^{230}Th dates for dedicatory corals from a remote alpine desert adze quarry on Mauna Kea, Hawai'i

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The authors show how sites in upland Hawai'i may be dated using uranium series radiogenic measurements on coral. The sites lie in a quarry, inland and at high altitude, with little carboniferous material around, and radiocarbon dating is anyway problematic here for the first millennium. Freshly broken coral had been transported to these sites, remote from the sea – no doubt for ritual purposes. Giving a date in the fifteenth century with an error range of only five years, the method promises to be valuable for the early history of the Pacific.

Keywords: Pacific, Hawai'i, uranium, thorium dating, coral, ritual

Method

Introduction

High precision dates for archaeological sites and major events in Hawaiian prehistory using ^{230}Th dating of well-preserved branch coral (*Pocillopora* spp.) have been obtained in recent studies (Kirch & Sharp 2005; Weisler *et al.* 2006). ^{230}Th dating holds the potential to revolutionise models of lowland settlement patterns and socio-political change given the common occurrence of branch coral in coastal sites, where it is interpreted as a religious offering based on ethnographic analogy (Handy 1927; Malo 1951). Because the radiocarbon calibration curve for late Hawaiian prehistory (about AD 1500-1778) is problematic with wide fluctuations often rendering large age spans that do not precisely date single events (Weisler *et al.* 2006: 273), ^{230}Th dating, with typical 2 sd errors of <5 years, offers new insights into defining significant events in Hawaiian prehistory. How applicable ^{230}Th dating will be in developing refined chronologies for sites located above the limits of agriculture and permanent settlement remains to be seen, but branch coral has been recovered in extremely remote areas. The epitome of long-distance transport of ritual offerings in Hawai'i is the Mauna Kea Adze Quarry Complex, on the island of Hawai'i (Figure 1), where various kinds of offerings, including branch coral, have been found at ~3750m elevation and more than 45km from the sea. The Mauna Adze Quarry Complex is the largest Neolithic quarry in

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the Pacific and the long-term use and intensity of adze manufacture is thought to mirror significant changes in Hawaiian socio-political organisation, including the development of craft specialisation. This paper presents the first dates for this remote, high elevation quarry using the ^{230}Th dating technique.

Background: the Mauna Kea Adze Quarry Complex and its context

The Mauna Kea Adze Quarry Complex, which was placed on the National Register of Historic Places as a National Historic Landmark in 1962, is one of the most remote archaeological site complexes in Hawai'i. The nearest permanent settlements in the pre-contact era (pre-1778) were ~45km distant, as 'the crow flies,' on the windward side of the island. The actual distance would, of course, have been even greater, in the ascent to the main quarry area, which is located near the 3750m elevation on the south flank of the mountain not far below the 4206m-high summit. Some discrete quarry areas are located in a sub-alpine forest, but most of the quarry complex is in a stony alpine desert, which has been characterised as a 'non-subsistence' environment because of the degree of biotic impoverishment and lack of food and fuel for fires (McCoy 1990).

Archaeological investigations of the Mauna Kea Adze Quarry Complex, in 1975-76 (McCoy 1977, 1990; McCoy & Gould 1977), indicate that it covers more area and contains a larger volume of debitage than all of the other known basalt adze quarries in the Hawaiian Islands combined. The structure of the Mauna Kea quarry 'industry' was inferentially more complex than any of the other quarries, based on the number and variety of activity remains. Recent investigations in the Pohakuloa Gulch area of the quarry indicate a number well in excess of the 264 workshops and 1566 individual chipping stations, 50 rockshelters, 200 open-air enclosures and 45 shrines, several panels of petroglyphs and pictographs and a local source of low-grade volcanic glass described in an earlier report (McCoy 1990: 96-7).

