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CHEMICAL CHARACTERIZATION AND PROVENANCE OF MANU'A ADZ MATERIAL USING A NON-DESTRUCTIVE X-RAY FLUORESCENCE TECHNIQUE

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INTRODUCTION

THE COLONIZATION STRATEGIES employed during the settlement of Polynesia and the subsequent diversification of island societies are key issues in Oceanic prehistory. Yet it is only recently that researchers have begun to amass empirical evidence of inter-island communication—throughout island sequences—that undoubtedly influenced the direction and tempo of post-settlement island histories. I refer here to recent finds of Tongan pottery in the Cook Islands (Walter and Dickinson 1989:465), of Samoan adz material in Fiji (Best 1984; Best et al. 1992) and the Cook Islands (Weisler 1993), and of inter-island transport of volcanic glass and fine-grained basalt in Hawaii during late prehistory (Weisler 1990; et al. In prep. [For a review of Polynesian basalt adz provenance studies, see Weisler In press a.]) . Isolation has been invoked as "the most fundamental" mechanism of divergence in Polynesia (Kirch and Green 1987:440), but "how . . . different extremes of isolation have influenced the evolution of human diversity from island to island—and perhaps even on the same island" (Terrell 1986:122-23) remains a problem that must be addressed for each island sequence. Dissimilarities may also originate because of continuing contact (see Terrell 1986:147). Isolation may have contributed to regional variations in portable artifacts, architecture, and language in New Zealand (Prickett 1982), Society Islands (Emory 1933), and Hawaii (Kirch 1985, 1990). In contrast, inter-island communication is inferred by parallel histories in subsistence and technological transformations in the northern and southern Marquesas (Rolett 1990:363) and similar changes in ceramic styles and adz evolution in the Samoa-Tonga-Fiji area at similar times imply continuous inter-island contact (Davidson 1977, 1978, 1979).

Tracking the spread and subsequent communication of prehistoric Polynesian societies has been difficult without the widespread occurrence of pottery and obsidian, artifact classes that have proven especially useful for demonstrating interaction in the southwest Pacific. Without inferring contact from similar styles of fishhooks, adzes, and architecture, Polynesian archaeologists are left with few items to track empirically the intra- and inter-island movement of things. Connecting stylistic nodes, however, may only reflect convergent evolution (Kirch and Green 1987). I may risk being accused of taking a hard-line empiricist view of culture contact and change, but I think it crucial to confront the problem with separating stylistic from functional dimensions (Dunnell 1971:26-30) in relation to documenting the movement of exotic raw materials and finished objects (e.g., pearlshell and industrial stone) between and within island groups. The spatial and temporal dimensions of contact spheres (Irwin 1990:92; Walter 1990; Weisler In press b), can be delimited more accurately using exotic materials than by connecting artifact styles. Consequently, the distribution of exotic materials provides a better framework for evaluating the role of isolation and communication in shaping historical developments of island societies.

This preliminary effort to document inter-island communication during the prehistory of the Manu'a Islands should take into account the region's geography. These islands are situated 100 km east of the most important source of adz material in central Polynesia, the Tatagamatau adz quarry, Tutuila (Leach and Witter 1987, 1990). The distance and often turbulent ocean conditions between Tutuila and the Manu'a Group may have reduced the frequency of contacts (Hunt and Kirch 1988:155).

THE COLLECTIONS

Two questions are addressed by XRF analysis of the Ta'u and Ofu island assemblages and source material: (1) Did any artifacts originate at the Tatagamatau adz quarry complex on Tutuila Island located 100 km to the west?; and (2) What was the geochemical variation of adz material and unmodified basalt flakes from Manu'a sites? Although it seemed unlikely that I would be able to assign a provenance to all artifacts, I could determine if specific geochemical groups were correlated with certain tool classes. Interaction spheres could be delineated by identifying similar rock at different sites and, perhaps, different temporal periods. An additional goal of the XRF analysis was to generate geochemical data for the important Tatagamatau quarry complex on Tutuila and two local To'aga sources that may have been used.

The Archaeological Sample

The archaeological contexts of the Ta'u and Ofu island assemblages are described elsewhere (Hunt and Kirch 1988; Kirch et al. 1990; chapters 5 and 11, this volume) and are not reiterated here. The artifacts selected for compositional analysis consisted of all whole or fragmentary adzes, all flakes exhibiting polished surfaces and assumed to be adz fragments, and a sample of unmodified basalt flakes which represented the macroscopic variability present. Table 12.1 presents characteristics of the analyzed artifacts. Specimens ranged from 1.2 to 421.9 gms and 22.08 to 136.30 mm in length. The thinnest sample was 3.53 mm.

Source Material

During their 1987 field season, Kirch and Hunt collected nine samples of source rock from the Tatagamatau quarry complex on Tutuila (Best et al. 1989; Leach and Witter 1987). On Ofu Island, they collected four samples from dike swarms at Mako Ridge and three samples from Fa'ala'aga. The Tatagamatau quarry complex consists of numerous cut-and-fill terraces, stone-working areas, pits, and possible fortifications along several ridges and scree slopes which together may cover more than 110 acres (Best et al. 1989; Leach and Witter 1987, 1990). The raw material derives from a dike complex at the foot of a waterfall at the head of a small gulch (P. Kirch, personal communication 1990; Leach and Witter 1987:39). Fine-grained dike rock may have been removed from dikes but most likely was prised from the soil and rock scree of slopes and from streambeds. Although I have not visited Tatagamatau, the geological setting appears to be similar to the Waiahole quarry on windward O'ahu (Dye et al. 1985), albeit on a much smaller scale. Two collections of source rock were made by Kirch and Hunt during a visit on July 3, 1989. Eight samples, consisting of large primary or secondary flakes with obvious bulbs of percussion, were collected at three locations along the main spur of the complex which trends NE-SW, and an additional flake was retrieved from Area 3 (figure 12.1). The exterior color of the source rocks varied from dark brown (10YR 3/3), dark gray (10YR 4/1), to dark grayish-brown (2.5Y 4/2) due to weathering and contact with lateritic soil. Fresh saw-cut surfaces are mostly dark bluish-gray (Gley card, 5B 4/1) grading to dark gray (7.5R 4/0 and 2.5Y 4/0). Even prior to geochemical analysis, it was not likely that nine samples would document the total variability of quarry rock from so large a quarry, but this collection did contribute significantly towards developing a strategy for collecting additional material.

Table 12.1
Basalt Artifacts Analyzed by EDXRF

Lab Number	Artifact Number	Weight (g)	Description
89-22*	Fiti'uta 1	24.8	Quadrangular, reworked adz
89-25	11-1-S-4	70.9	Quadrangular adz
89-26*	11-2-S-1	41.4	Quadrangular adz, front section
89-31	11-2-S-2	35.3	Quadrangular adz, butt section
89-30*	11-2-S-3	21.4	Quadrangular adz, front section
89-28	11-2-S-8	33.1	Quadrangular adz, front section
90-30*	11-2-9	60.9	Quadrangular adz, butt section
90-33	11-52-S-9	133.1	Quadrangular adz, front section
89-18	13-S-3	48.4	Quadrangular adz, front section
89-34*	13-S-5	44.7	Quadranglular (?) adz, front (?) section
89-33*	13-S-6	33.8	Quadrangular adz, front section
89-32	13-S-9	44.4	Quadrangular adz
89-19	13-1-S-36	63.9	Plano-convex adz
89-17*	13-2-3-1-1	63.4	Quadrangular adz, midsection
90-22	13-1-9-2-4	421.9	Plano-convex adz
90-23	13-1-13-87	0.7	Adz flake
90-42	13-1-16-1	5.5	Adz fragment
90-46	13-1-16-11	1.5	Unmodified flake
90-45	13-1-16-11-81	127.9	Retouched flake
90-38	13-1-16-12-83	20.5	Retouched flake
90-27*	13-1-20-4-118	3.4	Adz flake
90-37	13-1-20-5-121	1.2	Unmodified flake
90-41	13-1-20-5-122	4.4	Unmodified flake
90-34	13-1-20-5-123	11.3	Unmodified flake
90-48	13-1-20-6-139	11.4	Unmodified flake
90-29	13-1-20-6-140	128.4	Plano-convex adz, front section
90-36	13-1-20-6-141	56.7	Retouched flake
90-40	13-1-20-7-143	3.2	Unmodified flake
90-43	13-1-20-9-147	20.6	Unmodified flake
90-49	13-1-21-7-151	59.3	Used flake
90-44	13-1-22-2-171	3.7	Unmodified flake
90-25	13-1-22-2-173	2.1	Adz flake
90-24*	13-1-22-2-174	0.4	Adz flake
90-26	13-1-23-7-194	211.4	Plano-convex (?) adz
90-31	13-1-27-5-39	89.4	Quadrangular (?) adz
90-39	13-1-27-5-40	128.1	Quadrangular (?) adz, butt (?) section
90-47	13-1-27-5-41	2.1	Unmodified flake
90-35	13-1-27-6-42	9.5	Unmodified flake

* = Probable source is Tatagamatau.

