– ARTICLE –

Indirectly Dating one of the Oldest Adze Quarries in the Hawaiian Islands Provides Insights into the Colonisation Process and Community Networks

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ABSTRACT

Chemically characterising stone tools in distant habitation sites and matching artefacts to quarries is some of the strongest evidence archaeologists have to define the spatial and temporal limits of ancient interaction networks. We present the chemical analysis of five basalt flakes from three sites on Molokaʻi, Hawaiian Islands: a well-dated colonisation period stratified coastal mound, a craft specialisation locale and an upland buried habitation. Wavelength dispersive x-ray fluorescence (WDXRF) and inductively coupled plasma mass spectrometry (ICP-MS) were used to identify the origin of the artefacts. Radiocarbon dating results indicate that the recently discovered Puʻu Pāpaʻi (Molokaʻi) quarry was likely utilised from the colonisation period beginning in the 12th century through to the late 1600s, making it one of the oldest, continuously used quarries in the archipelago. Aspects of island colonisation and community networks are discussed including the possible emergence of the elite control of resources.

Keywords: interaction, trade, Oceania, wavelength dispersive x-ray fluorescence (WDXRF), inductively coupled plasma mass spectrometry (ICP-MS)

INTRODUCTION

Unlike other site classes in Polynesia, adze quarries are unique in their extremes of location – from the seashore to near the tops of the highest mountains; in essence, they can be found almost anywhere, geology permitting. These sites have attracted much interest as they are highly visible, generally well-preserved, and offer a wide range of research topics including the obvious stone artefact manufacture (Clarkson *et al.* 2014; Cleghorn 1982; Jennings *et al.* 2018; Jennings & Weisler 2023; McAlister & Allen 2017; Turner and Bonica 1994), defining the spatial and temporal dimensions of prehistoric interaction (Best *et al.* 1992; Clark *et al.* 2014; Collerson & Weisler 2007; Hermann *et al.* 2023), island colonisation strategies and post-colonisation connections (Rolett 2002; Walter *et al.* 2010; Weisler *et al.* 2016; Weisler & Walter 2017), and addressing craft specialisation (Bayman & Moniz Nakamura 2001; Hermann 2017). Importantly, the organisation and intensification of adze production (Cleghorn 1986; Rolett *et al.* 2015) are hallmarks used for tracking the development of social complexity (Kirch 2010; Earle & Spriggs 2015; Lass 1994; Leach 1993). Habitation sites have a relative wealth of dating material resulting from domestic activities, agricultural sites often have charcoal dispersed throughout buried sediment layers that can be dated using ^{14}C, and the chronology of ritual architecture can be ascertained by high precision U-series dating of coral offerings or pieces embedded within construction materials (Weisler *et al.* 2006). However, most adze quarries, consisting of variable concentrations of formed stone artefacts and debitage, spread over large areas and lack datable materials (*e.g.* Sinton & Sinoto 2015; Turner 2000; Weisler 2011). In few occasions rock shelters, with stratified layers, are located within quarries such as the Mauna Kea adze quarry complex on Hawaiʻi Island (McCoy *et al.* 2009) and the Haleakalā, Maui quarry (Carson & Mintmier 2006; Mintmier 2014) and in some cases habitation platforms and fortifications are integrated within quarry complexes, as exemplified by Tataga-matau, Samoa (Clark 1993; Leach & Witter 1987; Winterhoff 2007). But, for the most part, and unlike other Polynesian site classes, many adze quarries must be indirectly dated by geochemically identifying adze material at distant habita-

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tion sites. This holds more so for the geologic sources of tool quality stone that accumulate in stream drainages, along shorelines and across broad sloping terrain where there is no evidence of tool manufacture, but the geologic source has been identified by the chemical properties of artefacts at habitation sites.

Identifying exotic stone in distant habitation, ritual and agricultural sites allows for indirectly dating quarries and unlocks a range of interesting research avenues for understanding the process of colonisation and structure of communities. These include: 1) during the colonisation period, was tool quality exotic stone transferred between small founding communities as a survival mechanism (Weisler & Walter 2017); 2) was material obtained by direct access, down-the-line exchange, or transferred through elite persons signalling a prestige goods economy (Earle 1997; Quintus & Kahn 2023); 3) is exotic stone associated with high-status residences (Weisler & Kirch 1985; Kirch *et al.* 2012) or across a range of site types; and 4) can intensified quarry use be linked to increasing land-clearing activities for agriculture (Hommon 2010).

In this paper, a chronology is presented for what is now one of the oldest quarries in the Hawaiian Islands where adze material, geochemically linked to the recently confirmed Puʻu Pāpaʻi quarry (Sinton & Sinoto 2015), was unequivocally identified at a colonisation period coastal sandy mound habitation, a late prehistoric craft specialist site and a distant upland residence on the island of Molokaʻi documenting the duration of quarry use, intra-island distribution, and possible use of the stone as a prestige commodity in later prehistory. We describe the Puʻu Pāpaʻi adze quarry, the dating and context of three habitation sites where its adze material was identified by comprehensive geochemical analyses, and discuss the importance of the temporal and spatial distribution of the Puʻu Pāpaʻi material for elucidating aspects of island colonisation and community networks.

