ANCESTRAL POLYNESIAN POTTERY PRODUCTION AND EXCHANGE ANALYSIS USING LA-ICP-MS

A Senior Scholars Thesis

by

CHRISTOPHER LEE BARTEK

Submitted to the Office of Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2009

Major: Anthropology

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Approved by:

Research Advisor:	Suzanne Eckert
Associate Dean for Undergraduate Research:	Robert C. Webb

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ABSTRACT

Ancestral Polynesian Pottery Production and Exchange Analysis Using LA-ICP-MS.
(April 2009)

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This thesis examines the production and distribution of ancestral Polynesian pottery on Tutuila Island, American Samoa and evaluates the extent of intra-island interactions. Currently, very little is known about ceramic production and exchange in Samoa. Laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) is used to source clay and temper material to raw clay sources. Ceramic attribute analysis is used to identify technological styles, which will determine specific production groups. Variations of clays and tempers within a site determine the extent of exchange that occurred. By combining ceramic analysis and LA-ICP-MS, this research will help determine the number of production groups per village and demonstrate exchange patterns between villages. In 2006 Eckert argued that the presence of two technological styles in ancestral Polynesian pottery reflects two different production groups on the Samoan archipelago. Using LA-ICP-MS and ceramic attribute analysis, I show that exchange has occurred between four production groups.

DEDICATION

To M.

ACKNOWLEDGMENTS

I would first like to thank my colleagues for their contributions to my research, and I give a special thanks to my research advisor, Dr. Eckert, for giving me the opportunity to take on this research. I would also like to thank Dr. James of the Elemental Analysis Laboratory (EAL) at the Texas A&M University Center for Chemical Characterization for allowing me to use the equipment necessary to this research. Lastly, I want to thank the Texas A&M University Department of Anthropology for the funding they have provided towards my research and the presentation of it at the 74th Annual Society for American Archaeology Conference.

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CHAPTER I

INTRODUCTION: A REVIEW OF THE WEST POLYNESIAN CERAMIC SEQUENCE

This research is carried with the goal of gaining a greater understanding of the exchange and production of ancestral Polynesian pottery and how these two processes interact on a provenance level. This research uses methods of ceramic attribute analysis and geochemical characterization by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). LA-ICP-MS will source a ceramic assemblage collected during a 2008 survey, directed by Dr. Eckert, of the uplands on Tutuila Island, American Samoa. LA-ICP-MS is advantageous for its speed, precision, and bulk analysis of potsherds. It is also non-destructive to artifacts, and it generates reliable data for investigating prehistoric exchange and specialized production. Ceramic attribute analysis enables identification of specific technological styles and inferences about the production process. Combining the data of both methods enables a cross examination of the relationship between technological styles, production groups, and provenance.

Geography, geology, and history of west Polynesia

West Polynesia contains the Samoan Archipelago (figure 1.1), which consists of Tonga,

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This thesis follows the style of *American Antiquity*.

Niue, Uvea, Futuna, Ta’u, Olosega, Ofu, Aunu’u, Upolu, Manono, Apolima, Savai’i, and Tutuila (figure 1.2). American Samoa consists of the islands: Tutuila, Ta’u, Olosega, Ofu, and Aunu’u.

The chain of islands is situated on the Pacific Plate, north of the western Tonga-Kermadec Trench. Each island is composed of lavas and pyroclastics from basaltic shield volcanoes (Clark 1996; Wright 1986). Volcanism is recent in the east, and it is older towards the west. In the east, Ta’u is less than 100,000 years old (Clark 1996; McDougall 1985), and in the west, Savai’i dates to 2.52 MYA. The island chain was formed by a hotspot, 150 kilometers east of Ta’u, moving westward along with the Pacific Plate (Clark 1996; Duncan 1985).

Figure 1.1. Regional map of the Samoan Archipelago.

Samoa was discovered by Europeans in 1722 when Roggeveen observed the islands of Manu’a. Further observations were made in 1768 by Bougainville when he sailed past the islands. In 1786, La Perouse of France landed on Tutuila Island at A’asu Bay. La

Perouse and his crew were met with violence resulting in the death of 13 French sailors. Because of hostilities, the islanders gained a reputation that served to their benefit and were avoided by European sailors (Stair 1897). However, this did not stop whalers, merchants, beachcombers, deserters, and prison escapees from stopping at the island during the early 19th century. In 1899, the Samoan islands were politically divided between Germany and the United States. Germany acquired Western Samoa, while the United States acquired the eastern islands. In 1914, New Zealand attained Western Samoa from Germany, and in 1962, Western Samoa became independent (Clark 1996).

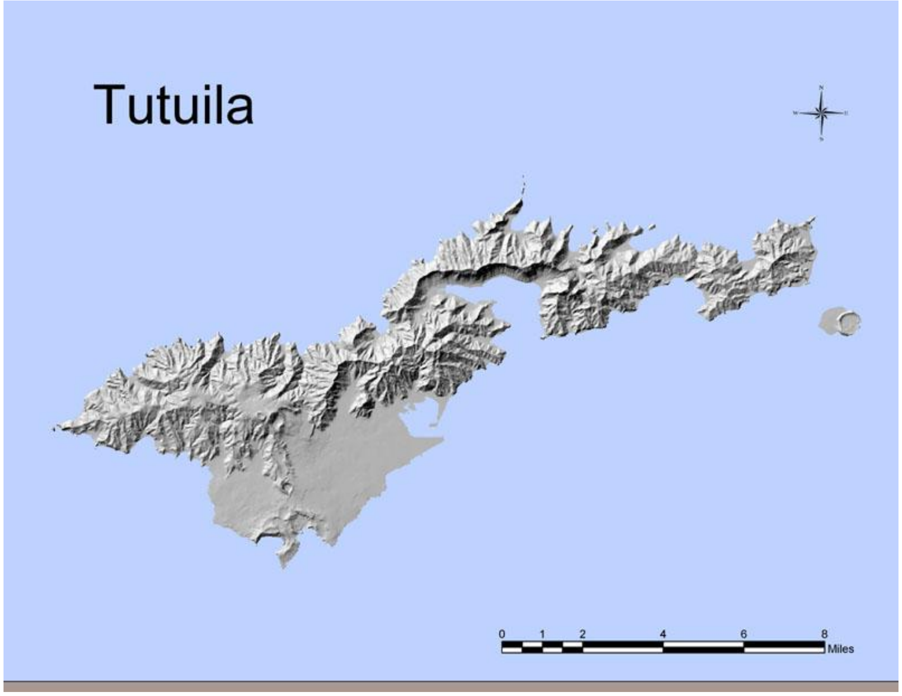


Figure 1.2. Map of Tutuila Island, American Samoa.

Previous research

Archaeological research in Western Samoa initially began in 1957 with the limited survey and excavation by Golson (1969). His investigations resulted in the recovery of undecorated pottery from Vailele, Upolu, indicating that pottery was being utilized as far east as Samoa. This was followed by the work of Green and Davidson in Savai'i and Apolima. During the late 1970s, Jennings, Holmer, and colleagues focused research on Upolu (Jennings *et al.* 1976; Clark 1996). Meanwhile, little research was being done in American Samoa (Frost 1978; Kikuchi 1963). Future research is challenged by significantly changing island coastlines and landscapes, acting as an obstacle for archaeologists in finding and investigating sites. One such obstacle has been the changing sea level, resulting from regional and local processes. Cultural activity has also impacted local ecosystems, significantly through deforestation and cultivation. Accelerated slope erosion and lowland infilling is a result of slash and burn cultivation of ridge slopes, which led to coastal progradation and the expansion of cultivable lowlands (Clark 1996; Spriggs 1981).

The 3000 year old submerged site at Mulifanua, Upolu Island, demonstrates the impact of changing sea levels on a site. A radiocarbon date from shell embedded potsherds gives a date of 3489 to 2771 years BP (Clark 1996; Leach and Green 1989). Potsherds were concentrated in a narrow band about 114 meters from the shore and sealed by a coralline crust up to 0.9 meters thick and 1.5 meters beneath mean sea level (Clark 1996; Green and Richards 1975; Jennings 1974).

Jennings (1974) explains the underwater context of Mulifanua as being a result of island subsidence, which may possibly be related to active effusive basalt volcanism (Bloom 1980:108). Evidence throughout the archipelago of a sea level above present indicates that Mulifanua was occupied (Kear and Wood 1959; Nunn 1990, 1991; Stearns 1944; Stice and McCoy 1968; Sugimura *et al.* 1988). This evidence is also consistent with patterns of mid to late Holocene sea levels, which are 1 to 2 meters above present throughout the central South Pacific (Clark 1989). Nunn (1990: 131) argues that the subsidence reflected by Mulifanua is a result of a rapid localized displacement of the land downwards rather than island-wide subsidence.

Further investigations of Mulifanua demonstrate the possible use of stilt-houses. Given a sea level of 2.6 to 3.0 meters below the present, the environmental context of the site would have been a coral sand beach fronting a shallow lagoon protected by two coral islets (Leach and Green 1989). A retrograding and a transitional shoreline are also demonstrated by the site's soil matrix. If there was stilt-house occupation, subsidence could have occurred less or not occurring at all with current depth deposits.

