Human-Caused Stratigraphic Mixing of a Coastal Hawaiian Midden During Prehistory: Implications for Interpreting Cultural Deposits

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Archaeologists rely on the spatial and temporal distribution of artifacts and other site-based materials to understand the stratigraphic integrity of the matrix in which remains are embedded. Although they are aware of taphonomic and site formation processes that can cause post-depositional movement of objects, misinterpretation can occur. We used high-precision ^{230}Th dating of branch corals found throughout cultural layers of a coastal Hawaiian midden to identify the effects of post-depositional disturbances to the archaeological record. Fifteen corals distributed in three cultural layers of a Mo'omomi bay site on west Moloka'i, Hawaiian Islands, were ^{230}Th dated between A.D. 1513 and A.D. 1623. Even though the cultural layers appeared visually intact, the positions of the dated coral samples indicate stratigraphic mixing as there is no positive age–depth correlation. Consequently, all cultural layers should be considered one analytical unit for analysis of contents. This study is applicable to other Pacific archaeological sites, especially throughout Hawaii and East Polynesia generally, that have well-preserved branch coral for ^{230}Th dating. © 2010 Wiley Periodicals, Inc.

INTRODUCTION

Stratigraphic integrity is fundamental to archaeological interpretation. During the past few decades, archaeologists have realized that the spatial distribution of surface and subsurface cultural materials can change over time and space by both anthropogenic and natural impacts (Grave & Kealhofer, 1999; Rosendahl, Ulm, & Weisler, 2007; Wood & Johnson, 1978). A new approach to recognizing post-depositional disturbances, proposed here, is the high-precision ^{230}Th dating of corals found in cultural layers at Pacific archaeological sites. In Hawaii (Kirch & Sharp, 2005; McCoy et al., 2009; Weisleret al., 2006) and elsewhere in East Polynesia (Hatanaka & Shibata, 1982), branch corals (*Porcillopora* spp. and *Acropora* spp.) harvested from the reef were placed as offerings on shrines and incorporated into subsurface

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cultural deposits. High-precision ^{230}Th dating of corals can accurately date the age of death often to within ± 2 to 5 years. We selected 15 well-preserved branch coral samples, which were identified by their fine structural details suggesting that they were harvested from the living reef and not collected as wave-rounded specimens from the beach. Since cultural layers within coastal sandy middens were often subject to disturbance processes such as digging holes for earth ovens, house posts, human burials, and trash pits by the ancient inhabitants, we wanted to see if the stratigraphy that appeared intact when viewed in profile had cultural contents that were displaced from different cultural layers. While we target a coastal midden in this example, the findings of this study are also applicable to other stratigraphically complex sites, especially rockshelters. In this latter context, fresh, sharp branch corals, used for manufacturing abrading tools to work pearlshell, were recovered during rockshelter excavations in Mangareva, southeast Polynesia (Green, 1960).

Coastal middens are key sites of archaeological research in Oceania as they often contain the earliest cultural layers for a typical island or region. This is especially true for Hawaii where important sites are located at the Bellows dune on windward O'ahu (Dye, 2000; Hunt & Holson, 1991; Pearson, Kirch, & Pietrusewsky, 1971; Tuggle & Spriggs, 2000); the A1-3 coastal habitation in Halawa Valley, Moloka'i (Kirch, 1971; Kirch & Kelly, 1975; Kirch & McCoy, 2007); and the mound site at Kawela, Moloka'i, along the south-central shore (Weisler, 1982; Weisler & Kirch, 1985). These sites consist of well-developed cultural layers, often between sterile sandy deposits.

The preservation and destruction of archaeological contexts depends on site location, sedimentary supply or site matrix, and subsidence, including the energy level of coastal processes (Waters, 1992:270). Like other Pacific islands, the Hawaiian Archipelago has experienced environmental catastrophes. In the past millennium, massive natural disturbance agents were documented, such as tsunamis (McMurtry et al., 2004; Moore, 2000; Rubin, Fletcher, & Sherman, 2000), El Niño–driven storm events (Engels et al., 2004; Nunn, 2000; Rooney et al., 2004), earthquakes (McMurtry et al., 2004; Rubin, Fletcher, & Sherman, 2000), and even lava flows that covered archaeological sites (Somers, 1991). Secondary effects include perturbation process, oceanic overwash, site deflation, erosion (Carson, 2004), and drought (Cochran, Roberts, & Evans, 2002; McCoy & Hartshorn, 2007). Wind, waves, storms, tides, and currents (Waters, 1992:249–251) also led to coastal erosion and/or mobilization. In contrast, sea level variations (Moore, 2000; Nunn, 1994) and temperature changes (Nunn, 1994, 2000; Rooney et al., 2004) during the study period had only minor effects.

Significant anthropogenic processes disruptive to archaeological site integrity have also occurred in the Hawaiian Archipelago. Many of these are relative to cultivation practices that lead to landscape disturbance (Athens & Ward, 1993; Carson, 2004; Kirch, Flenley, & Steadman, 1991; Leach, 1999). During A.D. 1270–1475, the Hawaiian population grew dramatically (Carson, 2006; Dye, 1994; Dye & Komori, 1992; McCoy, 2007), leading to environmental degradation, including the depletion of horticultural soils (Hartshorn et al., 2006; Kirch, 1994; Leach, 1999; Vitousek et al., 2004). Later, sugarcane, pineapple farming, and cattle ranching, introduced to the islands after European contact (Cochran, Roberts, & Evan, 2002; Summers, 1971), caused further soil erosion and landscape degradation.

At the site scale, anthropogenic events relate to site formation as well as disturbance processes. These repeated human activities include digging of storage pits, postholes, and combustion features, which imply stratigraphic mixing of layers. However, the actual movement of materials between layers can be difficult to empirically document.

