Interpolity exchange of basalt tools facilitated via elite control in Hawaiian archaic states

Patrick V. Kirch[a,1], Peter R. Mills[b], Steven P. Lundblad[c], John Sinton[d], and Jennifer G. Kahn[e]

[a]Departments of Anthropology and Integrative Biology, University of California, Berkeley, CA 94720; [b]Department of Anthropology, University of Hawai'i, Hilo, HI 96720; [c]Department of Geology, University of Hawai'i, Hilo, HI 96720; [d]Department of Geology and Geophysics, University of Hawai'i at Manoa, Honolulu, HI 96822; and [e]Department of Anthropology, Bernice P. Bishop Museum, Honolulu, HI 96817

Contributed by Patrick V. Kirch, November 21, 2011 (sent for review November 2, 2011)

Ethnohistoric accounts of late precontact Hawaiian archaic states emphasize the independence of chiefly controlled territories (*ahupua'a*) based on an agricultural, staple economy. However, elite control of unevenly distributed resources, such as high-quality volcanic rock for adze production, may have provided an alternative source of economic power. To test this hypothesis we used nondestructive energy-dispersive X-ray fluorescence (ED-XRF) analysis of 328 lithic artifacts from 36 archaeological features in the Kahikinui district, Maui Island, to geochemically characterize the source groups. This process was followed by a limited sampling using destructive wavelength-dispersive X-ray fluorescence (WD-XRF) analysis to more precisely characterize certain nonlocal source groups. Seventeen geochemical groups were defined, eight of which represent extra-Maui Island sources. Although the majority of stone tools were derived from Maui Island sources (71%), a significant quantity (27%) of tools derived from extraisland sources, including the large Mauna Kea quarry on Hawai'i Island as well as quarries on O'ahu, Moloka'i, and Lāna'i islands. Importantly, tools quarried from extralocal sources are found in the highest frequency in elite residential features and in ritual contexts. These results suggest a significant role for a wealth economy based on the control and distribution of nonagricultural goods and resources during the rise of the Hawaiian archaic states.

adze quarrying | geochemical sourcing | Polynesian archaeology

The varied sources of power used by elites during the processes of sociopolitical evolution are of great interest to historical anthropologists. Over the course of two centuries preceding initial contact with Europeans in A.D. 1778–1779, Hawaiian sociopolitical organization was transformed from a system of complex chiefdoms to one of emergent archaic states (1). Among the processes thought to have driven this transformation were population growth, intensification of agricultural production, materialization of ideology and ritual, and elite competition associated with territorial conquest (1–5). Hawaiian sociopolitical evolution has been characterized as a classic case of a "staple economy" in which elite control of agricultural surplus was key (3). Ethnohistoric descriptions of Hawaiian economic organization emphasize the independence of chiefly controlled territories called *ahupua'a*, which are often described as largely autonomous and self-sufficient (3, 6–8). Nonetheless, certain key resources were concentrated or available only in particular locales; control over their distribution and use is likely to have been an important source of economic power. Arguably, such control would have involved a form of "wealth economy" in which Hawaiian elites (*ali'i*) exercised control over economically important resources or materials that were differentially distributed over island landscapes (1).

Most of the resources that would have underwritten a wealth economy consisted of perishable materials (e.g., salt, fiber plants and cordage, *Pandanus* matting, large hardwood logs for canoe hulls, and the red and yellow feathers of certain species of forest birds), none of which preserve in most archaeological contexts. One resource, however, fine-grained isotropic volcanic rock used to produce adzes and other stone tools, is known to have been restricted to a limited number of quarry sources from which it was distributed widely into local communities. Finished adzes, flakes from adze use, and debitage from stone tool production are ubiquitous in Hawaiian archaeological contexts (9). In the past, archaeologists have presented conflicting hypotheses as to whether distribution of lithic tools in Hawai'i was carried out by craft specialists under chiefly aegis or by dispersed commoners with unhindered access to quarries (10–14). Advances in geochemical characterization of Hawaiian volcanic rocks permit the potential discrimination of local versus nonlocal sources of lithic tools (15–19). Here we report on the analysis of a large assemblage of lithic tools and debitage from archaeological sites in the Kahikinui district of Maui Island (Fig. 1) that allows us to test the hypothesis that elite control of fine-grained volcanic source rock was an important economic strategy in precontact Hawai'i.

Archeology of Kahikinui, East Maui. Occupying the arid, southeastern slopes of Haleakalā Volcano, Kahikinui constitutes one of 12 wedge-shaped political units that formerly made up the indigenous Maui Island polity. Data from archaeological surveys in selected sample areas of Kahikinui, covering a total of ~11 km^2, with >3,500 individual archaeological features recorded (20, 21), provides one of the largest archaeological databases for any comparable region in Hawai'i. Extensive archaeological excavations in 76 residential, agricultural, and ritual features have elucidated aspects of site chronology and function. A total of 169 radiocarbon dates from residential and ritual contexts and 10 U-series dates from temple sites (22, 23) indicate that Hawaiian settlement of Kahikinui commenced *ca.* A.D. 1400 and reached a population peak between A.D. 1700 and 1800, just before European contact. Our analytical sample consists of an assemblage of 328 flakes and core tools from 36 excavated or surface-collected features in Kahikinui, including both residential and ritual contexts. A summary of the sampled archaeological features is provided in Table S1; sample selection criteria are discussed in *Materials and Methods*.

