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Explaining Change in Production and Distribution of Olivine-Tempered Ceramics in the Arizona Strip and Adjacent Areas in the American Southwest

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Explaining Change in Production and Distribution of Olivine-Tempered Ceramics in the Arizona Strip and Adjacent Areas in the American Southwest

A Dissertation submitted in partial satisfaction of the
requirements for the degree of Doctor of Philosophy
in Anthropology

by

Sachiko Sakai

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Professor Michael Glassow, Chair
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June 2014

The dissertation of Sachiko Sakai is approved.

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Explaining Change in Production and Distribution of Olivine-Tempered Ceramics in the Arizona Strip and Adjacent Areas in the American Southwest

by

Sachiko Sakai

Dedicated to

my husband, Tsuyoshi Sakai

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I would like to thank many other people for helping and encouraging my study of the Virgin Branch Ancestral Pueblo culture. Thanks to Dr. Daniel Larson, who first involved me in his Virgin Ancestral Puebloan ceramic study and also allowed me to use his ceramic collections for my dissertation. I greatly appreciate

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Kennett D. J., **S. Sakai**, H. Neff, R. Gossett, and D.O. Larson

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ABSTRACT

Explaining Change in Production and Distribution of Olivine-Tempered Ceramics in the Arizona Strip and Adjacent Areas in the American Southwest

by

Sachiko Sakai

The Arizona Strip and adjacent areas in Utah and Nevada are in a very marginal environment. This dissertation investigates how small-scale farmers who survived more than 1000 years in this area coped with the challenges of this marginal environment by examining how and why social interaction patterns varied over time in different parts of the region.

Artifact assemblages from this area that date between A.D. 200 and 1350 are characterized by widely distributed ceramics tempered with olivine, a volcanic mineral. Sources of olivine lie in the vicinity of Mt. Trumbull and Tuweep, near the northwestern part of the Grand Canyon. The olivine-tempered ceramics were distributed mostly westward from Mt. Trumbull, up to 100 km to the lowland Virgin area in southern Nevada.

Ultimately, the goal of this study is to understand why ceramic production and circulation patterns changed during the Ancestral Pueblo occupation of this peripheral area of the American Southwest. I hypothesize that ceramic production and regional interaction patterns were shaped in part by the need to minimize subsistence risk in this marginal agricultural environment.

To reconstruct ceramic production and consumption pattern, laser-ablation inductively couple plasma mass spectrometry (LA-ICP-MS) was conducted on 1,069 sherds from the Mt. Trumbull/Tuweep and the lowland Virgin areas, along with source clay samples collected from the same areas. To examine how the use of clay resources changed over time, optically stimulated luminescence (OSL) dating was conducted on 113 sherd samples with compositional information.

The data presented here suggest that different environmental conditions favored different social interaction and local ceramic production patterns. In Mt. Trumbull, under unstable climatic conditions and low population density, near the beginning of the Puebloan occupation, pots moved along with human migration. Later, when populations were higher and environmental conditions were equally unstable, pots were moved through interregional trade. In addition, clay resource specialization was favored early but was replaced later by exclusive use of optimal clays when population numbers were higher. In the lowland Virgin area, exchange played an important role as a risk minimization strategy throughout the Puebloan occupation, but clay-resource specialization gained importance later on, when populations increased.

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Chapter I: INTRODUCTION

Once humans became dependent on domesticated crops for subsistence, climatic conditions that affected the growth potential of those crops became crucial challenges. Too little rainfall, too much rainfall, too much variability from year to year, conditions too favorable to insect pests, and other conditions related to the climate could tip the balance between survival and starvation. As a result, agricultural populations have devised a variety of means to buffer their subsistence risk and maintain conditions favorable for their survival, and this is especially true in environments that are marginal for agriculture. Agricultural adaptations to marginal environments are found throughout the world, such as in Saharan Africa (Clark 1984), the Peruvian coastal area (Willey 1963), and the Southern Central Andes, where annual rainfall totals only 10–20 mm (Zori and Brant 2012).

Some risk-buffering strategies are inferable from the archaeological record, and their long-term developmental trajectories can be investigated archaeologically. This is the basic premise of the study presented in this dissertation, in which I examine the evolution of human adaptation to the highly variable environment of the northwestern periphery of the American Southwest during the period of Puebloan occupation roughly from A.D. 200 to 1350.

The climate in most of the American Southwest is marked by low precipitation and high temporal fluctuations. Climatic conditions are also highly variable over space. Current annual precipitation in the low desert regions is less than 200 mm, while that in the steppe/mountainous region can exceed 500 mm (Cordell 1997). Climatic variations are present even over short distances; temperature, for instance, is affected by local and regional topography in addition to elevation (Dean et al. 1994).

Dendroclimatic reconstruction suggests that the Colorado Plateau has experienced several periods over the past 2000 years during which the climate varied greatly (Dean 1988a; Dean et al. 1994). During periods of high temporal variability, rainfall amounts fluctuated substantially from one year to the next, and spatial variation in rainfall was unpredictable (Dean et al. 1994). Tree-ring data suggest that the past 2000 years have been marked by a number of droughts of variable duration, magnitude, and frequency. Two major droughts had devastating impacts on Southwestern populations: one was the modest but prolonged drought between A.D. 1130 and 1180, which caused the collapse of villages in many areas, including the major culture centers in Chaco Canyon (Kantner 2004), and the other was “The Great Drought” between A.D. 1276 and 1299, which eventually caused abandonments in many areas of the American Southwest, including the Kayenta area (Dean 2002). Dendroclimatology also shows that, in addition to these major droughts, minor droughts lasting several years were relatively common during the last 2000 years.

Two climatic zones are recognized in the American Southwest—one with a bimodal distribution of annual precipitation in the western region and the other with a summer-dominant rainfall pattern in the eastern region (Dean 1988a).

Collaborative work based on the dendroclimatic reconstruction by Dean, Funkhouse and Graybill suggests that the boundary of the zone shifted through time and occasionally broke down (Dean 1996). Winter precipitation is crucial for maize agriculture in the Southwest, especially in the more elevated areas (Dean 1988a). Thus, a sudden change in the location of the boundary between bimodal and summer-dominant rainfall would have had a severe negative impact on maize agriculture in areas affected by the shift.

Low precipitation and unpredictable climatic conditions made dry farming in the American Southwest extremely challenging. Maize requires a minimum of 150–250 mm in annual precipitation (Kantner 2004). Although high-elevation areas may have enough annual precipitation for maize agriculture, farming was still risky. This is because summer afternoon rainwater evaporates quickly due to high temperatures. Moreover, intense thunderstorms can often destroy agricultural crops. In addition, temperatures in the highland area are low during the winter, so many highland areas are very close to the limit of maize agriculture, which requires a minimum of 120 frost-free days (Cordell 1997). Despite these challenging environments, Puebloan people survived for approximately 1300 years in the American Southwest with a subsistence system based at least partially on agriculture. In this dissertation, I would like to explore some of the means by which these small-scale farmers managed the risks and adapted to this marginal environment.

A number of researchers have developed models to explain how humans cope with risk in marginal environments. Risk is generally defined as an “unpredictable variation in some ecological or economical variable (e.g., variation in rainfall, agricultural production, hunting return)," and an outcome is viewed as riskier if it has a greater variance (Cashdan 1990). Risk can be caused by year-to-year variability, including environmental fluctuations and human-resource interactions (Winterhalder et al. 1988). Several tactics that promote subsistence stability may reduce the risks associated with agriculture (Larson et al. 1996). These include (1) changing resource production techniques (Hegmon 1991); (2) increasing storage of resources (Leonard 1989); (3) exchanges (e.g., Braun and Plog 1982; Glassow 1980; Jochim 1981); (3) pooling harvests within exchange networks (Boone 1992); (4) warfare to protect territories (Smith 1988); (5) community aggregation (Leonard and Reed 1993), and (6) reciprocity.

These tactics to reduce risks can also be observed among modern small-scale farmers. Ethnographic studies among the Basarwa of Northern Botswana suggest that reciprocity buffers fluctuations in food production among small-scale farmers (Cashdan 1985). Cashdan suggests sharing and gifting as the simplest forms of reciprocity acting as insurance to reduce risk. A risk is shared by a number of different individuals who participate in the reciprocity networks, and therefore each is protected from the chance of a catastrophic loss. In return for this protection, individuals incur obligations to help when someone else is in need. Generalized reciprocity refers to a situation in which those who have an abundant supply give to those who encounter a deficit. Reciprocity protects individuals from losses but prohibits accumulating a surplus. In this sense, reciprocity conflicts with storage, which is another method of risk reduction.

Cashdan (1985) discusses when and under what conditions reciprocity is favored over other risk reduction strategies, such as storage. The costs and benefits of various risk reduction strategies need to be considered to decide the most economical choice. The costs are determined by the nature of the risk, which might be an environmental factor such as climate, and are determined by mobility and geographical distance within the network. For example, reciprocity among sedentary populations is considered to have a high cost because of increased transportation costs.

Choices among risk management strategies also depend on the interaction of environmental, demographic, and behavioral variables that define the adaptive system at any point in time (Cordell and Plog 1979; Dean 1988a; Dean et al. 1985). Patterned behavior is a response mechanism that populations employ to adapt to environmental and demographic change (Dean 1988b). Thus, both population level and environmental factors need to be considered to understand which risk minimization strategy would be favored over others in a particular place and time. Based on dendroclimatic reconstruction, Dean et al. (1994) point out two aspects of high environmental variability (temporal and spatial) that favor different risk management strategies. During a period of high temporal climatic variability, accumulation of food storage to offset production failure is favored. During a period of high spatial climatic variability, which results in interlocality production differentials, interareal exchanges or plunder are more likely strategies for leveling out production differentials. Spielmann et al. (2011) suggest that small-scale farmers developed two types of strategies to cope with stress: short-term strategies that include storage and community-scale sharing and long-term strategies such as migration.

As discussed above, although a number of strategies can help minimize subsistence risk, I will focus here on those that involve social interaction. Numerous previous studies suggest that long-distance networking minimizes subsistence risks (Braun and Plog 1982) and that social interaction was a vital risk-buffering strategy for agriculturalists coping with variable environmental conditions of the American Southwest (Rautman 1993). Social interaction can take the form of population mobility, exchanges, and aggregation, and all of these may leave an imprint on ceramic compositional and formal diversity, the precise patterning of form on composition depending on the nature of risk-buffering strategies adopted at a particular time and place (Neff et al. 1997).

For example, in situations with low population densities, mobility is a viable adaptive strategy to cope with resource variability. This can be expressed as a high degree of compositional diversity in ceramics, as shown by Eerkens et al. (2002) in a study of brown wares from Death Valley. Even for agriculturalists, seasonal exploitation of wild resources of uplands and lowlands may supplement agricultural production in order to increase subsistence yields (e.g., Fairley 1989 for the Pueblo I period). A study undertaken in Black Mesa indicates that storage and mobility may have been combined to cope with risk during Basketmaker period (Wills and Huckell 1994). Although people moved frequently, they had a geographically fixed location where resources were stored (Graham and Roberts 1986).

With an increasing population, mobility becomes restricted, and instead sedentary residences with exchanges become a more viable adaptive strategy. In addition to the constraints on mobility, larger populations may also lead to agricultural intensification, thus reducing the time available for other non-agricultural activities. At the same time, however, a heavy dependence on agriculture was risky in this unstable environment, so exchanges to buffer the agricultural risk were required. Exchanges among small agricultural groups under conditions of high population can buffer risk in several ways: (1) by compensating for resource imbalances; (2) by reducing production cost (e.g., exporting excess production to exchange for goods not available locally); and (3) by maintaining social ties that allow people to ask for help from each other in case of agricultural failures.

Several studies demonstrate how ceramic compositional data can provide insights into exchanges that could have buffered agricultural risk in the American Southwest. In Chaco Canyon, a large number of ceramics were imported from multiple production areas from A.D. 900 to 1150, when the population density of the San Juan Basin probably reached its peak (Neitzel et al. 2002). Compositional data also suggest that San Juan Red Ware was distributed widely from specialized production centers in southeast Utah (Hegmon et al. 1997). Neff et al. (1997)

proposed two models of exchange: one is exchanges with local specialization under stable environmental conditions and the other is exchanges without local specialization under unstable environmental conditions (e.g., gift-exchange). They found that the patterning of compositional groups on formal characteristics in an assemblage from Pottery Knoll, southern Utah, conformed to the expectations of the latter situation.

When a population reaches even higher levels, village aggregation may emerge as a viable adaptive strategy. For instance, ceramic compositional data from 14th century sites in the Silver Creek area of the southern Colorado Plateau suggest that at aggregated villages White Mountain Red Ware was produced with local materials but with non-local decorations presumably favored by the various aggregating immigrant populations (Triadan 2002).

Adaptation to Marginal Environment in the Arizona Strip and Adjacent Areas

The study area for investigating these ideas includes the Arizona Strip, located at the far northwestern corner of Arizona and defined as the lands north of the Colorado River to the Utah border (Figure 1.1). Part of the study area is also within Nevada directly west of the Arizona Strip. The population of this region depended on small-scale agriculture for at least part of their subsistence between A.D. 200 and 1350. Archaeologists call the culture of this population the Virgin Branch Ancestral Pueblo and consider it as a regional branch of Ancestral Pueblo culture. The Virgin Branch Ancestral Pueblo tradition includes the Arizona Strip and

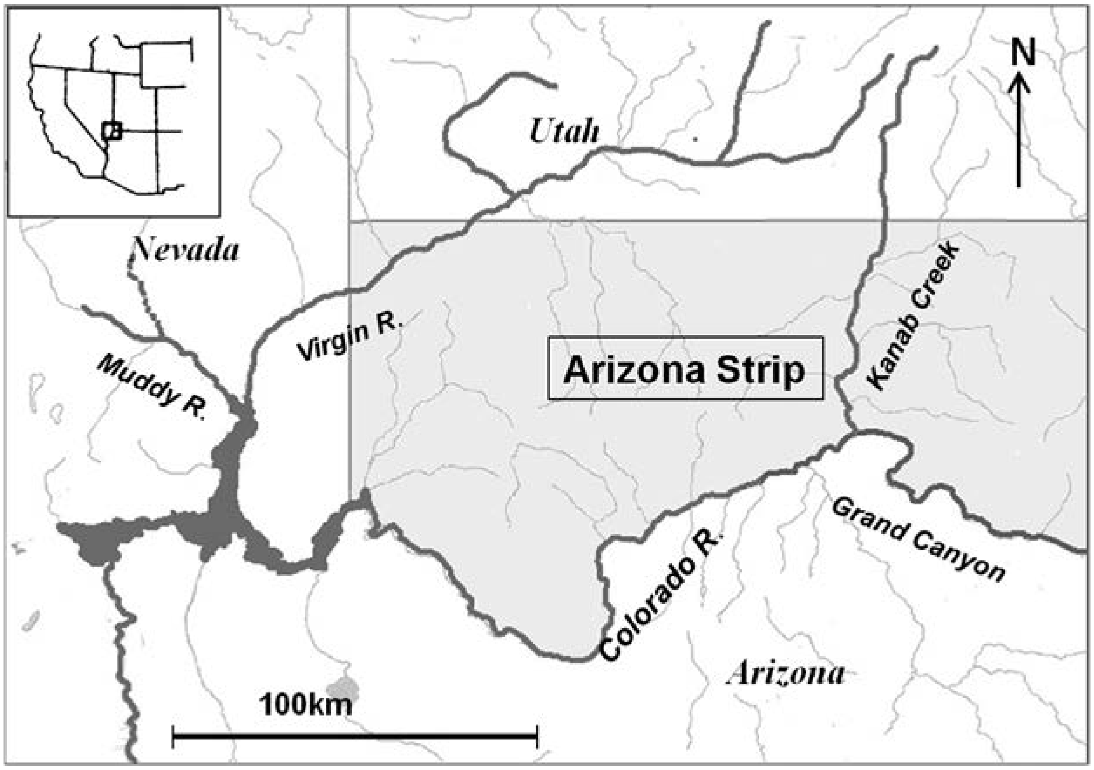


Figure 1.1. Map of the western section of the Arizona Strip.

the Virgin and Muddy river drainages of southern Nevada and southwestern Utah. Like other parts of the Colorado Plateau, the Arizona Strip and adjacent areas in Utah and Nevada are very marginal environments, due to extremely arid and fluctuating climatic conditions. Spatial variation is also pronounced, with environmental conditions varying markedly over short distances. Based on physiographic characteristics, the Arizona Strip and adjacent areas are divided into three ecological zones: the Plateaus, the lowland Virgin area in southern Nevada, and the St. George Basin (Figure 1.2). This study focuses on two of these areas: Mt. Trumbull and Tuweep in the Plateaus area and the lowland Virgin area. Because

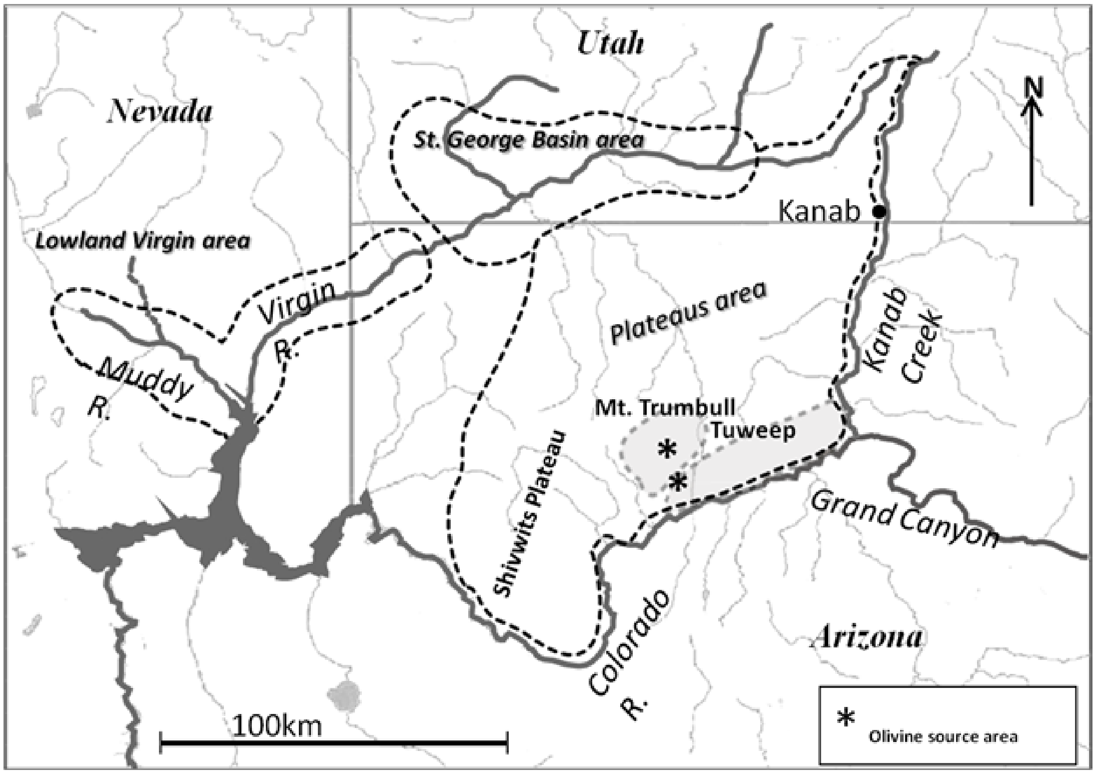


Figure 1.2. Map of the study area.

these two areas differ significantly, they provide comparative case studies of how adaptive responses to climatic fluctuation vary between different environments.

Mt. Trumbull is located on the Uinkaret Plateau at the western edge of the Colorado Plateau in Northern Arizona, 1,800 to 2,400 m above sea level (Moffitt and Chang 1975). The climatic conditions are typical of the plateau desert, with cool summers and a bimodal precipitation regime characterized by summer monsoon rains and winter snows. Current average annual precipitation is between 250 and 380 mm. Geologically, Mt. Trumbull is marked by past volcanic activities that left behind basaltic lava and cinder cones. The Mt. Trumbull locality represents one of the places most intensively occupied by prehistoric populations in the Plateaus area.

Although settlement patterns are not fully understood, one of the reasons why this locality attracted past population may be the winter snows and coarse texture of surface soil containing cinders (Buck et al. 2012), which could have facilitated the percolation of melting snow immediately before evaporative loss, while retaining subsurface moisture that would have helped the germination of maize in early spring, when most of the area experienced a lack of precipitation. Despite this favorable potential for agriculture, the dry farming of maize was still risky here, due to the absence of permanent streams, limited frost-free days due to the high elevation, and marked variability in rainfall already discussed.

The lowland Virgin area is a valley drained by two rivers, the Muddy River and the Virgin River (Larson and Michaelsen 1990). The topographic features are typical of the Great Basin, where steep, rugged mountains rise abruptly from flat basin floors (Hunt 1967) in sedimentary rock formations. The sites are located about 450 m above sea level, much lower than sites in the Plateaus area. The climatic conditions are characteristic of a desert environment—long, hot summers and short, mild winters. Precipitation is very limited, at approximately 100 mm annually (Larson 1987; Larson and Michaelsen 1990). Although most habitation sites are found adjacent to the two permanent rivers, farming in this extremely arid climate is very risky.

The early agricultural evidence in the Arizona strip area dates to as early as A.D. 1. Although one point of view holds that the Virgin Branch Ancestral Puebloan people depended heavily on agriculture in southern Utah (Martin 1996), most agree that populations in this study area practiced a mixed subsistence economy, combining agriculture with wild resource procurement (Moffit and Change 1978; Lyneis 1992). Most agree also that agricultural intensification occurred in later Puebloan times (Larson 1996; Larson and Michaelsen 1990; Larson et al. 1996). The population started to increase about A.D. 800, with a peak around A.D. 1150 (Larson and Michaelson 1990). Abandonment occurred in the Arizona Strip and adjacent areas sometime between A.D. 1150 and 1350. The relative population reconstruction in Tuweep in the Plateaus area suggests that lower-elevation sites were abandoned earlier than higher-elevation sites, even within small areas (Sakai 2001).

Research Problems

In this study, my aim is to investigate how populations coped with the challenges of the marginal environment of the Arizona Strip and adjacent areas by examining how and why social interaction patterns varied over time in different parts of the region. Several forms of social interactions may have been used as risk reduction, including mobility, exchanges with local specialization, exchanges without local specialization (e.g., gift exchange), and population aggregation. My strategy will be to examine the modes of social interaction that appear in different times and places in Mt. Trumbull and the lowland Virgin area. I assume that social interaction patterns would have responded to both environmental and demographic variability. Under stable environmental conditions, people would have experienced stability in agricultural production and therefore would not have worried about risk, and under conditions of predictable productivity they would have favored exchanges with local specialization (e.g., of pottery) to reduce costs. Under unstable conditions, which were more likely the case in this study area, mobility or exchanges without local specialization would have been favored to cope with risk. When population density was low in this unstable environment, mobility would have been favored over exchanges to manage the risk. With higher population density, on the other hand, mobility would have been less favored because the rising population density in the surrounding area would limit population movement. Instead, regional exchanges without specialization would have been favored to reduce agricultural risk, such as gift-exchanges to maintain social ties in case of agricultural failures in the future.

Ceramics in the Arizona Strip and adjacent areas in Utah and Nevada include widely distributed ceramics tempered with olivine, a volcanic mineral. The source of this olivine is thought to be at Mt. Trumbull and Tuweep, near the northwest rim of the Grand Canyon. The ceramic assemblages in Mt. Trumbull and Tuweep are dominated by olivine-tempered sherds, which make up more than 80 percent of both assemblages. Olivine was used for ceramic temper in these areas for at least two potential reasons. First, olivine is more accessible than quartz sand because there is no permanent streams in this area where quartz sand would be formed (the Colorado River is too difficult to access). Second, olivine is likely to be a better tempering material than quartz or calcite. Due to its stable thermal properties and much lower thermal expansion rate than quartz, which are closer to those of clay fabric, adding olivine can avoid thermal stress during the production and consumption of pots, which minimizes production failure and breakage. Olivine-tempered ceramics are distributed westward from these olivine source areas over a radius of more than 100 km, including the lowland Virgin area.

The wide distribution of olivine-tempered ceramics has stimulated earlier investigations of interregional exchanges in the Arizona Strip and adjacent areas. Lyneis (2000) regards the presence of olivine ceramics in the lowland Virgin area to be an indicator of economic and social ties between the Plateau area and the lowland Virgin populations. Allison (2000) argues that the lack of wood for fuel in the lowland Virgin area is the driving force behind the import of olivine-tempered pots from the Plateau. Left unanswered by these interpretations is whether the olivine-tempered pots were transported as a result of exchanges between sedentary communities or carried along with population movements. Under low population density, I would expect that olivine-tempered pots were carried along by the groups of people moving between different environmental situations. Under higher population densities, I would expect olivine-tempered pots to have been transported as a result of exchanges. Although temper does not travel over long distances generally (Arnold 1985), I also consider the possibility that olivine itself may have been transported from Mt. Trumbull to the lowland Virgin area. Thus, the focus of my research is on how human migrations and exchanges, as observed in olivine-tempered ceramics, fit into the broader adaptive strategies of populations inhabiting the marginal environments of the Arizona Strip and adjacent areas. For instance, does the relative importance of exchanges and mobility change according to population levels and climatic variability either over time or across space? Another concern is whether ceramic production patterns may have changed in response to the need for agricultural intensification in order to feed a growing population.

In order to use olivine-tempered ceramics as evidence for interaction patterns that may have buffered subsistence risk, ceramic production and consumption patterns have to be reconstructed, and the trajectory of changes over time in production and consumption have to be described. Reconstruction of production and consumption patterns requires the investigation of formal and compositional diversity in ceramics. Formal variation arises from choices made during ceramic production (forming, finishing, and decorating) together with consumption practices. Meanwhile, compositional variations, which may be defined as the mineralogy and chemistry of the ceramic paste, arise from choices made during raw material procurement and paste preparation together with consumption practices (Neff 1992, 1995; Neff et al. 1997; Neff and Larson 1997). In Neff's discussion (1992; Neff et al. 1997), ceramic artifacts are directly observable parts of phenotypes of past individuals and phenotypic variations are structured over time due to the effects of the differential persistence of inherited information caused by selection, chance, and linkage of neutral traits with other traits controlled by selection (see also Dunnell 1980). In this sense, compositional data and the patterning in the relationship between compositional and formal variations record the evolutionary history of ceramic production practices as they are shaped by selective forces originating in the natural and social environments (Neff 1992).

In this study, I propose models to explain how environmental instability affected social interaction in coping with risk based on two different levels of selection by using examples of the production and circulation of olivine-tempered ceramics. One level of selection acts on economic interaction and the other acts on local ceramic production. Based on the models proposed by Neff et al. (1997), I will test two models of how selection acted on economic interaction to shape the circulation of olivine-tempered ceramics. Under a stable environment, where locations have predictable comparative advantages from year to year, local specialization should be favored, and exchanges would then move goods from where they are relatively cheap to where they are relatively dear. Potters in different areas would have exploited distinct raw materials and specialized in different shapes or decorations. In this situation, a strong correlation between compositional groups and formal attributes would be expected.

However, since the environment in the Arizona Strip is unstable, local specialization would be a risky strategy because agricultural producers, ceramic craft specialists, and other specialists would face unpredictable returns from year to year. With specialization selected against, ceramics might still circulate, but the value of circulation in this case would lie in the population’s ability to maintain social networks, which would mitigate unpredictable imbalances in agricultural productivity. In this model, olivine-tempered pots would have been moved as a byproduct of human mobility or through gift-giving to maintain social networks. Archaeologically, weak or no association between form and composition would be expected (i.e., similar formal attributes should be found in multiple compositional groups).

The other level of selection would have acted on local ceramic production to explain ceramic compositional and formal diversity. I consider models of how the properties of local raw materials might have been selected for different patterns of production and circulation of olivine-tempered ceramics. Clay-resource specialization can be defined as the use of different clays with different performance properties for pots intended for different purposes. Clay-resource specialization would reduce the total cost of local ceramic production to the extent that the use of optimal clays improves vessel performance and reduces vessel-replacement costs. Archaeologically, it is expected that all compositional groups of olivine-tempered ceramics would match local clays in the Mt. Trumbull/Tuweep areas and that there should be a strong correlation between compositional groups and formal attributes. Additionally, some compositional groups may consist of only utilitarian wares found in Mt. Trumbull, while some groups may consist of only non-utilitarian wares found predominantly outside the Mt. Trumbull and Tuweep areas, which would have been exchanged as trade items.

Data Produced in this Study

As discussed above, I am concerned with how and why clay resource procurement patterns for olivine-tempered ceramics changed over time, the larger goal being to understand how human migrations or exchanges fit into the broader adaptive strategy by which Puebloan people of the Arizona Strip coped with a marginal environment. Since ceramic compositional data record the historical trajectory of pottery production and circulation, I want to determine how and why ceramic production and consumption patterns observed in the chemical composition of olivine-tempered ceramic paste changed over time in order to examine the role of interaction as a buffering strategy and how this role changed over time. In order to understand particular types of social interaction as adaptive strategies to cope with risk, I would like to answer the following questions concerning the movements of olivine-tempered ceramics between localities within the study area: (1) Did olivine-tempered pots circulate as a result of human migrations under unstable environmental conditions when population density was low? (2) Did olivine-tempered pots circulate through exchanges without specialization when environmental conditions were unstable and population density was higher? (3) Did olivine-tempered pots circulate through exchanges with specialization when environmental conditions were stable?

The compositional data used here include that analyzed by instrumental neutron activation analysis (INAA) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). INAA is a bulk analysis (entailing homogenization of all materials) that has been the most popular technique for chemical compositional analysis in archaeology for more than 40 years. ICP-MS is a relatively new technique for material characterization in archaeology. Combined with laser ablation, ICP-MS can analyze individual components of heterogeneous materials, which allows analysis of the clay matrix and inclusions separately. In this study, I analyzed 1,069 sherds from Mt. Trumbull/Tuweep and the lowland Virgin area using LA-ICP-MS. Of the 1,069 specimen sample, 50 olivine-tempered ceramics from Mt. Trumbull were also analyzed by INAA, as a check on the compositional groups found in the LA-ICP-MS data set.

To add a temporal dimension to the evidence of clay resource use, I also dated a large sample of sherds included in the compositional study by Optically Stimulated Luminescence (OSL) dating. OSL dating is a direct ceramic dating technique and use of OSL to date potsherds is a relatively new application in archaeology. OSL dating was conducted on 113 sherds for which compositional information was also available. Combining chemical compositional analysis for source determination with direct ceramic dating by OSL provides a chronologically resolved picture of change in ceramic production and distribution patterns.

In the following chapters, I develop various themes touched on above. In Chapter II, I present detailed information, including environmental and cultural backgrounds. This chapter also includes a summary of ceramic provenance (i.e., source) studies in the American Southwest, ceramic dating, and the study of olivine-tempered ceramics. Chapter III provides a detailed discussion of the theoretical background and research questions followed by a series of hypotheses to be tested. Chapter IV provides details of data collection, including the fieldwork and description of the archaeological sites where the sherd samples were collected. Chapter V provides a discussion of the methods used and consists of two parts, compositional analysis and OSL dating. Each section describes the methods, the process used to obtain the results, and the descriptive results. Chapter VI is a discussion about the analytical results with interpretations of the data. Finally, Chapter VII considers the compositional and luminescence dating results as they relate to the hypotheses advanced in Chapter III.

CHAPTER II: BACKGROUND TO STUDY

Geography and Natural Environment

The Arizona Strip encompasses five million acres in the far northwestern corner of Arizona, including lands north of the Colorado River to the Utah border (Figure 1.1). The Arizona Strip and adjacent areas in southern Utah and southern Nevada, which have multiple ecozones based on geography, are the focus of this study (Figure 1.2). Lyneis (1995, 1996) divided this region into three areas: the lowland Virgin area in southern Nevada, the St. George Basin, and the Plateaus. In the present study, I will examine these three areas, placing special emphasis on three localities within the Plateaus area: Mt. Trumbull, Tuweep, and the Shivwits Plateau.

The Plateaus Area

The Plateaus area is located at the western edge of the Colorado Plateau. Most archaeological sites have been identified in the southern part of the Plateaus area, which includes three localities: Mt. Trumbull, Tuweep, and the Shivwits Plateau. Considerably fewer sites have been recognized in the northern part of the Plateaus area, which is covered with grasslands. The Plateaus area features a bimodal pattern of precipitation, with summer monsoon rains and winter snows (Lyneis 1995; Moffitt and Chang 1975). As compared with the lowland Virgin area, fewer archaeological studies have focused on the Plateaus area.

The Mt. Trumbull locality (also simply stated as “Mt. Trumbull” in this dissertation) is located on the Uinkaret Plateau in Northern Arizona, and its elevation is 1,800 to 2,400 m above sea level (Moffitt and Chang 1975). The locality falls under the jurisdiction of the Grand Canyon-Parashant National Monument. The climatic conditions are typical of the plateau desert and are characterized by cool summers with monsoon rains and winter snows, with the current annual precipitation averaging between 25 and 38 cm. There are no permanent streams in Mt. Trumbull, but several year-round springs may have supported prehistoric populations.

Geologically, Mt. Trumbull is marked by past volcanic activity that left behind lava, basalt, and cinder cones, and small areas in the region have exposed sedimentary rocks. The basalt flows and cinder cones in Mt. Trumbull are the source of olivine for tempering pottery. Vegetation in this area includes juniper-piñon woodland, sagebrush, and ponderosa pine (Moffitt and Chang 1975). The Mt. Trumbull locality represents one of the places most intensively occupied by prehistoric populations in the Plateaus area, with more than 300 sites recorded since the 1970s within a five-km radius of Mt. Trumbull. Most of these sites, however, are too poorly described to help in understanding the site structure, size, affiliation, or chronology (Buck et al. 2004). The site types include crescent-shaped pueblos ranging in size from 4 to 20 clusters of rooms, pit house depressions, storage cists, and numerous artifact scatters.

Tuweep is located in the northwestern part of the Grand Canyon National Park within the Plateaus area and is between 1,350 and 2,000 m above sea level.

Multiple ecozones are found at different elevations within Tuweep. The locality includes two prehistoric permanent habitation areas: (1) the Pine Mountains, at 1,524 to 1,980 m above sea level, which are characterized by volcanic formations where olivine is found, and (2) the Kanab Plateau at 1,680 to 1,830 meters above sea level, which is underlain by sedimentary bedrock. The climatic conditions in the low-elevation areas in Tuweep are characterized by hot summers and relatively mild winters, with average annual precipitation of slightly more than 28 cm (Thompson 1970). The vegetation communities include juniper-piñon pygmy forest, scrub oak, yucca, and Mormon tea, with big sage dominant along the bottoms of the washes (Thompson 1971).

The Shivwits Plateau is located between the Uinkaret Plateau and the lowland Virgin River area, with an elevation that is slightly lower than the Uinkaret Plateau. Geologically, the southern part of the plateau consists primarily of ancient basalt flows (Allison 2000), though large sedimentary formations are also present. This locality is argued to be the possible production area of Shivwits ware, which has crushed sherd temper embedded with olivine inclusions (Jensen 2002). Shivwits ware is also found in the lowland Virgin area and in Mt. Trumbull.

Lowland Virgin Area

The lowland Virgin area, a lowland valley, is drained by two rivers: the Muddy River and the Virgin River (Larson and Michaelsen 1990). The topographic features are typical of the Great Basin, where steep, rugged mountains rise abruptly from flat basin floors (Hunt 1967). The sites are located about 450 m above sea level. The climatic conditions are characteristic of a desert environment, with hot, long summers and short, mild winters. Precipitation is only 10 cm annually (Larson 1987; Larson and Michaelsen1990). Vegetation in the lowland Virgin area includes edible plants such as mesquite, cat claw, screw bean, seep willow, sedges, rushes, cattails, and abundant grasses. The riparian environment attracts migratory waterfowl, rabbits, bobcats, and numerous rodents and reptiles. Mule deer and bighorn sheep also reside in this community (Larson and Michaelsen 1990). Geologically, this locality is composed of sedimentary rock formations, so there is no olivine source in this area.

St. George Basin Area

The St. George Basin is intermediate in elevation between the Plateaus and the lowland Virgin area, with an annual rainfall of about 21 cm and more than 200 days in the growing season (Lyneis 1995). Many archaeological sites were recorded during cultural resource management projects in the 1980s. Only a small percentage (less than one percent on average of all ceramics in this area) of olivine-tempered ceramics have been found in the ceramic assemblages in this area.

Previous Research in This Study Area

The cultural manifestations in this study area during the Formative Period are traditionally called the Virgin Branch Anasazi. Recently, however, archaeologists have more often used the term Ancestral Pueblo to refer to the Anasazi. Studies of the Virgin Branch Ancestral Pueblo have been carried out since the late 1920s, and Harrington (1927) was the first to publish a study undertaken in the lowland Virgin area. Synthesizing Harrington's (1927) work, Shutler (1961) defined four phases of Virgin Branch Ancestral Pueblo prehistory: Moapa, Muddy River, Lost City, and Mesa House Phases. During the 1960s, survey work increased, including Schroeder's (1955, 1961) Zion National Park and Willow Beach surveys, Rudy's survey in Southern Utah (Rudy and Stirland 1950), and Gunnerson's (1960) work in the St. George area. In the 1960s, Aikens developed a reconstruction of changes over time in subsistence, demography, and social organization among the Virgin Branch Ancestral Pueblo (Aikens 1965; Fowler and Aikens 1963). Aikens's work (1966) also contributed to understanding the Virgin-Kayenta cultural relationships. The first typology of ceramics in the Virgin Branch Ancestral Pueblo was developed by Harold Colton (1952) and later modified and updated by Thompson (unpublished), Dalley and McFadden (1985), Lyneis et al. (1989), and Lyneis (1992, 1999, 2008).

In the 1970s, site-specific investigations were undertaken by various institutions, including the Muddy River survey by the University of Nevada, Las Vegas (UNLV), the Tuweep survey by Richard Thompson of Southern Utah University (formerly named Southern Utah State Collage), and the Mt. Trumbull survey by Moffitt and Chang (1978) of the Museum of Northern Arizona. The Tuweep and Mt. Trumbull surveys are the only large-scale archaeological investigations in the Plateaus area until recently. UNLV field schools excavated various sites in the Muddy River valley within the lowland Virgin area in the 1980s (Lyneis et al. 1989). Buck and Sakai recently conducted the first systematic archaeological investigation in Mt. Trumbull through a field school sponsored by the Nevada State College and the Desert Research Institute (DRI) between 2001 and 2008 (Buck 2002, 2005, 2006, 2007, 2008, 2009; Buck et al. 2004; Buck and Sakai 2005), as well as by California State University, Long Beach, between 2010 and 2012 (Sakai 2011, 2012, 2013). MacFadden (2010a, 2010b) also conducted systematic surveys in the Little Spring and Potato Valley areas of Mt. Trumbull.

Since the 1980s, issue-oriented research has been conducted. Larson (1987) and Larson and Michaelsen (1990) investigated the role of climatic change and population pressure in the abandonment of the lowland Virgin area, and Lyneis (1992) identified a system of pottery production and distribution in this area. Allison (2000) examined craft specialization and exchange in small-scale societies through the investigation of ceramic distribution patterns, and Jensen (2002) examined the production area of Shivwits ware.

Cultural History and Chronology

The focus of this study is a time period characterized by a small agricultural population, the Virgin Branch Ancestral Pueblo. However, I will start with a review of the time period after the population started living in this location, even before agriculture began to be practiced, in order to understand how earlier populations coped with this marginal environment without agriculture. Also, I will review the time period after the Ancestral Pueblo left in this area. I used for this study luminescence dating to determine when the pots were last fired, although the dates determined by the luminescence technique may or may not be the time of pottery use by the Ancestral Pueblo (e.g., reuse of the pots by later occupants resulting in anomalously later dates).

Paleoindian/Archaic Period

As discussed above, the focus of my dissertation is ceramic production, which started during the Formative Period, so only a brief summary of the period prior to the Formative Period is included here. The Paleoindian Period began approximately 9500 BC on the Colorado Plateau (Fairley 1989), and Paleoindian finds are isolated and rare in the Arizona Strip. Although Clovis Points and other Paleoindian artifacts from the Mohave/Great Basin tradition have been reported (Fairley 1989), their presence may best be explained by curation and introduction by later mobile Archaic groups, particularly the Southern Paiute, who appear to have maintained connections with the Great Basin to the north and west (as evidenced by occasional obsidian flakes and early projectile point fragments [McFadden 2010a, 2010b]). The projectile points from the Archaic Period (7000 BC to roughly 300 BC) are also reported for the Arizona Strip; however, the number of Archaic finds is much lower than the artifacts found in Formative sites. The population levels of foragers during the Archaic Period presumably were much lower than those during the Formative Period, when dependence on agriculture increased.

Formative Period

In the study area, Ancestral Pueblo or Anasazi is commonly used to designate the Formative Period. The regional branches of Ancestral Pueblo culture are divided based on variations in ceramics and architecture (Fairley 1989). The olivine-tempered ceramics of the Virgin Branch Ancestral Pueblo culture compose one artifact type that is recognized as widely distributed in this area. The Virgin branch tradition includes the Virgin and Muddy river drainages of southern Nevada, southwestern Utah, and the Arizona Strip. Olivine-tempered ceramics are widely distributed in the Arizona Strip and adjacent areas.

There are two ways to divide the Virgin Branch Ancestral Pueblo temporal sequence of the Formative Period. One was proposed by Shutler (1961) for the Moapa Valley in the lowland Virgin area, and the other is a chronology based on the Pecos Classification. In this study, I employ the chronology proposed by Fairley (1989) based on the Pecos Classification with the modification of terminal dates of the Pueblo III Period. The dates for the Pecos Classification are based on well-dated ceramic types using radiocarbon dating or dendrochronology. However, no Virgin Branch ceramic types have been dated in this manner. The Virgin Branch Ancestral Pueblo ceramic types have been traditionally dated by reference to those of the Kayenta Ancestral Pueblo region, which is east of the Virgin Branch region (ceramic cross-dating) (Allison 2000), because the temporal trends and styles in the Kayenta Ancestral Pueblo ceramics are similar to those in the Virgin Branch Ancestral Pueblo. Moreover, the Kayenta Ancestral Pueblo ceramic types are well-dated using radiocarbon dating and dendrochronology. The application of ceramic cross-dating is considered the “most viable alternative” for dating Virgin Branch Ancestral Pueblo sites (Allison 2000) because no ceramic types found at these sites are well dated. However, the assumption that ceramic change is contemporaneous across a large area could be questioned, and similarities of style are sometimes exaggerated (Allison 2000). Therefore, true chronometric dating of Virgin Branch Ancestral Pueblo ceramic types is required to establish a better chronology. The application of luminescence dating of Virgin ceramics, undertaken as part of this study, will contribute to the development of a better chronological sequence of Virgin Branch Ancestral Pueblo ceramics. In the following section, the chronology proposed by Fairley (1989) is summarized. Note that I have modified the terminal date of Pueblo III Period.

Basketmaker II Period ca. 300 BC–A.D. 400

This period is characterized by the extensive use of baskets, sandals, rabbit fur blankets, human hair cordage, fiber and hide bags, dart foreshafts, atlatls, snares, nets, and other items commonly used by hunter-gathers (Fairley 1989). No ceramics were used during the Basketmaker II Period. The bow and arrow had not yet been introduced, so dart-sized points are common at Basketmaker II sites. During this period, the population consisted of highly mobile hunter-gatherers, but small-scale cultivation of corn and squash are recognized in the archaeological record. The earliest corn in the Arizona Strip dates prior to A.D. 1 (Fairley 1989). Slab-lined cists, basin milling stones and one-hand manos, and Gypsum and Elko-like side-and-corner-notched projectile points are common in the Basketmaker II sites.

Basketmaker III Period ca. A.D. 400–800

The Basketmaker III Period is characterized by the introduction of the bow and arrow as well as the production of ceramics. During this time, two-hand manos and trough metates also came into use. The atlatl and spear were replaced by the bow and arrow, so small projectile points started to dominate the point types. There are several arguments regarding the function of the earliest ceramics in the American Southwest. One argument is that large ceramic vessels were used as an alternative to cists in dry caves for storing seeds and perishable items. Another is that ceramic vessels replaced baskets for storing water and cooking (Fairley 1989).

The timing of the beginning of the Basketmaker III Period, which marks the start of pottery production, is controversial. The excavation of the Little Jug site in the Tuweep area, south of Mt. Trumbull, where early ceramic artifacts were found, supports dates before A.D. 400 (Thompson and Thompson 1974, 1978). The six radiocarbon dates from this site range between 1,850 ± 90 rcy B.P. and 1,630 ± 90 rcy B.P. The radiocarbon dates for two other Basketmaker III sites in the Arizona Strip also indicated occupation during the fourth century, suggesting that ceramic production may have begun prior to A.D. 400 (Fairley 1989). Gaining more information on the date for the beginning of ceramic production through the use of luminescence dating is one potential outcome from this dissertation. Utilizing information on luminescence dating from various locations and contexts will contribute to a better understanding of the introduction of pottery production in the study area. Early ceramics include gray ware and a limited amount of black-on-gray ware. In a typical Basketmaker III ceramics assemblage, decorated sherds are less than about 5 percent of the total number (Fairley 1989).

Fairley listed Lino Gray, Boulder Gray, and North Creek Gray Ware as Basketmaker III plain gray ware types. The early gray ware tends to have a dark core color. Dalley and McFadden (1985) reported that early gray ware has "earthy colors" that suggest a poorly controlled or predominately an oxidizing atmosphere for ceramic firing. Schroeder (1955) also recognized that the early Moapa Ware with olivine temper has a darker core.

During the Basketmaker III Period, both wild resources and agricultural products were utilized. The dependence on agriculture increased toward the end of Basketmaker III Period (Fairley 1989). Pithouses were still the dominant habitation form, and small pithouse clusters were often found with storage cists during this period (Fairley 1989).

Pueblo I Period ca. A.D. 800–1000

The Pueblo I Period is characterized by the development of small masonry pueblo units with a few rooms associated with pithouses. The architecture during this period shows considerable diversity (Fairley 1989). The pit structures continued to be used for habitation (Lyneis 1995), and the pithouses were often associated with contiguous storage rooms. The typical pithouses during this time had round, benched, and slab-lined walls with deep slab-lined storage cists arranged in a contiguous arc-shaped pattern (Fairley 1989; Dalley and McFadden 1985). The dependence on agriculture increased during the Pueblo I Period. Despite the lack of archaeological evidence, it is proposed that seasonal use of both uplands and lowlands for acquiring wild resources and for agriculture was practiced in order to increase productivity (Fairley 1989).

Although technological improvements in pottery and lithic production are recognized between the Basketmaker III and Pueblo I periods, many ceramic and projectile point types are common during both periods. This makes it difficult to distinguish Pueblo I sites from Basketmaker III sites on the Arizona Strip (Fairley 1989). Decorated pots became more common during the Pueblo I Period and are often decorated in a style similar to the Kana-a style of the Kayanta Ancestral Pueblo, with “narrow lines and solids with appended ticks” (Allison 2000).

The archaeological record suggests some degree of interregional exchange during the Pueblo I Period. In the lowland Virgin area, olivine-tempered ceramics have been found at sites dated as early as around A.D. 600 (Larson and Michaelsen

1990; Lyneis 1992), and olivine-tempered ceramic frequency approached a peak around A.D 1050. Lyneis (1986) reported that the olivine-tempered ceramics found at the Lost City site of the lowland Virgin area began to increase around A.D. 950. Thus, it is believed that the exchange between the upland and lowland in Virgin Branch Ancestral Pueblo area increased during the Pueblo I Period. Salt, turquoise, shell, mesquite beans, and agricultural products, including cotton, are believed to have been transported to Mt. Trumbull in return for olivine-tempered pots or even olivine itself (Fairley 1989).

Pueblo II Period ca. A.D. 1000–1150

More sites date to the Pueblo II Period than to any other period. The Pueblo II period was characterized by substantial population growth in the Arizona Strip and adjacent areas. Increased use of the uplands is also recognized archaeologically during this time (Fairley 1989). Climatic records suggest increased moisture across the central Colorado Plateaus between A.D. 1050 and 1150 (Dean et al. 1985), and this condition is likely applicable to other areas on the Colorado Plateau. Better climatic conditions along with the introduction of new crops that were more adapted to arid conditions made dry farming possible even in uplands (Euler et al. 1979). This is evidenced by the appearance of terraced agricultural fields, check dams, and other agricultural features in uplands during this time (Schwarts et al. 1981). Permanent occupations were established at certain optimal localities, and the seasonal use of particular localities (even within a single environmental zone) were also involved (e.g., summer field houses and winter pueblos) (Effland et al. 1981).

Artifact assemblages are characterized by the appearance of corrugated ware around A.D. 1050. Lyneis (1986) postulates a beginning date of corrugated ware around A.D. 950 or slightly later. Corrugated ware increased over time and became more than 20 percent of the entire pottery assemblage during the middle of the Pueblo II period (Allison 2000). During the Pueblo II Period red ware made a regular appearance (Allison 2000) in the Arizona Strip and adjacent area.

The habitation sites during this period are characterized by one to three masonry living rooms on the ground surface with associated storage rooms in a more formal arrangement. The large pueblo sites, containing up to 30 rooms, were often C- or U-shaped, but linear L-, V-, and E-shaped pueblos were also constructed (Fairley 1989). The existence of kivas in the Arizona Strip has been debated. Although kivas were found in the eastern part of the Arizona Strip (Schwartz et al. 1979, 1980), kiva architecture has not been discovered in the western sector of the study area, that is, the lowland Virgin area. Extensive trading networks existed during this time period, as evidenced by increased Kayenta-style pottery in the Arizona Strip and adjacent areas and olivine-tempered ceramics transported from Mt. Trumbull/Tuweep into the lowland Virgin area. The olivine-tempered ceramics in the lowland Virgin area increased to a peak during the early to middle Pueblo II Period, after which they decreased to less than 5 percent of all sherd assemblages (Lyneis 1986).

Pueblo III Period ca. A.D. 1150-1300 (?)

The introduction of polychrome ware and the high frequency of corrugated ware characterize the Pueblo III Period. Polychrome ware is very rare in the Arizona Strip but some has been found. The traditional argument concerning the abandonment of the Virgin Branch Ancestral Pueblo occupation is that it occurred around A.D. 1150. However, increasingly more post-A.D. 1150 radiocarbon dates from sites of this time period have been reported recently. Farley (1989) defined A.D. 1250 as the terminal date, and Allison (1996) suggests abandonment date as late as A.D. 1300 based on radiocarbon dates. In this dissertation, the terminal date of the Pueblo III Period, the occupation by the Ancestral Pueblo/Virgin Branch Ancestral Pueblo in the Arizona Strip is set around A.D. 1300.

The abandonment of Ancestral Pueblo occupation in the northern American Southwest is a controversial issue. According to Larson and his colleagues (Larson 1987; Larson and Michaelsen 1990), a prolonged drought occurring around A.D. 1150 and population pressure led to the abandonment of the lowland Virgin area. However, the abandonment may have occurred at different times in different areas. The reconstruction of relative population change in Tuweep in the Plateaus area demonstrates that only high-elevation areas saw a slight population increase after dramatic population decreases around A.D. 1150, when a prolonged drought occurred over large areas of the American Southwest. No sites dating after A.D. 1300 have been found in this area (Sakai 2001).

Neo-Archaic Period

Thompson et al. (1983) and Walling et al. (1986) refer to the period following the Ancestral Pueblo abandonment of the Arizona Strip as the Neo-Archaic Period. Three subdivisions were proposed: Late Prehistoric (A.D. 1200–1600), Protohistoric (A.D. 1600–1776), and Historic (after A.D. 1776). Historically, the Southern Paiute are known to have been present in the vicinity of Little Spring in the Mt. Trumbull area (Dellenbaugh 1907). However, the timing of the Southern Numic expansion, including the Southern Paiute, onto the Colorado Plateau, is not clear (Fairley 1989). Linguistic evidence indicates that Southern Numic speakers drifted eastward out of the Great Basin as early as A.D. 1000 (Lamb 1958).

Some archaeological evidence suggests the presence of the Southern Paiute in the Arizona Strip by the beginning of the 14th century (Jones 1986; Agenbroad et al. 1987), but the earliest date of their arrival is still in question. However, it seems clear that the reuse of Ancestral Pueblo artifacts by the Southern Paiute was a common practice in the Mt. Trumbull area (Kelly 1964; McFadden 2010a, 2010b). The diagnostic artifacts of the Southern Paiute, who were mobile hunter-gatherers, include the brown ware that is very different from the Ancestral Pueblo brown ware. Southern Numic sites are far fewer numbers than Formative Ancestral Pueblo sites in the study area (McFadden 2010a, 2010b). By the 1860s, Mormon settlements expanded into the Arizona Strip (Fairley 1989).

The Study of Ceramic Production and Consumption Patterns in the American Southwest

Assumptions about ceramic production and circulation patterns are based on at least three sources of data: (1) "the criterion of abundance," (2) stylistic description of sherds, and (3) materials used to make the pottery. "The criterion of abundance" is the argument that the ceramic types abundant at sites in the American Southwest are local wares (Rice 1987; Zedeño 1994). Early in the 1900s, this criterion of abundance was the popular way for determining the source of ceramics in the American Southwest (Rice 1987; Zedeño 1994). This traditional idea suggests that most prehistoric pueblos were self-sufficient communities that produced their own pots within the village (Cordell 1991; Plog 1980a; Neff et al. 1997; Zedeño 1994).

Between the 1960s and 1970s, scholars devoted their efforts to design analysis because they assumed that similar designs represented close social or economic relationships (Plog 1977, 1980b; Washburn 1977). Plog (1977, 1980b) is the first to explore style as being a result of exchanges or other processes in the American Southwest. Washburn (1977) established a method to describe similarities of ceramic attributes as objectively as possible. Somewhat earlier, the analyses of ceramics from Broken K Pueblo by Hill (1965, 1970) and from Carter Ranch by Longacre (1964, 1970) were the major studies entailing the investigation of intra-site stylistic variations.

The painted design styles of sherds are still widely used to investigate the source of pots in the American Southwest, such as Flagstaff Black-on-white as a trade ware from the Kayenta Ancestral Pueblo area to the Arizona Strip (Fairley 1989). The stylistic information, however, does not help to source the plain wares unless they are whole pots, which allows for examining distinctions in form. In the case of plain-ware sherd sourcing, the materials observed in the sherd core, such as temper and clay matrix (e.g., color or texture) can be used to investigate the production area. The particular temper type, such as olivine, may pinpoint the production area, providing clues about where the item was produced (Colton 1952; Lyneis 1992, 1999), since olivine occurs in a restricted area. Lyneis (1992) suggests Shivwits Ware found in the lowland Virgin area originated on the Shivwits Plateau based on its temper and clay color. Shivwits Ware contains the crushed Moapa Gray Ware (olivine-tempered pots) as a temper and is made with dark-firing clays that are not found in the Moapa Valley of the lowland Virgin area. Dark-firing clays are often found on the Colorado Plateau portion of the Virgin Ancestral Pueblo area. This area is considered to be near the source of olivine-tempered ceramics. Thus, Lyneis proposed the source of Shivwits Ware on Shivwits Plateau.

A Critique of the Early Provenance Studies

The largest problem in the visual characterization of ceramic design is that it is a subjective method and often lacks quantitative measurement of similarity. Furthermore, it is questionable whether pots with similar design styles always come from the same production area. The small sample size of specimens to be examined, as well as small sherd size, has also contributed to the ambiguity of ceramic typology and design analysis, further hindering the identification of ceramic sources (Plog 1977; Washburn 1977).

Depending on temper as the sole determinant of source also may be problematic. The existence of olivine-tempered pots in areas beyond the olivine source area suggests that there was movement of olivine from the source area to other areas, but this does not necessarily indicate the movement of olivine-tempered pots. The olivine-tempered ceramics found in non-olivine source areas, such as the lowland Virgin area, may have been made in Mt. Trumbull, the olivine source area, and brought to the lowland Virgin area. It also may be that olivine was transported from Mt. Trumbull to the lowland Virgin area, where potters made the pots with imported olivine temper with locally available clay. A better understanding of the sourcing of olivine-tempered ceramics requires more detailed objective testing such as chemical analysis.

Abbot and Watts (2010) provided another example of masking source information by examining only temper type. Phyllite-tempered Hohokam pottery from the Phoenix Basin was thought to be made within the basin as well as in the upland zone adjacent to the northern margin of the Phoenix Basin, where phyllite-containing bedrock is found. The exact source of phyllite-tempered pottery, however, cannot be distinguished based on temper alone because phyllite-containing bedrock is found at many locations. Thus, how many phyllite-tempered pots were made within the basin or in the upland zone is not known. The application of electron microprobes of clay and temper particles enabled the determination of a specific source locality of phyllite-tempered pottery, suggesting that quite a few phyllite-tempered pots were imported from the northern upland region.

Techniques for Testing Assumptions

As discussed above, assumptions about the production area of pottery have been based on the criterion of abundance, stylistic analysis, and the materials used for pottery production. The techniques for evaluating production locations based on the assumptions about these data sources are compositional analyses, including mineralogical and chemical analysis. The use of mineralogical analysis to identify the production locality of ceramics, such as optical petrography, has been applied since Shepard (1936) conducted a petrographic analysis of Rio Grande Glaze Ware from Pecos Pueblo in the 1930s. Many provenance studies (e.g., Abbott and Walsh-Anduze 1995) in the American Southwest still involve petrography.

Chemical analysis, on the other hand, has become popular within the last three decades. Colton was the one of the early archaeologists to challenge traditional self-sufficient models for pottery production, developing visual observations of ceramic paste constituents that were compared to raw materials such as clay and temper in order to examine the source (Colton and Hargrave 1937). Colton (1939) used refiring analysis of ceramics, a “low-tech” approach to the elemental characterization of ceramics, to indicate different raw materials of ceramic paste

(Neff 2005). Chemical compositional analysis, however, did not become popular until the 1980s, when instrumental neutron activation analysis (INAA) became the prevailing technique for the study of ceramic composition.

While other types of chemical analyses are used in the provenance study of ceramics in the American Southwest (e.g., Mills 1995; Habicht-Mauche 1995), INAA is the most popular technique and has become widespread during the last 30 years (Neff 2002, 2012; Speakman and Glascock 2007). INAA has been used to identify ceramic sources on large geographic scales such as the studies on black-on-white vessels from the Chaco Canyon area by Neitzel and Bishop (1990) and Gila Polychrome by Crown and Bishop (1991). INAA has also been conducted on smaller geographic scales, such as in a ceramic provenance study in the Grasshopper region by Zedeño (1994) as well as a study of White Mountain Red Ware in the Grasshopper region by Triadan (1994). Other examples include a study of Hohokam ceramics in the Tucson Basin by Fish et al. (1992), Hopi ceramics by Bishop et al. (1998), red ware and white ware in the Four Corners Region by Hegmon and her colleagues (1995), and black-on-white wares from the vicinity of Mesa Verde by Glowacki and her colleagues (Glowacki 1995; Glowacki et al. 1995, 1998).

More recently, INAA was used to study the Fremont Snake Valley series sherds from southwestern Utah (Reed and Speakman 2005). In the Arizona Strip and adjacent areas, a few chemical analyses have been conducted, including pottery from the lowland Virgin area (Larson et al. 2005), sherds from the Pottery Knoll site in southern Utah (Neff et al. 1997), and Shivwits Ware pottery from the Moapa Valley and Shivwits Plateau (Harry et al. 2013).

An INAA study of ceramics in the lowland Virgin area (Larson et al. 2005) resulted in new information about the sources of pottery in that area. First, two non-local groups were found within the ceramic assemblages: one includes only olivine-tempered sherds and the other includes only black-on-gray sherds, although some black-on-gray sherds were also assigned to the local group. Second, all red ware resulted from local production, contradicting the traditional belief that it is of non-local production. Recent ceramic provenance studies have incorporated ICP-MS, another technique for chemical compositional analysis. Those studies include provenance studies of ceramics from the lowland Virgin area and Tuweep using bulk digestion ICP-MS (Sakai 2001), microchemical analysis of pigments, slips, and glaze on Mesa Verde ceramics using LA-ICP-MS (Speakman and Neff 2002), and glaze and pigment analysis of Pueblo IV ceramics from east-central Arizona using LA-ICP-MS (Duwe and Neff 2007). The use of chemical compositional analyses of ceramic samples not only has provided source information regarding pots but has also demonstrated that the same design style is NOT synonymous with the same production area (e.g., Triadan 1994).

Development of Ceramic Chronology in the American Southwest

The traditional approach to the chronology of ceramics in the American Southwest combines seriation of ceramics with absolute dates through radiocarbon dating or dendrochronology. Although this approach is widely used in many areas in the American Southwest, it has several problems. First, the traditional approach has an inherent dating accuracy issue. Dated events through dendrochronology or the radiocarbon dating of tree log specimens (e.g., the age of death of the tree) often did not happen simultaneously with the targeted event (e.g., the use or production of pottery).

The second problem, which is especially troublesome in the Arizona Strip, is lack of a well-dated ceramic typology. As discussed above in the section concerning the chronology of the Virgin Branch Ancestral Pueblo, the ceramic chronology in the Arizona Strip and adjacent area is based on the assumption that the temporal trends of ceramic style in the Virgin Ancestral Pueblo are similar to those in the Kayenta Ancestral Pueblo region. Thus, the chronology in the Arizona Strip and adjacent areas is primarily based on the well-dated ceramic typology developed in the Kayenta Ancestral Pueblo area. The necessity of having an independent, well-dated typology in the Arizona Strip and adjacent areas has been suggested by many researchers. However, governmental restrictions that prevent larger-scale excavation make it difficult to obtain radiocarbon and dendrochronological samples to establish well-dated ceramic typology in Mt. Trumbull and Tuweep because sites are now within National Park and Monument lands. The direct dating of sherds from the surface collection or limited testing in the middens using luminescence dating represents a viable solution to the issue of inadequate control of ceramic chronology in Mt. Trumbull/Tuweep.

Although the ceramic chronology in the Arizona Strip and adjacent area remains "under development" (Lyneis 1992), there are some established diachronic trends based on temper, surface treatment, style, and form. Corrugated ware, for example, is believed to date around A.D. 1050. Lyneis (1986) proposed that the beginning of corrugated ware is about A.D. 950 or slightly later. It is also recognized that abundance of corrugated ware increased over time (Lyneis 1992; Allison 2000; Larson 1987). Red ware is generally thought to have started during the Pueblo II Period (Allison 2000). Logandale Gray Ware, which is tempered with limestone, is thought to be an early ceramic ware. All of this information may be useful for assessing the general site chronology, especially at the first stage of survey. However, many more well-dated ceramic assemblages, especially those using luminescence dating, are necessary to confirm these diachronic trends.

The Study of Olivine-Tempered Ceramics

Olivine-tempered ceramics are material remains that are unique to the Arizona Strip and adjacent areas. Because of this, numerous studies have been conducted on olivine-tempered ceramics.

Olivine Used as Temper

Lyneis (2008) describes in detail the temper used in olivine-tempered ceramics (Moapa Gray Ware). The temper used in Moapa Gray Ware is "crushed or disaggregated xenoliths from the vicinity of Mt. Trumbull" (Lyneis 2008). The most common xenoliths are made up about 65 percent olivine, 25 percent orthopyroxene, 10 percent clinopyroxene (chrome diopside), plus small quantities of amphibole and spinel. Xenoliths of other compositions are also found in the area (Menzies et al. 1987) and could show up as temper (Lyneis 2008).

Olivine is a volcanic mineral, a magnesium iron silicate with the formula $(Mg,Fe)_2SiO_4$ (Chesterman 1979). Olivine is a common mineral in the Earth's subsurface but weathers quickly on the surface. Because the main chemical constituents of olivine are iron and magnesium, the color of olivine varies depending on the degree of oxidization and the amount of iron. The color of olivine can be yellow-green (olive-green), dark green, red, brown, or almost black. Olivine occurs as inclusions of various sizes in basalt. It also may occur as nodules or sand. Olivine is found in various rocks in North America, but there are only few localities where one can find the mineral in any size other than grains (Chesterman 1979).

In Mt. Trumbull and the Tuweep area, olivine is found in various forms including grains and nodules embedded in basalt, nodules weathered out of ash deposits associated with cinder cones, and sand. During the field seasons between 2007 and 2012, I collected basalt specimens with olivine inclusions from various lava flows. The chemical composition of olivine from different lava flows is the subject of my future study determining a specific source of olivine temper, but it is recognized that olivine occurs in lava of various ages. I also found olivine nodules ranging from a few cm to more than 25 cm in length that weathered out of ash deposits at Mt. Trumbull. Lyneis (2008) suggests that olivine nodules in this form are likely source of olivine temper. She reasons that extracting the olivine nodules or grains from basalt would be difficult with stone tools. The olivine nodules are found in various areas in Mt. Trumbull and Tuweep, but there is a particular cinder cone area south of Mt. Trumbull where olivine nodules are abundant. The olivine nodules are easily found on/near the cinder cone and in drainages emanating from the cinder cone. Manos made of olivine have also been found in sites near this cinder cone area, although they are rare. The grains within nodules are easy to disaggregate, so not only are olivine nodules easy to access in Mt. Trumbull and Tuweep, they are easy to process into temper.

Olivine sand, another form of olivine, can be a potential source of temper for ceramics. However, Lyneis (2008) argued that olivine sand was not used as temper. Olivine sand can be found in many localities in the Mt. Trumbull area, but the olivine sand in Mt. Trumbull is not pure olivine such as that found on Green Beach in Hawaii. In Mt. Trumbull, the sand contains various other rock materials in addition to olivine grains. Nonetheless, it seems possible that the potter just grabbed sand at the bottom of the drainage and added it to the ceramic fabric to make pots, especially during earlier time periods. However, a lack of petrographic studies of Mt. Trumbull olivine-tempered sherds entailing comparison with olivine sand from Mt. Trumbull prevents the formation of conclusions on whether the olivine sand was used as temper. Considering the accessibility, ease of processing into temper, and its abundance, I concur that olivine nodules are the most likely the source of olivine temper, as Lyneis (2008) suggests.

There are at least two proposals regarding why olivine was used as a temper in Mt. Trumbull and Tuweep, the olivine source area discussed above. First, in this area, olivine is more accessible than quartz sand because there are no permanent streams. Second, olivine is likely to be a better temper material than quartz or calcite. Used as a refractory in industry (Amethyst Galleries, Inc. 1995), olivine has stable thermal properties, which makes it a particularly good tempering material. The study of the thermal expansion rates of minerals indicates that minerals with lower thermal expansion or those with expansions close to the clay fabric are especially suitable as a temper for avoiding thermal stresses during repeated heating and cooling of pots (Rye 1976; Arnold 1985).

According to Arnold (1985), olivine has a much lower thermal expansion rate than quartz, and the expansion rate of olivine is closer to that of the clay fabric than quartz. This may explain why olivine was a preferred temper. On the other hand, the thermal expansion rate of calcite, which was used in Logandale Gray Ware (often found in the lowland Virgin area), is actually much closer to that of the clay fabric than olivine. Indeed, the expansion rate of calcite is the closest to that of the clay fabric among the possible tempering materials. However, the problem with using calcite as a tempering material is the firing temperature. Calcite decomposes to calcium oxide and carbon dioxide at a firing temperature as low as 620 degrees (C), which results in spalling, cracking, and crumbling (Rye 1976). Some of the sherds from both Mt. Trumbull and the lowland Virgin area show cavities on the surface and inside the core, which may be a result of limestone being used as a temper or the inclusion of calcite in the clay fabric. Olivine has a high melting point and resistance to chemical reagents (Palmour et al. 1981, Goldschmidt 1938, Furlani et al. 2013) and can thus be used at higher temperatures. Therefore, olivine is a highly suitable material for temper when considering both the thermal expansion rate and the firing temperature of the pots.

Formal Attributes of Olivine-Tempered Ceramics

The pottery with olivine temper is classified as Moapa Gray Ware. There are different types of Moapa Gray Ware based on the clay color and surface treatment. Colton (1952) originally classified Boulder Gray as a type of Moapa Gray Ware that has a light color core, and Moapa Brown as a type that has a dark color core. Schroeder (1955) used Boulder Gray to refer to the early Moapa Gray Ware type with a dark color core and Moapa Gray to refer to the later Moapa Gray Ware with a light color core. Lyneis (1992, 2008) categorized all olivine-tempered gray plain sherds as Boulder Gray because the color/texture shift likely represents a gradual change rather than a dichotomy. In order to avoid confusion, I do not use a particular type name but instead use the term olivine-tempered plain ware or Moapa plain ware. One fact to note about the definition of the Boulder Gray type employed by previous researchers is that variations in the core color and texture of olivine-tempered ceramics do exist, with the early olivine-tempered ceramics tending to have a darker core color.

Colton (1952) stated that Moapa Gray Ware/olivine-tempered ceramics were constructed by coiling and scraping, after which they were fired in a badly controlled atmosphere. The olivine-tempered pots are either bowls or jars and included both utilitarian and non-utilitarian ware. The surface treatments include plain, corrugated, and black-on-gray paint. Occasionally, the plain ware is fugitive red, which is “a thin coating of finely ground hematite (red ocher) diluted in water and applied to the exterior of the vessel after fining” (Van Alfen 2008). The black-on-gray ware was decorated using organic paint (Colton 1952; Lyneis 1992, 2008). I also confirmed this through the cross-section analysis using LA-ICP-MS. Mineral paint has much higher concentrations of some elements such as manganese, and the LA-ICP-MS analysis of black paint on olivine-tempered ceramics shows no difference in manganese concentrations compared to that of the background surface. This suggests that the black paint is not mineral but organic.

The decoration style of black-on-gray Moapa Ware is similar to that of the Tusayan Black-on-Gray Ware (sand temper) found in the study area. The sherd assemblage from the Mt. Trumbull area shows that the black-on-gray Moapa Ware does not have a slip, with very rare exceptions. No red ware or polychrome sherds with olivine temper have been found. The shape, size, and amount of olivine included in sherds vary. Occasionally, other inclusions are found along with olivine, such as crushed sherds, sand, basalt, or other rocks. In this dissertation, sherds with olivine temper are categorized as olivine-tempered ceramics/Moapa Ware with the exception of Shivwits Ware. Shivwits Ware is a pottery with a very dark color, ironrich clay matrix, and crushed sherd temper (sherds are primarily Moapa Gray Ware) (Lyneis 1992, 2008). Shivwits Ware is found both in the Plateaus and the lowland Virgin areas. Lyneis (1992) suggests that the production area for Shivwits Ware is on the Shivwits Plateau, as discussed above. An investigation of the production area of Shivwits Ware found in Mt. Trumbull is also included in this dissertation because these sherds include olivine particles.

Spatial Distribution Pattern

Olivine-tempered ceramics are most common in the Mt. Trumbull/Tuweep olivine source area. In Mt. Trumbull and Tuweep, the majority of ceramics are tempered with olivine (Thompson 1970; Moffitt and Chang 1975, 1978; Lyneis 1992; Allison 2000). Thompson (1970) reported that the average frequency of olivine ceramics in all sites in Tuweep is over 75 percent of all ceramic assemblages. However, the olivine-tempered ceramics do not seem to be evenly distributed within the Mt. Trumbull or Tuweep olivine source areas (Figure 2.1). Although the majority of sites have an abundance of olivine-tempered ceramics, a few sites in both Mt. Trumbull and Tuweep have a small frequency of olivine-tempered ceramics.

Olivine-tempered ceramics are distributed westward from the Mt. Trumbull/Tuweep area over a range exceeding 100 km, to include the lowland Virgin area and the Shivwits Plateau. Although the frequency of olivine ceramics declines when moving west, the olivine-tempered ceramics are distributed widely within the lowland Virgin area, and as far as the Las Vegas Basin in Nevada. In the lowland

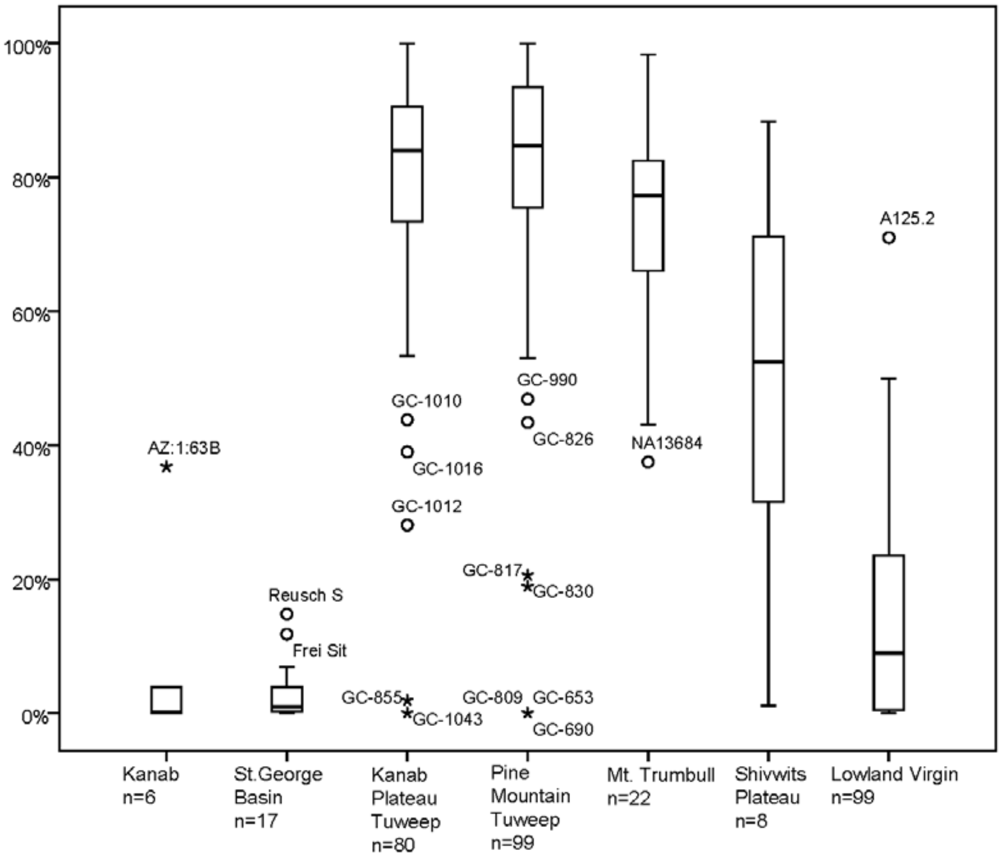


Figure 2.1. Olivine ceramic frequencies by site in each region. This graph is based on published data. Site designations are given for outliers. Tuweep olivine-tempered ceramics (Kanab Plateau and Pine Mountain) are from the sites with more than 20 sherds, and Mt. Trumbull and lowland Virgin olivine-tempered ceramics are from the sites with more than 30 sherds. Number of sites included in this graph is shown as "n". Percentage shows the proportion of olivine-tempered ceramics in all ceramics in the site.

Virgin area, the frequency of olivine-tempered sherds changed over time, and the peak of the olivine tempered ceramics within sherd assemblages reached as high as 36 percent (Larson 1987).

Olivine-tempered ceramics do not extend eastward of the olivine source areas (Figure 2.1). Olivine-tempered ceramics were found in large quantities a little farther east of Tuweep on the Kanab Plateau, but beyond the SB Point, which is 20 km east of Tuweep, the frequency of olivine-tempered ceramics declines to as low as 30 percent of the assemblage. The frequency of olivine-tempered ceramics at the Pinenut site, which is located 30 km east of Mt. Trumbull, is 29.4 percent of the assemblage. Very few olivine-tempered ceramics can be found beyond the Kanab Creek, which is 40 km east of the Mt. Trumbull/Tuweep areas.

Olivine-tempered ceramics are also rare in the area north of Mt. Trumbull area. At the north end of the Plateaus Area near Kanab, which is 80 km northeast of Mt. Trumbull, the frequency of olivine-tempered ceramics is extremely low. In Zion National Park near Kanab, hardly any olivine-tampered sherds are found (Schroeder 1955). In the St. George basin, which is about 100 km north of Mt. Trumbull, the frequency of olivine-tempered ceramics is also low. Olivine-tempered ceramics on Yellowstone Mesa, which is 50 km northeast of Mt. Trumbull, are around 13 percent of the assemblages (Allison 1988). There are few data available in the area within 40 km north of the Mt. Trumbull area from previous surveys. Because of this, it is unknown how the frequency of olivine-tempered ceramics changed based on the distance northward from Mt. Trumbull/Tuweep, or even whether there were any long-term occupations at habitation sites in this area.

Olivine-tempered ceramics were found in large quantities in Tuweep, within Grand Canyon National Park, the Colorado River being its southern boundary. No olivine-tempered ceramics are found south of the Colorado River.

At the southern foot of Mt. Trumbull where the olivine nodules originated, olivine is obviously the dominant temper type, although the frequency of olivine-tempered ceramics varies among sites. Recent pedestrian surveys conducted in 2010 and 2011 on the north side of Mt. Trumbull show that the ceramic assemblages immediately north of Mt. Trumbull are similar to those in the south side, in which olivine-tempered ceramics are dominant (Sakai 2011, 2012). The survey in 2011 was conducted at a distance of eight kilometers north of Mt. Trumbull and showed that the site densities are extremely low, with hardly any ceramic artifacts found in this locality. Further research is required to examine the nature of settlement patterns and artifact assemblages, including olivine-tempered ceramic frequency, in the area north of Mt. Trumbull.

Temporal Distribution Patterns

Olivine-tempered ceramics existed from the earliest time of Puebloan occupation in Mt. Trumbull and Tuweep. As discussed above, corrugated ware increased over time. The comparison of the olivine-tempered ceramic frequency to corrugated ware frequency suggests no change in the frequency of olivine-tempered pots in Tuweep over time, with an average of about 80 percent of all ceramics (Sakai 2001). In the lowland Virgin area, the use of olivine-tempered ceramics in the lowland Virgin area began around A.D. 600 (Larson and Michaelsen 1990; Lyneis 1992), and the frequency of olivine ceramics approached a peak around A.D. 1050. Olivine ceramics disappeared prior to the demise of the Virgin Ancestral Pueblo in the lowland Virgin area (Larson and Michaelsen 1990; Allison 2000). Allison (2000) noted a strong westward distribution of olivine-tempered pottery from

Mt. Trumbull/Tuweep toward the lowland Virgin area, reaching farther west to the Muddy River area in the lowland Virgin area during the Pueblo II time period (A.D.1050–1100) (Allison 2000). In the St. George Basin, olivine-tempered ceramics increased during the Late Pueblo II times (Lyneis 2008), although the frequency of olivine-tempered ceramics is low, as mentioned above.

Source of Olivine and Olivine-Tempered Ceramics

The source of olivine is thought to be the basalt flows and cinder cones in Mt. Trumbull and Tuweep (in the northwest part of the Grand Canyon area) discussed above. Petrographic analysis of sherds from Main Ridge Site in the lowland Virgin area and the Arizona Strip shows that olivine-tempered ceramics from both areas were tempered with crushed xenoliths from Tuweep, including in the Vulcan’s Throne, Toroweap Valley, and Mt. Emma areas (Lyneis 1988, 1992). The nearest alternative olivine source is near Flagstaff, Arizona, which is 200 km southeast of Mt. Trumbull on the other side of the Grand Canyon. However, it is unlikely that olivine temper was transported over such a long distance to the lowland Virgin area or even to Mt. Trumbull or Tuweep. Moreover, I did not see any large nodules in the lava near the Flagstaff area during my quick visit. No olivine-tempered pottery has been found near Flagstaff either. Large olivine nodules are reported to occur in Gila County in southern Arizona, which is also too far to transport (400 km from Mt. Trumbull).

The investigation of the olivine-tempered ceramic production areas is more complicated, although it is assumed to be near the olivine source in Mt. Trumbull and Tuweep. The ware name, Moapa Gray Ware, came after the locality where olivine-tempered ceramics were first reported in 1940s (Lyneis 2008), so this name does not necessarily represent a production area. Colton (1952) originally suggested that the source of the clay for Moapa Gray Ware "appears to have been from the lava in the Toroweap area." Schroeder (1961) suggested that the source of olivine-tempered ceramics is based on the location of olivine, not the clay. Allison (2000) conducted refiring experiments on olivine-tempered ceramics from Mt. Trumbull and the lowland Virgin area and observed multiple colors after refiring. He concluded that several different clays or clay recipes were involved in olivine-tempered ceramic production. Allison (2000) also recognized that the some colors were identified more often in the clay matrix of Mt. Trumbull olivine ceramics, although all colors are present in both areas (Figure 2.2).