THE PUʻU PĀPAʻI QUARRY

Almost all Hawaiian adze quarries have been discovered during archaeological survey or their locations brought to the attention of archaeologists by members of the local community, oftentimes hunters. In the case of the Puʻu Pāpaʻi quarry, it is one of the rare examples where the geochemistry of a stone adze led back to a known lava flow that was then confirmed to have evidence of adze production. A large complete adze (in fact, the longest adze in the Bishop Museum collection) was retrieved from the ocean off Oʻahu, and was subjected to several analytical techniques to convincingly ascertain its origin, leading to the identification of the Puʻu Pāpaʻi quarry (Sinton & Sinoto 2015). Although the quarry requires an archaeological survey to locate the boundaries and map internal details, there are cores (up to 30 cm long), adze blanks and likely preforms, and debitage scattered over ~200 m east-west by 50 m north-south towards the base of a broad slope that is truncated by the coastal highway (Sinton & Sinoto 2015: Figures 4 and 7). Puʻu Pāpaʻi is part of the Upper Member of the East Molokaʻi Volcanics (Sherrod *et al.* 2021; Stearns and Macdonald 1947), situated just inland from the south-central shoreline (Figure 1). Although thin-sections and apatite composition were reported by Sinton and Sinoto (2015), of interest here are six samples that were

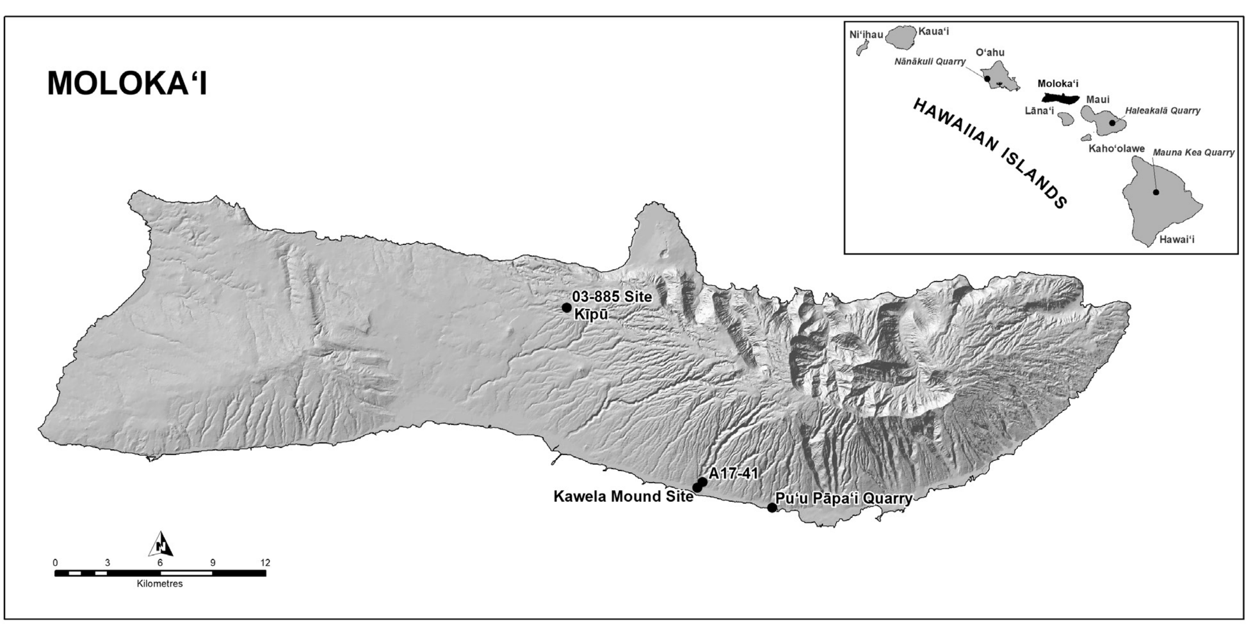

Figure 1. Location of the Hawaiian Islands, Molokaʻi, and archaeological sites mentioned in the text.

collected in and around the quarry and analysed for oxides and trace elements (Sinton and Sinoto 2015: Figure 4, Table 1) making the data directly comparable to the current study. As reported by Sinton and Sinoto (2015) Puʻu Pāpaʻi lavas have a basaltic composition with 45.9 to 46.6 wt.% SiO_2, 4.0 to 5.3 wt.% MgO, and 2.41 to 2.50 wt.% P_2O_5. The rock is classified as a tephrite (*e.g.* LeBas *et al.* 1986) or nepheline hawaiite (Coombs & Wilkinson 1969). Of importance to sourcing studies in the Hawaiian Islands is the: 1) very high P_2O_5 concentration (~2.5 wt.%) representing an extreme value; and 2) exceptionally high Sr content >2000 ppm which is the highest value for any quarry thus far. Within the Hawaiian Islands, hawaiites with such high phosphorus and Sr contents are found only at East Molokaʻi and Kohala volcanoes (Sinton *et al.* 2017). The Puʻu Pāpaʻi source has the highest values of P_2O_5 and Sr of any Hawaiian lavas analysed so far.

