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Interisland and interarchipelago transfer of stone tools in prehistoric Polynesia

(archaeology/Pacific Islands/sourcing/exchange/energy-dispersive x-ray fluorescence)

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ABSTRACT **Tracing interisland and interarchipelago movements of people and artifacts in prehistoric Polynesia has posed a challenge to archaeologists due to the lack of pottery and obsidian, two materials most readily used in studies of prehistoric trade or exchange. Here we report the application of nondestructive energy-dispersive x-ray fluorescence (EDXRF) analysis to the sourcing of Polynesian artifacts made from basalt, one of the most ubiquitous materials in Polynesian archaeological sites. We have compared excavated and surface-collected basalt adzes and adze flakes from two sites in Samoa (site AS-13-1) and the Cook Islands (site MAN-44), with source basalts from known prehistoric quarries in these archipelagoes. In both cases, we are able to demonstrate the importing of basalt adzes from Tutuila Island, a distance of 100 km to Ofu Island, and of 1600 km to Mangaia Island. These findings are of considerable significance for Polynesian prehistory, as they demonstrate the movement of objects not only between islands in the same group (where communities were culturally and linguistically related) but also between distant island groups. Further applications of EDXRF analysis should greatly aid archaeologists in their efforts to reconstruct ancient trade and exchange networks, not only in Polynesia but also in other regions where basalt was a major material for artifact production.**

Remote Oceania (1) was settled by Austronesian-speaking peoples between ≈3.6 and 1 kyr B.P., in one of the most remarkable feats of open-ocean voyaging and colonization in human history. Subsequent to colonization, communities frequently maintained contacts between islands and archipelagoes by regular two-way voyaging (2). Elaborate exchange networks linking dispersed communities, which were often socially and linguistically differentiated, are well documented *ethnographically* for Melanesia, Micronesia, and Western Polynesia at the time of early European contact (3–10). Tracing the history of such exchange networks back in time to the pre-European contact period, however, is a more challenging task, one that is currently engaging the efforts of many Pacific archaeologists.

Reconstructing interisland exchange and interaction networks in prehistory requires that archaeologists be able to identify artifact materials such as pottery or stone tools to a restricted *source* of origin, when these are excavated in exotic or nonlocal contexts (11–17). For example, obsidian deriving from two primary source localities in the Bismarck Archipelago has been shown to have been widely transported throughout western Melanesia during the Lapita cultural phase, ≈3.6–2.5 kyr B.P. (18). Indeed, most archaeological investigations of prehistoric interisland contacts to date have utilized either obsidian or pottery, two materials for which the techniques of provenance characterization are well developed (14).

Throughout most of Polynesia and much of Micronesia, unfortunately, obsidian and pottery were either lacking or of highly limited distribution, rendering archaeological studies of prehistoric interisland contact difficult. Pottery, for example, was manufactured only in Samoa and Tonga from 3.2 to 1.7 kyr B.P. and thereafter was abandoned. Its absence throughout the rest of Polynesia (excepting a handful of sherds in the Marquesas Islands and the southern Cook Islands) makes pottery useless for studying prehistoric exchange or interaction over this vast region. Probably the most ubiquitous and durable material used by Polynesians for tool production was basalt, especially fine-grained basalt suitable for manufacture of adzes and other kinds of formal and expedient tools (Fig. 1). Oceanic islands on the Pacific Plate (east of the Andesite Line) are dominantly constructed of basaltic lava flows issuing from "hot spots" (magma plumes) along linear fracture zones, such as those responsible for the Hawaiian and Society Island chains (19, 20). Thus basaltic rocks were commonly available to Polynesians for stone tool production, although fine-grained outcrops suitable for adze manufacture were of more limited occurrence.