Little is also known about the particular production zone within the Mt. Trumbull/Tuweep area. Olivine-tempered ceramics have been found at most of the sites in Mt. Trumbull and Tuweep, both of which are olivine source areas. However, no production sites have been identified in the Mt. Trumbull/Tuweep area during limited excavations. During the testing of the 131BLM site in 2005, unfired clay nodules/objects were found, but it was uncertain whether this was "waste from pottery production." It is interesting to note that large pueblos are concentrated near the cinder cone, where an abundance of olivine nodules is found. However, the

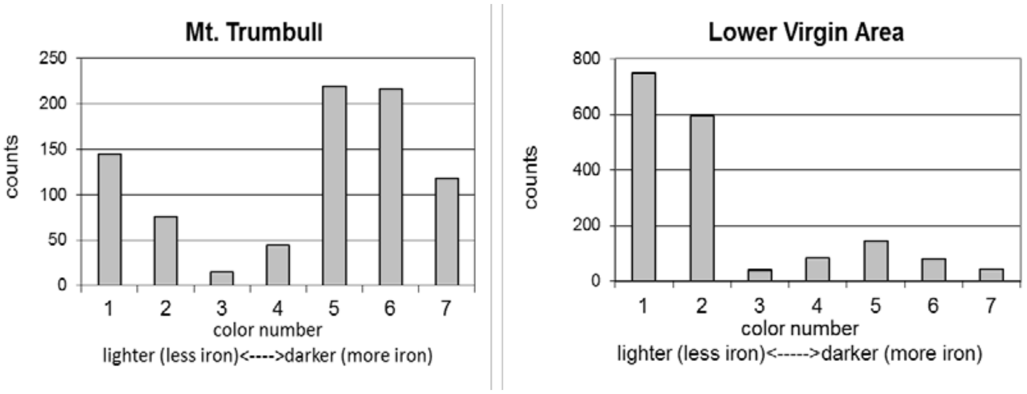


Figure 2.2. Refired colors of olivine-tempered ceramics (after Allison 2000).

evidence is not convincing enough to conclude that the location of the large pueblos was selected just because of easy access to the olivine source. The location of the large pueblos may have derived some benefit from easy access to olivine source, but the location may have been due to many other factors such as hydrogeology, which impacts successful agriculture, as suggested by Buck et al. (2012).

Olivine-Tempered Ceramic Exchange Issues

Although there is a scant amount of detailed information on the production area of olivine-tempered ceramics, as discussed above, because olivine is found only at particular locations, such as Mt. Trumbull and Tuweep, the existence of olivine ceramics in the lowland Virgin area indicates long-lasting economic and social ties between these populations (Lyneis 2000). Furthermore, the compositional analysis of ceramics from the lowland Virgin area demonstrates that olivine ceramics as well as some black-on-gray ceramics were produced outside the lowland Virgin area

(Sakai 2003; Larson et al. 2005). Thus, frequent movement of ceramics among various areas in the Arizona Strip and its adjacent areas may have occurred.

Based on a compositional study of the ceramics found at Pottery Knoll, Southern Utah, Neff et al. (1997) argue that ceramic exchange decoupled from local specialization was favored in order to buffer risk in unpredictable environments (Neff et al. 1997; Neff and Larson 1997). Thus, the reason for ceramic movement could be related to the risk management associated with the agriculture. Further discussion of this idea will be presented in Chapter III. Allison (2000), on the other hand, argues that the lack of wood for fuel in the lowland Virgin area is the driving force behind the import of olivine-tempered pots from the Plateaus.

Chemical Compositional Analysis to Source Olivine-Tempered Ceramics

As discussed above, the production areas of olivine-tempered ceramics and resource procurement strategies used for olivine-tempered ceramic production are relatively unknown. Two chemical analysis studies were conducted to source olivine-tempered pottery prior to this dissertation. As discussed in detail in Chapter V and also briefly discussed above in this chapter, two approaches are involved in chemical compositional analysis: (1) a bulk analysis in which all materials are homogenized including INAA or microwave digestion ICP-MS, and (2) point analysis (microchemical analysis), which targets only a specific portion of heterogeneous samples such as ceramics (e.g., temper particles in ceramic paste). LA-ICP-MS is one technique that allows for conducting this microchemical analysis.

The two chemical analyses used to source olivine-tempered ceramics prior to the research for this dissertation were both bulk analyses.

INAA Study on Ceramics in the Lowland Virgin Area

Instrumental neutron activation analysis (INAA) was used to investigate the source of pottery from the lowland Virgin area, involving a comparison with local source clay (Larson et al. 2005). At least four compositional groups were identified in the lowland Virgin area ceramic assemblage (Figure 2.3). Two groups were

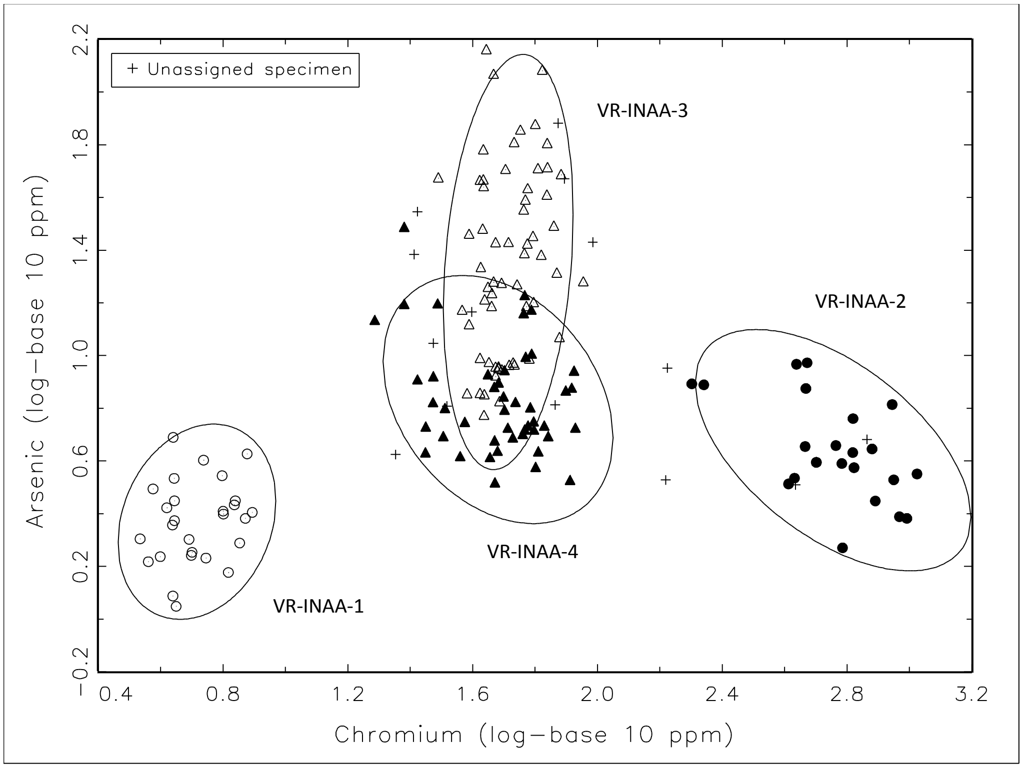


Figure 2.3. INAA results of ceramics from the lowland Virgin area (after Larson et at. 2005). Group names are modified in this dissertation to avoid confusion with Mt. Trumbull INAA study. VR-INAA-1 and VR-INAA-2 are non-local group. VR-INAA-2 includes exclusively olivine-tempered ceramics. VR-INAA-3 and VR-INAA-4 are local groups in the lowland Virgin area.

matched to the lowland Virgin local clay while the other two were not. Olivine-tempered ceramics in the lowland Virgin area (which comprises a single group) did not match the local clay and thus were considered non-local wares imported into the lowland Virgin area.

Microwave Digestion ICP-MS Study of Olivine-Tempered Ceramics

Microwave digestion ICP-MS was conducted on ceramic specimens from the Tuweep and lowland Virgin areas (Sakai 2001). This study demonstrated that the olivine-tempered ceramics from Tuweep and the lowland Virgin area are in the same compositional group (Figure 2.4). The clay samples from the two areas were also compared with the ceramic groups. The clay samples from Tuweep matched with the olivine-tempered ceramic group including sherds from both Tuweep and the lowland Virgin area, although some of the clay samples from the lowland Virgin were close to the olivine-tempered ceramics chemically. These findings suggest that most olivine-tempered ceramics were produced in Tuweep.

Microwave Digestion ICP-MS demonstrated that olivine-tempered ceramics from Tuweep and the lowland Virgin area probably have the same origin. However, this study did not show evidence of any subgroups. Thus, the use of various clay sources or recipes in olivine-tempered ceramic production, which was suggested by Allison (2000), was not demonstrated. Further analysis with point analysis, such as LA-ICP-MS, is required to investigate various clay sources and recipes used for the production of olivine-tempered ceramics in different areas.

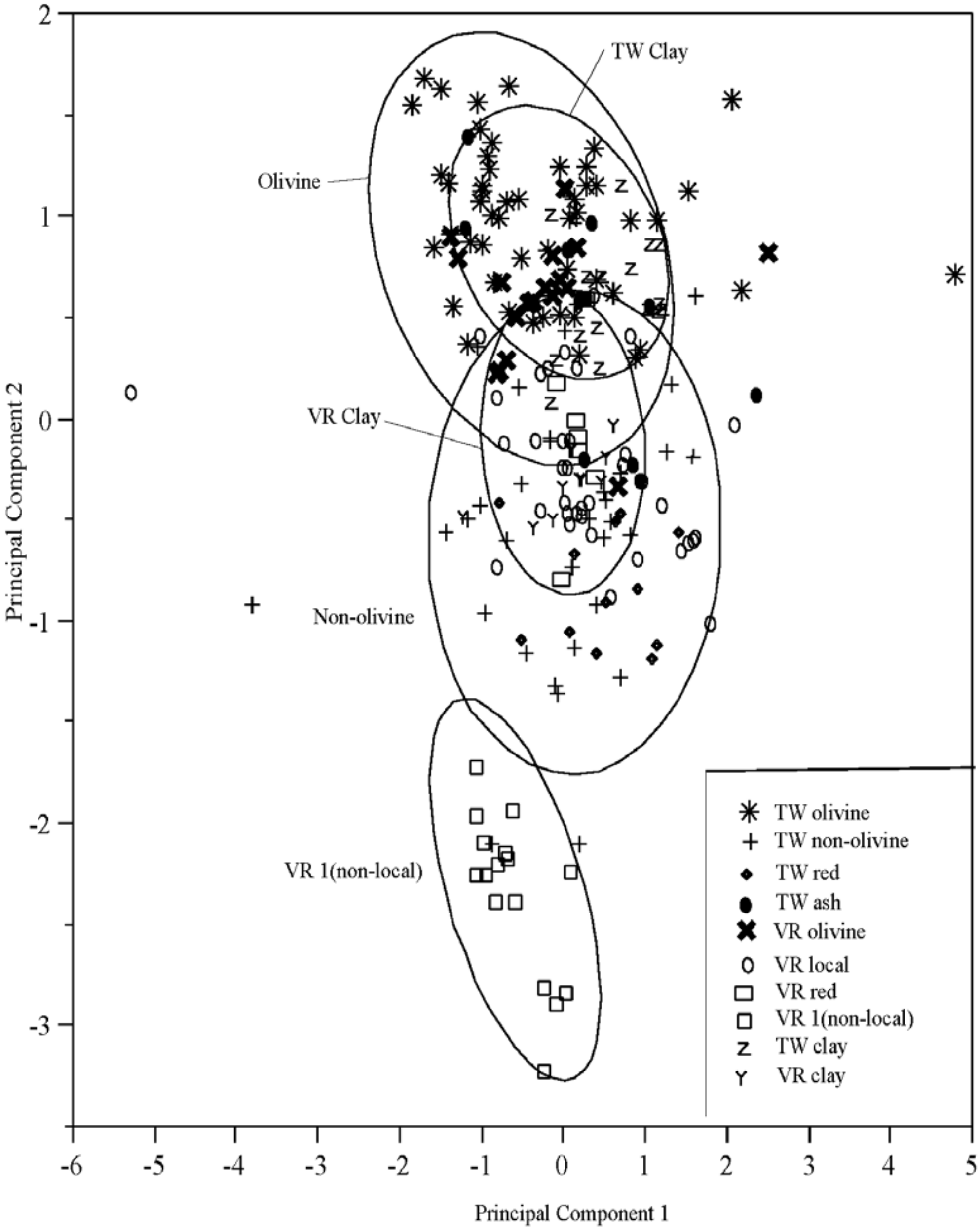


Figure 2.4. Microwave digestion ICP-MS results for the ceramics from Tuweep and the lowland Virgin area (after Sakai 2001). Ellipses indicate 95% probability level of membership in the groups. Three ceramic groups (olivine, non-olivine, VR1) and two clay groups (TW clay—Tuweep clay, and VR clay—the lowland Virgin clay) are presented.

In conclusion, this chapter covered the environmental background and cultural history of the Arizona Strip and the adjacent area. Included is a review of previous studies of the olivine-tempered ceramics, which are the focus of this dissertation. This information serves as a basis for understanding the context of my specific research question, which concerns the changes in production and distribution of olivine-tempered ceramics and a series of hypotheses proposed as possible answers to this question.

Chapter III: RESEARCH QUESTION AND THEORETICAL BACKGROUND

As discussed in the previous chapter, the Arizona Strip and adjacent areas in Utah and Nevada are very marginal environments. The climatic conditions of this part of the American Southwest are extremely arid and fluctuate frequently. Spatial variation is also pronounced, with environmental conditions varying markedly over short distances. Although current average annual precipitation is between 25 and 38 cm in Mt. Trumbull, which may be suitable for maize agriculture, the dry farming of maize was very risky here without permanent streams and limited frost-free days due to the elevation. Despite the challenging environments, the Virgin Branch Ancestral Pueblo people in both the lowland Virgin and Mt. Trumbull areas adapted successfully for at least 1,300 years.

The evidence of early agriculture in the Arizona strip area dates as early as A.D. 1. Although one point of view holds that the Virgin Branch Ancestral Pueblo people were heavily dependent on agriculture in southern Utah (Martin 1996), most agree that populations in this study area practiced a mixed subsistence economy, combining agriculture with wild resource procurement (Moffit and Change 1978; Lyneis 1992). Most also agree that agricultural intensification occurred in later Puebloan times (Larson 1996, Larson and Michaelsen 1990, Larson et al. 1996). Population started to increase about A.D. 800, with a peak around A.D. 1150 (Larson and Michaelsen 1990). Abandonment of the Arizona Strip and adjacent area occurred sometime between A.D. 1150 and 1350.

In this study, my aim is to investigate how populations coped with the challenges of such a marginal environment by examining how social interaction patterns varied over time in different parts of the region. Numerous previous studies suggest that long-distance networking minimized subsistence risks (Braun and Plog 1982) and that social interaction was a vital risk-buffering strategy for agriculturalists coping with the variable environmental conditions of the American Southwest (Rautman 1993). Social interaction can take the form of population mobility, exchanges, and aggregation.

As discussed in Chapter I, in marginal environmental conditions, different forms of social interaction would be preferred at different levels of population density. With low population density, mobility is a viable adaptive strategy to cope with resource variability. With increasing population, however, mobility becomes restricted, and instead sedentary residence with exchange becomes a more viable adaptive strategy. In addition to the constraints on mobility, higher populations may also lead to agricultural intensification, thus reducing time available for other nonagricultural activities. At the same time, exclusive dependence on agriculture was risky in this unstable environment, so exchange to buffer agricultural risk were required. Exchange among small agricultural groups under conditions of high population can buffer risk in several ways, as discussed in Chapter I. When population reaches even higher levels, village aggregation may emerge as a viable adaptive strategy.

Various forms of social interaction discussed above may be inferable from the archaeological record, ceramic data being a prime example. The different forms of social interaction may leave an imprint on ceramic compositional and formal diversity, the precise patterning of form and composition depending on the nature of risk-buffering strategies adopted at a particular time and place (Neff et al. 1997). In the Arizona Strip and adjacent areas, the presence of olivine ceramics in the lowland Virgin area indicates economic and social ties between the Plateaus area and the lowland Virgin populations (Lyneis 2000), which were discussed in Chapter I. Allison (2000) argues that the olivine-tempered pots were imported in the lowland Virgin area from the Plateaus due to the lack of wood for fuel, necessary for pottery production. Left unanswered by these interpretations is whether the olivine-tempered pots were transported as a result of exchanges between sedentary communities or carried along during population movement. Under low population density, I would expect that olivine-tempered pots were moved with groups of people moving between different environmental situations. Under higher population densities, I would expect olivine-tempered pots to have been moved as a result of exchange. Although temper does not travel for a long distance generally (Arnold 1985), I also consider the possibility that olivine itself may have been transported from Mt. Trumbull to the lowland Virgin area. Thus, the focus of my research is on how human migration and exchange, as observed in olivine-tempered ceramics, fit into the broader adaptive strategies of the populations inhabiting the marginal environments of the Arizona Strip and adjacent areas. For instance, does the relative importance of exchange and mobility change according to population levels and climatic variability, either over time or across space? Another concern is whether ceramic production patterns changed in response to the need for agricultural intensification in order to feed a growing population.

Research Focus

Previous research on olivine-tempered ceramics was focused on their spatial and temporal distributions outside the olivine source area. However, very little is known about the loci of their production and the resource procurement strategies for their production. Allison's (2000) refiring study, including samples from the Mt. Trumbull and the lowland Virgin areas, showed the existence of variations in chemical composition in ceramic paste that may indicate that multiple resources were used to make olivine-tempered ceramics. Thus, my research interest centers on how and why the production and consumption patterns of olivine-tempered ceramics changed over time among populations that lived as small-scale societies in unstable agricultural environments. To understand ceramic resource procurement patterns, I look at *space*, *form* and *time* in the distribution of ceramic artifacts and their interrelationships (Spaulding 1960).

Spaulding defined *spatial* loci as the three-dimensional locations where artifacts are found; here, *space* will also include the *spatial* locus where an artifact was made. That is, the *spatial* characteristics of artifacts will include where the artifacts are found as well as their sources. *Form*, on the other hand, is any physico-chemical property of an artifact: color, chemical composition, weight, length, shape, and so on (Spaulding 1960). A *time* dimension must be based on the analysis of the formal dimension, spatial dimension, or both. Direct-dating techniques, such as luminescence dating, applied to ceramic samples are based on the analysis of the radiogenetic properties of the ceramics, which are considered formal attributes.

Ceramics and Evolution

The diversity within a ceramic assemblage can be measured with reference to compositional properties as well as conventional formal properties. Formal variation arises from choices made during ceramic production (forming, finishing, and decorating) together with consumption practices. On the other hand, compositional variation, which may be defined as the mineralogy and chemistry of ceramic paste, arises from the choices made during raw material procurement and paste preparation together with consumption practices (Neff 1992, 1995; Neff et al. 1997; Neff and Larson 1997). Composition of an artifact made at any particular location within geographic space is a concrete manifestation of the raw material used by an individual in the past, which is a characteristic of a past human phenotype (Neff 1995). Thus, ceramic artifacts are directly observable parts of phenotypes of past individuals, and an investigation of ceramic variation constitutes an investigation of variation in past human phenotypes (Neff 1992; Neff et al. 1997; O’Brien et al.

1994). Phenotypic variation is structured over time due to the effects of differential persistence of inherited information caused by selection, chance, linkage of neutral traits with other traits controlled by selection, and historical processes (Dunnell 1980; Neff et al. 1997). Compositional data record the historical continuity, branching, and extinction of past traditions of ceramic production as well as past selective pressures that arose out of variation in the opportunities for survival through pottery production (Neff 1992).

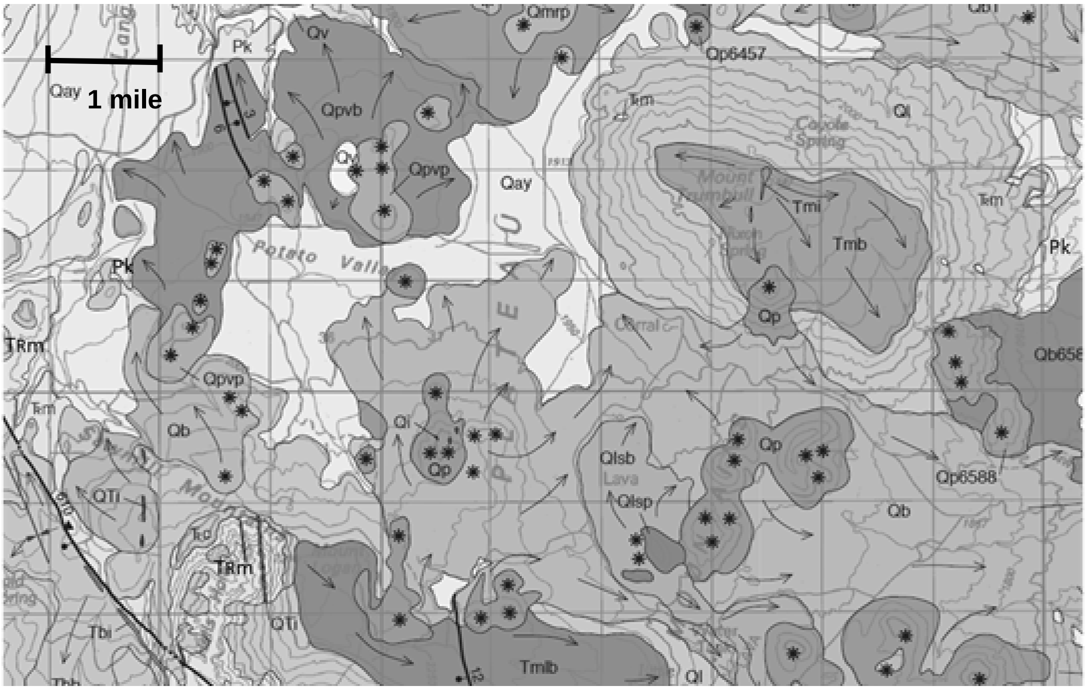
One of the goals in my effort to explain changes in compositional and formal diversity is to address how cultural practices, such as ceramic production and distribution patterns, structure ceramic compositional and formal diversity. Neff et al. (1997) discuss models to explain ceramic compositional and formal diversity among the prehistoric Southwestern Pueblos. In the traditional self-sufficient models discussed in Chapter II (Cordell 1991; Plog 1980a; Zedeño 1994), low compositional diversity among the ceramics within the region is expected because all ceramic items are made locally. As alternatives, Neff et al. (1997) proposed two models to explain high diversity in compositional data within a single assemblage: (1) local specialization and exchange and (2) exchange decoupled from local specialization. The local specialization and exchange model concerns instances in which particular types of pottery, such as red ware, were produced only in one location/community and subsequently distributed over space. If exchange is decoupled from local specialization, however, one type of pottery, such as red ware, may be produced at multiple locations and exchange will bring red ware from multiple production centers together in the same consumption assemblages. A detailed discussion of these models is presented below.

Models for Explaining the Compositional and Formal Diversity in Olivine-Tempered Ceramics

I propose four models based on two different levels of selection to explain how ceramic production and consumption patterns create the compositional and formal diversity found in widely distributed olivine-tempered ceramics. These evolutionary models compare traits in terms of how well their design qualifies them to persist under particular environmental conditions (O'Brien et al. 1994; Neff et al. 1997).

Selection that Acted on Local Ceramic Production

A set of circumstances may exist that leads to a strong association between formal and compositional properties of pottery. In this case, selection acts on ceramic production on a local level, shaping potters' choices about which local resources to exploit for particular classes of vessels. This process can affect resource procurement when a population has multiple choices of raw materials within a relatively small geographic area. This "clay resource specialization model" specifies that potters use specific clays to make certain types of pots, or pots with special functions or purposes, whenever they have choices between various clays with different performance characteristics.



Map Legend (not all legend is described)

- Surficial Deposit
  - Qay: Young alluvial fan deposit (Holocene and Pleistocene)
  - Ql: Landslide deposit(Holocene and Pleistocene)
  - Qv: Valley-fill alluvium (Holocene and Pleistocene)
- Sedimentary Rocks
  - T_Rm: Moenkopi Formation
  - T_Rc: Chinle Formation
  - Pk: Kaibab Formation
  - Pt: Toroweap Formation
- Volcanic Rocks
  - Qp: Basat of the Uinkaret Plateau (Pleistocene) pyroclastic deposits,
  - Qb: Basat of the Uinkaret Plateau (Pleistocene) basalt flows
  - Tmi: Basalt Mt. Trumbull (Pliocene) basalt rocks
  - Tmb: Basalt Mt. Trumbull (Pliocene) basalt flows
  - Qlsp: Little Spring Basalt (Holocene) pyroclastic deposit
  - Qlsb: Little Spring Basalt (Holocene) basalt flows

Figure 3.1. Geologic map of the Mt. Trumbull (Billingsley and Wellmeyer 2003)

Clay Resource Specialization

As the geology map of the study area (Figure 3.1) indicates, the Mt. Trumbull locality consists of multiple geologic formations, both volcanic and sedimentary.

These geologic formations and most of the archaeological sites in Mt. Trumbull are located within an area with about a five kilometer radius. Thus, all clays from these different formations would be within the range that individuals could travel to procure clay, as suggested by ethnographic examples (Arnold 1985). Although volcanic rocks are prevalent in this area, a few small outcroppings of sedimentary rock have been identified, including those of the Chinle and Moenkopi formations. The clays derived from these sedimentary formations are generally considered to be more suitable for ceramic production than clays from the volcanic rock formations. The sedimentary rock outcrops are located close to the Grand Canyon rim and in small pockets on the slope of Mt. Trumbull, as well as the area close to the west edge of the plateau. Many of these favorable clay sources are difficult to access but are nonetheless accessible.

Resource specialization, entailing different clays with different performance properties used for pots with different purposes, would reduce the total cost of local ceramic production to the extent that use of optimal clays improves vessel performance and reduces vessel-replacement costs. This would be one reason why potters might have invested more time to obtain better-quality clay for special purposes, such as the manufacture of items intended for gift exchange, and used lower-quality clay only for the manufacture of daily-use ware. For example, using good clay, potters could have produced stronger pots that might have been more attractive gift items and less breakable while transporting.

Archaeologically, it is expected that all compositional groups of olivine-tempered ceramics would match local clays in the Mt. Trumbull/Tuweep areas and that there should be a strong correlation between compositional groups and formal attributes. Additionally, some compositional groups may consist of only utilitarian wares found in Mt. Trumbull, while some groups may consist of only non-utilitarian wares found predominantly outside the Mt. Trumbull and Tuweep areas that may have been exchanged as trade items.

Absence of Clay Resource Specialization in Ceramic Raw Material Procurement

Another model for how selection acts on local ceramic production involves an absence of resource specialization in the ceramic raw material procurement. I consider two selective environments. One is the case of clays from different geological formations that do not differ in performance. This may not be the case with clays in the Mt. Trumbull and Tuweep vicinities, since multiple geologic formations with different qualities are found in these areas.

The second possibility is where there is no demand for better-quality or costly pots. As generally recognized, the study area is a risky agricultural environment. As discussed earlier, when population density is low, mobility is preferred over exchange to buffer agricultural risk. People can move to change locations of agricultural fields or even resort to a greater dependence on wild resources. Under these circumstances, people would be expected to use locally available clay from areas close to their sites to make pots and to allocate more time to preparing or maintaining agricultural fields or acquiring wild food resources. In this case, each compositional group will consist of sherds from only one area, and each group will match clay sources adjacent to the sites where it is found. It is also expected that similar formal attributes could be found in the variable compositional groups of all these ceramic assemblages.

Selection that Acted on Economic Interaction Patterns

Another set of circumstances that could create ceramic compositional and formal diversity involves the selection that acted on economic interaction patterns. Based on the general models proposed by Neff and colleagues (Neff et al. 1997), I propose two models for examining how selection acted to shape circulation of olivine-tempered ceramics.

Movement of Pots Coupled with Local Specialization

One theoretical model is exchange coupled with local specialization in a particular resource or goods. Neff et al. (1997) suggested that in predictable environments, geographic differences in the return from subsistence and other productive activities are consistent from year to year and that these consistent differences in comparative advantage favor differentiation of productive strategies. In this environmental context, local specialization of ceramics and regional exchange are favored to reduce the cost of producing subsistence resources and other goods, such as pottery. This is because the strategy of producing a slight excess of pots, which are produced easiest in one location, and obtaining necessary goods through exchange, minimizes the cost of obtaining these goods. Local specialization means that potters in different areas exploit distinct raw materials and specialize in different shapes or decorations. Therefore, a strong correlation between compositional groups and formal attributes is expected in all regional ceramic assemblages.

In line with this model, I propose that olivine-tempered ceramics were produced in particular shapes or types in the Mt.Trumbull/Tuweep localities and then exchanged with people living in geologically different areas. I also propose that particular types of pots, such as red ware, were produced in other locations and imported into the Mt. Trumbull/Tuweep localities. However, considering the general environmental conditions in the northern American Southwest, where subsistence resource productivity was unpredictable, this theoretical model may not be applicable to explain the circulation of olivine-tempered ceramics.

Movement of Pots without Local Specialization

An alternative model for explaining the circulation of olivine-tempered ceramics is exchange without local specialization in particular resources or goods. In the American Southwest, where climate tends to vary from year to year, returns from agricultural production also would have varied. Under these conditions, economic specialization would be a risky strategy, and one would not expect to see specific locations specializing in the production of particular types of pottery or other goods. Under these conditions, pots would have moved as a byproduct of population movement or through gift-giving and maintenance of social networks (Neff and Larson 1997). Thus, movement of pots in different geographic settings would have been a mechanism to buffer agricultural risk and would have been decoupled from local specialization. In this situation, each community made all kinds of pots that were needed, and non-local pots in the community were a result of gift-giving or population movement.

Archaeologically, weak or no association between form and composition is expected (i.e., similar form attributes found in varying compositional groups) in accordance to this model. I propose that olivine-tempered ceramics produced in the Mt. Trumbull/Tuweep areas were dispersed as a result of the movement of people or as a result of exchanges to mitigate the imbalance of agricultural productivity or to maintain social networks.

Based on this model, I also expect that not only olivine-tempered pots but also olivine itself was moved, as a result of population movement or as a result of exchange. As briefly introduced in Chapter I, ethnographic studies of ceramic resource procurement suggest that potters do not travel more than nine kilometers to obtain temper materials (Arnold 1985). Considering the long distances between the olivine source area and the areas where olivine-tempered ceramics are distributed, it is likely that all olivine-tempered ceramics were produced near the olivine sources in the Mt. Trumbull and Tuweep areas. However, because olivine is not ubiquitous within the study area, being found only in the Mt. Trumbull and Tuweep areas, it is also possible that olivine itself moved from Mt. Trumbull/Tuweep along with an emigrating population or as an exchanged commodity. Consequently, olivine-tempered ceramics would have been produced at multiple locations with locally available clay.

It is worthwhile considering here why olivine minerals might have been moved independently of manufactured ceramics. For formal reasons, olivine is an excellent tempering material for clay pots. As discussed in previous chapters, olivine has stable thermal properties (Amethyst Galleries, Inc. 1995). Furthermore, a thermal expansion rate of olivine is lower than quartz and close to that of clay, which can avoid thermal stress during heating and cooling of the pots (Rye 1976; Arnold 1985). These factors imply that the olivine is a good tempering material. Potters living in unpredictable environments also may have imported olivine and made olivine-tempered pots in various areas to buffer the imbalance of agricultural productivity or even to maintain social networks. The archaeological expectations of this possibility, that olivine itself was moved and olivine-tempered pots were made in multiple locations with locally available clay, would be a high correlation between at least some of compositional groups and spatial loci where the olivine-tempered ceramics were found. It is also expected that some compositional groups will match local clay in areas where olivine is not locally available (e.g., the lowland Virgin area).

Research Question

As discussed above, I am concerned with how and why clay resource procurement patterns for olivine-tempered ceramics changed over time, the larger goal being to understand how human migrations or exchanges fit into the broader adaptive strategy by which Puebloan people of the Arizona Strip coped with a marginal environment. Because chemical compositional data are the product of the historical sequence of ceramic production and consumption patterns, I propose this specific research question: how and why did ceramic production and consumption patterns observed in chemical composition of olivine-tempered ceramic paste change over time?

Hypothesis

To address the research question stated above, two steps must be taken: (1) propose and evaluate a series of hypotheses, and (2) identify and interpret the compositional groups.

Step One: Hypotheses

Based on the models discussed above, I propose several hypotheses to investigate why the ceramic production and consumption patterns observed in the compositional data changed over time. As a basis for testing the hypotheses, I dated the ceramic samples analyzed by INAA and LA-ICP-MS using the dating technique of optically stimulated luminescence (OSL). I also analyzed the formal attributes of vessels within each compositional group to determine whether compositional groups correlate with particular formal attributes, such as vessel shape or presence of painted decoration, in order to understand what contributes to the formation of the compositional groups.

Hypothesis 1: Under conditions of environmental instability and relatively high population density, social networks as opposed to migration would have been favored as a risk-reducing strategy; the existence of social networks, in turn would have favored clay-resource specialization.

Test implications: Olivine-tempered pots during Pueblo II and III, under the condition of environmental instability with high population density, would be expected to have moved between communities as a result of exchange, and clay-resource specialization would be expected to have occurred.

In marginal agricultural settings, such as the Arizona Strip, an exchange model decoupled from local specialization predicts the movement of pots to minimize risk, as discussed above. In this model, the mechanism for moving pots between different communities may be either exchange or population movement. In early time periods when the population density was relatively low it is more likely that pots moved as a byproduct of population movement, such as migration or seasonal movement, than as a result of economic exchange. I predict, therefore, that during the late Basketmaker and Pueblo I periods, when population density was low, people in Mt. Trumbull/Tuweep moved with their olivine-tempered pots to different communities during periods of food shortage, even if only seasonally. If population mobility rather than exchange is the buffering mechanism, there would be no need to make better pots that are more attractive for trade. In this case, it is expected that the pots were made in Mt. Trumbull and Tuweep with locally available resources obtained immediately adjacent to the habitation sites, and that the compositional groups represent various clay sources in the Mt. Trumbull and Tuweep vicinities. With no need to produce pots for exchange, potters would not have expended the extra energy required to obtain high-quality clays suitable for making pots as gifts. Instead, they would have used the most easily accessible suitable clay to make all pots they needed for domestic use. Although domestic pots ideally should have been made with high-quality clay to reduce breakage, considering the situation that people often moved, procuring especially high-quality clay, which would have required extra time, would not have been an economical choice. Accordingly, the olivine-tempered pots made in Mt. Trumbull and Tuweep would be expected to have moved to the lowland Virgin area with the populations migrating into this area during the time when population density was low.

Generally, in the Arizona Strip and adjacent areas, population size dramatically increased around A.D. 1000. When population density reached its highest level, I predict that exchange was preferred over mobility as a way to buffer agricultural risk. A growing population with restricted mobility also invests more time in the construction of storage facilities or intensification of agriculture. Thus, it is expected that a demand for better-quality pots to serve as attractive trading items stimulated resource specialization, as discussed above. In an environment where clays with different performance characteristics are available within a small area, the specialized use of locally available clays for different types of pottery, or pottery with different functions, would be favored. This resource specialization model entailing the use of locally available clay sources predicts that clay types with varying levels of performance were used to make pots intended for different purposes. Thus, it is predicted that in late times ancient potters spent more time obtaining better-quality clay that was less accessible or more distant from their home villages for the manufacture of pots for gift exchange, whereas any clay adjacent to their occupation areas, regardless of the quality, was still used to manufacture utilitarian pots.

Observable expectations of the archaeological data include: (1) a match of all compositional groups in olivine-tempered ceramics to local clays from the Mt. Trumbull/Tuweep area, (2) occurrence of any compositional group both early and late during the prehistoric sequence of the area, and (3) stronger associations between compositional groups and formal attributes of pots in late compared with earlier in time. For example, overall the ceramic compositional data should show use of all sources during all time periods, but later on, some compositional groups may be represented preferentially in the non-utilitarian wares found in the lowland Virgin area.

Hypothesis 2: Under conditions of environmental instability and relatively high population density, social networks as opposed to migration would have been favored as a risk-reducing strategy; the existence of social networks, in turn, would have favored production of olivine-tempered pots outside of Mt. Trumbull.

Test implications: During Pueblo II and III under the condition of environmental instability with high population density, not only olivine-tempered pots but also olivine itself would be expected to have moved between communities as a result of exchange. As a result, it is expected that potters in the lowland Virgin area would have made pots with olivine using their local clay during late times.

As discussed in Hypothesis 1, it is likely that while population density remained relatively low during late Basketmaker and Pueblo I period, olivine-tempered ceramics produced in Mt. Trumbull/Tuweep were distributed to sites in different biotic communities by means of population movement. As the population density in various areas increased, prospects for population movement became more constrained, so exchange was preferred over population movement. Therefore, it is predicted that under circumstances of high population density, the olivine-tempered ceramics were distributed as exchanged items or as containers for other exchanged items, such as food products. Moreover, it is also possible that the olivine (e.g., olivine nodule) itself was brought to other areas as a trade item. It is likely that the use of olivine as a temper was inherited from immigrants migrating from Mt. Trumbull and Tuweep as part of ceramic production traditions. Descendants of immigrants in other areas, including the lowland Virgin area, may have used local clay to make ceramics with olivine imported from Mt. Trumbull and Tuweep. As a result, it would be expected that more production centers of olivine-tempered ceramics came into existence during later periods, not only at Mt. Trumbull and Tuweep but also in other areas such as the lowland Virgin. Under circumstances when exchanges were preferred over migration to buffer risk, it is also likely that clay resource specialization occurred, as discussed in Hypothesis 1.

For Hypothesis 2, the observable expectations of the archaeological record include: (1) an increase in the number of compositional groups over time, (2) stronger associations in later assemblages between compositional groups and the locations where the ceramics were found, and (3) greater presence later during the prehistoric sequence of some compositional groups outside of Mt. Trumbull.

Hypothesis 3: Under conditions of short-term relative environmental stability and relatively high population density, maintenance of social networks as a risk-buffering strategy would have been selected against; the absence or minimal importance of social networks, in turn, would have favored specialized production of olivine-tempered pots within each community.

Test implications: During late Pueblo II and Pueblo III, when there were a few episodes of short-term stable climatic conditions and population density was high, olivine-tempered pots would have been produced within a community and moved less between communities as a result of exchange, and specialized production of olivine-tempered pots with optimal clay within the community would be expected to have occurred.

Although archaeologists generally agree that climatic conditions were unstable in the American Southwest throughout the time of human occupation, detailed dendroclimatic reconstructions using the Palmer Drought Severity Index (PDSI) demonstrate that the period between A.D. 1050 to 1120 was characterized by generally wet conditions, including some of the wettest consecutive years in the whole thousand-year record. Few years during that period were particularly dry (Larson et al. 1996). Therefore, one can hypothesize that the relatively favorable climatic conditions of this period selected for labor specialization in local ceramic production. During this interval of favorable climatic conditions, it is predicted that returns from subsistence and other productive activities remained relatively consistent from one year to the next and that labor specialization became a viable strategy within communities. Favorable climatic conditions also would have generated agricultural surpluses during some years, leading to the construction of more storage facilities to buffer the agricultural risk and a reduction in the advantage of exchange or population movements as buffering strategies. Thus, I propose that during this time period olivine-tempered ceramics were produced by increasingly specialized potters. In circumstances when the climatic conditions were favorable for agriculture, the accumulated surplus allowed specialized potters to devote more time to pottery production activities, including clay procurement. It is expected, therefore, that potters in Mt. Trumbull and Tuweep would have chosen only clay with better performance characteristics to make better and stronger pots even for daily use, despite the added expense of acquiring better clay. This growing specialization would have freed the non-potters to devote more time to agricultural production. As a result, archaeologically observable expectations include: (1) a decrease in the number of compositional groups over time, and (2) a continued weak association between compositional groups and formal attributes throughout the prehistoric sequence.

Step Two: Identify and Interpret the Compositional Groups

To test the hypotheses proposed above, the first task is to interpret what compositional groups identified in ceramic data represent with respect to ceramic production patterns. Both bulk analysis and pinpoint analysis discussed in Chapter II are involved in this study to test hypotheses. I will propose several potential interpretations of compositional groups based on these two approaches.

Bulk Data: Instrumental Neutron Activation Analysis (INAA)

In bulk analysis, all materials within the ceramic paste are homogenized. Fifty olivine-tempered sherds from Mt. Trumbull were analyzed by INAA in this study (see detail discussion in Chapter V). In the INAA analysis, surface materials such as paint were excluded, and the rest of the sample, including clay and tempering materials as well as other inclusions in the clay matrix, were all mixed together for the analysis. I will propose three potential interpretations of chemical compositional groups identified in INAA bulk analysis.

Proposition 1: Compositional Groups Represent Different Clay Sources.

The finding of distinct compositional groups may derive from different production areas or different resource procurement locations. The interpretation of the compositional groups includes two possibilities: (1) clay from various sources within the olivine source area (Mt. Trumbull and Tuweep), and (2) clay from the olivine source localities (Mt. Trumbull and Tuweep) as well as other localities.

Proposition 2: Compositional Groups Represent Different Paste Recipes.

This alternative proposition entails use of different paste recipes with two main possibilities. The first is the mixing of clay from one source with: (a) different amounts of olivine temper, (b) olivine and other temper materials such as quartz, or (c) olivine temper from different sources (e.g., from different lava flows with different ages). The second possibility is the mixing of clays from different sources.

Proposition 3: Compositional Groups Represent Chemical Alterations Due to Diagenesis.

Chemical alternation of paste may occur due to various uses of pottery, such as storing vs. cooking foods. Different groups may also result from diagenesis, that is, post-depositional chemical change in pastes. In this case, the chemical compositional groups do not represent either the clay sources or paste recipes.

Point Analysis Data (Clay Matrix Only): Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)

Another chemical compositional analytical technique involved in this study is LA-ICP-MS, which is a pinpoint analysis. In this analysis, only clay matrix is analyzed, avoiding temper or any inclusion. I will propose four potential interpretations of the compositional groups identified in clay matrix of sherd samples with LA-ICP-MS. The data set includes ceramic samples with both olivine and non-olivine temper from Mt. Trumbull/Tuweep and the lowland Virgin area.

Proposition 1: Compositional Groups Represent Different Clay Sources.

The compositional groups may indicate different production areas or different resource procurement locations. The interpretations of compositional groups include: (1) clay from various sources within the olivine source area (Mt. Trumbull and Tuweep), and (2) clay from the olivine source localities (Mt. Trumbull and Tuweep) and other localities.

Proposition 2: Compositional Groups Represent Different Paste Recipes.

The various paste recipes that created different compositional groups in the point analysis could have entailed mixing clays from multiple sources.

Proposition 3: Compositional Groups Represent Clay Preparation/Quarrying Techniques.

The compositional groups may be the result of using different techniques to prepare the clay; each technique resulting in different chemical properties of the substance, thus changing the chemical properties of clay matrix. If larger minerals are removed from the raw clay and only finer particles are used for pottery production, some of the element composition may change compared to the raw clay. In addition, clay from deeper deposits may have different chemical signatures than clay from shallower deposits because the deeper deposits may contain finer clay. Thus, the compositional groups may represent the acquisition of clay from different depths of deposits, even if they come from a single source.

Proposition 4: Compositional Groups Represent Chemical Alterations Due to Diagenesis.

As mentioned in the discussion about how to interpret bulk data, the chemical alteration of paste may occur due to various uses of pottery, such as storing vs. cooking. Different groups in the point analysis may also result from diagenesis, that is, post-depositional chemical change of pastes. In this case, the chemical compositional groups do not represent clay sources or paste recipes.

Summary

The ultimate goal of this study is to understand how small-scale farmers coped with a marginal environment through various forms of social interaction and why the pattern changed over time. These social interaction patterns can be inferable from production and consumption patterns of widely distributed olivine-tempered ceramics inferred from chemical compositional analysis combined with formal attribute analysis. Therefore, my specific research question is: how and why did ceramic production and consumption patterns observed in chemical composition of olivine-tempered ceramic paste change over time? To answer this question, I proposed three hypotheses based on two levels of selection; one acting on social/economic interaction patterns, and the other acting on ceramic local production, under the condition of different levels of environmental instability as well as population density. In the next chapter I will discuss the data collection procedures for the data analysis and for testing the hypotheses.

Chapter IV: DATA COLLECTION

The previous chapter presented a series of hypotheses to explain how and why the production and consumption patterns observed in the chemical composition of olivine-tempered ceramics changed over time. As the first step to test these hypotheses, ceramic samples were obtained for compositional analyses and luminescence dating. These samples were derived from my own fieldwork and from earlier collections. The ceramic samples from Mt. Trumbull were gathered from surface collections and test excavations during my fieldwork and those from Tuweep and the lowland Virgin area are from previous collections.

Fieldwork

Fieldwork that I conducted for this dissertation includes site recording/test pit excavation in Mt. Trumbull to collect ceramic samples, source clay samples for chemical compositional analysis, and background sediments for optically stimulated luminescence (OSL) dating. Site recording/test pit excavations were conducted at the following seven sites in Mt. Trumbull: AZ:A:12:30 (BLM); AZ:A:12:204 (BLM); AZ:A:12:131 (BLM); AZ:A:12:71 (ASM); AZ:A:12:136 (ASM); AZ:A:12:214 (ASM); and AZ:A:12:14 (MNA). For the sake of brevity, the "AZ:A:12" prefix will not be included in the site designations in this dissertation. The locations of these sites are shown in Figure 4.1. There were three purposes for site recording and test pit excavations. The first purpose was to obtain ceramic

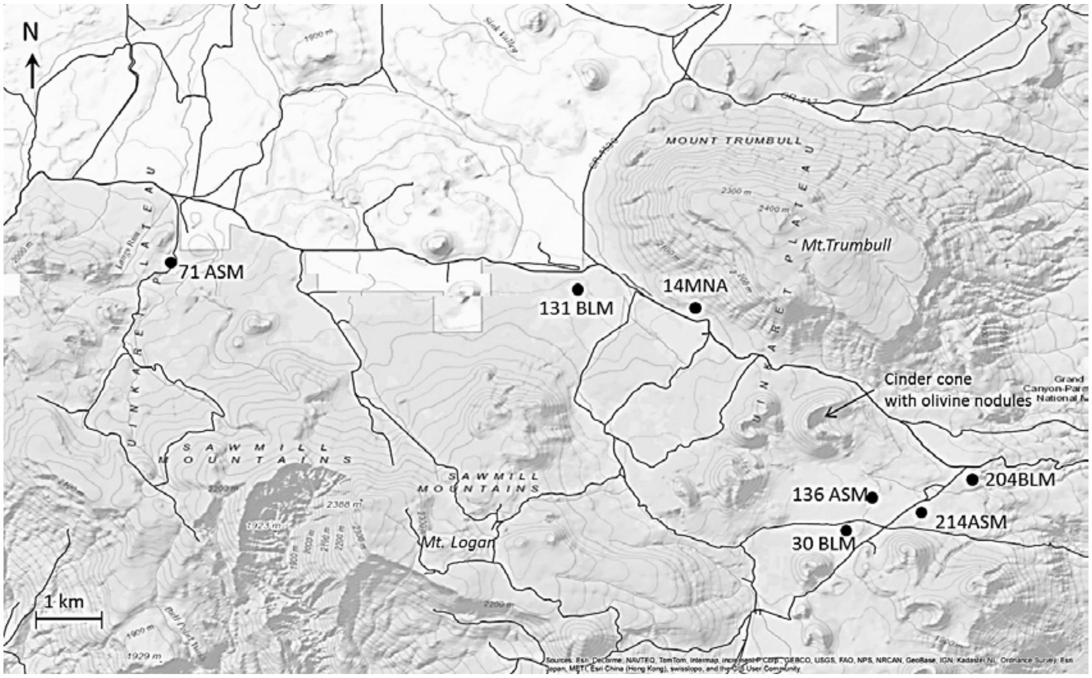


Figure 4.1. Map of archaeological sites in Mt. Trumbull included in this study. Olivine nodules are found at various locations in the area. The cinder cone indicated in this map is where olivine nodules are found most abundantly.

samples for compositional analysis and luminescence dating from both surface and subsurface contexts. The second was to gather contextual information for ceramic samples, such as the kind of site (e.g., C-shaped pueblo, pithouse), function of the site (e.g., house, storage), and time and duration of occupation of the site. This contextual information was used to understand the compositional groups, changes in compositional patterns, and consequently, changes in the production and distribution of olivine-tempered ceramics. The third purpose was to examine changes in the frequency of ceramic types, including olivine-tempered ceramics. The site recording/test pit excavations were conducted during archaeological field schools (Nevada State College/Desert Research Institute) co-taught by Paul Buck and me, except for site recording and testing of a looted room at 14 MNA. The clay and sediment samples were collected by me and volunteer helpers between the field school seasons.

Methods

The fieldwork for recording archaeological sites and collection of ceramic samples were conducted during annual field schools between 2001 and 2006 (except 2002), and the collections of clays for compositional analysis and sediments for luminescence dating were conducted between 2003 and 2008. Although small changes or adjustments were made for each site, standardized methods were generally employed.

Mapping

All seven sites in Mt. Trumbull considered in this dissertation were mapped at the onset of this study. Although all sites have structures/possible structures, site boundaries were based on the change in surface artifact densities. In order to determine a site boundary, field crews walked transects in the four cardinal directions from the center of the structure area marking with pin flags the locations of artifacts, artifact concentrations, and other features until no artifacts/features were found within 20 m of the last finds. However, the general background “noise” of artifacts is very high in most areas in Mt. Trumbull; artifacts are widely distributed and are often found continuously in areas between sites. Thus, in some cases, a site boundary was not based on “no artifacts/features found within 20 m of the last find.” Instead, when we did not see many artifacts/features roughly within 10–15 m, we stopped the survey and determined a site boundary arbitrarily based on the change in number of pin flags, which reflected changes in artifact frequency. A handheld GPS was used to record site boundary coordinates for a site boundary map.

Before mapping structures and other features, each room or room block was inspected carefully. A plane table, alidade and Philadelphia rod were used to prepare plan maps for five sites, including 30 BLM, 204 BLM, 71 ASM, 136 ASM, and 214 ASM. We mapped only those rocks that seemed to indicate the original wall alignments. The plan view maps of site 14 MNA and 131 BLM were produced differently. In both sites, grid systems were established using a total station, and surface features were mapped in each unit. These unit maps were combined and scanned to make electronic versions of the maps of the entire set of structures.

Surface Collection Units (SCUs)

In order to obtain representative samples of artifacts from site surfaces, I collected artifacts using surface collection units (SCUs) randomly laid over the surface of the site. In most sites, I used a stratified sampling strategy. At four sites (204 BLM, 136 ASM, 214 ASM, and 131 BLM), I separately collected surface ceramics from SCUs in the central structural parts of the site (SCU-A stratum) and from those within areas of artifact scatters and other features (SCU-B stratum). At the 71 ASM site, three dispersed structural areas were identified. Therefore, SCUs were placed at each of these: the SCU-A stratum was in the bottom of the hill area, the SCU-C stratum was in the middle of the hill area, and the SCU-D stratum was at the top of the limestone hill. The SCU-B stratum was placed on the periphery. At site 30 BLM, there were two structural areas, so the SCU-A and SCU-C strata were placed in those areas, while the SCU B stratum was placed outside of the structural areas. SCUs in SCU-A stratum and SCU-C and D strata at 71 ASM were 2 x 2 m grids due to the high density of artifacts, while the SCUs in the SCU-B grids were either 4 x 4 m or 5 x 5 m. The random number generator in MS Excel was used to choose at least 10 units in each sample stratum to avoid bias in selecting the area of surface collection. A handheld GPS was used to find the southwest corner of the SCU selected, and pin flags and metric tapes were used to triangulate the remaining three corners of the SCU. Covering vegetation within the SCU was removed to enhance visibility of artifacts, and the vegetation was also screened using 1/8” sieves to collect artifacts within the vegetation. Only artifacts visible on the surface were collected. The total area of the SCUs is a very small portion of the site, usually about 1 percent or less. Simple random sampling was used to select the SCU at 14 MNA.

Artifacts from each SCU were bagged by category (e.g., ceramics, lithics). Once they were brought to the laboratory, the ceramics were sorted and bagged by size (larger than 1 inch vs. smaller than 1 inch).

Surface General Collection (Grab Samples).

In addition to systematic surface collection, diagnostic artifacts were collected outside the randomly chosen SCUs. Decorated sherds are rare at all sites in Mt. Trumbull, so larger decorated sherds, which provide detailed design elements, and rim sherds, which may be time indicators, often were collected. Luminescence dating requires the larger, thicker sherds, so occasionally large sherds were also collected.

Soil Augering

A bucket auger (3” diameter-bit) was used to estimate the depth of the deposits and also to collect charcoal samples for ^{14}C dating. The soil augering was conducted prior to the year when test pit excavation was conducted.

Test Pit Excavation

For the research reported here, the purpose of test pit excavations was to obtain subsurface ceramic samples and to examine the change over time in frequency of ceramic types, including particularly olivine-tempered types. Therefore, the test pits were excavated in midden areas where artifacts from daily use had accumulated over substantial periods of time. The locations of test pit excavations were chosen intuitively within areas of high densities of artifacts, while avoiding the interiors of structures due to the permit limitations. Excavation in the cultural level was conducted using a trowel and dustpan. A small pick and/or shovel were used when artifacts were not present, especially close to the bottom of a test pit. Surface artifacts were collected before proceeding to excavation. The excavation was conducted in arbitrary 10 cm levels. All artifacts/ecofacts from the same level were bagged by artifact category. Small soil samples were also collected within each level for flotation and luminescence dating analysis. The remainder of the soil was sieved through 1/8”mesh. When a large diagnostic sherd suitable for luminescence dating analysis was found, the sherd was bagged separately from the rest of the artifacts, and the soil directly underneath the sherd was also collected. Large pieces of charcoal or potential carbonized seeds/corn kernels were collected with a trowel and then wrapped in aluminum foil for ^{14}C dating. Sherds with associated charcoal were also bagged separately. No further excavation was carried out if no artifacts were found within one or two successive levels. When a level of excavation was completed, a level recording form was filled out, and the profile of one or more of the walls was drawn. When a cultural feature was found during excavation, a plan-view map was drawn showing the location of the feature. After all excavation was completed, the test pits were backfilled to conserve the site and to prevent potential looting.

Clay Sampling

Clay samples for compositional analysis were collected between 2003 and 2008 in Mt. Trumbull. Clay samples were also collected from various other areas, including the lowland Virgin area and between Mt. Trumbull and the lowland Virgin area. In both Mt. Trumbull and the lowland Virgin areas, the clay samples came from various geologic formations.

Volcanic rock formations cover most of the Mt. Trumbull area (Billingsley and Hamblin 2001; Billingsley et al. 2003). Samples of mostly volcanic-derived clay were collected during site excavations from walls of washes near the seven archaeological sites and from wash walls or road cuts at other locations in Mt. Trumbull. In addition to volcanic formations, small pockets of sedimentary rock formations occur in Mt. Trumbull. For example, Chinle formation exposures were identified west of Mt. Logan and west of Hurricane Fault, less than 10 km from the area of archaeological site concentration in Mt. Trumbull. Small exposures of possible Chinle formation with petrified wood on the south slope of Mt. Trumbull were also identified during the field season. Most of the Triassic Moenkopi formation is covered by Quaternary basalt flows and landslide debris in the Sawmill Mountains, Mount Logan (both are within 5 km from the site concentration area), and Mt. Trumbull areas. Thus, some clay samples were acquired from exposures of the Moenkopi and Chinle formations. In most places, I collected these clay samples on the very steep slopes where the surface soil slid down. There are also secondary clay deposits just south of Mt. Trumbull, near site 14 MNA. The secondary clay samples collected from this location likely contain both weathered volcanic and sedimentary clays, because this deposit appears to be just below the location of the Chinle formation exposures.

In the lowland Virgin area, mostly sedimentary and secondary clays occur. Larson and his students collected clay samples in 1997 for INAA analysis (Larson et al. 2005), which I analyzed by LA-ICP-MS for this dissertation. Additional clay samples from various formations were also collected in the lowland Virgin area from along both the Virgin and Muddy Rivers.

In most cases in both Mt. Trumbull and other areas, clay was obtained either from road cuts, subsurface deposits between 10 cm and 50 cm below the surface, or from testing at the sites in Mt. Trumbull. When clay samples were obtained from road cuts or drainage walls, they were at least 10 cm from the exposed surface to avoid contamination. The clay was collected using a trowel and then bagged. Once clay samples were returned to the lab, a portion of the clay was dried. A portion was also "prepared" before analysis (see sample preparation for ICP-MS in Chapter V).

The following is a summary of the clay collections. Except for the test units, most of the clays were from relatively shallow deposits (10–50 cm below the ground surface). The clays in the test units came from deposits that were as much as 100 cm deep. Clays from 170 locations were sampled, including both primary (volcanic and sedimentary) and secondary clays that may be weathered volcanic or sedimentary clay, or clay from landslide deposits.

Clay samples were collected in the vicinity of Tuweep and on the Shivwits Plateau in addition to those obtained from Mt. Trumbull. Over 30 clays were collected in Tuweep during 2000, with a clay collection permit from Grand Canyon National Park. Most of the clays were from relatively shallow deposits. Fifteen clay samples were collected on the Shivwits Plateau in 2002. Again, the deposits of clay were relatively shallow (~40 cm).

In the lowland Virgin area, 37 samples of both sedimentary and secondary clays were collected. In addition to the clays in Mt. Trumbull and the lowland Virgin area, clay samples from more distant areas were collected and included in the analysis. Although it is unlikely that potters used clay from distant areas to make their pots, these clay samples were compared to the ceramic compositional groups, especially when the compositional groups did not match either Mt. Trumbull/Tuweep or the lowland Virgin clays. Comparing these compositional groups for which I could not identify the source to the distant clays may help in discovering what kinds of clay could be potential sources for the groups. These distant clays are of very good quality for pottery production; they include Chinle clays collected from southern Utah (near Hurricane and Quail Creek) and from near the road between Mt. Trumbull and Colorado City.

Background Sediment Collection for Luminescence Dating

From each level of the test excavations in Mt. Trumbull, a small portion of sediment was saved for luminescence dating as discussed above. Radioactive elemental concentrations of potassium, uranium, and thorium from the background soil will contribute to calibrating the luminescence dates. Thus, ideally, soil should be collected from exactly the same provenience of the analyzed sherds. However, because it is not realistic to choose in the field the samples that will be used for luminescence dating, at least 100 g of sediment was collected from each level in all instances where the matrix of the level is homogenous. When a large diagnostic sherd that was likely to be analyzed for this dissertation was found, it was saved, along with the sediments directly beneath it. When a cultural feature was found and a sherd associated with the feature was collected for luminescence dating, the sediment in which the sherd was embedded was also collected. For surface collection from SCUs and general surface collections, at least 100 g of sediment were collected within a 25 m diameter of the ceramic samples.

In the lowland Virgin area, Larson collected ceramic samples in the 1970s. The sediments for luminescence dating were collected in 2009 from a few locations along the Virgin River, which entailed collecting samples from all possible geological formations—the top of the mesa, the riverbank, and the flood plain. Four luminescence dating background sediment samples were collected from the east bank of the Virgin River and eight sediment samples were collected from the west bank. When calibrating the luminescence dating data, the distance between the site where the sherds originated and the locations of the sediment samples were considered in order to choose the appropriate luminescence dating sediment sample. The locations of the sediment samples in the lowland Virgin area are shown in Figure 4.2.

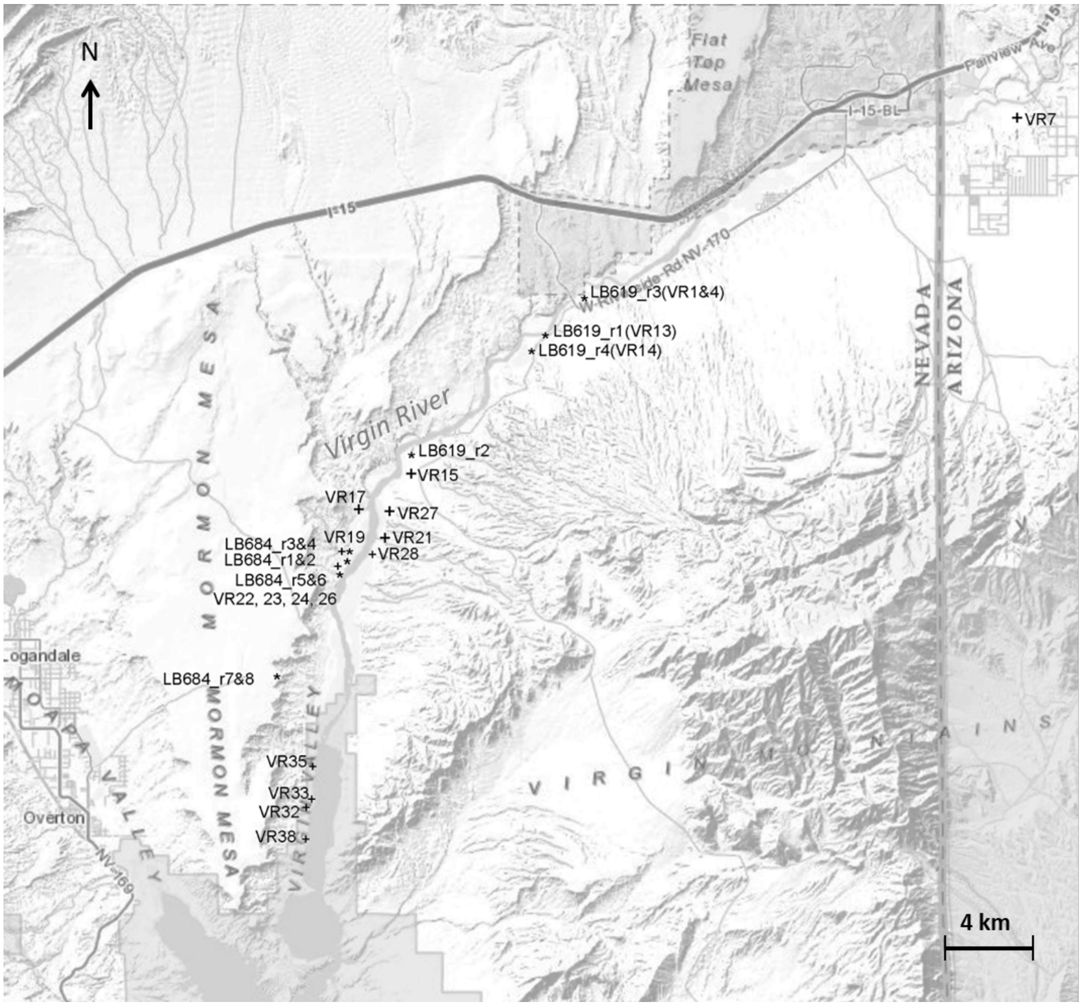


Figure 4.2. Map of the lowland Virgin area showing background sediment collection locations for the OSL dating and archaeological sites involved in this study. OSL sediment locations are shown as *LB###_R# (e.g., LB619_R2) and site locations are shown as +VR## (e.g., VR1).

Site Descriptions

All recording/test excavation was conducted during the archaeological field schools and also the field projects of the Desert Research Institute (DRI) and California State University, Long Beach (CSULB). The locations of the archaeological sites are shown in Table 4.1.

Table 4.1. List of the archaeological sites in Mt. Trumbull included in this study along with their UTM coordinates, elevations, and types.

Site		East	North	Elevation (m)	Type of site
30 BLM	12S	309380	4025340	1908	C-shaped pueblo
131 BLM	12S	304960	4030030	1969	Room blocks
204 BLM	12S	311080	4026170	1868	Depressions
71 ASM	12S	298650	4030800	1890	Room blocks
136 ASM	12S	309480	4025840	1917	E-shaped pueblo
214 ASM	12S	310246	4025563	1893	Room blocks
14 MNA	12S	306960	4029470	1987	C-shaped pueblo

In 2001, Paul Buck of DRI conducted a field project that involved mapping, systematic surface collection, and limited testing of disturbed rooms at site 14 MNA. During the 2003 field season, mapping, systematic surface collection, and augering were conducted at 131 BLM during a DRI archaeological field school. In 2004, the field school of DRI/Nevada State College (NSC) started mapping, systematic surface collection, and auguring at 30 BLM, 204 BLM, 136 ASM, and 71 ASM. The later fieldwork was carried out with the help of student volunteers at CSULB. In 2005, test pit excavations were conducted at 30 BLM, 204 BLM, 131 BLM, 71 ASM, and 136 ASM during a DRI/NSC field school, with the help of CSULB student volunteers. Mapping, systematic surface collection, and test pit excavation at 214 ASM was conducted in the same field season. Test pit excavation at 14 MNA was conducted during a DRI/NSC field school in 2006.

AZ:A:12:30 (BLM)

This site consists of a large C-shaped pueblo constructed of basalt rocks with a detached storage room and a dense artifact scatter. Approximately 15 rooms have been identified in this pueblo. The central plaza area is indicated by a shallow depression, which may be a pithouse structure. A map of the C-shaped pueblo is shown in Figure 4.3. The second structure, consisting of one to three rooms, is on a low knoll about 60 m west of the main C-shaped pueblo. It is not clear if these structures are contemporaneous. Collections from 29 SCUs were made, and about 2,300 sherds were collected (Table 4.2). A carbonized corn kernel was collected

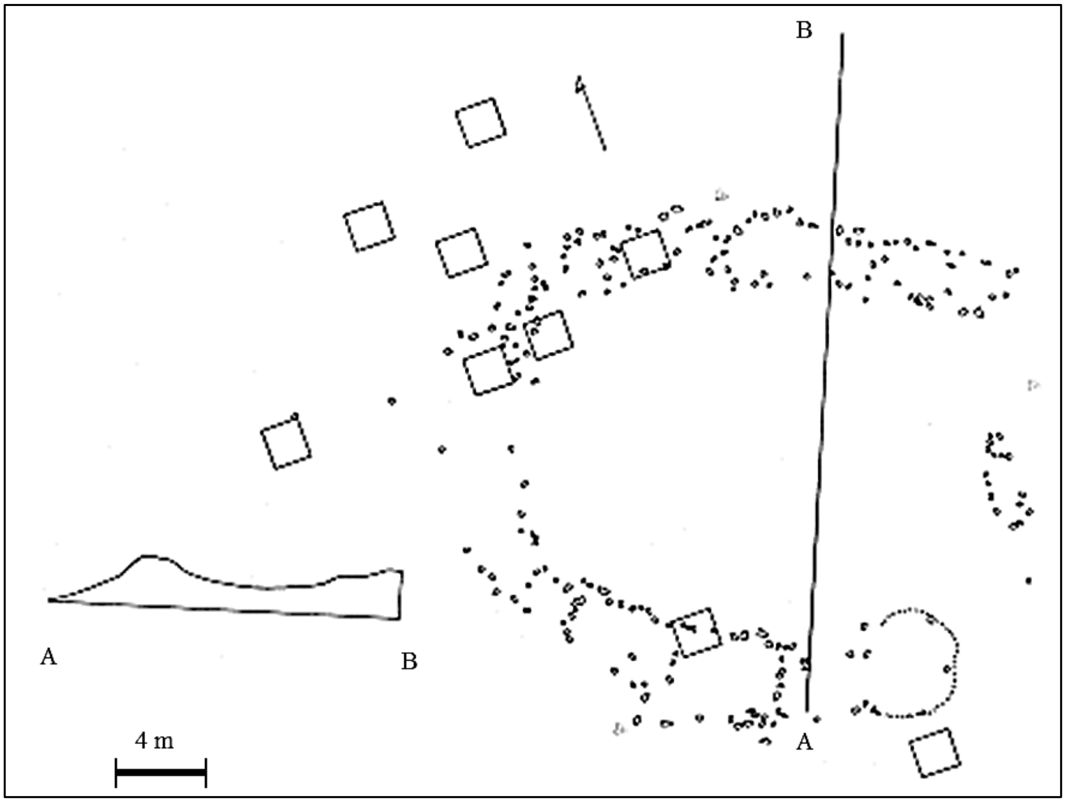


Figure 4.3. Map of site 30 BLM. The squares indicate 2 x 2 m surface collection units in area A. The figure in lower left lower corner is a cross sectional profile along the line shown on the map.

Table 4.2. Number of artifacts from systematic surface collection units (SCUs).

Site	Number of surface collection units	Total artifacts	Sherds	Lithics
30 BLM	29	2476	2270	206
131 BLM	21	5922	5052	870
204 BLM	24	138	105	33
71 ASM	35	462	350	112
136 ASM	24	2754	2618	136
214 ASM	24	558	432	126
14 MNA	13	1941	1096*	845
Total		14248	11923	1483

Note: Sherds from 14 MNA include only those greater than 1 inch in length, whereas those from other sites are of all sizes.

Table 4.3. Number of artifact counts from test pit excavation.

Site	Number of test pits	Total artifacts	Sherds	Lithic
30 BLM	3	3410	3027	383
131 BLM	3	5814	5189	625
204 BLM	3	147	111	36
71 ASM	4	256	206	50
136 ASM	5	4617	4133	484
214 ASM	5	533	473	60
14 MNA	15	9509	7412	2097
Total		24286	20551	3735

from a soil probe (65 cm deep) and was submitted for ^{14}C dating; an AMS date of A.D. 1110–1190 was returned. Three 1 x 1 m test pits were excavated in the area with high artifact density, and approximately 3,000 sherds were collected (Table 4.3). Test pit 2 was set on a gentle slope immediately west of the opening of C area, which may be a midden. This was the deepest pit and showed that this site contains at least 1.20 m of cultural deposits, including well-preserved charcoal and bone, in

Table 4.4. Frequency of sherds with olivine temper, sherd temper (with olivine inclusions), and sand temper.

	Olivine temper	Sherd temper (olivine inclusions)	Sand temper
30 BLM	86.7%	3.4%	10.0%
131 BLM	87.9%	0.9%	11.3%
204 BLM	88.1%	0.0%	11.9%
71 ASM	98.2%	0.0%	1.8%
136 ASM	89.6%	2.0%	8.4%
214 ASM	92.2%	2.3%	5.5%
14 MNA	91.3%	4.5%	4.2%
Average of all sites	89.8%	2.9%	7.2%

Note: Data are based on sherds (greater than 1 inch size) collected from test pits and surface collection units except 14 MNA. Both sherds from test pits and room testing (greater than 1 inch size) at 14 MNA were used.

Table 4.5. Ratio of corrugated ware from surface collection units (SCUs) and test pits (TPs),as well as radiocarbon dates from each site in Mt. Trumbull .

Site	% sherds >1' corrugated from SCU	% sherds >1' corrugated from TP	^{14}C dates (2 sigma calibration)
30 BLM	11.7	16.5	A.D. 1110–1190
131 BLM	2.0	1.2	A.D. 620–690, A.D. 680–880, A.D. 900–1030
204 BLM	0.0	0.0	A.D. 810–890
71 ASM	0.9	0.0	A.D. 880–1010
136 ASM	15.9	13.3	A.D. 790–1040, A.D. 960–1040, A.D.1020–1270
214 ASM	44.0	31.4	A.D. 640–770
14 MNA	39.3	26.6	A.D. 880–1010, A.D. 1000–1170, A.D. 1020–1210, 1160–1280

addition to abundant sherds and lithics. The proportion of olivine-tempered ceramics (sherds larger than 1 inch) from three test pits is 86.7 percent (Table 4.4). The ratio of corrugated ware from test pits is 16.5 percent, and that from the SCUs is 11.7 percent (Table 4.5). The decorated sherds include black-on-gray, red, and black-on-red wares (Table 4.6). A few polychrome sherds were found in both the SCUs and

Table 4.6. Summary of decorated wares from test pits and surface collection units at each site in Mt. Trumbull included in this study.

Site	Test Pits				Surface Collection Units			Presence in general surface collection	
	Total	Black-on-gray	Red	Poly-chrome	Total	Black-on-gray	Red	Red	Poly-chrome
30BLM	3027	148 (4.9%)	18 (0.6%)	1 (0.03%)	2267	76 (3.4%)	13 (0.6%)	O	O
131BLM	5189	171 (3.3%)	6 (0.1%)	0 (0.0%)	5052	226 (4.5%)	14 (0.3%)	O	X
204BLM	111	0 (0.0%)	0 (0.0%)	0 (0.0%)	105	3 (2.9%)	0 (0.0%)	O	X
71ASM	206	1 (0.5%)	0 (0.0%)	0 (0.0%)	350	30 (8.6%)	1 (0.3%)	O	X
136ASM	4133	136 (3.3%)	10 (0.2%)	1 (0.02%)	2618	79 (3.0%)	7 (0.3%)	O	O
214ASM	473	9 (1.9%)	3 (0.6%)	0 (0.0%)	432	15 (3.5%)	3 (0.7%)	O	X
14MNA	7412	303 (4.1%)	34 (0.5%)	0 (0.0%)	1096*	105 N/A	38 N/A	O	X

Note: Percentages in parentheses are the ratio of sherds with decoration to total sherds from the site (both greater and less than 1 inch size). Total sherds in surface collection units at 14MNA include only sherds greater than 1 inch; thus, a ratio was not calculated.

test units. The ^{14}C date (AD 1110–1190) and the existence of polychrome sherds suggest that 30 BLM was occupied until the early Pueblo III period.

AZ:A:12:131(BLM)

131 BLM (Zip Code Site) is located at the edge of a flat hill overlooking a valley covered in sagebrush. This flat hill extends to the slope of Mt. Logan. The site consists of a large pueblo complex at least 200 m long. Because about one-third of this site is on state land, only the federal portion of the land was surveyed and tested. Detailed mapping revealed the existence of about 20 rooms constructed of

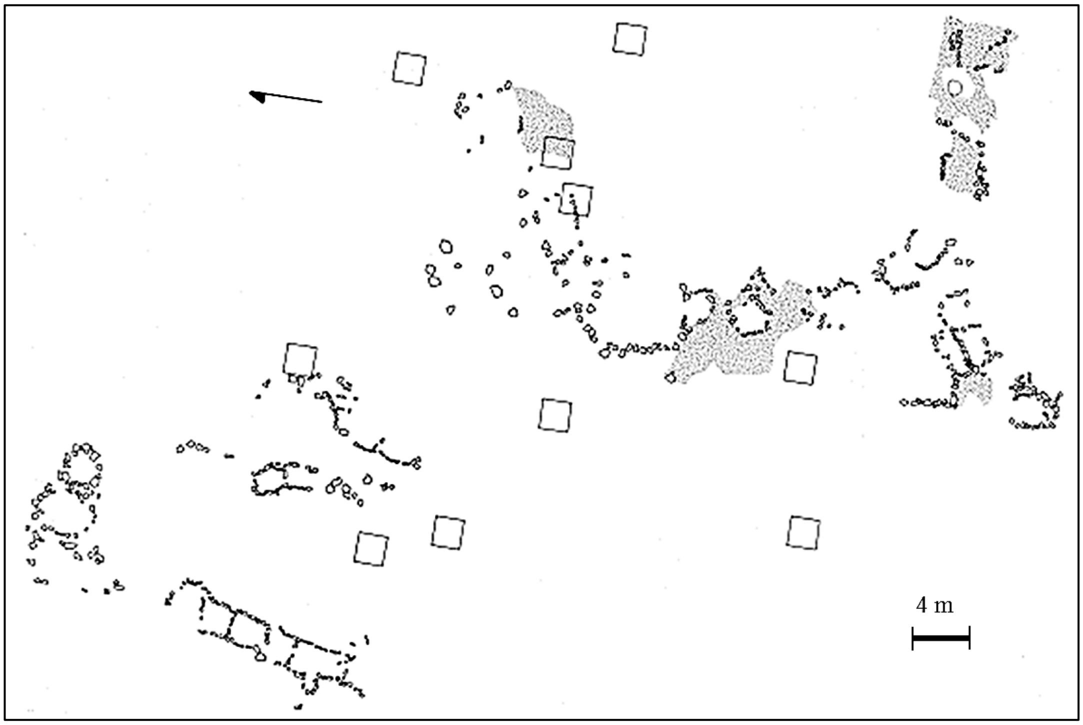


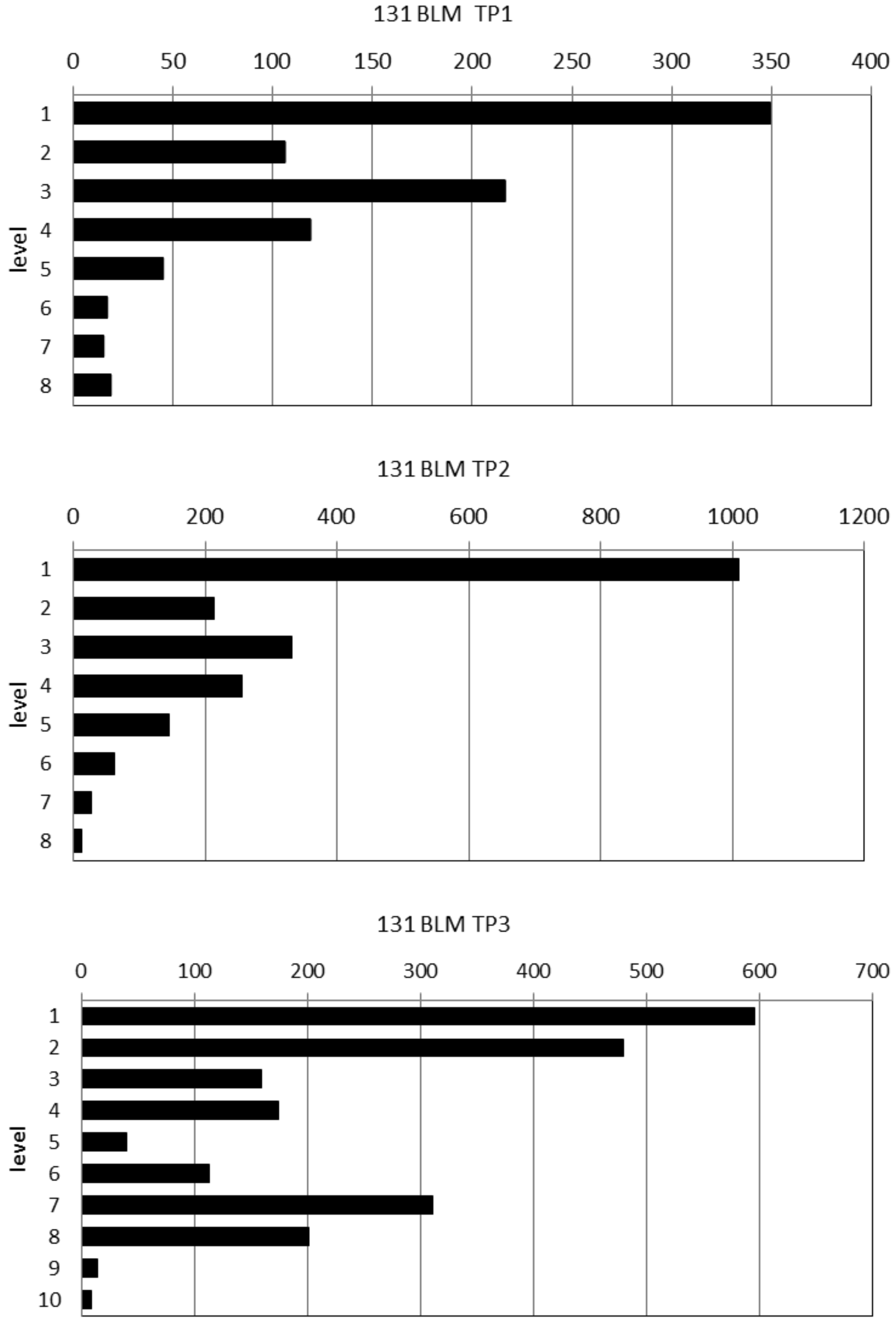
Figure 4.4. Map of site 131 BLM. Squares (2x2 m) are surface collection units.

basalt rocks (Figure 4.4). Several slight depressions indicate possible pit houses. Soil augering in one of the depression revealed a distinctive clay layer 80 cm deep that may be a prepared floor. Approximately 5,000 sherds were collected from 21 SCUs (Table 4.2). A very small number of the sherds are corrugated (Table 4.5), which implies that the site was occupied during the late Basketmaker III or Pueblo I period. The three charcoal samples from soil auger tests were dated at A.D. 620–690, A.D. 680–880, and A.D. 900–1300 (Table 4.7). Three 1 x 1 m test pits were excavated outside the structures in areas of high artifact density. Unlike other sites, the non-cultural layer at the base of the test pits was not cinders, but instead it was

Table 4.7. AMS radiocarbon dates for sites in Mt. Trumbull.

