

# *Provenance Studies of Polynesian Basalt Adze Material: A Review and Suggestions for Improving Regional Data Bases*



MARSHALL I. WEISLER

PACIFIC ARCHAEOLOGISTS have long been interested in the settlement of Polynesia, the origin of colonizing groups at distant archipelagoes, and subsequent social interaction between island societies (see, for example, Howard 1967; Irwin 1990; Kirch and Green 1987). Early material studies in Polynesia inferred migration routes and social interaction from the distribution of similar architecture, especially *marae* (Emory 1943; also R. Green 1970), adzes (Emory 1961), and fishhooks (Sinoto 1967). The identification of exotic raw materials and finished artifacts throughout Polynesia eliminates the ambiguity often presented by linking stylistic similarities across space and through time.

In relation to the long history of identifying exotic lithic materials from archaeological sites (see, for example, Grimes 1979), the compositional analysis of oceanic obsidians was begun quite recently (Key 1968). The efficacy of chemical characterization of artifacts and quarry material in New Zealand provided the incentive to apply similar techniques to obsidian of the southwest Pacific, where several large sources were known and where the archaeological distribution of this material was thought to be widespread (Ambrose 1976). Although it has been possible to define the spread and interaction of human groups in the southwest Pacific by determining the spatial and temporal distribution of obsidian and pottery, these materials are restricted to a few areas in Polynesia. Consequently, the effort to document prehistoric interaction throughout Polynesia must proceed without using obsidian or pottery. This leaves only basalt (debitage, formed artifacts, and oven stones), pearlshell, and volcanic glass as material for distributional studies (Best et al. 1992; Sheppard et al. 1989; Weisler 1990a, 1994).

Distributional studies of volcanic glass in Polynesia have produced encouraging results (Sheppard et al. 1989; Weisler 1990a, 1994), and the natural distribution of pearlshell (*Pinctada margaritifera*) in relation to imported raw material and finished artifacts can provide insight into social interaction spheres. This paper, however, focuses instead on basalt as the single most widely distributed commodity in prehistoric Polynesia and the one that potentially contributes most to an

Marshall I. Weisler is a Ph.D. candidate in the Anthropology Department, University of California at Berkeley.

*Asian Perspectives*, Vol. 32, no. 1, © 1993 by University of Hawaii Press. All rights reserved.

understanding of prehistoric exchange and social interaction. In this paper I discuss definitions used in basalt provenance studies, demonstrate the contribution of geological information and the relationship of the notion of scale to provenance analyses, review several analytical techniques used for distributional studies, and outline important areas where researchers can improve the utility of growing compositional data bases of basalt source material and artifacts.

#### SOME DEFINITIONS

##### *Provenance, Geological Knowledge, and Scale*

Before discussing the issues and techniques of provenance studies, it is necessary to define some key terms. The *provenance* of raw material and formed artifacts is defined here as the objects' place of origin—that is, the geological source. One may assume that an object is from one of several sources on the island where it was found, or from within the archipelago, or imported from another island-group. The assumption made dictates which analytical technique is necessary to assign an object to source, in concert with the knowledge of regional geology and of basalt sources. For example, the presence of particular minerals, or an unusual amount of a single element, may determine the provenance of an object in an area where the basalt sources and regional geology are well known. *Geological knowledge* consists of information on the macroscopic, petrographic, and geochemical attributes of geologic phenomena; it is crucial for selecting the techniques to be employed for determining the source of an object.

*Scale* refers to the spatial extent of a study. For example, on west Moloka'i, in the Hawaiian Islands, eight basalt sources have been documented, and the single attribute of banding can distinguish one of the largest basalt sources from all others (Weisler 1989). Banding, however, is also present at the Tautama, Pitcairn Island, basalt source (Gathercole 1964:44). Consequently, if the region of interest is Polynesia as a whole and not west Moloka'i, the presence of banding would not separate the two sources. If it is assumed that an artifact could be from any of the 19 known basalt sources in the Hawaiian Islands, then much more geological data would be necessary to assign a specific provenance to specimens. In other words, the less we know about the geology and basalt sources of a region, the more descriptive data we must have to characterize sources and assign objects to a *specific* source. As discussed below, a general source, such as anywhere on an island or volcano, can be determined by fewer attributes. This underscores the relationship of scale to provenance studies. In spatial terms within Polynesian provenance studies, scale refers to a petrologic province, archipelago, island, volcano, geologic feature, or event. Figure 1 (scale 1–6) illustrates how each sampling unit is contained within the scale above it. After a sample (scale 7) is collected, analysis may proceed to determine the macroscopic, petrographic, and/or geochemical (compositional) attributes of the object (Fig. 1, scale 8–10).

Provenance studies of basalt source material and artifacts have been undertaken in many island-groups of Polynesia, and data bases are fast accumulating for Samoa (Best 1984; Best et al. 1992; Weisler 1993a), the Cooks (Walter 1990), Pitcairn and Mangareva (Weisler 1993b), and Hawai'i (Cleghorn et al. 1985; Weisler

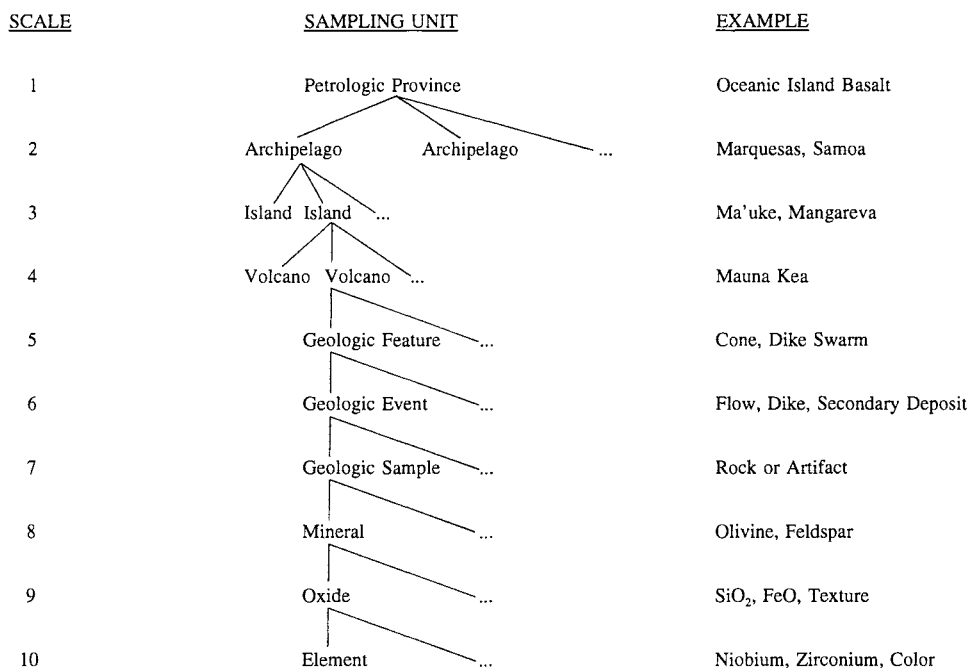


Fig. 1. The hierarchical relationship of geological and artifactual sampling units within Polynesia. Note that each sampling unit is contained within the scale above it.

1990a). Analytical studies have considered macroscopic attributes, such as rock color (R. Green 1974), texture (Cleghorn et al. 1985), banding (Weisler 1989), mineral composition (Best 1984; Cleghorn et al. 1985), and compositional analysis of trace elements and oxides (Best et al. 1992; Walter 1990; Weisler 1989, 1990a, 1993b, 1994). All techniques are subject to the analytical limitations of sensitivity, precision, and accuracy.

### *Sensitivity*

A technique must be selected that is sufficiently sensitive to determine differences between samples. This is especially important if sources are similar (Goldstein et al. 1981:434). As a macroscopic observation, rock color depends on a person's ability to discriminate a narrow color range and is subject to errors of interpretation. Therefore, color alone is not adequate to assign an object to source. Conversely, a technique must be suited to the level of discrimination necessary for the study (Bishop et al. 1990:539). In petrographic analysis, texture may discriminate groups, but it will be a sufficient attribute only when large differences exist between sources and there is little overlap between textural ranges (Cleghorn et al. 1985:244).

For geochemical studies using x-ray fluorescence, for example, sensitivity refers to the minimal amount of an element that can be detected. Sensitivity is reduced for qualitative and semiquantitative analyses, and can provide sufficient results

where large differences in elemental abundances occur between sources. These techniques are generally faster and less expensive than fully quantitative procedures, which are necessary whenever sources are similar in elemental abundance.

