UNIVERSITY *of* HAWAIʻI*at* HILO
CENTER FOR MAUNAKEA
STEWARDSHIP

May 8, 2026

MKSOA Monthly Meeting
May 14, 2026
CMS Operations Report

1. Agenda Item VII.A: VLBA Reroof/Repaint Project (Type A Project) – Information Only

   A. Project Description
   VLBA has determined facility maintenance to repaint the building exterior and replace the existing roof are urgent and necessary to avoid site damage and water leaks. As the project is limited to like-to-like replacements of the roof and painting, the following land use is determined to apply: HAR §13-5-22, P-8, Structures and Land Uses, Existing (A-1) Minor repair, maintenance, and operation to an existing structure, facility, use, land, and equipment… that involves mostly cosmetic work or like-to-like replacement of component parts, and that results in negligible change to or impact to land, or a natural and cultural resource. No other work is involved.

   B. Identified Resources and Impacts
   The project site is within the Mauna a Wākea Traditional Cultural Property, listed in 2023 as a State Inventory of Historic Places (SIHP) site #50-10-23-31382, and the Mauna Kea Traditional Cultural Property, listed in 2025 on the National Register of Historic Places. The project is strictly limited to the infrastructure of the support building and no historic or cultural resources, including any viewplanes or oceanic gridlines, will be impacted. CMS also does not anticipate any negative adverse impact on hydrological, geological, or recreational resources. The project will not extend or enlarge the VLBA footprint and does not change the permitted use of the parcel.

   C. Comprehensive Management Plan Compliance
   The request is consistent with the 2022 Comprehensive Management Plan (CMP), approved by the Board of Land and Natural Resources. The proposed land use is also consistent with UH's General Lease for the Science Reserve (S-4191).

   D. Reviews and Recomendations
   CMS recommends Best Management Practices and other project conditions be adhered to in carrying out this work. The project was presented for comments and recommendations to Kahu Ku Mauna on April 2, 2026 and Maunakea Management Board on April 16, 2026. Kahu Ku Mauna noted the need for observatories to

maintain their facilities for safety and aesthetic purposes; no additional recomendations were provided by either group.

The request is classified as a Type A project and will be submitted to the Office of Conservation and Coastal Lands (OCCL) for concurrence. The project will not proceed unless and until the Office of Conservation and Coastal Lands (OCCL) issues concurrence. VLBA will comply with any and all conditions. The project is being presented to the Mauankea Stewardship and Overisght Authority (MKSOA) here for comments. As a Type A project no formal action by MKSOA is required.

2. Agenda Item VII.B.: Geochemical characterization of CMS lithic collections (Research proposal from UHH Departments of Antropology and Geology) – Information Only

A. Principal Investigators
Peter Mills, Ph.D., UHH Department ot Anthropology and Steven Lundblad, Ph.D., UHH Department of Geology.

B. Project Description
The reserach proposes to analyze select lithic samples (approximately 100 individual items) housed at CMS. The objective is to characterize the geochemistry of previously-unexamined lithics from areas west of the Pōhakuloa Gulch. The analysis consists of analyzing the geochemistry of the samples using the non-destructive EDXRF method (see below). The analysis will be conducted in the UHH campus geoarchaeology lab. Samples will be returned to CMS upon completion of analysis which is expected within one month's time from commencement.

C. Background

During the original 2010 archaeological survey of the summit region conducted by Pacific Consulting Servcies Inc. (PCSI) for UH, additional adze quarry areas were identified beyond the bounds of the quarry that the Bishop Museum had identified in the 1970s. These additonal quarry areas are within the Maunakea Science Reserve (UH managed lands) stewarded by CMS. Samples from those additional sites were collected by PCSI and are now are housed at Hale Pōhaku.

Peter Mills (UHH Anthropology) Dr. Steve Lundblad (UHH Geology Dept.) propose to borrow flakes collected from these additional quarry areas for about a month to analyze their geochemistry through through the non-destructive Energy Dispersive X-ray Fluorescence (EDXRF) geochemical analysis method. EDXRF is a fast, non-destructive technique that determines the elemental composition (from sodium to uranium) of geological materials like rocks, sediments, and ores. The characterization will enable a more comprehensive understanding of the range in geochemistry and dispersion of ko‘i from Maunakea across the pae ‘āina and Pacific.

In the early 2000s, Mills and Lundblad received a Natural Area Reserve (NAR) permit to collect geological samples within the Mauna Kea Adze Quarry boundaries as they were known at the time. They analyzed approximately 1000 lithic specimens that the Bishop Museum had collected in the 1970s during excavations of 4 rockshelters in the quarry. The results of that study allowed publication of the first relatively comprehensive study of the geochemistry of the quarry stone so that it could be matched through EDXRF with artifacts found in domestic sites on the coast and throughout the islands (Attached).

The proposed reserach will include UHH Heritage Management MA students to help with the analysis as part of their stone tool analysis class that they are currently taking. The artifacts will be returned to CMS by the end of this semester. Per Mills and Lundblad, this case is an example of why having at least some collections from the quarry available for analysis has community benefits by limiting the need for researchers to return to original collection sites in order to do this work.

D. Reviews and Recommendations

As this research is not a proposed land use under Hawai‘i Administrative Rules (HAR) §13-5-22 Identified land uses in the protective subzone, the project does not require OCCL approval. However, as a research activity, the proposal is subject to research permit approval pursuant to HAR §20-26-62 Research permits. The proposal was presented and reviewed for comments by Kahu Ku Mauna on April 2, 2026 and by the Maunakea Management Board on April 16, 2026. Both groups strongly support the project and provided no additional comments or recommendations. The proposal is presented here for MKSOA comments.

Society for American Archaeology

Science and Sensitivity: A Geochemical Characterization of the Mauna Kea Adze Quarry Complex, Hawai'I Island, Hawaii
Author(s): Peter R. Mills, Steven P. Lundblad, Jacob G. Smith, Patrick C. McCoy, Sean P. Naleimaile
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SCIENCE AND SENSITIVITY: A GEOCHEMICAL CHARACTERIZATION OF THE MAUNA KEA ADZE QUARRY COMPLEX, HAWAI`I ISLAND, HAWAII

Peter R. Mills, Steven P. Lundblad, Jacob G. Smith, Patrick C. McCoy, and Sean P. Naleimaile

The Mauna Kea Adze Quarry Complex is the largest-known prehistoric quarry in the Pacific Basin. The main extraction areas are located at an extreme altitude (3,800 m), near the summit of Hawaii's tallest mountain. The Mauna Kea summit region and the quarry are considered by many Hawaiians to be a sacred landscape and archaeologists must consider the ethical tensions involved in conducting Western science in these areas. Although provenance studies of basalt adzes are integral to the examination of pre-contact Hawaiian economics, former studies of Hawaiian adze distribution have been limited in scope, and conventionally relied on destructive petrography and petrology for the analyses. Published geochemical data on the quarry are derived from only eight samples analyzed with destructive methods. In order to better define the variation within the quarry, and to develop a more culturally sensitive approach, we employed nondestructive energy-dispersive X-ray fluorescence (EDXRF) of whole-rock samples to characterize 820 flakes and 47 geological samples from the quarry complex. This study offers the first reliable estimation of the overall range of geochemical variability in the complex. These results suggest that nondestructive EDXRF can be used to differentiate Mauna Kea basalts from other known Hawaiian quarries, but more characterization of other quarries is necessary to confirm exclusive separation of sources. The results further demonstrate that EDXRF is capable of detecting intra-site geochemical variation in Mauna Kea quarry material.