Site	Provenience	Material and method	2 sigma calibration
14 MNA	Fill, Room #1	Wood charcoal AMS	A.D. 1000–1170
14 MNA	Fill, Room #2	Wood charcoal AMS	A.D. 1160–1280
14 MNA	Fill, Room #3, 3 cm above floor	Wood charcoal AMS	A.D. 880–1010
14 MNA	Fill, Room 3, 7 cm above floor	Wood charcoal AMS	A.D. 1020– 1210
131 BLM	Feature 2, slab covered pit	Wood charcoal AMS	A.D. 680–880
131 BLM	Soil probe #6, 20 cm deep—possible pithouse	Wood charcoal AMS	A.D. 620–690
131 BLM	Soil probe #15, 70-80 cm deep	Wood charcoal AMS	A.D. 900–1030
204 BLM	Soil probe #10, 111 cm deep	Wood charcoal AMS	A.D. 810–890
30 BLM	Soil probe #7, 65 cm deep	Maize kernel AMS	A.D. 1110–1190
71 ASM	Test Pit 3, Level 3	Wood charcoal AMS	A.D. 880–1010
136 ASM	Locus E testing, Unit 2, directly under corrugated jar	Wood charcoal AMS	A.D. 960–1040
136 ASM	Test Pit 1, Feature. 1, Level 4	Wood charcoal conventional ^{14}C	A.D. 790–1040
136 ASM	Test Pit 2, Level 5	Wood charcoal conventional ^{14}C	A.D. 1020–1270
214 ASM	Test Pit 5, bottom Level 2	Wood charcoal AMS	A.D. 640–770

chalky white, compact silt or possibly volcanic ash. The distribution of artifacts by layer especially in TP3 was bimodal (Figure 4.5). This suggests that this site had at least two phases of occupation, one of which might have been as early as A.D. 620 followed by a break in occupation and the second occupation after A.D. 900. Corrugated sherds (greater than 1 inch) from the test pits accounted for about 1.2 percent of the sherds (Table 4.5), and the proportion remained low throughout the depth of deposits (Figure 4.6). Although the purpose of the test pit excavation was to obtain artifacts from potential midden areas, one of the test pits (TP-2) was dug to catch the corner of a pithouse, the floor of which seemed to have been dug into the compact layer of white silt or ash. Initial occupation of the site seems to have been



131 BLM TP1

131 BLM TP2

131 BLM TP3

Figure 4.5. Variation in artifact frequencies from test pit excavations at 131 BLM. Horizontal bars show the frequency of artifacts, including both ceramics and lithics, by excavation level.

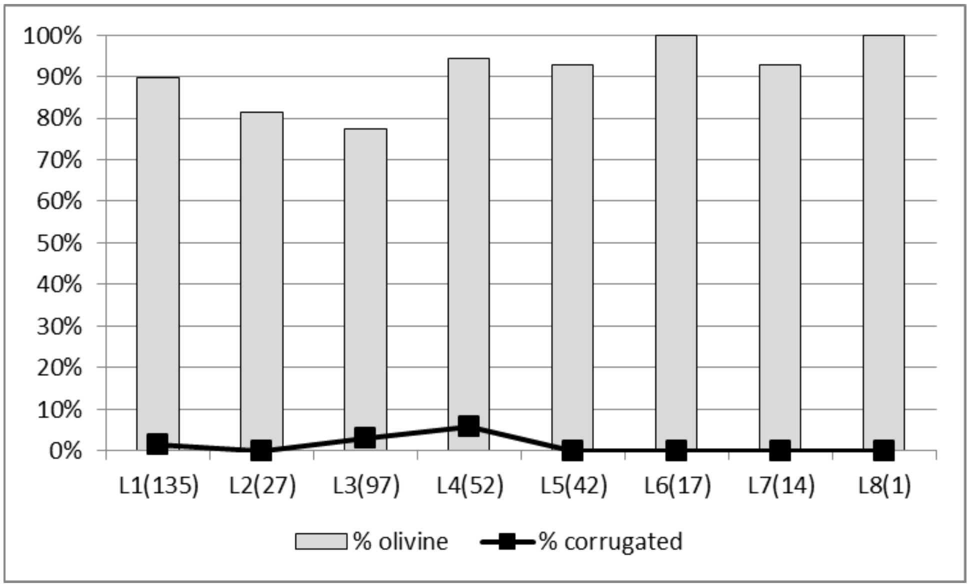


Figure 4.6. Frequency of olivine-tempered ceramics (> 1 inch) and corrugated ceramics from TP 2 at 131 BLM. Values in parentheses are the total number of sherds greater than one inch from each level.

on top of the compact white ash-like layer. Test pit 3, which is just outside the structure, revealed clear evidence of two occupational phases based on artifact frequencies per level. Burned adobe fragments that could have been a part of a wall were found in the upper level.

AZ:A:12:204 (BLM)

This site consists of four shallow 4–6 m diameter surface depressions, indicating pithouses (Figure 4.7). Systematic surface collection from 24 SCUs resulted in only 105 sherds. A very small number of black-on-gray ware sherds was found (3 of 105 sherds; Table 4.6), and corrugated red wares were absent (Tables 4.5). Soil augerings revealed at least 1 meter of cultural material in the

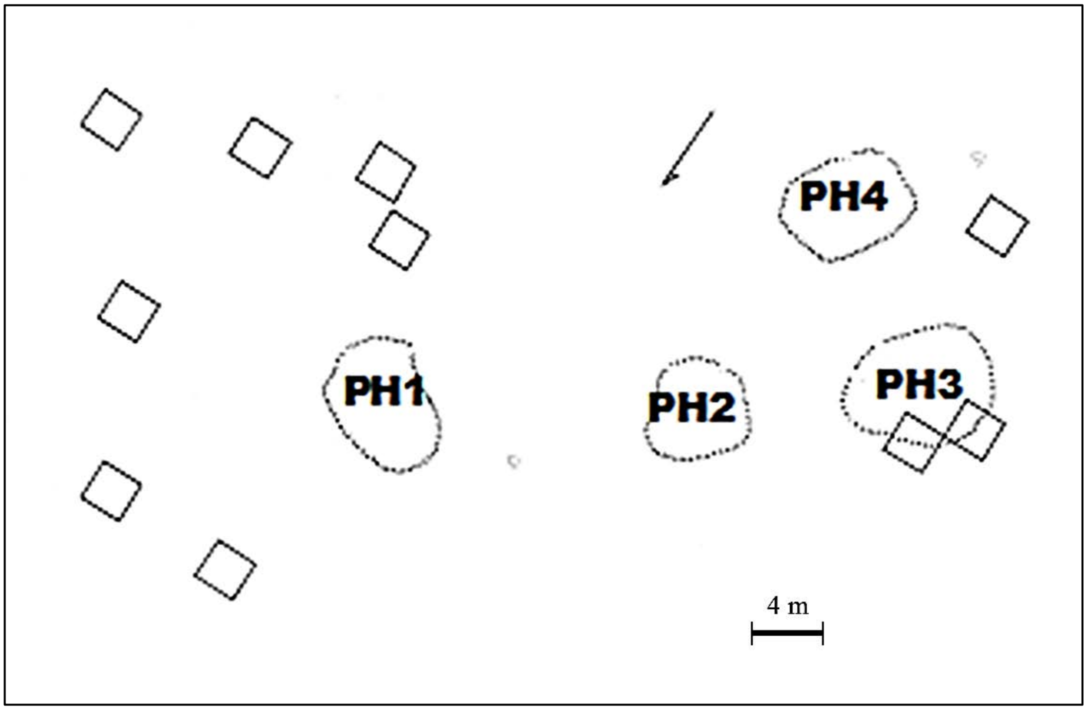


Figure 4.7. Map of site 204 BLM. Squares (2x2 m) are surface collection units.

depressions. A ^{14}C sample that yielded a date of A.D. 810–890 was obtained from a depth of 80–111 cm, which may be about 20 cm above a pithouse floor. This suggests that 204 BLM is an early Pueblo I period site. Three test pit excavations were made in the area of relatively dense artifact scatter beyond the depressions. One hundred and eleven sherds were recovered from the test pits (Table 4.3), and these did not include corrugated or decorated wares (Tables 4.5 and 4.6). The depth of all test pits was relatively shallow (< 40 cm).

AZ:A:12:136 (ASM)

This site is also known as “Ken’s ‘Big E’ site” or the “E-shaped Pueblo.” As indicated by its name, the main structure of this site is a large E-shaped pueblo. A shallow depression about 5 m in diameter exists just off the southeast end of the upper arm of the E, is suggested to be a kiva or pithouse on the original site record (Arizona State Museum Archaeological site card) created in 2004. A dense concentration of artifacts was associated to the structures and the depression. The original sketch map shows a very linear configuration of rooms in the shape of an E, which suggests an influence from the Kayenta Ancestral Pueblo culture. Traditionally, the arrangement of rooms within the Virgin Branch Ancestral Pueblo area is circular, whereas in the Kayenta area it is rectilinear. A detailed architectural map of the E-structure was made in 2005; it depicts the room arrangement as not

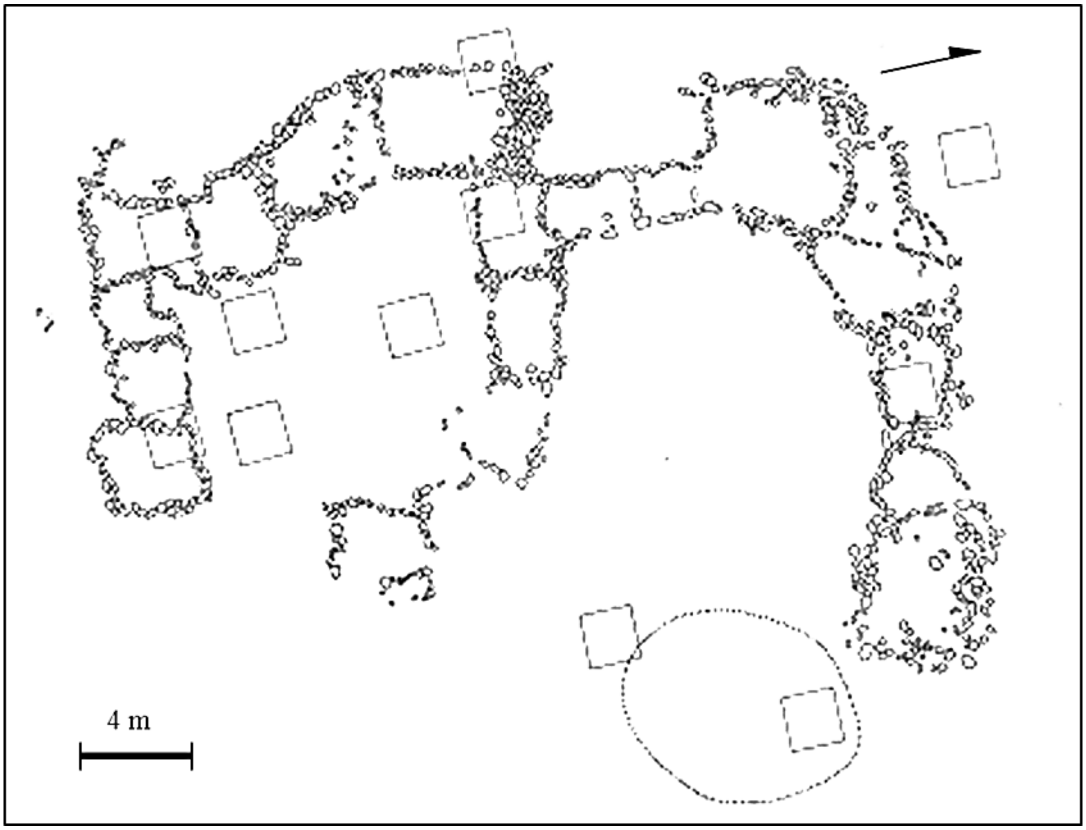


Figure 4.8. Map of site 136 ASM. Squares (2x2 m) are surface collection units.

completely a linear E-shape, but rather a C-shape with an attached middle arm (Figure 4.8). This weakens the traditional argument of Kayenta Ancestral Pueblo influence in this site. Approximately 20 rooms were identified in the E-shaped pueblo, with a dense midden southeast of the main pueblo. Systematic surface collection was conducted in 24 SCUs, with almost 3,000 artifacts collected, including 2,618 sherds (Table 4.2). Ceramic types identified in the surface assemblage are plain, corrugated, black-on-gray ware, red ware, and black-on-red ware. Polychrome sherds were also found. A small test was conducted in a disturbed area with heavy burning and historic clearing activities (e.g., cutting trees), and a ^{14}C sample was collected that was associated with large corrugated jar fragments; this sample yielded a date of A.D. 960–1040 (Table 4.7). Twenty soil auger samples were collected, these reaching almost 1 m in depth and resulting in the recovery of charcoal and sherds.

Five test pit excavations were conducted in an area with a high artifact concentration. Although the purpose of the test pit excavation was to understand changes in the material remains over time, part of a small circular hearth was exposed about 40 cm below the surface in TP-1. This pit is close to the middle arm of the E but outside the visible surface structure. A wood charcoal chunk recovered from this hearth yielded a date of A.D. 790–1040 (Table 4.7). At this point, it is not certain if this hearth was an “outside hearth” or an “inside hearth” that could be associated with another occupational period. TP-2 was the deepest pit, almost 130 cm deep, and did not reach to the cinder layer. Another ^{14}C date, from level 5 of this pit, is A.D. 1020–1270 (Table 4.7). TP-4 and TP-5 were terminated once the cinder layer was encountered.

The proportion of corrugated sherds (larger than 1 inch) from the test pits was 13.3 percent and that from the SCUs is 15.9 percent (Table 4.5). Considering the ^{14}C dates and presence of polychrome sherds, this site was occupied during Pueblo II–III times.

AZ:A:12:71(ASM)

This site is isolated from all others in Mt. Trumbull that are considered in this dissertation; it is at least 5 km from the nearest site, 131 BLM. This site is also the only one located in an area where sedimentary rock formation outcrops, although the area is close to basalt outcrops. The site consists of several discrete areas (at least three), each containing multiple structures at slightly different elevations. Area A (Figure 4.9), which is located at the lowest elevation and just above the sagebrush flats, includes several circular structures built mostly of limestone rocks. They likely represent collapsed or damaged slab-lined storage rooms. Area B is about 200 m west on a knoll approximately 10 m higher than Area A. This area includes at least two structures with attached circular rooms (Figure 4.10). The density of the artifacts in Area B is lower than in Area A. Area D lies farther to the east on a limestone plateau about 50 m higher than Area B. This area contains circular

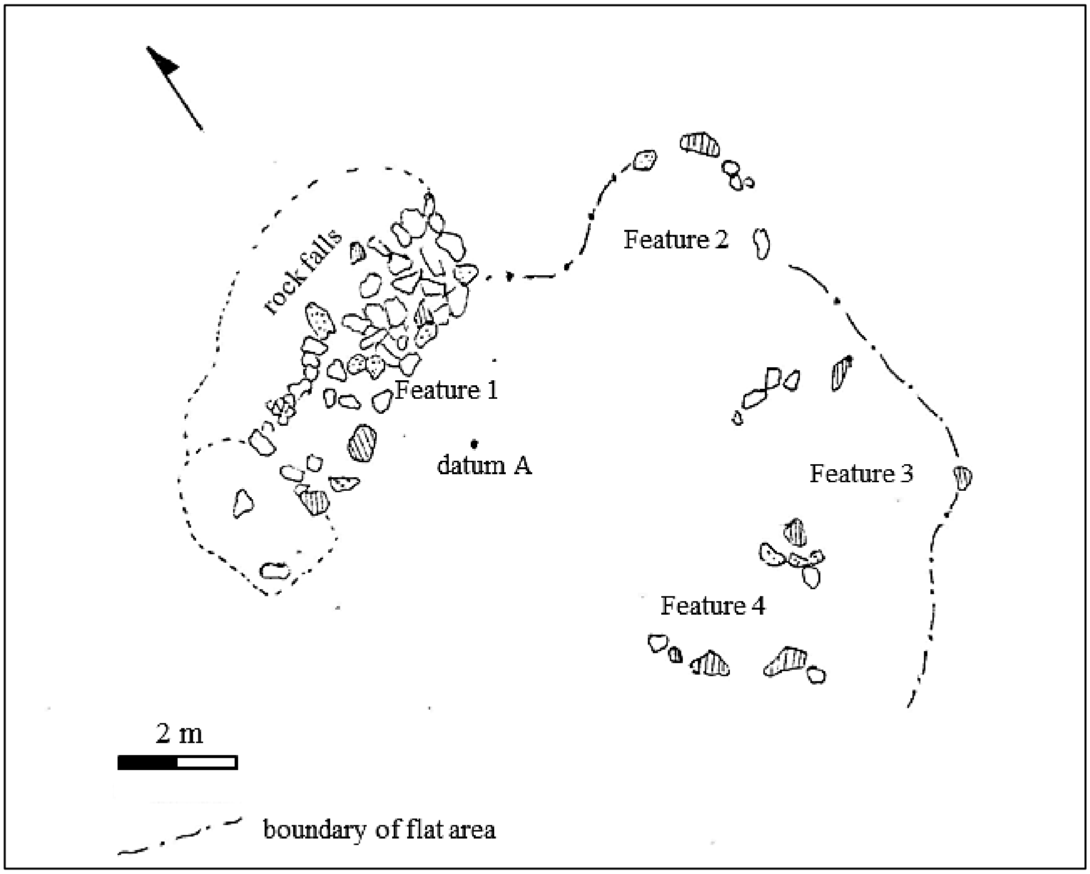


Figure 4.9. Map of site 71ASM_A area showing Features 1-4.

features near upright limestone slabs and depressions. The sherds in this area are somewhat different from those from the other areas, especially Area A; a large proportion of sherds in area C are coarse brown wares. Systematic surface collection from 35 SCUs resulted in a collection of 350 sherds (Table 4.2). Very few corrugated sherds were found, less than 1 percent of the ceramic assemblage (Table 4.5). However, this site, 71ASM, is notable for its relatively large number of black-on-gray ware sherds (Table 4.6), which were mostly found in Area A. This suggests that Area A is not contemporaneous with the other areas. Three test pits were

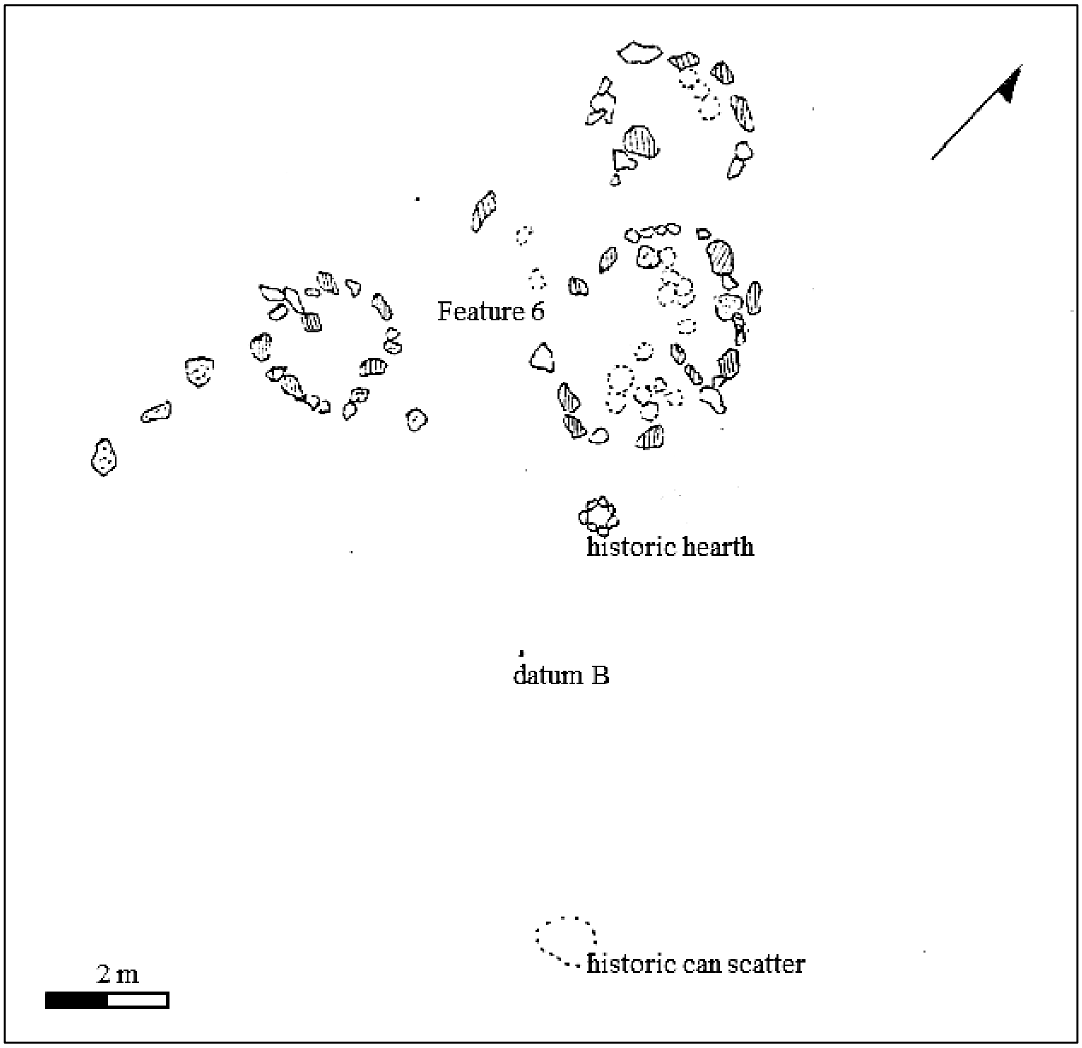


Figure 4.10. Map of 71 ASM_B area showing Feature 6.

excavated in Area D (TP-1–3) and one in Area A (TP-4), the area at the lowest elevation. A ^{14}C sample yielded a date of A.D. 880–1010 for level 3 (20–30 cm deep) of TP-3 (Table 4.7). No corrugated ware was found in any of the test pits (Table 4.5). Both the lack of corrugated ware and the ^{14}C date suggest that this site is relatively early, possibly pertaining to the Pueblo I period. Only one example of black-on-gray ware was found in the test-pit excavation (Table 4.6), despite the

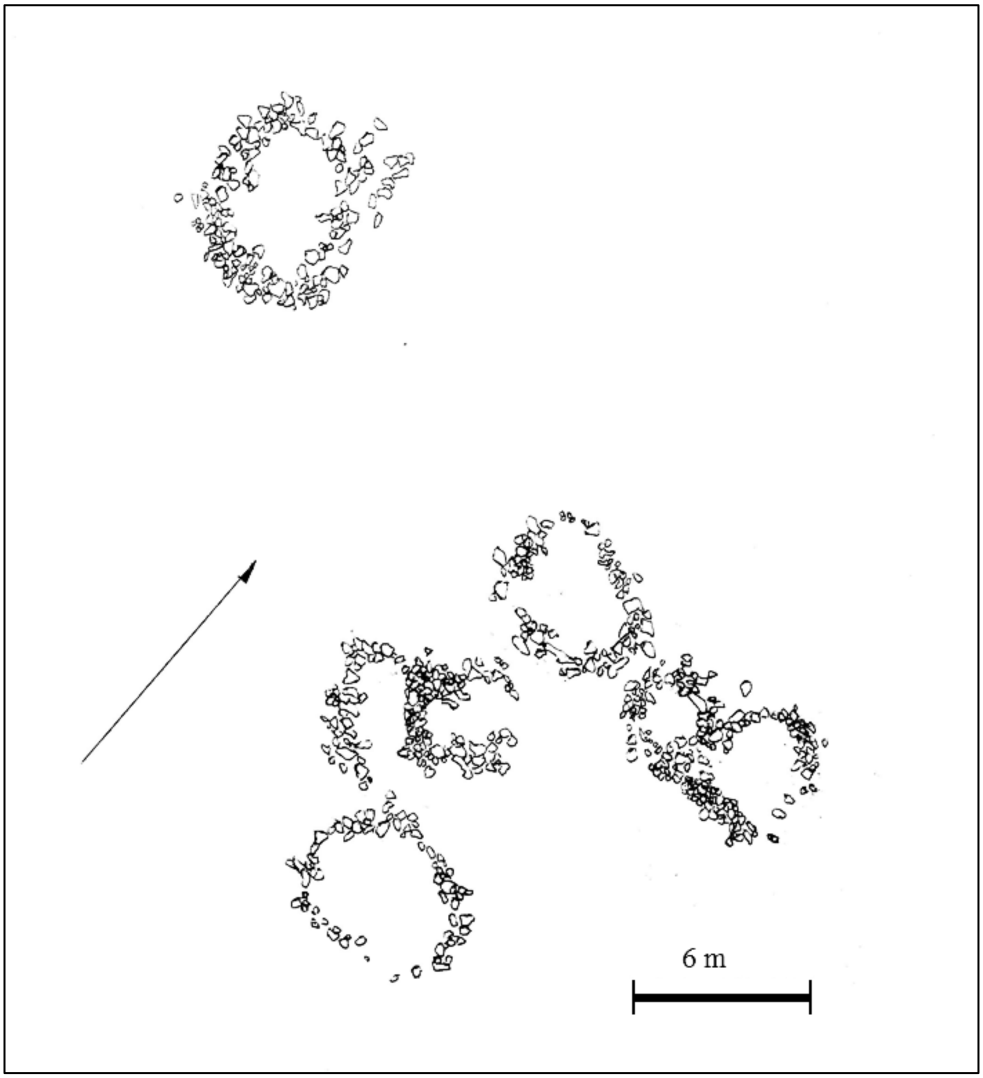


Figure 4.11. Map of site 214 ASM.

black-on-gray ware was found in the test-pit excavation (Table 4.6), despite the presence of a relatively large number of black-on-gray ware sherds from the SCUs.

AZ:A:12:214 (ASM)

This site consists of at least six one-room (with diameter of 3~5 m) blocks made of basalt boulders (Figure 4.11). One independent circular feature is located less than 10 m west of the room blocks. Fewer than 500 sherds were collected from five SCUs (Table 4.2), which included a very high frequency of corrugated ware, about 44 percent of the ceramic assemblage (Table 4.5). Five test pits were excavated. Most of the pits were shallow, and very few artifacts were found except within level 1 in TP-2. A high frequency of corrugated ware was also found in the test pit excavations, more than 30 percent of all sherds (Table 4.5) recovered from the site. The ^{14}C samples came from TP-5 at 10–20 cm deep and resulted in calibrated dates of A.D. 640–770, which contradicted our assumption about the site chronology based on the high proportion of corrugated ware found at this site.

AZ:A:12:14 (MNA)

This site, 14 MNA, consists of a C-shaped pueblo with a central plaza area having a diameter of approximately 33 m. It is located 1,200 m southwest of Nixon Spring on the flanks of Mt. Trumbull. The original survey sketch map made in 1975 shows between nine and 14 rooms. The map shows that most of the rooms are rectangular. Buck (2002) conducted additional work in 2001, including mapping the structure (Figure 4.12), making systematic surface collections, and testing three partially looted rooms. Four ASM dates from the ^{14}C samples obtained from these looted rooms are A.D. 880–1010; A.D. 1020–1210; A.D. 1000–1170, and A.D. 1160–1210 (Table 4.7). The variations in these dates, as well as the chronological placement of pottery styles ranging from the late Pueblo I to early Pueblo III period, suggests that this site was occupied for a considerable length of time. The use of the

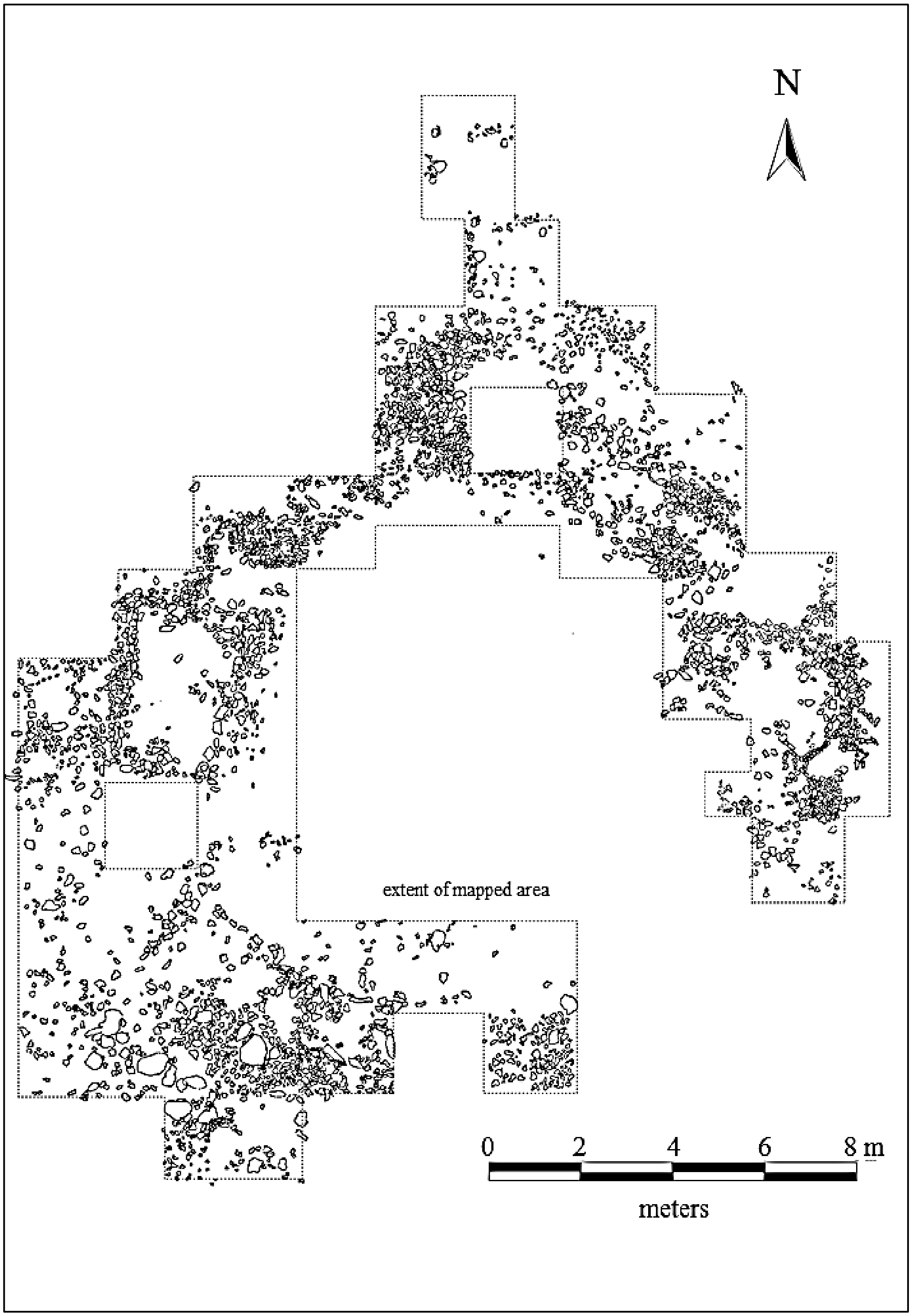


Figure 4.12. Map of site 14 MNA (after Buck 2002).

site was not intensive at any given point in time, and occupation may have been sporadic or cyclical (Buck 2002). The most reliable ^{14}C sample, which came from close to the floor of Room 3, yielded a date of A.D. 880–1010. Thus, the site may have been occupied earlier than A.D. 900. Systematic surface collection was conducted in 10 SCUs, and the proportion of corrugated ware (sherds >1 inch) was nearly 40 percent (Table 4.5).

In 2006, 15 1 x 1-m test pits were excavated to understand the change through time in material remains at this site. For this purpose, test pits were selected in the high artifact-density area, while avoiding the inside of the structure. Most of the test pits were approximately 50–60 cm deep; excavation was terminated at a very compact clay layer in all test units. That is, in all 15 units in site 14 MNA, excavations did not reach a cinder layer, unlike at other sites where test excavations were conducted. TP-7 was the deepest pit (100 cm deep), and it yielded a large quantity of diagnostic sherds, as well as black-on-gray bowl fragments that could be reconstructed as a whole pot. Decorated wares found at this site were black-on-gray and red/black-on-red ware, but there were no polychrome sherds (Table 4.6).

Changes in the Frequency of Ceramic Types in Mt. Trumbull

Systematic surface collection and test excavations conducted on seven sites in Mt. Trumbull provided almost 12,000 sherds from SCUs (Table 4.2) and more than 20,000 sherds from test excavations (Table 4.3). With these abundant ceramic data, I will examine in the following section the spatial distribution of ceramic types and their chronological distribution.

Distribution of Ceramic Types

The distribution of temper types among seven sites in Mt. Trumbull was examined (Table 4.4). Olivine is a dominant temper at all seven sites, as with other sites previously studied in Mt. Trumbull. The average frequency of olivine-tempered sherds from test pit excavations at the seven sites is nearly 90 percent of all sherds greater than 1 inch (Table 4.4). The proportion of olivine-tempered sherds ranges between 88 and 92 percent, except for one test pit at 71 ASM, where it is exceptionally high (98.2 percent). Conversely, the average number of sand-tempered sherds among all ceramics (greater than 1 inch) from test pit excavations is 7.2 percent, and especially small numbers of sand-tempered sherds were found at 71 ASM, 214 ASM, and 14 MNA (Table 4.4). In addition, the distribution among the sites of sherds tempered with olivine is uneven. While 30 BLM, 136 ASM, 214 ASM, and 14 MNA have relatively higher proportions of sherd temper with olivine inclusions, sites 131 BLM, 204 BLM, and 71 ASM have either none or very small quantities of potsherds with sherd temper including olivine particles (Table 4.4). It is interesting that sites with higher proportions of sherd temper with olivine inclusions also have a higher proportion of corrugated wares (Table 4.5). This suggests that the use/production of pots with sherd temper with olivine inclusions occurred relatively late in Mt. Trumbull.

The proportion of corrugated sherds larger than 1 inch varies among the sites (Table 4.5). Most of the sites with higher percentages of corrugated ware have relatively late ^{14}C dates, except for 214 ASM.

The proportion of painted ware is never high at any site (less than 5 percent among sherds from test pit excavations) and painted ware was not evenly distributed throughout the sites. Polychrome sherds were found in very small quantities and only at two sites, 30 BLM and 136 ASM. Very small number of red ware sherds was found at 204 BLM and 71 ASM, which are early sites based on the relatively low percentage of corrugated ware. Black-on-gray wares from surface collections were found at all sites. However, very little black-on-gray ware came from test pit excavations at 204 BLM and 71 ASM. It is puzzling that a very high percentage of black-on-gray ware came from SCUs at 71 ASM, despite the fact that only one black-on-gray ware sherd is present among the 206 sherds (> 1 inch) from test pit excavations (Table 4.6). Most of the black-on-gray ware from the surface was found in Area A, which is at the site's lowest elevation. It is possible that a portion of this site may not be contemporaneous with other parts of the site. Although it is unlikely, another possibility is that the large number of black-on-gray ware sherds on the surface at 71 ASM is the result of site disturbance, a possible "collector's pile," as hardly any black-on-gray ware was encountered in the test pit in Area A. Supporting this possibility, several historic features (e.g., historic camp fire, and small collector's pile) were found near Area A.

Changes through Time in Olivine-tempered Ceramics

The frequency of olivine-tempered sherds larger than 1 inch was examined in the deepest pits with high numbers of artifacts at 30 BLM, 131 BLM, 136 ASM, and 14 MNA to assess changes through time in their frequency (Figures 4.13–4.16). The data from 204 BLM, 214 ASM, and 71 ASM were not included, as the number of sherds from each level in all test pits was small. Overall, relatively little variation in the proportion of olivine-tempered sherds throughout the levels was recognized, except in the deeper deposits. In deeper deposits, the proportion of olivine-tempered sherds was nearly 100 percent in most of the test pits (Figures 4.13–4.16). However, only one or two sherds (>1 inch) were found in the deeper levels at most sites, thus the proportion of olivine-tempered sherds, close to 100%, may not be statistically significant in deeper deposits. Overall, the frequency of olivine-tempered ceramics was consistently high in all test pits examined here.

Corrugated Wares

Changes in the proportion of corrugated wares within the same set of test pits were also assessed, including those at 30 BLM, 131 BLM, 136 ASM and 14 MNA. Overall, the frequency of corrugated ware decreased with depth, as expected (Figures 4.13–4.16), or in the case of 131 BLM, remained low, where the average proportion of corrugated wares is very low (Figure 4.14). Interestingly, the frequency of corrugated ware in TP-14 in 14 MNA is relatively high at deeper levels,

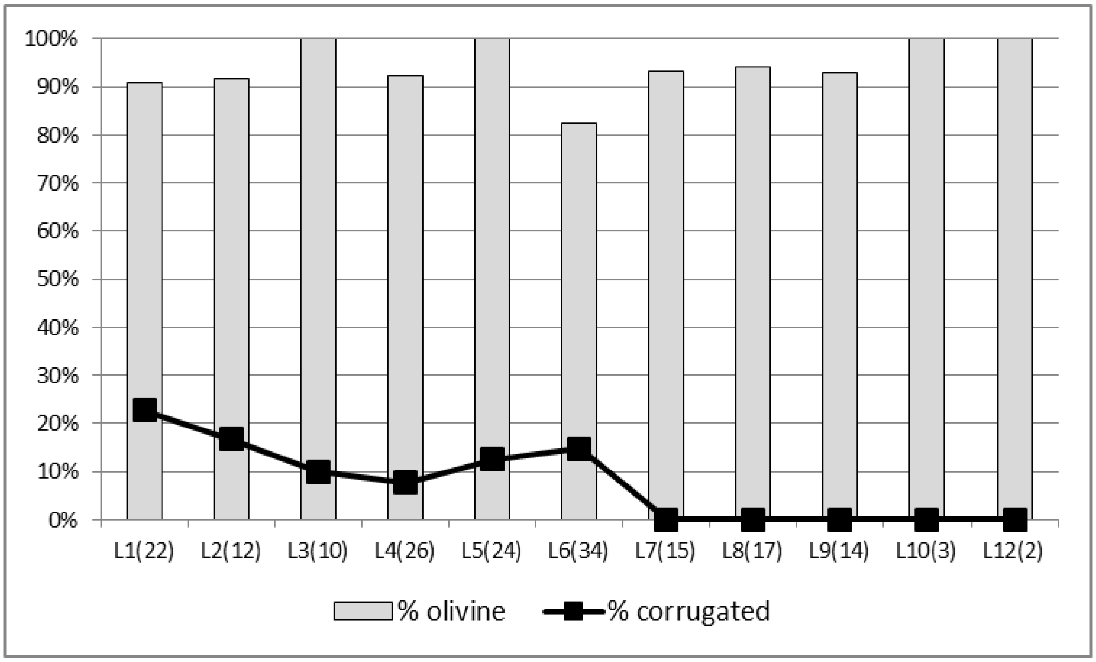


Figure 4.13. Frequency of olivine-tempered ceramics (> 1 inch) and corrugated ceramics from TP 2 at 30 BLM. Values in parentheses are the total number of sherds >1 inch in each level.

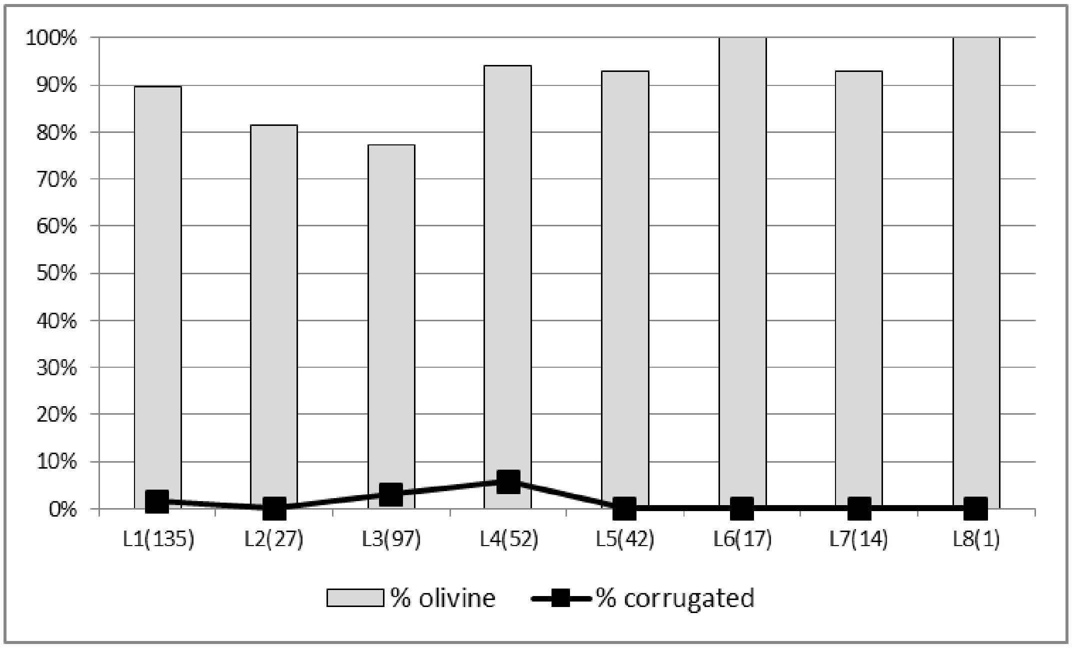


Figure 4.14. Frequency of olivine-tempered ceramics (> 1 inch) and corrugated ceramics from TP 2 at 131(BLM). Values in parentheses are the total number of sherds >1 inch in the level.

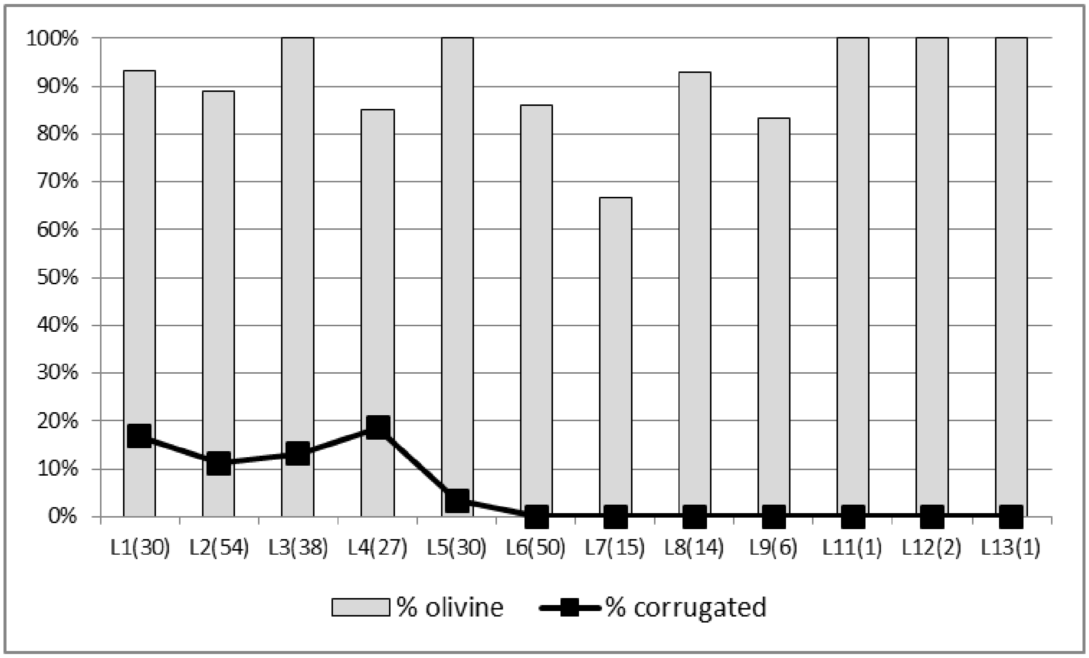


Figure 4.15. Frequency of olivine-tempered ceramics (>1 inch) and corrugated ceramics from TP2 at 136 ASM. Values in parentheses are the total number of sherds >1 inch in the level.

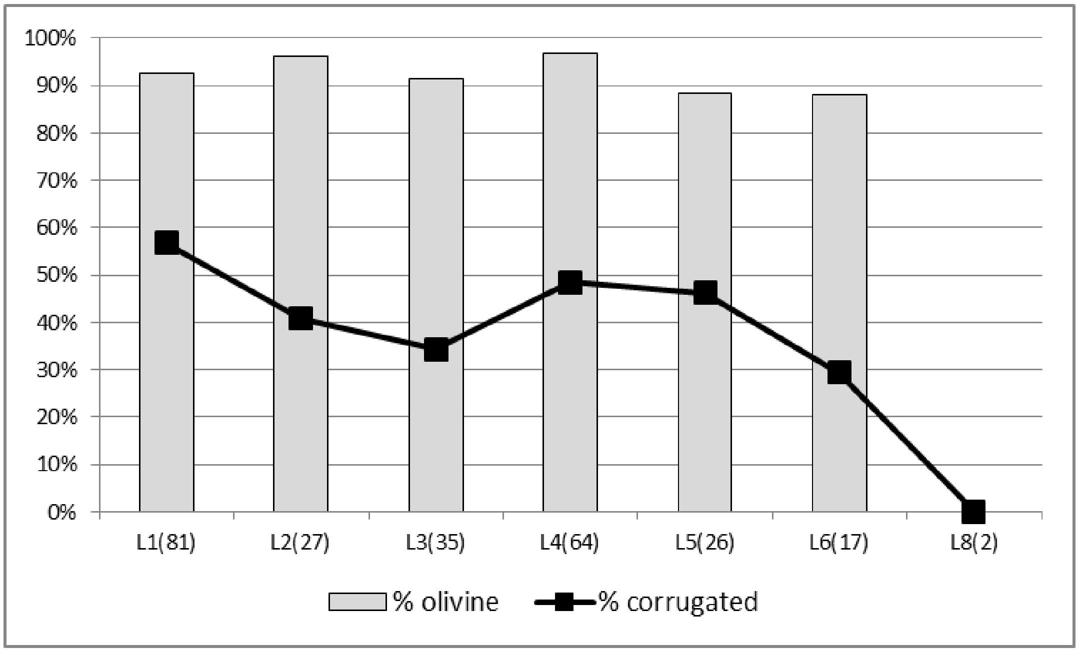


Figure 4.16. Frequency of olivine-tempered ceramics (>1 inch) and corrugated ceramics from TP14 at 14 MNA. Values in parentheses are the total number of sherds >1 inch in the level.

although the proportion slightly decreased with depth. This suggests that a portion of this site was occupied only during a late period.

The samples obtained from the fieldwork described above include full contextual information, which will useful in interpreting the compositional diversity of the ceramics collected (see Chapter V).

Extant Collection from Previous Work

In addition to the ceramic specimens collected during the fieldwork, I was able to obtain sherds from several previous investigations for the analysis.

Lowland Virgin Ceramic Samples

Two hundred ninety-eight sherds from the lowland Virgin area were analyzed for this dissertation. All of these sherd samples were collected by Larson in the 1980s (Larson 1987), and they are all from surface collections with provenience information. The sherds analyzed for this dissertation included both olivine and non-olivine ceramics, as well as decorated and non-decorated wares. Contextual information was obtained from Larson’s dissertation (1987).

Tuweep Ceramic Samples

Twenty sherds from Tuweep were included in this study. These sherds were borrowed from Southern Utah University and were collected by Thomson, primarily during his fieldwork in the 1970s (Thompson 1970, 1971; Thompson and Thompson

1974, 1978). Both olivine and non-olivine tempered, as well as decorated and non-decorated wares, were included; all sherds were from surface collections. Information regarding the context of the sherds was summarized in the literature by Thomson and his colleague (Thompson 1970, 1971; Thompson and Thompson 1974, 1978).

Conclusion

This chapter summarized the sample collections involved in this study, including those from the fieldwork in Mt. Trumbull. A detailed description of this fieldwork was included and will serve as the basis for interpreting the compositional diversity of the sherds.

All of the ceramic samples from Mt. Trumbull included in this study were obtained from systematic surface collections, test excavations, and general surface collections during the fieldwork. The ceramic samples from Tuweep and the lowland Virgin area were obtained from previous fieldwork and all are from surface collections. Those from Mt. Trumbull were collected from seven sites where either Pueblo structures or depressions that may have represented pithouse structures were observed. These sites range chronologically from early to late, based on proportion of corrugated ware, ^{14}C dates, and type of structures. Detailed site descriptions with maps were made for each site in order to understand the context of the sherds. Ceramic assemblages from both surface collection units and test excavations demonstrate that the majority of the sherds from all seven sites were tempered with olivine (around 90% of total sherds), as observed at many other sites previously surveyed in Mt. Trumbull.

Although corrugated ware was found at most of the sites included in this study, the proportions varied. A higher proportions of corrugated ware generally corresponded to later ^{14}C dates, except at the 214 ASM site. Polychrome and red ware sherds were not evenly distributed among the ceramic assemblages from the seven sites, while black-on-gray sherds were found at all sites.

The ceramic assemblages from the test excavations from 30BLM, 136ASM, 131BLM, and 14 MNA exhibit that very little variation in the proportion of olivine-tempered sherds among all sherds over time, although the proportion of corrugated ware sherds decreased in deeper deposits as expected.

The description of the collections of clay samples will be helpful in interpreting the compositional diversity of the samples, and that of the sediment collections for luminescence dating will assist in assuring the precision of luminescence dating for the sherds. Clay samples for compositional analysis were collected from Mt. Trumbull, Tuweep, the lowland Virgin area, as well as from between Mt. Trumbull and the lowland Virgin area. In both the Mt. Trumbull and the lowland Virgin areas, the clay samples came from various geological formations.

The sediment samples for luminescence dating were collected during the test excavations in Mt. Trumbull. Additional surface sediment samples were collected for dating the surface sherds within a 25 m diameter of the location of the ceramic samples at each site. For the dating for sherds from the lowland Virgin area, the sediment samples were collected from all possible geological formations along the Virgin River.

Chapter V: METHODS OF ANALYSIS AND DESCRIPTIVE RESULTS

In order to investigate where the pottery involved in this study was made, I conducted two chemical compositional analyses: instrumental neutron activation analysis (INAA) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). I also examined ceramic physical attributes in order to understand the compositional groups identified in INAA and LA-ICP-MS data. Ceramic attributes examined in this study include temper type, surface treatment, and core colors.

I studied temper types visible in the sherd cores and on the surfaces with a 15x binocular microscope. Most often I recognized multiple types of inclusions in the ceramic paste. In cases where I was able to recognize olivine particles as independent inclusions (i.e., not in sherd temper, which is discussed later), I recorded the temper simply as olivine temper. In some of the specimens, I found that crushed olivine-tempered sherds had been used as temper. This was recorded as sherd temper with olivine inclusions, or sherd (olivine). Since this study is focused on olivine vs. non-olivine ceramics, sherd temper with olivine inclusions were recorded separately from sherd temper without olivine. Sherd tempers without olivine particles are occasionally found with sand (quartz, feldspars) temper. If specimens had sherd temper without olivine inclusions, then their temper type was recorded as sherd without olivine inclusions or sherd (no olivine). If sand was a dominant temper, the temper type was recorded as sand. I also recorded surface treatments of sherds: plain and corrugated wares which I consider to be utilitarian wares, and some decorated wares which include black-on-gray, red, black-on-red, and polychrome wares. In order to investigate how ceramic compositional groups relate to chronological time periods I used the method of optically stimulated luminescence (OSL) dating. In this chapter, I discuss each of these analytical techniques and the procedure of the analysis.

Compositional Analysis

Chemistry-based provenance studies are premised on the "provenance postulate," which states that sourcing is possible as long as there exists some qualitative or quantitative, chemical or mineralogical difference between natural sources that exceeds the qualitative or quantitative variation within each source (Neff 2000; Neff and Glowacki 2002). There are two approaches to sourcing archaeological materials (Neff 2000; Neff and Glowacki 2002). One is used for sources that are localized and easily identified, such as obsidian flows. In this case, unknowns are tested against the source group. The other approach is used for sources that are widespread and have indistinct boundaries, such as ceramics. For this latter case, the chemical compositional groups are identified among the unknowns (e.g., ceramics) first, and then source materials (e.g., clay) are tested against the ceramic compositional groups. Two analytical approaches are involved in chemical compositional analysis. One is bulk analysis in which all materials are homogenized prior to analysis, as is the case with INAA or Microwave Digestion

ICP-MS. The other approach is point analysis (microchemical analysis), which targets only a specific portion of heterogeneous samples like ceramics (e.g., temper in ceramic paste). LA-ICP-MS is one of the techniques that allows this microchemical analysis. In the following sections I discuss each of these analytical methods.

Instrumental Neutron Activation Analysis (INAA)

For several reasons I conducted INAA analysis, a bulk analysis method, on a small data set (n = 50) prior to LA-ICP-MS, a method of point analysis, on a larger data set. First, any compositional study ideally should involve multiple analytical techniques to minimize the bias associated to a particular type of technique. Second, INAA has been a "technique of choice" in many archaeological applications over the past 40 years (Neff 2012). Furthermore, there are extant INAA data sets that include olivine-tempered ceramics in the lowland Virgin area (Larson et al. 2005). Therefore, it is worthwhile to conduct INAA on Mt. Trumbull olivine-tempered ceramics to examine whether any of them match the lowland Virgin olivine-tempered ceramic group.

Instrumentation and Analysis

Neutron activation analysis is a technique for characterizing the elemental composition of virtually any solid material. The potential of this technique for archaeological source determination was recognized in the 1950s. During the 1970s and 1980s, archaeologists began applying INAA to determine the sources of pottery, obsidian, chert, and other materials (Neff 2000). INAA depends on that fact that neutrons in the environment of a sample will interact with the nuclei of atoms in the sample, which produce the different isotopes. Many of the product isotopes are radioactive and can be monitored. Neutrons most commonly used in neutron activation analysis come from ^{235}U, produced via a chain reaction inside a nuclear reactor (Neff 2000). Thus, INAA is a technique whereby some of the elements in a sample are converted into artificial radioactive elements by irradiation with neutrons. Using suitable instrumentation, the radioactive decay can be detected, and by measuring the intensity of the emitted gamma-ray, the original concentration of the parent element in the irradiated sample is calculated (Pollard and Heron1996). The INAA for this study was conducted at the University of Missouri Research Reactor (MURR) using the established MURR procedure for pottery (Glascock 1992). In the case of pottery, the surface of a sample is removed (e.g., paint, slip, and adhering sediment) and the remaining portion of the sherd is ground. Two 200-mg powdered unknown samples from a sherd and standards are subjected to short (five second) and long (24 hour) irradiation (i.e., one 200-mg sample for short and another 200-mg sample for long irradiation), with a single gamma-counter after the long irradiation (Neff 2000). Thirty-three elemental concentrations are determined by comparing the gamma spectra in the standard with that of the unknown sample.

The strength of the INAA technique for characterizing archaeological materials include: (1) extremely high precision, high accuracy, and high sensitivities;

(2) small sample size requirement; (3) ease of sample processing; and (4) ability to measure simultaneously 30 or more elements (Neff 2000). Thus, INAA is the best bulk analysis technique for characterizing solid materials with heterogeneous matrices. Since it is a bulk technique, INAA will identify chemically distinct groups, whether these groups are the result of clay source differences, technology (temper), or diagenesis. Once the chemical groups are identified, additional analyses designed to determine the causes of chemical variation can be undertaken. The disadvantages of INAA are high cost, limited availability, and problems with nuclear waste. INAA's inability to identify the cause of group differences is sometimes cited as a disadvantage, but, as just mentioned, this is a misunderstanding: identifying a chemical variation is the first step, while explaining that variation (clay, temper or diagenesis) is the second step in the investigation.

Data set

INAA was conducted at MURR on 50 olivine-tempered ceramics obtained from Mt. Trumbull. Only olivine-tempered ceramics were included in this analysis to avoid detecting compositional groups with different types of temper. Both utilitarian wares, including 27 plain and 12 corrugated sherds, and non-utilitarian wares, including 11 black-on-gray sherds, were included in the analysis. Data from 24 olivine-tempered sherds from the lowland Virgin area (Larson et al. 2005) were combined with Mt. Trumbull data to increase the sample size for the statistical analysis. No source clay was examined in the analysis of Mt. Trumbull olivine-tempered ceramics. However, Larson et al. (2005) demonstrated in the earlier study that the olivine-tempered ceramics in the lowland Virgin area do not match the local clay. The raw data concerning 32 elements were converted to base-10 logs of ppm. Bivariate plots of principal component (PC) scores and multiple combination of various elemental concentrations were used to define the compositional groups. After the initial group recognition based on bivariate plots was achieved, Mahalanobis distance probabilities were used to assign more sherds to the two large compositional groups.

INAA Results

Bivariate plots by PC scores and elemental concentrations show at least five compositional groups in the INAA bulk data of the olivine-tempered ceramics from the Mt. Trumbull and the lowland Virgin areas (Figures 5.1, 5.2). Two of them (INAA Groups 1 and 2) are large enough to use Mahalanobis distance probabilities to examine the validity of group assignment.

Compositional Group and Provenience

Examination of compositional groups and provenience of the ceramics shows that some of the groups correlate with ceramic provenience (Table 5.1). For example, INAA Group 3 includes only Mt. Trumbull olivine-tempered ceramics, while both INAA Group 4 and VR2 include only lowland Virgin ceramics. Thus, three groups—INAA Groups 3, 4, and VR2— correlate with proveniences, which may suggest that these compositional groups represent production centers. In

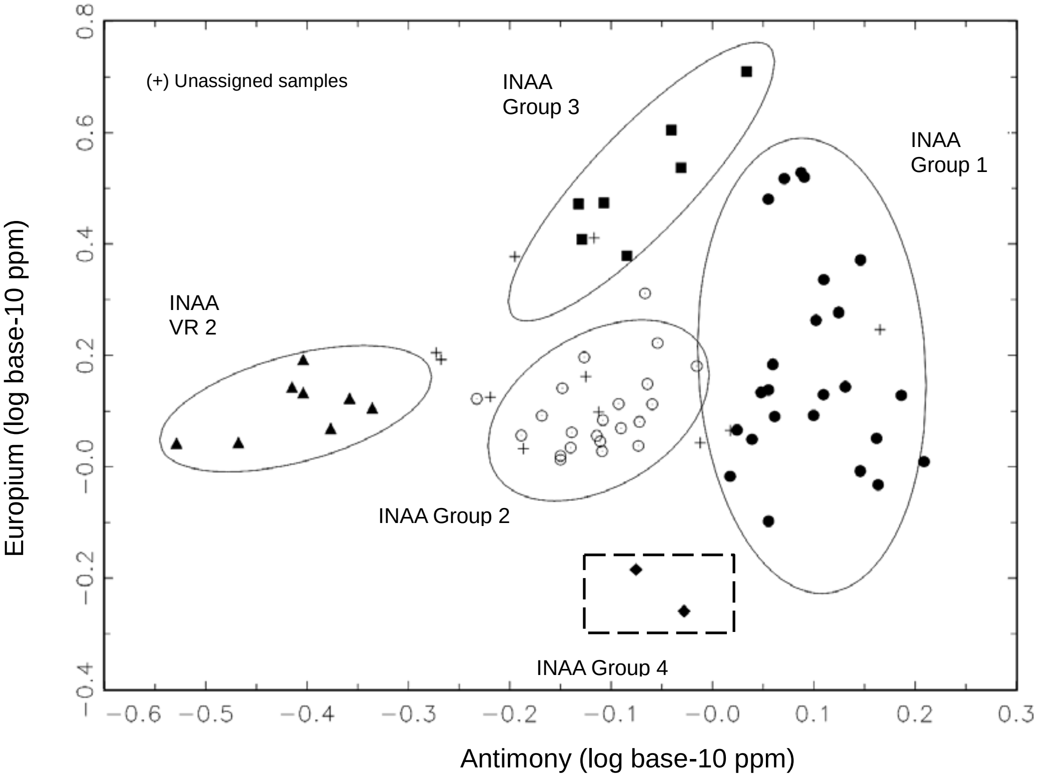


Figure 5.1. Bivariate plot of europium and antimony in INAA data to show five compositional Groups in olivine-tempered ceramics from Mt. Trumbull (n = 50) and the lowland Virgin area (n = 24).

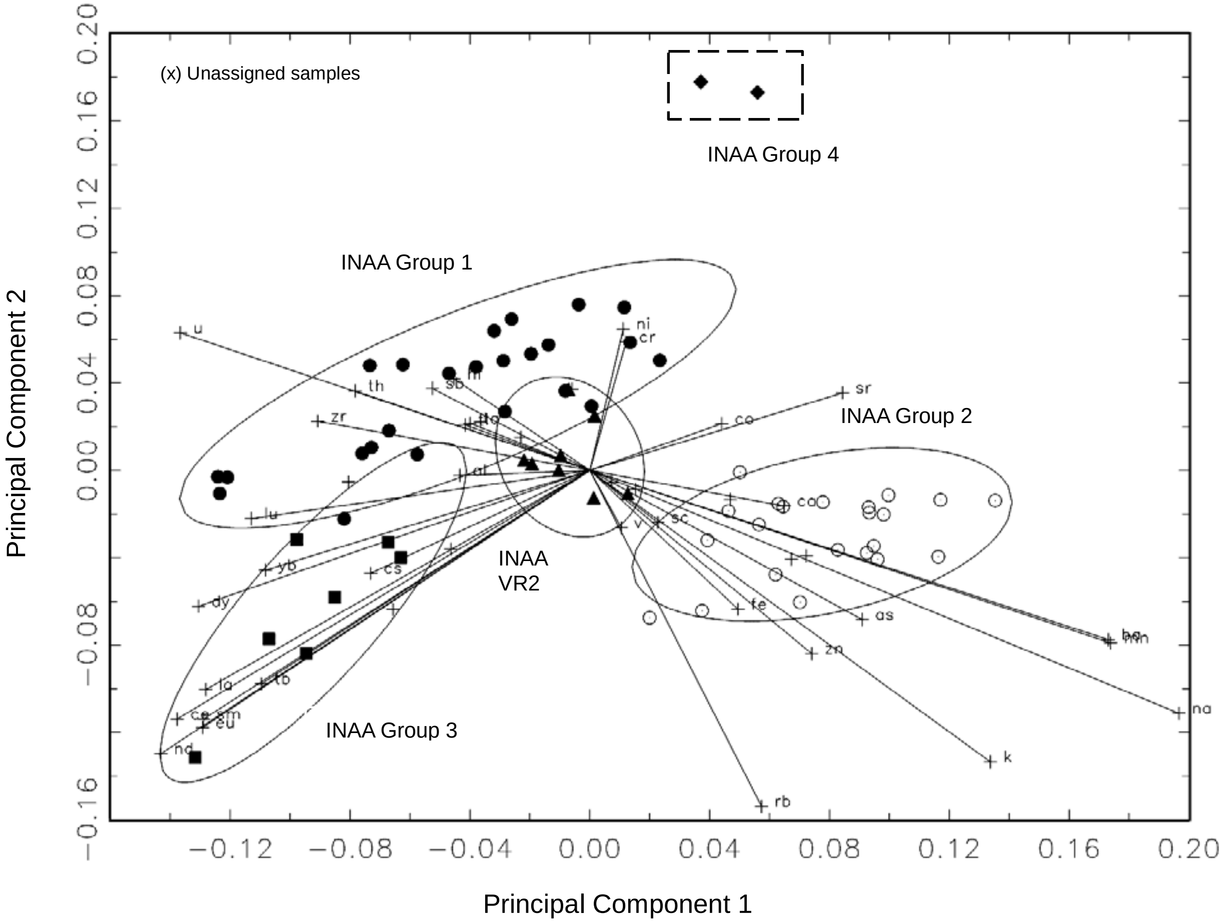


Figure 5.2. Bivariate plot of principal components 1 and 2 in INAA data showing five compositional groups in olivine-tempered ceramics from Mt. Trumbull (n = 50) and the lowland Virgin area (n = 24).

Table 5.1. Frequency of olivine-tempered sherds by INAA compositional group and provenience.

INAA Group	Mt. Trumbull	Lowland Virgin	Total
INAA Group-1	18	6	24
INAA Group-2	18	4	22
INAA Group-3	7	0	7
INAA Group-4	0	2	2
INAA VR-2	0	8	8
Unassigned	7	4	11
Total	50	24	74

contrast, INAA Groups 1 and 2 include ceramics from both Mt. Trumbull and the lowland Virgin areas.

Compositional Group and Surface Treatment

Examination of compositional groups and surface treatments also shows some degree of association (Table 5.2). Both utilitarian (plain and corrugated wares) and non-utilitarian (black-on-gray) wares are included in INAA Group 1. INAA Group 2 includes only utilitarian wares, whereas INAA Group 3 includes mostly plain utilitarian wares. While INAA Group 4 includes plain wares, INAA VR2 includes mostly black-on-gray wares. Note that these two groups include only the ceramics from the lowland Virgin area. Interestingly, Mt. Trumbull black-on-gray wares fall mostly within INAA Group 1, and the lowland Virgin black-on-gray wares are in INAA VR2 (Tables 5.3, 5.4).

Compositional Groups and Core Color

Two compositional groups show relatively clear color distinctions in sherd cross-sections. The core color of INAA Group 2 sherds is relatively dark, and that of

Table 5.2. Frequency of olivine-tempered sherds from Mt. Trumbull and the lowland Virgin area by INAA compositional group and surface treatment.

	Black-on-gray	Corrugated	Plain	Total
INAA Group-1	10	5	9	24
INAA Group-2	0	5	17	22
INAA Group-3	1	0	6	7
INAA Group-4	0	0	2	2
INAA VR-2	7	1	0	8
Unassigned	2	2	7	11
Total	19	13	41	74

Table 5.3. Frequency olivine-tempered sherds from Mt. Trumbull by INAA compositional group and surface treatment.

	Black-on-gray	Corrugated	Plain	Total
INAA Group-1	9	5	4	18
INAA Group-2	0	5	13	18
INAA Group-3	1	0	6	7
INAA Group-4	0	0	0	0
INAA VR-2	0	0	0	0
Unassigned	2	1	4	7
Total	11	11	27	50

Table 5.4. Frequency of olivine-tempered sherds from the Lowland Virgin area by INAA compositional group and surface.

	Black-on-gray	Corrugated	Plain	Total
INAA Group-1	1	0	5	6
INAA Group-2	0	0	4	4
INAA Group-3	0	0	0	0
INAA Group-4	0	0	2	2
INAA VR-2	7	1	0	8
Unassigned	0	1	3	4
Total	8	2	14	24

Table 5.5. Frequency of olivine-tempered sherds from Mt. Trumbull and the Lowland Virgin area by INAA compositional group and core color.

Group	Dark Gray	Brown	Gray	Tan	Light Gray	White	Total
INAA Group-1		2	7	2	11	2	24
INAA Group-2	6	3	13				22
INAA Group-3			2		4	1	7
INAA Group-4					2		2
INAA VR-2	2		1		5		8
Unassigned	2		3	2	4		11
Total	6	3	20	4	14	3	74

INAA Group 3 is relatively light, although the core color varies within these groups (Table 5.5).

Compositional Groups and Site Chronology

Site chronology was investigated by considering the relationship between the limited number of radiocarbon dates with frequencies of corrugated wares at individual archeological sites. Generally, corrugated wares are thought to date to after A.D. 1050 (Lyneis 2008). Testing of the middens at the 136 ASM site demonstrates that the frequency of corrugated ware sherds decreases in the deeper levels of the unit. Consequently, frequencies of corrugated wares were used as a time indicator along with the few available radiocarbon dates. At Mt. Trumbull, the ceramics from the 204 BLM site, which is an early site, belong to only INAA Group 2 (Table 5.6). This suggests that the use of INAA Group 2 ceramics started early, while INAA Groups 1 and 3 ceramics date later in the regional chronology. In the lowland Virgin area, ceramics in Group 2 are also from early sites. Conversely, the Lowland Virgin INAA data suggest that INAA VR 2 ceramics are from later sites (Table 5.7). Thus, the compositional groups may have some degree of association to time in both Mt. Trumbull and the lowland Virgin areas. However, to determine if this is actually true, it is necessary to directly date the ceramics by OSL dating techniques.

Table 5.6. Frequency of olivine-tempered sherds from Mt. Trumbull by INAA compositional group and site chronology.

Group	204BLM	131BLM	136ASM	30BLM	14BLM
INAA Group-1		4	3	5	6
INAA Group-2	4	4	5	2	3
INAA Group-3		4	1	1	1
INAA Group-4					
INAA VR-2					
Unassigned	2			2	3
Total	6	12	9	10	13
^{14}C dates (A.D.)	810–890	620–690 680–880 900–1030	960–1040	1110–1190	880–1010 1000–1170 1020–1210 1140–1220
% Corrugated	0%	2%	16%	14%	39%

Table 5.7. Frequency of olivine-tempered sherds from the Lowland Virgin area by INAA compositional groups and site chronology.

	VR 13	VR 15	VR 23	VR 20	VR 27	VR 34	VR 21	VR 38	VR 32	VR 19	VR 7
INAA Group-1					1		3	2			
INAA Group-2	2		2								
INAA Group-3											
INAA Group-4					2						
INAA VR-2				1	1	1	1			4	
Unassigned		1						1	1		1
Total	2	1	2	1	4	1	4	3	1	4	1
^{14}C dates (A.D.)	600				850		960				1130
% Corrugated	0	0	0	0	0.70	0.80	0.80	1	2	2.40	77.1

Summary of the INAA Analysis

INAA bulk analysis demonstrated the existence of at least five compositional groups among the olivine-tempered ceramics from Mt. Trumbull and the lowland Virgin areas. Examination of compositional groups with respect to ceramic attributes, as well as provenience showed some degree of association. I suggested that INAA Group 1 ceramics included both utilitarian and decorated wares that were tempered with both olivine and non-olivine inclusions. At Mt. Trumbull, more sherds from later sites belong to this group than from early sites. INAA Group 2 includes only olivine utilitarian ware from early sites in both the Mt. Trumbull and the lowland Virgin areas. INAA Group 3 includes only olivine utilitarian wares from the Mt. Trumbull area; no lowland Virgin olivine-tempered ceramics belong to this group. On the other hand, two compositional groups include exclusively sherds from the lowland Virgin area. INAA Group 4 includes ceramics from only one site in the lowland Virgin area, which dates to around A.D. 850. INAA VR2 includes only the lowland Virgin olivine-tempered ceramics. Most of the decorated sherds from the lowland Virgin area fall within this group.

As discussed above, this analysis demonstrated some degree of association between compositional groups and provenience. It is possible that some compositional groups (e.g., INAA Groups 3, 4, and VR2) may represent particular clay sources or production centers. However, no compositional groups identified in this study were compared to source clays.

INAA data also suggest that multiple compositional groups are represented among the olivine-tempered ceramics. These could represent different paste recipes involved in olivine-tempered ceramic production. Since the data set includes only olivine-tempered ceramics, there is no possibility that different types of temper contributed to paste recipes. The possible paste recipes that resulted in different compositional groups, may be a product of mixing clay from one source with (a) different amounts of olivine temper, (b) olivine and other temper materials such as quartz, (c) olivine temper from different sources, and/or (d) mixing clays from different sources. Testing various hypotheses derived from the bulk data requires additional analysis, such as LA-ICP-MS microchemical analysis.

Because some of the compositional groups show a strong association with formal attributes, the possibility of diagenesis creating some of the compositional groups is unlikely. It is known, for instance, that barium can be elevated due to diagenesis (Golitko el al. 2012: Iizuka 2012). In this INAA study, barium actually contributes to distinguishing compositional INAA Group 2 from other groups; however, other elements such as manganese and sodium also contribute to the distinction (Figure 5.2). Furthermore, because INAA Group 2 has a strong correlation with surface treatment (only utilitarian ware are included), this group is unlikely to be the result of post depositional chemical alternation. In summary, the compositional groups in INAA bulk analysis are likely to represent varying clay sources or paste recipes. They could be also related to temporal or other factors.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)

INAA bulk analysis of olivine-tempered ceramics from both Mt. Trumbull and the lowland Virgin areas demonstrated the existence of multiple compositional groups, which potentially represent different ceramic production centers or use of different paste recipes. To achieve greater clarification I conducted LA-ICP-MS analysis on selected sherds to focus on characterizing just the clay matrix and to avoid the temper particles. This distinction is not possible in INAA bulk analysis. All LA-ICP-MS analyses in this study were conducted at the Institute for Integrated Research in Materials, Environments, and Society (IIRMES) lab at California State University, Long Beach.

Instrumentation and Analysis

ICP-MS is a relatively new technique in archaeology for solid sample characterization. All techniques in material characterization have both strong and weak advantages for the archaeologist. INAA has several strong advantages as I discussed above. One of the advantages of ICP-MS over INAA, especially with the application of laser ablation, is the capability to analyze individual components of heterogeneous materials such as ceramics. Unlike INAA, LA-ICP-MS is able to analyze independently only temper particles or only clay matrices. The patterned elemental variation in ceramic fabric is ascribed not only to provenance differences, but also to different paste preparations or to diagenesis. Microchemical analysis, such as LA-ICP-MS or electron microprobe, offers a means to identify where within the ceramic fabric the important distinguishing elements are concentrated (Neff 2012). Moreover, this form of microchemical analysis can also target ceramic slips and paint pigments, as well as temper and clay matrices as I discussed above. The other advantage of ICP-MS over INAA is the ability to determine a broad range of elements, including copper and lead, which are important elements for any ceramic provenance study. In this study, 60 elements were measured by LA-ICP-MS. ICP-MS is also a means to determine isotopic ratios (e.g., strontium isotopes). Thus, the application of LA-ICP-MS has the potential to broaden the kind of archaeological questions we can ask about ceramic production and consumption patterns. Archaeologists began to use ICP-MS in the early 1990s. Since then, the application of ICP-MS to provenance study in archaeology has increased dramatically. Currently, large numbers of papers and posters presented at annual meetings of the Society for American Archaeology include the application of LA-ICP-MS.

ICP-MS is based on the fact that high-temperature argon plasmas efficiently ionize atoms in a sample so that different atomic masses can be measured (Neff 2012). There are two ways to introduce solid samples, such as ceramic sherds, to the ICP-MS torch for the analysis. One way is to introduce the solid sample to the plasma as a liquid that has been prepared by microwave digestion (Kennett et al. 2001, 2002; Sakai 2001). Pulverized ceramic samples are completely digested as liquids using a strong acid combined with high temperature and pressure. Accordingly, by mixing all ceramic paste constituents together, microwave digestion ICP-MS produces only bulk data. The microwave digestion of silicate materials, like ceramics, requires the use of hydrofluoric acid (HF), which is extremely hazardous, and this digestion process is also a very time-consuming process. The alternative way to analyze solid samples is to apply a laser beam directly onto a sample. In this study I used a 213-nm Nd-YAG laser to ablate the solid sample. ICP-MS analysis with laser ablation in this study was taken place in the IIRMES lab at CSULB. When the laser ablates the sample surface, the vaporized materials from the sample are ejected and entrained in a helium stream flowing through a chamber and eventually into the argon plasma of the ICP torch for the analysis (Neff 2012).

There are different types of ICP-MS, including quadrupole ICP-MS and Time-of-Flight (TOF) ICP-MS. Rather than scanning the mass range using quadrupole ICP-MS, TOF-ICP-MS entails detecting different masses by monitoring how long it takes them to reach a detector at a single instant in time (e.g., the heavier ions arrive at the detector later than lighter ions) (Neff 2012). Thus, TOF-ICP-MS allows for very fast analysis, which makes it possible to analyze very thin layers of materials, such as paint or slip (Speakman and Neff 2002). This is also ideal for the study of clay matrices exclusive of temper particles, since the chance of ablating inclusions under the clay matrices is minimized by this short-time analysis, with less ablation of materials. Long-time analysis of one small spot may ablate surface material completely and occasionally start ablating materials under the surface materials such as temper.

Sample Preparations

One of the benefits in using LA-ICP-MS is that it produces a minimum destruction of materials. This analysis requires very little preparation of ceramic samples. The analyst simply nips off a small piece of sherd and places it onto the slide of the laser chamber. One slide holds 40–50 pieces.

I analyzed both prepared and unprepared clays collected within the study region as part of this LA-ICP-MS study. Source clays were prepared to exclude some larger mineral particles, since this process may change the chemical signature of the clay. A portion of each clay sample (about 100 g) was soaked in water, stirred thoroughly, and allowed to stand overnight. Very solid clays were partially pulverized with an agate mortar and pestle before soaking in water. The clear water on top of the settled clay was decanted slowly, and the settled clay was dried in a 50°C oven. After the clay was completely dried, the top part of the dried clay (the finest particles) was carefully extracted and ground for the analysis. A small portion of both prepared and unprepared clays, about 30 g, was ground using an agate mortar and pestle, and then water was added to make a clay tile. The clay tile was then fired at 1000˚C for one hour. A small piece of the clay tile was nipped and placed onto the slide of the laser chamber.

Analysis Procedure and Calibration

A point on the ceramic clay matrix of each sherd sample was ablated by the laser and sent to ICP-MS for analysis, avoiding temper or any large inclusion in order to focus on only the clay matrix. The area that I analyzed by LA-ICP-MS was always from the core of each sherd, not including any surface materials (e.g., pigment). The material from the first a few seconds of the ablation was not included in the analysis in order to avoid the contamination on the surface of the clay matrix. The setting for the laser was: “spot” for ablation pattern (there are other ablation patterns such as line or raster), output 70–80 percent, rep rate 10 Hz, and spot size 75 µm. I conducted three analyses on each shred. Along with the unknown samples (i.e., the sherds), known standards were analyzed to standardize the data. Since ICP-MS data fluctuate slightly over time, I analyzed a set of standards after every 30-50 unknown samples analyzed. LA-ICP-MS was conducted on clay matrix of ceramics and source clays, and also on dosimetry samples for OSL dating as I will discuss later in this chapter. SRM 614, 612, 610, glass buttes, and SRM 679 (brick clay) were used to standardize the clay matrix. SRM 612, 610, 679 and New Ohio Red Clay were used to standardize powdered dosimetry samples.

Calibration of ICP-MS data involves using internal standard method. In bulk analysis, including liquid and ground solid samples, known concentrations of internal standards are used. The internal standards, which are not known to be present in the sample, are added in known concentrations (Neff 2012). In the case of dosimetry analysis for luminescence dating, which homogenizes ceramic pastes, an indium internal standard (40 ppm) is added to the unknown for calibration purposes. In the case of point analysis of solid materials without pulverizing, the internal standard sometimes can be assumed. For example, the silicon concentrations of obsidian are very close to 35 percent; thus, silicon can be used as an internal standard, assuming a 35 percent concentration for calibration. However, unlike obsidian, in the case of ceramics an internal standard cannot be assumed. The Gratuze method (Gratuze 1999; Gratuze et al. 2001) is the way to deal with silicate materials with unknown internal standard concentrations. The Gratuze method depends on oxide concentrations of elements that are summed to be 100 percent in whole ceramic samples. A modified Gratuze method, in which silica was used to standardize intensities, was used in this study to calibrate the unknown clay matrix data.

Pilot Study on a Smaller Data Set

As a pilot study, I first conducted LA-ICP-MS analysis on a small number of samples. This pilot study had two objectives. One was to determine whether the same compositional groups in the INAA bulk analysis were also identifiable in the LA-ICP-MS pinpoint analysis of clay matrix, or instead whether different or additional groups were identified. The other objective was to develop sample selection strategies for the larger-scale data analysis. Each compositional group needed to be large enough for vital statistical analysis. Once compositional groups were identified, and if some of these compositional groups were too small, additional samples that might potentially belong to the small group were selected for later analysis. The INAA study of olivine-tempered ceramics suggested some correlations between compositional groups and ceramic attributes and provenience. Thus, detailed examination of physical attributes (e.g., a group consisting of only black-on-gray ceramics with a light core color) in the small groups may suggest selection of additional samples for the LA-ICP-MS analysis of the larger data set.

In this pilot study, 311 sherd samples and 90 clay samples were included. Within the sherd samples, those that were used for INAA analysis discussed above (50 Mt. Trumbull olivine-tempered sherds and 23 the lowland Virgin olivine-tempered sherds) were also included in my LA-ICP-MS pilot study. The ceramic samples included both olivine and non-olivine tempered ceramics from Mt. Trumbull, Tuweep, and the lowland Virgin areas. Clay samples that were collected from both Mt. Trumbull and the lowland Virgin areas were also analyzed.

