ELEMENTAL AND TECHNOLOGICAL ANALYSES OF BASALT ADZE MANUFACTURE ON TUTUILA, AMERIKA SAMOA: ECONOMIC INTENSIFICATION AND SPECIALIZATION DURING THE MONUMENT BUILDING PERIOD

A Dissertation

by

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ABSTRACT

This dissertation research presents the elemental and technological analyses of basalt adze quarries from the Samoan Island of Tutuila. Both Instrumental Neutron Activation Analysis (INAA) and Energy Dispersive X-ray Fluorescence (EDXRF) were utilized in the chemical characterization of basalt samples and artifacts. Elemental concentration data derived from both INAA and EDXRF successfully differentiated between multiple Tutuilan basalt adze quarries, and these data were utilized to determine the most efficacious elemental analysis technique for Tutuilan basalt adze provenance study.

Elemental concentration data from the Lau'agae quarry were utilized with technological attribute analysis of artifacts recovered from that archaeological site to investigate the potential for economic specialization in the manufacture of basalt adzes. Analysis of both the technological attribute data and the elemental concentration data provided evidence for potential specialization at the Lau'agae quarry. When these data were compared to similar data from other Polynesian archaeological sites it further supported the potential for specialized production at Lau'agae. Ultimately, it was determined that multiple skilled producers created various types of basalt adzes at Lau'agae with the intent to export and exchange their products.

To my mom and dad who encouraged me to dream and made me follow through.

For my dearest Nicole and darling Alexander, without whom I could never have found the inspiration to complete this work.

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1. INTRODUCTION

This research was designed to explore, refine, and apply elemental analytical techniques towards the archaeological investigation of basalt adze production, distribution, consumption, and potential specialization on the Samoan island of Tutuila. Thusly, the following research is divided into three sections:

(1) Section two presents the analysis of elemental concentration data from chemical characterization to differentiate multiple basalt adze quarries on Tutuila.
(2) Section three provides an evaluation of the efficacy of two major chemical characterization techniques in the elemental analysis of basalt adze quarries on Tutuila.
(3) Section four presents an application of elemental analysis of a basalt adze quarry on Tutuila toward the investigation of economic specialization.

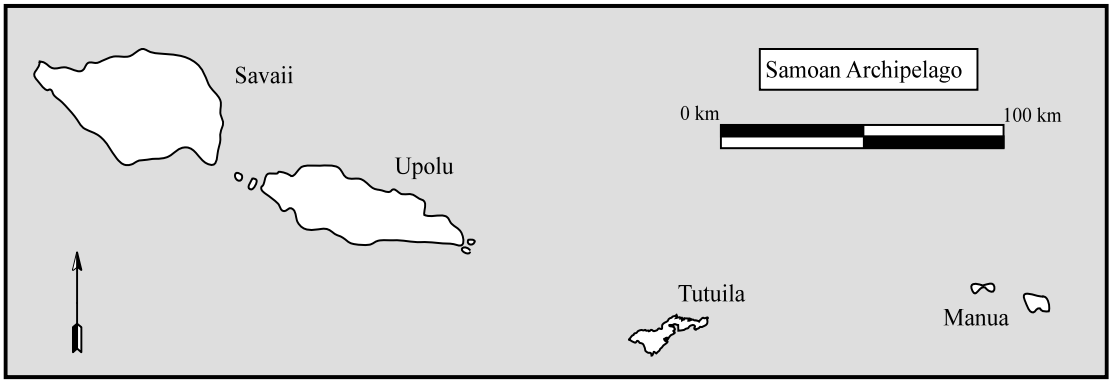

Figure 1.1. The Samoan Archipelago and Tutuila Island

1.1 RESEARCH AREA

Tutuila and the other islands within the Samoan archipelago are remnants of oceanic basalt shield volcanoes, which created high volcanic islands of alkalic olivine basalts and hawaiities (MacDonald 1968). While shield building volcanism ceased in the archipelago during the mid-Pleistocene, post-erosional volcanism has created a younger appearance to the

western islands in contrast to the highly eroded eastern islands where post-erosional volcanism has been less common (MacDougall 1985; Natland 1980). The deeply eroded island of Tutuila is near the center of the archipelago at 14° South Latitude and 170° E Longitude (Fig. 1.1), and at approximately 138 km^2 in total area it is the third largest island within the Samoan chain. The primary geological survey and descriptions of Tutuila were published by H.T. Stearns (1944) in the Bulletin of the Geological Society of America along with the petrographic descriptions of Gordon A. MacDonald (1944).

In his study Stearns (1944) divided Tutuila into five volcanic provinces including the four shield volcanic centers, Alofau, Olomoana, Pago, Taputapu, and the post-erosional Leone volcanics (Fig. 1.2). Recent research has complimented Stearns' foundational descriptions of Tutuilan geology (MacDougall 1985; Natland 1980). MacDougall's (1985) Ka-Ar dating supported Stearns' (1944) original chronology, but defines Stearns' Alofau volcanics as indistinct from the Pago volcanics.

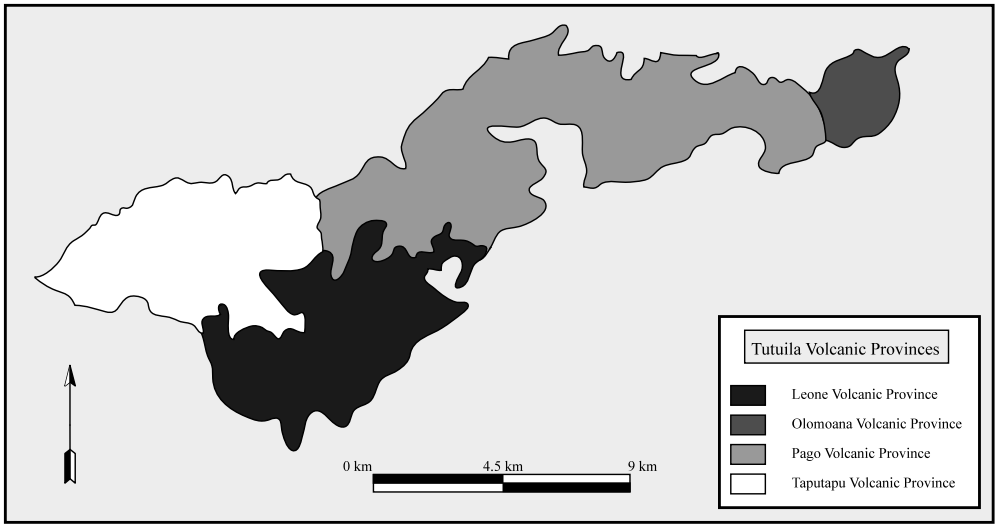

Figure 1.2. The Volcanic Provinces of Tutuila (from Stearns 1944 and MacDougall 1985)

Sites included in this research were selected to represent each volcanic province with recorded fine-grained basalt quarry complexes. (Section 2 and Section 3), but Section 4 focuses on a quarry complex in the Olomoana Province in the investigation of local basalt adze distribution. There are currently no recorded basalt quarry complexes in the Leone volcanic province, so that geological area is not included in this research. The sites of Alega (N=30) and Asiapa (N=30) were sampled from the Pago volcanics, Lau'agae (N=30) was sampled from the Olomoana Province, and Tataga-matau (N=30) was sampled from the Taputapu Province.

1.2 CULTURAL CHRONOLOGY AND THEORETICAL FRAMEWORK

For the past 40 years Janet Davidson's (1977) culture history of Fiji, Samoa, and Tonga has largely guided the archaeological investigation of Samoa and the greater West Polynesia Interaction sphere (e.g. Addison and Asaua 2006; Addison et al. 2006; Ayres and Eisler 1987; Ayres et al. 2001; Barnes and Hunt 2005; Bellwood 1987; Best 1993; Best et al. 1988; Best et al. 1992; Burley et al. 1995; Clark 1987 1993, 1996; Clark and Herdrich 1993; Clark and Michlovic 1996; Frost 1978; Green 2002; Herdrich 1989; Herdrich and Clark 1993; Hunt and Kirch 1988; Jennings and Holmer 1980; Johnson et al. 2007; Kirch 1984, 1997, 2000; Kirch and Green 2001; Leach 1993; Martinsson-Wallin 2007; Pearl 2004, 2006; Pearl and Johnson 2006; Reith and Hunt 2008; Weisler 1993a; Winterhoff and Rigtrup 2006; Winterhoff et al. 2007).

Davidson's (1977) chronology was informed by a fluorescence of research in Fiji, Samoa and Tonga during the sixties and seventies (Green and Davidson 1969, 1974; Jennings et al. 1976; Groube 1971; Kaeppler 1978; and Poulsen 1967). Although highly

dependent on material correlates, inter-island interaction is the overarching assumption employed by Davidson (1977) to explain a shared culture history for the region. Davidson, assumes that interaction is maintained between the archipelagos of West Polynesia; and argues that in addition to ethnohistorical accounts of interaction (Kaeppler 1978), similarities in precontact ceramic traditions and trajectories as well as the development of field monuments were substantive archaeological evidence to support a pan-regional culture history dependent on interaction and diffusion.

Davidson's culture history is comprised of four major periods that have become commonly referred to as (Reith and Hunt 2008): the Lapita Period (ca. 3000BP-2500BP), the Plain Ware Period (ca. 2500BP-1500BP), the Aceramic Period (ca. 1500BP-1000BP), and the Monument Building Period (1000BP-250BP). Ceramic artifacts and landscape use are the principal archaeological correlates that Davidson used to devise her culture history. Although the dominant material culture recovered from West Polynesia archaeological sites were basalt artifacts. Davidson noted that adze typologies had been developed in the region (Davidson 1961; Green and Davidson 1969, 1974), but she relied on pottery as a primary indicator for the majority of her transitions within the culture history of the region because pottery has a discrete association with the earliest Lapita settlers, and Green's (1974) typology of regional pottery styles (Early Eastern Lapita, Late Eastern Lapita, Plain Ware) was more discrete and better suited for creating a chronology than the problematic adze typology (Green and Davidson 1969).

The two earliest periods of Davidson's (1977) culture history are defined by the presence of pottery at archaeological sites, but pottery notoriously disappears from the archaeological records of Samoa and Tonga (while it is continuously maintained in Fiji) in

the first millennia A.D. The next period is defined by the conspicuous absence of pottery from archaeological sites. These sites comprise the Aceramic period, also often referred to as the "Dark Ages" (Davidson 1979). In addition to pottery, Davidson (1977) was guided by settlement practices and landscape use to define her final precontact period, she specifically refers to the inception of monumental architecture in Samoa and Tonga during this timeframe, which is often referred to as the Monument Building Period or Traditional Samoan Period (Burley et al. 1995; Green 2002). This final period and the shift in settlement and architectural practices has been associated with increased social complexity and economic intensification (Best 1993; Burley 1993), which on the island of Tutuila is typified by the development of upland basalt adze quarry complexes.

This research follows Davidson's general chronology, in that it is designed to test the archaeological record against theoretical implications of social changes proposed during the Monument Building Period (1000-250BP). Specifically, Section 4 of this research will investigate the potential for economic specialization at an upland basalt quarry complex (AS-21-100) on the island of Tutuila. Basalt artifacts and adze scatters are perhaps the most robust archaeological resources in the Polynesian archaeological record, which has made them a primary focus of archaeological research on Tutuila (e.g. Best et al. 1992; Clark 1980, 1993; Clark et al. 1997; Crews 2008; Johnson 2005, 2011; Johnson et al. 2007; Kikuchi 1963; Leach and Witter 1985, 1987, 1990; Winterhoff 2007; Winterhoff and Rigtrup 2006; Winterhoff et al. 2007).

Basalt adzes and quarries are ideal for testing the implications of economic intensification and specialization on Tutuila for multiple reasons. First, unlike organic materials that may have been incorporated in economic intensification and specialization,

basalt artifacts have endured millennia of environmental exposure relatively intact. Second, basalt adzes can be studied for evidence of specialization, but they are the product of a reductive manufacturing process left behind at multiple basalt scatters recorded across Tutuila (Clark 1987; Clark et al. 1997; Johnson et al. 2007; Winterhoff 2007), which also can be analyzed for evidence of specialization. Third, elemental analysis can provide provenance information on basalt, which informs the investigation of distribution and consumption if basalt tools.

These basalt adze quarries and scatters can be investigated to understand the organization of production involved in the manufacture of basalt adzes on Tutuila. Defining the organization of production for such an important and necessary technology has direct implications into understanding greater societal organization and interaction, because adzes were necessary tools for regular household activities; but were also required by other specialists in their endeavors such as building houses, canoes, and woodcrafting (Buck 1930). Ultimately this means that an investigation of adzes and adze scatters not only informs the organization of the production of that particular technology and the potential for increased specialization, but the evidence for increased production and specialization of basalt adzes can serve as a proxy for understanding the intensification of other potentially specialized economic activities that required basalt adzes (e.g. canoe specialists, house construction specialists, etc.).

The societies of the Polynesian islands have served as a paradigm for the anthropological definition of social stratification (e.g.; Earle 1978; Kirch 1984, 1997; Kirch and Green 2001; Sahlins 1958, 1972). A hallmark of increased social stratification and complexity within Polynesian chiefdoms is economic intensification and chiefly sponsored

specialization (Sahlins 1958, 1972; Kirch 1984). Kirch (1984) states that all Polynesian societies are marked by intensification of production and specialization. Sahlins (1972:148) defines this as, "intensification of domestic production by political means and for public purposes."

Polynesian economic specialization is often typified by the intensification in the Hawaiian Islands development of large-scale agricultural taro cultivation (Kirch 1984), and basalt adze manufacture at sites such as the Mauna Kea adze quarry (Cleghorn 1986). Sahlins (1972) description of the political motivation for specialized production is perhaps best represented archaeologically through the model of attached specialization (Earle 1981; Brumfiel and Earle 1987; Costin 1991). Attached specialization is the total dedication of labor to a specific task through the sponsorship or patronage of an elite political agent (Earle 1981).

An important concept of the Earle (1981), and Sahlins (1972) definitions of attached specialization is the dedication of labor to a specialized endeavor. Their models of attached specialization require total labor dedication towards the specific economic activity (i.e. plant cultivation, stone tool manufacture, pottery manufacture, etc.). Along with the notion of attached specialization, Costin (1991) also developed parameters for a mode of independent specialization. The primary differences between attached and independent specialization is the involvement of elites in production. While attached specialists produce for an elite patron, independent specialists operate outside of elite patronage and produce for the market.

Winterhoff (2007) recently investigated basalt adze manufacture on Tutuila, and determined there was specialized adze manufacture during the Monument Building Period as a result of economic intensification sponsored by local elites (i.e. Costin's (1991) Attached

Specialization). Costin (1991) has established that while defining production is an important criterion in the investigation of specialization, understanding the distribution and consumption of those technologies is just as crucial in the definition of economic specialization.

Accordingly, Sections 2 and 3 of this research describe elemental analysis methods utilized for investigating basalt adze distribution and consumption on Tutuila. Utilizing Davidson's (1977) chronology of Samoan culture, and incorporating Costin's (1991) parameters for specialization, Section 4 of this research will employ elemental and technological analyses data to evaluate the potential for specialization in fine-grained basalt adze production at the East Tutuila upland Lau'agae quarry complex (AS-21-100).

1.3 MATERIALS AND METHODS

This project utilized technological and elemental analyses of fine-grained basalt adze production, distribution and consumption on the Samoan island of Tutuila. The materials analyzed were fine-grained basalt artifacts. The majority of the artifacts analyzed in this research were recovered from fine-grained basalt adze quarry complexes and scatters. Archaeological sites included in these analyses were the fine-grained basalt quarries Alega (AS-23-22), Asiapa (AS-23-31), Lau'agae (AS-21-100), and Tataga-matau (AS-34-10), as well as basalt artifacts from the archaeological residential site of Tula (AS-21-001). Fine grained basalt debitage, adze flake blanks, and adze preforms were included in both the technological and elemental analyses. A total of 1,785 fine grained basalt artifacts were analyzed for this research.

The technological analyses utilized in this research included a modified mass analysis (Ahler 1989; Kahn et al. 2009; Turner and Bonica 1994; Winterhoff 2007) of debitage and typological attribute analysis on basalt adze blanks and adze preforms recovered from the site AS-21-100. The maximum width, length, thickness, and weight was recorded on each artifact. When discernable, the cross-section of basalt blanks and preforms (complete and incomplete) were recorded, and when possible typed according to Green and Davidson's (1974) typology of Samoan adzes. Various descriptive statistics were utilized to analyze and interpret the metric attribute data recorded during the technological analyses.

Elemental analyses were performed on 138 fine-grained basalt samples from the archaeological sites of Alega (n=30), Asiapa (n=30), Lau'agae (N=30), Tula (n=18), and Tataga-matau (n=30). Both Instrumental Neutron Activation Analysis (INAA) and Energy Dispersive X-ray Fluorescence (EDXRF) were utilized on samples from the four quarry complexes of Alega (AS-23-22), Asiapa (AS-23-31), Lau'agae (AS-21-100), and Tataga-matau (AS-34-10). However, only EDXRF analysis was conducted on the artifacts recovered from Tula (AS-21-001). Multivariate exploratory statistical analyses were utilized to explore the elemental concentration data of no less than 16 elements (EDXRF) and as many as 28 elements (INAA). Multivariate statistical analyses for Section 2 and Section 3 were performed using SPSS v11 for Mac OSX, and exploratory multivariate statistical analyses for Section 4 were performed with IBM SPSS v20.

Basalt and other fine-grained volcanic materials are extremely amenable to chemical characterization provenance studies due to their homogenous internal chemical composition. Although both INAA and EDXRF were successfully applied toward the differentiation of samples in this research, there are fundamental differences between the probing and resultant

quantification entities of these two methods. These differences should be understood in order to make an informed decision prior to choosing between the techniques for an analysis of archaeological lithic materials.

For XRF analysis, the probing entity is an X-Ray that strikes atoms in the target sample, and displaces an inner shell electron. The ejection of an inner shell electron is referred to as excitation, and when an atom is in an excited state it returns to its grounded state through the replacement of the vacancy left in the inner shell by an outer shell electron. As an outer shell electron replaces an inner shell electron, a corresponding x-ray is released. These x-rays are the quantification entity for XRF, and the process through which they are released is termed fluorescence. The fluorescent energy of an emitted quantification x-ray corresponds to the difference in energy between the displaced inner shell electron and the replacement outer shell electron. The energy of the fluorescent x-ray can in turn be measured because the energies of electrons are known and are unique to each element (Glascock 2011; Jenkins 1999; Shackley 2011).

To achieve quantitative analysis with EDXRF, a method must first be calibrated for the specific material using known concentrations of each target element (analyte) derived from comparable geologic standards. The EDXRF method utilized in this research was calibrated by the author utilizing 9 USGS and NIST fine-grained volcanic rock standards (Johnson 2011). The calibration established the expected range of elemental concentrations for the sample materials as well as the energy required by the instrumental probing entity to achieve excitation of the target analytes.

Unlike XRF, which affects electrons, INAA targets the nucleus of atoms within a sample. For INAA, the sample is irradiated by the probing entity (neutrons) resulting in

radioactive isotopes. These radioactive isotopes release gamma-rays, which are the quantification entity of INAA. Elemental concentrations can then be derived from these gamma-rays by counting radioactive decay rates for each isotope then comparing the rates of decay for unknown samples to rates of decay for geologic standards, which are irradiated and counted concurrently with the unknown samples. However, not all isotopes decay at the same rate. To compensate for differential decay rates between isotopes, multielemental characterization with INAA requires both a short irradiation and short count time and long irradiation and long count time. The short irradiation and count are used to measure isotopes with known short half-lives and long irradiation and counts is employed to measure those with longer half-lives (Eehman 1991; Glasscock 2011; Parry 1991). These multiple counts result in much longer analysis times than are routinely achievable with EDXRF.

Although there are fundamental differences in the probing and quantification entities of XRF and INAA, these differences were not factors in the selection of either technique for this research, because the samples included in this research exceeded the minimum size and surface requirements for XRF. However, the difference in probing entities of INAA and XRF can dictate the application of the methods when the physical dimensions of a sample fall below a certain threshold. INAA is a method of bulk analysis, wherein the entire sample is irradiated and analyzed, and thus is amenable to the analysis of small and irregularly shaped samples because the entire sample is targeted by the probing entity. Unlike INAA, XRF requires that a much larger minimum sample and relatively uniform surface be presented to the probing entity. The probing x-ray can be tailored to a specific size using a collimator, but it cannot overlap or envelope the entire sample. Research has established that

a geologic sample analyzed with EDXRF should be no less than 10 mm in diameter and 2 mm in thickness (Davis et al. 1998; Lunblad et al. 2008).

To that end, INAA has recently been successfully applied to the characterization of fine-grained volcanic rock microdebitage that didn't meet the minimum sample size requirements of XRF (Eerkens et al. 2007). Eerkens and colleagues (2007) analysis of fine grained volcanic rocks (FGVR) microdebitage utilizing INAA demonstrated distribution and consumption of FGVR in Western North America not previously detected through decades of analysis using EDXRF. Although samples smaller than 10 mm in diameter are not included in this research, applications of INAA for the analysis of microdebitage (Eerkens et al. 2007) could provide important data to future archaeological research in Polynesia, as the current research paradigm has focused primarily on larger basalt artifacts.

1.4 SECTION INTRODUCTIONS

Section 2 addresses the analysis of elemental concentration data from chemical characterization to differentiate multiple basalt adze quarries on Tutuila. This section presents the novel application of Instrumental Neutron Activation Analysis (INAA) in an attempt to differentiate between multiple basalt quarry complexes on Tutuila using elemental concentration data. The research in Section 2 utilized INAA for the first time in the analysis of Polynesia basalt adze quarries. INAA has been described as the "technique of choice" (Bishop et al 1990), and previous analyses utilizing x-ray fluorescence (XRF) had not differentiated fine-grained basalt quarries on Tutuila (Clark et al. 1997).

Section 3 addresses the evaluation of the efficacy of two major chemical characterization techniques in the elemental analysis of basalt adze quarries on Tutuila.

Section 3 explores the application of two different techniques of elemental analysis (INAA and EDXRF) to determine which technique is the most efficacious at provenance analysis on fine-grained basalt artifacts from Tutuila.

Although XRF had been previously unsuccessful in the differentiation of intra-island distribution and consumption of fine-grained basalt from Tutuila, a methodological comparison of the efficacy of EDXRF and INAA toward the elemental differentiation of Tutuilan basalt quarries was conducted. This comparison was conducted because XRF is the most popular and available elemental analysis technique employed in studies of Polynesia basalt. Additionally, XRF analysis is relative inexpensive, has considerably shorter analysis times than INAA, and can be conducted in a non-destructive manner.

Section 4 addresses the application of elemental concentration data from basalt adze quarries on Tutuila toward the investigation of economic specialization at the Lau'agae quarry. This section presents an application of the refined elemental analysis methods described in Section 3 toward the analysis and interpretation of basalt adze distribution and consumption, and economic specialization on Tutuila. Elemental analysis data augmented the technological analysis of basalt artifacts recovered from the Lau'agae ridge quarry complex, and provided evidence for potential economic specialization of basalt adze manufacture at AS-21-100.

2. ELEMENTAL ANALYSIS OF TUTUILAN BASALT QUARRIES*

2.1 INTRODUCTION

The Samoan island of Tutuila (Fig. 2.1) has long been thought of as a prominent source of fine-grained basalt in West Polynesia, as indicated by the missionary Heath in 1840 in a communication to the weekly Honolulu paper The Polynesian,

> ‘‘At Tutuila, however is found the hard stone (Trap) of which the Polynesian adzes and other tools were made previously to the introduction of iron. At the other islands the stone is almost uniformly porous of a dull black color. (Heath 1840)’’

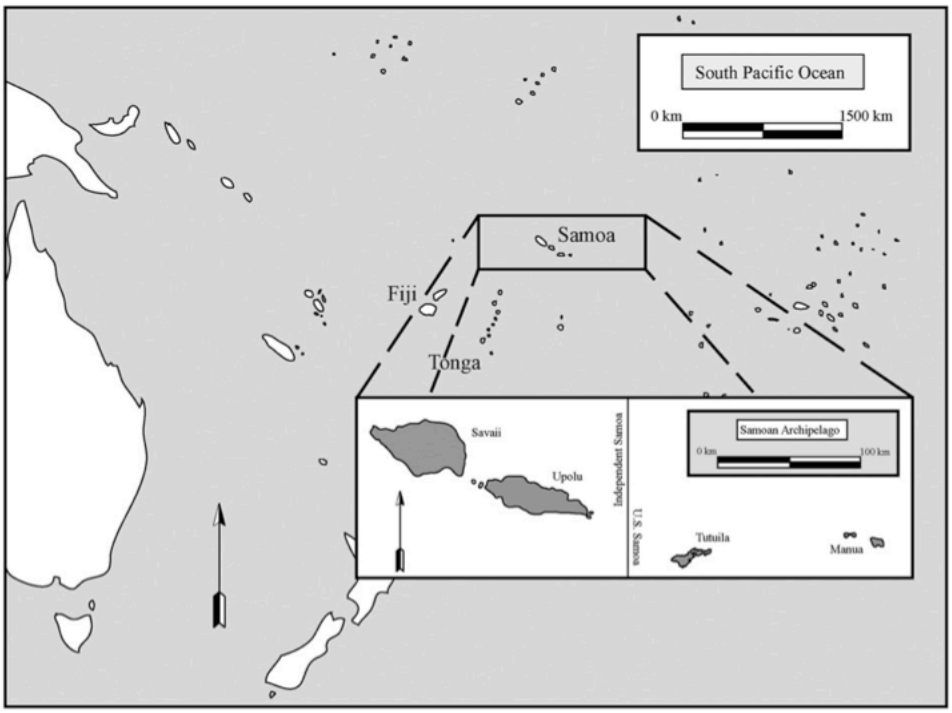

Figure 2.1. The Samoan Archipelago

*Reprinted with permission from “INAA of pre-contact basalt quarries on the Samoan Island of Tutuila: a preliminary baseline for an artifact-centered provenance study.” by Johnson, P., Pearl, F., Eckert, S., and James, W. (2007) *Journal of Archaeological Science* 34(7): 1078-1087. Elsevier Press

Sir Peter Buck (Te Rangi Hiroa) began the investigation of Tutuilan basalt quarries in 1927 with his search for the quarry known as Tataga-matau (Buck, 1930). In his investigation, Buck was told by Leone village elders that, ‘‘people came from all parts of Tutuila to obtain stone adzes at Tatagamatau’’ (Buck 1930:331). Although early research focused primarily on the Tataga-matau quarry complex (Buck 1930; Leach and Witter 1987, 1990), more recent investigations have discovered multiple basalt exploitation sites on the island of Tutuila (Clark 1989). In fact, Tutuila contains the only known basalt quarries in the Samoan archipelago (Green and Davidson, 1974). These sites range in size and scope from the large quarry complexes of Tataga-matau, Fagasa, and Faga’itua, to smaller less extensive areas of basalt exploitation and tool manufacture (Table 2.1).

Quarry	Site no.	Size (m^2)	References
Alega 1	AS-23-022	123	Clark (1992) and Clark et al. (1997)
Alega 2	AS-23-023	495	Clark (1992) and Clark et al. (1997)
Alega 3	AS-23-029	250	Clark (1992) and Clark et al. (1997)
Asiapa	AS-23-031	205	Clark (1989) and Clark et al. (1997)
Fagasa 1	AS-26-010	27000	Best (1993) and Clark et al. (1997)
Fagasa 2	AS-26-011	525	Best (1993) and Clark et al. (1997)
Faga’itua	–	16000	Clark (1989) and Clark et al. (1997)
Lau’agae	AS-21-100	10000	Clark (1989), Clark et al. (1997) and Moore and Kennedy (1996)
Le’aeno	AS-21-110	50	Clark (1989) and Clark et al. (1997)
Leafu	–	123	Best et al. (1992) and Leach and Witter (1985, 1987)
Masui’s	AS-25-071	–	Report on file at ASHPO
Tataga-Ml	AS-34-010	–	Best et al. (1992), Best et al. (1998) and Leach and Witter (1985, 1987)
Tataga-M2	AS-34-010	–	Best et al. (1992), Best et al. (1998) and Leach and Witter (1985, 1987)
Tataga-M3	AS-34-010	–	Best et al. (1992), Best et al. (1998) and Leach and Witter (1985, 1987)
Usi 1	AS-23-012	70	Clark (1989) and Clark et al. (1997)
Usi2	AS-23-014	300	Clark (1989) and Clark et al. (1997)
Vai’s	AS-25-072	–	Report on file at ASHPO

Table 2.1. Tutuilan Basalt Quarries

The scale and complexity of certain quarry sites and their association with large-scale assemblages of stone tool grinding dishes or whetstones (fo'aga) are factors that have led to the proposal of Tutuila as a possible industrial center of basalt tool manufacture for the purpose of exchange (Best et al., 1992; Clark et al., 1997). Provenance study of Tutuilan material has often tested the possibility of long-distance inter-island exchange (Best et al., 1992; Weisler 1993a; Weisler and Kirch 1996). Chemical characterization has identified basalts of Tutuilan origin as far as 1600 km from their source, on Mangaia (Weisler and Kirch 1996), and several provenance studies have linked Tutuila with stone tools recovered throughout the Pacific (Allen and Johnson, 1997; Best et al., 1992; Weisler 1993a).