Geology of East Maui and Kahikinui. The Kahikinui district lies on the southwest rift zone of Haleakalā Volcano (24). Surface geology in the central portion of the district is dominated by postshield volcanism younger than ~0.93 Ma, which has been divided into older (Kula volcanics more than ~150 ka) and younger (Hāna volcanics less than ~150 ka) formations. The most recent activity on Haleakalā involved at least 59 eruptive events in the last 50 Ka, with at least 9 of those eruptions occurring during the period of Polynesian settlement of the

Author contributions: P.V.K. designed research; P.V.K., P.R.M., S.P.L., J.S., and J.G.K. performed research; P.V.K., P.R.M., S.P.L., J.S., and J.G.K. analyzed data; and P.V.K., P.R.M., S.P.L., J.S., and J.G.K. wrote the paper.

The authors declare no conflict of interest.

[1]To whom correspondence should be addressed. E-mail: kirch@berkeley.edu.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1119009109/-/DCSupplemental.

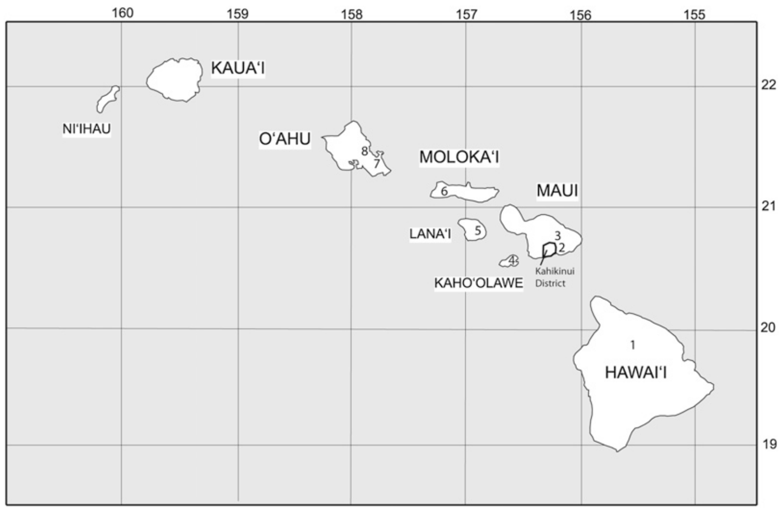

Fig. 1. Map of the main Hawaiian Islands, showing the location of Kahikinui district on Maui Island and the approximate positions of major adze quarries referred to in the text. Quarries are indicated by numbers as follows: 1, Mauna Kea, Hawai'i Island; 2, Nu'u, Maui Island; 3, Haleakalā, Maui Island; 4, Pu'umoiwi, Kaho'olawe Island; 5, Kapōhaku, Lāna'i Island; 6, Ka'eo and other Kaluako'i region quarries, Moloka'i Island; 7, Kailua, O'ahu Island; and 8, Waiahole, O'ahu Island.

Hawaiian Islands (25). Hāna volcanics blanket the Kahikinui district in its western portions, whereas Kula volcanics remain exposed over much of the eastern half of the district. The geology of Haleakalā's southwest rift zone has been described in a number of sources (26–34). Bergmanis et al. (ref. 25, p. 241) state "although the major and trace element compositions of Hāna and Kula lavas overlap, Kula lavas are generally less silica undersaturated and more differentiated than Hāna lavas." The most recent published geochemical database for Hawai'i (32), which presents a compilation of geochemical data from various studies, only contains major element data for Hāna and Kula volcanics. As we will outline below, distinguishable trend-line ratios for strontium (Sr) and zirconium (Zr) seem to occur in the Kahikinui dataset for aphyric rocks that may reflect the different volcanic series.

Despite extensive archaeological survey, no archaeological quarry sites have been identified in Kahikinui district. However, limited flaking of exposed outcrops throughout the district suggests that precontact Hawaiian occupants of the district used locally available volcanic rock in an expedient manner. Two adze quarries are known on East Maui outside of Kahikinui district: (*i*) the Haleakalā quarry located on the northwest rim of Haleakalā Crater (35) and (*ii*) the much smaller Nu'u quarry in Kaupō district to the east of Kahikinui (36).

Results

As described in *Materials and Methods*, we used a two-stage analytical procedure to define geochemical groups, first subjecting all 328 samples to nondestructive energy-dispersive X-ray fluorescence (ED-XRF) analysis, followed by a limited sampling with destructive wavelength-dispersive X-ray fluorescence (WD-XRF) to more precisely define probable sources of suspected nonlocal groups. Analytical data for all samples are available online at http://hilo.hawaii.edu/depts/geoarchaeology/index.php. Fig. 2 is a scatterplot plot showing Sr versus Zr concentrations for all specimens analyzed by ED-XRF, with samples assigned to 17 groups. Fig. 3 is a principal component analysis (PCA) plot showing how the qualitatively defined groups cluster when multivariate statistical analyses are applied to all of the trace element data and semiquantitative major element data. Summary geochemical data for all groups are provided in Table S2. Table S3 shows the frequency distribution of samples by group and archaeological feature.

Group A (*n* = 102). The geochemistry of this group, the most frequently represented in the Kahikinui assemblages, matches well with the postshield lavas of Haleakalā. It is relatively high in Sr relative to Zr. Ni content was measured between 0 and 3 ppm on the ED-XRF spectrometer, which is essentially below the detection limits for this element. Ni contents in East Maui postshield lavas range from <3 ppm to >300 ppm (25) but tend to be lowest in the more evolved, aphanitic lavas, such as those that Kahikinui residents might have selected from local sources. Group A matches reasonably well with Kahikinui geological samples. Because this group is the least similar of our three apparently "local" groups to the more differentiated Kula lavas of Nu'u and the Haleakalā summit adze quarries, we believe it represents the Hāna volcanic series lavas that dominate western Kahikinui.