A suite of 23 radiocarbon dates from eight excavated sites indicate that the quarry 'industry' spanned a period of approximately 700 years, between *c*. AD 1100-1800 (McCoy 1990: 92-3), although a shorter chronology now seems more likely based on recently obtained radiocarbon age-determinations for the settlement of the Hawaiian Islands. On current evidence, the period of peak production was *c*. AD 1400-1750. When the quarry was abandoned is unknown and may never be known with any certainty, but there is some evidence that it may have occurred prior to European contact in 1778 or shortly thereafter. Historic accounts indicate the rapid adoption of Western tools, clothing and other items in the major trading centres, initially by the chiefs and then the common people. By 1793-94, the chiefs in some areas were apparently no longer interested in trading for iron tools, such as adzes, because of a surplus of metal (Sahlins 1985: 44; McCoy 1990: 93). That some people, including canoe-making craft specialists, continued to use stone adzes for selected tasks into the historic period is well documented (Brigham 1902: 409-10; Bayman 2003). Remote quarries, such as the complex on Mauna Kea, may have been the first to be abandoned, although the manufacture of a small number of adze blades may have continued for a while given what is assumed to have been the high value of the adzes from this particular quarry (McCoy 1990: 96).

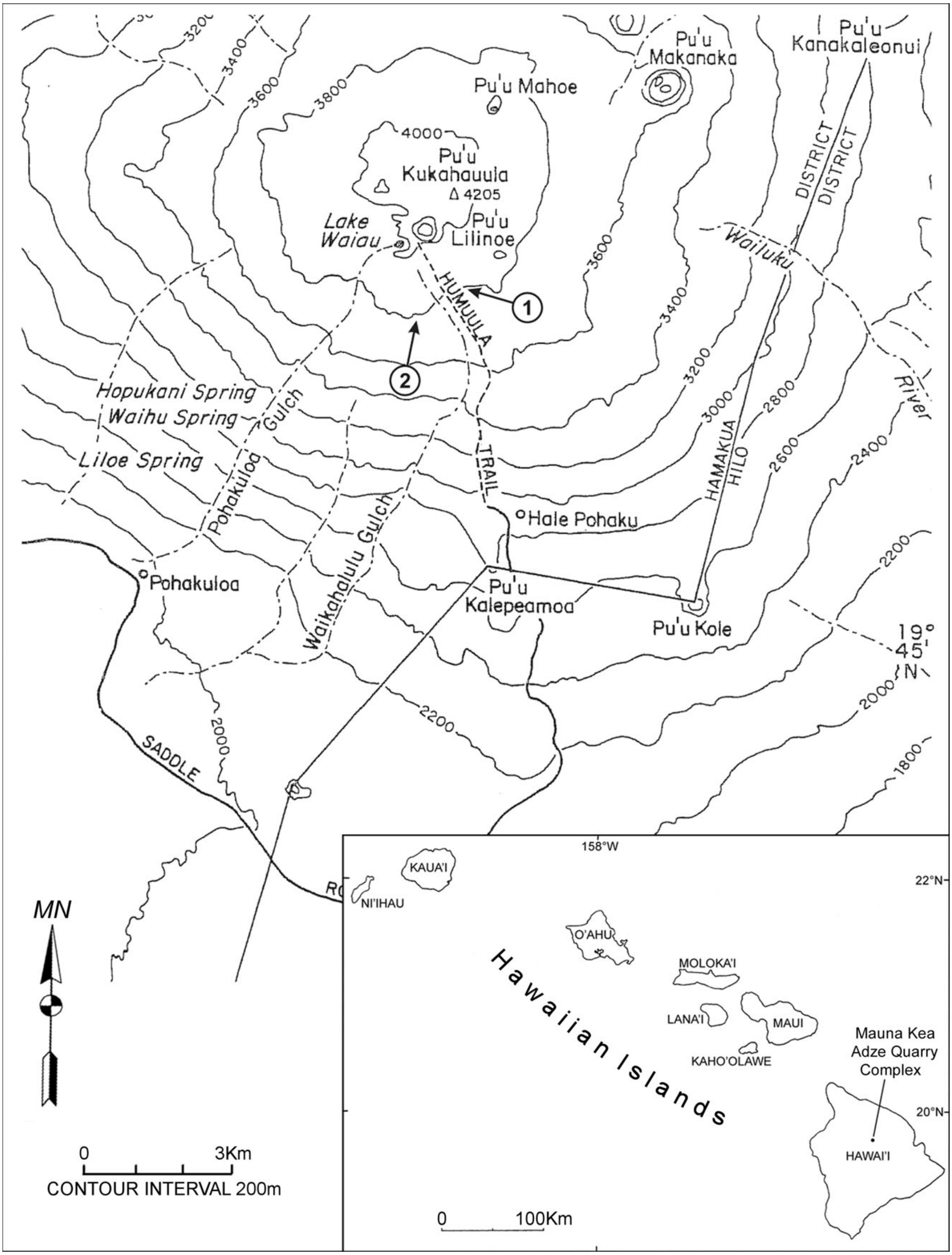

Figure 1. The Hawaiian Archipelago, Hawai'i Island, the Mauna Kea Adze Quarry Complex and the location of the two coral samples dated in this study: 1) the Keanakako'i rockshelter; 2) the shrine.

Method

The Mauna Kea Adze Quarry Complex has assumed a special place in an ongoing dialogue regarding markers of craft specialisation and its antiquity in Hawaiian prehistory. Until recently craft specialisation in the context of adze manufacture has been for the most part assumed rather than demonstrated through the analysis of archaeological data. One probable reason for this is the oft-cited statement by the Hawaiian historian, David Malo, that *'Ax-makers were a greatly esteemed class in Hawaii nei'* (Malo 1951: 51).