Although Tutuilan basalts have been identified on other Pacific islands they were not always confidently traced to an individual quarry of origin (Allen and Johnson 1997; Best et al. 1992; Clark et al. 1997). One factor that may have limited confident quarry-level artifact assignment is that Tutuilan provenance studies have primarily focused on artifacts and artifact assignment, not on the definition of quarry source geological variability. Initial attempts to distinguish intra-island quarry signatures did not achieve confident differentiation between multiple Tutuilan quarries (Best et al. 1992; Clark et al. 1997). In 1993, Marshall Weisler addressed this issue stating, ''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'' Weisler (1993b:68). Before an artifact can be confidently sourced to the Tutuilan quarry of its origin, a comprehensive analysis of each known Tutuilan quarry must be completed to properly define the study area. In order to achieve that goal, the rubric of Samoan provenance study must shift. To that end, the primary focus of this research is the definition of the geological

variability of individual Tutuilan basalt quarries, not the investigation of artifact assignment. Only geologic samples were considered for this project, as the immediate goal was to establish preliminary baseline data for select Tutuilan basalt quarries. To do this, we must meet two objectives. First, we must determine whether geochemical variation in Tutuilan basalts is detectable using instrumental neutron activation analysis (INAA) as the analytical approach. Second, any detected variation using INAA must be sufficient to differentiate between intra-island quarries. Successful completion of these two objectives stands to create the foundation for INAA provenance studies of Samoan basalt. With the continued progress of chemical characterization in Polynesia (Weisler 2002, 2003) and the complexity of questions centered on Samoan involvement in Polynesian basalt trade networks, this level of analysis will be a valuable contribution to Polynesian archaeological research.

2.2 GEOGRAPHY AND GEOLOGY

The Samoan archipelago lies east of the andesite line, a boundary that splits the South Pacific into separate geologic divisions. The extrusive rocks found on volcanic islands to the east of the andesite line are composed of basalt. The Samoan islands are a series of oceanic basalt shield volcanoes that trend easterly at approximately 14 south latitude and 170 west longitude (MacDougall 1985; Natland 1980), and Tutuila lies in the center of the archipelago (Fig. 2.1). The Tutuilan shield-building lavas are mostly alkalic olivine basalts and hawaiities that provide fine-grained material for lithic manufacture (MacDonald 1944). The Tutuilan landscape is deeply dissected, as a precipitously abrupt montane interior contrasts narrow coastal flats and valleys. The only substantial uninterrupted portion of the island is the broad level Tafuna plain. This area on the southwestern flank of the island was formed in the

Holocene by the post-erosional Leone volcanism (MacDougall 1985; Stearns 1944). H.T. Stearns (1944) conducted the definitive geologic survey of Tutuila. Stearns (1944) characterized the island as the end product of four major shield volcanic centers Alofau, Olomoana, Pago, and Taputapu, as well as the more recent post-erosional Leone Volcanics (Fig. 2.2). In 1985, Ian MacDougall (1985) argued that the Alofau volcanics are not a discrete shield episode, but in fact the ‘‘eastern flank’’ of the central Pago volcano. For this project, the Alofau volcanics are not designated as a distinct volcanic episode, and in accordance with MacDougall (1985) included in the Pago volcanic province (Fig. 2.2).

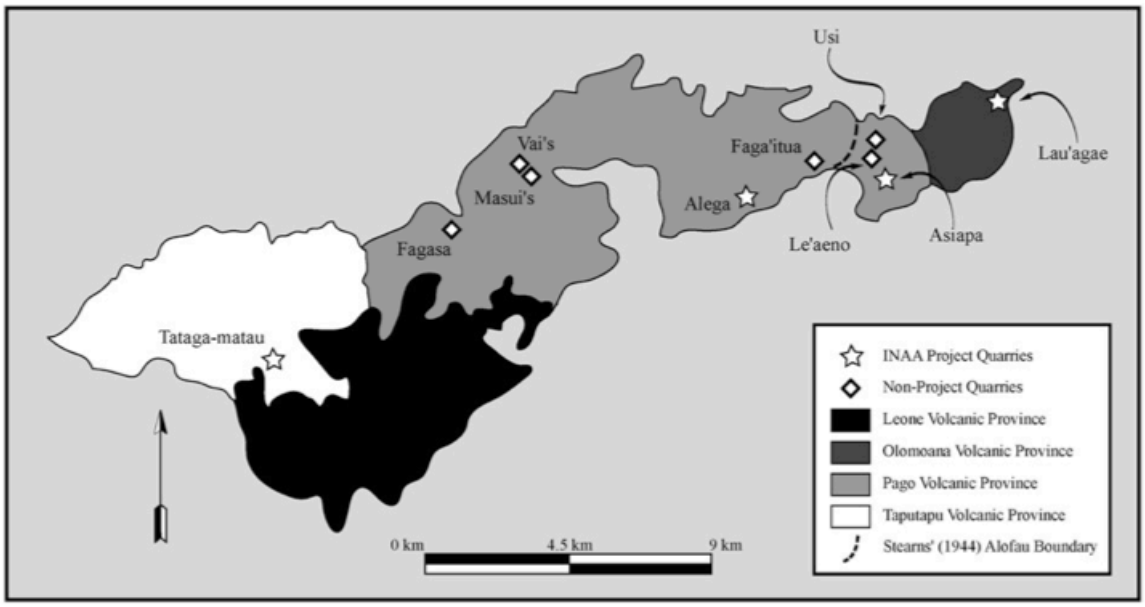

Figure 2.2. Samoan Island of Tutuila, adapted from Stearns (1944) and Clark et al. (1997)

2.3 TUTUILAN GEOCHEMICAL CHARACTERIZATION STUDIES

The archipelagos of Polynesia stretch great distances across the Pacific. Some islands are isolated by hundreds of kilometers of open water, but Polynesian ocean voyaging

tradition allowed for contact and interaction based on inter-island trade networks (Davidson 1977; Kaeppler 1978; Weisler 1997, 1998, 2002). Over the past two decades, provenance studies have become an integral method for investigation of Polynesian seafaring and inter-island interaction (Allen and Johnson 1997; Best et al. 1992; Clark et al. 1997; Rolett et al. 1997; Sheppard et al. 1997; Smith and Ambrose 1977; Walter and Sheppard, 1996; Weisler, 1993a; 1997; 1998; 2003; Weisler and Kirch 1996; Weisler and Sinton 1997; Weisler and Woodhead 1995; Weisler et al., 1994). In that time, Polynesian provenance studies have been primarily focused on the chemical characterization of basalt artifacts and their sources (Allen and Johnson 1997; Best et al. 1992; Clark et al. 1997; Moore and Kennedy 1996; Parker and Sheppard 1997; Rolett et al. 1997; Sheppard et al. 1997; Walter and Sheppard 1996; Weisler 1993a; 1997; 1998; 2002; Weisler and Kirch 1996; Weisler and Woodhead 1995; Weisler et al. 1994). Many chemical characterization studies of Polynesian basalt artifacts have included samples from the Samoan island of Tutuila (Allen and Johnson 1997; Best et al. 1992; Clark et al. 1997; Moore and Kennedy 1996; Weisler 1993a; Weisler and Woodhead 1995).

Prior to this project, geochemical provenance studies attempting to characterize Tutuilan basalts have primarily utilized X-ray fluorescence (XRF) (Allen and Johnson 1997; Best et al. 1992; Clark et al. 1997; Moore and Kennedy 1996; Weisler 1993a,b; Weisler and Kirch 1996), or isotope analysis (Weisler and Woodhead 1995). Beardsley and Goles (2001) used INAA to analyze obsidians from Rapa Nui, but this project represents the first application of INAA towards the characterization of Samoan basalts. Previous studies have successfully characterized individual quarry sources and identified inter-island movement of Polynesian basalts (Best et al. 1992; Clark et al. 1997). In Tutuilan provenance study, XRF

has successfully marked the inter-island exchange of Tutuilan basalts; see Allen and Johnson (1997), Walter and Sheppard (1996), and Weisler and Kirch (1996) for analysis of basalt from the Cook Islands; see Best et al. (1992) for analysis of basalt artifacts recovered in Fiji. These studies have succeeded in determining the island of origin for Tutuilan basalts, but no previous projects have confidently differentiated between multiple Tutuilan quarries.

2.4 SAMPLE SELECTION

Following Church (1994), our research is material-centered, and the necessary first step towards properly defining the variation of Tutuilan basalt quarries. While artifact-centered studies attempt to source artifacts to their geological origin, material-centered studies focus on geologic source material and are designed toward gathering baseline information (Church 1994). Material-centered analysis provides the foundation for confident artifact-centered provenance studies. Sample selection began with the determination of which quarries to include in the analysis. Two criteria were chosen to guide quarry inclusion. The first criterion was that all samples must be selected from quarries that had previously been chemically characterized to allow for the comparison of results with those previous attempts. Tutuilan quarries that had been previously characterized included: Alega, Asiapa, Faga'itua, Fagasa, Lau'agae, Le'aeno, Tataga-matau, and Usi (Best et al.1992; Clark et al. 1997; Moore and Kennedy 1996; Weisler 1993a; Weisler and Kirch 1996).

The second criterion was to choose quarries that would represent variation within volcanic provinces and between volcanic provinces (Weisler and Sinton 1997). As stated earlier, for this project the Alofau Volcanics (Stearns, 1944) are considered part of the Pago Volcanics according to MacDougall (1985). For this initial investigation, a single quarry was

analyzed from the Olomoana, Pago, and Taputapu volcanics to test inter-province variability, and a second Pago quarry was analyzed to test intra-province variation. No samples were tested from the Leone province because there are no known quarry sources in the Leone volcanics.

Statistical rigor required that the number of samples analyzed per quarry must be greater than the number of elements used in the analysis. The Elemental Analysis Laboratory typically reports 28 or 29 elements (based on their significance) in INAA characterization (Table 2.2). Rapp (1985) reports that the ideal number of samples to properly characterize a geological source using INAA is between 20 and 40. Considering these guidelines, it was determined that 30 individual samples would be an adequate preliminary amount to characterize each quarry. Phillip Johnson collected samples for this project in November 2004 from four separate quarry sites (Table 2.1): Alega from the Pago Volcanics (n =30), Asiapa also from the Pago Volcanics (n =30), Lau'agae from the Olomoana Volcanics (n =30), and Tataga-matau in the Taputapu Volcanics (n =30).

Geologic samples were selected using a stratified random strategy in an attempt to represent the variability of material and texture exploited at each site. Sample selection was restricted to the immediate area containing evidence of basalt exploitation. Artifacts were not selected because this was a material- centered attempt at defining the quarry source variation. Each of the 30 quarry samples were chosen from separate untested surface materials. Surface material was sampled because it is indicative of material exploited prehistorically (Clark et al. 1997; Leach and Witter 1985; Weisler and Sinton 1997). The term quarry is somewhat spurious when applied to Tutuilan archaeological sites. In accordance with Clark et al. (1997)

we use ‘‘quarry’’ to refer to a prehistoric site of fine-grained basalt exploitation and tool manufacture, and not necessarily to a method of basalt mining.

Element	Isotope produced[a]	Energy (keV)	Half-life
Short count (P-tube)			
Aluminum (AL)	^{28}Al	1779.5	2.24 min
Dysprosium (DY)	^{165}Dy	94.5	2.33 h
Magnesium (Mg)	^{27}Mg	1014.5	9.46 min
Manganese (Mn)	^{56}Mn	1811.4	2.58 h
Titanium (Ti)	^{51}Ti	319.7	5.76 min
Vanadium (V)	^{52}V	1434.1	3.75 min
Intermediate count			
Lanthanum (La)	^{140}La	1596.2	40.27 h
Lutetium (Lu)	^{177}Lu	208.4	6.71 days
Sodium (Na)	^{24}Na	1368.6	14.96 h
Samarium (Sm)	^{153}Sm	103.2	46.27 d
Uranium (U)[b]	^{239}Np	106.1	2.36 d
Ytterbium (Yb)	^{175}Yb	396.3	4.19 d
Long count			
Barium (Ba)	^{131}Ba	496.3	11.80 d
Cerium (Ce)	^{141}Ce	145.4	32.50 d
Chromium (Cr)	^{51}Cr	320.1	27.70 d
Cobalt (Co)	^{60}Co	1332.5	5.72 years
Europium (Eu)	^{152}Eu	1408.0	13.33 years
Hafnium (Hf)	^{181}Hf	482.2	42.39 days
Iron (Fe)	^{59}Fe	1099.2	44.50 days
Neodymium (Nd)	^{147}Nd	91.1	10.98 days
Rubidium (Rb)	^{86}Rb	1076.6	18.66 days
Scandium (Sc)	^{46}Sc	889.3	83.31 days
Strontium (Sr)	^{85}Sr	514.0	64.84 days
Tantalum (Ta)	^{182}Ta	1221.4	114.50 days
Terbium (Tb)	^{160}Tb	879.4	72.30 days
Thorium (Th)[c]	^{233}Pa	312.0	27.00 days
Zinc (Zn)	^{65}Zn	1115.6	243.90 days
Zirconium (Zr)	^{95}Zr	756.7	64.02 days

[a] Glascock, 1991.
[b] Neptunium (Np) is used to detect uranium.
[c] Protactinium (Pa) is used to detect thorium.

Table 2.2. INAA Elements

The actual mining of material is not probable for most Tutuilan ‘‘quarry’’ sites, with the possible exception of Tataga-matau (Clark et al., 1997; Leach and Witter, 1985). In fact throughout Polynesia there is scant evidence to support the extraction of fine-grained basalt for tool making; at most Polynesian quarries the exploited basalt was derived from erosional surface features and dykes (Weisler and Sinton, 1997).

2.5 CHEMICAL CHARACTERIZATION

Under the supervision of Dr. William D. James, of the Elemental Analysis Laboratory (EAL), all samples included in this project were processed at the Texas A&M University Center for Chemical Characterization and analyzed using instrumental neutron activation analysis at the Texas A&M Nuclear Science Center's 1 MW TRIGA research reactor. Sample preparation and analysis was conducted according to established EAL methods (James et al., 1995). The samples submitted for INAA were comprised of 50 mg of non-cortical material. Control measures included the duplication of every seventh sample as well as inclusion of National Institute for Standards and Technology (NIST) 1633a coal fly ash, and NIST SRM 688 basalt.

2.6 WHY INAA?

This is the first application of INAA towards the characterization of Samoan basalts. INAA was chosen as the analytical method for this project because it is one of the most sensitive and accurate tools for chemical characterization available through the Texas A&M Center for Chemical Characterization. INAA has greater analytical sensitivity than previous methods (Neff 2000; Bishop et al. 1990); Weisler and Kirch (1996:1383) suggest the use of

more sensitive methods such as INAA may be necessary when attempting to differentiate, ‘‘Oceanic basalts that are highly similar in geochemical composition.’’ According to Bishop et al. (1990:539), ’’ in comparison to fully quantitative XRF, INAA is more sensitive and can detect some elements having concentrations as low as a few parts per billion.’’ This sensitivity has established INAA as a preferred technique in archaeometric sourcing analyses (Bishop et al. 1990; Neff 2000). It was determined that the sensitivity of INAA over other methods, could be a key factor in the differentiation of Tutuilan basalt quarries.

2.7 STATISTICAL METHODOLOGY

To explore the possible affiliation of samples based on compositional variability, both canonical discriminant analysis (CDA) and principal component analysis (PCA) were applied to the INAA data (Baxter 1994; Glascock 1992). Initially, CDA was applied to test the affiliation of the samples with an assigned quarry of origin. After the application of CDA the samples were treated as of unknown origin and PCA was used to differentiate between the quarries. Prior to statistical analysis, all INAA data were log base-10 transformed (Baxter 1994; Glascock 1992). All multivariate statistical methods were applied to INAA results using SPSS version 11 for Mac OSX.

2.8 RESULTS

The results of the INAA characterization clearly differentiate between the four quarries; and these empirical data strongly support the overarching goals that inspired this project. However preliminary, the level of differentiation produced by this characterization is extremely encouraging for the application of INAA towards future comprehensive definition

of Tutuilan quarry variation, and artifact sourcing. The quarry differentiation achieved through CDA provides definitive separation of the analyzed Tutuilan quarry sources. In accomplishing this task CDA has identified a ‘‘core group’’ of samples that create the preliminary baseline for future artifact-centered provenance studies; and although the differentiation produced by PCA is less perceptible than CDA, the results are encouraging; and further bolstering of the CDA baseline can be achieved by refining the application of PCA.

2.9 CANONICAL DISCRIMINANT ANALYSIS

Overall, the CDA results provide very clear separation between quarries. The first two-discriminant functions created by CDA represent the variability of over 93% of the sample population (Table 2.3), and a biplot of these first two discriminant functions displays definite differentiation of the quarries (Fig. 2.3). Quarry membership for each individual sample was set at a confidence of 0.95. Initially, each of the 120 quarry samples was predicted to the proper quarry of origin with confidence of at least 0.99. Only eight of the 120 samples were not predicted to the proper quarry membership with 1.00 confidence, and seven of the remaining eight samples were all predicted with the extremely high confidence of 0.999.

Function	Eigenvalue	% of Variance	Cumulative %	Canonical correlation
1	38.273	77.8	77.8	0.987
2	7.890	16.0	93.9	0.942
3	3.007	6.1	100.0	0.866

Table 2.3. CDA Functions

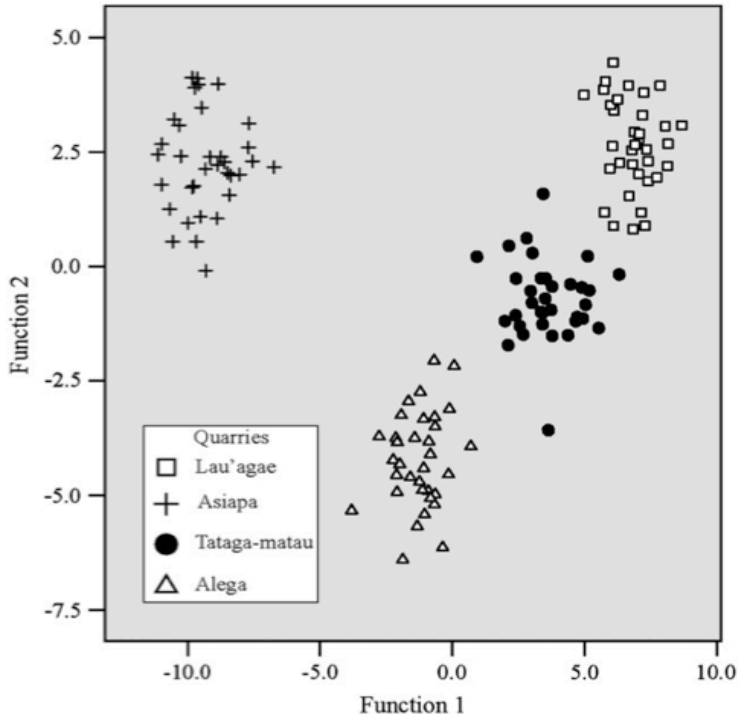

Figure 2.3. Biplot of CDA Functions 1-2

Of the 120 samples, sample PJ003 (collected at Lau'agae quarry) had the lowest initial confidence of quarry membership at 0.99747. After the initial CDA, the INAA data was analyzed using the stepwise or ''jack-knife'' CDA method to determine if the samples were appropriately assigned or if certain samples may be unknown (Duff 2002). After jack-knifing the data, only one sample's confidence dropped below 0.99. The probability of sample PJ003 belonging to Lau'agae quarry dropped from 0.99747 to 0.90123. This sample was deemed the only unassigned sample due to assignment confidence below 0.95.

2.10 PRINCIPAL COMPONENTS ANALYSIS

After successful differentiation of the quarries using CDA, the INAA results were explored using PCA, as if the samples were of unknown origin. This was done to test the

ability to distinguish between Tutuilan basalts of unassigned origin. Although PCA did differentiate the majority of quarry samples, it was predictably not as successful as CDA. This is apparent in the PCA biplot (Fig. 2.4). Although most of the intra-quarry samples group together, there is less apparent separation than in the CDA plot. The first two functions created by CDA represent 93% of the variability, while the first two PCA scores only provide 68%. The first two principal component scores simply do not represent enough variation to confidently differentiate between all analyzed quarries. When compared to the CDA results it is evident how the first two discriminant functions differentiate between the populations more successfully than the principal component scores.

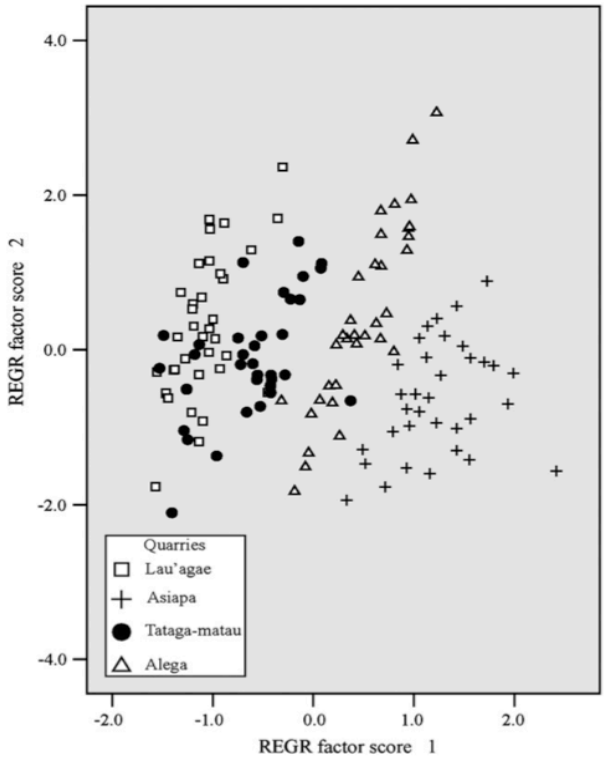

Figure 2.4. Biplot of PCA Scores 1-2

2.11 SUMMARY

The differentiation displayed in the INAA data illustrates clear separation of quarries based on inter-quarry chemical composition. The results of CDA on the data provide the unequivocal confidence of 1.00 assignment to proper quarry origin for 112 of the 120 samples. Of the eight samples below 1.00, seven were assigned with extremely high confidence at 0.999, while only sample PJ003 was rejected due to an assignment confidence of 0.90123. The remaining 119 samples create a definitive ‘‘core group’’ of geological quarry samples. This ‘‘core group’’ not only defines the individual quarries that are represented, but also establishes a preliminary baseline of geological quarry variation that can be used in comparative analysis and artifact provenance studies.

After the differentiation between the tested quarries was achieved, we attempted to determine if any particular elements may be observably driving the differentiation of the four quarries. The CDA structure matrix (Table 2.4) provided the significance for any given individual element in defining the variability between quarry samples.

According to the structure matrix, no single element significantly contributed to the variability for any of the three CDA functions. We plotted the most significant element in function 1 (vanadium) against the most significant element in function 2 (hafnium) to display the separation between quarries through individual elements (Fig. 2.5). These elements alone could not differentiate between all four analyzed quarries. Considering this data, it appears that the combination of multiple major and trace elements is necessary to differentiate between the selected quarry samples.

	Function 1	Function 2	Function 3
V	0.565	−0.087	0.012
TI	0.340	0.130	−0.029
CO	0.331	−0.055	−0.032
LA	−0.287	−0.081	−0.101
EU	−0.272	−0.084	−0.065
SM	−0.267	−0.090	−0.091
DY	−0.252	−0.084	0.017
CE	−0.247	−0.068	−0.097
YB	−0.232	−0.094	0.057
ND	−0.219	−0.076	−0.103
TB	−0.185	−0.060	−0.045
LU	−0.175	−0.126	−0.012
MG	0.172	0.039	0.135
ZR	−0.150	−0.124	−0.043
UR	−0.115	−0.040	−0.066
NA	−0.081	−0.026	−0.079
RB	−0.078	0.013	−0.050
HF	−0.161	−0.259	−0.191
CR	0.150	0.228	−0.225
SC	0.103	−0.168	0.030
FE	0.101	−0.146	−0.053
ZN	−0.083	−0.115	0.001
TA	−0.074	−0.146	−0.272
AL	−0.009	0.018	−0.216
TH	−0.171	−0.125	−0.205
BA	−0.096	0.011	−0.176
MN	−0.061	0.008	0.168
SR	−0.014	0.131	−0.134

Table 2.4. CDA Structure Matrix

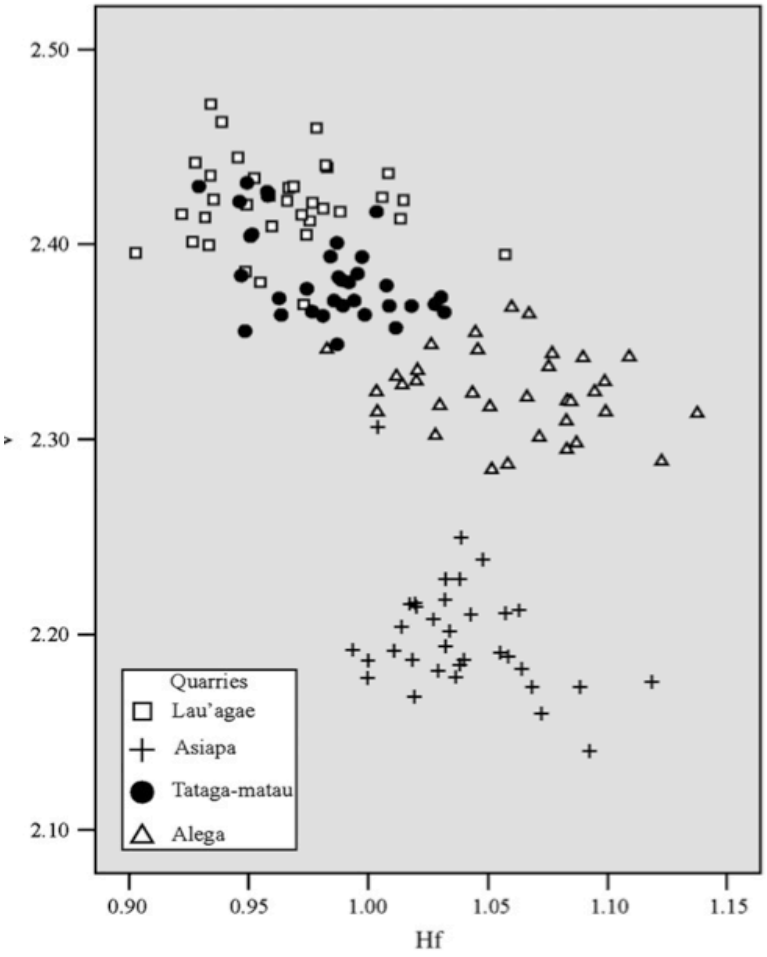

Figure 2.5. Biplot of Quarry Samples for Vanadium-Hafnium

2.12 CONCLUSION

Using compositional data generated with INAA we can confidently differentiate these four Tutuilan quarries based on their chemical variability. Unlike the results of prior characterizations, INAA resulted in clear quarry-level differentiation of all analyzed samples. Although successful in differentiating the quarries, data compiled in this project suggests that the chemical composition of the quarries analyzed offers a minute amount of inter-quarry variability. The detectable variability appears limited, but this project clearly displays that

Tutuilan intra-island quarry signatures are definable by sensitive methods of analysis such as INAA.

There were three key factors that allowed for successful differentiation of Tutuilan quarries. The first factor was sampling strategy. This project was designed as a material-centered characterization of quarry variation. Previous Tutuilan studies have included a majority of archaeological flakes; this project was strictly focused on material-centered characterization. This sampling strategy was used to ensure that only material derived at that source was included in the characterization of that source. The high level of cohesion within quarry samples supports this material-centered approach.

A second factor important to the success of this research was sample size. This project analyzed 30 samples per quarry in order to define the variation of each source. Although this number was a marginal amount of samples necessary for proper INAA characterization, it represented a much larger material-centered population than was attempted in any previous single characterization of geologic samples from Tutuilan quarries. The larger sample size allowed a more definitive characterization of quarry composition than previously attained.

The third important factor in the successful characterization of Tutuilan quarries was the use of INAA. Although INAA has been utilized in archaeological provenance studies of Pacific island ceramic vessels (Descantes et al. 2001, 2004) and obsidians (Beardsley and Coles 2001), it had not been previously utilized in the characterization of Samoan basalts. INAA is one of the most sensitive, precise and accurate methods of chemical characterization available (Bishop et al. 1990; Neff 2000). When considering the CDA structure matrix

(Table 2.4), this sensitivity appears to be key in differentiation between potentially highly similar samples.

2.13 DISCUSSION

The quarries included in this study were selected to test the ability of INAA to define intra-island variation, not to definitively establish that variation and construct a comprehensive baseline for future reference. As stated earlier there are multiple quarries on the island, the majority of which were not characterized in this analysis; but the results of the analysis were extremely encouraging for the prospect of differentiating individual quarries on Tutuila. As is often the case of any research project, the answers attained have left room for many other avenues of investigation.

Clearly future research needs to include the characterization of quarries not included in this project. To properly define Tutuilan intra-island basalt quarry variation it is necessary to characterize all known quarries as well as conduct surveys for locating more possible unknown quarries. At this point it is especially important to differentiate multiple quarries within the same volcanic province. Addition of more characterized quarries is necessary to increase confidence in the definition of variation among Tutuilan quarries. Our preliminary results display a distinguishable amount of variation between the analyzed quarries; however this trend of clear differentiation may not improve with the addition of future quarries.

Another important avenue of research includes the addition of samples from quarries characterized in this study. This study analyzed a marginal sample size required for rigorous statistical testing. Additional sampling for each quarry will increase the confidence of definitive characterization of a quarry. Further, basalt artifacts present at each quarry should

be characterized. Both material-centered and artifact-centered sampling should be employed to confirm the composition of each quarry.

Finally, future source analyses on Tutuila would benefit from a direct comparison of chemical characterization methods including isotopic analysis, XRF, INAA, and ICP-MS. A comparison of material-centered analyses will define which method (if any) is best suited for differentiating the fine-grained basalt quarries of Tutuila. This question is important because not all methods are widely available and some are more destructive than others (Shackley, 1998). Understanding the strengths and limitations of each method's ability to distinguish between quarries would allow for the optimal method to be applied in future provenance studies on Tutuila. This project represents a contribution to the foundation for provenance studies of Tutuilan basalts. The differentiation of multiple intra-island quarries was a necessary step in understanding Tutuilan basalt exploitation. The ability to clearly differentiate between multiple Tutuilan quarries was achieved using INAA, and the continued characterization of fine-grained basalts stands to create a wealth of knowledge and research into Tutuilan pre-contact economy, interaction and exchange.

