1798 (26.6%)
163460	46	TP-15	170–200 cm	*Cocos nucifera* endocarp	-26.2	140 ± 15	cal AD 1697–1726 (16.7%) cal AD 1807 (78.7%)
163461	48	TP-19	Layer IV, 109–114 cm	*Cocos nucifera* endocarp	-25.2	895 ± 15	cal AD 1161–1222 (95.4%)
163462	53	TP-30	Layer II, 70–75 cm	*Cocos nucifera* endocarp	-25.8	235 ± 15	cal AD 1655–1676 (21.1%) cal AD 1737–1799 (74.3%)

* SORC=Solomon Islands Radiocarbon; the SORC numbers were assigned by the Bishop Museum.
** Calibrated with OxCal v4.2.4 using the SHCal13 atmospheric calibration curve.
† These samples did not yield sufficient extra collagen to provide for EA/IRMS analysis of $\delta^{13}C$.

Samples UCIAMS-163475 and -163476 both came from site TK-35, part of the deep Sinapupu sequence, where they were associated with *Tridacna*-shell adzes, *Trochus* shell armrings and a drilled shell ornament. One of the new dates (UCIAMS-163461) came from a Late Sinapupu Phase context, TP-19, associated with exotic Sinapupu Ware ceramics and a *Tridacna* shell adze. The age of this sample provides a good estimate for the beginning of the Late Sinapupu Phase.

Three of the new dates (UCIAMS-163478, -163479 and -163456) derive from Early Tuakamali Phase contexts, all from excavation unit J5 in site TK-1. In these stratigraphic contexts, ceramics are entirely lacking and associated cultural artefacts include *Tridacna* shell adzes and obsidian of the Banks Islands (northern Vanuatu) source. The oldest (UCIAMS-163456) and the youngest (UCIAMS-163478) of these dates bracket the Early Tuakamali Phase.

The remaining four dates (UCIAMS-163458, -163459, -163460 and -163462) all can be assigned to Late Tuakamali or early Historic (i.e., post-European contact) phases. One sample (UCIAMS-163459) is associated with a traditional religious site (*marae*), while two samples (UCIAMS-163460 and -163462) come from occupation deposits directly underlying the modern village hamlets of Paepaevaru and Potu sa Kafika (Kirch and Yen 1982: 138-41, 160-62). All four samples yielded ages of less than 250 years BP, with calibrated age ranges in the 17th and 18th centuries. The relatively recent date from Potu sa Kafika is of particular interest, as this hamlet is situated on the low-lying sandy tombolo that forms a barrier between the crater lake (Te Roto) and the sea. The Potu sa Kafika date provides a *terminus ante quem* for the formation of the tombolo, which formed no later than the 18th century AD. As discussed in detail by Kirch and Yen (1982: 346-49), the formation of the tombolo was a key event in Tikopia history, because the resulting transformation of a marine embayment into a brackish-water lake had major consequences for the communities residing around the lake's perimeter.

The Sinapupu area on the island's northwestern side, which includes sites TK-1, TK-35, TK-36 and transect units TP-20 and TP-46 to -53 (inclusive), provided the key to the island's cultural sequence due to its deep and continuous stratigraphy (Kirch and Yen 1982: 89-111, Fig. 30). Seven of the original radiocarbon dates, and eight of the new AMS dates, come from these Sinapupu excavation units. Figure 1 shows these 15 radiocarbon dates, plotted in stratigraphic order. With one exception, the dates correspond to their relative stratigraphic positions. Sample I-10699, which came from site TK-1, is clearly out of stratigraphic order, and represents a "Type T" outlier (Bronk Ramsey 2009b), in which the dated sample does not properly correspond to the event presumed to be dated. This could either be because the unidentified wood charcoal consisted of old wood with an in-built age,

Table 3. Cultural associations of new AMS radiocarbon dates on Tikopia samples.

Lab No. UCIAMS-	SORC-	Site/ Locality	Stratigraphic Provenience	Sinapupu Strat Zone	Associated Material Culture	Tikopia Sequence Phase
163474	133	TK-4	Unit R16II, Layer II	—	Calcareous sand-tempered ceramics	Early Kiki
163475	136	TK-35	Unit A1, Level 2	B2	*Tridacna* shell adzes, *Trochus* shell armrings, volcaniclastic tempered ceramics	Early Sinapupu
163476	137	TK-35	Unit A2, Level 3	B2	*Trochus* shell armrings, volcaniclastic tempered ceramics, drilled shell	Early Sinapupu
163477	140	TK-36	Unit A2, Layer II	C2	Calcareous sand-tempered ceramics, obsidian	Early Kiki
163478	148	TK-1	Unit J5, 20–40 cm	A2	*Tridacna* shell adzes, shell bead, obsidian	Early Tuakamali
163479	149	TK-1	Unit J5, 40–55 cm	A3	*Tridacna* shell adzes, obsidian	Early Tuakamali
163456	23	TK-1	Unit J5, 40–60 cm (Fe 1)	A3/B1 interface	Obsidian, *Tridacna* shell adzes	Early Tuakamali
163457	28	TK-1	Unit J9, 140–160 cm	B2	Incised pottery with nubbins, *Trochus* shell arm rings, pig bone	Early Sinapupu
163458	33	TK-4	Unit T28II, 75–95 cm	—	Obsidian	Late Tuakamali
163459	37	TK-5	Pit A, 42–48 cm	—	Traditional *marae* ‘temple’ site	Late Tuakamali
163460	46	TP-15	170–200 cm	—	Paepaevaru hamlet	Late Tuakamali/Historic
163461	48	TP-19	Layer IV, 109–114 cm	B1	1 sherd, *Tridacna* shell adze	Late Sinapupu
163462	53	TP-30	Layer II, 70–75 cm	—	Potu sa Kafika hamlet	Late Tuakamali/Historic