La cantera de azuela en Mauna Kea es la cantera prehistórica más grande en la Cuenca Pacífica. La región principal de extracción se sitúa a una altitud extrema (3800 m), cerca de la cima de la montaña más alta en Hawaii, Mauna Kea. La cima de Mauna Kea y la cantera constituyen un paisaje sagrado de la cultura tradicional de Hawai, y los arqueólogos necesitan considerar los conflictos éticos al trabajar investigaciones científicas en estos sitios. Aunque los estudios sobre el origen de azuela basáltica son integrales para el análisis de la economía precolombina en Hawaii, los estudios precedentes de la distribución de azuelas hawaianas han sido limitados en alcance y, de una manera convencional, han sido basados en la petrología y la petrografía destructiva para sus análisis. Los datos geoquímicos publicados sobre la cantera se derivan de solamente ocho muestras que han sido analizadas por medio de métodos destructivos. Para definir mejor la variación geoquímica en la cantera, y para crear un método más sensible a la cultura hawaiana, empleamos la Fluorescencia de Rayos X para la Energía Dispersiva (EDXRF), no destructiva, de 820 lascas y 47 muestras geológicas de la cantera. Este estudio presenta la primera valoración sólida del alcance posible de la variabilidad geoquímica en la cantera. Los resultados sugieren que la EDXRF no destructiva se puede utilizar para diferenciar el basalto en Mauna Kea de otras canteras hawaianas, y también puede detectar la variación geoquímica desde dentro de la misma cantera.

Mauna Kea (elevation 4,205 m), on the Island of Hawai`i, is the highest mountain in the Hawaiian Islands and is often covered in snow in winter months. The summit region is associated with a pantheon of Hawaiian deities, including the first ancestors in genealogi-

Peter R. Mills ■ Department of Anthropology, University of Hawaii at Hilo, 200 W. Kawili St., Hilo, HI 96720 (millsp@hawaii.edu)

Steven P. Lundblad ■ Department of Geology, University of Hawaii at Hilo, 200 W. Kawili St., Hilo, HI 96720 (slundbla@hawaii.edu)

Jacob G. Smith ■ Department of Geology, University of Hawaii at Hilo, 200 W. Kawili St., Hilo, HI 96720 (smithjg@hawaii.edu)

Patrick C. McCoy ■ Pacific Consulting Services, Inc. 720 Iwilei Rd. Suite 424, Honolulu, HI 96817 (pat.mccoy@pcsi-hawaii.com)

Sean P. Naleimaile ■ Department of Anthropology, University of Hawaii at Manoa, 2424 Maile Way, Honolulu, Hawaii 96822 (naleimai@hawaii.edu)

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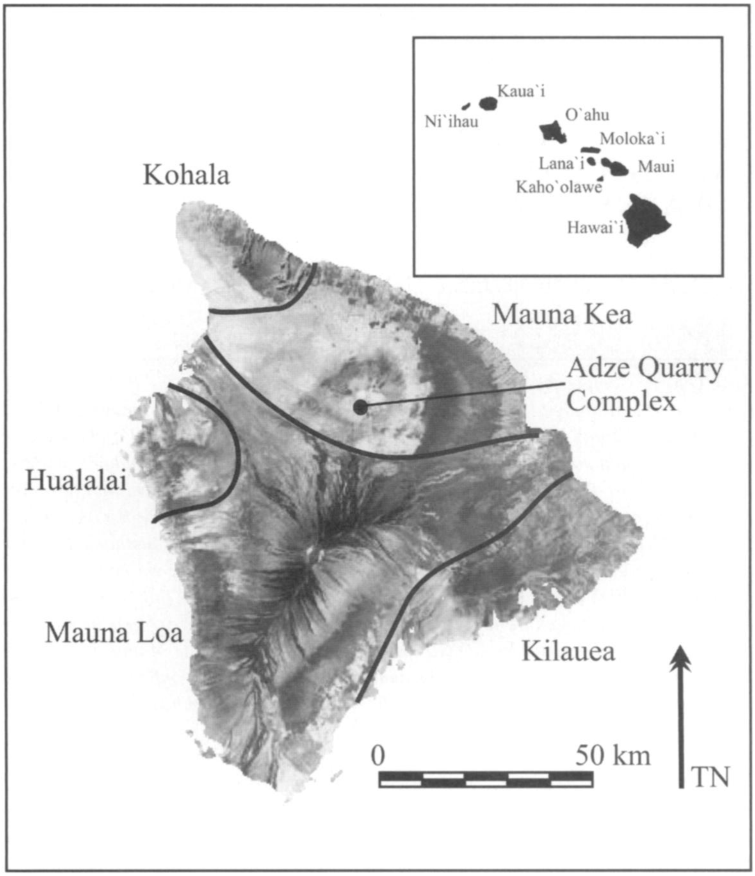

Figure 1. Location of the Mauna Kea Adze Quarry Complex in relation to the five major volcanoes forming Hawai`i Island.

cal chants, Wakea and Papa, as well as Poli`ahu—the goddess associated with snow and sister to the fire goddess Pele (Maly and Maly 2005:4–10). Situated approximately 400 m lower in elevation is the Mauna Kea Adze Quarry Complex (50-10-53-4136), which is one of the most remarkable prehistoric sites in the Pacific (Figure 1). Enormous debitage piles from the manufacture of possibly hundreds of thousands of stone adzes (*ko`i*) are concentrated along several escarpments composed of fine-grained basalts (Figure 2). The quarry is well above elevations that commonly induce altitude sickness, especially in people who live along the coast. Although some quarrying activity extends below the tree-line to 2,740 m, the majority of the complex lies above any readily available food or fuel. Standing at the quarry, one is struck by the extent to which Hawaiians explored their natural environment. It is equally impressive to consider the sophisticated economy that supported this high-altitude industry.