3. COMPARISON OF INAA AND EDXRF ON TUTUILAN BASALT QUARRIES*

3.1 INTRODUCTION

The following section presents the results from recent applications of energy dispersive x-ray fluorescence (EDXRF) in the provenance study of fine-grained basalt procurement and production sites from the island of Tutuila, American Samoa. This research was designed to address two primary objectives. The first objective was the differentiation of 4 precontact fine-grained basalt procurement and manufacture sites using elemental compositional data derived from EDXRF analysis. The second objective of the project was to evaluate the efficacy of EDXRF in the differentiation of those sites when compared against previous differentiation of the same sites (Johnson et al. 2007) using instrumental neutron activation analysis (INAA).

Both XRF and INAA are widely established techniques for archaeometric provenance analyses (Bishop et al. 1990, Glascock 1992, Green 1998, Neff 2000, Shackley 1998a; 2011), but XRF is the technique of choice for the provenance analysis of Polynesia basalt artifacts and sources (Best et al 1992; Clark et al 1997; Kahn 2005; Lebo and Johnson 2007; Mills et al 2008; Sheppard et al. 1997; Weisler 1993a, 1993b, 1997, 1998; Winterhoff et al 2007). XRF is the most commonly utilized technique in Polynesia provenance studies. However, INAA was previously selected by the author for the differentiation of Tutuila basalt sources (Johnson 2005; Johnson et al. 2007) because Clark et al. (1997:81) reported difficulty

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*Reprinted with permission from "Elemental analysis of fine-grained basalt sources from the Samoan Island of Tutuila: applications of energy dispersive x-ray fluorescence (EDXRF) and instrumental neutron activation analysis (INAA) toward an intra-island provenance study", by Johnson, P. (2011) in: M. Shackley (Ed.), *X-ray fluorescence spectrometry (XRF) in geoarchaeology*. New York: Springer, pp. 143-161. Springer Press

differentiating between multiple intra-island Tutuila basalt sources (including those selected for this project) through XRF compositional data. The application of INAA at the Texas A&M EAL is thus far the only use of INAA toward archaeometric analysis of basalt sources in West Polynesia, and resulted in differentiation of multiple intra-island basalt procurement sites (Johnson et al. 2007).

Although differentiation of intra-island fine-grained basalt procurement sites was achieved using INAA, there were several factors that lead to this application of EDXRF for the analysis of Tutuila basalt sources and production sites. The first factor was the aforementioned preference, frequency and success for XRF analysis in the archaeometric provenance study of Polynesia basalt artifacts and sources. The second factor was that sample preparation and analysis for EDXRF is less time consuming and destructive than sample preparation and analysis for INAA. The quicker turnaround in both the preparation and analysis of samples makes EDXRF attractive, especially when analyzing hundreds of samples.

In addition to quicker turnaround, the ability for possible nondestructive analysis of artifacts is especially compelling when dealing with culturally sensitive materials that may otherwise not be available for destructive analysis (Mills et al. 2008). The final factor leading to this research was the successful differentiation of several Tutuila basalt tool production sites by Winterhoff et al. (2007) using wavelength dispersive x-ray fluorescence (WDXRF). This successful WDXRF characterization of multiple basalt tool production areas located in a single valley was compelling support for the possibility to differentiate intra-island sources using EDXRF.

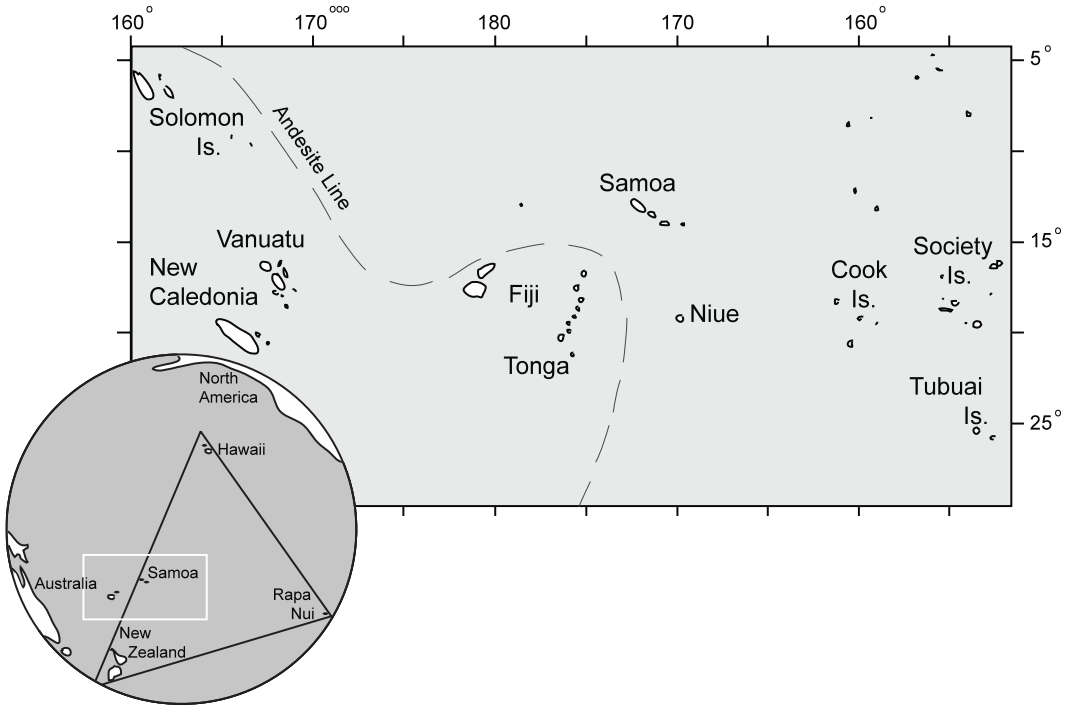

Figure 3.1. Map of the Polynesian Triangle and the Islands of West Polynesia

3.2 GEOGRAPHY AND GEOLOGY OF THE RESEARCH AREA

The Samoan archipelago is comprised of nine major islands formed by oceanic basalt shield volcanoes that trend easterly (MacDougall 1985). The West Polynesian island chain lies east of the andesite line (Fig. 3.1), a petrographic boundary that splits the South Pacific. Samoan shield building volcanism, comprised primarily of alkalic olivine basalts and hawaiities (MacDonald 1968), began several million years ago and ceased by approximately 1 million years ago (MacDougall 1985). The westernmost islands are the oldest and the Manu'a islands in the east are the youngest, but while shield building activity trended to the east, post-erosional volcanism trended westerly (MacDougall 1985; Natland 1980). The island of Tutuila lies in the center of the Samoan archipelago at approximately 14° South

Latitude and 170° E Longitude (Fig. 3.1). The third largest of the Samoan islands, Tutuila is a narrow mountainous landform approximately 138 km^2 in total area.

One of the earliest published commentaries on the geology of the Samoan islands was presented in a missive to the Honolulu based newspaper *The Polynesian* by the missionary T. Heath dated Saturday September 19, 1840. In his observations on the geological composition and diversity of the largest Samoan islands Heath said, "It has been stated that the surface of this group is almost entirely volcanic, so that the geologist will not find much variety. At Tutuila, however, is found the hard stone (Trap,) of which the Polynesian adzes and other tools were made previously to the introduction of iron. At the other islands the stone is almost uniformly porous and of a dull black color (Heath 1840)."

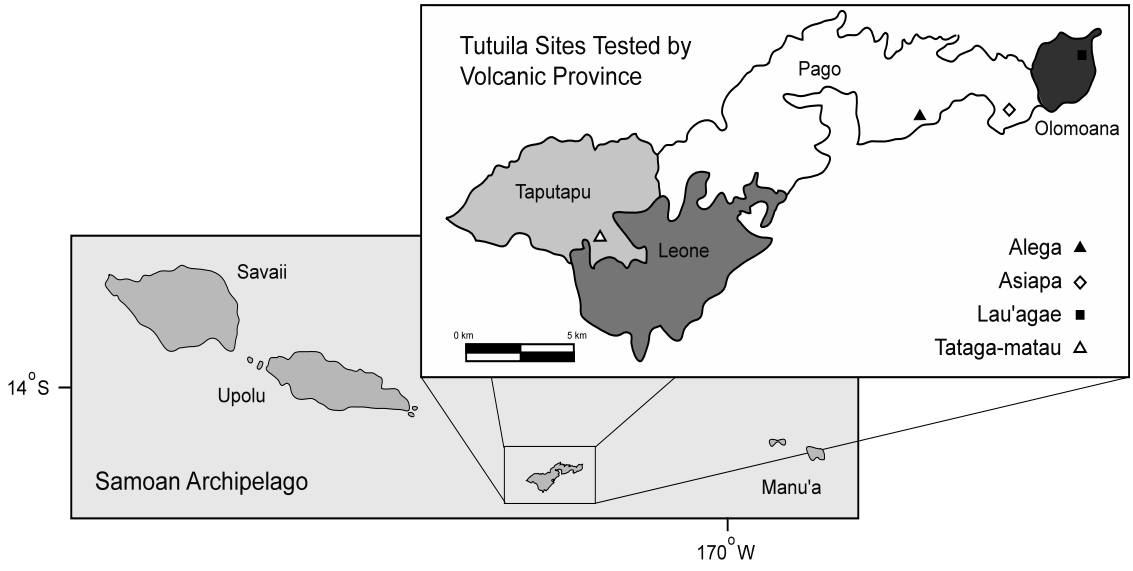

Figure 3.2. Map of Tutuila (from Stearns 1944)

Over 100 years after the observations of Heath, the Bulletin of the Geological Society of America published the foundational geologic survey and descriptions of Tutuila by H.T. Stearns (1944) along with the petrography of Gordon A. MacDonald (1944). Stearns (1944) defined five major volcanic provinces for Tutuila; the four essentially contemporaneous westward expanding shield volcanic centers Olomoana, Alofau, Pago, Taputapu and the post-erosional Leone Volcanics (Fig. 3.2).

Although the Stearns (1944) work remains a primary resource, recent research has added to the understanding of the island's formation (MacDougall 1985; Natland 1980, 2004; Wright 1986). MacDougall (1985) performed Ka-Ar dating that supports Stearns' (1944) chronology of contemporaneous shield building activity, but argues that the Alofau volcanics are actually contained within the eastern flank of the Pago volcanics. Sampling and analysis for this project was based primarily on Stearns' (1944) original interpretations but employed the interpretation of MacDougall (1985) and included the Alofau volcanics within the Pago volcanic province (Fig. 3. 2).

3.3 ARCHAEOLOGICAL CONTEXT

There are no less than 20 recorded fine-grained basalt procurement and production sites on the island of Tutuila (Clark et al. 1997, Johnson et al 2007, Winterhoff et al. 2007). The majority of recorded basalt procurement and production sites on the island have been briefly described (Clark 1989, Clark et al 1997), but the sites of Alega (Clark 1992), Lau'agae (Moore and Kennedy 1996), Maloata (Winterhoff 2007), and Tataga-matau (Leach and Witter 1987, 1990) have been the focus of more detailed discussions. This research sampled four previously recorded and characterized procurement sites from each shield

volcanic province (Fig. 3.2). The four sites included in this analysis were Alega (n=18), Asiapa (n=18), Lau'agae (n=18), and Tataga-matau (n=18). All four sites have been included in previous chemical characterization projects (Best et al. 1992; Clark et al. 1997; Johnson et al. 2007; Moore and Kennedy 1996). The sites of Alega and Asiapa were sampled from the Pago volcanics, samples from the site of Lau'agae in the Olomoana province were selected, and samples from Tataga-matau were selected to represent the Taputapu volcanics. There is currently no recorded basalt procurement site located in the Leone volcanics, which at the surface is comprised largely of post-erosional vesicular basalt and no samples were selected from this area.

Clark (1993) reported three areas of fine-grained basalt procurement and tool production above the modern village of Alega that he labeled Alega 1 (AS-23-22), Alega 2 (AS-23-22), and Alega 3 (AS-23-29). All samples for this research were collected from Alega 2 because modern industrial activity has destroyed the remnants of Alega 1 and Alega 3 (Johnson 2005). Asiapa (AS-22-31) is a site on the southeastern ridge of Asiapa mountain in the eastern flank of the Pago volcanics in the area that Stearns (1944) had previously identified as the Alofau volcanic province.

During the exploratory surveys of the East Tutuila Project Clark (1989) reported lithic scatters at the site that covered an area of approximately 205 m^2. The site known as the Lau'agae quarry (AS-21-100) is located on Cape Matatula in the eastern province of the Olomoana volcanics. Along with Alega and Asiapa this site was discovered during the survey of the East Tutuila Project (Clark 1989). Moore and Kennedy (1996) reported that the site consisted of no less than twelve discrete areas of basalt procurement and stone tool manufacture totaling approximately 10,000 m^2.

Tataga-matau (AS-34-10), located in the Taputapu Volcanics, is the most celebrated and investigated archaeological site on Tutuila, if not the entire Samoan archipelago. Investigation of this site began with Sir Peter Buck (Te Rangi Hiroa) in 1927 (Buck 1930), but it was not again investigated until Kikuchi (1963) and Clark (1980) revisited the Leone Valley. Tataga-matau was the subject of multiple investigations in the 1980's by Leach and Witter (1985, 1987, 1990) and Best and colleagues (1989). The site is described as a complex system of surface features including but not limited to: fortifications, mounds, pits, terraces, and three distinct basalt procurement and lithic manufacture areas (Best et al 1989). Tataga-matau has also featured very prominently over any other Tutuila basalt procurement and tool manufacture site in the investigation of long-distance interaction and exchange (Best et al. 1992; Clark et al.1997; Weisler and Kirch 1996).

3.4 REGIONAL CHEMICAL CHARACTERIZATION STUDIES

The island societies of Polynesia (Fig. 3.1) were established in the late Holocene through multiple long distance ocean voyages (Kirch and Green 2001) and maintained through inter-island and inter-archipelago maritime contact (Davidson 1977; Kaeppler 1978; Weisler 1998). This Polynesian diaspora and continued long-distance interaction has been a primary impetus for archaeological investigation, and the subsequent use of provenance analyses for investigation of ocean voyaging and interaction in the region.

Elemental analysis of lithic artifacts and their material sources has a long standing position in Polynesia archaeology, beginning with the early research of Roger Green (1962, 1964) on obsidian artifacts and sources and eventually the application of geochemical

provenance analysis on basalt artifacts and sources (e.g. Parker and Sheppard 1997; Weisler 1990, 1993b, 2003; Weisler and Sinton 1997; Weisler and Woodhead 1995).

Over the last two decades basalt artifacts have become the focus for the majority of geochemical provenance studies in Polynesia due to a dearth of pottery and volcanic glass or obsidian sources throughout the region. Most often basalt geochemical provenance analysis in Polynesia has been used in the investigation of inter-island exchange (Rolett et al. 1997; Sheppard et al. 1997; Weisler 1997, 1998, 2002; Weisler and Kirch 1996; Weisler et al. 1994).

The investigation of long-distance interaction has established the Samoan island of Tutuila as a significant source for fine-grained basalt throughout West Polynesia and across the South Pacific (Allen and Johnson 1997; Best et al. 1992; Clark et al. 1997; Weisler 1993a; Winterhoff 2007), and this evidence for the long-distance exchange of basalt artifacts has featured prominently in most geochemical provenance studies involving Tutuila. Although there are over 20 known basalt manufacture and production sites on Tutuila very few projects have focused primarily on the differentiation of multiple intra-island sources and artifacts (Clark et al. 1997; Crews 2008; Johnson et al. 2007; Winterhoff et al 2007). This project was designed as an addition to the growing body of research toward the characterization of intra-island fine-grained basalt source variability on Tutuila.

3.5 EDXRF MATERIALS AND METHODS

Sample preparation and EDXRF analysis for this project was conducted by the author at the Elemental Analysis Laboratory (EAL) in the Texas A&M University Center for Chemical Characterization. The EAL has been conducting archaeometric analyses for Texas

A&M and outside patrons for nearly two decades, but the majority of those projects have utilized INAA (James et al. 2007). This research represents the first application of quantitative EDXRF for an archaeometric provenance study at the EAL.

All analyses for this project were conducted on the EAL's Thermo *QuantX* EC EDXRF spectrometer equipped with a liquid nitrogen cooled Si(Li) detector. The spectrometer was calibrated for quantitative analysis using pure-element reference spectra and powdered geological standards from the United States Geological Survey (USGS) and the National Institute of Standards and Technology (NIST). A total of 9 USGS standards (AGV-1, BCR-2, BHVO-1, BHV0-2, BIR-1a, DNC-1, GSP-2, QLO-1, W-2) and 1 NIST standard (SRM-688) were used in this calibration.

All geologic standards used for calibration and control as well as the basalt samples from Tutuila were pressed into approximately 4g pellets. 18 samples from 4 separate sites were included in this research for a total number of 72 samples analyzed. All samples were collected in the field by the author in 2004, and the design for the original field sampling is detailed in Johnson and colleagues (2007). Basalt samples were selected for this project from reserved material previously collected for INAA (Johnson et al. 2007) and curated at the Texas A&M University Anthropology Department.

It was necessary to analyze pressed pellets because the majority of samples held in reserve from the previous INAA project were crushed internal fragments that were determined to be too small for direct (i.e. nondestructive) application of EDXRF (Lunblad et al 2008). For this project pellets were prepared by combining approximately 0.5 ml of a 3% solution of polyvinyl alcohol (PVA) binder with 4g of powdered rock material in a methylacrylate vial and ball set and then agitated for 5 minutes in a Spex Certiprep 8000

Mixer/Mill. After agitation, the powder/PVA mixture was pressed into pellets using a Spex Certiprep 25-ton laboratory press. After pressing the pellets were dried in a 110º oven for 3 hours.

During the analysis the USGS standard BHVO-2 and the NIST standard SRM 688 were included with the basalt samples as a control and repeatedly measured. EDXRF analytical conditions selected for the analysis for the Low-Za, Mid-Za, and Mid-Zc elements as designated in the WinTrace™ software were derived directly from the Polynesia basalt-specific methodology established at the University of Hawaii at Hilo by Lunblad and colleagues (2007:4; 2011)

3.6 RESULTS

This research reports concentrations for 15 elements attained through EDXRF analysis of basalt samples from Tutuila. Table 3.1 presents the mean and standard deviation of concentrations (ppm) for all reported elements from each site. As discussed above, the first objective of this project was to test the ability of EDXRF toward the differentiation of intra-island basalt procurement sites, and it is possible to differentiate between each analyzed site using the EDXRF elemental concentrations reported.

Biplots of the EDXRF elemental concentration (ppm) data achieve clear separation between the sites while displaying intra-site cohesion of samples with little or no observable inter-site overlap. Figure 3.3 is a biplot of titanium (Ti) and magnesium (Mg) concentrations that displays separation between all sites, with samples from the Pago volcanic province sites of Alega and Asiapa displaying the least amount of internal cohesion and some overlap with the Taputapu site of Tataga-matau.

Element	Lau'agae (n=18)			Asiapa (n=18)			Tataga-matau (n=18)			Alega (n=18)		
Al	89349.16	±	1860.93	89759.33	±	7715.37	86476.51	±	968.37	85807.30	±	2610.57
Ca	11560.67	±	311.75	13665.86	±	467.48	11990.28	±	337.30	12899.94	±	395.70
Cu	25.00	±	7.07	10.00	±	.00	14.44	±	6.16	11.11	±	3.23
Fe	100531.11	±	1479.17	90697.78	±	5238.21	97585.00	±	2084.18	97667.78	±	2106.797
K	13428.29	±	362.12	15873.58	±	542.10	13927.32	±	391.79	14983.93	±	459.62
Mg	25789.56	±	507.82	21769.23	±	1141.80	24806.84	±	441.63	22750.61	±	641.77
Mn	1243.87	±	42.59	1409.52	±	98.50	1351.86	±	52.07	1324.76	±	58.23
Rb	31.67	±	3.84	40.00	±	.00	32.78	±	4.61	37.78	±	4.28
Si	232030.46	±	1865.012	243541.95	±	2084.69	236857.56	±	2008.36	241356.93	±	1464.98
Sr	791.67	±	15.811	743.89	±	54.44	720.00	±	18.15	718.89	±	19.37
Ti	24219.54	±	400.93	18163.82	±	952.69	21566.37	±	508.73	19465.09	±	463.53
V	302.78	±	10.18	251.67	±	12.95	290.56	±	14.34	286.11	±	15.39
Y	41.11	±	4.71	56.67	±	8.402	42.22	±	4.28	51.11	±	3.23
Zn	170.56	±	8.02	182.78	±	14.061	167.78	±	6.47	176.11	±	11.95
Zr	89349.16	±	1860.93	463.33	±	21.69	401.67	±	15.44	478.89	±	11.32

Table 3.1. Mean and Standard Deviation for 15 Analytes Reported from EDXRF on the Four Fine-Grained Basalt Procurement Sites from Tutuila, American Samoa.

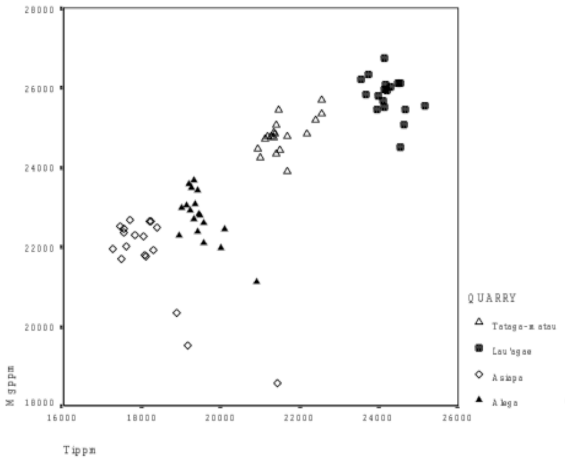

Figure 3.3. Biplot of Ti and Mg Concentrations (ppm) from EDXRF Data

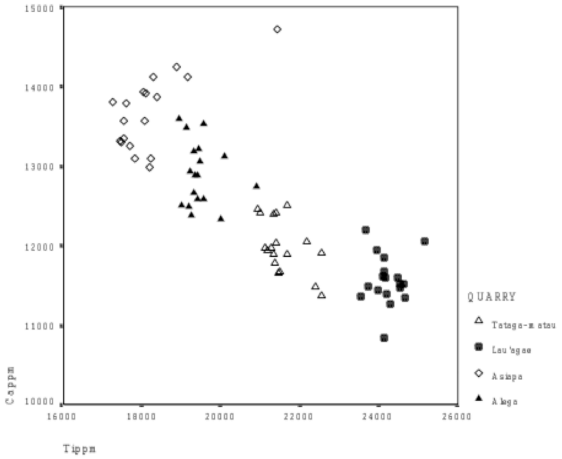

Figure 3.4. Biplot of Ti and Ca Concentrations (ppm) from EDXRF Data

Figure 3.4 displays differentiation of all 4 sites through a biplot of Ti and calcium (Ca), while again samples from Alega and Asiapa display the least amount of intra-site cohesion and some overlap with Tataga-matau. Although these biplots of EDXRF elemental concentrations display some overlap between several samples from the two Pago volcanic sites it is important to note that overall there is clear differentiation across and within intra-island volcanic provinces.

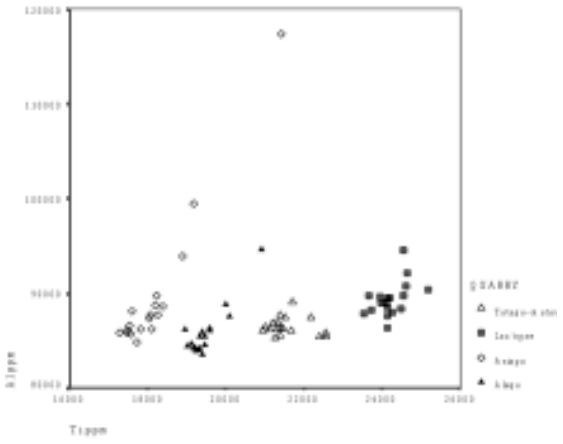

Figure 3.5. Biplot of Ti and Al Concentrations (ppm) from EDXRF Data

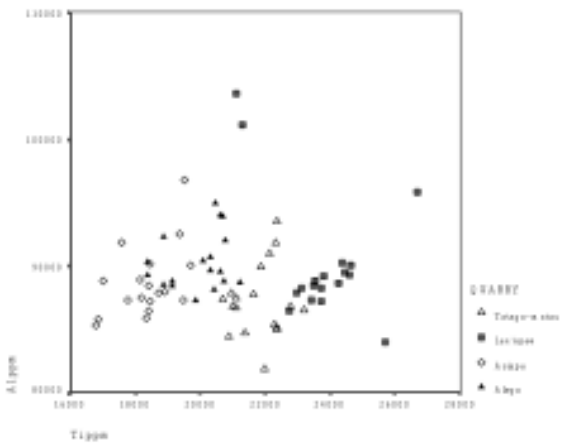

Figure 3.6. Biplot of Ti and Al Concentrations (ppm) from INAA Data

The second objective for this project was to compare the results of EDXRF analysis against the previous application of INAA (Johnson et al. 2007) on the same samples from the same sites. The purpose of this comparison is to investigate the efficacy of EDXRF for the differentiation of intra-island sites against differentiation achieved using INAA. Elemental concentrations for INAA on the same 72 samples from the sites of Alega, Asiapa, Lau'agae,

and Tataga-matau are not presented in this section but are reported by Johnson and colleagues (2007). The discussion of EDXRF data compared against INAA data is presented primarily through comparison of elemental concentration biplots, but also through the comparison of results from exploratory multivariate statistical analyses.

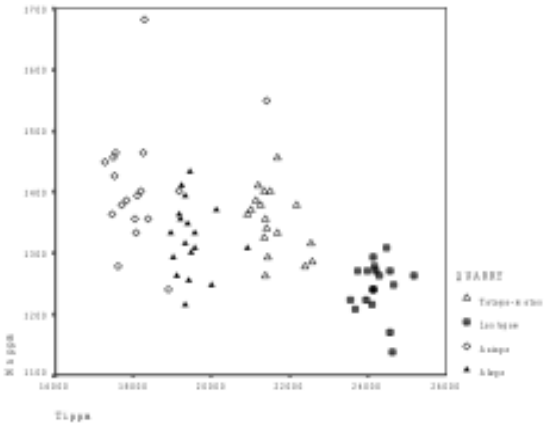

Figure 3.7. Biplot of Ti and Mn Concentrations (ppm) from EDXRF Data

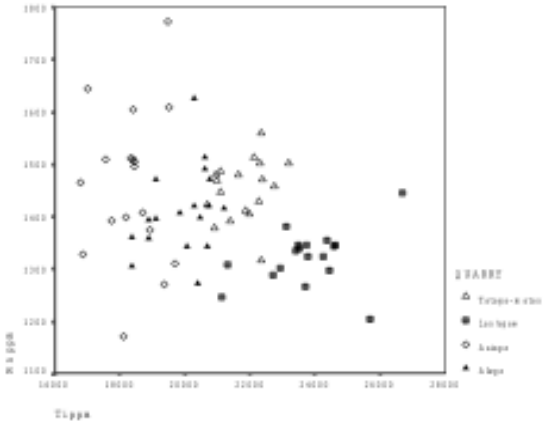

Figure 3.8. Biplot of Ti and Mn Concentrations (ppm) from INAA Data

Initially EDXRF and INAA data were compared through biplots of elemental concentrations (ppm) for titanium (Ti), manganese (Mn) and aluminum (Al). Figure 3.5 is a biplot of Ti and Al concentrations from EDXRF that displays intra-site group cohesion and clear separation between the 4 sites; while the INAA concentrations for Ti and Al (Fig. 3.6) produce a similar trend in differentiation for the same samples but display less evident intra-site cohesion and inter-site separation. A similar relationship between EDXRF and INAA data is evident in biplots for Ti and Mn concentrations. A biplot of EDXRF concentrations for Ti and Mn (Fig. 3.7) displays differentiation between sites, but a biplot for the same

elements from INAA concentrations (Fig. 3.8) does not display analogous inter-site differentiation.

Although the biplots of concentrations for certain elements reported for both EDXRF and INAA do not display similar levels of intra-site cohesion or inter-site differentiation there is a linear relationship in the separation of samples and sites that is evident in all of the biplots for both the EDXRF and INAA concentrations. In a previous application of XRF on basalt samples from Tutuila Clark and colleagues (1997:75) note a similar trend in the differentiation of multiple intra-island samples and sites and remark that, "Although the quarry samples fall into fairly well-defined groups that define a single fractionation trend on all applicable plots of major and trace elements, there is considerable overlap in quarries, even some that are widely separated geographically."

As the final step in this investigation of the EDXRF data, multivariate statistical analyses were applied to further explore variability and test the group cohesion between each site. Multivariate statistical analyses were also used in an attempt to mitigate the linear trend and overlap in site differentiation through the inclusion of multiple variables to define group cohesion and separation. The concentrations from the 15 elements reported for EDXRF and the INAA concentrations for 28 reported elements (Johnson et al. 2007) on the same 72 samples were included in the multivariate statistical analysis.

Principal component analysis (PCA) was used to further explore and classify possible groups beyond bivariate relationships, and then canonical discriminant analysis (CDA) was applied to confirm both bivariate and multivariate group affiliations (Glascock 1998, 2011). All data were Log (base 10) transformed (Baxter 1994) prior to multivariate exploratory

statistical analysis, and all multivariate statistical methods were conducted with SPSS version 11 for Mac OSX.

When the elemental concentration data for the 15 elements reported for EDXRF was explored using PCA the first two principal component scores represented over 71% of the total variability for the dataset, while the first two PCA scores of the INAA concentration data represented 67% of the variability for the same set of samples. Biplots of the first two PCA scores were produced for both the EDXRF (Fig. 3.9) and INAA (Fig. 3.10) elemental concentration data. The biplots of PCA scores for EDXRF and INAA data display dissimilar levels of inter-site differentiation and intra-site cohesion of samples as evident in the elemental concentration biplots and do not appear to display any sub-grouping.