BACKGROUND

Regional Setting and Archaeological Context

Situated near the center of the Hawaiian Islands, the elongated island of Moloka'i is 61 km long with an average width of 16 km. Two volcanoes, which overlap in the central saddle region, comprise the island. The summit of the east Moloka'i volcano rises to 1244 m, where the dense rainforest provides the watershed for much of the windward valleys. In contrast, the west Moloka'i volcano, at ~421 m, is situated entirely within the dry leeward region. This area of Moloka'i is dominated by the traditional land unit of Kaluako'i *ahupua'a*, which encompasses roughly the west quarter of the island, ~20,000 hectares. The south shore of this western region is fronted by a broad fringing reef, while the rocky west coast has shallow embayments ringed with late prehistoric residential complexes, and the north shore is dominated by towering cliffs in the northwest, descending through the island's saddle region before climbing east to form the tallest sea cliffs in the world. It is in this saddle region where the rocky shore brackets a wide sandy bay at Kawa'aloa and the rocky embayment of Mo'omomi. This latter bay, although somewhat rocky, is the first significant canoe landing west of the windward valleys. Today, the area remains relatively isolated and is accessed only by dirt road.

The small, seasonally changing sandy beach at Mo'omomi contains sedimentary deposits dating to the Pleistocene. At the most inland margin of the bay is our study site 50-60-02-2421 (State of Hawaii site number; Bishop Museum site number Mo-B6-79). The site measures ~90 m along the bay and extends ~20 m inland, judging from the midden layer exposed at the wave-cut cliff face and along the sides of a dry streambed. Excavations of a 2 m × 3 m area conducted in 1999 by Weisler (Figure 1) revealed three distinct cultural layers (total thickness of ~80 cm) consisting of abundant food remains dominated by limpets (in Hawaiian *opihi*, *Cellana sandwicensis* and *C. exarata*) and vertebrate fauna (predominantly fish, with lesser amounts of pig, dog, and bird). An infant burial was also encountered. Cultural features included a stone pavement, earth ovens and hearths, postholes, and refuse pits. Dense concentrations of fine-grained basalt debitage point to adze manufacturing as an important activity. A major adze source ("quarry") is located about a 30-minute walk southwest.

Mo'omomi Bay is an important prehistoric occupation site for two reasons. First, the dry leeward coastal zone was used for obtaining high-quality stone for adze manufacturing (Weisler & Clague, 1998; Weisler & Murakami, 1991), and Mo'omomi was the first significant canoe landing west of the more populated areas of the windward valleys. Settlement patterns, subsistence data, and artifact analysis suggest that many leeward habitation sites in Kaluako'i (literally, "the adze pit") were occupied

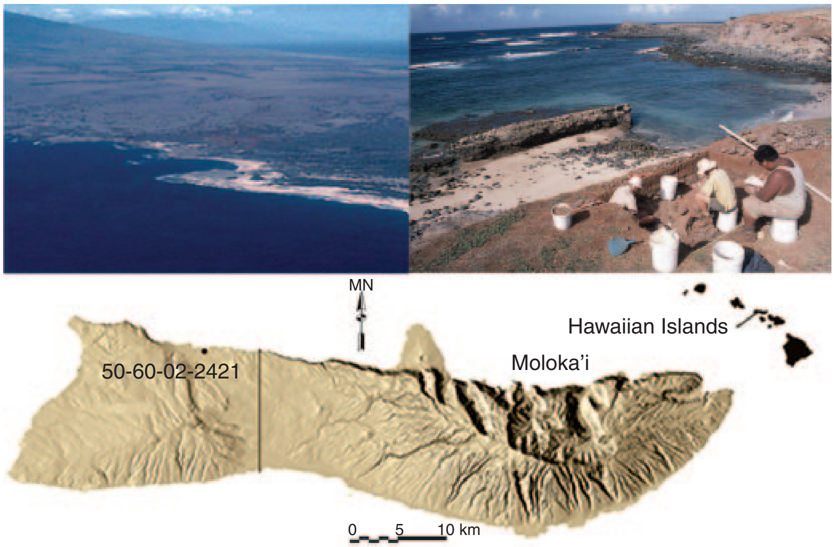

Figure 1. The study site (50-60-02-2421) is located on the northwest coast of Moloka'i Island. The site is situated ~4 m above sea level atop a wave-cut cliff. Some 22 ^{230}Th-dated corals document settlement between A.D. 1513 and A.D. 1623, the Late Expansion Period of Hawaiian prehistory.

sporadically to exploit seasonally abundant marine and terrestrial resources and to collect fine-grained basalt and volcanic glass in nearby quarries (Weisler & Clague, 1998). Second, people may have visited the calmer leeward coast in winter for marine subsistence because rough seas restricted such activities for half of the year along the windward coastline (Summers, 1971). Indeed, long-time resident G.P. Cooke suggested that ". . . the habitants of Pelekunu [a windward valley] would leave the valley at certain seasons of the year when schools of fish came to Mo'omomi. Here they caught and dried fish to be carried back to their valley homes at Pelekunu" (Cooke, 1949). Typical windward plants, such as *Sygysium* sp., were identified at a site close to Mo'omomi, suggesting seasonal movement between the two areas (Weisler & Murakami, 1991).

Of importance to our study are well-preserved branch coral found within all cultural layers at site 50-60-02-2421. These are interpreted as the remains of ritual offerings (Weisler et al., 2006; Weisler, Hua, & Zhao, 2009:957) that are usually associated with free-standing stone structures known ethnographically as *heiau* (temples) or fishing shrines (*ko'a*, literally, coral). In prehistory, Hawaiians obtained fresh branch coral, commonly *Pocillopora* spp., from the reef and placed coral heads and fingers on religious sites. While little information is found in the ethnographies about this practice in Hawaii, repeated associations of fresh branch coral and religious sites in the archaeological record point to its dedicatory significance. Due to the sharp, well-preserved state of coral samples from the study site, it is clear that coral was collected fresh and not from secondary, water-rounded beach contexts. Consequently, there is no significant time lag between death of the coral and placement within the site.