Despite some early and significant studies of archaeological quarries by William Henry Holmes (1890, 1900, 1919; see also Meltzer and Dunnell 1992), archaeological studies of quarry sites did not achieve prominence until the development of processual approaches to stone tool analysis (Bryan and Tuohy 1960; Ericson and Purdy 1984; Gramly 1980; Ritchie and Gould 1985; Shafer and Hester 1983; Singer and Ericson 1977; Torrence 1986). Many regional studies of lithic technology, political economies, and exchange networks have sustained archaeological interest in these sites (Arnold 1992; Lepper et al. 2001; Reher 1991; Root 1997; Shackley 2005), and the SAA now sponsors a "Prehistoric Quarry and Early Mines" interest group.

Processual archaeological interest in Polynesian stone tool quarries followed similar trends to

Figure 2. Photograph taken September 9, 1885 in front of Keanakako`i rockshelter (Bishop Museum Site 50-Ha-G28-2). Notations on the photo state "Ancient quarry and work place for stone adzes, on the southern slope of Mauna Kea at an elevation of 12,000 ft. The heap on which Alfred Deverill is standing consists of unfinished stone adzes. Under the place where Glades is seated is the entrance to a cave that shows evidence of early habitation—broken calabashes, *tapa* mats, *awa* roots, *opihi* shells." Eduard Arning collection, courtesy of the Hawaiian Historical Society.

those in the Americas (Leach and Witter 1985, 1987, 1990; McCoy 1976, 1977; McCoy and Gould 1977). Following surveys and excavations at the Mauna Kea Adze Quarry in the 1970s, McCoy (1977:236) estimated that the quarry covers over 18 km^2, but more recent fieldwork (McCoy 1986, 1991) further expands site boundaries. It is larger than all other known Hawaiian quarries combined. Associated features include a variety of workshops, rockshelters, open-air shelters, shrines, and a few examples of rock art. Twenty-three published radiocarbon dates from eight excavation areas within the complex indicate that the quarry may have been in use from A.D. 1100 to approximately A.D. 1800 (McCoy 1990:92). Lass (1994:24) indicates from petrographic analyses that Mauna Kea adzes appear in contexts dating before A.D. 1100, but these findings are based solely on two sites on the southern part of Hawai`i Island (H1, H8) that have been the subjects of much chronological reinterpretation (Cordy 2000:122–124).

A central issue in the chronology and development of the Mauna Kea Adze Quarry Complex is its relationship to the development of Hawaii's complex chiefdoms. By the A.D. 1400s, a traditional Polynesian land tenure system involving corporate kin groups had developed into a feudal-like system in the Hawaiian Islands (Cordy 2004; Hommon 1976). Hereditary chiefs collected tribute from commoners in the feudal system, but most daily necessities were produced within economically self-sufficient land divisions known as *ahupua`a* (Earle 1977; Sahlins 1992). The structure of *ahupua`a* limited the need for domestic resource redistribution through the chiefly class, and there were eventually over 600 *ahupua`a* on the island of Hawai`i alone.

The Mauna Kea Adze Quarry Complex is located in the single *ahupua`a* of Ka`ohe. The size of the quarry, however, leaves little doubt that Hawaiians distributed its products far beyond Ka`ohe, and this has generated a great deal of discussion regarding how it would fit within Hawaii's economic system (Bayman and Nakamura 2001; Cleghorn 1986; Lass 1994, 1998; McCoy 1990, 1991; Williams 1989; Withrow 1990, 1991). The difficulty individuals would have faced in reaching, working in, and distributing products from this high-elevation quarry indicates organized logistical support, either through chiefly sponsorship or through commoner social networks. The complex also was not the only adze production center on Hawai`i Island. Smaller formal quarries exist (Cleghorn et al. 1985; Lass 1994:22–23; Tuggle 1976), and domestic sites commonly contain primary reduction basalt flakes and adze preforms with cobble cortex, which indicate that many adzes were manufactured from locally available cobbles. These observations negate any potential argument that the high-altitude quarry was developed only because of a lack of more readily available materials. Thus, the reason for the existence of the Mauna Kea Adze Quarry Complex must fundamentally lie with cultural preferences rather than environmental determinism (McCoy 1991:25).

If initial use of the quarry is correctly dated to the A.D. 1100s, and the transition to the *ahupua`a* system occurred in the A.D. 1300s or 1400s, then we might expect that the mode of production at the quarry changed as well. Despite broad interest in the Hawaiian Islands as an anthropological case-study of complex chiefdoms (Earle 1977; Sahlins 1992), the mechanisms through which Hawaiians produced and distributed commodities such as adzes remain poorly understood (Lass 1994; McCoy 1991:30).

Sourcing of Mauna Kea Basalts

Our ability to understand the role of the Mauna Kea Adze Quarry Complex in the Hawaiian economy and in the development of Hawaii's complex chiefdoms hinges on sourcing lithic materials in domestic assemblages. Dense and fine-grained black basalts are poorly suited for macroscopic identification. In the 1980s and 1990s there were several small-scale sourcing studies in Hawaii that used thin-sections and optical petrography (Cleghorn 1982; Cleghorn et al. 1985; Lass 1994; McCoy 1986:14–15; Withrow 1990, 1991). This destructive process requires that artifacts be cut on a rock-saw so that a thin slice of the rock can be studied under a microscope. Comparing similarities and differences in thin-sections through this conventional method is also qualitative, and two different researchers could classify the same thin-sections differently. In the most ambitious petrographic study of Hawaiian adze material, Lass (1994; see also Withrow 1991) analyzed 155 adzes from Hawai`i Island, and assigned samples to the most similar-looking source material in her reference collection. Lass's ability to make meaningful statistical comparisons, however, was limited by the size of her representative sample. The development of Hawaii's complex society undoubtedly involved the production and distribution of at least hundreds of thousands of adzes. Sample sizes in the hundreds are simply insufficient to accurately represent such a large and complex economy through time and space.