The relationship between sea level change, terrestrial geomorphology, and human settlement on Tutuila is shared by geomorphological changes that were caused by multiple factors, which have been continuous and variable in rate (Clark *et al.* 1994). Within the last 2000 to 3000 years, Aoa valley was transformed to a backbarrier water body, to a marsh/swamp, and then to a valley floor. Sea level fall along with cultivation of the slopes came to be an important factor in landscape transformation. As the landscape developed over the years, human settlement dispersed through the lower and middle valley, eventually spreading to sections of the slopes. Leone Valley is characteristic of substantial change within the last 1000 years, and Alao underwent a swamp to valley transformation within the last 3000 years (Clark 1989). Within the last 400 years, Tula underwent shoreline progradation by approximately 0.4 kilometers, while shoreline progradation has occurred in Maloata as well, leaving behind 1500 year old cultural deposits (Ayres and Eisler 1987).

Studies in site formation processes at To'aga, Ofu resulted in a morphodynamic model for the development of the coastal plain at To'aga (Kirch 1993). This model demonstrates Holocene sea levels rose at range of 1 to 2 meters from 4000 to 2000 years B.P. The model also attributes island subsidence to point loading, and it explains biogenic sediment budget change as being a result of Holocene sea level rise and island subsidence with terrigeneous sedimentation increasing significantly over time. Initially, the To'aga terrace began as a small settlement 3000 years ago and expanded with progradation over the last 2000 years (Clark 1996).

Because of substantial changes in coastlines and valley landscapes, it is difficult to determine the location of sites. According to the Aoa and To'aga studies by Hunt and Kirch (1988), sites are most likely to be found buried under colluvial/alluvial deposits. Investigations at Aoa, Alao, and Leone report early sites inland of the existing shoreline.

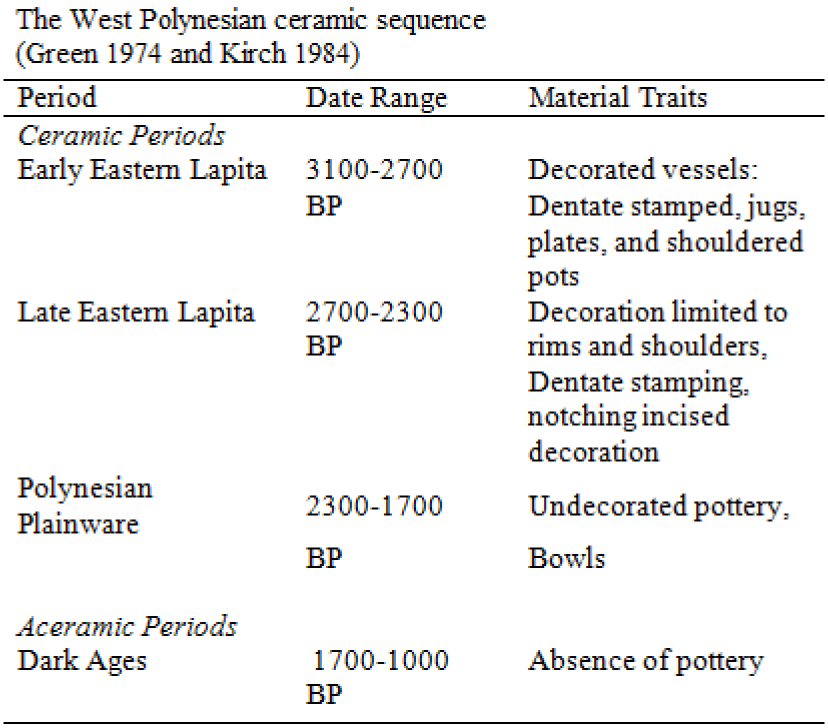
However, Tula and Maloata yield the same results for late sites. Mulifanua is an example that some sites may be located underwater rather than inland. Early site distribution is skewed to an unknown degree, but the understanding of local and regional morphodynamic processes can prove successful in locating early sites in American Samoa.

Welch's (2006) work with ground-penetrating radar (GPR) has revealed details pertinent to site stratigraphy, locations and depths of anomalies such as boulders, and geologic data of sites in the mountain settings of Tutuila. As well as basalt architecture, GPR has identified star mounds provenanced to the monument building period. The coastal research of Crews (2008) uses morphological and chemical analyses of lithics recovered from Aganoa. Results of this study provide evidence that Aganoa did not act as a lithic workshop and that separate quarries were utilized at different stages across a temporal time span.

The ceramic sequence

Green's (1974) ceramic sequence begins with dentate-stamped Lapita ranging from 3100 to 2300 years BP followed by Polynesian Plainware, which ranges from 2300 to 1700 years BP (table 1.1). Polynesian Plainware is distinct from Lapita by the lack of dentate-stamping and the minimal use of other decorations that are restricted to rims and lips (Green 1974:253). Other characteristics of Polynesian Plainware include simple vessel forms and sizes, such as simple bowls rather than open-mouthed sub-globular pots, shouldered vessels, and flat-bottomed dishes (Clark 1996). Green argues development began with predominantly thin-walled, fine-tempered ware with minimal decoration, making a transition to thick-walled, coarse-tempered ware with almost no decoration and restricted vessel forms (Green 1974:250; Clark 1996). This transition is proposed to have taken place from 3000 to 2000 years BP (Green 1974:248).

Table 1.1



The West Polynesian ceramic sequence
(Green 1974 and Kirch 1984)

Period	Date Range	Material Traits
Ceramic Periods		
Early Eastern Lapita	3100-2700 BP	Decorated vessels: Dentate stamped, jugs, plates, and shouldered pots
Late Eastern Lapita	2700-2300 BP	Decoration limited to rims and shoulders, Dentate stamping, notching incised decoration
Polynesian Plainware	2300-1700 BP	Undecorated pottery, Bowls
Aceramic Periods		
Dark Ages	1700-1000 BP	Absence of pottery

Lapita

The Mulifanua ceramic assemblage demonstrates this transition from Lapita to Polynesian Plainware with the coexistence of both diagnostic dentate-stamped sherds and undecorated sherds. Other sites of similar age to Mulifanua, but having only undecorated pottery, include Aoa and To’aga. Excavations at Aoa have revealed two primary components buried under alluvial and colluvial deposits (Clark and Herdrich 1993). The two components both contain pottery but with fewer potsherds in the upper component. A date of 3505 to 2809 years BP was received from the base of the lower component. A second date of 2814 to 2245 years BP was received from 20 centimeters above the base of the lower component. Four consistent dates of approximately 600 to 350 years BP were received from the upper component (Clark 1993a). Excavations at To’aga reveal an early ceramic site buried under colluviums, radiocarbon dated to range of 3401 to 2817 years BP (Kirch and Hunt 1993). Aceramic contexts suggest loss of pottery after approximately 1500 years BP (Clark 1996).

Decorated sherds from Mulifanua may represent trade ware from outside the archipelago. Petrographic analyses indicate that the decorated sherds are not substantially different from undecorated sherds from Mulifanua and other sites, and all are consistent within the Samoan archipelago (Dickinson 1974a, 1976). Because there is only a sample of three decorated sherds, a Samoan origin is indeterminate (Clark 1996). Adzes (n=2) recovered from Mulifanua include one that is similar to Lapita adzes from Tonga and another that is commonly found in Polynesian Plainware sites (Leach and Green 1989). Dentate-stamping may have been abandoned after initial colonization of Samoa, resulting in the development of Polynesian Plainware. Mulifanua may represent a colonization settlement, which may have been very limited in the case of material culture (Clark 1996).

Polynesian Plainware

Polynesian Plainware has been recorded at numerous sites throughout the archipelago including Upolu, Manono, Ofu, Ta'u and Tutuila. On Tutuila, these have been found at Aoa, Leone Valley, Tataga-matau, Alega, Aunu'u, Aganoa, and Ulu Tree. Recent investigations have recovered Polynesian Plainware from Aganoa (Eckert 2006) and Ulu Tree (Eckert & Pearl 2006).

Eckert's investigations at Aganoa address the question of production organization. Aganoa (AS-22-43), an ancestral Polynesian village on the southern coast of eastern Tutuila, was initially surveyed and excavated by Moore and Kennedy (2003:42-120) as part of a cultural resource evaluation for the East and West Tutuila Water Line Project. The site is located within the modern village of Aganoa. The geologic context of the site is composed of sandy coastal sediments overlying volcanic soils and beach rock (Goodwin and Grossman 2003; Nakamura 1984; Stearns 1944). Test excavations (Moore and Kennedy 2003:116-119) have yielded three calibrated radiocarbon dates of a period ranging from 2797 to 473 years BP. Features of the site include modern structures along the site's southeastern boundary and three historic surface features, including a basalt enclosure, terraces, and a possible buried platform. Test excavations report 12 subsurface features including post-holes, basalt paving, and a storage pit, all of which demonstrates a context of human activity (Moore and Kennedy 2003).