ARCHAEOLOGICAL FIELD METHODS

The Mo'omomi site is exposed in a ~4-m-high eroded cliff face composed of Pleistocene beach sands and terrigenous silt that fronts the bay near its inland extent. Just behind the cliff face, a 2 m × 3 m area was divided into six 1-m^2 excavation units. Units were designated on an alphanumeric grid in reference to the site datum (e.g., N26W7). The excavation proceeded in 10-cm spits (arbitrary levels) within layers, never crossing layer boundaries. Sediments were screened with stacked 6.4-mm and 3.2-mm sieves and the residues sprayed with fresh water, then air dried. All cultural material was inventoried by spit. This included water-rounded volcanic stones, fire-altered rock (oven stones), basalt debitage, coralline algae, branch coral, charcoal, shellfish, and bone. Artifacts and representative unweathered coral fingers were mapped *in situ* and given object numbers noting the x, y, and z coordinates, which were recorded on level records for each spit. Sediment characteristics were noted during excavation of each spit. After completion of the excavations, stratigraphic profiles were drawn of all the sidewalls. Layers were photographed and described by Weisler using standardized U.S. Department of Agriculture nomenclature, noting sediment color (Munsell system), texture, consistency, structure, plasticity, and layer thickness and horizon/stratum boundary (distinctiveness and topography) (Weisler et al., 2006).

Six discrete layers are identified in the stratigraphic profile (Figure 2). The noncultural deposits (layers IA, IB, and II) are all post-occupation and have a maximum depth of ~35 cm below the surface (cmbs). Layers IIIA, IIIB, IIIC represent the prehistoric occupation. Stratigraphic boundaries were clearly distinguished, primarily by color but also by subtle differences in sediment texture, structure, and consistency. Numerous postholes were identified in layer IIIC as they intruded into the sterile subsoil, ~60 to 80 cmbs. The stratigraphic break between cultural layers IIIA (very dark gray brown; 10YR3/2) and IIIB (dark brown; 7.5YR3/3) is clearly visible in Figure 3. Layer IIIC was differentiated in the field by its reddish-yellow (7.5YR7/6) color.

^{230}TH DATING METHOD

^{230}Th dating (also known as U-Th dating, ^{238}U-^{234}U-^{230}Th disequilibrium dating, ^{238}U-^{230}Th disequilibrium dating, U-series disequilibrium dating, or U-series dating) is a radiometric dating technique commonly used to determine the age of carbonate materials such as corals and speleothems (Zhao, Yu, & Feng, 2009). The ^{230}Th dating method is based on the decay of ^{238}U (with a half life $T_{1/2} = 4.469 \times 10^9$ years) to stable ^{206}Pb via intermediate daughters such as ^{234}U ($T_{1/2} \sim 245{,}000$ years) and ^{230}Th ($T_{1/2}$ ~75,400 years). In this decay series, ^{238}U-^{234}U-^{230}Th disequilibrium occurs when U is differentiated from Th during a particular geological or environmental event or process. In the case of natural aqueous systems such as seawater, for example, in which U is slightly soluble but Th is highly insoluble, coral carbonate precipitated from the seawater will contain a trace amount of U, usually 2–3 parts per million (ppm), but virtually no Th, leading to excess U in the decay chain (that is, ^{238}U and ^{234}U activities $\gg$ ^{230}Th activity). Once disequilibrium is established, it takes about

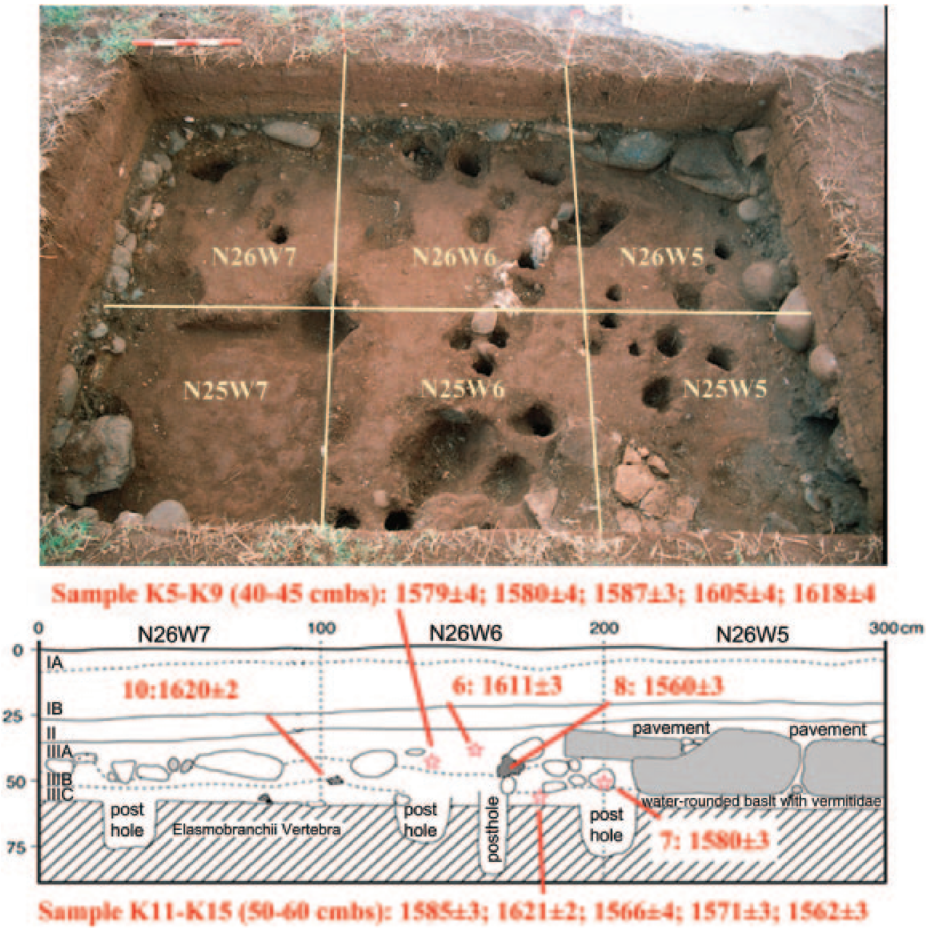

Figure 2. Top 2 m × 3 m excavation. Bottom north profile of units N26W7, N26W6, and N26W5 showing the location of most U-series dated coral samples, coral dates (in A.D.), and numerous postholes. The scale bar is 30 cm long (profile adapted from Weisler et al., 2006; photo, M. Weisler).

