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Volcanic glass at Kualoa, Oʻahu, Hawaiian Islands: Paired technological and geochemical sourcing analyses of an expedient tool industry

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ABSTRACT

The results of paired technological and geochemical sourcing analyses of 1258 pieces of volcanic glass collected during archaeological investigations in the coastal portion of Kualoa on the windward coast of Oʻahu, Hawaiian Islands are reported.

Geochemical analyses by EDXRF and microprobe indicate most of the volcanic glass pieces recovered at Kualoa derived from a source in the Waiʻanae Range on the leeward side of Oʻahu. Also present are three pieces from Puʻuwaʻawaʻa on Hawaiʻi Island. Much of the rest of the material resembles sources in the Koʻolau Range, however this is a common geochemical makeup that is widely distributed on Oʻahu and other islands in Hawaiʻi and precise sources for this material have not been identified.

Technological analyses of volcanic glass nodules, cores, flakes, and debris indicate that volcanic glass from each of the sources was brought to Kualoa as unworked nodules, a finding that supports previous conclusions that Hawaiians enjoyed direct access to volcanic glass sources. A reduction sequence based on observations of broken and whole flakes and of cortex on the dorsal faces of whole flakes with and without edge damage indicates that volcanic glass users habitually chose larger flakes for tasks that resulted in macroscopic traces of edge damage. Smaller flakes were either used for tasks that did not leave macroscopic traces of edge damage or were discarded without being used.

Paired technological and geochemical sourcing analyses indicate a volcanic glass industry at Kualoa oriented to the production of flakes that were likely used for a variety of expedient cutting and scraping tasks by people with direct access to unworked material from local and non-local volcanic glass sources up to 300 km away. The picture that emerges from the paired technological and geochemical sourcing analyses is of a highly connected society in which people traveled widely and enjoyed support for their productive activities with unfettered access to sources of volcanic glass.

1. Introduction

Recognition that pristine states developed rapidly in Hawaiʻi (Hommon, 2013; Kirch, 2010) following discovery and colonization of the islands around AD 1000–1100 (Athens et al., 2014) raises questions about the extent to which political development affected the quotidian habits of commoners. Two lines of thought have developed. One views the local *ahupuaʻa* community as self-sufficient, self-contained, and managed by a hierarchy of local officials appointed by the king. This managerial view of political development contrasts with a laissez-faire view of the *ahupuaʻa* community as a tribute district where local officials organized tribute collection and presentation, but were not

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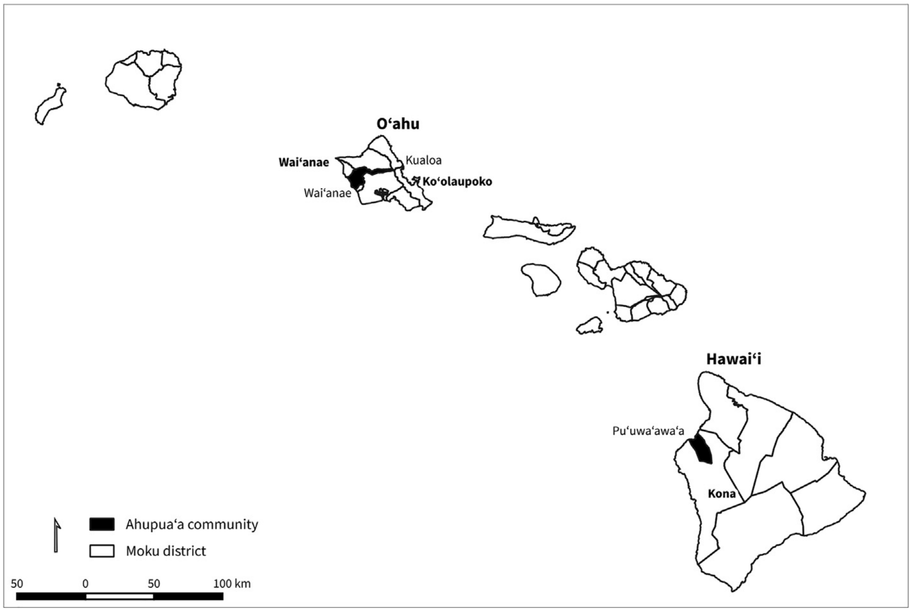

Fig. 1. The Hawaiian Islands with traditional district boundaries and *ahupua‘a* names mentioned in the text.

concerned with the quotidian habits of commoners.

Recent progress in the geochemical characterization of stone tools and identification of source locations has produced results cited in support of both views. The managerial view is supported by the differential distribution of fine-grained basalt imported from Hawai‘i Island among housing compounds of different size and complexity on Maui Island interpreted as an example of political control over access to high quality tools and their use within the *ahupua‘a* community (Kirch et al., 2012). The laissez-faire view is supported by the distribution of volcanic glass from the Pu‘uwa‘awa‘a source across political boundaries on Hawai‘i Island interpreted as an example of direct access by people from many *ahupua‘a* communities to an important source of high quality raw material free of political control (Putzi et al., 2015; McCoy et al., 2011).