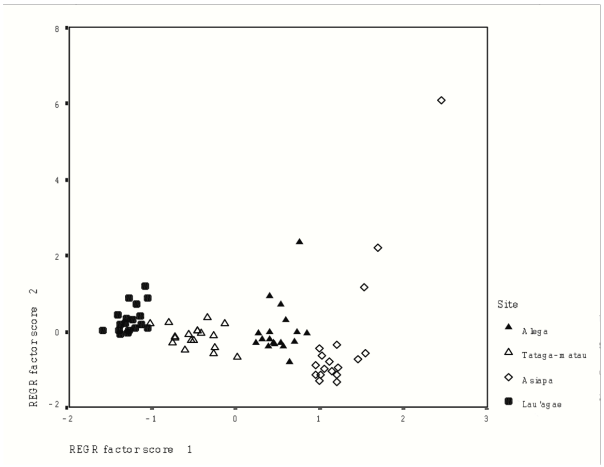

Figure 3.9. Biplot of the First Two PCA Scores from EDXRF Data

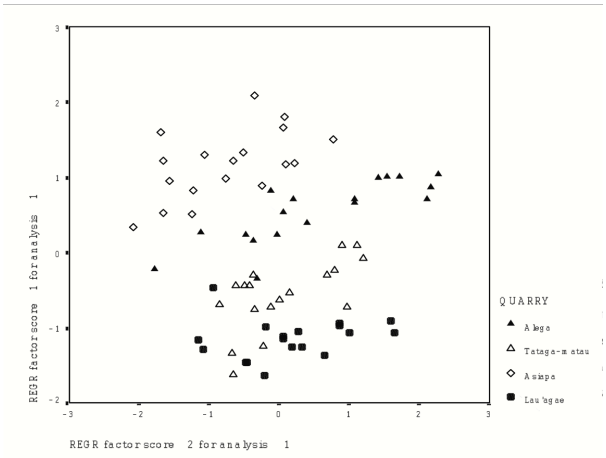

Figure 3.10. Biplot of First Two PCA Scores from INAA Data

The biplot of PCA scores for EDXRF data again displays a high level of intra-group cohesion and clear differentiation between the sites. The PCA data for INAA concentrations

displays a linear trend in intra-site clustering of samples and less evident differentiation between groups. Although the majority of PCA data for EDXRF clustered tightly, the linear trend more evident in the INAA plot is once again apparent in the samples from Alega and Asiapa.

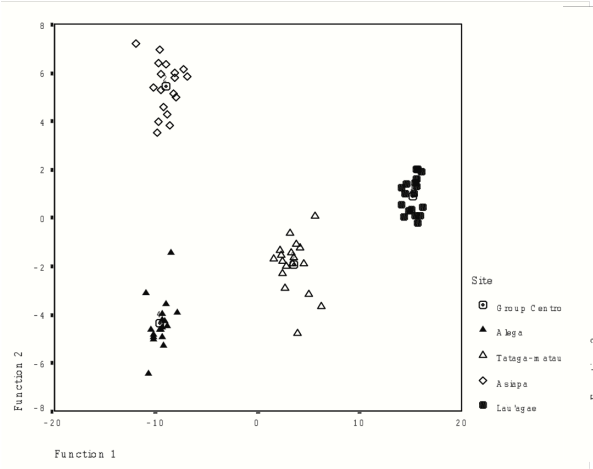

Figure 3.11. Biplot of the First Two CDA Functions from EDXRF Data

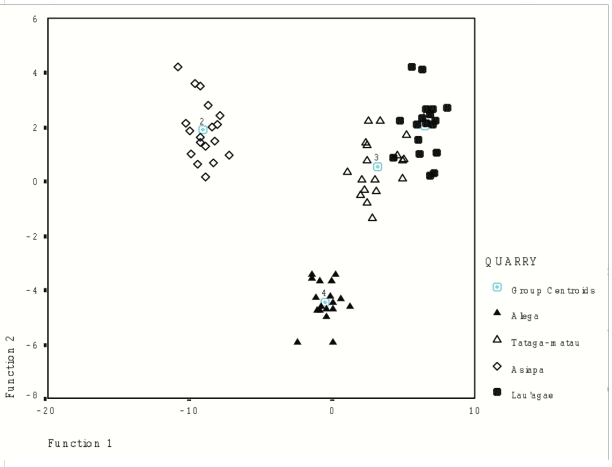

Figure 3.12. Biplot of First Two CDA Functions from INAA Data

After groups were classified through bivariate and multivariate analyses, a stepwise CDA was used to confirm the apparent group affiliation of the 18 samples for each of the assigned basalt procurement sites. For both the EDXRF and INAA datasets all 72 samples were assigned to the proper procurement site (or group) with no less than 95% confidence and at least 95% of the total variability for both datasets was represented in the first two discriminant functions. Biplots of the first two discriminant functions for both the EDXRF (Fig. 3.11) and INAA (Fig. 3.12) datasets are presented to display the differentiation of procurement sites as confirmed by canonical discriminant analyses. The plot of CDA

functions for EDXRF concentrations again displays high intra-group cohesion and shows very discrete separation of each site, and displays no overlap of the Pago Volcanic sites of Alega and Asiapa.

The plot of CDA functions for the INAA data also displays differentiation of each group including the previously overlapped Alega and Asiapa groups, but displays some overlap between the geographically isolated Lau'agae and Tataga-matau groups that is not evident in the same EDXRF plot. After applying multivariate exploratory analyses to the EDXRF concentration data both PCA and CDA confirm the expected intra-group cohesion and inter-group separation that was initially determined through bivariate plots of elemental concentrations.

3.7 CONCLUSIONS AND FINAL DISCUSSION

This research has achieved the two primary objectives set forth earlier in the section. The first objective was the differentiation of multiple intra-island basalt procurement and manufacture sites on Tutuila through EDXRF elemental compositional data. The four clearly defined groups displayed through exploratory analysis are consistent with the expectation that the 18 samples from each individual site should display group cohesion and that inter-site variability should exceed intra-site variability. The bivariate and multivariate exploratory analyses of EDXRF data display clear separation of each individual site while maintaining a high level of internal cohesion with little or no inter-site overlap between the 72 samples. These classification results were then further supported through discrimination using stepwise CDA, which confirmed the unambiguous differentiation of each individual fine-grained basalt procurement site.

The second objective of this research was to assess the efficacy of EDXRF in comparison to previous applications of INAA on the same samples. This section was not intended as a discussion of the analytical precision or capabilities of EDXRF or INAA. It was designed to discuss the suitability of EDXRF and INAA toward the differentiation of these specific sites and samples, and the implications therein for future provenance analysis of fine-grained basalts from Tutuila. As discussed in the previous section both EDXRF and INAA compositional data can be utilized for the differentiation of the expected groups, but the EDXRF data appears to display greater intra-site cohesion and inter-site separation for this particular set of samples.

When compared with INAA, the EDXRF compositional data provides a similar or higher level of differentiation between sites achieved through both biplots of compositional variability as well as exploratory multivariate statistical analyses. These preliminary comparative results have led the author to the determination that EDXRF is an appropriate technique for the analysis of fine-grained basalt procurement and tool production on the island of Tutuila.

The results of this comparison of EDXRF and INAA are not to be interpreted as a commentary on the analytical superiority or inferiority for either technique discussed. The dilemma for archaeologists attempting to determine which instrument of elemental analysis is “the best choice” for archaeological applications has been repeatedly discussed in the archaeometry literature (Bishop et al 1990; Neff 2000; Shackley 1998a).

The editor of this volume, M. Steven Shackley, addressed that very question by stating, "It depends…the problem of design and the level of precision needed to address that design will determine which instrument is the best for a given project (1998b:7)." Keeping in

mind the relative nature of "best technique" as described by Shackley, and considering the dominance of EDXRF over INAA as a technique of choice towards Polynesia basalt provenance studies, the results of this research suggest that EDXRF is currently a more suitable technique than INAA for the analysis of Tutuila fine-grained basalt sources.

That endorsement must be tempered with the final caveat that this analysis is preliminary and includes a very limited sample of the multiple procurement and production sites on Tutuila. As more sites are sampled and analyzed the results reported in this section may no longer be applicable. As project designs are adapted for changing research areas and project goals no single method of analysis may provide clear characterization and differentiation of all sites, and it is necessary to continue the evaluation of multiple instruments and methodologies to ensure that the best technique or combination of techniques for a particular research design may be chosen to address the future investigation of basalt sources and artifacts on Tutuila, in Polynesia and around the globe.

4. SPECIALIZATION AT THE LAU'AGAE BASALT ADZE QUARRY

This section presents an archaeological investigation of potential economic intensification and specialization in fine-grained basalt adze manufacture at the Lau'agae quarry complex (AS-21-100). To understand and characterize potential specialization at AS-21-100 this research must define the production, distribution, and consumption of basalt adzes manufactured at AS-21-100. To that end, technological analysis of debitage, blanks and preforms collected from AS-21-100 were used to define the organization and standardization of production at the site, while elemental analysis was employed to investigate the distribution and consumption of basalt from AS-21-100.

In addition to basalt materials and artifacts collected from AS-21-100, this research includes basalt artifacts collected from the adjacent prehistoric village site of Tula (AS-21-001). Tula (AS-21-001) was included in this research not only because of the site's proximity to the Lau'agae quarry complex (Fig 4.1), but also because of the historic and modern association of the Lau'agae ridge as land belonging to the village of Tula. Early archaeological investigations at Tula documented high volumes of basalt artifacts at the site (Frost 1978), and the site was suggested as a possible quarry. However, Clark (1987) noted the amount of lithic debris at AS-21-001 and stated, "it is not likely to be the actual quarry site. Instead, it is a village site where the final stages of basalt tool manufacturing were carried out."

Basalt artifacts from Tula were included in the research to better understand the relationship of local villages to activities at the Lau'agae quarry complex, as well as define local distribution and consumption of materials from AS-21-100. These data are evaluated

against multiple models of economic specialization to understand the potential organization of adze production at this region of Tutuila during the Monument Building Period (1000-250BP) in Samoa.

4.1 ECONOMIC SPECIALIZATION AND POLYNESIA

Kirch (1984) argues that although the economic means varied across islands, all Polynesian societies were marked by intensification of production, which required increasing dedication of labor to a specific task, ultimately resulting in specialization. Sahlins (1972:148) defines this resulting specialization as a politically motivated ultimatum that was "intensification of domestic production by political means and for public purposes." Sahlins' (1972) description of the motivation for specialized production is best represented archaeologically through the model of attached specialization (Earle 1981; Brumfiel and Earle 1987; Costin 1991). Attached specialization is the total dedication of labor to a specific task through the sponsorship or patronage of an elite political agent (Earle 1981). An important component of the Earle (1981), Kirch (1984), and Sahlins (1972) definitions of attached specialization is that the specialist's dedication of labor to a singular mode of production requires that producers supplement their subsistence with goods that they did not produce, presumably supplied by an elite patron.

Costin (1991) utilizes Earle's notion of elite attachment, but she also defines the role of independent specialists. Unlike attached specialists, independent specialists dedicate their labor to a specific task and then market the product themselves (i.e. no elite patronage). The driving forces behind the development of independent specialization are thought to be economic factors such as differential access to resources, increasing population size, etc.

(Costin 1991). Conversely, the primary forces that promoted attached specialization are thought to be political in nature (Costin 1991). It is this political impetus that Sahlins (1972:148) refers to when he describes Polynesian economic intensification as, "intensification of domestic production by political means and for public purposes."

This top down, elite-determined impetus for specialization has been the dominant paradigm in the investigation of the large basalt quarry complexes of Polynesia (Cleghorn 1986; Lass 1994; Kahn et al. 2009; Leach and Witter 1987, 1990). Recently, Winterhoff (2007) investigated basalt adze manufacture at multiple sites across Tutuila, and argued for attached specialization at some production sites during the Monument Building Period. In comparison to these sites, the Lau'agae quarry complex (Fig 4.2) appears more extensive and potentially more intensified. In fact, it appears larger in size and scale than the majority of basalt quarries on Tutuila (Johnson et al. 2007:1079), which has lead some to suggest that AS-21-100 could have been the site of elite sponsored specialized basalt adze manufacture (Moore and Kennedy 1996; Winterhoff 2007). Utilizing Davidson's (1977) chronology, and aided by Costin's (1991) parameters for specialization, my investigation of AS-21-100 employs elemental and technological analyses data to evaluate the potential for both attached or independent specialization of fine-grained basalt adze production at the east Tutuilan upland Lau'agae quarry complex.

Table 4.1 describes five archaeological parameters of specialization that guided this research. Data collected from two scatters (A1 and A8) at the Lau'agae quarry complex (Fig. 4.2) addressed the parameters of specialization: intensity of production, variety of adzes produced, standardization of adze types, evidence for elite control, and distribution of adzes produced at the site.

Specialization	Intensity	Types of Adzes	Standardization within Adze Types	Control	Distribution
Attached	Very High	Very Limited Within and Between Workshops	Very High	High (e.g.monumental archictecture, defensive features, etc...)	Export
Individual	Moderate to High	Potentially Varied Within and Between Workshops	High	Low (e.g. residential features)	Export or Local
None	Low	Varied Within and Between Workshops	None	Low (e.g. residential features)	Local

Table 4.1. Archeological Parameters for Specialized Basalt Adze Manufacture

The archaeological parameters of production intensity, standardization of production, elite control, and distribution are used to address the following hypothetical expectations for specialization.

> H1: If AS-21-100 provides evidence for attached specialization then the data collected will define high intensity of production at each scatter, a limited variety of internally standardized adze types produced at both scatters, export of adzes (i.e. no local consumption), and presence of evidence for elite control such as defensive features or monumental architecture.
>
> H2: If AS-21-100 provides evidence for independent specialization then the data collected from the site will define moderate to high intensity of production at each scatter, a varied range of standardized adze types produced at either scatter, and export of adzes or local consumption with no evidence for elite control.
>
> H0: If AS-21-100 provides evidence for individual production for personal consumption then the data collected from the site will define low to moderate intensity of production at each scatter, a varied range of unstandardized adze types produced at both scatters, the local distribution and consumption of materials from the Lau'agae quarry.

4.2 RESEARCH AREA, SITE DESCRIPTIONS, AND FIELD COLLECTIONS

This section presents the regional context, site descriptions and field methods. The Samoan Islands are located in the South Pacific at approximately 14° South Latitude and 170° West Longitude, and Tutuila (Fig. 4.1) lies in the center of the archipelago. Tutuila is a landform comprised primarily of steep ridges, narrow coastal flats, and deep valleys. Over the last 30 years of archaeological investigation there have been no less than 20 basalt quarries recorded on the island of Tutuila (Clark 1987; Leach and Witter 1985; Winterhoff 2007), and one of the earliest documented was the Lau'agae quarry complex.

Figure 4.1. Tutuila Island, American Samoa

Located at 14°15'10"S and 170 °34'00"W in far eastern Tutuila near Cape Matatula (Fig 4.1), the Lau'agae ridge quarry complex (AS-21-100) is a series of basalt artifact scatters that cover nearly 10,000 m^2 as it ascends the ridge above the modern village of Tula (Moore and Kennedy 1996). The site of AS-21-100 spans nearly the entirety of the Lau'agae

ridge, and the flora at the site consists of a mix of kula fernland, primary and secondary forest, as well as maintained agricultural areas of banana (*Musa* sp.), taro (*Colocasia esculenta*) and coconut (*Cocos nucifera*) (Amerson and Whistler 1982).

In total, AS-21-100 stretches over 200 m as it rises from approximately 10 m (AMSL) to approximately 70 m (AMSL) (Moore and Kennedy 1996). AS-21-100 was initially recorded by the East Tutuila Project (Clark 1987), but later it was the focus of Phase II archaeological evaluation by Moore and Kennedy (1996), which included detailed archaeological investigations of the site including subsurface testing to determine the site's eligibility for the United States National Register of Historic Places. In their efforts, Moore and Kennedy (1996) identified no less than ten basalt lithic scatters at AS-21-100 (Fig. 4.2), and a myriad of archaeological features including architectural remnants associated with World War II activities. My research is focused solely on the fine-grained basalt scatters at AS-21-100. Scatters A1 and A8 were selected for testing due to their similar size, locations in flat areas, and good depositional integrity.

Scatter A1 (Fig. 4.2, Fig. 4.5) sits atop a knoll near the crest of the Lau'agae ridge. There are no archaeological components recorded above this locality on the ridge, but the portion of Lau'agae ridge above A1 has been severely impacted by the construction of a NOAA weather station. This scatter is located in secondary forest. The entire surface of the approximately 200 m^2 knoll is covered by a 10-20 cm layer of fine-grained basalt artifacts (Fig.4.3).

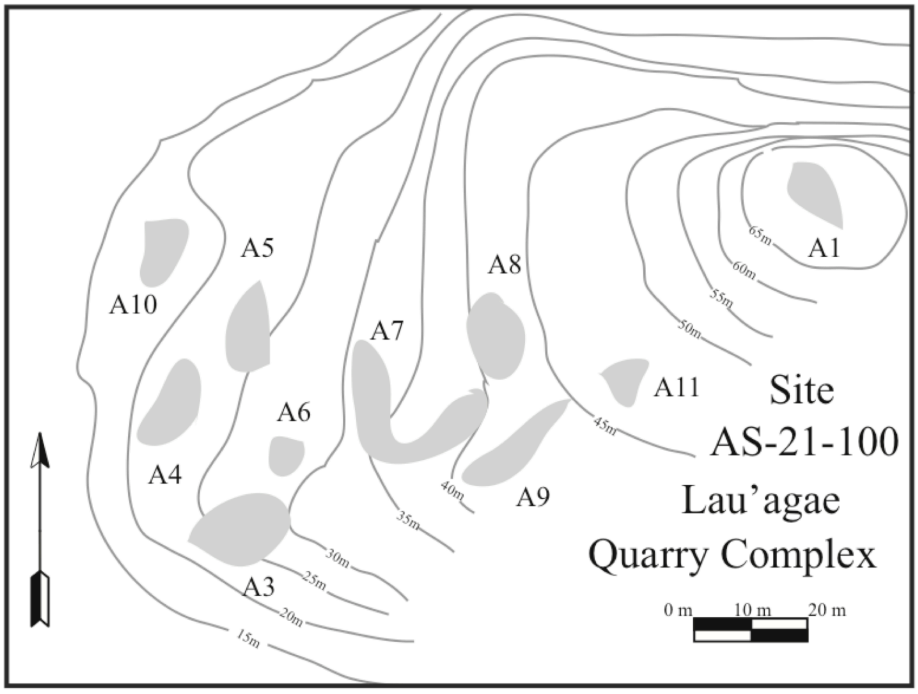

Figure 4.2. AS-21-100 Lau'agae Ridge Quarry (from Moore and Kennedy 1996)

The northeast margin of A1 was partially impacted by the construction of a WWII bunker. Remnants of the concrete bunker remain at the site (identified as Feature A2 by Moore and Kennedy 1996). Scatter A8 (Fig. 4.2, Fig. 4.6) lies nearly 50 m below A1 on a broad flat area midway down the ridge. This broad flat area contains several other discrete basalt scatter areas (Fig. 4.2) and is currently utilized as a banana and coconut plantation by local residents. Scatter A8 is approximately 300 m^2, and the surface is covered by an approximately 5-10 cm layer of basalt debitage and tools (Fig 4.4).

Figure 4.3. Surface Scatter at A1

Figure 4.4. Surface Scatter at A8

Initially scatters A1 and A8 were measured, mapped, and photographed. Two perpendicular transects were laid out at each scatter. To collect a representative sample of basalt adzes from each scatter, a systematic surface collection of fine-grained basalt adze blanks and adze preforms was conducted along each transect. Surface visibility at A1 was approximately 75% due to leaf litter. Surface visibility at A8 was closer to 100% due to agricultural clearing of understory. All basalt blanks, preforms, and finished tools (whole or fragmentary) recorded at the surface along the transects were collected (Fig 4.5, 4.6).

Upon completion of the systematic surface collection, 50 cm^2 test units were excavated at both scatter A1 (Fig. 4.7) and scatter A8 (Fig. 4.8) to collect a representative stratified sample of debitage and tools from each scatter. Each unit was excavated in arbitrary 10 cm levels, and all sediments were sifted through ¼" wire mesh screens. Both test units 1 and 2 were excavated to a depth of 40 cm below surface. Soil profiles were consistent in both units. The first 10 cm level in both units consisted of weak subangular blocky 7.5 YR 3/1

clay loam. A diffuse soil boundary was encountered in both units in the second level at approximately 15-20 cm below surface. The soil below this boundary was described in both units as a strong angular blocky 7.5 YR 4/3 clay horizon. In both test units artifact densities and size decreased from level one through three, and level four was sterile of cultural materials.

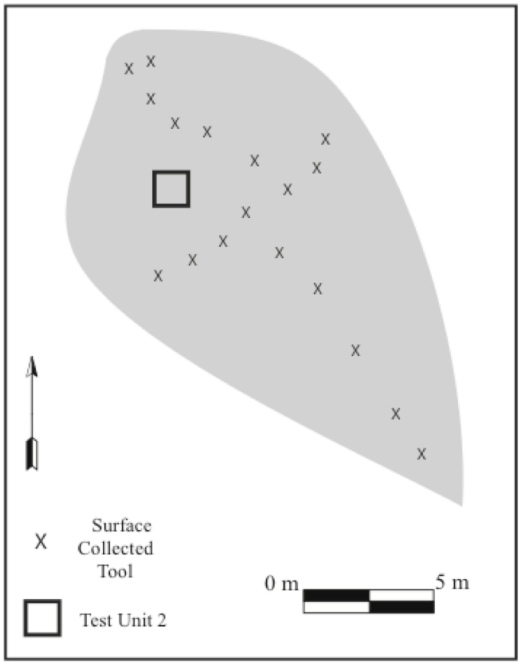

Figure 4.5. Planview Scatter A1

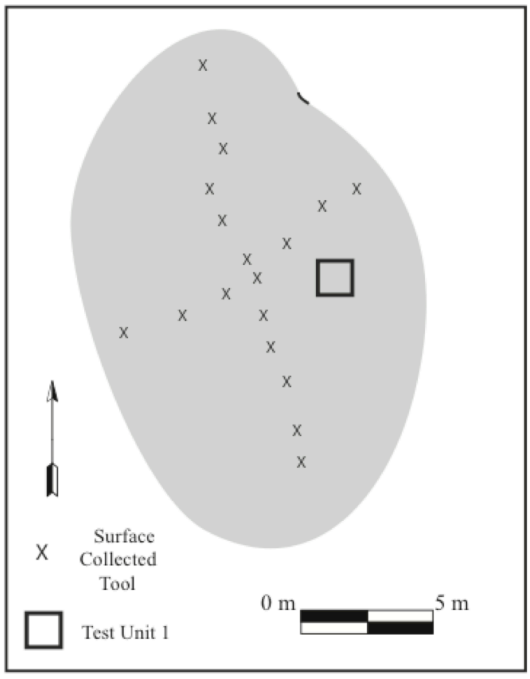

Figure 4.6. Planview Scatter A8

4.3 MATERIALS AND METHODS

This research analyzed basalt debitage, blanks, and preforms collected from AS-21-100, as well as basalt artifacts recovered from the nearby prehistoric residential site of Tula (AS-21-001). Elemental concentration data from AS-21-100 and the nearby archaeological

site of Tula (AS-21-001) were derived using Energy Dispersive X-ray Fluorescence (EDXRF) and these elemental data were used to investigate the distribution of basalt adzes from AS-21-100.

Figure 4.7. Test Unit 2 at Scatter A1

Figure 4.8. Test Unit 1 at Scatter A8

Elemental analysis of basalt artifacts and sources constitutes a prominent line of archaeological research in Polynesia (e.g. Allen and Johnson 1997; Best et al. 1992; Collerson and Weisler 2007; Johnson et al. 2007; Kahn et al 2006; Lunblad et al. 2008; Mills et al. 2008; Parker and Sheppard 1997; Rolett et al. 1997; Sheppard et al.1997; Weisler 1990, 1993b, 1997, 1998, 2002, 2003; Weisler and Sinton 1997; Weisler and Woodhead 1995). Tutuila has been the focus of multiple basalt elemental analysis studies (Best et al. 1992;

Clark et al. 1997; Crews 2008; Johnson 2011; Johnson et al. 2007; Weisler 1993a; Winterhoff (2007). Previous research has preliminarily established the nature and extent of intraisland and interisland distribution of basalt from the quarries of Tutuila, and elemental analysis of these materials from far eastern Tutuila was designed upon these previous studies.

EDXRF for this project was conducted by the author at the Texas A&M University Elemental Analysis Laboratory (EAL). Analysis was performed on a Thermo *QuantX* EC EDXRF spectrometer equipped with a liquid nitrogen cooled Si(Li) detector. Specific methodology for the elemental analysis is discussed in detail in Johnson (2011). This analysis included 36 samples collected from the scatters of AS-21-100 (Johnson et al. 2007), and 18 artifacts from Tula (AS-21-001). The sample size of 18 was chosen because a statistically valid sample must be greater than the number of variables (i.e. elements). There are a total of 17 elements analyzed with this EDXRF method, and the 16 elements included in this analysis that have been determined to provide definitive chemical characterization and differentiation of multiple quarry scatters on Tutuila (Johnson et al. 2007, Johnson 2011). These elemental concentration data were explored using Canonical Discriminant Function Analysis, which was tested group affiliations of the Lau'agae and Tula basalt samples (Baxter 1994). All multivariate exploratory statistical analysis were performed using IBM SPSS v20.

In addition to elemental analysis, technological attribute analysis was conducted on all artifacts recovered from AS-21-100. Descriptive typological analysis was performed on all basalt blanks and preforms recovered from AS-21-100. For this research blanks were defined as worked flakes with an indeterminate cross-section (Weisler 1990). Preforms were delineated from blanks because they had an identifiable cross-section, and finished adzes

were polished. No finished adzes were recovered from AS-21-100. The maximum width, length, thickness, and weight was recorded on each artifact. When discernable, the cross-section of each basalt preform (complete and incomplete) was recorded, and when possible, it was typed according to Green and Davidson's (1969) typology of Samoan adzes.

Following Eerkens (2000) I assessed the presence of standardization within the adze blanks and preforms at AS-21-100 through the application of the coefficient of variation (CV). I have chosen CV for three reasons. First, CV creates a single measurement that represents the level of standardization present in an assemblage. Second, it is derived by dividing the Standard Deviation of an artifact assemblage by its Mean, which are both easily derived or reproduced from metrics recorded during standard technological lithic analyses. Third, CV creates an independent measurement that can be compared across artifact attributes (Eerkens 2000).

Eerkens and Bettinger (2001) used the Weber fraction to define the range of standardization, with the lower limit of 1.7% CV being hyper standardized and the upper limit of 57.7% CV derived from a random dataset. A standardized assemblage is expected to fall within this range of 57.7% to 1.7%, but essentially the lower the CV the more standardized the assemblage and vice versa. Eerkens and Bettinger (2001) note that coefficients of variation can differ based on materials. For example, a reductive technology such as stone tool manufacture should be expected to produce a higher CV than an additive manufacture process such as pottery making, because stone tool production is less predictable than pottery production.

I applied the Eerkens and Bettinger (2001) CV analysis to the technological attribute data collected from adze blanks and preforms. CV data from Lau'agae is compared against

CV data derived from basalt artifacts recovered from two other Polynesian quarries. These two quarries provided CV percentages that guided the expectations for percentages indicative of potential standardization at AS-21-100.

The first comparative quarry was the Nu'u quarry on the Hawaiian Island of Maui, which was described by Kahn et al. (2009:135) as a "quarry that produced a diverse range of adze types, mainly for local population needs", and that "Data from the Nu'u quarry do not support the notion that later Hawaiian adze assemblages are highly standardized." The CV percentage data from the Nu'u quarry were used to represent a quarry with little to no standardization. The second quarry is Pololu from the Big Island of Hawaii (Lass 1994). Production efficiency and success data from Pololu compared favorably to the same data from the large specialized export quarry of Mauna Kea (Lass 1994). Although no analysis for standardization was made on the Pololu artifacts, Lass (1994:46) stated "There was not significant variability within the adze manufacturing sequence nor was more than one basic adze-making strategy used at Pololu." The CV percentage data from Pololu represented potentially standardized production.

Debitage pieces were analyzed utilizing mass analysis. This descriptive analysis was used to sort the debitage assemblage from AS-21-100. Mass analysis involves defining flake assemblages primarily by predetermined size grades or weight (Ahler 1989). Although mass analysis can be problematic, Kahn (1996) demonstrated that modified mass analysis can be effective at describing the organization of production at basalt quarries because assemblages at quarries represent fewer potential activities than at non-quarry sites. The mass analysis employed for this research was modified according to Kahn et al. (2009), Turner and Bonica (1994), and Winterhoff (2007).

After Winterhoff (2007), flakes were sorted into one of five size classes using a guide of five concentric circles. Size 5 flakes were designated as larger than 6 cm, Size 4 flakes were between 4-6 cm, Size 3 flakes were between 3-4 cm, Size 2 flakes were between 1.5-3 cm, and Size 1 flakes were smaller than 1.5 cm. After size sorting, individual attributes including weight, the presence or absence (as well as location) of cortex, platform complexity, and number of dorsal flake scars were also recorded for each flake.

	Scatter A8 TU1		Scatter A1 TU2	
	Count	Weight	Count	Weight
Surface	159	5698 g	58	6197 g
Level 1 (0-10 cmbs)	494	5288.g	593	17581 g
Level 2 (10-20cmbs)	171	994 g	33	2604 g
Level 3 (20-30cmbs)	65	384 g	-	0 g
TOTALS	889	12364 g	684	26382 g

Table 4.2. Debitage Counts and Weights Per Level from AS-21-100

4.4 RESULTS

Tables 4.2 and 4.3 describe debitage excavated from scatters A1 and A8 at Lau'agae. The debitage were described and analyzed to define the reduction activities at each scatter. The total number, size, and weight of debitage were tabulated to compare the production between these scatters as well as other Polynesian and Tutuilan quarries. Test excavations at AS-21-100 recovered a total of 1573 debitage pieces from scatter A1 and scatter A8. Test unit 1 produced 889 flakes, while test unit 2 produced 684 flakes (Table 4.2). Most flakes

from both scatters were recovered from the surface and excavation level one. 653 debitage pieces were recovered from the surface and level one at scatter A8 constituting 73% of the total debitage recovered from the scatter. 95% of the total debitage was recovered from the surface and level one at scatter A1.

