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– ARTICLE –

Geochemistry and Technology of Basaltic Glass Artefacts from an Embedded Source and Two High-altitude Base Camps in the Mauna Kea Adze Quarry Complex, Hawai'i

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ABSTRACT

Located at the base of an escarpment at ~3720 m elevation, in the Mauna Kea Adze Quarry Complex, Hawai'i Island, is a small outcrop of basaltic glass that was utilised by adze makers for at least several hundred years as a source of toolstone for the manufacture of small, expedient flake tools. A test excavation of this previously unknown source/quarry was undertaken in 1976 to obtain a sample of artefacts to compare with what appeared to be lithologically identical basaltic glass cores and flakes from excavations at two nearby rockshelters used by adze makers as base camps. Comprehensive geochemical analyses of a small sample of flakes from the source and base camps confirm that all but one of the rockshelter artefacts are local basaltic glass and that the manufacture and use of basaltic glass tools was therefore an activity embedded in the adze quarry 'industry'. The one anomalous sample, which was selected for analysis because of its unusually vitreous appearance, is a trachytic glass flake sourced to Pu'u Wa'awa'a, a volcanic cone located ~40 km west of the Mauna Kea Adze Quarry and source of the best quality and most used volcanic glass on Hawai'i Island. The provenance of the Pu'u Wa'awa'a flake suggests that it was an offering or gift and not part of some down-the-line exchange network, as often assumed in the case of volcanic glass artefacts found in coastal habitation sites. Although there is no conclusive evidence that any of the Mauna Kea basaltic glass was exported, it is a possibilty that needs to be considered in future studies of volcanic glass distribution patterns, which appear to have been far more complicated than previously thought. To characterise sources/quarries and to provide robust matches of artefacts to sources, we advocate using comprehensive geochemical techniques and reporting the data in full—not just mid-Z elements and select oxide values.

Keywords: Mauna Kea Adze Quarry, basaltic glass, trachyte, rockshelters, geochemistry, Pu'u Wa'awa'a, ICP-MS

INTRODUCTION

The renewed interest in trade and exchange studies in archaeology (e.g. Dillian & White 2010; Bauer & Agbe-Davies 2010) can be seen in the emphasis in Hawaiian archaeology on volcanic glass sourcing and interaction studies (M.D. McCoy *et al*. 2011; Weisler 1990, 2012; Weisler and Clague 1998), especially on the leeward (western) side of Hawai'i Island, where thousands of samples have been analysed using Energy-Dispersive X-Ray Fluorescence (EDXRF). Three sources of volcanic glass have been inferred from EDXRF analyses (Lundblad *et al.* 2013, 2014; Mills & Lundblad 2014). These include Pu'u Wa'awa'a, a well-known source of trachytic glass identified by geologists more than a century ago (Cross 1904; see also Clague & Hazlett 1989) and basaltic glass sources from Mauna Loa and Kilauea volcanoes (Lundblad *et al.* 2013, 2014; M.D. McCoy 2011; M.D. McCoy *et al.* 2011; see Figure 1). The present inability to identify specific sources within the Mauna Loa and Kilauea geochemical groups is due to the large number of sources that exist in dikes and the chilled margins of lava flows (Olson 1983: 338; Weisler 1990: Figure 1; Lundblad *et al.* 2013: 67; Williams 2004), and the fact that little attention has been given to the systematic recording, dating and geochemical characterisation of quarries. The Pōhakuloa Chill Glass Quarry Complex (Figure 1) is the only volcanic glass quarry that has been recorded in any detail and the only one with tightly controlled dates.

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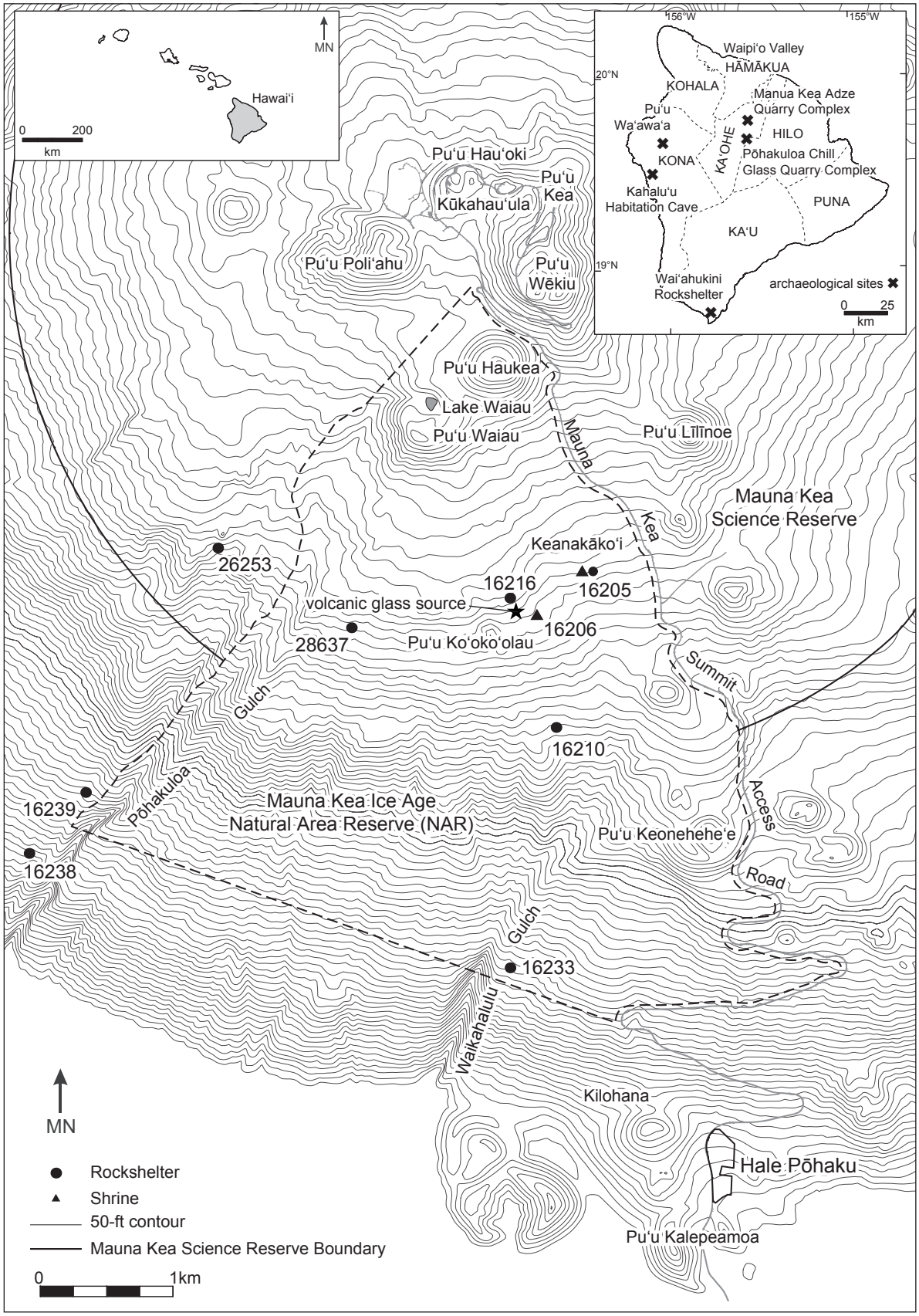

Figure 1. Location of the volcanic glass source, radiocarbon dated rockshelters in the Mauna Kea Adze Quarry Complex and other places mentioned in the text.

Surveys indicate that this quarry complex, located on a Mauna Loa lava flow radiocarbon dated to AD 1650–1750, is spread over an area of ~4050 ha and includes at least 12 discrete quarry areas and probably many more. The quarry may have been in use only between AD 1770 and 1820 (Williams 2002: 105).

With the recent interest in Hawaiian archaeology on volcanic glass sourcing and exchange, it is surprising how little is still known about the actual sources of toolstone, including raw material form and abundance, and the effect of these on procurement, reduction strategies and exchange value. This paper addresses the gap in our understanding of Hawaiian volcanic glass quarries and quarrying. We present the results of preliminary technological and comprehensive geochemical analyses of a small sample of basaltic glass artefacts recovered in excavations of a basaltic glass source/quarry and two nearby rockshelter base camps located above treeline (2804–2895 m) in the Mauna Kea Adze Quarry Complex (MKAQC), Hawai'i Island, in 1975–76 (Cleghorn 1982, 1986; McCoy 1976: 140; 1990: 97; McCoy & Gould 1977: 241). One objective of the basaltic glass source/quarry excavation was to obtain a sample of artefacts to compare with what appeared to be lithologically identical basaltic glass cores and flakes recovered in the rockshelter excavations. The underlying assumption was that the rockshelter cores and flakes had been manufactured from basaltic glass procured locally from the newly found source. Geochemical analyses of 10 major elements using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and 44 trace elements using ICP-MS were conducted on two flakes from the quarry and eight from rockshelters to test the validity of this assumption and to obtain a comprehensive characterisation or signature of the Mauna Kea basaltic glass for comparison with other Hawai'i Island volcanic glasses. The analyses demonstrate that all but one of the rockshelter flakes came from local sources, thus confirming that the procurement, manufacture and use of the local basaltic glass was embedded in the adze quarry 'industry'. The one anomalous sample, which was selected for analysis because of its noticeably more vitreous appearance, is a trachytic glass flake from the Pu'u Wa'awa'a source, located ~40 km west of the MKAQC (Figure 1).

We begin with a general overview of the MKAQC providing relevant background information on the environmental and socio-political context of the basaltic glass source/quarry and rockshelter base camps. Following is a description of the basaltic glass quarry and rockshelter excavations, including a summary of the stratigraphy, chronology and composition of the basaltic glass artefact assemblages. We provide counts and weights for chunks of unaltered raw material, cores and core fragments, whole flakes, and broken flakes and shatter. A more detailed attribute-based analysis will be presented elsewhere. The methods and results of the geochemical analyses are described and discussed. The paper concludes with a brief discussion of the importance of the Mauna Kea basaltic glass quarry, the inferred meaning of the trachytic glass flake, and the possibility that in addition to the rare import of non-local lithic material, some of the Mauna Kea basaltic glass may have been exported. We also demonstrate the importance of characterising quarry sources using complete analyses of oxides and trace elements and reporting geochemical data in full for artefacts, thus reducing potential errors in assigning artefacts to sources.