Reported cultural remains include stone tools and debitage, Polynesian Plainware, faunal remains, fishhooks, and beads. The stone tool assemblage includes retouched basalt unifaces and bifaces and polished basalt adzes and preforms. Nine marine shell fishhooks were recovered along with fishhook fragments. The beads are also produced from marine shell as well and bird bone. Polynesian Plainware recovered from the site is characteristic of Green's (1974) initial observation of the transition from thin ware to thick ware pottery. Attribute analysis reports that the mean thickness of body sherds decreased with excavation depth (Moore and Kennedy 2003:103-110). Further descriptions of the ceramic assemblage report the majority of the assemblage to be consisted of deteriorated undecorated sherds (Moore and Kennedy 2003:103). Rim sherds were found to vary in shape and thickness, and two rims were found decorated with incised grooves.

Eckert's (2006) investigation of the Aganoa ceramic assemblage has revealed 15 sherds characterized by red slip utilization. Furthermore, four sherds indicate production through grinding into specific shapes, specifically three triangles and one disk shaped. Eckert identifies half of the assemblage to be tempered with grog, or crushed potsherds, as well as the sand, shell, and basalt identified by Moore and Kennedy (2003). This is indicative of distinct technological styles in relation to ancestral production organization at Aganoa.

The purpose of utilizing temper in pottery production is to modify workability by making the clay less plastic and less sticky. Temper modifies a clay's drying behavior by decreasing shrinkage. Temper allows for a clay's vitrification temperature to decrease during the firing process. Temper's affect on the final product can determine color and increase porosity or strength of the pot (Rice 1987; Shepard 1954). Temper choice is highly variable, ranging from various types of igneous, metamorphic and sedimentary rocks, grog, salt, sand, ash, blood, bone, shell, coral, dung, and plant material (Matson 1989; Rice 1987; Shepard 1954; Stilborg 2001; Wettstaed 2005).

Temper choice is made based on what the potter wishes to achieve with the final product. In Aganoa, the options for which temper to choose consisted of a variety of nonplastic materials such as basalt, sand, and grog (Dickinson 1969, 1974b, 1976, 1993). However, these temper choices all have the same effect on clay, decreasing wet clay plasticity and drying shrinkage and increasing vessel strength (Rice 1987; Shepard 1954). Furthermore, these temper materials would not have been difficult to acquire nor would they have been in short supply. Choosing which type of material to temper clay may have been a matter of technological style based on a particular production group. 'A production group is a network of potters who learn and teach their craft to one another, probably through work groups composed of experienced and inexperienced potters of different generations and ages' (Eckert 2006). Different production groups are distinct by technological style as a result of different decisions made through the production process. However, all production groups would have used similar tool sets and techniques within a given area. Different production groups reflect different production interaction and learning spheres.

Polynesian Plainware has also been recovered from Ulu Tree (AS-31-127), located on the Tafuna Plain. The geological context consists of a broad flat plain of recent basaltic tuffs and Holocene age lavas on the southwest side of the island (Stearns 1944). The ceramic assemblage consists of 259 sherds, all of which are Polynesian Plainware. Temper material has been identified as mostly igneous rock including fine, grained homogenous rock with some vesicular pieces and a dark grey igneous rock (Eckert and Pearl 2006).

A date for the site has not been determined yet, but the ceramic assemblage from Ulu Tree is similar to Aoa, Mulifanua, and To’aga, while the temper material identified in the Ulu Tree ceramic assemblage is similar to the temper material found at To’aga (Dickinson 1993), Aoa (Clark and Michlovic 1996), Vailele (Dickinson 1969), Falefa (1969) and potsherds from smaller surveys (Cochrane *et al*. 2004). However, Eckert and Pearl (2006) report a greater diversity of temper types at Ulu Tree than to other sites. Seven distinct types of temper are identified at Ulu Tree, but the ceramic sequence reveals no pattern in vessel thickness, rim form, temper type, or paste color. Eckert and Pearl conclude that this may be due to the sample size of the assemblage, the secondary context of which the assemblage was recovered from, the short lived occupation of Ulu Tree, or the consistent production practices in Samoa.

Decline of pottery

Pottery was gradually abandoned throughout the archipelago over a period of two centuries. Pottery was still widely utilized from 2000 to 1500 years ago. After 1000 years, pottery became uncommon in Samoa and absent from many areas. Pottery became a rarity around 700 to 400 years BP, with the exception of being retained in small quantities in few locations. Pottery was abandoned throughout the islands by 400 years BP (Clark 1996).

Settlement pattern

Samoan settlements consist of *fale*, or a house, which is occupied by a household. Groups of related and/or interacting households compose *pitonu'u*, which are constituents of *nu'u*. A *nu'u* is a nucleated village, which consist of interacting kin groups, or *'aiga*. Other settlement units are specialized sites, including large house mounds, star mounds, or *tia 'ave*, defensive sites, quarries, terraces, paths, and raised-rim ovens, or *umu ti*. The most discussed special purpose feature is the star mound, or *tia 'ave*. These features can be described as earthen and/or stone mounds with one or more arms, or rays (Herdrich 1991). *Tia'ave* are commonly found in the central islands, including Tutuila. On Tutuila, 76 of these star mounds have been reported (Herdrich and Clark 1993:52). The mounds are normally found outside of residential areas. They were probably used for pigeon catching and ritual performances. Pigeon catching represented significant cosmological and social relationships, and the mounds may have been utilized as areas for chiefly competition for prestige, status, and power (Herdrich and Clark 1993).

Special purpose features such as defensive sites have been found throughout Samoa. These include isolated structures, deep ditches, large complexes consisting of terraces, ditches, and embankments. This indicates large-scale warfare and increasing socio-political integration (Clark and Herdrich 1993). An embankment at Luatuanu'u is radiocarbon dated to 1959 to 1328 years BP, which demonstrates a possible date range of land clearing prior to feature construction (Scott and Green 1969).

Basalt quarries have also been found throughout Tutuila. These can be found at Tataga-matau on the ridges above Leone, at Fagasa in central Tutuila (Best 1993), and in eastern Tutuila, which holds many small basalt quarries (Clark 1993b; Clark and Herdrich 1993). The Tataga-matau complex consists of a set of quarry subsources with terraces, defensive features, and star mounds (Best *et al*. 1992). Settlement patterns indicate coastal settlement began first. Coastal sites that demonstrate this pattern include Mulifanua, Aoa, and To'ago, which are dated to have been occupied 3000 years ago. Faleasi'u and Falemoa are dated to have been settled about 2500 years ago. Vailele and Ta'u Village (Hunt and Kirch 1988) are dated to have been occupied 2000 years ago. Smaller late coastal occupations include Lotofaga on Upolu, which is dated to 1300 years BP (Davidson 1969), and Alega on Tutuila, dated to 1000 years BP (Clark 1993b).

Inland settlement patterns in American Samoa are best represented in the Tafuna Plain. The soil development of the plain is very poor and water is scarce because of recent geological formations, while the western portion of the plain is characteristic of prehistoric occupation (Clark and Herdrich 1993). The extent of inland settlement reaches into the uplands, where settlements have been found on the ridges of Lefutu, Fa'iga, and Alva (Frost 1978).

Social interaction

Interisland contact can be outlined through geochemical analysis of fine-grained basalt, volcanic glass, and pottery. Such studies have demonstrated that Samoa has interacted on a social and economic scale with Tonga and Fiji (Davidson 1977). Through geochemical analysis, chemical compositions of adzes from the central Pacific demonstrate Tutuila basalts were traded within and beyond the Samoan archipelago (Best *et al*. 1992). Tutuila basalt sources were initially exploited at the Leafu subsource of Tataga-matau 2000 years ago, and by 900 years ago these basalts were reaching Fiji. Within the last 1000 years, they were reaching the Tokelaus. Within the last 600 years, Tutuila basalts were reaching the Cook Islands. By 300 years ago, they were reaching Tonga. Tutuila basalts have been reported as far as Taumako in the Southeast Solomons and Tuvalu. Kirch (1986), by using macroscopic analysis, demonstrates that Samoan or *'Uvean* adzes were reaching Tikopia 800 years ago.

Based on quarry size, the Tataga-matau complex and Fagasa are most likely to have been the primary suppliers of basalt, as well as ceramics, to other islands within the group and to neighboring groups. At 2000 years ago, Tutuila basalts were initially distributed within an intra-archipelagic network. At 1000 years ago, this network expanded into an inter-archipelagic system, concentrated in the central Pacific. Preceding basalt, volcanic glass may have been treated as a valued commodity. However, it may have lost its value and function as a trade commodity upon development of the inter-archipelagic network (Clark 1996). With the growing success of geochemical characterization of ceramics, the primary goal of this thesis is exploring intra-island exchange by using LA-ICP-MS.

CHAPTER II

METHODS: GEOCHEMICAL CHARACTERIZATION AND CERAMIC ATTRIBUTE ANALYSIS

Geochemical and ceramic attribute analyses will demonstrate social interaction between production groups and their technological styles. LA-ICP-MS will be used to source the ceramic paste matrix to a particular wild clay source on Tutuila. Ceramic attribute analysis will identify technological styles used by production groups. LA-ICP-MS is a potential method of sourcing artifacts by utilizing a laser to extract isotopes. The process is nondestructive and is efficient for bulk analysis of artifacts. A ceramic attribute analysis of diagnostic features will be used to build a typology for assemblage. This attribute analysis will focus on identifying temper material, building a rim form typology, and comparing sherd thickness with temper grain size.