	Scatter A8 TU1			Scatter A1 TU2		
	Count	%	Weight	Count	%	Weight
Size 5	93	10.4%	6659 g	144	21.%	22884 g
Size 4	174	19.6%	3368 g	80	11.5%	1874 g
Size 3	190	21.4%	1530 g	128	19.4%	1101g
Size 2	289	32.5%	738 g	205	31.5%	437 g
Size 1	143	16.1%	70 g	127	19.4%	86 g

Table 4.3. Flake Size Grade Counts, Percentages, and Weights Per Unit

Table 4.3 presents size sorting data for the debitage recovered from AS-21-100. All five flake sizes were well-represented at each scatter. The most abundant flake size recovered from both scatters is Size 2, which represents 32.5% of the assemblage from A1 and 31.5% of the debitage from A8. Size 3 flakes are the second most numerous recovered from A1, comprising 21.4% of the total, but Size 5 flakes are the second-most abundant at scatter A1, making up 21% of the total. Although the assemblages from each scatter differ in flake-size densities, both scatters contained all five sizes, and contained each size in densities that are indicative of the entire basalt adze reduction sequence from blank production, primary flake removal and reduction, to late stage shaping prior to polishing.

	Scatter A8		Scatter A1	
	BLANK	PREFORM	BLANK	PREFORM
Whole	4	8	4	5
Fragment	4	15	6	16

Table 4.4. Number of Adze Blanks and Preforms Recovered from AS-21-100

The two scatters display similarity in number of blanks and preforms recovered from each site (Table 4.4). In total 18 blanks and 44 preforms were recovered from AS-21-100 (Table 4.4). Ten blanks and 21 preforms were recovered from scatter A1, and 8 blanks and 23 preforms were recovered from scatter A8. No polished flakes or finished adzes were recovered from either scatter, suggesting that only blank and preform production activities were conducted at the scatters.

	A1	A8		A1	A8
Length (mm)			Width (mm)		
Max	159	142	Max	69	80
Min	115	102	Min	54	52
Mean	139	120.8	Mean	61.3	64.8
SD	18.9	17.8	SD	6.9	12.1
Thickness (mm)			Weight (g)		
Max	45.6	39.7	Max	687	358
Min	32.8	30.5	Min	258	235
Mean	40.2	37.3	Mean	433.3	298.5
SD	5.9	4.5	SD	181.2	50.3

Table 4.5. Metric Attributes Recorded on Whole Adze Blanks from AS-21-100 (after Kahn et al. 2009 and Winterhoff 2007)

Standard descriptive measurements were recorded for each blank including length, width, thickness, and weight. However, only the whole blanks were included in this analysis (Table 4.5). The maximum and minimum measurements, as well as the mean and standard deviation were derived for whole blanks (N=10) recovered from each scatter (Table 4.5). The metric data from debitage and blanks reflects some similarity between production at scatters A1 and A8. When comparing the whole blanks produced at scatter A1 and A8, these data on length, width, thickness, and weight suggest that the blanks produced at the two scatters were similar in size and shape.

	Scatter A1	Scatter A8
I	4	5
II	8	6
III	-	2
IV	-	1
V	1	2
VI	5	5
VII	-	1
VIII	-	-
IX	3	1
X	-	-
TOTALS	21	24

Table 4.6. Probable Adze Preform (Whole and Fragmentary) Types Based on Cross-section (after Green and Davidson 1969)

Nonetheless, there is evident variation in preforms recovered at the scatters (Tables 4.6). In addition to descriptive analysis on whole blanks, an attempt was made to describe the cross-section of each preform (Table 4.6). Describing the cross-section of these preforms is viewed as especially useful for two reasons. First, a cross-section can be confidently measured on both whole and fragmentary artifacts. This is possible because each broken or fragmentary preform recovered from A1 and A8 was damaged by end-shock and thus no less than 50% of the tool was present and its cross section could be confidently assessed. Second, the cross-section is the most useful attribute for applying the Green and Davidson (1969) typology of Samoan adzes (Table 4.6), which provided details on the types of finished tools likely produced at each scatter.

The cross-section data present differences in the types of preforms recovered at the two scatters. The majority of the preforms from both scatters were near completion in the reduction sequence, as evidenced by the identifiable cross-section. The late stage of reduction increased the potential for classifying the tools using the Green and Davidson (1969) typology of Samoan adzes. In total, potentially eight of the Green and Davidson (1969) Samoan adze types were identified at the scatters (Table 4.6). Potential adze types I, II, V, VI, and IX were identified at scatter A1, while potential adze types I, II, III, IV, V, VI, VII, and IX were identified at scatter A8 (Table 4.6). Overall the total numbers of quadrangular (I, II, III, IV, and V) and triangular (VI and VII) preforms produced at each scatter are very similar, but there is variation in the potential finished adze types produced at each scatter.

These technological data were used initially to describe and compare the basalt adze production sequences at scatters A1 and A8 in the Lau'agae quarry complex. These data

demonstrate that the entire adze reduction sequence prior to polishing was carried out at both scatters. The scatters display a similarity in production intensity, but there are differences in the relative percentages of flake sizes recovered between the two scatters.

Size 2 and size 3 flakes dominate the assemblage at both scatters. While frequencies of blanks and preforms recovered from each scatter were nearly identical, there is a difference in the potential adze types identified at each scatter. Three potential adze types (III, IV, and VII) were present at A8 that were not recovered at A1. These three types represent nearly a quarter of the preforms collected from A8. Conversely, all of the potential adze types identified at A1 are also represented at A8. Although there are differences in the debitage and adze data collected from scatters A1 and A8, these data do not display wide variability, but rather are more suggestive that adze manufacture at each scatter was internally heterogeneous.

After the scatters A1 and A8 were compared, this research addressed parameters of specialization outlined earlier in this section (Table 4.1). Specifically the data recorded at A1 and A8 was used to estimate intensity of production, the variety of adzes types produced at each scatter, and the amount of standardization in the adzes produced at AS-21-100. After these parameters were addressed using the technological data reported above, this research addressed the evidence for control of production at AS-21-100, and employed elemental concentration data derived from EDXRF on samples from AS-21-100 and AS-21-001 in a discussion of distribution and consumption of adzes produced at AS-21-100.

4.5 INTENSITY OF PRODUCTION

Although potentially problematic (Costin 2001; Leach 1999), intensity of production (i.e. volume of basalt artifacts at a site) has been a leading factor in the definition and investigation of basalt adze quarries in Polynesia. Estimating intensity of production at AS-21-100 and at most basalt quarries is problematic due to a lack of chronological control often encountered at such sites. It is impossible to accurately estimate the rate of intensity without understanding when and how long the site was used. However, the preceding caveats not included, intensity of production maintains an important role in the investigation of basalt adze production in Polynesia regardless of the lack of chronological data, and thusly will be utilized in this research.

Research on Tutuilan adze production has tended to focus on quarries where the intensity and scale of production are interpreted as exceeding local consumption, with the implication that excess production was intended for exchange (Best et al. 1992; Cleghorn 1986; Leach and Witter 1985, 1987). Additionally, specialized production is linked to excessive production at the largest quarry complexes, as relatively large volumes of production are interpreted as evidence of specialized producers (Cleghorn 1986; Lass 1994; Leach and Witter 1985). For example, Tataga-matau on Tutuila, Mauna Kea on Hawai'i, and other large-scale basalt quarries have been described as intensified scatters of specialized producers whose products entered long-distance exchange networks controlled by elites. Research at these quarry complexes, and the evidence for long-distance exchange of materials from them (Best et al. 1992; Weisler and Kirch 1996; Winterhoff 2007), has established the assumption that larger basalt quarries represent specialized production intended for exchange (Leach and Witter 1985, 1987, 1990; Winterhoff 2007). Recently,

some researchers have shifted focus from large-scale export quarries toward smaller-scale quarries in order to better understand household and local production, as well as craft specialization (Bayman and Moniz-Nakamura 2001; Clark 1993; Kahn et al. 2009; Winterhoff 2007).

Upon initial inspection, the Lau'agae quarry complex does not fit neatly into established models of Polynesian basalt tool production. The multiple individual scatters at Lau'agae are not as large as evidenced at other large Polynesian basalt export quarry complexes. However, while the individual scatters at Lau'agae do not appear as prolific as scatters at export quarries there are more scatters at Lau'agae than other large Tutuilan quarries (Johnson et al. 2007). There are a total of 10 associated scatters at Lau'agae, which far exceeds the total of 3 quarry areas recorded at the specialized export quarry of Tataga-matau.

Intensity of production can be measured in different ways, but for comparative purposes it is often measured by adze production material recovered per m^3 (Kahn et al. 2009; Mintmier 2007; Winterhoff 2007). Some have compared debitage counts per m^3 (Kahn et al. 2009, Mintmier 2007) while others have relied on weight of debitage recovered per m^3 (Winterhoff 2007). This research will use total debitage counts recovered per m^3 in order to compare the relative intensity of production at the Lau'agae quarry to other Polynesian quarries.

The volume of debitage per m^3 at specialized export quarries in Hawai'i can be staggering. Mintmier (2007) reported volumes as high as 70,000 debitage per m^3 at Haleakela), but research at Tutuilan quarries has demonstrated that even potentially specialized quarries on the island are not as prolific as those in Hawaii (Clark 1993; Cleghorn

1986; Leach and Witter 1985, 1987; Winterhoff 2007). Clark (1993) reports debitage counts from Test Unit 1 at the nearby specialized Tutuilan quarry of Alega (AS-23-21) that total an estimated intensity of production of 9,670 m^3. The counts reported by Clark (1993) for AS-23-21 provide a good comparison for the intensification of basalt adze production on the east side of Tutuila where AS-21-100 is located.

Test excavations at AS-21-100 recovered a total of 1573 debitage between scatter A1 and scatter A8. Test unit 1 produced 889 flakes, while test unit 2 produced 684 flakes (Table 4.2). Based on test excavations at the Lau'agae quarry, scatter A8 has an estimated volume of 11,735 m^3 and scatter A1 has an estimated volume of 13,680 m^3. Although intensity of production at Lau'agae appears modest in comparison with large specialized Hawaiian quarries, when compared to data from the nearby specialized Alega quarry complex there is potentially greater intensity of production at scatters A1 and A8 than at Alega (AS-23-21).

4.6 STANDARDIZATION

This research will now address the evidence for standardization at AS-21-100. To that end, the technological analysis data from scatters A1 and A8 at the Lau'agae quarry complex was analyzed using coefficient of variation (Eerkens and Bettinger 2001) and these data were compared to coefficient of variation data for other Polynesian quarries. When a specialist dedicates his or her time increasingly to a single activity it is assumed that the product of that specialist will become more standardized (Cleghorn 1986; Lass 1994; Torrence 1986). Therefore, after intensity of production, standardization is perhaps the most utilized parameter in the investigation of specialized production. The first criterion in the investigation of standardization at AS-21-100 is the discussion of variation in adze types

produced at the scatters. The expectation with full-time attached specialization is the reduction of types of adzes being produced as the specialist concentrates on efficiency of production (Costin 1991; Torrence 1996; Winterhoff 2007).

Each scatter investigated at AS-21-100 has evidence for the production of multiple adze types (Table 4.6). Potential adze types identified at scatter A1 include Types I, II, V, VI, and IX. Potential adze types identified at scatter A8 included Types I, II, III, IV, V, VI, VII, and IX. This variation in tool forms produced does not meet the expectations of highly specialized attached production (Cleghorn 1986; Lass 1994; Torrence 1986; Winterhoff 2007), where full-time attached specialists focus on the expedient manufacture of standardized tool forms. However, along with the expectation of fewer tool types as specialization increases, there is also the expectation for potential standardization within the tool types (Cleghorn 1986; Lass 1994; Torrence 1986).

Following Eerkens and Bettinger (2001), I derived the coefficient of variation (CV) for the length, width, and thickness of adze blanks and adze preforms at AS-21-100. These CV data were compared to CV data from adze blanks and adze preforms recovered from two other Polynesian quarries. The investigation of potential standardization at AS-21-100 began with an analysis of the blanks manufactured at scatters A1 and A8. Only whole blanks and preforms were included in this analysis, because the comparative data from Kahn et al (2009) and Lass (1994) were only reported for whole artifacts.

	Scatter A8			Scatter A1		
	Mean	STDEV	CV	Mean	STDEV	CV
Length (mm)	120.8	17.8	14.7%	139	18.9	13.6%
Width (mm)	64.8	12.1	18.7%	61.3	6.94	11.3%
Thickness (mm)	37.3	4.5	12.1%	40.2	5.9	14.7%

Table 4.7. Coefficient of Variation (CV) for 10 Adze Blanks from AS-21-100

Table 4.7 displays the mean, standard deviation, and the coefficient of variation for recorded maximum length, width, and thickness of whole blanks recovered from both scatters A1 and A8. There were a total of ten whole blanks recovered from AS-21-100, four from scatter A1 and six from scatter A8 (Table 4.4). Table 4.7 describes a relatively standardized assemblage of blanks from AS-21-100. Both workshops display percentages below 15% for the overwhelming majority of attributes, and only the CV for width at scatter A8 was higher, at 18.7%.

	Mean	STDEV	CV
Length (mm)	109.9	25.9	23.5%
Width (mm)	54	13.6	25.2%
Thickness (mm)	34.7	13.9	40.1%

Table 4.8. CV for 12 Adze Blanks from Nu'u (Kahn et al. 2009)

To further evaluate the potential for standardization at AS-21-100, the CV data from each scatter were compared to data from the Nu'u quarry on Maui (Kahn et al. 2009). Lass

(1994) did not report sufficient data on adze blanks from Pololu to be included in this comparison. The Nu'u quarry (Kahn et al. 2009) is described as a single scatter most likely utilized by non-specialized local producers with the intent of local distribution or personal consumption. I derived the coefficient of variation for the twelve whole blanks reported from Nu'u. The Nu'u quarry CV data for adze blanks range from 23.5% to 40.1% (Table 4.8).

The CV percentages for adze blanks and preforms from Nu'u (Tables 4.8, 4.10) were used to derive the expectation that CV percentages greater than 29% as indicative of unstandardized adze production. The CV percentages for adze preforms from the potentially specialized Pololu quarry (Table 4.11) confirmed that CV percentages for potentially standardized adze production are expected to be less than 29%. For the purpose of this research, all measured attributes on blanks and preforms must fall below 29% to meet the expectation for potential standardization at that quarry.

	A8 (N=4)	A1 (N=6)	Nu'u (N=12)
Length (mm)	14.7%	13.6%	23.5%
Width (mm)	18.6%	11.3%	25.2%
Thickness (mm)	12.1%	14.7%	40.1%

Table 4.9. Comparison of CV for Adze Blanks from A1, A8, and Nu'u

The CV data for all attributes recorded on blanks recovered at AS-21-100 (Table 4.9) are demonstrably lower than the previously established 29% upper limit for potential standardization. Additionally, the CV data from blanks recovered at AS-21-100 are

exceedingly lower than those at Nu'u, and provide compelling evidence for the potential standardization of blank production at both scatter A1 and A8. The adze reduction sequence at both scatter A1 and A8 began with blank production, and the exceedingly low CV data for blanks from scatters A1 and A8 (Table 4.9) provide compelling evidence for potentially intentional standardization of the adze manufacturing process at the Lau'agae quarry complex.

	Scatter A8 (N=9)			Scatter A1 (N=5)		
	Mean	STDEV	CV	Mean	STDEV	CV
Length (mm)	104.8	29.2	27.9%	145.5	12.8	8.8%
Width (mm)	48.4	10.9	22.5%	60.2	15.5	25.7%
Thickness (mm)	29.6	8.1	27.3%	36.6	4.9	13.4%

Table 4.10. Preform CV percentage data from AS-21-100

After blanks were analyzed for standardization, basalt preforms from AS-21-100 were analyzed using CV and compared to similar data from both Nu'u and Pololu (Table 4.11 and 4.12). As with the CV data from adze blanks, the CV data for preforms from scatter A1 are lower than the CV data for preforms from scatter A8. However, the CV percentages for preforms at both scatters A1 and A8 are higher than the CV percentages for blanks from those same scatters.

	Mean	STDEV	CV
Length (mm)	129.1	31.1	24.1%
Width (mm)	43.1	14.7	34%
Thickness (mm)	30.7	14	45.6%

Table 4.11. Preform (N=14) CV Data from Nu'u Quarry (Kahn et al 2009)

	Mean	STDEV	CV
Length (mm)	12.4	2.4	19.4%
Width (mm)	5.6	1.4	25%
Thickness (mm)	4.2	1.3	30.9%

Table 4.12. Preform (N=19) CV Data from Pololu Quarry (Lass 1994)

Table 4.10 demonstrates that the CV percentages for all attributes recorded on A8 preforms were below the 29% upper limit for potential standardization. Each of the CV percentages for preforms from scatter A1 were well below the expected 29% for potential standardization, and the percentages for length and thickness are 8.8% and 13.4%, respectively. These CV percentages below 29% for all measured attributes (length, width, and thickness) from preforms at A8 and A1 are indicative of potential standardization, especially those lowest percentages from scatter A1.

	A8	A1	Pololu	Nu'u
LENGTH (mm)	27.9%	8.8%	19.4%	24.1%
WIDTH (mm)	22.5%	25.7%	25%	34%
THICKNESS (mm)	27.3%	13.4%	30.9%	45.6%

Table 4.13. Inter-site Preform CV Percentage Comparison

Based on the CV percentages data for both blanks and preforms, there is evidence for potential standardization at both scatter A8 and scatter A1, but that CV data also suggests that the production of basalt adzes at scatter A1 was demonstrably more standardized than the assemblage collected at scatter A8. When compared to the Nu'u quarry (Kahn et al. 2009) and the Pololu quarry (Lass 1994) the CV data from AS-21-100 (Table 4.13) suggested that the production of basalt adzes was more standardized at the Lau'agae quarry complex than at other Polynesian quarries.

4.7 DISTRIBUTION

The final line of research included in this investigation of specialization at AS-21-100 is the application of elemental analysis to investigate the distribution of adzes from AS-21-100. As described earlier, because the intensification and specialization of production is often intended for exchange, the products of specialized adze manufacture are less likely to be distributed and consumed locally. To that end, elemental concentration data from AS-21-100 was compared to elemental concentration data from artifacts recovered from the nearby and associated prehistoric village of Tula AS-21-001.

Eigenvalues				
Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	366.662[a]	76.6	76.6	.999
2	111.704[a]	23.4	100.0	.996

a. First 2 canonical discriminant functions were used in the analysis.

Table 4.14. CDA Functions for Elemental Concentration Data, Lau'agae and Tula

Elemental concentration data from Lau'agae (N=18) and Tula (N=18) were compared to determine if there was any affiliation between the basalt utilized at adjacent villages and the Lau'agae quarry complex. The data were explored statistically using Canonical Discriminant Function Analysis (CDA). The first two CDA scores represented 100% of the variability (Table 4.14) for 16 elements and 36 individual basalt samples, and all samples were grouped with 100% probability.

The scatterplot of CDA functions (Fig. 4.9) shows very clear group cohesion in the samples from AS-21-100 and Tula. There is unequivocal differentiation between samples from Tula (AS-21-001) and AS-21-100. The strong group cohesion in the Tula samples suggests that they were produced from the same basalt source (i.e. quarry), but not from AS-21-100. The results of elemental analysis of the Lau'agae quarry scatters and the associated nearby village site of Tula are not indicative of local distribution and consumption of basalt from AS-21-100, and the total absence of local consumption of basalt from Lau'agae is likely indicative of export of adzes produced at AS-21-100.

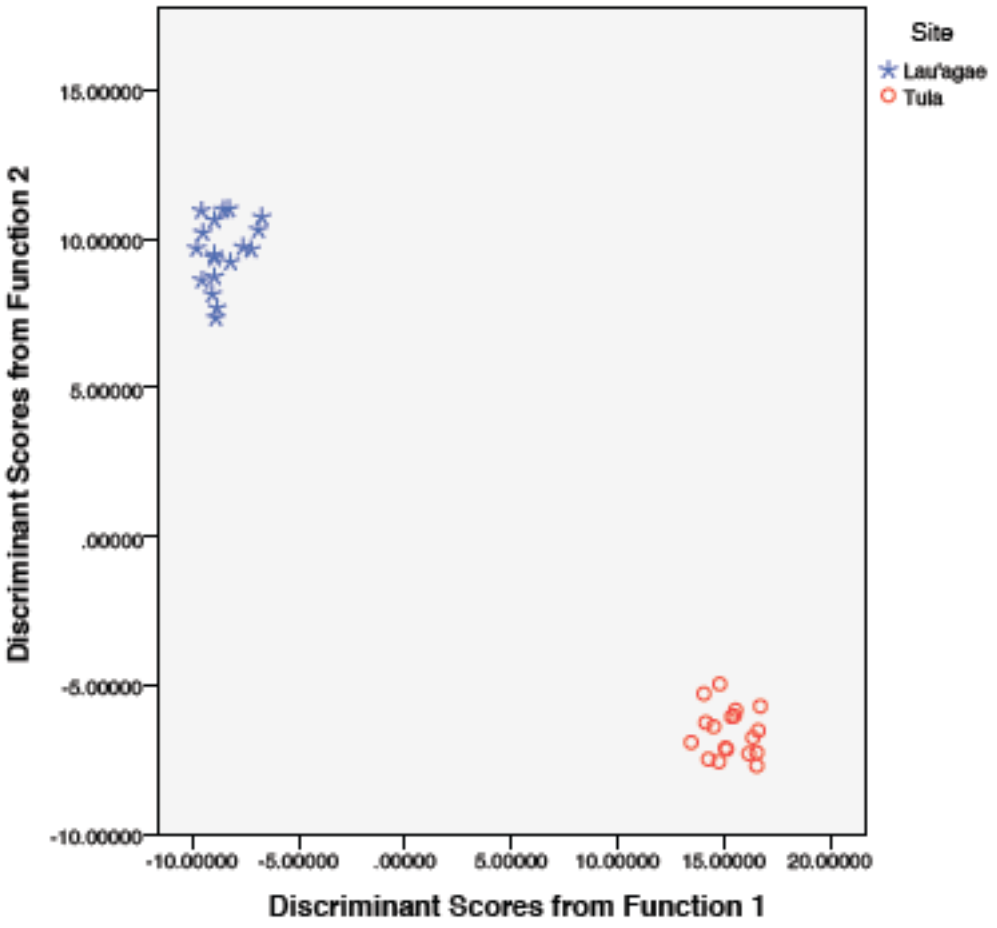

Figure 4.9. Scatterplot Displaying Elemental Differentiation of Lau'agae and Tula

4.8 DISCUSSION AND CONCLUSION

The utilitarian role of the basalt adze in Samoan daily life, as well as the reliance upon the adze by craft specialists that worked wood, built houses, and made canoes (Buck 1930, Goldman 1970) would have generated a large demand for a tool that was time intensive to produce. Under such circumstances it becomes evident how the demand for adzes could lead skilled producers towards potential specialization in adze manufacture.

When compared to other Polynesian basalt quarries, there is evidence for potential specialization at AS-21-100. A significant factor in the analysis of production at AS-21-100 are the CV percentages for the blanks produced at both scatters. The CV percentages for adze blanks were below 15% for many attributes, and that is exceedingly lower than the expected CV lower limit of 29% for potential standardization. The CV percentages for all attributes on preforms from both scatter A8 and A1 also fell below the 29% threshold and met the expectation for potential standardization.

The production of the blank was the first step in the process of producing an adze, and the evidence for standardization at this crucial step is significant. Creating a standardized adze blank from a single flake is indicative of a skilled producer, and as there were multiple adze forms being produced at Lau'agae this is potentially suggestive of multiple skilled producers. Although not as low as the CV percentages for blanks, the CV percentages for preforms at both scatter A1 and A8 present evidence for potential standardization. Specifically, the very low CV percentages for attributes on both blanks and preforms is indicative of potential standardization. Not only did the CV percentages for every attribute measured on blanks and preforms from scatter A1 and A8 fall below the potential specialization threshold of 29%, but they provided evidence for increased standardization at the Lau'agae scatters when compared to other Polynesian quarries. These data from Lau'agae were consistently lower than CV percentages for the same attributes measured on blanks and preforms from the Nu'u quarry on Maui (Kahn et al. 2009) and preforms from Pololu on Hawaii (Lass 1994).

Additionally, the elemental concentration data from Lau'agae and the associated village site of Tula provide evidence for export and exchange of the Lau'agae adzes. That

being said, other than export, there are alternate explanations for the results of the elemental analysis, but those scenarios are less likely for a number of reasons. First, there is an historic and modern association of the Lau'agae ridge as land belonging to the village of Tula. Second, other than Tula (AS-21-001) the adjacent prehistoric village of Lefutu (AS-21-002) would have most likely had access to the Lau'agae quarry. However, there is an ethnohistorically and archaeologically documented association between the villages of Lefutu and Tula (Clark 1987). Finally, the proximity and documented social affiliation between Tula and the Lau'agae ridge make it unlikely that adzes manufactured at AS-21-100 by producers from other nearby villages would not have been exchanged with Tula, especially if producers from Tula were not utilizing the source themselves.

Another potential alternative to export and exchange is that the material from Lau'agae was used at Tula, but the village did not use Lau'agae basalt exclusively. If the local village used multiple basalt sources including AS-21-100, then the small sample size from Tula (N=18) may not represent all material sources (including AS-21-100) utilized by Tula. However, if the village of Tula routinely utilized other basalt sources, it would be expected that those sources would be very near Tula, and thus chemically similar to the Lau'agae quarry complex. Also, if the Tula samples originated from multiple sources, the elemental concentration data would not display such strong internal group cohesion.

The unequivocal elemental differentiation and intra-group cohesion of the basalt samples from the Lau'agae and Tula does not suggest a local provenance of basalt analyzed from Tula. The elemental differentiation between the samples from these adjacent sites is as distinct as the differentiation displayed between basalt sources miles apart across Tutuila and within separate volcanic provinces (Johnson 2011). Based on the striking elemental

differentiation of the basalt from Lau'agae compared to basalt from Tula, and the potential standardization of adze manufacture at scatters A1 and A8, it is likely that the adzes being produced at Lau'agae were not intended for local distribution, but were produced for exchange.

As discussed above, the Lau'agae data have supported the potential for specialized manufacture of basalt adzes. The following discussion will apply these technological and elemental data against hypothetical parameters for attached and independent specialization (Costin 1991) to determine which model of specialization best describes the organization of production at AS-21-100.

Attached Specialization

> H1: If AS-21-100 is the result of attached specialization then the data collected will define high intensity of production at each scatter, a limited variety of highly standardized adze types produced at both scatters, as well as the export of adzes (i.e. no local consumption), and the presence of evidence for elite control such as defensive features or monumental architecture.

The intensity of production estimate at Lau'agae is greater than the nearby specialized Alega quarry, however when compared to larger elite controlled export quarries throughout Polynesia, the intensity at scatters A1 and A8 appears moderate. Additionally, there is evidence for potential standardization in the adzes being produced, but the multiple types of adzes present is not indicative of the type of efficiency of production expected by a full-time specialist. Although the potential export of adzes from AS-21-100 could be interpreted as evidence of elite control over distribution, there is no other evidence for elite control at AS-21-100. Other elite controlled specialized export quarries like Tataga-matau and Mauna Kea contain evidence for monumental and ceremonial architecture, as well as defensive features (Cleghorn 1986; Lass 1994; Leach and Witter 1985, 1987, 1990).

The Lau'agae quarry contains no mounds, defensive features, or other architectural remnants suggestive of elite control, but a portion of the end of the Lau'agae ridge has been impacted by modern construction and may have impacted archaeological remnants of the Lau'agae quarry complex including potential vestiges of elite control. Although this remains a possibility it is important to note that the majority of the ridge, and presumably AS-21-100, was not impacted by construction. Finally, the variability in the adze types produced suggests that multiple producers had access to the resource, and the access of multiple producers producing various adzes is not indicative of elite control over the labor at AS-21-100.

Independent Specialization

> H2: If AS-21-100 is the result of independent specialization then the data collected from the site will define moderate to high intensity of production at each scatter, a varied range of standardized adze types produced at either scatter, with no evidence for elite control, and either the export or the local consumption of adzes.

Based on the data collected from AS-21-100 and the parameters listed above, it is possible that production at scatters A1 and A8 at the Lau'agae quarry complex potentially best fit the model for independent specialization. There is little to no evidence for elite control at the site, but the intensity of production is moderate to high when compared to other quarries on Tutuila. Additionally, there are multiple adze types produced at each scatter, which is indicative of multiple producers. The evidence that these multiple adze types were also internally standardized can be interpreted as evidence of multiple skilled producers (i.e. potential specialists), each producing a standardized type of adze. Finally, based on the elemental analysis of samples from Lau'agae and Tula, there is no evidence for personal, local consumption of adzes produced at Lau'agae. These data suggest the possibility that the basalt adzes from Lau'agae were exported and not consumed by their local producers.

The size and scale of large quarry complexes on Tutuila such as Alega, Tataga matau, and Lau'agae are viewed as archaeological hallmarks of intensified production, especially when compared against local village and household production (Clark1993; Leach and Witter 1985, 1987, 1990; Winterhoff 2007). Essentially these large-scale quarries have been assumed to be the manifestation of economic intensification due to elite mandate. However, the archaeological evidence from Lau'agae does not conform to the expectations that a large quarry complex would most likely be the result of attached specialization (Lass 1994; Winterhoff 2007). This research challenges assumptions that large, potentially intensified quarry complexes on Tutuila were manifest through the elite sponsorship of full-time attached specialists.