Group B (*n* = 59). This group follows a different trend line in Sr/Zr ratios than that seen in group A, with lower Sr ratios relative to Zr. In all cases of multivariate analyses that we conducted and in the scatterplot data, group B is geochemically more similar to the

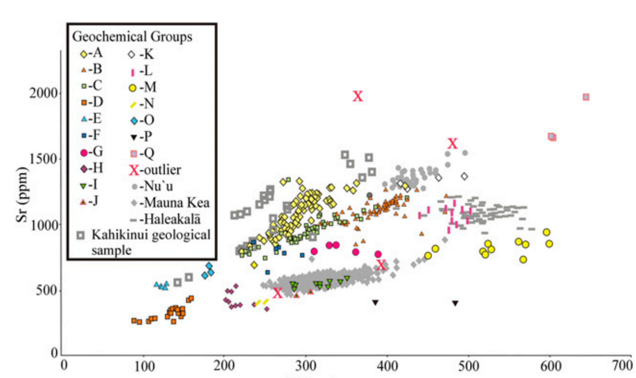

Fig. 2. Scatterplot showing the relationship of strontium (Sr) to zirconium (Zr) for 328 samples analyzed with ED-XRF in relation to geological samples from Kahikinui and to the Mauna Kea, Haleakalā, and Nu'u adze quarries.

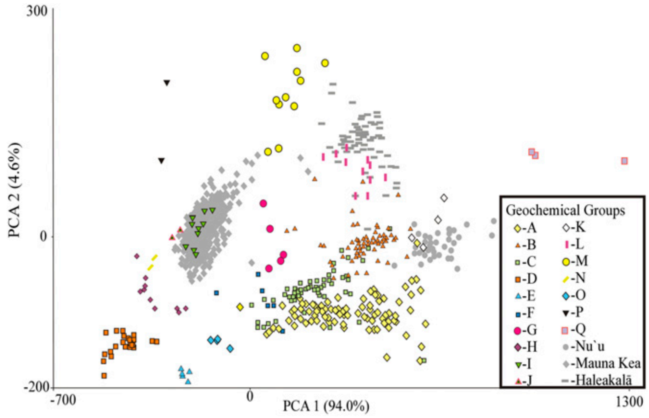

Fig. 3. PCA scatterplot using a covariance matrix for all samples and incorporating nickel (Ni), copper (Cu), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), and niobium (Nb). Additional PCA charts and data are posted online at http://hilo.hawaii.edu/depts/geoarchaeology/index.php.

Kula volcanic series lavas that compose the Nu'u and Haleakalā quarries than group A or group C, but it does not match either of those quarry sites closely. Like group A, Nu'u, and Haleakalā, group B also has Ni concentrations that fall near or below the ED-XRF spectrometer's detection limits.

Group C (*n* = 63). This group follows the same trend line for Sr/Zr ratios as seen in group B but tends to have lower concentrations of both of those elements. Ni concentrations are measured slightly higher (5–21 ppm) than what was detected in groups A and B. Both the higher Ni concentrations and lower amounts of Sr and Zr indicate a less differentiated (higher MgO, higher magmatic temperature) magma type in comparison with groups A and B. We regard this group as local to Kahikinui based primarily on the trace element concentrations.

Group D (*n* = 25). This group forms a discrete cluster on the Sr/Zr plot (Fig. 2), with the lowest detected concentrations of both of those elements, and exhibits relatively low concentrations of other mid-Z trace elements (Rb, Y, and Nb). On the PCA plot (Fig. 3), the group is consistently separated from groups A, B, and C. Group D also contains more elevated Ni concentrations (64–129 ppm); it plots lower in Na and K than groups A, B, and C. All of these factors suggest that group D is a shield-building basalt, which is not exposed in Kahikinui (neither on the surface nor in gulches). Group D matches well with a known basalt quarry at Kapōhaku on Lāna'i Island (37). It is also possible that this group represents more than one source; this is particularly evident in elevated concentrations of yttrium (Y) in six of the samples. One likely source of high Y would be the quarrying of basalts that have undergone low-temperature hydrothermal alteration (38, 39).

Group E (*n* = 5). This group does not appear to be consistent with the main clusters of geochemical samples from Kahikinui based on high Ni and low Sr/Zr, and it is almost certainly nonlocal. It is similar to a cluster observed at Kahalu'u, Kona (38), and at Nualolo Kai, Kaua'i (17), but the sample is too small to make any definitive associations.

Group F (*n* = 6). This group matches most closely with group C (presumed to be local to Kahikinui) on a cluster analysis, but it exhibits higher Ni concentrations (33–46 ppm) and falls on the periphery of group C in all trace element concentration covariation diagrams and PCA plots. The PCA correlation matrix of all analyzed elements shows the best separation between groups C and F. We are unable to make any strong inferences on the local or nonlocal origin of this group.

Group G (*n* = 5). This group does not appear to be local to Kahikinui based in part on higher Ni concentrations but also on its divergence from the Sr/Zr ratio trend lines of groups A, B, and C. The closest documented match is from Mo'omomi, Moloka'i Island, but the published data from that quarry (18) show significant differences in MnO, Ni, and Rb.