THE STUDY SITES AND ANALYTICAL SAMPLES

Colonisation period sandy coastal mound at Kawela

Situated along the south-central shore of Molokaʻi and 4.4 km west of the Puʻu Pāpaʻi quarry is the 1.5 m high Kawela Mound site (State of Hawaiʻi site number 50-60-04-144) formerly located immediately west of the Kawela Stream mouth just back from the sandy beach (Weisler *et al.* 2023: Figure 2). Excavations during the early 1980s revealed five cultural layers to a depth of nearly 3 m. Adze materials including finished adzes, preforms, polished basalt flakes and debitage were found in various quantities throughout the layers. The Bayesian modelled radiocarbon dates and cultural content are described after Weisler *et al.* (2023): Layer I, mixed with historic artefacts and historically introduced animals (sheep or goat, roof rat or brown rat), bones of chicken, sea birds, sea turtle, pig, dog, Polynesian rat, reef fish, crustacea, urchins and shellfish. There were few stone artefacts. Layer II, with a Bayesian modelled age starting at AD 1455–1558 (median, AD 1485), contained a low density of combustion features, artefacts and midden with less historic material. It's worth noting that all age ranges reported in this paper are at 95% CI (confidence interval). Several buried A horizons suggest intermittent use. Layer III, starting at AD 1447 to 1482 (median, AD 1464) with a duration of 0–94 years, was the most intensively occupied layer in the Mound site with numerous combustion features and the largest amount and greatest diversity of traditional artefacts represented by adze making, use and reworking. Typical marine midden included bones of reef fish, sea birds, pig, dog and rat as well as crustacea, urchins, and shellfish. In Trench 2 Layer III (Weisler *et al.* 2023: Figure 8), there were 193 complete and broken flakes only two of which were very fine grained (Irving 1998); one of these, analytical sample JS-1, was selected for geochemical analysis. A low-density midden with few combustion features and artefacts (including a polished basalt flake probably from adze reworking), Layer IV represents minimal occupation starting at AD 1429–1470 (median, AD 1451) with a duration of 0–38 years. With a start date modelled to AD 1121–1262 (median, AD 1210), and a duration of 181–334 years, the basal cultural Layer V had several combustion features, dense midden and an adze preform, a finished adze, polished basalt flakes, and 203 pieces of debitage. Some 23 flakes were very fine-grained and two comprised the analytical samples from this deepest cultural layer: sample 2022-027 from Trench 7, 225–230 cm below surface and sample 2022-030 from Trench 7, 220–225 cm bs (Weisler *et al.* 2023: Figure 11).

Late prehistoric craft specialist site at Kawela

A large scale 7.7 km² intensive survey encompassing three traditional land units (*ahupuaʻa*) and an excavation program (442.4 m² excavated) was directed by MIW in the early 1980s (Weisler & Kirch 1985). Descending from high elevation dense forest, Kawela Gulch dominates this otherwise dry leeward landscape. Narrow ridgelines are sandwiched between seasonal drainages, and it is along these ridges below about 150 m elevation that a late prehistoric community was situated consisting of residential complexes – aggregates of dry-laid stone structures surrounding level soil areas used as domestic space. Each residential complex consists of a primary dwelling, one or more smaller secondary dwellings, and a place of ritual function which can be a separate structure or simply an upright godstone (*ʻaumakua*) in the northeast corner of the main house (Weisler & Kirch 1985: Figures 7, 9 and 10). Some residential complexes have lithic scatters that represent stone tool making, use and refurbishing. Situated at ~100 m elevation and 1.1 km from the coast is a ~750 m² lithic scatter, the largest in the settlement area, associated with a low stone level platform (4.5 × 1.2 m) constructed of boulders to 30 cm high (Bishop Museum site number 50-Mo-A17-41). The lithic scatter consisted of about a hundred artefacts including finished adzes (one 37 mm long), small preforms, awls, polished basalt flakes (which made up over half of the formed artefact assemblage), debitage, cores and hammerstones – all evidence for making, using and reworking adzes and awls. Additional to the wood-working tools were *pohaku ʻanai ʻumeke laʻau* (Hiroa 1964: 257) – fine-grained and vesicular plano-convex cobbles and pebbles (ranging from 25 to 118 mm long) used for shaping and polishing wood. The relatively small size of the finished adzes and preforms suggests woodworking of small objects, perhaps bowls. There is no other comparable site in the settlement system. Some 70 m² were surface collected and 4 m² excavated with eight species of marine shellfish identified (mostly the brackish water gastropod, *Theodoxus neglectus*), bones of birds, and reef fish such as wrasse (Labridae) and parrotfish (Scaridae), urchin and coral were inventoried. Analytical sample JS10 was collected from the site surface.

Buried late prehistoric upland midden at Kīpū

About 7.5 km equidistant to accessible shores on the north and south coastlines, in the uplands of Kīpū, situated at the base of a broad slope in an area known locally as Slaughterhouse Gulch, and immediately above an intermittent stream channel at 305 m elevation is a deeply buried cultural layer (Weisler 1998: Figure 13). These kinds of sites are rare since there are no surface indications of cultural material with no archaeological sites nearby. It was only discovered while conducting mechanical backhoe trenching as part of an intensive archaeological survey for a proposed golf course. Six stratigraphic layers were identified to a maximum depth of 320 cm. All layers consist of sandy to gravelly mud (after Folk 1954) deposited as colluvium; that is, sediments deposited at the base of slopes by sheetwash or rain. Layers VI and VII were compact and culturally sterile. Layers I to IV contained dispersed charcoal but no artefacts or midden. The main cultural Layer V, a dark reddish brown (5YR 3/3), was 86 to 160 cm below surface and contained a combustion feature (40 cm maximum diameter) with vesicular basalt stones averaging 104 ± 10.9 mm long. All charcoal identified by Jennifer Huebert was *Psydrax odorata-alaheʻe*, a medium size flowering shrub or tree up to 8 m found in dry to mesic forests (Wagner *et al.* 1990: 1119). Other layer contents included fish bone, rocky shore shellfish (mostly *Cellana sandwicensis* and *Purpura aperta*), urchin (*Colobocentrotus atratas*) that live on high energy shorelines, *kukui* endocarps (*Aleurites* sp.) and four basalt flakes (one of which was analytical sample 2022-158) and a core. The oven and cultural material were concentrated near the base of the layer, at least 130 cm below surface. A limpet shell (*Cellana sandwicensis*) was removed from the oven for accelerator mass spectrometry (AMS) ^{14}C dating (described below).