Because oceanic basalts are relatively uniform in their modal compositions, traditional petrographic methods are insufficient for discriminating between sources, making it difficult to determine whether prehistoric basalt tools from a given Polynesian archaeological site were of local or exotic origin (21, 22). Here we report on the application of the nondestructive energy-dispersive x-ray fluorescence (EDXRF) analysis of basalt artifacts, which in many cases permits discrimination between specific basalt sources. As documented below, we have been able to demonstrate the prehistoric transfer of basalt adzes between a major quarry site on Tutuila Island (American Samoa) and two receiving localities: the Manu'a group (American Samoa), and Mangaia Island (Cook Islands) some 100 and 1600 km distant, respectively (Fig. 2). The application of EDXRF analysis to basalt tools opens up new possibilities for documenting ancient trade, exchange, and interaction networks among the prehistoric peoples of Polynesia. The method may also be applicable in other regions of the world, such as in western North America, where basalt was a common material for stone tool production.

MATERIALS AND METHODS

The materials utilized in this study consist of archaeologically excavated and surface collected adzes and adze flakes of basalt from three localities in the Samoa and Cook archipelagoes, as well as control samples of locally occurring basaltic rocks from Ofu and Mangaia Islands. The archaeological contexts of these

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Abbreviations: XRF, x-ray fluorescence; EDXRF, energy-dispersive XRF.
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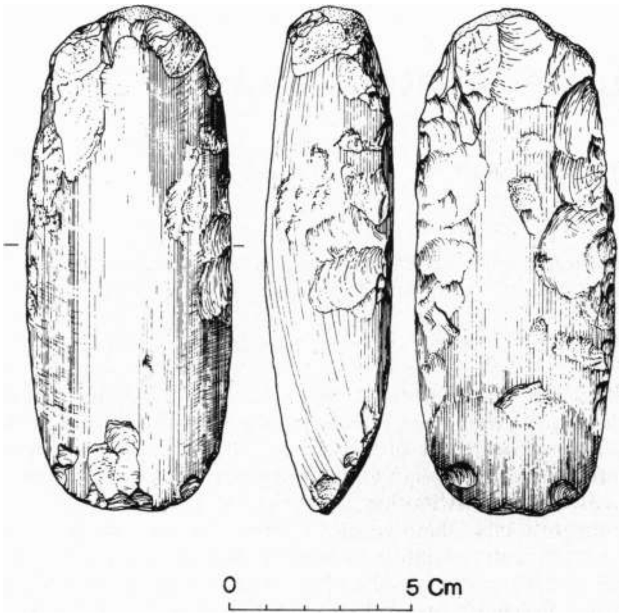

FIG. 1. Front, side, and back views (left to right) of a flaked and polished basalt adz of planoconvex cross section from the To'aga site, Ofu Island.

samples, including radiocarbon-dated chronologies, are briefly described below.

Tataga-matau Quarry Site. The extensive Tataga-matau basalt quarry site, covering several steep ridges inland of Leone Village on Tutuila Island (American Samoa), was first reported by Buck (23), and has recently been the focus of an intensive archaeological project (11, 24, 25). The site consists of an extensive set of artificial earthworks (terraces, ditches, pits) with associated basalt workshop areas and flaking floors. Radiocarbon dates from the site span a period from 906 ± 157 B.P. (N.Z. 7593) to 580 ± 63 B.P. (N.Z. 7954), indicating use for more than 300 years. Nine samples of flaked basalt from this quarry were collected by P.V.K. and T. Hunt in 1987 and analyzed by Weisler using nondestructive EDXRF; these provided the Tataga-matau source controls for this study (26).

Manu'a Island Samples. The Manu'a Islands of American Samoa lie 100 km west of Tutuila (Fig. 2) and include the geologically youthful (0.3–0.1 Myr) volcanic islands of Ofu, Olosega, and Ta'u. The rocks of the Manu'a group consist primarily of olivine basalt, hawaiites, and ankaramites, interbedded with pyroclastic tuffs and breccias (27). Reconnaissance archaeological survey of all three islands was carried out in 1986 by Kirch and Hunt (28), followed by intensive excavations at the deeply stratified To'aga site (AS-13-1) on Ofu Island (29, 30). During this work we collected basalt adzes and adze flakes both from surface contexts (on Ta'u and Ofu) and from excavated strata (in the To'aga site). The excavated tools derive from strata bracketed by ^{14}C dates of 3820 ± 70 B.P. (Beta-25035) and 1600 ± 70 B.P. (Beta-26465), indicating a long occupation of the site (29). In addition, samples of locally occurring basalt dike rock were obtained from Ofu Island as local controls. Weisler (17, 26), using EDXRF, analyzed 38 archaeological basalt adzes and flakes from Ofu and Ta'u, as well as control samples from Mako Ridge and Fa'ala'aga.