Base-10 logs of elemental concentrations, principal component analysis (PCA), and canonical discriminant analysis were used to identify compositional groups. The bivariate plot of canonical discriminant function 1 and 3 shows six compositional groups identified in the ceramics from Mt. Trumbull, Tuweep, and the lowland Virgin areas (Figure 5.3). Three of the groups were large enough to calculate Mahalanobis distances for comparison with the clay data. Two of these compositional groups, S-ICP Groups 1 and 2M, matched to Mt. Trumbull clay, and one group, S-ICP Group VR2, matched the lowland Virgin clay. Thus LA-ICP-MS analysis of 311 sherds was able to identify several compositional groups based on clay matrix data. Some of the groups may correspond to INAA groups. This pilot study indicates that these compositional groups that are identified in the INAA bulk analysis are not due to different amounts of temper or temper type, but to different

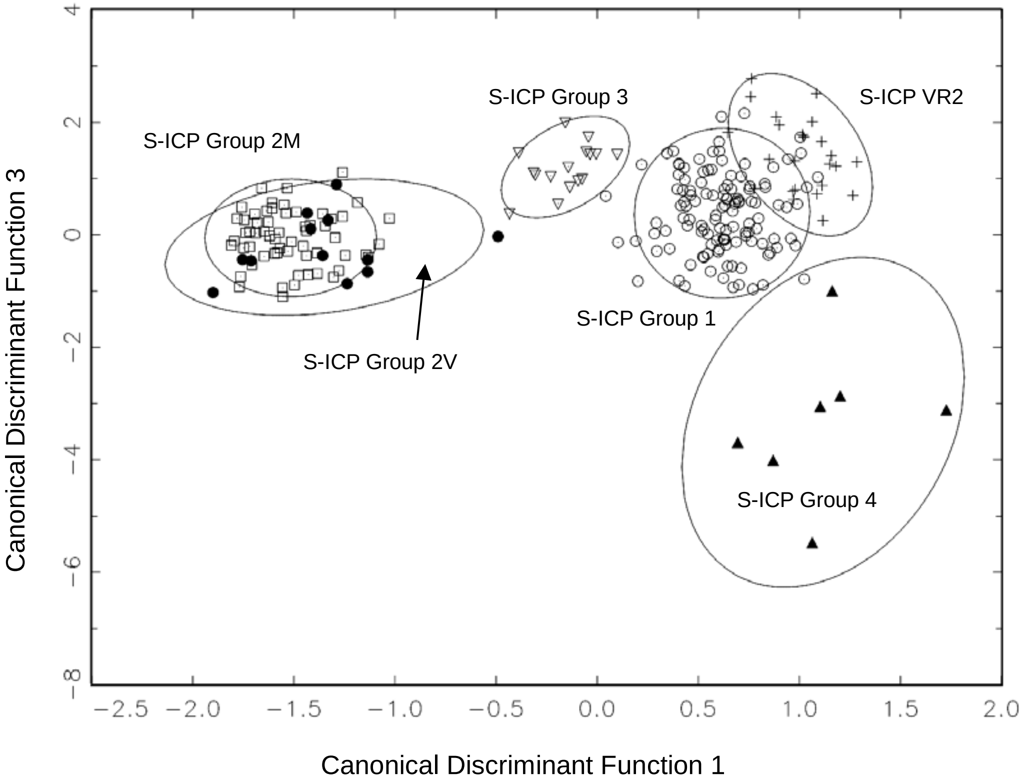


Figure 5.3. Bivariate plot of canonical discriminant functions 1 and 3 showing six compositional groups in the pilot LA-ICP-MS study of ceramics from Mt. Trumbull and the lowland Virgin area (olivine and non-olivine ceramics) (n = 311).

clay sources or paste recipes (e.g., mixing multiple clays, or preparing clay to reduce larger particles of minerals).

Table 5.8 is a summary of compositional groups in this pilot study. Note that ceramics from Tuweep are included in Mt. Trumbull group in this summary, since Tuweep is located adjacent to Mt. Trumbull, and sources of olivine occur in both areas. S-ICP Group1 is a Mt. Trumbull local group matched to Mt. Trumbull clay. The ceramics in this group contain both olivine and non-olivine tempers, and they are both utilitarian and black-on-gray wares from both Mt. Trumbull and the lowland Virgin area. This group may correspond, at least in part, to INAA Group 1. S-ICP Group 2M is another Mt. Trumbull local group, which is matched to Mt. Trumbull clay and includes only Mt. Trumbull olivine utilitarian ware. This may correspond to INAA Group 2. S-ICP Group 2V includes the olivine-tempered utilitarian wares from both Mt. Trumbull and the lowland Virgin area. The clay source is unknown for this compositional group, but potentially it is from Mt. Trumbull, since olivine utilitarian wares are strongly represented in the group. However, this is not certain at this point. S-ICP Group 3 includes olivine and non-olivine wares and both utilitarian and black-on-gray wares that derive only from only Mt. Trumbull. The clay source for this group is unknown but it is possibly Mt. Trumbull, since all ceramics in this group were from only Mt. Trumbull. S-ICP VR2 is a Lowland Virgin local group that matched to local clay in the lowland Virgin area. This group includes both olivine and non-olivine temper, and utilitarian and black-on-gray wares from both areas. S-ICP Group 4 includes only olivine tempered utilitarian and black-on-gray

Table 5.8. Results of the pilot LA-ICP-MS study of 311 ceramic samples and 90 clay samples.

				Temper		Surface Treatment	
Group	Total	Clay Source	Provenience	Olivine	Non-olivine	Plain / Corrugated	Decorate
S-ICP Group1	132	Mt.Trumbull	MT	89	8	76	21
			VR	34	1	30	5
S-ICP Group 2M	59	Mt.Trumbull	MT	59		58	1
S-ICP Group 2V	12	Lowland Virgin?	MT	4		4	
			VR	8		8	
S-ICP Group 3	16	Mt.Trumbull ?	MT	14	2	11	5
S-ICP Group VR2	22	Lowland Virgin	MT	3	4	3	4
			VR	14	1	4	11
S-ICP Group 4	7	Lowland Virgin?	MT	2		1	1
			VR	5		3	2
Unassigned	63			28	35	44	19
Total	311			260	51	242	69

MT: Mt. Trumbull, VR: Lowland Virgin

wares from both Mt. Trumbull and the lowland Virgin area. Again, the source for the clay is unknown, but it is possibly in the lowland Virgin area because most sherds in this group are from that area.

In conclusion, the pilot LA-ICP-MS study of 311 sherds from Mt. Trumbull and the lowland Virgin area demonstrated that some of compositional groups in INAA bulk data were also identifiable in the LA-ICP-MS clay matrix data. Some of the groups are small (e.g., S-ICP Groups 2V, 3, VR2 and 4); thus, it was necessary to increase the sample sizes in order to undertake statistical analysis of these small groups.

The Larger Data Set

The smaller data set of the LA-ICP-MS pilot study showed at least six compositional groups within clay matrices of sherds from Mt. Trumbull/Tuweep and the lowland Virgin areas. The next step was to increase the sample size to detect more compositional groups to compare with the source clay data using powerful statistics. A total of 1,069 sherd samples from Mt. Trumbull/Tuweep and the lowland Virgin area were included in this larger data set for LA-ICP-MS analysis (Table 5.9). Temper materials of these samples include olivine, sherd (with olivine inclusion), and sand or sherd (without olivine) (Table 5.10). Surface treatments include plain, corrugated, black-on-gray, red and polychrome (Table 5.11). Also included were 194 source clay samples (98 unprepared and 96 prepared clays). Clay samples were from 111 sources in Mt. Trumbull and its vicinity (e.g., Tuweep), the lowland Virgin area, and other distant areas. Specifically, 75 are in Mt. Trumbull, three in the Mt. Trumbull vicinity, 24 in the lowland Virgin area, and nine in other distant areas (Table 5.12).

Procedures Used in Compositional Pattern Recognition

Since the data set is large, pattern recognition may be easier if analysis starts with data exhibiting less variation, such as just one ware type. Therefore, compositional patterns were examined by initially considering only olivine-tempered ceramics (n = 819). After identification of groups within the olivine-tempered ceramics, data from non-olivine sherds were added to determine whether they

Table 5.9. Number of ceramic and clay samples involved in the LA-ICP-MS analysis.

Ceramics	Mt. Trumbull	751
	Tuweep	20
	Lowland Virgin	298
	Total	1069
Clay	Clay (unprepared)	98
	Clay (prepared)	96
	Total	194

Table 5.10. Number of ceramic samples involved in the LA-ICP-MS analysis by temper type and provenience.

Provenience	Total	Temper		
		Olivine	Sherd (olivine)	Sand or Sherd (non-olivine)
Mt. Trumbull	751	587	36	128
Tuweep	20	13	1	6
Lowland Virgin	298	219	10	69
Total	1069	819	47	203

Table 5.11. Number of ceramic samples involved in the LA-ICP-MS analysis by provenience and surface treatment.

Provenience	Total	Plain	Corrugated	Black-on-gray	Red	Polychrome
Tuweep	20	7	5	8	0	0
Mt. Trumbull	751	494	145	94	15	3
Lowland Virgin	298	211	11	70	6	0
Total	1069	712	161	172	21	3

Table 5.12. Number of clay sources involved in the LA-ICP-MS analysis.

Source	Frequency
Mt. Trumbull	75
MT. Trumbull vicinity	3
Lowland Virgin	24
Other	9
Total	111

belonged to either olivine compositional groups or to new groups. Once compositional groups were determined based on data generated from all sherds, the unassigned samples were evaluated against groups to examine if any could be included. After group assignment was completed, source clay data were compared with the compositional groups.

Statistical Analysis

Fifty-three elemental concentrations identified by LA-ICP-MS were used for the statistical analysis. The data from the three spots in each sample were averaged prior to statistical analysis. Zero values in the data were excluded during averaging. Any anomalies or erroneous values were also excluded. Averaged values were converted to base-10 logs of elemental concentrations in ppm for statistical analysis.

The GAUSS statistical program was used to conduct base-10 log transformations, PCA, canonical discriminant analysis, hierarchical cluster analysis, Mahalanobis distance classification, and Mahalanobis distance projection. Mahalanobis distance classification was used to determine if specimen membership in a group is valid or misplaced based on PC scores, canonical discriminant function scores, and/or base-10 logs of elemental concentrations. Initial compositional groups were hypothesized by observation of bivariate plots of elements. Once these hypothetical compositional groups were detected, the members of each group were examined to see if they were a valid member or misplaced. Mahalanobis distance projection was used to determine if miscellaneous specimens (e.g., unassigned specimen) could be placed into known compositional groups considering

Mahalanobis distance based on PC scores, canonical discriminant function scores, and/or base-10 logs of elemental concentrations. Once all compositional groups in the ceramic clay matrices were identified, source clay samples were evaluated against these ceramic groups to examine if any could be included in these ceramic compositional groups.

Identification of Compositional Groups in Olivine-tempered Ceramics

Recognition of the initial four compositional groups The first step was to examine if chemical compositional diversity exists among the data set by examining bivariate plots of various elements. Elemental concentrations were converted to base-10 logs of ppm for bivariate plots. Several bivariate plots actually showed some compositional groups among the olivine-tempered sherds. Examples of combinations of elements that show these compositional groups are magnesium and rubidium, rubidium and copper, rubidium and iron, rubidium and lead, and rubidium and manganese. Based on bivariate plot of rubidium and magnesium, four groups were hypothetically defined. As a result, all olivine-tempered ceramics from Mt. Trumbull, Tuweep and the lowland Virgin areas were tentatively placed into four groups (Figure 5.4). The cutoff values for each group are shown in Table 5.13.

Table 5.13. Hypothetical Compositional Groups.

Group	Rubidium (log base-10 ppm)	Magnesium (log base-10 ppm)	Frequency
Group 1	Rb > 1.6	Mg 3.0 < 3.6	536
Group 2	Rb > 1.6	Mg > 3.6	221
Group 3	Rb > 1.6	Mg < 3.0	21
Group 4	Rb < 1.6		41

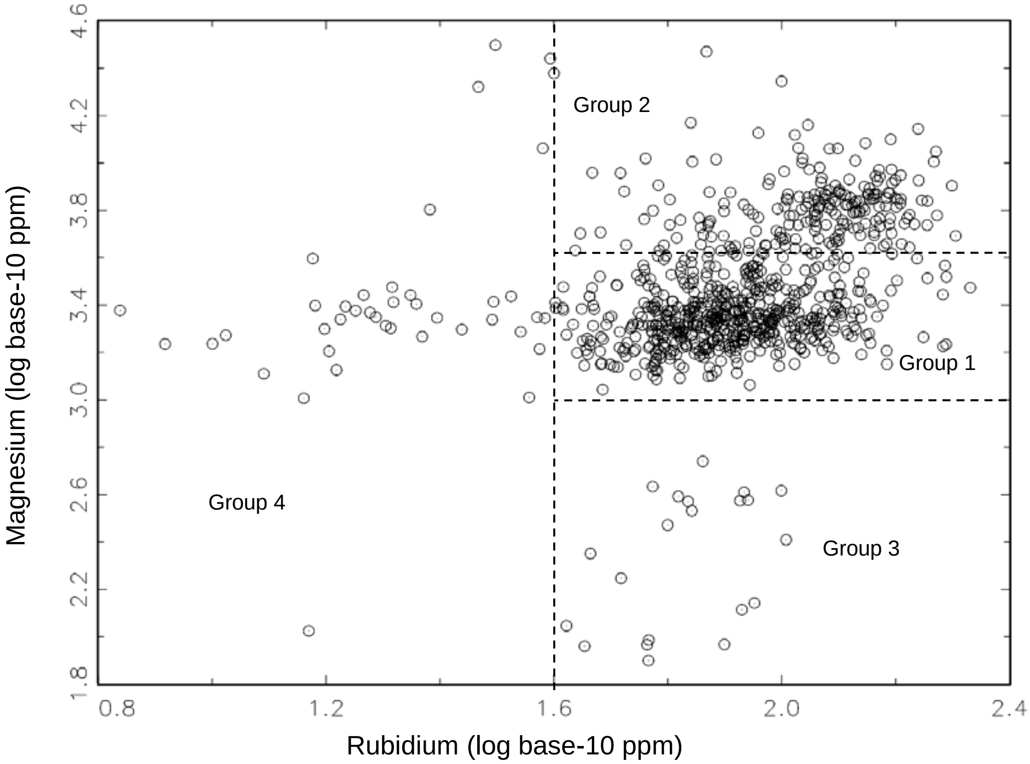


Figure 5.4. Bivariate plot of magnesium and rubidium from the LA-ICP-MS analysis of all olivine ceramics (n = 819).

The next step was to determine if the tentative assignments of the specimens to these compositional groups are valid or misplaced using Mahalanobis distance classification. Prior to this, PC scores were calculated on the complete data set (n = 1,069), including both olivine and non-olivine ceramics. All 53 elements were used for PC calculation. Canonical discriminant function scores to separate four compositional groups in the olivine-tempered ceramics were also calculated. PC scores 1-10, which explain 68 percent of variability of the data set, and canonical discriminant function 1-3 were used for Mahalanobis distance classification. The cutoff values for Mahalanobis distance probability in this data set was 5 percent. If the probability of the specimen being a member of the group was less than 5 percent, or if there were high probabilities with multiple groups, then at this point the specimen was grouped as “unassigned”. This process was to eliminate any invalid member in the group in order to tighten group cohesiveness. When the Mahalanobis distance probabilities showed a distinctively higher probability of membership in another group than the assigned group, the specimen was moved to the suggested group.

Mahalanobis distance classification was used to examine mainly Group 1 and Group 2, which were large enough for a viable analysis. To use Mahalanobis distance classification, an absolute minimum group size is the number of variables plus one. In this study, I set the preferred minimum number of specimens at 30 for most comparisons, since sample sizes less than 30 have been observed to yield erroneous results. Group 3 originally had 21 samples, but I included it in the

Mahalanobis distance classification with caution. If all or too many specimens in one of the other groups are suggested to be members of Group 3, the suggestions are likely erroneous due to the small sample size of Group 3. Only extremely low-probability samples were excluded from Group 3 and moved to the unassigned category. Group 4, which originally had 41 samples, was not included in Mahalanobis distance classification, since extremely low rubidium made this Group 4 very distinctive. Thus, no statistical analysis was needed. Only obvious outliers based on bivariate plots by elements and PC scores were excluded from Group 4. After excluding or moving specimens in the compositional groups, Mahalanobis distance classification was conducted again based on new members to examine if all members were assigned correctly. This process was repeated until most of the specimens were correctly assigned.

Once most of the specimens were assigned, unassigned samples were assessed to determine whether they could be assigned to any of the larger compositional groups. This was done by projecting specimens using Mahalanobis distance (Mahalanobis distance projection as discussed above). For small groups, bivariate plots by elements, PC scores, and canonical discriminant function scores were used to determine whether any unassigned specimens could be assigned to these groups. Any unassigned specimens with extremely low rubidium and low potassium were assigned to Group 4 and those with low lead and low magnesium were assigned to Group 3.

After all the processes were completed, 589 samples were assigned to one of the four compositional groups (Figure 5.5). Of these, 388 samples were assigned to Group 1, 160 samples to Group 2, 18 samples to Group 3, and 23 samples to Group 4, leaving 230 samples as unassigned. A bivariate plot of PC 1 and 3 showed lead, cadmium, manganese, and magnesium were the elements that explained the diversity of the data set (Figure 5.6).

The results of Mahalanobis distance classification based on PC scores indicated that five specimens were misclassified into Group 2; the remaining specimens were assigned to the group successfully. The results of Mahalanobis distance classification based on canonical discriminant function scores suggested that three samples in Group 1 were misclassified; all others were classified successfully. The results of Mahalanobis distance classification based on both PC scores and canonical discriminant function scores suggested all specimens in Group 3 were assigned correctly. Thus classification of samples into these three compositional groups (Group 1, 2, and 3) were successful based on Mahalanobis distance classification. Bivariate plots by PC scores (PC 1-3), canonical discriminant function scores (CD1-3), and elements (rubidium-magnesium) showed the clear separation of all four compositional groups (Figures 5.5–5.8).

Quick observation of ceramic physical attributes and provenience information in each compositional group showed some degree of association. Group 1 included both utilitarian and black-on-gray ware. Group 2 included predominately utilitarian ware. Group 3 ceramics were mostly from the 71 ASM site (the only site

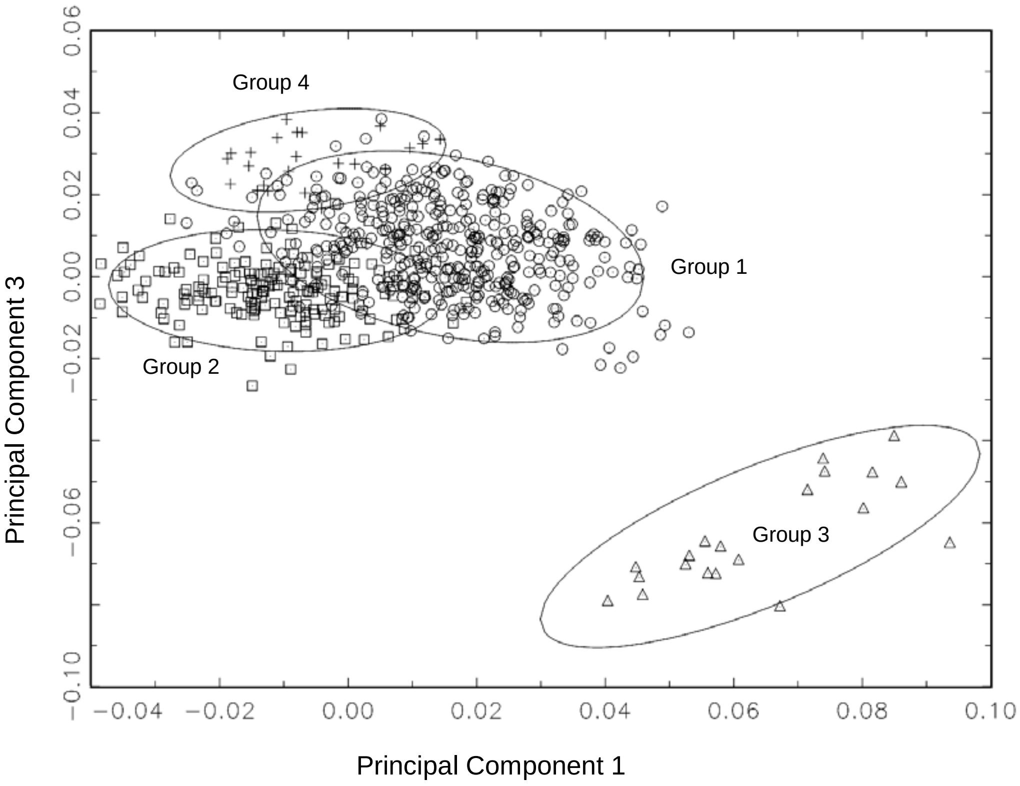


Figure 5.5. Bivariate plot of principal components 1 and 3 showing four compositional groups in the LA-ICP-MS data derived from all olivine-tempered ceramics.

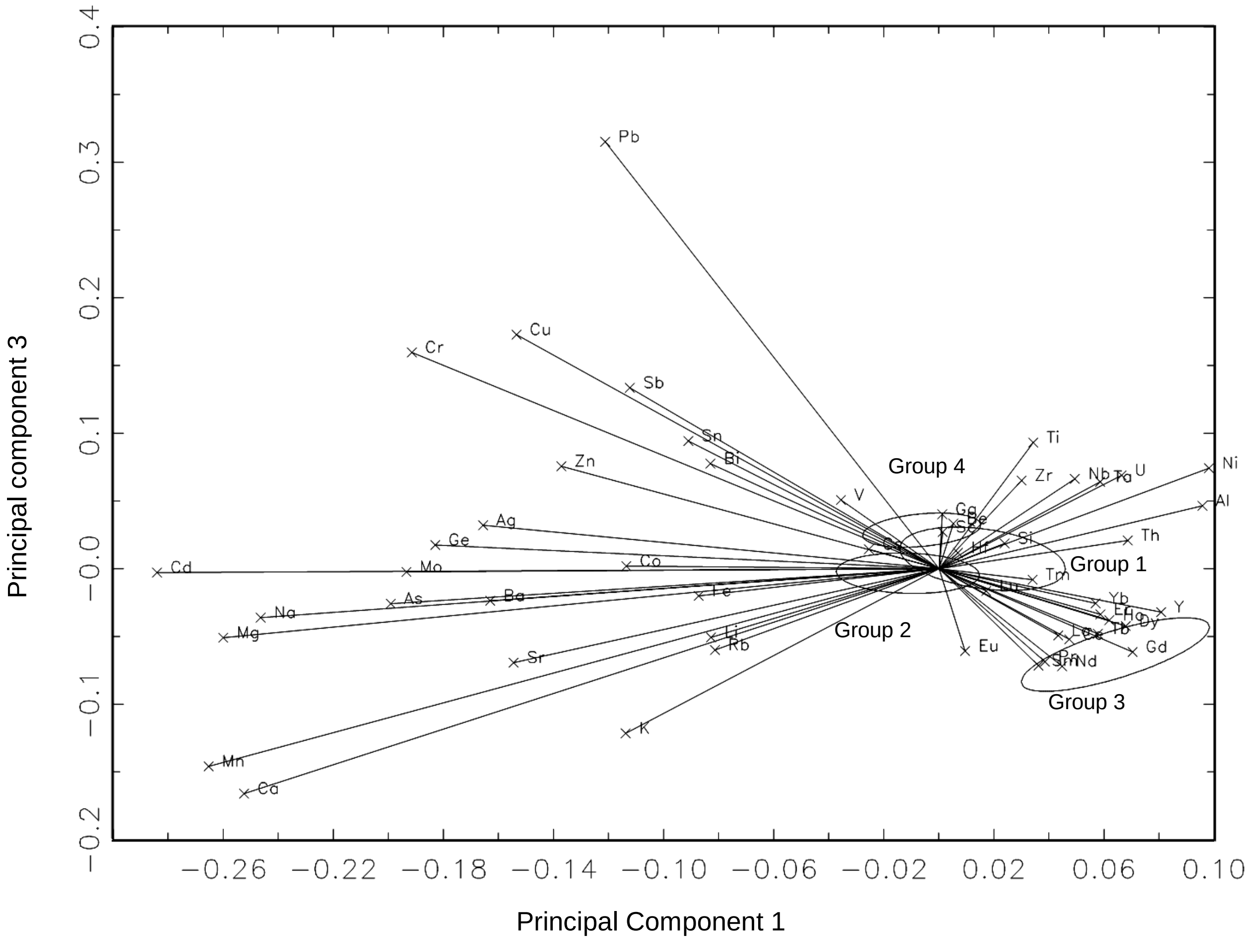


Figure 5.6. Bivariate plot of principal components 1 and 3 with elements showing four groups in the LA-ICP-MS data derived from all olivine-tempered ceramics.

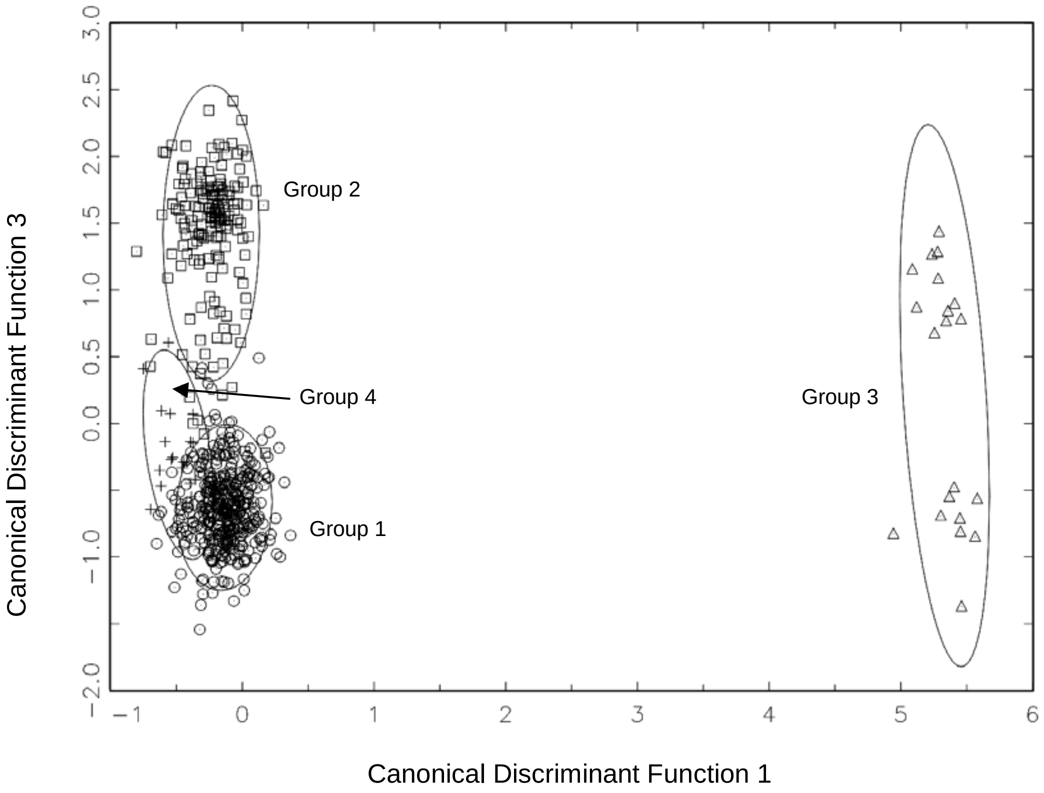


Figure 5.7. Bivariate plot of canonical discriminant functions 1 and 3 showing four groups in the LA-ICP-MS data derived from all olivine ceramics

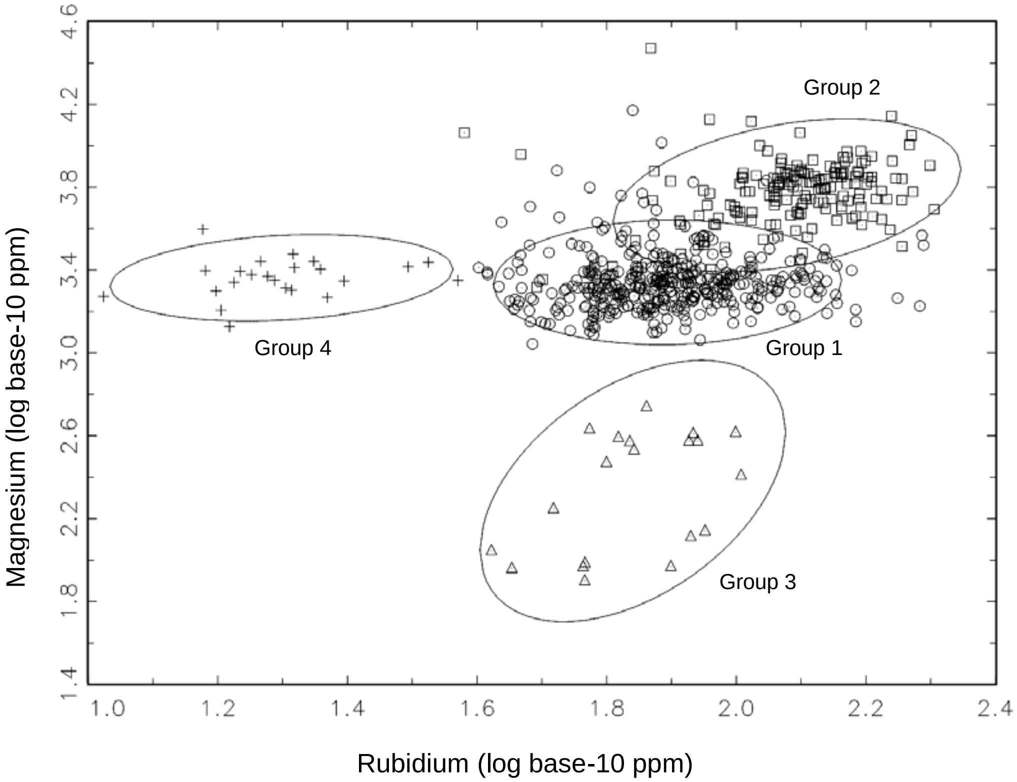


Figure 5.8. Bivariate plot of rubidium and magnesium showing four compositional groups in the LA-ICP-MS data derived from all olivine ceramics.

located on limestone formation in the Mt. Trumbull vicinity from which sherds for the analysis were collected). Note that rare-earth elements and significantly low rubidium distinguish this group (Figure 5.6). Group 4 specimens were mostly from the lowland Virgin area.

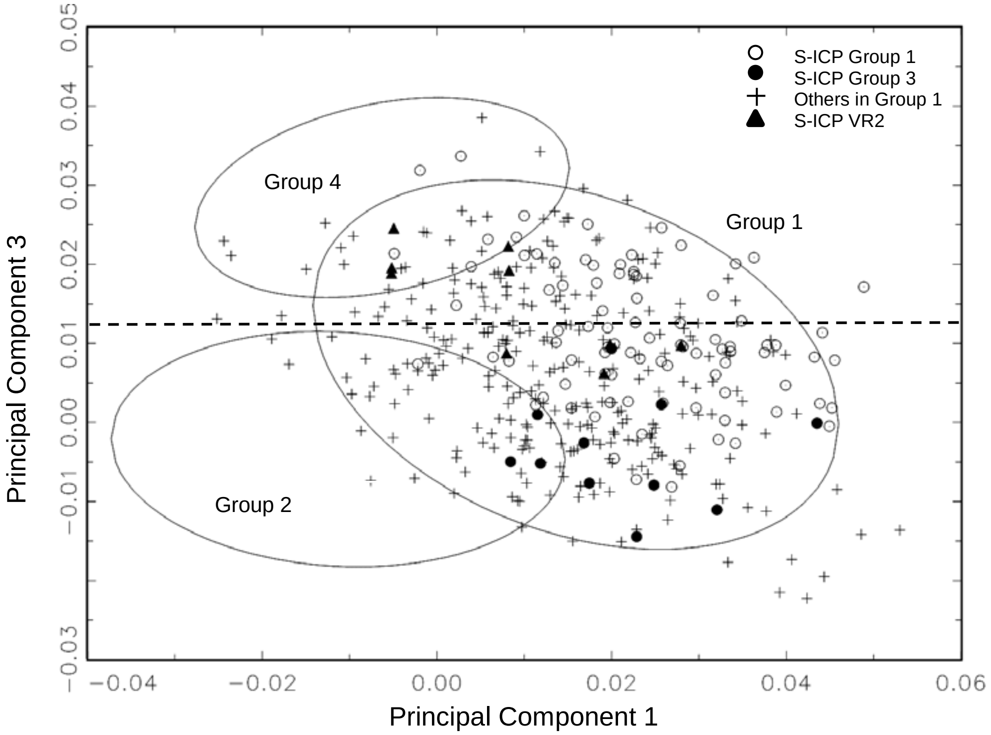
Recognition of Subgroups in Group 1 Since Group 1 is a very large group, subgroups were suspected. Three questions were raised: (1) Did different surface treatments contribute to create the subgroups? (2) Did compositional groups identified in the smaller data set of the pilot study or INAA study form subgroups? (3) Does cluster analysis identify any subgroups? Mahalanobis distance classification based on surface treatment (plain, corrugated, black on gray) revealed no subgroups in Group 1 based on surface treatment. Thus, the answer to the first question is no.

The second question concerns whether compositional groups found in the ICP-MS pilot study and INAA data are related to subgroups in Group 1. To address this question, the four compositional groups identified in the olivine-tempered ceramics were compared to the groups identified in the ICP-MS pilot study (smaller data set) (Figure 5.3) and INAA analysis (Figure 5.1, 5.2). In this regard, some minor chemical differences within Group 1 were difficult to recognize due to the large group size. Therefore, comparison of compositional groups identified in this study to those identified in any other study, such as the INAA or even the ICP-MS smaller data sets, may help to identify these subgroups. In LA-ICP-MS, only clay matrices were analyzed to avoid temper. However, it is possible that three spots from very small areas of paste analysis by LA-ICP-MS may pick up small inclusions in the clay that may not be distributed equally throughout the paste. INAA data, on the other hand, are bulk data, which average everything including temper, clay and all inclusions in the clay. Therefore, comparing LA-ICP-MS compositional groups to those in INAA may show subgroups in the large groups in LA-ICP-MS data. It is also useful to compare compositional groups in this large data set with the compositional groups in smaller data sets to find subgroups. Pattern recognition in a smaller data set is much easier and clearer, although it could be erroneous due to its small sample size. The large data set, at this point, still contained many specimens that may or may not be a part of a group. This could potentially broaden this large group and mask potential subgroups.

Comparison between four compositional groups in the LA-ICP-MS data and the compositional groups in the smaller ICP-MS data set, as well as the INAA data set, suggested that there were some correlations not only with Group 1 but also with other groups. Group 2 includes specimens also included in either S-ICP Groups 2M or 2V that were identified in a smaller data set. Thus, Group 2 in the larger data set may correspond to S-ICP Groups 2M and 2V. S-ICP Group 4 in the smaller data set is distinguished from other groups due to lower canonical discriminant function 3 scores. This may suggest that this group in the pilot study may correspond to Group 4 in the larger data set, which is also very distinctive from other groups, due to low rubidium concentrations (Figure 5.4). Group 1 includes most of S-ICP Groups 1, 3, and VR2 in a smaller data set, as well as INAA Groups 3 and 1. This supports the hypothesis that Group 1 in this large data set includes at least two or three subgroups.

In order to identify these potential subgroups, Group 1 samples, with compositional information in the smaller data set, were plotted with the bivariate plot of PC 1 and 3 (Figure 5.9). This plot was examined to determine if the three groups (S-ICP Groups 1, 3, and VR2) identified in smaller data sets, are also distinctive within Group 1 (Figure 5.9). Figure 5.9 shows most of specimens that were assigned as S-ICP Group VR2 in smaller data set are plotted with a high score on PC 3 in this larger data set and specimens that were assigned as S-ICP-Group 3 in smaller data set are plotted with a low score on PC 3. On the other hand, specimens that were assigned as S-ICP Group 1 in smaller data set are plotted randomly within Group 1. Therefore, I propose at least two subgroups existed in Group 1 which may reflect groups identified in smaller data set, separated by PC 3 scores (high PC 3 group that may reflect S-ICP VR2 recognized in the smaller data set and low PC 3 group that may reflect S-ICP Group 3), are hypothesized. The cutoff score for PC 3 to separate these two groups is 0.012. Based on this, members of Group 1 are placed into two subgroups: Group 1G, which may reflect S-ICP Group 3 (PC 3 score < 0.012), and Group 1V, which may reflect S-ICP VR2 (PC 3 score > 0 012) (Figure 5.9).

To determine whether these hypothetical Groups 1G and 1V were valid subgroups in Group 1, I conducted cluster analysis within Group 1, using PC scores 1–10. This cluster analysis showed that two large clusters (Clusters 1 and 2) can be recognized (Figure 5.10). In order to test if these clusters represented these



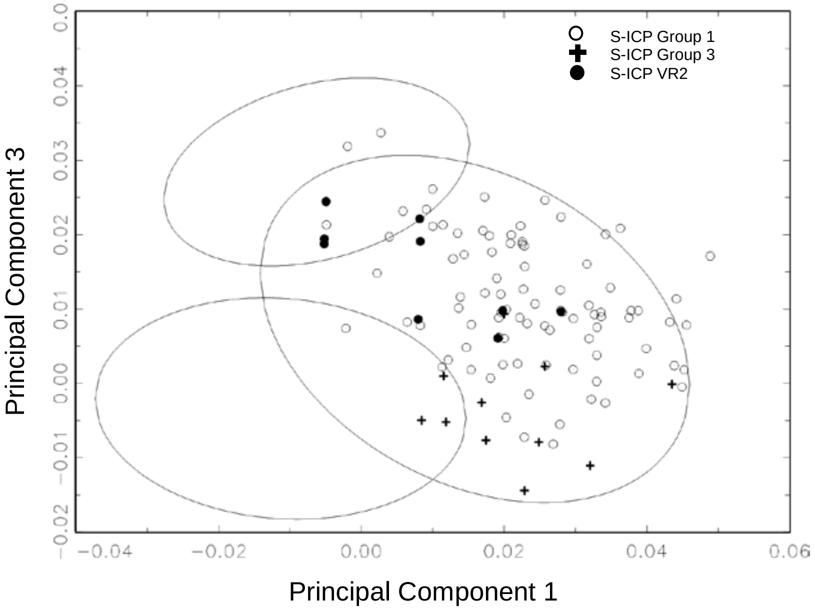


Figure 5.9. Comparison of Group 1 identified in the larger data set with the compositional group identified in pilot study of smaller data set. Ellipses are based on Groups 1, 2, and 4. The specimens with circle and triangle symbols also have pilot study compositional group information. Points are based on the PCA of the larger data set and labeled with the smaller data set compositional groups if they were also included in smaller data set (S-ICP Groups 1, 3, and VR2). All points and ellipses are derived from the PCA of this larger data set. The bottom plot shows only data that also have smaller data set information.

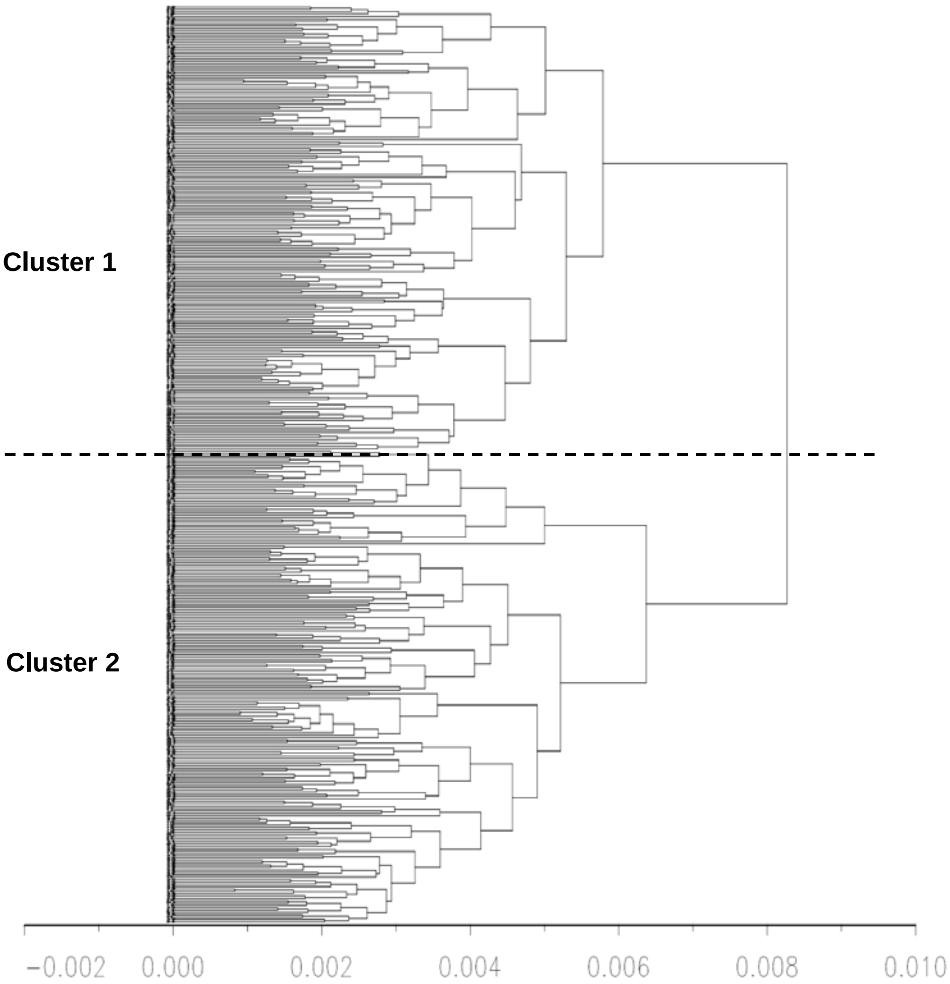


Figure 5.10. Cluster analysis of Group 1 based on principal component scores.

Table 5.14. Comparison of cluster groups in this study and compositional groups in a smaller data set, as well as the hypothetical subgroups in Group 1.

	Groups in Smaller Data Set			Hypothetical Subgroups in Group 1	
	S-ICP Group1	S-ICP VR2	S-ICP Group3	Group 1G	Group 1V
Cluster 1	56	8		67	112
Cluster 2	34		11	163	14

hypothetical subgroups (Groups 1G and 1V), memberships in each cluster group were examined (Table 5.14). The comparison of cluster groups to compositional groups, identified in smaller data sets, suggests that: (1) most of S-ICP Group 1 specimens found in the smaller data set belong to both Clusters 1 and 2 of the larger data set, (2) eight specimens of S-ICP VR2 belong to only Cluster 1, and 11 samples of S-ICP Group 3 in the smaller data set belong to only Cluster 2. Therefore, it is suggested that Cluster 1 reflects S-ICP VR 2 and that Cluster 2 reflects S-ICP Group 3 of the smaller data set. The comparison of proposed subgroups to cluster groups suggested that 112 specimens of Group 1V, one of the proposed compositional groups, belong to Cluster 1, while only 14 of them belong to Cluster 2. This confirmed that proposed Group 1V was actually a subgroup within Group 1. The comparison also suggested more specimens in Group 1G, the other proposed group, belong to Cluster 2 other than to Cluster 1. That is, 163 of Group 1G specimens belong to Cluster 2, while 67 samples belong to Cluster 1. This may suggest Group 1G is also a potential subgroup, although validity of membership in Group 1G has not been examined yet. In summary, Group 1G corresponds to Cluster 2, which may be the same group as S-ICP Group 3 identified in the smaller data set. Group 1V may correspond to Cluster 1, which may be the same group as S-ICP VR 2 in the smaller data set. In conclusion, cluster analysis confirmed that two subgroups exist in Group 1.

As noted in the discussion of cluster analysis, some specimens in these subgroups may be misplaced. As a first step in refining these subgroups, the obvious outliers in each subgroup, Groups 1G and 1V, were excluded by observing several bivariate plots of canonical discriminant function scores. After excluding obvious outliers, Mahalanobis distance classifications, using PC 1–10, canonical discriminant function scores, and base-10 logs of elemental concentrations, were conducted to exclude or reassign any mis-assigned samples in each group, including these subgroups. Canonical discriminant function scores were calculated for all five groups; however, Mahalanobis distance classification was conducted on only three large groups, Groups 1G, 1V, and 2. Based on Mahalanobis distance probabilities, any specimens with low probabilities (< 10 percent) and specimens showing no high probability in any of groups were excluded as unassigned. Specimens with a low probability in the currently assigned group and a high probability in another group were moved into the suggested group. Specimens with high probabilities in multiple groups were unassigned to any other group at this moment. To reassign the specimens into another group, specimens were moved to a suggested group only when the result of Mahalanobis distance probabilities based on all PC scores, canonical discriminant function scores and base-10 logs of elemental concentrations all agreed, or at least the results based on PC scores and canonical discriminant function scores agreed. This process was repeated until the summary of classification success showed good separation without many miss-assignments. Once most of specimens were assigned correctly, unassigned specimens were examined to determine whether they belonged to these compositional groups using Mahalanobis distance projection. In summary, classification success (Tables 5.15–5.17) based on

Table 5.15. Summary of classification success using principal component scores derived from olivine-tempered ceramics.

	Into:			
From:	Group 1G	Group 1V	Group2	Total
Group 1G	182	0	0	182
Group 1V	0	91	0	91
Group 2	0	1	147	148
Total	182	92	147	421

Variables used: Principal components 1–10.

Table 5.16. Summary of classification success using canonical discriminant analysis scores of olivine-tempered ceramics.

	Into:			
From:	Group 1G	Group 1V	Group 2	Total
Group 1G	180	2	0	182
Group 1V	1	90	0	91
Group 2	0	0	148	148
Total	181	92	148	421

Variables used: Canonical discriminant functions 1–4.

Table 5.17. Summary of classification success using log 10 based values derived from olivine-tempered ceramics.

	Into:			
From:	Group 1G	Group 1V	Group 2	Total
Group 1G	153	29	0	182
Group 1V	1	90	0	91
Group 2	0	5	143	148
Total	154	124	143	421

Variables used: LI, BE, NA, MG, AL, SI, K, CA, SC, TI, V, CR, MN,FE, NI, CO, CU, ZN, GA, GE, AS, RB, SR, Y, ZR, NB, MO, AG, CD, SN, SB, CS, BA, LA, CE, PR, ND, SM, EU, GD, TB, DY, HO, ER, TM, YB, LU, HF, TA, PB, BI, TH, U.

all PC scores, canonical discriminant function scores, and base-10 logs of elemental concentrations demonstrated that all specimens were assigned correctly into the large three groups (Groups 1G, 1V, and 2).

Summary of Compositional Groups among Olivine-tempered Ceramics As discussed above, there are at least five compositional groups identified in the clay matrices of olivine-tempered ceramics from Mt. Trumbull, Tuweep, and the lowland Virgin areas. The bivariate plot of PC 1 and 3 was examined to confirm these five compositional groups (Figures 5.11, 5.12). The bivariate plot of canonical discriminant functions 1 and 2 shows that Groups 3 and 4 are distinct from Groups 1G, 1V, and 2, which partially overlap (Figure 5.13). However, the bivariate plot of canonical discriminant functions 4 and 3 shows that these three groups (Groups 1G, 1V, and 2) are independent groups (Figure 5.14). The bivariate plot of rubidium and magnesium clearly shows four compositional groups (Figure 5.15). As recognized in the initial analysis, the subgroups in the original Group 1 (Groups 1G and 1V) overlap (Figure 5.15). However, the bivariate plot of lanthanum and magnesium shows that these two subgroups, Groups 1G and 1V, are separate (Figure 5.16). Thus, bivariate plots of PC scores, canonical discriminant function scores, and base-10 logs of elemental concentrations confirmed these five compositional groups identified in the olivine-tempered ceramics.

Examination of compositional groups with respect to surface treatment and provenience shows some degree of association (Figures 5.17, 5.18). Group 1G (n = 181) includes olivine-tempered ceramics from both Mt. Trumbull and the lowland

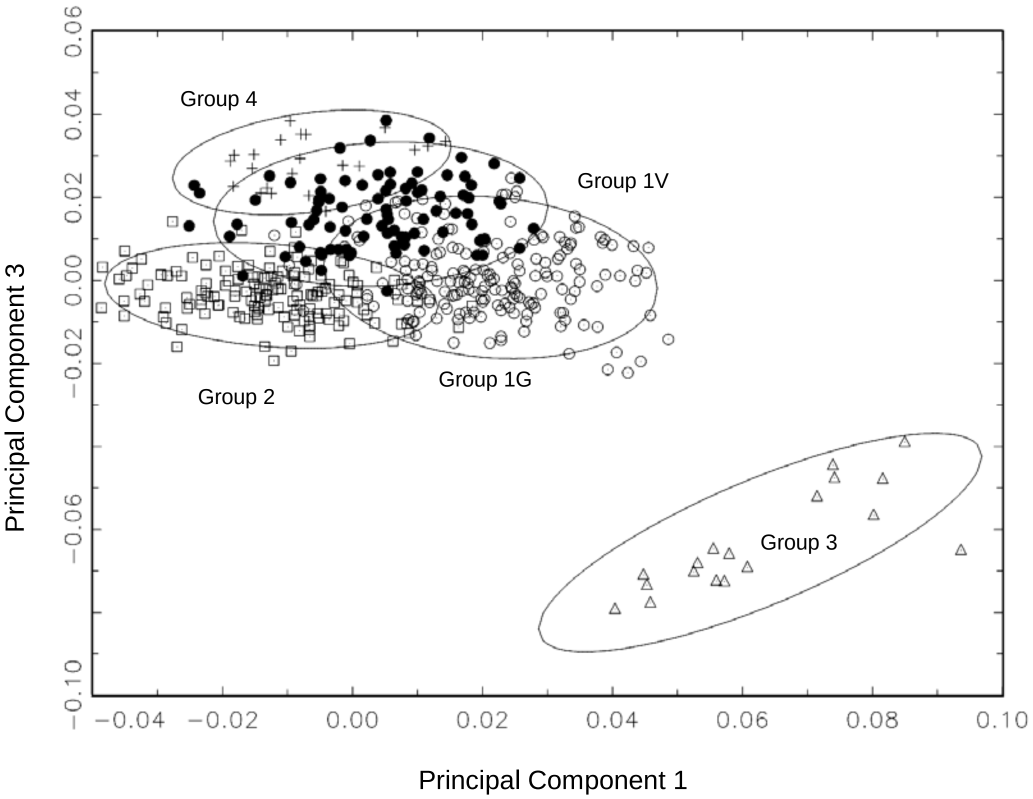


Figure 5.11. Bivariate plot of principal components 1 and 3 showing five compositional groups in olivine-tempered ceramics.

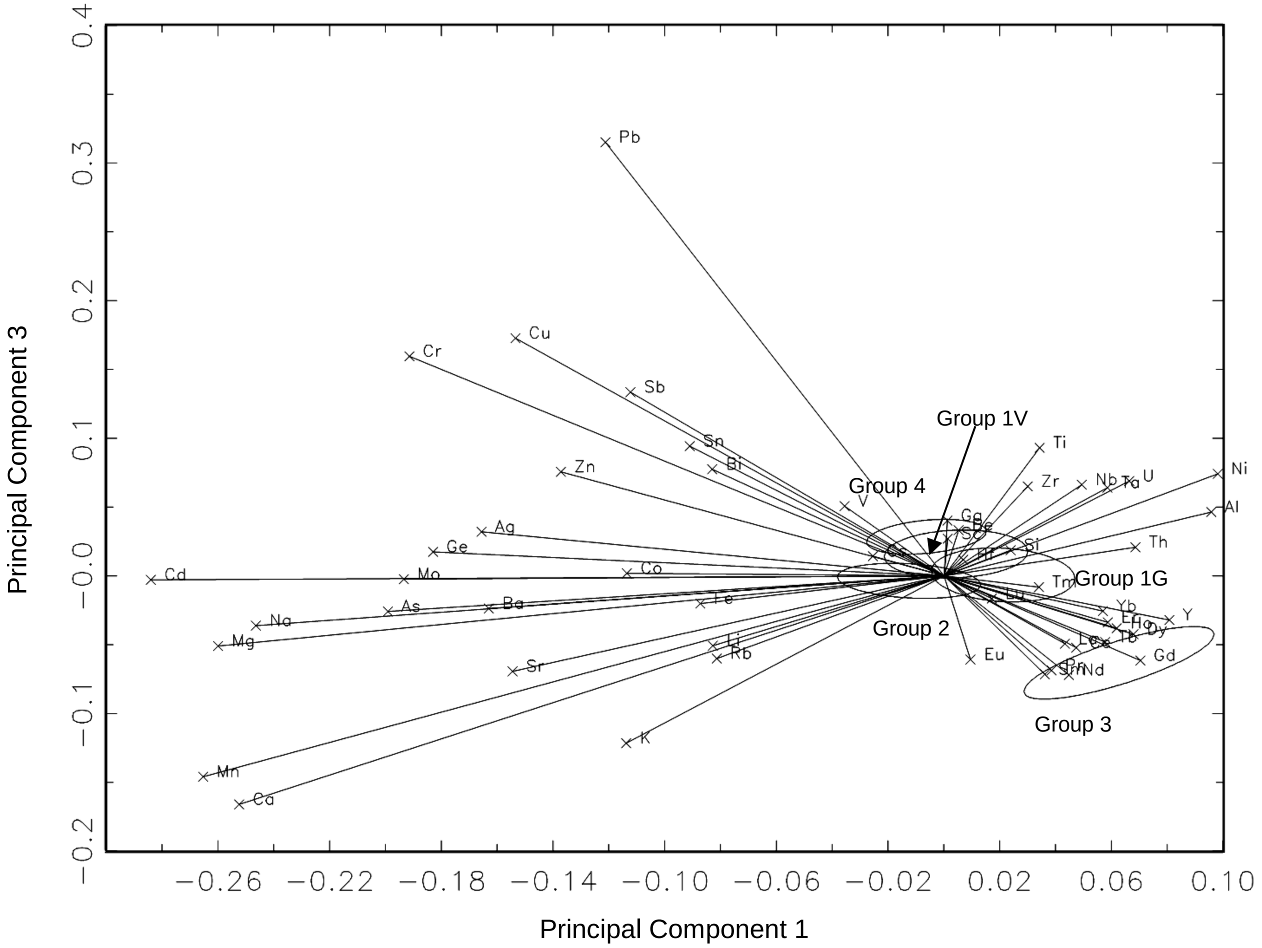


Figure 5.12. Bivariate plot of principal components 1 and 3 showing five compositional groups in olivine-tempered ceramics with elemental vectors.

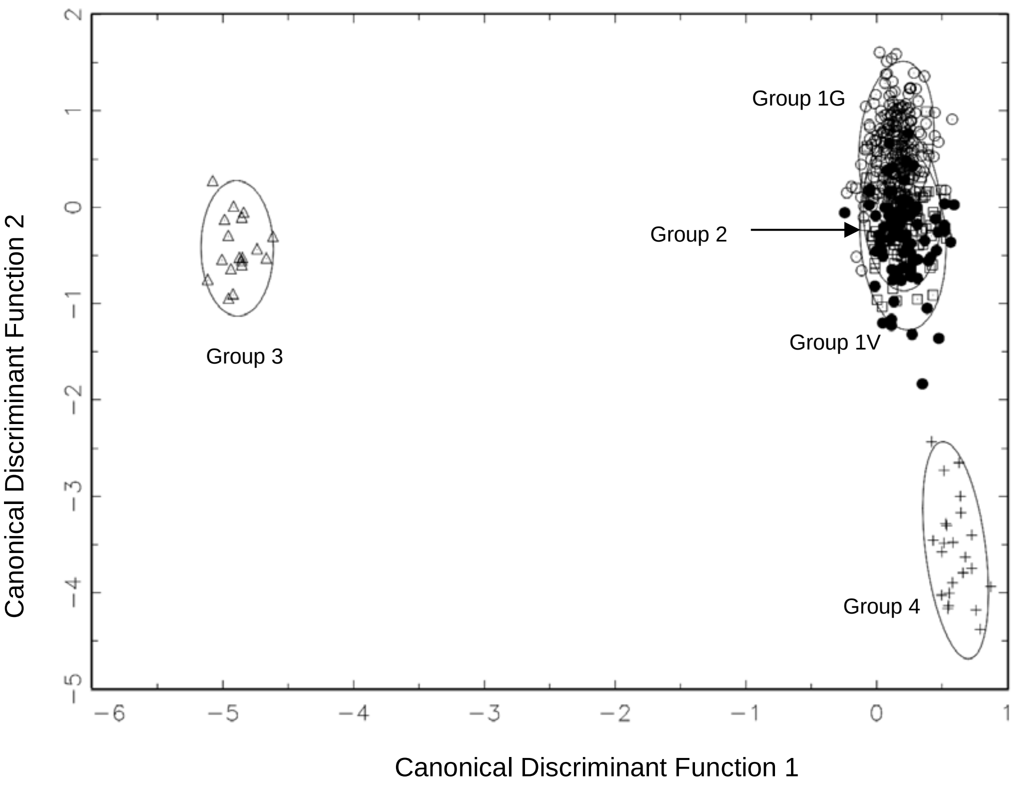


Figure 5.13. Bivariate plot of canonical discriminant functions 1 and 2 showing five compositional groups in olivine-tempered ceramics.

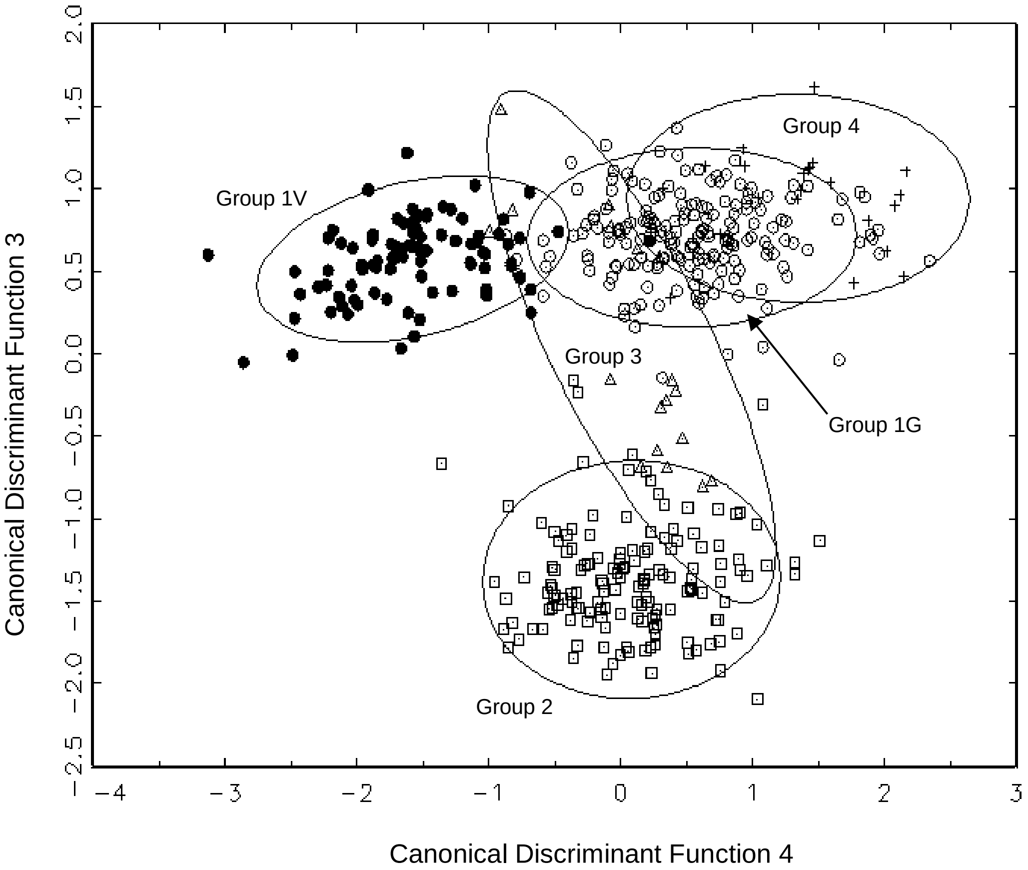


Figure 5.14. Bivariate plot of canonical discriminant functions 3 and 4 showing five compositional groups in olivine-tempered ceramics.

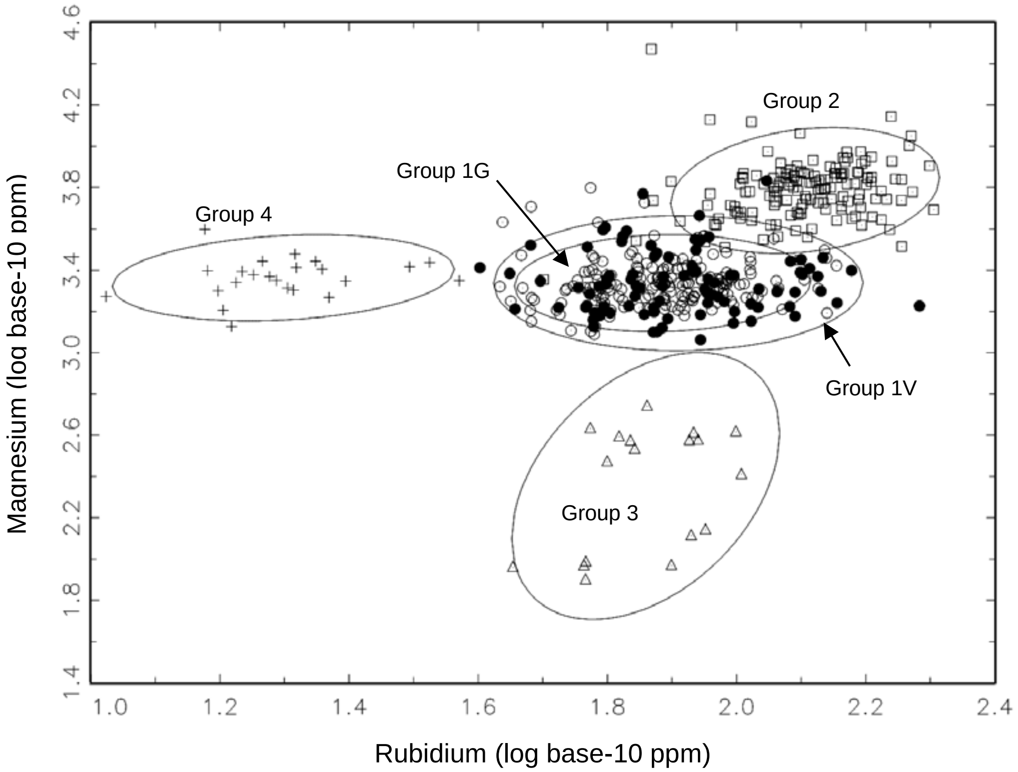


Figure 5.15. Bivariate plot of rubidium and magnesium showing five compositional groups in olivine-tempered ceramics.

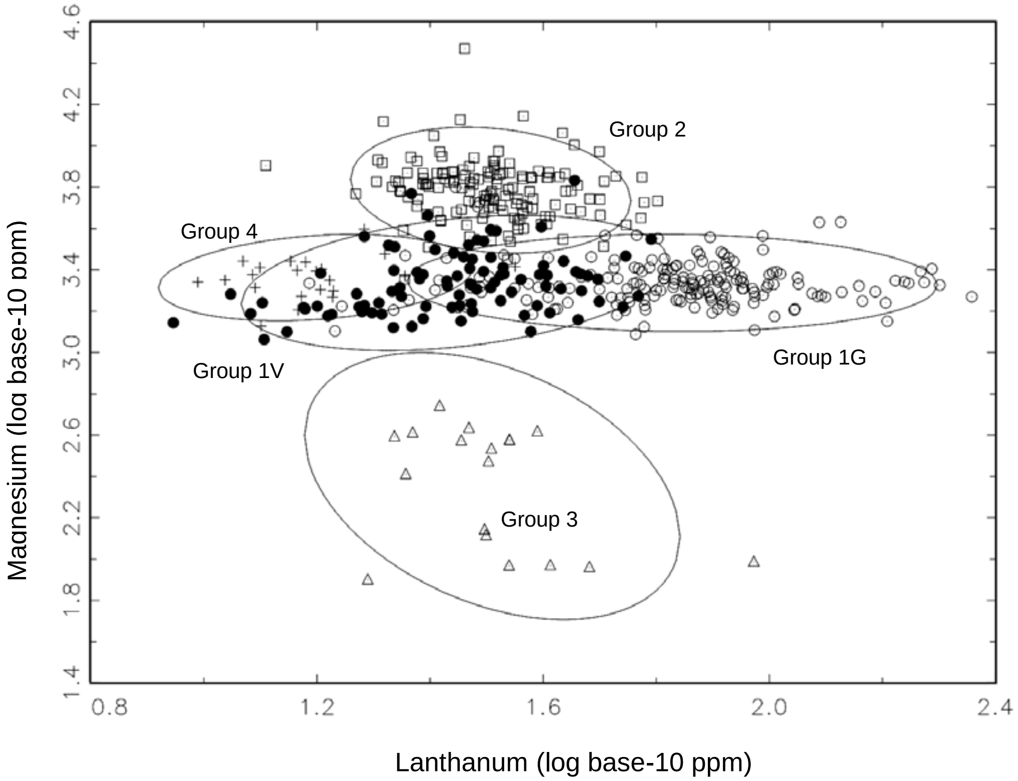
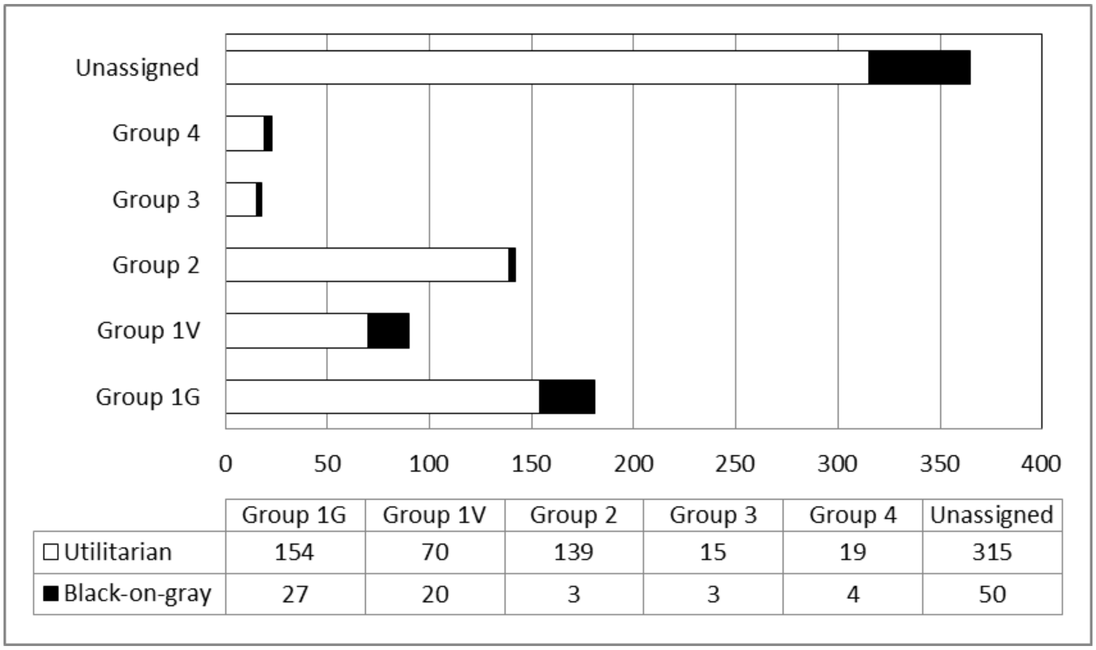
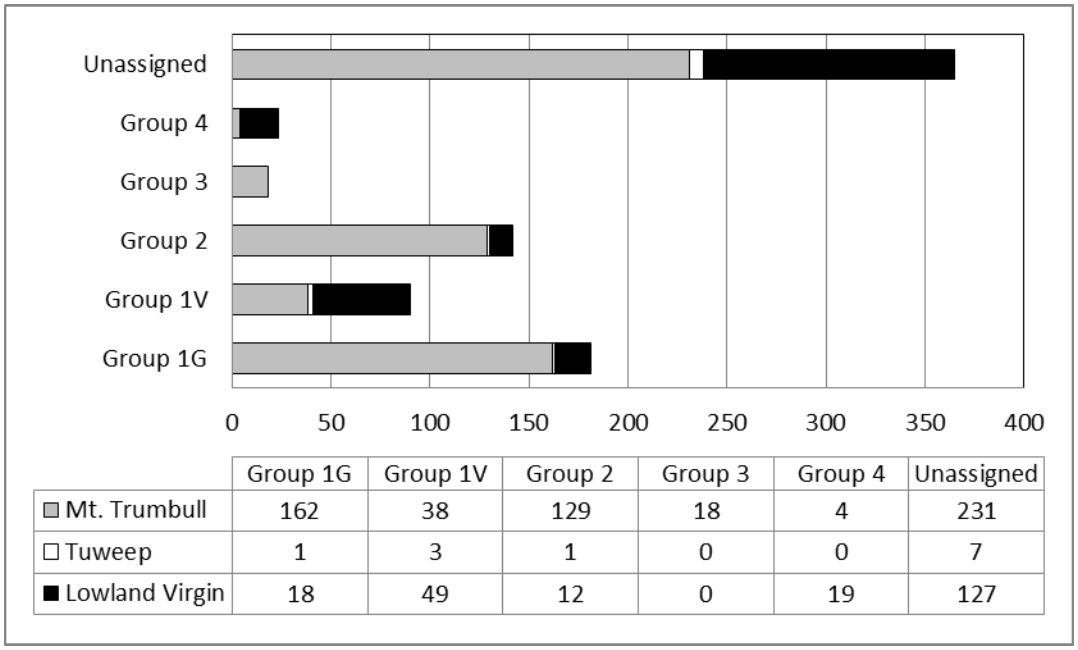


Figure 5.16. Bivariate plots of lanthanum and magnesium showing five compositional groups in olivine-tempered ceramics.



	Group 1G	Group 1V	Group 2	Group 3	Group 4	Unassigned
☐ Utilitarian	154	70	139	15	19	315
■ Black-on-gray	27	20	3	3	4	50

Figure 5.17. Frequency of olivine-tempered ceramics by the five compositional groups and surface treatment.



	Group 1G	Group 1V	Group 2	Group 3	Group 4	Unassigned
▨ Mt. Trumbull	162	38	129	18	4	231
☐ Tuweep	1	3	1	0	0	7
■ Lowland Virgin	18	49	12	0	19	127

Figure 5.18. Frequency of olivine-tempered ceramics by the five compositional groups and provenience.

Virgin area, although Mt. Trumbull/Tuweep sherds dominate this group. This group also has a relatively strong association with site 131 BLM in the Mt. Trumbull area. As well, no ceramics from site 214 ASM in the Mt. Trumbull area are assigned to this group. Both utilitarian and black-on-gray wares are included in this group. Group 1V (n = 90) includes a large proportion of the sherds from the lowland Virgin area. A few ceramics from 71 ASM, which is the only site on the sedimentary rock formation in Mt. Trumbull, are also included in this group. Ceramics in this group are either utilitarian ware or black-on-gray. Group 2 (n = 142) includes predominantly utilitarian wares. Group 3 (n = 18) is chemically very different from other groups. Rare earth elements and significantly low magnesium values distinguish this group from others (Figures 5.12, 5.15, 5.16). This group includes predominantly sherds from site 71 ASM, which is the only site located on a limestone formation among the sites included in this study in the Mt. Trumbull area as mentioned above. Group 4 (n = 23) includes sherds mostly from the lowland Virgin area. At this point, 365 olivine-tempered sherds of the total of 819 are unassigned to any group.

Comparison of Clay Data to Ceramics Groups Five compositional groups identified in the olivine-tempered ceramics were compared to clay data. Prior to Mahalanobis distance projection, bivariate plots of PC scores were examined to compare the clay data to compositional groups to determine the degree of correlation. A bivariate plot of PC 1 and 3 shows that many clay data overlap with Group 2 (Figure 5.19). Some clay data also overlap with Groups 1G and 1V. After

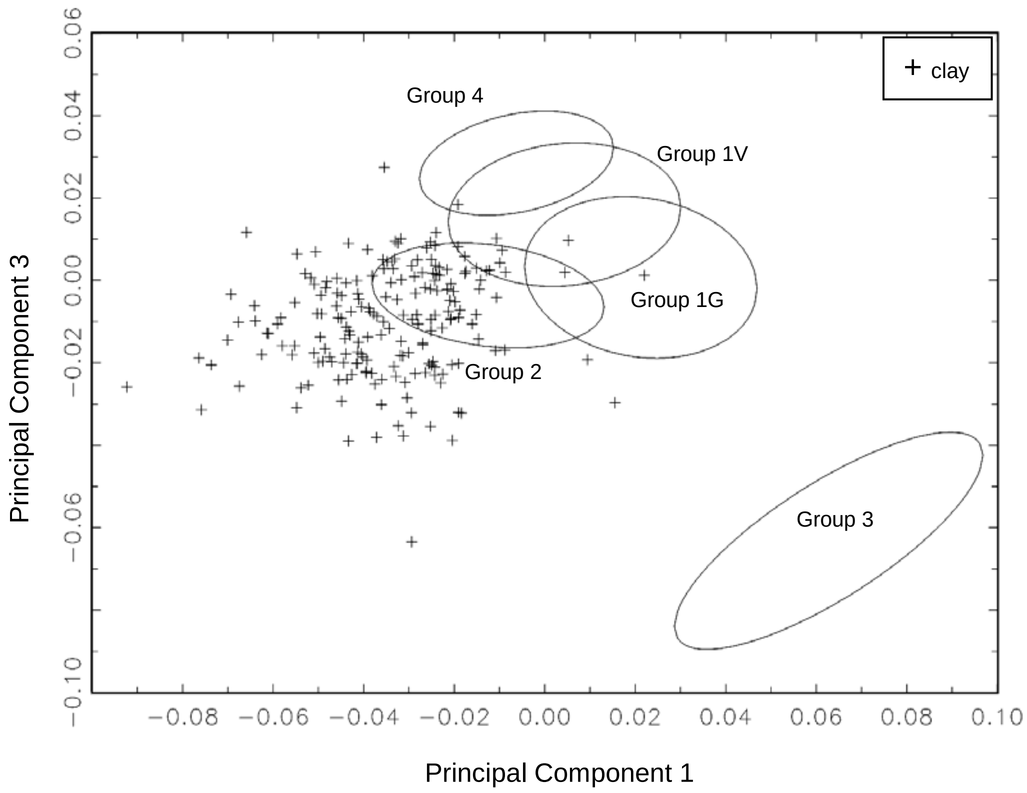


Figure 5.19. Bivariate plot of principal components 1and 3 showing clay data and olivine-tempered ceramic compositional groups. Point (+) shows clay data, and ellipses are based on the five compositional groups of olivine-tempered ceramics.

examination of bivariate plots, the clay data were examined to determine if any clays were matched to the larger groups, Groups 1G, 1V, and 2, using Mahalanobis distance projections based on PC 1–10. The results show that: (1) Group 1G is matched to one Mt. Trumbull clay sample at a very low probability, which suggests this clay (one from sedimentary formation: Chinle clay) is a potential source clay for Group 1; (2) Group 1V is matched to a lowland Virgin clay sample with a low probability, which suggests that this clay is a potential source clay for Group 1V (Mahalanobis distance probability of the clay is extremely small or 0 to any other group); and (3) Group 2 is matched to at least 18 Mt. Trumbull vicinity clays with high probabilities. Consequently, some of the compositional groups identified in the olivine-tempered sherds potentially represent a production area: two Mt. Trumbull local groups (Groups 1G and 2) and one lowland Virgin local group (Group 1V).

Identification of Compositional Groups among All Sherds

Five compositional groups were identified in the olivine-tempered ceramics as discussed above. The next step was to determine if sherds with temper other than olivine belong to any of these compositional groups.

Five Compositional Groups First, non-olivine specimens (with sand temper and sherd temper including olivine particles) and unassigned olivine-tempered specimens were examined to determine if any could be matched to the five compositional groups identified in the olivine-tempered ceramics. Mahalanobis distance projection based on PC scores, canonical discriminant function scores, and base-10 logs of elemental concentrations were used to examine if any of sand-tempered, sherd/olivine-tempered, or unassigned olivine-tempered could be assigned to any of the larger groups, i.e., Groups 1G, 1V, and 2. Based on the results, the samples with high probabilities were placed into the suggested compositional groups. Canonical discriminant function scores were calculated based on all five groups, although Mahalanobis distance projection could be applied to only these three large groups. The cutoff probability for assigning a specimen to a suggested group is 10 percent. After adding new specimens to the suggested groups, Mahalanobis distance classification was conducted on all specimens, including the new specimens, to determine if all were assigned correctly. Once the validity of membership was confirmed, the rest of unassigned non-olivine and olivine-tempered ceramics were again projected using Mahalanobis distance to see if any more specimens could be assigned to any of the compositional groups. Canonical discriminant analysis needed to be recalculated each time before using this process. This process was repeated until no further high probabilities were seen.

Subgroups in Five Compositional Groups My first attempt at placing non-olivine ceramics (with sand temper and sherd temper including olivine particles) and unassigned olivine-tempered ceramics into five compositional groups showed: (1) most sherd-tempered (containing olivine particles) sherds were placed into Group 2, (2) sand-tempered ceramics from the lowland Virgin area were placed only in Group 1V, and (3) sand-tempered ceramics from Mt. Trumbull were placed in all three large groups (Table 5.18). As discussed above, in the olivine-tempered ceramic data set,

Table 5.18. Results of first projection of non-olivine ceramics (sand temper, and sherd temper including olivine particles) and olivine-tempered ceramics unassigned to any of the five compositional groups.

	Mt. Trumbull		Lowland Virgin	
	Sand	Sherd (olivine)	Sand	Sherd (olivine)
Group 1G	8	0	0	0
Group 1V	4	0	6	0
Group 2	3	19	0	0
Group 3	NA	NA	NA	NA
Group 4	NA	NA	NA	NA
Unassigned	119	18	63	10

Group 1V was matched to local clays from the lowland Virgin area. In addition, based on INAA analysis, most of sand-tempered utilitarian wares in the lowland Virgin area were a product of local production (Larson et al. 2005). However, Group 1V includes olivine-tempered sherds collected in both the Mt. Trumbull and lowland Virgin areas, as well as Mt. Trumbull sand-tempered ceramics. It is puzzling to find Mt. Trumbull olivine-tempered sherds in the lowland Virgin local group. One possible explanation is that lowland Virgin potters imported olivine from Mt. Trumbull and made olivine-tempered pots to export back to Mt. Trumbull. However, this scenario does not seem likely, given that the production of Mt. Trumbull olivine-tempered ceramics in the lowland Virgin area does not seem to have selective benefit over production in the Mt. Trumbull area, which is the olivine source area. Consequently, Group 1V may include two subgroups, potentially one with a Mt. Trumbull origin including Mt. Trumbull olivine-tempered ceramic production and the other with lowland Virgin origin.

The bivariate plot of PC 1 and 3 (Figure 5.11) shows that Group 1V is placed between Group 4 and Group 1G among the olivine-tempered sherds. Group 4 includes mostly the sherds from the lowland Virgin area, and Group 1G is a Mt. Trumbull local group, since one local clay sample was matched to this group. This may suggest that Group 1V is, in part, very close to Group 1G, which is of Mt. Trumbull origin chemically and, in part, close to Group 4, which is likely from lowland Virgin origin. This is consistent with the possibility of subgroups. One subgroup is a Mt. Trumbull local group consisting of Mt. Trumbull olivine-tempered ceramics. The other is the lowland Virgin local group consisting of sand-tempered ceramics, some of which were transported into the Mt. Trumbull area, as well as Lowland Virgin olivine-tempered ceramics.

In light of the possibility of subgroups, I tested two propositions. One proposition is that subgroups do not exist, and Group 1V is one compositional group. That is, Group 1V is a lowland Virgin local group that includes both Mt. Trumbull and lowland Virgin olivine-tempered ceramics, in addition to sand-tempered ceramics. This would be the case if (1) Mt. Trumbull olivine-tempered pottery in this group was made in the lowland Virgin area, or (2) the olivine-tempered pottery from Mt. Trumbull in this group was made from clay very similar chemically to the lowland Virgin clay group. The alternative proposition is that subgroups exist in Group 1V. If so, the Mt. Trumbull olivine-tempered ceramics in this group are similar chemically to the lowland Virgin local group, but they are not in the same compositional group. Thus, one of the subgroups in Group 1V should include exclusively Mt. Trumbull olivine-tempered ceramics. The other subgroup should be a local group pertaining to the lowland Virgin area consisting of sand-tempered ceramics. In addition, the sand-tempered pottery from Mt. Trumbull in Group 1V would have been made in the lowland Virgin area, and the same clay may have been used to make olivine-tempered ceramics in the lowland Virgin area. In summary, two subgroups were hypothesized: Group 1VM, which includes only Mt. Trumbull olivine-tempered ceramics, and Group 1VV, which includes all sand-tempered ceramics, as well as the lowland Virgin olivine-tempered ceramics.