GEOCHEMICAL METHODS

Chemical analysis was conducted at the University of Melbourne in 2007 for artefacts JS-1 and -10 (14 trace elements) and at Washington State University (10 oxides and 19 trace elements) for artefacts 2022-027, -030 and -158 in 2023. The salient details of these methods are described below.

Specimens for all analyses were chosen that were representative of the macroscopic characteristics of the stone tool assemblages considering grain size and phenocrysts present and, to a lesser extent, overall colour. All selected specimens were photographed and described (Figure 2 and Table 1). The preparation for inductively coupled plasma mass spectrometry (ICP-MS) required drilling of samples to form rock powder for two key reasons: 1) a powder is presumed to be homogenous and thus more accurately reflects the bulk composition of the specimen; and 2) a powdered form is necessary to simplify the subsequent acid digestion of the specimen. Prior to drilling all specimens and drill bits were washed with ethanol in a sonic bath to

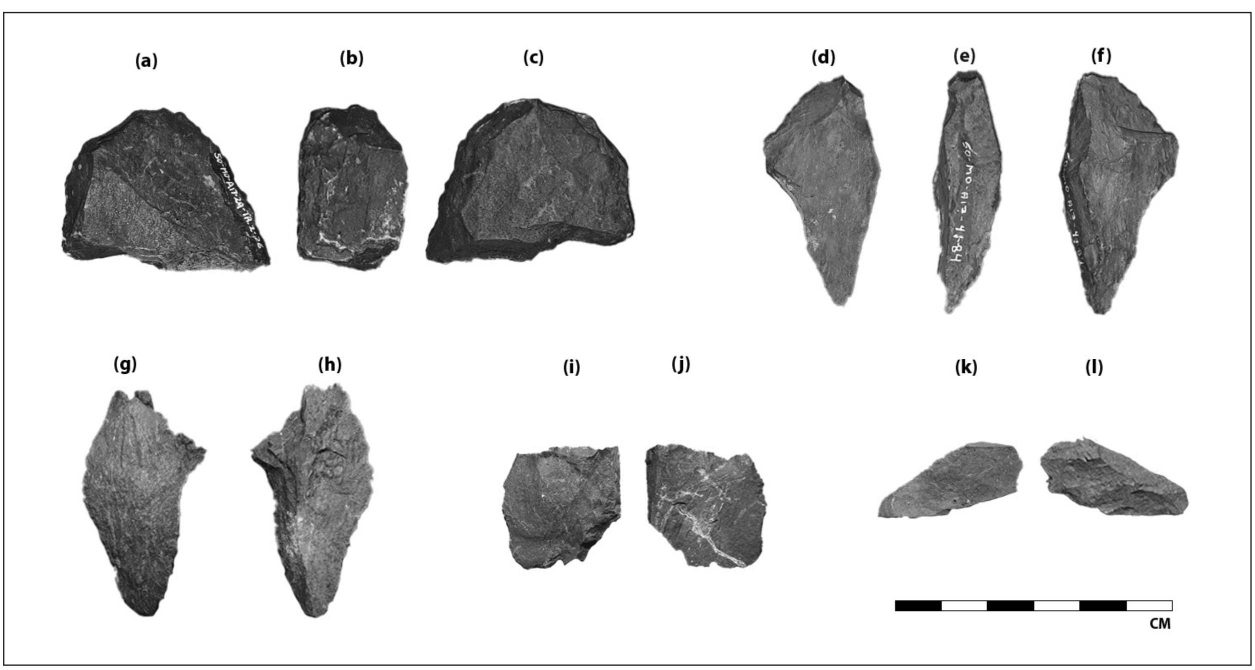

Figure 2. Artefacts from distant habitation sites assigned to the Pu'u Pāpa'i adze quarry. a–c, analytical sample JS1, adze preform butt front, side and back views; d–f, sample JS10 corner of adze preform front, side and back views; g and h, sample 2022-027, secondary flake dorsal and ventral views; i and j, sample 2022-030, secondary flake dorsal and ventral views; and k and j, sample 2022-158, secondary flake dorsal and ventral views. See Table 1 for artefact attributes. (Photos, M. Weisler)

