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NEW ZEALAND JOURNAL OF ARCHAEOLOGY

Tool Production at the Nu'u Quarry, Maui, Hawaiian Islands:

Manufacturing Sequences and Energy-Dispersive X-Ray Fluorescence Analyses

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ABSTRACT

We discuss a recently discovered basalt quarry, Site NUU-123, on the island of Maui and present a case study of small scale adze production in the Hawaiian archipelago. Our detailed reduction stage analysis of adze preforms, blanks, and debitage documents that the full range of production activities, from early stage blank manufacture to late stage preform trimming, is represented at the quarry. New EDXRF data refine the geochemical characterisation of the Nu'u quarry with respect to Haleakalā, the other known quarry on Maui Island. Multiple lines of evidence suggest that the quarry produced a diverse range of adze types, mainly for local population needs. Data from the Nu'u quarry do not support the notion that later Hawaiian adze assemblages are highly standardised or that manufacture focused exclusively on rectangular cross-sectioned adzes. Finally, we argue that production at small to moderate scale quarries in Hawai'i like Nu'u was sometimes more diverse than that described for the regional production centre at Mauna Kea.

Key words: ADZE QUARRY, HAWAI'I, ADZE TYPES, MANUFACTURING STAGES, REDUCTION MODEL, GEOCHEMICAL CHARACTERISATION, PRODUCTION AND CONSUMPTION.

INTRODUCTION

In this article we discuss a recently discovered basalt quarry[1] situated in Nu'u *ahupua'a*, Kaupō District, Island of Maui, Hawaiian Islands. Our analysis of adze preforms, blanks, and debitage collected from the quarry surface, along with a sample recovered from a test excavation, leads us to argue that Nu'u represents a small scale quarry where adzes were most probably produced for local, or *ahupua'a* scale, consumption.

Although small scale quarries in the Hawaiian archipelago have been known for decades (Bayman and Moniz-Nakamura 2001; Brigham 1902; Cleghorn 1984; Cleghorn *et al*. 1985; Dixon *et al*. 1994; Dye *et al*. 1985; Emory 1924; Weisler 1990), the emphasis throughout Polynesia has been on adze production and distribution at the largest, most extensive quarries, such as Mauna Kea in Hawai'i (Cleghorn 1982, 1986; McCoy 1977, 1986, 1990,

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New Zealand Journal of Archaeology, 2009, Vol. 30 (2008), pp. 135–165.

1999; Mills *et al*. 2008; Williams 1989), Eiao in the Marquesas (Candelot 1980; Linton 1925; Rolett 2001; Rolett *et al*. 1998) or Tataga-matau in Samoa (Buck 1930; Leach and Witter 1987, 1990). At these large quarries, adzes were produced for exchange, perhaps on almost an industrial scale. Smaller quarries have tended to be neglected by Polynesian archaeologists. Case studies and theoretical research on the organisation of production and consumption, in Hawai‘i and elsewhere (Bayman and Moniz-Nakamura 2001; Costin 1991; Kahn 2005; McAnany 1989; Mintmier 2007; Olszewski 2007; Pope and Pollock 1995; Schortman and Urban 2004; Spence 1986), stress that data from both large scale and small scale manufacturing locales are needed to model production processes and the distribution and circulation of stone tools most accurately. Regional export quarries, where production output exceeded local demands, are likely to vary from smaller scale quarries in the scale of output, the organisation of labour, perhaps the degree of artefact standardisation, and the level of specialist skill.

Our case study of the Nu‘u adze quarry focuses on the following research questions: What can small scale adze quarries tell us about the nature of adze production in the Hawaiian archipelago, with respect to scale, intensity, types of adzes produced, and their circulation and distribution? Second, how were these process affected by the ‘market’ or the intended audience for consumption? To address these questions, we present detailed reduction stage

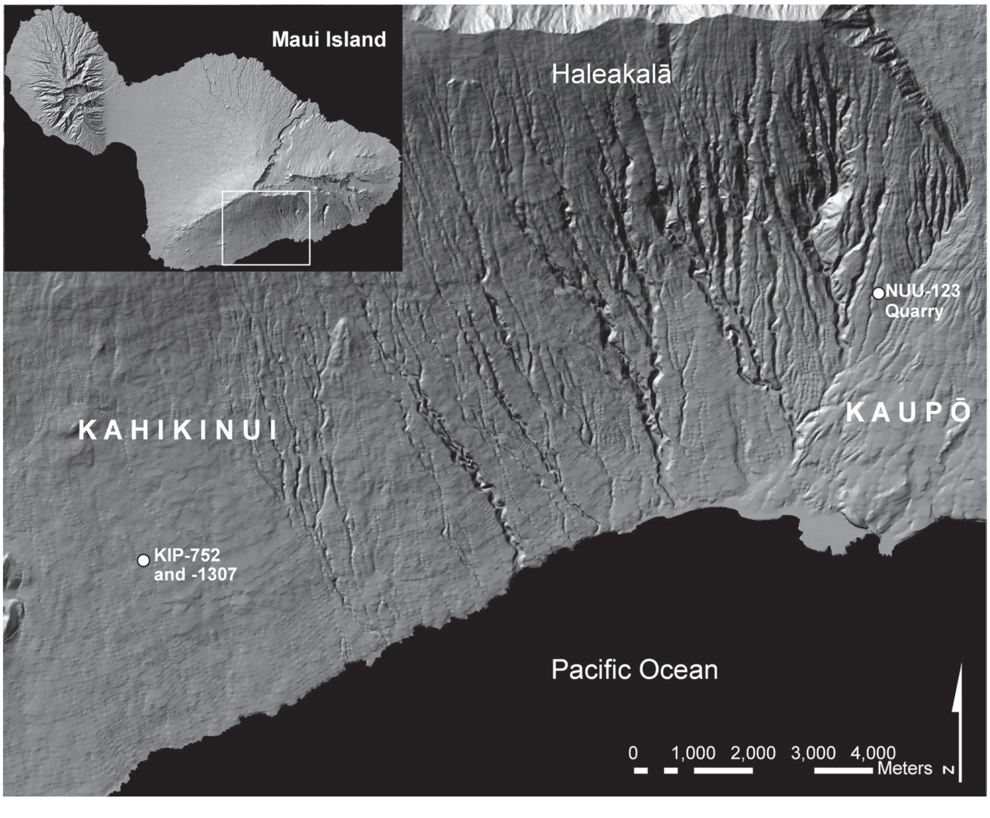

Figure 1: The Kaupō region of southeastern Maui, showing the location of the Nu‘u basalt quarry and other sites mentioned in the text.

analysis of adze preforms, blanks, and debitage in order to document the stages of manufacture and organisation of production at the quarry. We provide new EDXRF data to refine the geochemical characterisation of the Nu‘u quarry with respect to Haleakalā, the other known quarry on Maui Island. Finally, EDXRF data on the distribution of the Nu‘u quarry materials into the adjacent socio-political district, Kahikinui, provide a preliminary assessment of when the quarry was first used and offer data about the scale of distribution. We end with a comparative discussion of how adze manufacture at the Nu‘u quarry relates to other production sites in the Hawaiian archipelago. Our case study demonstrates that in-depth analyses of small scale production sites are needed for a more holistic understanding of the organisation of adze production in Hawai‘i. Such analyses have relevance to interpreting socio-economic systems in the prehistoric Hawaiian chiefdoms, including access to raw materials and specialist labour.

THE NU‘U QUARRY (SITE NUU-123)

The Nu‘u basalt quarry, formally designated site NUU-123, was discovered by Patrick V. Kirch on November 11, 2005 during reconnaissance survey in an upland portion of Nu‘u Mauka Ranch, Kaupō District, Island of Maui (Fig. 1).

A full day was devoted to mapping the quarry site with plane table and telescopic alidade at 1:100 scale, taking photographs and representative surface collections, and excavating a 50 x 50 cm test pit in the area of highest flake density. During this surface investigation, all cobbles with flaked or worked surfaces >25 cm diameter were piece-plotted, and some 26 basalt preforms or blanks were collected for laboratory analysis.

SETTING

Site NUU-123 lies at an elevation of 580 m above sea level, and is situated on a steeply sloping ridge or interfluve with intermittent stream gullies on the west and east. This location enjoys a commanding view westwards across the adjacent *ahupua‘a* of Nakula and beyond to the slopes of Kahikinui District. Vegetation on the ridge consists of low lantana (*Lantana camarra*) and scattered grass, making ground surface visibility good. A four-wheel drive track runs along the western edge of the lithic scatter, and may have disturbed the westernmost edge of the site. The approximate centre of the surface scatter of worked basalt defining the site is defined by coordinates 795448E and 2287128N in the Universal Transverse Mercator system (Zone 4N, Datum NAD83).

The geological substrate here consists of deeply weathered *‘a‘a* lava flows of the Kula Volcanic Series (Sherrod *et al*. 2007; Stearns and MacDonald 1942), which dates to between 140 and 780 kyr. Individual surface flows have not been mapped in detail or dated, but a surface flow of the same Kula surface and degree of weathering at Manawainui (7.4 km to the west) was dated by K-Ar to 226 kyr (Kirch *et al*. 2004), and the Nu‘u surface is likely to be of similar age. The Kula Volcanics date to the shield building phase of Haleakalā volcano, and typically consist of basalts, basanites, and hawaiites (Sherrod *et al*. 2007: fig. 25). The NUU-123 quarry is concentrated around basalt outcrops created by faulting of the *‘a‘a* flow. Individual outcrops, averaging around 1 m in diameter, provided the raw material source for adze production at the quarry. The outcrops were not worked *in situ*, but appear to have been prized out of the ground for reduction at the quarry site.

