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Age of the O18 site, Hawai'i

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Abstract

Seven new ^{14}C age determinations on short-lived materials yield a sound evidential basis for the chronology of the O18 site on O'ahu Island, Hawai'i, long thought to be an early settlement site. Calibration within a model-based, Bayesian framework indicates that the site was established in AD 1040–1219, some 260–459 years after the current estimate of first settlement, and abandoned in the late eighteenth or early nineteenth centuries. Previously published age determinations are mostly too old, probably due to the 'old wood' effect. O18 appears to be the oldest site on the Waimānalo Plain, but earlier sites in Waimānalo likely exist inland of the plain.

The age of the O18 site has been an important datum in Hawaiian prehistory since the first estimate was published in the pages of this journal nearly 40 years ago (Pearson *et al*. 1971). Based on an internally inconsistent set of ^{14}C age determinations, the site was interpreted by its excavators as having been established in the seventh century AD and abandoned by the twelfth century. The estimated date of establishment was subsequently pushed back to the fourth century AD by Kirch (1985), based primarily on volcanic glass hydration dates that are no longer believed to be valid (Tuggle and Spriggs 2001). Kirch considered O18 to be one of only two sites representing the earliest phase of Polynesian settlement of the Hawaiian Islands. This characterization exerted a strong hold on the archaeological imagination. In the early 1980s, it inspired Matthew Spriggs to pull additional samples from storage and have them dated. These samples yielded a stratigraphically inconsistent set of ^{14}C age determinations that was interpreted more than a decade later with some difficulty by Tuggle and Spriggs (2001) as indicating an occupation span beginning perhaps as early as the eighth century AD and ending in the middle of the fifteenth century AD.

Here, we present the results of nine new ^{14}C age determinations from O18, most of them on short-lived materials. The age determinations on short-lived materials are internally consistent and provide, for the first time, a sound evidential basis for the site's chronology. The ^{14}C age determinations are interpreted within a model-based, Bayesian framework. An estimate of site establishment yielded by the model-based analysis, supported by the age of an *Aleurites moluccana* nutshell dated by Spriggs, indicates that O18 was established several centuries after the islands were first settled by Polynesians.

The O18 chronology yielded by the site-specific Bayesian model is extended to include ^{14}C age determinations from four other sites in the region. The chronologies of all five sites are broadly similar. Like these other sites, O18 was abandoned late in traditional Hawaiian times.

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The O18 site

Site O18 is located on the Waimānalo Plain, at the coast (Fig. 1). It is a small part of a larger traditional Hawaiian settlement pattern in which the coastal plain was used on a regular basis, primarily for activities associated with fishing and shellfishing, by people who kept more established residences inland on the volcanic soils that supported their food gardens. A large portion of the coastal plain was developed as a military installation in the twentieth century, especially during World War II, and much of the traditional Hawaiian deposit was lost during this development. The pattern of sites on the plain today is probably due more to military development than it is to patterns of traditional activity in the past.

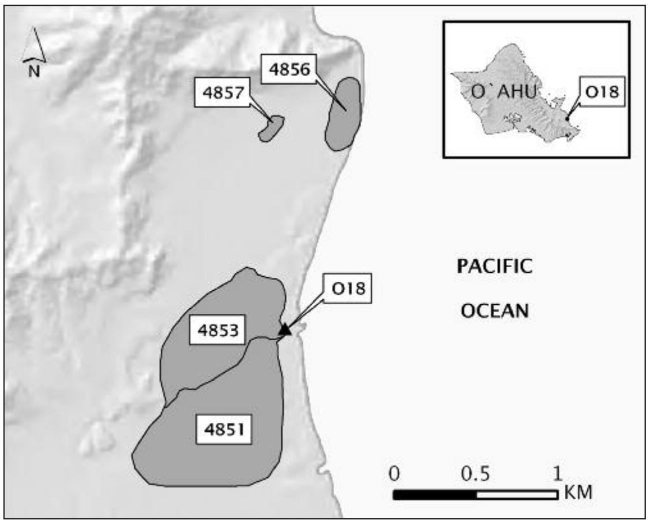

Figure 1. Traditional Hawaiian sites on a portion of the Waimanalo Plain.