In this paper we define *volcanic glass* as a class of non-crystalline glasses, where *obsidian* is a subclass of high-silica rhyolitic volcanic glass (Weisler & Clague 1998: 104) and *basaltic glass* refers to Hawaiian glasses that are more or less basaltic in composition and are commonly found as chilled margins of dikes (Weisler 1990: Figure 4), as surface chills on lava flows (Williams 2004: Figure 4) or associated with hydrothermal deposits atop Mauna Kea described herein. Although trachytic volcanic glass typically has silica (SiO_2) >57% (Le Maitre *et al.* 2002) and is rare, the largest source in Hawai'i is at Pu'u Wa'awa'a (Macdonald & Abbott 1970: 109; Stearns & Macdonald 1946: 205).

THE MAUNA KEA ADZE QUARRY COMPLEX

The MKAQC (Figure 1), the largest basalt adze quarry in Polynesia, is located in a remote alpine desert and subalpine forest environment that was uninhabitable on a permanent basis because of a combination of biogeoclimatic factors, such as high-altitude (>3500 m), rugged topography and poorly developed soils, low temperatures and extreme biotic impoverishment. The alpine desert is a 'non-subsistence' environment incapable of supporting even a small human population without the introduction of food, warm clothing and firewood (McCoy 1990: 91–92).

The boundaries of the MKAQC coincide with the occurrence of fine-grained basalts of different ages and composition (Wolfe *et al.* 1997; Porter 1979; McCoy 1990: Figure 5). The primary source is a series of basalt flows found along and below an escarpment at the 3750 m elevation in the vicinity of Pu'u Ko'oko'olau and at similar elevations in the Pōhakuloa and Waikahalulu gulch drainages (Figure 1). These basalts are assigned to the Liloe Spring Volcanic Member of the Hāmākua Volcanic Series, dated to between 150,000 and 70,000 years ago (Wolfe *et al.* 1997: 34–40). Here are found the largest and most diverse sites in the quarry complex, defined in terms of the number, density and variety of extraction areas, other workshops, habitation rockshelters, shrines, petroglyphs, possible burials and the basaltic glass source/quarry that is the subject of this paper.

The earliest cultural deposits in the MKAQC are most likely buried under huge debitage piles up to 7 m thick meaning that absolute dates for the earliest quarrying will be difficult to obtain (McCoy & Nees 2014: 47, note 10). The first activity in the quarry may have occurred ~AD 1200–1300 and lasted up until ~AD 1800. Although the beginning

and terminal endpoints of the quarry sequence are not yet firmly established, there is accumulating evidence for intensified adze manufacture in the MKAQC involving multiple raw material procurement strategies and reduction methods by the middle of the 15th century AD and possibly earlier. ^{230}Th dates of AD 1398±13 and 1441±3 for two shrines (sites 16205 and 16206, Figure 1) and AD 1355±28 for one rockshelter (site 28637, Figure 1) in the upper elevation portion of the MKAQC have confirmed what earlier, less precise radiocarbon dates obtained in the 1970s suggested, that different parts of the quarry complex were in use at the same time, in the 14th and 15th centuries (McCoy *et al.* 2009, 2012; McCoy & Nees 2013). An AMS date of 450±40 BP (Beta-256935), corrected to AD 1420–1480 at the 95% confidence level, on a piece of short-lived *Dubautia* sp. charcoal from a rockshelter at site 26253 (Figure 1) provides additional support for increased production during this time period (McCoy & Nees 2013; McCoy *et al.* 2012: 415).

The peak period of production at the MKAQC spanned a period of ~350 years, between AD 1400 and 1750. Support for this conclusion comes from coastal habitation sites containing debitage sourced to the MKAQC using EDXRF analysis, including the Kahalu'u Habitation Cave Complex (Kona District), where there is evidence that the MKAQC was a major source of adzes from ~AD 1600 through the early contact period (Mills *et al.* 2011; Mills & Lundblad 2014: 36), and from the recently re-dated Wai'ahukini Rockshelter Site (H8) in Ka'ū (Figure 1), where MKAQC adze material appears in stratigraphic contexts dated to 550±30 BP (Beta-377382), corrected to AD 1315–1355, 1390–1430 at the 95% confidence level (Mulrooney *et al.* 2014:Table 1; Lundblad *et al.* 2014: 83).

When research on the MKAQC began, in 1975–76, it was assumed that the scale of production, which clearly exceeded the needs of the small community of Ka'ohe (the name of the *ahupua'a* or traditional land unit in the Hāmākua District in which the quarry is located), was based on production for trade or exchange (Figure 1), contrary to the widely accepted ethnographic model of *ahupua'a* self-sufficiency (e.g. Earle 1977). There is mounting evidence that the MKAQC was a 'common resource' exploited by groups from possibly every region and political district on the island from ~AD 1400–1500 (McCoy 1990: 112; P.C. McCoy 2011: 96; McCoy *et al.* 2012: 410; McCoy & Nees 2010, 2013).

THE BASALTIC GLASS SOURCE/QUARRY

Location and geologic characteristics

Naturally occurring basaltic glass has been found during archaeological surveys at several locations in the summit region of Mauna Kea, mostly in association with exposures of palagonitic hyaloclastite tuff (a hydrated tuff-like breccia formed during volcanic eruptions under water or ice) that belongs to the Liloe Spring Volcanic Member of the Hāmākua Volcanic Series. Exposures of this tuff, which has a distinctive yellowish or reddish-orange colour, occur at several areas along the upper reaches of Waikahalulu Gulch, including near the rockshelter known as Keanakako'i (literally 'Cave of the Adze') at Site 16205 (Figure 1), and on Pōhakuloa Gulch (Wolfe *et al.* 1997: 37). A third exposure and the only known basaltic glass quarry in the summit region of Mauna Kea is at site 50–10–23–16216 (Hawai'i state site number; Bishop Museum site 50–10-G28–14).

The basaltic glass at Site 16216 is located within an outcrop of red scoriaceous basalt that is exposed near the base of a northeast-trending ridge forming a prominent (15–25 m high) escarpment (Porter 1979: 1034) at the 3720 to 3780 m elevation in the vicinity of Pu'u Ko'oko'olau (Figures 2 and 3). The stratigraphic position of the basaltic glass bearing rocks is not entirely clear because of erosion along the escarpment, which Porter has interpreted as the downslope margin of a subglacial lava flow (Porter 1979: 1034, 1987). Glacial 'erratics' occur along the ridge and are found in the vicinity of the basaltic glass outcrop. According to Wolfe, who described the outcrop of bright yellowish-orange palagonitic tuff at the base of the escarpment (Figure 3), the tuff 'overlies red scoria, which it separates from overlying scoriaceous to dense mafic hawaiite' (Wolfe 1987: 31).

The glass-bearing flow shows characteristics of differential cooling that resulted in flow seams of opaque to clear, slightly transparent, glass. The seams do not appear to exceed 5–7 cm in thickness and are minimally weathered. Naturally occurring fragments of glass are angular and blocky and found with and without attached scoriaceous basalt crusts (Figure 4). There is little or no cortex as normally defined due to the age of the material and minimal weathering in the local environment.

Areal Extent

The source/quarry area is difficult to precisely establish because it lies on a slope that is covered with boulder talus, colluvium and finely sorted gelifluction lobe deposits that have formed and are continuing to form stone-banked terraces (Washburn 1956, 1979; Embleton & King 1975: 112–16; Ugolini n.d.). The terraces, which consist of a riser or rampart of larger, poorly sorted rocks at the front and a tread of finer, better sorted rocks, cinder and sand upslope, appear to be primarily depositional rather than erosional (Davies 1972), although both kinds of processes are occurring simultaneously. The surface scatter of cores and flakes covers an area of roughly 450 m², but occasional cores, flakes and unworked chunks of raw material were found 50 to 75 m downslope on the surfaces of gelifluction lobes. Debitage may extend even further downslope based on the presence of a few pieces of basaltic glass at site 16206 (Figure 1). Surface artefacts tend to be concentrated

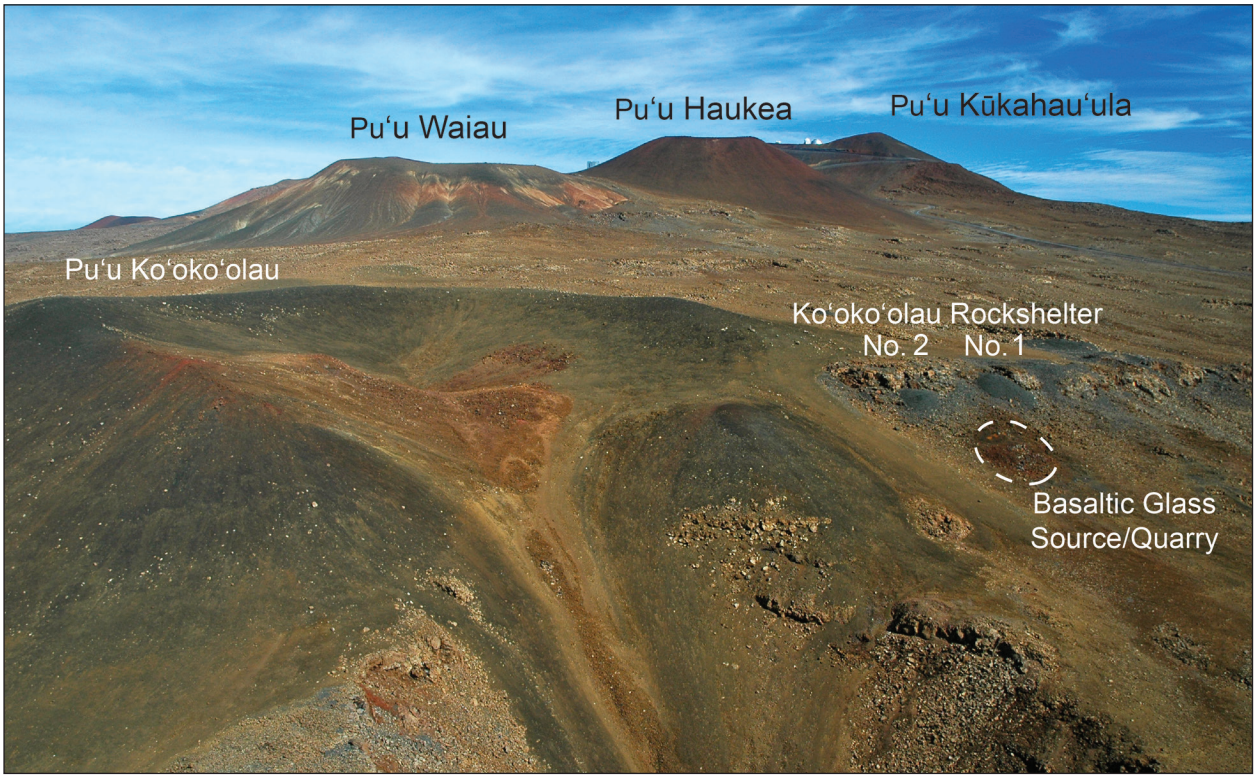

Figure 2. Aerial view of the basaltic glass source, Ko'oko'olau Rockshelters No. 1 and No. 2, as well as nearby landmarks. (Photo, P. McCoy, 2008).