seven times the half life of ^{230}Th (~500 ka) for the system to return to near secular equilibrium (that is, when the activities of the parent and daughter nuclides are equal), or to the level where the degree of disequilibrium is below the limit of detection by mass spectrometry. For young coral, ^{230}Th ages are almost linearly correlated with the ^{230}Th/^{238}U ratio. The application of the ^{238}U-^{234}U-^{230}Th systematic allows accurate age determinations spanning the last 500,000 years, covering ~7 times the half life of ^{230}Th. The Centre for Microscopy and Microanalysis, University of Queensland, generally provides an average precision of 0.5%; therefore, ± 1 year precision is achievable from 200-year-old coral.

The procedure for ^{230}Th dating of corals from archaeological sites in Hawaii using the thermal ionization mass spectrometry (TIMS) technique was reported in

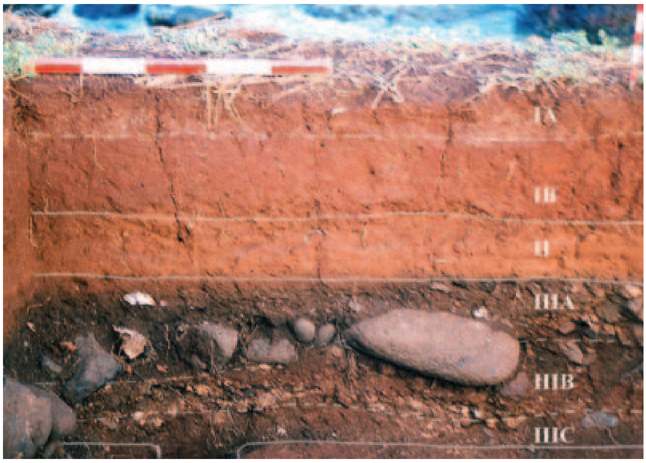

Figure 3. Photograph of unit N26W7 north profile showing the boundaries between the prehistoric cultural layers (IIIA–C). Note the clear color differences between layers IIIA (very dark gray brown; 10YR3/2) and IIIB (dark brown; 7.5YR3/3). Layer IIIC was defined by its reddish-yellow color (7.5YR7/6). The scale bar is 50 cm long.

Figure 4. Unweathered *Pocillopora* spp. branch coral offerings distributed in habitation site 50-60-02-2421: (a) N25W5/6-A, (b) N26W6/6-B, (c) N26W6/5-E.

Weisler et al. (2006). Only fresh-looking, well-preserved corals that exhibited minute sculptural details were used for dating; water-rounded or otherwise eroded corals were considered unsuitable. As branch coral growth rates are 10–40 mm/year (based on the X-ray images), ~10 mm of the coral tip, representing the last episode of living coral, was our typical sample. The extremely low Th content and $^{234}U/^{238}U$, which are < 180 parts per trillion (ppt) and between 1.14 and 1.18, respectively, are identical to seawater values, suggesting these branch corals were alive when collected. It also agrees with the fresh visual appearance of corals. The ^{230}Th ages were calculated using the Isoplot/Ex version 2 program of Ludwig (1999), and the corrected ^{230}Th ages include corrections for nonradiogenic ^{230}Th (Ludwig, 1999; Ludwig et al., 1992; Yu et al., 2006; Zhao et al., 2001). An example of well-preserved dedicatory coral used for dating is shown in Figure 4.

RESULTS

Fifteen corals dated in this study were combined with seven previous coral dates from Weisler et al. (2006:279) to address two major problems: (1) defining stratigraphic integrity of the cultural layers and (2) determining the chronology of site use. The inventory of dated coral samples, thorium concentrations, isotopic ratios, and dating results is presented in Table I.

Mean U concentration in coral is 2.83 ± 0.37 ppm, which is typical of modern pristine corals. The ^{232}Th content ranges from 33.42 ± 0.46 to 267.02 ± 0.68 ppt, typical of pristine corals from oceanic settings far away from terrestrial influence. The ^{232}Th content in corals may be derived from a number of sources, such as ongoing erosion of carbonate sands, seawater, and wind-blown dust (Cobb et al., 2003; Thompson et al., 2003). In fact, if the ^{232}Th concentrations are < 100 ppt, the impact of nonradiogenic ^{230}Th on the ^{230}Th dates may be negligible (Cobb et al., 2003). Even with ^{232}Th levels between 100 and 300 ppt, the correction for nonradiogenic ^{230}Th is still insignificant, resulting in only < 5 years difference between the corrected and uncorrected ^{230}Th dates (Zhao, Yu, & Feng, 2009). All coral dates in our study spanned A.D. 1513 to 1623, the Late Expansion period of Hawaiian prehistory (Weisler, 1989).

DISCUSSION

Analyzing cultural contents by stratigraphic layer lies at the cornerstone of archaeological method and interpretation. In our example of a coastal, sandy midden site, the stratigraphy appeared intact, yet dated coral samples throughout the three cultural layers did not have a linear age–depth correlation. Consequently, for this particular site, we advocate collapsing the three cultural layers into one analytical unit.