Although the data from scatters A1 and A8 at the Lau'agae quarry complex do not provide unequivocal evidence for specialization in adze production, these data do provide evidence for multiple skilled producers, relative standardization of tool forms, and the potential exchange of adzes. Prior to this research, the expectation of the organization of production for a basalt quarry complex like AS-21-100 did not include the potential for multiple independent producers, but this research has provided evidence for multiple skilled producers, some of whom may have been craft specialists. Future research on the remaining eight uninvestigated adze production scatters at Lau'agae and other Tutuilan quarries should build upon these data, and further evaluate the organization of production and the potential manifestations of specialized production on the Samoan Island of Tutuila.

5. CONCLUSION

This dissertation research project applied novel analytical methodologies and techniques to the successful chemical characterization of Tutuilan basalt quarry complexes, and the investigation of basalt adze production, distribution, consumption and potential specialization. The research began with the first application of Instrumental Neutron Activation Analysis (INAA) towards the chemical characterization of Polynesian basalt adze quarries and artifacts. This application of INAA not only represented the first use of this technique in the region, but it also accomplished the first successful differentiation of Tutuilan basalt adze quarries using elemental concentration data. In the next section of this research, I created a new method for Energy Dispersive X-Ray Fluorescence (EDXRF), which was calibrated specifically for the chemical characterization of Tutuilan basalt. This method was partially devised from lessons learned in the application of INAA to the successful differentiation of Tutuilan basalt quarries. Although EDXRF had previously been unsuccessful in the differentiation of multiple basalt quarries in Tutuila, the new method presented in Section 3 successfully differentiated those same multiple quarries and can be applied elsewhere on the island.

After the successful application of EDXRF, Section 3 compares the results of INAA and EDXRF using elemental concentration data from the same samples and demonstrates that EDXRF can be as effective as INAA in the elemental analysis of Tutuilan basalt. Section 4 applies both technological and elemental analysis in the investigation of basalt adze production on Tutuila. Ultimately each analytical method contributed data that led to the

interpretation for the potential of specialized production at the Lau'agae basalt adze quarry complex (AS-21-100).

5.1 METHODOLOGICAL CONTRIBUTIONS

The broader implications of this research include contributions to the elemental analysis of fine grained volcanic rocks, which were utilized prehistorically by peoples worldwide, not only in Polynesia. This research demonstrates the efficacy of two popular elemental analysis techniques—not only in the characterization and differentiation of individual sources and production locales, but most importantly in the characterization and interpretation of production, distribution, and consumption of FGVR within a regional and local context.

The initial application of INAA in the region extended the use of an analytically powerful, but not widely available methodology, which is otherwise a gold standard in archeological chemical characterization studies. INAA was employed in my initial analysis because EDXRF had failed to differentiate between multiple quarries on the island of Tutuila (Clark et al. 1997). As INAA is analytically more powerful and precise than XRF, it was expected that if INAA could not differentiate between Tutuilan quarries, then the chemical composition of the basalt on Tutuila was too homogenous to be differentiated. Not only was this application of INAA successful in the differentiation of multiple basalt adze quarries on Tutuila, it demonstrated unequivocally that the elemental concentrations of Tutuila basalt were amenable to intra-island provenance projects utilizing elemental analysis.

Another important methodological contribution of this research was the successful application of EDXRF towards the differentiation of Tutuilan basalt quarries. After INAA

demonstrated that elemental concentration data could differentiate Tutuilan basalt quarries, it was determined that EDXRF also had the potential to successfully differentiate where it had previously failed. Using the remaining portions of samples collected from the quarries of Tutuila previously utilized for the INAA study and known geological standards, I calibrated an EDXRF method specific to the analysis of the basalt of Tutuila which, when combined with a rigorous sampling strategy, did successfully differentiate between multiple basalt quarries on Tutuila (Johnson 2011). This was a crucial success, as EDXRF is the technique of choice in the elemental analysis of basalt artifacts from Polynesia.

A significant methodological implication of my research concerns the comparison of the efficacy of INAA and EDXRF toward the chemical characterization and differentiation of Tutuilan basalt adze quarries. As my prior research had established both techniques could successfully differentiate Tutuilan quarries, it became important to determine which technique was the most efficacious for archeological applications. Although this comparison involves the chemical characterization precision of the techniques, it also concerned other factors such as cost, analysis time, data comparability, and destruction of samples when determining which technique was best for the archeologist analyzing FGVR. Individually, both methods are adept at the chemical characterization of FGVR. However, when I directly compared the results of INAA and EDXRF analysis conducted on the same basalt samples from Tutuila, EDXRF provided a more discrete differentiation of those samples than did INAA (Johnson 2011). That being said, it is important to note that the sample preparation requirements between INAA and EDXRF are very different, and could be responsible for the differing results in the comparison of the two techniques presented in Section 3.

As stated earlier, INAA requires a much smaller sample for analysis. In this research each sample subjected to INAA was a 50 mg internal piece of a larger basalt sample that was crushed. For EDXRF the remainder of those crushed basalt samples were powdered, then homogenized and pressed into 4 g pellets. As a result of these differing sample preparation procedures, it is possible that the samples analyzed for INAA were more heterogeneous and potentially less representative of the entire basalt sample than the larger, powdered, homogenized basalt pellets used for EDXRF.

That being said, it is equally important to note that although this differential sample preparation may have adversely affected INAA in comparison to EDXRF analysis, it does not negate the effective characterization results from EDXRF. Regardless of how INAA results may have been potentially affected by smaller, potentially less homogenized samples, the EDXRF results still provide unequivocal differentiation between these Tutuilan quarries through elemental concentration data.

This is an important contribution because it demonstrates the efficacy of EDXRF in the differentiation of basalt and FGVR, even when compared directly against other more precise and powerful techniques. In fact, according to Shackley (2011: 5), Johnson's (2011) analysis of basalts and Glascock's (2011) analysis of obsidians provides, "what I consider the defining characterization of EDXRF versus INAA." When the efficacy of EDXRF is considered along with its ability for non-destructive analysis, relatively low cost, widespread availability, and popularity in analyzing FGVR, I determined that at this time EDXRF is rightly the technique of choice for FGVR, including basalt adze quarries on Tutuila and elsewhere.

No matter how powerful or precise the chemical characterization, elemental concentration data derived from these techniques is most powerfully utilized in conjunction with other archeological analytical techniques and data. In this research, elemental analysis was used to define the distribution and consumption of basalt in conjunction with technological analysis which was used to define the production of basalt artifacts. Together, data derived from technological analysis and elemental analysis of artifacts guided the interpretation of organization of production, when either methodology alone would have left the description incomplete. The combination of technological and elemental analyses provides the only avenue for the complete analysis and interpretation of basalt adze manufacture, distribution, and consumption, as well as the potential social implications on Tutuila.

Finally, in addition to novel applications of elemental analysis techniques, this research also presents a novel application of statistical analysis of technological attribute data in the investigation of standardization of basalt adze manufacture. Coefficient of Variation (CV) was applied to the technological attribute analysis data. CV is a statistical analysis that divides the standard deviation of a group by its mean. This simple statistical application (Eerkens 2000; Eerkens and Bettinger 2001) provided for a reliable measurement of standardization within the basalt adze blanks and preforms from the Lau'agae quarry complex. The CV data from scatters A1 and A8 suggested standardization in basalt adze blanks and preforms when compared to other basalt quarry assemblages. This statistical measure of standardization can be easily applied to existing datasets that have not been investigated for standardization, because the mean and standard deviation are two measurements which are often present or easily derived from existing technological attribute

analysis data of basalt adze manufacture. This application of CV was the first such investigation of morphological standardization in adze manufacture on Tutuila. The CV data together with the elemental analysis data provided two of the most compelling lines of evidence for the potential specialization of basalt adze manufacture at AS-21-100.

5.2 THEORETICAL CONTRIBUTIONS

Relative size and scale of basalt quarries throughout Polynesia have been a primary defining factor used to determine the organization of production at those sites. As Kirch (1984) noted, all Polynesian societies undergo economic intensification, which leads to specialized production. Large-scale basalt quarries located across the Pacific have been interpreted as the manifestation of elite-sponsored economic intensification and attached specialization, because it was assumed that the intensity of production at these quarries far exceeded the need for local consumption and therefore must have been intended for chiefly-sponsored export and exchange (Cleghorn 1986; Leach and Witter 1985, 1987, 1990).

Tataga Matau on Tutuila is one of the quarries that has been interpreted as a site of elite-mandated economic intensification and attached specialization (Leach and Witter 1990, Winterhoff 2007). Although Tataga Matau is a large basalt quarry complex, there are several quarry complexes on Tutuila that are as large or larger (Clark et al 1997, Johnson et al 2007). One of those complexes is Lau'agae. As stated earlier, AS-21-100 has no less than 10 basalt quarry areas, where Tataga Matau has 3 quarry areas. If size and scale of production are direct indicators of elite sponsored economic intensification, then basalt adze production at the Lau'agae quarry complex should indicate chiefly sponsored attached specialization.

The results of this research indicate, however, that although the intensity of production at AS-21-100 was higher than other Tutuilan quarries, there was little evidence to suggest chiefly patronage or attached specialization at the site. There are no monuments on the landscape representing elite control of the resources. Also, there is no evidence for elite control of labor given the varied types of adzes produced at AS-21-100.

In contradiction to the highly organized production associated with attached specialization, there was ample evidence at both scatters for multiple producers manufacturing varied forms of adzes. Although there was little evidence for elite-sponsored attached specialization at AS-21-100, and there was clear evidence for multiple producers, the technological and elemental analysis did provide evidence for potentially specialized adze production at the site.

Rather than the product of a few attached, full-time specialists, the data from AS-21-100 suggests that adzes produced at the site were produced by multiple, independent producers. The data from each scatter provides evidence of standardization within the preforms, and beginning with highly standardized adze blanks, which were the first step in the manufacture process. The evidence for internal standardization of multiple adze types at scatters A1 and A8 is potentially suggestive of multiple producers who specialized in the manufacture of a standard adze type as opposed to a few producers making multiple adze types.

Finally, the elemental analysis demonstrates no local consumption of basalt from AS-21-100. This lack of local consumption is also potentially indicative of specialized production, which was intended for exchange. This was the final line in multiple lines of

evidence that indicated the potential for specialized production at the Lau'agae quarry complex.

A regional contribution of this finding is that large-scale intensified quarry complexes do not inherently represent the manifestation of chiefly sponsored attached specialization. Rather, in this case, the intensity and scale of production at AS-21-100 appears to be the result of multiple producers, some of whom were skilled and potentially specialists. To that end, another theoretical contribution of this work is defining specific archeological parameters for independent specialization in basalt adze manufacture on the island of Tutuila.

Finally, defining the organization of technology for basalt adzes, which are inherently important in Samoan society, both for utilitarian and specialized purposes, aids in our understanding of the organization of Tutuilan society. The Monument Building Period on Tutuila is defined as a period of social change and increasing social stratification (Davidson 1977). The presence of economic intensification and the potential for specialization would be expected in association with such social transformations. The potential for independent production for personal consumption or independent specialization at one of the largest basalt quarries on Tutuila during that time poses new questions about the social organization on Tutuila during the Monument Building Period.

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APPENDIX A

MASS ANALYSIS DATA ON DEBITAGE FROM AS-21-100

KEY FOR MA DATA

TYPE	PLATFORM
C= Cortical Removal	A= Absent
D= Distal Fragment	C= Cortical
F= Complete Flake	F= Faceted
M= Medial Fragment	P= Polished
P= Proximal Fragment	S= Simple
S= Shatter	

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	1	3	N	F	1	S
A8	1	1	1	2	N	F	0.5	S
A8	1	1	1	2	N	S	0.25	A
A8	1	1	1	>4	N	S	0.25	A
A8	1	1	1	3	N	S	0.25	A
A8	1	1	1	3	N	F	0.25	F
A8	1	1	1	>4	N	F	2	S
A8	1	1	1	0	N	D	1	A
A8	1	1	1	2	N	S	0.25	A
A8	1	1	1	0	N	M	0.5	A
A8	1	1	1	>4	N	F	2	F
A8	1	1	1	0	N	D	1	A
A8	1	1	1	0	N	P	0.25	S
A8	1	1	1	0	N	F	0.5	S
A8	1	1	1	>4	N	F	2	S
A8	1	1	1	3	N	S	1	A
A8	1	1	1	2	N	F	1	S
A8	1	1	1	0	N	F	0.25	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	1	0	N	F	3	S
A8	1	1	1	3	N	F	1	S
A8	1	1	1	2	N	S	0.025	A
A8	1	1	1	2	N	S	0.25	A
A8	1	1	1	>4	N	F	1	S
A8	1	1	1	3	N	D	2	A
A8	1	1	1	2	N	D	0.5	A
A8	1	1	1	3	N	S	0.25	A
A8	1	1	1	0	N	D	0.25	A
A8	1	1	1	3	N	D	0.5	A
A8	1	1	1	0	N	F	0.25	S
A8	1	1	1	2	N	F	1	S
A8	1	1	1	2	N	D	2	A
A8	1	1	1	2	N	D	0.5	A
A8	1	1	1	2	N	D	0.5	A
A8	1	1	1	0	N	D	0.5	A
A8	1	1	1	0	N	D	1	A
A8	1	1	1	0	N	D	1	A
A8	1	1	1	2	N	D	1	A
A8	1	1	1	2	N	D	1	A
A8	1	1	1	2	N	D	0.25	A
A8	1	1	1	2	N	D	0.25	A
A8	1	1	1	2	N	D	1	A
A8	1	1	1	2	N	D	0.25	A
A8	1	1	1	2	N	D	0.25	A
A8	1	1	1	0	N	D	0.25	A
A8	1	1	1	0	N	D	0.25	A
A8	1	1	1	0	N	D	0.25	A
A8	1	1	1	2	N	F	0.5	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	1	4	N	F	0.5	S
A8	1	1	1	0	N	F	0.25	S
A8	1	1	1	3	N	F	0.5	S
A8	1	1	1	0	N	S	0.25	A
A8	1	1	1	0	N	S	0.25	A
A8	1	1	1	0	N	S	0.25	A
A8	1	1	1	0	N	S	0.25	A
A8	1	1	1	0	N	S	0.25	A
A8	1	1	1	0	N	S	0.25	A
A8	1	1	1	0	N	S	0.25	A
A8	1	1	1	0	N	S	0.25	A
A8	1	1	1	0	N	S	0.25	A
A8	1	1	1	0	N	S	0.25	A
A8	1	1	1	0	N	F	0.25	S
A8	1	1	1	>4	N	F	0.5	S
A8	1	1	1	3	N	F	0.5	S
A8	1	1	1	>4	N	F	0.5	S
A8	1	1	1	3	N	P	0.5	S
A8	1	1	1	0	N	P	0.25	S
A8	1	1	1	0	N	D	0.25	A
A8	1	1	1	2	N	D	0.5	A
A8	1	2	1	4	N	F	0.25	S
A8	1	2	1	0	N	S	2	A
A8	1	2	1	0	N	F	0.5	S
A8	1	2	1	0	N	D	0.25	A
A8	1	2	1	2	N	F	0.25	S
A8	1	2	1	0	N	S	3	A
A8	1	2	1	2	N	F	0.25	S
A8	1	2	1	3	N	F	0.25	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	2	1	2	N	F	0.25	S
A8	1	2	1	0	N	F	0.25	S
A8	1	2	1	2	N	F	0.25	S
A8	1	2	1	2	N	F	0.25	S
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	3	N	D	0.25	A
A8	1	2	1	0	N	D	0.25	A
A8	1	2	1	0	N	D	0.25	A
A8	1	2	1	0	N	D	0.25	A
A8	1	2	1	0	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	0	N	D	0.25	A
A8	1	2	1	0	N	D	0.25	A
A8	1	2	1	0	N	S	0.25	A
A8	1	2	1	0	N	S	0.25	A
A8	1	2	1	0	N	S	0.25	A
A8	1	2	1	0	N	S	0.25	A
A8	1	2	1	3	N	S	0.25	A
A8	1	2	1	3	N	S	0.25	A
A8	1	2	1	3	N	S	0.25	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	2	1	0	N	S	0.25	A
A8	1	2	1	0	N	P	0.25	S
A8	1	2	1	0	N	P	0.5	S
A8	1	2	1	0	N	P	0.25	S
A8	1	2	1	0	N	P	0.25	S
A8	1	2	1	0	N	P	0.25	S
A8	1	2	1	0	N	P	0.25	S
A8	1	2	1	0	N	S	0.25	A
A8	1	2	1	0	N	S	0.25	A
A8	1	2	1	0	N	S	0.25	A
A8	1	2	1	0	N	S	0.25	A
A8	1	2	1	0	N	P	0.25	S
A8	1	2	1	0	N	P	0.25	S
A8	1	2	1	0	N	P	0.5	S
A8	1	2	1	0	N	P	0.25	S
A8	1	2	1	0	N	P	0.25	S
A8	1	2	1	0	N	P	0.5	S
A8	1	2	1	3	N	F	1	S
A8	1	2	1	2	N	P	0.5	S
A8	1	2	1	0	N	P	0.25	S
A8	1	2	1	0	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	0	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	2	1	2	N	D	0.25	A
A8	1	3	1	0	N	D	0.5	A
A8	1	3	1	0	N	F	0.5	S
A8	1	3	1	2	N	F	0.25	S
A8	1	3	1	0	N	F	0.25	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	3	1	0	N	F	0.25	S
A8	1	3	1	0	N	F	0.25	S
A8	1	3	1	2	N	F	0.25	S
A8	1	3	1	0	N	S	1	A
A8	1	3	1	0	N	S	1	A
A8	1	3	1	0	N	S	0.25	A
A8	1	3	1	0	N	S	0.25	A
A8	1	3	1	0	N	S	0.5	A
A8	1	3	1	0	N	S	0.5	A
A8	1	1	2	2	N	M	2	A
A8	1	1	2	0	N	P	4	S
A8	1	1	2	>4	N	S	1	A
A8	1	1	2	3	N	F	5	S
A8	1	1	2	0	N	F	2	S
A8	1	1	2	>4	N	F	2	F
A8	1	1	2	2	N	D	3	A
A8	1	1	2	3	N	F	6	S
A8	1	1	2	2	N	F	4	S
A8	1	1	2	4	N	M	4	A
A8	1	1	2	2	N	F	3	S
A8	1	1	2	2	N	F	3	S
A8	1	1	2	2	N	F	7	S
A8	1	1	2	1	N	D	4	A
A8	1	1	2	0	N	F	2	S
A8	1	1	2	2	N	F	4	F
A8	1	1	2	3	N	F	3	S
A8	1	1	2	3	N	S	0.5	A
A8	1	1	2	C	Y	P	3	C
A8	1	1	2	>4	N	F	3	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	2	>4	N	S	3	A
A8	1	1	2	>4	N	F	8	S
A8	1	1	2	0	N	F	3	S
A8	1	1	2	3	N	F	3	S
A8	1	1	2	0	N	F	4	S
A8	1	1	2	2	N	F	2	S
A8	1	1	2	2	N	F	1	S
A8	1	1	2	>4	N	F	5	S
A8	1	1	2	3	N	F	4	S
A8	1	1	2	0	N	F	0.5	S
A8	1	1	2	>4	N	F	3	S
A8	1	1	2	>4	N	F	3	S
A8	1	1	2	1	Y	P	4	S
A8	1	1	2	2	N	S	2	A
A8	1	1	2	3	N	S	0.5	A
A8	1	1	2	3	N	S	0.5	A
A8	1	1	2	>4	N	S	0.25	A
A8	1	1	2	2	N	S	0.25	A
A8	1	1	2	2	N	S	0.5	A
A8	1	1	2	3	N	S	0.25	A
A8	1	1	2	>4	Y	F	4	S
A8	1	1	2	0	N	F	2	S
A8	1	1	2	2	N	F	1	S
A8	1	1	2	C	Y	F	4	C
A8	1	1	2	2	Y	F	6	F
A8	1	1	2	2	N	F	2	S
A8	1	1	2	>4	N	P	3	F
A8	1	1	2	3	N	F	3	S
A8	1	1	2	3	N	S	0.5	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	2	3	N	S	0.5	A
A8	1	1	2	3	N	S	0.5	A
A8	1	1	2	0	N	F	2	S
A8	1	1	2	3	N	P	4	F
A8	1	1	2	4	N	F	3	S
A8	1	1	2	2	N	F	4	S
A8	1	1	2	>4	N	P	3	S
A8	1	1	2	>4	N	M	1	A
A8	1	1	2	>4	N	F	2	S
A8	1	1	2	4	N	F	4	S
A8	1	1	2	4	N	D	2	A
A8	1	1	2	C	Y	F	6	C
A8	1	1	2	3	N	D	3	A
A8	1	1	2	3	N	D	2	A
A8	1	1	2	2	N	F	3	S
A8	1	1	2	4	N	F	2	S
A8	1	1	2	3	N	S	1	A
A8	1	1	2	3	N	S	2	A
A8	1	1	2	0	N	P	2	S
A8	1	1	2	0	N	M	0.5	A
A8	1	1	2	>4	N	F	9	S
A8	1	1	2	2	N	F	4	F
A8	1	1	2	2	N	S	4	A
A8	1	1	2	3	Y	F	6	S
A8	1	1	2	2	N	F	3	S
A8	1	1	2	0	N	F	3	S
A8	1	1	2	>4	Y	F	3	S
A8	1	1	2	3	N	F	6	S
A8	1	1	2	3	N	D	2	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	2	2	N	P	0.5	S
A8	1	1	2	>4	N	F	3	S
A8	1	1	2	2	N	F	3	S
A8	1	1	2	2	N	F	2	S
A8	1	1	2	2	N	F	4	S
A8	1	1	2	>4	N	F	3	F
A8	1	1	2	>4	N	F	5	S
A8	1	1	2	2	N	P	3	S
A8	1	1	2	2	N	F	4	S
A8	1	1	2	3	N	F	3	S
A8	1	1	2	0	N	F	3	S
A8	1	1	2	C	Y	S	5	A
A8	1	1	2	>4	N	D	2	A
A8	1	1	2	0	N	D	2	A
A8	1	1	2	2	N	F	2	S
A8	1	1	2	3	N	F	4	S
A8	1	1	2	3	N	F	7	S
A8	1	1	2	>4	N	F	6	F
A8	1	1	2	>4	N	D	3	A
A8	1	1	2	>4	N	F	4	S
A8	1	1	2	2	N	S	2	A
A8	1	1	2	3	N	S	1	A
A8	1	1	2	0	N	F	3	S
A8	1	1	2	>4	N	F	3	S
A8	1	1	2	0	N	D	3	A
A8	1	1	2	3	N	P	5	S
A8	1	1	2	0	N	S	3	A
A8	1	1	2	C	Y	F	2	S
A8	1	1	2	2	N	F	4	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	2	2	N	M	3	A
A8	1	1	2	3	N	F	3	S
A8	1	1	2	>4	N	F	3	S
A8	1	1	2	3	N	S	4	A
A8	1	1	2	C	Y	D	2	A
A8	1	1	2	3	N	F	8	S
A8	1	1	2	2	N	F	0.5	S
A8	1	1	2	>4	N	F	2	F
A8	1	1	2	>4	N	F	4	F
A8	1	1	2	0	N	F	1	S
A8	1	1	2	0	N	F	2	S
A8	1	1	2	0	N	F	2	S
A8	1	1	2	0	N	M	0.25	A
A8	1	1	2	2	N	S	0.25	A
A8	1	1	2	2	N	S	0.25	A
A8	1	1	2	3	N	S	0.25	A
A8	1	1	2	3	N	S	0.25	A
A8	1	1	2	2	N	S	0.25	A
A8	1	1	2	4	N	D	3	A
A8	1	1	2	3	N	P	3	S
A8	1	1	2	>4	N	F	2	S
A8	1	1	2	2	N	S	0.25	A
A8	1	1	2	2	N	S	0.5	A
A8	1	1	2	3	N	S	0.5	A
A8	1	1	2	3	N	S	0.75	A
A8	1	1	2	2	N	S	0.25	A
A8	1	1	2	2	N	S	0.25	A
A8	1	1	2	2	N	S	0.25	A
A8	1	1	2	3	N	S	0.25	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	2	3	N	S	0.25	A
A8	1	1	2	2	N	S	0.25	A
A8	1	1	2	2	N	F	2	S
A8	1	1	2	3	N	F	1	S
A8	1	1	2	>4	N	P	4	S
A8	1	1	2	2	N	D	4	A
A8	1	1	2	0	N	F	4	S
A8	1	1	2	3	Y	F	3	S
A8	1	1	2	C	Y	D	3	A
A8	1	1	2	4	N	F	6	F
A8	1	1	2	>4	N	F	5	F
A8	1	1	2	2	N	M	3	A
A8	1	1	2	2	N	F	10	F
A8	1	1	2	C	Y	F	4	C
A8	1	1	2	>4	N	F	5	S
A8	1	1	2	2	Y	S	3	A
A8	1	1	2	2	Y	F	5	F
A8	1	1	2	>4	Y	F	3	S
A8	1	1	2	3	N	F	2	S
A8	1	1	2	3	N	F	5	F
A8	1	1	2	>4	N	F	5	S
A8	1	1	2	>4	N	F	3	S
A8	1	1	2	C	Y	S	3	A
A8	1	1	2	3	N	F	4	S
A8	1	1	2	2	N	D	5	A
A8	1	1	2	2	N	F	7	F
A8	1	1	2	4	N	F	3	S
A8	1	1	2	0	N	S	6	A
A8	1	1	2	3	N	F	4	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	2	2	N	F	4	S
A8	1	1	2	>4	N	F	5	S
A8	1	1	2	2	N	F	3	S
A8	1	1	2	2	N	D	2	A
A8	1	1	2	>4	N	P	1	S
A8	1	1	2	3	N	P	2	F
A8	1	1	2	NA	N	S	3	A
A8	1	1	2	>4	N	P	4	F
A8	1	1	2	>4	N	P	2	F
A8	1	1	2	>4	N	F	1	S
A8	1	1	2	2	N	F	3	S
A8	1	1	2	3	N	F	2	S
A8	1	1	2	0	N	S	0.5	A
A8	1	1	2	0	N	S	0.5	A
A8	1	1	2	0	N	S	0.25	A
A8	1	1	2	0	N	S	0.5	A
A8	1	1	2	0	N	S	0.25	A
A8	1	1	2	0	N	S	0.5	A
A8	1	1	2	0	N	S	1	A
A8	1	1	2	0	N	S	2	A
A8	1	1	2	0	N	S	1	A
A8	1	1	2	3	N	D	0.5	A
A8	1	2	2	2	N	M	8	A
A8	1	2	2	0	N	S	6	A
A8	1	2	2	0	N	D	0.5	A
A8	1	2	2	2	N	P	6	S
A8	1	2	2	>4	N	P	3	S
A8	1	2	2	2	N	D	2	A
A8	1	2	2	>4	N	F	4	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	2	2	>4	N	F	2	S
A8	1	2	2	3	N	F	2	S
A8	1	2	2	3	N	F	3	S
A8	1	2	2	0	N	F	0.5	S
A8	1	2	2	3	N	F	2	S
A8	1	2	2	2	N	F	0.5	S
A8	1	2	2	3	N	F	0.5	F
A8	1	2	2	>4	N	F	3	F
A8	1	2	2	3	N	F	3	S
A8	1	2	2	4	N	F	5	S
A8	1	2	2	2	N	F	3	S
A8	1	2	2	0	N	F	1	S
A8	1	2	2	2	N	F	2	S
A8	1	2	2	3	N	F	2	S
A8	1	2	2	3	N	F	3	S
A8	1	2	2	>4	N	F	3	F
A8	1	2	2	3	N	F	1	S
A8	1	2	2	2	N	F	4	S
A8	1	2	2	4	N	F	3	S
A8	1	2	2	0	N	D	0.5	A
A8	1	2	2	2	N	D	0.25	A
A8	1	2	2	0	N	D	1	A
A8	1	2	2	2	N	D	0.25	A
A8	1	2	2	0	N	D	0.25	A
A8	1	2	2	0	N	D	0.25	A
A8	1	2	2	3	N	D	0.25	A
A8	1	2	2	0	N	D	0.5	A
A8	1	2	2	0	N	D	0.25	A
A8	1	2	2	0	N	D	0.25	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	2	2	2	N	D	0.25	A
A8	1	2	2	2	N	D	0.25	A
A8	1	2	2	2	N	D	0.25	A
A8	1	2	2	2	N	D	0.25	A
A8	1	2	2	0	N	D	0.5	A
A8	1	2	2	0	N	P	0.5	S
A8	1	2	2	2	N	P	1	S
A8	1	2	2	2	N	P	2	S
A8	1	2	2	2	N	P	1	F
A8	1	2	2	0	N	P	0.5	S
A8	1	2	2	0	N	S	0.25	A
A8	1	2	2	0	N	S	1	A
A8	1	2	2	0	N	S	1	A
A8	1	2	2	0	N	S	0.25	A
A8	1	2	2	0	N	S	0.25	A
A8	1	2	2	0	N	S	0.5	A
A8	1	2	2	0	N	S	1	A
A8	1	2	2	0	N	S	2	A
A8	1	2	2	0	N	S	1	A
A8	1	2	2	0	N	S	1	A
A8	1	2	2	0	N	S	0.5	A
A8	1	2	2	0	N	S	9	A
A8	1	2	2	0	N	S	2	A
A8	1	2	2	3	N	F	3	F
A8	1	2	2	3	N	F	2	S
A8	1	2	2	0	N	S	3	A
A8	1	3	2	0	N	F	5	S
A8	1	3	2	3	N	F	3	S
A8	1	3	2	>4	N	F	4	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	3	2	2	N	P	4	S
A8	1	3	2	0	N	F	2	S
A8	1	3	2	2	N	M	3	A
A8	1	3	2	>4	N	F	4	S
A8	1	3	2	0	N	F	3	S
A8	1	3	2	2	N	F	3	F
A8	1	3	2	2	N	F	3	F
A8	1	3	2	0	N	S	1	A
A8	1	3	2	0	N	S	1	A
A8	1	3	2	0	N	S	2	A
A8	1	3	2	0	N	S	3	A
A8	1	3	2	0	N	S	1	A
A8	1	3	2	0	N	S	1	A
A8	1	3	2	0	N	S	1	A
A8	1	3	2	0	N	S	2	A
A8	1	3	2	0	N	S	1	A
A8	1	3	2	0	N	S	1	A
A8	1	3	2	2	N	M	1	A
A8	1	3	2	0	N	M	1	A
A8	1	3	2	2	N	M	1	A
A8	1	3	2	0	N	M	0.5	A
A8	2	3	2	0	N	P	2	S
A8	2	3	2	0	N	S	1	S
A8	1	3	2	0	N	S	0.5	S
A8	1	3	2	0	N	S	0.5	S
A8	2	3	2	0	N	S	1	S
A8	1	3	2	0	N	S	1	S
A8	1	S	2	0	Y	M	6	A
A8	1	S	2	2	N	S	9	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	S	2	>4	N	S	7	A
A8	1	S	2	2	N	D	4	A
A8	1	S	2	>4	N	F	4	F
A8	1	S	2	3	N	M	4	A
A8	1	S	2	3	N	F	1	S
A8	1	S	2	>4	N	F	6	S
A8	1	S	2	2	N	P	2	F
A8	1	S	2	>4	N	F	6	F
A8	1	1	3	3	N	F	9	S
A8	1	1	3	>4	N	F	6	S
A8	1	1	3	>4	N	F	5	S
A8	1	1	3	0	N	F	8	F
A8	1	1	3	>4	Y	F	16	S
A8	1	1	3	3	N	F	14	S
A8	1	1	3	>4	N	F	9	S
A8	1	1	3	>4	N	M	8	A
A8	1	1	3	2	N	F	7	S
A8	1	1	3	2	N	S	6	A
A8	1	1	3	>4	N	F	4	S
A8	1	1	3	3	N	F	6	S
A8	1	1	3	>4	Y	F	6	F
A8	1	1	3	2	Y	S	6	A
A8	1	1	3	2	N	F	5	S
A8	1	1	3	>4	N	F	11	F
A8	1	1	3	2	N	F	12	S
A8	1	1	3	0	N	F	2	S
A8	1	1	3	3	N	F	6	S
A8	1	1	3	>4	N	F	4	S
A8	1	1	3	2	N	D	4	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	3	>4	N	D	7	A
A8	1	1	3	>4	N	F	6	S
A8	1	1	3	>4	N	F	4	S
A8	1	1	3	>4	N	F	10	S
A8	1	1	3	3	N	F	6	S
A8	1	1	3	2	N	F	6	S
A8	1	1	3	>4	N	F	7	S
A8	1	1	3	>4	N	P	3	F
A8	1	1	3	>4	N	F	8	F
A8	1	1	3	2	N	F	6	S
A8	1	1	3	2	N	S	2	A
A8	1	1	3	1	Y	D	3	A
A8	1	1	3	C	Y	F	12	S
A8	1	1	3	3	N	F	7	F
A8	1	1	3	>4	N	D	6	A
A8	1	1	3	2	N	F	9	F
A8	1	1	3	>4	N	F	19	S
A8	1	1	3	>4	N	F	12	S
A8	1	1	3	3	N	F	9	F
A8	1	1	3	>4	N	F	13	S
A8	1	1	3	>4	N	F	13	S
A8	1	1	3	2	N	F	11	F
A8	1	1	3	2	N	F	5	F
A8	1	1	3	>4	N	F	10	S
A8	1	1	3	>4	N	F	12	S
A8	1	1	3	>4	N	D	10	A
A8	1	1	3	2	Y	F	7	S
A8	1	1	3	>4	N	F	6	S
A8	1	1	3	>4	N	F	4	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	3	3	N	P	5	S
A8	1	1	3	>4	N	S	4	A
A8	1	1	3	2	Y	F	6	S
A8	1	1	3	4	N	F	9	S
A8	1	1	3	>4	N	F	10	F
A8	1	1	3	2	N	D	5	A
A8	1	1	3	0	N	F	10	S
A8	1	1	3	2	N	F	9	S
A8	1	1	3	>4	N	D	12	A
A8	1	1	3	3	N	F	6	S
A8	1	1	3	2	N	F	9	S
A8	1	1	3	2	Y	F	5	S
A8	1	1	3	2	N	F	5	S
A8	1	1	3	>4	N	F	8	F
A8	1	1	3	>4	N	F	2	S
A8	1	1	3	>4	N	F	12	S
A8	1	1	3	>4	N	F	6	S
A8	1	1	3	>4	N	F	9	S
A8	1	1	3	>4	N	F	7	F
A8	1	1	3	3	N	F	4	F
A8	1	1	3	>4	N	D	4	A
A8	1	1	3	>4	N	F	9	F
A8	1	1	3	>4	N	F	10	S
A8	1	1	3	2	N	F	6	S
A8	1	1	3	C	Y	F	7	S
A8	1	1	3	0	N	P	7	S
A8	1	1	3	2	N	F	10	S
A8	1	1	3	>4	N	F	5	S
A8	1	1	3	0	N	F	3	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	3	2	N	S	7	A
A8	1	1	3	0	N	D	3	A
A8	1	1	3	>4	N	F	9	F
A8	1	1	3	C	Y	F	8	C
A8	1	1	3	>4	N	P	12	S
A8	1	1	3	C	Y	F	5	S
A8	1	1	3	>4	N	D	7	A
A8	1	1	3	>4	N	F	12	F
A8	1	1	3	>4	N	F	5	S
A8	1	1	3	>4	Y	F	8	S
A8	1	1	3	0	N	P	5	S
A8	1	1	3	2	N	F	12	F
A8	1	1	3	2	N	F	8	S
A8	1	1	3	3	N	F	14	S
A8	1	1	3	4	Y	F	14	S
A8	1	1	3	>4	N	S	21	A
A8	1	1	3	>4	N	F	19	F
A8	1	1	3	0	N	F	9	S
A8	1	1	3	>4	N	F	8	S
A8	1	1	3	C	Y	P	10	S
A8	1	1	3	>4	N	F	6	S
A8	1	1	3	2	Y	F	12	S
A8	1	1	3	2	Y	D	9	A
A8	1	1	3	3	N	F	11	F
A8	1	1	3	3	N	F	10	S
A8	1	1	3	>4	N	D	6	A
A8	1	1	3	>4	N	F	5	S
A8	1	1	3	C	Y	S	8	A
A8	1	1	3	C	Y	D	8	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	3	3	N	F	6	S
A8	1	1	3	C	Y	F	6	C
A8	1	1	3	C	Y	F	9	S
A8	1	1	3	>4	N	P	13	F
A8	1	1	3	>4	N	F	4	S
A8	1	1	3	2	Y	F	8	C
A8	1	1	3	>4	Y	F	5	F
A8	1	1	3	3	N	D	6	A
A8	1	1	3	>4	N	F	8	S
A8	1	1	3	2	N	F	6	S
A8	1	1	3	>4	N	F	5	F
A8	1	1	3	2	N	F	4	S
A8	1	1	3	2	N	F	3	F
A8	1	1	3	0	N	D	9	A
A8	1	1	3	>4	N	F	6	S
A8	1	1	3	>4	N	F	5	F
A8	1	2	3	>4	Y	F	14	S
A8	1	2	3	>4	N	F	11	S
A8	1	2	3	>4	N	F	14	F
A8	1	2	3	NA	N	S	14	A
A8	1	2	3	>4	N	F	15	S
A8	1	2	3	4	N	F	13	S
A8	1	2	3	>4	N	F	9	S
A8	1	2	3	2	N	F	9	S
A8	1	2	3	3	N	F	5	F
A8	1	2	3	0	N	F	9	S
A8	1	2	3	2	N	F	7	S
A8	1	2	3	0	N	P	6	S
A8	1	2	3	2	Y	F	10	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	2	3	2	N	F	7	S
A8	1	2	3	>4	N	F	6	S
A8	1	2	3	>4	N	F	7	S
A8	1	2	3	>4	N	F	9	F
A8	1	2	3	4	N	D	6	A
A8	1	2	3	3	N	F	13	F
A8	1	2	3	>4	N	F	5	S
A8	1	2	3	3	N	F	5	S
A8	1	2	3	2	N	D	4	A
A8	1	2	3	2	N	D	5	A
A8	1	2	3	>4	N	F	3	S
A8	1	2	3	3	N	F	9	F
A8	1	2	3	0	N	S	15	A
A8	1	2	3	0	N	F	6	S
A8	1	2	3	C	Y	F	6	S
A8	1	2	3	4	N	F	6	S
A8	1	2	3	>4	N	F	3	S
A8	1	3	3	2	N	P	11	S
A8	1	3	3	0	N	F	9	S
A8	1	3	3	0	N	F	6	S
A8	1	3	3	2	N	F	10	S
A8	1	3	3	2	N	F	7	S
A8	1	3	3	2	N	F	6	F
A8	1	3	3	2	N	F	5	S
A8	1	3	3	C	Y	F	3	S
A8	1	3	3	>4	N	F	6	S
A8	1	3	3	0	N	D	5	A
A8	1	3	3	2	N	F	5	S
A8	1	S	3	1	N	F	9	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	S	3	3	N	P	11	S
A8	1	S	3	0	N	P	7	S
A8	1	S	3	3	N	F	14	S
A8	1	S	3	3	N	F	11	F
A8	1	S	3	1	N	D	11	A
A8	1	S	3	0	Y	F	16	S
A8	1	S	3	>4	Y	F	13	F
A8	1	S	3	>4	Y	F	8	C
A8	1	S	3	3	Y	S	14	A
A8	1	S	3	>4	N	F	10	S
A8	1	S	3	C	Y	F	9	S
A8	1	S	3	3	N	S	8	A
A8	1	S	3	2	N	S	5	A
A8	1	S	3	>4	N	F	13	S
A8	1	S	3	>4	N	D	6	A
A8	1	S	3	2	N	F	9	S
A8	1	S	3	3	N	S	6	A
A8	1	S	3	1	N	S	5	A
A8	1	S	3	3	N	F	11	S
A8	1	S	3	C	Y	F	14	S
A8	1	S	3	>4	Y	F	9	F
A8	1	S	3	>4	N	P	11	S
A8	1	S	3	>4	N	F	6	S
A8	1	S	3	I	N	S	5	A
A8	1	1	4	>4	N	F	54	F
A8	1	1	4	2	Y	F	32	S
A8	1	1	4	>4	N	S	45	A
A8	1	1	4	3	N	F	13	S
A8	1	1	4	>4	N	F	14	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	4	0	N	P	22	S
A8	1	1	4	>4	Y	F	28	F
A8	1	1	4	3	N	D	13	A
A8	1	1	4	4	Y	F	41	C
A8	1	1	4	>4	N	F	24	S
A8	1	1	4	>4	N	F	21	F
A8	1	1	4	>4	N	S	8	A
A8	1	1	4	1	Y	F	13	S
A8	1	1	4	3	N	F	22	F
A8	1	1	4	>4	N	F	11	S
A8	1	1	4	>4	N	F	8	S
A8	1	1	4	>4	N	P	16	S
A8	1	1	4	>4	N	F	18	S
A8	1	1	4	2	N	F	14	S
A8	1	1	4	>4	Y	F	18	S
A8	1	1	4	3	Y	F	14	C
A8	1	1	4	>4	N	F	18	F
A8	1	1	4	>4	N	F	20	S
A8	1	1	4	2	N	F	12	S
A8	1	1	4	1	Y	F	20	S
A8	1	1	4	1	Y	F	12	S
A8	1	1	4	>4	Y	P	31	S
A8	1	1	4	3	N	F	24	S
A8	1	1	4	>4	N	F	12	S
A8	1	1	4	4	N	F	22	F
A8	1	1	4	0	N	F	26	F
A8	1	1	4	2	N	P	11	F
A8	1	1	4	2	N	F	29	S
A8	1	1	4	3	N	F	26	F