Figure 3. View of debitage mounds associated with Ko'oko'olau Rockshelters No. 1 (right) and No. 2 (left) and hydrothermal deposit with associated basaltic glass source/quarry in reddish coloured scoriaceous basalt. (Photo, M. Weisler, 2013).

around boulder ramparts at the fronts of gelifluction lobes or directly below, where the sediments have breached the boulder margin.

Excavation methods and stratigraphy

The basaltic glass source/quarry was found during the initial phase of the first modern archaeological survey of the MKAQC, in 1975. Excavation of a 1 m² test pit in 1976, followed the recovery of basaltic glass cores and flakes from two habitation rockshelters nearby (McCoy 1977: 231–234; McCoy & Gould 1977: 241; McCoy 1990: 97; McCoy & Nees 2013). The primary objective of the excavation was to obtain a sample of cores and flakes for technological analysis and comparison with the basaltic glass assemblages from the rockshelters.

The excavation unit was located on a gelifluction terrace which consisted of small pieces of angular cinder, a reddish coloured pyroclastic lava with bands of basaltic glass rarely more than 3–4 cm thick, and a fine to medium sand (Figures 4 and 5). Excavation proceeded using natural sedimentary layers and arbitrary 5 cm thick levels or spits. The horizontal locations of individual artefacts were not plotted, as it was obvious that the material was in a secondary context, having eroded from upslope.

The excavation extended to 15 cm below surface and revealed a simple sequence of three stratified deposits. The surface is a desert pavement resting unconformably on top of a buried B2 and C horizon profile. Layer I, levels 1 and 2, correspond to the desert pavement. Layer II encompasses the two other soil horizons. Soil horizon and cultural layer descriptions are presented in Table 1.

The artefact assemblage

The test excavations yielded 1285 artefacts weighing 8690.3 g, including 76 basalt flakes weighing 403.9 g. Numbers and weights of artefacts by layer and level are shown in Table 2 and Figure 6. Of the 1209 pieces of basaltic glass 820 or 67.8% are broken flakes and shatter with the majority of whole flakes < 2.5 cm long (McCoy & Nees 2013). One flake is retouched. Fifteen cores are predominantly unidirectional and < 3 cm in length or height. One minimally flaked piece of interbedded glass and scoriaceous basalt weighing 566 g is a good example an embryonic core (Crabtree 1972: 54, 56) that seems common at this quarry.

Over two thirds (75.8%) of the flakes and 100% of the cores and core fragments were contained within layer I, the desert pavement. The large number of broken flakes and shatter in the bottom level of layer I, level 2 was a concentration at the base of the desert pavement. Most of the cultural material in layer II was at the interface between the desert pavement and the buried B2 soil. There is a significant decrease in the number and size of flakes in the B2 and C horizons (layer II). This change and the absence of cores demonstrates that the flakes are intrusive and that

Figure 4. Basaltic glass artefacts *in situ* on the surface of a gelifluction terrace at the source. The knife is 9 cm long. (Photo, P. McCoy, 1976.)

core reduction post-dates development of the buried soil. The occurrence of basalt flakes in the same stratigraphic context (interface of layers I–II) suggests erosion of an older adze workshop upslope prior to or coeval with the deposition of the basaltic glass cores and flakes since there is no adze preform manufacturing debitage on the surface at this locale.

THE ʻUAʻU ROCKSHELTER AND KOʻOKOʻOLAU ROCKSHELTER NO. 1 BASALTIC GLASS ARTEFACT ASSEMBLAGES

Some 48 rockshelters (defined as natural rock overhangs that are wider than they are deep) have been recorded in the MKAQC (McCoy & Nees 2013: 5–51), varying in size and function. There are overhangs with ash and midden deposits used as temporary habitations and small overhangs probably used to store food, firewood and other bulky provisions. Seven widely dispersed rockshelters have been excavated (Figure 1). Basaltic glass artefacts were recovered in only two, at ʻUaʻu Rockshelter (Hawaiʻi state site 50–10–23–16205; Bishop Museum site 50-Ha-G28–2-R2)

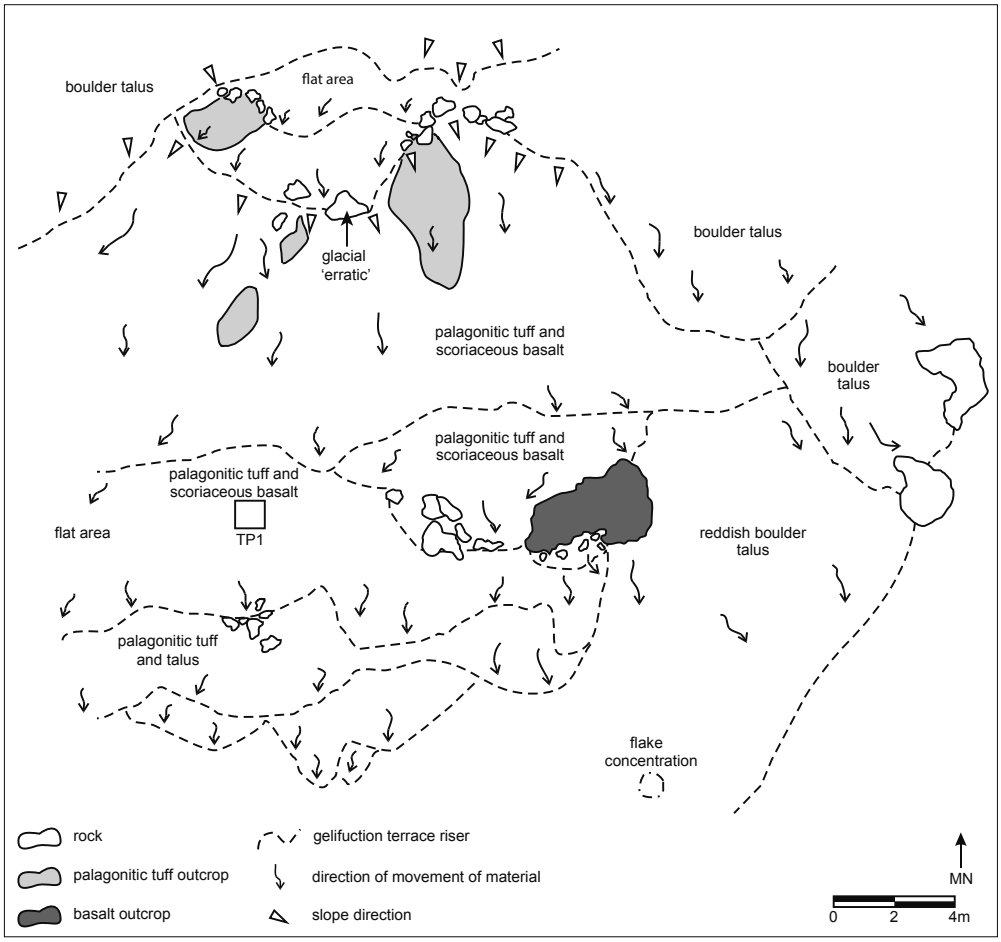

Figure 5. Map of the basaltic glass source showing location of test pit 1 and details of topography.

and Koʻokoʻolau Rockshelter No. 1 (Hawaiʻi state site 50–10–23–16216; Bishop Museum site 50-Ha-G28–14-R1).

ʻUaʻu Rockshelter and Koʻokoʻolau Rockshelter No. 1 contain well-stratified deposits comprised of both anthropogenic and natural layers. The cultural layers consist of tonnes of debitage, but also include midden comprised of bone, shell and plant remains, some of it concentrated in what were earlier interpreted as possible living surfaces (McCoy 1977: 232). The non-cultural layers, which suggest short hiatuses in the cultural sequence, are oxidised sediments with some of the colour and textural characteristics of B horizon soils.