### *Accuracy*

Accuracy reflects how close a measurement is to the actual concentration in a sample (Bishop et al. 1990:539). Accuracy is measured by reference to a standard with known values. Absolute accuracy, however, is impossible to quantify as no absolute standards are available (Hooper and Johnson 1987). Even internationally recognized standards can vary slightly. Consequently, it is imperative to use standards that are well analyzed and distributed among laboratories. The use of standards should apply to all techniques used, whether the application is macroscopic, petrographic, or geochemical.

### *Precision*

How well results can be repeated defines precision, which is directly related to the research questions asked. More precision is needed for intraregional ceramic compositional analyses (Bishop et al. 1990:540) than for basalt provenance studies, in which precision is directly related to the similarity of sources at any scale. The more similarities in macroscopic, petrographic, and/or geochemical attributes between sources—no matter at what scale—the more analytical precision is needed. Precision can be controlled by careful sample preparation and close attention to analytical procedures.

## THE ROLES OF GEOLOGICAL INFORMATION AND SCALE IN PROVENANCE STUDIES OF POLYNESIAN BASALT ADZE MATERIAL

Fortunately, much detailed geologic information in many areas of Polynesia is available to aid in assigning provenance to adze material. Unlike the bewildering array of geological variability between islands on the continental plate of the southwest Pacific, most islands in Polynesia originated from hot spots on the Pacific plate where Oceanic basalt pinnacles rose from the sea floor. Many highly weathered islands are now devoid of volcanic rock, among them coral atolls (such as the Northern Cooks and Tuamotus) and raised limestone islands sitting atop submerged volcanic peaks (such as Henderson and Makatea). Most island-groups within Polynesia are linear volcanic chains, the “plume traces” originating from stationary hot spots (Duncan and Clague 1985), and thus share many characteristics. The petrogenetic evolution of individual volcanoes, as well as the age-progressive nature of island chains, has major implications for provenance studies (see Clague and Dalrymple 1987 for the Hawaiian Islands; Natland 1980 for Samoa). A brief look at the Hawaiian chain will serve to illustrate this point.

### *A Case Study: The Hawaiian Islands*

The Hawaiian-Emperor volcanic chain is the most studied archipelago in the world (for a recent excellent summary of Hawaiian volcanism, see Clague and Dalrymple

# HAWAIIAN ADZE QUARRIES: GEOLOGIC ASSOCIATIONS

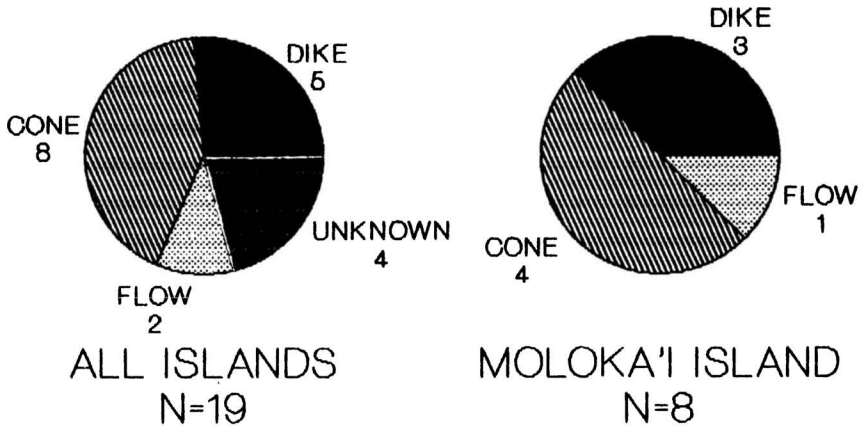


Fig. 2. The geologic associations of Hawaiian basalt quarries. Most sources of fine-grained basalt derive from relatively small, discrete features, such as cones and dikes. Source material found at lava flows is generally widely dispersed, as exemplified by Kapohaku, Lāna'i (Weisler 1990b) and Mauna Kea, Hawai'i Island (McCoy 1990).

1987). Volcanic activity continues with the formation of the Loihi Seamount at the southeastern end of the chain. From this point, the archipelago trends 1200 km to Kaua'i, the northernmost inhabited island, which is 5–6 million years old (McDougall 1964). The progressive aging of islands distant from the active hot spot can be measured with chronometric methods and is also evident in the degree of erosion, subsidence, and geological evolution along the chain (Clague and Dalrymple 1987:7). The surfaces of older islands are deeply weathered with large expanses of lateritic soils. Different degrees of weathering between islands—weathering is more pronounced at the northern end—were used to propose a sequence of island emergence before the advent of chronometric dating (Cross 1904). On relatively older islands, basalt of stone-tool quality is often limited to flows that have eroded into subrounded boulders and cobbles contained within a soil matrix (such as Kapohaku, Lāna'i [Weisler 1990b], or Maunaloa, Moloka'i), or else rock may be deposited in secondary contexts in gulches and stream channels. Quarry rock directly associated with relatively unweathered geologic features should be limited to intrusive rocks, such as dikes, or to late-stage volcanic features, such as cinder and spatter cones—an observation supported by the available data on Hawaiian basalt quarries (Fig. 2).

Hawaiian volcanoes evolve through a series of four stages (following the discussion of Clague and Dalrymple 1987:7–8), each with *distinctive chemical composition*.

Developmental sequences have also been described for the Societies (Stearns 1978), Samoa (Stearns 1944), and the Marquesas (Brousse 1978; Brousse and Guille 1978). Building from the sea floor, the first preshield stage is alkalic, as exemplified by the recently erupted Loihi Seamount. (Of course, preshield rocks were not available to prehistoric Hawaiians—or even to geologists until the advent of sophisticated technology.) The tholeiitic, or shield, stage accounts for more than 95 percent of a volcano's mass and builds over a relatively short period of time, on the order of 1 million years. During the third, postshield phase a thin cap of alkalic basalt forms and accounts for less than 1 percent of the volume of the volcano. After a period of quiescence and erosion, minor amounts of lava poor in silica ( $\text{SiO}_2$ ) may erupt from vents during the posterosional, or alkalic-rejuvenated, fourth stage.

The implications for provenance studies are that quarry rock will either be tholeiitic (low in alkali) from the shield-building stage or will derive from the alkali-rich rocks from the phase of rejuvenation. If we know whether quarry rock is tholeiitic or alkalic—and this can be accomplished with a single sample from the geologic feature—we can immediately sort artifacts into one of two groups, thus eliminating many quarries from further consideration. As seen in Figure 3, tholeiitic and alkalic rocks can be separated by plotting the concentrations of just three oxides:  $\text{SiO}_2$  and total alkalis ( $\text{K}_2\text{O} + \text{Na}_2\text{O}$ ). During weathering  $\text{K}_2\text{O}$  and  $\text{Na}_2\text{O}$  are lost and  $\text{SiO}_2$  increases, but this is probably not important for quarry rock that is fresh (David Clague, personal communication, 1990). Such a plot is even more useful because not all islands have the fourth, alkalic-rich stage. For example, no posterosional stage is known for the island of Lāna'i, so that any basalt artifacts rich in alkali must be imported.

Study of Figure 3 also demonstrates that the majority of large quarries in the Hawaiian Islands and throughout Polynesia are of alkalic origin. These include Mauna Kea atop Hawai'i Island (McCoy 1990); Haleakala at the summit of Maui; Mo'omomi of west Moloka'i; Tatagamatau, Samoa (Leach and Witter 1987); and Tautama, Pitcairn Island. These quarries are all relatively recent geological features, where weathering has not reduced the dense rock to a soft residuum. In contrast, tholeiitic rock quarries for the most part are found where source rock, although geologically older than alkalic material, has been exposed relatively recently in deeply incised gulches and valley sides, and weathering has been limited (WaiaHewahewa and Lower Mānalo Gulch, Moloka'i; Waiāhole, O'ahu; Kapohaku, Lāna'i). Therefore, if we wanted to locate an unknown quarry of tholeiitic rock (based solely on artifacts found at habitation sites), we might first search in areas with deeply weathered gulches and stream valleys, rather than surveying areas with late volcanic features.