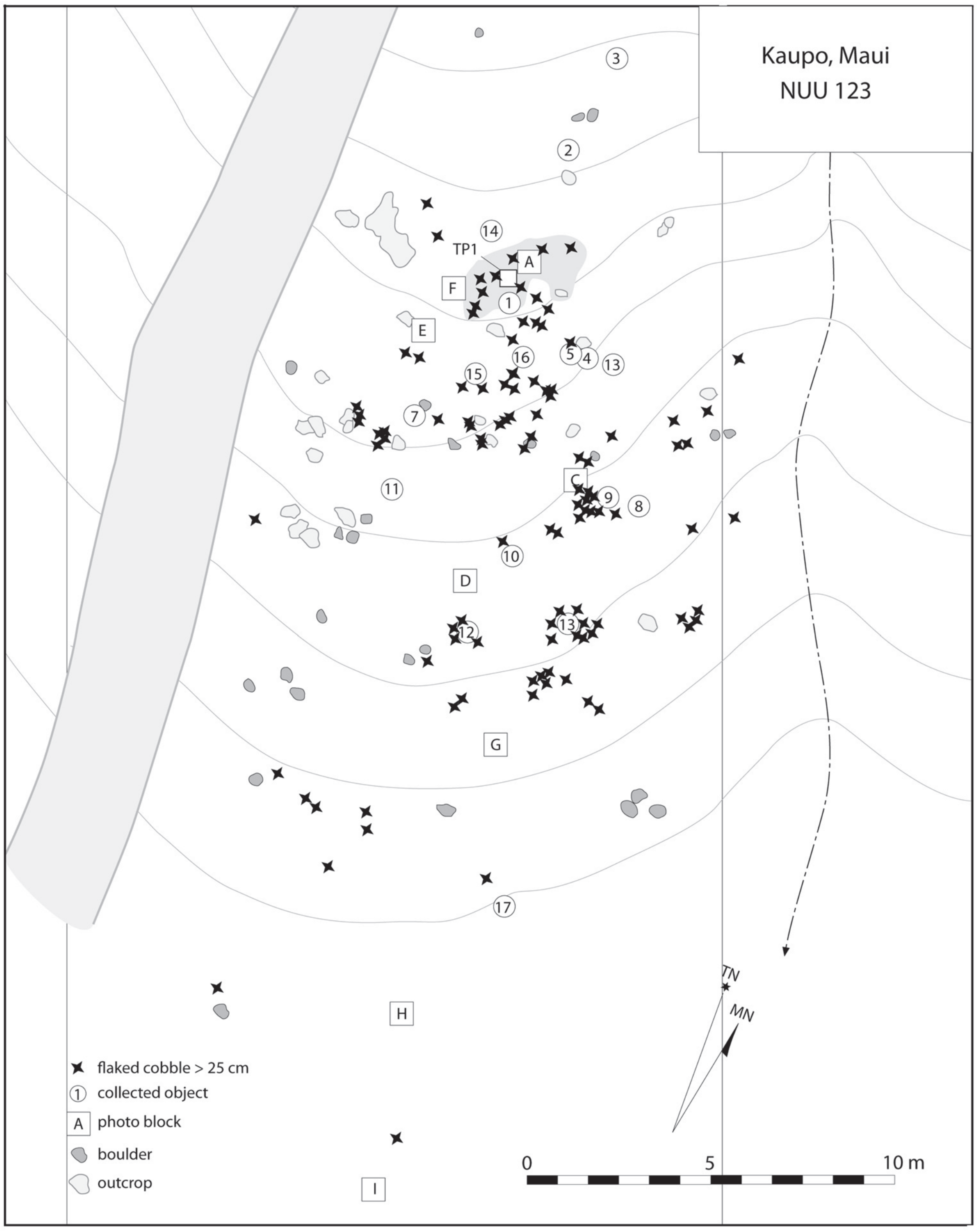

Figure 2: Map of the surface of the Nu‘u Quarry. Sample locales are designated with capital letters.

With respect to the broader settlement pattern at Nu‘u, site NUU-123 lies in a zone of relatively low site density, above the main zone of pre-contact Hawaiian habitation and agricultural activity in Nu‘u *ahupua‘a*. A few individual basalt flakes were observed lying on the open ridge to the north of the quarry, up to an elevation of about 675 m. Across a small gully and 68 m to the east of the quarry is NUU-124, a lithic scatter (*sensu* McCoy *et al*. 1993: 53) with fewer than 10 flakes observed on the surface; one complete basalt adze was also found at this spot. Roughly 250–300 m further downslope (southwards), stone structures such as stone-faced terraces and small enclosures begin to appear on the landscape. A relatively dense settlement landscape including agricultural terraces in swales, habitation features of various kinds, and ritual sites (*heiau*) extends from about 400 m asl to sea level. In short, the quarry lies in an upland zone, inland of the main zone of precontact habitation and land use.

SITE DESCRIPTION

The main lithic scatter measures 25 m from north to south (with the slope) and 19 m from west to east; a few isolated flakes and cores were found beyond these limits. A map of the site surface is shown in Figure 2, with contour intervals of 1 m. The highest density of worked basalt is found in the northern, or upslope, part of the surface scatter. A dense concentration of small (1–3 cm size) flakes, about 2 x 4 m in extent and surrounding several low outcrop boulders, appears to be a localised workshop area. Our test excavation was situated within this dense zone of fine basalt flakes. The density of flaked stone diminishes as one moves downslope. In order to document the density of debitage on the surface, photographs were taken of sample localities, which are designated with capital letters in Figure 2. A selection of these photos has been compiled in Figure 3, visually depicting the variation in debitage density. The quarry map also shows the locations of all flaked cobbles >25 cm in diameter, and the locations of 17 surface collected preforms.

TEST EXCAVATION

In order to obtain a representative sample of lithic material found within the upslope workshop, a 50 x 50 cm test pit was excavated, with all sediment sieved through ½, ¼, and ⅛ inch mesh (Fig. 4). All lithics retained in these sieves were bagged in the field for later washing and sorting in the laboratory. Prior to excavation, the surface of the unit was drawn at a scale of 1:5 and all surface lithics were collected. In the absence of any discernible stratigraphy, excavation proceeded in 5 cm arbitrary levels. Throughout the excavation, the sediment matrix consisted of a fine reddish brown (5 YR 4/4) silty clay loam; no charcoal or cultural materials other than basalt lithics were observed. At 15 cm depth, approximately 50 percent of the unit consisted of exposed basalt bedrock and at 20 cm, 90 percent of the surface was bedrock; excavation was terminated at 20 cm below surface. In sum, the excavation shows a single, undifferentiated deposit containing substantial quantities of flaked basalt to a depth of about 20 cm, at which bedrock was encountered.

AGE OF THE QUARRY

Unfortunately, no organic materials suitable for radiocarbon dating were obtained from the test excavation. However, as described further below, basalt flakes tentatively assigned to the Nu'u quarry source on the basis of EDXRF analysis were excavated by Kirch from sites in the adjacent Kahikinui District of Maui. Four flakes assigned to the Nu'u source were recovered from site KIP-752, and one additional flake matching Nu'u geochemistry was recovered from the nearby site KIP-1307. These two sites lie within the main upland habitation zone in Kipapa *ahupua'a* at Kahikinui, about 13.2 km west of NUU-123 (Fig. 1).