Table 1. *Attributes of sourced artefacts*

Site	Trench or Unit	Layer	Length (mm)	Width (mm)	Thickness (mm)	Weight (g)	Description
144	2	III	36.11	37.20	19.48	38.3	adze preform butt fragment, 1 face ground
144	7	V	49.07	21.63	6.28	6.2	secondary flake, remnant platform, diffuse bulb, feather term, abundant apatite microphenocrysts
144	7	V	25.89	26.74	3.70	4.3	secondary flake, platform, diffuse bulb, feather term, no cortex
41	S10E2	surface	54.12	25.42	12.33	15.2	corner of adze preform, no cortex, no striking platform
03-885	2	V	15.76	35.64	8.06	5.0	secondary flake, platform, no cortex, arris, snap term, abundant apatite microphenocrysts

remove surface contaminants and debris. Drilling was performed at the University of Queensland Geological Laboratory using a Muss Dental GMBH M MA 30 drill fitted with diamond encrusted drill bits. A minimum of 80 mg of rock powder is required for ICP-MS. However, approximately 200 mg was collected to allow for additional samples to be archived. It is noted here that while this drilling technique, described in detail in Ma *et al.* (2011), is useful when the goal is to achieve a broad array of trace elements within acceptable values of accuracy and precision, Ni, Cu, Zn and Pb alloys commonly employed in diamond-smelted drill bits, and sometimes in diamond-coated bits, may affect values for these elements (Ma *et al.* 2011: 894); in this case, only Ni had unusually high values for the artefacts (see below). The ICP-MS analysis was performed at the University of Melbourne laboratory facilities in the School of Earth Science using a Varian ICP Mass Spectrometer. Prior to analysis, rock powder samples were dissolved in accordance with the acid digestion protocol (Appendix 1) using the University of Queensland Centre for Microscopy and Microanalysis (CMM) clean (class 100–1000) laboratory.

At the Washington State University Peter Hooper GeoAnalytical Lab, x-ray fluorescence analysis (XRF) for major and trace elements were analysed on a single low dilution Li-tetraborate fused bead and the protocol is fully described in Johnson *et al.* (1999). Major and trace elements were analysed and compared to accepted standard values (*e.g.* Govindaraju 1994) and to values acquired by other techniques in different laboratories. Rock (artefact) samples are ground in a swing mill with tungsten carbide surfaces and 3.5 g of powder is normally used for analysis. The weight of fine-grained basalt flake samples for this analysis ranged from 4.3 to 6.2 g. Loss on ignition (LOI) was determined but is often a minor value since artefacts were mostly manufactured from unweathered source rock.

RESULTS

Chemistry

Table 2 presents the oxides and XRF trace element chemistry for five artefacts and four lava samples from Puʻu Pāpaʻi. Table 3 provides the ICP-MS data for artefacts 2022-027, -030 and -158. All rocks are classified as tephrites on total alkali-silica (TAS) plots (Cox *et al.* 1979). When comparing artefacts and source samples, as a group, they are homogeneous in composition. In fact, the chemical values for samples 2022-027, -030 and -158 are remarkably consistent in the variability across values, within analytical error of the technique; this is certainly true for the oxides. As described by Sinton and Sinoto (2015: 404) the Puʻu Pāpaʻi source has unusually high values for P_2O_5 at ~2.5 wt% which is the exact concentration for the three artefacts (2022-027, -030 and -158) that have oxide values. There are no other quarries in the Hawaiian Islands that have such high P_2O_5 concentrations. Another defining characteristic of the Puʻu Pāpaʻi source is the 'exceptionally high Sr contents >2000 ppm, making it the most Sr-rich adze quarry known for the Hawaiian Islands' (Sinton & Sinoto 2015: 407). The five artefacts in our study have Sr values from 2381 to 2497 ppm, consistent with the Puʻu Pāpaʻi source. Comparison of virtually all chemical values of the artefacts and Puʻu Pāpaʻi source rocks show an exceptionally high correspondence.

DISCUSSION

The oldest quarries in the Hawaiian Islands and the chronology of the Puʻu Pāpaʻi source

There are few well-dated adze quarries in the Hawaiian Islands where most radiocarbon age determinations were made on unidentified wood charcoal with an unknown amount of inbuilt age (Rieth & Athens 2013). However, the Haleakalā, Maui quarry complex situated between ~2000–3000 m elevation in harsh sub-alpine to alpine environments has two of 12 dates with medians in the mid-14th century. Carson and Mintmier (2006) recorded 57 archaeological sites consisting of caves, rock shelters, enclosures, platforms, cairns, and surface scatters of basalt debitage with habitations used repeatedly for short stays. Both calibrated AMS dates are on *pūkiawe*, cf. *Styphelia tameaimeia*, a shrub to small tree (Wagner *et al.* 1990: 590–591); the oldest date is from a rock shelter adjacent to a platform of