This paper presents the results of paired technological and geochemical sourcing analyses of 1258 volcanic glass pieces collected during archaeological investigations carried out in the 1970’s and early 1980’s in the coastal portion of Kualoa Ahupua‘a, located in the Ko‘olaupoko District of O‘ahu Island (Fig. 1). The technological analyses identify a reduction sequence designed to produce flakes larger than 8 × 7 mm in size. The geochemical sourcing results identify an important O‘ahu Island volcanic glass source at Pu‘u Ka‘īlio in Wai‘anae Ahupua‘a, Wai‘anae District, which supplied Kualoa residents with most of their volcanic glass. In addition, Kualoa residents had access to volcanic glass from the Pu‘uwa‘awa‘a source on Hawai‘i Island, some 300 km away.

The results of the paired technological and geochemical sourcing analyses are interpreted as supporting the laissez-faire view of political development. Nevertheless, questions remain and it is recommended that similar technological and geochemical sourcing analyses be carried out at locations with well-dated contexts capable of tracking changes over time in the *chaîne opératoire* for volcanic glass.

2. Volcanic glass studies in Hawai‘i

Volcanic glass artifacts were first recognized and reported by Bishop Museum archaeologists in the early 1960’s (Soehren, 1962). Since then, archaeologists have carried out technological, edge-damage, dating, and sourcing studies (see Supplementary Materials).

Technological and edge-damage investigations culminated in the early 1980’s with an elaborate study of 675 flakes and 25 cores of volcanic glass collected from seven sites on the leeward side of Hawai‘i Island (Schousboe et al., 1983, 353). Qualitative and quantitative observations on 23 attributes were recorded with the aid of a 20× binocular microscope. Observations focused on details of flaking platforms, characteristics of scars on the dorsal face of flakes, and edge damage. The study concluded that volcanic glass was flaked using “hard-hammer percussion” (Schousboe et al., 1983, 362) in a reduction sequence characterized as a “continuum where initially hand-held cores were eventually reduced to a point where a bipolar technique became necessary for further flake removal” (Schousboe et al., 1983, 362). Cores were turned frequently during reduction, presumably to identify or set up suitable flaking platforms (Schousboe et al., 1983, 363). The detailed study of edge damage left the authors unable “to make any definitive statements on the functions of the … volcanic glass artifacts” (Schousboe et al., 1983, 368). The high cost/benefit ratio indicated by this result frustrated the authors’ “hope that other archaeologists in Hawai‘i will take the time to examine their volcanic-glass assemblages with this perspective” (Schousboe et al., 1983, 368).

Technological studies have contributed to sourcing projects that interpret the distribution of material away from the source in terms of trade and exchange. In these studies, direct access is indicated by the presence of cortex on flakes and by large flakes, whereas movement of used cores in down-the-line exchange is indicated by rare cortex and small flakes (Putzi et al., 2015; McCoy et al., 2011).

Hydration rind dating of volcanic glass was introduced to Hawaiian archaeology in the early 1970’s (Morgenstein and Rosendahl, 1976; Morgenstein and Riley, 1974; Barrera and Kirch, 1973), but the technique was criticized (Graves and Ladefoged, 1991; Olson, 1983) and most Hawaiian archaeologists now regard it as “scientific noise” (Tuggle, 2010, 177). A recent attempt to resurrect the hydration rind dating of Pu‘uwa‘awa‘a volcanic glass yielded dates that defy archaeological interpretation (Stevenson and Mills, 2013).

By the late 1970’s, archaeologists working on Hawai‘i Island had learned that hand samples of Pu‘uwa‘awa‘a volcanic glass were identifiable in hand sample (Schousboe et al., 1983; Reeve, 1983; Kirch, 1979). Early attempts to distinguish volcanic glass sources chemically (Weisler, 1990; Olson, 1983) were followed by establishment of an EDXRF (Energy-dispersive X-ray fluorescence) facility at the University of Hawai‘i at Hilo, which used the technique to distinguish Pu‘uwa‘awa‘a from unknown sources chemically consistent with Mauna Loa and Kīlauea lava flows on Hawai‘i Island (Lundblad et al., 2013).