Situated at about 350 m elevation and exposed by a recent road-cut, the Mako Ridge dike swarm on Ofu consists of relatively dense basalt. Weathering has smoothed the normally angular, loose dike rock into sub-rounded cobbles which lie buried within a thick soil matrix. It is doubtful that this material was used for making stone tools, but four samples were collected for chemical analysis. The weathered exterior surface was gray in color (7.5YR 5/0) and fresh breaks, dark gray (2.5Y 4/0).

A large concentration of dikes is found along a steep ridge towards the east end of Ofu. The Fa'ala'aga dike swarm (Stice and McCoy 1968) may have been a more important source of local, medium-grained basalt during prehistory. Angular rock from the eroding dikes form a large scree slope which descends to the To'aga coastal zone where stone is readily available (see Kirch, chapter 2). Three fresh samples were removed from dikes exposed by a modern road-cut (see fig. 12.2) to provide the general chemical composition of the dike swarm although many dozens of dikes may exist each with varying chemical compositions. Surface color of these rock samples is very dark gray (2.5Y 3/0) with fresh breaks being gray (2.5Y 5/0).

METHODS

Because this specific technique of non-destructive, energy-dispersive XRF had not been used previously with adz material from Oceania, each individual source sample was divided and analyzed by two techniques: destructive XRF using pelletized samples and non-destructive XRF using whole specimens. Destructive XRF analyzes a wider range of elements, and results are fully quantitative for most elements and comparable to other data sets now being developed for adz source rock in Polynesia. The non-destructive technique focused on those elements that are more reliably detected with this procedure, and results presented are considered here as semi-quantitative.

Destructive XRF

Source samples from Tatagamatau, Mako Ridge, and Fa'ala'aga were analyzed by Dr. Peter R. Hooper at the Department of Geology, Washington State University, on 16 and 17 October 1989. The equipment and operating procedure are paraphrased from Hooper and Johnson (1987; this manuscript is available from Dr. Hooper or myself). Twenty-seven elements were analyzed on an automatic Rigaku 3370 spectrometer. For the oxides, SiO_2, Al_2O_3, TiO_2, FeO*, MnO, CaO, MgO, K_2O, Na_2O, and P_2O_5, the weight percents are presented. For the other seventeen elements, the weight percent or ppm (parts-per-million) of the element are provided. All elements are analyzed on a single 2:1 lithium tetraborate:rock powder fused disk. Each element analysis is fully corrected for line interference and matrix effects of all other analyzed elements. The results are normalized and printed out with total iron expressed as FeO*.

Whole rock samples were reduced with a tungsten carbide jaw crusher to small chips generally about 1 cm in average size. Chips were hand picked and reduced further in a Tema swingmill shatterbox with tungsten carbide surfaces where they were milled for two minutes. Rock powder weighing 3.5 grams was mixed with pure lithium tetraborate and emptied into a 34.9 mm-internal-diameter, graphite crucible. The samples were fused in a muffle furnace at 1000°C. After grinding, the samples were fused a second time. The lower, flat surfaces of the fused disks were ground on coarse (240) grit and fine (600) grit. Then, they were washed in an ultrasonic cleaner, dried, and loaded into the XRF spectrometer.

The x-ray intensity of each element from unknown samples was measured and compared to values of two beads from each of eight international rock standards (U.S. Geological Survey [U.S.G.S.] standards PCC-1, BCR-1, BIR-1, DNC-1, W-2, AGV-1, GSP-1, and G-2). Standards were run and recalibrated after processing between one and two hundred unknown samples. U.S.G.S. BCRP-84 and GSP-1 were used as internal standards and routinely run after every twenty-eight samples to check instrument performance. Drift between standard calibrations was due almost entirely to iron which produced slightly higher values for other elements presented as oxides, weight %. When thirty analyses of the U.S.G.S. standard BCRP were compared to accepted values, the precision or standard deviation of oxide values to known measures is 0.22% ppm. Values reported for thirteen trace elements in ppm were below 6% ppm at one standard deviation, except barium (16.2%) and vanadium (10.0%). The highest precision was achieved with Rb, Sr, Zr, Y,

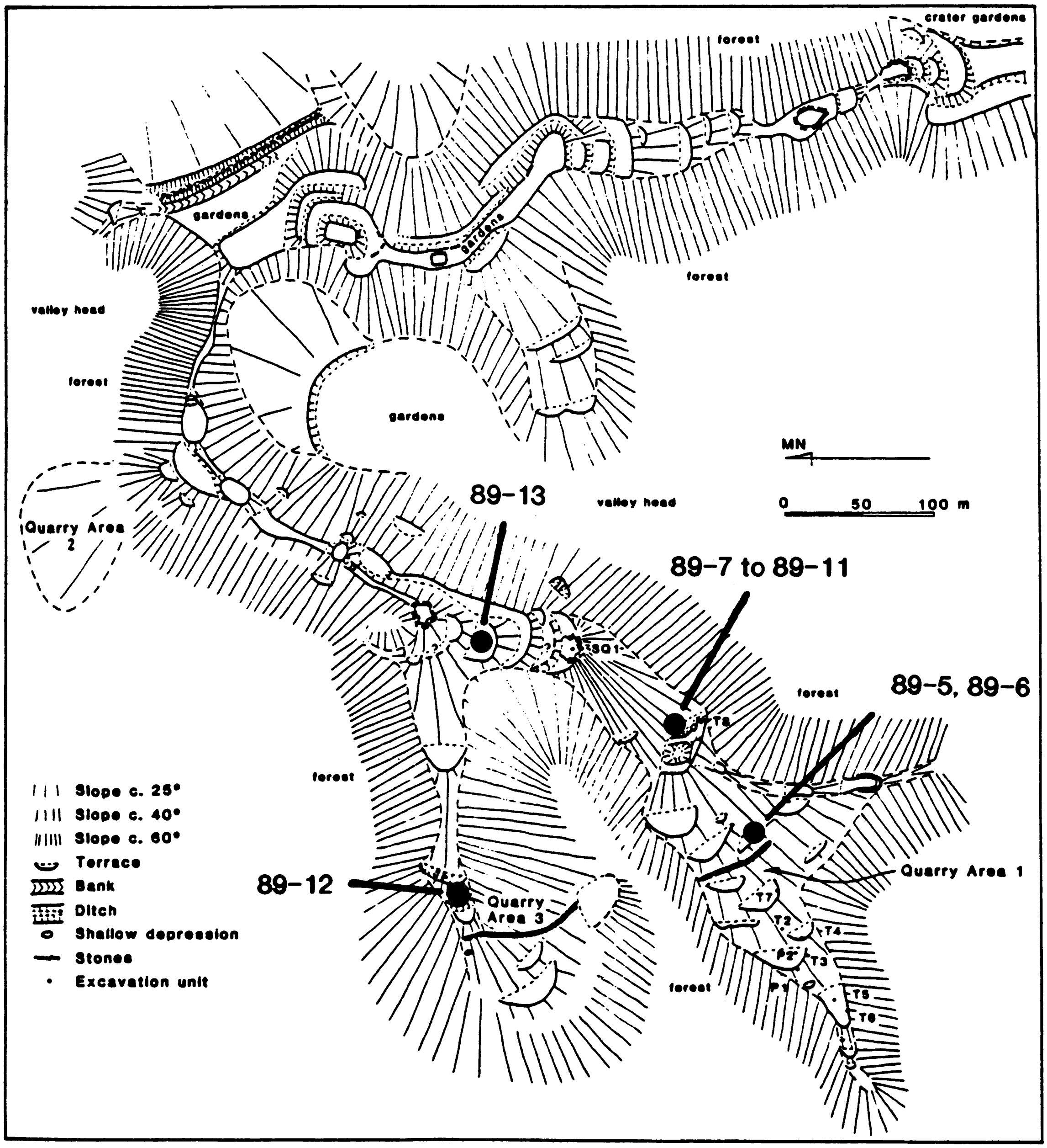

Figure 12.1 Map of Tatagamatau quarry showing locations of source samples (after Best et al. 1989, fig. 21).

Ga, Cu, and Zn. Ni, Cr, Sc, V, and Ba should be regarded as semi-quantitative below the 30 ppm level. Rb, Sr, Zr, Nb, and Y have satisfactory precisions and accuracies down to one to three ppm, while Y and Nb could be measured to 0.1 ppm. Evaluation of accuracy suggested that variation between different samples of standard powder or nonhomogeneity resulting from sample preparation is greater than inaccuracies caused by inadequate matrix and interference correction.