Quantitative and replicable geochemical characterizations of source materials can overcome some of the limitations of qualitative research. Both destructive and nondestructive geochemical techniques such as Wavelength dispersive X-ray fluorescence (WDXRF), energy-dispersive X-Ray fluorescence (EDXRF), instrumental neutron activation analysis (INAA), and inductively coupled plasma mass spectrometry (ICP-MS) have now become widely and successfully used in the Pacific (Best 1984; Collerson and Weisler 2007; Johnson et al. 2007; Lebo and Johnson 2007; Rolett 1998; Walter 1998; Walter and Sheppard 1996; Weisler 1990, 1993, 1997, 1998; Weisler and Clague 1998; Weisler and Kirch 1996; Weisler and Woodhead 1995; Williams 2002; Winterhoff 2003). Although many of these studies have focused on more homogeneous volcanic glasses, there have been some successful geochemical studies of basalts and andesites in the Pacific and on the American continent (Collerson and Weisler 2007; Johnson et al. 2007; Jones et al. 1997; Latham et al. 1992; Northwest Obsidian Research Laboratory 2006; Walter 1998; Weisler and Kirch 1996). Craig Skinner and colleagues at the Northwest Research Obsidian Studies Laboratory (NROSL) list 69 XRF studies of archaeological basalt conducted between 1995 and 2006. In the most comprehensive geochemical study of Hawaiian Island basalt quarries to date, Sinton and Sinoto (1997) published data garnered from destructive WDXRF analyses of 12 known basalt quarries throughout the archipelago as part of a Pacific-wide survey. That data set, however, only included 58 samples from all the known Hawaiian quarries. Sinton and Sinoto's own assessment was that these data are far too limited to identify the ranges of geochemical variability in each quarry. For example, the geochemistry of the sprawling Mauna Kea Adze Quarry Complex was derived from eight samples for major elements and only two samples for trace elements (Sinton and Sinoto 1997:200). In sum, the limited sampling in quarries, and in domestic assemblages, has severely limited our understanding of the distribution patterns of Hawaiian adzes.

Ethical Considerations

Archaeological ethics are particularly pertinent to investigations of the Mauna Kea Adze Quarry Complex because of the cultural significance of the landscape in which it exists (Maly 1999). Numerous shrines are present (McCoy 1990, 1999), and in 1862 a 1.5 m tall wooden anthropomorphic statue (often associated with Hawaiian ritual sites) was collected from in front of one of the rockshelters there (McCoy 1990:99; Maly and Maly 2005: 18–19). These site features, in combination with the ancestral associations of the summit region with Papa, Wakea, and Poli`ahu, make our juxtaposition of the profane and industrialized word "quarry" over the Hawaiian landscape rather inadequate as a defining term for the complex. This kind of semantic problem of translating concepts from colonized cultures into the languages of the colonizers is pervasive in anthropology (Kane 1997:265), and greatly affects our implicit ideas about the cultural significance of the places that we study.

Through the second half of the twentieth century, Mauna Kea's summit has become a hotly contested cultural landscape. Development for astronomical research continues amid strong protests from Hawaiian cultural practitioners. When the quarry is contextualized within this contested landscape, it is important to recognize that destructive archaeological research on the site readily can be perceived as an additional intrusion of Western science in a sacred realm.

Cultural tensions between colonizers and indigenous peoples often lead to amplified dichotomies between Western science and Native spiritualism that do not adequately reflect the identities and commonalities on either side of the cultural divide. There are numerous examples of pre-European Hawaiians using rigorous science. These include the development of sophisticated open-ocean voyaging techniques, medicinal uses of plants, and the extensive geological observations that Hawaiians must have conducted to locate high-quality adze material. In this study, we have attempted to apply scientific methodologies that are more culturally sensitive to these commonalities. The duality of the concept of "sensitivity," however, when dealing with science and culture, can often create conflict. It should therefore not solely be the scientific community that decides what is sensitive science and what is not. The research contained herein involved over a year of consultation with Native Hawaiian community members to establish a protocol on how the project should be conducted, if at all. Details of the consultation process are presented below, and additional information can be found in Mills and Lundblad (2006:11–12).

When the SAA Ethics in Archaeology Committee began redrafting its principles in the 1990s, the idea of "stewardship" was the first of the principles discussed (Lynott and Wylie 1995:23, 28–32). That principle involved the long-term conservation and preservation of the archaeological record, which specifically includes archaeological collections (see also Kintigh 1996). The Smithsonian Institution's guidelines for sampling are even more explicit: "The analytical methods proposed should yield the intended results, and are the least intrusive analytical means of obtaining those results" (Smithsonian Institution 2007). It is very likely that there will be many instances when destructive analytical techniques will be required to discriminate between sources, but it is imperative from an ethical standpoint that we determine the parameters of what can be achieved with nondestructive approaches before considering destructive approaches.

We report on the first large-scale attempt to use nondestructive energy-dispersive X-ray fluorescence (EDXRF) to characterize archaeological basalts in the Hawaiian Islands. EDXRF spectrometers have been improved considerably since the 1980s, and can rapidly generate broad-spectrum geochemical analyses with levels of precision in the parts per million range for certain elements. In addition to EDXRF's analytical capacity to be conducted nondestructively, spectrometers are relatively easy to maintain, making them suited for undergraduate use. The authors have been working with undergraduate and graduate students (many of Pacific Islander descent) in the hope that they will be able to embrace such nondestructive

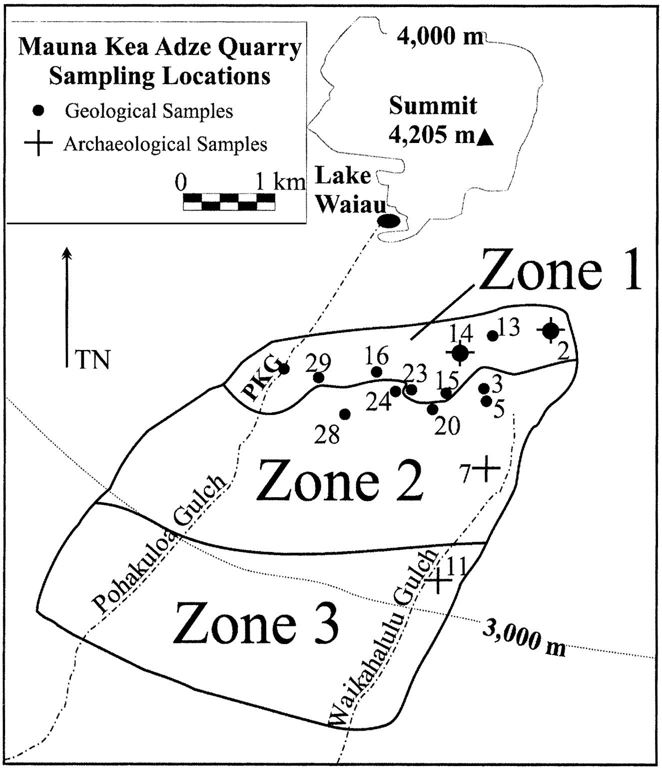

Figure 3. Sampling locations and production zones (McCoy 1990) within the quarry complex. The numbers next to sampling locations refer to Bishop Museum site numbers for each area.

analytical methods to reconnect their own identities with culturally sensitive forms of scientific inquiry. Ongoing projects by people of indigenous ancestry are re-examining museum collections gathered throughout the archipelago, including the Northwest Hawaiian Islands. Students have presented their findings at annual meetings of the Society for Hawaiian Archaeology. Dissertations and several publications pertaining to this student research are forthcoming.