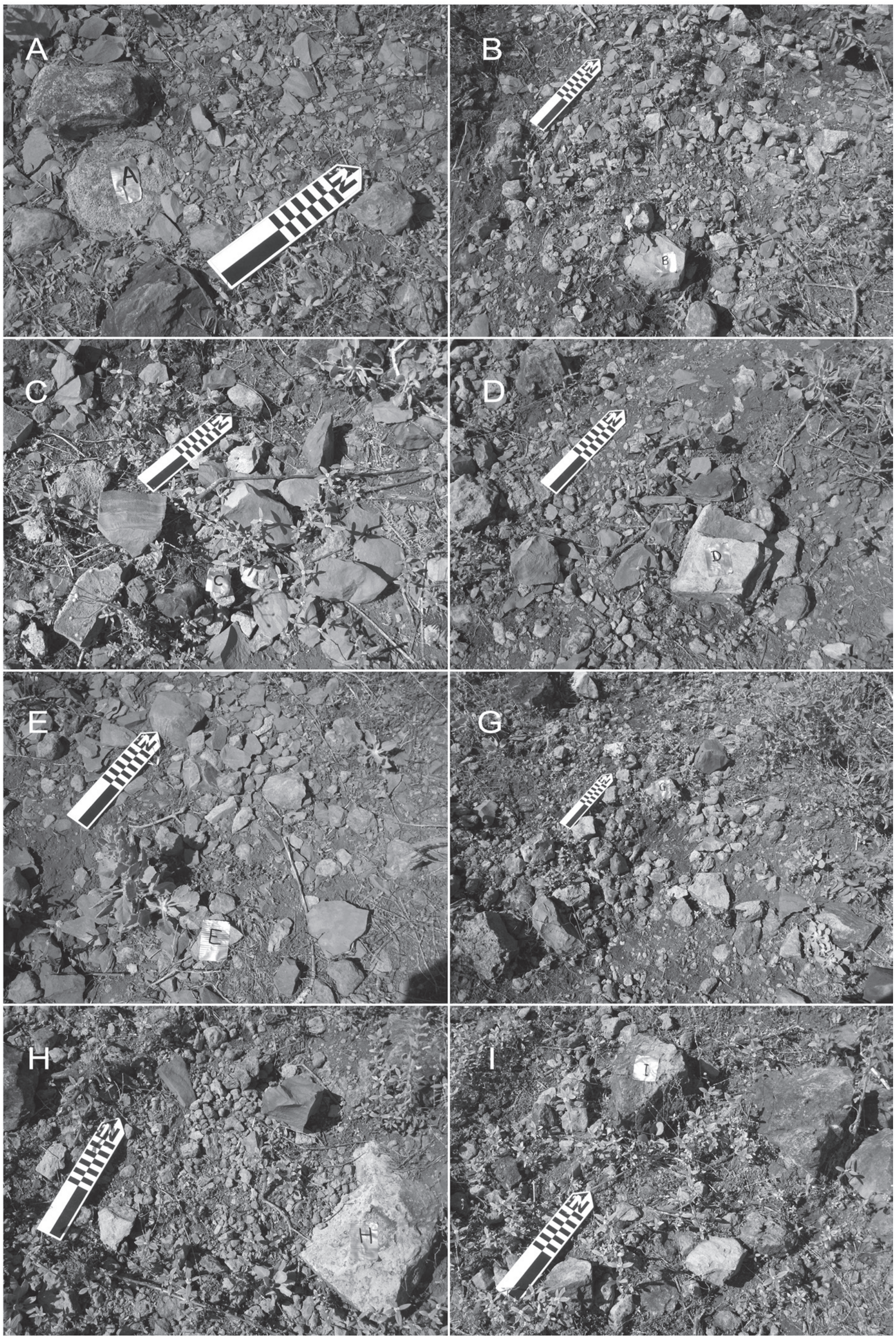

Figure 3: Photos of selected surfaces within the Nu‘u Quarry, showing the variation in density of debitage and flaked boulders. Sample locality numbers A–I correspond to locations shown in Figure 2. Note the high frequency of small flakes in blocks A to D in the upper part of the quarry, as opposed to the low density of large flakes in E to I.

Figure 4: Test Pit 1 before excavation.

Both sites have been radiocarbon dated, and the date ranges for these sites can be used to approximate the time span during which the Nu'u basalt quarry was in use. Six ^{14}C dates from sites KIP-752 and KIP-1307 indicate that the KIP-752 habitation terrace may have been in use as early as the sixteenth century, and the other dates clearly document use of these sites during the seventeenth to eighteenth centuries. We therefore infer that the Nu'u quarry, from which flakes deposited in these two Kahikinui sites derived, was likely to have been in use during the last two centuries before European contact.

TECHNOLOGICAL ANALYSES OF THE NU'U QUARRY ASSEMBLAGE

METHODS

We used a modified form of Mass Analysis (MA, also known as Flake Aggregate Analysis, see Ahler 1989a, 1989b) to grade the Nu'u debitage assemblage according to size. The MA technique facilitates analysis of large assemblages by size grading assemblages, most commonly through nested screens. The analysis concentrates on weight and size; these are two frequently used attributes for determining reduction stage, based on the assumption that as reduction proceeds flakes will tend to get smaller and lighter (Andrefsky 1998, 2001). Varying forms of the MA technique have seen recent use in Polynesia (Holm 2006; Kahn 1996; Mintmier 2007; Turner *et al*. 2001; Turner and Bonica 1994).

Some lithic analysts have noted that size and weight variables must be used cautiously, as small flakes are produced in large amounts in nearly all stages of adze production

(Cleghorn 1982) and biface reduction (Stahle and Dunn 1982: 86–87). In 1996, Kahn compared results from the MA technique and the Individual Flake Analysis technique (IFA) during her technological analysis of a Marquesan lithic assemblage. In IFA analysis, several attributes are identified on *individual* chipped stone artefacts. Attributes are measured by recording either their presence or absence or by measuring or tabulating a feature (Carr 1994; Kahn 1996; Magne 1985) and combinations of specific attributes are then used to discern which reduction stages are present. Kahn's results (1996: 282) broadly demonstrated concurrence between the two types of analyses, leading her to argue that the size grading technique, particularly when coupled with other attribute analysis including the recording of cortex coverage and dorsal scar complexity, offers a viable alternative to the more time consuming IFA technique. A strict MA approach ignores variability in the individual flake attributes (see also Shott 1994), particularly with respect to blank size and/or the original form and size of the reduced raw material (Andrefsky 2007), yet coupling MA analysis with limited attribute analysis can obviate these deficiencies. We argue that modified MA analysis can be used as an effective technique for inferring reduction stages at specialised sites such as adze quarries, which lack evidence for numerous types of production technologies and/or numerous types of produced artefacts. Following this, we used a coupled Mass Analysis-Individual Flake Analysis approach (or Modified Mass Analysis) in the Nu‘u debitage analysis.

A 100 percent (N=1,689) sample of the Nu‘u debitage obtained from our test excavation was size graded through nested screens (1 inch, ½ inch, ¼ inch, ⅛ inch). After size grading, variables were recorded for debitage types in each size grade. Each artefact was typed according to debitage class (complete flake, proximal flake fragment, distal or medial flake fragment, shatter[2], see Kahn [2005] for further descriptions). For each artefact, the presence or absence of cortex, cortex location (striking platform or dorsal surface), and number of dorsal scars (0, 1, 2, 3, 4, >4) were recorded.

In the preform and blank analyses, typological and technological attributes were used to build a multi-scalar model of variation in adze manufacture and adze use. Following Weisler (1990) and Dye and colleagues (1985), we define adze *blanks* as worked cores or flakes where it is not possible to determine the finished cross-section with certainty. This is because blanks represent items discarded at a stage where they could have been further modified into more than one cross-section form.[3] *Preforms* have a determinable cross-section but lack surface grinding. Taken as a whole, the broken and discarded blanks and preforms recorded in the present study correspond to adze *rejects*, as defined by McCoy (1990; McCoy *et al*. 1993) and by Bayman and Moniz-Nakamura (2001). We define rejected flake blanks as flakes of suitable size and form for further reduction into adzes that were discarded after only minimal reduction and/or use.

To gather data relevant to modelling local adze production, we measured artefact size and weight and recorded artefact condition (whole or fragmentary), series (undeterminable, flake, core), cortex coverage, and the number and location of edges with bi-directional flaking (see Kahn 2009). Bi-directionally flaked edges have flakes detached from both adjacent surfaces of an edge between two faces (Leach 1981; Leach and Leach 1980). We make a distinction between uni-lateral flaking across a single face and bi-directional flaking. The number of edges with bi-directional flaking is expected to increase as the object progressed along the reduction sequence (Cleghorn 1982: 196; Weisler 1990: 38). Patterns of bi-directional flaking (whether bilateral, trilateral, or quadrilateral) can also vary with the type of parent material reduced (Leach and Leach 1980).

RESULTS: DEBITAGE

The test excavations yielded a total of 1,689 basalt flakes, flake fragments, and shatter (Table 1). The estimated volume of debitage per m^3 is high at 33,780,[4] indicative of an adze manufacturing locale with a moderate scale of production.[5] For comparison, Mintmier (2007: 13) reports a volume estimate of 78,660 per m^3 for Haleakalā, and much lower estimates for Pōhakuloa and Pololū. At Mauna Kea, excavations at Workshop 2, Site 2, Feature 10 produced a high volume of debitage per m^3 of 32,458 (see Cleghorn 1982: 101–102). However, the inclusion of surface collected flakes from the 40 x 60 cm unit that was excavated would increase the Mauna Kea estimate even further, as the density of surface debitage found at the Mauna Kea workshops can be extremely high.[6]

TABLE 1
Debitage counts by excavation layer.

Depth	**Count**
Surface	144
Level 1, 0–5 cm	680
Level 2, 5–10 cm	771
Level 3, 10–15 cm	64
Level 4, 1–20 cm	19
Wall cleaning	11
Total	**1689**

TABLE 2

Debitage counts by size grade.
Size (mm) refers to the size of artefacts that can pass through the "actual diagonal opening size" for each screen (after Ahler 1989a; Brisland 1992:95).