Following on the 1975-76 research project there have been efforts to identify craft specialisation in the quarry based on: (1) the scale of production (McCoy 1977, 1981, 1990); (2) standardisation of adze forms (Cleghorn 1982; Kirch 1990); (3) standardisation of manufacturing techniques and indications of apprenticeship based on measures of differential skill (Cleghorn 1982, 1986); and (4) the degree of ritual investment in the manufacturing process (McCoy 1977, 1981, 1990, 1991).

McCoy (1990: 100-101) has criticised the normative view linking craft specialisation to standardisation. He has challenged the conclusions of Cleghorn and others (e.g. Arnold 1987; Kirch 1990) who use standardisation of tool form and manufacturing procedures as unambiguous signatures of craft specialisation. While quadrangular cross-section adze blades are the most common 'type' in the quarry and in collections of finished adzes (Emory 1968: 162-4; Kirch 1990), there is also evidence for a multiplicity of reduction strategies and tool forms throughout the history of the quarry complex (McCoy 1990: 101) and, indeed, at other Hawaiian quarries as well (Dye *et al.* 1985; Weisler 1990: 35–6). Some of the diversity of adze forms in the Mauna Kea Adze Quarry Complex and other Hawaiian adze quarries (e.g. Dye *et al.* 1985; Weisler 1990; McCoy *et al.* 1993) is related to variability in raw material properties. Mauna Kea is unlike any other Hawaiian adze quarry in the presence of massive bedrock exposures, unconsolidated glacial drift deposits containing rounded cobbles and boulders, and an abundance of thick tabular slabs of minimally weathered basalt resting on the surface. Indeed, the thick tabular slabs facilitate the manufacture of quadrangular-sectioned adze blades and probably contribute to the predominance of these types in the complex. Smaller, more diverse adze forms are found more commonly in the glacial drift deposits.

Lass, who agrees with McCoy that standardisation of Hawaiian adze forms is a problematical marker of craft specialisation (Lass 1998: 25), has challenged his view that the adze makers on Mauna Kea were 'attached specialists' rather than 'independent specialists' as defined by Brumfiel and Earle (1987: 5-6). Lass believes that the quarry complex was used on an occasional basis by 'independent specialists', defined by her as specialists that were neither sponsored nor supported by chiefs (Lass 1998: 47). Bayman and Moniz (2001) are in agreement with McCoy regarding a high degree of specialisation and elite sponsorship.