Welch's (2009) upland survey provides a ceramic assemblage to be studied. This analysis will include surface collected and excavated potsherds from seven sites (PAV005, PAV006, PAV012, PAV014, PAV015, AAS001, and ALF004) located in Pavai'ai, A'asufou, and Aoloaufou (figure 2.1). Ceramics were excavated only in PAV015 with three test pits.

Ceramic attribute analysis

Attributes for the recovered ceramic assemblage (n=92) include: sherd size, presence and location of soot, thickness of the body or rim, sherd weight, type of rim termination, paste color, and temper and temper size (appendix A). These particular attributes were chosen to determine chronological provenance, identify vessel forms, and technological styles.

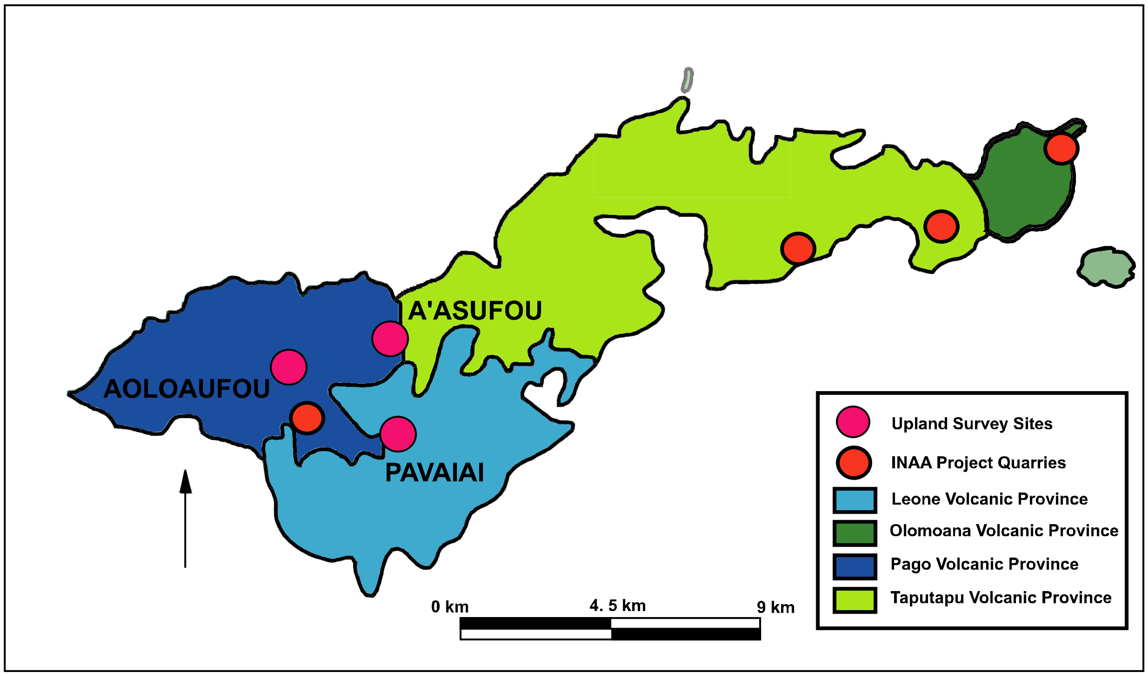


Figure 2.1. Upland sites in relation to basalt quarries and volcanic provinces.

This assemblage consists entirely of Polynesian Plainware. Radiocarbon dates have not been acquired yet, but by identifying soot on sherds, samples can be selected for carbon dating. The presence of soot is direct evidence of the pot being used over a fire. Soot will commonly be located at the shoulder and maximum diameter of a vessel (Hally 1983:8).

An instance of soot and its placement allows for inferring how the pot was positioned over a fire. Soot allows for the potsherd to be radiocarbon dated as well. Determining provenance will also involve using Green's (1974) ceramic sequence, which places thin fine ware vessels with fine temper early in the ceramic sequence and thick coarse ware vessels tempered with coarse basaltic material later in the sequence. Identifying this relationship will be determined by measuring the thicknesses of the body or rim of the sherd, using digital calipers, and measuring the grain size of temper inclusions by the Wentworth scale. Vessels forms can also be identified by quantitative measurements of diagnostic attributes including weight (grams) and size (cm^2). Potsherds are identified by what part of the vessel it came from, which is either the body or rim in this assemblage. Patterns of vessel lip termination found in this assemblage consist of either rounded or flat termination. These along with illustrations of rim profiles help build a typology (appendix B). Paste color, particularly from the most oxidized part of a potsherd, is determined with a Munsell soil color chart using hue/value/chroma measurements. Within the paste matrix, types of temper material identified include angular coarse dark-gray igneonous rock, shell, volcanic rock inclusions, sub-rounded coarse quartz, mica, sub-rounded fine white volcanic rock, and/or angular light-gray volcanic rock (figure 2.2).

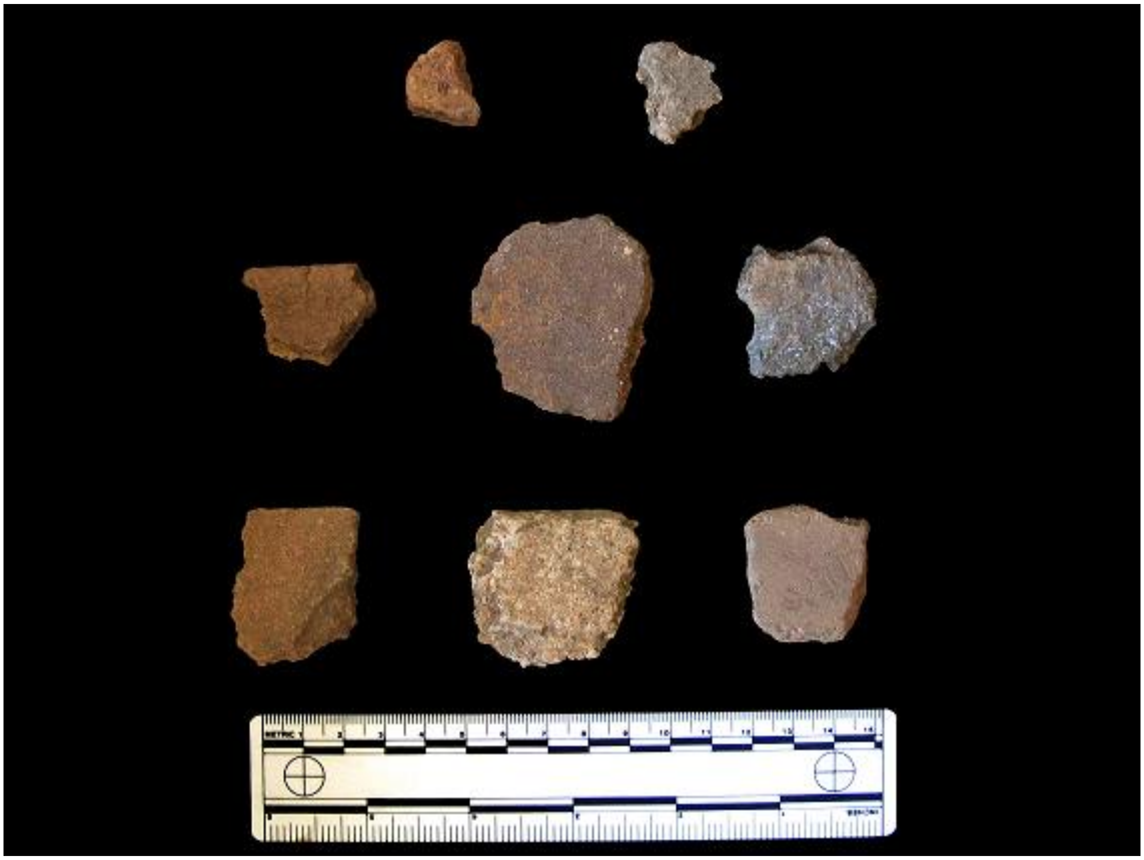


Figure 2.2. Potsherds containing various types of temper inclusions.

Geochemical characterization

Chemical analysis will use laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS), provided under the supervision of Dr. William D. James of the Elemental Analysis Laboratory (EAL) at the Texas A&M University Center for Chemical Characterization. Advantages of using LA-ICP-MS include obtaining a bulk analysis and conservation of artifacts, and its potential for surface analysis, such as slips on Mesoamerican Plumbate ware as demonstrated by Neff (2003). Geochemical characterization will indicate intra-island social interaction and exchange by an elemental analysis of the ceramic paste matrix, which can then be sourced to a particular quarry. A sample of potsherds (n=64) from the upland survey ceramic assemblage will be laser ablated, obtaining an elemental abundance of the ceramic paste matrix. Samples for ablation will be selected by the color of the ceramic paste matrix. LA-ICP-MS procedure begins with placing the potsherd inside a holder where laser ablation (LA) takes place. Digital images of the laser cell are taken with a video camera inside of the LA unit which projects them onto a computer screen. From the computer screen, areas of interest, such as temper inclusions, can be magnified, and the loci on the sample can be identified and targeted for ablation. Computer software integrated with the LA system allows for raster patterns to be superimposed over an area of interest that will be targeted during ablation (Speakman and Neff 2005).