ʻUaʻu Rockshelter and Koʻokoʻolau Rockshelter No. 1 are interpreted as base camps based on the presence of fire hearths, enclosing walls, diverse food residues, personal gear, basaltic glass cores and flakes, unfinished bone awls and picks, large debitage mounds, and shrines located above the entryways (McCoy 1990). The 'roof-top' shrines, which may have made plain and visible the identity of small work groups of related craftsmen, suggest that these and other rockshelters with large debitage mounds, were akin to 'club houses.' Both of these camps may have functioned as daytime work centres for a collective labour force that, with the exception of the few permanent and

Table 1. *Basaltic glass source/quarry soil profile description.*

Horizon	Layer/Level	Description
—	I/1 and I/2	0–4 cm thick, reddish yellow (7.5YR 6/8 dry) desert pavement; structureless; loose; nonsticky, non plastic; abrupt wavy boundary.
B2	II	0–5 cm strong brown (7.5YR 5/8 moist) loamy fine sand; massive; friable; slightly sticky, slightly plastic; abrupt smooth boundary.
C	II	5–20 cm+ strong brown (7.5YR 5/8 moist) gravelly loamy sand; structureless; friable, slightly sticky, slightly plastic.

presumably high ranking occupants, dispersed to other camps at night. The thin, sharp edges of the basaltic glass

Table 2. *Stratigraphic distribution of artefacts from the basaltic glass source/quarry excavation.*

	Layer I										Layer II				Total			
	Level I				Level 2				Level 3									
Artefact Category	**No.**	**% T**	**Wt.**	**% T**	**No.**	**% T**	**Wt.**	**% T**	**No.**	**% T**	**Wt.**	**% T**	**No.**	**% T**	**Wt.**	**% T**	**No.**	**% T**	**Wt.**	**% T**
BASALTIC GLASS																				
Retouched Flake	0	0	0	0	0	0	0	0	0	0	0	0	1	0.31	10.5	2.98	1	0.08	10.5	0.00
Cores & core frags	2	1.90	39.85	3.95	7	1.28	45.7	1.16	6	1.95	736.6	21.56	0	0.00	0	0.00	15	1.17	822.15	9.46
Whole Flakes	38	36.19	51	5.06	226	41.32	160.01	4.08	3	0.98	10.28	0.30	106	32.52	38	10.79	373	29.03	259.29	2.98
Broken Flakes & Shatter	50	47.62	770.6	76.41	292	53.38	3625	92.38	297	96.74	2526.13	73.95	181	55.52	283.2	80.41	820	63.81	7204.93	82.91
Subotals	**90**	**85.71**	**861.45**	**85.41**	**525**	**95.98**	**3830.71**	**97.62**	**306**	**99.67**	**3273.01**	**95.82**	**288**	**88.34**	**331.7**	**94.18**	**1209**	**94.09**	**8296.87**	**95.35**
BASALT																				
Flakes	15	14.29	147.1	14.59	22	4.02	93.5	2.38	1	0.33	142.8	4.18	38	11.66	20.5	5.82	76	5.91	403.9	4.65
TOTAL	**105**	**100**	**1008.55**	**100**	**547**	**100**	**3924.21**	**100**	**307**	**100**	**3415.81**	**100**	**326**	**100**	**352.2**	**100**	**1285**	**100**	**8700.77**	**100**

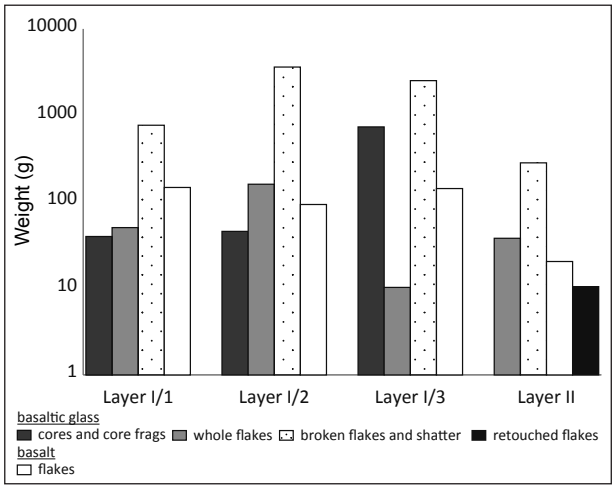

Figure 6. Histogram of the stratigraphic distribution of artefacts from the basaltic glass source/quarry.

flakes were ideally suited to working a variety of materials (McCoy & Gould 1977: 241; Allen *et al.* 1995; Weisler & Haslam 2005), including fire sticks, fibres, and bird bones used in the manufacture of awls and picks that were found in these two rockshelters. The flakes, like most Hawaiian volcanic glass flake tools, were expedient tools used for short periods of time then discarded (Dockall 2003; Olszewski 2003; Schousboe *et al.* 1983; Barrera & Kirch 1973). The use of the locally occurring basaltic glass was opportunistic, especially since some of the posited tool applications could have been done with sharp-edged basalt flakes resulting from adze manufacture.

The stratigraphy, chronology and general characteristics of the basaltic glass assemblages found at each of the two rockshelters are summarised below.

'Ua'u rockshelter

'Ua'u Rockshelter is located at ~3720 m elevation on the eastern margin of the quarry. A 6 m² trench, representing 28.5% of the interior floor area of this ~21 m² rockshelter, was excavated in 1975 (McCoy 1977, 1990). The trench extended from the back of the rockshelter to the dripline and beyond onto the top of a large debitage mound which has an estimated depth of 2 m (Figure 7). The stratigraphic sequence is similar to Ko'oko'olau Rockshelter No. 1, with a total of nine layers, including bedrock (Layer IX) and three other 'non-cultural' deposits–a massive deposit of gravelly to cobbly reddish cinder from roof collapse or another source (Layer V) and two lenses of grey to yellowish-brown oxidised sediments at the interface of Layers II/III and III/IV.

The basaltic glass artefact assemblage from 'Ua'u Rockshelter (n=143) is remarkably similar to that from Ko'oko'olau Rockshelter No. 1 in the number of cores and flakes (Table 3), all of which are <3 cm long. One poten-

Figure 7. View toward the interior of ʻUaʻu Rockshelter showing enclosing wall reset in a flake deposit (front) and stone-lined fire hearth (rear). (Photo, P. MCoy, 1975.)

tially significant difference between the two assemblages is more chunks of unaltered raw material at ʻUaʻu Rockshelter (n=20) and several larger cores (Figure 8). This might be due to the greater distance from the source, compared to Koʻokoʻolau Rockshelter No. 1, which is virtually 'on the source.'

Cultural layers II, IV, VI and VIII have radiocarbon age-determinations on unidentified charcoal ranging from 190 ± 80 BP to 655 ± 80BP (McCoy 1977: Table 2, 1990). No dates are available for Layer I which, though containing artefacts and some midden, does not appear to have been a habitation layer because of the absence of a hearth; it is a fill layer that post-dates the final occupation in layer II.

Koʻokoʻolau rockshelter no. 1

Koʻokoʻolau Rockshelter No. 1 is located at ~3780 m elevation on the same escarpment as the basaltic glass source/quarry, which is roughly 70 m downslope (Figures 1 and 2). Some 4 m² or 50% of the roughly 8 m² interior floor area and 2 m² just outside of the entryway was excavated in 1975–76. Eleven stratigraphic units were identified in the excavations, including bedrock (Layer XI) and four other non-cultural layers (III, V, VII and X) that consist of oxidised sediments with colour and textural characteristics similar to B horizon soils. There is no evidence of a hearth in Layer I, which appears to be another non-habitation fill deposit like that found at ʻUaʻu Rockshelter and several other rockshelters in the quarry complex.

A total of 147 pieces of basaltic glass were recovered in the excavations from eight layers, including 23 pieces from non-cultural layers III, V and VII (Table 4, Figure 8). As might be expected given the proximity to the basaltic glass source immediately downslope, there are only six chunks of unaltered raw material – all found in Layer VI (Table 4). The 26 cores are < 3 cm in length, include unidirectional and multidirectional varieties, and range from barely formed embryonic cores to well-shaped polyhedral cores. The flakes are of similar dimensions to those found at the source.

Cultural layers IV, VI and VIII have radiocarbon age-determinations on unidentified charcoal ranging from 355 ± 80 BP to 755 ± 80 BP (McCoy 1977: Table 2, 1990).

Table 3. *Stratigraphic distribution of basaltic glass artefacts from ʻUaʻu Rockshelter.*

Artefact Category	Layer														Total			
	I/II		II		III		IV		V		VI		VII					
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	%T	Wt.	%T
Raw Material (chunks)	0	0	1	25.1	1	12.9	7	31.8	0	0.0	10	94.9	1	0.8	20	13.99	165.5	25.84
Cores & Core Fragments	2	22	2	25.0	2	14.0	4	110.4	1	1.1	13	123.3	3	3.7	27	18.88	299.3	46.74
Whole Flakes	2	2	3	0.8	14	9.8	37	45.6	1	1.4	17	12.5	10	14.6	84	58.74	86.6	13.52
Broken Flakes & Shatter	0	0	3	30.0	2	5.6	2	3.6	1	2.6	4	47.4	0	0.0	12	8.39	89.0	13.90
Total	**4**	**24**	**9**	**80.8**	**19**	**42.2**	**50**	**191.3**	**3**	**5.1**	**44**	**278.0**	**14**	**19.1**	**143**	**100**	**640.4**	**100**

Table 4. *Stratigraphic distribution of basaltic glass artefacts from Ko'oko'olau Rockshelter No. 1.*

Artefact Category	Layer																Total			
	I		II		III		IV		V		VI		VII		VIII					
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	%T	Wt.	%T
Raw Material (chunks)	0	0	0	0	0	0	0	0	0	0	6	22.1	0	0	0	0	6	4.08	22.1	4.12
Cores & Core Fragments	6	48.0	5	102.0	0	0	2	8.6	2	21.3	6	53.8	1	3.2	4	48.1	26	17.69	285.0	53.13
Whole Flakes	3	3.9	4	18.1	1	0.4	15	15.8	1	3.8	39	42.2	12	9.2	9	6.6	84	57.14	99.9	18.63
Broken Flakes and Shatter	0	0	2	1.0	0	0	0	0	0	0	22	55.3	6	8.5	1	64.6	31	21.09	129.4	24.12
Total	**9**	**51.9**	**11**	**121.1**	**1**	**0.4**	**17**	**24.4**	**3**	**25.1**	**73**	**173.4**	**19**	**20.9**	**14**	**119.3**	**147**	**100**	**536.4**	**100**