Non-destructive Energy Dispersive XRF

Portions or splits of all source samples from Tatagamatau, Mako Ridge, and Fa'ala'aga were analyzed by Weisler along with thirty-eight artifacts during four runs in late 1989 and early 1990. Sample preparation consisted of submerging specimens

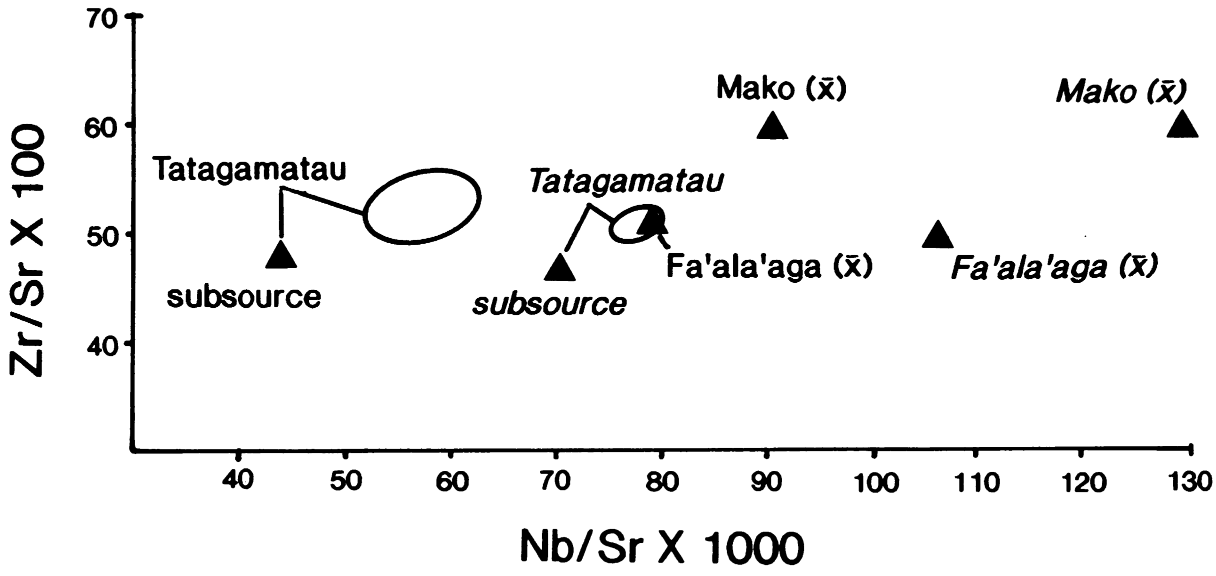

Figure 12.2 A comparison of source rocks analyzed by non-destructive x-ray flourescence using whole specimans and XRF with fused disks (indicated by italic type).

in a sonic bath of distilled water for up to one hour then air drying. Some artifacts, deeply stained with lateritic soil, were scrubbed with brushes as well. Carbonate encrustations on a few artifacts were removed with a 10% solution of HCl and then rinsed in distilled water. The EDXRF instrument is limited to the maximum weight and size of specimen that can be analyzed. Although the opening of the sample holder where the x-ray beam is directed through to the specimen is 32 mm in diameter, careful placement of the artifact or rock in the EDXRF instrument may accommodate samples (as in this analysis) up to 421 gms and 136 mm long. Molding clay can be used to secure specimens on the tray which can hold up to twenty samples. Each artifact was carefully examined to locate the flattest surface for analysis that could be accommodated within the space parameters of the sample chamber (see illustration in Bouey 1991:fig. 5). Source samples were cut to size and only fresh saw-cut surfaces were analyzed.

Laboratory facilities and equipment were provided by the Department of Geology and Geophysics, University of California, Berkeley. The same equipment and nearly identical operating conditions were used as reported by Hughes (1986:esp. 25-30) in his comprehensive study of California and Oregon artifactual and source obsidian. The XRF spectrometer consisted of a Spectrace 440 energy dispersive machine and 572 power supply (50kV, 1mA), 534-1 pulsed tube control, 588 bias/protection module, 514 pulse processor or amplifier, Tracor Northern 1221 100 mHz ADC converter, and a Tracor Northern 2000 computer based analyzer with an LSI-11 microcomputer (Hughes 1986:25). The Si(Li) solid state detector with 144 eV resolution (FWHM) at 5.9 keV in a 30 mm squared area was used for detecting all x-ray intensities. For analysis of trace elements in the mid-z energy range, a rhodium (Rh) x-ray tube was used for primary x-ray excitation at 30.0 keV, .20 mA pulsed, with a .05 mm Rh primary beam filter in an air path at 300 seconds livetime. Analytical lines used for analysis were Ni (Ka), Cu (Ka), Zn (Ka), Ga (Ka), Pb (Lb), Th (La), Rb (Ka), Sr (Ka), Y (Ka), Zr (Ka), and Nb (Ka). For rare earth elements, an Am241 100 mCi radioscope source was used in the 20-60 keV range at 300 seconds livetime (Hughes 1986:26), and analytical values were derived from the Ka lines of Cs, Ba, La, Ce, Pr, Nd, and Sm. The x-ray tube was operated at 15.0 kV, .40 mA pulsed, with an Al primary beam filter in a vacuum path at 200 seconds livetime for Ka lines of Fe, Mn, and Ti.

The elemental data as reported represent one analysis per specimen. While Bouey (1991) has demonstrated some variability with multiple analyses of the same obsidian specimens when values are presented in strictly quantitative (ppm) data, these effects are minimized when presenting data as ratios (see, for example, Jack and Carmichael 1969).

The XRF technique has its greatest accuracy in detecting elements in the mid-z range (e.g., rubidium, strontium, yttrium, zirconium, and niobium) which was confirmed by this study for both destructive and non-destructive sample preparations analyzed on their respective instruments. It is fortunate that these elements are of particular interest to igneous petrologists (Cox et al. 1979:332). For pressed pellets or fused disks these particular mid-z elements have satisfactory precisions and accuracies down to 1 - 3 ppm, while niobium and yttrium could probably be measured to 0.1 ppm (Hooper and Johnson 1987). In basalt, mid-z elements are also present in sufficient concentrations to be easily measured, and detection in whole, unaltered specimens ranges from 10 ppm to 100% with an accuracy of ± 2 - 5% under favorable conditions (Parkes 1986:153). Lighter elements are not only harder to detect and measure by XRF, but they are usually not present in great abundance. Iron, titanium, and magnesium values, reported here, were detected under vacuum. Lead (Pb), although detected during the mid-z analysis, was not used to discriminate sources or characterize artifacts due to its presence in low abundance and its susceptibility to atmospheric contamination (Flanagan 1969:82).

Rock standards have been used in routine XRF analyses for about twenty-five years (Flanagan 1969), and currently at least 272 geostandards are in use worldwide (Govindaraju 1989). Standards are important for calibrating the XRF instrumentation for matrix effect corrections and for monitoring the precision and accuracy during analysis (Germanique and Briand 1985). Using standards thought to be close in composition to the unknowns limits the efficacy of matrix correction programs to a restricted range of elements. Conversely, many different standards provide a greater range of elements and values for calibrating the program and evaluating unknowns. Therefore, more than ten internal standards were used to calibrate the Spectrace 440 machine used in this study. U.S.G.S. standard RGM-1, a rhyolite from Glass Mountain, California, was used to monitor precision and accuracy during analysis and the results are presented in table 12.2. Ppm values reported by Govindaraju (1984, 1989) are preferred "working values" which are the average of at least forty results from more than four techniques of analysis (1989:7). The accuracy and precision values reported for this study in ppm and selected ratios are reasonably close to accepted standard "working values."

Due to its cryptocrystalline texture and homogeneous distribution of elemental abundances, it is not surprising that obsidian has garnered most analytical attention in XRF studies. Large grain sizes can

Table 12.2
Evaluation of Analytical Accuracy and Precision for U.S.G.S. Standard RGM-1

	Govindaraju 1984	Govindaraju 1989	This study (n=4)	
			Accuracy	Precision
Rb	155	149	159.9	156.3-163
Sr	100	108	107.3	106-108
Zr	200	219	227.2	225.3-229.9
Y	25	25	27.7	25.9-29.2
Nb	9.4	8.9	10.3	9-11.7
Pb	21	24	28.6	27.1-31.1
Th	15	15.1	20.4	18.9-22.1
Zr/Sr	2	2.03	2.12	
Nb/Sr	0.094	0.082	0.096	

Govindaraju (1984, 1989) pressed powder samples; this study, whole specimens analyzed.

distort XRF analysis of whole samples. Pressed pellet samples are prepared by reducing whole rock to a fine powder estimated to be 90% less than 400 mesh (Bice 1980:19) or ca. 40 microns. However, very fine-grained basalt may have more than 130 grains per mm (ca. 160 microns per grain). While this grain-size is early four times larger than pressed pellet samples, it has not been demonstrated that grains of this size adversely effect XRF analysis. This subject should be investigated further. The distribution of elemental abundances within a single basalt specimen may not be as homogeneous as obsidian, but a comparison of the date in table 12.3 is quite instructive. Here, the distribution of selected elements within a quarry (1.8 hectares in size) are indeed quite regular, and perhaps this is more so for individual rocks or artifacts.

Another factor which can affect XRF analysis is an uneven specimen surface. Analyzing adz material has a distinct advantage, however, especially over bifacially flaked obsidian artifacts, because, almost by definition, most adz surfaces are extremely flat and, in many cases, are ground to a near mirror-like finish. Recalling that fused disks are finished by 240 (coarse) and 600 (fine) grit prior to XRF analysis (Hooper and Johnson 1987), I examined under 10-40X magnification source rock from eight west Moloka'i Island basalt quarries whose material exhibited a range of textures and phenocryst sizes and densities. These samples were polished with 600 grit mesh and compared to the adz material in the present study. The prepared specimens had uniform, smooth surfaces and occasional striations formed by disintegrating phenocrysts that had been trapped between the rock and grinding plate. Although the artifacts were not as uniform in contour and had many more striations, portions of the artifacts were as smooth—if not more finely polished—than the prepared specimens. Therefore, careful selection of artifact surfaces for EDXRF analysis may limit the amount of analytical distortion caused by uneven sample surfaces.