Size grade	**Screen size**	**Size (mm)**	**Count**	**% overall assemblage**
1	1 inch (25.4 mm)	>35.90	155	9.2
2	½ inch (8.38 mm)	18.0–35.9	411	24.3
3	¼ inch (6.35 mm)	8.01–17.9	880	52.1
4	⅛ inch (3.18 mm)	<8.0	242	14.3

Nine percent of the flakes were recovered from the surface of the test pit, while the majority were found in the cultural deposit between 0 and 10 cm below the surface. Table 2 illustrates how the MA size grades conform to metric size ranges and nested screen sizes and also presents data on counts and percentages of the size grades for the Nu'u assemblage. The moderate frequency of flakes in the largest size class, G1, illustrates that *in situ* adze manufacture was carried out at the site. The broad range of flake sizes, with representation in size grades 1–4, demonstrates that the full range of production activities,

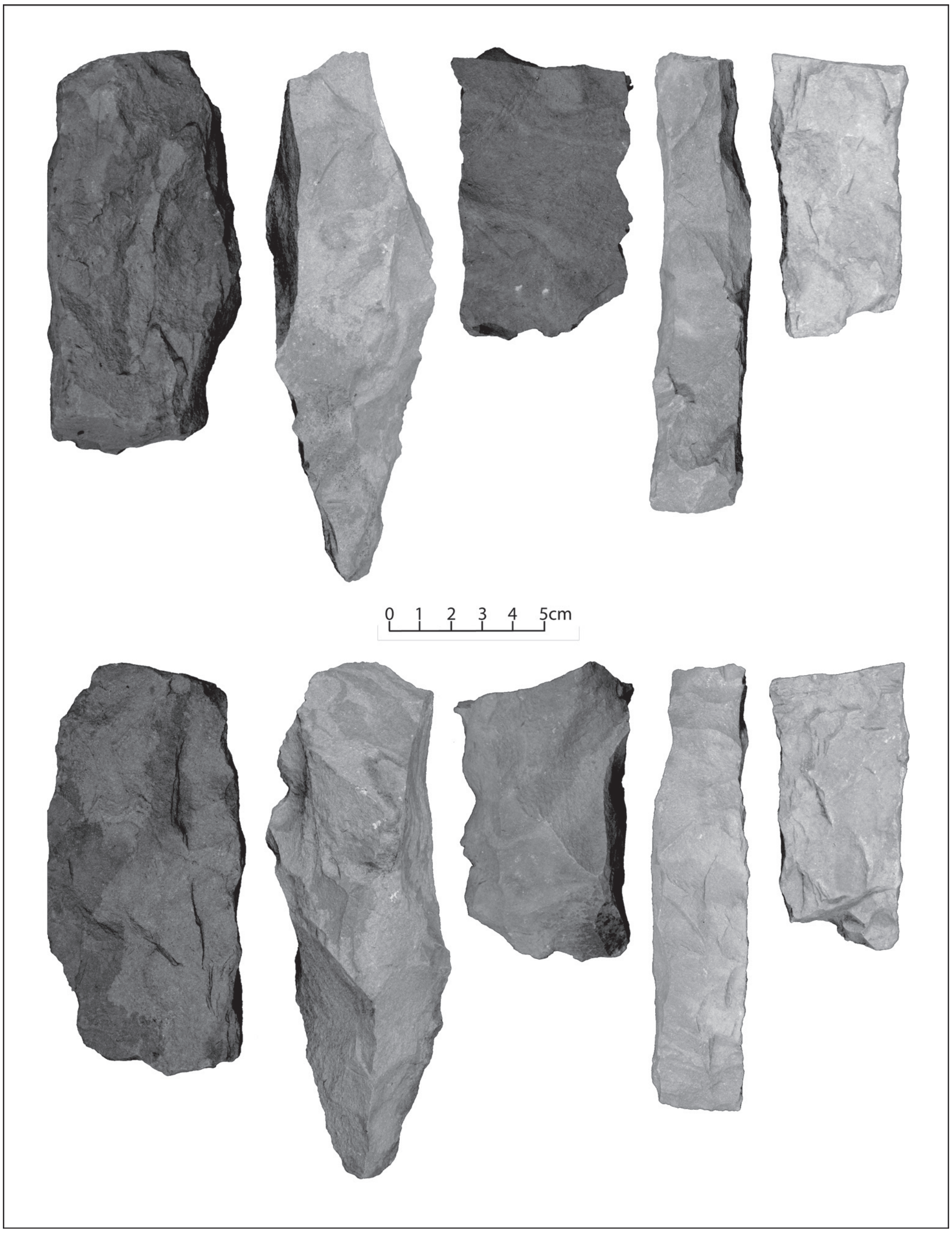

Figure 5: Examples of basalt artefacts from Nu‘u Quarry, site 123.

Figure 6: Examples of basalt artefacts from Nu‘u Quarry, site 123.

from early stage blank manufacture to late stage preform trimming, are represented. Eighteen percent of the Nu‘u debitage assemblage retained cortex coverage, while 79 percent had low dorsal scar counts. This is consistent with data from adze replication experiments where the full range of adze manufacture was completed. The cortex coverage frequencies are most similar to adze replication experiments where flake blanks were reduced (Cleghorn 1982: 257).

TOOLS

Thirty-five basalt tool artefacts from Nu‘u Site 123 were analysed, including numerous blanks and preforms, six rejected/used flake blanks, two blanks for disk-shaped objects, and a hammerstone (Table 3). A selection of these artefacts is illustrated in Figures 5 and 6.

TABLE 3
Basalt tools, Nu‘u Site 123.

Artefact Class	**Count**
Blank	12
Preform	14
Rejected/used flake blanks	6
Disk blank?	2
Hammerstone	1
Total	**35**

RESULTS: BLANKS AND PREFORMS

On the basis of the surface survey, adze blanks and preforms were the dominant artefacts produced at the Nu‘u quarry. Of the 26 blanks and preforms recovered, 9 (35%) are whole. The remaining 17 (65%) are broken, mostly at the mid-section, either at or near the juncture of the poll/shoulder. Two (12%) of the broken preforms or blanks represent cutting edge to mid-body sections. As in other Hawaiian quarries, rejection because of end-shock fractures accounts for most (63%) of the discarded items. Discard because of ridges isolated by step terminations or hinge flakes ranges from 25 percent for blanks to 7 percent for preforms.

The majority of specimens where reduction series could be determined were reduced as flake blanks (n=9, 75%) (Table 4). The orientation of the ventral face for flake blanks was to the front (n=9, 75%) (Table 5). The striking platform was commonly situated at either end (bevel or poll), with a preference for the poll. The original striking platform was often used as a platform to remove trimming flakes along the sides and back of the blanks. One flake blank (specimen #13) has a ventral face oriented to the front and the striking platform oriented to the side. This wide expanding flake blank was rejected early in the reduction sequence and about 50 percent cortex cover remains on the back surface. The specimen was probably rejected as difficulties were encountered in the removal of cortex along the back, including erroneous flake removal leaving a deep flake scar, which prohibited further refinement of the cross-section. Although the flake series predominates, the reduction of cores is also evident, comprising 25 percent of the Nu‘u specimens on which reduction series could be determined.

TABLE 4
Descriptions of Nu'u Quarry adze blanks and adze preforms
(modelled after McCoy 1986 and Weisler 1990).

	Blanks	**Preforms**
Sample size	12	14
Mean Metric Attributes†		
length (mm) [4,5]	109.9 ± 25.9	129.1 ± 31.1
width (mm) [4,5]	54.0 ± 13.6	43.1 ± 14.7
thickness (mm) [4,5]	34.7 ± 13.9	30.7 ± 14.0
weight (g) [3,4]	452.0 ± 190.9	253.3 ± 171.1
Discrete Attributes		
Condition:		
Whole	4	5
Fragment	8	9
Series:		
Undeterminable	3	11
Flake series	6	3
Core series	3	0
Cortex:		
Yes	5	1
No	7	13
# Edges bi-directionally flaked per specimen:		
None (trimming only)	4	2
One	6	3
Two	2	1
Three	0	4
Four	0	4
Longitudinal Profile:		
Undeterminable	3	3
Tanged	3	5
Untanged	6	6
Bevel Formation:		
Undeterminable	4	5
Yes	0	7
No	8	2
Cross-section:		
Undeterminable	1	0
Rectangular	4	7
Square	1	4
Trapezoidal	5	1
Reverse triangular	0	2
Triangular	1	0

†Metric measurements provided for complete specimens only.
Numbers in brackets provide sample size: [4,5] = 4 blanks, 5 preforms.

TABLE 5
Orientation of Nu‘u Quarry flake blanks.

Ventral face:	
Undetermined	3
Front	9
Back	0
Platform location:	
Undetermined	5
Poll	4
Side	1
Bevel	2

A moderately high percentage of blanks retain cortex cover (n=5, 42%), ranging from 25 percent to 75 percent of their surface (Table 6). In contrast, only a single preform retains cortex. The marked frequency of cortex coverage in blanks and its rarity in preforms illustrates that a focus of the reduction strategy in the blank to preform transition was removal of remaining cortex in order to refine the cross-section. Flake blanks had both a higher frequency of cortex cover and a larger percentage of their surface area covered than core blanks.

Preforms had a higher incidence of edges with bi-directional flaking (86%) than blanks (67%) (Table 4). Hence, the number of edges reduced with bi-directional flaking clearly increased as the manufacturing sequence progressed. Sixty-four percent of preforms have two or more edges with bi-directional flaking; of these 44 percent have three edges with bi-directional flaking and 44 percent have bi-directional flaking on all four edges. In contrast, blanks lacked bi-directional flaking on all edges and only had 1–2 edges reduced in this manner. This demonstrates that directional flaking was a principal reduction strategy used to refine the cross-section in later phases of the manufacturing sequence. At Nu‘u, early blank reduction emphasised uni-directional trimming of the front, back, and particularly the sides. The latter was accomplished by removing flakes struck from striking platforms on the front or back. Later stage blanks had evidence for bi-directional shaping of either the back or front and an adjacent side. As manufacture progressed to the final preform shaping, the remaining surface (either front or back) and side were bi-directionally flaked.

As seen in Table 4, there is a higher incidence of tang formation among preforms (36%) than blanks (25%). Given that tanged adzes were ubiquitous in late pre-contact Hawai‘i (Emory 1968; Kirch 1985, see also Cleghorn 1992: 140), the period to which most sites in the Kaupō district date, it is likely that many of the Nu‘u blanks and preforms were rejected prior to tang formation. The data suggest that tang reduction sometimes commenced at the late blank stage, occurred more frequently at the preform stage, and was probably most frequent at the latter stages of preform reduction/final finishing. Fashioning and refining the bevel was clearly a step carried out late in the reduction sequence during preform reduction. Fifty percent of the preforms exhibit evidence for bevel formation, while none of the blanks exhibited flaking on the blade consistent with bevel formation.