Using chemical variation between stages within single volcanoes is useful for provenance studies aimed at locating new quarries, but “even among volcanoes whose lavas fall within the tholeiitic class *sensu stricto*, the unique individuality of each stands out on plots of simple chemical parameters” (Carmichael et al. 1974:412). In other words, with ample background information for an island group (which may be available through a perusal of the geological literature), we should be able to isolate artifacts to single volcanoes, then to a stage within that volcano, thus effectively delimiting the area where artifacts originated. Sinton (1990:2) agrees that “chemical composition of volcanic rocks can be used to dis-

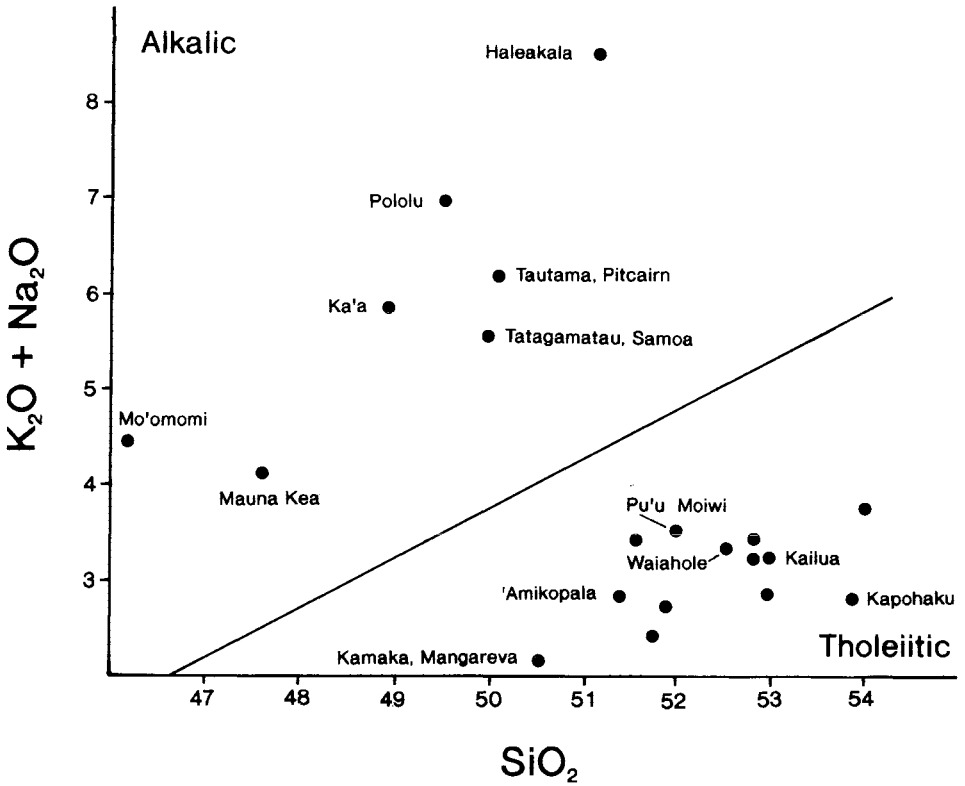


Fig. 3. Plot of Hawaiian and selected Polynesian basalt quarries illustrating the separation of alkali-rich and alkali-poor geochemical groups. Most of the major quarries in Polynesia consist of alkali-rich rocks, which are relatively young and consequently less weathered. Sources without an island designation are from Hawai'i. Unlabeled dots are small sources on west Moloka'i. Data from Best (1984), Fodor et al. (1992), and Weisler (1990b and unpublished).

tinguish . . . in some cases individual volcanoes, volcanic successions within volcanoes or even individual flows." Whenever possible, archaeologists should select elements that are petrogenetically sensitive and indicative of specific geologic events, features, or stages in volcano development (Cox et al. 1979:12–22; Jack and Carmichael 1969). These elements may include the ratios of potassium/rubidium, potassium/barium, or rubidium/strontium (Carmichael et al. 1974:10). Also, elements that normally are not altered during weathering include niobium, zirconium, tantalum, hafnium, thorium, titanium, and yttrium (David Clague, personal communication, 1990). The benefits are twofold: First, as we learn more about the "provenance environment"—that is, as we gain knowledge of geologic features containing basalt of stone-tool quality—we may be able to *predict* where additional sources of adze-quality rock exist. Second, acquiring chemical data from geologic features also provides archaeologists with important information that can be disseminated to geologists, thus facilitating interdisciplinary cooperation.

I have discussed provenance studies at the scales of geologic feature, volcano, island (one or more volcanoes), and archipelago. Another scale exists, however, at the petrologic province, which is controlled by regional tectonics (Dickinson and Shutler 1979). I refer to the division created by the northern Melanesian borderland (Brocher 1985), where the Andesite Line separates Samoa and the rest of Polynesia (alkalic Oceanic basalts) from the andesitic-plutonic rocks of Tonga and Fiji (Dickinson and Shutler 1979; Sinton et al. 1985). This division has been instrumental in defining the areas of sand tempers available for Pacific island pottery (Dickinson and Shutler 1979), yet only White (1987) has used this boundary effectively to address the origin of adzes recovered from archaeological sites in Tonga. The Andesite Line affects a relatively small region of Polynesia (separating the islands of Samoa, Futuna, and 'Uvea from Tonga and Fiji), but it is an extremely important area archaeologically, because it is the ancestral Polynesian homeland (Kirch and Green 1987).

#### *Scale and Provenance Studies*

Figure 1 summarizes the hierarchical relationship of 10 sampling units within Polynesia. It is important for archaeologists engaged in provenance studies to understand the scale at which they can most profitably operate. For example, it must be recognized at which scale the data are most useful for addressing the archaeological problem(s) at hand. Determining what petrologic province artifacts came from (White 1987) may be all that is needed in some circumstances. Conversely, identifying which artifacts are alkalic in composition may be sufficient to eliminate source rocks within the tholeiitic field. Certain trace elements may suggest a particular volcano of origin (Carmichael et al. 1974), which may focus investigation, again, by eliminating other possibilities. Until most of the major sources of adze material in Polynesia (or a particular study area) have been identified and their chemical variability understood, specifying a particular quarry for each artifact may not be possible, and it may be unnecessary for some research questions.

#### REVIEW OF BASALT ANALYTIC STUDIES IN POLYNESIA

Past use of basalt for tracking prehistoric exchange and interaction in Polynesia (here I include Fiji and exclude New Zealand from discussion) involved several types of analysis. These included macroscopic descriptions of adzes and polished flakes (Dye 1987:266; R. Green 1974:141; Kirch 1988:192), thin-section analysis (Best 1984; Buist 1969; Cleghorn et al. 1985; Emory 1975; T. Green 1984; Kirch 1975; Weisler 1990b; White 1987; Withrow 1990, 1991), and geochemical analysis of adze material (Best 1984; Best et al. 1992; Walter 1990; Weisler 1989, 1990b, 1993a).

#### *Macroscopic Observations*

Macroscopic descriptions by themselves provide unreliable indications of basalt quarry sources and are most profitably used in concert with geochemical data (Ayers and Goles 1990:4). Best (in Leach and Witter 1987:51) found that sorting



Samoan adze rock into light gray or dark gray, and nearly black color groups (see Dye 1987; R. Green 1974) did not match specific adze rock sources since both colors are present at the Leafu, Tutuila Island, source. On fresh surfaces the Tata-gamatau source rock is "consistently very dark weathering to a light grey" (Leach and Witter 1987:51; Weisler 1993a). Therefore, identification of sources by color alone may simply reflect weathering processes rather than quarry source.

Under very controlled circumstances other petrographic attributes, such as a "distinctive glistening appearance on weathered surfaces" (Best 1984:401) or banding (Weisler 1989), appear to discriminate rock groups from assemblages of adze material where the regional geology and basalt quarry petrography are well known. Assigning sources by macroscopic characteristics may be possible within explicitly defined contexts, such as the well-studied obsidian sources of northern California (see Bettinger et al. 1984 for an application of visual identification of sources) or the identification of Pitcairn volcanic glass in southeast Polynesia (Weisler 1993b) and the green obsidian from Mayor Island, New Zealand (Davidson 1972). Assigning basalt to source on macroscopic characteristics, however, is a task that should be approached cautiously.

#### *Thin-Section Descriptions*

Describing stone artifacts in thin-section has perhaps the longest history of the various techniques used in provenance studies, beginning in England over a century ago (see Grimes 1979 for a review of British pursuits). In fact, the Implement Petrology Committee of the Council for British Archaeology has published over 7600 petrological descriptions of stone implements, attesting to the coordination of regional chapters and organizational systematics (Clough and Cummings 1988). Yet despite this grand effort, the textural and mineralogical variations of source rock are not adequately known, and "a satisfactory mechanism is still needed for the accurate correlation of thin-sections *between petrologists*" (Clough and Woolley 1985:97; emphasis added). When thin-sections of basalt source rock from the Hawaiian Islands were presented for description to four geologists (including two advanced graduate students), not all attributes were described in a consistent manner and some characteristics received more attention than others (Weisler 1989:8). This underscores the problems with thin-section petrography as a provenance technique whenever careful attention is not paid to analytic accuracy and precision.