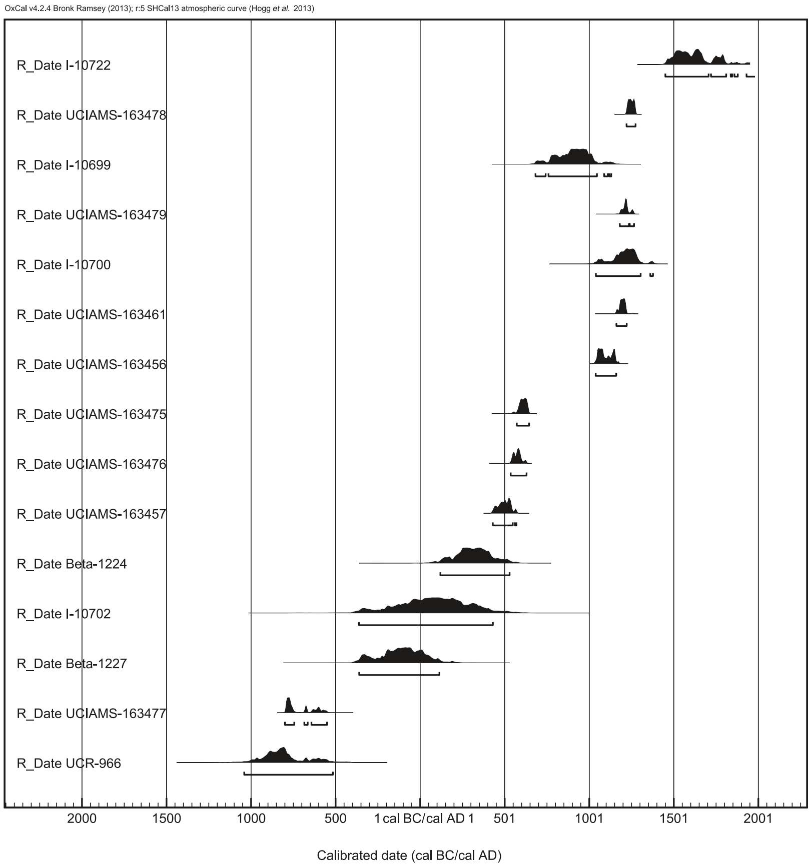

Figure 1. OxCal plot of 15 original and new radiocarbon dates from the Sinapupu area of Tikopia, plotted in stratigraphic order.

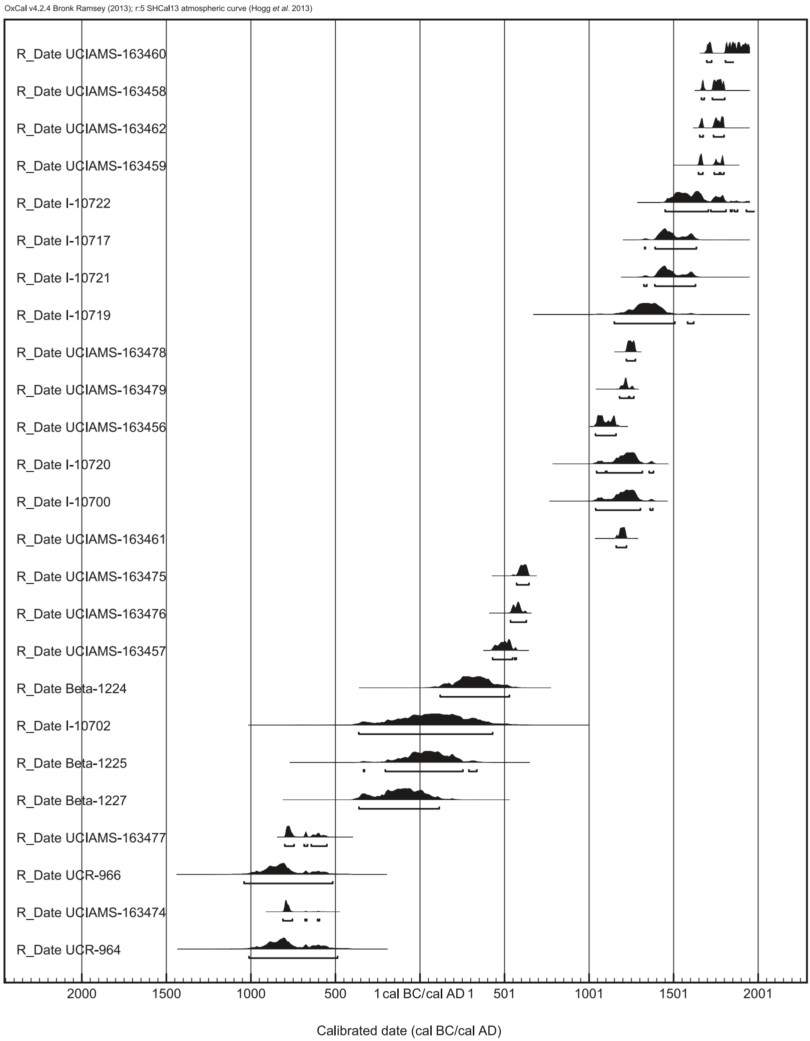

Figure 2. OxCal plot of 25 old and new radiocarbon dates from Tikopia, in inferred stratigraphic order.

or—more likely—due to the vertical displacement of older charcoal within the TK-1 site due to the digging of deep burial pits within the confines of this structure in the Late Tuakamali Phase.