A variety of cross-sections are found in the Nu‘u quarry assemblage, albeit some with low frequency. The blank assemblage is dominated by trapezoidal (42%) and rectangular (33%) forms, while square, triangular, and indeterminate cross-sections are each found with low frequency (8%). The triangular cross-section blank was discarded at an early stage before the front and back were differentiated from one another; thus whether this was intended to be a triangular or reverse triangular cross-section is unknown. The preforms also have a range of cross-sections, but in contrast to the blanks, rectangular forms predominate (50%) and trapezoidal forms are much reduced in number (7%). This suggests that with further side reduction and cross-section refinement, a number of the trapezoidal blanks might have been intended to be further reduced to rectangular preforms. Square (33%) and reverse triangular (14%) preforms are also represented.

TABLE 6
Cortex cover, Nu'u Site 123 blanks and preforms.

	Blanks			**Preforms**		
% Cortex cover	**flake**	**core**	**undet.**	**flake**	**core**	**undet.**
0	3	1	3	3	-	10
1–24%	1	2	-	-	-	1
25–49%	1	-	-	-	-	-
50–74%	1	-	-	-	-	-
75–99%	-	-	-	-	-	-
100%	-	-	-	-	-	-

TABLE 7
Metric data (length, thickness, width [mm], weight [g]) for complete blanks and preforms recovered from the Nu'u Quarry.

	Blanks (n=4)	*Preforms (n=5)*
Length		
Mean	109.9	129.1
Min.	83.9	79.5
Max.	140.3	162.7
SD	25.9	31.1
Thickness		
Mean	34.7	30.7
Min.	23.3	13.1
Max.	53.3	51.2
SD	13.9	14.0
Width		
Mean	54.0	43.1
Min.	36.1	29.4
Max.	67.1	63.2
SD	14.7	13.6
Weight		
Mean	452.0	253.3
Min.	125.5	53.0
Max.	452.0	469.5
SD	190.9	171.1

One can argue that size characteristics of adze rejects found at quarries serve as more reliable indicators of the intended size of finished adzes than used and re-used adzes recovered from habitation sites. In East Polynesia, quarry specimens typically lack evidence for recycling and resharpening, activities which can leave re-used adzes in habitation assemblages smaller than their size at original production or diverging from their initial design shape (see Cleghorn 1992; Turner 2005; Turner and Bonica 1994). However, the extent to which smaller adzes were purposefully selected for use at residential sites, because of functional needs and different activities than those carried out at other site types such as *heiau* or canoe production zones, warrants further attention (see Kahn 2005: 388–390 for a Society Islands example). Notably, the size statistics for the complete (unbroken) blanks and preforms at the Nu‘u quarry demonstrate a lack of standardisation (Table 7). In particular, weight and length vary substantially and the high standard deviation suggests that a range of adze sizes, including both smaller, lighter adzes and longer, heavier ones, were manufactured at this site.

Figures 7 and 8 illustrate a broad range in the size/weight distribution of the Nu‘u complete preforms and blanks and demonstrate that there are two distinct clusters in the Nu‘u assemblages. The first are short, thin, and light preforms and blanks represented by three specimens of either trapezoidal or rectangular cross-section.

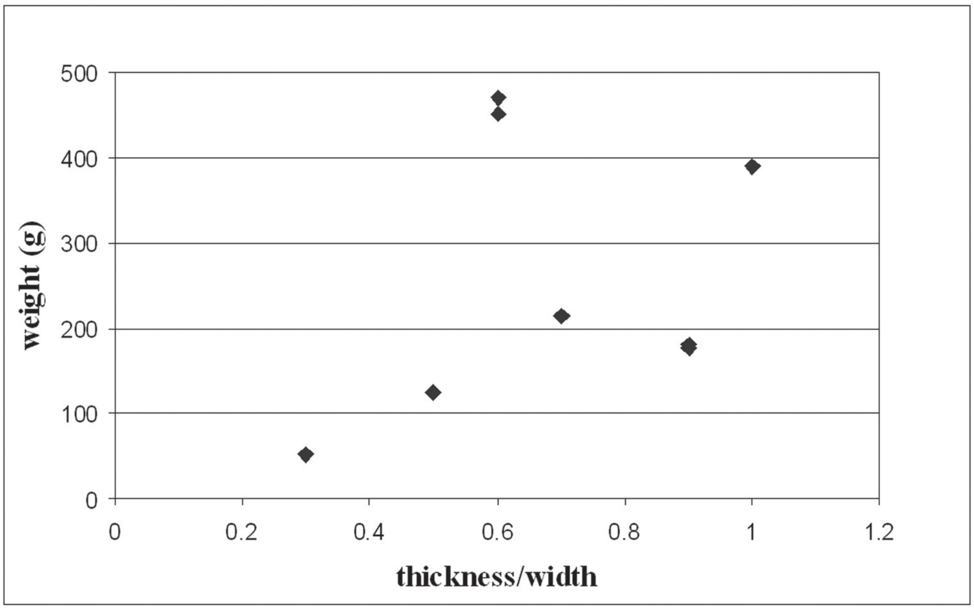

Figure 7: Plot of complete preform and blank thickness/width by weight.

These small adze rejects are broad and thin. The second cluster represents thick heavy preforms and blanks that range from long (n=3) to moderately long (n=3) to short (n=1) in length. These robust specimens exhibit a range of cross-sections, including reverse triangular, triangular, trapezoidal, rectangular, and square. These plots demonstrate that adze production at the Nu‘u quarry was quite varied; adzes of diverse size, cross-section, and girth were manufactured.

Five of the flakes represent thin, small blanks classified as Blank Type A in Leach and Witter’s 1987 typology, although at 15.2–21.8 mm they slightly exceed the 5–10 mm thickness reported by Leach and Witter. These flake blanks would be suitable for further

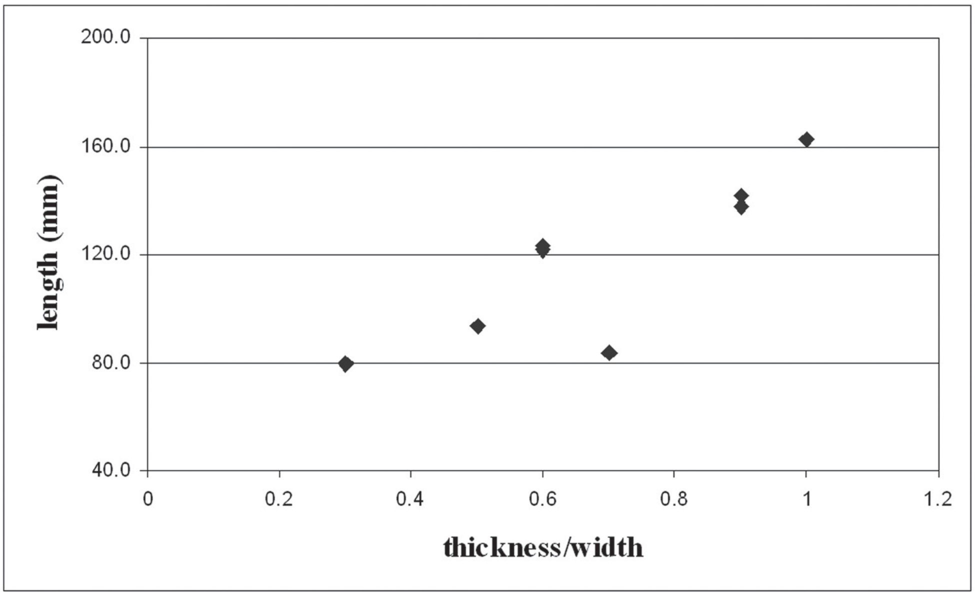

Figure 8: Plot of complete preform and blank thickness/width by length.

reduction into small adzes of rectangular or quadrangular cross-sections. Less common are expanding flake blanks, such as Leach and Witter's Blank Type B2, suitable for reduction into rectangular, quadrangular, or triangular adzes. Data from the rejected flake blanks indicate that these were most often oriented with the striking platform to the poll or bevel end. Occasionally, expanding flake blanks were reduced with their striking platform oriented to a lateral margin.

HAMMERSTONES AND DISCOIDS

A single hammerstone and two 'discoid' blanks were recovered (Table 3). The hammerstone is an uncommon type, formed from an expanding flake that has been bifacially flaked on its striking platform, distal edge, and one lateral edge to 'back' or blunt these edges. An ovoid portion of the non-backed lateral edge was used and exhibits extensive battering and pitting. The two discoid blanks are round and thin and have evidence of bifacial reduction along their margins. Both items retain cortex along both surfaces and lack evidence of use along their margins (bashing or pitting), suggesting they were not hammerstones. These disks were discarded in an unfinished state, making it difficult to determine their intended function. They are too thin to represent *ulu maika* blanks. One specimen clearly has a plano-convex cross-section. Their shape and cross-section tentatively suggest they may be blanks for gaming quoits (see Hiroa 1957: 372–374).

REDUCTION MODEL

The blank and preform data presented above, along with the debitage analysis, suggest that the Nu'u quarry assemblage represents a full range of adze manufacture, from early stage blank production to later stage preform trimming. This allows us to propose the following model for the production of rectangular adze preforms from flake blanks, the most ubiquitous type found at the quarry.