Group H (*n* = 10). This group does not appear to be local to Kahikinui based on high Ni, low Sr and Zr, and low Na. The best match to a known quarry is Pu'umoiwi, Kaho'olawe Island (18). It is also similar to another apparently nonlocal geochemical group defined at Kahalu'u, Kona (40).

Group I (*n* = 10). This group is well-removed from the three main geochemical groups of inferred local sources. Like group H, it is low in Sr and high in Ni. Geochemically, these 10 samples fall within the defined range of the Mauna Kea adze quarry samples, although several of the samples plot out near the periphery of the Mauna Kea cluster.

Group J (*n* = 2). Two flakes recovered from site 1307 plot out close to the presumed Mauna Kea quarry cluster (group I) but do not match up well with that group on several elements (Mn, Sr, Zr, and Nb). Because it is so different from the main local clusters at Kahikinui, we infer that it is nonlocal. Other than its similarities to group I, it is closely related to group H but differs from that group substantially on a correlation matrix PCA.

Group K (*n* = 4). These flakes fall out in the general region of a known quarry at Nu'u, Maui (36), but the range of variation is greater than what was obtained from the quarry flakes.

Group L (*n* = 11). As in group K, these flakes plot out in the general range of the Haleakalā summit quarry but show more geochemical variation than what has been identified at the quarry itself. Different weathering regimes in the Kahikinui sites might be responsible for the greater range of detected variation, or these flakes could be from related Kula volcanics.

Group M (*n* = 11). This group is similar to group L except that it is lower in Sr and falls well below the Sr content of the Haleakalā summit quarry. It seems to be a good candidate for Kula series volcanics in general, and it does not match any known quarry geochemistry in Hawai'i.

Group N (*n* = 2). Two samples that are otherwise similar to group H have enriched Y concentrations above 140 ppm. These levels of Y enrichment are rare in Hawai'i and, to date, are only documented on Kaho'olawe, O'ahu, and Moloka'i.

Group O (*n* = 3). Two samples from site 286 and one from site 72 form a tight and distinct cluster that follows a similar Sr/Zr ratio to local basalts but has lower concentrations than groups A or C. Although this may be a local source, its isolated representation leaves that interpretation suspect.

Group P (*n* = 2). This diffuse group of two samples plots out low in Sr and high in Zr and Y. One flake comes from site 77 and the other comes from site 752. The geochemistry does not match well with the main trend lines for the Hāna and Kula volcanic series.

Group Q (*n* = 3). Three flakes have considerably higher concentrations of incompatible elements Sr, Zr, Nb, and Rb than any of the other samples. They appear to be basanites and could derive from local flows in Kahikinui.

Outliers (n = 5). Five samples do not match well with any others. Individual comments for each of these outliers are provided in the analytical database (Dataset S1).

Further Analysis. Nine basalt specimens representing groups D (two samples), H (one sample), and I (six samples) were further analyzed with destructive WD-XRF (Table S4). The six samples representing group I, all with <50 wt % SiO_2, have compositions similar to the well-known adze quarry on Mauna Kea, Hawai‘i Island (Table S5). The three samples representing groups D and H have significantly higher SiO_2 contents, unlike any known lava compositions on Maui, confirming that these groups derive from nonlocal sources. Adze sources with high SiO_2 are known from the islands of O‘ahu, Kaho‘olawe, Lānai and West Moloka‘i (Table S5). Although data for Hawaiian sources are still remarkably sparse, it is notable that data for sample 76-F5-FE1-12 (group D) is identical to that for the Kaunolu sample (A6-50-6) from Lāna‘i within error for all oxides except Na_2O, which is easily affected by volatilization during the high-temperature fusions used in this study; thus, we do not consider this difference to be significant. Such a perfect match for all elements is a strong argument that this artifact is derived from a Lāna‘i source.

Sample 117-K17-1-9 (group D) contains >54 wt % SiO_2, a composition that is extremely rare in the Hawaiian Islands. The only known source with SiO_2 values >54 wt % is the Kailua quarry on O‘ahu Island (Table S5). Our analytical data for sample 117-K17-1-9 generally agrees with that of the single analysis of the Kailua source (18), but the match is not perfect. Most significant are differences in FeO (total Fe is reported as FeO), CaO, TiO_2, and K_2O (Fig. 4*B*). Other sources with SiO_2 values >53 wt % are the Waiahole source on O‘ahu Island and the Pu‘u Mōiwi source on Kaho‘olawe Island (Fig. 4*A*), but these sources show much greater differences in most oxide values from that of sample 117-K17-1-9. Clearly the Kailua source needs to be much better characterized, but the correspondence in SiO_2 and most other oxide values leads us to conclude that the most likely source for sample 117-K17-1-9 is Kailua, O‘ahu.

The other artifact sample with moderately high SiO_2 is sample 1309-TP2-2-20 (group H). Analytical data for this sample are close to that for the Ka‘eo source of West Moloka‘i, although differences between data for this sample and that for Ka‘eo are outside analytical error for several oxides, the most important of which are Al_2O_3, FeO (total Fe is reported as FeO), MgO, and P_2O_5. K_2O and TiO_2 values for sample 1309-TP2-2-20 are identical to those of the Ka‘eo source and unlike those of any other known high-SiO_2 adze sources in Hawai‘i. Thus, we conclude that the most likely source for this sample is Ka‘eo, Moloka‘i Island, although the lack of a perfect match for all oxides makes this conclusion somewhat uncertain.