Geology of the Mauna Kea Adze Quarry Complex

The most recent geological mapping of the Mauna Kea Adze Quarry Complex places the quarried material within the post-shield Liloe Spring volcanic member of the Hamakua volcanic series (Wolfe et al. 1997:34–40). Because it is an evolved post-shield lava, it is compositionally distinct from the tholeiitic shield-building lavas of Kilauea and Mauna Loa that cover more than half of Hawai`i Island (Figure 1). Wolfe et al. (1997:38–39) date the Liloe Spring member between 150,000 and 70,000 years ago, and identify the main escarpments quarried by Hawaiians as a possible subglacial fissure ridge surrounding Pu`u Ko`oko`olau. McCoy (1990:93) refers to this portion of the quarry complex as "production zone 1" (Figure 3). Each production zone is based on gross differences in raw material sources and selected raw material properties within each source. Earlier, Porter (1987:93) had interpreted the escarpments as the leading edge of a subglacial eruption of Pu`u Waiau, which is nearer to the summit. Wolfe et al. reject Porter's interpretation, however, due to the different geochemistry of the more hawaiitic Pu`u Waiau flow. The Liloe Spring volcanic member is quite diverse. Prominent plagioclase phenocrysts occur in many dense basalt flows in the eastern portion of the quarry that are lacking elsewhere, and dikes (Wolfe et al. 1997:38), palagonite, welded tuff, and many other separate eruptive events are present in the quarry complex.

Separate eruption events could have affected the range of geochemistry within extraction areas, and the geological features are too poorly dated to assume that they were all produced in a single short-lived eruption.

Wolfe and colleagues' published data do not include trace-element composition, which is the most significant group of elements for discerning stone sources using EDXRF. They do, however, note the work of Frey et al. (1990), who found that strontium (Sr) is an excellent indicator of the difference between Hamakua lavas, including the Liloe Spring series, and more recent lavas on Mauna Kea such as the Pu`u Waiau eruption. Liloe Spring series volcanics continue well beyond the current boundaries of the Mauna Kea Adze Quarry, and major exposures exist in Pohakuloa Gulch and Waikahalulu Gulch in what McCoy refers to as Zones 2 and 3 of the complex, where additional chipping debris and some extraction activities have been identified (McCoy 1986, 1990:93).

McCoy's Zone 2 begins directly below the main escarpments (1990:93). Glacial drift deposits cover much of the Liloe Spring flows in this area, but bedrock protrudes in "whaleback ridges." In many cases, boulders of adze-quality basalt are in the glacial drift, dispersed in outwash plains and moraines. These drift deposits are part of the Makanaka glacial member, dated between 40,000 and 13,000 years ago (Wolfe et al. 1997:53–56), and there is ample evidence that Hawaiian craftspeople opportunistically quarried adze-quality material from the glacial deposits.

Lower still in the quarry complex (McCoy's Zone 3), the Makanaka glacial deposits are interspersed with older moraines and outwash deposits of the Waihu glacial member. The Waihu glacial member is roughly contemporaneous with the Liloe Spring volcanics (Wolfe et al. 1997:22), and Waihu glacial deposits appear in lenses within the Liloe Spring volcanics in Zone 3. Again, McCoy (1990:93) has identified adze quality material in this zone, both as glacial outwash, and in "patches" of varying quality.

Confounding Variables

Several factors might induce archaeometrists to be skeptical of the ability of nondestructive EDXRF to discriminate between Hawaiian basalts. Unlike continental basalts, andesites, and felsites that have been successfully differentiated (Hermes and Ritchie 1997; Latham et al. 1992; Northwest Research Obsidian Studies Laboratory 2006), virtually all of the basalt in the Hawaiian Islands is derived from the same source—a deep magma plume underneath the Pacific tectonic plate. This factor does indeed limit overall variation in basalt geochemistry throughout the archipelago, but as shield volcanoes evolve, the magma is altered as it interacts with the lithosphere. The ongoing Pu`u `O`o eruption on Kilauea Volcano offers an optimistic analogy. Kilauea Volcano is still in an early shield-building stage, and these basalts tend to be more geochemically similar than evolved post-shield basalts, such as those at the Mauna Kea Quarry. Nevertheless, during the first 15 years of the ongoing Pu`u `O`o-Kupanaha eruption at Kilauea, Mid-Z trace elements (Rb, Sr, Y, Zr, and Nb), showed measurable variation in concentrations (Garcia et al. 1992, 2000). This kind of variation indicates the potential to differentiate Hawaiian basalts from the same source, even if they are from shield-building phases, and from virtually contemporaneous eruptions in geologic time.

A second potentially confounding factor is that when compared with obsidian, which has been successfully studied with EDXRF in many contexts (Eerkens et al. 2007; Shackley 1998, 2005), basalt is more heterogeneous, and is consequently difficult to characterize by analyzing a single spot on an artifact. This factor makes the characterization of a basalt source from a small number of analyses more unreliable. By increasing sample sizes, however, it should be possible to address the range of variability encountered in any particular source. The loss of some precision with nondestructive analyses can also quickly be offset by more rapid sample preparation and processing associated with nondestructive EDXRF. Other confounding factors such as sample thickness, shape, and chemical weathering need to be considered in nondestructive analyses (Lundblad et al., 2008; Weisler 1993:74), but as we present below, nondestructive analyses offer great promise in differentiating Mauna Kea Adze Quarry basalts from other major quarries. Only after more extensive sampling of all the major quarries, however, will it be possible to determine whether or not major sources remain entirely distinguishable with nondestructive EDXRF.

Methods

Two classes of lithic material were sampled from the quarry complex. The first group consisted of 820 flakes obtained from the Bishop Museum, during the 1975 and 1976 excavations (Sites 2, 7, 11, and 14, Figure 3). The samples were selected from four separate rockshelter excavations located in Zones 1, 2, and 3 of the complex (Cleghorn 1982; McCoy 1990; Williams 1989). The samples represent a total of 24 different stratigraphic levels within the four different rockshelter workshops. This sampling maximized our geographic coverage of the quarry complex and controlled for potential chronological changes in the types of material that had been quarried. By nondestructively analyzing debitage as opposed to remnant geological exposures, we could build a database from materials that Hawaiians themselves had chosen, as opposed to analyzing rocks that they had left behind in outcrops. A limitation of this data set, however, is that it was impossible to determine from which location within the quarry complex each flake had been quarried. In order to determine the distribution of potential intra-site geochemical variability, we also collected 47 geological samples from 12 sites in Zones 1 and 2, as well as two additional samples from bedrock in Pohakuloa Gulch on the northeastern edge of the complex (Figure 3). In consultation with interested Native Hawaiian cultural practitioners, and following a protocol developed in conjunction with them, we collected 47 unaltered rock samples of less than 1 kg each. We documented sample locations with GPS coordinates and before-and-after photos (Mills and Lundblad 2006:13). Although our research was not considered a federal undertaking, our consultation process followed an established Section 106 consultation process for prior federal undertakings in the summit region of Mauna Kea. We contacted individuals and organizations who had been recognized as interested parties for other projects near the summit. Our collection procedure evolved in discussions with these individuals and organizations as a balance between the scientific value of extensive geological sampling and the cultural value of minimizing impacts to the quarry. While some may argue that a greater number of samples would be preferable, we nevertheless were able to sample all the known outcrops containing primary extraction areas in the complex.