Immediately inland of Site O18, and at one time probably coterminous with it, is Site 50–80–15–4853, a large expanse of discontinuous cultural deposits on the north bank of Puhā Stream that represent primarily cooking and eating activities (Tuggle 1997; Desilets and Dye 2002). South of Puhā Stream is Site 50–80–15–4851, which is broadly similar to Site –4853, but also includes low-lying swamp deposits in old stream meanders that were used to cultivate taro (Tuggle 1997; Dye 1998). On the north part of the plain, nearer the foothills of Keolu Hills, are Sites 50–80–11–4856 and –4857, which were also likely coterminous, and which appear to represent the same range of activities as Site –4853.

Excavations for cultural resources management carried out at sites on the plain provide data for a model of regional cultural stratigraphy. The model groups deposits into one of three horizons: Horizon 1 is the modern surface consisting of secondarily deposited sand, historic-era and traditional Hawaiian cultural materials, and pockets of volcanic fill material laid down during construction of military facilities; Horizon 2 is the traditional Hawaiian cultural deposit, often truncated by heavy machinery during construction of military facilities; and Horizon 3 is the underlying basal sand that was laid down as local sea level fell from its mid-Holocene +1.8 m highstand (Fletcher and Jones 1996) prior to settlement of the islands.

The model was developed to capture variability with distance from the coast, the source of trade wind-driven sand that represents the primary natural mode of deposition since the plain was first inhabited, and the degree to which cultural activities included excavation of pits primarily for cooking fires, but also for posts and trash disposal. Pit excavation is responsible for moving artifacts and other cultural materials down the stratigraphic profile and contributes markedly to the thickness of the cultural deposit (Fig. 2).

At the inland edge of the plain, illustrated by profile *A* in Figure 2, sand deposition is slight and few pits were excavated in traditional Hawaiian times. The cultural deposit here can be characterized as a paleosol whose surface includes a low density of cultural material that appears to have been discarded upon it in a more-or-less random fashion. Moving toward the coast, through profiles *B*, *C*, and *D,* both the intensity of cultural deposition and pit excavation increases, creating a thicker cultural deposit beneath which individual pit features can be discovered as dark stains in the light-colored basal sands. Closer to the coast, represented in the figure by profile *E*, the thickness of the cultural deposit reaches a maximum due to a higher intensity of use and a larger volume of aeolian sand deposit from the nearby beach. The frequency of pit excavation here is such that it is rarely possible to identify individual features in the underlying basal sand. Instead, the base of the cultural deposit consists entirely of the bases of pits excavated atop and through one another. At Site 50–80–15–4856, where the stratigraphy corresponded to the model represented by profile *E*, it was estimated that the number and volume of pits excavated in traditional Hawaiian times were sufficient to turn over the cultural deposit completely three times. Closer to the beach, the level of cultural activity drops somewhat and the influx of aeolian sand increases markedly, creating a relatively complex stratigraphy in which cultural deposits are interspersed with layers and lenses of beach sand. This is the situation encountered during excavations at O18, where two primary traditional Hawaiian cultural deposits, Layers II and III, along with several smaller sub-layers or lenses were identified.

One implication of the model is that the relatively complex stratigraphy at O18 in comparison to sites farther inland on the plain is not an indication of greater antiquity. Instead, it is a function of the site's proximity to the beach. In this view, the O18 site is the coastal fringe of traditional Hawaiian settlement on the plain, where the focus of activity was a short distance inland, away from the constant influx of windblown sand and from periodic inundation by storm waves.