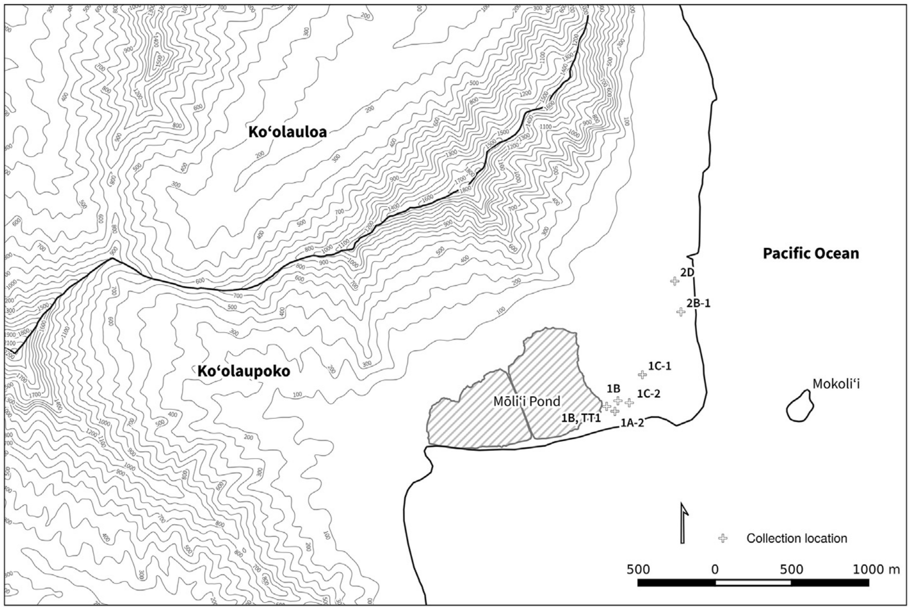

Fig. 2. Collections locations at Kualoa, with places mentioned in the text.

EDXRF was used to establish that the proportion of Puʻuwaʻawaʻa volcanic glass in an archaeological collection declines with distance from the source (McCoy et al., 2011). Later, a distance decay function was fit to the Hawaiʻi Island data (Putzi et al., 2015).

3. Archaeological investigations at Kualoa

Kualoa is located at the northern end of Kāneʻohe Bay along the windward coast of Oʻahu Island. It is the northernmost *ahupuaʻa*, or land, in the Koʻolaupoko district. Kualoa is a small *ahupuaʻa* consisting of a narrow coastal plain and a sandy peninsula, with steep cliffs towering above the landscape (Fig. 2). Nevertheless, it is famous in Hawaiian tradition as a sacred place, a symbol of island sovereignty, and an established place of refuge.

The sandy peninsula of Kualoa where the volcanic glass pieces were collected is today a public park owned and managed by the City and County of Honolulu. In the mid-nineteenth century there were two settlements in Kualoa, one near the beach on the north and another on the alluvium adjoining the open water of Mōliʻi Pond. Sugarcane was cultivated during the 1860's. After the sugarcane operation folded, the land was used to pasture horses and cattle. When the first archaeological survey of Kualoa was completed as part of an island-wide survey no trace could be found of two temples identified by Hawaiian tradition (McAllister, 1933). The volcanic glass analyzed here was collected by City and County archaeologists in the 1970's and also during University of Hawaiʻi archaeological field schools in 1977, 1983, and 1984 (Gunness, 1993), primarily at seven locations that roughly coincide with the locations of the mid-nineteenth century settlements (see Fig. 2). The archaeological collections were augmented by a small geological collection from dikes exposed on the east side of Mokoliʻi Island by Robert D. Connolly.

4. Materials and methods

Paired technological and geochemical sourcing analyses were carried out on 1258 pieces of volcanic glass on loan from the City and County of Honolulu.

Technological observations included: length, width, and thickness measured to the nearest 0.01 mm with a digital caliper; weight measured to the nearest 0.1 g with a digital scale; formal classification of the volcanic glass piece as an unworked nodule, core, flake, edge-altered flake, or debris; number of facets; presence/absence of macroscopic edge alteration; completeness; and identification of primary, secondary, and tertiary cortex; along with notes about the condition of the piece and its possible interpretation (see Supplementary Materials).

Non-destructive geochemical analysis was carried out with a ThermoNoran QuantX^{TM} EDXRF spectrometer at the Geoarchaeology Laboratory of the University of Hawaii at Hilo. Data were acquired for 18 elements: Na, Mg, Al, Si, K, Ca, Ti, V, Mn, Fe, Ni, Cu, Zn, Rb, Sr, Y, Zr, and Nb. The elements Rb, Sr, Y, Zr, and Nb most often exhibit the best analytical precision with EDXRF (Mills et al., 2010). A scatterplot of the concentration of elements Sr and Zr was used to identify clusters and distinguish 11 compositional groups by eye. A principal components analysis yields results that support the grouping (see Supplementary Materials). The low cost and high throughput of EDXRF analysis have made it a valuable method for revealing general patterns in geochemistry within a volcanic glass collection. The results of EDXRF analysis can be used to guide application of expensive, destructive, and/or time-consuming techniques (Kirch et al., 2012).

Twenty-four broken and/or unworked pieces of volcanic glass were subsequently analyzed at the School of Ocean and Earth Science and Technology (SOEST) Microprobe Facility at the University of Hawaiʻi at Mānoa. Data were acquired for SiO_2, TiO_2, Al_2O_3, FeO*, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5. These data support and augment the EDXRF analysis. They were compared with published analyses to identify volcanic glass sources (see Supplementary Materials).