To investigate further the existence of these proposed subgroups, PC scores were calculated on only Groups 1G, 1VV, and 1VM, which were combined in one group (Group 1) in the initial olivine-tempered ceramic analysis. A bivariate plot of PC 1 and 3 shows that these subgroups within Group 1V are different compositional groups (Figure 5.20). The validity of membership of each subgroup was examined by Mahalanobis distance classification based on PC and canonical discriminant function scores. As discussed above, PC scores were calculated only within the three groups. Principal components 1–12, which explain 71.23 percent of the variability, were used in the Mahalanobis distance classification. Canonical discriminant function scores were calculated also for these three groups. The first result of the Mahalanobis distance classification showed many Group 1VM specimens to have high probabilities of membership with Group 1VV, which suggests these specimens in Group 1VM should have moved to Group 1VV. This suggested that Group 1VV was still too broad chemically. Therefore, some specimens with low probabilities

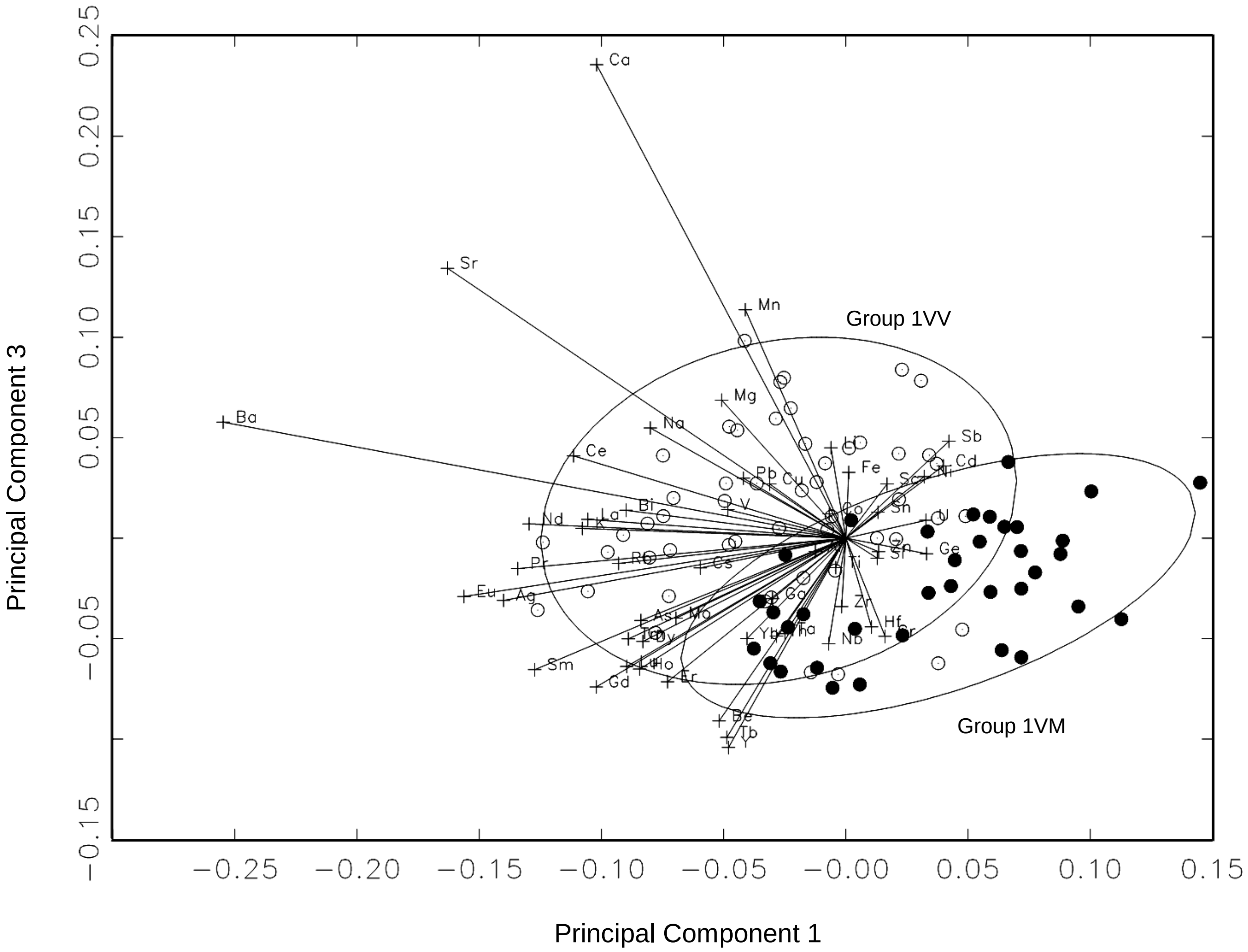


Figure 5.20. Bivariate plot of principal component scores 1 and 3 based on only Group 1 ceramic data to examine subgroups, G1VV and G1VM.

needed to be excluded from Group 1VV to tighten this group before conducting the Mahalanobis distance classification. The specimens with low probabilities from both Groups 1VV and 1VM were excluded, and the specimens with high probabilities within another group were moved into the suggested groups. This process was repeated until results of classification success showed clear separation.

The result of the Mahalanobis distance classification using PC 1–12 showed that seven samples out of 52 were mis-assigned in Group 1VV, and 11 samples out of 36 were mis-assigned in Group 1VM (Table 5.19). This was not as clear a separation as expected. However, Mahalanobis distance classification using canonical discriminant scores showed that Groups 1G, 1VV, and 1VM were separate groups. The summary of classification success demonstrated that almost all samples were assigned correctly to the three groups (Table 5.20). The bivariate plot of

Table 5.19. Summary of classification success in Groups 1VV and 1VM using principal components scores.

		Into:		
		Group 1VV	Group 1VM	Total
From:	Group 1VV	45	7	52
	Group 1VM	11	25	36
	Total	56	32	88

Variables used: Principal component analysis scores 1–12.

Table 5.20. Summary of classification success in Groups 1G, 1VV and 1VM using canonical discriminant scores.

		Into:			
		Group 1VV	Group 1VM	Group1G	Total
	Group 1VV	52	0	0	52
From:	Group 1VM	0	36	0	36
	Group 1G	2	1	188	191
	Total	54	37	188	279

Variables used: Canonical Discriminant scores 1–2.

canonical discriminant scores 1 and 2 also confirmed that these three groups were separate groups (Figure 5.21). Thus, Groups 1G, 1VV, and 1VM, which are similar chemically, were confirmed to be three different groups.

Six Compositional Groups After confirming two subgroups in Group 1V as discussed above, six compositional groups are identified so far: Groups 1G, 1VM, 1VV, 2, 3, and 4. Now the rest of unassigned olivine- and non-olivine-tempered ceramics were evaluated to see if any of them could be placed into any of the six groups.

Bivariate plots of elemental concentrations, PC scores, and canonical discriminant function scores were used to examine if any of unassigned samples could be placed in small compositional groups, such as Groups 3 and 4. Group 3 was defined by low lead, low magnesium, low chromium and low copper. Thus, unassigned samples with low values in these elements were placed into Group 3. Group 4 samples were defined by low rubidium and low potassium. Unassigned samples with low values in these elements were placed into Group 4.

The rest of the unassigned samples were evaluated to see if any of them could be placed in four large compositional groups using Mahalanobis distance probabilities. Only PC scores and canonical discriminant function scores were used for the calculations to conduct Mahalanobis distance projection; the base-10 logs of elemental concentrations were not used. Specimens were moved from the unassigned to the assigned group only when the Mahalanobis distance projections, based on both PC scores and canonical discriminant function scores, agreed.

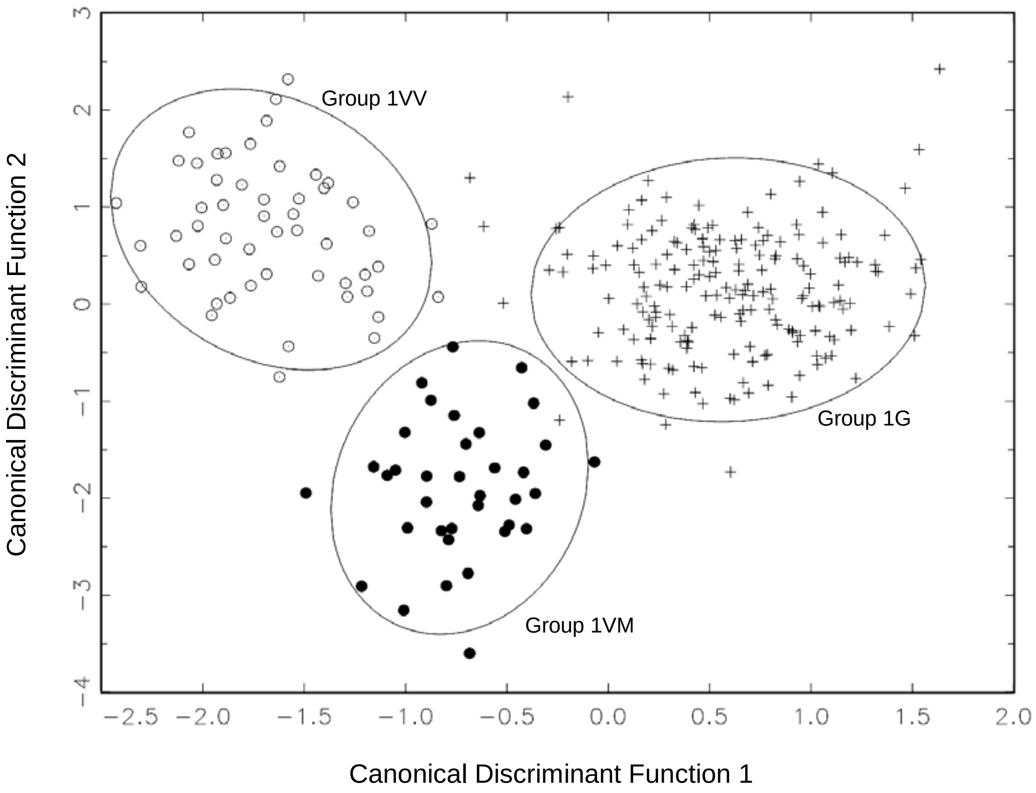


Figure 5.21. Bivariate plot of canonical discriminant functions 1 and 3 showing Groups 1VV, 1VM and 1G.

Canonical discriminant function scores were calculated for all six compositional groups, although Mahalanobis distance projection was conducted only for the four larger groups. After moving the unassigned specimens to either of the compositional groups, Mahalanobis distance classification was conducted again to examine if all samples were assigned correctly. This process was repeated until no unassigned samples showed high probabilities for any of the groups.

Note that unassigned specimens were moved as a *solid member* or *possible member* based on the Mahalanobis distance probabilities described below. After moving the solid members, the Mahalanobis distance classification was re-examined to assure the group was still tight, as discussed above. If the unassigned specimens were identified as a *possible member,* the Mahalanobis distance probabilities were not re-calculated, since adding a *possible member* to a known group could broaden the group's boundary and could cause problems when the groups were compared later to clay samples. Described below are examples of how unassigned samples were assigned as a *solid member, possible member,* or unassigned based on the Mahalanobis distance probabilities.

<u>Case 1: Assigned to a known group and included in the Mahalanobis distance classification: *solid member.*</u> To be a solid member, the cutoff probability was five percent. If the specimen had a probability greater than five percent for multiple groups, the cutoff ratio of highest probability group to the sum of probability to other groups was 5:1. In the case of specimen MT131-247 (Table 5.21), Mahalanobis distance probability based on canonical discriminant function scores clearly

Table 5.21. Mahalanobis distance projection of unassigned specimens to a known group. An example of moving unassigned specimens to known groups: Case 1 (MT131-247).

	Group1G	Group 1VV	Group 1VM	Group 2
Mahalanobis distance probabilities based on canonical discriminant analysis	0.001	21.931	0.002	0.000
Mahalanobis distance probabilities based on principal component analysis	5.800	80.469	6.655	0.001

suggested that this sample should be assigned into Group 1VV, since there is little possibility for assigning this specimen to other groups. However, Mahalanobis distance probability based on PC scores shows some probabilities to multiple groups other than Group 1VV. When the probability of being a member of Group 1VV is compared to the sum of probabilities for assigning to other groups, the ratio is 80.469:12.456 (≈6.5: 1). This ratio is high enough to assign this sample to Group 1VV. Thus, this sample is assigned as a *solid member* of Group 1VV and included in the further Mahalanobis distance calculations.

Case 2: Assigned to a known group but not included in the Mahalanobis distance calculations: *possible member*. The criteria to be a *possible member* of a compositional group, especially the four large groups (Groups 1G, 1VV, 1VM, and 2), are as follows. Unassigned samples are assigned to one of the known groups when the specimen fulfills *either* of these criteria: (1) The results of Mahalanobis distance probabilities based on both PC scores and canonical discriminant function scores agree and the cutoff probability is > 5 percent. (2) Mahalanobis distance probability based on either PC scores or canonical discriminant function scores is > 10 percent in a single group without having equally high probability for assignment to other groups. (3) The probability based on either PC scores or canonical discriminant function score is clearly high in a single group and relatively high in other groups, and then the ratio of the probability in the suggested group to the sum of the probabilities to other groups is much greater than 1:1. (4) The probabilities based on both PC scores and canonical discriminant function scores suggest membership in multiple groups, and the ratio in the suggested group to the sum of other groups is greater than 3:1. In the case of specimen MT214-19 (Table 5.22), Mahalanobis distance probabilities based on canonical discriminant function scores suggest that it may be assigned to Group 1VV, since the probabilities of this specimen being a member of other groups are extremely low. The ratio of this specimen's probability of membership in Group 1VV to others is 75.689:0.569. However, those based on PC scores show some probabilities of membership to multiple groups as well. When the probability of this specimen's membership in Group 1VV is compared to the sum of probabilities of membership in others, the ratio is 95.692: 24.314 (≈3.9: 1), which is not strong enough to assign it as a solid member. Thus, this sample is assigned as a *possible member* in Group 1VV and is not included in the further Mahalanobis calculations.

Table 5.22. Mahalanobis distance projection of unassigned specimens to a known group. An example of moving unassigned specimens to known groups: Case 2 (MT214-19).

Group	Group 1G	Group 1VV	Group 1VM	Group 2
Mahalanobis distance probabilities based on canonical discriminant analysis	0.122	75.689	0.446	0.001
Mahalanobis distance probabilities based on principal component analysis	9.677	95.692	14.587	0.050

Table 5.23. Mahalanobis distance projection of unassigned specimens to a known group. An example of moving unassigned specimens to known groups: Case 3 (MT204-24).

Group	Group 1G	Group 1VV	Group 1VM	Group 2
Mahalanobis distance probabilities based on canonical discriminant analysis	16.344	0.005	0.251	22.772
Mahalanobis distance probabilities based on principal component analysis	0.000	0.000	0.000	52.174

Case 3: Unassigned. In the case of specimen MT204-24 (Table 5.23), Mahalanobis distance probability based on PC scores for assignment to Group 2 is very clear and high (52.174). However, Mahalanobis distance probabilities based on canonical discriminant function scores show high probabilities for being a member of multiple groups; that is, the probability for being a member of Group 2 is close to others. The ratio of probability for being a member of Group 2 to the sum of probabilities for being a member of others is 22.772:16.6 (≈1.4: 1). Thus, this sample remained unassigned.

As a result, 599 specimens out of 1,069 were assigned to either of six groups as solid members and 86 samples were assigned as possible members; that is, a total of 685 ceramic samples (solid and possible) out of 1,069 were assigned to six compositional groups (64 percent of all samples in the data set) (Table 5.24). The bivariate plot of PC 1 and 3 shows that these six compositional groups are separate (Figure 5.22). The bivariate plot of canonical discriminant function scores 1 and 2 shows that most of the compositional groups are separate, although Groups 1G, 1VM, 1VV, and 4 partially overlap (Figures 5.23, 5.24). However, Groups 2 and 3 are clearly discriminated from the other groups in this plot. In addition, the bivariate

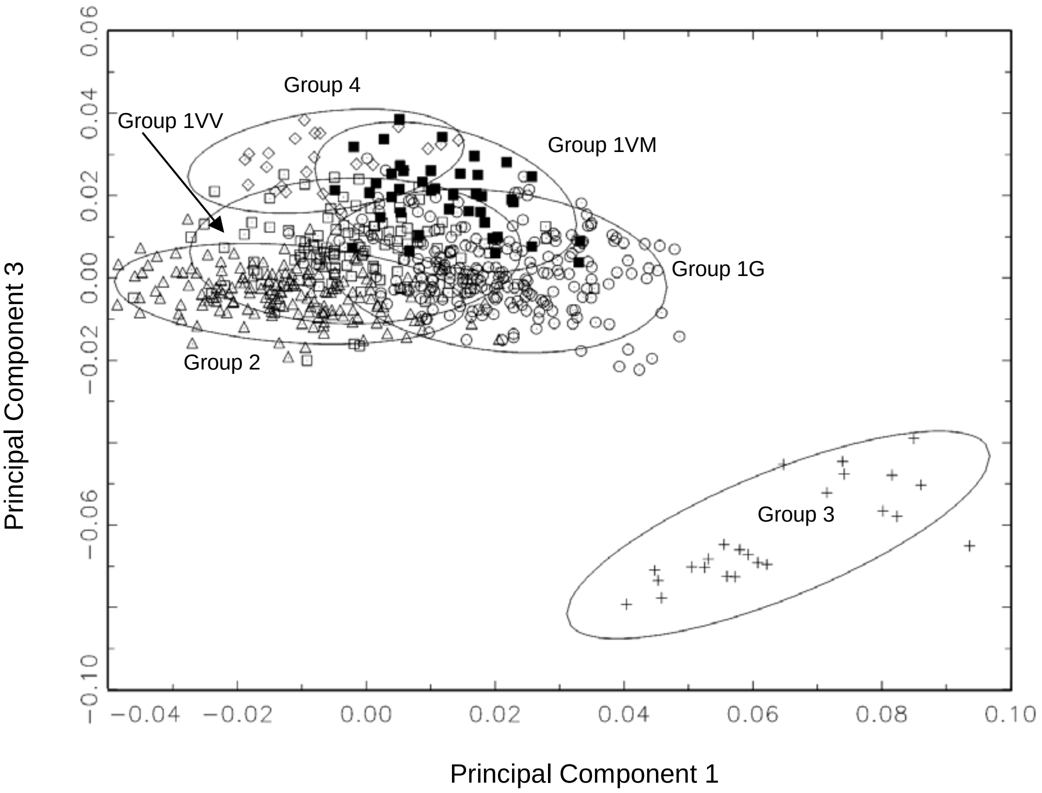


Figure 5.22. Bivariate plot of principal component scores 1 and 3 showing the final six compositional groups among all ceramics from Mt. Trumbull, Tuweep and the lowland Virgin areas.

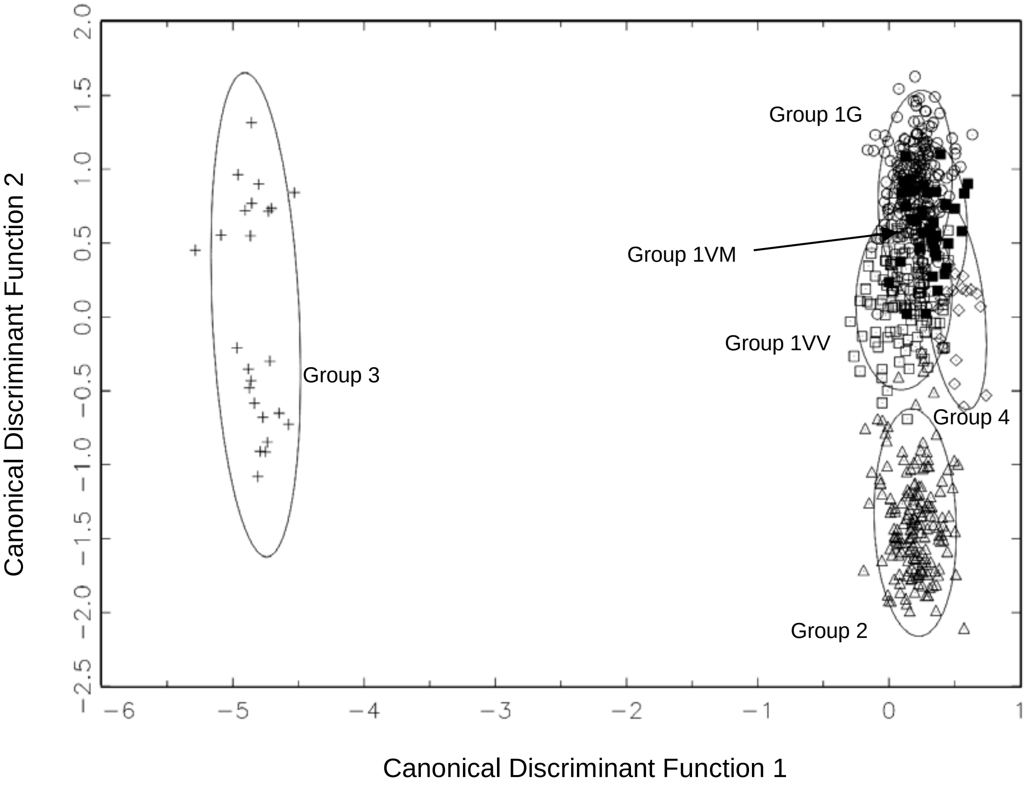


Figure 5.23. Bivariate plots of canonical discriminant functions 1 and 2 showing the final six compositional groups among all ceramics from Mt. Trumbull, Tuweep and the lowland Virgin areas.

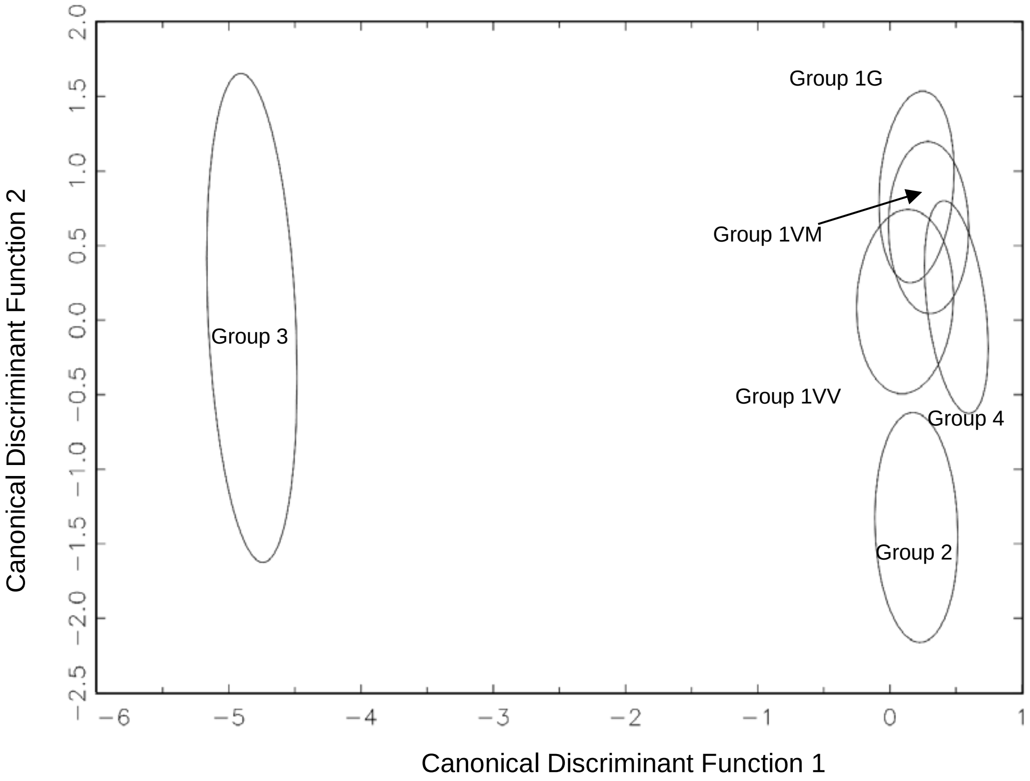


Figure 5.24. Bivariate plot of canonical discriminant functions 1 and 2 showing the final six compositional groups among all ceramics from Mt. Trumbull, Tuweep and the lowland Virgin areas (ellipse only).

Table 5.24 Summary of members in compositional groups in all ceramics in Mt. Trumbull, Tuweep and the lowland Virgin areas.

Group	Solid or Possible Member	Frequency
Group 1G	Solid member	222
	Possible member	20
Group 1VV	Solid member	116
	Possible member	40
Group 1VM	Solid member	41
	Possible member	14
Group 2	Solid member	173
	Possible member	12
Group 3	Solid member	24
Group 4	Solid member	23
Total		685

plot of canonical discriminant function 1 and 4 shows that Group 3 and 4 are discriminated from the others (Figures 5.25, 5.26). Three subgroups, which were initially in one group (Groups 1G, 1VM, and 1VV), are clearly separated in the bivariate plots of canonical discriminant function scores calculated within the three groups (Figure 5.27). A summary of the Mahalanobis distance classification results (Table 5.25, 5.26) also confirms that samples are correctly assigned to four large compositional groups (Groups 1G, 1VM, 1VV, and 2).

Possible Compositional Groups among Unassigned Samples. To examine if any other compositional group possibly existed among the unassigned specimens, the six compositional groups and the unassigned category were compared to the compositional groups identified in the INAA study of the ceramics from the lowland Virgin area discussed in Chapter II (Larson et. al 2005). The comparison between LA-ICP-MS compositional groups to INAA groups suggests that most of the specimens assigned to VR-INAA-VR4 in the INAA study (Figure 2.3) were assigned

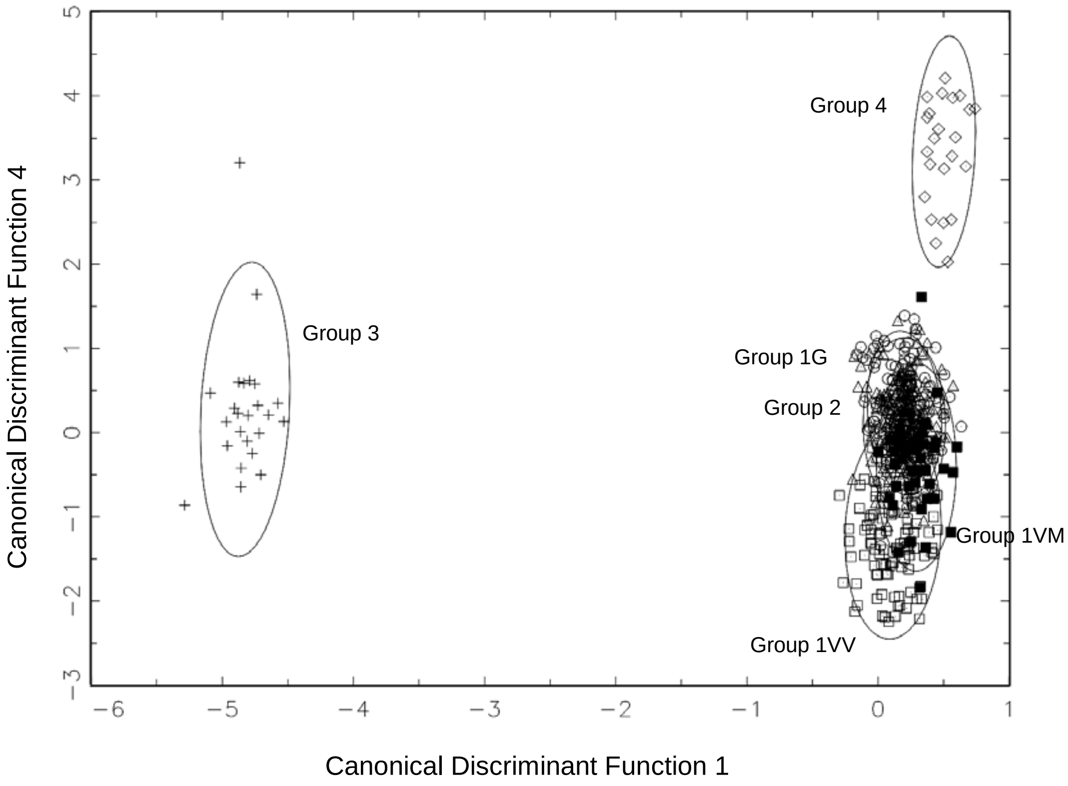


Figure 5.25. Bivariate plots of canonical discriminant functions 1 and 4 showing the final six compositional groups among all ceramics from Mt. Trumbull, Tuweep and the lowland Virgin areas.

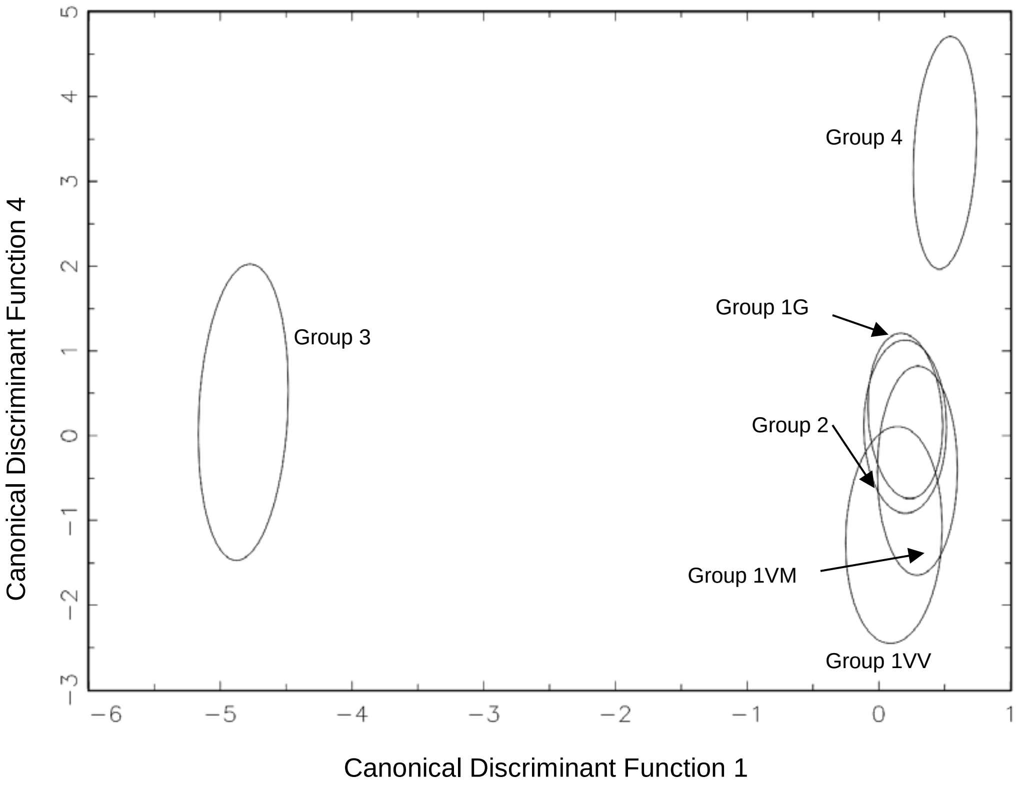


Figure 5.26. Bivariate plots of canonical discriminant functions 1 and 4 showing the final six compositional groups among all ceramics from Mt. Trumbull, Tuweep and the lowland Virgin areas.

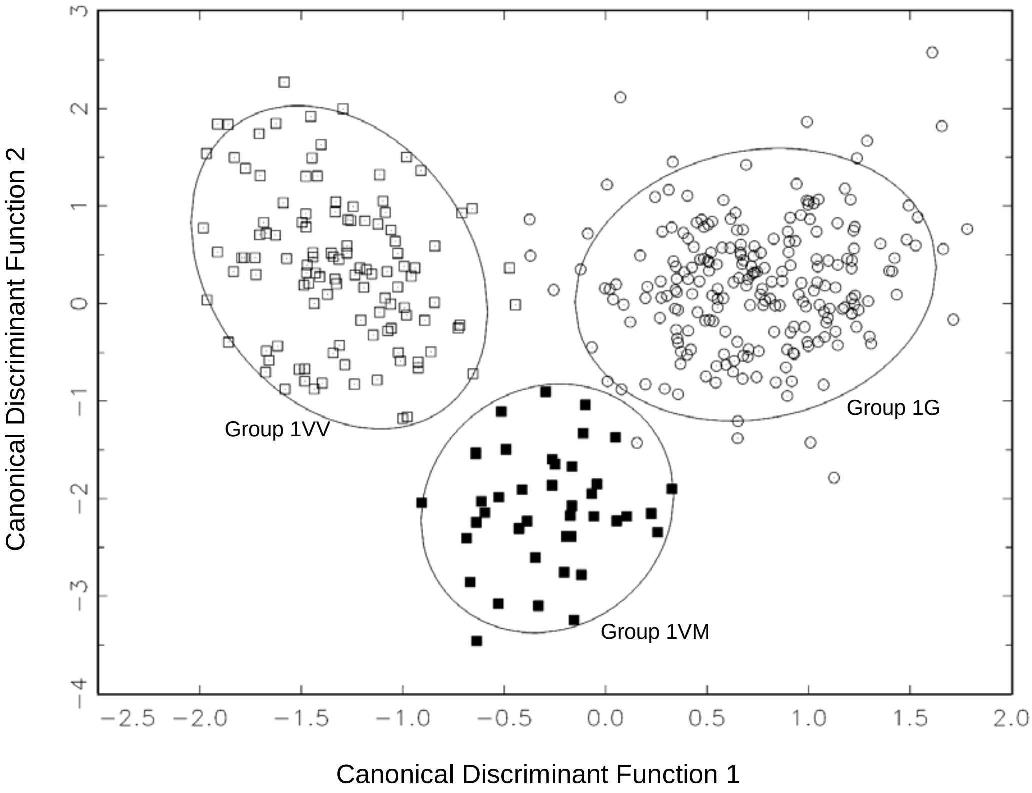


Figure 5.27. Bivariate plot of canonical discriminant functions 1 and 2 showing Groups 1G, 1VM and 1VV.

as Group 1VV in the LA-ICP-MS study (Table 5.27). VR-INAA-4 and VR-INAA-3 are two local groups in the lowland Virgin area (Larson et al, 2005) (Figure 2.3). The comparison also shows that most of the VR-INAA-3 ceramics are *unassigned* to any of the groups in the LA-ICP-MS data set. Consequently, VR-INAA-3 may be an independent compositional group in the LA-ICP-MS data set.

Table 5.25. Summary of classification success in all ceramics in Mt. Trumbull, Tuweep and the lowland Virgin areas based on principal component analysis scores.

		Into:				
		Group 1G	Group 1VV	Group 1VM	Group 2	Total
From:	Group 1G	220	0	2	0	222
	Group 1VV	0	109	7	0	116
	Group1VMA	0	6	35	0	41
	Group 2	0	2	0	171	173
	Total	220	117	44	171	552

Variables used: Principal component analysis scores 1–10.

Table 5.26. Summary of classification success in all ceramics in Mt. Trumbull, Tuweep and the lowland Virgin areas based on canonical discriminant scores.

		Into:				
		Group 1G	Group 1VV	Group 1VM	Group 2	Total
From:	Group 1G	218	1	3	0	222
	Group 1VV	0	115	1	0	116
	Group 1VM	1	1	39	0	41
	Group 2	0	2	0	171	173
	Total	219	119	43	171	552

Variables used: Canonical discriminant scores 1–5.

Table 5.27. Comparison of LA-ICP-MS compositional groups to the lowland Virgin ceramic INAA groups.

	VR-INAA-4	VR-INAA-3	Note
ICP-MS Group 1VV	12	3	All three VR-INAA-3 samples are a *possible member* in Group 1VV in ICP-MA data.
ICP-MS Group 2	1		
ICP-MS Group 4	1		
ICP-MS Unassigned	4	22	

Note: Group members in LA-ICP-MS compositional groups are in both solid and possible members.

In the lowland Virgin INAA data set, there are two non-local groups, VR-INAA-1 and VR-INAA-2. VR-INAA-2 includes only the olivine-tempered ceramics and is the only compositional group with olivine-tempered specimens. VR-INAA-1, on the other hand, includes mostly black-on-gray wares with very fine sand temper in very light-colored paste. Most of the VR-INAA-1 samples are *unassigned* in LA-ICP-MS data set. It is possible, therefore, that the VR-INAA-1 could also be another independent compositional group in the LA-ICP-MS data set.

Based on these comparisons, VR-INAA-1 and VRE-INAA-3 in the INAA study may be identified as independent groups in the unassigned category of the LA-ICP-MS data set. To assess this possibility, PC scores of all unassigned samples, including those identified as VR-INAA-1 and VR-INAA-3 in the INAA data, were plotted. Note that the proposed group identified as VR-INAA-1 is named as VR 1 and that identified as VR-INAA-VR3 as VR 3 in LA-ICP-MS data set. The bivariate plot of PC 1 and 3 shows that VR1 and VR3 generally do not overlap with any of the six compositional groups (Figure 5.28). Close examination of this plot also shows that most of VR3 samples are grouped together, as are VR1 samples. Thus, the bivariate plot demonstrates that these groups, originally identified in the lowland Virgin INAA data, also form independent compositional groups in LA-ICP-MS data sets (Figure 5.29). Canonical discriminant analysis was also conducted on eight compositional groups including VR1 and VR3. The bivariate plots of canonical discriminant functions 3 and 2, as well as canonical discriminant functions 3 and 6,

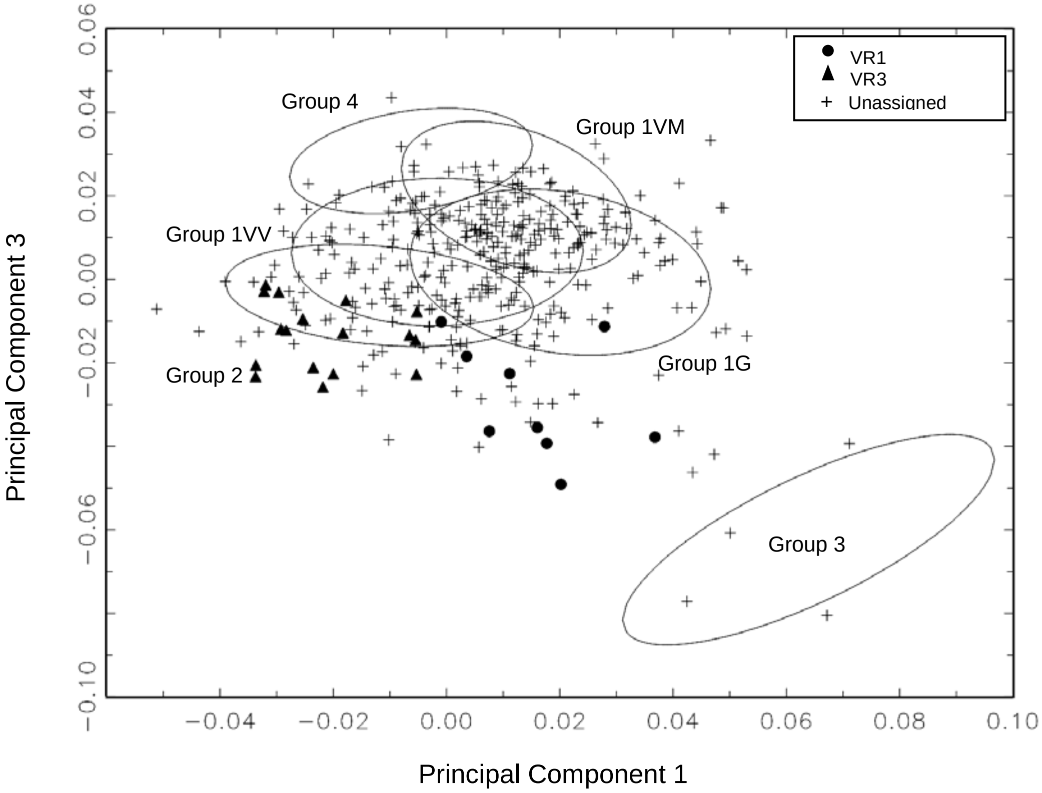


Figure 5.28. Bivariate plot of principal components 1 and 3 showing VR1 and VR3 ceramic data from the lowland Virgin area. This plot shows that most of the VR1 and VR3 samples do not overlap with any of six compositional groups.

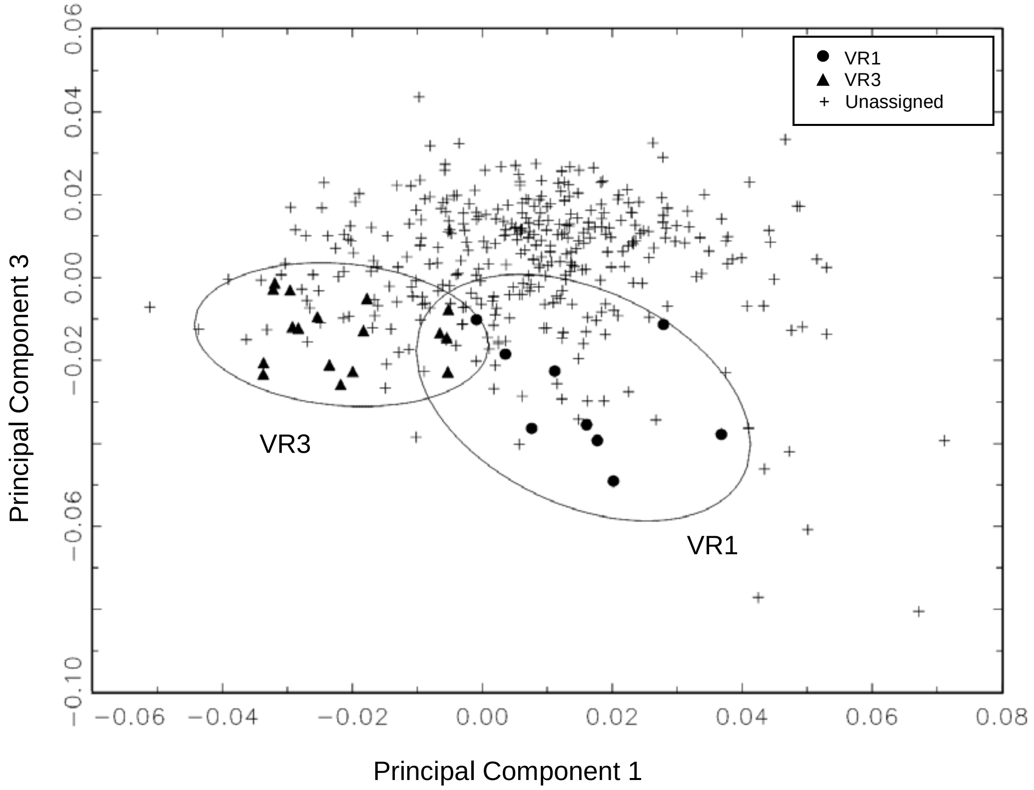


Figure 5.29. Bivariate plot of principal component scores 1 and 3 showing VR1 and VR3 groups and unassigned samples in the LA-ICP-MS data. Ellipses are based on compositional groups VR1 and VR3.

confirm that VR1 and VR3 are independent compositional groups and are distinguished from any other groups (Figures 5.30, 5.31).

Using multiple sets of bivariate plots of PC scores and canonical function scores on eight groups and base-10 logs of elemental concentrations, especially vanadium- and magnesium-based combinations, some of the unassigned samples could be assigned to VR1 group. It should be noted that only samples that were always found near the center of ellipse of these groups by different bivariate plots (PC scores, canonical discriminant function scores, and base-10 logs of elemental concentrations) were assigned to VR1. Figure 5.32 is an example of a bivariate plot of canonical discriminant function scores for determining if any unassigned sample could be assigned to VR1. Attempts to place unassigned samples into the VR3 group using bivariate plots were also made. Since separation of VR3 from the other groups was not as clear as that of VR1, samples were assigned as VR3 only when bivariate plots of both canonical discriminant function scores and PC scores agreed.

After assigning samples to VR1 and VR3, I recalculated the canonical discriminant function scores of the eight groups. Both PC scores and canonical discriminant function scores were plotted to ensure that VR1 and VR3 samples were grouped within the 90 percent of confidence ellipse on the plots (Figures 5.33–5.36). This was the final step in assigning specimens to compositional groups identified among all specimens collected from Mt. Trumbull, Tuweep, and the lowland Virgin area. A total of 729 of 1,069 specimens are now classified into eight compositional groups, leaving 32 percent unassigned (Table 5.28).

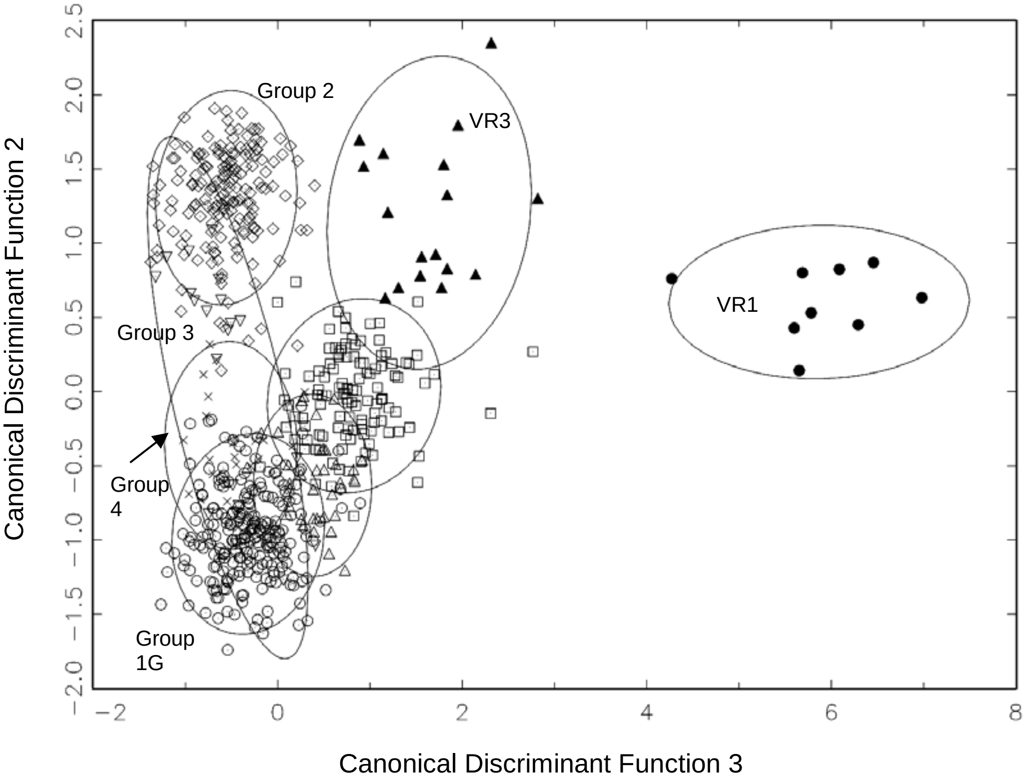


Figure 5.30. Bivariate plot of canonical discriminant functions 2 and 3 showing VR1 and VR3 are independent compositional groups in the LA-ICP-MS data set.

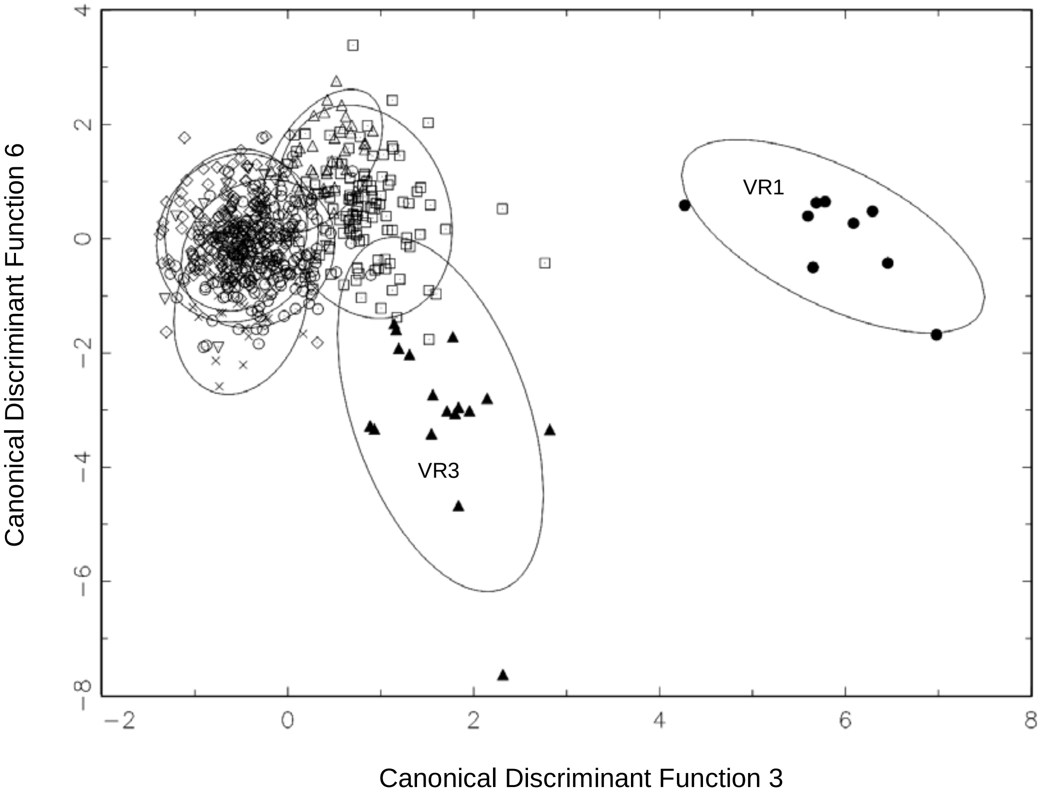


Figure 5.31. Bivariate plot of canonical discriminant functions 3 and 6 showing that VR1 and VR3 are independent compositional groups in the LA-ICP-MS data set.

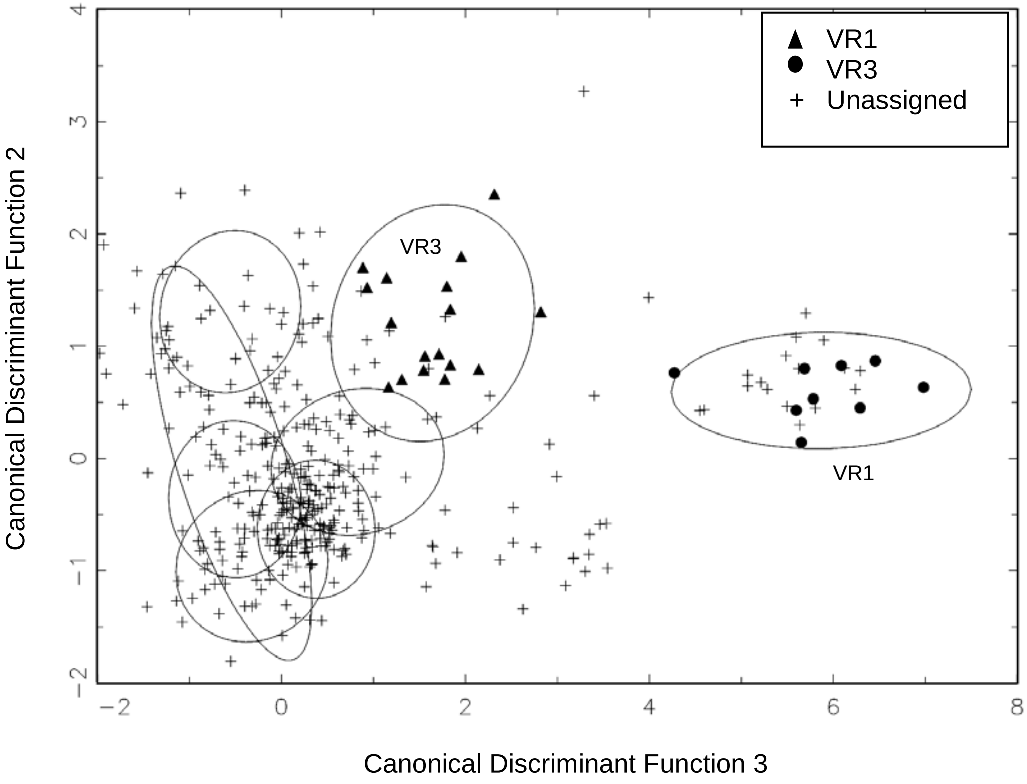


Figure 5.32. Bivariate plots of canonical discriminant functions 2 and 3 to examine whether unassigned samples are grouped as VR1 and VR3.

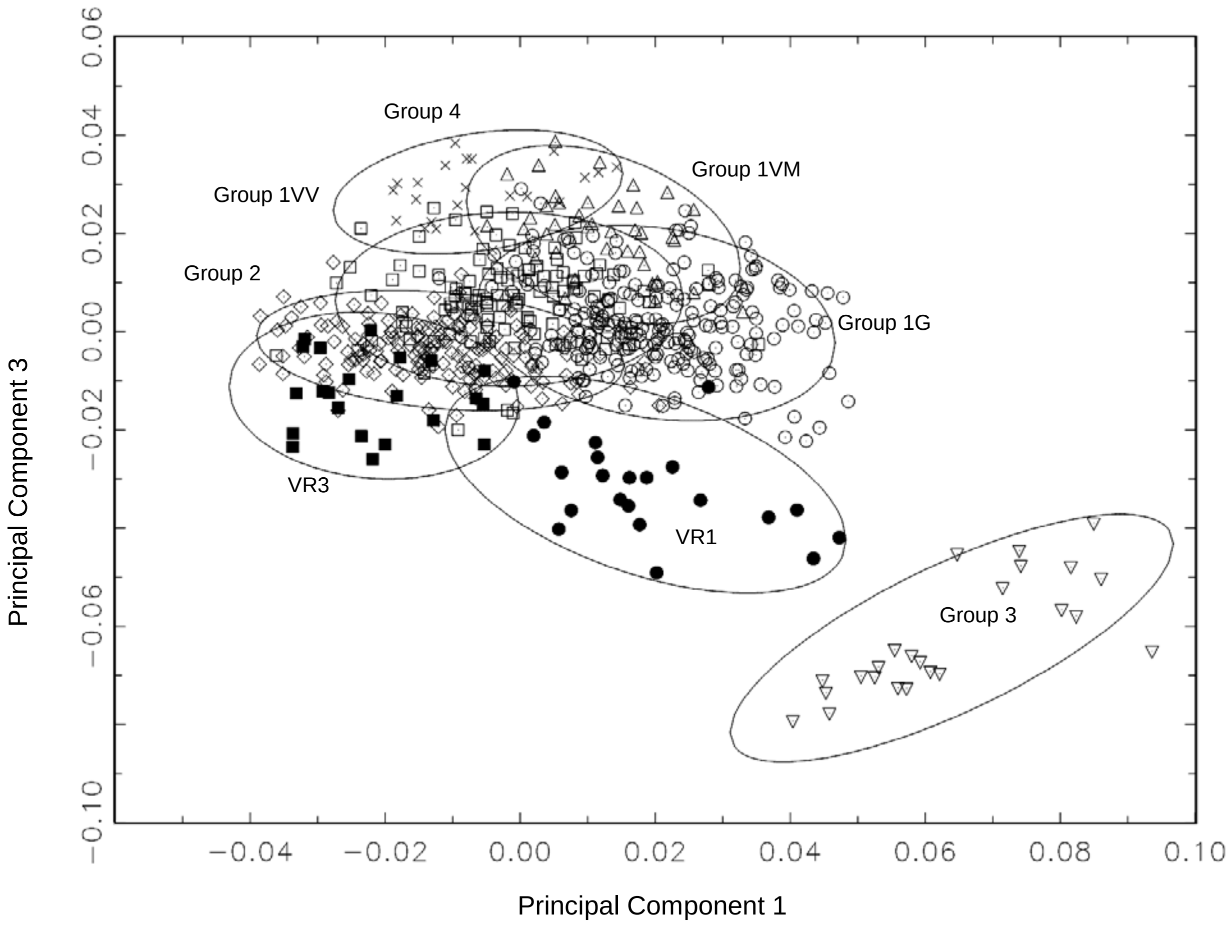


Figure 5.33. Bivariate plot of principal components 1 and 3 showing the final eight compositional groups among all ceramics in Mt. Trumbull, the lowland Virgin area, and Tuweep. This plot does not show possible group members (n = 643).

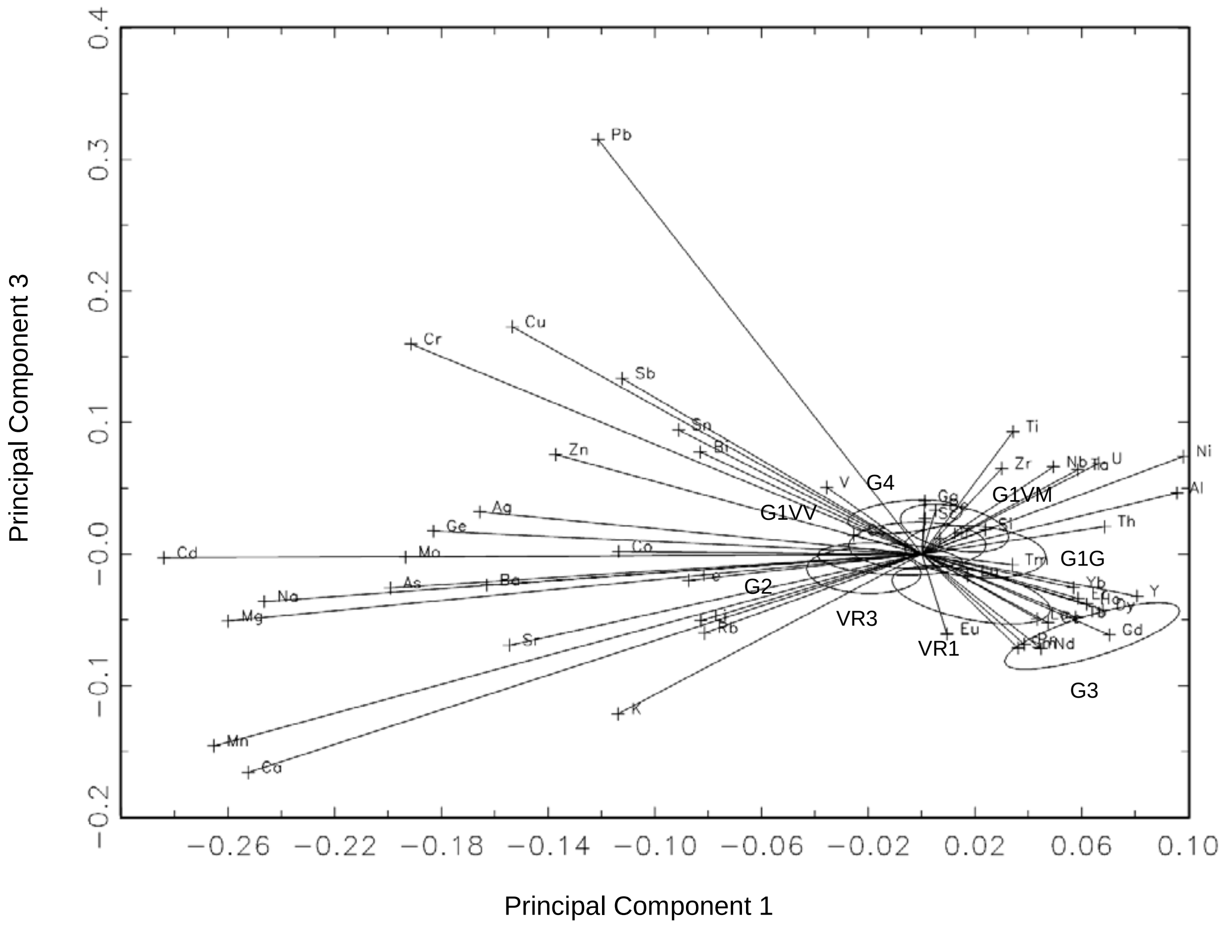


Figure 5.34. Bivariate plot of principal components 1 and 3 with element vectors showing the final eight compositional groups in among all ceramics in Mt. Trumbull, Tuweep, and the lowland Virgin area. Some of group names are abbreviated—G1G: Group 1G; G1VM: Group 1VM; G1VV: Group 1VM; G2: Group 2; G3: Group 3; and G4: Group 4.

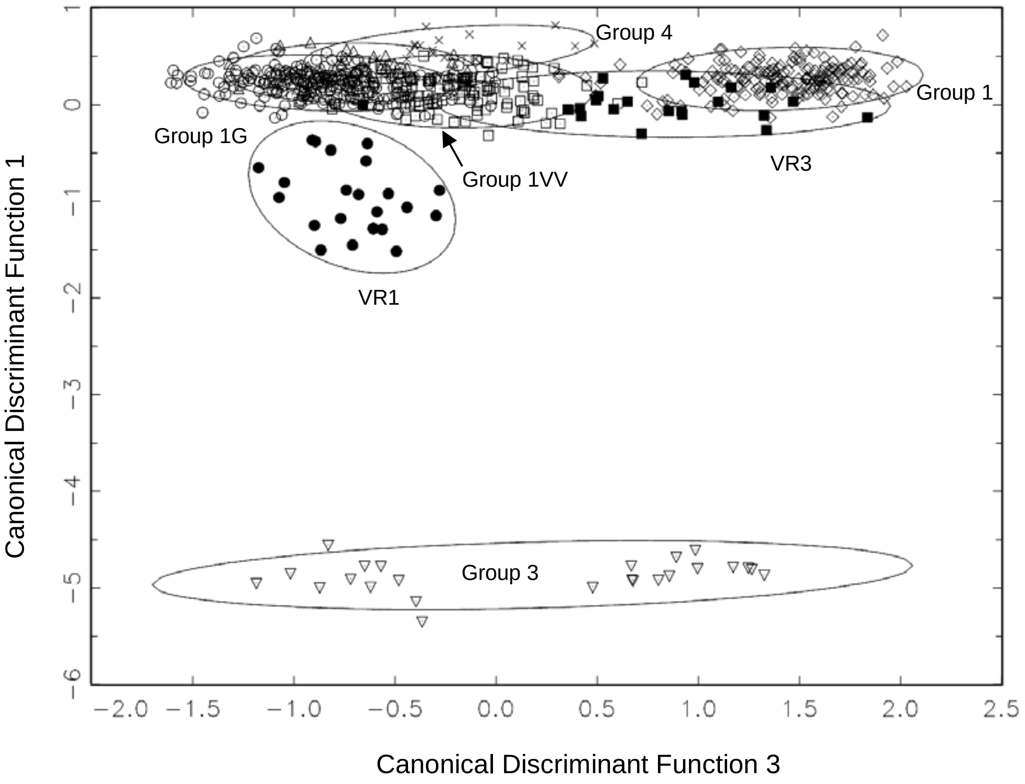


Figure 5.35. Bivariate plots of canonical discriminant functions 1 and 3 showing the final eight compositional groups among all ceramics in Mt. Trumbull, Tuweep and the lowland Virgin area. This plot does not show possible group members (n = 643).

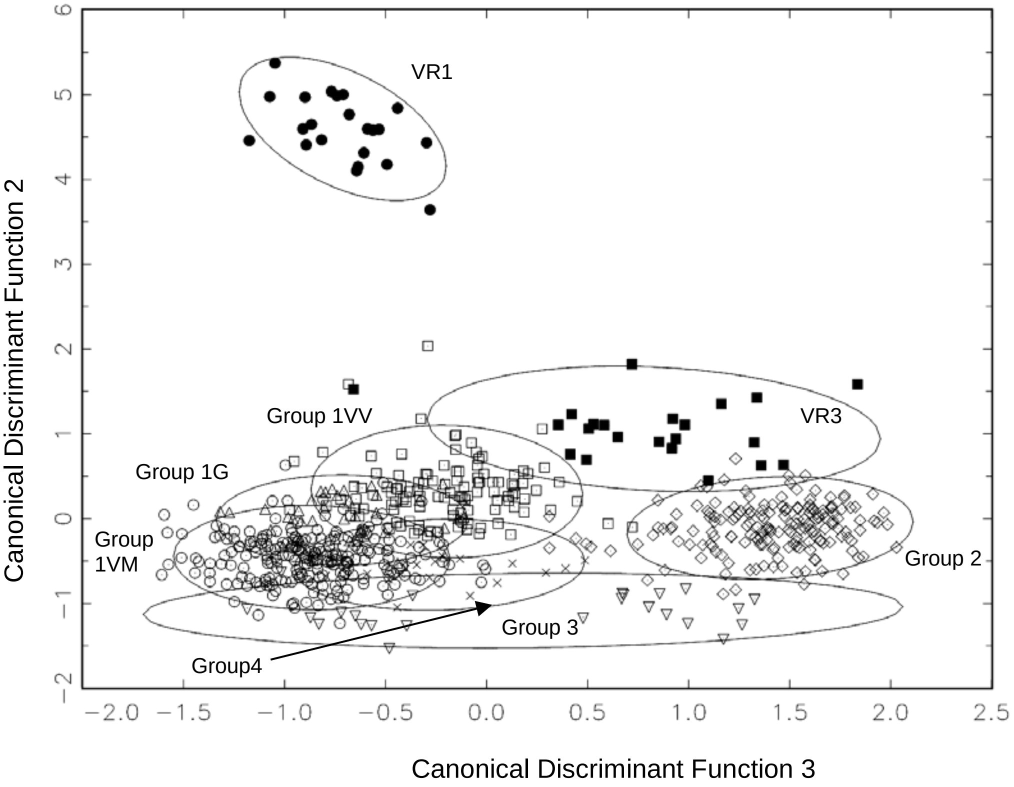


Figure 5.36. Bivariate plot of canonical discriminant functions 2 and 3 showing the final eight compositional groups among all ceramics in Mt. Trumbull, Tuweep and the lowland Virgin area. This plot does not show possible group members (n = 643).

Table 5.28. Summary of final eight compositional groups among all ceramics.

Group	Frequency in Group	Solid / Possible Member	Frequency
Group 1G	242	Solid member	222
		Possible member	20
Group 1VV	156	Solid member	116
		Possible member	40
Group 1VM	55	Solid member	41
		Possible member	14
Group 2	185	Solid member	173
		Possible member	12
Group 3	24	Solid member	24
Group 4	23	Solid member	23
VR1	22	Solid member	22
VR2	22	Solid member	22
Assigned Total	**729**		**729**
Unassigned olivine-tempered ceramics	253		253
Unassigned sand-tempered ceramics	69		69
Unassigned shed temper (including olivine particles)	18		18
Total of all ceramics analyzed	1069		1069

Comparison of Clay Data with Ceramic Groups. To determine the source of ceramic groups, the eight groups recognized within the ceramic samples from Mt. Trumbull, Tuweep, and the lowland Virgin areas identified above were compared with the clay data. Four large compositional groups, Groups 1G, 1VM, 1VV, and 2 were examined using Mahalanobis distance projection based on PC 1–10. Clay data were projected against these four ceramic compositional groups to determine if any of clays could be matched to the ceramic groups.

Group 2 The results suggest that data from 20 clay samples (prepared and unprepared clay from 15 sources) from Mt. Trumbull and its vicinities are matched to Group 2. Therefore, Group 2 is a Mt. Trumbull local group. Some prepared and unprepared clay samples were matched to Group 2 (Table 5.29), that is, some clays

Table 5.29. Mahalanobis distance probabilities showing how clays are matched to four compositional groups (Groups 1G, 1VV, 1VM and 2).

ID. NO.	Source Clay Area	Group 1G	Group 1VV	Group 1VM	Group 2	Clay Type, Note	Geology
MT105C	Mt. Trumbull	0.002	0	0	8.659	Secondary 14 MNA test pit 70 cm deep	Surficial deposit, Qt. Talus deposit (Holocene and Pleistocene)
MT105PC (prepared)	Mt. Trumbull	4.637	0.981	0.147	18.77	Secondary 14MNA test pit 70 cm deep	Surficial deposit, Qt. Talus deposit (Holocene and Pleistocene)
MT106PC (prepared)	Mt. Trumbull	0.026	0.001	0	16.94	Secondary 14MNA test pit 30 cm deep	Surficial deposit, Qt. Talus deposit (Holocene and Pleistocene)
MT116PC (prepared)	Mt. Trumbull	0.026	0.012	0	10.17	Volcanic Big Spring area	Basalt flow (Pleistocence), Qb
MT148C	Mt. Trumbull	0	0	0	5.531	Volcanic 204BLM test pit 20 cm deep	Basalt flow (Pleistocence), Qb
MT17C	Mt. Trumbull	0.003	0	0	8.185	Secondary Between 14MNA and 131BLM	Surficial deposit, Qa2 young-intermediate alluvial fan deposit (Holocene and Pleistocene)
MT22C	Mt. Trumbull	0.124	1.899	0.114	23.51	Secondary 14MNA 10cm deep	Surficial deposit, Qt. Talus deposit (Holocene and Pleistocene)
MT22PC (prepared)	Mt. Trumbull	0.094	0.002	0	23.42	Secondary 14 MNA 10 cm deep	Surficial deposit, Qt. Talus deposit (Holocene and Pleistocene)
MT28C	Mt. Trumbull	0	0	0	44.52	Secondary Near 14MNA road cut wall 30 cm deep	Surficial deposit, Qt. Talus deposit (Holocene and Pleistocene)
MT63C	Mt. Trumbull	4.472	0	0.009	0	Sedimentary Mt. Logan possible Chinle Formation near canyon rim	

Table 5.29. Mahalanobis distance probabilities showing how clays are matched to four compositional groups (Groups 1G, 1VV, 1VM and 2). (continued)

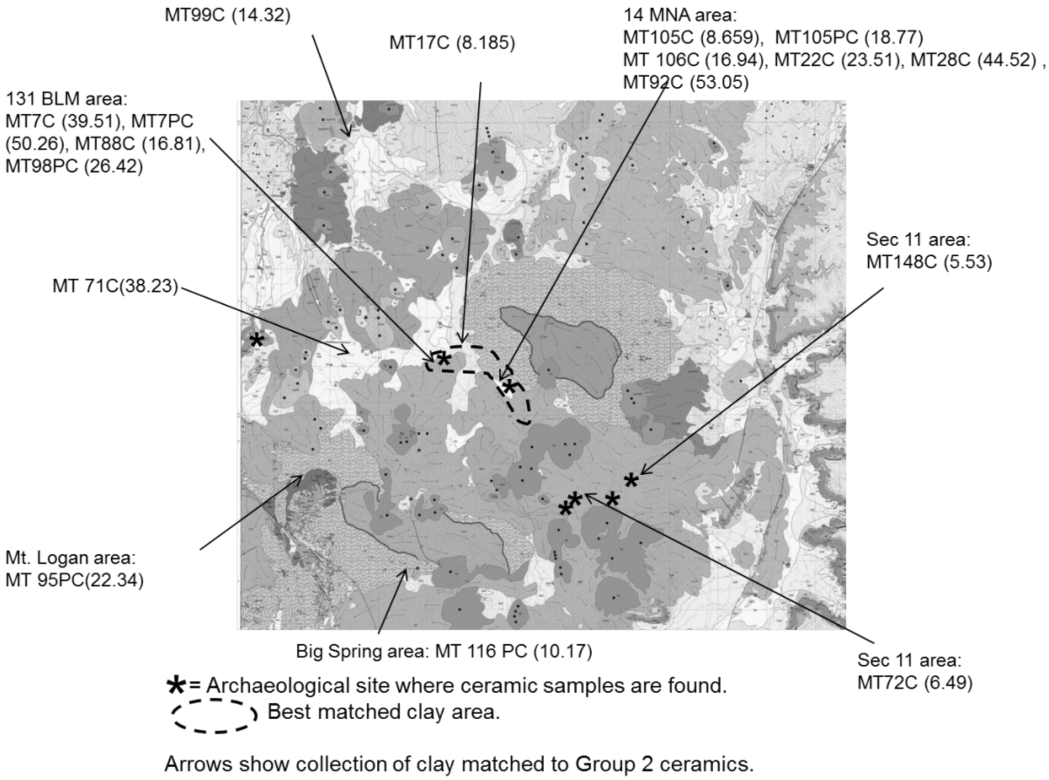
ID. NO.	Source Clay Area	Group 1G	Group 1VV	Group 1VM	Group 2	Clay Type, Note	Geology
MT71C	Mt. Trumbull	0	0.046	0.001	38.23	Secondary 2 km west of 131BLM Bottom of dried cow pond	Surficial deposit, valley-fill deposit (Holocene and Pleistocene) Qv
MT72C	Mt. Trumbull	0	0	0	6.491	Volcanic 136ASM test digging	Basalt flow (Pleistocence), Qb
MT7C	Mt. Trumbull	0.051	0.136	0.001	39.51	Volcanic Near 131BLM drainage wall	Basalt flow (Pleistocence), Qb
MT7PC (prepared)	Mt. Trumbull	7.552	0.205	0.051	50.26	Volcanic Near 131BLM drainage wall	Basalt flow (Pleistocence), Qb
MT88C	Mt. Trumbull	0.204	0.006	0.001	16.81	Volcanic 131BLM test pit 30 cm deep	Basalt flow (Pleistocence), Qb
MT92C	Mt. Trumbull	0.042	0.044	0.008	53.05	Secondary 14MNA test pit 47cm deep	Surficial deposit, Qt. Talus deposit (Holocene and Pleistocene)
MT95PC (prepared)	Mt. Trumbull	0.001	0.002	0.012	22.34	Sedimentary Mt. Logan Chinle or Moenkopi Formation	Chinle Formation (TRcp), Moenkopi Formation (TRml)
MT98PC (prepared)	Mt. Trumbull	0.006	0.004	0	26.42	Volcanic 131 BLM test pit 30 cm deep	Basalt flow (Pleistocence), Qb
MT99C	Mt. Trumbull	0.003	0	0	14.32	Secondary Sink Valley, wash wall	Surficial deposit, Qa1 young alluvial fan deposit (Holocene)

Table 5.29, Mahalanobis distance probabilities showing how clays are matched to four compositional groups (Groups 1G, 1VV, 1VM and 2). (continued)

ID. NO.	Source Clay Area	Group 1G	Group 1VV	Group 1VM	Group 2	Clay Type, Note	Geology
SV9C	Shivwits plateau (Plateau region)	0.001	0.001	0	47.22	Volcanic Shivwits plateau, near Yellow Jones Mt, 30 km west of Mt. Trumbull Drainage wall, 50 below surface.	
TWP1C	Tuweep (Plateau region)	0	0.001	0	5.623	Secondary Toroweap dry Lake, 10 km south of Mt. Trumbull	
VR14PC (prepared)	Lowland Virgin	0	7.142	0	0	Sedimentary Wash wall 10cm below surface	Chinle Formation (TRcp), Moenkopi Formation (TRml)
VR22C	Lowland Virgin	0.159	29.963	0.495	0.675	Sedimentary 10 cm deep	Chinle Formation (TRcp)
VR29C	Lowland Virgin	0	6.284	0	0	Secondary Near Lost City museum	

matched to Group 2 with preparation and others matched without preparation. Moreover, both primary (volcanic and sedimentary) and secondary clays were matched to this group. Secondary clays seem to be matched with the highest probabilities. These latter clays are considered smectite; however, since no XRD analysis has been performed, this attribution is not conclusive. The clays matched to Group 2 with a high probability are from the 14MNA and 131BLM site areas (Figure 5.37). The geology of the Mt. Trumbull area is characterized by a volcanic formation resting on sedimentary bedrocks, both the Chinle and Moenkopi formations. The Chinle formation bedrock of unknown thickness is present under the Tertiary basalt flows that cap the Mt. Trumbull area. This is evidenced by Chinle float material occurring in landslide debris on the western and northern flanks of Mt. Trumbull (Billingsley and Hamblin 2001). Indeed, during fieldwork in 2008, some small pockets of Chinle and Moenkopi formations were recognized near the Nixon Spring Trail on the slope of Mt. Trumbull (Figures 5.37, 5.38). This geological setting may suggest that secondary clays from some locations contain weathered Chinle/Moenkopi formation clays mixed with volcanic clays.

Most of the best-matched clays near site 14 MNA are secondary clays. This site is located at the bottom of steep slope from Nixon Spring on Mt. Trumbull, where a small exposure of the Chinle formation was recognized (as mentioned above). Thus, it is likely that clays near site 14 MNA are mixtures of volcanic and Chinle clay. The location of the site of the 131 BLM clays coincides with a volcanic formation according to the geologic map. However, this site is located at the bottom



MT99C (14.32)

MT17C (8.185)

14 MNA area:
MT105C (8.659), MT105PC (18.77)
MT 106C (16.94), MT22C (23.51), MT28C (44.52) ,
MT92C (53.05)

131 BLM area:
MT7C (39.51), MT7PC (50.26), MT88C (16.81), MT98PC (26.42)

Sec 11 area:
MT148C (5.53)

MT 71C(38.23)

Mt. Logan area:
MT 95PC(22.34)

Big Spring area: MT 116 PC (10.17)

Sec 11 area:
MT72C (6.49)

* = Archaeological site where ceramic samples are found.

Best matched clay area.

Arrows show collection of clay matched to Group 2 ceramics.

Figure 5.37. Location of Mt. Trumbull clays matched to Group 2. Numbers are the probabilities based on Mahalanobis distance.

Figure 5.38. The deposit of sedimentary clay near the Nixon Spring Trail on the slope of Mt. Trumbull.

of the slope of Mt. Logan (5 km downhill), where the Chinle formation is exposed. Often petrified woods were found in the vicinity of site BLM131, which suggests the clays near the BLM131 site may contain weathered volcanic materials, as well as the Chinle and Moenkopi sedimentary formation materials. Thus, the best-matched clays to Group 2 specimens are those containing weathered volcanic clays and some portion of Chinle/Moenkopi clays. Moreover, these clays naturally occur near sites 14MNA and 131 BLM.

Many clay samples were collected in the section 11 area near Mt. Trumbull (Figure 5.37), which contains a very high site density of large C-shaped pueblos. The section 11 area includes lava flows and cinder cones, and the clays are primarily volcanic. Interestingly, there were only two clays from the section 11 area that were matched to Group 2, with relatively low probabilities (MT148C and MT72C) (Figure 5.29). This supports the proposal that clays used for Group 2 pottery contain not only volcanic but also some Chinle/Moenkopi clays. Since some clays matched to Group 2 with high probability are found naturally, the clays used to make Group 2 ceramics may not have undergone much preparation.

Group 1G Mahalanobis distance probabilities show that three clay samples from Mt. Trumbull (MT63C, MT7PC, and MT105PC) were matched to Group 1G (Table 5.29). Therefore, Group 1G is another Mt. Trumbull local group. One of them (MT63C) is from the Chinle/Moenkopi formation on Mt. Logan, a long distance from the archaeological site concentration. Moreover, the location of clay collection on Mt. Logan is a very steep slope adjacent to the canyon rim (Figure 5.39). Two of the clays are from 131BLM (MT7PC) and 14MNA (MT105PC), where many sites are located, including C-shaped pueblos. These two clays were also used for Group 2 ceramics and their probability of matching to Group 1G increased only after preparation (Table 5.29).

The probabilities of all three clays being matched to Group 1G are relatively low, compared to the clays matched to Group 2. This suggests that clays used for Group 1G may have gone through a much more sophisticated preparation process,

Figure 5.39. The location of clay collection near Mt. Logan.

which changed their chemical constituents significantly, or were quarried from much deeper deposits. It is possible that clay obtained for the analysis is much different chemically from the clay from deeper deposits in the same clay source. The clay used for Group 1G may have been prepared in a more elaborate way than just soaking in water to eliminate larger inclusions, or the clay may have been quarried from deeper deposits. In any regard, it is likely that more energy was devoted to the procurement and/or preparation of the clay for Group 1G ceramics, compared to Group 2 clay.

Group 1VV Three clays (VR14PC, VR22C, and VR29C) from the lowland Virgin area were matched to 1VV (Table 5.29), which suggests Group 1VV is a local group in the lowland Virgin area. This is also confirmed by the fact that samples identified as VR-INAA-4, one of local groups in the lowland Virgin area in the INAA data, are included in this group. Two of the clays are from the Chinle/Moencopi formations. One is a secondary clay, and the location of the clay collection is near exposures of Chinle/Moencopi bedrocks. Thus, the clay used to make Group 1VV pottery contains Chinle/Moencopi formation clay, at least in some proportion.

In addition to the local clay from Mt. Trumbull and the lowland Virgin areas, there are some clays, distant from these areas, that are included in the data set (Appendix A: Table A2). Chinle clays collected near Hurricane, Utah, are also matched to Group 1VV. Since Hurricane is more than 100 km from both Mt. Trumbull and the lowland Virgin areas, it is not plausible that the clays were transported from Hurricane to Mt. Trumbull or the lowland Virgin areas. Rather, it is possible that the chemical signature of the clays derived from the same formations will be similar, wherever they occur. Consequently, correlations with these two distant clays support the proposal that the clays used to make 1VV pottery contain Chinle formation clays.

Group 1VM No clays were matched to this group. Identification of the clay source for this group requires examination of the relationships between compositional groups and physical attributes and provenience of the specimens, to be discussed later.

Other groups To assess whether the smaller ceramic compositional groups can be matched to clay samples collected for this study, bivariate plots of PC scores and canonical discriminant function scores were examined (Figures 5.40–5.42). Based on these plots, no clays analyzed in this study could be matched to Group 1VM, Group 3, Group 4, and VR1.   However, previous INAA analysis of ceramics and clays from the lowland Virgin area demonstrated that Group VR3 was matched to local clays in the lowland Virgin area (Larson et al. 2005). The number of ceramics identified as VR3 in the lowland ceramic INAA study is much larger than those in this study. It is possible that VR3 may be too tight to match to any of lowland Virgin clays in this study due to the small sample size. However, it is still possible that the VR 3 is a lowland Virgin local group. Group VR1 did not match with the lowland Virgin clay in the INAA study, nor to Mt. Trumbull local clay in ICP-MS analysis. Therefore, VR1 may be a non-local group from beyond Mt. Trumbull and the lowland Virgin area. The clay sources of Groups 3 and 4 are unknown at this point; the source determination requires assessment of the relationship between the compositional groups and the physical attributes and provenience of the studied ceramics.