As a descriptive geologic technique, the procedures of petrography have been established for more than 100 years (Sorby 1858), but "few petrological investigations are complete without chemical analyses of at least some of the rocks that come under discussion, and particularly is this the case in the study of igneous rocks" (Holmes 1921:384). A novice may, with serious effort, identify minerals and describe the texture and structure of igneous rocks in thin-section. Quantitative microscopic analysis, however, which is necessary for distinguishing the relative homogeneity of Oceanic basalts, has led geologists to serious debates during the 1950s and 1960s on how to refine techniques for estimating bulk composition of rocks from thin-sections (Bankier 1955; Chayes 1956; El-Hinnawai 1966; Jackson and Ross 1956; Plafker 1956; Solomon 1963; Whitten 1961) and for accurately counting mineral components (Bayley 1960; Chayes 1949; Chayes and Fairbairn

1951). Operator misidentifications and counting mistakes are principal sources of error (El-Hinnawai 1966:28). One particularly common mineral found in Oceanic basalts is olivine, which is highly susceptible to hydrothermal alteration and weathering; its altered products are sometimes difficult or impossible to identify precisely by optical methods (Deer et al. 1966:5). Thin-section descriptions, however, can provide data on texture, banding, or unusual phenocrysts that can be useful in assigning material to source (Cleghorn et al. 1985; Weisler 1989).

Powers may have been the first geologist to describe thin-sections of adze material in the Hawaiian Islands when he compared rock from the Haleakalā, Maui, source to the famous quarry complex atop Mauna Kea (Powers 1939). Others have continued this effort in Hawai'i (most are reviewed in Cleghorn et al. 1985:237; see also Kirch 1975; Weisler 1990b; Withrow 1990, 1991), Samoa (Buist 1969), Fiji (Best 1984), Tonga (White 1987), Norfolk (T. Green 1984), and the Tuamotus (Emory 1975) with varying degrees of success. Kirch (1975) compared petrographic descriptions of Hālawā Valley, Moloka'i, artifacts to adze quarry rock 48 km distant and suggested a west Moloka'i source. My geochemical analysis of a similar artifact and suspected source material found only 1 in 16 trace element abundances in common (Weisler 1989). Consequently, artifacts and suspected source rock that look identical in hand specimen—and appear similar in thin-section—may prove to be from different sources based on the finer distinctions provided by geochemical analysis. Cleghorn and colleagues (1985) described 43 petrographic thin-sections from eight Hawaiian adze quarries and provided the first key for discriminating source rock. But keys must be amended when new information is available, as otherwise errors in assignment are possible (Weisler 1990b:43).

A petrographic description of a Takapoto adze was given by Wentworth, who considered it very similar to Ko'olau basalt of O'ahu (Emory 1975:102). White (1987), using thin-section analysis, was able to assign two Tongatapu adzes to one of three igneous rock associations in the Tongan region. Although limited in scope, the *scale* of analysis chosen had significant implications. That is, White determined that certain adzes probably originated in Samoa or 'Uvea (islands consisting of alkaline oceanic basalts) and crossed the Andesite Line south to Tonga, where islands are predominantly tholeiitic (Dickinson and Shutler 1979:1664; Sinton et al. 1985; White 1987:280–281). Although White could not assign adzes to a particular quarry, he was able to suggest a likely province of origin based on gross petrographic characteristics. Sinton (1990:5) agreed that “the petrographic characteristics and chemical composition of volcanic rocks can be used to distinguish petrologic provinces (e.g., oceanic islands versus arc volcanic provinces, Hawaiian versus Marquesan provinces, etc.).”

Working with excavated material from Fiji, Best (1984) analyzed thin-sections from 157 stone tools and flakes and compared them to rocks of the Lau Islands, which may have been suitable for stone tool manufacture. He suggested that southern Lau adzes were imported, possibly from Samoa. He confirmed a Samoan source for eight Lau adzes using geochemical characterization (Best 1984:402), demonstrating the need to augment thin-section data with the finer distinctions made possible by geochemical assay (see Best et al. 1992).

T. Green (1984) examined 16 thin-sections of artifacts from Norfolk Island and compared them to source material from New Zealand. The findings suggested a

local or east Australia source for the artifacts. Withrow (1990, 1991) has examined the spatial and temporal distribution of the Mauna Kea adze material from several habitation sites on Hawai'i Island, concluding that access to this large quarry was not restricted to specialists, and that quarry rock was not socially controlled. Much of the adze material was of local "country" rock.

In sum, thin-section analyses have provided useful data to discriminate sources in specific circumstances, but others have argued (Best et al. 1992:50), and I agree, that these studies should be combined with the finer distinctions made with geochemical techniques. Despite over 50 years of thin-section analyses of Polynesian adze material, several problems have not been adequately resolved and continue to hinder long-term progress in adze distributional studies. These include the failure to report replication of results between analysts; inaccuracy in counting and identifying mineral components and measuring average grain diameter (texture); difficulty of estimating bulk composition from what is essentially a two-dimensional surface; and the failure to report the specific methods used for determining mineral abundances, making comparisons between studies less meaningful. Careful attention to analytic accuracy and precision could eliminate many of these problems. In spite of the benefits of thin-section analysis, one must also consider the problems of counting (the necessity for large numbers to encompass variability), areal measurements (measuring a portion of a slide and extrapolating to the total area), linear analysis (counting grains along a line), and point counting at lines of intersection. The technique is also destructive and normally requires specimens at least 40 mm in diameter.

Thin-section studies, however, have been able to address two basic questions of widely different scale: whether adze rock comes from a local source (Best 1984; Withrow 1990, 1991), and what is the geologic province of origin (White 1987). The benefits of petrographic thin-sections are to provide information on texture, rock structure, and basic mineral composition—data not available from other techniques.

### *Geochemical Studies*

The advent of geochemical studies of Polynesian adze material acknowledges the necessity of using methods that provide replicable results between analysts, have a high degree of accuracy and precision, and provide data that are partly or fully quantitative and conducive to computerized statistical manipulations. Geochemical studies of Polynesian adze material are few to date, and Best (1984; Best et al. 1992) should be credited with taking the first steps in this direction. After grouping adze material using thin-section data, Best selected 10 Fijian adzes for analysis of major and minor elements by destructive x-ray fluorescence (XRF) (Best 1984:402–405, app. L). Results were compared to 35 other samples of fine-grained basalt from most known Polynesian quarries and workshops. The major elements titanium, iron, and phosphorus were plotted on a ternary diagram for all 45 samples, and several Fijian adzes fell within a Samoan source envelope (Best 1984:404). Best reported fully the equipment used, instrumental settings, sample preparation, matrix corrections, calibration standards, and data reduction program, so that his results are comparable to other data sets.

Following Best's 1984 work, Best et al. (1992) distinguished various Oceanic

island basalts and compared them to adzes from Fiji with a potential source in Samoa. Some 157 archaeological and geological samples were analyzed from Fiji and Polynesia (including samples from his previous study). The goals were to ascertain when the Tatagamatau, Samoa, quarry was used and when it was in full production. Major elements were analyzed, and iron, titanium, and phosphorus were used to discriminate source material and artifacts. Trace elements were analyzed for 28 samples to define further the source assignment. Cluster analysis and step-wise discriminant analysis facilitated assigning artifacts to source.

Samoa adze material continues to be the most studied geochemically. Using artifacts from Ta'u and Ofu islands, I analyzed, by nondestructive x-ray fluorescence, 38 specimens and 9 source samples from the Tatagamatau quarry and 2 dike complexes on Ofu (Weisler 1993a). Two questions were addressed: Did adze material found at habitation sites on Ta'u and Ofu islands originate from the Tatagamatau quarry on Tutuila? What is the geochemical variability of adze material and unmodified basalt flakes? I was able to tentatively assign 9 artifacts to the Tatagamatau source by plotting ratios of zirconium/strontium and niobium/strontium. The equipment used and operating conditions were reported in detail. Analytic precision and accuracy were evaluated with international standards.

Using XRF Walter (1990) examined 15 samples of adze material from the Cook Islands and 1 specimen from a suspected source. He included data previously reported by Best (1984), and reference material analyzed by Best and R.C. Green (unpublished data) and determined geochemical groups by cluster analysis using major and minor elements as variables. Walter reasoned that because the southern Cooks have many small, localized deposits of fine-grained basalt, matching archaeological material to sources would be difficult and would have to await more in-depth studies. Consequently, a primary goal of his analysis was to determine if stone had been imported to the Anai'o site (Ma'uke Island), by comparing artifacts to local island rock (Walter 1990:230)—a procedure used successfully in Fiji by Best (1984). By determining the range of geochemical variability for the Anai'o adze assemblage and adzes from other islands in the southern Cooks, Walter determined whether multiple sources had been used and whether any "highly characteristic" geochemical signatures were present. He defined social interaction spheres by identifying similar material at several sites. Unfortunately, no details of the XRF analysis were provided, making comparisons with other data less reliable.