To reduce or eliminate the effects of uneven sample surface, many researchers have advocated presenting elemental abundance values as ratios. "In spite of variations in effective sample surface of randomly broken pieces or loosely packed grains, relative intensities may be very precisely determined" (Jack and Carmichael 1969:30; see also Stross et al. 1968:82). Sheets et al. (1990:149-50) concur that errors introduced by sample size and shape are largely cancelled by "the use of abundance ratios of elements having nearly the same energy (e.g., Rb, Sr, and Zr)." These observations were

Table 12.3
Variation of Oxides and Elements from the Mo'omomi Basalt Quarry, Hawaiian Islands

	Mean n=10	Range
Oxide (weight %)		
SIO2	46.16 ± 0.12	45.96-46.36
AL2O3	15.72 ± 0.04	15.66-15.81
TIO2	4.17 ± 0.01	4.157-4.183
FEO*	14.21 ± 0.20	13.91-14.04
MNO	0.19 ± 0.01	0.178-0.202
CAO	8.53 ± 0.03	8.50-8.58
MGO	6.32 ± 0.08	6.18-6.42
K2O	0.92 ± 0.02	0.90-0.95
NA2O	3.52 ± 0.07	3.40-3.67
P2O5	0.62 ± 0.01	0.613-0.634
Element (ppm)		
Ni	68.30 ± 1.90	64-70
Cr	5.40 ± 1.69	3-8
Sc	18.50 ± 2.58	15-23
V	302.20 ± 7.70	283-310
Ba	215.50 ± 20.69	187-258
Rb	14.40 ± 0.92	12-15
Sr	786.00 ± 6.62	775-798
Zr	272.50 ± 2.91	268-278
Y	37.80 ± 0.98	37-40
Nb	27.09 ± 1.19	25.0-28.9
Ga	23.30 ± 1.79	21-26
Cu	11.80 ± 5.62	4-21
Zn	133.30 ± 1.90	131-137
Pb	4.30 ± 1.35	2-6
La	18.80 ± 9.05	2-31
Ce	62.00 ± 9.89	49-80
Th	0.80 ± 0.98	0-3

*total iron

Analyst: Dr. Peter R. Hooper, Dept. of Geology, Washington State University taken into consideration for the present study.

Ever since the pioneering work of Parks and Tieh (1966), selection of elements for obsidian analysis has been fairly standard. Regarding data reduction, however, two "camps" have emerged somewhat recently. For reasons cited above, elemental abundances are usually presented in semi-quantitative ratio form including ternary diagrams (e.g., Best 1984; Jack and Carmichael 1969; Shackley 1988; Stross et al. 1968) or scatter plots (see fig. 12.3, this study; Jack and Carmichael 1969). Hughes (1986, 1988a, b) suggests that simple bivariate plots of zirconium and rubidium in ppm are sufficient for distinguishing raw material and determining artifact provenance in some regions. However, Bouey (1991) demonstrated that multiple analyses of the same specimens produced "widely divergent determinations in ppm concentrations," while ratio level presentation reduces this error significantly (cf. Jack and Carmichael 1969; Sheets et al. 1990). Hughes (1986) and Walter (1990) have applied statistical clustering programs to define geochemical groups. Multivariate statistics are quite appropriate for some problems, however their use eliminates any consideration of the elemental abundances (either in ppm or at a nominal level) as having any geological value. For example, on west Moloka'i, Hawaiian Islands, relatively high values of Y signal one particular quarry (David Clague, personal communication, 1989) and, simple bivariate plots of silica and total alkalis can be very informative for determining sources and characterizing geochemical groups. Statistical clustering techniques should only be used after the data have been examined for geological information that can inform on the "provenance environment," that is, the geology of the suspected interaction sphere. Conversely, groups created by statistical manipulation are an end in themselves.

RESULTS

The results of the fused disk XRF analysis of sixteen source rocks from Tatagamatau, Mako Ridge, and Fa'ala'aga are presented in tables 12.4-6 and summarized in table 12.7. According to a recent comprehensive and international evaluation of the systematics of igneous rocks (Le Maitre 1989), the Tatagamatau and Mako Ridge rocks are classified chemically as hawaiites and the Fa'ala'aga rock as basalt. Rock names were assigned by plotting silica values between total alkalis. Between sources, marked differences are found with the oxides, Al_2O_3, FeO, CaO, and P_2O_5, and most trace elements. The samples from the Tatagamatau source reveal important intra-source variability between Areas 1 and 3. Oxide values for Al_2O_3, MnO, Na_2O, and P_2O_5 demonstrate marked differences as well as the trace elements Ni, Cr, and Cu. Until additional samples collected from several areas of the 110-acre Tatagamatau quarry complex are analyzed and the geochemical variability of source rock is understood in greater detail, Ni and Cr may well be significant trace elements for demonstrating intra-source variability; that is, at least between Areas 1 and 3.

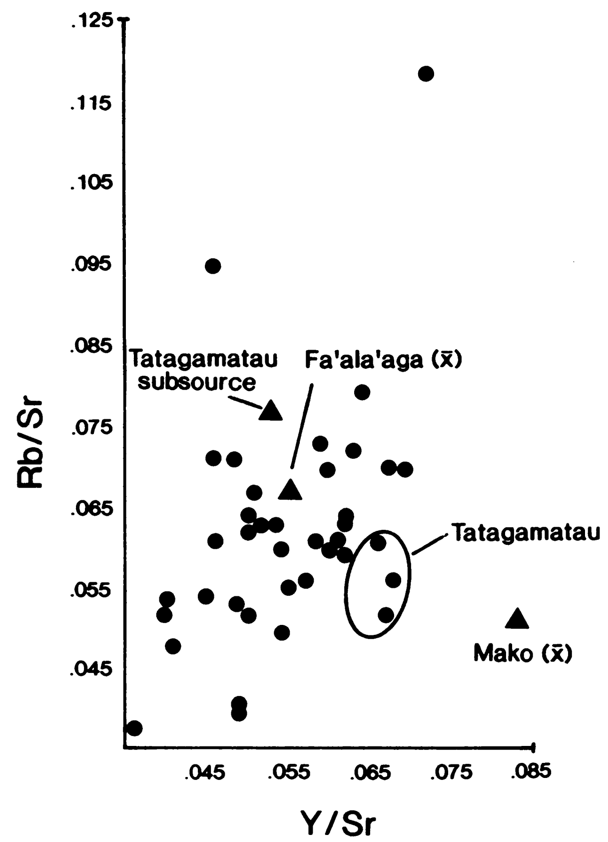

Figure 12.3 A wide dispersion of data points results when ratios of rubidium, strontium, and yttrium are used to assign specimens to possible sources.

Table 12.4
Geochemistry of Tatagamatau Source Rock (Fused Disks)

	Sample No.									Range	Mean
	89-5	89-6	89-7	89-8	89-9	89-10	89-11	89-12	89-13		
Oxide (Weight %)											
SiO2	49.66	49.66	50.26	49.94	50.4	49.56	50.56	49.32	50.11	49.32-50.56	49.94
Al2O3	15.62	15.35	15.43	15.43	15.46	15.4	15.5	13.86	15.4	13.86-15.62	15.27
TiO2	3.429	3.413	3.385	3.412	3.39	3.385	3.42	3.649	3.467	3.385-3.649	3.439
FeO*	12.64	12.9	12.56	12.82	12.63	12.81	12.34	12.4	12.73	12.34-12.90	12.65
MnO	0.178	0.179	0.173	0.176	0.178	0.175	0.179	0.167	0.177	0.167-0.179	0.176
CaO	7.62	7.56	7.7	7.6	7.63	7.58	7.68	7.8	7.69	7.56-7.80	7.65
MgO	4.65	4.67	4.55	4.62	4.77	4.7	4.76	7.06	4.76	4.55-7.06	4.95
K2O	1.54	1.62	1.6	1.57	1.57	1.58	1.59	1.79	1.54	1.54-1.79	1.60
Na2O	4.06	4.02	4.01	3.96	4.01	4.06	4.09	3.45	3.95	3.45-4.09	3.96
P2O5	0.814	0.792	0.802	0.805	0.803	0.796	0.805	0.71	0.783	0.710-0.814	0.790
Total	100.211	100.164	100.47	100.333	100.841	100.046	100.924	100.206	100.607		100.425
Element (PPM)											
Ni	0	0	0	0	0	0	0	173	0	0-173	19.2
Cr	2	0	3	3	0	1	0	181	0	0-181	21.1
Sc	16	17	22	19	16	23	15	27	22	15-27	19.7
V	202	217	200	204	214	207	203	233	215	200-233	210.6
Ba	293	286	302	282	268	292	301	331	300	268-331	295.0
Rb	42	43	45	43	42	43	43	50	42	42-50	43.7
Sr	698	704	707	707	706	708	699	683	694	683-708	700.7
Zr	357	362	354	360	355	357	352	325	348	325-362	352.2
Y	47	48	49	48	47	49	48	37	45	37-49	46.4
Nb	55	56	54.8	55.5	55.2	53.9	52.9	47.9	52.4	47.9-56.0	53.73
Ga	29	30	30	30	27	28	31	26	30	26-30	29.0
Cu	9	0	0	1	0	1	0	31	1	0-31	4.8
Zn	176	168	167	172	165	174	178	153	170	153-178	169.2
Pb	8	5	4	6	8	4	6	5	8	0-8	6.0
La	43	36	34	13	50	29	44	43	33	13-50	36.1
Ce	99	98	88	108	109	102	88	99	110	88-110	100.1
Th	6	6	3	5	7	6	6	2	3	2-7	4.9

* total iron

Analyst: Dr. Peter R. Hooper, Dept. of Geology, Washington State University, 16-17 October 1989.