Though space does not allow a full discussion of all the arguments for the involvement of chiefs in the Mauna Kea Adze Quarry Complex production system, including a site at Pu'u Kalepeamoa (see Figure 1; McCoy 1991), some of the evidence includes the presence of rarely found faunal remains recovered in the excavations of selected rockshelters. The remains, all of which are interpreted as ritual offerings, include: (1) the bones of immature dark-rumped petrels (cf. *Pterodroma phaeopygia sandwichensis*) that according to ethnographic information were considered a great delicacy and were tabooed for the exclusive use of the chiefs (Henshaw 1902: 120); (2) bones of the threadfin fish (*Polydactylus sexfilis*), also reserved for chiefs (Goto 1986: 422); and (3) a small number of cranial fragments of immature dogs and pigs that are said to have been the share of chiefs (Titcomb 1969: 14, 18) and were used in sacrifices as mediators between men and gods (Valeri 1985: 119).

In addition to the faunal evidence just described, there is stratigraphic evidence of 'ritual fill' deposits in the rockshelters. These have been interpreted, following the late Mary Douglas (1966: 160, 1975: xv), as the result of deliberative actions intended to remove from view the accumulated residues of meals and offerings to the gods that are polluting and thus dangerous to man in a sacred context (McCoy 1990: 103). Evidence of a sacred context exists, for example, in the Hawaiian name of the region in which the quarry complex is located (*wao akua* which translates as 'wilderness of the gods', Malo 1951: 18, footnote 6), and at the Pu'u Kalepeamoa site, a treeline campsite occupied by adze makers on the ascent to and descent from the quarry complex (McCoy 1991). This transitional site contains evidence suggesting that it was the locus of rites of passage involving a change in social status from *noa* to *kapu*, Hawaiian terms that are commonly but, according to Shore (1989), not adequately glossed as sacred and profane. According to him *kapu* and *noa* represent the relations possible between the divine and the human, with *kapu* being '*a state of contact with the divine*' and *noa*, '*an unbounded state of separation from the divine*' (Shore 1989: 164-5). Located on the margins of the quarry complex, at a higher elevation, is a site complex consisting of a group of ridgetop shrines with upright stones called *'eho* (god-stones), two clusters of small rock outlines below the shrines, and a diffuse scatter of flakes, unfinished adze blades and hammerstones associated with the shrines and the rock outlines. The site, which is quite unlike any other found in the quarry, has been interpreted as a place where the initiation of apprentice adze makers may have taken place (McCoy 1999).

Context of the dated samples

In addition to having been the locus of adze blade manufacture over hundreds of years, the summit region of Mauna Kea was used as a burial ground for persons of presumably high rank and other ritual activities. Of the nearly 250 sites within the complex that have been recorded in surveys around the top of the mountain, from the 4206m summit down to the *c*. 3600m elevation, branch coral has been found on only a couple of sites, all of them in the quarry complex. The two samples submitted for dating are from surface contexts at two different localities.

Sample 1: Keanakako'i rockshelter

Sample 1 is from Keanakako'i (literally 'cave of the adze'), a habitation rockshelter (Bishop Museum site no. 50-Ha-G28-2-R6; State of Hawai'i site no. 50-10-23-16205) with a large mound of debitage in front of the entrance at the *c*. 3780m elevation. The name, which appears in several historic accounts (Alexander 1892; Arning 1931) and on the United States Geological Survey map of Mauna Kea, is widely assumed by many to have been the traditional name of the quarry complex, although a similar name, Kaluako'i, also appears

Figure 2. Looking west at the lower and middle section of the massive debitage pile at Keanakako'i ('cave of the adze'). The single piece of coral was found at the top of the mound on the surface.

in the literature. Keanakako'i is well known because of its location on a modern section of the Humu'ula Trail.