For the past several years I have conducted archaeological surveys on Moloka'i, Hawaiian Islands, to locate sources of adze-quality rock and volcanic glass (Weisler 1989, 1990a), and to characterize the material geochemically to facilitate identifying adze material at distant habitation sites. My research focuses on the antiquity and dynamics of exchange in Hawaiian prehistory. To date, I have analyzed 8 adze quarries (total of 24 samples) on west Moloka'i and 1 on Lāna'i (Weisler 1990b), using destructive XRF, for 10 oxides and 17 trace elements. To determine the geochemical variability of the important adze quarry at Mo'omomi, Moloka'i (a very eroded cone; John Sinton, personal communication, 1987), the quarry was surveyed and the macroscopic variability of raw material was collected and analyzed. This is the only adze quarry in Polynesia where the range of major and trace element abundance is documented in detail (Weisler 1990b:45). With compositional data of 14 basalt flakes from 12 habitation sites (several samples come from dated contexts), I was able to determine the original source of some flakes and the period

when several west Moloka'i quarries were in use. Assigning basalt flakes to source was accomplished by plotting elemental ratios of zirconium/strontium and niobium/strontium. These ratios were also useful for separating the Kapohaku quarry of Lāna'i from other west Moloka'i sources (Weisler 1990*b*). Encouraged by these results, I have experimented with nondestructive XRF with west Moloka'i adze material. Initial trials proved successful, and the application of this technique to adze material from the Cook Islands, and southeast Polynesia is in progress (Weisler 1993*b*).

Provenance research by Ayers and Goles (1990) on Pohnpei Island, Micronesia, is germane. Using instrumental neutron activation (INAA) and destructive XRF, Ayers and Goles (1990:4) identified the sources of lithic building material found at several archaeological sites with monumental architecture; they then postulated social interaction spheres between sites sharing geochemically similar rock. Their XRF procedures are identical to those I used (Weisler 1990*b*); in fact, we used the same labs. Abundance of zirconium and niobium was effective in discriminating Pohnpei sources (Ayers and Goles 1990:8), as with the west Moloka'i and Lāna'i quarries. Additionally, scandium and barium elemental ratios distinguish columnar rock building materials to quarry (Ayers and Goles 1990:4).

In sum, archaeologists using XRF and INAA techniques are beginning to accumulate important data on a wide range of research questions. Studies by Best (1984; Best et al. 1992) and Walter (1990) have relied on the abundance of major elements to characterize and assign artifacts to source, but it is now recognized that the finer distinctions provided by trace elements are also helpful to discriminate basalts (Walter 1990:231; see also Weisler 1989, 1990*b*). Ternary diagrams (Best 1984:404), average linkage cluster analysis (Walter 1990:234), and elemental abundance ratios (Ayers and Goles 1990; Weisler 1990*b*, and unpublished data) have been used to assign artifacts to quarry.

Geochemical analysis is a powerful analytical tool for several reasons: (1) its results are reproducible; (2) instrument specifications and operating conditions can be reported in full; (3) identification of chemical components is not subject to human error; (4) elemental abundances can be determined with accuracy and precision parameters noted; (5) use of standards facilitates interlab comparisons of data bases; and (6) the analytical sample taken to analyze bulk chemical constituents more closely represents the whole specimen, in contrast to a two-dimensional thin-section.

#### *Nondestructive, Energy-Dispersive X-Ray Fluorescence Technique*

The specific technique chosen for chemical analysis of archaeological and geological specimens must be matched to the questions addressed. Some techniques analyze only the specimen's exterior surface, while others yield information about the bulk properties of the material. With some techniques, elements of low atomic numbers are difficult to detect. Sample preparation and analysis can vary greatly. The process may involve total destruction (crushing specimens into fine particles, which are pressed into pellets or fused into disks), no sample modification at all (using whole, unaltered specimens), or radiation effects that can leave the specimen contaminated for long periods of time (such as with INAA).

Nondestructive, energy-dispersive x-ray fluorescence (EDXRF) is a fast, reli-

able, and relatively inexpensive technique for determining the elemental composition of a wide range of inorganic compounds where no special sample preparation is required. (See Bertin 1978; Goffer 1980; Goldstein et al. 1982; Hampel 1984; Macdonald 1980; and Parkes 1986 for reviews of the techniques of XRF spectrometry.) It is not necessary to describe the technique in detail here, but any analysis consists of the following steps: (1) sample preparation; (2) excitation of the specimen by a high- or low-power x-ray tube and collection of secondary x-rays emitted from the sample characteristic of the elements (Parkes 1986:152); (3) application of matrix correction procedures; (4) storage of concentration values and energy spectra on computer disk; and (5) graphic presentation of energy spectra on cathode ray tube. An example of EDXRF equipment is illustrated in Hughes (1986:27).

EDXRF can be used with archaeological specimens if a relatively flat surface at least 30 mm square is present on artifacts and geologic samples, and if the surface is free from dirt, carbonate encrustations, and patina. Bird and colleagues (1978:2083) noted that 5–10 percent of the southwest Pacific obsidian artifacts they analyzed differed widely from expected results due to extraneous surface material or surface deterioration. Surface residues, such as dark midden staining, lateritic dirt, and carbonates, can be removed by submerging the sample in distilled water in a sonic cleaner for one hour. Dilute hydrochloric acid (HCl) will also dissolve carbonate encrustations. Sleelenfreund and Bollong (1989:175) report brushing New Zealand obsidian specimens with acetone, technical grade ethanol, and distilled water to remove surface contaminants.

The specimen surface should be representative of the object as a whole. That is, phenocrysts must be avoided because they would overrepresent certain elements. Although no data are available for the minimum sample for EDXRF analysis of basalt, minimum specimen size for obsidian is 10 mm in diameter and 1–1.5 mm thick (Hughes 1986:37, 1988a:298) and 7.5 mm by 2.5 mm thick (T. Jackson, personal communication, 1990). I have found (Weisler 1990c) acceptable results with Hawaiian volcanic glass measuring 14 mm by 3.9 mm thick, although this may be too thin for heavy elements, such as niobium and barium (David Clague, personal communication, 1990).

For specimen analysis a rhodium x-ray tube is used to excite atomic elements in the mid-Z range. A slightly greater atomic number (Z) than the energy region to be analyzed is necessary (Hughes 1986:23). The emitted energy intensities are acquired for analyte peaks after correction for overlapping energy peaks and background effects. Unknown elements are evaluated by reference to stored spectra and reference standards (both internal and international standards can be used). Machine drift (changes in the emitted energy of the x-ray tube over time), accuracy, and precision are monitored and evaluated with reference to standards.

### *Applications*

In the early 1960s, the Department of Geology and Geophysics at the University of California, Berkeley, in collaboration with archaeologists from the Department of Anthropology, initiated wavelength XRF research of archaeological obsidians from North and Central America (Heizer et al. 1965; Weaver and Stross 1965). (It

was also during this time that R. Green 1962 introduced analysis of obsidian to New Zealand archaeologists.) Since then, thousands of samples, including projectile points, flakes, and geological source material, have been analyzed using these facilities (Hughes 1986; Jack and Carmichael 1969; Jack and Heizer 1968; Jack et al. 1967; Jackson 1974, 1986; Stross et al. 1968). This specific technique is now widely used at several other institutions for compositional studies of archaeological obsidian from throughout California (Bouey 1991; Hughes 1984, 1988a, 1988b, 1989), the American Southwest (Shackley 1988, 1990, 1991), and Mesoamerica (Sheets et al. 1990). In light of this overwhelming success in addressing regional exchange, prehistoric hunter-gatherer interaction, and lithic resource procurement strategies (problems notwithstanding: see Bouey 1991), it is curious that the technique has not been expanded to include other geologic materials (but see Latham et al. 1992 for applications to basaltic and andesitic rocks from California). Hawaiian volcanic glass (Weisler 1990c) and Samoan basalt (Weisler 1993a), however, have been analyzed with encouraging results.

#### TOWARD IMPROVING DATA BASES

Compositional data bases are rapidly developing in the history of Polynesian archaeology. It is of paramount importance that the effort, the financial outlay, and the destructive analyses of nonrenewable unique artifacts yield results of value to long-term research. The distinct advantage of such a program is that standardizing analytical results within instruments and between institutions will ensure comparability of long-term data bases. Otherwise, we may find that data sets accumulated over the course of many years and at much expense will not be comparable. The following suggestions are intended to contribute to the development of data bases that are useful for long-term research.