Table 12.5
Geochemistry of Mako Ridge Source Rock (Fused Disks)

	Sample No.				Range	Mean
	89-1	89-2	89-3	89-4		
Oxide (Weight %)						
SiO2	46.48	49.84	43.44	48.12	43.44-49.84	46.97
Al2O3	18.22	17.22	19.72	18.33	17.22-19.72	18.35
TiO2	3.552	3.238	3.886	3.473	3.238-3.886	3.537
FeO*	12.10	10.68	13.20	11.48	10.68-13.20	11.87
MnO	0.21	0.193	0.231	0.208	0.193-0.210	0.211
CaO	6.65	8.42	5.50	7.29	5.50-7.29	6.966
MgO	4.44	4.41	4.42	4.24	4.24-4.44	4.38
K2O	1.89	1.79	1.98	1.37	1.37-1.98	1.76
Na2O	3.45	4.18	2.55	3.84	2.55-4.18	3.51
P2O5	0.988	0.897	1.070	0.960	0.897-1.070	0.979
Total	97.980	100.868	95.997	99.311		98.533
Element (PPM)						
Ni	0	0	0	0	0	0
Cr	3	0	8	1	0-8	3
Sc	23	13	19	12	12-23	16.75
V	228	206	246	204	204-246	221
Ba	433	421	471	450	421-471	443.75
Rb	46	39	52	14	14-52	37.75
Sr	660	883	481	856	481-883	720
Zr	433	397	469	429	397-469	432
Y	97	46	61	58	46-97	65.5
Nb	96.3	82.7	104.8	89.3	82.7-104.8	93.275
Ga	36	30	39	35	30-39	35
Cu	0	2	0	0	0-2	0.5
Zn	163	154	188	167	154-188	168
Pb	7	3	7	6	3-7	5.75
La	86	68	62	87	62-87	75.75
Ce	141	121	144	161	121-161	141.75
Th	7	7	8	6	6-8	7

* total iron

Analyst: Dr. Peter R. Hooper, Dept. of Geology, Washington State University, 16-17 October 1989.

EDXRF analysis of Tatagamatau, Mako Ridge, and Fa'ala'aga source rock are presented in tables 12.8-10; mean and range for sources are summarized in table 12.11. Elemental values are presented with one standard deviation which represents the uncertainty of counting statistics at 300 seconds livetime. A comparison of EDXRF and fused disk samples for source means and the Tatagamatau source envelopes is illustrated in figure 12.2. Zr/Sr values are very comparable, whereas Nb/Sr ratios are higher for fused disk values. This probably corresponds to the greater detection efficiency (machine sensitivity) for niobium by the Rigaku spectrometer (Hooper and Johnson 1989); or it could be a sample thickness problem since niobium x-rays are excited as deep as 5-7 mm into the specimen (David Clague, written

Table 12.6
Geochemistry of Fa'ala'aga Source Rock (Fused Disks)

	Sample No.			Range	Mean
	89-14	89-15	89-16		
Oxide (Weight %)					
SiO2	46.89	46.69	46.79	46.69-46.89	46.79
Al2O3	13.68	13.79	13.80	13.68-13.80	13.76
TiO2	5.412	5.426	5.335	5.335-5.426	5.391
FeO*	13.04	12.93	13.06	12.93-13.06	13.01
MnO	0.172	0.178	0.174	0.172-0.178	0.175
CaO	10.54	10.56	10.75	10.54-10.75	10.62
MgO	4.72	4.8	4.76	4.72-4.80	3.16
K2O	1.68	1.73	1.60	1.60-1.73	1.67
Na2O	3.00	3.13	2.97	2.97-3.13	3.03
P2O5	0.674	0.684	0.627	0.627-0.684	0.662
Total	99.808	99.918	99.866		98.268
Element (PPM)					
Ni	57	88	72	57-88	72.3
Cr	24	25	38	24-38	29
Sc	21	25	19	19-25	21.7
V	344	357	359	344-359	353.3
Ba	300	305	307	300-307	304
Rb	45	46	42	42-46	44.3
Sr	644	642	651	642-651	645.7
Zr	323	330	313	313-330	322
Y	34	36	35	34-36	35
Nb	68	71.1	66.6	66.6-71.1	68.57
Ga	28	30	29	28-30	29
Cu	104	117	101	101-117	107.3
Zn	128	138	129	128-138	131.7
Pb	5	7	6	5-7	6
La	40	45	31	31-45	38.7
Ce	115	108	104	104-115	109
Th	4	6	3	3-6	4.3

* total iron

Analyst: Dr. Peter R. Hooper, Dept. of Geology, Washington State University, 16-17 October 1989.

communication, 1990). The larger source envelope for EDXRF may relate to the greater variability in specimen surface.

After selecting elements for analysis (based on analytical precision, accuracy, and sufficient elemental concentrations), assigning artifacts to source was facilitated initially by trial and error. Figure 12.3 illustrates a wide dispersion of data points with most artifacts plotting outside the source envelope when Rb/Sr and Y/Sr ratios are used. Figure 12.4, however, using ratios of Zr/Sr and Nb/Sr, is much more useful for assigning artifacts to the Tatagamatau source. The source envelope is delimited by taking into account the variability in analytical precision.

Table 12.7
Geochemistry of Fa'ala'aga, Mako Ridge, and Tatagamatau Source Rock (Fused Disks)

	Fa'ala'aga (n=3)		**Mako Ridge (n=4)**		**Tatagamatau (n=8)**		**Tatagamatau sub-source (n=1)**
	Range	**Mean**	**Range**	**Mean**	**Range**	**Mean**	
Oxide (Weight %)							
SiO2	46.69-46.89	46.79	43.44-49.84	46.97	49.56-50.56	50.02	49.32
Al2O3	13.68-13.80	13.76	17.22-19.72	18.35	15.35-15.62	15.45	13.86
TiO2	5.335-5.426	5.391	3.238-3.886	3.537	3.385-3.467	3.413	3.649
FeO*	12.93-13.06	13.01	10.68-13.20	11.87	12.34-12.90	12.68	12.40
MnO	0.172-0.178	0.175	0.193-0.210	0.211	0.173-0.179	0.177	0.167
CaO	10.54-10.75	10.62	5.50-7.29	6.966	7.56-7.70	7.63	7.80
MgO	4.72-4.80	3.16	4.24-4.44	4.38	4.55-4.77	4.69	7.06
K2O	1.60-1.73	1.67	1.37-1.98	1.76	1.54-1.62	1.58	1.79
Na2O	2.97-3.13	3.03	2.55-4.18	3.51	3.95-4.09	4.02	3.45
P2O5	0.627-0.684	0.662	0.897-1.070	0.979	0.783-0.814	0.800	0.710
Element (PPM)							
Ni	57-88	72.3	0	0	0	0	173
Cr	24-38					1.1	181
Sc	19-25					18.8	27
V	344-359					207.8	233
Ba	300-307					290.5	331
Rb	42-46	44.3	14-52	37.8	42-43	42.9	50
Sr	642-651	645.7	481-883	720	694-708	702.9	683
Zr	313-330	322	397-469	432	348-362	355.6	325
Y	34-36	35	46-97	65.5	45-49	47.6	37
Nb	66.6-71.1	68.57	82.7-104.8	93.3	52.4-56.0	54.5	47.9
Ga	28-30	29	30-39	35	27-31	29.4	26
Cu	101-117	107.3	0-2	0.5	0-9	1.5	31
Zn	128-138	131.7	154-188	168	165-178	171.3	153
Pb	5-7	6	3-7	5.8	4-8	6.1	5
La	31-45	38.7	62-87	75.8	13-50	35.3	43
Ce	104-115	109	121-161	141.8	88-110	100.3	99
Th	3-6	4.3	6-8	7	3-7	5.25	2

* = total iron

Analyst: Dr. Peter R. Hooper, Dept. of Geology, Washington State University, 16-17 October 1989.

Nine artifacts fall within the envelope and four others are very close. Taken together, fifty percent of the adzes and other artifacts with one or more polished surfaces (adz flakes) can be assigned to the Tatagamatau quarry on Tutuila. Weathered surfaces of these specimens were gray (2.5Y 5/0; 2.5YR 5/0; 7.5YR 5/0), dark gray (2.5Y 4/0), to very dark gray (7.5R 3/0; 2.5Y 3/0; 7.5Y 3/0). Freshly broken surfaces on two specimens were very dark gray (2.5Y 3/0; 7.5Y 3/0).