Table 2. *Chemical analyses of artefacts and lava samples from Puʻu Pāpaʻi.*

	Artefacts			**Source**					
	2022-027	2022-030	2022-158	JS-1	JS-10	C-159	EMO-5	EMO-3	EMO-2
Locality	Kawela	Kawela	Kīpū	Kawela	Kawela	Puʻu Pāpaʻi	Puʻu Pāpaʻi	Puʻu Pāpaʻi	Puʻu Pāpaʻi
Site	04-144	04-144	03-885	04-144	A17-41				
Trench/spit	Tr7/225–230	Tr7/220–225	Tr2/130–155	Tr2-Layer III	surface				
Sample size (g)	6.2	4.3	5.0	0.08	0.08				
SiO2	45.16	45.14	45.29			45.91	46.64	45.71	45.27
TiO2	3.121	3.090	3.140			3.020	2.870	3.120	3.230
Al2O3	16.51	16.60	16.56			16.63	17.20	16.80	16.16
FeO*	12.09	11.65	11.94			12.23	11.56	12.00	12.23
MnO	0.233	0.230	0.234			0.23	0.23	0.23	0.22
MgO	4.70	4.71	4.67			4.14	4.02	4.04	5.29
CaO	8.13	8.18	8.23			8.10	7.79	8.29	8.72
Na2O	5.20	5.17	5.27			5.44	5.62	5.35	4.89
K2O	1.66	1.65	1.66			1.84	1.76	1.68	1.48
P2O5	2.486	2.490	2.501			2.43	2.41	2.50	2.41
Sum	**99.28**	**98.91**	**99.50**			**99.97**	**100.11**	**99.72**	**99.91**
LOI %	**0.33**	**0.62**	**–0.02**			**1.10**	**2.37**	**1.04**	**1.02**
Ni	16	10	16	1150	265		12	17	47
Cr	4	6	5	11	14		9	11	51
Sc	8	9	9	9	8		11	11	11
V	123	128	129	123	117		91	110	141
Ba	823	791	847	783	951		894	906	831
Rb	34	34	35	32	31		35	33	30
Sr	2455	2497	2448	2381	2461		2521	2471	2294
Zr	264	276	265	241	249		273	252	240
Y	46	44	45	40	41		47	45	43
Nb	65.4	65.3	66.3	63	65		69	64	61
Ga	20	21	21	21	21		nd	nd	nd
Cu	18	16	16	19	19		26	29	33
Zn	136	132	137	139	133		133	141	135
Pb	3	6	5	3	3		3	4	3
La	66	65	66	65	67		nd	nd	nd
Ce	164	149	162	149	154		nd	nd	nd
Th	4	5	4	4	4		4	3	3
Nd	88	89	87	87	89		nd	nd	nd
U	2	2	1	1	1		nd	nd	nd

Ni values for samples JS-1 and -10 are inflated due to drill bit contamination.
Source analyses from Macdonald (1968) and Sinton and Sinoto (2015).

possible ritual function dating to AD 1290–1405 (median, AD 1349; Beta-209582 620 ± 40 BP) and the other from a firepit in a camp site dating to AD 1300–1425 (median, AD 1352; Beta-209591 580 ± 40 BP). Both dates were recalibrated for this study using OxCal v.4.4 (Bronk Ramsey 2009) and IntCal20 (Reimer *et al.* 2020).

There are several U-series dates from quarries on three islands across the Hawaiian archipelago. The oldest is from the surface of a rock shelter at the Nānākuli quarry on leeward Oʻahu – the largest identified quarry on the island – where a ~35 mm fragment of *Pocillopora* sp. branch coral dated to AD 1234 ± 6 (Weisler *et al.* 2013: 38). Although a surface find, the sample was closely associated with dense basalt debitage, adze preforms and hammerstones (Weisler *et al.* 2013: Figure 4A, B, 5). The next oldest U-series dates are from two sites at the Mauna Kea adze quarry complex, Hawaiʻi Island situated near 3750 m elevation just below the summit. The quarry complex sprawls across several square kilometres with more than 250 workshops, in excess of 1500 flaking stations, 50 rock shelters, 200 open-air enclosures

Table 3. *ICP-MS chemistry for three artefacts.*

ICP-MS (ppm)	2022-027	2022-030	2022-158
La	66.91	67.11	67.08
Ce	149.99	150.86	151.34
Pr	20.31	20.44	20.28
Nd	87.22	87.95	87.84
Sm	17.92	18.13	17.73
Eu	5.69	5.69	5.64
Gd	15.31	15.08	15.16
Tb	2.04	2.04	2.02
Dy	10.04	10.06	9.89
Ho	1.69	1.67	1.64
Er	3.80	3.78	3.77
Tm	0.48	0.48	0.46
Yb	2.60	2.56	2.56
Lu	0.35	0.34	0.36
Ba	801.00	794.00	830.00
Th	4.11	4.03	4.08
Nb	65.08	64.88	64.92
Yb	44.40	44.44	43.77
Hf	5.86	5.77	5.92
Ta	3.65	3.66	3.65
U	1.15	1.16	1.15
Pb	3.10	3.05	3.23
Rb	32.0	31.20	32.70
Cs	0.31	0.26	0.35
Sr	2494.00	2460.00	2479.00
Sc	8.00	7.90	7.80
Zr	248.00	245.00	248.00

and 45 shrines (McCoy 1990; McCoy *et al.* 2009). From the surface of rock shelter site 50-10-23-28637, a U-series date of AD 1355 ± 28 is associated with adze manufacturing (McCoy *et al.* 2012: 414), while a AD 1398 ± 13 date refers to the occupation of rock shelter site 50-10-23-16205 and the formation of an associated large debitage pile (McCoy *et al.* 2009).