Analyses of these combined 867 whole-rock samples (artifacts and geological specimens) were completed on a QuanX™ EDXRF spectrometer with an extended sample chamber, using a rhodium (Rh) stable-isotope X-ray tube, thermoelectrically cooled detector, and supporting Edmunds vacuum pump. Data were processed on Wintrace™ software, version 3.1, build 33. UH Hilo's EDXRF spectrometer also has a customized sample chamber that accommodates large artifacts such as adze blanks, poi pounders and stone bowls.

Conducting EDXRF analyses involves using variable X-ray energies to quantitatively analyze different elements. By varying the kinds of X-rays produced, one can optimize the fluorescence of particular elements of analytical interest. We analyzed a suite of 17 elements using a methodology that is fully described in 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 the data for major elements is less precise. Until further research is completed on major element analyses with nondestructive EDXRF, we consider our major-element data to be partially quantitative. We analyzed the 820 archaeological flakes by placing the flattest noncortical surfaces over the X-Ray beam. The geological samples were analyzed on flat interior polished surfaces. Each sample run included the analysis of a known geological standard prepared by the USGS from a basalt source in Kilauea Caldera (BHVO-2).

In order for EDXRF spectrometers to conduct quantitative analyses, the spectrometers also need to be calibrated by analyzing 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).

Elemental concentration data using nondestructive analyses can be affected by surface irregulari-

Table 1. Mean Values (μ) and Standard Deviations (σ) for Sr and Zr from Four Rockshelter Excavations at the Mauna Kea Adze Quarry Complex.

Site	Sr μ (ppm)	Sr σ (ppm)	Zr μ (ppm)	Zr σ (ppm)	*N*
Site 2, Rockshelter 2 (`U`au)	574	28.2	319	21.4	388
Site 7, Rockshelter 1 (`Ahinahina)	558	25.6	310	17	10
Site 11, Rockshelter 1 (Waikahalulu)	570	28.6	315	24.5	82
Site 14, Rockshelter 1 (Ko`oko`olau)	563	27.6	323*	20.9	340

*$p < .01$

ties in the samples, and as a consequence, some nondestructive analyses have relied on ratios of various trace elements to identify geological groups (Latham et al. 1992; Weisler and Kirch 1996). Ratios, however, can also obfuscate real quantitative differences in sources if in fact elemental concentrations covary, and the amount of error introduced from minor surface irregularities, such as a flaked basalt adze surface, have been insignificant (Lundblad et al. 2008). Consequently, we have attempted to conduct initial characterization of sources with elemental concentrations rather than ratios.

Results

Full geochemical datasets for all 17 analyzed elements are available online (UH Hilo Geoarchaeology Lab 2007). In Figure 4, the trace-element concentrations of Sr and Zr for the 820 analyzed archaeological flakes are compared to the preliminary Hawaiian quarry data published by Sinton and Sinoto (1997:200). These two trace elements appear to be the best discriminators for Hawaiian basalt samples when using EDXRF, both because of the higher precision and accuracy of our calibrations for these elements, and because there are concentrations of Sr and Zr in Hawaiian basalts that fall well above the detection limits of the spectrometer. Although multivariate statistical methods can offer more powerful tools for discriminating between data sets involving 17 elemental variables, we have found that Sr and Zr concentrations provide an excellent initial sorting of Hawaiian basalts, and in this case, the bivariate analysis has proven more effective than Principal Components Analysis (PCA). Overall, the scatter-plot demonstrates a consistent cluster for the Mauna Kea Quarry material with the greatest concentration of flakes falling between 530–600 ppm for Sr, and 290–340 ppm for Zr. These concentrations remain unique relative to data collected to date from other Hawaiian quarries (Sinton and Sinoto 1997:20). Several quarries on Moloka`i and one quarry on Kaho`olawe (the Pu`umoiwi quarry) are somewhat similar to the Mauna Kea samples, and it may be that some overlap between these major quarries will occur for the Sr and Zr plots as more samples from the other quarries are processed. The 15 other measured elements, however, offer possibilities for discriminating these sources, especially when multivariate statistical analyses similar to those used to discriminate other closely related lithic sources (Glascock et al. 1998; Johnson et al. 2007) are applied to any overlapping data sets.

No significant variation in assemblage geochemistry was noted between the stratigraphic layers sampled in each rockshelter (Table 1). Based on Sr and Zr concentrations, and indeed the entire range of elements analyzed, the detected differences from the rockshelters are also too small to allow for the diagnostic determination of single flakes to certain rockshelter assemblages, even with multivariate statistics. There is, however, a statistically significant increase (t-test, $p < .01$) in zirconium (Zr) concentrations for Ko`oko`olau rockshelter #1, Site 14 (a designation from the 1970s Bishop Museum fieldwork) when compared with the three other assemblages. This difference is most likely due to geochemical variability in the flows surrounding the rockshelters. Because Hawaiians could have also transported material from one portion of the quarry to another before reducing blocks of raw material into adze blanks, the range of variability in a workshop assemblage may be greater than what is observed in flows immediately surrounding each workshop.

Geological Samples

Table 2 lists the trace-element concentrations for 47 geological samples obtained from the quarry complex. University of Hawaii at Hilo (UHH) sample designations refer to the site of origin followed by a letter designation to identify each sample. The exceptions to this system are two samples obtained from the western edge of the site complex in Pohakuloa Gulch (UHH PKG 1, UHH PKG 2) where there was no observed quarrying activity. A full description of the sample collection procedure can be found in Mills and Lundblad (2006).

Five geochemical outliers in Table 2 are indicated by asterisks. All five of these samples were collected from quarry areas where there was no immediate evidence of quarrying (UHH PKG 1 and 2, UHH 13A, UHH 14L, and UHH 14VG). Three outliers that appear to be Liloe Spring members like the preferred basalt at the quarry are a volcanic glass sample (UHH 14VG), and two basalts (UHH 13A, UHH PKG 2). Samples UHH PKG 1 and UHH 14 L are the most divergent, and reflect geochemistry consistent with Laupahoehoe volcanics as defined by Frey et al. (1990). The sample UHH PKG1 was collected from the capstone flow on the eastern edge of Pohakuloa Gulch, and UHH 14L was collected from a ridge north of the main extraction area, which was mapped by Wolfe et al. (1997) as part of the Pu`u Waiau flow (Laupahoehoe volcanics).