Additional samples from this quarry will undoubtedly define a much larger source envelope since the Tatagamatau sub-source is well outside the limits of the eight samples used to define the geochemical dimensions of the quarry. This underscores the need to collect sufficient samples to define the geochemical variability of adz quarry sources.

The diagonal line in figure 12.4 separates

Table 12.8
Geochemistry of Tatagamatau Source Rock (Whole Specimen)

	Sample									Range
(PPM)	89-5	89-6	89-7	89-8	89-9	89-10	89-11	89-12	89-13	
Oxide										
TiO2	33934.8	33134.9	33311.1	31595.3	32801.2	31746	34162.6	34135	34899.3	31595.3-
	± 249.3	± 237.2	± 234.6	± 230	± 231.5	± 257.6	± 249.5	± 240.4	± 250.3	34899.3
FeO	164927.6	160026.7	161479.5	153319.4	160936.1	146043.9	164807.9	155495.7	168513.3	146043.9-
	± 1134.6	± 1078.8	± 1067.5	± 1043.8	± 1064.3	1104	1127.7	± 1025.4	± 1135	168513.3
MnO	2294.8	2369.2	2271.7	2224.9	2314.5	2062	2432	2204.9	2367.8	2062-2432
	± 44.2	± 43.1	± 42	± 42.2	± 42.2	± 46.1	± 44.7	± 41.2	± 44	
Element										
Ni	0	0	0	0	0	0	0	188 ± 9	0	0-188
Ba	228.7 ± 6.4	222.5 ± 6.8	223.1 ± 5.9	223.5 ± 7.7	209.2 ± 6.4	262.4 ± 10.6	219.9 ± 6.7	259.2 ± 6.3	220.9 ± 6	209.2-262.4
Rb	36.4 ± 2.5	37.5 ± 2.3	42.8 ± 2.4	36.9 ± 2.5	43.4 ± 2.4	41.3 ± 3.2	46 ± 2.6	56.5 ± 2.4	41.4 ± 2.4	36.4-56.5
Sr	740.5 ± 7	762.5 ± 6.5	769.7 ± 6.5	718.1 ± 6.8	767.9 ± 6.5	748.4 ± 8.4	744.9 ± 7	738.6 ± 6.2	750.4 ± 6.4	718.1-769.7
Zr	385.4 ± 5.9	401 ± 5.5	409.6 ± 5.5	387.5 ± 5.9	409.5 ± 5.5	376.4 ± 7	401.4 ± 6	357 ± 5.1	395.3 ± 5.4	357-409.6
Y	48 ± 3.1	50 ± 2.9	52.2 ± 2.8	48.1 ± 3.1	53.1 ± 2.9	47.1 ± 3.7	48.7 ± 3.1	38.8 ± 2.6	50.1 ± 2.8	38.3-53.1
Nb	44.9 ± 3.9	41.1 ± 3.6	46.4 ± 3.5	44.5 ± 3.9	47.3 ± 3.6	43.8 ± 4.7	41 ± 3.9	32.7 ± 3.4	45.9 ± 3.6	32.7-47.3
Ga	30.8 ± 2.7	29.7 ± 2.7	31 ± 2.7	28.6 ± 2.7	36.8 ± 2.6	30 ± 3.2	27.3 ± 2.6	28.3 ± 2.4	31.2 ± 2.8	27.3-36.8
Cu	22.9 ± 4.2	59.6 ± 5	19.1 ± 4.1	95.3 ± 5.8	26.3 ± 3.9	55 ± 6.1	22.4 ± 3.7	61.2 ± 4.6	35 ± 4.5	19.1-95.3
Zn	183.1 ± 5.9	178.1 ± 5.6	190.2 ± 5.7	170.2 ± 5.8	170.5 ± 5.2	159 ± 6.9	179.1 ± 5.6	149.2 ± 4.9	191.1 ± 5.9	149.2-191.1
Pb	0	6.3 ± 1.9	8.6 ± 1.8	10.8 ± 2	7.9 ± 1.8	13.1 ± 2.3	9.7 ± 1.9	0	7.8 ± 1.8	0-13.1
La	28.3 ± 3.4	29 ± 3.6	41.4 ± 3.4	33.9 ± 4.3	40.4 ± 3.6	34.5 ± 6	30.4 ± 3.6	33.1 ± 3.2	35.6 ± 3.3	28.3-41.4
Ce	84.5 ± 4.2	70.5 ± 4.4	81.1 ± 3.9	70.6 ± 5	72.7 ± 4.1	75 ± 6.7	75 ± 4.2	75.9 ± 3.8	76.1 ± 3.9	70.5-84.5
Nd	45.5 ± 4.2	42.6 ± 4.5	49.5 ± 4	34.1 ± 5	40.5 ± 4.2	49.1 ± 6.8	46.9 ± 4.4	38.3 ± 3.9	52.3 ± 4	34.1-52.3
Cs	0	0	0	0	0	0	0	0	0	0
Fr	12.8 ± 3.8	6.9 ± 4	0	9.9 ± 4.5	10.5 ± 3.7	19.4 ± 6.1	5.9 ± 3.9	0	5.9 ± 3.5	0-19.4
Th	0	0	0	13.1 ± 4.1	0	0	0	0	0	0-13.1
Co	0	0	0	0	0	0	0	0	0	0
As	1.6 ± 0.4	1.5 ± 0.4	1 ± 0.5	1.4 ± 0.5	1.4 ± 0.4	2.1 ± 0.5	0.8 ± 0.4	1.5 ± 0.4	0.9 ± 0.5	0.8-2.1

Analyst: Marshall Weisler, September 1989.

Table 12.9
Geochemistry of Mako Ridge Source Rock (Whole Specimen)

	Sample No.				Range	Mean
(PPM)	89-1	89-2	89-3	89-4		
Oxide						
TiO2	32214.3 ± 219.1	30327.9 ± 207	30691.3 ± 199.4	32630.1 ± 225.2	30327.9-32630.1	31465.9
FeO	147154 ± 943.5	136482.1 ± 876.9	141893.9 ± 872.1	147794.6 ± 960.2	136482.1-147794.6	143331.2
MnO	2847.8 ± 44.3	2384.2 ± 40.6	2470.6 ± 39	2605.8 ± 43.5	2384.2-2847.8	2577.1
Element						
Ni	0	0	0	0	0	0
Ba	327.1 ± 7.2	347.9 ± 7.3	354.2 ± 7.4	330.7 ± 7	327.1-354.2	339.96
Rb	52.2 ± 2.3	44.3 ± 2.3	50.3 ± 2.3	14.6 ± 1.9	14.6-52.2	40.35
Sr	752.4 ± 6	959.7 ± 7.1	551.6 ± 5.1	903.9 ± 6.8	551.6-959.7	791.9
Zr	475.4 ± 5.4	466.1 ± 5.6	497.1 ± 5.4	472.1 ± 5.6	466.1-497.1	477.68
Y	94.8 ± 3	48.2 ± 2.8	57.6 ± 2.7	63.6 ± 2.8	48.2-94.8	66.05
Nb	70 ± 3.5	66.4 ± 3.6	75.3 ± 3.5	73.1 ± 3.6	66.4-75.3	71.2
Ga	32.1 ± 2.3	32.7 ± 2.4	33.2 ± 2.1	33.9 ± 2.7	32.1-33.9	32.98
Cu	19 ± 3.4	11 ± 3.4	8.3 ± 2.8	26.4 ± 4.1	8.3-26.4	16.18
Zn	178.3 ± 4.9	163.9 ± 5.1	161.6 ± 4.6	171.1 ± 5.3	161.6-178.3	168.73
Pb	5.9 ± 1.9	7.7 ± 1.8	9.8 ± 1.8	7.7 ± 1.8	5.9-9.8	7.78
La	66.5 ± 4.2	47.2 ± 3.7	54.7 ± 3.9	60.6 ± 4	47.2-66.5	57.25
Ce	122.4 ± 4.6	118.1 ± 4.4	115.2 ± 4.5	131.3 ± 4.6	115.2-131.3	121.75
Nd	75.3 ± 4.5	60.2 ± 4.2	66.3 ± 4.4	73.2 ± 4.4	60.2-75.3	68.75
Cs	2.4 ± 0.7	0	0	0	0-2.4	0.6
Fr	15.1 ± 3.8	10.2 ± 3.8	10.1 ± 4	11 ± 3.8	10.1-15.1	11.6
Th	0	13.8 ± 3.8	0	0	0-13.8	3.45
Co	0	0	0	0	0	0
As	1.3 ± 0.4	1.2 ± 0.4	1.8 ± 0.3	2.2 ± 0.5	1.2-2.2	1.63

Analyst: Marshall Weisler, September 1989.