Of the dozen adze quarries on west Molokaʻi none date prior to the 15th century considering only a few AMS dates on short-lived wood collected at well-defined combustion features at quarries, or U-series dated pristine *Pocillopora* coral from shrines with adze material originating from the quarries (Weisler 2011). The context of the five chemically analysed basalt flakes from three habitation sites unequivocally assigned to the Puʻu Pāpaʻi quarry are discussed in turn. At the upland buried midden at Kīpū, a sample of limpet shell (*ʻopihi ʻālinalina*, *Cellana sandwicensis*; Wk-54467, 886 ± 21 BP) was recovered from Trench 2, Layer V inside an oven and AMS dated to AD 1380 to 1649 with a median age of AD 1493 using OxCal v.4.4 version (Bronk Ramsey 2009) and Marine20 curve (Heaton *et al.* 2020) with a ΔR of −128 ± 29 yr for Molokaʻi (Weisler *et al.* 2009). Although analytical sample JS-10 from Kawela site A17-41 is a surface find from a craft specialisation locale and there are no dates for this particular site, 45 AMS dated short-lived wood and nutshell fragments, and U-series dated coral offerings (to be reported elsewhere) place occupation of the surrounding community during the 16th century and later. Because the craft specialisation site is integrated into this well-dated settlement system (Weisler & Kirch 1985), the site was most likely occupied no earlier than the 16th century; that is, ~200 years before Contact. Sample JS-1, from the Kawela Mound site (04-144), Trench 2, Layer III, 57 cm below surface is associated with five AMS dated samples with a Bayesian modelled age of AD 1447–1558 and a duration of from 0 to 94 years (Weisler *et al.* 2023: Table 1, Figure 8). Samples 2022-027 and -030 are both from the Kawela Mound site, Trench 7, Layer V with a modelled initial occupation beginning at AD 1121–1262 (median, AD 1210), and a duration of 181–334 years. Near the bottom half of this layer are four AMS dated samples (OZY083, -084, -086 and Beta-351163, see Weisler *et al.* 2023: Table 1, Figures 5 & 11) that are within 10 cm above or below the analytical samples in Trench 7 and Strat Trench 2. We selected dated samples immediately above and below the artefacts because the loose sandy sediments that comprise Layer V are susceptible to post-depositional movement (Carson 2004: 106; Khaweerat *et al.* 2010). The dated samples have median calibrated ages of AD 1430 (OZY083), AD 1243 (OZY084), AD 1289 (OZY086) and AD 1270 (Beta-351163). These samples have calibrated ages of AD 1182 to 1447. No other quarry in the Hawaiian Islands is dated to the 12th century. Considering the associated dates with the five artefacts from three sites, it is likely that since its discovery during the colonisation period, the quarry was used for five centuries until late prehistory, perhaps sometime in the late 17th century.

The colonisation process and defining community networks

It has been long accepted that when tropical Polynesian colonists arrived on the shores of a newly discovered island, they sought environments that were advantageous for small founding populations (*e.g.* Burley *et al.* 2018); that is, ecologically diverse settings with ample fresh water, nutrient-rich soils for gardening and easy access to the shoreline for harvesting previously untapped marine bounty. This strategy, as Anderson (2001: 20) states, targeted in part 'the early abundance of high-quality food at low foraging cost, [that] encouraged rapid population growth amongst colonizing populations.' The Kawela Mound site, located on an alluvial plain, astride the Kawela Stream, just back from the sandy beach that fronts a 1-km wide reef and a short walk from an inland marsh replete with shore, migratory and marine birds, was an ideal setting for small founding populations of human colonists (Weisler *et al.* 2023). Although fine-grained rock was available in the Kawela drainage for stone tool manufacture (Weisler & Kirch 1985: 134) and coarser grained cobbles readily found on the broad slopes were also used, the Puʻu Pāpaʻi quarry, <5 km distant, was discovered during the colonisation period and stone flakes from this locale were found in the earliest cultural deposits of the Mound site amongst the daily accumulation of mundane food shells, fish bones and hearths providing few clues to its importance. Indeed, at this early time, the stone may have been considered merely another source of fine-grained rock for stone tool production. But quarries are well defined spatially with access more easily controlled by elites than stone cobbles strewn the length of a drainage or sub-rounded rocks spread across an upland landscape. It is not clear yet if the form and flaking properties of the Puʻu Pāpaʻi quarry rock were superior to locally available material but, sometime around the 15th century (and perhaps as early as the late 1300s), the source rock was transferred ~14 km (straight-line distance) to the Kīpū uplands connecting its inhabitants to those of the Kawela Mound whose refuse was forming Layer III at a similar time. These two dispersed communities were indirectly linked by the transfer of upland (*uka*) and coastal (*kai*) resources. Handy & Pukui (1958: 2–3) describe the dispersed community as *ʻohana* ('the offshoots of a family stock') joined by blood, marriage and adoption with some living inland and others by the sea. Although the archaeological evidence is limited to a small number of flakes, the presence of exotic material is a direct indicator of inter-community contact.

Indeed, in the Hawaiian Islands, the context and diversity of exotic stone found in habitation sites is more revealing thus far than the sheer number and weight of transferred adze material. In an early study, non-local lithic material was associated with larger and higher status households at the late prehistoric community of Kawela (Weisler & Kirch 1985: 148, Table 3) suggesting that goods are produced, distributed and consumed within specific social contexts or some manner of elite control (Earle & Spriggs 2015). And decades later, Kirch *et al.* (2012: 1060) found that nonlocal lithic sources were more common in ritual contexts within a late prehistoric Maui settlement system. Yet, the amount of material would scarcely fill a coffee cup. The point is that the diversity of exotic sources represented at habitations distant from adze quarries is key to defining spheres of household and community interaction as the magnitude of adze material was never on a scale like that during the colonisation period of New Zealand (Walter *et al.* 2010; Weisler & Walter 2017) where the transfer of hundreds of adzes connected coastal communities as part of a colonisation strategy.