1. Production of either a thin, small flake blank with long parallel sides or, less commonly, a thicker expanding flake blank.
2. Orientation of the ventral face of the flake to the front and striking platform to the poll.
3. Removal of trimming flakes struck from the edges of the back or front down a side.
4. Removal of trimming flakes along the front and back by striking flakes off the original striking platform of the flake blank.
5. Bi-directional flaking of the front or back and an adjacent side, in doing so removing the bulb of percussion along the central surface of the original flake blank.
6. Bi-directional flaking of the remaining face and the remaining side.
7. Tang reduction.
8. Bevel formation.

Analysis of a larger sample might allow for other reduction stage trajectories and those relating to other types of preform cross-sections to be developed in the future.

EDXRF ANALYSIS OF THE NU'U QUARRY ASSEMBLAGE

A sample of 47 flakes recovered from the Nu'u Quarry was analysed for geochemical composition. This sample was selected with the aim of documenting raw material variability; items which varied in either raw material colour or the number, type, or colour of inclusions were chosen. The analyses were completed on a QuanX™ EDXRF spectrometer with an extended sample chamber, using a rhodium (stable-isotope) X-ray tube, thermoelectrically-cooled detector, and supporting Edmunds vacuum pump, with data processed on Wintrace ™ software, version 3.1, build 33. Conducting EDXRF analyses involves using variable X-ray energies to detect different elements. By varying the kinds of X-rays produced, one can optimise the fluorescence of particular elements of analytical interest. We analysed a suite of 16 elements, using the methodology described by Lundblad *et al*. (2008). Certain trace elements in basalt, particularly rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), and niobium (Nb), exhibit the best analytical precision with EDXRF, while data for major elements are less precise. The 47 flakes were analysed by placing the flattest interior surface on the flake over the X-Ray beam. Each sample run also included the analysis of a known geological standard prepared by the USGS from a basalt source in Kilauea Caldera (BHVO-2; Wilson 1997).

In order for EDXRF spectrometers to yield quantitative analyses, the spectrometers must be calibrated by analysing similar geological reference standards that contain well-established concentrations of elements. The UH Hilo spectrometer has been calibrated for the analysis of basalt with 27 geological standards. They include 12 USGS standards (AGV-2, BCR-1, BCR-2, BHVO-1, BHVO-2, BIR-1, DNC-1, DTS-2, GSP-2, QLO-1, STM-1, W-2), 12 Geological Survey of Canada standards (LKSD 1-4, FER 1-4, TILL 1-4), two basalt standards from the Geological Survey of Japan (JB-2, JB-3), and one Geological Survey of China basalt standard (NCS DC 73303).

TABLE 8
EDXRF results for the Nu'u Quarry compared with the measured and accepted values for the USGS geological standard BHVO-2.
Individual analyses for each sample can be downloaded from
http://www.uhh.hawaii.edu/uhh/faculty/lundblad/EDXRFandtheGeoarchaeologyLab.php

Element/ Oxide	**Nu'u average measured value**	**Nu'u SD (N=47)**	**BHV0-2 average measured value**	**BHV0-2 SD (N=3)**	**BHV0-2 accepted value**
Na_2O	4.3	3.7	2.6	1.2	2.22
MgO (%)	1.9	0.29	7.7	0.04	7.23
Al_2O_3 (%)	17.3	1.24	13.5	0.09	13.5
SiO_2 (%)	49.1	2.08	48.0	0.25	49.9
K_2O (%)	1.9	0.07	0.6	0.02	0.52
CaO (%)	7.2	0.42	11.9	0.15	11.4
TiO_2 (%)	3.0	0.13	2.9	0.03	2.73
V (ppm)	217	20.88	339	10.66	317
MnO (ppm)	2515	153.1	1668	30.52	1666
Fe (%)	9.3	0.99	8.5	0.05	8.6
Ni (ppm)	0.5	1.23	99	4.41	119
Cu (ppm)	15	6.68	109	5.26	127
Zn (ppm)	140	8.06	95	2.37	103
Rb (ppm)	64	4.14	12	0.21	9.8
Sr (ppm)	1361	3.05	366	1.73	389
Y (ppm)	44	2.52	25	0.49	26
Zr (ppm)	430	0.85	175	2.54	172
Nb (ppm)	84	3.94	19	0.3	18

RESULTS

Table 8 presents the average measured values and standard deviations for the Nu'u samples in comparison with three concurrent analyses of the USGS geological standard BHVO-2. These data can be compared with those obtained for previously analysed quarried materials from the Hana volcanic series near the summit of Haleakalā (Sinton and Sinoto 1997: 200). The Haleakalā quarry complex, discussed by Cleghorn *et al*. (1985) and more recently studied by Mintmier (2007) is situated on the northwest rim of the crater. Sinton and Sinoto analysed two samples from the Haleakalā summit for trace elements, and three samples for major elements using destructive WDXRF techniques. A bivariate plot of strontium (Sr) and zirconium (Zr) is presented in Figure 9, and demonstrates measured differences between the two sources. More recently, seventy-five geological samples from the Haleakalā summit region have also been analysed on the EDXRF spectrometer at Hilo. The range of values

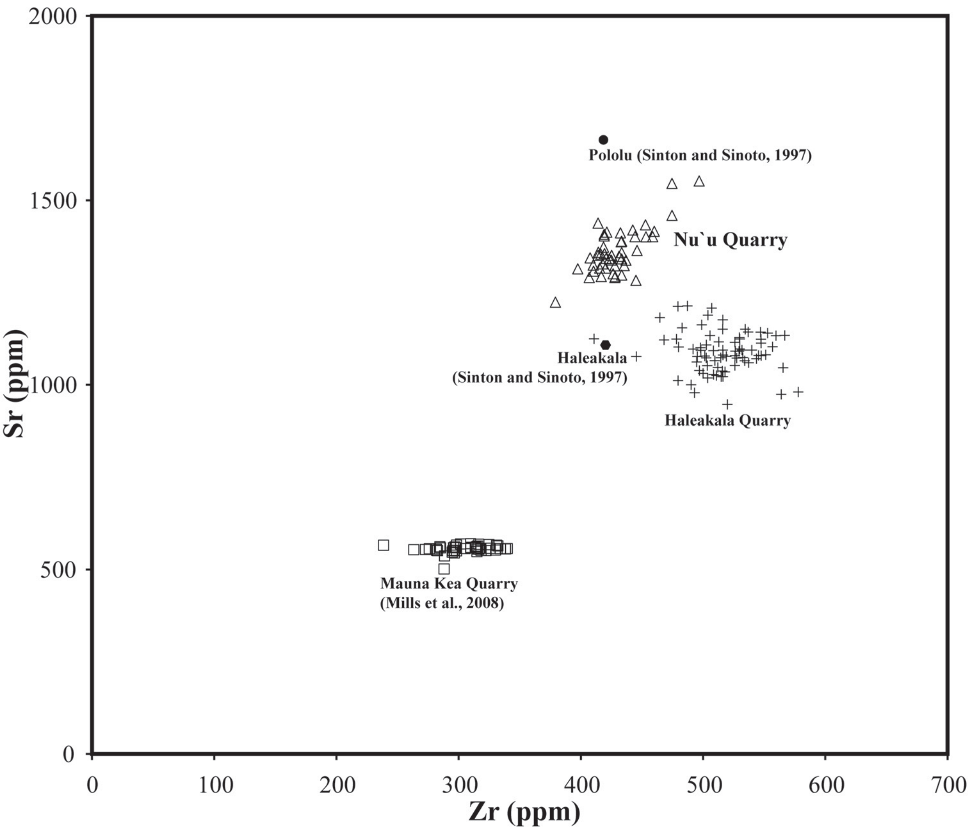

Figure 9: Bivariate plot of strontium (Sr) and zirconium (Zr), showing the relationship of Nu‘u Quarry geochemistry to that of other known basalt quarries on Maui and the Big Island.

for Sr and Zr is indicated in Figure 9; the entire dataset is posted online (http://www.uhh.hawaii.edu/uhh/faculty/lundblad/Haleakala.htm). These datasets show general agreement between analyses conducted by Sinton and Sinoto (1997) and on Hilo’s EDXRF spectrometer and, in all cases, the Haleakalā material has lower strontium concentrations than those measured in the Nu‘u samples. Zirconium concentrations for the Haleakalā material are equal to, or greater, than those measured for Nu‘u.

EXTRA-AREAL COMPARISONS WITH OTHER HAWAIIAN QUARRIES

Utilising volume estimates, Mintmier (2007: 13) highlighted diversity in production scale for Hawaiian quarries. Mauna Kea production output is recorded as high, perhaps in the 2,000,000 m^3 range (see end note 6); Haleakalā (Maui) as moderate (78,660 m^3); and Pōhakuloa and Pololū (both on Hawai‘i Island) as low (486 m^3 and 3,850 m^3 respectively). We estimate the Nu‘u quarry volume as moderate at 33,780 m^3, similar to but lower than Haleakalā values yet much higher than values reported for smaller ‘expedient’ quarries

(Pōhakuloa and Pololū). This provides some support for the inference that Nu‘u produced adzes for a local population rather than for regional export.