One need only walk along a sandy beach or coastal dune system to realize that human trampling can be a significant agent for displacing cultural materials. Add to this the excavation of postholes, refuse pits, combustion features, and burials by the ancient inhabitants and it is certain that layer contexts can be displaced up and/or down the profile—as our study has demonstrated. What is unusual here is that the stratigraphy appeared intact, with no evidence of mixing when the profiles were examined. The reason that displacement of materials throughout seemingly intact cultural layers is rarely identified in oceanic coastal middens is due, in part, to the routine selection of charcoal from combustion features for ^{14}C dating. While this is a time-honored practice, there is a higher probability that stratigraphically positioned intact combustion features (such as earth ovens and hearths) from different depths will exhibit a linear time–depth correlation. Nonlinear time–depth correlations are much more common when individual charred wood fragments from dispersed contexts and individual fish bones and shells are dated. It should also be noted that age reversals are more common during the last 300 years or so due to secular variations in the ^{14}C calibration curve. The fact that we dated individual items that were not part of intact features (like earth ovens), allowed us to chart their possible displacement between cultural layers. In our study site, stratigraphic mixing between layers displaced individual items that are more likely to move in sandy deposits due

Table I. Fifteen ^{230}Th-dated corals from site 50-60-02-2421.

Sample Code	Depth (cm)	^{232}Th (pg/g)	(^{230}Th/^{232}Th)	(^{230}Th/^{238}U)	(^{234}U/^{238}U)	Uncorrected ^{230}Th Age (A.D.)	Corrected Initial (^{234}U/^{238}U)	Corrected Age (A.D.)
K1-N25W5/6-A	39–50	72.52 ± 0.48	579	0.00457 ± 0.00003	1.1500 ± 0.0013	1575 ± 3	1.1502 ± 0.0013	1575 ± 3
K2-N25W5/6-B	39–50	267.02 ± 0.68	177	0.00476 ± 0.00003	1.1514 ± 0.0020	1558 ± 3	1.1516 ± 0.0020	1559 ± 3
K3-N25W6/4-A	28–42	55.25 ± 0.56	754	0.00419 ± 0.00003	1.1509 ± 0.0013	1612 ± 3	1.1511 ± 0.0013	1611 ± 3
K4-N25W6/5-A	39–50	70.19 ± 0.34	649	0.00465 ± 0.00003	1.1853 ± 0.0011	1581 ± 3	1.1856 ± 0.0011	1580 ± 3
K5-N26W6/5-A	40–45	97.48 ± 0.57	366	0.00452 ± 0.00004	1.1475 ± 0.0012	1579 ± 4	1.1477 ± 0.0012	1579 ± 4
K6-N26W6/5-B	40–45	127.17 ± 0.99	339	0.00451 ± 0.00004	1.1482 ± 0.0010	1580 ± 4	1.1483 ± 0.0010	1580 ± 4
K7-N26W6/5-C	40–45	67.34 ± 1.23	652	0.00442 ± 0.00003	1.1461 ± 0.0010	1587 ± 3	1.1462 ± 0.0010	1587 ± 3
K8-N26W6/5-D	40–45	74.42 ± 0.39	462	0.00459 ± 0.00004	1.1523 ± 0.0017	1575 ± 4	1.1525 ± 0.0017	1574 ± 4
K9-N26W6/5-E	40–45	58.86 ± 0.33	482	0.00412 ± 0.00004	1.1502 ± 0.0018	1617 ± 4	1.1504 ± 0.0018	1618 ± 4
K10-N26W6/6-1	50–61	175.12 ± 1.46	245	0.00518 ± 0.00003	1.1471 ± 0.0014	1516 ± 3	1.1473 ± 0.0014	1516 ± 3
K11-N26W6/6-A	50–61	66.88 ± 1.16	558	0.00444 ± 0.00003	1.1457 ± 0.0016	1585 ± 3	1.1459 ± 0.0016	1585 ± 3
K12-N26W6/6-B	50–61	33.42 ± 0.46	1204	0.00408 ± 0.00002	1.1502 ± 0.0014	1621 ± 2	1.1504 ± 0.0014	1621 ± 2
K13-N26W6/6-C	50–61	63.81 ± 0.59	547	0.00465 ± 0.00004	1.1465 ± 0.0022	1566 ± 4	1.1467 ± 0.0022	1566 ± 4
K14-N26W6/6-D	50–61	87.60 ± 0.56	407	0.00461 ± 0.00003	1.1495 ± 0.0022	1571 ± 3	1.1497 ± 0.0022	1571 ± 3
K15-N26W6/6-E	50–61	74.94 ± 0.27	463	0.00469 ± 0.00003	1.1463 ± 0.0019	1562 ± 3	1.1465 ± 0.0019	1562 ± 3

Note: All errors are quoted at 2σ. All ages are calculated by the Isoplot/Ex version 2 program. Uncorrected ^{230}Th ages are calculated assuming a detrital ^{232}Th/^{238}U ratio of 1.21. The corrected dates are calculated assuming nonradiogenic ^{230}Th by measuring ^{232}Th/^{229}Th.