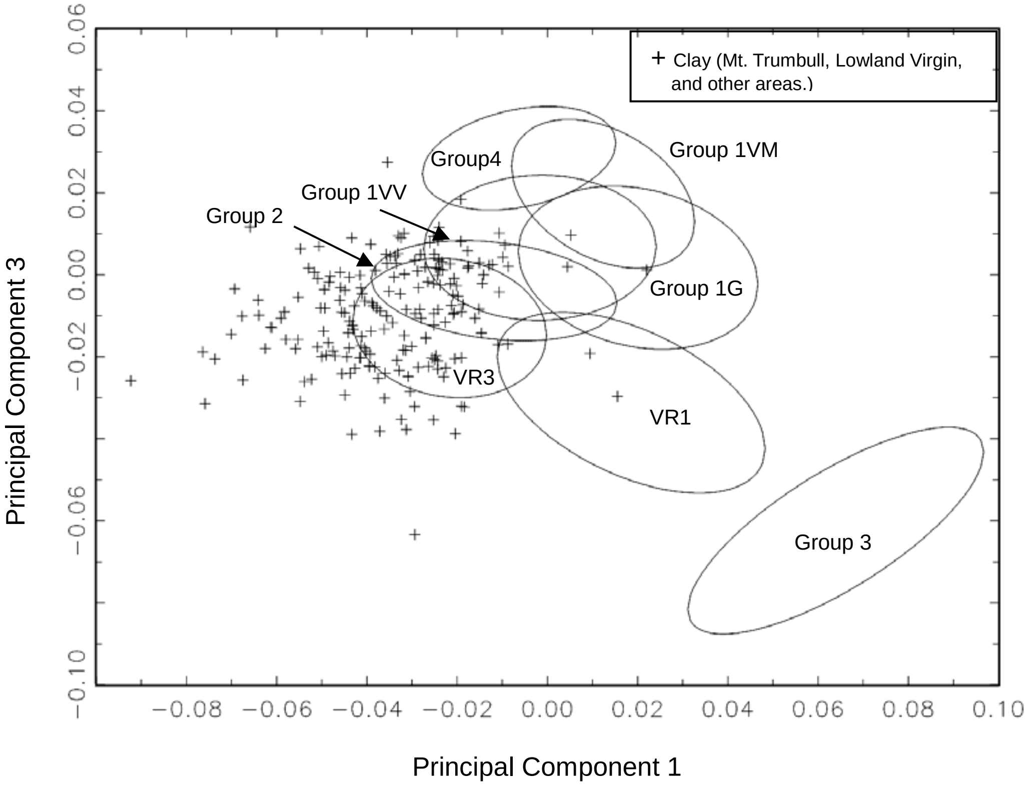


Figure 5.40. Bivariate plot of principal component scores 1 and 3 showing the final eight ceramic compositional groups among all ceramics in Mt. Trumbull, Tuweep and the lowland Virgin area and clay.

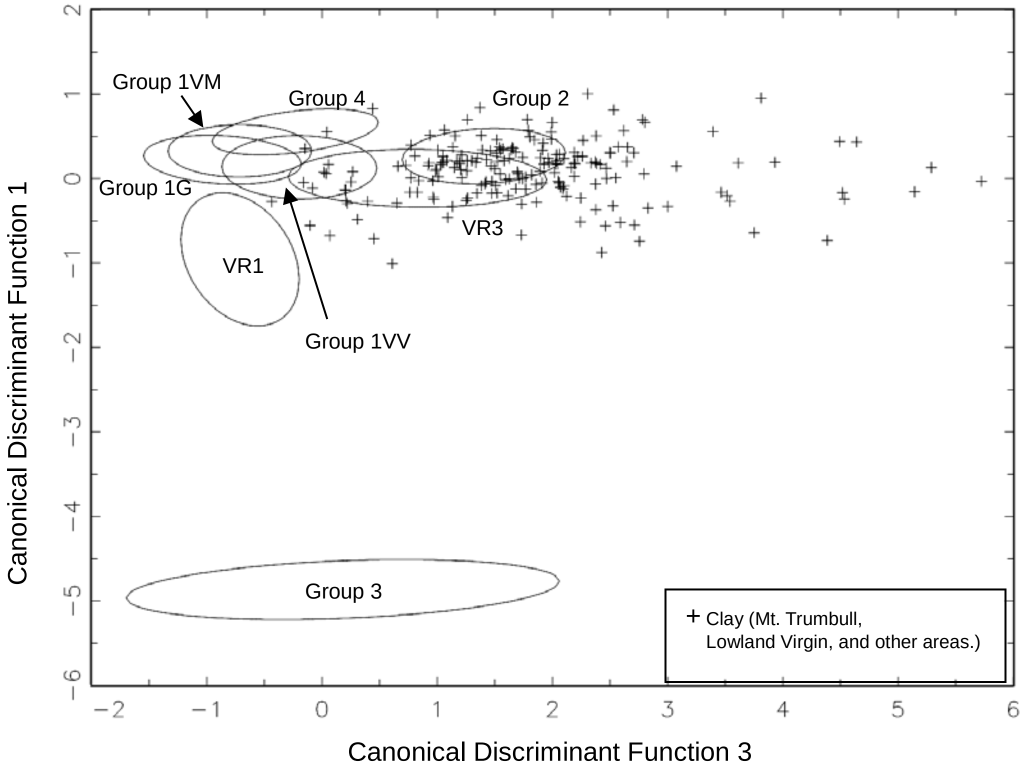


Figure 5.41. Bivariate plot of canonical discriminant functions 1 and 3 showing the final eight ceramic compositional groups among all ceramics in Mt. Trumbull, Tuweep and the lowland Virgin area and clay.

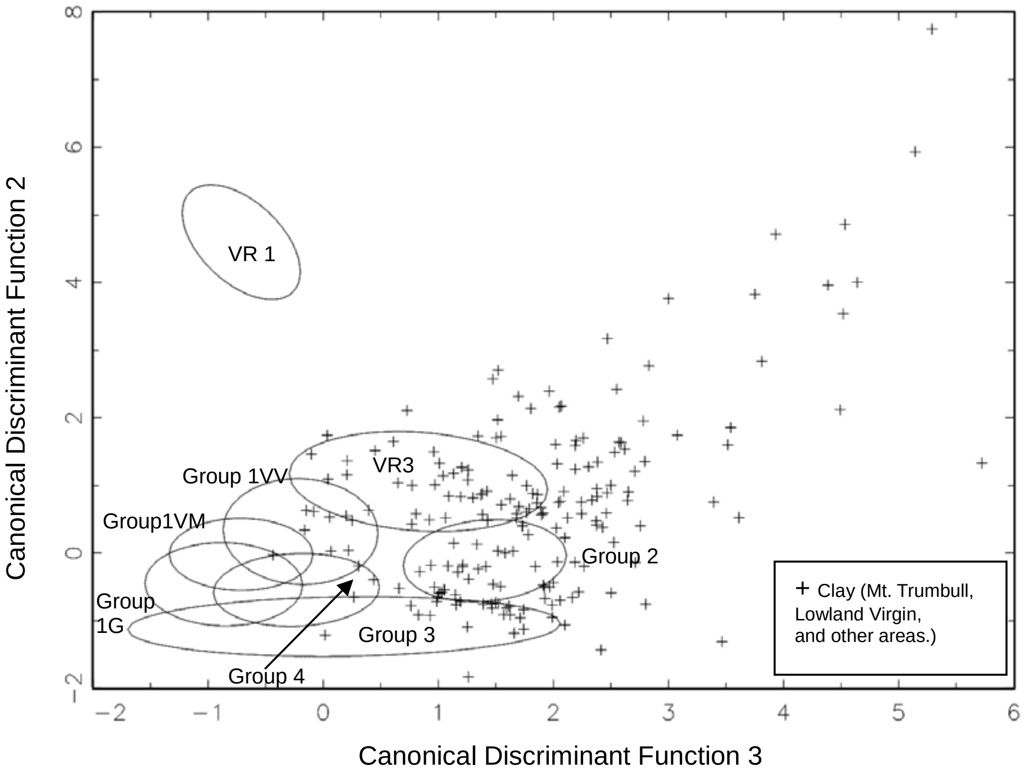


Figure 5.42. Bivariate plot of canonical discriminant functions 2 and 3 showing the final eight ceramic compositional groups among all ceramics in Mt. Trumbull, Tuweep and the lowland Virgin area and clay.

Formal Attribute Analysis

Formal attributes of ceramics were examined in order to understand what contributed to the creation of each compositional group. The formal attributes recorded in this study are temper types, surface treatment, and core color. Temper types included in this study are olivine, sherd (olivine) and sand, as discussed above. The surface treatments of sherds included in this study are, plain, corrugated, black-on-gray, red, and polychrome. Some of the plain wares have fugitive red on the surface, which was also recorded. Core color was also examined. Because the purpose of recording the core color is to determine only the general color tendency in the group, a Munsell color chart was not used. However, for consistency, the core color of all sherds was examined with same microscope light setting.

The classification of Virgin Ancestral Pueblo ceramics is not easy work. Some of the pottery wares and types in this particular study area are somewhat controversial (e.g., Shinarump wares) and difficult to distinguish from others.

The ceramic typology has a hierarchical classification system (Colton 1952). The first level of classification is *ware*. A ware is identified based on materials used to make pottery, including clay and temper, according to Lyneis (1999). Within each ware, *types* are identified based on the way the surface is finished (e.g., plain, corrugated or painted) or the painted design. Another category is *series.* Originally, Colton defined series as “a group of pottery types within a ware which have genetic relation to each other” (Colton and Hargrave 1937). However, the term series currently is used in a pragmatic sense (Lyneis 1999), as a regional grouping of types.

Series is now used to assign the ware associated to specific region. For example, *Virgin series of Tusayan Gray Ware* separates the sand-tempered pottery of the Arizona Strip and adjacent areas from that of the Kayenta area. This category is problematic because it is not clear whether the region means where the pottery was found or made. This study involves pottery from only the Arizona Strip and adjacent areas and source of ceramics are identified through chemical compositional group. Thus, this category, series, is not used in this study.

To avoid the confusion, I will define the ware and types used in this study based on the version of the typology proposed by Lyneis (1999, 2008) with some modifications listed below. The main focus of this study is the procurement of clay and temper for the production of ceramics. Thus, for this purpose, the presence of a slip coating the sherd surface was not considered in distinguishing wares (e.g., white ware is with a slip, gray/brown ware is without slip).

Moapa Ware: Sherds with olivine temper are Moapa Ware. The types included in this study are: Moapa Plain (MP), Moapa Plain fugitive red (MPF), Moapa Corrugated (MC), and Moapa Black-on-gray (MBG).

Tusayan Gray Ware: Sherds with sand temper in a light-to-medium-gray clay are Tusayan Ware. Colton (1952) identified two gray wares: Tusayan Gray Ware and Tusayan White Ware (slipped). Slips on some of the surfaces of the sherds included in this study are very difficult to identify with the naked eye. However, the identification of slip is not the focus of this study. Thus, a distinction between Gray and White Ware is not made. Another ware, Shinarump Ware, also includes sand temper. The description of Shinarump Ware is still controversial, and it is very difficult to distinguish it from Tusayan Ware in some cases. All other sand-tempered ceramics were categorized as Tusayan Gray Ware. The types in this ware include Tusayan Plain (TP), Tusayan Plain fugitive red (TPF), Tusayan Corrugated (TC), and Tusayan Black-on-gray (TBG).

Shinarump Ware: Shinarump Ware has sand temper in a dark clay or vitrified red clay (Lyneis 1999). As mentioned above, this is very difficult ware to identify, since the identification of clay color is very unclear. In this study, only the sherds with extremely dark core (almost black) are considered as Shinarump Ware. The types include Shinarump Plain (SNP) and Shinarump Black-on-gray (SNBG).

Shivwits Ware: This ware includes crushed Moapa Ware sherds as temper (with some olivine within the sherds) in dark-gray clay matrix. The types in this ware include Shivwits Plain (SVP) and Shivwits Corrugated (SVC).

Tsegi Orange Ware (TO): There are at least three red wares found in the study area. Tegi Orange Ware is a red/orange ware with sherd temper in an orange paste.

Shinarump Red Ware (SNA): This red ware includes sand temper in dark, red, or vitrified clay.

San Juan Red Ware (SJR): The dominant temper in this red ware is andesite.

Unidentified Red Ware (RED): The red wares not categorized as Tsegi Orange, Shinarump Red Ware or San Juan Red ware, are grouped as unidentified red ware.

Polychrome (POL): Since there are only a few polychrome sherds included in the study, no ware types were assigned. They were categorized simply as polychrome.

Optically Stimulated Luminescence Dating

In order to examine the relationship between the compositional groups in the ceramic clay matrix and time, ceramic samples from each compositional group have to be dated. Radiocarbon (^{14}C) dating is the chronometric technique most often used by archaeologists for dating artifacts. However, this usage for any ceramic assemblage has several problems, the first of which is accuracy: the temporal relationship between the radiocarbon-dated event and the targeted event is often unknown (Lipo et al. 2005).

Wood charcoal is used most often in many archaeological contexts for ^{14}C dating. For example, the wood charcoal may have originated from the wooden beams used to construct pueblos at the site or it may have been used as the fuel for firing pots or cooking. Whatever its use, the dated event determined by ^{14}C dating on wood charcoal is the death of a tree. The targeted event in this study is the production and use of the pots at the site. If the wood charcoal was from a part of the building where the pots were likely used, then we cannot know if the production and use of these pots happened at the same time that the tree was cut down or died. What is more likely is that the construction of the building long predated the production and use of the pots. Even if the wood charcoal is from wood used as fuel for firing pottery, the dated event may not be contemporary with the targeted event. Noted as an "old wood problem" (Schiffer 1986), the ^{14}C dates for the wood charcoal can potentially indicate earlier dates than targeted events such as the last use of the hearth, since fuel woods may have been dead for decades before use.

The second problem in associating ^{14}C dates with ceramic samples is related to the special association between ^{14}C samples and potsherds. The main concern is that the spatial association between the sherd and the radiocarbon sample is not always a reliable indicator of a temporal association (Lipo et al. 2005). Carbonized corn or annual seeds from a house floor can be used for ^{14}C dating to avoid the old wood problem discussed above. However, even in this case, it is not certain that the dated radiocarbon sample, which is spatially associated with the sherd sample, is the same age due to various transformational processes (e.g., animal burrowing and erosion). Thus, using ^{14}C dating to examine the age of a ceramic assemblage involves several uncertainties and a more direct dating technique for ceramics is necessary for creating a high-resolution chronological sequence of a ceramic assemblage.

Luminescence dating of ceramics is a well-established technique that avoids the ambiguity of the association between dated events and targeted events (Dunnell and Feathers 1994; Feathers 2003; Lipo et al. 2005). Therefore, luminescence dating should be a suitable alternative for this study since it provides direct dating that is nearly free from the problem of the association between the dated materials and the pottery production. Moreover, luminescence dating measures the time since the pots were last exposed to a high heat, so the dated event is the firing of the pots for the last time, and this should be close to the target event in this study, which is the production and use of these pots.

Background

The detailed principles and techniques for luminescence dating are discussed elsewhere (Aitken 1985, 1998). Here, only a brief summary of luminescence dating is given based on the description of the technique by Feathers (2003) and an unpublished IIRMES luminescence dating lab report from California State University, Long Beach (Lipo and Sakai n.d.). Luminescence dating is based on the emission of light (luminescence) from crystalline materials that have accumulated dose (e.g., dosage by natural radiation) over time by the absorption of natural radioactivity (Feathers 2003). This method of dating is based on the principle that crystalline materials in ceramics, such as quartz and feldspar, trap electrons released by natural radiation into the materials, and these trapped electrons accumulate over time. Then when sufficient energy is applied, these accumulated electrons are released in the form of light (Feathers 2003). This amounts to a zeroing event. A stimulus required to release the absorbed energy is either heat, resulting in thermoluminescence (TL) or, light, resulting in optically stimulated luminescence (OSL). The amount of emitted light is proportional to the time since the last zeroing event. Thus, the amount of time since a sample was fired or exposed to light for the last time can be determined when the amount of emitted light, the sensitivity of the sample to luminescence and the dose rate is measured. The age equation is expressed as follows:

$$Age\ (ka) = D_E\ (Gy) / D_R\ (Gy/ka)$$

where D_E is an equivalent dose in grays (*Gy*) (unit for absorbed dose) and D_R is the average dose rate over time. Age is shown in thousand years (*ka*) in this equation. An equivalent dose is the amount of radiation dose acquired since the last zeroing event, as calibrated against laboratory irradiation (Feathers 2003). The dose rate consists of an internal component from the sample and an external component from the environment (Feathers 2003), including the soil surrounding the sample as well as cosmic rays.

In general, laboratories conduct a luminescence analysis by extracting quartz grains from a sherd in the silt-to-sand size of 90–200 microns (coarse-grained analysis) or polymineral fine grains of 1–8 microns (fine-grained analysis). Coarse-grained quartz analysis has several benefits over fine-grained mixed minerals. First, quartz has relatively few internal sources of radiation, so the interiors of the grains are not significantly influenced by alpha radiation. Second, any influence of alphas on the surface may be greatly reduced by etching the grains with hydrofluoric acid (HF) in coarse-grain analysis. This will minimize the required step of alpha calibration that is required for fine-grained analysis. In addition, these grains are small enough to limit beta attenuation and avoid complex geometry due to irregularities of shape. Quartz is also preferable over feldspars since it does not have problems with anomalous fading, which is a thermal loss of signal with time. With feldspars, fading is common and can result in the dates appearing younger than they really are. In this dissertation, I chose to use coarse-grained quartz because of the apparent large amounts of quartz in the samples. This study focuses on coarse-grained, 90–125 micron, quartz.

To extract the minerals from the ceramic sample, the outer 2 mm of the sherd is removed using a rotary tool. This outer portion is excluded from the luminescence dating since it was exposed to light, which presumably dates to “today” due to the bleaching by sunlight/room lights. The removal of the outer portion also excludes influence of betas from the environment. So only the interior portion of the sample was used for the dating process. All procedures for the preparation are conducted in a dark room with minimal filtered light. The extracted materials are subjected to the sample preparation procedure discussed later, including chemical treatment, grain size separation, mineral separation, and HF etching. After the sample preparation process, the quartz particles are placed on several disks for measurement. Each disk serves as a separate aliquot for which a date can be determined using a single aliquot regeneration technique (Murrary and Wintle 2000).

Each sample is analyzed by using the Risø TL/OSL Reader with blue-light (BOSL) and infrared (IROSL) stimulation discussed below. To measure the equivalent dose in the sample, a single-aliquot regeneration sequence (SAR) protocol is used with a double IR “wash” to eliminate the signals from the feldspar. When measuring optically stimulated luminescence (OSL), we stimulate the material with light, usually at a particular wavelength known to release luminescence from the material in a well-understood and measurable fashion (400–550 nm range, centering at 470 ± 30 nm for quartz analysis in the IIRMES lab). The amount of light released under stimulation is measured using a photomultiplier tube (PMT) with a UV filter. The release of energy simulates a "zeroing" event that empties crystals of the charged particles that have accumulated since the paleo-"zeroing event" (e.g., firing of the pots). This "zeroing event" would have occurred during the exposure of crystals to the sun or substantial heat. After the accumulated paleo-signals are measured, a series of subsequent measures are made by exposing the material to known amounts of beta radiation. These measurements allow us to determine the rate at which luminescence is generated in the sample as a function of dose and thus the accumulated dose.

In addition, calculating a date requires an estimate of the radioactivity in the sample and in the surrounding environment (a dosimetry sample is measured to estimate radiation in the sherd, and radiation sample is measured for background sediments). This results in the dose rate. Because of the long half-lives of the relevant radionuclides, the current dose rate is usually assumed to be the average dose rate through time. An annual dose rate of radiation is determined by measuring radioactivity that comes from uranium, thorium, and potassium isotopes in the sample and in the surrounding sediments. For ceramic dating, the outer portion of the sample, which cannot be used for luminescence measurement, is often used for the dose rate analysis. However, for this study, only the inner portion was used because some samples have INAA data for their inner portion, which allowed me to cross-check the radioactive elemental concentrations of potassium, thorium, and uranium as determined by ICP-MS and portable X-Ray Fluorescence, which will be discussed later. The contribution from cosmic rays is also estimated based on the elevation, latitude, and longitude, as well as the depth of the deposit from which the sample came.

Using the information discussed above, including the amount of the archaeologically accumulated luminescence signal, the sensitivity of a sample to radiation, the moisture content of a sherd and soil (moisture affects how much radiation reached the quartz grains), and the annual dose rate of radiation, a direct date can be calculated. Since the zeroing event for ceramics is a one-moment event (e.g., firing of the pots), assuming all/most of the quartz is bleached at a temperature over 500°C, the averaged equivalent dose from multiple aliquots in one sample is used to estimate an equivalent dose for age determination. Dispersion of an equivalent dose among aliquots in one sample is examined to estimate an equivalent dose of the sample using a central age model or a common age model, as is discussed later.

History of Luminescence Dating and Ceramic Dating

In the past two decades, the application of luminescence dating has gradually increased in the study of ceramics in the U.S. Several studies using luminescence dating for ceramics have been published, including the dating of ceramics from the American Southwest (Feathers 2000), Great Basin (Feathers and Rhode 1998; Rhode

1994), and the Mississippi Valley (Lipo et al. 2005; Feathers 2008). During the past 50 years, luminescence dating for heated materials and sediments has undergone three phases of development: the first 22 years (1957–1979) were devoted to development of TL dating for heated materials such as ceramics, the second phase (1979–1985) involved applying TL dating to sediment dating, and the third phase was the development after 1985 of OSL dating for sediments (Wintle 2008). The basic procedure for TL dating was developed by Martin Aitken at the Oxford Laboratory (Aitken 1985). OSL was originally developed for dating sediments (Huntley et al. 1985). More recently, OSL has been used for dating ceramics on the premise that the heating events also reset the optically sensitive traps (Liritzis et al. 2013), although TL dating has continued to be used for dating ceramics even after development of OSL (Feathers 2003). OSL dating was applied to the dating of ceramic assemblages from the Mississippian Valley (Lipo et al. 2005: Feathers 2006, 2008), and the Great Basin (Feathers and Rhode 1998; Eerkens and Lipo 2012).

The single-aliquot technique is the way that both the paleodose and the rate at which luminescence accumulates in the sample are measured by one aliquot analysis, while the multi-aliquot technique requires several aliquots to measure the rate of luminescence accumulation, which is required especially in TL dating. Single-aliquot OSL appears to be a useful complement for TL dating, as TL and OSL dates for the same sample agreed (Feathers and Rhode 1998). Single-aliquot OSL dating has some advantage for ceramic dating. One advantage of using OSL is that it requires a small sample size (Feathers 1997, 2003). In addition, the application of

OSL has rapid and cost-effective throughput of the samples (Liritzis et al. 2013). These benefits of using OSL—small sample size and rapid and cost-effective analysis—have aided the development of chronologies in archaeology. Many of the targeted events of interest in archaeology have duration, such as the duration of occupation of sites or use of the particular clay resources for pottery production. For the occupations, durations can be up to several centuries and therefore a single date estimate based on an artifact or ecofact is not sufficient. Instead, the distribution of multiple dates is required to estimate the duration of the event (Lipo et al. 2005). Consequently, it is crucial to obtain many single-age estimates to ascertain the duration of an event. In this study, the unit of analysis is the source of a sherd and age. Thus, single-aliquot OSL technique, which is a cost-effective method requiring only a small sample size, is the preferred way to estimate the time range of the event of interest. To understand the change in the use of clay resources, multiple samples are analyzed by OSL to estimate the duration of the clay use.

Measurement Protocols

The samples were prepared according to standard procedures modified from Aitken (1985) and Banerjee at al. (2001) and adopted from the University of Washington Luminescence Dating Laboratory under the direction of Dr. James Feathers. In this study, the samples were prepared using a coarse-grained quartz protocol with grain size at 90–125 μ (Table 5.30), since quite a few quartz particles were recognized in most of the ceramic pastes and the sherds were large enough to

Table 5.30. Coarse-grain Sample Preparation Protocol.

Step	*Procedure*
1	Calculate percent water absorption
2	Remove 2 mm outer portion
3	Crush sample and disaggregate sample in shaker mill/mortar and pestle.
4	Treat samples with HCL and H202 to remove carbonates and organics.
5	Grain size separation using sieve (90-125 μ).
6	Mineral separation using sodium polytungstate.
7	Etching quartz surface by HF.
8	Place quartz particle on the disks.

extract quartz to make a few aliquots. In this study, I conducted all work, including the preparation of the coarse grain samples, OSL measurement, and dosimetry analysis, at the Luminescence Dating Laboratory in the IIRMES Lab at CSULB.

Sample Preparation

After taking photographs and initial physical measurements (e.g., weight, thickness), the water absorption was measured (Step 1) because the presence of water in the sample and the environment affected the dose-rate of the sample. The sherd was covered by deionized water in a beaker and weighed after 24 hours (saturated weight). Next, the sherd was dried in an oven at 60°C for 24 hours and then weighed (dry weight). The water absorption was calculated as follows:

Water absorption = (saturated weight – dry weight)/dry weight

After the water absorption was measured, all subsequent processes were undertaken in a dark room to avoid exposure to light. Part of the sherd was saved as an archive sample and another part was used for dosimetry analysis. Two millimeters from the outer portion of the remaining sherd was removed using a rotary tool with very slow speed to avoid heating or sparking (Step 2). The inner portion of the sherd was roughly crushed and disaggregated using an agate mortar and pestle (Step 3). Then the disaggregated sample was treated with hydrochloric acid (HCL) and hydrogen peroxide (H2O2) to remove carbonates and organics, which can have spurious luminescence effects (Step 4). The disaggregated sample was transferred with deionized (DI) water into the beaker to which a small amount of HCL was added. After the reaction by HCL was completed, a small amount of H2O2 was added. Neither the Mt. Trumbull or lowland Virgin sherds included much limestone and the sherds were fired until most of the organics were burnt out. Thus, the chemical treatments of the samples involved in this study were completed in less than two hours. After completing the chemical treatments, the acid was rinsed off, and the rest of the samples were separated using 90-μ and 125-μ screens (Step 5). The samples with grain sizes of 90–125 μ were dried completely in the oven at 60°C, and the mineral separation of the samples was conducted using sodium polytungstate, which is a heavy liquid. Because quartz has a specific gravity of 2.65 g/cm^3, the samples were separated using sodium polytungstate with a density of 2.68. The light fraction from this separation was dried and then the quartz was separated from the K-feldspars using sodium polytungstate with a density of 2.58 g/cm^3. In order to eliminate the portion of the grain that had been given a signal due to the alpha particles, the surface of quartz needed to be chemically etched (Step 7). The dried quartz was added to about 5 ml of hydrofluoric acid (HF) and soaked for 40 minutes to remove the surface of quartz. After HF was neutralized, a small amount of HCL was added to rinse away the chemical byproducts of the HF etching: CaF2. Dried quartz samples were placed onto the disks for the luminescence measurements (Step 8).

Luminescence Measurements

Luminescence signals were measured by an automated Risø TL/OS 12B/C reader with calibrated beta sources (^{90}Sr) to evaluate the rate of luminescence signal accumulation. In this study, blue-light OSL (BOSL) stimulation was used with a single aliquot regenerative dose (SAR) protocol (Murray and Wintle 2000). To obtain TL measurements, multiple aliquot additive doses are necessary and multiple aliquots require a larger sample size. For OSL measurement, however, a SAR that requires a much smaller sample size can be used. The SAR protocol allows us to complete the measurements of an equivalent dose in one aliquot analysis. A U-340 filter was used to eliminate spillover from stimulation light and thus isolate the sample luminescence. A double-IR “wash” was used to eliminate contributions to the luminescence signal by feldspar contaminations (Banerjee et al. 2001), although feldspar should have been excluded at the stage of sample preparation in this study. For this step, samples were stimulated using infrared diodes. Table 5.31 outlines the SAR BOSL stimulation sequence used for this study.

In the SAR protocol, accumulated luminescence (paleodose) was measured as a part of the stimulation sequence. The rate at which radiation creates luminescence signals was measured through a series of beta irradiations. The aliquot

Table 5.31. OSL/SAR Sequence (BOSL).

Step	*Procedure*
1	Give dose, D1, for 5 s
2	Preheat sample to 240°C for 10 s
3	Stimulation with infrared light at 125°C for 50 s
4	Stimulation with infrared light at 200°C for 50 s
5	Stimulation with blue light at 125°C for 100 s
6	Measure OSL
7	Give test dose, Dt, for 15 s
8	Heat reduced to 160°C for 5 s
9	Stimulation with infrared light at 125°C for 50 s
10	Stimulation with infrared light at 200°C for 50 s
11	Stimulation with blue light at 125°C for 100 s
12	Measure OSL
13	Repeat steps 2–12

was irradiated by beta source for 10, 20, 30, 40, 50, and 70 seconds. The response curve based on these artificial doses was used to determine the equivalent dose, which is the amount of radiation that must have been present to generate the

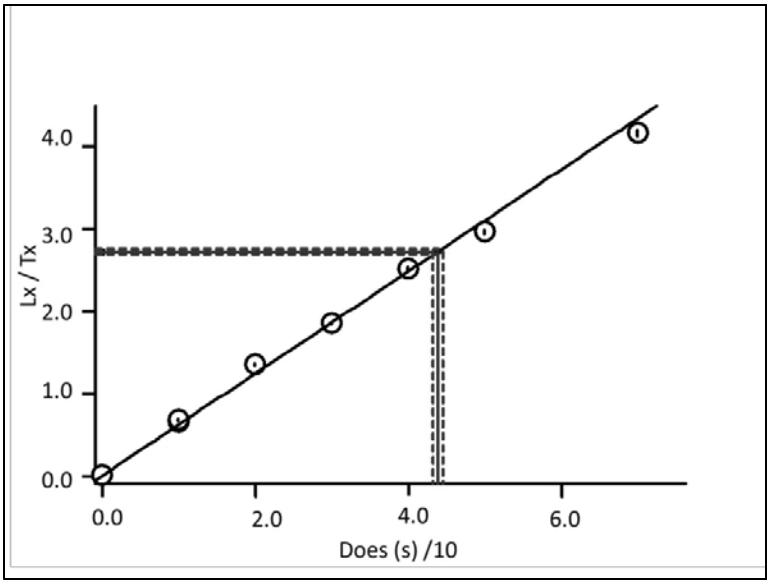


Figure 5.43. An example of a regeneration curve and the interpolation of the natural signal to determine equivalent dose(s). For this sample (LB655_3), the equivalent dose(s) is 43.83 ± 0.7. Each point on the curve is the luminescence from an artificial dose divided by the luminescence from the test dose.

paleoluminescence signal. An example of the regeneration curve and the equivalent dose (s) is shown in Figure 5.43. When using the SAR protocol, several checks and tests are required to ensure the equivalent dose is valid. For this study, the criteria for passing these tests were as follows: (1) a recycling ratio limit 20 percent to ensure the sensitivity correction is consistent for an identical dose (Liritzis 2013), (2) a maximum test dose error of 30 percent, and (3) signals > 3 sigma above background. Any equivalent dose that did not pass these criteria was rejected.

Estimation of Averaged Equivalent Dose and Error

To estimate the mean value of the equivalent dose and error, the dispersion of the equivalent dose values among aliquots in one sample was considered. Two alternative statistical models were used based on the distribution of the equivalent dose. When equivalent doses were the same or very similar for all aliquots with no overdispersion, the "common age" model was used to average the equivalent dose and error. When the equivalent doses were dispersed, the "central age model" was used (Galbraith and Roberts 2012). The overdispersion refers to the amount of spread beyond what can be accounted for by measurement error. Overdispersion rate in this study indicates the ratio of aliquots beyond two standard deviations based on the averaged value.

Dose Rate Information

At the IIRMES facility at in CSULB, measurements were taken to determine the amount of radioactivity that was present in the sample and the local environment. Measurement of the annual radiation dose rate was calculated from the amount of these elements in the surrounding soils as well as estimates of cosmic rays at the location of the deposit. For the latter purpose, the location of the sherd (latitude, longitude, the elevation of the site, as well as the depth of the deposit) is required. For the analysis of thorium and uranium, laser ablation Time of Flight ICP-MS (LA-ICP-MS) was used. Detailed information about LA-ICP-MS was described above in the section concerning the analysis of LA-ICP-MS in the compositional analysis. Both the sherd and its surrounding soil were ground into extremely fine powder with a mortar and pestle and then added to a 40-ppm indium internal standard solution. The samples were dried and then mixed thoroughly using a shaker mill. Since LA-ICP-MS is a point analysis, it is extremely important to homogenize the solid material with a heterogeneous matrix such as ceramics. Mixed samples were made into pellets with a binding powder by using a 15-ton geological sample press. The resulting pellet was analyzed for more than 45 elements, including thorium and uranium, by using LA-ICP-MS. The same settings (e.g., laser power, scan speed) were used for the clay matrix analysis as discussed above in the section on compositional analysis. Three analyses were conducted on each sherd using LA-ICP-MS, and averaged elemental concentrations were used for dose rate information. All intensity counts were normalized to the internal standard (indium 40 ppm), and calibration curves for each element were generated using external calibration standards, including SRM 610, 612, and 679 (fired-brick clay). Since all samples were prepared as pellets, these standards were also made into pellets at 60 percent dilution before the analysis.

In order to obtain the concentration of potassium, the same pellets were analyzed using a Bruker portable X-ray Fluorescence (pXRF) instrument. The pellets were measured with a titanium filter and a 28-micro-amp current setting and 15kV voltage utilizing a vacuum for five minutes to simulate low-energy elements, including potassium. All raw counts were calculated into the concentrations by the calibration curves based on 30 ceramic samples with known concentrations through INAA and ICP-MS analysis, as well as SRM679 and the New Ohio Red Clay standard (Table 5.32). As mentioned in the background to luminescence dating section above, only the inner part of the sherd was used for dose rate measurements in this study. Therefore, the elemental concentrations on these pellet samples also provide information that is potentially useful for a sourcing and compositional study as bulk data.

Table 5.32. XRF settings and calibration.

XRF setting for low energy elements (Mg, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe)	
	Voltage: 15 kV Current: 26 micro amp With Vacuum and Ti filter Time: 5 minutes
Calibration standards	
	Thirty ceramic samples with INAA and LA-ICP-MS known values SRM 679 and New Ohio Red Clay

Table 5.33. Number of sherds with OSL dates.

Group	OSL dates	(Total Sherds in the Compositional Group)
Group 1G	29	(242)
Group 1VM	11	(55)
Group 1VV	14	(156)
Group 2	27	(185)
Group 3	9	(24)
Group 4	10	(23)
VR1	8	(22)
VR3	5	(22)
Total	113	

Results of OSL Dating in This Study

In this study, I conducted OSL dating on 113 sherd samples for which compositional information was also available (Table 5.33). Five to 29 samples from each compositional group were chosen for this analysis. Samples were not chosen evenly, as some of the groups include more samples than others. Although an effort was made to choose sherds with variations in surface treatment and temper, they do not represent the whole population of ceramic physical attributes in the compositional group.

Evaluation of Equivalent Dose

Overall, the luminescence signals of sherds from both Mt. Trumbull and the lowland Virgin are strong and easily measured (Figure 5.43). Although the majority of the samples have strong OSL signals, some of the samples in the VR1 group had weak signals and they also produced relatively younger dates than expected. Ideally the sherds for OSL dating should be thicker than 4–5 mm, since the outer 2 mm surface is removed before the OSL analysis. Although many of the VR1 sherds are relatively thin, they were analyzed. Even thin sherds sometimes give enough OSL signals. However, the dates obtained on some of the VR1 sherds may suggest that they probably experienced light contamination that resulted in loss of OSL signals.

After the naturally accumulated signal was measured, subsequent measures were made by exposing the material to calibrated amounts of radiation as discussed. These measures allowed us to determine the rate at which luminescence signals are generated in the sample. From these analyses, the regeneration curves of most aliquots were shown to be linear. Generally a linear relation indicates a predictable relation between radiation and luminescence. Either a linear or exponential linear curve was applied to most of the aliquots in this study. After the measurements of OSL signals were taken, each aliquot was carefully examined and only the equivalent dose of aliquots that passed the criteria discussed above was accepted. Although it was not often the case in this study, the aliquots that showed extremely small signals or "noisy" luminescence from calibrated known irradiation and did not show a linear relationship were rejected. After each aliquot was examined, two out of 113 samples were excluded for the date determination, since I was able to extract only one aliquot from each sample and they did not pass all criteria (see detail discussion of criteria for equivalent dose to pass in Luminescence Measurement section above).

All accepted equivalent doses of the samples are shown in Appendix B: Table B1. For the age determination, the averaged equivalent dose was used. As discussed, the central age model or common age model was used to summarize the equivalent dose values. The overdispersion rates of most samples with a central age model are less than 20 percent, with some exceptions. The overdispersion rate information was considered when evaluating the final dates. Using the dose rate information from the sherds and surrounding sediments (Appendix B: Table B2) and locational information, thickness, and water absorption (Appendix B: Table B3), the final dates were calculated. All dates were evaluated for reliability after they were calculated based on three criteria: (1) number of aliquots, (2) error term of the age, and (3) overdispersion rate if the sample has more than one aliquot. Error term is calculated on the years before present as follows.

$$\text{Error term (\%)} = \text{Error } (ka) \,/\, \text{Age } (ka)$$

For example, if the date of a sample is A.D. 414 (1600 years) ± 200, then the error term of 200 is 12.5 percent. Overdispersion rate indicates the ratio of aliquots beyond two standard deviations based on the averaged value. The cut-off to pass the criteria for number of aliquot is more than two, for error term it is set at 15 percent and for overdispersion it is at 25 percent. Based on three criteria, the dates were ranked with A as most reliable date. If the sample passes all three criteria, then A was assigned. B was assigned to the sample that passes only two criteria and C to the samples that passes just one. If a sample does not pass any of the criteria, then D is assigned. The totals of 87 As, eight Bs, 13 Cs, and three Ds were assigned to all 111 samples. These ranks were used when the dates are compared for the change in the compositional groups. The results of age evaluation for the 111 samples are shown in Appendix B: Table B4.

The Background Sediment Sample Issue in the Lowland Virgin Area

In Mt. Trumbull, the background sediment samples (radiation sample) for OSL dating were collected from the same context as the sherds, or at least within a 50-meter distance from the sherds at the same site. Thus, there is no uncertainty regarding the relationship between the sherds and sediment samples among the Mt. Trumbull OSL dates. In the lowland Virgin area, however, some questions remain about the soil samples collected from the background environment, and it is uncertain whether these soil samples collected for the OSL analysis represent the same radiation level as the soil context of the sherd samples. Since the sherd samples were from a collection made during the 1970s, no sediment was collected from the same original provenience of the sherds. In 2009, I made an effort to collect sediment samples in the lowland Virgin area. Unfortunately, I was unable to relocate some of the sites identified in the original collection report. Thus, the background sediment samples were collected from eight locations, and all of them are from possible landforms on which the sites exist: the top of a mesa, a riverbank, and the Virgin River flood plain, as discussed in Chapter IV. In some locations, the matrix of the sediment was not homogeneous and included large rocks and sand. Although the finer grains within the soil could be the weathered products of these large rocks, both rocks and sandy soil were collected for the comparison. Both LA-

ICP-MS and XRF showed that the rocks and soil in the same context have relatively similar concentrations of potassium, thorium, and uranium (Table 5.34). Note in Table 5.34 that each of the following pairs of samples, LB684_r1 and 2, LB684_r3 and 4, LB684_r5 and 6, and LB684_r7 and 8, is from the same location. Overall, the range of potassium, thorium, and uranium concentrations is relatively small for the sediment samples analyzed, except the sediment samples collected near the possible VR 22 site area (LB684_r5 and 5) from the west bank area (although no site was found at the location recorded on the original site record for VR22). Rocks and soil were analyzed separately, and both showed similarly high levels of thorium. Therefore, these high thorium values are not an analytical error. Four other sediment samples (LB684_r 1-4) were collected from the west bank area in addition to these samples with high thorium values (LB6894_r 5&6), and these four samples have much lower thorium (4–10 ppm), as generally expected. Because all samples on the west bank were collected within a two-km diameter area, the high-thorium sediment is likely from a distinct “hot spot” that may contain some unique minerals or rocks. Based on these results, the high-thorium sediment samples (LB684_r 5&5) were excluded from the dose rate information used to generate the final dates of most of the samples. VR22, 23, 24, and 26 are located within a 500-meter diameter area based on the original report on the west bank, and the sediments were collected adjacent to these sites. Although the average dose rate values of the west bank(LB684_r1-4) were used for the final dates of the samples from VR22, 23, 24, and 26, the dates based on the high-thorium sediment (LB684_r 5&6) were also

Table 5.34. Summary of radiation samples from the lowland Virgin area.

Sample ID	Area	Provenience	Materials	K (ppm) XRF	Th (ppm) ICP-MS	U (ppm) ICP-MS
LB619_r 1	East bank	VR13	soil	18301.19	9.07	0.37
LB619_r 2	East bank	VR11?	soil	14579.78	4.51	0.55
LB619_r 3	East bank	VR3	soil	16934.57	6.42	0.59
LB619_r 4	East bank	VR14	soil	13612.46	7.14	0.75
LB619_r 1-4	East bank	Average of sediments from east bank	soil	15857.00	6.78	0.57
LB684_r 1	West bank	Between VR19&22	soil+rock	13315.32	5.60	0.34
LB684_r 2	West bank	Between VR19&22	soil only	13897.82	7.80	0.92
LB684_r 3	West bank	Near possible VR19	soil+rock	8671.10	4.05	0.36
LB684_r 4	West bank	Near possible VR19	soil only	10388.15	10.33	0.55
LB684_r 1-r 4	West bank	Average of sediments from west bank except LB684_r 5&r 6	soil+rock	11568.10	6.94	0.54
LB684_r 5	West bank	Possible VR22	soil+rock	5071.90	32.90	0.11
LB684_r 6	West bank	Possible VR22	sand only	6087.32	22.60	0.20
LB684_r 7	Mormon mesa	6 km from VR19	sand+rock	8512.19	2.36	0.42
LB684_r 8	Mormon Mesa	6 km from VR19	sand only	6425.08	4.22	0.24
LB614_r1-4, LB684_r1-4 and r 7, r 8	all	Average all lowland Virgin sediments except LB684_R 5 &6	soil+rock	10590.59	5.08	0.44
LB614_r 1-4, LB684_r 1-4	all	East and west bank sediments average	Soil+rock	13712.55	6.86	0.55

evaluated.

Sediment samples were chosen by carefully examining the distance between the location of the site where the sherds were collected and that of the sediment sample collection for the lowland Virgin ceramic dating (Figure 4.2 in Chapter IV). A summary of the lowland Virgin sediment samples is presented in Table 5.34. VR 7, located upstream along the Virgin River, and VR 32, 33, and 35, located downstream close to Lake Mead, may be too far from any of the collected sediment samples, thus the final dates were evaluated more carefully.

At Mt. Trumbull, the background sediments were collected with sherds in the test excavation. A few sediment samples were collected for dating the surface collection sherds within 50-meter diameter radius of the same site. The concentrations of potassium, thorium, and uranium of most of the sediments in Mt. Trumbull are similar. The final dates are shown in Appendix B: Table B4. In the following section, the evaluation of the final dates for each compositional group are discussed.

Evaluating Equivalent Dose and Dates in Each Compositional Group

As discussed above, the final dates are evaluated for the reliability based on three criteria: number of aliquots, error term, and overdispersion. The date is assigned as A if it passes three of them, B if passes two and C if passes one. The following section will summarize the evaluation of dates in each compositional group. The summary of the dates is presented in Appendix B: Table B4.

Group 1G

Twenty-nine samples were analyzed by OSL dating in Group 1G and 22 dates are evaluated as A, five dates as B, and two dates as D. One of the samples evaluated as D—MT204-28 (LB126) dating A.D. 1683 ± 93—was rejected since this sample has only one aliquot with a very weak signal, which consequently revealed a very high error term (28.2 percent). The other sample with D is MT30-10 dating A.D.769 ± 199. This sample is assigned a D because it is based on only one aliquot that produced a date with high error terms. However, the OSL signal was strong and the error term (16 percent) is just beyond the cut-off. For these reasons, MT30-10 was not rejected and included for the examination of compositional analysis and time.

Five samples are evaluated as C. Three of them are based on only one aliquot: MT30-40, VR22-4, and VR27-6. Since all of them are based on strong signals with an error term less than 15 percent, these dates were accepted. However, these dates need to be evaluated carefully when examining the relation between the use of clay and time. The date of MT30-40 (LB146) is A.D. 205 ± 205, which is a little older than traditional dates for the start of ceramic production in the area (Basketmaker III starting A.D. 400). VR22-4 (LB1078) is from the VR 22 site close to the collection of the high-thorium (LB684_r 5&6) sediment previously discussed. Consequently, the average of sediment samples from the west bank of the Virgin River without high-thorium samples was used as sediment information. The final date reported here is A.D. 521 ± 172 based on the west bank average. Using the average of high-thorium sediments, LB684_4 and 5, the date is A.D. 849 ± 126; thus, the date may be later than that reported here. Two samples assigned as C are based on multiple aliquots but raise some concerns. Both MT14-70 and VR32-7 have large error terms and high overdispersion rates. The dates of MT14-70 is A.D. 1313 ± 304 with a 43.3 percent error term and 60.1 percent overdispersion and the date of VR32-7 is A.D. 553 ± 319 with 21.8 percent error term and 53.1 percent overdispersion rate. Both samples have strong OSL signals, so they were accepted. However, due to these high error term and overdispersion, these dates may or may not be valid.

The date of MT136-7 (LB148) is A.D. 1655 ± 28, which is too late for the traditional arguments on the Ancestral Pueblo occupation in the study area. However, it was accepted since the OSL signals were strong and passed three criteria. It is possible that the date of this sample represents a post-depositional event, such as the reuse of the pot by later occupants of the area, the Southern Paiute.

The dates for a few samples leave some uncertainty about the dose rate information of the background sediment from the lowland Virgin previously discussed. The date of VR35-6 (LB1077) is A.D. 388 ± 132 based on the average value of the Virgin River west bank sediment samples (Table 5.34). The OSL signals of all aliquots are strong and they are not dispersed as their overdispersion is just 3.5 percent. Thus, the equivalent dose is solid. However, no sediment samples were collected within 5 km for VR32, 33, 35, and 38, and the location of sediment samples used for this sherd is at least 5 km upstream. Thus, the dates may be different if the sediment samples were collected adjacent to the VR35. VR24-1

(LB875) is close to the location of sediment sample with high thorium. The final date, which is A.D. 849 ± 118, is based on the west bank average. Using the average of the high-thorium sediment samples, LB684_4 and 5, the date would be A.D. 1107 ± 86. In conclusion, 28 samples out of 29 are accepted, although some careful evaluation will be required for the dates with an evaluation of C and D when examining chronological change in the use of clay resource of the sherds.

Group 1VM

Eleven sherds were selected for OSL dating from Group 1VM, and dates for all samples are accepted. The dates for three samples are evaluated as C, two of which are based on a single aliquot. MT131-168 (LB1113) dates to A.D. 696 ± 105 with 8.0 percent error term based on a single aliquot. The date for MT214-8, based on a single aliquot, is A.D. 1465 ± 43, which is a little late, considering the traditional argument about Ancestral Pueblo occupation. However, these dates based on a single aliquot are accepted, since OSL signals are strong and error terms are relatively small. The other sample receiving C is MT30-36 (LB0098), dating to A.D. 1091 ± 321 based on two aliquots. Although this sample is accepted, it may or may not be valid, since the error term and overdispersion rates are very high (34.8 percent and 47.4 percent, respectively). Two samples are assigned to B: both MT30-151 and MT136-76 entail relatively high error terms (15.4 percent and 16.2 percent, respectively). MT30-151, dating 1304 ± 109, is accepted, because the date is based on multiple aliquots with strong OSL signals. The date for MT136-76 (LB1111) is A.D. 1815 ± 32, which is too late for the Ancestral Pueblo occupation. This date is accepted because of very little dispersion of three equivalent doses. However, the OSL signals are very small, and two other aliquots did not pass the criteria. Thus, this date is a somewhat questionable. The date for TW143 (LB1114) is A.D. 569 ± 149 and it is evaluated as A. However, the signals of all aliquots in this sample are extremely small, thus it may or may not be a reasonable date.

Group 1VV

Fourteen sherd samples from Group 1VV were selected for OSL dating, but one sample was rejected since the sample has only one aliquot, of which the equivalent dose did not pass all criteria. Thus a date was not calculated for this sample. The dates for all remaining 13 samples are accepted. Eleven samples are evaluated as A, one is B, and one is C. The date for VR17-2 (LB679) is A.D. 1478 ± 93, which may be too late for the Ancestral Pueblo occupation in the lowland Virgin area. This date is evaluated as C, due to large error term (17.4 percent) and extremely high overdispersion rate (39.9 percent). Although it is accepted due to its strong OSL signals, this date may or may not be valid. MT136-336 (LB1130) is assigned B since the overdispersion of seven aliquots is very high (30 percent). VR26-1 (LB1121) is from the VR26 site, which is close to the location of sediment sample with high thorium. The final date, for VR26-1 (LB1121), is A.D. 866 ± 119 based on the west bank average sediments. Based on the average of high-thorium sediments, the date of this sherd may be later, A.D. 1078 ± 84.

Group 2

Twenty-seven samples were selected for OSL dating, but one sample was rejected because the sample has only aliquot, of which the equivalent dose did not pass all criteria. Thus no date was calculated on this sample. The dates were calculated on the remaining samples. Twenty-one samples are evaluated as A, one as B, three as C, and one as D. The date for MT30-18 (LB0135) is A.D. 1984 ± 10, which is evaluated as D. This date was rejected because it is based on only one aliquot with weak OSL signals that resulted in a large error term (34.5 percent).

Three samples are assigned C because their dates are based on single aliquot. Dates for MT204-13 (LB0097), which is A.D. 490 ± 110; MT71-39 (LB0119), which is A.D. 587 ± 85; and MT131-14 (LB0129), which is A.D. 476 ± 115 are all accepted since the OSL signals are very strong. MT71-40 (LB0120) is evaluated as B because the error term is high (17.3 percent). Although this is accepted due to strong OSL signals, relatively high overdispersion rates of two aliquots raise a question about this date.

The dates for five samples are too late based on radiocarbon dates for the site, as well as the traditional arguments about the Ancestral Pueblo occupation in these areas: MT136-27 (LB0099) dating to A.D. 1656 ± 32, MT136-16 (LB0131) dating to A.D. 1730 ± 17, MT204-4 (LB133) dating to A.D. 1581 ± 33, MT136-9 (LB0258) dating to A.D. 1592 ± 30, and MT30-260 (B0599), dating to A.D. 1461 ± 52. All five dates are evaluated as A because of small error terms, very strong OSL signals, and low overdispersion rates. It is interesting to note that the proportion of the samples that date too late in Group 2 is much higher than for any other compositional groups. The Group 2 sherds are characterized by a dark core color, and it may be that the sherds with late dates could be from pottery made by the Southern Paiute, the possible later occupants in the area. However, none of these samples are typical Paiute sherds, which have a very crude and rough surface with dark surface and core colors. This suggests that these sherds are not Southern Paiute, and that they are result of post-depositional events related to later occupants or to natural disasters such as wildfires.

Group 3

Nine sherd samples were selected for OSL dating and all dates were accepted. Eight samples are evaluated as A and only one is evaluated as B. MT30-81 (LB0107) yielded a date of A.D. 1472 ± 84, which is a little late for Ancestral Pueblo occupation in this area. This sample is assigned as B, due to a high error term (15.5 percent). Although strong OSL signals support this date being accepted, two aliquots for this sample do not agree, which results in a relatively higher dispersion rate. Thus, this date is questionable. The date for MT71-57 is A.D. 1467 ± 37, which is also a little late. However, this date was accepted because six aliquots had strong OSL signals and overdispersion of equivalent doses was about 10 percent, which justifies an A assignment. It is possible that this date represents an after-deposit event.

Group 4

Ten samples from Group 4 were selected for OSL dating, and all samples were evaluated as A and accepted. Two samples appear to be extremely early dates. The date of VR21-22 (LB1100) is 95 ± 207 BC based on nine aliquots. This sample yielded strong OSL signals with a relatively small error term (9.8 percent) but relatively high dispersion of equivalents among nine aliquots (14.9 percent). Of note, the potassium concentration in the sherd (dosimetry) is extremely small (3012 ppm) (Appendix B: Table B2). There are five more dates from the same site, VR21, from which this sample came, and all dates are much later than this sample (A.D. 763 ± 243 for LB1092, A.D.1075 ± 125 for LB1075, A.D. 509 ± 151 for LB624, A.D. 1154 ± 110 for LB1107, and A.D. 838 ± 124 for LB1129) (Appendix B: Table B4) and a ^{14}C date for this site is A.D. 960 (Larson and Michaelsen 1990). Thus, the date of sample VR21-22 (LB1100) is an outlier and should not be included in the analysis of compositional groups and time. The date for VR7 (LB1102) is 373 ± 206 BC, which is also extremely early. This date is, however, accepted because the OSL signals of nine aliquots were strong, the error term is relatively small (8.6 percent), and the overdispersion rate among the equivalent doses is small. However, there are a few uncertainties associated with this date. No sediment samples were collected near VR 7 and the potassium concentration of the sherd is very small (3025 ppm). Another date for VR 7 is A.D. 1073 ± 73 (LB1086), and a ^{14}C date is A.D. 1130 (Larson and Michaelsen 1990). Thus, this extremely early date for VR7 (LB1102) is also an outlier and should be excluded for the analysis of compositional groups and time. The date of VR35-4 (LB1106), A.D. 229 ± 183, also appears to be too early for the ceramic production in the lowland Virgin. However, it was accepted because the OSL signals of four aliquots were strong, the overdispersion of equivalent doses is small, and the error term also is small (10.3 percent).

VR1

Eight samples from VR1 were selected for OSL dating. All dates were accepted, although three of them had very weak OSL signals. The ratio of the samples from VR1 with small OSL signals is much higher than that for other compositional groups. Interestingly, all three samples with very low OSL signals are from the same site in Mt. Trumbull—the 30 BLM site. However, it is not certain that the provenience of the sherds is the cause for low OSL signals since they were from different depths of the deposit, and most of the sherds from 30 BLM in other compositional groups had stronger signals. One possible cause could be the thinness of the sherds, which may have caused partial bleaching. However, two of the sherds from the lowland Virgin in the 1VV group also were relatively thin but produced stronger OSL signals, so it is not conclusive that the weak OSL signals for sherds from 30 BLM were due to the thinness of the sherds.

Five samples are evaluated as A, 2 as B, and 1 as C. The sample assigned a C, MT30-77 (LB1094), yielded a date of A.D. 1402 ± 81, which seems a little young. There are four aliquots for this sample and all OSL signals were weak. One of the aliquots yielded extremely small signals that did not exhibit a peak and therefore was rejected. Regenerated values from one of the aliquots were scattered, which provides a less reliable equivalent dose, and one aliquot did not pass the criteria. Thus only one aliquot was accepted for MT30-77. Although this date based on single aliquot is accepted, it may or may not be valid since the date entails relatively large error term (13.3 percent). Two samples are assigned B. VR21-11 (LB1092), dating to A.D. 790 ± 238, has a large error term (19.5 percent). Although this date is accepted, it is questionable since overdispersion of two aliquots is relatively high (23.5 percent). VR17-5 (LB1098) dates to A.D. 1188 ± 107 and is also evaluated as B because of a high overdispersion rate (28.6 percent) for seven aliquots.

Two samples evaluated as A raise some concerns due to extremely small OSL signals. The date for MT30-266 (LB1093) is A.D. 1494 ± 62, which seems a little late. The OSL signals of four aliquots were too small as most of the regenerated signals were scattered. One aliquot was rejected because it did not pass the criteria. This sherd is very thin, about 4.5 mm, and its inner part may be partially bleached. The date of MT30-201(LB1097) is also quite late (A.D. 1529 ± 48), and the OSL signals from all four aliquots were very small. Since equivalent doses of three aliquots that passed the criteria agree (Appendix B: Table B1), the date was accepted. However, the signals from regeneration were relatively scattered. In sum, these two dates may not be valid.

<u>VR3</u>

Five samples were selected for OSL dating and all dates were accepted. Four samples are evaluated as A and one is as B. VR28-2 (LB1090), dating to A.D.1156 ±

95, is assigned B due to a high overdispersion rate of eight aliquots (25.4 percent). VR23-4 (LB1087) was from the site, which is close to the location of sediments with high thorium. The final date of VR23-4 (LB1087), based on the average value from the west bank, is A.D. 602 ± 121. Using the sediment samples with a high-thorium value (LB684 r 5&6), the date for this sample is A.D. 850 ± 90.

In summary, this chapter has examined the compositional diversity among the ceramic samples from Mt. Trumbull and the lowland Virgin area, and eight compositional groups were identified. At least two groups have a Mt. Trumbull source, and two groups have a lowland Virgin source. One group has an unknown source. A total of 111 samples from the compositional groups were dated using OSL dating. As discussed above, two of the samples that were assigned D were excluded from examination of compositional groups and time. In the next chapter, the compositional data and OSL dates are combined in order to evaluate what these compositional groups represent in terms of ceramic production and consumption patterns and how those patterns changed over time.

Chapter VI: ANALYTICAL RESULTS

As a result of the analysis presented in the previous chapter, I found eight groups in the compositional data derived from laser ablation ICP-MS (LA-ICP-MS) analysis of the clay matrix of ceramics from Mt. Trumbull and the lowland Virgin areas. I also dated sherds from each compositional groups using optically stimulated luminescence (OSL) dating. In this chapter, I will first examine what compositional groups found in the clay-matrix data represent in terms of production locations, raw-material choice, and paste preparation and then will use the OSL dates to examine how resource choices and clay preparation changed over time.

Interpretation of Compositional Groups

As discussed in the previous chapter, the LA-ICP-MS elemental analysis of ceramic matrices demonstrates that at least eight compositional groups exist among the ceramics from the Mt. Trumbull and lowland Virgin areas. The analysis presented in the previous chapter also shows that at least two of the groups are Mt. Trumbull local groups and two are the lowland Virgin local groups, when comparing raw clay samples with the ceramic compositional groups. These interpretations are supported in the present chapter by considering the provenience and physical attributes represented in the various compositional groups as well as the INAA results. In brief, the comparison of raw clays to the ceramic groups and the additional evidence presented in this chapter support the following source assignments.

Group 1G is a Mt. Trumbull local group used for both utilitarian and non-utilitarian wares and for domestic use and trading. Three clays from Mt. Trumbull are matched to Group 1G. However, two of these clays resemble Group 2 and fall within the range of variation of Group 1G only after clay preparation. Thus, Group 1G may be the result of clay preparation (i.e., the removal of larger particles).

No clay is matched to Group 1VM, but this group is likely to be the Mt. Trumbull local group used exclusively for domestic purpose because only olivine-tempered ceramics found in Mt. Trumbull are included in this group. The higher frequency of corrugated wares in this group suggests that the use of this clay may date late during the occupational sequence.

Group 2 is another Mt. Trumbull local group mostly used for utilitarian wares. Data from 20 clays (15 sources) from Mt. Trumbull fall within the range of variation of this group with high probabilities. The best matched clays are found near the area where many archaeological sites are concentrated, suggesting that the clay used for the ceramics in this group was used in its natural state without further preparation. The ceramics in Group 2 also appear to have been transported to the lowland Virgin area.

The chemical signature of Group 3 is very different from that of any other compositional group, and it also differs from the raw clays in the data set. Group 3 is too small for Mahalanobis distance comparison of clays to the group, but it is likely to be a Mt. Trumbull local group, considering that all ceramics in this group are from Mt. Trumbull, especially from one particular site: 71 ASM.

Group 1VV is the lowland Virgin local group and includes both utilitarian and non-utilitarian wares that were used for domestic and trading purposes. Three clays from the lowland Virgin area fall within the range of variation of Group 1VV. Although the proportion of sand-tempered ceramics in this group is much larger than that in any other group, this group also includes olivine-tempered specimens.

The small size of Group 4 did not allow for a Mahalanobis distance-based comparison of clays to this group. However, bivariate plots of canonical discriminant function scores show that no clays fall within the range of variation of this group. Considering that Group 4 includes only olivine-tempered ceramics that are mostly from the lowland Virgin area, Group 4 is likely to be a lowland Virgin local group. As discussed later in this chapter, Group 4 may represent the result of clay resource specialization exclusively for the production of olivine-tempered ceramics.

VR3 is the lowland Virgin local group used for both utilitarian and non-utilitarian wares with sand temper. Clays from the lowland Virgin area are matched to this group in the INAA study. Some VR3 ceramics were moved to Mt. Trumbull (only red ware).

VR1 includes mostly sand-tempered black-on-gray sherds found in both Mt. Trumbull and the lowland Virgin area. This group could not be matched to clays from either of these areas. Therefore, the source of VR1 is unknown but may lie outside of Mt. Trumbull and the lowland Virgin area. It is proposed that Mt. Trumbull and the lowland Virgin regions had a common trading partner that distributed the VR1 black-on-gray pots.

In order to understand what these compositional groups represent, the relationship between compositional groups, formal attributes, and proveniences are examined in what follows.

Compositional Groups and Provenience

As a first step in examining the relationship between compositional groups and provenience, I explored whether specimens from particular regions dominate any of the compositional groups (Figure 6.1 and Table 6.1). This examination showed that: (1) Groups 3 and 1VM include only Mt. Trumbull/Tuweep sherds, and (2) Groups 1G and 2 predominately include sherds from Mt. Trumbull/Tuweep, while VR1, VR3, Group 4, and Group 1VV predominately include sherds from the lowland Virgin area. Thus, some of the compositional groups have a strong association with specific regions.

Second, I examined whether any compositional group dominates in the sherd assemblage within each region. The results show that the compositional groups are not equally represented in the sherd assemblages of different regions. Among the sherds from Mt. Trumbull/Tuweep, at least 50 percent are included in Groups 1 and 2, which are produced locally, and at least seven percent of sherds are from the lowland Virgin production centers (Group 1VV; Figure 6.2). On the other hand,

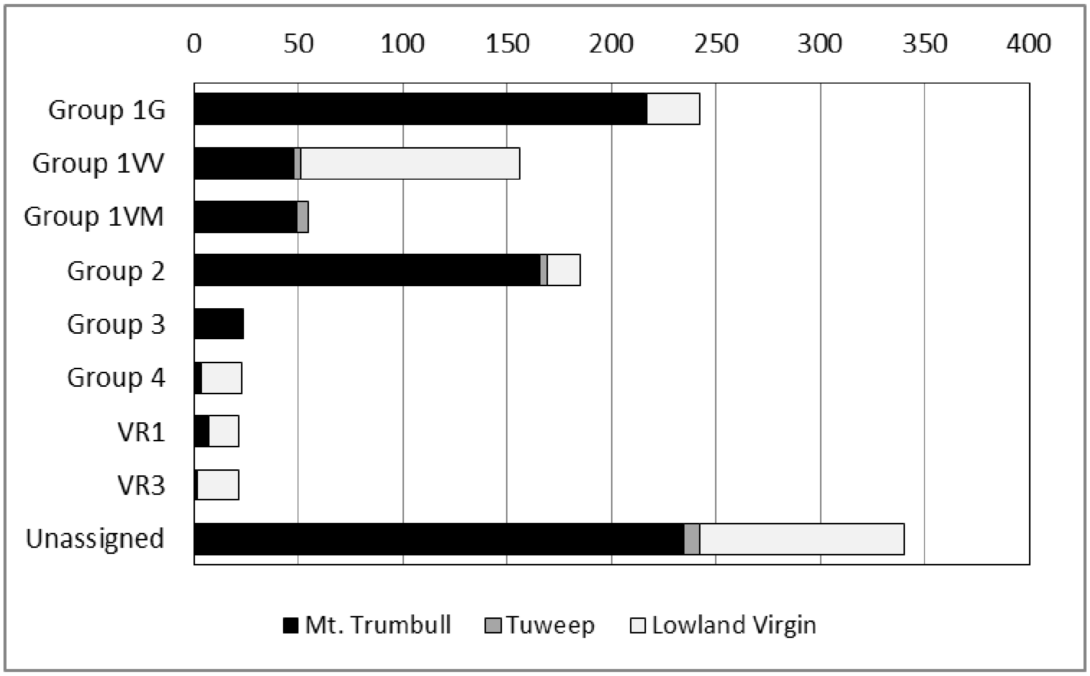


Figure 6.1. Frequency of all sherds from Mt. Trumbull/Tuweep and the lowland Virgin area by compositional group and provenience.

Table 6.1. Frequency of all sherds from Mt. Trumbull,/Tuweep and the lowland Virgin area by compositional group and provenience.

Group	Mt. Trumbull	Tuweep	Lowland Virgin	Total
Group 1G	216	1	25	242
Group 1VV	48	3	105	156
Group 1VM	49	6	0	55
Group 2	166	3	16	185
Group 3	24	0	0	24
Group 4	4	0	19	23
VR1	7	0	15	22
VR3	2	0	20	22
Unassigned	235	7	98	340
Total	751	20	298	1069

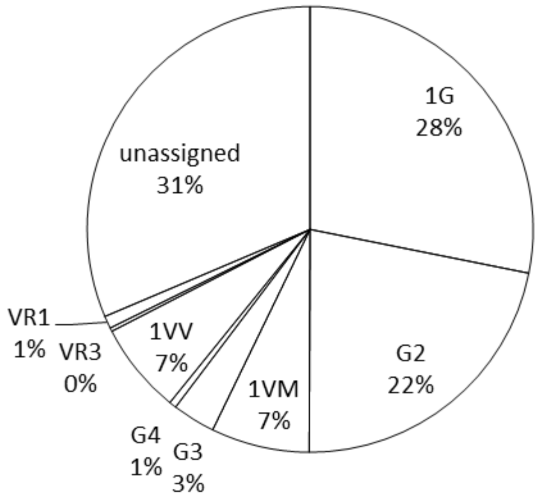


Figure 6.2. Percentage of Mt. Trumbull/Tuweep sherds by compositional group (n = 771).

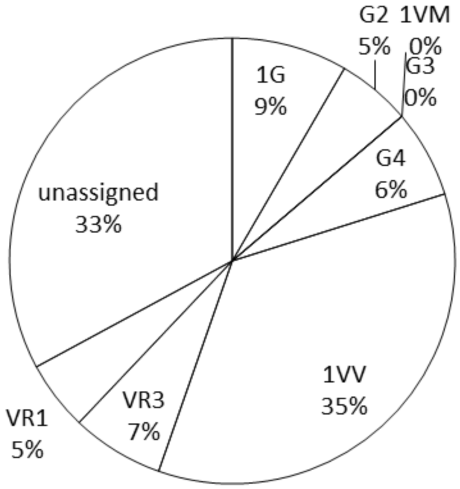


Figure 6.3. Percentage of lowland Virgin sherds by compositional group (n = 297).

among the sherds from the lowland Virgin area, at least 42 percent come from local production centers (Groups 1VV and VR3; Figure 6.3), while at least 14 percent are from Mt. Trumbull/Tuweep (Groups 1 and 2; Figure 6.3). Although not all compositional groups are confidently matched to sources, these results indicate that at least 40 percent of the sherds are from local production centers in the Mt. Trumbull/Tuweep and lowland Virgin areas. This result shows that the people in Mt. Trumbull/Tuweep and the lowland Virgin areas depended on their own pottery production to a large degree, while also importing pots from outside the respective regions.

Compositional Groups and Sites

The association of compositional groups and provenience at the site level was also examined. Since relatively small numbers of samples came from each site in the lowland Virgin area and Tuweep, samples from the lowland Virgin area were grouped together as “lowland Virgin”, and samples from Tuweep were grouped as “Tuweep” for this examination. In the Mt. Trumbull area, where more ceramics from each site were analyzed, the distribution of compositional groups across the Mt. Trumbull sites (131 BLM, 204 BLMA, 30 BLM, 136ASM, 71 ASM, 214 ASM, and 14 MNA) is examined.

As shown in Table 6.2 and Figures 6.4–6.5, there is some association between the compositional groups and sites. First, Group 1G has a relatively strong association with the 131 BLM site and a weak association with the 214 ASM site

Table 6.2. Frequency of all sherds from Mt. Trumbull/Tuweep and lowland Virgin area by compositional group and site.

Site name	131BLM	136ASM	14MNA	204BLM	214ASM	30BLM	71ASM	Tuweep	Lowland Virgin	Total
Region	MT	MT	MT	MT	MT	MT	MT	Tuweep	Lowland Virgin	
Group1G	94	22	50	6	1	39	4	1	25	242
Group1VV	18	9	4	2	5	8	2	3	105	156
Group1VM	3	13	1	7	5	12	8	6	0	55
Group2	15	47	39	19	9	25	12	3	16	185
Group3	0	0	0	2	0	3	19	0	0	24
Group4	0	0	1	0	0	0	3	0	19	23
VR1	3	0	1	0	0	3	0	0	15	22
VR3	0	0	1	0	0	1	0	0	20	22
Unassigned	26	54	45	15	16	57	22	7	98	340
Total	159	145	142	51	36	148	70	20	298	1069

MT: Mt. Trumbull

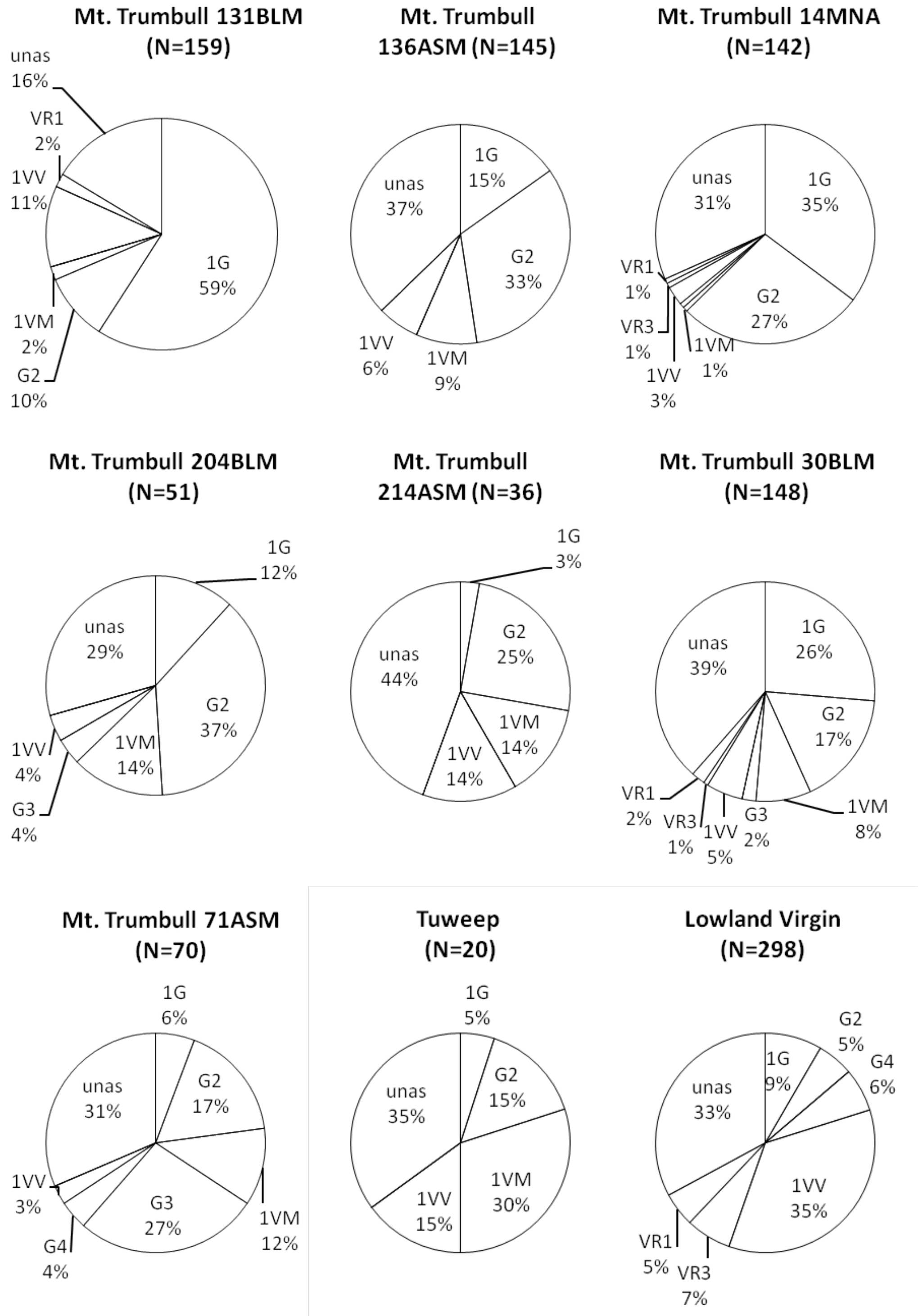


Figure 6.4. Percentage of all sherds by compositional group from sites where ceramic samples were obtained, within the Mt. Trumbull, Tuweep, and lowland Virgin areas. All sites in Tuweep and the lowland Virgin area are grouped as Tuweep and the lowland Virgin, respectively.

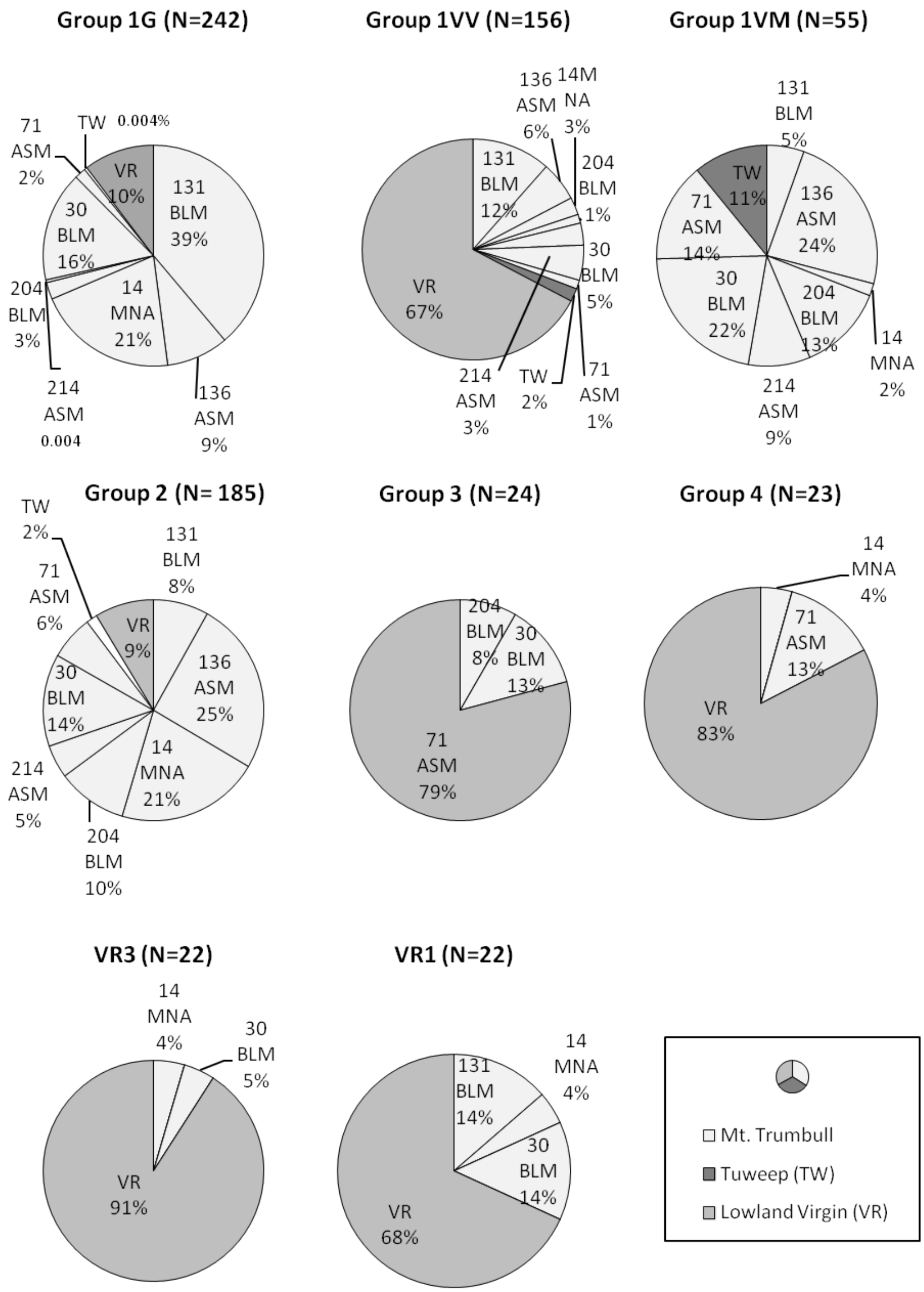


Figure 6.5. Percentage of all sherds within each compositional group by the site where ceramic samples were obtained, within Mt. Trumbull, Tuweep and lowland Virgin areas. All sites in Tuweep and the lowland Virgin area are grouped as Tuweep and the lowland Virgin, respectively.

based on percentage of sherds by compositional group within each site (Figure 6.4). Group 1G is the Mt. Trumbull local group, so a relatively high proportion of Group 1G specimens is expected at all Mt. Trumbull sites. However, Group 1G is represented by only a single sherd at the Mt. Trumbull site of 214 ASM. In contrast there is a greater-than expected representation of Group 1G at 131 BLM site: almost 39 percent of the Group 1G sherds are from the 131 BLM site (Figure 6.5), while 59 percent of the sherds from this site belong in Group 1G (Figure 6.4).

Second, there is a strong association between Group 3 and the 71 ASM site. Seventy-nine percent of Group 3 sherds are from the 71 ASM site (Figure 6.5), and 27 percent of the sherds from the 71 ASM site belong to Group 3 (Figure 6.4). This suggests that the 71 ASM site could be a production center of Group 3 pots, while residents at the site also imported pots from other sources. Unfortunately, however, no clay is matched to the 71 ASM site despite the fact that some clay samples were collected directly from the 71 ASM site.

The chemical signatures of Group 3 sherds are very different from those in any other compositional group or clay in the data set. Thus, it is possible that specialized potters produced Group 3 pots at or near the 71 ASM site using a special clay that I could not find or a special paste recipe/preparation. It is also possible that Group 3 is the result of chemical alteration, i.e., diagenesis. Because the 71 ASM site is the only site located on the limestone formation (other sites are on volcanic formations), there is a possibility of chemical alterations that did not occur in any other area. However, the examination of chemical alteration discussed later in this chapter does not show any evidence of diagenesis. Furthermore, only 27 percent of the sherds from the 71 ASM site belong to Group 3 (Figure 6.4), which argues against the possibility that local diagenesis produced the distinctive Group 3 chemical signature. That is, if chemical alteration occurred in the 71 ASM site, Group 3 sherds and all other sherds from 71ASM would be affected by diagenesis, which is not shown in the analysis. The other possibility is that Group 3 is a non-local group distributed only to a few sites in Mt. Trumbull (mainly the 71 ASM site). However, this possibility seems unlikely because most of the sherds have olivine temper, as will be discussed later in the section of compositional groups and temper. Thus, it is likely that Group 3 is a Mt. Trumbull local group.

Lastly, there is a strong association between Group 4 and the lowland Virgin sites. Eighty-three percent of Group 4 samples are from the lowland Virgin area (Figure 6.5). Only four of 23 Group 4 samples are from Mt. Trumbull, three of which come from the 71 ASM site (Table 6.2). I hypothesize that Group 4 is a lowland Virgin local group. The other possibility is that Group 4 is a Mt. Trumbull local group that was exclusively used for trading purposes. However, examination of compositional groups and surface treatments discussed later in this chapter demonstrates that Group 4 includes a relatively high proportion of utilitarian ware and small amount of decorated wares for trading purpose (Table 6.3). This implies that the latter proposal that Group 4 is a Mt. Trumbull local group for trading purposes should be rejected. Thus, Group 4 is likely a lowland Virgin local group.

No significant differences were found in the distribution of compositional groups between the Mt. Trumbull and Tuweep sherd assemblages. This makes sense because these two localities are in very close proximity and the archaeological sites are continuously distributed between the Mt. Trumbull and Tuweep site concentration areas. Therefore, the samples from both Mt. Trumbull and Tuweep are grouped as samples from Mt. Trumbull/Tuweep, or simply the Mt. Trumbull area, in the following analysis.

Compositional Groups and Surface Treatments

Examination of the compositional groups and surface treatments of the sherds also shows some degree of correlation (Tables 6.3–6.8 and Figures 6.6–6.7). Group 1G includes both utilitarian (plain and corrugated) ware and black-on-gray ware. Group 1VM also includes both utilitarian and black-on-gray wares. The proportion of corrugated ware among all of the ceramic types in Group 1VM, at 27 percent, is higher than that in any other group (Table 6.4). Group 1VV includes utilitarian (plain and corrugated), black-on-gray, and red ware. Group 2 includes mostly utilitarian wares (plain and corrugated), the proportion being very high (86 percent plain ware and 11 percent corrugated ware) when compared with other groups (Table 6.4, Figure 6.7). Groups 3 and 4 both include utilitarian ware (mostly plain ware and limited corrugated ware) and black-on-gray ware. Compositional group VR3 includes utilitarian (plain and corrugated), black-on-gray, and red ware. In the Mt. Trumbull sherd assemblage, only two sherds fall in Group VR3, but they

Table 6.3. Frequency and all sherds from Mt.Trumbull/Tuweep and the lowland Virgin area by compositional group and surface treatment, and percentage of the sherds within type of surface treatment by compositional group.