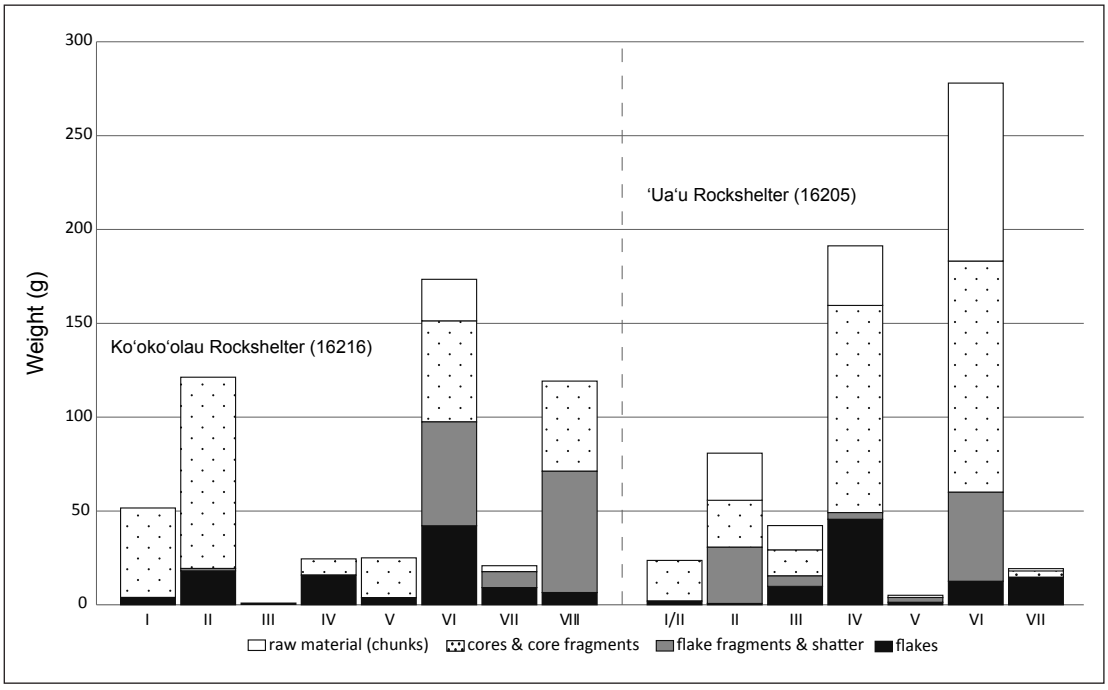

Figure 8. Histogram of the stratigraphic distribution of basaltic glass artefacts from the 'Ua'u and Ko'oko'olau rockshelters.

GEOCHEMICAL ANALYSES

Research objectives and sample selection criteria and rationale

The geochemical analyses had several objectives. The first was to empirically confirm that the cores and flakes recovered in the excavations of Ko'oko'olau Rockshelter No. 1 and 'Ua'u Rockshelter had originated from the basaltic glass exposure nearby. The second objective was to assess the range of variability in the source material for comparison with other Hawai'i Island volcanic glasses.

Unlike the larger, geologically more complex basalt adze quarry, a large part of which has been extensively sampled and partially characterised based on hundreds of EDXRF analyses (Mills & Lundlbad 2006; Mills *et al.* 2008; McCoy & Nees 2010, 2013), two samples were considered adequate for characterising the geochemistry of the basaltic glass source, which is small (~450 m^2), has a homogenous glass matrix, and appears to represent a single geological event. Sampling of the rockshelter assemblages was constrained with funding to process eight samples. Four samples were selected from each of the major stratigraphic units in each of the two rockshelters. We selected what appeared in hand-specimen to be the variety of different textures, which range from opaque to clear and vitreous in the case of one sample (2011-257) from Ko'oko'olau Rockshelter No. 1. Table 5 presents a list of samples, including

Table 5. *University of Queensland lab number, provenance, and associated radiocarbon age determinations for Mauna Kea basaltic glass artefacts.*

Lab No.[a]	Artefact No.	Associated ^{14}C Dates BP	Lab. No.[b]
	Basaltic Glass Source (Site 16216)		
253	TP 1/1-21		
254	TP 1/2-140		
	ʻUaʻu Rockshelter (Site 16205)		
255	B5/III-15		
276	D5/IV-23	490 ± 80	I-9069
277	B5/VI-24	425 ± 80	I-9071
256	B5/VII/2-95		
	Koʻokoʻolau Rockshelter (Site 16216)		
257	B3/I-55		
274	B2/VI-48	470 ± 75	I-9743
275	B3/VI-19	470 ± 75	I-9743
258	B3/VIII-43	775 ± 80	I-9744

a - University of Queensland lab number prefaced by 2011-
b - Teledyne Isotopes Lab

provenance information, associated radiocarbon dates and the University of Queensland laboratory number.

METHODS

The geochemical characterisation of 10 artefacts was done using 10 fully quantitative major element concentrations and 44 trace elements obtained using quadrupole ICP-MS (for trace elements) and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES, for major elements). Both fully quantitative oxides and trace elements are required for a comprehensive analysis.

Major element analysis–ICP-OES

Analytical techniques are modified from Collerson and Weisler (2007). Volcanic glass samples were digested by fusion protocols whereby 0.1 g of powder samples were thoroughly mixed with lithium metaborate flux, heated to 1000°C and combined with 5% HNO_3 for complete dissolution. Major element concentrations were measured on a Perkin Elmer Optima 3300DV ICP-OES at the Geochemistry Laboratory, School of Earth Sciences, University of Queensland. Instrumental drift was monitored with an internal standard (Lu, Sc, Y). Quality control was ensured by analysing reference standards from US Geological Survey (USGS) BHVO-2 (basalt, Hawaiian Volcano Observatory), Geological Survey of Japan (GSJ) JGb1 (gabbro), JB2 and JB3 (basalt), JA2 (andesite), and procedural blanks. Random samples were selected for duplicate fusions to ensure the reproducibility of the results. Results were adjusted to account for the loss on ignition (LOI).

Sample digestion and ICP-MS trace element analysis

Powdered basalt samples and Hawaiian Basalt Standard BHVO-2 were digested with a mixture of Milli-Q H_2O, HCl (hydrochloric acid), HNO_3 (nitric acid) and HF (hydroflouric acid) and then completely dried down at 80°C. The sample was re-dissolved in HCl and refluxed for 12 hours to convert flourides to dissoluable chlorides then dried down again. Complete conversion of flourides and chlorides to nitrates was ensured with the 2 times addition of HNO_3 and drying down of the sample. Samples were finally redissolved in 15ml 2% HNO_3 and refluxed at 120°C after which aliquots were separated for trace element analysis. Trace element abundances were measured on a Thermo X Series II quadruple ICP-MS at the Radiogenic Isotope Facility, University of Queensland and analytical procedures were modified from Eggins *et al.* (1997), following those outlined in Kamber *et al.* (2003). Sample solutions were diluted 4000 times with 2% HNO_3 and spiked with 6 ppb Rh, In, Re, Bi and ^{235}U and 12ppb ^{6}Li. A silicate monitor and international reference standards (W2a, Bir-1 and BHVO-2) were also spiked to correct for instrumental drift and ensure quality control.

RESULTS

The geochemistry of mafic (an igneous rock having abundant dark coloured minerals) to felsic (an igneous rock having abundant light coloured minerals) volcanic samples is best evaluated using a combination of major and trace element geochemical data (Tables 6 & 7). Ten basaltic glass artefacts from the source/quarry and the Koʻokoʻolau and ʻUaʻu rockshelters are plotted in a total alkali-silica (TAS) diagram (Figure 9), which is commonly used to classify mafic to felsic volcanic rocks based on major element characteristics. Nine of the ten samples have a narrow range in SiO_2 contents (47–49 wt%) and thus fall within the compositional field of basalts. A further subdivision within the basaltic field is based on the content of Na_2O+K_2O (alkalis) relative to a given SiO_2 content. Although the ten samples form a tight cluster, two samples (2011-256 and -276) are classified as tholeiitic basalts while the eight other samples plot in the alkaline basalt fields. The lower total alkali of the tholeiitic samples probably reflects variability in olivine content and not different sources. One sample (2011-257) shows an elevated SiO_2 content (>60 wt%) at high Na_2O+K_2O (>13 wt%) contents, consistent with a large degree of igneous differentiation. Compositionally, this sample is classified as a trachyte (Figure 9) and is consistent with a Puʻu Waʻawaʻa source (Cousens *et al.* 2003: Table 2, sample PWW-5).

To further evaluate compositional differences and similarities between the studied samples, trace element compositions were used in normalised diagrams (Figure 10). Trace element concentrations provided further dis-

Table 6. *Oxide values for the basaltic glass source/quarry and the 'Ua'u and Ko'oko'olau rockshelters.*

Sample Name	2011 -253	2011 -254	2011 -255	2011 -256	2011 -257	2011 -258	2011 -274	2011 -275	2011 -276	2011 -277	BHVO-2	BHVO-2 Accepted Values	SD
SiO_2	46.77	47.94	48.3	48.41	61.29	47.98	47.36	48.11	48.04	47.58	49.73	49.9	0.6
Al_2O_3	13.08	12.79	12.99	13.14	16.97	13.64	13.04	12.62	12.79	12.88	13.02	13.5	0.2
TiO_2	4.01	4.11	4.13	4.14	0.392	4.13	4.04	4.14	3.28	4.08	2.78	2.73	0.04
Y-Fe_2O_3	14.62	14.93	15.01	15.12	4.48	14.99	14.79	15.03	14.27	14.86	12.32	12.3	0.2
MnO	0.199	0.204	0.207	0.207	0.309	0.202	0.2	0.204	0.192	0.198	0.174	0.17	0.005
CaO	8.5	8.96	9.05	9.18	0.867	8.91	8.69	8.85	10.46	8.89	11.36	11.4	0.2
MgO	4.73	4.78	4.89	4.88	0.44	4.78	4.76	4.81	5.83	4.69	7.42	7.23	0.12
K_2O	1.18	0.825	1.19	1.28	4.63	1.09	1.2	1.21	0.705	1.16	0.55	0.52	0.01
Na_2O	3.27	3.16	2.89	1.73	8.29	2.7	2.33	2.34	2.4	2.1	2.21	2.22	0.08
P_2O_5	0.533	0.523	0.539	0.528	0.231	0.535	0.543	0.533	0.36	0.527	0.263	0.27	0.02
SUM	**96.89**	**98.21**	**99.18**	**98.62**	**97.89**	**98.94**	**96.94**	**97.86**	**98.33**	**96.98**	**99.83**		

tinctions as major element chemistries in mafic volcanics tend to be similar due to the control of similar mineral phases that crystallise in shallow magma chambers and fractionate the composition in the course of igneous differentiation (Collerson & Weisler 2007:1909; Weisler & Woodhead 1995:1882). In a Primitive Mantle-normalised multi-element diagram, trace elements are ordered according to their incompatibility during partial melting in the Earth's mantle, whereby incompatibility refers to the tendency of an element to partition into a mineral phase, rather than entering the melt phase. Normalised trace element patterns are typically diagnostic of the degree of partial melting and, to a lesser extent, the degree of fractional crystallisation. In Figure 10a, eight of the nine volcanic samples previously identified as basalts form a coherent, parallel array, with virtually indistinguishable patterns and concentrations. Subtle differences exist only for elements Rb and Sr, both known to be very sensitive to elemental mobilisation during weathering.