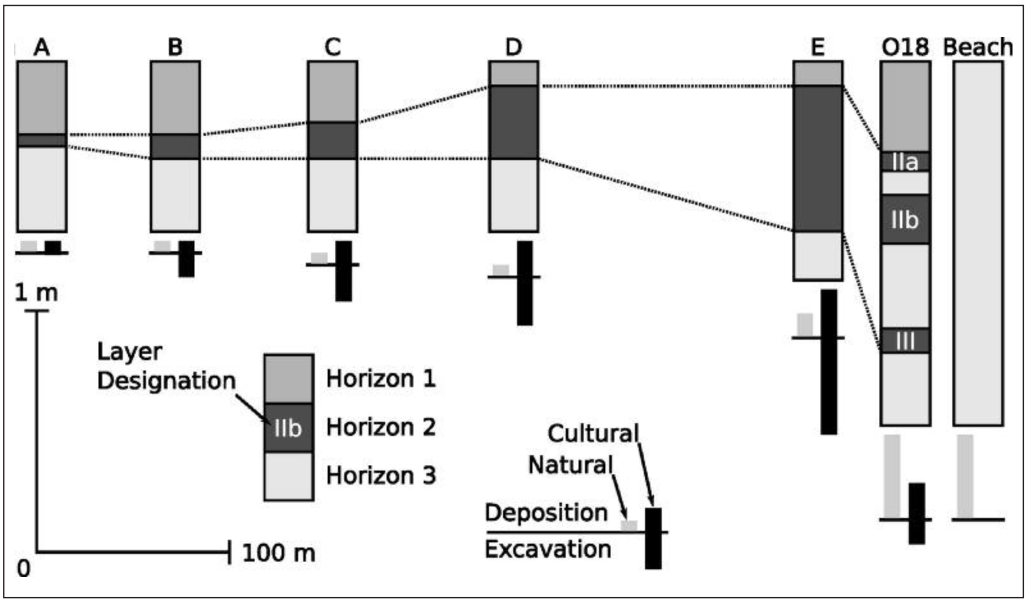

Figure 2. Regional cultural stratigraphy along a hypothetical transect running inland from the beach, showing the relative effects of ongoing sand deposition and traditional Hawaiian pit excavation.

Sample	Unit	Material	$\delta^{13}C$	CRA	Age (AD)*	j	Pj_1	Pj_2
Layer II								
Beta-248821	B-20	Pearl shell	-1.6	620±40	1670–1859	θ_1	0.14	0.05
Beta-231223	A-3	***Nestegis sandwicensis***	-23.5	**710±40**	—	θ_2	0.98	—
Layer III								
Beta-231220	EE-15	*Dodonaea viscosa*	-24.6	870±40	1060–1279	θ_3	0.10	0.09
Beta-231221	EE-15	*Diospyros sandwicensis*	-26.2	**680±40**	1260–1399	θ_4	0.11	0.11
Beta-231222	C-5	*Canthium odoratum*	-26.5	490±40	1310–1499	θ_5	0.14	0.15
Beta-248818	C-6	Pearl shell	+0.5	820±40	1430–1689	θ_6	0.12	0.08
Beta-248819	C-6	Pearl shell	+2.3	840±40	1420–1679	θ_7	0.11	0.08
Beta-248820	A-6	Pearl shell	+1.5	790±40	1440–1699	θ_8	0.15	0.09
Layer not identified								
Beta-231224	A-3	*Canthium odoratum*	-24.0	690±40	—	—	—	—

* = 95% highest posterior density region.

Table 1. Age determinations on mostly short-lived specimens.

Age determinations and analysis

The nine new age determinations were processed in two batches independently of one another. Five collections of wood charcoal, two made by Lloyd Soehren of Bishop Museum in 1966 and three by the University of Hawaii field school in 1967, were submitted by Valerie Curtis, then an archaeologist with the U.S. Air Force, to Gail Murakami of the International Archaeological Research Institute, Inc. Wood Identification Laboratory for taxon identification. The identified samples were submitted to Beta-Analytic, Inc. for ^{14}C dating by the accelerator mass spectrometry (AMS) method (Table 1).

A second set of four age determinations on pearl shell manufacturing waste was selected from the O18 collections held by the U.S. Air Force and submitted by T.S. Dye & Colleagues, Archaeologists to Beta-Analytic, Inc. for AMS dating (Table 1). Pearl shell, produced by mollusks in the genus *Pinctada*, was a favored material for fishhook manufacture in traditional Hawai'i. The cross-laminar structure of the shell gives it exceptional strength for applications like fishhooks that generate high levels of stress at the bend. Pinctada shell is a suitable dating material because the animal is a sessile filter-feeder that takes up its carbon from the general ocean water around it, and not from an old limestone substrate (Dye 1994). The current best estimate of the apparent age of the ocean water around Hawai'i yields a reservoir correction factor of 110±80. The large standard deviation of this estimate is likely due to regional patterns of variability in the apparent age of surface waters around Hawai'i that are not yet understood completely. Additional information on this variability might make it possible in the future to apply a more precise estimate in the calibration of these samples. This might yield slightly different calibrated ages for the samples, one from Layer II and three from Layer III, but will not alter the fact that these samples returned ^{14}C age estimates that were internally consistent, a first in the long history of ^{14}C dating at O18.