Group	Plain		Corrugated		Black-on-gray		Red		Polychrome		Total	
Group 1G	**161**	23%	**46**	29%	**35**	20%	**0**	0%	**0**	0%	**242**	23%
Group 1VV	**99**	14%	**11**	7%	**42**	24%	**4**	21%	**0**	0%	**156**	15%
Group 1VM	**32**	4%	**15**	9%	**8**	5%	**0**	0%	**0**	0%	**55**	5%
Group 2	**160**	22%	**20**	12%	**5**	3%	**0**	0%	**0**	0%	**185**	17%
Group 3	**18**	3%	**1**	1%	**5**	3%	**0**	0%	**0**	0%	**24**	2%
Group 4	**18**	3%	**1**	1%	**4**	2%	**0**	0%	**0**	0%	**23**	2%
VR1	**2**	0.3%	**0**	0%	**20**	12%	**0**	0%	**0**	0%	**22**	2%
VR3	**12**	2%	**3**	2%	**2**	1%	**5**	26%	**0**	0%	**22**	2%
Unassigned	**212**	30%	**64**	40%	**51**	30%	**10**	53%	**3**	100%	**340**	32%
Total	**714**	100%	**161**	100%	**172**	100%	**19**	100%	**3**	100%	**1069**	100%

Table 6.4. Frequency of all sherds from Mt. Trumbull/Tuweep and the lowland Virgin area by compositional group and surface treatment, and percentage of the sherds within the compositional group by surface treatment.

Group	Plain		Corrugated		Black-on-gray		Red		Polychrome		Total	
Group 1G	**161**	67%	**46**	19%	**35**	14%	**0**	0%	**0**	0%	**242**	100%
Group 1VV	**99**	63%	**11**	7%	**42**	27%	**4**	3%	**0**	0%	**156**	100%
Group 1VM	**32**	58%	**15**	27%	**8**	15%	**0**	0%	**0**	0%	**55**	100%
Group 2	**160**	86%	**20**	11%	**5**	3%	**0**	0%	**0**	0%	**185**	100%
Group 3	**18**	75%	**1**	4%	**5**	21%	**0**	0%	**0**	0%	**24**	100%
Group 4	**18**	78%	**1**	4%	**4**	17%	**0**	0%	**0**	0%	**23**	100%
VR1	**2**	9%	**0**	0%	**20**	91%	**0**	0%	**0**	0%	**22**	100%
VR3	**12**	55%	**3**	14%	**2**	9%	**5**	23%	**0**	0%	**22**	100%
Unassigned	**212**	62%	**64**	19%	**51**	15%	**10**	3%	**3**	1%	**340**	100%
Total	**714**	67%	**161**	15%	**172**	16%	**19**	2%	**3**	0%	**1069**	100%

Table 6.5. Frequency of Mt. Trumbull/Tuweep sherds by compositional group and surface treatment, and percentage of the sherds within the type of surface treatment by compositional group.

Group	Plain		Corrugated		Black-on-gray		Red		Polychrome		Total	
Group 1G	**141**	28%	**45**	30%	**31**	30%	**0**	0%	**0**	0%	**217**	28%
Group 1VV	**31**	6%	**4**	3%	**13**	13%	**3**	20%	**0**	0%	**51**	7%
Group 1VM	**32**	6%	**15**	10%	**8**	8%	**0**	0%	**0**	0%	**55**	7%
Group 2	**144**	29%	**20**	13%	**5**	5%	**0**	0%	**0**	0%	**169**	22%
Group 3	**18**	4%	**1**	1%	**5**	5%	**0**	0%	**0**	0%	**24**	3%
Group 4	**3**	1%	**1**	1%	**0**	0%	**0**	0%	**0**	0%	**4**	1%
VR1	**1**	0%	**0**	0%	**6**	6%	**0**	0%	**0**	0%	**7**	1%
VR3	**0**	0%	**0**	0%	**0**	0%	**2**	13%	**0**	0%	**2**	0%
Unassigned	**131**	26%	**64**	43%	**34**	33%	**10**	67%	**3**	100%	**242**	31%
Total	**501**	100%	**150**	100%	**102**	100%	**15**	100%	**3**	100%	**771**	100%

Table 6.6. Frequency of Mt. Trumbull/Tuweep sherds by compositional group and surface treatment, and percentage of the sherds within the compositional group by surface treatment.

Group	Plain		Corrugated		Black-on-gray		Red		Polychrome		Total	
Group 1G	**141**	65%	**45**	21%	**31**	14%	**0**	0%	**0**	0%	**217**	100%
Group 1VV	**31**	61%	**4**	8%	**13**	25%	**3**	6%	**0**	0%	**51**	100%
Group 1VM	**32**	58%	**15**	27%	**8**	15%	**0**	0%	**0**	0%	**55**	100%
Group 2	**144**	85%	**20**	12%	**5**	3%	**0**	0%	**0**	0%	**169**	100%
Group 3	**18**	75%	**1**	4%	**5**	21%	**0**	0%	**0**	0%	**24**	100%
Group 4	**3**	75%	**1**	25%	**0**	0%	**0**	0%	**0**	0%	**4**	100%
VR1	**1**	14%	**0**	0%	**6**	86%	**0**	0%	**0**	0%	**7**	100%
VR3	**0**	0%	**0**	0%	**0**	0%	**2**	100%	**0**	0%	**2**	100%
Unassigned	**131**	54%	**64**	26%	**34**	14%	**10**	4%	**3**	1%	**242**	100%
Total	**501**	65%	**150**	19%	**102**	13%	**15**	2%	**3**	0%	**771**	100%

Table 6.7. Frequency of lowland Virgin sherds by compositional group and surface treatment, and percentage of the sherds within the type of surface treatment by compositional group.

Group	Plain		Corrugated		Black-on-gray		Red		Polychrome		Total	
Group 1G	**20**	9%	**1**	9%	**4**	6%	**0**	0%	**0**	0%	**25**	8%
Group 1VV	**66**	31%	**7**	64%	**29**	41%	**3**	50%	**0**	0%	**105**	35%
Group 1VM	**0**	0%	**0**	0%	**0**	0%	**0**	0%	**0**	0%	**0**	0%
Group 2	**16**	8%	**0**	0%	**0**	0%	**0**	0%	**0**	0%	**16**	5%
Group 3	**0**	0%	**0**	0%	**0**	0%	**0**	0%	**0**	0%	**0**	0%
Group 4	**15**	7%	**0**	0%	**4**	6%	**0**	0%	**0**	0%	**19**	6%
VR1	**1**	0%	**0**	0%	**14**	20%	**0**	0%	**0**	0%	**15**	5%
VR3	**12**	6%	**3**	27%	**2**	3%	**3**	50%	**0**	0%	**20**	7%
Unassigned	**81**	38%	**0**	0%	**17**	24%	**0**	0%	**0**	0%	**98**	33%
Total	**211**	100%	**11**	100%	**70**	100%	**6**	100%	**0**	0%	**298**	100%

Table 6.8. Frequency of lowland Virgin sherds by compositional group and surface treatment, and percentage of the sherds within the compositional group by surface treatment.

Group	Plain		Corrugated		Black-on-gray		Red		polychrome		Total	
Group 1G	**20**	80%	**1**	4%	**4**	16%	**0**	0%	**0**	0%	**25**	100%
Group 1VV	**66**	63%	**7**	7%	**29**	28%	**3**	3%	**0**	0%	**105**	100%
Group 1VM	**0**	NA	**0**	NA	**0**	NA	**0**	NA	**0**	NA	**0**	NA
Group 2	**16**	100%	**0**	0%	**0**	0%	**0**	0%	**0**	0%	**16**	100%
Group 3	**0**	NA	**0**	NA	**0**	NA	**0**	NA	**0**	NA	**0**	NA
Group 4	**15**	79%	**0**	0%	**4**	21%	**0**	0%	**0**	0%	**19**	100%
VR1	**1**	7%	**0**	0%	**14**	93%	**0**	0%	**0**	0%	**15**	100%
VR3	**12**	60%	**3**	15%	**2**	10%	**3**	15%	**0**	0%	**20**	100%
Unassigned	**81**	83%	**0**	0%	**17**	17%	**0**	0%	**0**	0%	**98**	100%
Total	**211**	71%	**11**	4%	**70**	23%	**6**	2%	**0**	0%	**298**	100%

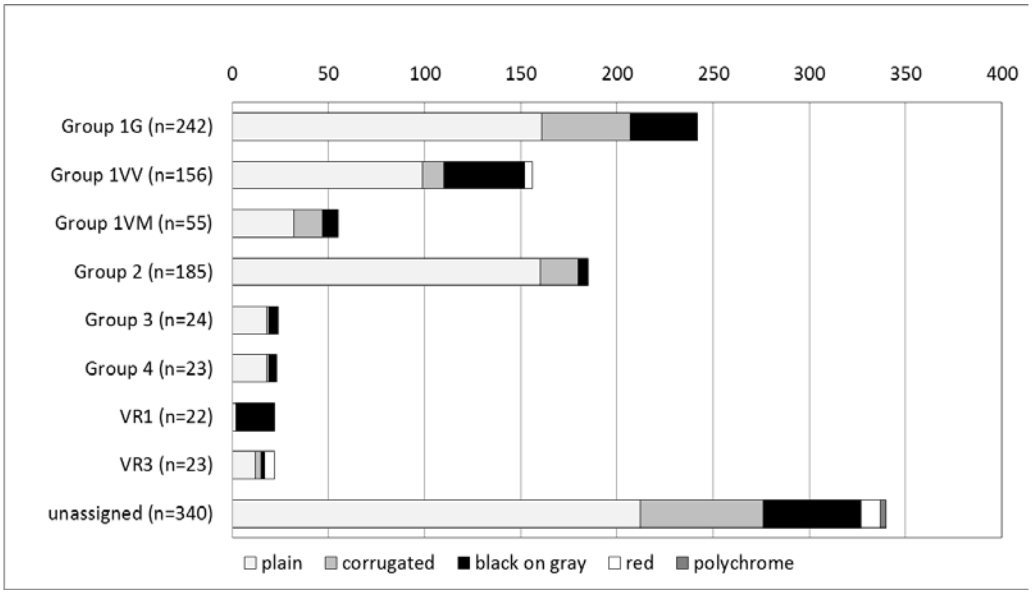


Figure 6.6. Frequency of all sherds from Mt. Trumbull/Tuweep and the lowland Virgin area by compositional group and surface treatment.

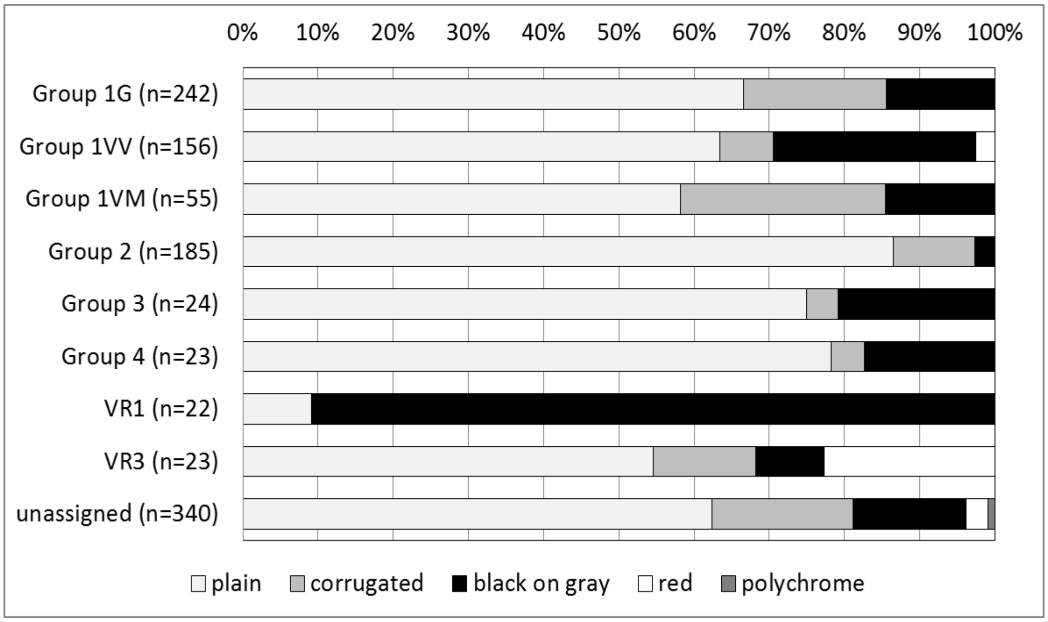


Figure 6.7. Percentage of all sherds from Mt. Trumbull/Tuweep and the lowland Virgin area by compositional group.

are both red ware (Table 6.6). In other words, VR3 pots were used for both domestic and trading purposes, but only the red ware in this group was transported to Mt. Trumbull. VR1 includes mostly black-on-gray ware, including 20 out of the 22 VR1 sherds (Table 6.4).

Groups 1VV and VR3 are the only compositional groups that include red ware, with nine of the 19 red ware sherds analyzed (Table 6.3). The remaining red ware sherds (10 out of 19) are not assigned to any compositional group in the data set. This unassigned proportion of the red ware (53 percent) is higher than that of any other ceramic types (Table 6.3), which probably indicates that there are red ware sources other than the lowland Virgin and Mt. Trumbull areas. No red wares are in the Mt. Trumbull local groups. In the Mt. Trumbull red ware assemblage, five red ware sherds are in the lowland Virgin local group, leaving 10 red ware sherds unassigned (Table 6.5). In the lowland Virgin red ware assemblage, on the other hand, all six specimens belong to lowland Virgin local groups, Group 1VV and VR3 (Table 6.7). In summary, this examination of compositional groups and red ware demonstrates that: (1) all red ware is non-local to Mt. Trumbull, and some of it derives from the lowland Virgin area; (2) all of the red ware in the lowland Virgin area was made locally, which confirms the results of the INAA study of lowland Virgin pottery (Larson et al. 2005); and (3) some of the red ware found in the Mt. Trumbull area was not produced either in Mt. Trumbull or in the lowland Virgin area.

Black-on-gray pots were produced in both Mt. Trumbull and the lowland Virgin area, and they seem to have been exchanged between the two areas. In Mt. Trumbull/Tuweep, at least 36 sherds of the 102 black-on-gray sherds are from locally made pots (Groups 1G and G2), and at least 13 sherds were from pots made in the lowland Virgin area (Group 1VV) (Table 6.5). In the lowland Virgin area, 31 black-on-gray sherds of the 70 are from locally made pots (Group 1VV and VR3), and four sherds were from Mt. Trumbull pots (Table 6.7).

Compositional group VR1, a non-local group in both Mt. Trumbull and the lowland Virgin areas, includes mostly black-on-gray ware sherds found in both areas. This suggests that people in the Mt. Trumbull/Tuweep and lowland Virgin areas had a common trading partner that distributed the VR1 black-on-gray ware. An alternative view is that either the Mt. Trumbull/Tuweep or Lowland Virgin people imported the VR1 black-on-gray pots from an unknown area and then exported them to the other area (Mt. Trumbull or Lowland Virgin) through down-the-line trading. Interestingly, more VR1 type black-on-gray pots were transported to the lowland Virgin area than to Mt. Trumbull (20 percent of all black-on-gray samples belong to VR1 in the lowland Virgin area, while 6 percent belong to VR1 in Mt. Trumbull) (Tables 6.5 and 6.7).

All polychrome wares are unassigned, suggesting that no polychrome pottery was made in either the Mt. Trumbull or lowland Virgin areas. These results support the traditional argument that the source of polychrome is from outside the Mt. Trumbull and lowland Virgin areas.

Compositional Groups and Temper Types

The results show some associations between compositional groups and temper types (Figures 6.8-6.9 and Tables 6.9-6.14). As discussed in Chapter III, the temper types are categorized as follows: (1) olivine temper—predominately olivine but occasionally containing crushed sherds as well; (2) sherd temper (olivine)—crushed Moapa Gray ware sherds including olivine particles, that is, the sherd temper itself has olivine inclusions; and (3) sand temper or crushed sherd temper (without olivine).

The associations between temper types and compositional groups can be summarized as follows. Groups 1VM and 4 include only olivine temper, with the exception of one sample with sherd temper (without olivine) in Group 1VM (Table 6.10). As discussed above, Group 1VM includes only samples from Mt. Trumbull, and it is likely that Group 1VM is the Mt. Trumbull local group because all sherds have olivine temper. Olivine is the dominant temper type in Groups 1G, 2, and 3 (Table 6.10). VR1 and VR3 include only sand/sherd (without olivine) temper. There is a relatively high frequency of sand or sherd (without olivine) temper in the specimens in Group 1VV (Table 6.10). The sherd temper (olivine) samples are mostly found in Group 2 or are unassigned (Table 6.9).

I also examined the relation between compositional groups and temper types within each area (Mt. Trumbull/Tuweep and the lowland Virgin areas). In Mt.

Trumbull/Tuweep, most of the olivine-tempered ceramics were from local production (Groups 1G, 1VM, 2, and 3), which was expected because Mt.

Table 6.9. Frequency of all sherds from Mt. Trumbull/Tuweep and the lowland Virgin area by compositional group and temper, and percentage of the sherds within the temper type by compositional groups.

Group	Olivine		Sherd (olivine)		Sand or Sherd (no olivine)		Total	
Group 1G	**226**	28%	**4**	9%	**12**	6%	**242**	23%
Group 1VV	**88**	11%	**0**	0%	**68**	33%	**156**	15%
Group 1VM	**55**	7%	**0**	0%	**0**	0%	**55**	5%
Group 2	**150**	18%	**28**	60%	**7**	3%	**185**	17%
Group 3	**21**	3%	**0**	0%	**3**	1%	**24**	2%
Group 4	**23**	3%	**0**	0%	**0**	0%	**23**	2%
VR1	**0**	0%	**0**	0%	**22**	11%	**22**	2%
VR3	**0**	0%	**0**	0%	**22**	11%	**22**	2%
Unassigned	**256**	31%	**15**	32%	**69**	34%	**340**	32%
Total	**819**	100%	**47**	100%	**203**	100%	**1069**	100%

Table 6.10. Frequency of all sherds from Mt. Trumbull/Tuweep and the lowland Virgin area by compositional group and temper, and percentage of the sherds within the compositional group by temper types.

Group	Olivine		Sherd (olivine)		Sand or Sherd (no olivine)		Total	
Group 1G	**226**	93%	**4**	2%	**12**	5%	**242**	100%
Group 1VV	**88**	56%	**0**	0%	**68**	44%	**156**	100%
Group 1VM	**55**	100%	**0**	0%	**0**	0%	**55**	100%
Group 2	**150**	81%	**28**	15%	**7**	4%	**185**	100%
Group 3	**21**	88%	**0**	0%	**3**	13%	**24**	100%
Group 4	**23**	100%	**0**	0%	**0**	0%	**23**	100%
VR1	**0**	0%	**0**	0%	**22**	100%	**22**	100%
VR3	**0**	0%	**0**	0%	**22**	100%	**22**	100%
Unassigned	**256**	75%	**15**	4%	**69**	20%	**340**	100%
Total	**819**	77%	**47**	4%	**203**	19%	**1069**	100%

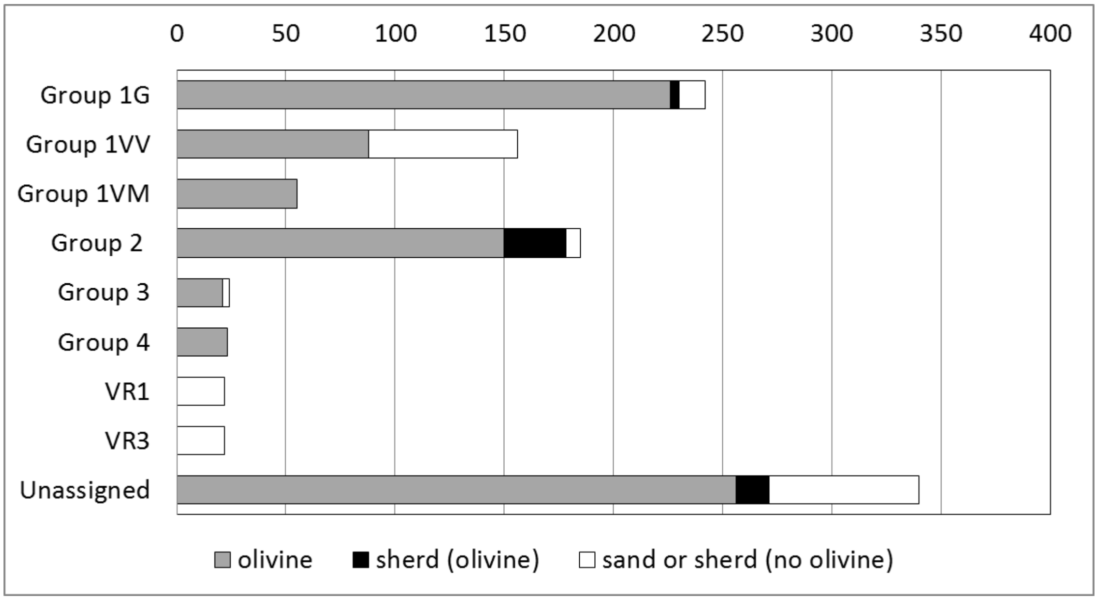


Figure 6.8. Frequency of all sherds from Mt. Trumbull/Tuweep and lowland Virgin area by compositional group and temper.

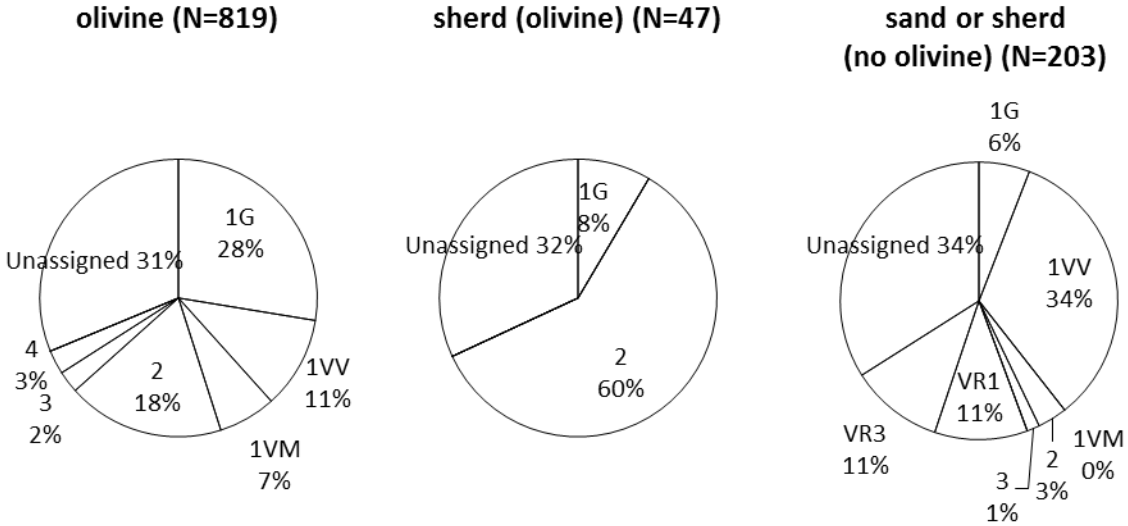


Figure 6.9. Percentage of all sherds within temper types from all areas by compositional groups.

Trumbull/Tuweep is an olivine source area. Only a few olivine-tempered sherds (at least five sherds in Group 1VV, one percent) from Mt. Trumbull have lowland Virgin origin (Table 6.11). The majority of samples tempered with crushed sherd (olivine) are in Group 2, suggesting that the sherd (olivine) tempered pots (most of them are Shivwits ware to be discussed later) are likely to have come from local production in Mt. Trumbull/Tuweep. At least 13 percent of sand-tempered sherds are from local production in Mt. Trumbull (Groups 1G and 2), while at least 35 percent of the sand-tempered sherds are from the lowland Virgin area (Group 1VV and VR3), and 5 percent are from the unknown VR1 area (Table 6.11). This suggests that more sand-tempered pots were imported than produced locally in Mt. Trumbull.

In the lowland Virgin area, olivine-tempered pots were imported from Mt. Trumbull, as suggested in previous research, but they were also made locally in the lowland Virgin area. The lowland Virgin olivine-tempered sherds are in Groups 1VV, 1G, 2, and 4. At least 83 of the 219 lowland Virgin olivine-tempered sherds belong to the lowland Virgin local group (Group 1VV), and 40 sherds belong to the Mt. Trumbull local group (Groups 1G and 2) (Table 6.13). Consequently, at least 38 percent (Group 1VV) of the lowland Virgin olivine-tempered pots were made locally, and at least 18 percent were transported from Mt. Trumbull (Groups 1G and 2) (Table 6.13). The source of Group 4 is unknown at this point (although likely to be in the lowland Virgin area). It is possible that more olivine-tempered pots were made locally in the lowland Virgin area than were imported from Mt. Trumbull.

Table 6.11 Frequency of Mt. Trumbull/Tuweep sherds by compositional group and temper, and percentage of the sherds within the temper type by compositional groups.

Group	Olivine		Sherd (olivine)		Sand or Sherds (no olivine)		Total	
Group 1G	**201**	34%	**4**	11%	**12**	9%	**217**	28%
Group 1VV	**5**	1%	**0**	0%	**46**	34%	**51**	7%
Group 1VM	**55**	9%	**0**	0%	**0**	0%	**55**	7%
Group 2	**135**	23%	**28**	76%	**6**	4%	**169**	22%
Group 3	**21**	4%	**0**	0%	**3**	2%	**24**	3%
Group 4	**4**	1%	**0**	0%	**0**	0%	**4**	1%
VR1	**0**	0%	**0**	0%	**7**	5%	**7**	1%
VR3	**0**	0%	**0**	0%	**2**	1%	**2**	0%
Unassigned	**179**	30%	**8**	14%	**58**	43%	**242**	31%
Total	**600**	100%	**37**	100%	**134**	100%	**771**	100%

Table 6.12. Frequency of Mt. Trumbull/Tuweep sherds by compositional group and temper, and percentage of the sherds within the compositional group by temper types.

Group	Olivine		Sherd (olivine)		Sand or Sherds (no olivine)		Total	
Group 1G	**201**	93%	**4**	2%	**12**	6%	**217**	100%
Group 1VV	**5**	10%	**0**	0%	**46**	90%	**51**	100%
Group 1VM	**55**	100%	**0**	0%	**0**	0%	**55**	100%
Group 2	**139**	80%	**28**	17%	**6**	4%	**169**	100%
Group 3	**21**	88%	**0**	0%	**3**	13%	**24**	100%
Group 4	**4**	100%	**0**	0%	**0**	0%	**4**	100%
VR1	**0**	0%	**0**	0%	**7**	100%	**7**	100%
VR3	**0**	0%	**0**	0%	**2**	100%	**2**	100%
Unassigned	**179**	74%	**5**	2%	**58**	24%	**242**	100%
Total	**600**	78%	**37**	5%	**134**	18%	**771**	100%

Table 6.13. Frequency of lowland Virgin sherds by compositional group and temper, and percentage of the sherds within the temper type by compositional groups.

Group	Olivine		Sherd (olivine)		Sand or Sherds (no olivine)		Total	
Group 1G	**25**	11%	**0**	0%	**0**	0%	**25**	8%
Group 1VV	**83**	38%	**0**	0%	**22**	32%	**105**	35%
Group 1VM	**0**	0%	**0**	0%	**0**	0%	**0**	0%
Group 2	**15**	7%	**0**	0%	**1**	1%	**16**	5%
Group 3	**0**	0%	**0**	0%	**0**	0%	**0**	0%
Group 4	**19**	9%	**0**	0%	**0**	0%	**19**	6%
VR1	**0**	0%	**0**	0%	**15**	22%	**15**	5%
VR3	**0**	0%	**0**	0%	**20**	29%	**20**	7%
Unassigned	**77**	35%	**10**	100%	**11**	16%	**98**	33%
Total	**219**	100%	**10**	100%	**68**	100%	**298**	100%

Table 6.14. Frequency of lowland Virgin sherds by compositional group and temper, and percentage of the sherds within the compositional group by temper types.

Group	Olivine		Sherd (olivine)		Sand or Sherds (no olivine)		Total	
Group 1G	**25**	100%	**0**	0%	**0**	0%	**25**	100%
Group 1VV	**83**	79%	**0**	0%	**22**	21%	**105**	100%
Group 1VM	**0**	NA	**0**	NA	**0**	NA	**0**	NA
Group 2	**15**	94%	**0**	0%	**1**	6%	**16**	100%
Group 3	**0**	NA	**0**	NA	**0**	NA	**0**	NA
Group 4	**19**	100%	**0**	0%	**0**	0%	**19**	100%
VR1	**0**	0%	**0**	0%	**15**	100%	**15**	100%
VR3	**0**	0%	**0**	0%	**20**	100%	**20**	100%
Unassigned	**77**	79%	**10**	10%	**11**	11%	**98**	100%
Total	**219**	73%	**10**	3%	**69**	23%	**298**	100%

Very few sand-tempered pots in the lowland Virgin were transported from Mt. Trumbull; they were either made locally or transported from the VR1 unknown area (Table 6.13). All sherd temper (olivine) samples in the lowland Virgin area are unassigned, which suggests that pots with sherd temper (olivine) were not from local production in the lowland Virgin area. This also suggests that sherd temper (olivine) pots, which are mostly Shivwits Ware (see discussion about Shivwits Ware in Chapter III), in the lowland Virgin area were not from Mt. Trumbull.

Compositional Groups and Core Colors

All cores were examined under a light microscope in the same laboratory conditions to determine relative differences in core color discussed in Chapter V. I used subjective color categories rather than Munsell Soil Color categories. The results of the comparison of compositional groups to core color are shown in Table 6.15 and Figure 6.10. Group 2 sherds have relatively dark cores that may indicate a short firing time. In contrast, sherds in Groups 1VM, 4, and VR1 have cores that are relatively lighter in color, which may indicate longer firing times at higher temperatures. Although no further investigation has been made at this point, core color may indicate different firing techniques. Therefore, it is possible that the compositional groups are somehow related to different production techniques. The general trends of core color in each compositional group are: (1) Group 1G: medium to light core color, (2) Group 1VV: medium to light core color, (3) Group 1VM: light core color, (4) Group 2: darker core color, (5) Group 3: either dark or light core color, (6) Group 4: lighter core color, (7) VR1: light core color, and (8) VR3: medium core color.

Table 6.15. Frequency of all sherds from Mt. Trumbull, Tuweep and the lowland Virgin area by compositional group and core color.

Group	Black	Dark Brown	Brown	Dark Gray	Gray	Medium Gray	Tan	Light Gray	White	Red	Orange	Other	Total
Group 1G	6	0	1	11	27	77	10	103	1	0	5	1	242
Group1VV	1	0	0	21	19	44	0	70	0	0	1	0	156
Group 1VM	1	0	1	2	1	15	1	33	1	0	0	0	55
Group 2	25	1	6	68	55	21	4	3	0	0	2	0	185
Group 3	4	0	0	6	4	0	0	10	0	0	0	0	24
Group 4	0	0	0	0	2	8	0	13	0	0	0	0	23
VR1	0	0	0	1	2	1	0	18	0	0	0	0	22
VR3	0	0	0	1	3	14	4	0	0	0	0	0	22
Unassigned	14	1	1	58	47	82	7	123	1	4	2		340
Total	51	2	9	168	160	262	26	373	3	4	10	1	1069

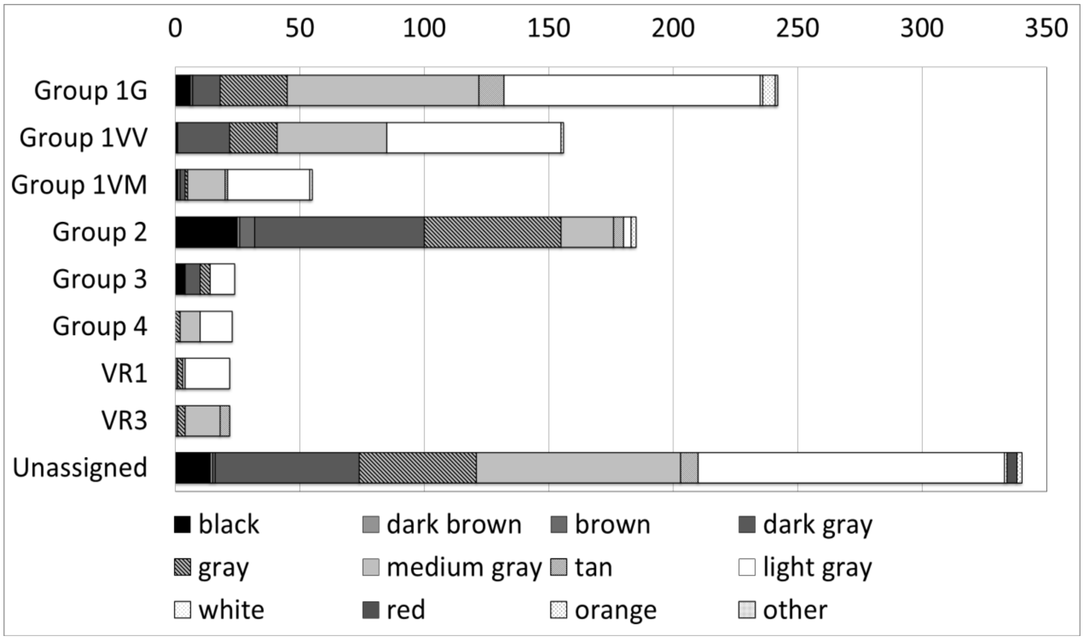


Figure 6.10. Frequency of all sherds from Mt. Trumbull, Tuweep, and the lowland Virgin area by compositional group and core color.

Compositional Groups and Sherd Thickness

The thickness of the sherds was also compared across compositional groups. No significant differences in the thickness of the sherds among the compositional groups were found (Figure 6.11). However, the range of the thickness in VR1 was much smaller compared with other compositional groups. Considering that most of the sherds in VR1 are black-on-gray ware with fine quartz temper and light cores, it is proposed that pots in VR1 were made utilizing a relatively standardized technique.

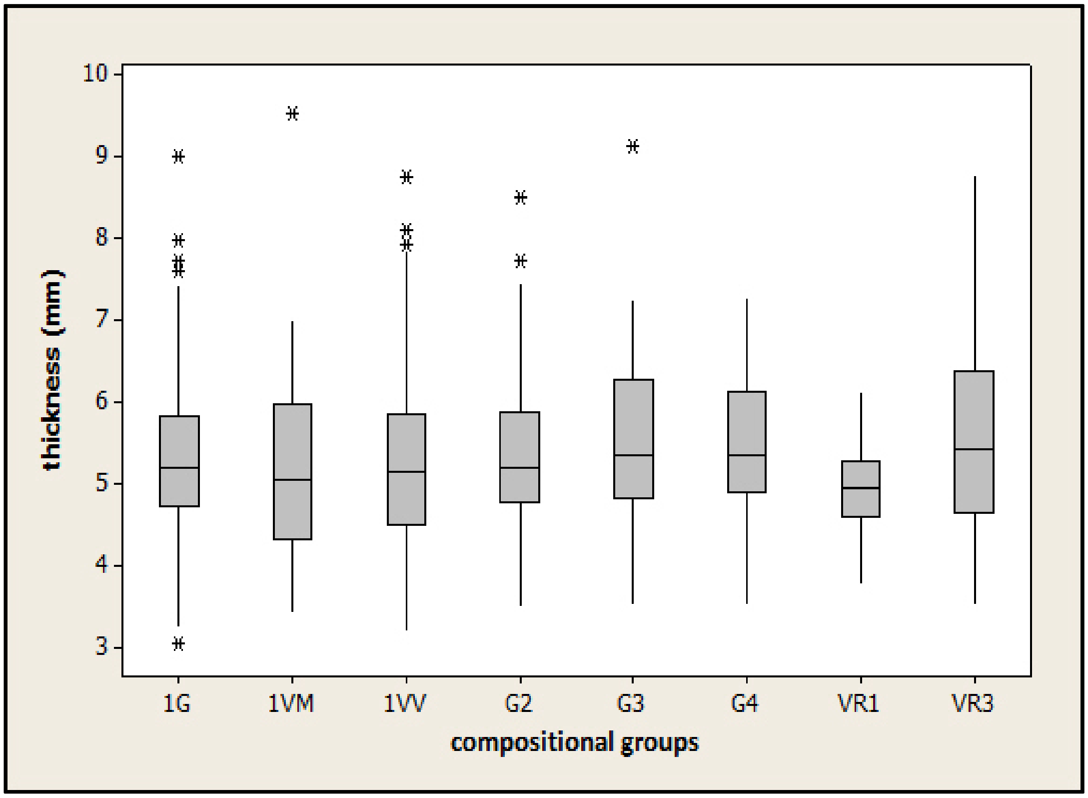


Figure 6.11. Distribution of all sherds based on compositional group and sherd thickness.

Table 6.16. List of ceramic wares and types included in this study.

Description of Ceramics	Type Name	Abbreviation
Olivine-tempered ceramics	Moapa Plain	MP
	Moapa Plain Fugitive Red	MPF
	Moapa Corrugated	MC
	Moapa Black-on-gray	MBG
Sand-tempered ceramics	Tusayan Plain	TP
	Tusayan Plain Fugitive Red	TPF
	Tusayan Corrugated	TC
	Tusayan Black-on-gray	TBC
	Shinarump Pain	SNP
Sherd- tempered (olivine) ceramics with dark clay matrix.	Shivwits Plain	SVP
	Shivwits Corrugated	SVC
Red ware	Tegi Orange Ware	TO
	San Juan Red Ware	SJR
	Shinarump Red Ware	SNR
	Other red ware	RED
Polychrome	Polychrome	POL

Compositional Groups and Ware Type

There is some controversy regarding certain ware/types of ceramics in this study area, as discussed in the previous chapter (e.g., Shinarump wares). The wares, type names, and abbreviations used for the comparison are summarized in Table 6.16.

Moapa Ware

Table 6.17 shows that Moapa Plain Ware occurs in a relatively high frequency in Groups 1G and 2 and that 137 and 140 samples respectively were found in these groups, for a total of 562 Moapa Plain Ware sherds. This was expected because Groups 1G and 2 are major Mt. Trumbull local groups. On the other hand,

Table 6.17. Frequency of all sherds from Mt. Trumbull/Tuweep and the lowland Virgin area by compositional group and ware type.

Ceramic Category		Moapa Ware				Sand Temper				Shivwits Ware		Redware				Poly-chrome
group	Total	MP	MPF	MC	MBG	TP	TC	TBG	SNP	SVP	SVC	TO	SJR	SNR	RED	POL
Group1G	242	137	17	44	32	6	2	3	1	0	0	0	0	0	0	0
Group1VV	156	62	2	4	20	32	7	22	1	0	0	4	0	1	1	0
Group1VM	55	32	0	15	8	0	0	0	0	0	0	0	0	0	0	0
Group2	185	140	1	12	5	5	0	0	2	12	8	0	0	0	0	0
Group3	24	17	0	1	3	1	0	2	0	0	0	0	0	0	0	0
Group4	23	18	0	1	4	0	0	0	0	0	0	0	0	0	0	0
VR1	22	0	0	0	0	2	0	20	0	0	0	0	0	0	0	0
VR3	22	0	0	0	0	12	3	2	0	0	0	0	1	0	4	0
Unassigned	340	156	7	56	38	29	9	13	4	15	0	1	4	3	2	3
Total	1069	562	27	133	110	87	21	62	8	27	8	5	5	4	7	3

MP: Moapa plain, MPF: Moapa plan fugitive red, MC: Moapa corrugated, MBG: Moapa black-on-gray, TP:Tusayan plain, TPF: Tusayan plain fugitive red, TC: Tusayan corrugated, TBG: Tusayan black-on-gray, SNP: Shinarump plain, SVP: Shivwits plain, SVC: Shivwits corrugated, TO: Tegi orange ware, SJR: San Juan red ware, SNR: Shinarump red ware, RED: other red ware, POL: polychrome

Table 6.18. Percentage of all sherds from Mt. Trumbull/Tuweep and the lowland Virgin area within the ware type by compositional group.

Ceramic Category		Moapa Ware %				Sand Temper %				Shivwits Ware %		Redware %				Poly-chrome %
Group	Total	MP	MPF	MC	MBG	TP	TC	TBG	SNP	SVP	SVC	TO	SJR	SNR	RED	POL
Group1G	23	24	63	33	29	7	10	5	13	0	0	0	0	0	0	0
Group1VV	15	11	7	3	18	37	33	35	13	0	0	80	0	25	14	0
Group1VM	5	6	0	11	7	0	0	0	0	0	0	0	0	0	0	0
Group2	17	25	4	9	5	6	0	0	25	44	100	0	0	0	0	0
Group3	2	3	0	1	3	1	0	3	0	0	0	0	0	0	0	0
Group4	2	3	0	1	4	0	0	0	0	0	0	0	0	0	0	0
VR1	2	0	0	0	0	2	0	32	0	0	0	0	0	0	0	0
VR3	2	0	0	0	0	14	14	3	0	0	0	0	20	0	57	0
Unassigned	32	28	26	42	35	33	43	21	50	56	0	20	80	75	29	100
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

MP: Moapa plain, MPF: Moapa plan fugitive red, MC: Moapa corrugated, MBG: Moapa black-on-gray, TP:Tusayan plain, TPF: Tusayan plain fugitive red, TC: Tusayan corrugated, TBG: Tusayan black-on-gray, SNP: Shinarump plain, SVP: Shivwits plain, SVC: Shivwits corrugated, TO: Tegi orange ware, SJR: San Juan red ware, SNR: Shinarump red ware, RED: other red ware, POL: polychrome

Table 6.19. Percentage of all sherds from Mt. Trumbull/Tuweep and the lowland Virgin area within the compositional group by ware type.

Ceramic Category		Moapa Ware %				Sand Temper %				Shivwits Ware %		Redware %				Poly-chrome %
Group	Total	MP	MPF	MC	MBG	TP	TC	TBG	SNP	SVP	SVC	TO	SJR	SNR	RED	POL
Group1G	100	57	7	18	13	2	1	1	0	0	0	0	0	0	0	0
Group1VV	100	40	1	3	13	21	4	14	1	0	0	3	0	1	1	0
Group1VM	100	58	0	27	15	0	0	0	0	0	0	0	0	0	0	0
Group2	100	76	1	6	3	3	0	0	1	6	4	0	0	0	0	0
Group3	100	71	0	4	13	4	0	8	0	0	0	0	0	0	0	0
Group4	100	78	0	4	17	0	0	0	0	0	0	0	0	0	0	0
VR1	100	0	0	0	0	9	0	91	0	0	0	0	0	0	0	0
VR3	100	0	0	0	0	55	14	9	0	0	0	0	5	0	18	0
Unassigned	100	46	2	16	11	9	3	4	1	4	0	0	1	1	1	1
Total	100	53	3	12	10	8	2	6	1	3	1	0	0	0	1	0

MP: Moapa plain, MPF: Moapa plan fugitive red, MC: Moapa corrugated, MBG: Moapa black-on-gray, TP:Tusayan plain, TPF: Tusayan plain fugitive red, TC: Tusayan corrugated, TBG: Tusayan black-on-gray, SNP: Shinarump plain, SVP: Shivwits plain, SVC: Shivwits corrugated, TO: Tegi orange ware, SJR: San Juan red ware, SNR: Shinarump red ware, RED: other red ware, POL: polychrome

Moapa Corrugated Ware, which is another type of Moapa utilitarian ware, is distributed differently within Groups 1G and 2. Only nine percent of all Moapa Corrugated Ware sherds belong to Group 2, but a much higher frequency of Moapa Corrugated Ware sherds belongs to Group 1G (33 percent of all Moapa corrugated ware) (Table 6.18). This suggests that the use of Group 2 clay for pottery production stopped relatively early and that the use of Group 1G clay was continued for a longer period because the use of corrugated ware is thought to begin in the study area about A.D. 1050. Group 2 Moapa Ware sherds from the lowland Virgin area are exclusively plain ware (Table 6.25). This suggests that Group 2 Moapa Plain pots were not transported to the lowland Virgin area as trade items; instead, they accompanied human migration or were containers to transport trading items. This also suggests that Group 2 pots were transported to the lowland Virgin area during early time periods (no lowland Virgin corrugated wares belong to Group 2).

Moapa Black-on-gray ware has a relatively weak association with Group 2 compared with Group 1G (Table 6.18), suggesting that in Mt. Trumbull Group 2 clay was preferred for domestic use and Group 1G for multipurpose use. The source of Group 1VM is not known with confidence at this point (no Mt. Trumbull or lowland Virgin clay is matched this group), but it is likely to have a Mt. Trumbull source because Group 1VM includes only the Mt. Trumbull Moapa ware, as discussed earlier in this chapter.

Table 6.17 shows that Group 1VM clay was used for plain, corrugated, and black-on-gray ware, which suggests that in Mt. Trumbull, Group 1VM is another clay group used for a variety of purposes, like Group 1G. A relatively higher percentage of corrugated ware (among all ceramic types) was found in Group 1VM than in Groups 1G and 2 (Table 6.19). This suggests that the use of Group 1VM clay may be later or that Group 1VM was functionally suitable for corrugated ware production. Moapa Plain Fugitive Red Ware sherds were found in Mt. Trumbull but not in the lowland Virgin area.

Tables 6.17 and 6.18 show that Moapa Plain Fugitive Red Ware has a strong association with Group 1G, 17 samples of the total of 27 Moapa Plain Fugitive Red Ware belonging to Group 1G.

In conclusion, the relation between the three Mt. Trumbull local groups (Group 1G, 2, and potentially Group 1VM) and the Moapa ware types suggest that there was some degree of clay selection for different functions of pots or differences in the time of production in Mt. Trumbull.

Tusayan Ware

Some degree of association exists between Tusayan Ware and the compositional groups. There seems to be a strong association between the Tusayan Plain/Corrugated Ware and Group 1VV and VR3, which are the lowland Virgin local groups, although a small number of sherds are also in the Mt. Trumbull local group (Tables 6.17 and 6.18).

Table 6.18 shows that 35 percent of all Tusayan Black-on-gray (sand-tempered) ware belongs to Group 1VV and 3 percent to VR3. Thus, at least 38 percent of Tusayan Black-on-gray originated in the lowland Virgin local area (Group 1VV and VR3). About 32 percent of Tusayan Black-on-gray belongs to VR1 (unknown source, non-local group), leaving only a small number of sherds in the Mt. Trumbull local group (Table 6.18). Thus, the majority of Tusayan Black-on-gray sherds are *not* from Mt. Trumbull.

Interestingly, much of the VR1 Tusayan Black-on-gray has finer quartz sand temper compared with the sherds originating in the lowland Virgin area, and these also have a thinner core, as previously discussed. Therefore, the Tusayan Black-on-gray in the VR1 group was likely made using a different production technique from that used for the pots produced in the Mt. Trumbull and lowland Virgin areas.

Shivwits Ware

There is a strong association between Shivwits Ware and Group 2. No other compositional groups include Shivwits Ware (Table 6.17). All Shivwits Corrugated Ware and 44 percent of the Shivwits Plain Ware are in Group 2, leaving 56 percent of Shivwits Plain Ware unassigned (Table 6.18).

A close examination of the ware types by area shows that the sources of the Shivwits Ware found in the Mt. Trumbull and lowland Virgin areas are different (Tables 6.20–25). All Shivwits Corrugated Ware and 71 percent of Shivwits Plain Ware in Mt. Trumbull/Tuweep belong to Group 2 (i.e., the Mt. Trumbull local group) (Table 6.21), while none of the Shivwits Ware in the lowland Virgin area is assigned to any of the compositional groups (Table 6.23). This indicates that the Shivwits

Table 6.20. Frequency of Mt. Trumbull/Tuweep sherds by compositional group and ware type.

Ceramic Category		Moapa Ware				Sand Temper				Shivwits Ware		Redwares				Poly-chrome
Group	Total	MP	MPF	MC	MBG	TP	TC	TBG	SNP	SVP	SVC	TO	SJR	SNR	RED	POL
Group1G	217	117	17	43	28	6	2	3	1	0	0	0	0	0	0	0
Group1VV	51	4	1	0	0	25	4	13	1	0	0	1	0	1	1	0
Group1VM	55	32	0	15	8	0	0	0	0	0	0	0	0	0	0	0
Group2	169	125	1	12	5	4	0	0	2	12	8	0	0	0	0	0
Group3	24	17	0	1	3	1	0	2	0	0	0	0	0	0	0	0
Group4	4	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0
VR1	7	0	0	0	0	1	0	6	0	0	0	0	0	0	0	0
VR3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Unassigned	242	92	6	56	25	23	9	9	4	5	0	1	4	3	2	3
Total	771	390	25	128	69	60	15	33	8	17	8	2	4	4	5	3

MP: Moapa plain, MPF: Moapa plan fugitive red, MC: Moapa corrugated, MBG: Moapa black-on-gray, TP:Tusayan plain, TPF: Tusayan plain fugitive red, TC: Tusayan corrugated, TBG: Tusayan black-on-gray, SNP: Shinarump plain, SVP: Shivwits plain, SVC: Shivwits corrugated, TO: Tegi orange ware, SJR: San Juan red ware, SNR: Shinarump red ware, RED: other red ware, POL: polychrome

Table 6.21. Percentage of Mt. Trumbull/Tuweep sherds within the ware type by compositional group.

Ceramic Category		Moapa Ware %				Sand Temper %				Shivwits Ware %		Redwares %				Poly-chrome %
Group	Total	MP	MPF	MC	MBG	TP	TC	TBG	SNP	SVP	SVC	TO	SJR	SNR	RED	POL
Group1G	28	30	68	34	41	10	13	9	13	0	0	0	0	0	0	0
Group1VV	7	1	4	0	0	42	27	39	13	0	0	50	0	25	20	0
Group1VM	7	8	0	12	12	0	0	0	0	0	0	0	0	0	0	0
Group2	22	32	4	9	7	7	0	0	25	71	100	0	0	0	0	0
Group3	3	4	0	1	4	2	0	6	0	0	0	0	0	0	0	0
Group4	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
VR1	1	0	0	0	0	2	0	18	0	0	0	0	0	0	0	0
VR3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0
Unassigned	31	24	24	44	36	38	60	27	50	29	0	50	100	75	40	100
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	10	100

MP: Moapa plain, MPF: Moapa plan fugitive red, MC: Moapa corrugated, MBG: Moapa black-on-gray, TP:Tusayan plain, TPF: Tusayan plain fugitive red, TC: Tusayan corrugated, TBG: Tusayan black-on-gray, SNP: Shinarump plain, SVP: Shivwits plain, SVC: Shivwits corrugated, TO: Tegi orange ware, SJR: San Juan red ware, SNR: Shinarump red ware, RED: other red ware, POL: polychrome

Table 6.22. Percentage of Mt. Trumbull/Tuweep sherds within the compositional group by ware type.

Ceramic category		Moapa Ware %				Sand Temper %				Shivwits Ware %		Redwares %				Poly-chrome %
Group	Total	MP	MPF	MC	MBG	TP	TC	TBG	SNP	SVP	SVC	TO	SJR	SNR	RED	POL
Group1G	100	54	8	20	13	3	1	1	0	0	0	0	0	0	0	0
Group1VV	100	8	2	0	0	49	8	25	2	0	0	2	0	2	2	0
Group1VM	100	58	0	27	15	0	0	0	0	0	0	0	0	0	0	0
Group2	100	74	1	7	3	2	0	0	1	7	5	0	0	0	0	0
Group3	100	71	0	4	13	4	0	8	0	0	0	0	0	0	0	0
Group4	100	75	0	25	0	0	0	0	0	0	0	0	0	0	0	0
VR1	100	0	0	0	0	14	0	86	0	0	0	0	0	0	0	0
VR3	100	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
Unassigned	100	38	2	23	10	10	4	4	2	2	0	0	2	1	1	1
Total	100	50	3	17	9	8	2	4	1	2	1	0	1	1	1	0

MP: Moapa plain, MPF: Moapa plan fugitive red, MC: Moapa corrugated, MBG: Moapa black-on-gray, TP:Tusayan plain, TPF: Tusayan plain fugitive red, TC: Tusayan corrugated, TBG: Tusayan black-on-gray, SNP: Shinarump plain, SVP: Shivwits plain, SVC: Shivwits corrugated, TO: Tegi orange ware, SJR: San Juan red ware, SNR: Shinarump red ware, RED: other red ware, POL: polychrome

Table 6.23. Frequency of lowland Virgin sherds by compositional group and ware type.

Ceramic Category		Moapa Ware				Sand Temper				Shivwits Ware		Redwares				Poly-chrome
Group	Total	MP	MPF	MC	MBG	TP	TC	TBG	SNP	SVP	SVC	TO	SJR	SNR	RED	POL
Group1G	25	20	0	1	4	0	0	0	0	0	0	0	0	0	0	0
Grroup1VV	105	58	1	4	20	7	3	9	0	0	0	3	0	0	0	0
Group1VM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Group2	16	15	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Group3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Group4	19	15	0	0	4	0	0	0	0	0	0	0	0	0	0	0
VR1	15	0	0	0	0	1	0	14	0	0	0	0	0	0	0	0
VR3	20	0	0	0	0	12	3	2	0	0	0	0	1	0	2	0
Unassigned	98	64	1	0	13	6	0	4	0	10	0	0	0	0	0	0
Total	298	172	2	5	41	27	6	29	0	10	0	3	1	0	2	0

MP: Moapa plain, MPF: Moapa plan fugitive red, MC: Moapa corrugated, MBG: Moapa black-on-gray, TP:Tusayan plain, TPF: Tusayan plain fugitive red, TC: Tusayan corrugated, TBG: Tusayan black-on-gray, SNP: Shinarump plain, SVP: Shivwits plain, SVC: Shivwits corrugated, TO: Tegi orange ware, SJR: San Juan red ware, SNR: Shinarump red ware, RED: other red ware, POL: polychrome

Table 6.24. Percentage of lowland Virgin sherds within the ware type by compositional group.

Ceramic Category		Moapa Ware %				Sand Temper %				Shivwits Ware %		Redwares %				Poly-chrome %
Group	Total	MP	MPF	MC	MBG	TP	TC	TBG	SNP	SVP	SVC	TO	SJR	SNR	RED	POL
Group1G	8	12	0	20	10	0	0	0	NA	0	NA	0	0	NA	0	NA
Group1VV	35	34	50	80	49	26	50	31	NA	0	NA	100	0	NA	0	NA
Group1VM	0	0	0	0	0	0	0	0	NA	0	NA	0	0	NA	0	NA
Group2	5	9	0	0	0	4	0	0	NA	0	NA	0	0	NA	0	NA
Group3	0	0	0	0	0	0	0	0	NA	0	NA	0	0	NA	0	NA
Group4	6	9	0	0	10	0	0	0	NA	0	NA	0	0	NA	0	NA
VR1	5	0	0	0	0	4	0	48	NA	0	NA	0	0	NA	0	NA
VR3	7	0	0	0	0	44	50	7	NA	0	NA	0	100	NA	100	NA
Unassigned	33	37	50	0	32	22	0	14	NA	100	NA	0	0	NA	0	NA
Total	100	100	100	100	100	100	100	100	NA	100	NA	100	100	NA	100	NA

MP: Moapa plain, MPF: Moapa plan fugitive red, MC: Moapa corrugated, MBG: Moapa black-on-gray, TP:Tusayan plain, TPF: Tusayan plain fugitive red, TC: Tusayan corrugated, TBG: Tusayan black-on-gray, SNP: Shinarump plain, SVP: Shivwits plain, SVC: Shivwits corrugated, TO: Tegi orange ware, SJR: San Juan red ware, SNR: Shinarump red ware, RED: other red ware, POL: polychrome

Table 6.25. Percentage of lowland Virgin sherds within the compositional group by ware type.

Ceramic Category		Moapa Ware %				Sand Temper %				Shivwits Ware %		Redwares %				Poly-chrome %
Group	Total	MP	MPF	MC	MBG	TP	TC	TBG	SNP	SVP	SVC	TO	SJR	SNR	RED	POL
Group1G	100	80	0	4	16	0	0	0	0	0	0	0	0	0	0	0
Group1VV	100	55	1	4	19	7	3	9	0	0	0	3	0	0	0	0
Group1VM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Group2	100	94	0	0	0	6	0	0	0	0	0	0	0	0	0	0
Group3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Group4	100	79	0	0	21	0	0	0	0	0	0	0	0	0	0	0
VR1	100	0	0	0	0	7	0	93	0	0	0	0	0	0	0	0
VR3	100	0	0	0	0	60	15	10	0	0	0	0	5	0	10	0
Unassigned	100	65	1	0	13	6	0	4	0	10	0	0	0	0	0	0
Total	100	58	1	2	14	9	2	10	0	3	0	1	0	0	1	0

MP: Moapa plain, MPF: Moapa plan fugitive red, MC: Moapa corrugated, MBG: Moapa black-on-gray, TP:Tusayan plain, TPF: Tusayan plain fugitive red, TC: Tusayan corrugated, TBG: Tusayan black-on-gray, SNP: Shinarump plain, SVP: Shivwits plain, SVC: Shivwits corrugated, TO: Tegi orange ware, SJR: San Juan red ware, SNR: Shinarump red ware, RED: other red ware, POL: polychrome

Ware found in the lowland Virgin area came from somewhere other than Mt. Trumbull, while most of the Mt. Trumbull Shivwits Ware was produced locally in Mt. Trumbull. These results support the idea, first proposed by Lyneis (1992, 1999, 2008), that the Shivwits Ware in the lowland Virgin area (especially in the Moapa Valley) came from the Shivwits Plateau. Further investigation is required to confirm this argument, such as an analysis with more source clays from the Shivwits Plateau.

Red Ware and Polychrome

Previous researchers have been concerned with the source of red ware in the Arizona Strip and adjacent areas. The traditional arguments are that the red ware in these areas did not come from local production centers but rather were transported as trade items from outside areas. However, the present study demonstrates that some of the red ware was produced locally within the Arizona Strip and adjacent areas, as discussed in the compositional analysis and surface treatment sections. In the lowland Virgin area, all six red ware samples involved in this study came from local production (Table 6.7). In Mt. Trumbull, five out of 15 red ware samples were from the lowland Virgin area and 10 were not assigned to any group, suggesting that they came from a source other than Mt. Trumbull and the lowland Virgin areas (Table 6.5). Although the number of red ware sherds included in this study is small, most of the San Juan Red Ware from the Mt. Trumbull assemblage is not assigned to any compositional group (Table 6.20). This supports the traditional argument that San Juan Red Ware in the study area was a trade ware from outside the Arizona Strip and adjacent areas. In the lowland Virgin sherd assemblage, only one San Juan Red Ware sample was included, belonging to VR3, the lowland Virgin local group (Table 6.23). Due to the small sample size, there is still not enough evidence to support the proposition that San Juan Red Ware was produced in the lowland Virgin area.

Lyneis (1992) argued that the source of San Juan Red Ware is southwestern Colorado or southeastern Utah. Further analysis is required to determine the source of San Juan Red Ware in Mt. Trumbull and the lowland Virgin area. Nonetheless, it is safe to conclude that the San Juan Red Ware found in Mt. Trumbull was not produced in Mt. Trumbull or the lowland Virgin area. The source determination of San Juan Red Ware in the lowland Virgin area is not conclusive in this study due to the small sample size.

Tsegi Orange Ware samples, on the other hand, are only in Group 1VV (Table 6.17). All three Tsegi Orange Ware samples from the lowland Virgin area belong to Group 1VV (Table 6.23), and one of two Tsegi Orange Ware samples from Mt. Trumbull belongs to Group 1VV (Table 6.20). Thus, it is likely that Tsegi Orange Ware was produced in the lowland Virgin area and that some of the Tsegi Orange Ware found in Mt. Trumbull was transported from the lowland Virgin area.

All polychrome ware samples are unassigned in this data set. Thus, it is likely that this ware is a product of non-local production outside of the Mt. Trumbull and lowland Virgin areas, which supports the traditional arguments.

Table 6.26. Frequency and percentage of black-on-gray sherds by source and provenience.

Provenience	Source	Frequency	%	Compositional Groups
Mt. Trumbull	Local	49	48%	Groups 1G 1VM, 2, and 3
	Lowland Virgin	13	13%	Group 1VV
	VR1 source	6	6%	VR1
	Unassigned	34	33%	
	Total	102	100%	
Lowland Virgin	Local	35	50%	Groups 1VV, 4 and VR3
	Mt. Trumbull	4	6%	Group 1G
	VR1 source	14	20%	VR1
	Unassigned	17	24%	
	Total	70	100%	

Black-on-gray Ware

As discussed, the examination of surface treatment and compositional groups shows that black-on-gray ware was traded between Mt. Trumbull/Tuweep and the lowland Virgin area. Close examination of compositional groups and black-on-gray ware (Table 6.26) suggests that: (1) almost half of black-on-gray ware was produced locally in the Mt. Trumbull and lowland Virgin areas, and (2) more black-on-gray pots were moved from the lowland Virgin area to Mt. Trumbull than from Mt. Trumbull to the lowland Virgin area. To better understand the black-on-gray pottery exchange among regions with their own black-on-gray pot production, the ware types, compositional groups, and proveniences were closely examined.

Moapa Black-on-gray (Olivine Temper)

Examination of the ware types in Mt. Trumbull/Tuweep and the compositional analysis (Table 6.27) demonstrates that 44 Moapa Black-on-gray sherds, that is, 64 percent of all Moapa Black-on-gray ware in Mt. Trumbull/Tuweep,

Table 6.27. Frequency and percentage of black-on-gray sherds by compositional group and provenience.

Ware Type	Group	Provenience	
		Mt. Trumbull/Tuweep	Lowland Virgin
Tusayan Black-on-gray	Group1G	3 (9%)	0 (0%)
	Group1VV	13 (39%)	9 (31%)
	Group1VM	0 (0%)	0 (0%)
	Group2	0 (0%)	0 (0%)
	Group3	2 (6%)	0 (0%)
	Group4	0 (0%)	0 (0%)
	VR1	6 (18%)	14 (48%)
	VR3	0 (0%)	2 (7%)
	Unassigned	9 (27%)	4 (14%)
	Total	33 (100%)	30 (100%)
Moapa Black-on-gray	Group1G	28 (41%)	4 (10%)
	Group1VV	0 (0%)	20 (49%)
	Group1VM	8 (12%)	0 (0%)
	Group2	5 (7%)	0 (0%)
	Group3	3 (4%)	0 (0%)
	Group4	0 (0%)	4 (10%)
	VR1	0 (0%)	0 (0%)
	VR3	0 (0%)	0 (0%)
	Unassigned	25 (36%)	13 (32%)
	Total	69 (100%)	41 (100%)

probably had their origins in Mt. Trumbull (Groups 1G, 1VM, 2, and 3). No Moapa Black-on-gray sherds were found in Group 1VV or VR3, which are local groups in the lowland Virgin area. Thus, all Mt. Trumbull Moapa Black-on-gray (olivine-tempered) was from local production in Mt. Trumbull, and no Moapa Black-on-gray produced in the lowland Virgin area was transported to Mt. Trumbull.

On the other hand, at least 49 percent of Moapa Black-on-gray in the lowland Virgin area came from local production (Group 1VV) (Table 6.27). This suggests that Moapa Black-on-gray was also produced in the lowland Virgin area, but it was not transported to Mt. Trumbull. This may be because using olivine imported from Mt. Trumbull to make black-on-gray pots for trading was too costly, considering the fact that the potters in the lowland Virgin area likely had easier access to sand temper found near the Virgin and Muddy Rivers.

Tusayan Black-on-gray (Sand Temper)

Table 6.27 shows that the Tusayan Black-on-gray sherds from the lowland Virgin area belong to Groups 1VV, VR3, and VR1. Thus, the source of Tusayan Black-on-gray in the lowland Virgin area is either local production or from an unknown area (VR1), but not Mt. Trumbull. In Mt. Trumbull, however, a few Tusayan Black-on-gray sherds were in the local groups (Groups 1G and 3), but, the Tusayan Black-on-gray from Mt. Trumbull sources is much less frequent than that originating from outside the area. Thus, most of the Tusayan Black-on-gray in Mt. Trumbull came from outside that area (Table 6.27). Moreover, no Tusayan Black-on-gray produced in Mt. Trumbull was transported to the lowland Virgin area (Table 6.27). This is not surprising because sand temper used in Tusayan Black-on-gray production may have been more expensive and less accessible than olivine in Mt. Trumbull, which has no river or permanent stream.

In sum, black-on-gray pots were exchanged between Mt. Trumbull and the lowland Virgin area. Only olivine-tempered black-on-gray pots were transported to the lowland Virgin area from Mt. Trumbull, and only sand-tempered black-on-gray pots were transported from the lowland Virgin area to Mt. Trumbull. Thus, this study demonstrates that only the black-on-gray pots produced with more accessible/less expensive temper (e.g., olivine in Mt. Trumbull) were used for trading between areas.

Compositional Groups and Site Chronology (Rough Scale)

As discussed, the ratio of corrugated wares in each compositional group demonstrates that this ratio in Group 2 is smaller than that in Groups 1G and 1VM among the Mt. Trumbull local groups (Figure 6.7). This indicates that the use of Group 2 clay started relatively early and/or stopped early, while Group 1G and 1VM clays were not used until a later period. However, this inference is tentative, and further investigation (e.g., luminescence dating of sherds) is required.

In the lowland Virgin area, some degree of correlation exists between compositional groups and approximate time. The comparison of compositional groups to the area's chronology based on the ratio of corrugated ware based on a limited number of ^{14}C dates shows that: (1) Group 2 sherds came only from early sites (0 percent corrugated); (2) Group 1VV sherds were found in various sites dating to different time periods, suggesting that Group 1VV pots were made/used during all time periods; and (3) Group 1G and 4 sherds came from the later sites (corrugated > 0 percent) (Table 6.28). Based on this comparison, it appears that Group 2 olivine-tempered pots were transported from Mt. Trumbull to the lowland Virgin area early and that the Group 1G olivine pots were transported later.

Table 6.28. Frequency of lowland Virgin sherds by site, compositional groups, percentage of corrugated wares, and ^{14}C dates.

Site	^{14}Cdate	Corrugated	1G	1VV	G2	G4	VR1	VR3	Unassigned
VR1		0.0%		4	4				1
VR4		0.0%			2				1
VR13		0.0%		1	6			1	1
VR14		0.0%			2				
VR35		0.1%	2	7		3			6
VR17		0.2%		2		2	3	2	6
VR27	A.D. 850	0.7%	4	9		2		1	10
VR21	A.D. 960	0.8%	11	5		7	2		7
VR34		0.8%		7			2	1	6
VR33		1.4%	1	8			1	2	8
VR36		4.0%		3					10
VR28		28.2%		2			1	1	4
VR22	A.D. 1020	30.2%	1	9				1	3
VR7	A.D. 1130	77.1%	2	3		2		2	2

1G: Group 1G; 1VV: Group 1VV; G2: Group 2; G4: Group 4.

For some reason, Group 2 olivine pots were no longer transported to the lowland Virgin area during later periods. It could be that Group 2 olivine-tempered pots, which possibly are lower-quality pots due to less clay preparation, were not attractive trading items during later periods. Group 1VV sherds were found in both early and late sites in the lowland Virgin area. This suggests that the lowland Virgin potters may have started making their own olivine-tempered pots relatively early and that the same clay source/preparation technique was used throughout these time periods. However, this proposition requires further examination using luminescence dating, which will be discussed later.

Compositional Groups and Post-Depositional Alteration

Certain elemental concentrations indicate possible post-depositional chemical alteration. As shown in other studies, the only element elevated by chemical alteration is barium (Golitko et al. 2012; Iizuka 2012). On the other hand, calcium decreases under rainy environmental conditions. In the data set used in the present study, barium does not contribute much to group separation (Figure 5.34). Moreover, some of the compositional groups have a strong association with formal attributes and/or are matched to local clay. Thus, it is unlikely that the compositional groups are the result of post-depositional chemical alteration due to diagenesis.

Comparison of LA-ICP-MS Compositional Groups to INAA Compositional Groups

As discussed in the previous chapter, the comparison of compositional groups derived from the LA-ICP-MS data to those derived from the INAA data provided some clues that were used to find possible compositional groups/subgroups in the LA-ICP-MS data. Some of the compositional groups in the microchemical analysis using LA-ICP-MS correspond to groups in the INAA bulk data (Table 6.29). For example, Group 2 in the LA-ICP-MS data corresponds to INAA Group 2. This suggests that the formation of INAA Group 2 in the bulk data is at least partly due to the chemical signature of clay itself, not the amount of temper, natural inclusions other than olivine, or olivine from a different source. Group 4 derived from the LA-ICP-MS data potentially corresponds to Group 4 in the INAA data. However, the

Table 6.29. Frequency of sherds by INAA and LA-ICP-MS compositional groups.

	LA-ICP-MS Group									
	1G	1VM	1VV	G 2	G 3	G4	VR1	VR3	Unassigned	Total
INAA Group 1	9	3	1						8	21
INAA Group 2				18					3	21
INAA Group 3	6									6
INAA Group 4						1			1	2
INAA VR1							9			9
INAA VR2			6						1	7
INAA VR3			3					17		20
INAA VR4			12	1				2	4	19
Unassigned	2		3	1					6	12
Total	17	3	25	20	0	1	9	19	23	117

samples sizes are too small for a firm conclusion. Group 1VV derived from the LA-ICP-MS data corresponds to INAA VR2 and INAA VR4. Some of the groups defined in the INAA bulk data are likely due to different types of temper; in particular, INAA VR2 includes only olivine-tempered sherds and INAA VR4 contains only sand-tempered sherds, suggesting that the contribution of the tempers may be helping to create their distinctive compositional signatures.

Evaluation of Compositional Groups

As discussed above, the comparison of the compositional analysis with formal attributes and provenience shows some degree of association between compositional groups and formal attributes as well as provenience. The results also demonstrate that some of the compositional groups found in LA-ICP-MS correspond to those found in the INAA data. Four propositions are proposed to interpret the compositional groups discussed in Chapter III: compositional groups represent (1) clay sources, (2) paste recipes, (3) clay preparation/quarrying techniques, or (4) the effects of diagenesis. The following section presents an examination of what the compositional groups defined in this project represent. As noted above, I have ruled out the possibility that chemical alteration due to diagenesis created the compositional groups observed in this data set. The following section concerns the other three propositions.

Group 1G: Mt. Trumbull Local Group

The chemical compositional data of three clays from Mt. Trumbull are matched to those of Group 1G sherds. Thus, Group 1G represents clay sources in Mt. Trumbull. Two of the clays matched to Group 1G are prepared clays, and these two prepared clays and the unprepared clay from the same source also match with Group 2 (Table 5.29). This shows the probabilities of these two clays to match Group 1G increased only after clay preparation. Thus, Group 1G represents the possible results of clay preparation, which may exclude larger mineral particles that could change the chemical signature. In this sense, Group 1G also represents a paste recipe or preparation technique.

Group 1VM: Unknown, But Potentially a Mt. Trumbull Local Group.

No clays are matched to Group 1VM. However, this group is likely a Mt. Trumbull local group because Group 1VM includes only olivine-tempered ceramics found in Mt. Trumbull; thus it is difficult to imagine that the source of this group is outside Mt. Trumbull/Tuweep. The lack of a match with a clay could be because I did not find the clay that potters used to make the pots represented by sherds used for this analysis or because the ceramic paste went through clay preparation to eliminate larger particles of particular minerals in order to increase clay performance, thus potentially changing the chemical characteristics of the clay matrix. In this sense, Group 1VM may also represent paste recipe/preparation in addition to a clay source.

Group 1VV: Lowland Virgin Local Group

Three local clays in the lowland Virgin area are matched to this group, suggesting that this group represents a clay source

Group 2: Mt. Trumbull Local Group

Twenty clay samples in the data (15 sources) from Mt. Trumbull and its vicinities are matched to Group 2. Thus, this group represents a clay source.

Group 3: Unknown but Potentially Mt. Trumbull Local Group

The sample size in Group 3 is too small for using Mahalanobis distance projection to compare clays with this group. Bivariate plots of the canonical discriminant function scores show that no clay analyzed in this study is matched (overlapped) to Group 3 (Figure 5.40). However, Group 3 is likely a Mt. Trumbull local group, considering that all ceramics in this group are from Mt. Trumbull and most of them are from one particular site (71 ASM). Another proposal is that Group 3 is a non-local group that is distributed only to a few sites in Mt. Trumbull (mainly the 71 ASM site).

This proposal, however, raises questions because most of the sherds in Group 3 have olivine temper. It is unlikely that the olivine-tempered pots were produced outside of the olivine source area and transported back to the Mt. Trumbull area. Thus, it is likely that Group 3 is a Mt. Trumbull local group. The chemical signature of Group 3 is very different from that in any other compositional group and the clays in the data set. Thus, it is possible that Group 3 ceramics were produced in/near the 71 ASM site using special clay that was not sampled for this study or that was manufactured using a special clay preparation.

Group 4: Unknown, but either Mt. Trumbull or the Lowland Virgin Group (likely to be a lowland Virgin local Group)

The sample size of Group 4 is too small for using Mahalanobis distance projection to compare the clay data to this group. Bivariate plots of canonical discriminant function scores (Figure 5.40) show that no clay analyzed in this study is matched (overlapped) to Group 4, which includes only olivine-tempered sherds from relatively later sites. The olivine-tempered sherds in this group are found in both

Mt. Trumbull and the lowland Virgin areas; however, the majority of the Group 4 sherds come from the lowland Virgin area. Two alternatives regarding the source of Group 4 items are proposed.

One proposal is that Group 4 pots was produced in the lowland Virgin area using clays that were specifically chosen for use with olivine temper. This hypothesis is suggested by the fact that another clay group for the olivine-tempered ceramics, Group 1VV, exists in the lowland Virgin area. Group 1VV clay was used for multiple purposes, both with and without olivine. It is also noted that the use of Group 1VV with olivine-temper potentially started early and continued to be used during later periods. Group 4, in contrast, consists of sherds with only olivine temper from relatively later sites. Thus, it is proposed that the selection of a clay (which was not sampled for this study, or is from deeper deposits of the clay source where I sampled for this study) or special clay preparation was involved in olivine-tempered ceramic production in the lowland Virgin area during later periods. Olivine seems to be an expensive temper material in the lowland Virgin area, as it was imported from Mt Trumbull. Thus, it is possible that clay selection or special preparation of the paste for better performance was required to decrease the breakage rates during production so that no olivine temper was wasted.

The other proposal for the origin of Group 4 involves resource specialization for pottery production in Mt. Trumbull; that is, Group 4 represents clay selection or a special recipe for the production of pottery for trade in Mt. Trumbull, especially at the 71 ASM site, because three out of four Mt. Trumbull Group 4 sherds come from this site. However, the majority of sherds in Group 4 come from the lowland Virgin area (19 of 23 sherds in Group 4). If the Mt. Trumbull site is the production center, then I would expect that more sherds from Mt. Trumbull would be found in Group 4. Moreover, a relatively high proportion of utilitarian ware is present in Group 4, so it is unlikely that Group 4 is a Mt. Trumbull local group consisting of pottery produced exclusively for trading purposes.

Although the second proposal seems less likely, it is not possible to have high confidence in the first proposal based on the limited evidence currently available. To support the first proposal, which posits a lowland Virgin source and clay selection practices adopted later in time, it is essential to date olivine-tempered ceramics in Group 4 and Group 1VV.

VR1: Unknown, Neither Mt. Trumbull Nor the Lowland Virgin Area

VR1 did not match a lowland Virgin clay in the INAA analysis or Mt. Trumbull local clay in the ICP-MS analysis, so VR1 is classified as a non-local group with an unknown source.

VR3: Lowland Virgin Local Group

Lowland Virgin clays were matched to VR3 in the previous INAA study, so this group represents a clay source.

Conclusion

Examination of the relationship between compositional groups and ceramic physical attributes, as well as the INAA results suggests that some of the compositional groups in ceramics found in Mt. Trumbull/Tuweep and the lowland Virgin area represent clay sources and some represent clay preparation/paste recipes. In the following chapter, I will examine how the use of these clays changed over time considering the results of optically stimulated luminescence (OSL) dating of selected potsherds.

Optical Luminescence Dating Results

The main purpose for applying OSL dating to the ceramic samples in this study is to examine the changing patterns of ceramic resource use over time. However, the OSL dates initially need to be compared with the other available chronological information related to the study area because cross-checking the dates with those derived from other dating techniques is always necessary to ensure their validity.

The distribution of OSL dates based on ceramic attributes and their provenience will be also examined to provide better information about the regional chronology and an accurate reconstruction of ceramic chronology, which are both necessary to understand the evolution of pottery production and consumption discussed in this study.

As discussed in a previous chapter, only a few ^{14}C dates are available for establishing a site's chronology and estimating the length of the use of particular clays for pottery production. Nonetheless, it is worthwhile to compare the OSL dates with ^{14}C dates to assess the validity of these OSL dates. Table 6.30 shows the OSL dates for each site in the sample, the ^{14}C dates, and the ratios of corrugated to non-corrugated wares that have been used as a "time indicator" in the study area. Overall, at most of the sites in Mt. Trumbull, the OSL dates overlap the ^{14}C dates.

All of the ^{14}C dates for the 131 BLM site were found to be within the range of OSL dates. Based on these OSL dates, this site was occupied as early as A.D. 476 ± 115, and an earlier phase of A.D. 476–830 and a later phase of A.D. 1080–1350 appears to have occurred at the site. This pattern corresponds with the distribution of artifacts from test pit excavations that show a bimodal pattern of distribution.

The range of ^{14}C dates from 136 ASM are within the distribution of OSL dates. Although the earliest OSL date is A.D. 436 ± 127, the majority of the dates are after A.D. 830, which may correspond to the relatively higher corrugated ware ratio. Five OSL dates in 136ASM are possibly too late, considering the traditional arguments of the Anasazi occupations in this area.

The ^{14}C dates from 14 MNA are also within the range of the OSL pertaining to this site. Most OSL dates range after A.D. 1000, which corresponds to a very high corrugated ware ratio. A single ^{14}C date is available for 204 BLM and is within the range of the OSL dates for this site. Except for one late date, most of the OSL dates

Table 6.30. OSL dates of sherds from Mt. Trumbull sites.

131BLM **^{14}C dates*** **A.D. 620–690, A.D. 680–880, A.D. 900–1030**

% sherds >1' Corrugated ware from SCU: 2.0%

Cat#	ID		date	provenience	group	evaluation
131-14	LB0129	A.D.	476 ± 115	SCU A-3	G2	C
131-318	LB1125	A.D.	569 ± 154	TP-2 L6N	1VV	A
131-74	LB0276	A.D.	599 ± 123	SCU A-11	1G	A
131-168	LB1113	A.D.	696 ± 105	surface general	1VM	C
131-9	LB0101	A.D.	739 ± 125	SCU A-2	1G	A
131-53	LB0275	A.D.	830 ± 73	SCU A-7	G2	A
131-314	LB1071	A.D.	1080 ± 66	TP2 L3N	VR1	A
131-45	LB0130	A.D.	1085 ± 80	SCU A-7	G2	A
131-308	LB1150	A.D.	1152 ± 79	TP-2 L7S	1G	A
131-244	LB1151	A.D.	1179 ± 83	TP-3 L7	1G	A
131-307	LB0641	A.D.	1236 ± 90	TP-2 L3	1G	A
131-236	LB0655	A.D.	1275 ± 63	TP-1 L3	1VV	A
131-96	LB0139	A.D.	1350 ± 64	SCU B-1	1G	A

136ASM **^{14}C dates*** **A.D. 790–1040, A.D. 960–1060, A.D. 1020–1270**

% sherds >1' Corrugated ware from SCU: 15.9%

Cat#	ID		date	provenience	group	evaluation
136-18	LB0141	A.D.	436 ± 127	surface general	1G	A
136-26	LB0260	A.D.	833 ± 81	surface general	G2	A
136-336	LB1130	A.D.	923 ± 148	TP2 L4	1VV	B
136-271	LB1112	A.D.	941 ± 109	TP2 L3	1VM	A
136-63	LB1123	A.D.	1063 ± 89	surface general	1VV	A
136-34	LB0149	A.D.	1264 ± 61	surface general	1VM	A
136-9	LB0258	A.D.	1592 ± 30	surface general	G2	A
136-7	LB0148	A.D.	1655 ± 28	surface general	1G	A
136-27	LB0099	A.D.	1656 ± 32	surface general	G2	A
136-16	LB0131	A.D.	1730 ± 17	surface general	G2	A
136-76	LB1111	A.D.	1815 ± 32	surface general	1VM	B

14MNA **^{14}C dates*** **A.D. 880–1010, A.D. 1000–1170, A.D. 1020–1210, A.D. 1160–1280**

% sherds >1' Corrugated ware from SCU: 39.3%

Cat#	ID		date	provenience	Group	evaluation
14-140	LB0137	A.D.	590 ± 203	SCU-2	G2	A
14-83	LB0268	A.D.	1002 ± 52	ROOM 2 FILL	G2	A
14-152	LB0271	A.D.	1067 ± 85	SCU-3	G2	A
14-116	LB0270	A.D.	1282 ± 45	ROOM 3 FILL	G2	A
14-297	LB1084	A.D.	1299 ± 45	TP1 L1	VR3	A

Table 6.30. OSL dates of sherds from Mt. Trumbull sites (continued).