Discussion

Based on our two-stage analytical methodology, the 328 basalt tool specimens analyzed from Kahikinui district fall into the following major categories: (*i*) those from local or probably local Kahikinui sources (groups A, B, C, F, and Q); (*ii*) those from sources likely to be located elsewhere on East Maui, such as the Haleakalā and Nu‘u quarries (groups K, L, and M); (*iii*) those from the Mauna Kea adze quarry on Hawai‘i Island (group I); (*iv*) those from extra-Maui sources, including quarries on Lāna‘i, Kaho‘olawe, O‘ahu, and possibly Moloka‘i (groups D, E, G, H, J, N, and P); and (*v*) a residual set that cannot be assigned to provenance at present (group O and Outliers). Artifacts from local or presumed local Kahikinui sources make up 71% of the total, indicating that volcanic stone tool production in the district drew heavily on locally available stone resources. However, a significant 27% of the artifacts are derived from sources external to the district, either from quarries in other districts of East Maui or from quarries on at least three and probably four

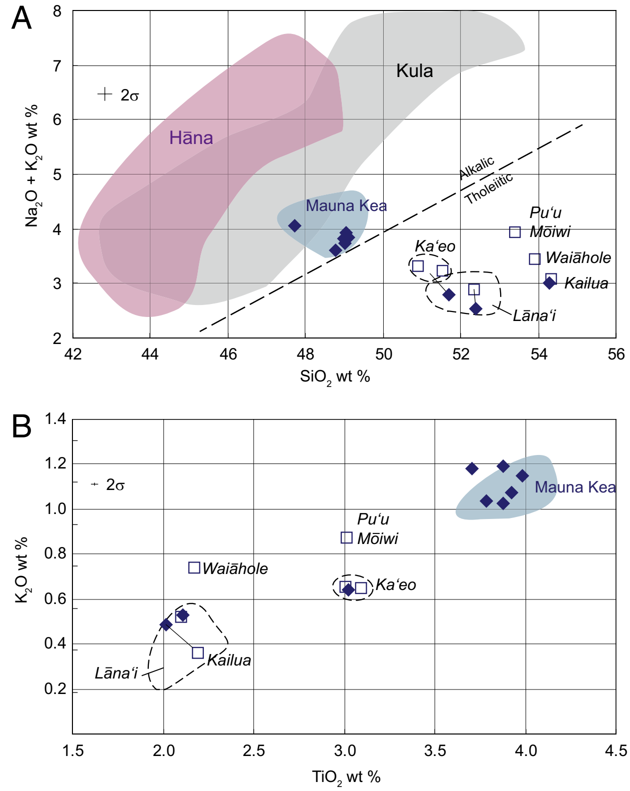

Fig. 4. Comparison of Kahikinui sample major element oxide data (blue diamonds) determined by WD-XRF with comparable data for selected other Hawaiian samples. Fields for Hāna and Kula volcanics are from data of Bergmanis et al. (25) and Sherrod et al. (32). Sample data for Pu‘u Mōiwi, Waiāhole, and Kailua adze sources is from Sinton and Sinoto (18). The field for the Mauna Kea adze quarry includes data from Sinton and Sinoto (18). Ka‘eo samples include those of Sinton and Sinoto (18). The alkalic–tholeiitic dividing line is after Macdonald (46). The unlabeled square within the Lāna‘i field is data from Sinton and Sinoto (18) for sample A6-50-6 from Kaunolu. Tie lines show interpretative matches of artifact data to known sources.

other islands in the archipelago. These extra-Maui quarries lie beyond the political boundaries of the late precontact Maui kingdom, falling in the separate political territories of the Hawai‘i Island kingdom (the Mauna Kea adze quarry), and of the O‘ahu Island kingdom. Lāna‘i was within the political sphere of the Maui kingdom, but Moloka‘i (another probable source) became a political pawn between the Maui and O‘ahu kingdoms in late precontact times (1). Our results, as well as recent findings on Hawai‘i Island (40), thus demonstrate that the classic model (3, 6, 8) of economically sufficient and autonomous territories (*ahupua‘a*), or even districts (*moku*) is unsupported, at least as far as this particular resource is concerned. Not only was high-quality volcanic rock being imported from outside Kahikinui district, but such imports not infrequently crossed the political boundaries between independent kingdoms.

The number of different volcanic rock source groups represented at any particular archaeological site in Kahikinui is largely a function of sample size, as shown in Fig. 5. This strong correlation between sample size and group diversity is a well-known phenomenon in archaeological assemblages (41). However, one site (site 752, with 13 groups present) has a larger diversity of lithic sources than expected. Site 752 is a large habitation terrace with an unusually thick midden deposit found within a residential complex overlooking one of the best agricultural localities in central Kahikinui. Several lines of evidence (architecture, high frequency of dog bone, and formal hearths) point to this site

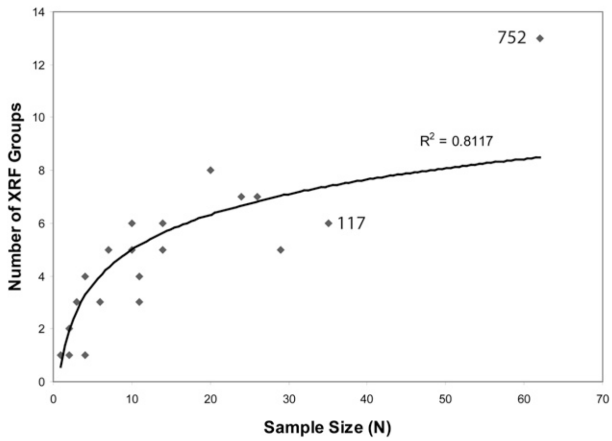

Fig. 5. Scatterplot showing the relationship between sample size of archaeological site assemblages and number of volcanic rock source groups present. See text for discussion of site assemblages 117 and 752.

having been the residence of a prominent household, quite likely the community leader for this part of Kahikinui. Associated with site 752 is a cookhouse feature (site 1011), which contained a specimen from the Mauna Kea source. Clearly, the occupants of this complex had access to the greatest range of imported basalt materials of any household that we sampled, in keeping with the interpretation of it as an elite residence.