Notable features of Table 1 have been set off in boldface. One of the samples, Beta-231224, could not be assigned to either Layer II or Layer III and is not considered further here. The single wood charcoal sample from Layer II is from a tree known in Hawai'i as *olopua*. Although the life span of *olopua* is not known, the fact that it is a tree indicates the possibility that the sample has in-built age. In fact, the age determination returned by the laboratory is stratigraphically inverted with two of the Layer III samples. Beta-231220, the age estimate for charcoal from a shrub known in Hawai'i as *'a'ali'i*, does not suffer the effects of in-built age and is the most reliable estimate for the antiquity of settlement at O18.

A Bayesian model of O18 stratigraphy relates each of the dated samples to the calendric ages represented by the two primary cultural deposits. The symbols $\theta_{2\text{-}5}$ represent the calendar ages of the archaeological events associated with burning the four dated wood charcoal pieces and θ_1 and $\theta_{6\text{-}8}$ represent calendar ages of manufacturing events, presumably of pearl shell fishhooks (Table 1, column j). These are related to the calendar ages of the start and end of deposition of the two primary cultural deposits; α_3 and β_3 represent the start and end of deposition, respectively, of Layer III, and α_2 and β_2 represent the start and end of deposition, respectively, of Layer II. The known stratigraphic relations of $\theta_{2\text{-}8}$ to the layer boundaries are set out in (1), where > means "is older than" and ≥ means "is older than or the same age as".

$$\phi_2 \geq \alpha_3 \geq \theta_{3\text{–}8} \geq \beta_3 > \alpha_2 \geq \theta_{1,2} \geq \beta_2 \geq \phi_1 \quad (1)$$

For the sake of brevity, (1) groups the θ from each layer in an unconventional way; the θ are understood to be unordered so there are no stratigraphic relations among them.

The salient points of (1) are:

- the onset of Layer III deposition, α_3, began either at, or sometime after, the time Hawai'i was colonized by Polynesians, which is modeled here as normally distributed, ϕ_2 = AD 800±50 (Athens *et al*. 2002);
- the calendar ages of three dated burning events, $\theta_{3\text{-}5}$, and three dated manufacturing events, $\theta_{6\text{-}8}$, fall within the period of time represented by the deposition of Layer III;
- the calendar ages of the burning and manufacturing

events, $\theta_{3\text{-}8}$, are unordered, i.e. there is no stratigraphic information on their ages relative to one another;

- the calendar ages of a burning event, θ_2, and a manufacturing event, θ_1, fall within the period of time represented by the deposition of Layer II;
- the calendar ages of the burning and manufacturing events, θ_2 and θ_1, are unordered, i.e. there is no stratigraphic information on their ages relative to one another;
- there is a hiatus between the end of deposition of Layer III, β_3, and the start of deposition of Layer II, α_2, as indicated by the > symbol; and
- the end of layer II deposition, β_2, was either before or during the time cattle ranching was established on the Waimānalo Plain, which is modeled here as normally distributed, ϕ_1 = AD 1830±20.

This model was implemented with the BCal software package (Buck *et al*. 1999) using the most recent atmospheric and marine calibration curves (Reimer *et al*. 2009). In an effort to identify outliers among the age determinations, each one was assigned an uninformative outlier prior probability of 0.1, following a procedure set out by Christen (1994). The initial run of the software clearly identified Beta-231223 as an outlier; the value of 0.98 in the column, P_{j1} stands out from the rest of the values in the column, which differ little from their initial values. Beta-231223 was omitted from the analysis and a subsequent run of the software failed to detect outliers, as shown in the column, P_{j2}, where values are all close to their initial values. The seven age determinations for O18 used in subsequent analyses are one more than the six potentially useful age determinations available previously.

Age estimates returned by the software for parameters of the model establish a chronology for the O18 site and its constituent layers. The 67% highest posterior density region, equivalent to a one standard deviation estimate, for initial settlement of the site, α_3, is AD 1040–1219 (Fig. 3, bottom left). This initial period of deposition at the site, identified by archaeologists as Layer III, came to an end in AD 1580–1699 (Fig. 3, bottom right). After a hiatus marked stratigraphically by a layer of beach sand, cultural deposition of Layer II began in AD 1670–1789 (Fig. 3, top left) and continued until AD 1770–1859 (Fig. 3, top right). There is little evidence that the site was abandoned in traditional Hawaiian times. For example, the probability that β_2 is older than AD 1778, the year Cook sailed to Hawai'i, is 0.31. Thus, given the present dating evidence and the stratigraphic model of the O18 site, it is more than twice as likely that the site was abandoned sometime after Cook.