Variation in the size of the quarries can also be used as an index of scale. Individual chipping stations and workshop sites at Mauna Kea vary in size from a few m^2 in area with thin deposits, to over 100 m^2 with debitage piles up to 3 m thick (Cleghorn 1982; McCoy 1977, 1986, 1991). The total estimated surface area of the Mauna Kea quarry is over 18 km^2, larger than the combined surface area of *all* other known Hawaiian quarries (Mills *et al*. 2008). The known flaking areas at Pololū (345 m^2, see Tuggle 1976: 43) and Haleakalā (range for sites = 84 to 180 m^2, total area = 424 m^2, see Mintmier 2007: 6–8, figs 2, 4, 6) are moderate in size, while that found at the Pōhakuloa Site 5003 (*c*. 53.5 m^2, Bayman *et al*. 2001: 27, fig. 2.10) was considerably smaller.[7] At 345 m^2, the Nu‘u quarry is moderate in both size and production output and somewhat smaller in total area and production output than its nearest known neighbour on Maui, Haleakalā. Our case study thus adds support to the interpretation that there was a ‘continuum’ of adze production sites (Mintmier 2007) ranging from small to medium to large in scale.

Adze production strategies at the Nu‘u quarry share much in common with those documented for other small to moderate scale quarries in Hawai‘i. For example, as with many Hawaiian quarries (Dixon *et al*. 1994; Dye *et al*. 1985; McCoy 1990; McCoy *et al*. 1993; Mintmier 2007; Weisler 1990), raw material procurement emphasised stone acquired from weathered natural outcrops or nearby talus accumulations, as opposed to actual mining of raw material, which is found at the Mauna Kea quarry (McCoy and Gould 1977: 238). Hawaiian knappers at the Nu‘u quarry preferred to reduce flake blanks; a similar pattern was found at Haleakalā quarry sites (Mintmier 2007) and those on Lāna‘i and Moloka‘i (Dye *et al*. 1985; Weisler 1990). However, core reduction is found with moderate frequency at Nu‘u (25%); this dual reduction strategy is comparable to that at Kaho‘olawe production sites, where flake reduction predominates (67%) but core reduction is also represented (19%) (McCoy *et al*. 1993). Dual reduction strategies are also represented at Mauna Kea, where both core and flake blanks were reduced; McCoy (1986: 379) notes that flake blank reduction was often reserved for high quality materials and for the production of smaller adzes. Core series reduction is also found with some frequency at the Waiāhole quarry on O‘ahu (Dye *et al*. 1985).

Nu‘u flake blanks were commonly oriented with ventral face to the front and striking platform to the poll, strikingly similar to reduction strategies used at Kapōhaku adze quarry (Weisler 1990); however, at Nu‘u, knappers occasionally reduced expanding flakes with striking platforms oriented to the side. The Nu‘u data demonstrate that the number of bi-directionally flaked edges increases as reduction proceeded from blank to preform. Studies of other Hawaiian quarries have illustrated the importance of bi-directional reduction, particularly as a technique for refining the cross-section in later phases of the manufacturing sequence (Weisler 1990) and for the reduction of rectangular cross-sectioned adzes (Cleghorn 1982).[8]

Hawaiians engaged in most stages of the adze reduction sequence at the Nu‘u quarry, including early stage blank production and later stage preform manufacture, but not final polishing. Fifty percent of Nu‘u preforms had clearly formed bevels and 25 percent of blanks and 42 percent of preforms had evidence for tang formation; this correlates well with Hawaiian quarries where the full range of adze production, minus final polishing, took place. The low incidence of tang formation at Nu‘u and other quarries (e.g. ‘Amikopala, Mauna Kea, Mo‘omomi, Kaho‘olawe, Waihole) demonstrates that tang production was one of the final stages in the reduction sequence. Yet the Nu‘u data differ from Haleakalā sites where some adze rejects had formed bevels and all lacked tang formation (Mintmier 2007: 10), and Pololū, where only 25 percent of adze rejects had bevel flaking and all lacked tang formation. Pololū has been described as a production area where only the early stages of adze manufacture were carried out (Lass 1994: 41). Mintmier (2007: 13) notes that the Haleakalā quarry site probably focused only on extraction, whereas activities at the cave shelters on the outer rim emphasised early preform reduction. Thus, there is some diversity in the range of adze production stages represented at quarries across the archipelago.

At first glance, the variety of cross-sections represented in the Nu‘u assemblage seems at variance with other production locales in Hawai‘i, such as Mauna Kea, Kapōhaku, and Haleakalā, where untanged quadrangular forms dominate (Cleghorn 1982; McCoy 1977; Mintmier 2007; Weisler 1990). However, non-quadrangular forms (triangular, lenticular) are represented at Mauna Kea and Haleakalā with low frequency (Cleghorn 1982: 209; Mintmier 2007: 10), while plano-convex, sub-triangular, and lenticular blanks and preforms are also found with low regularity at Kapōhaku (Weisler 1990). Kaho‘olawe quarries also lack high frequencies of rectangular adzes and are dominated by non-quadrangular forms, including reverse trapezoidal and reverse triangular adzes (McCoy *et al*. 1993). Similarly, ‘Amikopala and Waiāhole have a range of cross-sections, with numerous rectangular and reverse-trapezoidal forms, along with lower numbers of reverse triangular forms.

It appears that small to moderate scale adze quarries in Hawai‘i produced a wider variety of adze cross-sections than the main quarry zone at Mauna Kea, which produced almost exclusively rectangular adzes. Raw material availability was probably a factor (McCoy *et al*. 1993: 156). At Mauna Kea, the dominant raw material was relatively uniform tabular blocks of dense basalt (Cleghorn 1982; Porter 1979). The reduction of these tabular blocks probably added to the homogeneity of Mauna Kea adze types, whereas flake reduction at other quarries led to a more opportunistic reduction of different shaped flakes into a wider variety of adze forms. This typological variability may also be related to various socio-economic factors, including production context and scale (i.e., proximity to high quality sources, production output) and the intended audience for consumption (whether for export or local use). McCoy (1977: 241) notes that adze cross-section at Mauna Kea varies with distance from the high-quality raw material and the scale of production, as trapezoidal and triangular cross-sections are found with greater frequency at smaller workshops in the lower quarry region (see also McCoy 1986). Elsewhere in the archipelago there is tentative evidence that some quarries emphasised production of particular adze types to a greater extent than others, including production of small reverse triangular adzes at Mo‘omomi, and small, long, narrow chisel-like adzes at Site 108, at Kaho‘olawe, as well as Kapohaku. Future studies incorporating larger sample sizes will be needed to test this hypothesis.

Hawaiian adze production data also demonstrate substantial diversity in adze size. Table 9 illustrates the difficulties in dealing with size variability, as data reporting has not been systematic. Some researchers lump blanks and preforms into an adze reject category, which is problematic because those case studies that report length separately for adzes and preforms overwhelmingly illustrate a decrease in size as the reduction process proceeds. Similar problems are encountered in data sets that report mean length values and range statistics, and others that provide standard deviation values. When standard deviation is taken into consideration, Mauna Kea clearly produced the largest adzes, yet other quarries, notably Waiāhole, appear to have produced adzes of considerable size. Site 108, Kaho‘olawe, Kapōhaku, and Pōhakuloa stand out as producers of smaller adzes. This may represent evidence for intentional production of small adzes for households for everyday tasks (Weisler 1990) and/or expedient use of debitage derived from the flaking of larger blanks (Leach 1981) to produce small adzes.

TABLE 9
Lengths (mm) of complete (unbroken) blanks and performs from select quarry sites in the Hawaiian archipelago.
(modified from Bayman and Moniz-Nakamura 2001).

Site	**N**	**Mean L**	**SD†**	**References**
Haleakalā, Maui¶	13	100	NA	Mintmier 2007: 10
Kapohaku, Lāna'i blanks	40	84	15	Weisler 1990: 37
'Amikopala, Moloka'i blanks	19	137	47	Dye *et al*. 1985: 12
'Amikopala, Moloka'i preforms?	40	108	58	Dye *et al*. 1985: 12
'Amikopala, Moloka'i preforms	31	97	84	Dye *et al*. 1985: 12
Mo'omomi, Moloka'i blanks	47	274	12	Dye *et al*. 1985: 49
Mo'omomi, Moloka'i preforms?	35	155	39	Dye *et al*. 1985: 49
Mo'omomi, Moloka'i preforms	40	140	50	Dye *et al*. 1985: 49
Waiahole, O'ahu blanks	20	175	52	Dye *et al*. 1985: 70
Waiahole, O'ahu preforms?	48	200	15	Dye *et al*. 1985: 70
Waiahole, O'ahu preforms	52	174	12	Dye *et al*. 1985: 70
Pōhakuloa, O'ahu	2	83	range=39	Bayman *et al*. 2001
Polulū, Hawai'i	19	124	range=80	Lass 1994: 42
Mauna Kea, Hawai'i blanks	40	194	range=266	Cleghorn 1982: 182–183
Mauna Kea, Hawai'i preforms	63	158	range=224	Cleghorn 1982: 182–183
Site 108, Pu'u Moiwi, Kaho'olawe	35	105	24	McCoy *et al*. 1993: 138
Site 208, Pu'u Moiwi, Kaho'olawe	49	167	62	McCoy *et al*. 1993: 138
Site 210, Pu'u Moiwi, Kaho'olawe	34	195	62	McCoy *et al*. 1993: 138
Site 211, Pu'u Moiwi, Kaho'olawe	28	194	59	McCoy *et al*. 1993: 138

† Where standard deviations are not available, range values are reported where possible.
¶ Where blank or perform is not specified, data refer to rejects (both blanks and preforms).