An additional 11 radiocarbon dates from sites and transect pits outside of the Sinapupu area can be placed along with those from Sinapupu into a relative stratigraphic sequence based on their cultural contents (this excludes the five dates listed in Table 1 from the Rakisu agricultural area and the Muripera swamp, both of which lack associated artefact assemblages, and one very recent date from TP-39). Figure 2 is an integrated plot of these 25 dates (excluding the TK-1 outlier I-10699) from all cultural contexts.

BAYESIAN MODELLING OF THE TIKOPIA SEQUENCE

The original set of radiocarbon dates from Tikopia (Table 1) was characterised by low precision, with standard errors (68% probability) ranging from 65 up to 165 years. Given the inherent uncertainty in this suite of dates, and following common practice three to four decades ago, Kirch and Yen (1982) assigned temporal spans to the three culturally defined phases of the Tikopia sequence based on an *ad hoc* approach, which can be described as "eyeballing". The recent development of Bayesian modelling for the calibration of radiocarbon data sets, which incorporates prior knowledge regarding the stratigraphic relationships among sets of samples, now allows for a more rigorous approach to temporally calibrating cultural sequences such as that for Tikopia. Bayesian modelling has recently been applied with considerable success in Pacific prehistory, as for example in Tonga (Burley *et al.* 2015), Sāmoa (Clark *et al.* 2016), Hawai‘i (Athens *et al.* 2014), and Aitutaki (Allen and Morrison 2013) and Mangaia (Kirch 2017) in the Cook Islands.

We applied Bayesian modelling to the integrated suite of 25 radiocarbon dates shown in Figure 2. In addition to excluding sample I-10699 for reasons discussed above, we also excluded an anomalously early date from a pre-Kiki Phase deposit in TP-52 at Sinapupu (UCR-965; see Table 1). This sample predates any known cultural deposits elsewhere in this part of Remote Oceania (Sheppard *et al.* 2015), and must also be regarded as a Type T outlier, probably due to in-built age. Our Bayesian model also did not incorporate the samples from the Rakisu agricultural zone (I-10724, Beta-1228 and I-10723) or the Muripera swamp area (I-10754 and ANU-2942) as these do not have artefact assemblages permitting them to be assigned to the Tikopia cultural phases. The Bayesian calibration was thus based on 25 radiocarbon dates: four from the Early Kiki Phase, one from the Late Kiki Phase, six from the Early Sinapupu Phase, three from the Late Sinapupu Phase, three from the Early Tuakamali Phase and eight from the Late Tuakamali to Historic Phases.

We used the BCal online calibration tool hosted by the University of Sheffield (http://bcal.shef.ac.uk/; see Buck *et al.* 1999) to construct our Bayesian model. Six groups were specified in the model, each corresponding to one of the phases just mentioned. Based on prior stratigraphic information, the boundary parameters between the phases were specified as sequential and non-overlapping (i.e., Late Kiki Phase earlier than Early Sinapupu Phase, and so on). No floating parameters were specified. For each group, the BCal program calculated α and β statistical parameters (highest posterior density estimates, HPD) defining the beginning and ending probabilities for the group. For those unfamiliar with Bayesian terminology, given a group or phase, *k*, within a stratigraphic or chronological sequence, with one or more radiocarbon dates, the time period represented by phase *k* can be stated as α_k minus β_k, where α (the alpha parameter) is the early bounding temporal estimate for group *k* and β (the beta parameter) is the later bounding temporal estimate. Individual likelihood estimates are provided by the radiocarbon dates (the theta parameters) associated with group *k*, designated $\theta k_{(1),}\, \theta k_{(2)} \ldots \theta k_{(n)}$. The relationship between all three parameters can be stated as: $\alpha_k > \theta_{k(1\ldots n)} > \beta_k$. If group *k* overlies or supersedes another group *j*, then the relationship between those two groups would be specified as:

$$\alpha_j > \theta_{j(1\ldots n)} > \beta_j \geq \alpha_k > \theta_{k(1\ldots n)} > \beta_k .$$

Results of the calibrated Bayesian model for the Tikopia Phase are presented in Table 4, with the HPD estimates (at 95%) for the α and β parameters for each phase. Table 5 presents the calibrated age ranges (HPD ranges for the θ parameters) for each of the 25 radiocarbon dates used in the Bayesian model. Figures 3, 4 and 5 graphically display the HPD regions (95% probability) for the α and β parameters for the Kiki, Sinapupu and Tuakamali Phases of the Tikopia sequence. Finally, Table 6 presents estimated elapsed time ranges for each of the modelled groups.

DISCUSSION

Kirch and Yen (1982) "eyeballed" the settlement of Tikopia at 900 BC based on the original set of radiocarbon dates. A Bayesian model now more precisely brackets initial human colonisation of Tikopia to sometime between 1046–1031, 1029–769 cal BC (α1 parameter, Table 4). The new AMS dates from the earliest cultural deposits at sites TK-4 and TK-36 (UCIAMS-163474 and -163477; see Table 2) have HPD regions of 805–767 cal BC (θ2) and 801–746, 680–669 cal BC (θ4), allowing us to more precisely define the time frame for initial occupation at these localities. Based on radiocarbon dating and a Bayesian calibration for the SE-SZ-8 Lapita site of Nanggu, Santa Cruz Islands (Nendö), Green *et al.* (2008) put the initial Lapita incursion into

Table 4. Highest posterior density (HPD) estimates for Tikopia phases.