A second site of particular interest is site 117, a large and substantially constructed habitation enclosure and terrace situated on a high ridge and surrounded by several temple (*heiau*) structures. Several lines of evidence, summarized by Kirch et al. (42), suggest that this was the residence of a priest who officiated at the Naka'ohu temple complex. This site had six specimens from an extra-Kahikinui source on Maui but also seven specimens from groups D and E, including one specimen (117-K17-1-9) sourced to Kailua, O'ahu Island. This finding again demonstrates the access of elites to a greater diversity of extralocal basalt sources.

Perhaps the most unusual and significant aspect of our results is the strong correlation between nonlocal sources and ritual archaeological contexts. Our sample of archaeological sites includes several stone foundations of temples (*heiau*), which when excavated often exhibited evidence of substantial basalt flaking activities, probably because these sites served as aggregation areas for males in addition to being places of ritual activity. These temples include four that are clustered together on the Naka'ohu ridge surrounding the site 117 priest's house (sites 75, 76, 77, and 115), along with three other temples or shrines (sites 1156, 1304, and 1307). It is notable that, of 10 specimens in group I sourced to the Mauna Kea adze quarry on Hawai'i Island, 7 come from sites 76, 77, and 115, the Naka'ohu temple complex. When we examine the distribution of local versus nonlocal sources in commoner residential versus ritual contexts, whether in terms of absolute numbers (Fig. S1) or in terms of relative frequencies (Fig. S2), it is evident that nonlocal sources are much more heavily represented in the ritual contexts. Whereas in residential contexts local sources on average comprise 76% of the basalt artifacts, in ritual contexts local sources comprise only 56%, with extralocal sources making up the other 44%.

Conclusion

Geochemical analysis of a large assemblage of volcanic stone artifacts drawn from a variety of residential and ritual archaeological sites in Kahikinui district, Maui, shows that, although the district's residents exploited local stone sources for the majority of their tool production, they nonetheless imported slightly more than one-quarter of their lithic resources from outside of their own political district. Clearly, even though they were capable of being self-sufficient in stone resources, they chose to import a significant quantity of high-quality volcanic rock, either as raw material or as finished adzes. These findings contradict the classic ethnohistoric model of the Hawaiian economy as being based on autonomous territorial units (the *ahupua'a* territories), with little exchange or trade and with the production of staple starches as the main economic power strategy (3, 6–8). Although control over agricultural production was doubtless central to the Hawaiian political economy, to this we can add a significant role for a wealth economy based on the control and distribution of other kinds of goods and resources (1). One such resource, which fortunately is well represented in the archaeological record, consists of high-quality, fine-grained volcanic rock. Moreover, the disproportionately high frequency of extralocal, fine-grained volcanic rock artifacts in either high-status residence sites or ritual, temple contexts strongly suggests that control over access to and distribution of these stone resources was controlled by elites, who would likely have included the district chief (*ali'i 'ai moku*) and *ahupua'a*-level subchiefs (*ali'i 'ai ahupua'a*) as well as the land managers (*konohiki*) and the priests (*kāhuna*). Further investigation of the ways in which elites used control over scarce and unevenly distributed resources as a power strategy should aid in understanding the remarkable transformation of Hawaiian polities from chiefdoms to archaic states in the period immediately preceding European contact.

Materials and Methods

Artifact Sampling. The artifacts selected for compositional analysis included all whole or fragmentary adzes (n = 57), all flakes and shatter with polished surfaces that were assumed to be adze fragments (n = 111), and a sample of unmodified flakes and shatter (n = 160) that represent the macroscopic variability present in the overall assemblage. Unmodified flakes and debitage were informally divided into groups based on macroscopic characteristics, such as relative grain size, color, and presence of inclusions, and a sample of these ad hoc groups was included in the compositional analysis. We processed larger overall samples for complexes that had larger excavation samples, such as features 117, 725/726, and 1307/1309. These features offered the best contexts for controlled sampling, where the time–space contexts of the lithic assemblages could be best understood and related to other factors, such as feature context and function. In total, 328 archaeological samples from surface survey and excavation in the Kahikinui region were analyzed in an effort to provide a sample that would sufficiently record the variability of the raw material used across the Kahikinui region for adze manufacture. The sample included artifacts from 36 discrete archaeological features.

ED-XRF Analysis. We used a ThermoNoran QuanX ED-XRF spectrometer at the University of Hawai'i, Hilo, for nondestructive ED-XRF analysis. Concentration data on 19 elements were acquired by using the methodology of Lundblad et al. (15). Initial groupings were established by using a qualitative approach that favors elements that exhibit the highest precision and accuracy on the ED-XRF spectrometer, particularly Zr and Sr. These two incompatible elements are present in Polynesian volcanic rocks at levels well above the detection limits of the spectrometer. Group assignments were initiated with a scatterplot of Sr to Zr, with obvious clustering based on these two elements used to define preliminary groups. Other trace element scatterplots were then used to identify any additional clusters not evident on the Sr and Zr plots. We then used PCA to observe how these qualitatively defined groups cluster when multivariate statistical analyses were applied.