5. Results

The 1258 volcanic glass pieces in the technological analysis included 58 unworked nodules, 3 cores, 609 flakes with macroscopic evidence for edge alteration, 522 flakes without macroscopic evidence for edge alteration, and 69 pieces of debris. Two locations yielded the bulk of this material. The University of Hawaiʻi field school excavations in area 2B-1 yielded 744 pieces of volcanic glass, and the surface collection from Area 1B contributed 439 pieces. In contrast, the other locations each yielded between 2 and 31 pieces of volcanic glass. The distribution of classes across the collection areas is relatively even. Nevertheless, nodules and debris are more common in the excavated collection from area 2B-1 than in the surface collection from area 1B, and all three cores came from the excavations in area 2B-1.

The size of a volcanic glass piece varies according to class. Cores are

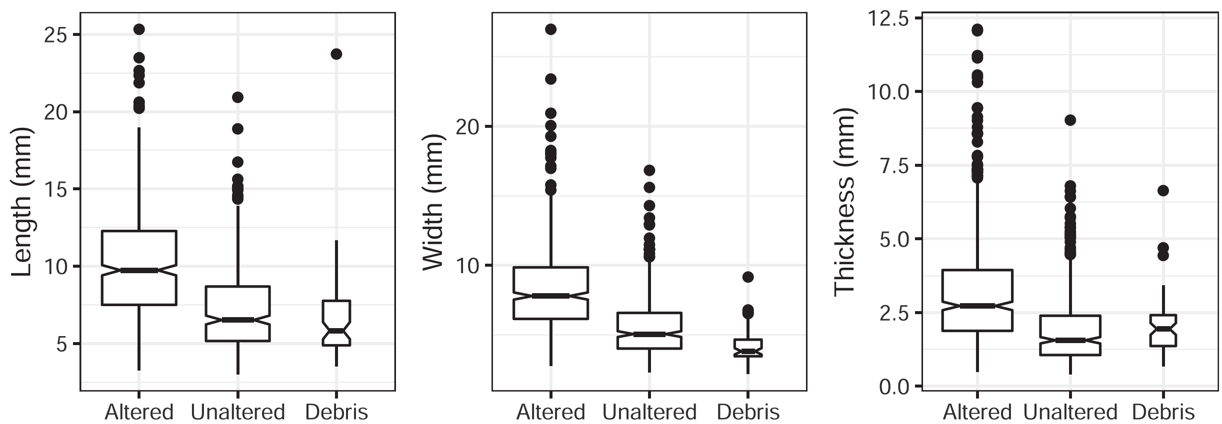

Fig. 3. Box and whisker plots comparing the sizes of 609 complete volcanic glass flakes with macroscopic evidence for edge alteration, 522 complete flakes without macroscopic evidence for edge alteration, and 69 pieces of debris. Box widths are proportional to the number of instances. The notches in the boxes approximate 95% confidence intervals for comparing medians.

on average slightly larger than the unworked nodules. The mean complete flake with macroscopic evidence for edge alteration is longer, wider, and thicker than the mean complete flake with an unaltered edge (Fig. 3). Flakes without evidence for edge alteration are close in size to pieces of debris.

The size of complete edge-altered flakes varies according to whether the flake exhibits primary, secondary, or tertiary cortex (Fig. 4). The length and width of flakes with primary and secondary cortex cannot be distinguished, but flakes with tertiary cortex are shorter and narrower. In contrast, thickness declines through the sequence.

A second dimension of variation is evident in the size relationship between complete edge-altered flakes with tertiary cortex and complete unaltered flakes with secondary cortex. Edge-altered flakes with tertiary cortex are longer and wider than unaltered flakes with secondary cortex, but thickness can't be distinguished.

A third dimension of variation compares the numbers of altered and unaltered flakes at each stage. Flakes with primary and secondary cortex more frequently show edge alteration than not. In contrast, flakes with tertiary cortex more frequently have unaltered edges (see Supplementary Materials).

Flakes were typically discarded before they broke. 894 flakes in the collection are complete and 235 flakes are broken. Breakage patterns vary according to edge alteration; flakes without macroscopic evidence for edge alteration are more likely broken than flakes with macroscopic evidence for edge alteration (see Supplementary Materials).

Geochemical source analysis indicates that some of the vitreous material identified by archaeologists as volcanic glass is either not glass or is not completely vitrified (see Supplementary Materials). EDXRF analysis identified 44 pieces whose chemistry is outside the known range of Hawaiian rocks; these pieces likely include bits of burned bone, burned shell, charcoal, and possibly coal. Microprobe analysis identified one piece—the proximal end of a flake with tertiary cortex—as metallic, most likely the Fe hydroxide goethite, a weathering product of Hawaiian volcanic rocks. In addition, 2 of the 24 pieces submitted for microprobe analysis are partially devitrified, showing evidence for incipient crystallization (Fig. 5). One of the partially devitrified pieces is the proximal end of a flake with macroscopic evidence of edge alteration, and the other was a nodule that appeared to have been used as a scraper but had not had flakes removed from it.