Model Groups	Parameter	95% HPD Intervals (cal BP)	95% HPD Intervals (cal BC/AD)
Early Kiki Phase	α1	2996–2981 2979–2719	1046–1031 cal BC 1029–769 cal BC
	β1	2747–2524 2508–2497	797–574 cal BC 558–547 cal BC
Late Kiki Phase	α2	2650–2636 2629–2614 2602–2003	700–686 cal BC 679–664 cal BC 652–53 cal BC
	β2	2282–2270 2268–1804	330–320 cal BC 318 cal BC–cal AD 146
Early Sinapupu Phase	α3	2067–1640	117 cal BC–cal AD 310
	β3	1374–1050	cal AD 576–900
Late Sinapupu Phase	α4	916–874 849–751	cal AD 1034–1076 cal AD 1101–1199
	β4	879–866 795–743	cal AD 1071–1084 cal AD 1155–1207
Early Tuakamali Phase	α5	792–738	cal AD 1158–1212
	β5	730–552	cal AD 1220–1398
Late Tuakamali Phase	α6	610–339	cal AD 1340–1611
	β6	200–1	cal AD 1750–1949

the Reef–Santa Cruz Islands at approximately 1250 cal BC. More recently, based on a re-excavation at the Nanggu site and Bayesian calibration of all radiocarbon dates from Nanggu and the Nenumbo (RF-2) site in the Reef Islands, Sheppard *et al.* (2015) conclude that Lapita movement into the Santa Cruz Islands did not commence before about 1050 cal BC. This suggests that the colonisation of Tikopia took place 200 to 250 years following the first entry of humans in this part of Remote Oceania.

It is also instructive to compare the estimated date of colonisation of Tikopia with the settlement chronologies of two other Polynesian Outliers in the region, Anuta and Taumako. Anuta, a very small island (area 0.4 km^2) situated 137 km northeast of Tikopia, was archaeologically investigated by Kirch and

Table 5. Bayesian posterior age estimates for individual radiocarbon dates from Tikopia.

BCal Model Parameter	Lab No.	Phase	95% HPD Intervals (cal BP)	95% HPD Intervals (cal BC/AD)
θ1	UCR-964	Early Kiki	2856–2676 2630–2614	906–726 cal BC 680–664 cal BC
θ2	UCIAMS-163474	Early Kiki	2755–2717	805–767 cal BC
θ3	UCR-966	Early Kiki	2867–2683	917–733 cal BC
θ4	UCIAMS-163477	Early Kiki	2751–2696 2630–2619	801–746 cal BC 680–669 cal BC
θ5	Beta-1227	Late Kiki	2313–1923	363 cal BC–cal AD 27
θ6	Beta-1225	Early Sinapupu	1941–1576	cal AD 9–374
θ7	I-10702	Early Sinapupu	1927–1467 1465–1453 1449–1439 1437–1418	cal AD 23–483 cal AD 485–497 cal AD 501–511 cal AD 513–532
θ8	Beta-1224	Early Sinapupu	1795–1764 1752–1448 1446–1423	cal AD 155–186 cal AD 198–502 cal AD 504–527
θ9	UCIAMS-163457	Early Sinapupu	1519–1403	cal AD 431–547
θ10	UCIAMS-163476	Early Sinapupu	1413–1346	cal AD 537–604
θ11	UCIAMS-163475	Early Sinapupu	1378–1308	cal AD 572–642
θ12	UCIAMS-163461	Late Sinapupu	796–751	cal AD 1154–1199
θ13	I-10700	Late Sinapupu	899–871 816–748	cal AD 1051–1079 cal AD 1134–1202
θ14	I-10720	Late Sinapupu	900–870 815–748	cal AD 1050–1080 cal AD 1135–1202
θ15	UCIAMS-163456	Early Tuakamali	784–736	cal AD 1166–1214
θ16	UCIAMS-163479	Early Tuakamali	764–716 704–687	cal AD 1186–1234 cal AD 1246–1263
θ17	I-10719	Early Tuakamali	772–612	cal AD 1178–1338

— Table 5 continued over page

BCal Model Parameter	Lab No.	Phase	95% HPD Intervals (cal BP)	95% HPD Intervals (cal BC/AD)
θ18	UCIAMS-163478	Early Tuakamali	730–680	cal AD 1220–1270
θ19	I-10721	Late Tuakamali	532–433 418–307	cal AD 1418–1517 cal AD 1532–1643
θ20	I-10717	Late Tuakamali	526–424 422–309	cal AD 1424–1526 cal AD 1528–1641
θ21	I-10722	Late Tuakamali	470–254 221–147	cal AD 1480–1696 cal AD 1729–1803
θ22	UCIAMS-163459	Late Tuakamali	302–277 310–180 171–154	cal AD 1648–1673 cal AD 1640–1770 cal AD 1779–1796
θ23	UCIAMS-163462	Late Tuakamali	295–275 214–153	cal AD 1655–1675 cal AD 1736–1797
θ24	UCIAMS-163458	Late Tuakamali	286–267 220–149	cal AD 1664–1683 cal AD 1730–1801
θ25	UCIAMS-163460	Late Tuakamali	266–221 146–81 72–60	cal AD 1684–1729 cal AD 1804–1869

Table 6. Modelled elapsed time estimates for Tikopia cultural phases.