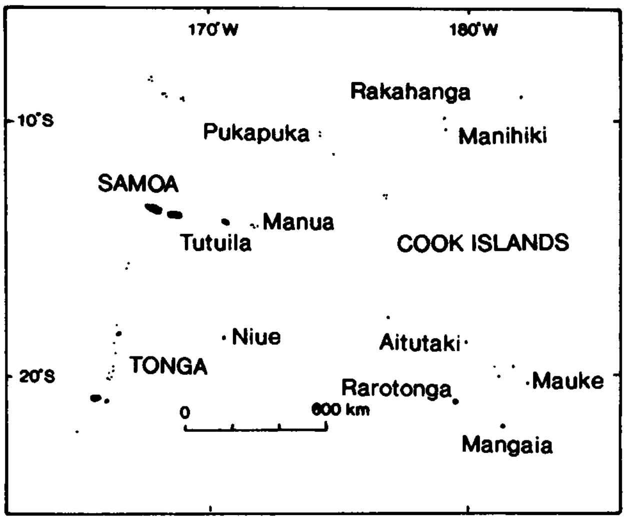

FIG. 2. Map of the central Pacific region, showing the location of the Manu'a Islands and Mangaia Island.

Mangaia Island Samples. Mangaia is the southernmost of the Cook Islands (Fig. 2), with a highly weathered volcanic cone (17–19 Myr in age) surrounded by elevated limestone reefs of late Pleistocene age (31–33). Because Mangaia's volcanic cone is deeply weathered, fresh basalt suitable for stone tool manufacture occurs only as restricted dike exposures at the heads of several radiating stream valleys (31). One such source (Mata'are) was identified during archaeological fieldwork in 1991 (34), and control samples from this dike quarry, along with samples from two other dikes of inferior quality, were subjected to destructive wavelength x-ray fluorescence (XRF) analysis (17). Archaeological excavations directed by Kirch in 1989 and 1991 at the well-stratified Tangatatau Rockshelter (site MAN-44) on Mangaia (35, 36) yielded a collection of basalt adzes and adze flakes from dated contexts. More than 30 ^{14}C dates bracket these basalt tools to an occupation period between 980 ± 70 B.P. (Beta-32826) and 330 ± 80 B.P. (Beta-32822). Sixty-nine adzes, adze preforms, adze flakes, and unmodified flakes from the Tangatatau Rockshelter were analyzed by EDXRF by Weisler (17, 36), along with the three local source controls.

EDXRF Methods. Sample preparation consisted of submerging specimens in a sonic bath of distilled water for 15 min to 1 hr followed by air drying. A few specimens that were deeply stained from lateritic soil were scrubbed with brushes. Carbonate encrustations on some artifacts were dissolved with a solution of 5–10% HCl, and the specimens were given a final rinse in distilled water. Source rocks were cut to size with a diamond saw and the cut surface was analyzed. Careful placement of the specimens on the EDXRF sample tray permitted artifacts up to 421 g and 136 mm long to be analyzed (37). Molding clay was used to secure the specimens and to permit analysis of the flattest area of each artifact.