During ablation, the ablated material is transported from the laser cell using a 0.9- to 1.5-liter/minute flow of argon and/or an argon/helium/nitrogen-mixed carrier gas through Tygon tubing and introduced into the ICP-MS torch, where argon gas plasma capable of sustaining electron temperatures between 8,000 and 10,000 K is used to ionize the injected sample. The ions then pass through a two-stage interface, the sample and skimmer cones. These enable the transition of the ions from atmospheric pressure to the vacuum chamber of the ICP-MS system. Once the ions are inside the mass spectrometer, they are accelerated by high voltage and pass through a series of ion optics, an electrostatic analyzer (ESA), and then a magnet. Ions are then separated by the magnet according to mass/charge ratio and passed through a slit into the detector. The detector records a small atomic mass range at a given time.

Procedure for sampling sherds is followed by alternating batches of ten sherds with standards and a blank analysis. Blanks are subtracted from the intervening unknowns and the NIST standards SRM 612, the glass buttes obsidian, and the Ohio red clay standard used at MURR. Known values of the standards are used to develop calibration parameters for the bracketed batch of sampled sherds (Speakman and Neff 2005). Running standards after every ten samples of unknowns corrects for instrumental drift over the course of geochemical analysis and allows for monitoring measurement consistency of the ICP-MS. Subtracting background noise and calculating for final element abundances is accomplished by using formulas from the Gratuze method (figure 2.3). The process begins by subtracting the blank from the signal and an average value is calculated from the three ablations. Internal standardization is done for each sample. Corrections for isotopic abundance ratios and interferences are then made. A standardized signal for element Y is then obtained (Gratuze *et al.* 2001).

1)

$$\text{counts}_y = \frac{\text{raw counts}_y - \text{blank counts}_y}{\text{isotopic abundance}_y}.$$

2)

$$\text{std signal}_y = \frac{\text{counts}_y}{\text{counts}_{\text{internal standard}}}.$$

3)

$$\text{std signal}_y = K_y\left(\frac{\text{conc}_y}{\text{conc}_{\text{internal standard}}}\right).$$

4)

$$\left(\frac{\text{conc}_{\text{internal standard}}\text{ in ref material}}{\text{conc}_y\text{ in ref material}}\right).$$

5)

$$\text{oxide conc}_y = \left(\frac{O_y(\text{std signal}_y)/K_y}{\sum_{i=1}^{m} O_i(\text{std signal}_i)/K_i}\right)100,$$

Figure 2.3. Formulas from Gratuze method used in calculating element abundances.

Reference materials are used to calculate response coefficient factors *Ky*. The results obtained for the first element of the sample are then normalized to 100% for each sample. A correction factor, *Oy*, is applied to correct for the presence of oxygen. Here, standard geochemical stoichiometric coefficients are used to calculate the factors. For the other samples, the internal standard concentration is known, since it has been measured in one of the preceding menus. The concentration is then given by dividing the standardized signal of Y by *Ky* and multiplying them by the concentration of the internal standard. With the calculated concentrations, statistical analysis indicate particular groupings of samples and how they relate to each other accordingly by artifact provenance and the temper and paste of the individual potsherd

CHAPTER III

RESULTS

Tutuila contains the only known basalt quarries in the Samoan archipelago. These include Tataga-matau, Fagasa, and Faga’itua. Given the local resources Tutuila was a possible industrial center of basalt tool manufacture with the purpose of exchange (Best *et al.* 1992). Stearns (1944) characterized the island as an end product of four major shield volcanic centers: Alofau, Olomoana, Pago, and Taputapu. Using a ceramic assemblage from Pavai’ai, A’asufou, and Aoloaufou, geochemical results are anticipated to demonstrate processes of exchange occurring between these upland sites.

Clay-source differences will be detectable by laser ablation of the clay matrix component of ceramic pastes of the potsherds recovered from a surface collection and excavation from three test pits in PAV015. This should then be sourced to originate from a distant quarry, thus indicating interaction between upland groups. Ceramic attribute analysis will provenance this assemblage using Green’s (1974) ceramic sequence, particularly the relationship between thin fine ware vessels with fine temper and thick coarse ware vessels tempered with coarse basaltic material will be tested for correlation.

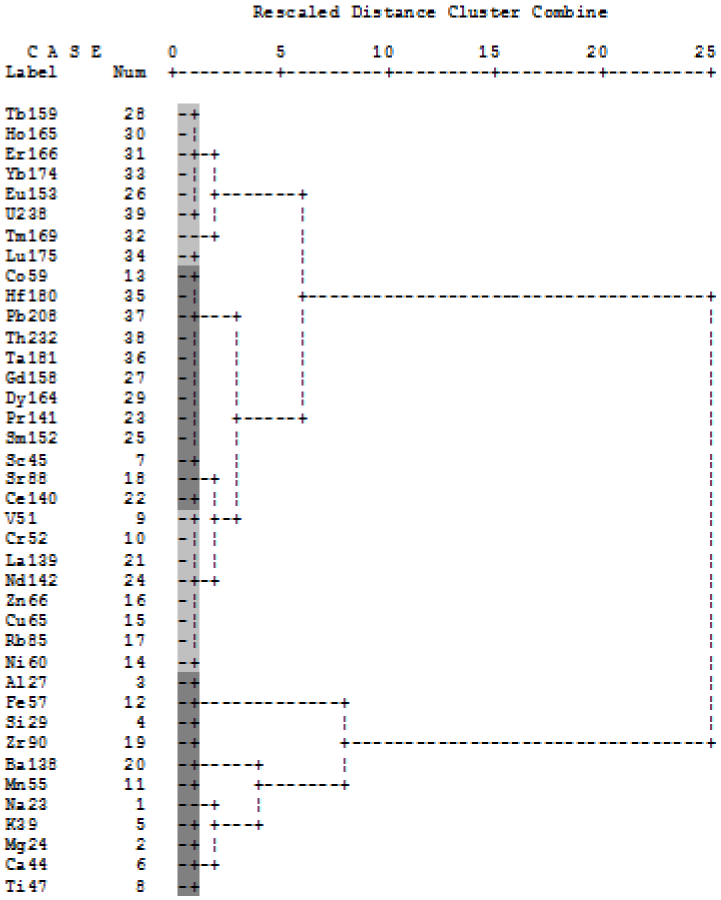
Geochemical characterization results

Four chemical compositional groups have been identified within this assemblage. Geochemical analysis has also identified these four distinct compositional groups to be distributed across seven sites in Pavai'ai (PAV005, PAV006, PAV012, PAV014, PAV015), A'asufou (AAS001), and Aoloaufou (ALF004). Exploratory statistics demonstrates the grouping of ceramic pastes and their correlation with chemical composition.

Statistical analysis is used with SPSS version 16 for Windows, and the analysis uses hierarchical cluster analysis, canonical discriminant analysis (CDA), and principal component analysis (PCA). These methods have proven to be successful as demonstrated by Johnson *et al.* (2007) in sourcing the basalt quarries of Tutuila and Cochrane and Neff's (2006) analysis of Fijian ceramics. Initial analysis began by log base-10 transforming all LA-ICP-MS data (Baxter 1994). Hierarchical cluster analysis was utilized to explore the grouping tendencies in the chemical composition of the ceramic pastes. Among 39 elements, four agglomerative clusters were formed using between-groups linkage and within-groups linkage, both measured by squared Euclidean distance (table 3.1). Both dendrograms using average linkage between groups and within groups reveal four large clusters each with identifiable elemental structures.

Following hierarchical cluster analysis, CDA was applied using all elements to test the relationship of ceramic pastes to provenance. CDA requires an assumption of the known number of groups, which I have assumed there to be four groups on the basis of paste color. The first two-discriminant functions received a confidence level of 0.82 and 0.75. Biplots of function 1 against function 2 provided a definitive separation between the four pastes (figure 3.1). PCA was then used to test the ability to distinguish between the chemical compositions of ceramic pastes. Variance percentage of factor analysis showed to be 70%. Factor 1 was plotted against factor 2, of which the result showed less separation than the biplot using CDA functions 1 and 2 (figure 3.2).

Table 3.1. Dendrogram using Average Linkage (Between Groups).



This differentiation still demonstrates distinct separation of ceramic pastes into groups between seven sites. This is further determined by plotting elements against each other in order to observe what is driving the differentiation of the four pastes. Using the CDA structure matrix which provides the significance for all elements, it was determined that sodium (Na) of function 1 against lead (Pb) of function 2 would best show separation between ceramic paste groups (figure 3.3).

Frequencies of compositional group, identified to ceramic paste, distributions across sites are then illustrated using frequency graphs. These reveal which group is most prominent in a particular site. High frequency of a particular group at a site is an indication of provenance and the presence of a raw clay source in the given area. Cross comparison frequencies display PAV015 containing the highest amount (n=30) of ceramic paste group four (figure 3.4). Meanwhile, PAV014 contains the highest amount (n=10) of ceramic paste group two out of all sites. All other sites share smaller frequencies of paste groups, with the exception of AAS001, ALF004, and PAV005. All three sites similarly lack ceramic paste group three. Ceramic paste groups one and two overlap due to artifact frequency.