Phase	Elapsed Time (years)
Early Kiki	0–401, 403–417
Late Kiki	0–525, 527–560, 562–609
Early Sinapupu	323–893, 895–934
Late Sinapupu	0–106
Early Tuakamali	17–234
Late Tuakamali	165–562

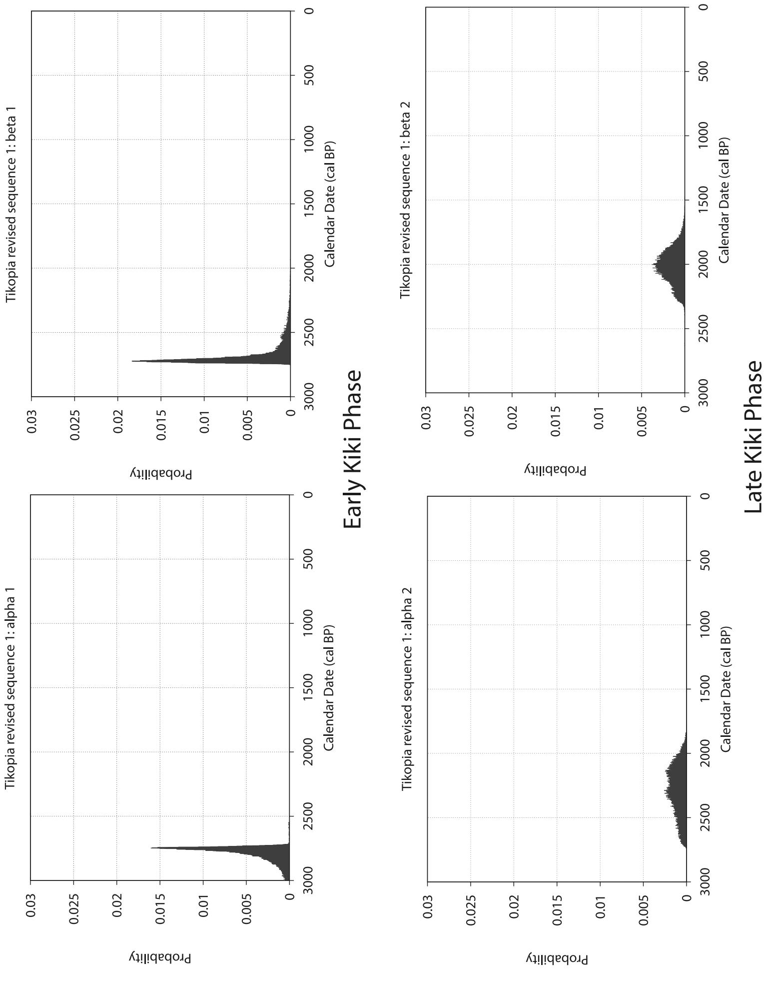

Figure 3. Alpha and beta parameters (HPD regions) for Early and Late Kiki Phases.

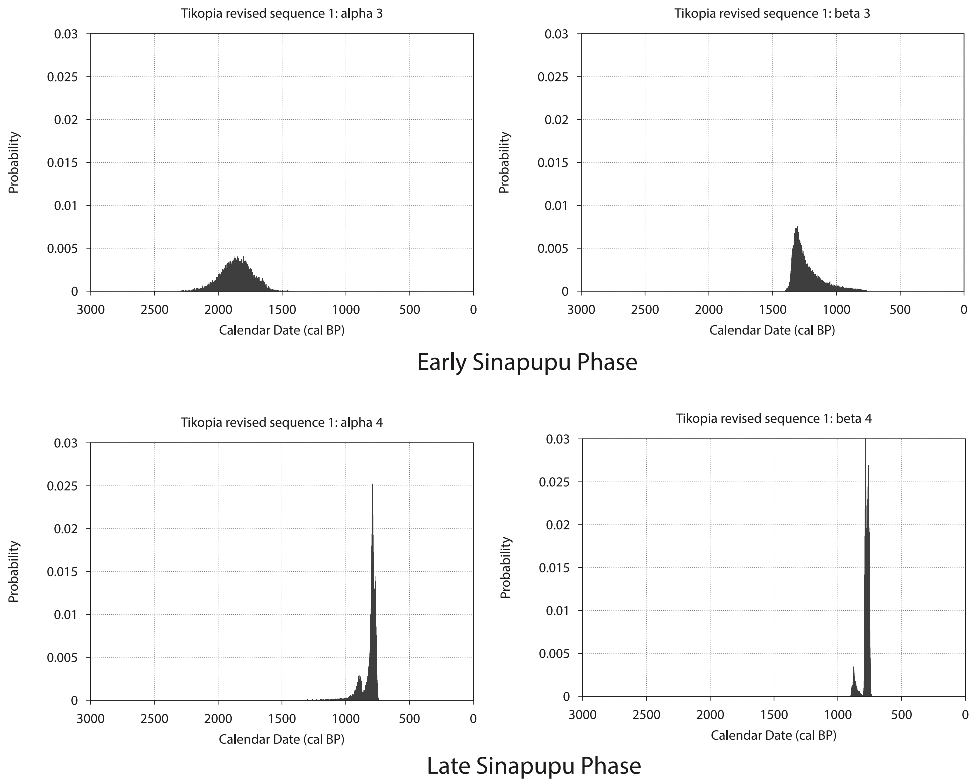

Figure 4. Alpha and beta parameters (HPD regions) for Early and Late Sinapupu Phases.