The 1258 volcanic glass pieces in the geochemical source analysis were divided into 10 groups by the EDXRF analysis. The collection is dominated by Groups 9 and 4, which contain 638 and 535 pieces, respectively. 36 pieces were assigned to source Group 8. Source groups 2, 3, 5–7, 10, and 11 are all small, ranging from 1 to 12 pieces (see Supplementary Materials).

The EDXRF groups are distributed evenly among the collection areas at Kualoa. The two large collections from areas 2B-1 and 1B each contain volcanic glass pieces from source groups 3–11. EDXRF Group 9 is more numerous than Group 4 in each of these large collections, consistent with its representation in the collection as a whole (see Supplementary Materials).

EDXRF Groups 9 and 4 are each dominated by flakes with and without macroscopic edge damage. Group 4 has proportionally more debris than Group 9. There are unworked nodules assigned to 9 of the groups; only the sparsely populated Group 5 does not include unworked nodules of volcanic glass (see Supplementary Materials).

The complete edge-altered flakes assigned to Groups 4 and 9 differ little in size (Fig. 6).

A specific source has been identified for 2 of the 11 groups distinguished by the EDXRF analysis (see Supplementary Materials). Microprobe analysis confirmed that a piece of volcanic glass from Group 11 derives from the distinctive Puʻuwaʻawaʻa source on Hawaiʻi Island, a result that lends further support to the claim that EDXRF analysis confidently identifies materials from this distinctive source.

Microprobe analysis indicates 11 volcanic glass pieces assigned to Group 9 as deriving from a single silicic glass source at Puʻu Kaʻīlio in the Waiʻanae Range. One volcanic glass piece assigned to Group 9 was identified as deriving from a basaltic glass source in the Waiʻanae Range, as were one piece assigned to Group 6 and another piece assigned to Group 4 (see Supplementary Materials).

Volcanic glass from the dikes on Mokoliʻi Island would be assigned to Group 4. However, microprobe analyses of glasses in Group 4 are sufficiently different from one another to suggest at least 7 separate volcanic glass sources, most likely in the Koʻolau Range, and at least one source in the Waiʻanae Range. Basaltic glass sources on other islands might also have contributed material to the Kualoa collection. In addition, the microprobe analysis assigns EDXRF Group 3 to a basaltic source in the Koʻolau Range.

6. Discussion

Interpretation of the results of the paired technological and geochemical sourcing analyses of 1258 pieces of volcanic glass from Kualoa attempts to reconstitute the *chaîne opératoire* for an expedient tool that is nearly ubiquitous in Hawaiian archaeological collections.

Technological analyses are best interpreted as a reduction sequence involving small nodules of volcanic glass flaked with a hard hammer using both hand-held and bipolar techniques, in which the core was turned frequently to find a suitable striking platform (Schousboe et al., 1983, 362). Flake removal typically yielded some debris along with flakes of various sizes. Macroscopic observation of edge damage was used in the technological analysis to distinguish between flakes selected