Standard deviations were calculated for each of the trace elements, excluding the five outliers mentioned above. It is significant to note that the standard deviation for Zr is 19 ppm. For comparison, 98 runs of the geological standard BHVO-2, conducted concurrently with the archaeological and geological samples, resulted in a standard deviation of 2.6 ppm. All standard deviations for trace elements for BHVO-2 are significantly lower than what was measured for the geological samples. Given that both the BHVO-2 pellet and the geological samples were analyzed on flat homogeneous surfaces, the differences in standard deviations, especially for Zr, cannot be attributed to surface topography or weathering, and appear to reflect intra-site differences in geochemical composition within the adze quarry. These data indicate that Zr concentrations could be used to identify intra-site variation. In contrast, although Sr proved to be an excellent discriminator for inter-archipelago variation in basalts (Figure 4), the range of variation for Sr within the quarry is only slightly above that noted for our geological standard.

Figure 5 illustrates the measured concentrations of Sr and Zr for the 44 basalt samples that fall in the main geochemical cluster (excluding UHH 14L, 14VG, and PKG 1). Samples from the same sites tend to be closely related within the scatter-plot. Similar to the Bishop Museum flake samples, Site 14 specimens, combined with samples directly down slope from Site 14 (Sites 3, 5, 15, and 20), have elevated Zr concentrations relative to other sites.

Discussion

The ethical principles of the SAA, and most museum collection sampling guidelines, support using the least destructive analytical method to answer posed research questions. Eerkens et al. (2007) have recently demonstrated the applicability of INAA over XRF when studying microdebitage, and destructive techniques that yield higher precision than EDXRF may be needed to discriminate between certain closely related sources. Collerson and Weisler (2007), for example, make a strong argument for the value of isotopic analyses with ICP-MS when one is attempting to conclusively determine the sources of basalts involved in pan-Pacific voyaging. This study raises the bar, however, on the need to resort to destructive analyses of Hawaiian basalts in archaeological contexts when considering exchange patterns at the level of islands and archipelagos. We demonstrate that (1) nondestructive EDXRF is capable of discriminating between Mauna Kea Adze Quarry basalts and other major basalt sources on Hawaii Island, and (2) EDXRF can detect intra-site variability in Mauna Kea Adze Quarry basalts. Geochemical results from various rockshelter assemblages and from geological samples both demonstrate geographically patterned differences in trace-element concentrations across the quarry complex, particularly for zirconium (Zr). Intra-site variability in the complex could be employed to address whether or not access to specific portions of the quarry was socially regulated. Site 14 is the highest part of the quarry, it is the most intensively exploited, and it appears to have had some of the best quality material within the complex. Because the geochemistry of the raw material there is slightly different, we may be able to address whether or not that portion of the quarry was reserved for elite use.

Table 2. Geological Sample Trace Element Concentrations and Standard Deviations (σ) Compared with 98 Analyses of BHVO-2.

Sample	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)
UHH 2A	24	554	38	273	29
UHH 2B	20	554	36	263	27
UHH 2C	28	570	42	310	33
UHH 2D	26	552	38	282	30
UHH 2E	26	556	37	276	31
UHH 2F	26	551	39	283	30
UHH 2G	26	555	40	282	29
UHH 2H	27	547	39	295	32
UHH 2I	30	556	44	338	35
UHH 3A	26	568	43	316	31
UHH 5A	31	557	43	334	36
UHH 13A*	18	566	39	239	23
UHH 14A	24	555	43	315	33
UHH 14B	26	560	42	310	33
UHH 14C	30	564	44	332	35
UHH 14D	30	553	43	330	36
UHH 14E	31	558	44	326	35
UHH 14F	29	558	42	318	35
UHH 14G	27	564	42	315	34
UHH 14H	29	562	42	314	34
UHH 14I	28	552	43	327	34
UHH 14J	29	549	42	315	35
UHH 14K	28	552	43	318	36
UHH 14L*	47	1182	60	612	63
UHH 14VG*	56	156	27	464	43
UHH 15A	23	555	43	317	31
UHH 15B	25	566	45	331	33
UHH 15C	23	566	39	298	30
UHH 15D	26	552	43	322	33
UHH 15E	26	557	45	340	35
UHH 15F	24	569	42	302	31
UHH 16A	26	552	40	296	33
UHH 16B	27	501	37	288	32
UHH 16C	27	551	40	298	33
UHH 16D	25	559	42	310	33
UHH 16E	24	551	39	295	32
UHH 20A	20	561	40	297	31
UHH 20B	24	559	42	314	31
UHH 23A	19	559	41	296	30
UHH 23B	17	559	39	285	29
UHH 24A	28	545	39	296	33
UHH 28A	25	559	41	298	31
UHH 28B	22	562	38	285	28
UHH 29A	29	557	41	305	35
UHH 29B	27	537	40	288	32
UHH PKG1*	42	995	55	528	55
UHH PKG2*	21	568	43	325	31
σ	3.1	10.8	2.3	19.0	2.3
σ BHVO-2	.9	4.1	.9	2.6	1.3

* Outlier geological samples with no evidence of prehistoric quarrying, excluded from σ.