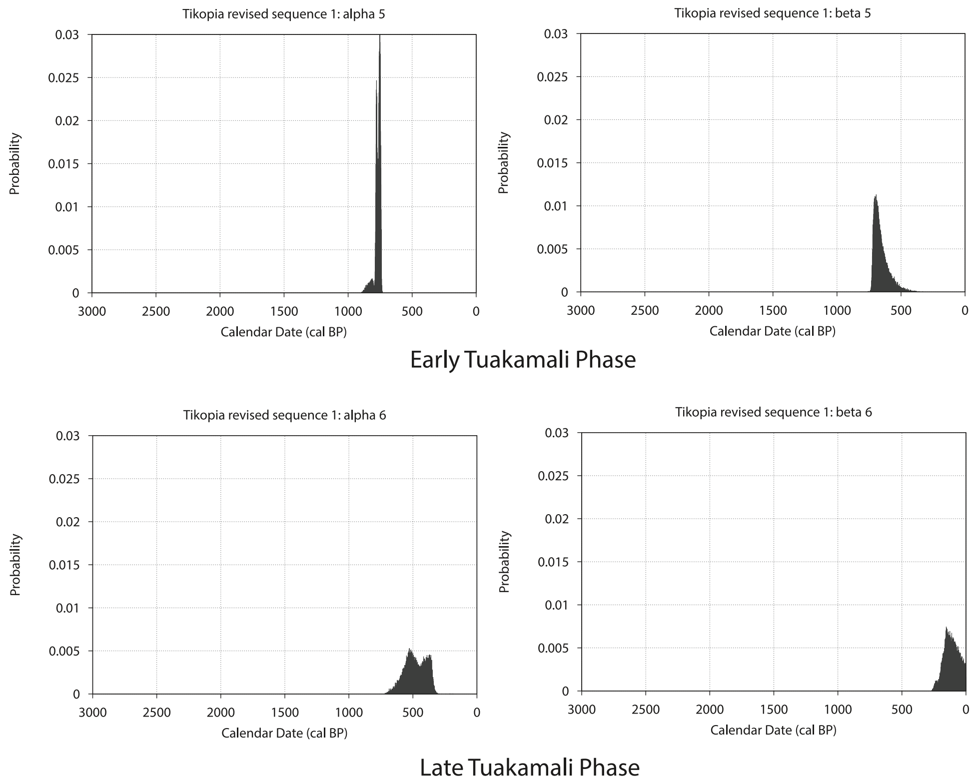

Figure 5. Alpha and beta parameters (HPD regions) for Early and Late Tuakamali Phases.

Rosendahl (1973). Layer III at the AN-6 site, which contained calcareous-tempered ceramics nearly identical to the Kiki Ware of Tikopia, was dated with three charcoal samples (I-6274, -6272 and -6275, Kirch and Rosendahl 1973, Table 31). The samples yielded calibrated age ranges (95.4% probability) of 843–406, 896–427 and 1297–833 cal BC. The last of these seems improbably old and may reflect an "old wood" issue, but the first two are consistent with the estimated age of the Kiki Phase on Tikopia. For Taumako, the earliest occupation deposits in the Ana Tavatava site likewise yielded a ceramic assemblage not unlike that from the TK-4 site, with an associated radiocarbon date (NZ-4641) of 2602 ± 64 BP, with a calibrated range of 834–475 cal BC (Leach and Davidson 2008: 295-96, Table A12.1). This is again consistent with the Early Kiki Phase dating. In sum, all three of these islands—Tikopia, Anuta and Taumako—appear to have been first settled at approximately the same time by populations all producing similar, largely plainware ceramics.

The transition from the Kiki Phase to the Early Sinapupu Phase is the most difficult to pin down in absolute chronological terms. There is just one radiocarbon date (Beta-1227) from a Late Kiki Phase context, TP-48 of the Sinapupu site transect (see Table 1). Bayesian calibration yields a 95% HPD estimate for this date (θ5) of 363 cal BC to cal AD 27. Parameter β2, for the end of the Kiki Phase, has HPD intervals of 330–320 cal BC and 318 cal BC to cal AD 146. Parameter α3, for the beginning of the Early Sinapupu Phase, has a 95% HPD region of 117 cal BC to cal AD 310. In sum, the Kiki to Sinapupu transition occurred sometime between the late first millennium BC and the early first millennium AD. Defining the timing of this transition more precisely would require further datable samples from Late Kiki Phase or Early Sinapupu Phase contexts.

The Sinapupu Phase on Tikopia is characterised by a number of distinct changes in material culture and in the exploitation of particular faunal resources, but the most notable feature is the importation of distinctive incised ceramics from one or more sources in the Vanuatu archipelago (the Sinapupu Ware ceramics, described by Kirch and Yen 1982: 200-202). This incised pottery falls within the overall ceramic tradition known as Mangaasi, originally defined by Garanger (1971, 1972). Bedford (2006, Fig. 8.16) has defined the ceramic traditions of various subgroups within the extensive Vanuatu archipelago, noting that Mangaasi-style ceramics occur in both the Shepherd Group and on Efate between approximately 250 cal BC and cal AD 750. This correlates reasonably well with the time frame estimated for the Early and Late Sinapupu Phases, bracketed between 117 cal BC to cal AD 310 (α3) and cal AD 1071–1084, 1155–1207 (β4) (Table 4).