Keanakako'i is an example of a base camp, defined by the presence of a living area, workshop area, and 'roof-top' shrines (McCoy 1990) located above the rockshelter opening. The openings are walled, except for a narrow crawl-way. Keanakako'i is interesting for several reasons, not least is that there is no local source of tool-quality basalt in the immediate area. It is further removed from a raw material source than any other major camp. There are no radiocarbon dates for this camp, which has not been excavated. The size of the associated debitage pile, which is some 18-20m across and ~7m high in the middle (Figure 2), indicates an extended period of use, thus suggesting that this particular natural shelter was selected as a base camp because of its isolation from other workshops and camps. The extent to which separation may imply 'sacredness' and high rank seems especially clear in this case because of the presence of the rooftop shrine and the fact that this is the place from which a 'curious idol' was collected in 1862, together with *'Bones of pigs and dogs, kapa, pieces of coconut shells, fragments of hewn wood implements, sea shells, and many other curiosities'* (Pacific Commercial Advertiser, 23 October 1862: 2; see also Alexander 1892). Eduard Arning, a German who visited Keanakako'i in the 1880s, published a photograph of the site, which he described as containing broken calabashes, small pieces of tapa (barkcloth), 'awa root and 'opihi (limpet) shells (Arning 1931).

Figure 3. View east towards the historically 'restored' shrine at the c. *3675m elevation showing the approximate location of the coral offering.*

The single piece of branch coral was collected from the surface of the debitage mound near the opening to the rockshelter during the 1975-76 research project. Although in a secondary position, it probably came from what appears to be the remains of a small shrine located directly above the rockshelter entrance. Here there is a pavement-like surface covered with adze manufacturing by-products that have been interpreted as offerings to the tutelary gods of adze manufacture wherever they are found in the quarry. Below the pavement there are a couple of stone slabs that appear to be fallen uprights.

Sample 2: shrine

The second sample, which has a secure provenance, is from a shrine (Bishop Museum Site No. 50-Ha-G28-3-S1; State Site No. 50-10-23-16206) located at the *c*. 3675m elevation, approximately 500m south of Keanakakoʻi. The shrine is located on a flat outcrop down slope of a massive escarpment that was the locus of intensive quarrying and manufacture and from all indications the 'central place' in the quarry (Figure 3). Though it is visible and within easy walking distance of the large site on the edge of the escarpment, it is one of the most isolated shrines in the quarry complex in terms of its physical separation from major workshops. The degree of separation is similar to that of Keanakakoʻi.

The shrine, which consists of three adjoining rows of uprights, has a U-shaped ground plan. The maximum dimensions of the semi-enclosed space are 6 × 4m. It is the largest shrine in the quarry complex in terms of the number of uprights. When it was mapped in 1975 there were 27 uprights – 21 in an erect or semi-erect position and 6 fallen or horizontal (see photo in McCoy & Gould 1977). The structure was 'restored' by some unknown group in the early 1980s (Figure 3). One of the uprights is offset from the main row of uprights. Its location, which is the same as that of backrests on the courts of Eastern Polynesian religious structures, demonstrates a cultural link to areas outside of Hawai'i. On the interior (landward) side of the uprights is a crude stone pavement on which were found 941 artefacts, excluding the single piece of branch coral. The artefacts, which were collected in 1975 after detailed mapping of their exact location, include 28 cores, 689 flakes, 220 adze blades in various stages of completion and 4 hammerstones. This is one of the largest shrine artefact assemblages in the quarry complex (McCoy 1981). In some places the artefacts were several courses thick. The piece of branch coral (Figure 4) was found below the artefacts, between two uprights in the main alignment. The coral represents a different kind of offering than the artefacts, which are interpreted as gestures of respect to the tutelary gods of adze making (McCoy 1999).

Figure 4. Coral sample 2 (shrine, site no. 50-Ha-G28-3-S1) illustrating the fine sculptural details of this well-preserved branch coral.