##### *Analytical Precision and Accuracy*

Sample preparation, analytical equipment, operating conditions, and evaluation of machine precision and accuracy should be reported in full for each analysis. (See Hooper and Johnson 1987 for procedures used at the Washington State University geology lab.) Reference could be made to previously published procedures to eliminate repetition. Precision may be evaluated by analyzing multiple samples or "splits" of the same specimen and comparing results. This will help demonstrate the quality of the data. Accuracy can be demonstrated by reference to well-analyzed standards.

##### *Standards*

We may not be able to eliminate all problems that arise when comparing data sets between labs (due to idiosyncrasies of instruments and various operating conditions), but I suggest that we use identical standards for our analyses. Standards should be chosen that closely match the specimens. For example, the U.S. Geological Survey standard BHVO-1 can be used when analyzing basalts. International standards are routinely used by geologists and can be acquired by all researchers,

often free of charge. Results from different instruments—operated under an array of conditions—may then be comparable. This suggestion follows Govindaraju (1984, 1989; see also Flanagan 1969) who compiles, on a regular basis, XRF determinations of standards analyzed by labs throughout the world. Internal standards—those made specifically by individual labs for their in-house use—may also be distributed. (The labs at the departments of geology and geophysics at the University of Hawai'i and University of California, Berkeley, use internal standards made from the same powder.)

### *Source Sampling*

At this time, it is necessary to increase the number of samples from most known basalt sources in Polynesia. The Mo'omomi, Moloka'i, quarry and, perhaps, Mauna Kea are the only two adequately sampled to date. Since sampling procedures structure all subsequent analyses and interpretations, it is crucial that archaeologists pay close attention to acquiring source samples. Aside from collecting nonrandom samples from Polynesian adze quarries (as has been done in the past), determining the variability within each source is a logical precursor to continued provenance studies. This can be achieved for a particular quarry by *demonstrating* the geochemical variability over the entire source area. (Koch and Link 1970 provide an excellent summary of geological sampling procedures.) One may proceed by collecting rock exhibiting the range of macroscopic variability (color, and the presence/absence of phenocrysts and vesicles), sorting samples into groups, and testing group fitness by geochemical analysis (Weisler 1990b:45).

Samples should be selected from geological material (that is, fresh unmodified rock) as well as artifacts, such as large flakes. Individual specimens should be at least 100 grams so that "splits," or subsamples, can be distributed to other institutions along with geochemical analyses. Descriptions of the equipment used and operating conditions should also accompany source material. This will permit other researchers to evaluate interlaboratory precision and accuracy. In planning for the long term, each working group could select a single institution to be responsible for curating source samples and analyses. When new and perhaps very different techniques are used in the future, we should then be able to calibrate elemental values to older data if we distribute source material and use standards now.

### SUMMARY

The settlement of Polynesia, the origin of colonizing groups, and identification of subsequent social interaction between islands and archipelagoes are central themes in Oceanic prehistory. I have argued that the identification of exotic objects—both raw materials and finished artifacts—is our strongest inferential link to this past. Analysis of basalt material can proceed most profitably with knowledge of regional geology. As I have demonstrated by a geologic overview of the Hawaiian Islands, information on the age, melting history, composition of magma source material, and weathering history of individual volcanoes forms an important foundation for any provenance study.



Macroscopic observations, petrographic thin-sections, and geochemical analyses have all been used for assigning artifacts to source. Exterior color of adze material can reflect postdepositional weathering and is not a good indication of raw material source. Petrographic thin-sections provide important information on texture, rock structure, banding, and general mineral composition, but should be used with geochemical techniques.

Over the past 10 years, geochemical analyses have become more frequent, particularly since results are replicable with a high degree of precision and accuracy. Data are semi- or fully quantitative and conducive to computer manipulation. The nondestructive application of energy-dispersive x-ray fluorescence to Polynesian adze material is one alternative to destructive techniques of geochemical analysis. Even as analytical techniques improve, source assignments of artifacts are still subject to adequate sampling of source rock from Polynesian basalt sources. Consequently, acquiring source samples must be a high priority. Looking ahead, we can only benefit from mutual cooperation in understanding the Polynesian past.

#### ACKNOWLEDGMENTS

I thank David Clague, Robert Gargett, Michael Graves, Roger Green, Joachim Hampel, Terry Hunt, Patrick Kirch, M. Stephen Shackley, and Barbara Withrow for comments on an earlier version of this paper.

#### REFERENCES

- AMBROSE, WAL  
1976 Obsidian and its prehistoric distribution in Melanesia, in *Ancient Chinese Bronzes and South-east Asian Metal and Other Archaeological Artifacts*: 351–378, ed. N. Barnard. Melbourne: National Gallery of Victoria.
- AYERS, WILLIAM, AND G. GOLES  
1990 *Report on Geological and Geochemical Provenance Studies of Archaeological Materials, Nan Madol Project, Pohnpei, Micronesia*. Houston: Margaret Cullinan Wray Charitable Lead Annuity Trust.
- BANKIER, J.  
1955 The theory of thin-section analysis: A discussion. *Journal of Geology* 63:287–290.
- BAYLEY, M.  
1960 Errors in point-counter analysis. *American Mineralogist* 45:447–449.
- BERTIN, EUGENE P.  
1978 *Introduction to X-Ray Spectrometric Analysis*. New York: Plenum Press.
- BEST, SIMON B.  
1984 Lakeba: The Prehistory of a Fijian island. Ph.D. diss., University of Auckland, New Zealand.
- BEST, SIMON B., P. SHEPPARD, R.C. GREEN, AND R. PARKER  
1992 Necromancing the stone: Archaeologists and adzes in Samoa. *Journal of the Polynesian Society* 101:45–85.
- BETTINGER, ROBERT L., M. DELACORTE, AND R. JACKSON  
1984 Visual sourcing of central eastern California obsidians, in *Obsidian Studies in the Great Basin*: 63–78, ed. R. Hughes. Berkeley: Contributions of the University of California Archaeological Research Facility 45.
- BIRD, J., L. RUSSELL, M. SCOTT, AND W. AMBROSE  
1978 Obsidian characterization with elemental analysis by proton-induced gamma-ray emission. *Analytical Chemistry* 50:2082–2084.

- BISHOP, RONALD L., V. CANOUTS, P.L. CROWN, AND S.P. DE ATLEY  
 1990 Sensitivity, precision, and accuracy: Their roles in ceramic compositional data bases. *American Antiquity* 55:537–546.
- BOUEY, PAUL  
 1991 Recognizing the limits of archaeological applications of non-destructive energy-dispersive x-ray fluorescence analysis of obsidians. *Proceedings of the Materials Research Society, Symposium 6. Materials Issues in Art and Archaeology II* 185:309–320.
- BROCHER, THOMAS M.  
 1985 *Investigations of the Northern Melanesian Borderland*. Earth Science Series Vol. 3. Houston: Circum-Pacific Council for Energy and Mineral Resources.
- BROUSSE, ROBERT  
 1978 Éléments d'analyses de quelques Iles des Marquises: Fatu Hiva, Tahuata, Motane, Ua Pou. *Cahiers du Pacifique* 21:107–144.
- BROUSSE, ROBERT, AND G. GUILLE  
 1978 Volcanisme et pétrologie de l'île de Nuku-Hiva dans les Iles Marquises (Pacifique Central), présentation générale. *Cahiers du Pacifique* 21:145–153.
- BUIST, A.  
 1969 Field archaeology on Savai'i, in *Archaeology in Western Samoa*: 1:34–68, ed. R. Green and J. Davidson. Auckland: Bulletin of the Auckland Institute and Museum 6.
- CARMICHAEL, IAN S.E., F. TURNER, AND J. VERHOOGEN  
 1974 *Igneous Petrology*. New York: McGraw-Hill.
- CHAYES, FELIX  
 1949 A simple point counter for thin-section analysis. *American Mineralogist* 34:1–11.  
 1956 *Petrographic Modal Analysis: An Elementary Statistical Appraisal*. New York: John Wiley and Sons.
- CHAYES, FELIX, AND H. FAIRBAIRN  
 1951 A test of the precision of thin-section analysis by point counter. *American Mineralogist* 36:704–712.
- CLAGUE, DAVID, AND G. DALRYMPLE  
 1987 The Hawaiian-Emperor volcanic chain, part 1: Geologic evolution, in *Volcanism in Hawaii*: 1350:5–54, ed. R. Decker, T. Wright, and P. Stauffer. U. S. Geological Survey Professional Paper.
- CLEGHORN, PAUL L., T. DYE, M. WEISLER, AND J. SINTON  
 1985 A preliminary petrographic study of Hawaiian stone adze quarries. *Journal of the Polynesian Society* 94:235–251.
- CLOUGH, TIMOTHY, AND W. CUMMINGS  
 1988 *The Petrology of Prehistoric Stone Implements from the British Isles*. Council for British Archaeology, Research Report 67.
- CLOUGH, T., AND A. WOOLLEY  
 1985 Petrography and stone implements. *World Archaeology* 17:90–100.
- COX, KEITH G., J. BELL, AND R. PANKHURST  
 1979 *The Interpretation of Igneous Rocks*. London: George Allen and Unwin.
- CROSS, WHITMAN  
 1904 An occurrence of trachyte on the island of Hawaii. *Journal of Geology* 12:510–523.
- DAVIDSON, JANET M.  
 1972 Archaeological investigations on Motutapu Island, New Zealand: Introduction to recent fieldwork and some recent results. *Records of Auckland Institute and Museum* 9:1–14.
- DEER, WILLIAM A., R. HOWIE, AND J. ZUSSMAN  
 1966 *An Introduction to the Rock-Forming Minerals*. Essex: Longman.
- DICKINSON, WILLIAM, AND R. SHUTLER  
 1979 Petrography of sand tempers in Pacific Islands potsherds: Summary. *Geological Society of America Bulletin* 90:993–995.