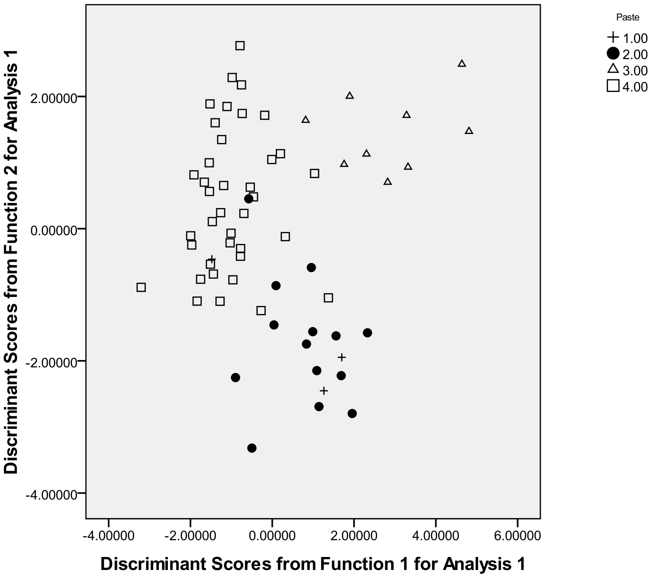


Figure 3.1. CDA biplot function 1 and function 2.

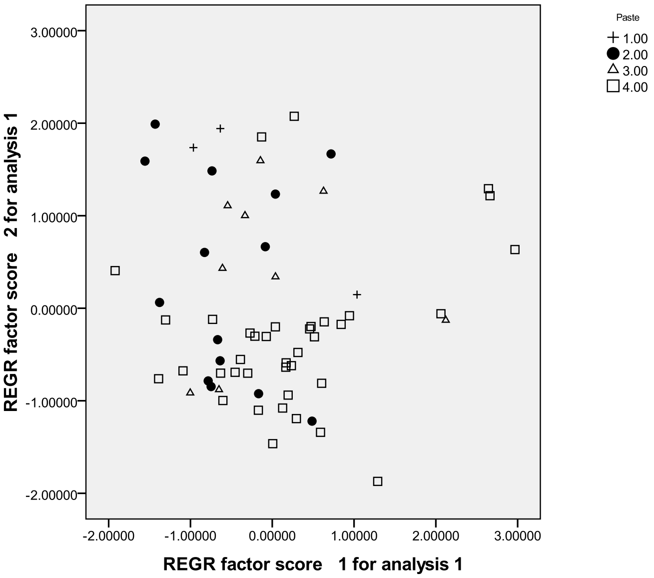


Figure 3.2. PCA biplot of scores for factor 1 and factor 2.

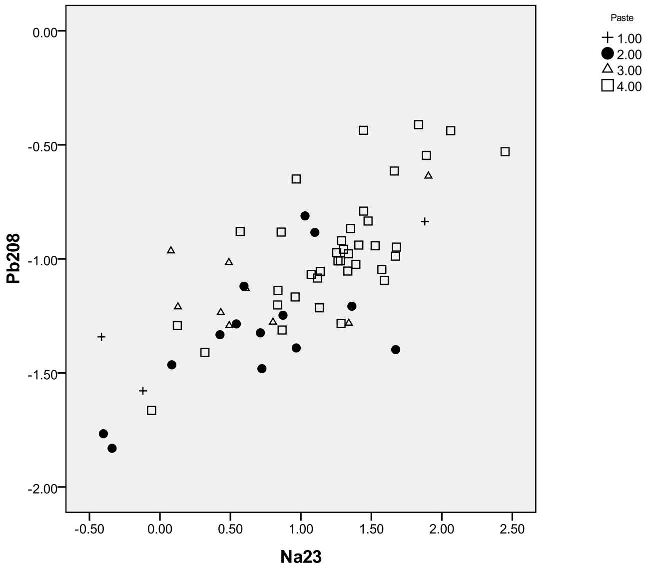


Figure 3.3. Sodium (Na) of function 1 against lead (Pb) of function 2.

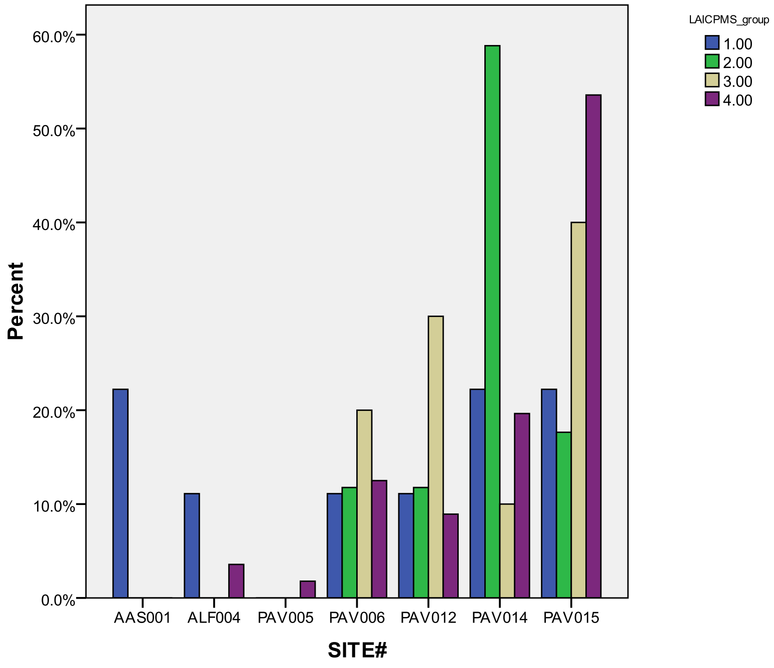


Figure 3.4. Ceramic paste group distribution across sites.

Attribute frequencies are demonstrated to test correlation with Green’s (1974) ceramic sequence, where thin fine ware is tempered with fine temper inclusions and is found in early periods of the ceramic sequence. Thick coarse ware is tempered with coarse inclusions, and appears later in the ceramic sequence (Smith 2002). Despite the ranging subjectivity of vessel thickness, Smith’s (1976: 86) standard for thickness (≥ 10 mm) is used for this analysis.

Ceramic attribute analysis results

Assuming vessel thickness is related to function, frequency analysis of sherd body thickness and temper size of the upland ceramic assemblage (n=92) demonstrates there is a definitive vessel functional difference between sites in Pavai’ai, A’asufou, and Aoloaufou. Frequencies of ceramic attributes exclude sites AAS001, ALF004, and PAV005 due to low artifact frequency. PAV006 has a higher frequency of thick coarse ware sherds in comparison with thin fine ware sherds. In PAV012 there is a higher frequency of fine thin ware sherds in comparison with thick coarse ware sherds. PAV014 has a higher frequency of thin fine ware sherds in comparison with thick coarse ware sherds. PAV015 has a significantly higher frequency of thin fine ware sherds to thick coarse sherds. Overall, there is no relationship of vessel thickness to temper size that is apparent (figures 3.5 & 3.6). Other attributes from the analysis, such as rim form, allows for identification of technological styles. Using illustrations of rims drawn to scale, this analysis has built a typology of three distinct bowl forms on the basis of the rim’s angle to lip ratio (appendix B). Rim forms I, II, and III include lips with flat and rounded termination. All rim forms contain thin and thick ware vessels. This can either be interpreted as mixed provenance or the coexistence of thin and thick ware vessels.

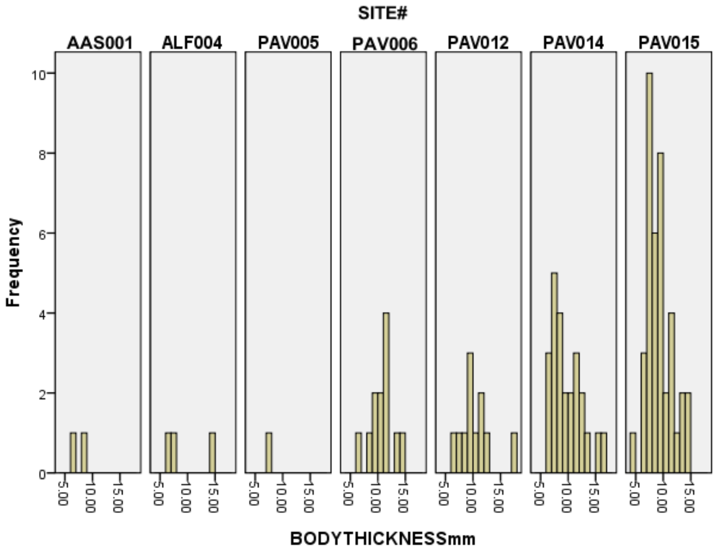


Figure 3.5. Frequency of potsherd thickness distribution across sites.