An advantage of a model-based Bayesian calibration is that it is possible to derive estimates for time intervals of interest. The O18 site has figured in interpretations of initial Polynesian settlement of Hawai'i (Kirch 1985); it is interesting to estimate the interval between settlement and establishment of the site. The 67% highest posterior density region for the time interval between ϕ_2 and α_3 is 260–459 years (Fig. 4, top left). The initial period of cultural deposition at the site, represented by Layer III, was quite long. The 67% highest posterior density region for the time interval between α_3 and β_3 is 400–629 years (Fig. 4, top right). In contrast, the hiatus between Layers III and II appears to have been relatively short. The estimated duration of this hiatus, which is represented stratigraphically by a layer of light-coloured beach sand, has a 67% highest posterior density region of 10–109 years (Fig. 4, bottom left). The duration of Layer II was short compared to Layer III. The 67% highest posterior density region for the time interval between α_2 and β_2 is 10–80 years.

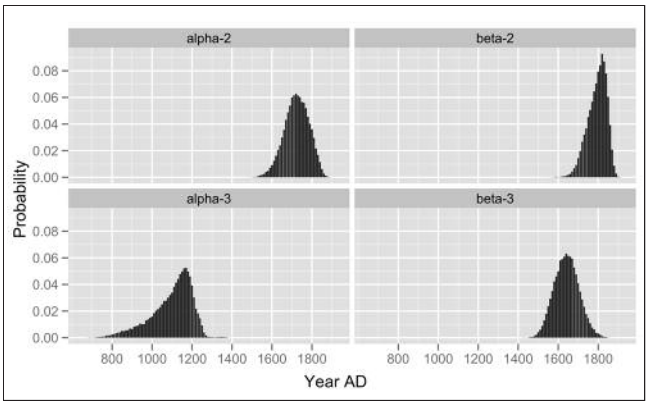

Figure 3. Estimated ages of Layers II and III at O18: top left, early boundary of Layer II; top right, late boundary of Layer II; bottom left, early boundary of Layer III; bottom right, late boundary of Layer III.

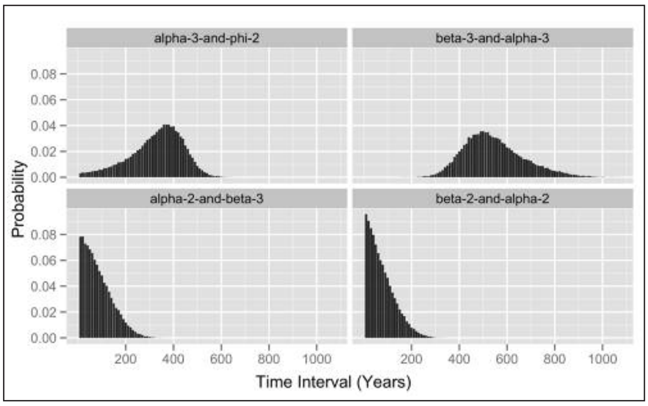

Figure 4. Time intervals at O18: top left, the interval between Polynesian settlement of Hawai'i and establishment of O18; top right, duration of Layer III; bottom left, duration of hiatus between Layers II and III; bottom right, duration of Layer II.

O18 in regional perspective

The Bayesian model can be extended to include other sites on the Waimānalo Plain. Cultural resources management excavations at sites 50–80–15–4851 and –4853 and 50–80–11–4856 and –4857 have yielded 37 ^{14}C age determinations, 35 on charcoal from identified short-lived taxa and two on pearl shell manufacturing waste (Table 2). Each of the sites consists of the remnants of a single cultural deposit that typically lacks internal stratification. Because no stratigraphic relationships between the deposits of these sites and the layers of O18 have been established, they are each modeled as single phases independent of one another and of Layers II and III at O18. Using the short-hand described earlier, the model can be extended with the addition of the following inequalities:

$$\alpha_{4851} \geq \theta_{9-11} \geq \beta_{4851} \quad (2)$$

$$\alpha_{4853} \geq \theta_{12-27} \geq \beta_{4853} \quad (3)$$

$$\alpha_{4856} \geq \theta_{28-41} \geq \beta_{4856} \quad (4)$$

$$\alpha_{4857} \geq \theta_{42-45} \geq \beta_{4857} \quad (5)$$

Laboratory	Fire-pit (feature no.)	Material	$\delta^{13}C$	CRA*	j
Site 50–80–15–4851					
Beta-111023[1]	(3)	cf. *Rauvolfia sandwicensis*	-26.9	310±40	θ_{9}
Beta-111024[1]	(2)	*Sida* cf. *fallax*	-26.8	140±60	θ_{10}
Beta-111025[1]	(1)	*Sida* cf. *fallax*	-24.2	540±50	θ_{11}
Site 50–80–15–4853					
Beta-101869[1]	(6)	*Chamaesyce* sp.	-12.9	230±60	θ_{12}
Beta-101871[1]	(9)	cf. *Osteomeles anthyllidifolia*	-25.3	720±40	θ_{13}
Beta-101872[1]	(10)	cf. *Osteomeles anthyllidifolia*	-24.7	680±40	θ_{14}
Beta-111022[1]	(1)	*Sida* cf. *fallax*	-27.5	150±40	θ_{15}
Beta-120317[1]	(1)	*Sida* cf. *fallax*	-21.3	140±50	θ_{16}
Beta-120318[1]	(5)	*Sida* cf. *fallax*	-26.1	150±50	θ_{17}
Beta-120319[1]	(9)	*Aleurites molucanna* nutshell, *Chenopodium oahuense*, *Sida* cf. *fallax*	-25.9	350±80	θ_{18}
Beta-120320[1]	(13)	*Aleurites molucanna* nutshell	-25.6	230±50	θ_{19}
Beta-120321[1]	(15)	*Aleurites molucanna* nutshell	-25.0	110±70	θ_{20}
Beta-120322[1]	(16)	*Chamaesyce* sp.	-16.8	310±60	θ_{21}
Beta-120323[1]	(17)	*Aleurites molucanna* nutshell, *Chenopodium oahuense*, *Sida* cf. *fallax*	-27.5	170±60	θ_{22}
Beta-120324[1]	(18)	*Aleurites molucanna* nutshell	-25.2	250±50	θ_{23}
Beta-120325[1]	(19)	*Aleurites molucanna* nutshell	-25.2	270±70	θ_{24}
Beta-120326[1]	(20)	*Aleurites molucanna* nutshell, *Chenopodium oahuense*, *Sida* cf. *fallax*	-14.0	330±60	θ_{25}
Beta-120327[1]	(24)	*Aleurites molucanna* nutshell	-23.0	400±70	θ_{26}
Beta-120328[1]	(25)	*Sida* cf. *fallax*	-25.5	220±50	θ_{27}
Site 50–80–11–4856					
Beta-208589[2]		*Chenopodium oahuense* wood charcoal	-26.6	140±40	θ_{28}
Beta-208590[2]		*Sida* cf. *fallax* wood charcoal	-24.9	90±40	θ_{29}
Beta-208591[2]		*Aleurites moluccana* nutshell	-25.7	140±40	θ_{30}
Beta-246786[3]	(4)	*Sida* cf. *fallax* wood charcoal	-25.4	380±40	θ_{31}
Beta-251245[3]	(5)	*Chenopodium oahuense* wood charcoal	-24.5	260±40	θ_{32}
Beta-251243[3]	(9)	*Aleurites moluccana* nutshell charcoal	-24.9	350±40	θ_{33}
Beta-251244[3]	(10)	*Sida* cf. *fallax* wood charcoal	-24	250±40	θ_{34}
Beta-251242[3]	(12)	*Sida* cf. *fallax* wood charcoal	-24.4	200±40	θ_{35}
Beta-251246[3]	(17)	*Chenopodium oahuense* wood charcoal	-21.9	240±40	θ_{36}
Beta-251247[3]	(22)	*Cordyline fruticosa* wood charcoal	-22.6	450±40	θ_{37}
Beta-251248[3]	(23)	*Aleurites moluccana* nutshell charcoal	-25.6	390±40	θ_{38}
Beta-200230[4]	(22)	*Chamaesyce* sp. wood charcoal	-11.3	550±40	θ_{39}
Beta-208588[2]		Pearl shell	-0.1	630±40	θ_{40}
Beta-208587[2]		Pearl shell	-2.7	630±40	θ_{41}
Site 50–80–11–4857					
Beta-200229[4]	(11)	*Sida* cf. *fallax* wood charcoal	-25.6	170±40	θ_{42}
Beta-200228[4]	(12)	*Chamaesyce* sp. wood charcoal	-25.7	200±40	θ_{43}
Beta-260904[5]	(12)	cf. *Chamaesyce* sp. wood charcoal	-23.4	580±40	θ_{44}
Beta-260905[5]	(13)	*Sida* cf. *fallax* wood charcoal	-26.4	400±40	θ_{45}