During the 2½-yr period between the analysis of the Samoa and Cook Island specimens by Weisler, certain changes were made in the EDXRF equipment used at the Department of Geology and Geophysics, University of California, Berkeley. These slight changes are noted where relevant, while a full description of both analyses is provided elsewhere (17). Elemental analyses were obtained by using a Spectrace (Sunnyvale, CA) model 440 EDXRF spectrometer equipped with a Tracor x-ray (Spectrace) TX 6100 analyzer with a dedicated IBM PC-based microprocessor and Tracor Northern (Madison, WI) reduction software. Oxides (TiO_2, MnO, and FeO) and trace elements (Ni, Cu, Zn, Ga, Pb, Th, Rb, Sr, Y, Zr, and Nb) were analyzed with a rhodium x-ray tube operated at 30 keV, 0.20-mA pulsed, with a 0.127-mm rhodium primary beam filter (0.05 mm for Samoa specimens) under vacuum at 500-sec irradiation time (300 sec for Samoa specimens). Oxides and trace element intensities were converted to concentrations by a least-squares calibration line calculated for each element of interest by analyzing 10 international standards: G-2, AGV-1, GSP-1, SY-2, BR, BHVO-1, STM-1, QLO-1, RGM-1, and W-2. The U.S. Geological Survey standard BHVO-1 (basalt from Kilauea, HI) or RGM-1 (a rhyolite glass from Glass

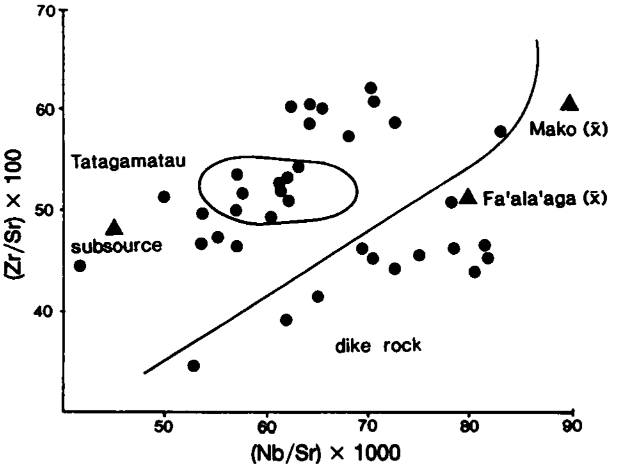

FIG. 3. Bivariate plot of Samoan basalt sources (▲) and artifacts (●) analyzed by EDXRF. Elemental values of Zr (zirconium), Sr (strontium), and Nb (niobium) are reported in ppm. The oval source envelope indicates the ratios for the Tataga-matau basalt quarry on Tutuila Island; artifacts enclosed by the envelope are from Manu'a archaeological sites some 100 km distant from probable sources. The diagonal line separates fine-grained basalt—probably all imported—from coarse-grained dike rock of local origin.

Mountain, CA) was used along with the analysis of every 19 unknowns for monitoring machine accuracy and precision. The values for accuracy and precision for all analyses are reported by Weisler (17). Elemental data as reported represent one analysis per specimen.

RESULTS

The XRF technique has its greatest accuracy in detecting elements in the mid-Z range (e.g., Rb, Sr, Y, Zr, and Nb), an observation that was confirmed by this study. These elements are of particular interest to igneous petrologists, as they are used in discussing the evolution of magma chambers and extrusive events and are reported routinely in the geological literature (38). 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 (39). Lighter elements not only are harder to detect and measure by XRF but also are usually not present in great abundance. For these reasons, mid-Z elements were used in the characterization of source rocks and in the discrimination of artifact provenance. We acknowledge also that it may be necessary to augment the EDXRF results with other instrumental techniques such as neutron activation analysis when discriminating Oceanic basalts that are highly similar in geochemical composition (22).