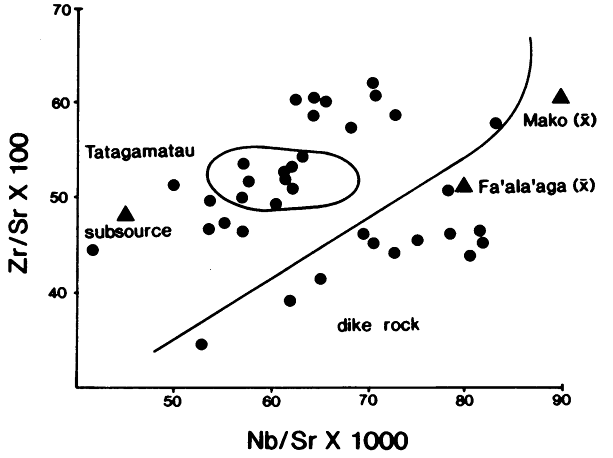

Figure 12.4 Artifacts and source rocks plotted by ratios of zirconium, strontium, and niobium resulting in many specimens plotting within the Tatagamatau source envelope.

Tatagamatau source rock from adz material deriving from the dike sources of Fa'ala'aga and Mako Ridge on Ofu and from all unmodified flakes. The source for the flakes was probably the scree slope below the Fa'ala'aga dike swarm. There are indeed several flakes that plot close to this source mean. The dike source rock and flakes recovered from the site are all medium- to coarse-grained, and eight specimens (61.5% of the total flakes) have one or more naturally flat surfaces characteristic of dike rocks. Several flakes, however, exhibit retouching and one distal margin is smoothed from use. These medium- to coarse-grained rocks were probably not conducive to adz manufacture, and it is perhaps noteworthy that all fine-grained rocks were manufactured into, or are

Table 12.10
Geochemistry of Fa'ala'aga Source Rock (Whole Specimen)

	Sample No.			Range	Mean
(PPM)	89-14	89-15	89-16		
Oxide					
TiO2	50476.8 ± 358	50757.1 ± 366.8	47928.1 ± 334	47928.1-50757.1	49720.7
FeO	168791.1 ± 1153.7	171686.3 ± 1191.4	156480.4 ± 1047.1	156480.4-171686.3	165652.6
MnO	2391.4 ± 44.6	2396 ± 45.5	1978.4 ± 40	1978.4-2396	2255.3
Element					
Ni	84.6 ± 7.9	103.2 ± 8.1	89.7 ± 7.1	84.6-103.2	92.5
Ba	234.4 ± 6.1	230.3 ± 7.1	233.3 ± 6.1	230.3-234.4	232.67
Rb	45.4 ± 2.4	48.4 ± 2.6	42.9 ± 2.4	42.9-48.4	45.57
Sr	691.6 ± 6.2	675.3 ± 6.6	704.8 ± 6.3	675.3-704.8	690.57
Zr	362.4 ± 5.3	359.2 ± 5.7	341.7 ± 5.2	341.7-362.4	354.43
Y	40 ± 2.8	36.1 ± 3	39.1 ± 2.7	36.1-40	38.4
Nb	51.8 ± 3.7	60 ± 4	52.3 ± 3.6	51.8-60	54.7
Ga	25.7 ± 2.7	30.1 ± 2.6	33.9 ± 2.5	25.7-33.9	29.9
Cu	135.9 ± 6.5	134.7 ± 6.4	134.4 ± 5.7	134.4-135.9	135
Zn	143.1 ± 5.5	137.6 ± 5.4	115.9 ± 4.6	115.9-143.1	132.2
Pb	7 ± 1.8	7.4 ± 2	7.6 ± 1.8	7-7.6	7.33
La	40.1 ± 3.3	39.7 ± 3.9	26.8 ± 3.2	26.8-40.1	35.53
Ce	70.2 ± 3.9	81.3 ± 4.5	91.2 ± 3.9	70.2-91.2	80.9
Nd	43.7 ± 3.9	40.8 ± 4.4	34.4 ± 3.9	34.4-43.7	39.63
Cs	0	0	0	0	0
Fr	8.3 ± 3.5	7.9 ± 4	9.2 ± 3.5	7.9-9.2	8.47
Th	0	0	0	0	0
Co	0	0	0	0	0
As	1.7 ± 0.5	1.8 ± 0.4	1.6 ± 0.4	1.6-1.8	1.7

Analyst: Marshall Weisler, September 1989.

Table 12.11
Geochemistry of Fa'ala'aga, Mako Ridge, and Tatagamatau Source Rock (Whole Specimen)

	Fa'ala'aga (n=3)		Mako Ridge (n=4)		Tatagamatau (n=8)		Tatagamatau sub-source
(PPM)	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**(n=1)**
Oxide							
TiO2*	4.793-5.076	4.972	3.033-3.393	3.147	3.160-3.490	3.320	3.414
FeO*	15.65-17.17	16.57	13.65-14.78	14.33	14.60-16.85	16.00	15.55
MnO*	0.198-0.240	0.226	0.238-0.285	0.258	0.206-0.243	0.230	0.220
Element							
Ni	84.6-103.3	92.5	nd	nd	nd	nd	188.0
Ba	230.3-234.4	232.6	327.1-354.2	340.0	209.2-262.4	226.7	259.2
Rb	42.9-48.4	45.6	14.6-52.2	40.4	36.4-46.0	40.7	56.5
Sr	675.3-704.8	690.6	551.6-959.7	791.9	718.1-769.7	750.3	738.6
Zr	341.7-362.4	354.4	466.1-497.1	477.7	376.4-409.6	395.8	357.0
Y	36.1-40.0	38.4	48.2-94.8	66.1	47.1-53.1	49.7	38.8
Nb	51.8-60.0	54.7	66.4-75.3	71.2	41.0-47.3	44.4	32.7
Ga	25.7-33.9	29.9	32.1-33.9	33.0	27.3-36.8	30.8	28.3
Cu	134.4-135.9	135.0	8.3-26.4	16.2	19.1-95.3	42.0	61.2
Zn	115.9-143.1	132.2	161.6-178.3	168.7	159.0-191.1	177.7	149.2
Pb	7.0-7.6	7.3	5.9-9.8	7.8	0.0-13.1	8.0	nd
La	26.8-47.6	38.0	47.2-66.5	57.3	28.3-41.4	33.9	33.1
Ce	70.2-81.3	77.6	115.2-131.3	121.8	70.5-84.5	75.7	75.9
Nd	34.4-43.7	39.6	60.2-75.3	68.8	34.1-52.3	45.1	38.3
Cs	nd	nd	0.0-2.4	0.6	nd	nd	nd
Fr	7.9-9.2	8.5	10.1-15.1	11.6	0.0-19.4	8.9	nd
Th	nd	nd	0.0-13.8	3.5	0.0-13.1	1.6	nd
Co	nd	nd	nd	nd	nd	nd	nd
As	1.6-1.8	1.7	1.2-2.2	1.6	0.8-2.1	1.3	1.5

* x 10^{-4}

Analyst: Marshall Weisler, September 1989.

the by-products of, adz production. Geochemical data for all artifacts are presented in table 12.12.

Nine artifacts assigned to the Tatagamatau adz quarry complex on Tutuila are from three archaeological sites on Ta'u Island and two localities within the large To'aga coastal habitation area (see table 12.1). Unfortunately, only three artifacts are from excavated contexts, and the remaining are surface finds. All stylistically diagnostic specimens are quadrangular-sectioned adzes or fragments dating to the late prehistoric period (Green 1974; Green and Davidson 1969). By connecting the six sites with adz material that originated from the Tatagamatau quarry, we can document several nodes of an interaction sphere between the islands of Tutuila, Ta'u, and Ofu. These results seem quite promising for additional provenance studies of the kind employed here.

Table 12.12
Geochemistry of To'aga and Ofu Island Basalt Artifacts (Whole Specimen)