^{230}Th dating methods and results

Similar to radiocarbon dating, ^{230}Th dating, which is often referred to as the U-series dating method, is based on the ratios of isotopes controlled by radioactive decay of a parent isotope; in this case, the decay of ^{238}U through ^{234}U to ^{230}Th. Specifically, this dating method is based on the decay of ^{238}U (with a half life $\tau_{1/2} = 4.469 \times 10^9$ years) to stable ^{206}Pb via intermediate daughters such as ^{234}U ($\tau_{1/2} \sim 245\,000$ years) and ^{230}Th ($\tau_{1/2} \sim 75\,400$ 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. For instance, when coral forms, uranium atoms in seawater are absorbed into the carbonate skeleton of the living coral but Th is excluded, resulting in ^{238}U-^{234}U-^{230}Th disequilibrium in the coral carbonate. Once disequilibrium is established, it takes about seven times the half life of ^{230}Th ($\sim$500 000 years) for the system to regain secular equilibrium (that is, 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 thermal ionisation mass spectrometry (TIMS) or multi-collector inductively-coupled plasma mass spectrometry (MC-ICPMS). Determining the

$^{230}Th/^{238}U$ and $^{234}U/^{238}U$ ratios thus allows us to obtain a precise calendar date reckoned from the time of measurement. The exact details of sample preparation, dating protocols and calibration can be found in Weisler *et al.* (2006: 276-7) and references therein. The two dated samples were extremely fresh, sharp to the touch, with well-preserved fine sculptural details suggesting that the corals were collected live from the reef. There is no taphonomic evidence, such as water rounding, to suggest that these samples were collected from the beach, in secondary contexts, with unknown inbuilt age. Only the growing tips (or terminal fingers) were selected for dating thus insuring the precise time when the coral was taken live from the reef.

The two dated samples have U in the 2–3ppm range, and initial ^{234}U of 148 and 150, similar to modern pristine corals. All carbonate samples contain a small amount of non-radiogenic ^{230}Th, i.e. pre-existing ^{230}Th at the time of coral formation, which is unrelated to radioactive decay of ^{238}U in the coral. The contribution of non-radiogenic ^{230}Th toward the age must be removed in order to obtain the accurate age of the coral. To correct for non-radiogenic ^{230}Th contribution, knowledge of the $^{230}Th/^{232}Th$ ratio in the non-radiogenic component is needed. This ratio varies depending on the sources of this component. Sample 2 (shrine) is of high purity, containing only 0.08ppb ^{232}Th, suggesting the level of non-radiogenic ^{230}Th (pre-existing ^{230}Th at the time of coral formation) is extremely low. Because of this, the non-radiogenic ^{230}Th contribution to the age is negligible. As can be seen in Table 1, the choice of two different assumptions for the non-radiogenic $^{230}Th/^{232}Th$ ratio only makes up to a 2-year difference (AD 1439$\pm$3 to 1441$\pm$3). In contrast, sample 1 (Keanakako'i) contains 2.5ppb ^{232}Th, $\sim$30 times higher than sample 2. Consequently, the correction for non-radiogenic ^{230}Th has a significant impact on the corrected age and its 2 sd uncertainty (see Table 1). The choice of correction schemes depends on the source of the non-radiogenic Th. If the non-radiogenic Th was derived by contamination from the surrounding non-carbonate sediment or particulates (e.g. aeolian dust and volcanic ash) in seawater, then the first correction scheme is more realistic, which returns a corrected ^{230}Th age of AD 1398$\pm$13. If the non-radiogenic Th was derived from soluble Th in seawater, the second one, which involves the use of measured $^{230}Th/^{232}Th$ ratio in a live coral of known age in the area (Kirch & Sharp 2005), is probably more realistic. This correction scheme results in a corrected age of AD 1451$\pm$39, which is analytically indistinguishable from the age of sample 2 (AD 1441$\pm$3). According to Weisler *et al.* (2006) and Kirch and Sharp (2005), all other dated corals in Hawai'i contain <0.6ppb ^{232}Th, with most <0.2ppb. Thus, it is more likely that the high level of ^{232}Th (2.5ppb) in this coral was related to the incorporation of non-carbonate sediments at the sample site or aeolian dust/particulates within the seawater during coral growth, and thus the corrected ^{230}Th age of AD 1398$\pm$13 is more realistic.

Discussion

The two dates, which are the first for any of the more than 200 known shrines in the adze quarry complex and the summit region of Mauna Kea, are somewhat earlier than what had been anticipated, although they fall comfortably within the existing quarry complex

Table 1. U-Th isotope data and ages for branch coral samples.