Tabular data for the EDXRF analysis of Tataga-matau, Mako Ridge, and Fa'ala'aga source rocks and artifacts have been presented elsewhere (26). Fig. 3 illustrates the efficacy of using ratios of the mid-Z elements of Zr/Sr and Nb/Sr for assigning Manu'a artifacts to source. The use of ratios in nondestructive EDXRF analysis reduces abundance errors introduced when analyzing uneven sample surfaces inherent in most artifacts. Nine artifacts fall within the Tataga-matau source envelope, while four others are quite close. Of additional interest in Fig. 3 is the diagonal line that separates Tataga-matau source rock and all fine-grained rock from the local sources of Mako Ridge and Fa'ala'aga on Ofu Island. These latter specimens are unmodified flakes of coarse-grained rock that is an inferior raw material for adze manufacture. With additional source samples from the Tataga-matau quarry, the source envelope illustrated in Fig. 3 may be more accurately delimited, yet it is likely, on the basis of this analysis, that all fine-grained artifacts were imported to the Manu'a islands. Considering the association of the fine-grained artifacts to radiocarbon-dated contexts, basalt adze material—whether brought to the Manu'a islands as unfinished or complete adzes—was imported for about three millennia.

Data for the elemental concentrations for the Cook Islands source rocks and adzes were published by Weisler (34), while Table 1 presents selected geochemistry for polished basalt flakes discussed in this study. In assigning artifacts to source, all specimens with a Sr value >1000 ppm were separated from the assemblage, as values exceeding this figure were likely to

Table 1. Selected geochemistry of adze flakes from site MAN-44

Lab no.	Artifact no.	Sr, ppm	Zr, ppm	Nb, ppm	(Zr/Sr) × 100	(Nb/Sr) × 1000
92-187	C31-8-1	1300.22	397.49	102.28	30.57	78.66
92-188	D34-9-8	642.94	298.81	32.90	46.48	51.17
92-190	D34-8-10	816.24	275.72	83.28	33.78	102.02
92-192	D32-3-5	799.11	410.16	50.48	51.33	63.17
92-194	D32-11-1	823.35	412.42	54.99	50.09	66.79
92-196	D31-5-14	739.45	259.74	68.04	35.13	92.02
92-199	E32-5-1	1150.75	417.31	105.78	36.26	91.92
92-200	E34-7-3	1346.81	401.57	106.00	29.82	78.70
92-202	E35-8-2	1348.84	404.95	103.77	30.02	76.93
92-203	E33-9-12	737.36	262.81	79.20	35.64	107.41
92-204	F35-9-5	799.18	281.16	79.12	35.18	99.00
92-206	D31-8-3	704.49	232.88	62.20	33.06	88.28
92-208	D33-3-6	578.04	199.15	53.68	34.45	92.87
92-210	D33-3-7	2006.40	744.24	193.62	37.09	96.50
92-211	C32-3-3	1137.42	340.64	83.53	29.95	73.43
92-214	E34-4-3	611.72	185.41	50.01	30.31	81.76
92-215	D32-8-3	1524.68	480.38	120.61	31.51	79.10
92-217	D31-7-1	631.06	180.88	51.85	28.66	82.16
92-220	E33-3-1	760.02	268.48	78.75	35.33	103.61
92-221	D33-8-2	777.44	398.40	52.90	51.25	68.05
92-222	F36-9-5	1698.28	380.59	71.08	22.41	41.85
92-229	E36-9-19	746.30	241.91	70.46	32.41	94.42
92-239	D33-10-2	634.00	218.26	70.72	34.43	111.54

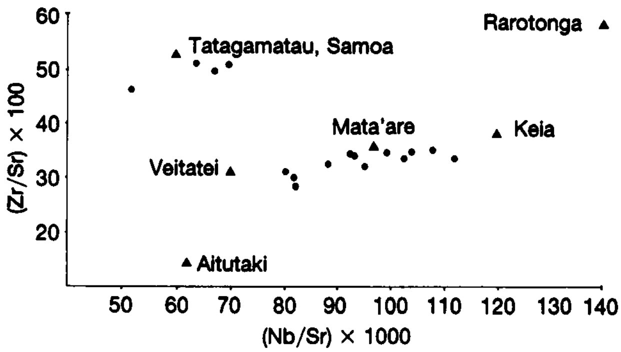

FIG. 4. Geochemical distribution of Cook Island polished adze flakes analyzed by EDXRF. Bivariate plot utilizes the mid-Z elements of Zr, Sr, and Nb, reported in ppm. ▲, Basalt sources; ●, artifacts. While most artifacts were assigned to the Mata'are source on Mangaia, several outliers are artifacts from other local Mangaia sources. Four artifacts are most likely from the Tataga-matau source or other source(s) on Tutuila, Samoa, some 1600 km distant. Nine specimens with Sr values >1000 ppm are not plotted here and may have originated from sources on Rarotonga or Aitutaki.