The transition from the Late Sinapupu to the Early Tuakamali Phase marks another major cultural transition on the island, one that is reflected in material culture with distinctively Polynesian traits such as basalt adzes and trolling lures of Western Polynesian forms (Kirch and Yen 1982: 236-37, 244, 333). This phase is believed to represent the successive arrival of several Polynesian-speaking groups who were the direct ancestors of the various social lineages presently occupying the island (Kirch and Yen 1982: 341-43). The Bayesian model allows us to define the timing of this transition quite precisely. Parameter $\alpha5$, for the Early Tuakamali Phase, has an HPD region of cal AD 1158–1212. The earliest radiocarbon date from a Tuakamali Phase context is UCIAMS-163456 from site TK-1, which is associated with Banks Islands obsidian and *Tridacna* shell adzes (Table 3), and has a modelled age range of cal AD 1166–1214 ($\theta15$, Table 5).

It may not be coincidental that the arrival of these Polynesian groups in Tikopia occurred around AD 1100–1200, contemporaneous with the dispersal of Polynesians out of the Western Polynesian homeland region into the archipelagos of Eastern Polynesia (i.e., the Society Islands, Marquesas, Cook Islands, Mangareva and others). While the settlement histories of the Polynesian Outliers and of Eastern Polynesia have typically been treated by culture historians as separate phenomena, it seems possible that both were part of a larger diaspora that extended both east and west out of the Western Polynesian core after AD 1000. In this regard, the linguistic analysis of Wilson (2012), which identifies a common origin in the dialects of certain Polynesian Outliers and those of Eastern Polynesia, may be relevant.

* * *

Additional new high-precision AMS dates for the Tikopia cultural sequence, combined with a Bayesian calibration of a total of 25 radiocarbon dates from the island, allows a reassessment of the original temporal framework proposed by Kirch and Yen (1982). In general terms the new AMS dates confirm the sequence as originally proposed, but it is now possible to more precisely estimate the time spans for the phases of the Tikopia sequence. Initial settlement of Tikopia, originally estimated by Kirch and Yen (1982) to have occurred slightly later than 900 BC, can now be estimated to have occurred sometime between 1046–1031, 1029–769 cal BC. The transition between the Kiki and Sinapupu Phases remains less precisely dated due to the limited number of radiocarbon dates, but occurred sometime between 117 cal BC and cal AD 310. The final major change in the cultural sequence, from the Sinapupu to Tuakamali Phases, marked by the arrival of new settlers who had a distinctive Western Polynesian material culture and were presumably the direct ancestors of the ethnographically documented Tikopia, occurred sometime during the period cal AD 1158–1212.

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REFERENCES

Allen, M.S. and A.E. Morrison, 2013. Modelling site formation dynamics: Geoarchaeological, chronometric and statistical approaches to a stratified rockshelter sequence, Polynesia. *Journal of Archaeological Science* 40: 4560-75.

Athens, J.S., T.M. Rieth and T.S. Dye, 2014. A paleoenvironmental and archaeological model-based assessment for the colonization of Hawaiʻi. *American Antiquity* 79: 144-55.

Bedford, S., 2006. *Pieces of the Vanuatu Puzzle: Archaeology of the North, South, and Centre*. Terra Australis 23. Canberra: Pandanus Books, Australian National University.

Bronk Ramsey, C., 2009a. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51: 337-60.

——2009b. Dealing with outliers and offsets in radiocarbon dating. *Radiocarbon* 51:1023-45.

Buck, C.E., J.A. Christen and G.N. James, 1999. BCal: An on-line Bayesian radiocarbon calibration tool. *Internet Archaeology* 7: http://intarch.ac.uk/journal/issue7/buck/.

Burley, D., K. Edinborough, M.I. Weisler and J. Zhao, 2015. Bayesian modeling and chronological precision for Polynesian settlement of Tonga. *PLOS-One*, DOI:10.1371/journal.pone.0120795

Clark, G., F. Petchey, S. Hawkins, C. Reepmeyer, I. Smith and W.B. Massey, 2013. Distribution and extirpation of pigs in Pacific Islands: A case study from Palau. *Archaeology in Oceania* 48 (3): 141-53.

Clark, J.T., S. Quintus, M.I. Weisler, E. St Pierre, L. Nothdurft and Y. Feng, 2016. Refining the chronology for West Polynesian colonization: New data from the Samoan archipelago. *Journal of Archaeological Science: Reports* 6: 266-74.

Damon, P.E., A. Long and E.I. Wallick, 1972. Dendrochronologic calibration of the Carbon-14 time scale. In T.A. Rafter and T. Grant-Taylor (eds), *Proceedings of the Eighth International Radiocarbon Dating Conference*. Bulletin of the Royal Society of New Zealand 14. Lower Hutt, New Zealand, 18-25 October 1972, pp. 27-43.

Feinberg, R. and R. Scaglion (eds), 2012. *Polynesian Outliers: The State of the Art*. Ethnology Monographs No. 21. Pittsburgh: Department of Anthropology, University of Pittsburgh.

Firth, R., 1936. *We the Tikopia: A Sociological Study of Kinship in Primitive Polynesia.* London: Allen and Unwin.

——1939. *Primitive Polynesian Economy*. London: Routledge & Sons.

——1961. *History and Traditions of Tikopia.* Memoir 33. Wellington: The Polynesian Society.

Garanger, J., 1971. Incised and applied-relief pottery, its chronology and development in southeastern Melanesia, and extra areal comparisons. In R.C. Green and M. Kelly (eds), *Studies in Oceanic Culture History.* Volume 2. Pacific Anthropological Records 12. Honolulu: Bishop Museum, pp. 53-66.