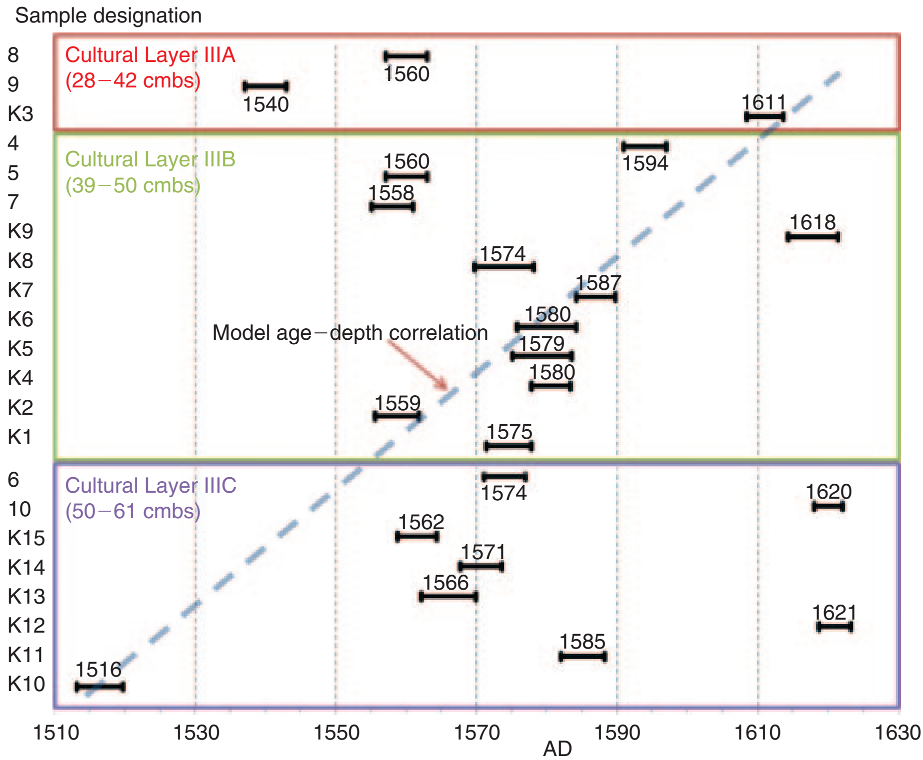

Figure 5. Illustration of ^{230}Th coral dates with 2σ error bars grouped by three discrete cultural layers. Samples KI to K15 are this study's results and 4–10 are from Weisler et al. (2006).

to their relatively small size, but the *intensity* of mixing was not sufficient to homogenize all sediment characteristics that are routinely used to describe layers. For example, the upper cultural layer (IIIA) was very dark gray brown (10YR3/2), layer IIIB was dark brown (7.5YR3/3), and the lowest cultural layer (IIIC) was reddish-yellow (7.5YR7/6). However, the texture, structure, consistency, plasticity, and density of roots and pores were similar across layers.

The density of unweathered corals throughout the cultural layers is consistent with their use as religious offerings. Dated branch coral samples from all three cultural layers of the Mo'omomi site document the chronology of site use and human-caused prehistoric disturbance processes throughout the cultural deposits. Some 22 ^{230}Th-dated branch coral samples bracket habitation activities between A.D. 1513 and 1623 for a 2 m × 3 m area of the site. Dense concentrations of shell and predominantly bones of fish relate to intensive use of the adjacent coastal zone. The nearby fine-grained rock source was used throughout this period for securing stone for adze manufacture. It is significant that this period of the Hawaiian chiefdom underwent rapid evolution in political, economic, and social organization (Hommon, 1986; Kirch & McCoy, 2007; Kolb, 2006; McCoy, 2005; Weisler, 1989). Environmental changes and ecosystem stress (Allen, 2006; Nunn, 2000) may have contributed to expansion into the dry leeward areas during late prehistory.

Three major phases of site use are suggested by coral dating, as shown in Figure 5. Phase I, the earliest occupation, ranges A.D. 1513–1543 and is represented by only two coral samples. Phase II is represented by 16 coral samples dated to A.D. 1555–1597, suggesting a period of more intensive site use. Phase III is represented by four coral samples and dates A.D. 1608–1623. No coral samples dated later than A.D. 1623, which suggests that this area of the site, at least, was abandoned by then, well before European contact in A.D. 1778.

The cultural deposits contain clear stratigraphic breaks when observed in the field (Figure 3); however, there is no linear age–depth correlation for the 22 coral dates. In fact, the oldest and youngest samples are from the lowest cultural layer. Coral dates from these layers suggest relatively rapid accumulation of dense cultural deposits over approximately one century. Numerous postholes suggest that stratigraphic mixing has changed the original locations of artifacts and middens. Interestingly, the excavation of features not only moved the older artifacts up but the younger ones down. Our dated samples document two corals that moved upward from the lowest cultural layer. In contrast, 8 out of 22 samples moved downward.

The stratigraphic distribution of artifacts is not random but controlled by facies changes and episodic accumulation (Holz & Simoes, 2004) and, in the example here, human activities over the course of occupation. During site occupation, relative sea level at Moloka'i was stable (Calhoun & Fletcher, 1996; Clague & Moore, 2002; Nunn, 1994). Although the surrounding ground surface has undergone significant soil erosion, site 50-60-02-2421 at Mo'omomi is well preserved. Its elevation is a few meters above current sea level, with no evidence of marine flooding. In 1946, Halawa Valley, on the east end of the island, experienced a large tsunami. Some locations on the northern, eastern, and western sides of the island were flooded (Kirch & McCoy, 2007; Walker, 2004), including Mo'omomi (Keating, Whelan, & Bailey-Brock, 2004), but at the site, erosional features associated with the tsunami are absent.

CONCLUSIONS

Our results document a narrow time span of occupancy that is important for understanding the short, $<$ 900-year-old cultural sequence of Hawaii. Based on high-precision ^{230}Th dating of corals from a mixed stratigraphic context, we conclude that even though site 50-60-02-2421 contains discrete stratigraphic layers clearly visible in section profile, dating suggests stratigraphic mixing of cultural contents. Hence, macrostratigraphic indications of minimal mixing and well-preserved site integrity when viewed in profile may be misleading. Our investigation indicates that this leeward coastal site was first occupied in ~A.D. 1513, the beginning of the Late Expansion Period, followed by intensive use during A.D. 1555–1597. The site area, reported here, was abandoned by ~A.D. 1623.

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REFERENCES

Allen, M.S. (2006). New ideas about Late Holocene climate variability in the central Pacific. Current Anthropology, 47, 521–535.