Artifact Number	Lab Number	Trace Element Concentrations (PPM)						
		Pb	Th	Rb	Sr	Y	Zr	Nb
Fiti'uta 1	89-22	11.3 ± 1.3	0.0	65.4 ± 2.4	832.5 ± 6.3	52.0 ± 2.7	438.8 ± 5.2	50.5 ± 3.3
11-1-S-4	89-25	11.1 ± 2	0.0	68.1 ± 6	724.0 ± 6	51.9 ± 2.7	449.1 ± 5.4	51.1 ± 3.4
11-2-S-1	89-26	11.0 ± 1.6	0.0	52.4 ± 2.2	812.8 ± 6.1	49.6 ± 2.6	397.6 ± 5	49.4 ± 3.2
11-2-S-2	89-31	7.7 ± 1.7	0.0	49.0 ± 2.2	782.3 ± 6	41.1 ± 2.6	369.4 ± 4.9	43.2 ± 3.2
11-2-S-3	89-30	11.1 ± 1.7	0.0	50.5 ± 2.3	816.8 ± 6.2	40.3 ± 2.6	422.8 ± 5.2	46.9 ± 3.3
11-2-S-8	89-28	0.0	0.0	30.2 ± 2.1	578.0 ± 5.3	39.2 ± 2.6	339.1 ± 4.8	36.7 ± 3.3
11-2-9	90-30	10.4 ± 2.1	0.0	57.8 ± 2.4	815.7 ± 6.4	51.1 ± 2.8	427.4 ± 5.4	49.9 ± 3.5
11-52-S-9	90-33	8.9 ± 1.8	0.0	59.3 ± 2.5	750.7 ± 6.2	48.0 ± 2.8	457.0 ± 5.5	53.1 ± 3.5
13-S-3	89-18	6.5 ± 1.6	0.0	48.7 ± 2.3	823.3 ± 6.5	43.7 ± 2.7	406.9 ± 5.3	44.3 ± 3.4
13-S-5	89-34	11.7 ± 1.8	0.0	49.0 ± 2.2	824.4 ± 6.1	50.4 ± 2.6	438.0 ± 5.1	50.9 ± 3.3
13-S-6	89-33	6.6 ± 2	0.0	43.0 ± 2.3	772.1 ± 6.2	44.0 ± 2.7	413.1 ± 5.3	43.9 ± 3.4
13-S-9	89-32	7.6 ± 2	0.0	46.3 ± 2.4	691.2 ± 6	34.7 ± 2.7	322.5 ± 5	37.4 ± 3.4
13-1-S-36	89-19	5.3 ± 1.9	0.0	38.9 ± 2.4	635.8 ± 6.2	39.1 ± 2.9	365.1 ± 5.6	53.0 ± 3.8
13-1-3-1-1	89-17	9.2 ± 1.6	0.0	58.9 ± 2.4	854.1 ± 6.5	50.9 ± 2.7	464.6 ± 5.5	54.3 ± 3.4
13-1-9-2-4	90-22	0.0	0.0	48.9 ± 2.5	894.5 ± 7.2	49.0 ± 3	527.1 ± 8.2	64.5 ± 3.8
13-1-13-87	90-23	12.0 ± 2.1	0.0	26.4 ± 2.2	660.0 ± 5.8	31.6 ± 2.6	292.1 ± 4.8	27.8 ± 3.3
13-1-16-1-84	90-42	8.3 ± 1.8	0.0	31.5 ± 2.3	545.5 ± 5.6	33.6 ± 2.8	329.7 ± 5.1	34.1 ± 3.6
13-1-16-11	90-46	9.6 ± 2	0.0	32.5 ± 2.2	638.5 ± 5.8	32.4 ± 2.6	293.2 ± 4.8	49.7 ± 3.5
13-1-16-11-81	90-45	9.6 ± 2.2	0.0	40.8 ± 2.6	856.3 ± 7.5	35.3 ± 3.1	333.8 ± 5.7	53.0 ± 4
13-1-16-12-83	90-38	9.7 ± 1.8	0.0	37.3 ± 2.3	967.8 ± 7.3	34.7 ± 2.6	331.0 ± 5.2	51.1 ± 3.5
13-1-20-4-118	90-27	6.9 ± 1.7	0.0	48.5 ± 2.3	772.8 ± 6.2	40.8 ± 2.7	386.0 ± 5.1	44.4 ± 3.4
13-1-20-5-121	90-37	10.9 ± 2.1	0.0	33.5 ± 2.3	691.7 ± 6	36.8 ± 2.6	317.7 ± 4.9	48.3 ± 3.5
13-1-20-5-122	90-41	0.0	0.0	38.7 ± 2.4	733.0 ± 6.7	29.3 ± 2.8	321.3 ± 5.4	58.5 ± 3.8
13-1-20-5-123	90-34	9.1 ± 1.7	0.0	37.2 ± 2.2	700.9 ± 5.9	33.9 ± 2.6	324.5 ± 4.9	56.6 ± 3.5
13-1-20-6-139	90-48	8.0 ± 1.8	0.0	40.1 ± 2.4	739.8 ± 6.5	33.2 ± 2.7	335.7 ± 5.2	52.1 ± 3.7
13-1-20-6-140	90-29	7.4 ± 1.6	0.0	46.4 ± 2.1	724.4 ± 5.5	35.7 ± 2.4	368.9 ± 4.6	36.0 ± 3
13-1-20-6-141	90-36	11.8 ± 2	0.0	31.1 ± 2.3	758.6 ± 6.6	37.0 ± 2.8	342.1 ± 5.3	61.7 ± 3.8
13-1-20-7-143	90-40	9.1 ± 1.7	0.0	35.6 ± 2.2	694.4 ± 6.2	27.9 ± 2.7	314.2 ± 5.1	52.0 ± 3.6
13-1-20-9-147	90-43	11.4 ± 1.9	0.0	69.0 ± 2.8	969.8 ± 7.9	44.7 ± 3.1	401.7 ± 6	63.4 ± 4
13-1-21-7-151	90-49	8.7 ± 2	0.0	49.8 ± 2.5	524.1 ± 5.5	24.4 ± 2.8	264.6 ± 4.9	41.4 ± 3.7
13-1-22-2-171	90-44	8.8 ± 1.7	0.0	52.3 ± 2.4	786.8 ± 6.3	37.5 ± 2.7	385.8 ± 5.2	49.6 ± 3.5
13-1-22-2-173	90-25	8.7 ± 1.9	0.0	46.1 ± 2.7	722.4 ± 7	45.2 ± 3.1	335.4 ± 5.7	40.8 ± 3.9
13-1-22-2-174	90-24	12.8 ± 2.4	0.0	41.5 ± 2.7	712.3 ± 6.8	49.6 ± 3.1	361.9 ± 5.8	43.6 ± 3.9
13-1-23-7-194	90-26	7.6 ± 1.9	0.0	48.2 ± 2.2	689.7 ± 5.6	47.1 ± 2.6	415.3 ± 5	45.4 ± 3.3
13-1-27-5-39	90-31	8.6 ± 1.9	0.0	49.6 ± 2.3	793.6 ± 6.2	50.2 ± 2.7	455.4 ± 5.4	53.7 ± 3.4
13-1-27-5-40	90-39	7.6 ± 1.6	0.0	50.5 ± 2.2	729.7 ± 5.7	50.0 ± 2.6	440.0 ± 5.1	47.3 ± 3.2
13-1-27-5-41	90-47	7.1 ± 1.9	0.0	38.1 ± 2.2	676.3 ± 5.7	30.8 ± 2.5	298.1 ± 4.6	48.9 ± 3.3
13-1-27-6-42	90-35	9.1 ± 1.8	0.0	43.4 ± 2.4	703.6 ± 6.4	40.7 ± 2.8	392.7 ± 5.6	43.0 ± 3.6

Analyst: Marshall Weisler, September 1989 to February 1990.

SUMMARY AND CONCLUSIONS

Defining the spatial and temporal dimensions of intra- and inter-island communication is an important precursor for evaluating historical developments on insular landscapes. Because Polynesia generally lacks the "footprints of pottery" throughout sequences of most island groups, and large quantities of obsidian are absent in this geologic province, fine-grained basalt manufactured into adzes and widely distributed must of necessity form an important basis for tracking regional interaction. Knowledge of the "provenance environment" or geologic features and their chemical signatures are essential aspects for identifying and predicting the occurrence of fine-grained, stone-tool-quality basalt. Two material characterization and provenance techniques have been described and evaluated, and geochemical analysis is argued to be the most profitable for long-term and regional-scale distributional studies as: (1) the results are reproducible; (2) instrument operating conditions can be reported in full facilitating comparison of regional databases; (3) identification of elements is not subject to human error as with thin-section descriptions; (4) elemental abundances can be reported with precision and accuracy values for specimens and standards; and (5) geochemical sampling locales on specimens more closely represent the population rather than petrographic thin-sections which are limited by two-dimensional surfaces. The efficacy of non-destructive x-ray fluorescence spectroscopy has been demonstrated and its continued use for distributional studies of Polynesian adz material is warranted. Although the technique, as applied here, is limited to elements that can be analyzed with high precision and accuracy (those in the mid-z range), future applications should seek to expand these limits. A major benefit of EDXRF is the wide range of specimen sizes that can be analyzed *without destruction*. In this study, artifacts ranged from as small as 2.1 grams up to 421.9 grams with lengths of 22 to 136 mm. Accommodating a wide range of specimen sizes can be advantageous when analyzing assemblages with a high proportion of small adz flakes, a common situation with most collections of adz material. In fact, with nearly 1000 m^2 of archaeological excavations on the island of Moloka'i, small adz flakes outnumber whole or stylistically diagnostic adzes by more than 10 to 1. Moreover, most adzes are surface finds whereas adz flakes are more often from excavated contexts.

Application of the non-destructive, energy-dispersive technique to source material and artifact assemblages from several sites on Ta'u and Ofu islands has permitted delineation of an interaction sphere during late prehistory that links habitation complexes on these islands to the large adz quarry complex at Tatagamatau, Tutuila Island, some 100 km to the west. Local dike rock from Ofu Island is chemically similar to most of the non-polished and unground flakes. Geochemical analysis has shown that these medium- to coarse-grained rocks were not fashioned into adzes, but this material was restricted to a few retouched, "awl-like" tools and one flake with use-wear along a distal margin. The vast majority, however, were unmodified.

EDXRF is not the answer to all provenance studies, but the results reported here suggest that the technique merits further use and refinement with adz material from Polynesia and possibly throughout Oceania (e.g., Weisler 1993; Weisler et al. In prep.). As the ownership and preservation of archaeological sites and museum collections become increasingly the focus of controversy between the scientific and native communities, discovering more about the past without destroying the evidence itself, may help to bridge our common goals.

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