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	4	>4	N	F	27	F
A8	1	1	4	>4	N	F	30	S
A8	1	1	4	>4	N	F	16	F
A8	1	1	4	2	N	F	15	F
A8	1	1	4	2	Y	F	15	S
A8	1	1	4	0	N	F	22	F
A8	1	1	4	>4	Y	F	19	F
A8	1	1	4	>4	N	M	20	A
A8	1	1	4	>4	N	F	18	S
A8	1	1	4	3	Y	F	33	S
A8	1	1	4	2	Y	F	34	S
A8	1	1	4	2	N	F	17	F
A8	1	1	4	>4	Y	F	15	C
A8	1	1	4	>4	N	F	10	S
A8	1	1	4	3	N	F	19	S
A8	1	1	4	0	N	F	6	S
A8	1	1	4	>4	N	F	9	S
A8	1	1	4	>4	N	F	24	F
A8	1	1	4	4	N	F	20	S
A8	1	1	4	>4	N	F	12	S
A8	1	1	4	>4	N	F	16	S
A8	1	1	4	C	Y	F	20	S
A8	1	1	4	2	N	F	41	S
A8	1	1	4	2	Y	F	48	S
A8	1	1	4	4	Y	F	27	S
A8	1	1	4	>4	N	F	23	S
A8	1	1	4	0	N	D	18	A
A8	1	1	4	3	Y	F	9	S
A8	1	1	4	1	Y	F	24	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	4	3	N	F	29	S
A8	1	1	4	2	N	D	15	A
A8	1	1	4	2	Y	F	15	F
A8	1	1	4	>4	N	F	8	S
A8	1	1	4	C	Y	M	12	A
A8	1	1	4	>4	N	F	11	S
A8	1	1	4	>4	N	F	10	F
A8	1	1	4	>4	N	F	18	S
A8	1	1	4	2	N	F	11	F
A8	1	1	4	C	Y	D	15	A
A8	1	1	4	>4	N	F	28	F
A8	1	1	4	>4	Y	F	24	C
A8	1	1	4	>4	N	F	9	S
A8	1	1	4	2	Y	D	9	A
A8	1	1	4	4	N	P	25	S
A8	1	1	4	3	N	D	6	A
A8	1	1	4	2	N	F	5	S
A8	1	2	4	2	N	F	24	S
A8	1	2	4	>4	N	F	37	S
A8	1	2	4	3	N	F	21	S
A8	1	2	4	>4	N	F	19	S
A8	1	2	4	3	N	F	33	S
A8	1	2	4	>4	N	F	24	F
A8	1	2	4	3	N	D	7	A
A8	1	2	4	>4	N	F	11	S
A8	1	2	4	C	Y	F	19	S
A8	1	2	4	>4	N	F	33	F
A8	1	2	4	0	N	P	21	S
A8	1	2	4	>4	N	D	11	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	3	4	3	N	P	23	F
A8	1	3	4	2	N	M	18	A
A8	1	3	4	>4	N	F	18	S
A8	1	3	4	>4	Y	F	13	F
A8	1	3	4	2	N	D	9	A
A8	1	3	4	4	Y	F	14	S
A8	1	3	4	3	N	D	28	A
A8	1	3	4	2	Y	F	29	S
A8	1	3	4	2	N	F	8	S
A8	1	S	4	2	N	F	33	S
A8	1	S	4	1	Y	F	41	S
A8	1	S	4	2	Y	M	25	S
A8	1	S	4	1	Y	F	40	S
A8	1	S	4	3	N	F	33	S
A8	1	S	4	>4	N	F	32	F
A8	1	S	4	>4	N	F	24	S
A8	1	S	4	0	Y	D	32	A
A8	1	S	4	>4	Y	P	18	S
A8	1	S	4	>4	N	F	20	S
A8	1	S	4	1	N	P	24	S
A8	1	S	4	3	N	C	28	F
A8	1	S	4	2	N	D	14	A
A8	1	S	4	>4	N	D	21	A
A8	1	S	4	0	N	P	11	S
A8	1	S	4	3	N	P	12	S
A8	1	S	4	3	N	F	10	F
A8	1	S	4	>4	Y	S	39	A
A8	1	S	4	>4	N	F	13	F
A8	1	S	4	2	Y	D	31	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	S	4	1	Y	F	9	S
A8	1	S	4	1	N	F	25	S
A8	1	S	4	3	N	F	35	S
A8	1	S	4	4	N	F	53	S
A8	1	S	4	>4	N	M	36	A
A8	1	S	4	2	N	F	11	S
A8	1	S	4	>4	N	F	24	F
A8	1	S	4	>4	N	F	30	F
A8	1	S	4	>4	N	F	26	F
A8	1	S	4	0	Y	F	22	S
A8	1	S	4	>4	N	S	9	A
A8	1	S	4	3	Y	P	21	S
A8	1	S	4	3	Y	F	20	S
A8	1	S	4	1	Y	S	10	A
A8	1	S	4	>4	Y	F	7	S
A8	1	S	4	>4	N	F	7	F
A8	1	S	4	>4	N	F	8	S
A8	1	S	4	0	Y	F	18	S
A8	1	S	4	>4	Y	P	24	F
A8	1	S	4	0	Y	F	21	C
A8	1	S	4	2	Y	F	16	C
A8	1	S	4	C	Y	F	19	S
A8	1	S	4	>4	N	F	18	F
A8	1	S	4	2	Y	F	18	F
A8	1	S	4	>4	N	D	12	A
A8	1	S	4	C	Y	F	12	F
A8	1	S	4	2	Y	F	25	S
A8	1	S	4	>4	Y	P	6	C
A8	1	S	4	>4	N	F	4	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	S	4	>4	N	P	24	F
A8	1	S	4	3	N	F	9	F
A8	1	S	4	>4	N	S	21	A
A8	1	S	4	>4	N	P	15	F
A8	1	S	4	>4	N	S	12	A
A8	1	S	4	4	Y	P	12	F
A8	1	S	4	>4	N	D	8	A
A8	1	S	4	2	Y	F	5	C
A8	1	S	4	>4	N	F	16	S
A8	1	S	4	C	Y	F	19	S
A8	1	S	4	1	Y	D	10	A
A8	1	S	4	>4	Y	F	30	F
A8	1	S	4	C	Y	S	24	A
A8	1	S	4	C	Y	F	12	C
A8	1	S	4	>4	N	F	10	F
A8	1	S	4	2	N	D	20	A
A8	1	S	4	>4	N	F	13	S
A8	1	S	4	3	N	F	9	F
A8	1	S	4	>4	N	F	16	F
A8	1	S	4	>4	Y	F	8	S
A8	1	S	4	>4	N	F	9	F
A8	1	S	4	3	N	F	9	S
A8	1	S	4	>4	N	S	12	A
A8	1	S	4	2	N	F	9	S
A8	1	1	5	2	N	F	143	F
A8	1	1	5	>4	Y	F	87	F
A8	1	1	5	0	N	F	43	S
A8	1	1	5	>4	N	S	59	A
A8	1	1	5	>4	Y	F	27	F