Athens, J.S., & Ward, V.J. (1993). Environmental change and prehistoric Polynesian settlement in Hawaii. Asian Perspectives, 32, 205–223.

Calhoun, R.S., & Fletcher, C.H., III. (1996). Late Holocene coastal plain stratigraphy and sea-level history at Hanalei, Kauai, Hawaiian Islands. Quaternary Research, 45, 47–58.

Carson, M.T. (2004). Resolving the enigma of early coastal settlement in the Hawaiian Islands: The stratigraphic sequence of the Wainiha Beach Site in Kaua'i. Geoarchaeology, 19, 99–118.

Carson, M.T. (2006). Chronology in Kaua'i: Colonisation, land use, demography. Journal of the Polynesian Society, 115, 173–185.

Clague, D.A., & Moore, J.G. (2002). The proximal part of the giant submarine Wailau landslide, Molokai, Hawaii. Journal of Volcanology and Geothermal Research, 113, 259–287.

Cobb, K.M., Charles, C.D., Cheng, H., Kastner, M., & Edwards, R.L. (2003). U/Th-dating living and young fossil corals from the central tropical Pacific. Earth and Planetary Science Letters, 210, 91–103.

Cochran, S.A., Roberts, L.M., & Evans, K.R. (2002). Moloka'i fieldtrip guidebook. U.S. Department of the Interior, Geological Survey.

Cooke, G.P. (1949). Moolelo O Molokai a ranch story of Molokai. Honolulu Star-Bulletin, 106.

Dye, T. (1994). Population trends in Hawai'i before 1778. Hawaiian Journal of History, 28, 1–20.

Dye, T. (2000). Effects of ^{14}C sample selection in archaeology: An example from Hawai'i. Radiocarbon, 42, 203–217.

Dye, T., & Komori, E. (1992). A pre-censal population history of Hawai'i. New Zealand Journal of Archaeology, 14, 113–128.

Engels, M.S., Fletcher, C.H., Field, M.E., Storlazzi, C.D., Grossman, E.E., Rooney, J.J.B., et al. (2004). Holocene reef accretion: Southwest Molokai, Hawaii, USA. Journal of Sedimentary Research, 74, 255–269.

Grave, P., & Kealhofer, L. (1999). Assessing bioturbation in archaeological sediments using soil morphology and phytolith analysis. Journal of Archaeological Science, 26, 1239–1248.

Green, R.C. (1960). Preliminary report for the American Museum of Natural History on archaeological research in the Gambier Isles (Mangareva) July 2, 1959 to December 6, 1959. Report on file.

Hartshorn, A.S., Chadwick, O.A., Vitousek, P.M., & Kirch, P.V. (2006). Prehistoric agricultural depletion of soil nutrients in Hawai'i. Proceedings of the National Academy of Sciences of the United States of America, 103, 11092–11097.

Hatanaka, S., & Shibata, N. (1982). REAO Report: A study of the Polynesian migration to the Eastern Tuamotus. Japan: University of Kanazawa.

Holz, M., & Simoes, M.G. (2004). Taphonomy: Overview of main concepts and applications to sequence stratigraphic analysis. Applied Stratigraphy, 249–278.

Hommon, R.J. (1986). Social evolution in ancient Hawaii. In P.V. Kirch (Ed.), Island societies: Archaeological approaches to evolution and transformation (pp. 55–68). Cambridge, UK: Cambridge University Press.

Hunt, T., & Holson, R. (1991). An early radiocarbon chronology for the Hawaiian Islands. Asian Perspectives, 30, 147–161.

Keating, B., Whelan, F., & Bailey-Brock, J. (2004). Tsunami deposits at Queen's Beach, Oahu, Hawaii: Initial results and wave modelling. International Journal of the Tsunami Society, 22, 23–44.

Kirch, P.V. (1971). Halawa dune site (Hawaiian Islands): Preliminary report. Journal of the Polynesian Society, 80, 228–236.

Kirch, P.V. (1994). The wet and the dry: Irrigation and agricultural intensification in Polynesia. Chicago, IL: University of Chicago Press.

Kirch, P.V., & Kelly, M. (1975). Prehistory and ecology in a windward Hawaiian valley: Halawa Valley, Molokai. Honolulu: Department of Anthropology, Bernice Pauahi Bishop Museum.

Kirch, P.V., & McCoy, M.D. (2007). Reconfiguring the Hawaiian cultural sequence: Results of re-dating the HÄLAWA dune site (MO-A1-3), Moloka'i Island. Journal of the Polynesian Society, 116, 385–406.

Kirch, P.V., & Sharp, W.D. (2005). Coral Th-230 dating of the imposition of a ritual control hierarchy in precontact Hawaii. Science, 307, 102–104.

Kirch, P.V., Flenley, J.R., & Steadman, D.W. (1991). A radiocarbon chronology for human-induced environmental change on Mangaia, Southern Cook Islands, Polynesia. Radiocarbon, 33, 317–328.

Kolb, M.J. (2006). The origins of monumental architecture in ancient Hawaii. Current Anthropology, 47, 657–665.

Leach, H.M. (1999). Intensification in the Pacific: A critique of the archaeological criteria and their application. Current Anthropology, 40, 311–339.

Ludwig, K.R. (1999). Users manual for Isoplot/Ex version 2: A geochronological toolkit for Microsoft Excel. Berkeley, CA: Berkeley Geochronology Center Special Publications.

Ludwig, K.R., Simmons, K.R., Szabo, B.J., Winograd, I.J., Landwehr, J.M., Riggs, A.C., & Hoffman, R.J. (1992). Mass-spectrometric ^{230}Th-^{234}U-^{238}U dating of the Devils Hole calcite vein. Science, 258, 284–287.

McCoy, M.D. (2005). The development of the Kalaupapa field system, Moloka'i Island, Hawai'i. Journal of the Polynesian Society, 116, 339–358.