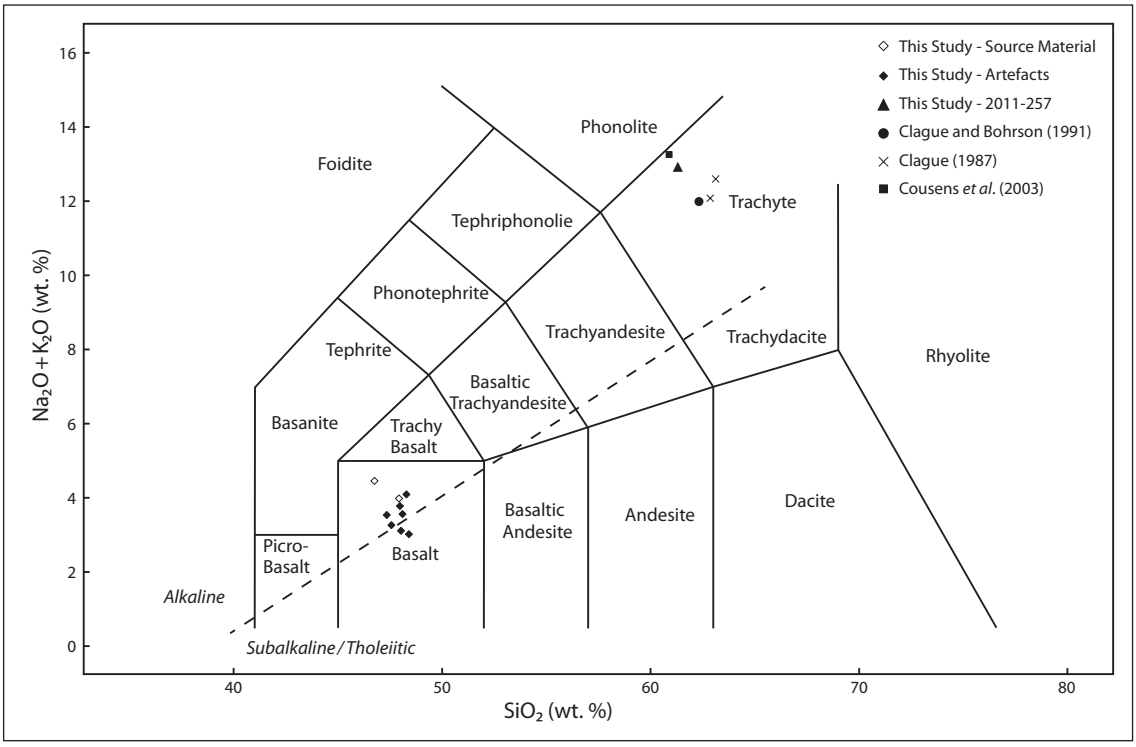

Figure 9. Total alkaline-silica diagram (TAS: Le Bas *et al.* 1986), showing major element compositions of 10 volcanic artefacts from the basaltic glass source and the Ko'oko'olau and 'Ua'u rockshelters. Nine samples are classified as basalts and one sample (2011-257) is classified as trachyte.

Table 7. *Trace element values (ppm) for the basaltic glass source/quarry and the ʻUaʻu and Koʻokoʻolau rockshelters.*

Sample Name	2011 -253	2011 -254	2011 -255	2011 -256	2011 -257	2011 -258	2011 -274	2011 -275	2011 -276	2011 -277	BHVO-2	BHVO-2 Recomm. Values*	SD
Li	2.41	3.11	6.47	2.62	33	8.94	8.06	16.2	5.34	3.04	4.76	4.8	0.2
Be	2.12	2.09	2.11	2.05	7.99	2.06	2.08	2.08	1.42	2.12	1.51	1	0.1
P	3026	2991	2998	2932	961	3061	3017	3025	1981	3186	1351	1179	
Ca	64863	65282	64101	64266	6662	62886	63790	61370	73699	63458	81279	81429	
Sc	26.3	26.6	25.9	26.2	7.95	26.1	25.9	25.6	29.6	25.8	31.8	31	1
Ti	23642	23507	23473	23821	2335	23661	23323	23136	18818	23543	16226	16300	2000
V	399	399	395	403	1.93	398	403	392	353	409	310	317	11
Cr	15	12.2	10.4	10.9	2.3	11	16.1	16	43.7	15.6	298	280	19
Co	43.3	43.2	42.8	43.6	0.418	43.3	42.8	42.3	47.9	43	44.9	45	3
Ni	28.1	27.9	27.1	27.7	1	27.5	28.9	27	62	27.6	117	119	7
Cu	59.9	35.9	49.8	39.8	32.6	46.7	45.5	69	121	38	128	127	7
Zn	155	146	150	157	205	156	148	148	127	149	105	103	6
Ga	25	24.7	24.9	25.3	25	24.8	24.5	23.8	22.2	24.8	21.1	22	2
Rb	25.2	27.8	24.9	25.1	122	26.2	22.8	24.3	14.8	25.8	9.16	9.11	0.04
Sr	536	533	531	522	56.5	476	528	493	522	526	397	396	1
Y	38.6	38.1	38.1	38.7	50.5	38.2	37.9	37.5	29.5	38.5	24.4	26	2
Zr	320	315	320	320	958	319	315	313	217	320	170	172	11
Nb	38.6	38.1	38.4	38.7	134	38.6	38	37.9	24	38.9	18.2	18.1	1
Mo	1.86	1.82	1.85	1.86	7.28	1.84	1.8	1.77	1.15	1.91	4.36	4	0.2
Cd	0.154	0.145	0.159	0.171	0.4	0.157	0.157	0.148	0.127	0.148	0.091	0.06	0.006
Sn	0.93	0.952	0.902	0.966	1.784	0.944	0.9	0.831	0.687	0.964	1.05	1.7	0.2
Cs	0.234	0.232	0.235	0.232	1.257	0.234	0.222	0.231	0.144	0.236	0.106	0.1	0.01
Ba	363	359	359	365	340	342	354	340	222	357	130	131	1
La	33.8	33.4	33.5	33.8	69	33.8	33.2	33.1	21.6	34.1	15.2	15.2	0.1
Ce	79.3	78.5	78.8	79.6	143	79.4	78	77.5	51.5	80.3	37.8	37.5	0.2
Pr	10.6	10.5	10.5	10.7	15.5	10.6	10.4	10.3	7.1	10.7	5.37	5.35	0.17
Nd	46.1	45.4	45.5	46.2	53.1	46	45.2	44.9	31.4	46.4	24.4	24.5	0.1
Sm	10.5	10.5	10.5	10.6	10	10.6	10.4	10.3	7.58	10.6	6.04	6.07	0.01
Eu	3.35	3.29	3.29	3.35	2.41	3.31	3.29	3.25	2.52	3.37	2.04	2.07	0.02
Tb	1.54	1.52	1.52	1.54	1.52	1.53	1.51	1.49	1.16	1.54	0.94	0.92	0.03
Gd	10.4	10.4	10.3	10.5	8.62	10.4	10.3	10.2	7.795	10.5	6.27	6.24	0.03
Dy	8.36	8.27	8.24	8.39	9.24	8.3	8.24	8.16	6.4	8.38	5.27	5.31	0.02
Ho	1.58	1.57	1.56	1.59	1.94	1.57	1.55	1.54	1.22	1.58	1.002	0.98	0.04
Er	3.93	3.9	3.89	3.95	5.64	3.9	3.87	3.83	3.02	3.94	2.53	2.54	0.01
Tm	0.514	0.511	0.513	0.518	0.911	0.513	0.505	0.503	0.397	0.518	0.334	0.33	0.01
Yb	3.05	3	2.99	3.03	5.95	3.02	2.97	2.93	2.34	3.03	1.97	2	0.01
Lu	0.417	0.412	0.413	0.419	0.907	0.413	0.409	0.407	0.322	0.416	0.275	0.274	0.005
Hf	7.73	7.62	7.67	7.76	20.9	7.67	7.59	7.54	5.4	7.67	4.34	4.36	0.14
Ta	2.27	2.24	2.24	2.28	7.69	2.27	2.21	2.22	1.41	2.28	1.09	1.14	0.06
W	0.33	0.321	0.321	0.354	1.117	0.323	0.316	0.305	0.191	0.317	0.103	0.21	0.11
Tl	0.042	0.09	0.037	0.082	0.21	0.038	0.06	0.011	0.032	0.039	0.0188	0.0223	0.0037
Pb	2560	2164	2105	2017	10768	1957	1954	2772	1427	1991	1.39	1.6	0.3
Th	2.54	2.52	2.52	2.54	8.58	2.53	2.48	2.49	1.54	2.56	1.19	1.22	0.06
U	0.847	0.841	0.842	0.86	2.636	0.851	0.84	0.827	0.523	0.858	0.424	0.403	0.001

* USGS BHVO-2 Preferred Values are taken from GeoReM (Reference Material Database), Jochum and Nehring (Max-Planck-Institute fuer Chemie).