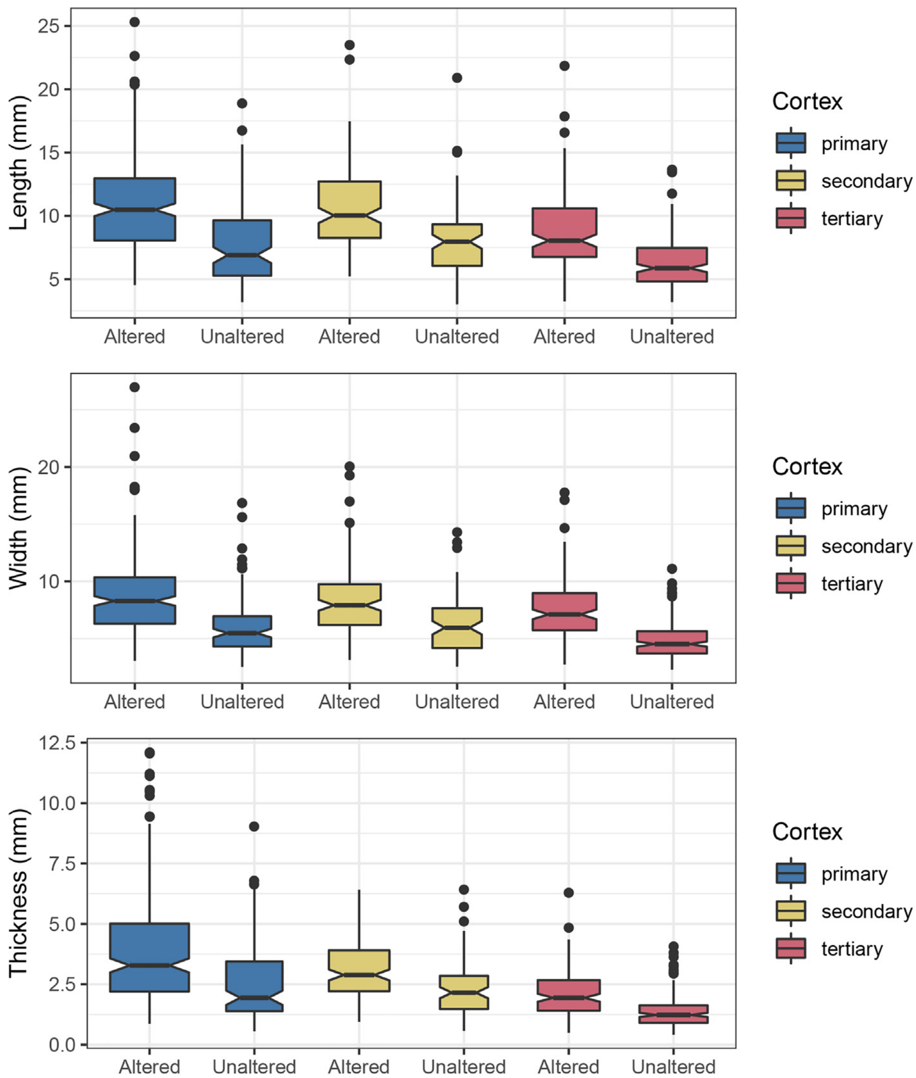

Fig. 4. Box and whisker plots comparing the sizes of 352 complete volcanic glass flakes with primary cortex, 225 complete volcanic glass flakes with secondary cortex, and 319 complete volcanic glass flakes with tertiary cortex. Box widths are proportional to the number of instances. The notches in the boxes approximate 95% confidence intervals for comparing medians.

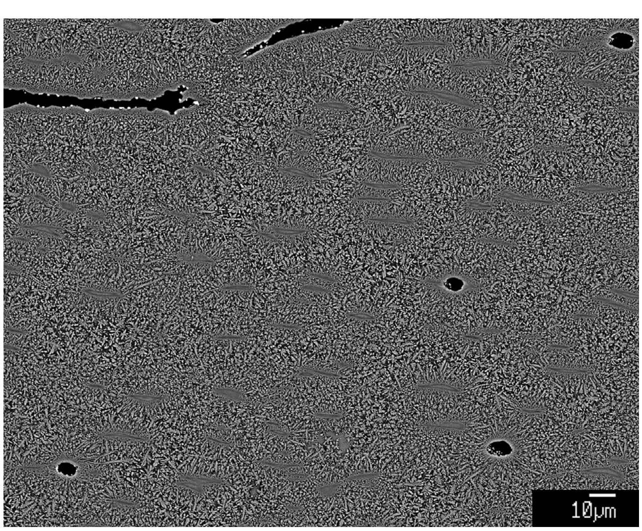

Fig. 5. Backscatter electron image showing partially devitrified volcanic glass with evidence for incipient crystallization; note scale bar in lower right hand corner. Sample 443–221–1 is the proximal end of a broken flake with macroscopic evidence for edge alteration.

for use and those that were used for tasks that didn't result in macroscopic traces of edge damage or were discarded without being used. This interpretation is supported by the marked differences in size between the edge-altered and unaltered complete flakes, where a strong bias for large flakes is evident.

Nevertheless, this interpretation is potentially tempered by the possibility that edges might be damaged by some activity other than use. In particular, trampling of discarded flakes might produce edge damage similar to that produced when a flake is used for cutting or scraping tasks. The trampling problem has been studied experimentally by archaeologists who have identified three variables that influence the probability an edge will be damaged by trampling:

(i) stiffness of substrate on which the flakes are deposited
(ii) density of flakes in the deposit, and
(iii) flake size (Gifford-Gonzalez et al., 1985; McBrearty et al., 1998).

Experiments show consistently that flakes are more often damaged on stiff substrates such as loam, where trampling does not cause flakes to penetrate the substrate, than on softer substrates such as unconsolidated sand, where trampling pushes flakes into the substrate (Gifford-Gonzalez et al., 1985; McBrearty et al., 1998). The volcanic glass collections from Kualoa were all recovered from deposits of