The archaeology of Henderson Island, Pitcairn Group, southeast Polynesia provides another example of the greater diversity and amount of artefact transfer compared to the Hawaiian Islands. The transfer of exotics was not only a colonisation strategy for the isolated Henderson Island but created a lifeline that continued for several centuries between there and the better resourced Pitcairn Island (an overnight voyage) and the Mangareva archipelago ~400 km west. Imports defined about four centuries of interaction which, when it ceased, rendered the isolated Henderson community as no longer viable (Weisler 1995). It is noteworthy that more than 400 exotic artefacts including adze materials, volcanic glass and oven stones weighing ~3.5 kg were imported to nine habitation sites on Henderson (Weisler 1997: Table 9.1) with far less excavation than the Maui study mentioned above. Consequently, unlike some other Polynesian islands and archipelagos, on present evidence, relatively less exotic material was transferred during the Hawaiian cultural-historical sequence, in what Earle (1997: 225) refers to as 'modest exchange'. Could this modest exchange relate to the greater use of local rock for adze production than previously thought?

The examples from New Zealand and Henderson Island highlight the marked variability in the broad and encompassing term 'interaction networks'. And we would expect that the characteristics of interaction networks within an archipelago and even across a single island would change and adapt to needs, whether for day-to-day survival or instituted by social dictates such as fostering and maintenance of strategic alliances for the acquisition of high-status goods. In this regard, the Puʻu Pāpaʻi flake in the late prehistoric craft specialisation site at Kawela *hints* at elite control for what may have become a higher status exotic material at that time.

CONCLUSIONS

For the Polynesian region, there are relatively few adze quarries that have been described and the chemistry reported in detail (Jennings *et al.* in press). The Puʻu Pāpaʻi chemistry is certainly unique in its extreme values for P_2O_5 and Sr which, on present evidence, is distinctive to this quarry when considering rocks across the Hawaiian Islands. The values for virtually all 10 oxides and 19 trace elements are unequivocal matches for five artefacts that originated at Puʻu Pāpaʻi providing robust source assignments. As more quarries are discovered and their chemistry reported, we may come to find some overlap in values between quarries; consequently, we advocate reporting a wide range of oxides, trace elements and even isotopes (*e.g.* Weisler *et al.* 2013) that are useful to characterise quarries. In a biological sense, this is akin to describing new species with all the pertinent details.

After identifying non-local material across an interaction system, the next important step is to bracket the spatial distribution into a rigorously dated context as we have presented here. We believe that with more studies characterising non-local basalt including volcanic glass artefacts (*e.g.* Weisler 2012), and other kinds of lithics in distant habitation, ritual and even agricultural contexts, the necessary data to further understand the development of one of the most complex societies in the Pacific Islands and, indeed, world prehistory, will be elucidated more fully.

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APPENDIX 1: SAMPLE PREPARATION FOR ICP-MS

Protocol provided by Radiogenic Isotope Facilities, Centre for Microscopy and Microanalysis, University of Queensland, 2007.
Note: Use Teflon beakers (clean prior to use).

Sample Weighing

1. Add 3 drops of 2% triple distilled HNO_3 to beakers to reduce electrostatic effect.
2. Weigh 50–100 mg of sample using weighing paper

Sample Digestion

1. Add 1ml of triple distilled concentrated HNO_3 and 3 ml of double distilled concentrated HF to beakers, cap them and leave on the hot plate 80°C overnight.
2. Cool down and add 2 ml of HNO_3 and dry down to incipient dryness on hotplate at 80°C.
3. Add 1ml of triple distilled concentrated HNO_3 and 3 ml of double distilled concentrated HF and leave at on hotplate at 110°C overnight.
4. Cool down and add 2 ml of triple distilled concentrated HNO_3 to beakers.
5. Dry down on the hotplate to incipient dryness at 80°C.
6. Add 3 ml of double distilled 6M HCL and dry down on the hotplate at 100°C.
7. Add 3 ml of double distilled 6M HCL and leave on the hotplate at 110°C overnight.
8. Dry down at 100°C. (Note: last three points are optional)
9. Add 1 ml of triple distilled concentrated HNO_3 and put capped beakers on hotplate at 100°C for 1 hour, then dry down.
10. Add 1 ml of Mili Q water and 1 ml of triple distilled concentrated HNO_3 and put capped beakers on the hot plate at 100°C for 1 hour, then dry down at 100°C.
11. Repeat last step but leave beakers on the hotplate overnight to reflux.
12. Wash, dry and weigh polycarbonate centrifuge tubes with caps.
13. Add 0.5 ml of triple distilled concentrated HNO_3 and 4.5 ml of Milli-Q water and leave overnight on hotplate at 120°C.
14. Cool down and centrifuge at 4000 rpm for 15 minutes.
15. Check for complete dissolution.
16. If completely dissolved, add 5 ml of Milli-Q water to the beakers, cap them and shake well.
17. Centrifuge for 2 minutes at 4000 rpm.
18. Transfer to centrifuge tubes.
19. Centrifuge for 15 minutes at 4000 rpm. Check again for complete dissolution.
20. If completely dissolved weight sample, acid and tube and calculate dilution factor.