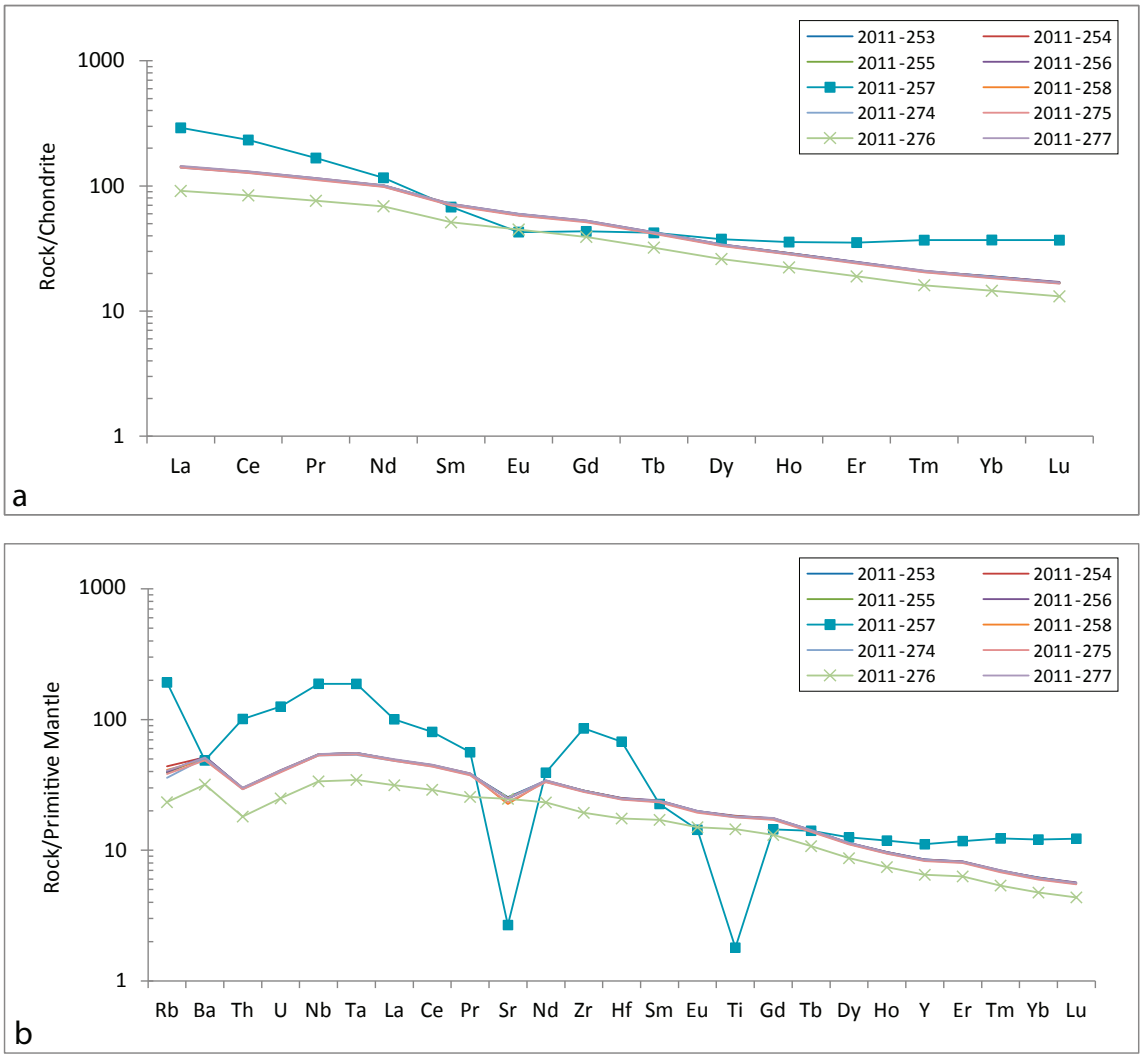

Figure 10. a) Chondrite-normalized (McDonough & Sun 1995) rare earth element (REE) diagram showing compositions of trachyte and alkaline/tholeiitic basalts. Note the difference in REE patterns between trachyte (2011-257; elevated LREE, HREE; negative anomaly for Eu) and basalts. b) Primitive Mantle-normalized (Sun & McDonough 1989) multi-element (REE) diagram showing compositions of trachyte and alkaline/tholeiitic basalts. Note the difference in patterns between trachyte (2011-257; negative anomalies for Ba, Sr and Ti and positive anomalies for Zr, Hf, Nb and Ta) and basalts, which show relatively smooth patterns. Concentration differences between basalts are ascribed to higher abundance of olivine in sample 2011-276.

Basaltic glass sample 2011-276 displays a subparallel pattern at lower concentrations when compared to the other samples, and this difference in trace element composition requires assessment. As previously noted, major element compositions of mafic volcanics may be insensitive to mineral fractionation due to the similarity in composition of the main fractionating phase (e.g. Clague 1987). However, differences in major element composition are discernible between sample 2011-276 and the other eight basaltic glass samples; specifically, the former is characterised by higher CaO and MgO, and lower P_2O_5, K_2O and TiO_2 (Table 6). Furthermore, this sample shows higher concentrations in the compatible elements Cr, Co and Ni which support higher modal abundances of olivine, also consistent with the subparallel pattern. The lower levels of trace elements reflect dilution by olivine, without showing effects from mineral fractionation on normalised trace element patterns.

Trachyte sample 2011-257 displays a drastically different trace element pattern, which is characterised by anomalously low Ba, Sr and Ti, and relative enrichment in Zr, Hf, Nb and Ta (Figure 10). In terms of major and trace element systematics, sample 2011-257 is identical to post-shield 92–115 ka trachytes from Hualālai volcano on Hawai'i Island (Clague 1987; Clague & Bohrson 1991; Cousens *et al.* 2003). As previously observed, one basaltic

glass sample displays lower REE concentrations, attributable to higher abundances of olivine. In all but extremely rare cases where one or a few elements can identify an artefact to a particular source, we advocate assigning 'unknowns' (i.e. artefacts) to a source based on matches of numerous elements figured on multi-element geochemical plots routinely used by geochemists (Figures 10a and b).

Comparison of the Mauna Kea source to other Hawai'i Island sources

Using the same bivariate plot as Lundblad *et al.* (2013: Figure 2) to discriminate Pu'u Wa'awa'a, Kilauea and Mauna Loa (Hawai'i Island) sources and to assign artefacts to one of these groups, we plotted the Mauna Kea source samples and artefacts from the two rockshelters to determine if the Mauna Kea source was unique using only the trace elements Sr, Y and Zr; at first glance, this appears so (Figure 11). As determined previously, our sample 2011-257 plotted within the Pu'u Wa'awa'a source (Group 1); this sample is readily assigned to Pu'u Wa'awa'a by its high silica (SiO_2) value in a standard TAS plot (Figure 9) routinely used by geochemists. The olivine rich sample (2011-276) however, plotted within the Group 2 Mauna Loa cloud (Figure 11). This sample we knew, based on a comprehensive array of oxides and trace elements, was from the Mauna Kea source. Table 8 lists the oxides and trace elements analysed by Lundblad *et al.* (2013) in their study of prehistoric volcanic glass artefact use on Hawai'i Island. What is readily apparent is that the Sr value of sample 2011-276 is ~10 standard deviations (σ) out from the Mauna Loa Sr mean. Likewise, the Zr value for sample 2011-276 is more than 5 σ from the Mauna Loa source mean. Lundblad *et al.* (2013:70) also state that the Group 2 Mauna Loa source generally has Sr <340 ppm, Rb <10 ppm and Nb <13 ppm, which are all far less that sample 2011-276 (Table 8). Consequently, it is impossible that sample 2011-276 is from this Mauna Loa source. So what accounts for the incorrect source assignment in the bivariate plot? The use of ratio data in Figure 11 is responsible for obscuring relevant geochemical variability: the source mean for Mauna Loa calculated for Sr/Zr*100 is 210.6 and Y/Zr*100 is 18.3, and sample 2011-276 is 240.6 and 13.6, respectively. This similarity in ratio is sufficient to plot the artefact within the Mauna Loa source cloud, but it is clearly not from there. Consequently, we advocate analysing artefacts with a comprehensive array of oxides and trace elements to provide more accurate source assignments for artefacts (e.g. Figure 10).