* = conventional ^{14}C age (Stuiver and Polach 1977); [1] Dye (2000); [2] McElroy, Dye and Jourdane (2006); [3] Lebo, Dye and Dye (2009); [4] Putzi and Dye (2005); [5] Dye and Dye (2009).

Table 2. ^{14}C ages of short-lived materials from other sites on the Waimanalo Plain.

Based on the current dating evidence, sites 50–80–15–4851 and –4853 and 50–80–11–4856 and –4857 were all established after O18. Site 50–80–15–4851, located on the opposite bank of Puhā Stream from O18, is likely to be the oldest among the four. It was established AD 1160–1429, based on the 67% highest posterior density region (Fig. 5, top left). Penecontemporaneously, Site 50–80–11–4857, located inland and north of O18, was established in AD 1190–1409 (Fig. 5, bottom right). Site 50–80–15–4853, immediately inland of site O18, has been extensively dated and appears to have been established at a later time. The 67% highest posterior density region for the site's establishment is AD 1240–1379 (Fig. 5, top right). Finally, site 50–80–11–4856, located on the coast north of O18, was established in AD 1360–1429 (Fig. 5, bottom left), apparently later than Site 50–80–11–4857 located

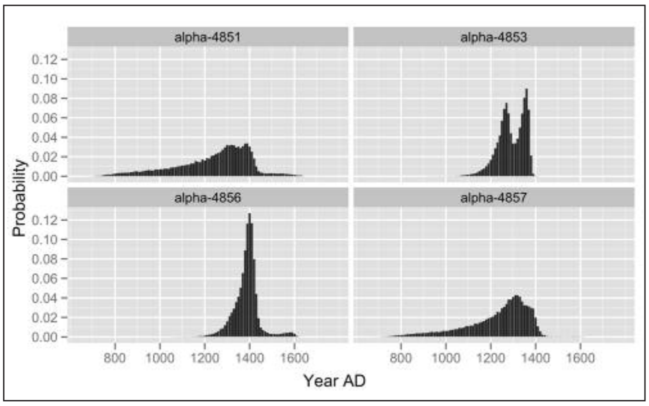

Figure 5. Initial site use on the Waimanalo Plain: top left, 50–80–15–4851; top right, 50–80–15–4853; bottom left, 50–80–11–4856; bottom right, 50–80–11–4857.

immediately inland. The probability that 50–80–11–4857 was established earlier than 50–80–11–4856 is 0.88.

Another way to look at the site establishment estimates is relative to the establishment of O18. All of the posterior probability distributions have left tails that extend past zero and thus each site retains some probability of having been established before O18. These probabilities are all rather slim, however. The site with the greatest probability of having been established before O18, 50–80–11–4851, has a probability of 0.2. Using 67% highest posterior density regions: Site 50–80–15–4851 was settled 10 years earlier than to 349 years after O18 (Fig. 6, top left); site 50–80–11–4857 was settled at the same time as O18 to 319 years later (Fig. 6, bottom right); site 50–80–11–4853 was settled 60–279 years after O18 (Fig. 6, top right); and site 50–80–11–4856 was settled 160–359 years after O18 (Fig. 6, bottom left).

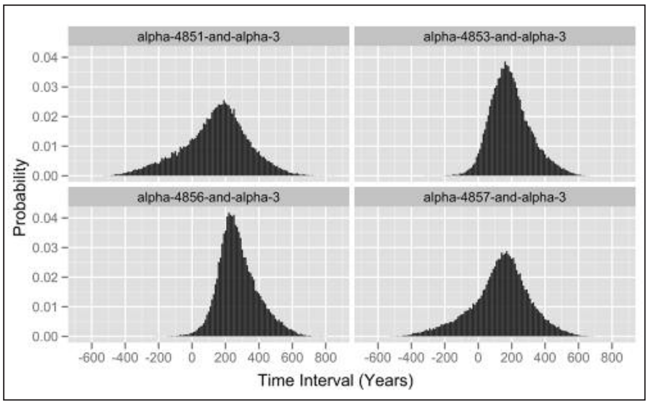

Figure 6. Sequence of site establishment – the interval between establishment of O18 and other sites: top left, Site 50–80–15–4851; top right, Site 50–80–15–4853; bottom left, Site 50–80–11–4856; bottom right, Site 50–80–11–4857. Note that there is a small probability that each of the sites was established before O18.