- DUNCAN, ROBERT, AND D. CLAGUE  
 1985 Pacific plate motion recorded by linear volcanic chains, in *The Ocean Basins and Margins*: 7:89–121, ed. A. Nairn, F. Stehli, and S. Uyeda. New York: Plenum Press.
- DYE, THOMAS  
 1987 Social and Cultural Change in the Prehistory of the Ancestral Polynesian Homeland. Ph.D. diss., Yale University, New Haven.
- EL-HINNAWAI, ESSAM E.  
 1966 *Methods in Chemical and Mineral Microscopy*. Amsterdam: Elsevier.
- EMORY, KENNETH P.  
 1943 Polynesian stone remains, in *Studies in the Anthropology of Oceania and Asia*: 9–21, ed. C.S. Coon and J.M. Andrews IV. Cambridge, Mass.: Peabody Museum of American Archaeology and Ethnology Paper 20.  
 1961 East Polynesian relationships as revealed through adzes, in *Prehistoric Culture in Oceania*: 151–169, ed. I. Yawata and Y.H. Sinoto. Honolulu: Bishop Museum.  
 1975 *Material Culture of the Tuamotu Archipelago*. Pacific Anthropological Records 22. Honolulu: Bishop Museum.
- FLANAGAN, FRANCIS J.  
 1969 U. S. Geological Survey standards II: First compilation of data for the new U.S.G.S. rocks. *Geochimica et Cosmochimica Acta* 33:81–120.
- FODOR, R.V., F.A. FREY, G.R. BAUER, AND D.A. CLAGUE  
 1992 Age, petrogenesis, and rare-earth element enrichment of tholeiitic and alkalic basalts from Kahoolawe, Hawaii. *Contributions to Mineralogy and Petrology* 110:442–462.
- GATHERCOLE, PETER  
 1964 *Preliminary Report on Archaeological Fieldwork on Pitcairn Island, January–March 1964*. Department of Anthropology, University of Otago.
- GOFFER, ZVI  
 1980 *Archaeological Chemistry: A Sourcebook on the Applications of Chemistry to Archaeology*. New York: John Wiley and Sons.
- GOLDSTEIN, JOSEPH A., D. NEWBURY, P. ECHLIN, D. JOY, C. FIORI, AND E. LIFSHIN  
 1981 *Scanning Electron Microscopy and X-Ray Microanalysis*. New York: Plenum Press.
- GOVINDARAJU, K.  
 1984 1984 compilation of working values and sample description for 170 international reference samples of mainly silicate rocks and minerals. *Geostandards Newsletter* Special Issue 8.  
 1989 1989 compilation of working values and sample description for 272 geostandards. *Geostandards Newsletter* Special Issue 13:1–113.
- GREEN, ROGER C.  
 1962 Obsidian: Its application to archaeology. *New Zealand Archaeological Association Newsletter* 5:8–16.  
 1970 Settlement pattern archaeology in Polynesia, in *Studies in Oceanic Culture History*: 1:13–32, ed. R.C. Green and M. Kelly. Pacific Anthropological Papers 11. Honolulu: Bishop Museum.  
 1974 Review of portable artifacts from Western Samoa, in *Archaeology in Western Samoa* 2:245–275, ed. R.C. Green and J. Davidson. Auckland: Bulletin of the Auckland Institute and Museum 7.
- GREEN, T.  
 1984 Appendix I: Petrologic evaluation of artifact material from Norfolk Island, in *The Prehistoric Archaeology of Norfolk Island*: 53–56, ed. J. Specht. Pacific Anthropological Records 34. Honolulu: Bishop Museum.
- GRIMES, W.  
 1979 The history of implement petrology in Britain, in *Stone Axe Studies*: 1–4, ed. T. Clough and W. Cummins. Council for British Archaeology, Research Report 23.
- HAMPEL, JOACHIM  
 1984 Technical considerations in x-ray fluorescence analysis of obsidian, in *Obsidian Studies in the*

*Great Basin*: 21–25, ed. R. Hughes. Berkeley: Contributions of the University of California Archaeological Research Facility 45.

HEIZER, ROBERT, H. WILLIAMS, AND J. GRAHAM

1965 Notes on Mesoamerican obsidians and their significance in archaeological studies. *Contributions of the University of California Archaeological Research Facility* 1:94–103.

HOLMES, ARTHUR

1921 *Petrographic Methods and Calculations with Some Examples of Results Achieved*. London: Thomas Murby and Co.

HOOPER, PETER R., AND D. JOHNSON

1987 Major and trace element analyses of rocks and minerals by automatic x-ray spectrometry. Unpublished manuscript, Geology Department, Washington State University Pullman, Washington.

HOWARD, ALAN

1967 Polynesian origins and migrations: A review of two centuries of speculation and theory, in *Polynesian Culture History, Essays in Honor of Kenneth P. Emory*: 45–101, ed. G.A. Highland, R.W. Force, A. Howard, M. Kelly, and Y.H. Sinoto. Bishop Museum Special Publication 56. Honolulu: Bishop Museum.

HUGHES, RICHARD E.

1984 *Obsidian Studies in the Great Basin*. Berkeley: Contributions of the University of California Archaeological Research Facility 45.

1986 *Diachronic Variability in Obsidian Procurement Patterns in Northeastern California and Southcentral Oregon*. University of California Publications in Anthropology 17. Berkeley: University of California Press.

1988a Archaeological significance of geochemical contrasts among southwestern New Mexico obsidians. *The Texas Journal of Science* 40:297–307.

1988b The Coso volcanic field reexamined: Implications for obsidian sourcing and hydration dating research. *Geoarchaeology* 3:253–265.

1989 *Current Directions in California Obsidian Studies*. Berkeley: Contributions of the University of California Archaeological Research Facility 48.

IRWIN, GEOFFREY

1990 Human colonization and change in the remote Pacific. *Current Anthropology* 31:90–94.

JACK, ROBERT, AND I. CARMICHAEL

1969 The chemical “fingerprinting” of acid volcanic rocks, in *Special Report* 100:17–32. Sacramento: California Division of Mines and Geology.

JACK, R., AND R. HEIZER

1968 “Finger-printing” of some Mesoamerican obsidian artifacts. *Contributions of the University of California Archaeological Research Facility* 5:81–100.

JACK, R., K. LAJOIE, AND I. CARMICHAEL

1967 “Fingerprinting” of obsidian and pumice from the western United States. Paper presented at the Geological Society of America 80th Annual Meeting, New Orleans.

JACKSON, E., AND D. ROSS

1956 A technique for modal analysis of medium- and coarse-grained (3–10 mm) rocks. *American Mineralogist* 41:648–651.

JACKSON, TOM

1974 The Economics of Obsidian in Central California Prehistory: Applications of X-ray Fluorescence Spectrography in Archaeology. M.A. thesis. San Francisco State University.

1986 Late Prehistoric Exchange in Central California. Ph.D. diss., Stanford University, Stanford, Calif.

KEY, C.A.

1968 Trace element identification of the source of obsidian in an archaeological site in New Guinea. *Nature* 219:360.

KIRCH, PATRICK V.

1975 Excavation at sites A1-3 and A1-4: Early settlement and ecology in Halawa Valley, in *Prehistory and Ecology in a Windward Hawaiian Valley: Halawa Valley, Moloka'i*: 17–70, ed. P. Kirch and M. Kelly. Pacific Anthropological Records 24. Honolulu: Bishop Museum.