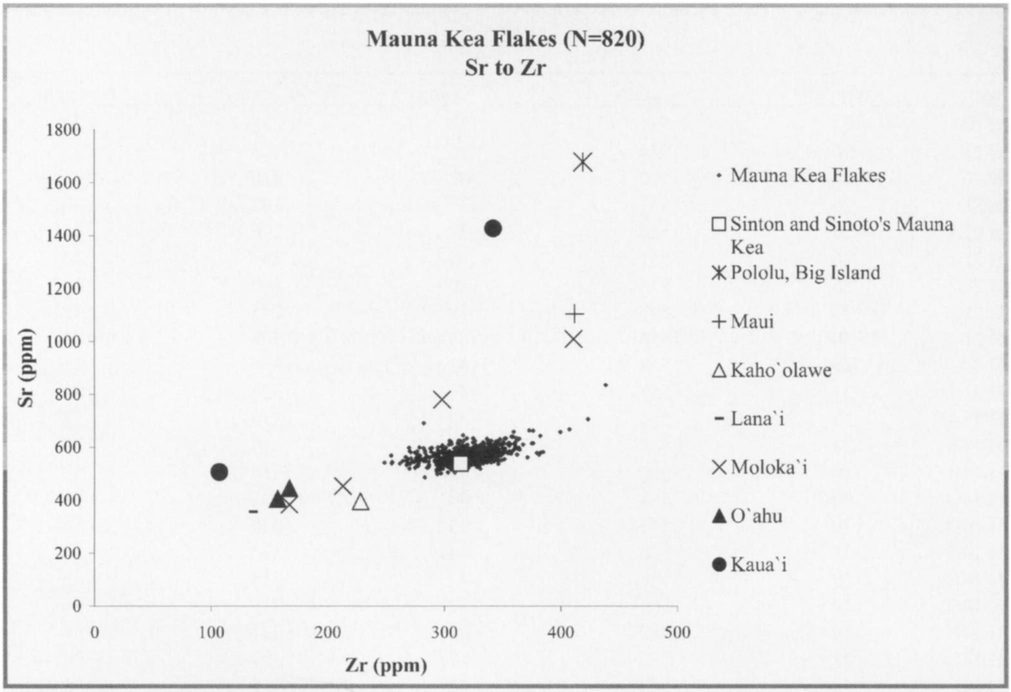

Figure 4. Scatter plot of strontium (Sr) and zirconium (Zr) concentrations showing the relationship of the 820 analyzed flakes to Sinton and Sinoto's (1997) data for Hawaiian adze quarries.

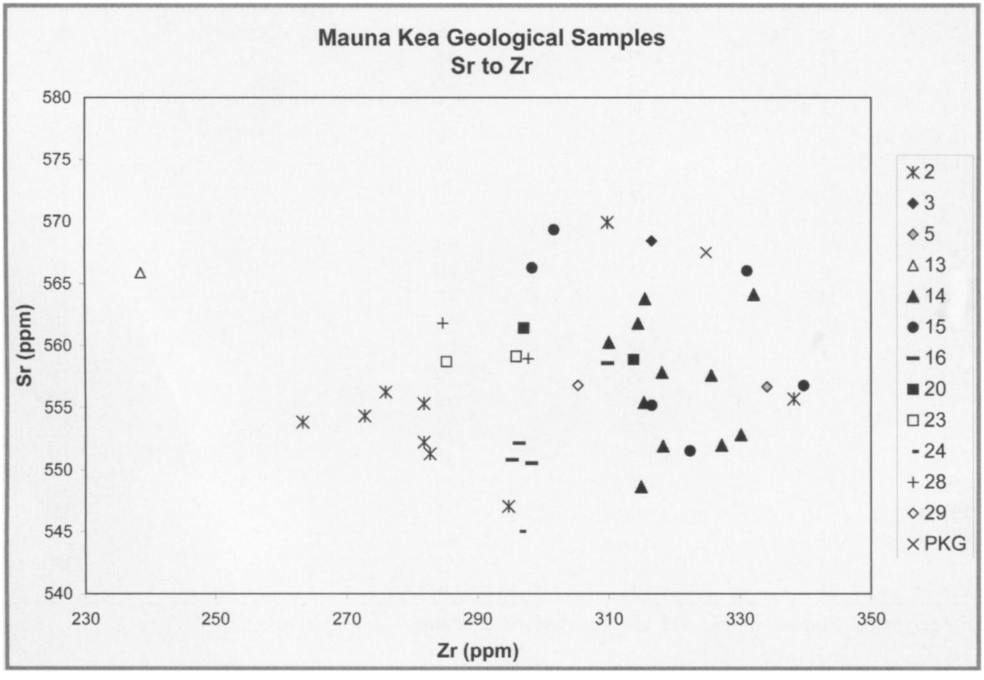

Figure 5. Scatter plot of strontium (Sr) and and zirconium (Zr) concentrations for the main group of geological samples from the Mauna Kea Adze Quarry Complex.

An issue that will take considerable future research, and that may prove to be beyond the precision of nondestructive EDXRF, is whether or not the Mauna Kea Adze Quarry basalts are distinguishable from closely related smaller source areas that have yet to be studied. This factor will be most relevant to research on coastal gulches and outcrops on Hawai`i Island where Hamakua volcanics (of which the Liloe Springs volcanic member that composes the quarry complex is a part) cover most of the shorelines along the eastern and northern slopes of Mauna Kea.

Hawai`i Island adzes were undoubtedly taken on voyages to other islands, and possibly other archipelagoes or continents. Collerson and Weisler (2007) have demonstrated this with the discovery of a single Hawaiian adze in the Tuamoto archipelago. EDXRF has already been employed to identify inter-archipelago movement of basalt in other parts of Polynesia (Weisler 1998; Weisler and Kirch 1996), and should prove useful in Hawaii by identifying anomalous samples that do not match well with local geochemistry. As Weisler (1993) demonstrates, however, Oceanic basalts often do have a great deal of similarity in some instances, and more time-consuming isotopic analyses may be used as a second sampling tier, following EDXRF sampling, to determine whether or not particular samples originated in other archipelagoes.

Continued applications of EDXRF on debitage in domestic sites will also greatly enrich our understanding of changing patterns in lithic procurement. Broad-scale changes in the acquisition of natural resources in Polynesia should correlate with the evolution of island political economies. As debitage and adzes from dated stratigraphic contexts in domestic sites are linked to the adze quarry, it will be possible both to test the dates inferred from the quarry rockshelters and to quantify the relative intensity with which material from the quarry was being used in any particular location and era. A related research question has been the timing of abandonment of the quarry in the historical era, as iron adzes began to replace stone tools (Bayman 2003; McCoy 1990:92–93).

By approaching these issues through nondestructive, low-cost, and large-scale sampling, EDXRF brings "the power of plenty" to provenance studies in an ethically sound archaeometric approach. Ahler (1989) made the case for mass-analyses of flaking debris by arguing that one can learn a great deal by studying the forest instead of the tree. An analogous argument is made here with lithic geochemistry. Large-scale sampling will address in much finer detail some of the ongoing debates regarding chiefly support of craft specialists, and related structures of the Hawaiian political economy (Lass 1998; McCoy 1990, 1991). A diachronic model of Hawaiian economics is imperative if we are to understand how Hawaiian culture changed from the relatively small founding populations at the time of initial settlement, to the complex chiefdoms that Captain James Cook observed in 1778. Hawaii's population in 1778 had reached several hundred thousand people by the lowest estimates and nearly a million by the highest estimates (Kirch and Rallu 2007; Stannard 1989). The massive growth of Hawaii's population from the time of initial settlement, by definition, would have involved drastic changes in the exploitation of Hawaii's natural resources. These changes must have resulted in a general pattern of economic intensification, accompanied by changes in land tenure and sociopolitical organization (Cordy 2004; Hommon 1976; Sahlins 1992). There could also be fluctuations in use of the quarry associated with these developments, caused by stresses such as warfare and famine that may not otherwise be apparent. Quantifiable data on the history of quarry use, and changing patterns in the distribution of that material, thus serve as proxies for understanding population dynamics, political change, and land tenure accompanying the evolution of one of the most complex societies in the Pacific.

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