Summary and conclusion

Seven new ^{14}C age determinations on short-lived materials yield a chronology for O18 that differs from previous estimates. The results clearly indicate that O18 was settled later than previously estimated. The 67% highest posterior density region for the true age of α_3 is AD 1040–1219, which is 4–9 centuries younger than previous estimates. The hypothesis that O18 was occupied during an early phase of Polynesian settlement is, on present evidence, false. The best estimate, based on present evidence, places initial site use 260–459 years after the archipelago was discovered and colonized. With this new, 'late' chronology, O18 joins site H1 on Hawai'i Island (Dye 1992) and the Hālawa Dune site on Moloka'i (Kirch and McCoy 2007) in a growing group of relatively late sites once believed to have been examples of early Hawaiian settlement.

The situation is similar with respect to when O18 was abandoned. The new dates on short-lived materials, calibrated and interpreted within a Bayesian framework, indicate that the site was abandoned at the end of traditional Hawaiian times in the late eighteenth or early nineteenth centuries, some 3–6 centuries later than earlier estimates. The estimate brings the abandonment of O18 in line with abandonment date estimates for other sites on the Waimānalo Plain.

One reason that previous estimates of O18 chronology were too old by centuries was a failure to control for the potential effects of old wood during the dating process, but errors assigning the dated samples to their correct archaeological contexts in a field school situation, and statistical and other errors in the dating laboratory probably had effects, too. It is worthwhile to emphasize the ill effects of old wood; cultural resources management archaeologists working in Hawaii routinely date unidentified wood charcoal. There is no reason to believe that their age determinations on unidentified wood charcoal will perform any better than those from O18, which proved to be poor estimators of site chronology. They are essentially worthless for establishing archaeological chronologies.

In most cases, the old dates that do a poor job of estimating the age of O18 provide no other useful information. An exception to this is Beta-20852b on *A. moluccana* nutshell. This age determination does a poor job of estimating the age of its archaeological context in Layer II, but because the identified material derived from a tree introduced to the islands by Polynesians the age estimate itself is of interest. If the calendar age, θ_{46}, of this age determination is associated with the archaeological event of planting *kukui* trees in Waimānalo and calibrated in the context of a model that specifies only that this event dates to traditional Hawaiian times (6), then the 67% highest posterior density region for θ_{46} is AD 840–1159, an estimate that has a 70% probability of dating an event older than the establishment of O18. Thus, it is likely that the *A. moluccana* tree was planted by Hawaiians who lived at some other site in Waimānalo prior to settlement at O18. Because dates from nearby sites indicate that O18 was established before them, this putative earlier settlement is likely to be located somewhere inland, probably on the volcanic soils that supported gardens in traditional Hawaiian times. Whether cultural deposits associated with this putative early settlement still exist is a question for future research.

$$\phi_2 \geq \theta_{46} \geq \phi_1 \quad (6)$$

Finally, development of an explicit chronological model relating regional archaeological events to one another and set out in inequalities (1–6) means that anyone can replicate the estimate and explore how different parameters of the model affect it. It is not possible to do this in a precise way with an approach that is not strictly model-based. Changes in chronological estimates for sites on the Waimānalo Plain will most likely result from new dates on short-lived materials from secure stratigraphic contexts both on the Waimānalo Plain and beyond. Excavation of deposits at the coastal fringe of Site 50–80–11–4856, for instance, might help clarify the processes responsible for deposition of charcoal in this active and variable environment at the fringe of traditional Hawaiian settlement on the Waimānalo Plain. And certainly, any change in the estimated settlement date of the Hawaiian Islands would have a direct effect on the estimate of the interval between this event and establishment of O18. If the change in the estimated settlement date were sufficiently large, it might even have an effect on the estimate of when O18 was established.

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