Sample number	Sample name	U (ppm)	^{232}Th (ppb)	(^{230}Th/ ^{232}Th)	(^{234}U/ ^{238}U)	(^{230}Th/ ^{238}U)	uncorr. ^{230}Th Age (AD)	corr. ^{230}Th Age-I (AD)	corr. ^{230}Th Age-II (AD)	Initial δ^{234}U
1	Keanakako'i	2.534 ± 0.002	2.54 ± 0.01	20.2	1.1463 ± 0.0011	0.00667 ± 0.00004	1372 ± 4	1398 ± 13	1451 ± 39	148 ± 1
2	Shrine	2.932 ± 0.003	0.0787 ± 0.0002	675.5	1.1480 ± 0.0017	0.00598 ± 0.00003	1439 ± 3	1440 ± 03	1441 ± 03	150 ± 2

Note: Errors are quoted at 2 sd. Ratios in parentheses refer to activity ratios, calculated using decay constants from Cheng *et al.* (2000). All ages were calculated using Isoplot EX 2.3 program of Ludwig (1999). Uncorrected age was calculated assuming no non-radiogenic ^{230}Th, whereas corrected age I and II, assuming $^{230}Th_{nr}/^{232}Th$ atomic ratio of $4.4 \pm 2.2 \times 10^{-6}$ (bulk-earth value), and $1.4 \pm 0.7 \times 10^{-5}$ (determined from a modern coral at Kahikinui [Kirch & Sharp 2005]). See Weisler *et al.* (2006) for detailed analytical procedures.

chronology, which until now has been based on radiocarbon dates alone. Radiocarbon age-determinations for two rockshelters at the ~3700m elevation and another rockshelter at ~3100m, indicate the possibility of adze manufacture in this remote, high altitude quarry as early as AD 1100-1200 (McCoy 1990). The AD 1398±13 date for Keanakakoʻi may be from a small shrine located above the rockshelter entrance. Based on the assumption that the shrine was constructed at the time the shelter was first occupied, this sample also dates the initial development of the associated large debitage mound. The size, depth and volume of debitage in the mound have all of the hallmarks of having been produced by high ranking craft specialists.

The AD 1441±3 date for the shrine, which was probably used by generations of adze makers based on the size of the artefact assemblage, is most likely associated with its initial construction and dedication. This is based on the provenance of the coral, which was found beneath the large assemblage of adze manufacturing by-products that are assumed to have accumulated over hundreds of years but which, in any event, clearly post-date the construction of the shrine, or at least the placement of the first of what might have been a series of uprights added over time. The dedication of such a large and obviously important shrine at this date implies a much higher level of organisation early in the quarry complex chronology. The isolated location, large number of uprights, and substantial number of offerings suggest that this was a communal shrine, in contrast to the much smaller and architecturally simpler shrines found elsewhere in the quarry, including those found at base camps like Keanakakoʻi. This shrine is one of several ritual centres in the quarry complex that hint at the possibility that the adze makers working there were organised into a guild (McCoy 1990, 1999).

While caution obviously has to be used in interpreting single dates, the dates for Keanakakoʻi and the shrine are very close to one another suggesting near-contemporaneity. That, perhaps, the earliest generation of adze makers occupying the locality that became known in modern times as Keanakakoʻi were the same people involved in the construction and dedication of the shrine is easy to envision, but not possible to prove.

It is only with the recent development of high precision ^{230}Th dating that it is now possible to obtain dates clearly associated with shrines that lack organic material suitable for radiocarbon dating. Though branch coral may not be common in remote areas of Hawaiʻi (indeed, only two of the more than 200 documented shrines in the summit region had associated coral offerings), even in such important localities as Mauna Kea where there are large numbers of shrines, the presence of just a few pieces is highly significant. Here we have been able to clearly place organised craft specialisation and associated shrine use in the mid-fifteenth century AD, thus greatly refining the chronology of significant events at the largest Neolithic adze quarry in the Pacific Islands.

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