WD-XRF Analysis. Samples were broken into 2- to 5-mm chips, handpicked to eliminate those with obvious signs of alteration, and crushed in a WC ball mill to produce a fine powder. Powders were then ignited at 900 °C overnight to determine loss on ignition, a measure of the amount of volatile components. Negative loss-on-ignition values indicate that more oxygen was gained by oxidation of FeO during ignition than volatiles lost during this process. Then, 0.45 g of ignited powder was thoroughly mixed with 2.95 g of Spectroflux 105 (47% LiB_4O_9, 36.7% Li_2CO_3, and 16.3% La_2O_3) and fused at ~950 °C to form a homogeneous melt that was then poured onto graphite disks and pressed into a glass "button." These buttons were then measured on the University of Hawai'i at Manoa's Siemens SRS 303 AS WD-XRF spectrometer

ANTHROPOLOGY

with an end-window, Rh-target X-ray tube and reduced according to methods of Norrish and Hutton (43). Only one sample (77-S174-25) yielded enough powder (5.5 g) for trace element analysis on a pressed powder pellet with the University of Hawai'i WD-XRF. Peak intensities for trace elements were corrected for backgrounds, line interferences, and matrix absorption by using methods similar to those of Chappell (44). Corrected intensities were then calibrated against a wide range of natural and synthetic rock standards. Accuracy and precision for major and trace element analyses of the University of Hawai'i WD-XRF system have been previously reported in Sinton and Sinoto (18) and Sinton et al. (45).

ACKNOWLEDGMENTS. We thank Teresa Ingalls for preparing the WD-XRF samples. This research was funded by National Science Foundation Archaeology Program Grant SBR-9805754 (to P.V.K.) and by the Class of 1954 Chair Fund at the University of California, Berkeley. The University of Hawai'i, Hilo, ED-XRF was funded by National Science Foundation Major Instrumentation Grant BCS 0317528.