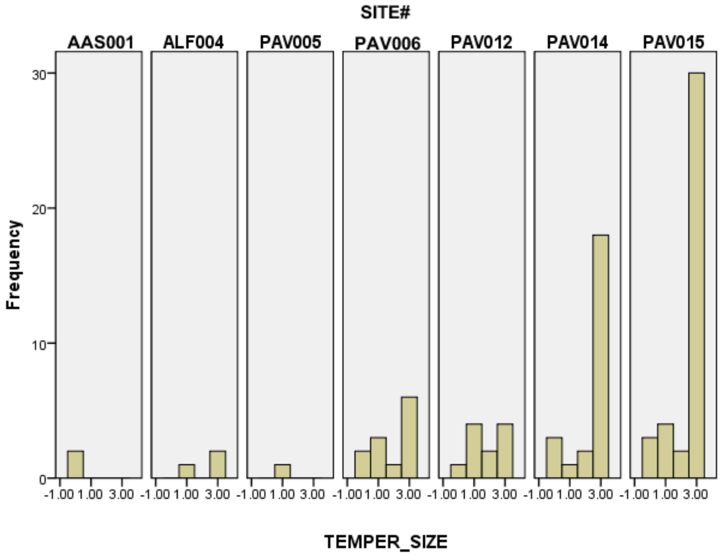


Figure 3.6. Frequency of temper size across sites.

Using exploratory statistics with the assumption that ceramic pastes will correlate with chemical compositions is demonstrated with successful grouping. Furthermore, comparison between sites and frequency of pastes demonstrates particularly raw clay sources are accessible to some groups and inaccessible to others. There appears to be no correlation between the thickness of a vessel and the size of temper inclusions. This can be attributed to poor provenance due to surface collection.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The goals of this research are methodological and substantive. It is methodological for exploring new methods for sourcing ceramics, and it is substantive for understanding intra-island interaction through identification of distinct production groups and their technological styles. LA-ICP-MS has successfully demonstrated its archaeological application by identifying at least four production groups with a correlation between ceramic chemical composition and ceramic paste. Exploratory statistics has allowed for all spectrums of geochemical and ceramic attribute data to be taken into consideration for the purpose of identifying these groups and their relationship to technological style. Contrary to Green's (1974) ceramic sequence maintaining temper size and vessel thickness to increase in size through time, my attribute analysis indicates no relationship between vessel thickness and temper size. However, this assemblage was recovered by surface collection with just a few from excavated test pits, while Green's ceramic sequence was built from *in situ* potsherds

Geochemical characterization has identified distinct chemical differences that separate into four groups. However, characterization data of raw clay sources is unavailable. Being that this is the case, "Criterion of Abundance" is used to evaluate the compositional variation of ceramics. A ceramic unit, such as ceramic paste, that is significantly represented at a site is assumed to be from a local production group, while scarcely represented ceramic pastes may be of nonlocal origin (Bishop *et al.* 1982). Geochemical analyses and ceramic attribute analysis show ceramic pastes are in significant abundance at sites such as PAV015, while some sites have scare amounts of clay away from PAV015. PAV015 may possibly be a production site that participated in little exchange. The basic assumption of “Criterion of Abundance” presumes that a greater proportion of pottery produced locally is consumed rather than used for exchange. This is illustrated by declining frequency of the particular ceramic group away from PAV015. Ceramic paste distribution data indicate that sites in A’asufou and Aoloaufou contain at least one ceramic paste group. These two particular sites are located further inland in Tutuila, and this may have been a factor contributing to the scarcity of these particularly clay resources. Using LA-ICP-MS and ceramic attribute analysis has shown there are at least four compositional groups associated with ceramic paste. The distribution of these groups across PAV005, PAV006, PAV012, PAV014, PAV015, AAS001, and ALF004 demonstrates “Criterion of Abundance”.

Future research needs to be directed towards surveying for more upland sites, recovering *in situ* ceramics from them, and applying other geochemical characterization techniques to acquire a stratigraphic chronology and test chemical compositional grouping against assemblages of coastal sites. This is anticipated to expand our understanding of ancestral Polynesian intra-island interactions.

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APPENDIX A

CERAMIC ATTRIBUTE ANALYSIS

PART
Indeterminate = 0
Body = 1
Rim = 2

TYPE
Indeterminate = 0
Polynesian Plainware = 1
Lapita = 2

RIM FORM
Indeterminate = 0
Rim Form I = 1
Rim Form II = 2
Rim Form III = 3

LIPSECT
Indeterminate = 0
Flat = 1
Round = 2

SOOT
Indeterminate = 0
Sooting present on exterior = 1
Sooting present on interior = 2
Sooting is not present = 10

BINOCTEMPER
Indeterminate = 0
Angular, coarse, dark-gray igneonous rocks = 1
Shell mixed with volcanic rock inclusions = 2
Angular, volcanic rock mixed with sub-rounded, coarse, quartz and mica inclusions = 3
Mica inclusions = 4
Sub-rounded, fine, white volcanic rock mixed with quartz inclusions = 5

Angular, light-gray volcanic rock = 6
Inclusions consisting of quartz and mica = 7

TEMPER SIZE
Indeterminate = 0
Fine sand = 1
Medium sand = 2
Coarse sand = 3
Very coarse sand = 4
Very fine gravel = 5

SITE	SITE#	FS#	LOT	PART	SIZE	WEIGHT	BODYTHICKNESS	RIMTHICKNESS	RIM FORM
PAVAIAI	PAV006	22	1	1	3	13.96	11.13		
PAVAIAI	PAV006	23	2	1	3	4.02	6.88		
PAVAIAI	PAV006	23	3	1	3	9.14	10.45		
PAVAIAI	PAV006	23	4	1	3	5.28	9.13		
PAVAIAI	PAV006	23	5	1	5	18.4	11.39		
PAVAIAI	PAV006	23	6	1	3	3	8.48		
PAVAIAI	PAV006	23	7	1	3	12.84	11.2		
PAVAIAI	PAV006	23	8	1	3	4.98	14.09		
PAVAIAI	PAV006	23	9	1	3	4.98	10.36		
PAVAIAI	PAV006	23	10	1	3	9.7	9.72		
PAVAIAI	PAV006	23	11	1	5	22.7	13.03		
PAVAIAI	PAV006	25	12	1	5	35.26	11.68		
PAVAIAI	PAV012	27	13	1	5	37.46	10.99		
PAVAIAI	PAV012	27	14	1	3	7.66	12.77		
PAVAIAI	PAV012	27	15	1	3	3.3	9.93		
PAVAIAI	PAV012	27	16	0	1	1.62	8.1		
PAVAIAI	PAV012	27	17	1	3	5.3	9.36		
PAVAIAI	PAV012	27	18	1	3	12.92	17.37		
PAVAIAI	PAV012	27	19	2	3	9.2	7.49	7.9	2
PAVAIAI	PAV012	27	20	1	3	15.4	11.11		
PAVAIAI	PAV012	27	21	1	3	5.06	11.2		
PAVAIAI	PAV012	27	22	1	3	4.9	6.87		
PAVAIAI	PAV014	30	23	1	3	15.38	12.12		
PAVAIAI	PAV014	30	24	1	3	7.34	11.6		
PAVAIAI	PAV014	30	25	2	5	27.72	16.19	12.47	3
PAVAIAI	PAV014	30	26	1	3	15.04	15.34		
PAVAIAI	PAV014	30	27	1	3	10.96	11.68		
PAVAIAI	PAV014	30	28	1	1	2.5	7.67		
PAVAIAI	PAV014	30	29	2	3	4.76	7.81	7.96	2
PAVAIAI	PAV014	30	30	1	3	9.24	13.79		
PAVAIAI	PAV014	30	31	1	1	2.48	8.58		
PAVAIAI	PAV014	30	32	1	1	3.46	9.23		
PAVAIAI	PAV014	30	33	2	1	3.6	8.49	8.84	3
PAVAIAI	PAV014	30	34	1	1	2.22	8.26		
PAVAIAI	PAV014	30	35	2	3	5	11.56	10.89	1
PAVAIAI	PAV014	30	36	1	3	3.22	6.26		
PAVAIAI	PAV014	30	37	1	1	2.76	8.83		
PAVAIAI	PAV014	30	38	1	3	16.1	10.5		
PAVAIAI	PAV014	30	39	1	3	4.7	7.86		
PAVAIAI	PAV014	30	40	1	3	5.66	9.03		
PAVAIAI	PAV014	30	41	1	3	5.08	10.58		
PAVAIAI	PAV014	30	42	1	3	5.04	7.38		
PAVAIAI	PAV014	30	43	1	3	4.9	7.95		
PAVAIAI	PAV014	30	44	1	3	10.02	12.22		