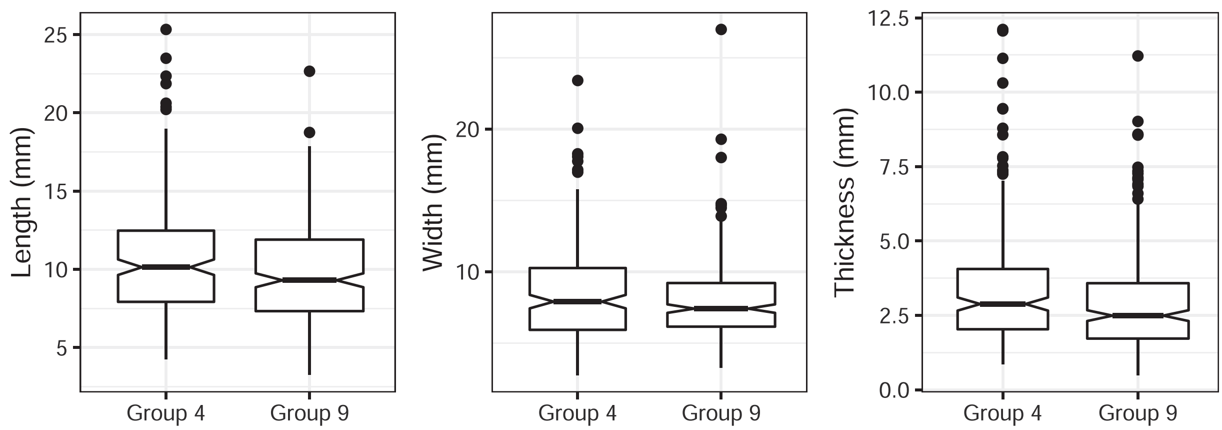

Fig. 6. Box and whisker plots comparing the sizes of 210 complete edge-altered flakes assigned to Group 4 and 269 complete edge-altered flakes assigned to Group 9. Box widths are proportional to the number of instances. The notches in the boxes approximate 95% confidence intervals for comparing medians.

unconsolidated calcareous sand, a soft substrate. The experiments also show that most of the damage caused by trampling occurs when two flakes come into contact with one another or when a flake comes into contact with another hard object. Thus, edge damage from trampling is relatively common at chipping stations where there is a dense distribution of flakes and debris and less common in situations where flakes are sparsely distributed. In one experiment, densities ranged from 100 to 500 artifacts per m^2 (McBrearty et al., 1998, 112), while another experiment used a fixed density of 250 artifacts per m^2 (Gifford-Gonzalez et al., 1985, 805). At Kualoa, densities of volcanic glass artifacts are difficult to establish because collections in any one area were typically made over long periods of time and in circumstances ranging from surface collection after grading and grubbing to controlled excavation by field school students. In any case, volcanic glass density ranged from about 0.2 per m^2 in Area IB, which was graded and grubbed and subsequently subject to limited test excavations, to about 1–2 per m^2 in areas 2B, 2C, and 2D where construction-related disturbance was augmented with large scale excavations carried out by university field schools. In all cases, volcanic glass densities at Kualoa were orders of magnitude lower than the experimental situations. Finally, the experiments demonstrated that flakes longer than 2 cm were fractured by trampling much more frequently than shorter flakes (Gifford-Gonzalez et al., 1985, 807), especially on a soft substrate. Edge damage to the shorter flakes was extremely rare on both stiff and soft substrates (Gifford-Gonzalez et al., 1985, 814). The vast majority of volcanic glass artifacts from Kualoa are small, with only a few flakes longer than 2 cm (see Fig. 3). The diminutive size of these artifacts makes them unlikely candidates for damage from trampling.

By all measures—substrate stiffness, flake density, and flake size—the volcanic glass artifacts from Kualoa are unlikely to show damage from trampling that might be confused with edge damage caused by use wear. Thus, comparisons of the sizes of flakes with and without edge damage in the Kualoa assemblage can be interpreted as a result of habitual practices of Hawaiian craftsmen who selected some flakes for uses that left macroscopic damage to the cutting edge, such as working wood or bone, and either discarded others or used them for working softer materials in such a way that macroscopic edge damage did not result (Young and Bamforth, 1990; Shen, 1999).

The selection habits of volcanic glass producers and users can be tracked through the reduction sequence by comparing the sizes of edge-altered and unaltered flakes with primary, secondary, and tertiary cortex (see Fig. 4). Selection for length and width appear to have operated more strongly than selection for thickness, as indicated by the fact that edge-altered tertiary flakes are longer and wider than unaltered secondary flakes. Flakes longer than 8 mm or wider than 7 mm were typically selected for use, while flakes shorter or narrower than this were not selected. This pattern of selection might be expected for an expedient tool industry, where a flake had to be large enough to grip securely between the thumb and forefinger. In this interpretation, flakes smaller than 8 × 7 mm were too small to grip securely for cutting and scraping tasks. If this is correct, then a core of volcanic glass would have been considered exhausted and ready for discard when it was no longer able to yield a flake of this size.

The selection habits of volcanic glass producers and users also can be tracked through the reduction sequence by comparing the numbers of edge-altered and unaltered flakes with primary, secondary, and tertiary cortex (see Fig. 4). The proportion of flakes selected for use decreases through the reduction sequence. About 2 of every 3 flakes with primary cortex are selected for tasks that leave macroscopic evidence of edge damage. The selection rate drops to 3 out of 5 among flakes with secondary cortex. By the time the cortex is removed, fewer than half the flakes show evidence of edge damage. The selection habits of volcanic glass workers clearly illustrate the process by which a core was exhausted.

Another potential reason for selection of larger flakes for tasks that result in macroscopic edge damage appears to be the tendency of smaller flakes to break during use. The implication here is that volcanic glass flakes used as tools often broke relatively quickly, before macroscopic edge damage occurred.