have originated from Rarotonga or Aitutaki (40). Subsequently, a bivariate plot of Zr/Sr and Nb/Sr was used to tentatively assign specimens to source (Fig. 4). Most polished basalt flakes originated from the local Mata'are source (34) on Mangaia, while several outliers seen in Fig. 4 probably came from local Mangaian sources. However, four artifacts most likely originated from the Tataga-matau source or other locales on Tutuila, Samoa, a distance of ≈1600 km. These artifacts are associated with radiocarbon dates from 1 kyr B.P. to European contact.

CONCLUSIONS

Our results have substantive significance for Polynesian prehistory and have methodological significance for the archaeological study of ancient trade and exchange networks. With regard to Polynesian prehistory, we have been able to demonstrate the movement of basalt adzes between ancient settlements ranging from 100 to 1600 km distant. The first case, involving the transport of basalt adzes manufactured of Tataga-matau source rock (from Tutuila Island) to the To'aga site on Ofu Island, during the first millennium B.C., is perhaps expectable from ethnohistoric descriptions of interisland contacts within the Samoan archipelago (41). The second case, in which basalt adzes of Samoan origin were transported 1600 km to the southern Cook Islands, is noteworthy, however, for it evidences interarchipelago movements of great significance for Polynesian prehistory. Whereas Samoa is part of Western Polynesia, the Cook Islands are classified by anthropologists as Eastern Polynesia, and it has long been held that cultural differences between these regions resulted from long periods of isolation. However, the results of our EDXRF analysis of stone adze flakes from the Tangatatau rockshelter on Mangaia indicate that contacts between Samoa and the southern Cook Islands probably occurred throughout prehistory. These results call into question the assumption of isolation once any given island group had been discovered and settled by Polynesian voyagers. Indeed, our results lend considerable support to the view that regular long-distance voyaging between distant archipelagoes was common throughout much of Polynesia, at least during the earlier phases of its settlement (2).

Most archaeologists have assumed that it would be difficult if not impossible to track the prehistoric movement of artifacts between Polynesian islands, owing to the dearth of both pottery and obsidian in Polynesian sites. Our study demonstrates that the nondestructive application of EDXRF analysis is an effective technique for discriminating fine-grained basalt artifacts and source rocks from Polynesia. This is of considerable importance, given that basalt is the most common material used by the Polynesians for stone tool manufacture. In addition to its nondestructive application—of great importance when analyzing unique artifacts—it is the most inexpensive of the XRF techniques, and operation of the equipment is relatively easy to learn. These two factors should encourage its widespread use. Indeed, until recently, it has been used most often for the analysis of Oceanic obsidian (42).

While we would not discourage the use of petrographic techniques as they are also useful for characterizing rock texture, noting the presence of flow banding, and identifying minerals in Oceanic basalts, we suggest that problems with its routine use are magnified when comparing results between two or more operators (21). Conversely, geochemical analyses are usually reported with machine sensitivity, and accuracy and precision values in relation to recognized geological standards, thus facilitating interlaboratory comparisons.

We believe that the nondestructive EDXRF technique is an excellent procedure for sorting large numbers of fine-grained basalt artifacts into geochemical groups. Its efficacy is enhanced when it is used with more powerful destructive-wavelength XRF and Pb isotope analysis (22) to confirm group and source assignment of exotic Polynesian fine-grained basalt artifacts. Further application of these methods to the analysis of basalt tools and artifacts from Polynesian archaeological sites should permit a more thorough understanding of the nature, duration, and persistence of interisland and interarchipelago communication among prehistoric Polynesian societies. These methods may also prove to be of value in other areas of the world where basalts were extensively used by ancient peoples, as in parts of North America (43).

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