- 1988 *Niutopotupu: The Prehistory of a Polynesian Chiefdom*. Seattle: Thomas Burke Memorial Washington State Museum Monograph 5.
- KIRCH, PATRICK V., AND R.C. GREEN  
1987 History, phylogeny, and evolution in Polynesia. *Current Anthropology* 28:431-456.
- KOCH, GEORGE S., JR., AND R.F. LINK  
1970 *Statistical Analysis of Geological Data*. New York: John Wiley and Sons.
- LATHAM, THOMAS S., P.A. SUTTON, AND K.L. VEROSUB  
1992 Non-destructive XRF characterization of basaltic artifacts from Truckee, California. *Geoarchaeology* 7:81-101.
- LEACH, HELEN, AND D. WITTER  
1987 Tataga-matau "rediscovered." *New Zealand Journal of Archaeology* 9:33-54.
- MACDONALD, GORDON  
1980 X-ray spectrometry. *Analytical Chemistry* 52:100R-106R.
- MCCOY, PATRICK  
1990 Subsistence in a "non" subsistence environment: Factors of production in a Hawaiian alpine desert adze quarry, in *Pacific Production Systems: Approaches to Economic Prehistory*: 85-119, ed. D.E. Yen and J.M.J. Mummery. Occasional Papers in Prehistory 18. Canberra: Australian National University.
- MCDUGALL, IAN  
1964 Potassium-argon ages from lavas of the Hawaiian Islands. *Geological Society of America Bulletin* 75:107-128.
- NATLAND, JAMES H.  
1980 The progression of volcanism in the Samoan linear volcanic chain. *American Journal of Science* 280-A:709-735.
- PARKES, PENELOPE A.  
1986 *Current Scientific Techniques in Archaeology*. London: Croom Helm.
- PLAFKER, GEORGE  
1956 A technique for modal analyses of some fine- and medium-grained (0.1-5 mm) rocks. *American Mineralogist* 41:652-655.
- POWERS, HOWARD  
1939 Hawaiian adz materials in the Haleakala section of Hawaii National Park, in *Proceedings of the Hawaiian Academy of Science, 14th Annual Meeting 1938-1939*: 24. B.P. Bishop Museum Special Publication 34. Honolulu: Bishop Museum.
- SHACKLEY, M. STEPHEN  
1988 Sources of archaeological obsidian in the Southwest: An archaeological, petrological, and geochemical study. *American Antiquity* 53:752-772.  
1990 Early Hunter-Gatherer Procurement Ranges in the Southwest: Evidence from Obsidian Geochemistry and Lithic Technology. Ph.D. diss., Arizona State University, Tempe.  
1991 Tank Mountains obsidian: A newly discovered archaeological obsidian source in east-central Yuma county, Arizona. *The Kiva* 57:17-25.
- SHEETS, PAYSON D., K. HIRTH, F. LANGE, F. STROSS, F. ASARO, AND H. MICHEL  
1990 Obsidian sources and elemental analyses of artifacts in southern Mesoamerica and the northern intermediate area. *American Antiquity* 55:144-158.
- SHEPPARD, PETER, R. HANCOCK, L. PAVLISH, AND R. PARKER  
1989 Samoan volcanic glass. *Archaeology in Oceania* 24:70-74.
- SINOTO, YOSHIKO H.  
1967 Artifacts from excavated sites in the Hawaiian, Marquesas, and Society Islands: A comparative study, in *Polynesian Culture History, Essays in Honor of Kenneth P. Emory*: 341-351, ed. G.A. Highland, R.W. Force, A. Howard, M. Kelly, and Y.H. Sinoto. Bishop Museum Press Special Publication 56. Honolulu: Bishop Museum.
- SINTON, JOHN M.  
1990 Geologic and archaeologic reference collections for south Polynesian adze studies. Honolulu: Hawaii Bishop Research Institute.

SINTON, JOHN M., K. JOHNSON, AND R. PRICE

- 1985 Petrology and geochemistry of volcanic rocks from the northern Melanesian borderland, in *Investigations of the Northern Melanesian Borderland*: 35–65, ed. T. Brocher. Earth Science Series Vol. 3. Houston: Circum-Pacific Council for Energy and Mineral Resources.

SLEELENFREUND, ANDREA, AND C. BOLLONG

- 1989 The sourcing of New Zealand archaeological obsidian artefacts using energy dispersive xrf spectroscopy, in *Saying So Doesn't Make It So: Papers in Honour of B. Foss Leach*: 168–189, ed. D. Sutton. New Zealand Archaeological Association Monograph 17, The University of Otago.

SOLOMON, M.

- 1963 Counting and sampling errors in modal analysis by point counter. *Journal of Petrology* 4:367–382.

SORBY, HENRY C.

- 1858 On the microscopic structure of crystals, indicating the origin of minerals and rocks. *Geological Society of London* 14:453–500.

STEARNS, HAROLD

- 1944 Geology of the Samoan Islands. *Bulletin of the Geological Society of America* 55:1279–1332.  
1978 Comparison of the geology of the Society and the Hawaiian Islands, *Occasional Papers Bernice P. Bishop Museum* 24:275–290. Honolulu: Bishop Museum.

STROSS, FRED H., J. WEAVER, G. WYLD, R. HEIZER, AND J. GRAHAM

- 1968 Analysis of American obsidians by x-ray fluorescence and neutron activation analysis. *Contributions of the University of California Archaeological Research Facility* 5:59–79.

WALTER, RICHARD

- 1990 The Southern Cook Islands in Eastern Polynesian Prehistory. Ph.D. diss., University of Auckland, Auckland, NZ.

WALTER, RICHARD, AND W. DICKINSON

- 1989 A ceramic sherd from Ma'uke in the southern Cook Islands. *Journal of the Polynesian Society* 98:465–470.

WEAVER, J., AND F. STROSS

- 1965 Analysis by x-ray fluorescence of some American obsidians. *Contributions of the University of California Archaeological Research Facility* 1:89–93.

WEISLER, MARSHALL

- 1989 Towards documenting exchange in a complex chiefdom: An essay in method. Paper presented at the 54th Annual Meeting of the Society for American Archaeology, Atlanta, Georgia.  
1990a Sources and sourcing of volcanic glass in Hawai'i: Implications for exchange studies. *Archaeology in Oceania* 25:16–23.  
1990b A technological, petrographic, and geochemical analysis of the Kapohaku adze quarry, Lāna'i, Hawaiian Islands. *New Zealand Journal of Archaeology* 12:29–50.  
1990c Chemical characterization and sourcing of volcanic glass artifacts from Poka'i Bay, O'ahu. Honolulu: Environmental and Energy Services Co.  
1993a Chemical characterization and provenance of Manuan adz material using a non-destructive x-ray fluorescence technique, in *The Toaga Site: Archaeological Investigations at an Early Polynesian Site in the Manu'a Group, American Samoa*, ed. Patrick Kirch and Terry Hunt. Berkeley: University of California Archaeological Research Facility Contributions 51.  
1993b Human Colonization and Extinction in Marginal Polynesia: Henderson Island Prehistory. Ph.D. diss., University of California, Berkeley.  
1994 The settlement of marginal Polynesia: New evidence from Henderson Island. *Journal of Field Archaeology* 24:1.

WHITE, A.J.R.

- 1987 Appendix 7: Petrography of some stone adzes from Tongatapu, Tonga group, in *Early Tongan Prehistory*: 279–281, ed. Jens Poulsen. Terra Australis 12. Canberra: Department of Prehistory, Research School of Pacific Studies, Australian National University.

## WHITTEN, E.H. TIMOTHY

- 1961 Quantitative areal modal analysis of granitic complexes. *Geological Society of America Bulletin* 72:1331-1360.

## WITHROW, BARBARA

- 1990 Prehistoric distribution of stone adzes on Hawai'i Island: Implications for the development of Hawaiian chiefdoms. *Asian Perspectives* 29:235-250.
- 1991 Prehistoric Production, Distribution, and Use of Stone Adzes: Implications for the Development of Hawaiian Chiefdoms. Ph.D. diss., University of Minnesota, Minneapolis.

## ABSTRACT

Polynesian basalt adze material is the most widely distributed commodity for tracking prehistoric social interaction across space and through time. Since data bases are rapidly developing, the problems and prospects of current distributional studies need review and evaluation. Definitions common to those undertaking basalt provenance studies are provided; the roles of geological information and spatial scale to distributional studies are discussed; basalt analytic and provenance studies are reviewed; macroscopic, petrographic, and geochemical techniques are evaluated; and suggestions for improving data bases are offered. It is concluded that the nondestructive x-ray fluorescence technique is an alternative to destructive analyses. Careful attention to analytical precision, accuracy, and the use of standards will improve intra- and inter-lab comparison of data sets. Additional sampling of Polynesian basalt sources is urgently needed. **KEYWORDS:** Polynesia, adze material, provenance studies, macroscopic, petrographic, geochemical, data standardization, nondestructive x-ray fluorescence.