EDXRF and microprobe analyses confirm the Pu'uwa'awa'a origin of 3 pieces of volcanic glass, one of which was identified in hand sample and reported as "the first archaeologically documented evidence of inter-island transport of what might be called a 'high-status' consumer good" (Gunness, 1993, 58). The 3 pieces identified in the analysis is one fewer than the 4 pieces predicted by the distance decay function (Fig. 7). The predictive accuracy of the distance decay function extends

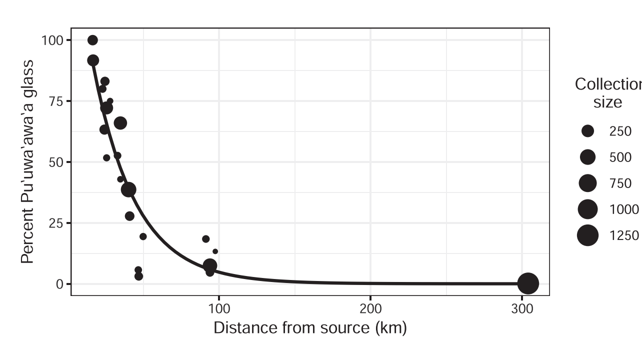

Fig. 7. Distribution of Pu'uwa'awa'a volcanic glass away from the source. The distance decay function is defined as $p = exp(5.104315 - 0.035707 * d)$, where p is the percentage of Pu'uwa'awa'a volcanic glass in the assemblage, and distance, d, is measured as the shortest path in km from Pu'uwa'awa'a to the find spot. *Sources:* McCoy et al. (2011),Putzi et al. (2015).

its utility to instances of inter-island movement of volcanic glass across political boundaries. The Hawai'i Island data showed that volcanic glass moved across *ahupua'a* and *moku* district boundaries, either by transport over land or by canoe (Putzi et al., 2015). Identification of 3 pieces of Pu'uwa'awa'a glass in the Kualoa collection show that volcanic glass also moved across *mokupuni* island boundaries by canoe. The unworked nodule of Pu'uwa'awa'a glass recovered at Kualoa suggests that volcanic glass workers at Kualoa enjoyed direct access to the Pu'uwa'awa'a source, and were not dependent on down-the-line exchange for access to this material.

EDXRF and microprobe analyses support the inference that most of the volcanic glass in the Kualoa collection derives from a source in the vicinity of Pu'u Ka'īlio in Wai'anae Ahupua'a, a distance of about 32 km from Kualoa. Somewhat surprisingly, the distance decay function for Pu'uwa'awa'a correctly predicts the proportion of the Pu'u Ka'īlio source in the Kualoa collection. The distance decay function predicts that a source 32 km distant should make up 52 percent of the volcanic glass collection; the observed proportion of Group 9 glass at Kualoa is 51 percent. Assignment to Group 9 of 29 unworked volcanic glass nodules indicates Kualoa volcanic glass workers enjoyed direct access to the Pu'u Ka'īlio source, too, and did not have to rely on down-the-line exchange.

These results suggest the distance decay function might be applied to the distribution of volcanic glass from sources other than Pu'uwa'awa'a. If so, archaeologists might claim evidence for a widespread tradition of social relations unaffected by development of state political institutions (Renfrew, 1977). Because the Pu'u Ka'īlio source appears to be reliably identified by EDXRF, it should be possible to test the distance decay function with other large volcanic glass assemblages.

7. Conclusions

The results of paired technological and geochemical sourcing analyses of 1258 volcanic glass pieces from Kualoa are interpreted to indicate that the quotidian habits of Kualoa volcanic glass workers connected them directly with resources well outside the *ahupua'a* community. Development of a political hierarchy in the islands does not appear to have influenced these habits. If this characterization is correct, then Hawai'i conforms to the typical situation in pre-capitalist social formations in which leaders concern themselves with controlling the ways in which status is acquired and how wealth assets are distributed, rather than the quotidian habits of common folk and the distribution of consumables, such as volcanic glass (Rowlands, 1982; Goldman, 1970). The picture that emerges from the paired technological and geochemical sourcing analyses of the Kualoa volcanic glass collection is of a society in which people traveled widely and enjoyed support for their productive activities with unfettered access to sources of volcanic glass.

This interpretation is tempered somewhat by the tradition of Kualoa as a sacred place. A single paired technological and geochemical sourcing analysis cannot establish the pattern of distribution away from the Pu'u Ka'īlio source, and subsequent inquiry at other locations might show Kualoa to be a special case where the high status of *ahupua'a* residents entailed preferred access to resources such as volcanic glass. Also, the Kualoa volcanic glass derives from poorly dated contexts that frustrate the possibility of tracking changes in the *chaîne opératoire* for volcanic glass. These questions about the Kualoa collection can be addressed by paired technological and geological sourcing analyses at other Hawaiian sites with large volcanic glass collections from well-dated contexts.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jasrep.2019.102117.

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