SITE	SITE#	FS#	LOT	PART	SIZE	WEIGHT	BODYTHICKNESS	RIMTHICKNESS	RIM FORM
PAVAIAI	PAV014	30	45	1	3	2.6	6.69		
PAVAIAI	PAV014	30	46	1	1	1.76	6.2		
PAVAIAI	PAV015	32	47	1	5	20.06	11.94		
PAVAIAI	PAV015	32	48	2	3	7.82	8.83	10.28	2
PAVAIAI	PAV015	32	49	1	3	11.22	8.64		
PAVAIAI	PAV015	32	50	2	5	27.82	14.64	14.84	2
PAVAIAI	PAV015	32	51	1	3	15.82	13.05		
PAVAIAI	PAV015	32	52	1	3	21	14.97		
PAVAIAI	PAV015	32	53	1	3	5.94	9.95		
PAVAIAI	PAV015	32	54	1	3	3.82	8.85		
PAVAIAI	PAV015	32	55	1	3	5.2	7.29		
PAVAIAI	PAV015	32	56	1	3	5.34	9.76		
PAVAIAI	PAV015	32	57	2	3	6.96	12.56	14.57	3
PAVAIAI	PAV015	32	58	1	3	3.14	11		
PAVAIAI	PAV015	32	59	1	3	2.94	6.7		
PAVAIAI	PAV015	32	60	1	3	3.44	7.91		
PAVAIAI	PAV015	32	61	1	3	6.06	11.78		
PAVAIAI	PAV015	32	62	1	1	1.46	10.84		
PAVAIAI	PAV015	32	63	1	3	6.66	10.83		
PAVAIAI	PAV015	32	64	1	3	2.98	6.23		
PAVAIAI	PAV015	32	65	1	3	7.72	9.36		
PAVAIAI	PAV015	32	66	1	3	3.52	7.89		
PAVAIAI	PAV015	32	67	1	3	3.38	9.04		
PAVAIAI	PAV015	32	68	1	3	3.84	8.95		
PAVAIAI	PAV015	32	69	1	3	10.06	7.89		
PAVAIAI	PAV015	33	70	1	3	7	8.6		
PAVAIAI	PAV015	33	71	1	1	2.96	7.49		
PAVAIAI	PAV015	33	72	1	1	1.2	4.73		
PAVAIAI	PAV015	33	73	2	3	8.5	11.06	11.27	3
PAVAIAI	PAV015	33	74	2	3	12.82	9.95	11.74	1
PAVAIAI	PAV015	33	75	1	3	13.34	9.83		
PAVAIAI	PAV015	33	76	1	3	11.24	7.53		
PAVAIAI	PAV015	33	77	1	3	3.38	7.55		
PAVAIAI	PAV015	33	78	1	1	4.06	9.83		
PAVAIAI	PAV015	39	79	1	1	3.88	13.14		
PAVAIAI	PAV015	40	80	1	3	15.04	9.1		
PAVAIAI	PAV015	41	81	1	3	2.78	7.29		
PAVAIAI	PAV015	41	82	1	3	3.56	7.35		
PAVAIAI	PAV015	41	83	1	1	2.48	7.89		
PAVAIAI	PAV015	41	84	1	3	4.06	8.58		
PAVAIAI	PAV015	45	85	1	3	5.82	6.58		
AOLOAUFO	ALF004	N/A	86	2	5	35.28	14.17	12.61	3
AOLOAUFO	ALF004	N/A	87	1	3	11.04	7.58		
AOLOAUFO	ALF004	N/A	88	1	3	5.26	6.25		

SITE	SITE#	FS#	LOT	PART	SIZE	WEIGHT	BODYTHICKNESS	RIMTHICKNESS	RIM FORM
A'ASUFOU	AAS001	N/A	89	1	3	3.96	8.94		
A'ASUFOU	AAS001	N/A	90	1	1	1.38	6.64		
PAVAIAI	PAV005	N/A	91	1	3	4.08	7.97		
PAVAIAI	PAV012	27	92	1	5	16.28	9.16		

LOT	LIPSECT	SOOT	PASTE	BINOCTEMPER	TEMPER SIZE	LA-ICP-MS group
1		10	5yr 5/4	2	1	1
2		10	2.5yr 5/8	6	3	3
3		10	5yr 7/6	4	1	4
4		10	5yr 6/6	6	3	4
5		2	5yr 7/6	6	3	4
6		10	2.5yr 5/8	0	0	3
7		2	5yr 8/4	1	3	2
8		0	2.5yr 6/8	0	0	2
9		2	7.5yr 7/8	4	2	4
10		2	5yr 4/6	2	1	4
11		1	5yr 6/6	6	3	4
12		1	5yr 6/6	6	3	4
13		10	2.5yr 5/8	6	3	3
14		10	5yr 4/6	7	1	4
15		10	7.5yr 6/8	0	0	4
16		10	5yr 5/8	3	2	4
17		10	2.5yr 4/8	6	3	3
18		0	5yr 7/4	4	1	2
19	1	10	7.5yr 7/8	7	1	4
20		0	7.5yr 6/6	6	3	4
21		0	2.5yr 3/6	5	1	1
22		0	7.5yr 8/4	6	3	2
23		10	2.5yr 6/6	1	3	2
24		0	5yr 7/8	1	3	4
25	1	10	7.5yr 8/4	0	0	2
26		10	5yr 7/6	6	3	4
27		10	5yr 8/4	1	3	2
28		10	2.5yr 6/8	1	3	2
29	2	10	7.5yr 8/6	0	0	4
30		10	5yr 8/4	6	3	2
31		10	2.5yr 6/8	1	3	2
32		10	7.5yr 8/4	3	2	2
33	1	10	5yr 6/8	1	3	4
34		10	5yr 7/6	1	3	4
35	1	10	5yr 6/8	6	3	4
36		10	7.5yr 7/6	6	3	4
37		10	5yr 7/8	6	3	4
38		0	2.5yr 5/6	0	0	3
39		10	7.5yr 8/3	1	3	2
40		0	5yr 4/4	1	3	1
41		10	2.5yr 7/8	1	3	2
42		0	5yr 2/4	5	1	1
43		10	5yr 6/8	1	3	4
44		0	5yr 7/8	6	3	4

LOT	LIPSECT	SOOT	PASTE	BINOCTEMPER	TEMPER SIZE	LA-ICP-MS group
45		10	5yr 7/8	3	2	4
46		10	7.5yr 7/4	1	3	2
47		10	5yr 7/6	6	3	4
48	1	10	5yr 7/6	1	3	4
49		10	5yr 6/8	1	3	4
50	1	0	5yr 7/6	1	3	4
51		10	5yr 7/8	6	3	4
52		10	5yr 7/6	2	1	4
53		0	5yr 5/6	3	2	4
54		0	5yr 6/6	6	3	4
55		10	5yr 7/6	6	3	4
56		10	2.5yr 6/8	1	3	2
57	2	10	2.5yr 5/8	6	3	3
58		10	2.5yr 4/8	0	0	3
59		0	7.5yr 7/6	1	3	4
60		10	5yr 6/6	1	3	4
61		10	5yr 8/4	1	3	2
62		10	7.5yr 6/6	6	3	4
63		10	5yr 6/6	6	3	4
64		10	5yr 5/8	2	1	4
65		10	5yr 6/8	1	3	4
66		10	2.5yr 3/6	0	0	1
67		10	7.5yr 8/3	1	3	2
68		0	5yr 6/6	1	3	4
69		0	7.5yr 7/6	6	3	4
70		10	7.5yr 6/8	4	2	4
71		10	5yr 6/6	1	3	4
72		10	5yr 7/6	1	3	4
73	1	10	5yr 7/8	1	3	4
74	1	10	2.5yr 5/8	1	3	3
75		10	5yr 7/6	1	3	4
76		0	5yr 7/8	6	3	4
77		0	5yr 7/8	1	3	4
78		0	7.5yr 4/6	7	1	4
79		10	5yr 7/8	1	3	4
80		0	7.5yr 7/6	1	3	4
81		10	5yr 2/3	0	0	1
82		10	5yr 6/6	1	3	4
83		10	5yr 6/8	1	3	4
84		0	5yr 6/6	1	3	4
85		10	2.5yr 4/4	5	1	3
86	1	10	5yr 6/6	1	3	4
87		10	5yr 3/6	5	1	1
88		10	7.5yr 7/6	1	3	4

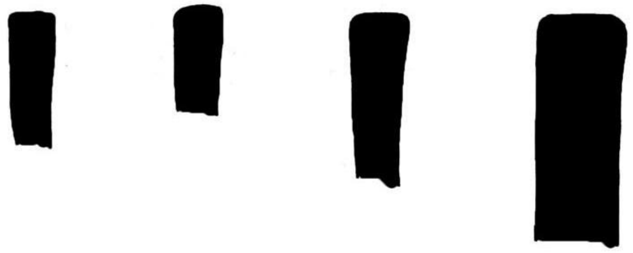
LOT	LIPSECT	SOOT	PASTE	BINOCTEMPER	TEMPER SIZE	LA-ICP-MS group
89		10	2.5yr 3/6	0	0	1
90		0	2.5yr 3/6	0	0	1
91		10	5yr 6/6	4	1	4
92		1	2.5yr 5/8	3	2	3

APPENDIX B

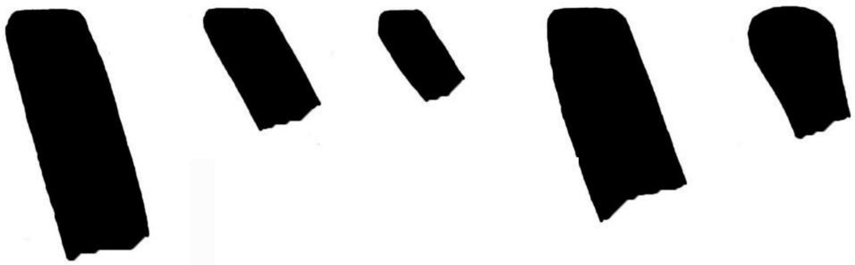
RIM FORMS

Rim Form I

Rim Form II



Rim Form III



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