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	5	0	N	F	44	F
A8	1	1	5	C	Y	F	100	S
A8	1	1	5	3	N	P	78	S
A8	1	1	5	>4	N	P	36	S
A8	1	1	5	>4	N	F	38	S
A8	1	1	5	C	Y	F	36	C
A8	1	1	5	>4	N	F	223	S
A8	1	1	5	2	N	D	72	A
A8	1	1	5	>4	N	F	28	S
A8	1	1	5	>4	N	F	52	S
A8	1	1	5	>4	N	D	37	A
A8	1	1	5	>4	N	F	39	S
A8	1	1	5	3	N	F	199	F
A8	1	1	5	>4	Y	F	57	S
A8	1	1	5	>4	N	F	46	F
A8	1	1	5	2	N	F	51	S
A8	1	1	5	>4	N	F	39	F
A8	1	1	5	2	N	F	27	S
A8	1	1	5	>4	Y	F	21	S
A8	1	1	5	>4	N	F	35	F
A8	1	1	5	3	Y	F	38	S
A8	1	1	5	2	Y	F	48	C
A8	1	1	5	2	Y	F	88	S
A8	1	1	5	1	Y	P	106	S
A8	1	1	5	>4	Y	F	60	F
A8	1	1	5	4	Y	F	69	S
A8	1	1	5	4	Y	F	66	S
A8	1	1	5	>4	N	F	23	S
A8	1	1	5	>4	N	F	48	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	1	5	2	Y	F	30	C
A8	1	2	5	>4	Y	F	205	F
A8	1	2	5	0	Y	F	38	S
A8	1	2	5	>4	Y	F	35	S
A8	1	2	5	1	Y	F	39	S
A8	1	2	5	>4	N	F	32	S
A8	1	3	5	1	Y	F	58	F
A8	1	3	5	2	Y	F	30	S
A8	1	S	5	0	Y	F	99	c
A8	1	S	5	1	Y	F	127	C
A8	1	S	5	3	Y	F	145	S
A8	1	S	5	1	Y	F	136	C
A8	1	S	5	0	Y	F	93	S
A8	1	S	5	3	Y	F	183	S
A8	1	S	5	>4	N	F	66	S
A8	1	S	5	0	Y	F	94	C
A8	1	S	5	4	N	F	70	F
A8	1	S	5	2	Y	F	196	S
A8	1	S	5	2	Y	F	201	S
A8	1	S	5	1	Y	F	67	C
A8	1	S	5	3	N	F	88	S
A8	1	S	5	>4	Y	F	30	S
A8	1	S	5	2	Y	P	60	C
A8	1	S	5	1	Y	F	45	S
A8	1	S	5	0	Y	S	46	A
A8	1	S	5	0	Y	F	47	S
A8	1	S	5	1	Y	P	97	S
A8	1	S	5	2	Y	D	48	A
A8	1	S	5	>4	N	C	37	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A8	1	S	5	>4	Y	F	41	S
A8	1	S	5	3	Y	F	195	C
A8	1	S	5	1	Y	F	201	S
A8	1	S	5	>4	Y	F	205	F
A8	1	S	5	4	Y	F	81	F
A8	1	S	5	>4	N	F	46	S
A8	1	S	5	>4	N	F	38	S
A8	1	S	5	>4	Y	F	74	S
A8	1	S	5	3	Y	F	36	C
A8	1	S	5	0	Y	F	28	C
A8	1	S	5	1	Y	F	67	S
A8	1	S	5	1	Y	F	34	S
A8	1	S	5	>4	Y	F	29	S
A8	1	S	5	3	Y	F	16	F
A8	1	S	5	3	Y	F	43	C
A8	1	S	5	>4	N	F	96	F
A8	1	S	5	0	Y	F	252	S
A8	1	S	5	>4	N	M	56	A
A8	1	S	5	>4	N	F	30	F
A8	1	S	5	C	Y	F	18	S
A8	1	S	5	0	N	F	24	S
A8	1	S	5	C	Y	F	54	S
A8	1	S	5	1	N	F	151	S
A8	1	S	5	3	Y	P	40	S
A8	1	S	5	>4	N	F	33	S
A8	1	S	5	>4	Y	F	30	F
A8	1	S	5	3	Y	F	48	S
A8	1	S	5	>4	N	F	42	S
A8	1	S	5	C	Y	F	18	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	5	>4	Y	F	527	C
A1	2	1	5	C	Y	D	272	F
A1	2	1	5	>4	N	D	645	S
A1	2	1	5	>4	N	D	411	A
A1	2	1	5	>4	N	D	135	A
A1	2	1	5	>4	Y	F	687	A
A1	2	1	5	>4	N	F	1075	C
A1	2	1	5	3	N	F	140	F
A1	2	1	5	3	Y	D	85	S
A1	2	1	5	>4	Y	D	152	S
A1	2	1	5	>4	Y	P	374	S
A1	2	1	5	>4	N	D	84	A
A1	2	1	5	>4	Y	P	370	A
A1	2	1	5	>4	Y	P	136	A
A1	2	1	5	>4	Y	P	135	S
A1	2	1	5	>4	Y	P	445	C
A1	2	1	5	>4	Y	P	286	C
A1	2	1	5	>4	N	M	77	A
A1	2	1	5	>4	Y	D	160	A
A1	2	1	5	>4	N	D	44	A
A1	2	1	5	>4	N	D	72	F
A1	2	1	5	>4	Y	P	277	A
A1	2	1	5	>4	N	F	616	S
A1	2	1	5	2	N	D	114	A
A1	2	1	5	2	Y	D	519	A
A1	2	1	5	>4	N	D	45	A
A1	2	1	5	>4	N	F	124	F
A1	2	1	5	>4	N	F	137	S
A1	2	1	5	>4	N	F	219	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	5	>4	N	F	224	S
A1	2	1	5	C	Y	F	166	S
A1	2	1	5	>4	Y	F	142	S
A1	2	1	5	>4	N	F	58	S
A1	2	1	5	C	Y	F	105	S
A1	2	1	5	1	Y	F	212	S
A1	2	1	5	2	N	F	423	S
A1	2	1	5	>4	N	F	88	F
A1	2	1	5	>4	N	F	110	S
A1	2	1	5	3	N	F	89	F
A1	2	1	5	1	Y	F	21	F
A1	2	1	5	3	Y	F	150	S
A1	2	1	5	2	N	F	53	S
A1	2	1	5	3	N	F	44	F
A1	2	1	5	>4	N	F	178	S
A1	2	1	5	>4	Y	F	132	S
A1	2	1	5	C	Y	F	282	S
A1	2	1	5	4	N	F	39	S
A1	2	1	5	3	N	F	29	F
A1	2	1	5	4	N	F	201	C
A1	2	1	5	3	N	F	210	S
A1	2	1	5	>4	Y	F	222	C
A1	2	1	5	2	Y	F	51	S
A1	2	1	5	C	Y	F	51	C
A1	2	1	5	C	Y	F	141	S
A1	2	1	5	3	N	F	125	F
A1	2	1	5	1	Y	F	266	S
A1	2	1	5	2	N	F	108	S
A1	2	1	5	>4	N	F	321	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	5	3	N	F	51	S
A1	2	1	5	>4	N	F	72	S
A1	2	1	5	>4	N	F	42	S
A1	2	1	5	>4	N	F	149	S
A1	2	1	5	4	Y	F	331	C
A1	2	1	5	2	N	F	56	S
A1	2	1	5	>4	Y	F	48	S
A1	2	1	5	2	Y	F	60	S
A1	2	1	5	>4	N	F	51	S
A1	2	1	5	2	N	F	79	S
A1	2	1	5	4	N	F	43	S
A1	2	1	5	2	Y	F	42	S
A1	2	1	5	>4	N	F	43	S
A1	2	1	5	3	Y	F	64	S
A1	2	1	5	1	N	F	88	S
A1	2	1	5	>4	Y	F	41	S
A1	2	1	5	>4	Y	F	53	S
A1	2	1	5	C	Y	F	99	C
A1	2	1	5	>4	Y	F	63	C
A1	2	1	5	3	Y	F	59	C
A1	2	1	5	>4	N	F	69	S
A1	2	1	5	C	Y	F	187	S
A1	2	1	5	>4	N	F	89	F
A1	2	1	5	>4	Y	F	80	C
A1	2	1	5	>4	N	F	51	F
A1	2	1	5	>4	N	F	68	S
A1	2	1	5	3	N	F	69	S
A1	2	1	5	>4	N	F	133	S
A1	2	1	5	>4	N	F	24	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	5	C	Y	P	64	S
A1	2	1	5	C	Y	P	106	S
A1	2	1	5	C	Y	S	39	A
A1	2	1	5	C	Y	S	30	S
A1	2	1	5	>4	N	S	33	C
A1	2	1	5	>4	N	S	73	F
A1	2	1	5	>4	Y	S	66	S
A1	2	2	5	>4	Y	F	183	S
A1	2	2	5	>4	Y	F	557	S
A1	2	2	5	>4	N	D	179	A
A1	2	2	5	3	N	F	83	S
A1	2	2	5	>4	N	F	45	F
A1	2	2	5	>4	Y	F	165	F
A1	2	2	5	>4	Y	F	134	C
A1	2	2	5	>4	Y	F	42	S
A1	2	2	5	2	Y	F	106	S
A1	2	2	5	>4	Y	F	188	S
A1	2	2	5	>4	Y	F	93	F
A1	2	2	5	3	N	F	69	F
A1	2	2	5	>4	Y	F	56	F
A1	2	2	5	C	Y	P	56	S
A1	2	S	5	C	Y	F	276	C
A1	2	S	5	2	N	F	154	S
A1	2	S	5	3	N	F	269	S
A1	2	S	5	4	N	F	217	S
A1	2	S	5	>4	Y	P	162	A
A1	2	S	5	>4	N	P	122	A
A1	2	S	5	>4	Y	P	211	S
A1	2	S	5	3	Y	P	235	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	S	5	>4	N	P	296	S
A1	2	S	5	>4	Y	D	38	A
A1	2	S	5	C	Y	F	219	S
A1	2	S	5	C	Y	F	219	S
A1	2	S	5	>4	Y	F	128	S
A1	2	S	5	>4	Y	F	160	S
A1	2	S	5	>4	N	F	248	S
A1	2	S	5	C	Y	F	178	S
A1	2	S	5	1/C	Y	F	216	F
A1	2	S	5	3	N	F	157	F
A1	2	S	5	2/C	Y	F	214	S
A1	2	S	5	>4	N	F	271	S
A1	2	S	5	>4	Y	F	300	S
A1	2	S	5	3	Y	F	298	F
A1	2	S	5	4	N	F	83	S
A1	2	S	5	2	N	F	127	S
A1	2	S	5	C	Y	F	61	S
A1	2	S	5	>4	N	F	53	S
A1	2	S	5	C	Y	F	65	S
A1	2	S	5	C	Y	F	42	C
A1	2	S	5	>4	N	F	132	S
A1	2	S	5	>4	N	F	69	S
A1	2	S	5	C	Y	F	137	S
A1	2	S	5	>4	N	F	48	S
A1	2	S	5	3	Y	F	54	S
A1	2	S	5	>4	N	F	33	S
A1	2	S	5	C	Y	M	39	A
A1	2	S	5	4	N	S	78	A
A1	2	S	4	C	Y	D	14	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	4	4	N	D	14	A
A1	2	1	4	2	Y	D	20	A
A1	2	1	4	3	N	D	30	A
A1	2	1	4	>4	N	D	21	A
A1	2	S	4	3	N	F	36	S
A1	2	S	4	0	N	F	28	S
A1	2	S	4	3	N	F	21	F
A1	2	S	4	>4	N	F	14	F
A1	2	S	4	>4	N	F	28	S
A1	2	S	4	2	N	F	22	S
A1	2	S	4	>4	N	F	31	S
A1	2	S	4	4	Y	F	29	C
A1	2	1	4	2	N	F	23	S
A1	2	1	4	4	N	F	16	S
A1	2	1	4	>4	N	F	55	S
A1	2	1	4	>4	N	F	15	S
A1	2	1	4	>4	N	F	16	F
A1	2	1	4	>4	N	F	30	S
A1	2	1	4	3	N	F	17	S
A1	2	1	4	>4	N	F	20	F
A1	2	1	4	2	Y	F	11	C
A1	2	1	4	>4	Y	F	41	S
A1	2	1	4	>4	N	F	38	S
A1	2	1	4	C	Y	F	33	S
A1	2	1	4	>4	N	F	19	S
A1	2	1	4	3	N	F	21	F
A1	2	1	4	>4	N	F	4	S
A1	2	1	4	4	N	F	13	S
A1	2	1	4	>4	N	F	6	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	4	3	N	F	30	S
A1	2	1	4	2	N	F	9	F
A1	2	1	4	2	N	F	21	S
A1	2	1	4	2	N	F	20	S
A1	2	1	4	3	N	F	31	F
A1	2	1	4	>4	N	F	16	F
A1	2	1	4	>4	N	F	22	S
A1	2	1	4	2	N	F	11	S
A1	2	1	4	2	Y	F	13	S
A1	2	1	4	>4	Y	F	18	S
A1	2	1	4	4	N	F	17	S
A1	2	1	4	1	N	F	15	S
A1	2	1	4	3	N	F	28	F
A1	2	1	4	>4	N	F	16	S
A1	2	1	4	>4	N	F	29	F
A1	2	1	4	4	N	F	18	F
A1	2	1	4	>4	N	F	23	F
A1	2	1	4	C	Y	F	21	C
A1	2	2	4	3	N	F	23	S
A1	2	2	4	>4	Y	F	43	F
A1	2	2	4	>4	N	F	17	S
A1	2	2	4	>4	N	F	47	F
A1	2	2	4	>4	Y	F	34	F
A1	2	2	4	2	N	F	16	S
A1	2	2	4	>4	N	F	45	S
A1	2	2	4	>4	N	F	18	S
A1	2	1	4	C	Y	M	36	A
A1	2	S	4	C	Y	P	27	S
A1	2	S	4	2	Y	P	13	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	4	3	N	P	29	S
A1	2	1	4	3	N	P	19	S
A1	2	1	4	1	N	P	24	S
A1	2	1	4	2	N	P	29	F
A1	2	2	4	3	N	P	37	S
A1	2	1	4	NA	N	S	14	A
A1	2	1	4	>4	N	S	22	A
A1	2	1	4	>4	N	S	30	S
A1	2	1	4	NA	Y	S	14	A
A1	2	1	4	>4	N	S	14	A
A1	2	1	4	C	Y	S	33	S
A1	2	1	4	>4	N	S	38	A
A1	2	1	4	>4	Y	S	23	C
A1	2	1	4	>4	N	S	15	A
A1	2	1	4	>4	N	S	15	S
A1	2	1	4	>4	N	S	18	A
A1	2	1	4	>4	N	S	35	A
A1	2	1	4	4	N	S	20	S
A1	2	2	4	3	N	S	16	A
A1	2	1	4	>4	N	F	32	S
A1	2	1	4	>4	N	S	34	A
A1	2	S	3	>4	N	D	9	A
A1	2	S	3	2	N	D	6	A
A1	2	1	3	C	Y	D	15	A
A1	2	1	3	2	N	D	5	A
A1	2	1	3	1	N	D	4	A
A1	2	1	3	2	N	D	12	A
A1	2	1	3	>4	N	D	9	A
A1	2	1	3	1	N	D	9	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	3	2	N	D	14	A
A1	2	1	3	2	N	D	5	A
A1	2	1	3	>4	Y	D	9	A
A1	2	1	3	>4	N	D	12	A
A1	2	1	3	1	N	D	14	A
A1	2	2	3	2	N	D	6	A
A1	2	S	3	>4	N	F	9	S
A1	2	S	3	>4	N	F	13	S
A1	2	S	3	1	Y	F	11	S
A1	2	S	3	3	N	F	10	S
A1	2	S	3	>4	N	F	10	S
A1	2	1	3	4	N	F	8	S
A1	2	1	3	>4	N	F	13	S
A1	2	1	3	>4	N	F	11	S
A1	2	1	3	4	Y	F	15	S
A1	2	1	3	>4	N	F	10	S
A1	2	1	3	3	N	F	9	S
A1	2	1	3	2	N	F	11	S
A1	2	1	3	3	N	F	5	S
A1	2	1	3	4	N	F	15	S
A1	2	1	3	2	N	F	14	S
A1	2	1	3	3	N	F	6	F
A1	2	1	3	2	Y	F	6	S
A1	2	1	3	2	N	F	5	S
A1	2	1	3	2	N	F	5	S
A1	2	1	3	>4	N	F	8	F
A1	2	1	3	2	N	F	3	S
A1	2	1	3	3	N	F	13	C
A1	2	1	3	>4	N	F	9	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	3	3	N	F	14	S
A1	2	1	3	3	N	F	6	S
A1	2	1	3	>4	N	F	6	S
A1	2	1	3	3	N	F	11	F
A1	2	1	3	1	N	F	9	S
A1	2	1	3	1	N	F	7	F
A1	2	1	3	>4	N	F	6	F
A1	2	1	3	>4	N	F	5	S
A1	2	1	3	3	N	F	11	S
A1	2	1	3	2	N	F	2	S
A1	2	1	3	>4	N	F	6	S
A1	2	1	3	>4	N	F	15	S
A1	2	1	3	2	N	F	3	S
A1	2	1	3	>4	N	F	4	S
A1	2	1	3	2	N	F	6	S
A1	2	1	3	2	N	F	9	S
A1	2	1	3	>4	N	F	9	S
A1	2	1	3	>4	N	F	11	S
A1	2	1	3	3	N	F	6	S
A1	2	1	3	>4	N	F	5	S
A1	2	1	3	>4	N	F	12	S
A1	2	1	3	3	N	F	8	S
A1	2	1	3	1	N	F	6	S
A1	2	1	3	>4	N	F	6	F
A1	2	1	3	3	N	F	5	S
A1	2	1	3	2	N	F	8	S
A1	2	1	3	>4	N	F	6	S
A1	2	1	3	2	N	F	2	S
A1	2	1	3	1	N	F	2	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	3	2	N	F	2	S
A1	2	1	3	>4	N	F	2	S
A1	2	1	3	2	N	F	2	S
A1	2	1	3	2	N	F	7	S
A1	2	1	3	>4	N	F	4	S
A1	2	1	3	2	N	F	9	S
A1	2	1	3	4	N	F	4	S
A1	2	1	3	1	N	F	5	S
A1	2	1	3	>4	N	F	9	S
A1	2	1	3	>4	N	F	13	S
A1	2	1	3	1	N	F	11	S
A1	2	2	3	3	N	F	8	S
A1	2	2	3	>4	N	F	8	S
A1	2	2	3	2	Y	F	7	S
A1	2	1	3	1	N	M	6	A
A1	2	1	3	1	N	M	3	A
A1	2	1	3	1	N	M	6	A
A1	2	1	3	>4	N	N	6	S
A1	2	S	3	2	N	P	15	S
A1	2	1	3	3	N	P	7	F
A1	2	1	3	2	N	P	11	S
A1	2	1	3	4	N	P	4	F
A1	2	1	3	3	N	P	8	S
A1	2	1	3	2	N	P	7	F
A1	2	1	3	NA	N	S	10	A
A1	2	1	3	NA	N	S	11	A
A1	2	1	3	2	N	S	6	A
A1	2	1	3	NA	N	S	9	A
A1	2	1	3	3	N	S	15	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	3	2	N	S	6	A
A1	2	1	3	>4	N	S	9	S
A1	2	1	3	>4	N	S	13	F
A1	2	1	3	>4	N	S	5	A
A1	2	1	3	3	N	S	18	S
A1	2	1	3	>4	Y	S	10	S
A1	2	1	3	3	N	S	19	S
A1	2	1	3	>4	N	S	12	F
A1	2	1	3	>4	N	S	16	S
A1	2	1	3	>4	N	S	10	S
A1	2	1	3	2	N	S	6	S
A1	2	1	3	1	N	S	6	A
A1	2	1	3	>4	N	S	9	S
A1	2	1	3	2	N	S	6	S
A1	2	1	3	1	Y	S	10	S
A1	2	1	3	2	N	S	8	S
A1	2	1	3	3	N	S	3	S
A1	2	1	3	>4	Y	S	12	C
A1	2	1	3	3	N	S	11	A
A1	2	1	3	>4	N	S	13	A
A1	2	1	3	>4	N	S	8	S
A1	2	1	3	>4	N	S	4	S
A1	2	1	3	>4	N	S	12	A
A1	2	1	3	C	Y	S	7	C
A1	2	1	3	>4	N	S	6	S
A1	2	1	3	>4	N	S	11	A
A1	2	1	3	2	N	S	9	S
A1	2	1	3	>4	N	S	9	A
A1	2	1	3	>4	N	S	7	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	3	>4	N	S	11	A
A1	2	2	3	>4	N	S	22	A
A1	2	2	3	>4	N	S	9	S
A1	2	2	3	>4	N	S	15	A
A1	2	1	2	C	Y	D	4	A
A1	2	1	2	>4	N	D	3	A
A1	2	1	2	2	N	D	3	A
A1	2	1	2	4	N	D	5	A
A1	2	1	2	2	N	D	2	A
A1	2	1	2	1	N	D	3	A
A1	2	1	2	2	N	D	3	A
A1	2	1	2	>4	N	D	1	A
A1	2	1	2	2	N	D	1	A
A1	2	1	2	1	N	D	1	A
A1	2	1	2	2	N	D	1	A
A1	2	1	2	1	N	D	1	A
A1	2	1	2	2	N	D	1	A
A1	2	1	2	3	N	D	2	A
A1	2	1	2	2	N	D	1	A
A1	2	1	2	>4	N	D	1	A
A1	2	1	2	2	N	D	2	A
A1	2	1	2	1	N	D	1	A
A1	2	1	2	1	N	D	1	A
A1	2	1	2	1	N	D	1	A
A1	2	1	2	1	N	D	2	A
A1	2	1	2	1	N	D	1	A
A1	2	1	2	1	N	D	1	A
A1	2	1	2	1	N	D	2	A
A1	2	S	2	4	N	F	6	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	S	2	>4	N	F	2	S
A1	2	S	2	2	N	F	5	S
A1	2	1	2	>4	N	F	7	S
A1	2	1	2	>4	N	F	2	S
A1	2	1	2	2	N	F	3	S
A1	2	1	2	>4	N	F	3	S
A1	2	1	2	>4	N	F	4	S
A1	2	1	2	3	N	F	3	S
A1	2	1	2	3	N	F	3	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	3	Y	F	3	S
A1	2	1	2	3	N	F	5	S
A1	2	1	2	4	N	F	3	F
A1	2	1	2	2	N	F	2	S
A1	2	1	2	>4	N	F	3	S
A1	2	1	2	2	N	F	4	S
A1	2	1	2	>4	N	F	4	S
A1	2	1	2	>4	N	F	3	S
A1	2	1	2	3	N	F	4	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	2	S
A1	2	1	2	1	N	F	4	S
A1	2	1	2	>4	N	F	3	S
A1	2	1	2	3	N	F	3	S
A1	2	1	2	2	N	F	4	S
A1	2	1	2	4	N	F	5	S
A1	2	1	2	3	N	F	5	S
A1	2	1	2	>4	N	F	9	S
A1	2	1	2	>4	N	F	2	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	2	3	N	F	2	S
A1	2	1	2	>4	N	F	5	S
A1	2	1	2	>4	N	F	4	S
A1	2	1	2	>4	N	F	6	C
A1	2	1	2	>4	N	F	3	F
A1	2	1	2	>4	N	F	2	S
A1	2	1	2	>4	N	F	3	S
A1	2	1	2	3	N	F	2	S
A1	2	1	2	3	N	F	1	S
A1	2	1	2	>4	N	F	2	S
A1	2	1	2	>4	N	F	3	F
A1	2	1	2	3	N	F	0.5	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	4	N	F	3	S
A1	2	1	2	3	N	F	3	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	1	Y	F	2	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	3	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	>4	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	2	1	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	3	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	3	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	3	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	2	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	2	F
A1	2	1	2	2	N	F	1	S
A1	2	1	2	1	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	1	N	F	2	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	1	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	1	N	F	2	S
A1	2	1	2	1	N	F	2	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	1	N	F	1	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	2	N	F	2	S
A1	2	1	2	1	N	F	3	S
A1	2	1	2	1	N	F	3	S
A1	2	1	2	1	N	F	3	S
A1	2	1	2	1	N	F	2	S
A1	2	1	2	1	N	F	3	S
A1	2	1	2	2	N	F	1	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	2	>4	N	F	2	F
A1	2	1	2	1	N	F	2	S
A1	2	1	2	1	N	F	3	S
A1	2	1	2	2	N	F	1	S
A1	2	1	2	>4	N	F	2	F
A1	2	1	2	>4	N	F	2	S
A1	2	2	2	3	N	F	3	S
A1	2	1	2	2	N	M	4	A
A1	2	1	2	3	Y	P	3	C
A1	2	1	2	>4	N	P	4	S
A1	2	1	2	1	N	P	1	S
A1	2	1	2	1	N	P	1	S
A1	2	1	2	2	N	S	7	S
A1	2	1	2	C	Y	S	1	A
A1	2	1	2	C	Y	S	7	S
A1	2	1	2	>4	N	S	3	S
A1	2	1	2	2	N	S	1	A
A1	2	1	2	>4	N	S	4	A
A1	2	1	2	>4	N	S	7	S
A1	2	1	2	3	N	S	3	A
A1	2	1	2	2	N	S	3	A
A1	2	1	2	1	N	S	3	S
A1	2	1	2	2	N	S	4	S
A1	2	1	2	>4	N	S	3	S
A1	2	1	2	2	N	S	1	S
A1	2	1	2	3	N	S	7	A
A1	2	1	2	>4	N	S	4	A
A1	2	1	2	>4	Y	S	4	C
A1	2	1	2	>4	Y	S	4	C

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	2	1	Y	S	1	S
A1	2	1	2	1	N	S	1	S
A1	2	1	2	1	N	S	2	A
A1	2	1	2	1	N	S	1	S
A1	2	1	2	1	N	S	0.5	A
A1	2	2	2	3	Y	S	6	A
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	1	N	D	0.5	S
A1	2	1	1	1	N	D	0.5	S
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	2	N	D	0.5	A
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	1	N	D	0.5	A
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	2	F
A1	2	1	1	3	N	F	1	F
A1	2	1	1	4	N	F	4	S
A1	2	1	1	>4	N	F	1	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	3	N	F	0.3	S
A1	2	1	1	>4	N	F	0.5	S
A1	2	1	1	>4	N	F	0.25	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	>4	N	F	1	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	>4	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	3	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	1	F
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	2	N	F	0.5	S
A1	2	1	1	1	N	F	1	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	1	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	1	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	1	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	1	N	F	0.5	S
A1	2	1	1	NA	N	S	1	A

Site	TU	Level	Size	Scars	Cortex	Type	Weight	Platform
A1	2	1	1	NA	N	S	1	A
A1	2	1	1	NA	N	S	1	A
A1	2	1	1	NA	N	S	1	A
A1	2	1	1	NA	N	S	1	A
A1	2	1	1	NA	N	S	1	A
A1	2	1	1	>4	N	S	4	A
A1	2	1	1	1	N	S	3	S
A1	2	1	1	1	N	S	0.5	A
A1	2	1	1	3	N	S	0.5	S
A1	2	1	1	2	N	S	0.5	S
A1	2	1	1	2	N	S	0.5	S
A1	2	1	1	>4	N	S	0.5	S
A1	2	1	1	>4	N	S	1	A
A1	2	1	1	2	N	S	0.5	A
A1	2	1	1	2	N	S	1	S
A1	2	1	1	>4	N	S	3	A
A1	2	1	1	>4	N	S	2	A

APPENDIX B

DATA RECORDED ON ADZE BLANKS FROM AS-21-100

SITE	Level	Whole	MX L	MX W	MX TH	WEIGHT
A1	S	Y	134	57	44.5	407
A1	S	Y	115	65	37.8	381
A1	S	Y	148	54	32.8	258
A1	1	Y	159	69	45.57	687
A1	S	N	141	89	59.75	758
A1	S	N	120	57	43.85	396
A1	1	N	122	64	39.34	413
A1	2	N	71	52	20.79	86
A1	S	N	111	62	41.3	225
A1	1	N	50	38	14.7	45
A8	S	Y	111	52	30.5	235
A8	S	Y	128	59	39.67	297
A8	1	Y	142	80	39.33	358
A8	S	Y	102	68	39.53	304
A8	S	N	98	64	32.16	280
A8	S	N	77	39	19.5	191
A8	S	N	109	82	37.2	355
A8	S	N	72	31	21.4	203

APPENDIX C

DATA RECORDED ON ADZE PREFORMS FROM AS-21-100

SITE	LEVEL	Whole	TYPE	MX L	MX W	MX TH	WEIGHT
A1	S	Y	2	153	82	42.16	496
A1	S	Y	2	139	55	36.69	262
A1	S	Y	2	131	64	38.05	325
A1	S	Y	1	159	61	37.47	436
A1	S	Y	9	84	39	28.79	103
A1	S	N	1	99	79	29.47	299
A1	S	N	1	109	85	41.8	530
A1	1	N	1	52	66	29.25	134
A1	S	N	2	73	68	25.13	174
A1	1	N	2	117	88	41.97	527
A1	1	N	2	163	67	28.87	152
A1	1	N	2	101	57	18.86	190
A1	1	N	5	74	45	18.98	66
A1	S	N	6	116	59	49.12	331
A1	S	N	6	135	74	49.37	617
A1	S	N	6	132	84	52.64	698
A1	S	N	6	108	51	29.8	185
A1	1	N	6	118	73	63.75	645
A1	S	N	9	107	56	37.57	310
A1	S	N	9	69	58	26.01	127
A1	S	N	9	58	35	32.75	106
A8	S	Y	1	78	47	23.32	137
A8	S	Y	1	114	42	28.17	243

SITE	LEVEL	Whole	TYPE	MX L	MX W	MX TH	WEIGHT
A8	S	Y	1	97	40	24.27	107
A8	S	Y	2	153	68	44.62	598
A8	S	Y	2	135	62	35.43	256
A8	S	Y	5	63	40	18.85	61
A8	S	Y	9	94	39	32.65	119
A8	S	Y	6	104	49	29.55	190
A8	S	N	1	85	37	19.35	91
A8	S	N	1	71	49	24.4	109
A8	S	N	1	73	75	30.7	218
A8	S	N	2	105	49	42.61	402
A8	S	N	2	85	85	47	21.32
A8	S	N	2	40	43	18.45	56
A8	S	N	3	60	55	14.8	85
A8	S	N	3	50	47	10.8	49
A8	S	N	4	69	44	18.56	72
A8	S	N	5	40	72	29.31	120
A8	S	N	6	109	60	46.13	337
A8	S	N	6	57	43	20.11	54
A8	1	N	6	41	39	26.97	56
A8	S	N	6	49	47	24.06	65
A8	1	N	7	51	55	29.54	107

APPENDIX D

ELEMENTAL CONCENTRATION DATA

Site	Al2O3	MgO	SiO2	K2O
LAU'AGAE	17.133%	4.1544%	49.824%	1.612%
LAU'AGAE	16.895%	4.2324%	49.856%	1.657%
LAU'AGAE	17.081%	4.2330%	49.282%	1.686%
LAU'AGAE	17.413%	4.2177%	48.989%	1.587%
LAU'AGAE	16.696%	4.3295%	49.853%	1.622%
LAU'AGAE	16.553%	4.3236%	50.246%	1.621%
LAU'AGAE	16.961%	4.3276%	49.400%	1.605%
LAU'AGAE	16.913%	4.2962%	49.031%	1.593%
LAU'AGAE	16.659%	4.3662%	49.165%	1.607%
LAU'AGAE	16.946%	4.2810%	49.357%	1.706%
LAU'AGAE	16.936%	4.2195%	49.985%	1.671%
LAU'AGAE	16.609%	4.3150%	49.934%	1.575%
LAU'AGAE	16.812%	4.2542%	50.451%	1.624%
LAU'AGAE	16.703%	4.3043%	49.752%	1.633%
LAU'AGAE	17.869%	4.0606%	49.596%	1.612%
LAU'AGAE	16.799%	4.2753%	49.576%	1.600%
LAU'AGAE	16.603%	4.3471%	49.454%	1.589%
LAU'AGAE	16.299%	4.4336%	49.743%	1.516%
TULA	19.429%	3.6670%	39.364%	1.351%
TULA	19.793%	3.6670%	44.201%	1.702%
TULA	18.040%	4.0442%	36.398%	1.199%
TULA	19.632%	3.5670%	39.652%	1.619%

Site	Al2O3	MgO	SiO2	K2O
TULA	19.394%	3.6374%	39.267%	1.454%
TULA	18.740%	3.6407%	38.609%	1.533%
TULA	17.445%	3.5989%	33.619%	1.054%
TULA	19.268%	3.7512%	43.457%	1.719%
TULA	17.978%	3.6563%	36.065%	1.277%
TULA	15.252%	3.5888%	30.949%	0.852%
TULA	18.927%	3.7629%	44.160%	1.698%
TULA	19.080%	3.6908%	43.596%	1.705%
TULA	19.351%	3.6943%	41.786%	1.692%
TULA	19.023%	3.7841%	45.717%	1.812%
TULA	18.444%	3.9274%	44.423%	1.743%
TULA	18.996%	3.7612%	46.800%	1.860%
TULA	18.452%	3.5754%	33.129%	1.249%
TULA	19.144%	3.6318%	39.733%	1.406%

Site	CaO	TiO2	V	MnO
LAU'AGAE	7.601%	4.1060%	0.02920%	0.1472%
LAU'AGAE	7.750%	4.0240%	0.03100%	0.1604%
LAU'AGAE	7.564%	4.1980%	0.03050%	0.1627%
LAU'AGAE	7.482%	4.1110%	0.03000%	0.1606%
LAU'AGAE	7.841%	4.0820%	0.02880%	0.1688%
LAU'AGAE	7.750%	4.0280%	0.03140%	0.1649%
LAU'AGAE	7.753%	4.0940%	0.03040%	0.1640%
LAU'AGAE	7.701%	4.0370%	0.02930%	0.1639%
LAU'AGAE	7.828%	3.9580%	0.03230%	0.1640%
LAU'AGAE	7.685%	3.9460%	0.03100%	0.1563%

Site	CaO	TiO2	V	MnO
LAU'AGAE	7.693%	3.9930%	0.03030%	0.1583%
LAU'AGAE	7.694%	4.0490%	0.03080%	0.1625%
LAU'AGAE	7.888%	4.0220%	0.03070%	0.1574%
LAU'AGAE	7.657%	4.0250%	0.02900%	0.1595%
LAU'AGAE	7.513%	4.0950%	0.03190%	0.1514%
LAU'AGAE	7.730%	3.9980%	0.02940%	0.1636%
LAU'AGAE	7.681%	3.9250%	0.03000%	0.1577%
LAU'AGAE	7.711%	4.0270%	0.02990%	0.1674%
TULA	5.431%	2.7170%	0.01624%	0.1001%
TULA	6.539%	3.4140%	0.01570%	0.1057%
TULA	6.238%	3.9400%	0.01733%	0.0928%
TULA	5.200%	2.8500%	0.01472%	0.0929%
TULA	5.668%	2.9120%	0.01541%	0.0956%
TULA	5.353%	2.8020%	0.01541%	0.0911%
TULA	4.494%	2.1113%	0.01303%	0.0672%
TULA	6.694%	3.4320%	0.01620%	0.1197%
TULA	5.205%	2.5849%	0.01289%	0.0829%
TULA	3.718%	1.6094%	0.01241%	0.0557%
TULA	6.766%	3.5320%	0.01500%	0.1168%
TULA	6.609%	3.3570%	0.02080%	0.1172%
TULA	6.395%	3.3750%	0.01650%	0.1043%
TULA	7.335%	3.9320%	0.01580%	0.1362%
TULA	7.323%	3.6040%	0.01560%	0.1441%
TULA	7.489%	3.8420%	0.01650%	0.1339%
TULA	4.106%	2.4524%	0.01523%	0.0813%
TULA	5.404%	2.7230%	0.01500%	0.0956%

Site	Fe	Cu	Zn	Rb
LAU'AGAE	9.971%	0.00266%	0.01885%	0.003391%
LAU'AGAE	10.069%	0.00225%	0.01657%	0.003561%
LAU'AGAE	10.419%	0.00368%	0.01815%	0.003485%
LAU'AGAE	10.105%	0.00215%	0.01687%	0.003283%
LAU'AGAE	10.203%	0.00352%	0.01674%	0.003323%
LAU'AGAE	9.831%	0.00204%	0.01817%	0.003330%
LAU'AGAE	10.176%	0.00267%	0.01686%	0.003425%
LAU'AGAE	10.118%	0.00199%	0.01667%	0.003385%
LAU'AGAE	10.040%	0.00286%	0.01620%	0.003122%
LAU'AGAE	9.890%	0.00281%	0.01608%	0.003586%
LAU'AGAE	9.951%	0.00316%	0.01705%	0.003295%
LAU'AGAE	10.130%	0.00237%	0.01686%	0.003439%
LAU'AGAE	10.032%	0.00219%	0.01657%	0.003358%
LAU'AGAE	10.118%	0.00217%	0.01802%	0.003352%
LAU'AGAE	9.847%	0.00200%	0.01695%	0.003559%
LAU'AGAE	9.985%	0.00238%	0.01579%	0.003324%
LAU'AGAE	9.891%	0.00199%	0.01621%	0.003226%
LAU'AGAE	10.180%	0.00239%	0.01734%	0.002956%
TULA	5.563%	0.00167%	0.01858%	0.005760%
TULA	6.217%	0.00208%	0.02159%	0.006610%
TULA	5.271%	0.00099%	0.01517%	0.005410%
TULA	5.763%	0.00125%	0.01847%	0.006570%
TULA	5.501%	0.00189%	0.01738%	0.005200%
TULA	5.213%	0.00152%	0.01696%	0.005990%
TULA	3.659%	0.00150%	0.01317%	0.003742%
TULA	6.811%	0.00216%	0.02253%	0.006300%

Site	Fe	Cu	Zn	Rb
TULA	4.753%	0.00172%	0.01570%	0.005300%
TULA	2.772%	0.00144%	0.00959%	0.003094%
TULA	6.990%	0.00132%	0.02325%	0.007350%
TULA	6.815%	0.00270%	0.02391%	0.006460%
TULA	6.367%	0.00204%	0.02224%	0.006990%
TULA	7.775%	0.00181%	0.02733%	0.007880%
TULA	7.790%	0.00246%	0.02906%	0.007860%
TULA	7.812%	0.00287%	0.02669%	0.007090%
TULA	4.545%	0.00176%	0.01415%	0.005210%
TULA	5.873%	0.00186%	0.01765%	0.005590%

Site	Sr	Y	Zr	Nb
LAU'AGAE	0.082800%	0.004250%	0.042620%	0.004690%
LAU'AGAE	0.081540%	0.004130%	0.040950%	0.004360%
LAU'AGAE	0.078690%	0.005680%	0.041690%	0.004420%
LAU'AGAE	0.076940%	0.003870%	0.040170%	0.004120%
LAU'AGAE	0.079970%	0.004100%	0.040330%	0.004140%
LAU'AGAE	0.078460%	0.004040%	0.039610%	0.004480%
LAU'AGAE	0.079470%	0.004030%	0.040020%	0.004400%
LAU'AGAE	0.078720%	0.004000%	0.040120%	0.004320%
LAU'AGAE	0.079990%	0.004130%	0.038720%	0.004220%
LAU'AGAE	0.078140%	0.003920%	0.038840%	0.004220%
LAU'AGAE	0.078560%	0.004040%	0.039600%	0.004180%
LAU'AGAE	0.079170%	0.004000%	0.039830%	0.004250%
LAU'AGAE	0.080670%	0.004100%	0.039910%	0.004160%
LAU'AGAE	0.078270%	0.003870%	0.040050%	0.004270%

Site	Sr	Y	Zr	Nb
LAU'AGAE	0.076920%	0.003850%	0.039710%	0.004020%
LAU'AGAE	0.079380%	0.003880%	0.039350%	0.004060%
LAU'AGAE	0.077570%	0.003900%	0.039130%	0.004260%
LAU'AGAE	0.078880%	0.003900%	0.040320%	0.004340%
TULA	0.075690%	0.003520%	0.040920%	0.005300%
TULA	0.094110%	0.004390%	0.049560%	0.006020%
TULA	0.050000%	0.003120%	0.029330%	0.003470%
TULA	0.071290%	0.003640%	0.044110%	0.004690%
TULA	0.075450%	0.003660%	0.040560%	0.005260%
TULA	0.070600%	0.003500%	0.039620%	0.004770%
TULA	0.051010%	0.002542%	0.027670%	0.003790%
TULA	0.101850%	0.004800%	0.055130%	0.006320%
TULA	0.064600%	0.003060%	0.035340%	0.004360%
TULA	0.038350%	0.002111%	0.022120%	0.003320%
TULA	0.102540%	0.004790%	0.056970%	0.006470%
TULA	0.102950%	0.004640%	0.057210%	0.006570%
TULA	0.094090%	0.004440%	0.051670%	0.006060%
TULA	0.121900%	0.005510%	0.066720%	0.007630%
TULA	0.116750%	0.005340%	0.063910%	0.007160%
TULA	0.119470%	0.005430%	0.064870%	0.006950%
TULA	0.056390%	0.002827%	0.032420%	0.004100%
TULA	0.074680%	0.003710%	0.043140%	0.005110%