——1972. *Archéologie des Nouvelles-Hébrides*. Publications de la Société des Océanistes 30. Paris.

Green, R.C., 1979. Lapita. In J.D. Jennings (ed.), *The Prehistory of Polynesia*. Cambridge: Harvard University Press, pp. 27-60.

Green, R.C., M. Jones and P. Sheppard, 2008. The reconstructed environment and absolute dating of SE-SZ-8 Lapita site on Nendö, Santa Cruz, Solomon Islands. *Archaeology in Oceania* 43: 49-61.

Hogg, A.G., Quan H., P.G. Blackwell, M. Niu, C.E. Buck, T.P. Guilderson, T.J. Heaton, J.G. Palmer, P.J. Reimer, R.W. Reimer, C.S.M. Turney and S.R.H. Zimmerman, 2013. SHCal13 Southern Hemisphere calibration, 0–50,000 Years Cal BP. *Radiocarbon* 55: 1889-903.

Kirch, P.V. 1984. The Polynesian outliers: Continuity, change, and replacement. *Journal of Pacific History* 19: 224-38.

——1986. Exchange systems and inter-island contact in the transformation of an island society: The Tikopia case. In P.V. Kirch (ed.), *Island Societies: Archaeological Approaches to Evolution and Transformation*. Cambridge: Cambridge University Press, pp. 33-41.

——1997. Microcosmic histories: Island perspectives on "global" change. *American Anthropologist* 99: 30-42.

——2017. Radiocarbon dating and Bayesian modeling of the chronology of Tangatatau Rockshelter. In P.V. Kirch (ed.), *Tangatatau Rockshelter: The Evolution of an Eastern Polynesian Socio-Ecosystem.* Monumenta Archaeologica 40. Los Angeles: Cotsen Institute of Archaeology Press, pp. 75-90.

Kirch, P.V. and P.H. Rosendahl, 1973. Archaeological investigation of Anuta. In D.E. Yen and J. Gordon (eds), *Anuta: A Polynesian Outlier in the Solomon Islands*. Pacific Anthropological Records 21. Honolulu: Bishop Museum, pp. 25-108.

Kirch, P.V. and D.E. Yen, 1982. *Tikopia: The Prehistory and Ecology of a Polynesian Outlier*. Bernice P. Bishop Museum Bulletin 238. Honolulu: Bishop Museum Press.

Leach, F. and J. Davidson, 2008. *Archaeology on Taumako: A Polynesian Outlier in the Eastern Solomon Islands*. New Zealand Journal of Archaeology Special Publication. Dunedin, New Zealand.

Michael, H.N. and E.K.Ralph, 1972. Discussion of radiocarbon dates obtained from precisely dated sequoia and bristlecone pine samples. In T.A. Rafter and T. Grant-Taylor (eds), *Proceedings of the Eighth International Radiocarbon Dating Conference*. Bulletin of the Royal Society of New Zealand 14. Lower Hutt, New Zealand, 18-25 October 1972, pp. 12-47.

Petchey, F., M. Spriggs, S. Bedford, F. Valentin and H. Buckley, 2014. Radiocarbon dating of burials from the Teouma Lapita cemetery, Efate, Vanuatu. *Journal of Archaeological Science* 50: 227-42.

Sheppard, P. J., S. Chiu and R. Walter, 2015. Re-dating Lapita movement in Remote Oceania. *Journal of Pacific Archaeology* 6 (1): 26-36.

Southon, J.R., G. Santos, K. Druffel-Rodriguez, E. Druffel, S. Trumbore, X.M. Xu, S. Griffin, S. Ali and M. Mazon, 2004. The Keck Carbon Cycle AMS Laboratory, University of California, Irvine: Initial operation and a background surprise. *Radiocarbon* 46: 41-49.

Spriggs, M.J.T. and A. Anderson, 1993. Late colonization of East Polynesia. *Antiquity* 67: 200-217.

Stuiver, M. and H.M. Polach, 1977. Discussion: Reporting of ^{14}C data. *Radiocarbon* 19 (3): 355-63.

Wilson, W., 2012. Whence the East Polynesians? Further linguistic evidence for a Northern Outlier source. *Oceanic Linguistics* 51: 289-359.

ABSTRACT

The Polynesian Outlier of Tikopia, situated in the Santa Cruz Islands group (Temotu Province) of the Solomon Islands, has one of the best-defined archaeological sequences in the southwestern Pacific. Archaeological excavations in 1977–78 yielded a rich record of material culture and faunal remains, with a chronological framework provided by 20 radiocarbon dates. These dates, however, were processed on unidentified wood charcoal using the older liquid-scintillation method; the large standard errors associated with these dates rendered this chronology rather imprecise. Here we report 13 new, high-precision AMS radiocarbon dates on carbonised coconut endocarp, rat bone and pig teeth from the original excavations. The new AMS dates confirm the original sequence and, when combined with the original radiocarbon dates in a Bayesian calibration model, allow for a refinement of the cultural chronology for Tikopia. This updated model provides a more precise chronology for key events in Tikopian prehistory including first human colonisation, the arrival of Polynesian-speaking populations to the island and the formation of the sandy tombolo transforming Te Roto into a brackish-water lake.

Keywords: Lapita, *Rattus exulans*, Tikopia, Polynesian Outliers, Bayesian modelling, Solomon Islands, Remote Oceania

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