CONCLUSIONS

Our Nu'u quarry study is a first step in identifying the organisation of adze production and consumption at the local scale, within the island of Maui in the Hawaiian Islands. Multiple lines of evidence indicate that the Nu'u quarry served as a small scale adze manufacturing locale, for a local population. The surface remains, while dense, suggest that the lithic workshop within the quarry was moderate in size. A volume estimate derived from excavation indicates that output was not on the scale of regional quarries where adzes were produced in part for export. Adze manufacture at Nu'u targeted production of both small and large adzes. At least some of the small adzes were probably distributed to residential sites in the Kaupō area, beginning their use lives as small adzes, probably less than 85 mm in length, while robust adzes of some size were also produced for local distribution and use. Although additional EDXRF analysis of Kaupō district assemblages must be completed, our current data from Kahikinui suggest that adzes manufactured at Nu'u were only occasionally traded into Kahikinui, the adjacent socio-political district. This supports an interpretation that the Nu‘u quarry produced mainly for local population needs. We have also demonstrated that a diverse range of adze types were produced at the Nu‘u quarry. Manufacture targeted production of both small, thin adzes and large chunky adzes with a range of cross-sections.

How can we best explain the diversity in adze production at the Nu‘u quarry? The argument that raw material quality and technological solutions to working raw material create diversity in adzes (Turner 2005) seems to hold little explanatory weight in the Nu‘u case. At Nu‘u, both flake blanks and cores were reduced utilising a variety of reduction techniques, while bi-directional flaking was emphasised.

We believe there are at least two other potential explanations. Polynesian archaeologists have argued that adzes of differing size and shape were used for differing functions. In Hawai‘i, size discrepancies between large adzes produced at the Mauna Kea adze quarry and smaller adzes produced at outlying areas have been linked to differing intended functions for adze use and patterns of adze resharpening and recycling (Bayman and Moniz-Nakamura 2001; Cleghorn 1992; Weisler 1990). Data from adze use experiments show that different sizes and shapes of adzes are needed for different types of wood-working activities. For example, Turner and Bonica’s experimental manufacture of a small outrigger canoe with traditionally replicated New Zealand adze types (Turner 2005) illustrated that large, thick, heavy adzes were effective for tree felling, chopping and roughing out logs, and the initial stages of other big projects such as canoe and house manufacture. Thinner wide-bladed adzes, often small in size, were effective for trimming timber or timber dressing.

Following this, one could interpret diversity in the Nu‘u quarry assemblages as indicating that adze production focused on creating the full adze kit needed for the variety of woodworking tasks that would be carried out in this *ahupua‘a*. This is in line with our current EDXRF data which fail to support that Nu‘u adzes were produced in large part for export. This explanation emphasises the functional requirements of different adze types and highlights the importance of local consumption needs in driving production output at smaller scale quarries.

An alternative explanation focuses on largely chronological issues and reputed changes in adze forms in Hawai‘i through time. Researchers have argued that the early Hawaiian adze kit was markedly varied, with untanged and tanged varieties and several ‘early’ forms represented by plano-convex, triangular, reverse-triangular, and quadrangular cross-sections (Emory 1968: 162–164; Kirch 1985: 185). These ‘early’ adze forms and non-tanged varieties are postulated to represent culture-historical links with central eastern Polynesia and further to the West (Samoa). Proponents of this argument suggest that later Hawaiian assemblages are highly standardised, typically tanged and rectangular in cross-section. The reasons for this shift are debated but explanations focus on the advent of adze-making specialists. More recent studies have questioned the notion that non-quadrangular adze types are ‘early’ forms and advance the proposition that non-quadrangular adzes were manufactured over a long time period, at Mauna Kea (McCoy 1986, 1991), the Mo‘omomi quarry on Moloka‘i (Dye *et al*. 1985) and elsewhere in the archipelago (Cleghorn 1992; see also McCoy *et al*. 1993: 165). The debate is on-going and resolution will require adze typological studies from well-dated quarry contexts, which are generally lacking.

We developed a proxy measurement of when the Nu‘u quarry was used from our EDXRF study, by tracking when artefacts with the Nu‘u geochemical signature began to appear in the adjacent Kahikinui district. Use of the Nu‘u quarry extends well into the late pre-contact era during the seventeenth to eighteenth centuries. Our data from this small quarry do not support the notion that later Hawaiian adze assemblages are highly standardised or that manufacture focused exclusively on rectangular cross-sectioned adzes. Rather, the Nu‘u data support the view that adzes with varied cross-sections were produced late into the pre-contact era in the Hawaiian Islands. Current data suggest that production at small to moderate scale quarries in Hawai'i, such as at Nu'u, was sometimes more diverse than that described for the regional production centre at Mauna Kea. This is probably related to several factors, including the availability of raw materials and qualitative differences between the organisation of labour, craft specialists, the structure of production, and control over resources. We suggest that one factor which deserves more attention is the extent to which the intended market — whether for local communities or for regional exchange — drove production. At the Nu'u quarry, local needs rather than exchange appear to have driven production output, while at the larger export quarry of Mauna Kea the reverse is likely to hold true.

Finally, our case study provisionally supports an independent *ahupua'a* economic model (*sensu* Earle 1978) for adze production within the Kaupō district within which the Nu'u quarry was situated. This hypothesis will be tested in the future with excavations at Kaupō sites and the additional recovery of lithic artefacts from dated contexts which can then be submitted for geochemical analyses.

Endnotes

1. We use the term quarry in a broad sense (similar to that of Johnson *et al*. 2006; Weisler and Sinton 1997: 180). Raw material from Nu'u was not mined or extracted; however, it was collected from erosional surface features and reduced *in situ* at its geological source.

2. Shatter (also referred to as debitage chunks or waste by other researchers) is an angular or blocky piece of material which cannot be oriented with reference to dorsal or ventral surfaces. Shatter lacks a recognisable platform, termination, or bulb of percussion (Kahn 1996: 122).

3. When we report cross-section data for blanks in the data analysis (see Table 4), cross-section is coded as indeterminable if the artefact could be further reduced into more than one cross-section (similar to the blank category of Dye *et al*. 1985: 11). If the blank has taken on a shape where the final probable cross-section can be inferred with a high degree of confidence, the cross-section was noted accordingly (similar to the preform? category of Dye *et al*. 1985: 11, see also Weisler 1990: 41).

4. We define the volume of debitage as the density of flakes in a defined volume of excavated material. Our Nu'u estimate includes items recovered from the surface of the excavated unit in addition to those found in the excavated deposits.

5. Artefact density or volume estimates have been used as comparative indices for analysing production at varied archaeological sites worldwide (Mallory 1986; Schortman and Urban 2004; among others). The scale of manufacture is considered one of many variables for assessing production output and distribution (Costin 1991). Estimating scale of production at Polynesian quarries is not without its problems; most notably, excavation samples tend to be small and these have to be used to extrapolate the debitage population of the entire site. Because of this, we use the estimated volume of debitage, in addition to the size of the quarry (as estimated based on surface remains), to discuss production output in our extra-areal comparisons.

6. Cleghorn (1982) notes that a 40 cm by 60 cm unit was excavated to a depth of 20 cm at Workshop 2, Feature 10 at Mauna Kea. 1558 flakes were recovered in these excavations and we based our volume estimates on these counts. Surface flake counts were recorded only for the Workshop 2 area

as a whole (a 20 m^2 area) and were not broken down for the excavated unit; as such we cannot include surface flakes in our Mauna Kea volume estimates. The Nu‘u volume estimate includes both debitage recovered from the surface and debitage found in the excavations. Because workshops at Mauna Kea often have mounded surface deposits of some height, our estimations for debitage volume from Workshop 2 at Mauna Kea must be considered low. Other data suggest that the Mauna Kea debitage volume estimates are significantly higher than those found at Nu‘u. Excavations at three 1 m units at Ko‘oko‘olau rockshelter (Units B2, B3, and B4) produced 600,000 pieces of debitage; only half of the deposits from these units were screened and saved (Williams 1989: 76). The depth of the excavated deposits was approximately 60 cm deep (see Williams 1989: 43–45). If we assume 0.60 m deep deposits, and estimate the volume as if three 1 m x 0.50 m units were excavated (because only the northern quadrant of each unit was screened and sampled), this leaves us with an estimated volume of 2,000,000, which is significantly higher than that found at the Nu‘u quarry.

7. Quarry size/flaking area size is reported following size measurements provided in available publications. If size measurements were not reported they were estimated by the authors from available site maps.

8. Cleghorn recorded bi-directional flaking per surface rather than per edge, contra other earlier studies such as Leach 1981 and Leach and Leach 1980, leaving his data difficult for comparison. However, Cleghorn’s category of bi-directional flaking on all four surfaces does correspond to our category of bi-directional flaking of all four edges.

ACKNOWLEDGEMENTS

Fieldwork at the Nu‘u Quarry was supported by the Class of 1954 Endowed Chair Fund at the University of California, Berkeley. PVK thanks Andy and Bernie Graham of Nu‘u Mauka Ranch for their unstinting support of our research in the Nu‘u area. Sidsel Millerstrom also assisted in the mapping of the quarry site. JK thanks the University of Queensland for providing an Early Career Research Grant which funded her analysis and the Bishop Museum for providing support while she completed the final write up of the text. Special thanks to Melanie Mintmier and Elizabeth Gordon for their permission to use the geological data from the Haleakalā summit quarry.

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Received 3 November 2008
Accepted 20 March 2009