McCoy, M.D. (2007). A revised late Holocene culture history for Moloka'i Island, Hawai'i Radiocarbon, 49, 1273–1322.

McCoy, M.D., & Hartshorn, A.S. (2007). Wind erosion and intensive prehistoric agriculture: A case study from the Kalaupapa field system, Moloka'i Island, Hawai'i. Geoarchaeology, 22, 511–532.

McCoy, P., Weisler, M., Zhao, J., & Feng, Y. (2009). ^{230}Th dates for dedicatory corals from a remote alpine desert adze quarry on Mauna Kea, Hawai'i. Antiquity, 83, 445–457.

McMurtry, G.M., Watts, P., Fryer, G.J., Smith, J.R., & Imamura, F. (2004). Giant landslides, mega-tsunamis, and paleo–sea level in the Hawaiian Islands. Marine Geology, 203, 219–233.

Moore, A.L. (2000). Landward fining in onshore gravel as evidence for a late Pleistocene tsunami on Molokai, Hawaii. Geology, 28, 247–250.

Nunn, P.D. (1994). Oceanic Islands. Oxford: Blackwell.

Nunn, P.D. (2000). Environmental catastrophe in the Pacific Islands around A.D. 1300. Geoarchaeology, 15, 715–740.

Pearson, R., Kirch, P.V., & Pietrusewsky, M. (1971). An early prehistoric site at Bellows Beach, Waimanalo, Oahu, Hawaiian Islands. Archaeology and Physical Anthropology in Oceania, 6, 204–234.

Rooney, J., Fletcher, C., Grossman, E., Engels, M., & Field, M. (2004). El Niño influence on Holocene reef accretion in Hawai'i. Pacific Science, 58, 305–324.

Rosendahl, D., Ulm, S., & Weisler, M.I. (2007). Using foraminifera to distinguish between natural and cultural shell deposits in coastal eastern Australia. Journal of Archaeological Science, 34, 1584–1593.

Rubin, K.H., Fletcher, C.H., & Sherman, C. (2000). Fossiliferous Lana'i deposits formed by multiple events rather than a single giant tsunami. Nature, 408, 675–681.

Somers, G.F. (1991). The effects of rapid geological change on archaeology in Hawaii. Asian Perspectives, 30, 133–146.

Summers, C.C. (1971). Molokai: A site survey. Pacific Anthropological Records 14. Honolulu: Department of Anthropology, Bernice Pauahi Bishop Museum.

Thompson, W.G., Spiegelman, M.W., Goldstein, S.L., & Speed, R.C. (2003). An open-system model for U-series age determinations of fossil corals. Earth and Planetary Science Letters, 210, 365–381.

Tuggle, H.D., & Spriggs, M. (2000). The age of the Bellows dune site O18, O'ahu, Hawai'i, and the antiquity of Hawaiian colonization. Asian Perspectives, 39, 165–188.

Vitousek, P.M., Ladefoged, T.N., Kirch, P.V., Hartshorn, A.S., Graves, M.W., Hotchkiss, S.C., et al. (2004). Soils, agriculture, and society in precontact Hawaii. Science, 304, 1665–1669.

Walker, D.A. (2004). Regional tsunami evacuations for the State of Hawaii: A feasiblility study based on historical run-up data. Science of Tsunami Hazards, 22, 3–22.

Waters, M.R. (1992). Principles of geoarchaeology: A North American perspective. Tucson: University of Arizona Press.
Weisler, M.I. (1982). The archaeological resources of Kawela, Moloka'i: Their nature, significance, and management. Honolulu: Department of Anthropology, Bernice Pauahi Bishop Museum.
Weisler, M.I. (1989). Chronometric dating and late Holocene prehistory in the Hawaiian Islands: A critical review of radiocarbon dates from Moloka'i Island. Radiocarbon, 31, 121–145.
Weisler, M.I., & Clague, D.A. (1998). Characterization of archaeological volcanic glass from Oceania: The utility of three techniques. In M.S. Shackley (Ed.), Archaeological obsidian studies: Method and theory (pp. 103–128). New York: Plenum Press.
Weisler, M.I., Collerson, K.D., Feng, Y.X., Zhao, J.X., & Yu, K.F. (2006). Thorium-230 coral chronology of a late prehistoric Hawaiian chiefdom. Journal of Archaeological Science, 33, 273–282.
Weisler, M.I., & Kirch, P.V. (1985). Structure of settlement space in a Polynesian chiefdom: Kawela, Molokai, Hawaiian Islands. New Zealand Journal of Archaeology, 7, 129–158.
Weisler, M.I., & Murakami, G.M. (1991). The use of mountain-apple (Syzygium malaccense) in a prehistoric Hawaiian domestic structure. Economic Botany, 45, 282–285.
Weisler, M.I., Hua, Q., & Zhao, J.X. (2009). Late Holocene ^{14}C marine reservoir corrections for Hawai'i derived from U-series dated archaeological corals. Radiocarbon, 51, 955–968.
Wood, W., & Johnson, D. (1978). A survey of disturbance processes in archaeological site formation. Advances in Archaeological Method and Theory, 1, 315–381.
Yu, K.F., Zhao, J.X., Shi, Q., Chen, T.G., Wang, P.X., Collerson, K.D. (2006). U-series dating of dead Porites corals in the South China Sea: Evidence for episodic coral mortality over the past two centuries. Quaternary Geochronology, 1, 129–141.
Zhao, J.X., Hu, K., Collerson, K.D., & Xu, H.K. (2001). Thermal ionization mass spectrometry U-series dating of a hominid site near Nanjing, China. Geology, 29, 27–30.
Zhao, J.X., Yu, K.F., & Feng, Y.X. (2009). High-precision ^{238}U-^{234}U-^{230}Th disequilibrium dating of the recent past: A review. Quaternary Geochronology, 4, 423–433.

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