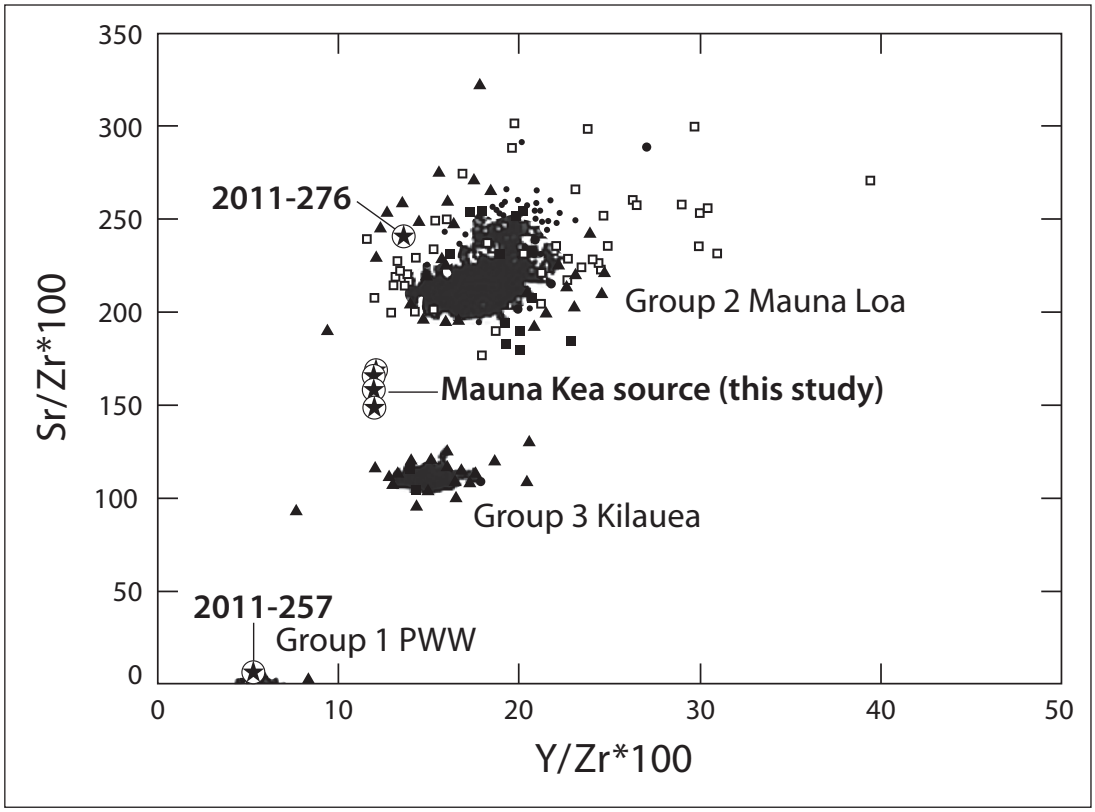

Figure 11. Bivariate plot using Sr (strontium), Y (yttrium) and Zr (zirconium) to separate Pu'u Wa'awa'a, Kilauea and Mauna Loa volcanic glass sources by Lundblad *et al.* 2013:Figure 2; used with permission of publisher). One flake of volcanic glass (sample 2011-257) from the Mauna Kea assemblage came from Pu'u Wa'awa'a, while sample 2011-276 was incorrectly assigned to Group 2 Mauna Loa using this plot. However, this latter sample is from Mauna Kea (see discussion).

Table 8. *Selected oxide and trace element mean values reported by Lundblad* et al. *(2013: Table 1) for the Group 2 Mauna Loa volcanic glass source compared to 2011-276 from Mauna Kea showing greatly different values* (in bold).

Geochemistry	Group 2	Sample 2011-276
Oxides		
SiO_2	46 ± 7.0	48.04
Al_2O_3	10.4 ± 1.7	12.79
TiO_2	**2.1 ± 0.30**	**3.28**
FeO	**8.4 ± 1.80**	
Fe_2O_3 (total iron)	**9.34**	**14.27**
CaO	9.9 ± 1.2	10.46
K_2O	0.5 ± 0.10	0.705
Na_2O	1.90 ± 0.40	2.4
Trace Elements		
Rb	**8 ± 2.0**	**14.8**
Sr	**299 ± 30**	**522**
Y	26 ± 2	29.5
Zr	**142 ± 14**	**217**
Nb	**11 ± 3**	**24**

FeO converted to Fe_2O_3 after (Weisler & Sinton 1997:189)

DISCUSSION

The efficacy of volcanic glass sourcing studies was established some 25 years ago (Weisler 1990). This paper is one contribution toward the long-term goal of obtaining a better understanding of volcanic glass quarries and quarrying, including the geochemical variability of source rock. The remote, high-altitude basaltic glass source/quarry and associated flake tool assemblages on Mauna Kea provide a new and different perspective on access to, and use of, Hawaiian volcanic glass sources and to different kinds of exchange.

The geochemical analyses conducted in this study confirmed that the procurement, manufacture and use of basaltic glass flake tools from local sources on Mauna Kea was embedded in the adze quarry 'industry'. The stratigraphic distribution of cores and flakes in the two rockshelters indicates that the source was found relatively early in the quarry sequence, which began sometime before 550±30 BP (AD 1300–1400) if we: (1) accept the recent AMS radiocarbon date for a basal layer in the Wai'ahukini Rockshelter Site (H8) containing MKAQC sourced basalt (Mulrooney *et al.* 2014), and (2) assume that this site, located on the southern tip of the island, is unlikely to contain the earliest evidence of quarrying and distribution of adzes from Mauna Kea.

The presence of basaltic glass artefacts in only two of the seven excavated rockshelters in the MKAQC, both located in close proximity to the source (Figure 1), may signal a pattern of restricted access within the larger community of adze makers who, as discussed above, are believed to have come from different districts. It is one more tantalizing indication of territoriality within the MKAQC, which to reiterate, is interpreted to have been a 'commons' (cf. Dillian 2003).

Geochemical analyses have shown that the Pu'u Wa'awa'a trachytic glass was widely distributed, particularly on the leeward side of Hawai'i Island, where it has been interpreted as having been obtained through direct access by people living in the general area of the source and through down-the-line exchange by those living farther afield (M.D. McCoy *et al.* 2011; Lundblad *et al.* 2013, 2014; Hommon 2013: 111–113). No basaltic glass with a Mauna Kea geochemical signature has been identified in EDXRF analyses of over 3900 volcanic glass flakes from a number of sites on Hawai'i Island (Mills & Lundblad 2014: 35), but this may, in part, be a result of a geochemical technique that only analysed a restricted range of oxides and elements. The incorrect source assignment for sample 2011-276, using ratio data from only three mid-Z trace elements, hints that some Mauna Kea basaltic glass artefacts may have been mistakenly identified as Mauna Loa glass.

We suspect that the basaltic glass found in the MKAQC was probably never exported in large quantities, even though it is abundant, easily procured from the surface, appears to have the same basic edge-holding properties as other Hawaiian volcanic glass, and could have been easily transported in core or flake form. We predict that small amounts of this geochemically distinctive basaltic glass, which could have had a high symbolic value because of its place of orgin in a remote wilderness that was the realm of the gods and direct association with craft specialists (Brigham 1902: 76; McCoy *et al.* 2009: 448–49), will be identified in future studies if comprehensive geochemical data are obtained for artefacts. We also predict that the distribution pattern of Mauna Kea volcanic glass will be spotty and possibly restricted to just a few localities on the eastern side of the island, in the Hamakua, Hilo and Kohala districts (Figure 1). This would be in sharp contrast to the widespread distribution of adzes manufactured in the quarry (cf. Mills & Lundlbad 2014:Figure 1), which were among the most labour-intensive, 'expensive' and inferentially highly-valued woodworking tools produced in precontact Hawai'i when travel distances and transportation costs are included in the calculus (cf. Dillian (2002) for a similar argument concerning biface production in the Glass Mountain obsidian quarry in Northern California, and Helms (1993) on the value of resources produced or obtained through long-distance trade or exchange).

The most important thing in interpreting the Pu'u Wa'awa'a flake from Layer I of Ko'oko'olau Rockshelter No. 1 is its stratigraphic context, which as previously noted, is a surface deposit without a hearth. The lack of a fire hearth, unfathomable in a shelter located at 3780 m, where night time temperatures commonly reach the freezing point or

lower, is one indication of a non-habitation fill. Another is the unusual array of associated artefacts and presence of rare vertebrate faunal remains. All but a few of the perishable artefacts and many of the wild and domesticated plants and vegetal food remains found in the MKAQC are from a compacted, surface deposit in one corner of Koʻokoʻolau Rockshelter No. 1 and the upper portion of Layer I directly below (Allen 1981; McCoy 1977, 1990). The artefacts include fire ploughs, pandanus matting, tapa cloth, fragments of a possible ti-leaf rain cape, sandal fragments (?), twisted cordage of coconut fibres from a possible carrying net and braided sennit (McCoy 1977: Figure 4; Allen 1981: 103–05, Figures 18–20, Summers 1990: Table 14 and Figure 36). The only pig bone (*Sus scrofa*) found in Koʻokoʻolau Rockshelter No. 1, and one of just three pig bones found in all of the seven excavated rockshelters in the MKAQC, is a fragment of a parietal bone with cut marks from a piglet estimated to have been less than one month old (McCoy 1990: 107). Ethnographically, pigs were used in sacrifices as mediators between men and gods (Valeri 1985: 119). We interpret this unusual collection of artefacts, including the Puʻu Waʻawaʻa trachytic glass flake and cut pig bone, as ritual offerings or gifts, perhaps left by the last of the traditional adze makers at the time the quarry was abandoned, or by their immediate descendants *c.* AD 1800 or shortly thereafter, in the fulfilment of social obligations.

The ritual offering or gift interpretation is considered the best or most plausible explanation for what the Puʻu Waʻawaʻa flake means in terms of a cultural behaviour, almost certainly having nothing to do with utilitarian uses or values as a 'tool' because of the specific context in which it was found: a non-habitation fill deposit with a nearby local source of volcanic glass. Context is everything here.

How the flake got there is a difficult question to answer. It could have been obtained through either direct access or down-the-line exchange by an adze maker in Kona, on the leeward side of the island, and then transported to the adze quarry along one of the ascent-descent routes. Or, it might have been introduced by an adze maker from the windward (east side) of the island who had obtained it through barter (cf. Hommon 2013: 107–113). Unfortunately, there is no way to choose between either of these or other possible scenarios, or to even know if the flake was part of an exchange network and, if it was, whether it was part of a one-way or two-way transaction (Smith 2004: 84).

The Puʻu Waʻawaʻa flake illustrates the need in archaeological studies of trade and exchange to 'bring to the forefront the more subtle aspects of social interaction which have often been obscured by universalizing models' (Bauer & Doonan 2002: 5). In Hawaiian archaeology, the prevailing model is the political economy, with its emphasis on the exercise of chiefly power in production for exchange (e.g. Bayman & Moniz 2001; Earle 1997; Kirch 1984, 2010). Archaeologists are finding this model, which is a 'top-down' approach, does not adequately account for all the complexities that are coming to light as a result of recent studies of adze and volcanic glass production, distribution and consumption (Mills *et al.* 2011: 90). There is clearly a need for alternative approaches to production and exchange (cf. Smith 2004; Wells 2006; Bauer & Agbe-Davies 2010; Dillian & White 2010) that not only emphasise the 'social, symbolic, and ideational roles of exchange over the economic' (Hodder 1982; Kirch 1991: 158), but that also take into consideration that something so mundane as a volcanic glass flake can in some circumstances possess significance other than utilitarian or exchange value.

Whatever approaches or theoretical constructs are used in the future in interpreting Hawaiian volcanic glass acquisition and consumption, they must include more studies of quarries and quarrying to obtain a better understanding of raw material properties and the technical and social aspects of production.

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