1. Kirch PV (2010) *How Chiefs Became Kings: Divine Kingship and the Rise of Archaic States in Ancient Hawai'i* (Univ of California Press, Berkeley).
2. Cordy R (2000) *Exalted Sits the Chief: The Ancient History of Hawai'i Island* (Mutual Publishing, Honolulu).
3. Earle TK (1997) *How Chiefs Come to Power: The Political Economy in Prehistory* (Stanford Univ Press, Stanford, CA).
4. Hommon RJ (1986) *Island Societies: Archaeological Approaches to Evolution and Transformation*, ed Kirch PV (Cambridge Univ Press, Cambridge, UK), pp 55–68.
5. Kirch PV, ed (2011) *Roots of Conflict: Soils, Agriculture, and Sociopolitical Complexity in Ancient Hawai'i* (School for Advanced Research Press, Santa Fe, NM).
6. Earle TK (1977) *Exchange Systems in Prehistory*, eds Earle TK, Ericson J (Academic, New York), pp 213–229.
7. Handy ESC, Pukui MK (1958) *The Polynesian Family System in Ka-'u, Hawai'i* (Polynesian Society, Wellington, New Zealand).
8. Sahlins M (1958) *Social Stratification in Polynesia* (American Ethnological Society, Seattle).
9. Kirch PV (1985) *Feathered Gods and Fishhooks: An Introduction of Hawaiian Archaeology and Prehistory* (Univ of Hawai'i Press, Honolulu).
10. Bayman JM, Moniz Nakamura JJ (2001) Craft specialization and adze production on Hawai'i Island. *J Field Archaeol* 28:239–252.
11. Cleghorn PL (1986) Organizational structure at the Mauna Kea adze quarry complex, Hawai'i. *J Archaeol Sci* 13:375–387.
12. Lass B (1994) *Hawaiian Adze Production and Distribution: Implications for the Development of Chiefdoms* (Cotsen Institute of Archaeology Press, Los Angeles).
13. Lass B (1998) Crafts, chiefs, and commoners: Production and control in precontact Hawai'i. *Craft and Social Identity,* Archaeological Papers of the American Anthropological Association Number 8, eds Costin CL, Wright RP (American Anthropological Association, Arlington, VA), pp 19–30.
14. McCoy PC (1977) The Mauna Kea adze quarry project: A summary of the 1975 field investigations. *J Polynesian Soc* 86:223–244.
15. Lundblad SP, Mills PR, Hon K (2008) Analyzing archaeological basalt using nondestructive energy dispersive X-ray fluorescence (EDXRF): Effects of postdepositional chemical weathering and sample size on analytical precision. *Archaeometry* 50:1–11.
16. Mills PR, Lundblad SP, Smith JG, McCoy PC, Nāleimaile SP (2008) Science and sensitivity: A geochemical characterization of the Mauna Kea adze quarry complex, Hawai'i Island, Hawai'i. *Am Antiq* 73:743–759.
17. Mills PR, et al. (2010) Geochemical sourcing of basalt artifacts from Kaua'i, Hawaiian Islands. *J Archaeol Sci* 37:3385–3393.
18. Sinton J, Sinoto Y (1997) *Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach*, ed Weisler MI (New Zealand Archaeological Association, Auckland), pp 194–204.
19. Xu G, et al. (2007) Geochemical characteristics of West Molokai shield- and postshield-stage lavas: Constraints on Hawaiian plume models. *Geochem Geophys Geosyst* 8: 1–40.
20. Kirch PV, ed (1997) *Na Mea Kahiko o Kahikinui: Studies in the Archaeology of Kahikinui, Maui* (Archaeological Research Facility, Univ of California, Berkeley).
21. Dixon B, Conte PJ, Nagahara V, Hodgins WK (1999) Risk minimization and the traditional *ahupua'a* in Kahikinui, Island of Maui, Hawai'i. *Asian Perspect* 38:229–255.
22. Kirch PV (2007) *The Growth and Collapse of Pacific Island Societies: Archaeological and Demographic Perspectives*, eds Kirch PV, Rallu J-L (Univ of Hawai'i Press, Honolulu), pp 90–107.
23. Kirch PV, Sharp WD (2005) Coral ^{230}Th dating of the imposition of a ritual control hierarchy in precontact Hawaii. *Science* 307:102–104.
24. Stearns HT, Macdonald GA (1942) *Geology and Ground-Water Resources of the Island of Maui, Hawaii* (Hawaii Division of Hydrography, Honolulu).
25. Bergmanis EC, Sinton JM, Trusdell FA (2000) Rejuvenated volcanism along the southwest rift zone, East Maui, Hawai'i. *Bull Volcanol* 62:239–255.
26. Brill RC (1975) Geology of the lower southwest rift of Haleakala, Maui. M.S. thesis (Univ of Hawai'i, Honolulu).
27. Chen CY, Frey FA (1985) Trace element and isotopic geochemistry of lavas from Haleakala Volcano, East Maui, Hawai'i: Implications for the origin of Hawaiian basalts. *J Geophys Res* 90:8743–8768.
28. Chen CY, Frey FA, Garcia MO (1990) Evolution of alkalic lavas at Haleakala Volcano, East Maui, Hawai'i. *Contrib Mineral Petrol* 105:197–218.
29. Crandell DR (1983) *Potential Hazards from Future Volcanic Eruptions on the Island of Maui, Hawai'i* (US Geological Survey, Reston, VA), Miscellaneous Investigations Series Map I-1442, scale 1:100,000.
30. Horton KA (1977) Geology of the upper southwest rift zone of Haleakala Volcano, Maui, Hawai'i. M.S. thesis (Univ of Hawai'i, Honolulu).
31. Macdonald GA, Powers HA (1968) A further contribution to the petrology of Haleakala Volcano, Hawai'i. *Geol Soc Am Bull* 79:877–888.
32. Sherrod DR, Sinton JM, Watkins SE, Brunt KM (2007) *Geologic Map of the State of Hawai'i* (Hawaiian Volcano Observatory, Hawaii National Park, HI) US Geological Survey Open-File Rep 2007-1089, Version 1.0, http://pubs.usgs.gov/of/2007/1089/.
33. West HB, Leeman WP (1987) Isotopic evolution of lavas from Haleakala Crater, Hawai'i. *Earth Planet Sci Lett* 84:211–225.
34. West HB, Leeman WP (1994) The open-system geochemical evolution of alkalic cap lavas from Haleakala Crater, Hawai'i. *Geochim Cosmochim Acta* 54:773–796.
35. Cleghorn PL, Dye T, Weisler MI, Sinton JM (1985) A preliminary petrographic study of Hawaiian stone adze quarries. *J Polynesian Soc* 94:235–251.
36. Kahn JG, Mills P, Lundblad S, Holson J, Kirch PV (2008) Tool production at the Nu'u Quarry, Maui, Hawaiian Islands: Manufacturing sequences and energy-dispersive X-ray fluorescence analyses. *NZ J Archaeol* 30:135–165.
37. Weisler MI (1990) A technological, petrographic, and geochemical analysis of the Kapohaku adze quarry, Lana'i, Hawaiian Islands. *NZ J Archaeol* 12:29–50.
38. Patino LC, Velbel MA, Price JR, Wade JA (2003) Trace element mobility during spheroidal weathering of basalts and andesites in Hawai'i and Guatemala. *Chem Geol* 202:343–364.
39. Fodor RV, Dobosi G, Bauer GR (1992) Anomalously high rare-earth element abundances in Hawaiian lavas. *Anal Chem* 64:639A–643A.
40. Mills PR, et al. (2011) Reappraising craft specialization and exchange in pre-contact Hawai'i through non-destructive sourcing of basalt adze debitage. *J Pac Archaeol* 2: 79–92.
41. Grayson D (1984) *Quantitative Zooarchaeology* (Academic, New York).
42. Kirch PV, Millerstrom S, Jones S, McCoy M (2010) Dwelling among the gods: A late pre-contact priest's house in Kahikinui, Maui, Hawaiian Islands. *J Pac Archaeol* 1: 144–160.
43. Norrish K, Hutton J (1977) An accurate X-ray spectrographic method for the analysis of a wide range of geological samples. *Geochim Cosmochim Acta* 33:431–441.
44. Chappell B (1992) Trace element analysis of rocks by X-ray spectrometry. *Adv X-Ray Anal* 34:263–276.
45. Sinton JM, Grönvold K, Saemundsson K (2005) Post-glacial eruptive history of the Western Volcanic Zone, Iceland. *Geochem Geophys Geosyst* 6:1–34.
46. Macdonald GA (1968) Composition and origin of Hawaiian lavas. *Geol Soc Amer Mem* 116:477–522.