Cat#	ID		date	provenience	Group	evaluation
14-106	LB0144	A.D.	1309 ± 60	ROOM 3 FILL	1G	A
14-6	LB0264	A.D.	1312 ± 104	SCU-5	1G	A
14-70	LB0138	A.D.	1313 ± 304	ROOM 2 FILL	1G	C
14-120	LB0145	A.D.	1375 ± 62	ROOM 3 FILL	1G	A
204BLM	**^{14}C dates***	**A.D. 810–890**				
	% sherds >1' Corrugated ware from SCU: 0 %					
Cat#	ID		date	provenience	group	evaluation
204-13	LB0097	A.D.	490 ± 110	surface general	G2	C
204-41	LB0661	A.D.	798 ± 86	TP3 L1	G3	A
204-2	LB0279	A.D.	977 ± 109	SCU A-4	1G	A
204-20	LB1122	A.D.	982 ± 106	TP4 L1	1VV	A
204-4	LB0133	A.D.	1581 ± 33	SCU A-6	G2	A
214ASM	**^{14}C dates***	**A.D. 640–770**				
	% sherds >1' Corrugated ware from SCU: 44.0%					
Cat#	ID		date	provenience	group	evaluation
214-11	LB1127	A.D.	938 ± 83	TP-1 L2	1VV	A
214-5	LB0588	A.D.	1049 ± 53	TP-5 L1	G2	A
214-8	LB0586	A.D.	1465 ± 43	TP-3 L1	1VM	C
30BLM	**^{14}C dates***	**A.D. 1110–1190**				
	% sherds >1' Corrugated ware from SCU: 11.7%					
Cat#	ID		date	provenience	group	evaluation
30-40	LB0146	A.D.	205 ± 205	surface general	1G	C
30-7	LB0136	A.D.	493 ± 137	surface general	G2	A
30-10	LB0140	A.D.	769 ± 199	surface general	1G	D
30-88	LB0123	A.D.	804 ± 140	surface general	1G	A
30-36	LB0098	A.D.	1091 ± 321	surface general	1VM	C
30-261	LB0600	A.D.	1130 ± 96	surface general	1G	A
30-158	LB0616	A.D.	1132 ± 63	TP2 L7	G2	A
30-168	LB0878	A.D.	1141 ± 70	TP3 L2	1VM	A
30-166	LB0673	A.D.	1146 ± 74	TP4 L5	1VM	A
30-37	LB0263	A.D.	1177 ± 123	surface general	1G	A
30-262	LB0601	A.D.	1250 ± 65	surface general	1G	A
30-173	LB0650	A.D.	1253 ± 59	TP3 L6	1VV	A
30-80	LB0106	A.D.	1255 ± 80	surface general	G3	A
30-82	LB0108	A.D.	1264 ± 45	surface general	G3	A
30-151	LB1109	A.D.	1304 ± 109	TP2 L3	1VM	B
30-77	LB1094	A.D.	1402 ± 81	surface general	VR1	C

Table 6.30. OSL dates of sherds from Mt. Trumbull sites (continued).

Cat#	ID		date	provenience	Group	evaluation
30-16	LB0262	A.D.	1410 ± 54	surface general	1G	A
30-260	LB0599	A.D.	1461 ± 52	surface general	G2	A
30-81	LB0107	A.D.	1472 ± 84	surface general	G3	B
30-266	LB1093	A.D.	1494 ± 62	surface general	VR1	A
30-201	LB1097	A.D.	1529 ± 48	TP2 L6	VR1	A
71ASM	**^{14}C dates***	**A.D. 880–1010**				
	% sherds >1' Corrugated ware from SCU: 0.9%					
Cat#	ID		date	provenience	group	evaluation
71-64	LB1099	A.D.	468 ± 148	TP4 L1	G4	A
71-39	LB0119	A.D.	587 ± 85	surface general	G2	C
71-48	LB0868	A.D.	606 ± 83	TP3 surface	G3	A
71-58	LB1117	A.D.	748 ± 90	surface general	G3	A
71-47	LB1119	A.D.	758 ± 110	TP4 L1	G3	A
71-40	LB0120	A.D.	895 ± 193	surface general	G2	B
71-56	LB1118	A.D.	1055 ± 94	surface general	G3	A
71-57	LB0870	A.D.	1467 ± 37	surface general	G3	A

*2 sigma calibration ^{14}C dates. Evaluation “A” is most reliable based on the criterion passed.

fall between A.D. 500 and 1000, which corresponds to the absence of corrugated ware.

Site 214 ASM presents an interesting case of the disagreement between the ^{14}C date on the one hand, and the OSL dates and corrugated ware ratio on the other. Despite the extremely high ratio of corrugated ware, the ^{14}C date at this site is anomalously early, A.D. 640–770. The OSL dates for two sherds from 214 ASM are around A.D. 1000 and one is very late.

A single ^{14}C date is available for 30 BLM, but this date is based on carbonized maize kernels that minimized the old-wood problem. The date is within the range of OSL dates. These OSL dates range from early to late, and the majority of these dates are after A.D. 1150, which corresponds to relatively high ratio of corrugated ware. Like OSL dates from 136 ASM, quite a few dates for 30 BLM are after A.D. 1400, which is too late for Anasazi occupation. Interestingly, the locations of 30 BLM, 136 ASM, 204 BLM, and 214 ASM, all of which include post-A.D. 1400 dates, are within a two-km area containing a concentration of large pueblos. Since they are not from the same type of provenience (some are from the surface while others are from deeper deposits) and are of various dates, it is unlikely that these late dates are due to a single natural event such as a forest fire. Instead, this may be the result of occupation by a later population, such as the Southern Paiutes. The large pueblo area may have been attractive to the later occupants for some reason. Indeed, the large pueblo area is likely to have been better for agriculture because of its potential subsurface water (Buck et al. 2012) and this environmental feature could have attracted the later occupants. Although the Southern Paiutes were highly mobile and those in Mt. Trumbull probably were not introduced to horticulture until 1700–1800s, they tended to choose the location of base camps close to permanent water resources (Fairley 1989). Thus, the OSL dates suggest the large pueblo area was also attractive to the later occupants.

The single ^{14}C date from 71 ASM is also within the range of OSL dates for this site. The OSL dates are mainly relatively early, as most are before A.D. 1050, which corresponds to the small ratio of corrugated ware.

Distribution of OSL Dates in Mt. Trumbull and the Lowland Virgin Area

Figure 6.12 shows the distribution of all OSL dates derived from sherds found in Mt. Trumbull and the lowland Virgin area. As discussed in the previous chapter, most of the dates after A.D. 1400 presented here appear to be accurate, as the equivalent dose passed the criteria with strong signals. It is likely that these post-A.D. 1400 dates represent the post-use effects on the ceramic samples, such as intense surface firing (e.g., forest fires or campfires) or the reuse of the pots/site by later occupants. Forest fires have occurred often, especially in Mt. Trumbull. However, a quick brush fire will not raise the temperature over 500°C, and an event to zero luminescence signals must be a very intense fire for a long time, such as a fire in the Ponderosa pine forests or the burning of structures rather than a brush fire. The later occupants, perhaps the Southern Paiute, could have reused the pots made by the Ancestral Pueblo or reoccupied the Ancestral Pueblo sites and made hearths

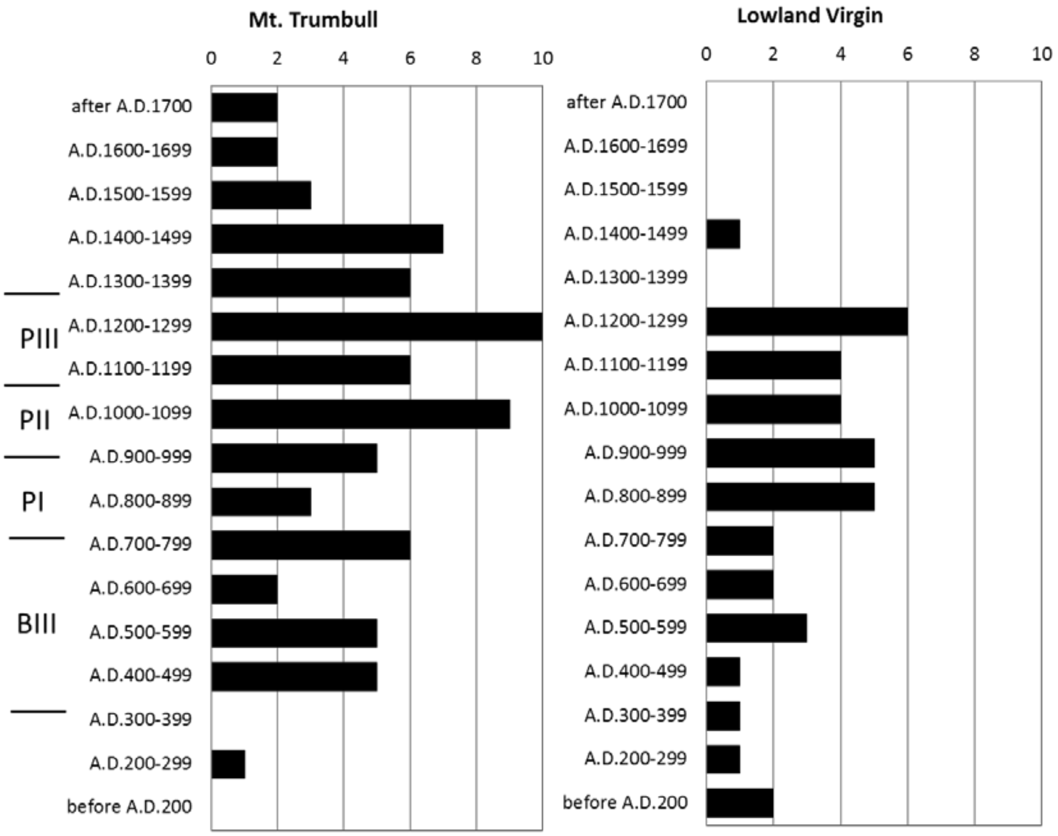


Figure 6.12. Frequency of Mt. Trumbull and lowland Virgin sherds by time interval based on OSL dates. Basketmaker III is circa A.D. 400–800, Pueblo I is circa A.D. 800–1000, Pueblo II is circa A.D. 1000–1150, and Pueblo II is circa A.D. 1150–1300.

that resulted in heating the ground surface, which would then have burned the broken Ancestral Pueblo sherds on surface.

Among the lowland Virgin sherds, a few dates are very early. As discussed in the previous chapter, the extremely early dates, especially before A.D. 200 (95 ± 207 B.C. and 373 ± 206 B.C.) may be erroneous, as hardly any very early ^{14}C dates have been reported for the Ancestral Pueblo sites in other lowland Virgin areas. The earliest dates accepted for both Mt. Trumbull and the lowland Virgin area seem to be sometime in the A.D. 200s. However, the numbers of the sherds with earlier dates are extremely low, the majority dating from A.D. 400, and the number of dates increases gradually over time, with a peak around A.D. 1200–1299 for both Mt. Trumbull and the lowland Virgin area.

Interestingly, quite a few sherds date to after A.D. 1300 in Mt. Trumbull, whereas hardly any sherds date to after A.D. 1300 in the lowland Virgin area. It is therefore likely that people continued to live in Mt. Trumbull, even after the lowland Virgin area was abandoned around A.D. 1300. The OSL dates also suggest that Mt. Trumbull was reoccupied or continued to be used by a later population after A.D. 1400, while hardly any people lived in the lowland Virgin area at this time. Note that the total numbers of sherds from each area does not represent the relative population level between Mt. Trumbull and the lowland Virgin area, as more Mt. Trumbull sherds were analyzed by OSL dating than sherds from the lowland Virgin area.

Ceramic Physical Attributes and OSL Dates

Figure 6.13 presents OSL date frequencies and surface treatment of the sherds from Mt. Trumbull and the lowland Virgin area. Notably, all of the corrugated wares date to after A.D. 900 (A.D. 938 ± 83), except for one sample that falls in the A.D. 600s (A.D. 696±105). This supports the “beginning date of corrugated ware around A.D. 950 [being] slightly later”, as proposed by Lyneis (1986). The distribution of OSL dates indicates that corrugated ware increased after Pueblo I (after A.D. 1000).

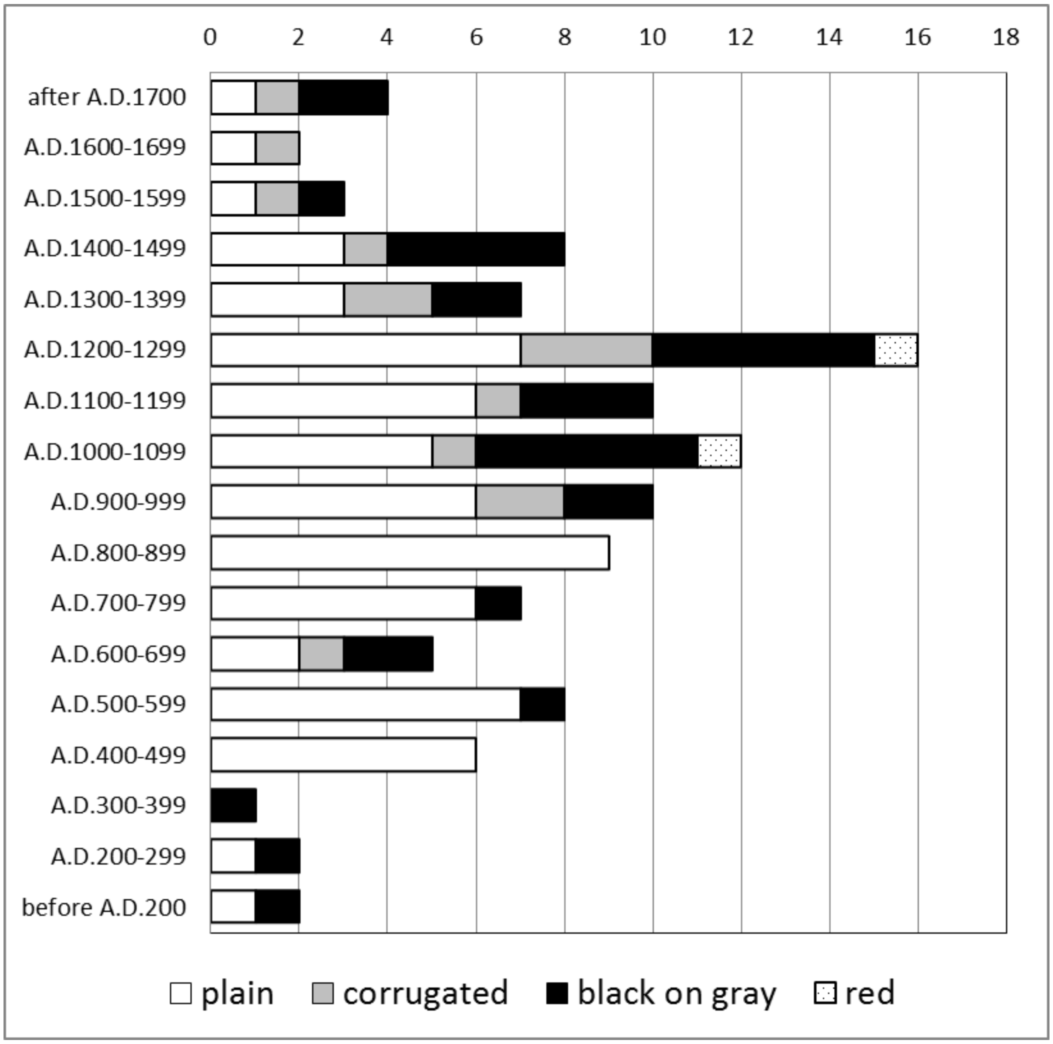


Figure 6.13. Frequency of all sherds from the Mt. Trumbull and lowland Virgin areas by time interval based on OSL dates and surface treatment.

Although dates for black-on-gray sherds span the whole time interval, the OSL dates demonstrate that they were more popular after Pueblo II (A.D. 1000–1150), which supports the traditional arguments about the black-on-gray wares in this study area (Chapter II). Only two red ware sherds were analyzed by OSL in this study. One from Mt. Trumbull dates to A.D. 1299 ± 45, and the other from the lowland Virgin area dates to A.D. 1073 ± 73 (Appendix B: Table B4). Thus the OSL dates support Alison's (2000) argument that the earliest regular appearance of red ware occurred after Pueblo II (A.D. 1000–1150).

Figure 6.14 presents OSL date frequencies and temper types. Although more olivine-tempered ceramics were dated by OSL than non-olivine-tempered ceramics (84 olivine-tempered sherds and 25 sand-tempered sherds), the distribution of the OSL dates suggests that the olivine-tempered sherds span the whole chronological sequence, whereas sand-tempered sherds to later time intervals. Their occurrence began around A.D. 600–699 (A.D. 602 ± 121 in the lowland Virgin area), and their frequency increased during the Pueblo II and early Pueblo III period. The majority of the sherds in the lowland Virgin area are sand-tempered, and if more lowland Virgin sherds were analyzed by OSL, their distribution over time may be different. However, the data set included in this study suggests that the sand-tempered pots appeared later.

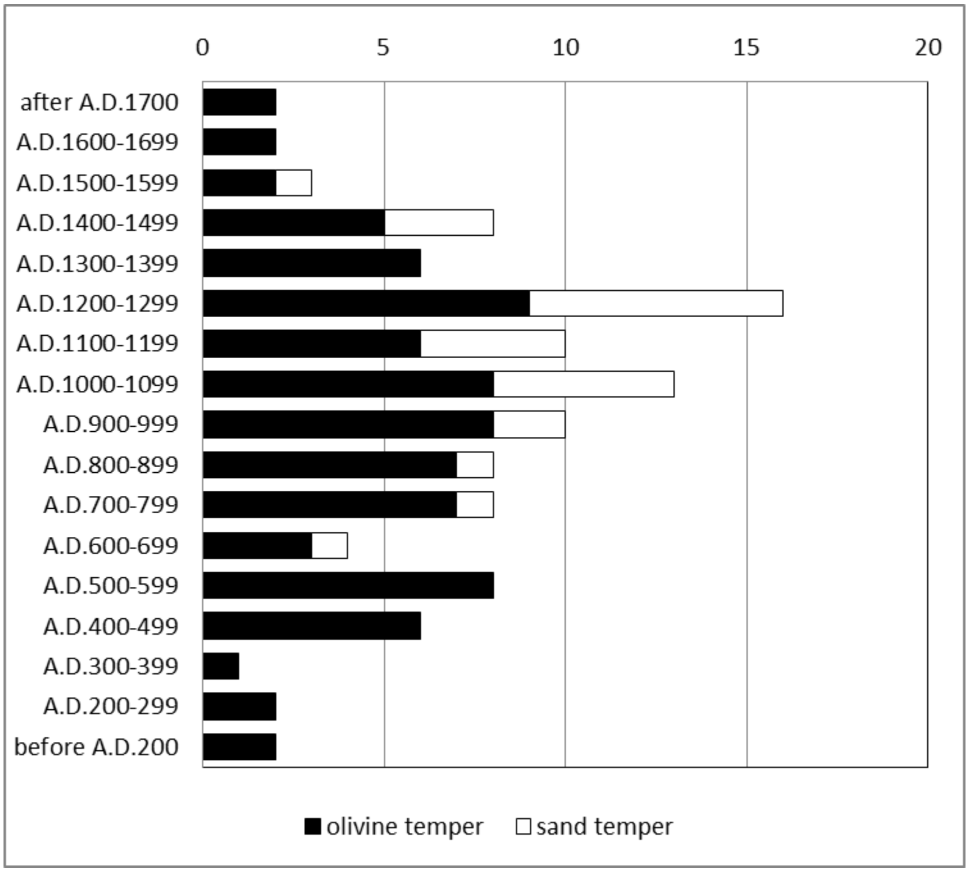


Figure 6.14. Frequency of all sherds from the Mt. Trumbull and the lowland Virgin areas by time interval based on OSL dates and temper.

Summary of OSL Dates in Each Compositional Group

The examination of the ceramic physical attributes and their provenience, as well as INAA results, indicates some degree of association among the compositional groups over time, as discussed earlier in this chapter. In this section, the distribution of OSL dates within the compositional group is examined closely in order to discover temporal trends in the use of these clay sources or recipes represented by compositional groups. As discussed in Chapter V, four Mt. Trumbull local groups and three lowland Virgin local groups were identified. So, in the following section, I will examine if these multiple groups were used contemporaneously or if the use of particular clay shifted over time and, if so, what contributed to the change of clay use. The dates of each sherd are presented in Appendix B: Table B4.

Group 1G (Figure 6.15)

Group 1G is one of the major Mt. Trumbull local groups used as utilitarian and non-utilitarian wares and for domestic and trading purposes. Both olivine and sand-tempered sherds are in this group. Group 1G sherds chemically matched three local clays in Mt. Trumbull. Two of these clays matched this group only after preparation to remove larger particles in the clay. This may indicate that Group1G clay has undergone special clay preparation. Note also that Group 1G matched much fewer clays with lower probabilities compared to Group 2. This suggests that the clay used for Group 1G may have been quarried from a much deeper deposit or from a clay source that was remote or difficult to find. Group 1G sherds have relatively lighter cores, which suggest a long firing process. Thus, considerable time and effort were likely devoted to produce the Group 1G pots.

The earliest OSL date for the sherds in this group is A.D. 205 ± 205, but most dates are after the A.D. 400s (Figure 6.15). The OSL date distribution for the sherds in Group 1G demonstrates that the use of Group 1G pots started relatively early and continued until late, even after A.D. 1100 when Group 2, the other major Mt. Trumbull group, mainly used for the utilitarian wares, ceased to be used by the Ancestral Pueblo. There are two recognized clusters of OSL dates, one is early,

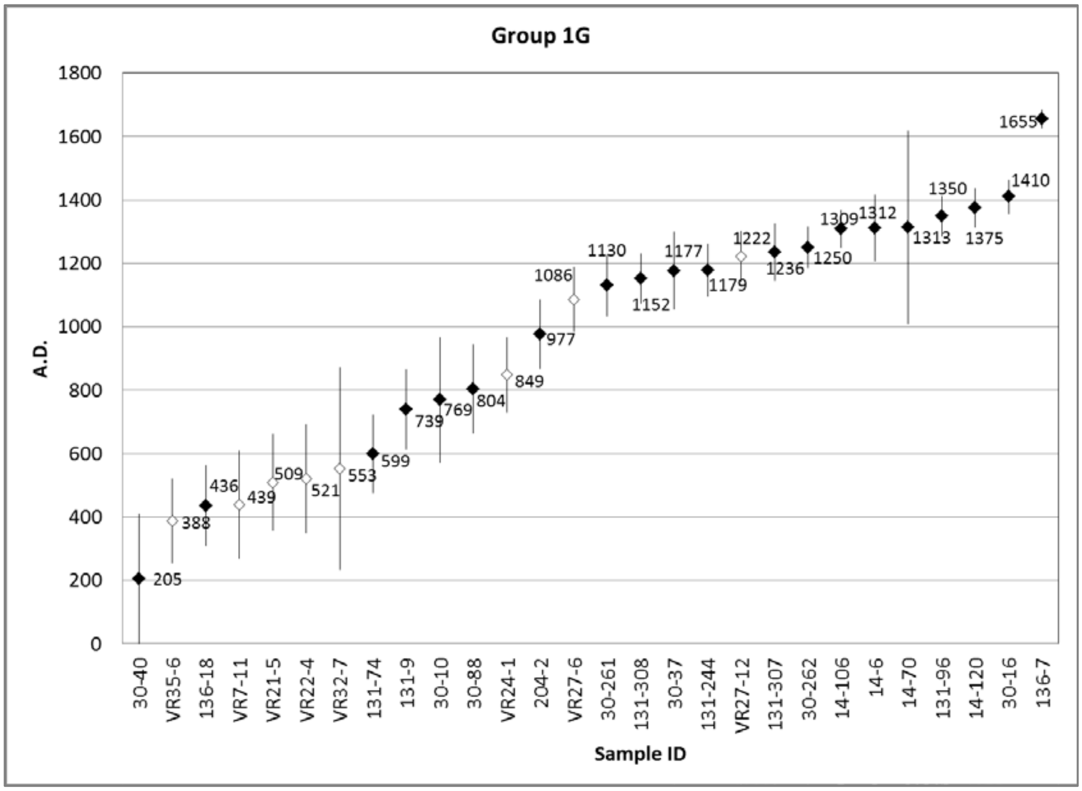


Figure 6.15. Distribution of OSL dates for sherds in Group 1G. Black diamonds are the samples from Mt. Trumbull and white diamonds are the samples from the lowland Virgin area.

around A.D. 400–600 during the Basketmaker III period (A.D. 388–599), and the other is later, about A.D. 1130–1400, during Pueblo III. Interestingly, the sherds in the earlier date cluster were mostly found in the lowland Virgin area (five of seven sherds) and the sherds from the later date cluster were mainly found in Mt. Trumbull (12 of 13 sherds). This pattern suggests clay resource selection for different purposes during early times, when Group 1G clay was more likely used to produce pots for trading. As discussed earlier, the Group 1G pots may have been expensive pots entailing either special clay preparations or clay quarried with effort (e.g., deeper deposits, distant sources). These pots also appear to be more resistant and used for longer periods, after firing for longer times at potentially higher temperatures.

In contrast to Group 1G, Group 2 ware was mainly used for utilitarian wares, and more clays matched the ceramic groups without further preparation. Sherds in Group 2 have darker cores that suggest shorter firing times at lower temperatures. Indeed, the distribution of OSL dates demonstrates that use of Group 2 wares started early (Figure 6.16), and these early uses were exclusively for Mt. Trumbull pots, especially before A.D. 600. Comparing the distributions of OSL dates for Group 1G and Group 2 supports the hypothesis concerning clay resource specialization in Mt. Trumbull during early times. Group 1G pots were used for trading purposes, and Group 2 pots were used in domestic contexts.

The comparison of OSL dates between Group 1G and Group 2 also demonstrated that the use of Group 2 for the pottery production by the Ancestral Pueblo was replaced by Group 1G clay after A.D. 1130. This suggests that only good-quality clay was used for pottery production during the later time period. It is generally assumed that after A.D. 1000 the population became larger in the study area. To support the large number of people, the people living in Mt. Trumbull may have focused on more intensive agriculture and the construction of storage facilities during the post-A.D. 1000 period. Under these circumstances, people may have focused their efforts on agricultural activities and minimized efforts on non-agricultural activities, such as pottery production. Pots less subject to failure during production and more durable during use may have been in high demand because potters did not need to make their pots so often. The potters may have spent more time obtaining and preparing the clay for the pottery production, as the use of a better clay such as Group 1G ultimately decreased the production cost for the pots by avoiding failure during production or breakage during use. Once potters produced less breakable pots, they would not have to spend much time for additional pottery production and would have been able to devote more time to agriculture. Climatic reconstruction by PDSI shows that the time period from A.D. 1175 to 1275 was relatively wet in the study area (Larson et al. 1996). In circumstances where the climatic conditions were favorable for agriculture, it is possible that the accumulated surplus allowed specialized potters to devote more time to pottery production activities, including clay procurement. This growing specialization would have freed the non-potters to devote more of their time to agricultural production to increase yields for supporting the large population.

Group 2 (Figure 6.16)

Group 2 is another major Mt. Trumbull local group used mainly for utilitarian wares. The pots in this group not only were used for domestic purpose but were also transported to the lowland Virgin area. Group 2 was matched to more than 20 local clays, and as mentioned above the sherds in this group have a darker core color, which may indicate a short firing time. OSL dates for the sherds in this group suggest that the use of Group 2 clay started in the late A.D. 400s, similar to the beginning date of Group 1G. However, the use of Group 2 clay decreased after A.D.

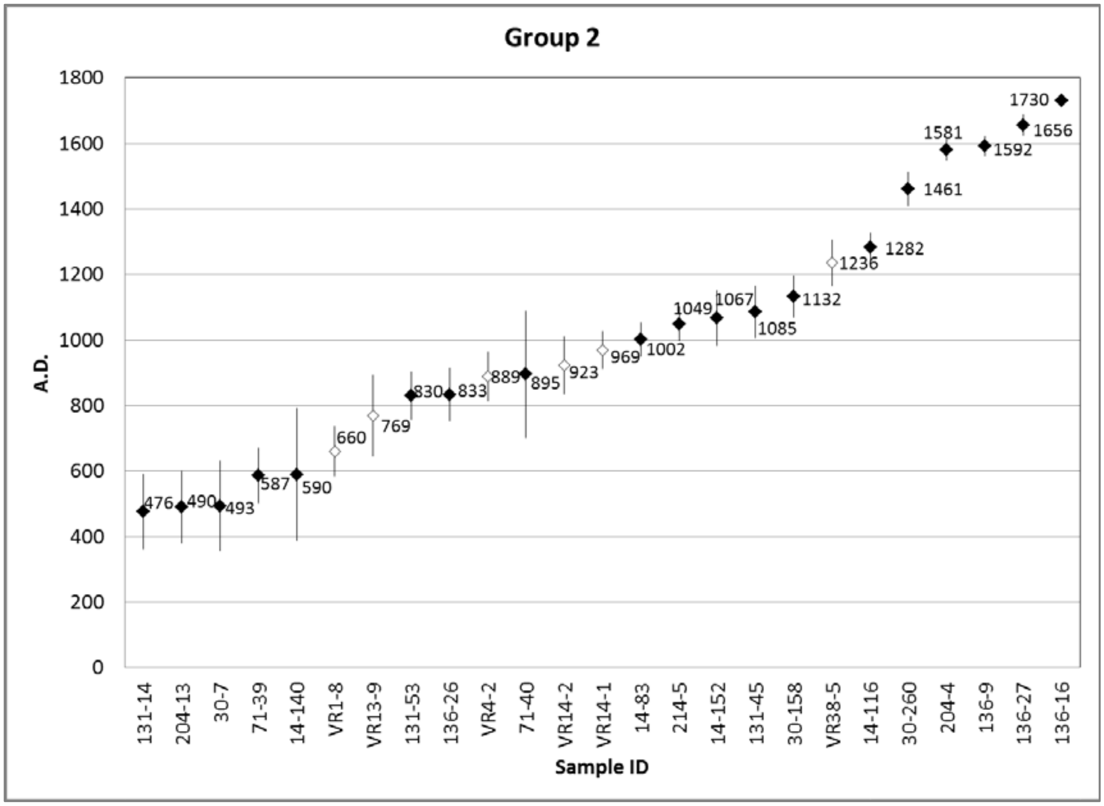


Figure 6.16. Distribution of OSL dates for sherds in Group 2. Black diamonds are the samples from Mt. Trumbull and white diamonds are the samples from the lowland Virgin.

1130, although the use of Group 1G continued (Figure 6.16). Considering the fact that more local clays are matched to Group 2 than Group 1G and that a dark core color suggests a shorter firing time at a lower temperature, the clay or clay preparation used for Group 2 may have been less expensive and resulted in lower-quality pots than pots made with Group 1G clay. As discussed, focusing on more intensified agriculture at a later time may have favored use of more resistant pots. Consequently, Group 2 clay was not favored during later times.

The distribution of OSL dates also suggests that a few sherds in this group date very late, after A.D. 1460 (Figure 6.16). As discussed above, these dates are valid and possibly represent after-depositional events such as the reuse of the pots or occupation by a later population at the site. Group 2 has a far higher frequency of very late dates than any other compositional group. In addition to reuse by a later population, there are two more possibilities can be considered. The one possibility is that the sherds with very late dates could be from Southern Paiute pottery, which also has a dark core. However, none of these sherds shows the features of the typical Southern Paiute sherds, which have a dark clay fabric with a very rough surface. The other possibility is related to the presumably lower quality of pottery made with Group 2 clay. The abandonment of Mt. Trumbull by the Ancestral Pueblo is still a controversial issue. Environmental factors such as prolonged droughts may have caused the Mt. Trumbull populations either to perish or to migrate eastward. If they migrated out of Mt. Trumbull, they may have carried their high-quality/more resistant pots with them and left the lower-quality pots behind. Thus, it is possible that the Ancestral Puebloans left more Group 2 pots than pots of any other group, and these abandoned pots could have been reused by the later occupants of the area. However, most of the sites where Group 2 sherds are found are open-air, not like rock shelters in Mt. Trumbull and it is unlike that the whole pots were left on surface and reused by the later occupants. Thus, the possibility of this circumstance (the Southern Paiute's reuse of the pots left by the Ancestral Pueblo) may be questionable, unless the abandonment of Ancestral Pueblo and the visit by the mobile Southern Paiutes happened almost simultaneously.

Group 1VM (Figure 6.17)

No clay was matched to Group 1VM, but this group is likely to be the Mt. Trumbull local group because Group 1VM includes only olivine-tempered sherds from Mt. Trumbull, and it is therefore difficult to imagine this group originating anywhere other than Mt. Trumbull. The sherds in this group have relatively light-colored cores, and they are of utilitarian and non-utilitarian wares (black-on-gray). All pots were used for domestic purposes, as discussed. Two sherds date relatively early (A.D. 569 ± 140 and A.D. 696 ± 105). However, these dates may or may not be their real ages, due to either a single aliquot being available or weak OSL signals. Indeed, one of the sherds with early data, 131-168, is evaluated as C for its validity (Appendix B: Table B4). Two of the samples date late (A.D. 1465 ± 43; evaluated as C and A.D. 1815 ± 32; evaluated as B) and these may not be valid dates either, for the same reasons. Thus, to be safe, the majority of the dates in Group 1VM occur around A.D. 1100–1300 (Pueblo II and III), which suggests the use of Group 1VM is relatively late. This pattern appears to be consistent with the longer use of Group 1G wares, which also have a lighter-colored core indicating longer firing to make more resistant pots.

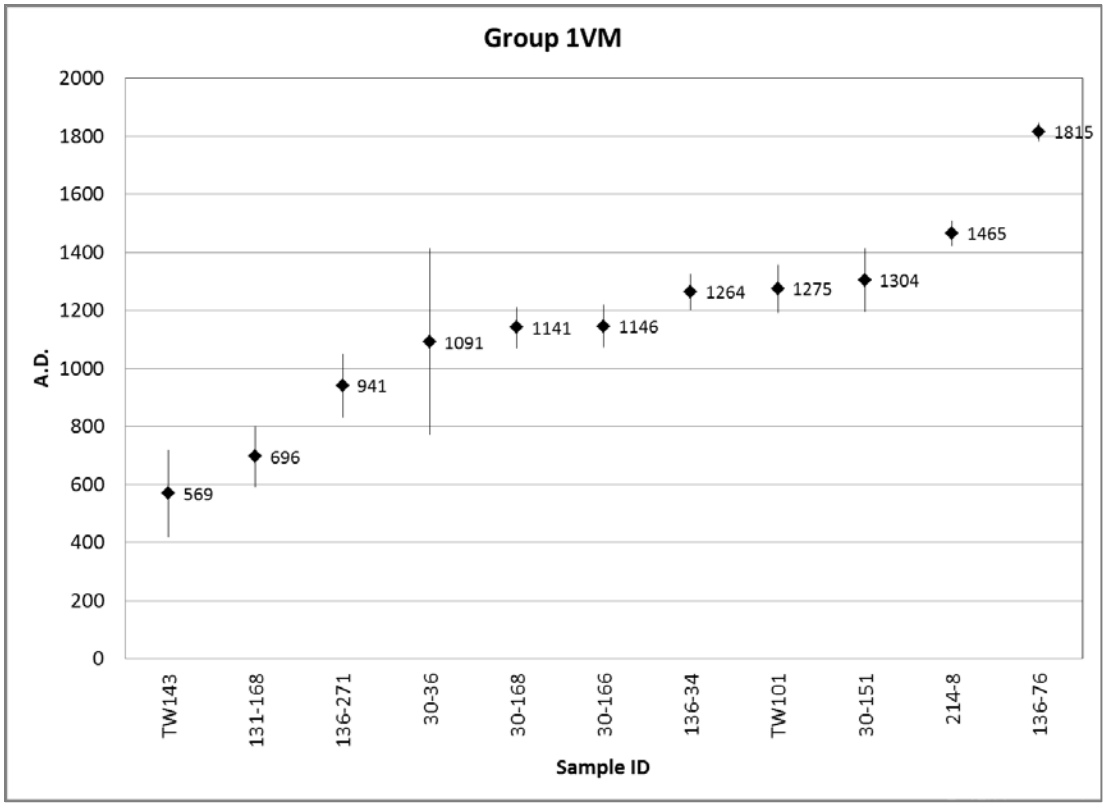


Figure 6.17. Distribution of OSL dates for sherds in Group 1VM.

Group 3 (Figure 6.18)

No clay was tested against Group 3 ceramic samples based on the Mahalanobis distance, as this group is too small for statistical analysis. However, Group 3 could be a Mt. Trumbull local group since all sherds in this group are from Mt. Trumbull and mostly used with olivine tempers. Group 3 sherds are very distinct chemically from any other groups, and they are mostly from one particular site (71 ASM) in Mt. Trumbull. There are two clusters of OSL dates in this group. One cluster is early, around A.D. 600–800, and the other is after A.D. 1000. The earlier dates are consistent with the ^{14}C dates for 71ASM.

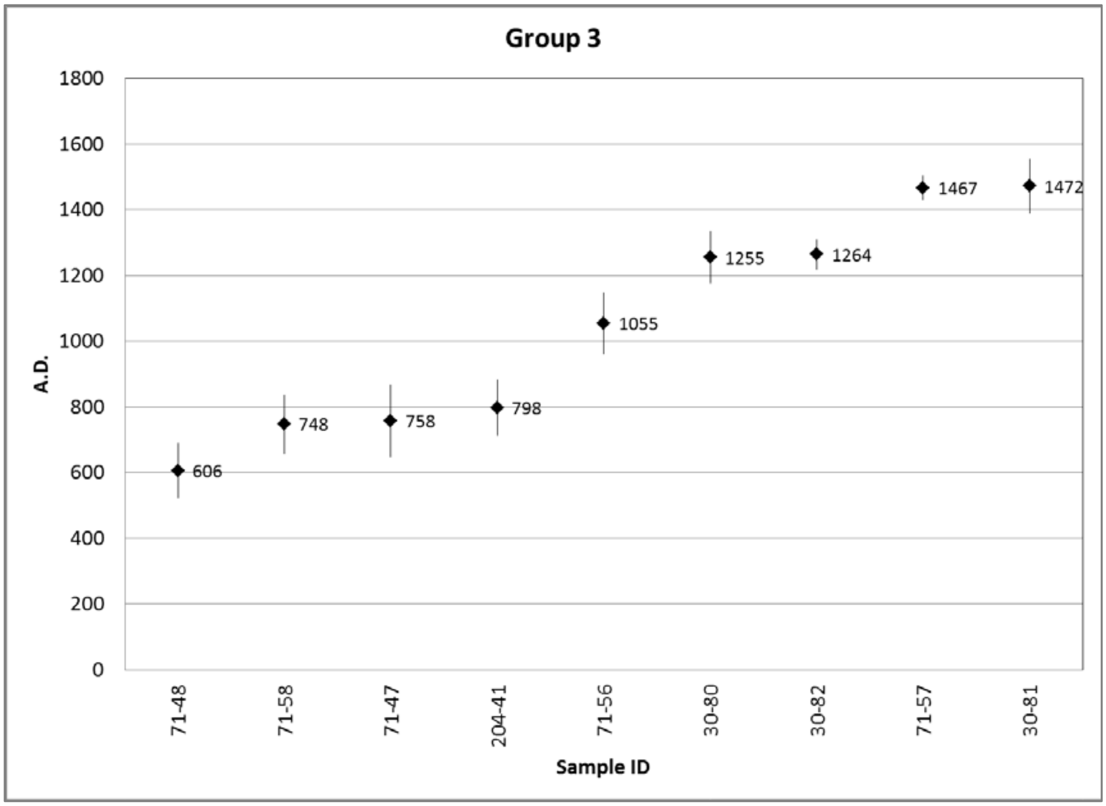


Figure 6.18. Distribution of OSL dates for sherds in Group 3.

Group 1VV (Figure 6.19)

Of the three lowland Virgin local groups, Group 1VV is the major one and is matched to the local clays in the lowland Virgin area. The clay of this group was used for multiple purposes, and the pots are both utilitarian and non-utilitarian ware used for domestic and trading purpose. The Group 1VV clay was used with olivine temper as well as with sand temper. The earliest date in this group is A.D. 569 ± 154; however, the remainder occurs after A.D. 800. Thus, the use of Group 1VV probably started around A.D. 800 and continued until A.D. 1200s. The distribution of the OSL dates suggests that Group 1VV clay was used mainly between A.D. 800

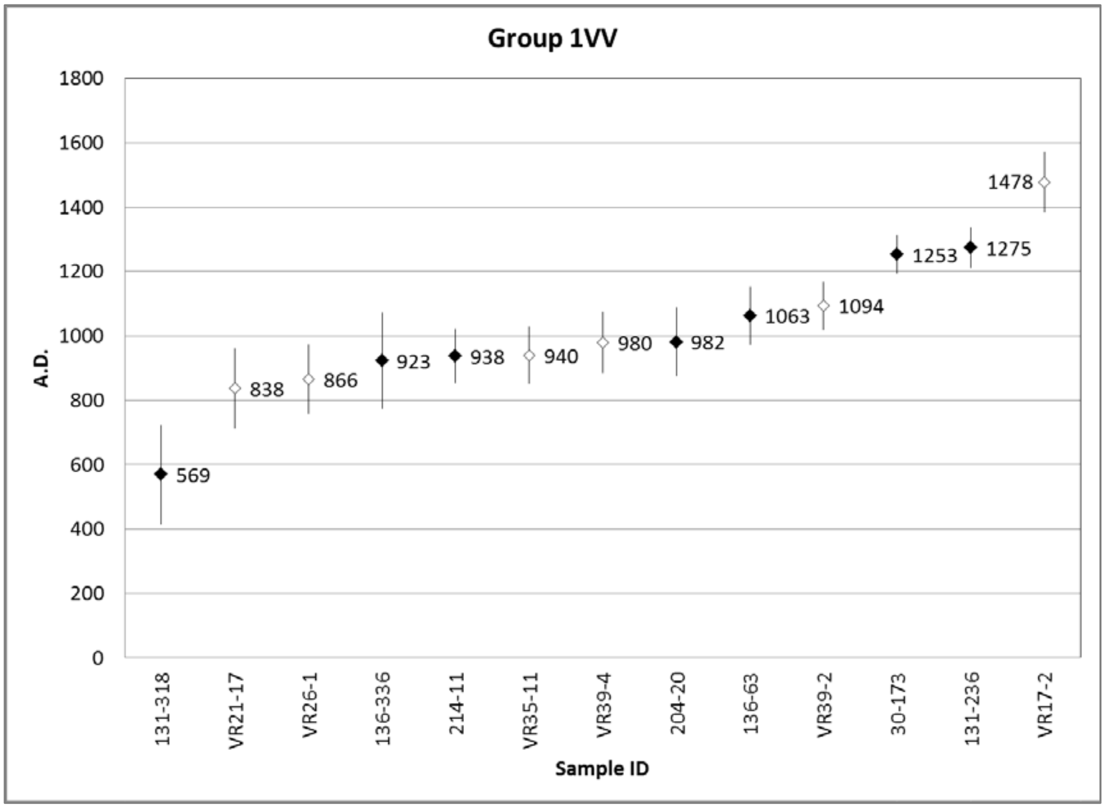


Figure 6.19. Distribution of OSL dates for sherds in Group 1VV. Black diamonds are the samples from Mt. Trumbull and white diamonds are samples from the lowland Virgin area.

and A.D. 1100 (Pueblo I and II) and that use decreased after A.D. 1100, when other groups became more important, as will be discussed later.

Group 4 (Figure 6.20)

Due to the small group size, no clay was tested against the ceramic composition of the Group 4 using the Mahalanobis distance. Several bivariate plots of elements did not show that Group 4 matched any of the clay samples. However, Group 4 may have been a lowland Virgin local group because almost all of the sherds in this group are from the lowland Virgin area and were used only with

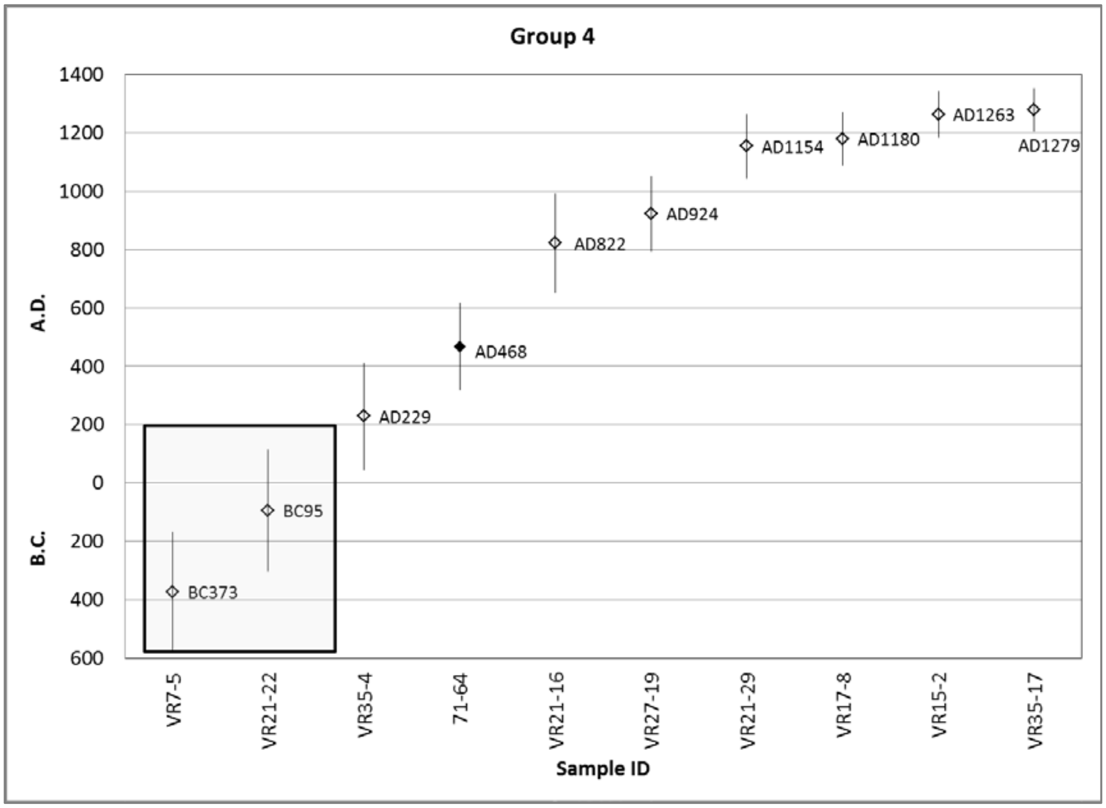


Figure 6.20. Distribution of OSL dates for sherds in Group 4. Black diamonds are the samples from Mt. Trumbull and white diamonds are samples from the lowland Virgin area. The two early dates (B.C. 373 and B.C. 95) within the rectangle appear to be outliers, and they were excluded the analysis of the compositional groups and temporal variation.

olivine temper, as discussed in the previous chapter. Two extremely early dates (373 ± 206 B.C. and 95 ± 207 B.C.) should be excluded from the examination of compositional groups and time because they are far earlier than the expected dates and do not agree with other OSL dates from the same site. The distribution of OSL dates suggests the use of Group 4 started early and increased over time. It also shows that OSL dates in Group 4 are mainly later, after A.D. 1100. Interestingly, this is the time when the use of Group 1VV ceased. As will be discussed later, another lowland Virgin group, VR3, was exclusively used with sand temper, and the use of this group was also concentrated after A.D. 1100. The use of Group 1VV, which was used for multiple purposes, was replaced around A.D. 1100 with Group 4, used only with olivine temper, and VR3, used only with sand temper. This indicates that use of clay for different purposes became more selective later in time in the lowland Virgin area and that the time needed for clay procurement and preparation to make pottery became optimized.

The core color of Group 4 is relatively light, which implies long firing times (Figure 6.10). In addition, Group 4 ceramics do not chemically overlap with any of the collected clays, which suggests that the clay used for Group 4 underwent further clay preparation to change its chemical characteristics. Thus, the clay used for Group 4 or the preparation may have been more expensive, but its better quality would have decreased the failure rate of pottery during production. The chemical signatures of sherds in VR3, on the other hand, were matched to multiple local clays in the lowland Virgin area based on INAA, and clay samples were analyzed without preparation in INAA study. Thus, it is possible that more expensive clay was used for pottery production with expensive imported olivine temper to avoid breakage during production and use, while easily accessed clay without special preparation was used with sand temper, which is also easy to obtain in the lowland Virgin area.

VR3 (Figure 6.21)

As discussed, the VR3 sherds were matched to the local clays in the lowland Virgin and thus this is a lowland Virgin local group used exclusively with sand

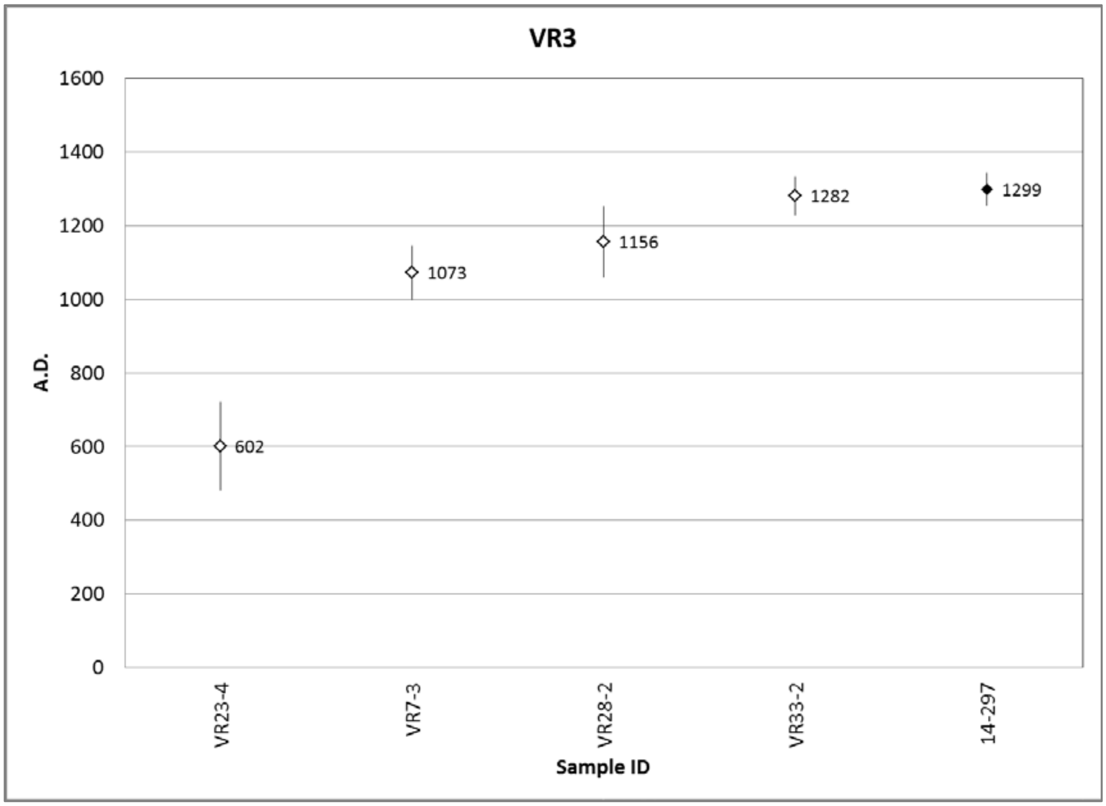


Figure 6.21. Distribution of OSL dates for sherds in VR3. The black diamond is the sample from Mt. Trumbull and white diamonds are the samples from the lowland Virgin area.

temper. The earliest date for VR3 sherds is A.D. 602 ± 121, but more dates are clustered after approximately A.D. 1100, which suggests the replacement of Group 1VV with VR3 and Group 4 for various purposes, as discussed.

VR1 (Figure 6.22)

The source of VR1 pots is unknown. The VR1 sherds were found in both Mt. Trumbull and the lowland Virgin area, but they were not produced in either area. The sherds in this group are mostly black on gray with a very light color core and very fine quartz temper. Thus it is possible that populations in the Mt. Trumbull and

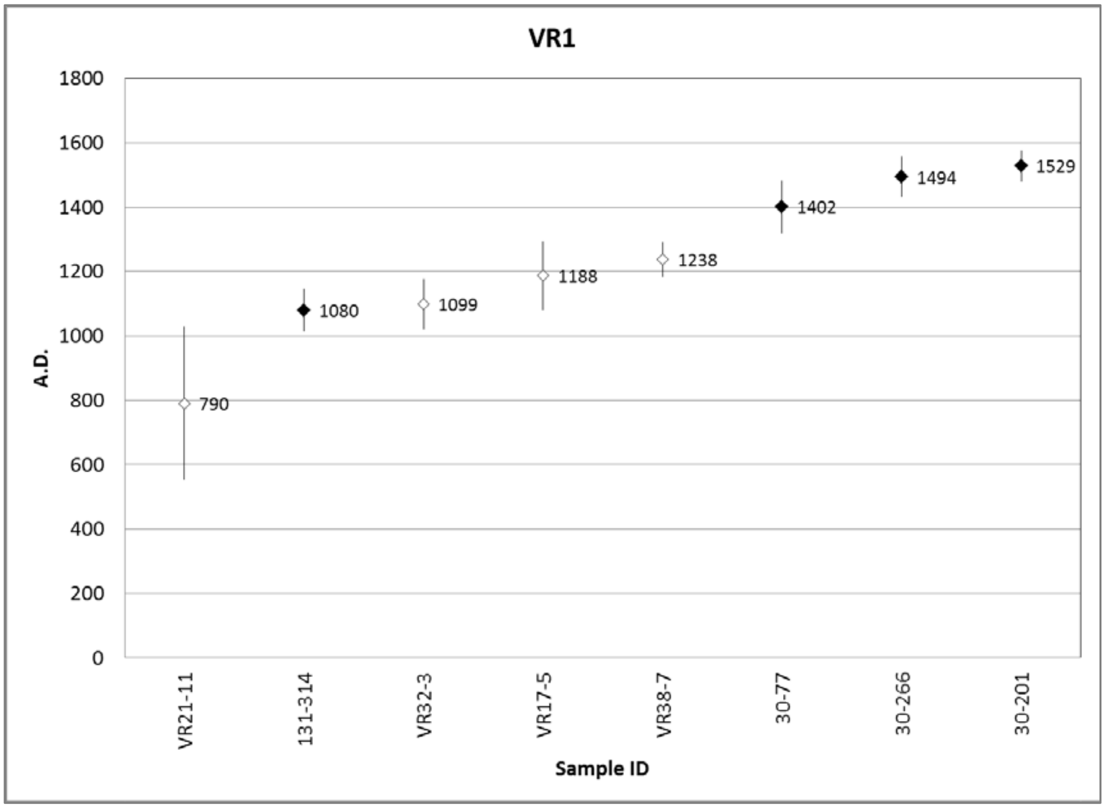


Figure 6.22. Distribution of OSL dates for sherds in VR1. Black diamonds are the samples from Mt. Trumbull and white diamonds are the samples from the lowland Virgin area.

the lowland Virgin areas shared trading partners to import the fine black-on-gray pots. The distribution of OSL dates suggests that the dates of VR 1 are clustered after A.D. 1050. Note also that three of the sherds in the VR1 group date late, after A.D. 1400, and all of them were found at the same site in Mt. Trumbull (30BLM), as discussed in the previous chapter.

In summary, the OSL dates of the 109 sherds demonstrated the changes over time in the uses of clay and/or clay preparation techniques represented by the compositional groups. In the next chapter, I will discuss how the production and distribution pattern of pots changed over time by combining the results of the compositional analysis and OSL dating.

Chapter VII: DISCUSSION

This chapter explores the implications of compositional and OSL dating results for spatial and temporal variations in olivine-tempered ceramic production and circulation patterns of the Mt. Trumbull (this category includes Tuweep) and the lowland Virgin areas. Results are examined for the entire study region (Mt. Trumbull and the lowland Virgin), for the Mt. Trumbull area alone, and for the lowland Virgin area alone. For each geographic area, production patterns are addressed by describing changes over time in how local potters used clay and temper resources. Consumption patterns are addressed by examining changes over time in the places where locally consumed pots originated.

Ultimately, the goal of this study is to understand why ceramic production and circulation patterns changed during the Ancestral Pueblo occupation of this peripheral area of the American Southwest and to understand how different forms of social interaction were favored as risk minimization strategies. As outlined in Chapter III, the basic assumption of the study is that ceramic production and circulation were shaped by selection acting on choices of pottery producers and consumers. Selection pressures would have originated in the social environment as well as in the natural environment, the latter including such conditions as variability in moisture availability for agricultural production and the different availability and quality of ceramic resources in different locations and times, and choice of different clays and tempering materials. At the most general level, severe climatic downturns may have decreased agricultural production to the point that populations would have decreased across the whole region, with consequent reductions in ceramic production and trade. It may also be expected that different conditions in the Mt. Trumbull and lowland Virgin areas would have led to different trajectories of ceramic production and circulation in these two areas.

Trends in Ceramic Production and Circulation at the Macro-Regional Scale

As the first examination I will focus on the ceramic production and circulation pattern involving a large geographic region to understand economic/social interaction between distant areas in different environments.

Production and Circulation of All Ceramics

At a broad geographic scale, encompassing both Mt. Trumbull and the lowland Virgin areas, the OSL dates indicate that humans began producing and moving ceramics across the landscape by around A.D. 400 (Table 7.1 and Figure 7.1). Since a few sherds date to the A.D. 200s, the beginning of pottery production in the region may have been earlier. The number of OSL dates indicates that the population of pottery producers and consumers generally increased after A.D. 400, with the peak between A.D. 1200 and 1300. In addition, there are two phases between A.D. 600 and 700 and between A.D. 1100 and 1200 that raise the possibility that population decreased, based on the frequency of OSL dates. These two phases of population decrease seem to correspond to times of fluctuating

Table 7.1. Frequency of sherds by time interval and compositional group (Mt. Trumbull and the lowland Virgin area).

	Group 1G	Group 1VM	Group 2	Group 3	Group 1VV	Group 4	VR3	VR1	Total
after A.D. 1600	0	1	1	0	0	0	0	0	2
A.D. 1600-1699	1	0	1	0	0	0	0	0	2
A.D. 1500-1599	0	0	2	0	0	0	0	1	3
A.D. 1400-1499	1	1	1	2	1	0	0	2	8
A.D. 1300-1399	5	1	0	0	0	0	0	0	6
A.D. 1200-1299	3	2	2	2	2	2	2	1	16
A.D. 1100-1199	4	2	0	0	0	2	1	1	11
A.D. 1000-1099	1	1	5	1	2	0	1	2	13
A.D. 900-999	1	1	2	0	5	1	0	0	10
A.D. 800-899	2	0	3	0	2	1	0	0	7
A.D. 700-799	2	0	2	3	0	0	0	1	7
A.D. 600-699	0	1	1	1	0	0	1	0	5
A.D. 500-599	4	1	2	0	1	0	0	0	8
A.D. 400-499	2	0	3	0	0	1	0	0	6
A.D. 300-399	1	0	0	0	0	0	0	0	1
A.D. 200-299	1	0	0	0	0	1	0	0	2
before A.D.200	0	0	0	0	0	2	0	0	2
Total	28	11	25	9	13	10	5	8	109

climatic conditions occurring between A.D. 600 and 700 (Sakai 2001) and the prolonged drought around A.D. 1150 (Larson et al. 1996) (Figure 7.32).

The OSL dates suggest also that the peak usage of the different clay resources differed over time. Whereas Group 1VV peaked around A.D. 900–1000, Group 2 resources were utilized before A.D. 1100 but decreased thereafter. Group 1G was the dominant clay group during A.D. 1300–1400. As discussed in the previous chapter, OSL dates that fall after A.D. 1400 are more likely the result of after-deposit events. The absence of post-A.D. 1400 sherds in the lowland Virgin area may indicate that occupation ended before A.D. 1400.

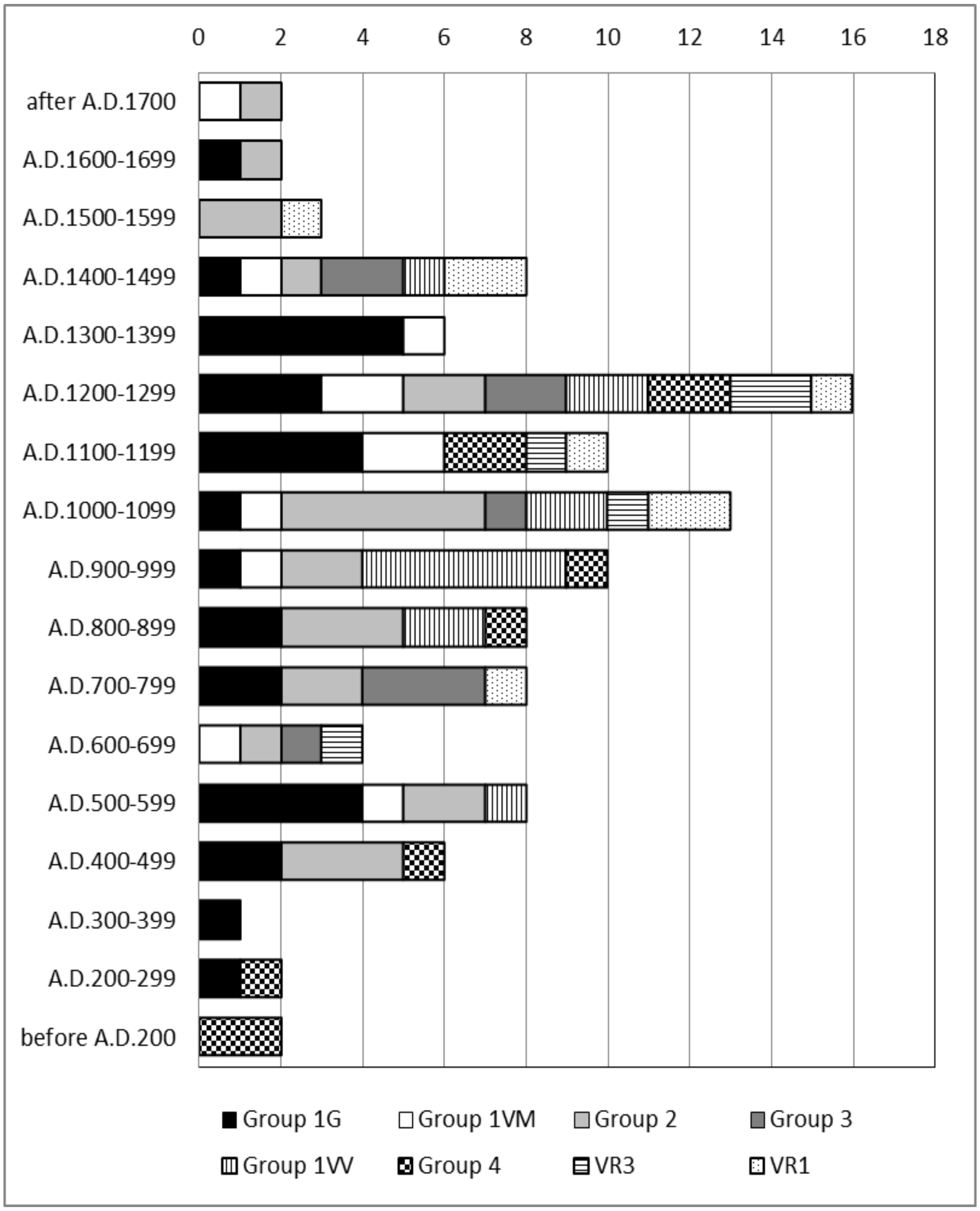


Figure 7.1. Frequency of sherds by time interval and the compositional group.

Figure 7.2 displays the use of olivine temper over time in the study area. More olivine-tempered sherds than sand-tempered sherds were analyzed in this study, so the proportions do not reflect the actual proportions of olivine versus sand temper in the whole pottery assemblage. However, it is clear that the use of the olivine as temper decreased over time in the region as a whole.

Figure 7.3 shows how the use of clay sources and clay preparation techniques changed over time, using large chronological categories of the Pecos Classification. I expect that using large chronological units gives us a broad picture of how clay resource procurement changed over time across the study area as a whole. This figure shows that the use of Group 2, one of the major Mt. Trumbull local groups, was important during the Late Basketmaker to Pueblo II periods, but that it decreased during the Pueblo III period. Group 1G, the other major Mt. Trumbull local group, was dominant early, decreased during the Pueblo I and II periods, and increased again during the Pueblo III period to become a dominant clay group. The use of Group 1VM, which is also a Mt. Trumbull local group, gradually increased over time and reached a peak during the Pueblo II period.

Only a few sherds assigned to a lowland Virgin source date to the Late Basketmaker period. Group 1VV, which is a major lowland Virgin group, was at its peak during the Pueblo I period and became one of the dominant clay groups at this time.

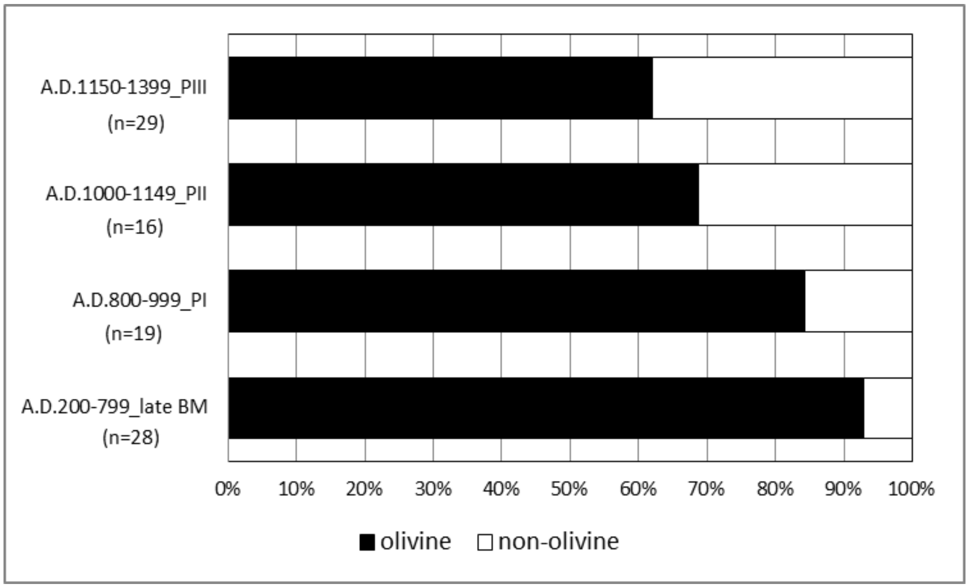


Figure 7.2. Percentage of all sherds from both Mt. Trumbull and the lowland Virgin areas by time period and temper type. Sherds dating after A.D. 1400 and before A.D. 200 are excluded (n = 92). Late BM: Late Basketmaker period, PI: Pueblo I, PII: Pueblo II, PI: Pueblo III (these abbreviations are used for following figures as well).

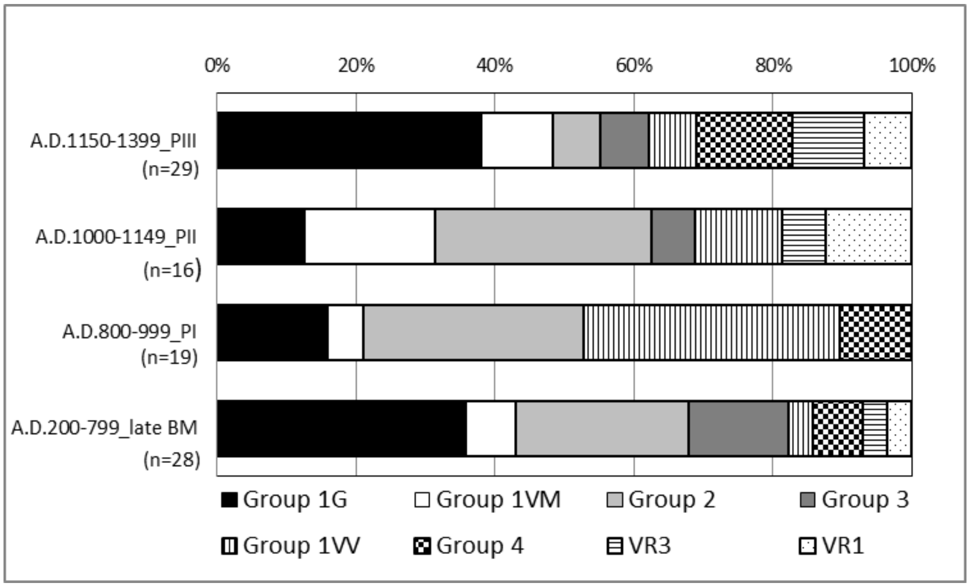


Figure 7.3. Percentage of all sherds (olivine and non-olivine) by time period and compositional group. Sherds dating after A.D. 1400 and before A.D. 200 are excluded. (n = 92).

The distribution of OSL dates shows that the number of compositional groups changed over time. The Late Basketmaker samples include all eight compositional groups, but for the following comparison Groups 1VV, VR3, and VR1 are excluded from the Late Basketmaker period because each is represented by only a single sherd. With these remaining Late Basketmaker samples, the number of compositional groups increases over time until all eight groups are found in the Pueblo III period.

During the Late Basketmaker period, all Mt. Trumbull local clays except Group 3 were evenly used. This may suggest that earlier potters did not systematically select clay for different purposes, but instead chose clay from areas adjacent to their habitation area. Later, during Pueblo III, Groups 1G and 4 became the dominant clay groups, and both clays are good quality. Thus, during Pueblo III, optimal clays were preferred for pottery production over expediently available clays.

The total output of Mt. Trumbull and the lowland Virgin potters is compared in Figure 7.4. The distribution of OSL dates suggests that local production in the lowland Virgin area increased during Pueblo I (A.D. 800–1000) and decreased during Pueblo II (A.D. 1000–1150). Previously, it was shown (Figure 6.12) that the population in the lowland Virgin area increased during the A.D. 800s and remained stable until A.D. 1300 based on the distribution of the OSL dates of the sherds. It is therefore not surprising that more pots were produced locally to meet rising demand from increasing population after A.D. 800. However, local production was lower between A.D. 1000 and 1150 in the lowland Virgin area, even though the population

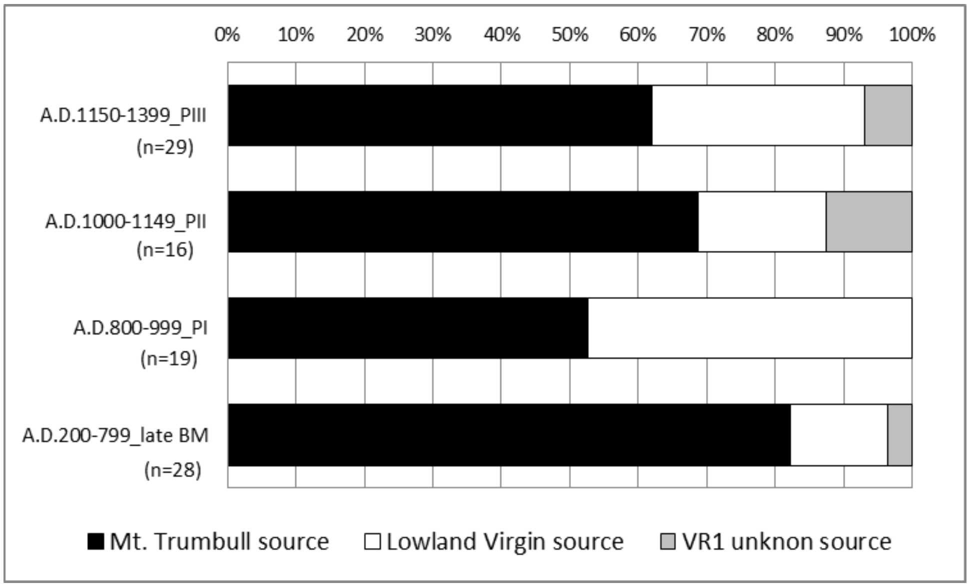


Figure 7.4. Percentage of all sherds by time period and geographic source. Sherds dating after A.D. 1400 and before A.D. 200 are excluded. (n = 92).

apparently remained high. One possible reason why local ceramic production declined during this period is that enhanced opportunities for agriculture favored a shift away from ceramic production among Lowland Virgin people, considering that climatic condition was relatively wet (Larson et al. 1996). In Mt. Trumbull, climatic events apparently had less impact on agricultural practices, and other activities, such as pottery production, continued at their earlier levels, with some of the output apparently flowing into the Lowland Virgin area. In other words, excess pots produced in Mt. Trumbull could have been exported to the lowland Virgin area in exchange of other commodities that were likely obtained more easily in the lowland Virgin area, such as salt or cotton. As well, people who made pottery with the VR1 group clay, coming from an unknown source area, became trading partners for both Mt. Trumbull and the lowland Virgin area during Pueblo II. Thus, an expanded trading network seems to have stimulated more intensive agriculture, keeping the lowland Virgin farmer away from non-agricultural activities such as pottery production. This is one way in which selection acted on regional economic environment in order to shape ceramic production and circulation patterns at the macro-regional scale.

Production and Distribution of Olivine-Tempered Ceramics

Figures 7.5 and 7.6 present changes at the macro-regional scale only for olivine-tempered ceramics. All six compositional groups used for olivine-tempered ceramics were present during the Late Basketmaker period (Figure 7.6). Group 1G decreased during Pueblo I and II period but became the dominant group during Pueblo III. The use of Group 1VM increased over time. Group 2 was constantly high until Pueblo II, but seems to have been replaced later by Group 1G and 1VM. This pattern suggests that the use of optimal clay for production of olivine-tempered ceramics increased over time, and only good quality clays (Groups 1G, 1VM, and 4) were used for the production of olivine-tempered pots during the latest time period, Pueblo III. If Groups 2 and 3 are excluded from the Pueblo III sample (each represented by only a single sample), the number of compositional groups represented among the olivine-tempered ceramics shows a clear decrease over time.

The OSL dates and sources of the olivine-tempered sherds suggest that most of the olivine-tempered pots were produced in Mt. Trumbull during early time periods. Also, olivine-tempered ceramic production started early in the lowland

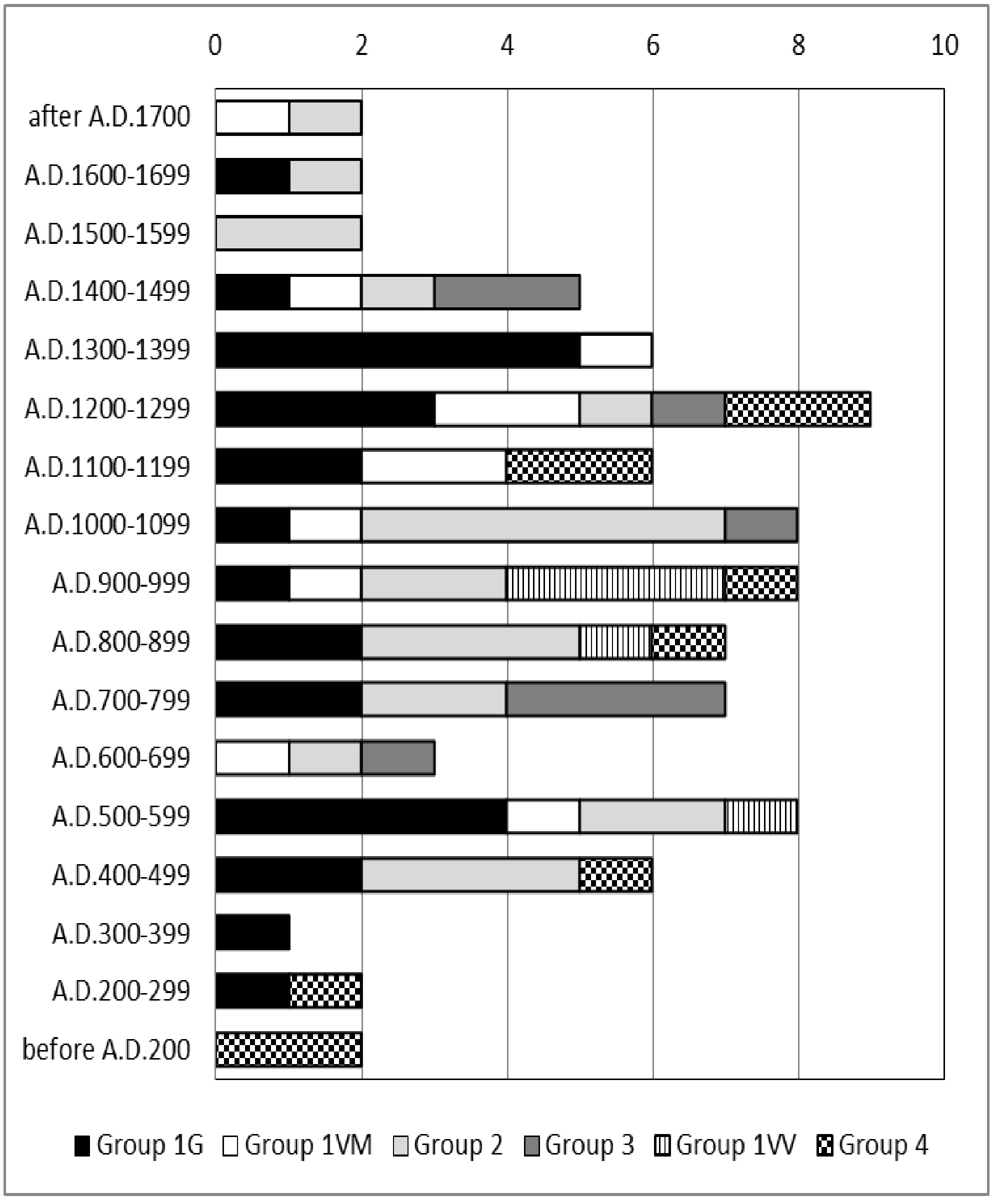


Figure 7.5. Frequency of olivine-tempered sherds by time interval and compositional group (Mt. Trumbull and Lowland Virgin).

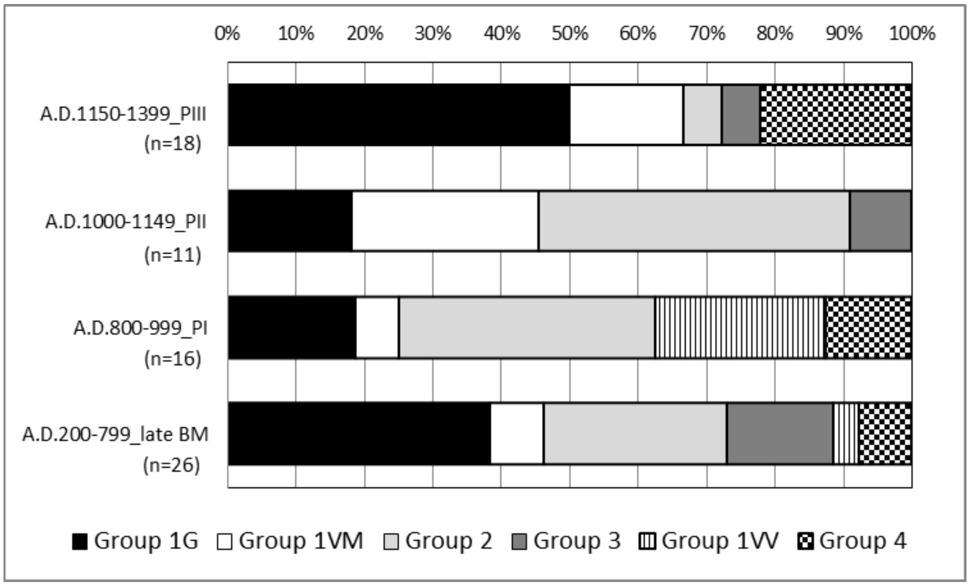


Figure 7.6. Percentage of olivine-tempered sherds by time period and compositional group (Mt. Trumbull and Lowland Virgin). Sherds dating after A.D. 1400 and before A.D. 200 are excluded (n = 71).

Virgin area and increased during the Pueblo I period. Interestingly, there was no olivine-tempered ceramic production in the lowland Virgin area during the Pueblo II period, although local olivine-tempered ceramic production began again during the Pueblo III period but with only one clay source (Group 4) represented (Figure 7.6). As discussed above, ceramic production declined in the lowland Virgin area during Pueblo II, and the ceramics that were made locally were tempered with sand, an easier-to-obtain temper in the lowland Virgin area. This absence of the use of the expensive, imported olivine temper during Pueblo II also supports the proposition that Lowland Virgin people shifted away from pottery production to maximize the investment of time in agricultural activities during this period.

Production and Distribution of Sand-Tempered Ceramics

Although fewer sand-tempered sherds were analyzed than olivine-tempered sherds, the distribution of OSL dates nonetheless suggests that the use of sand

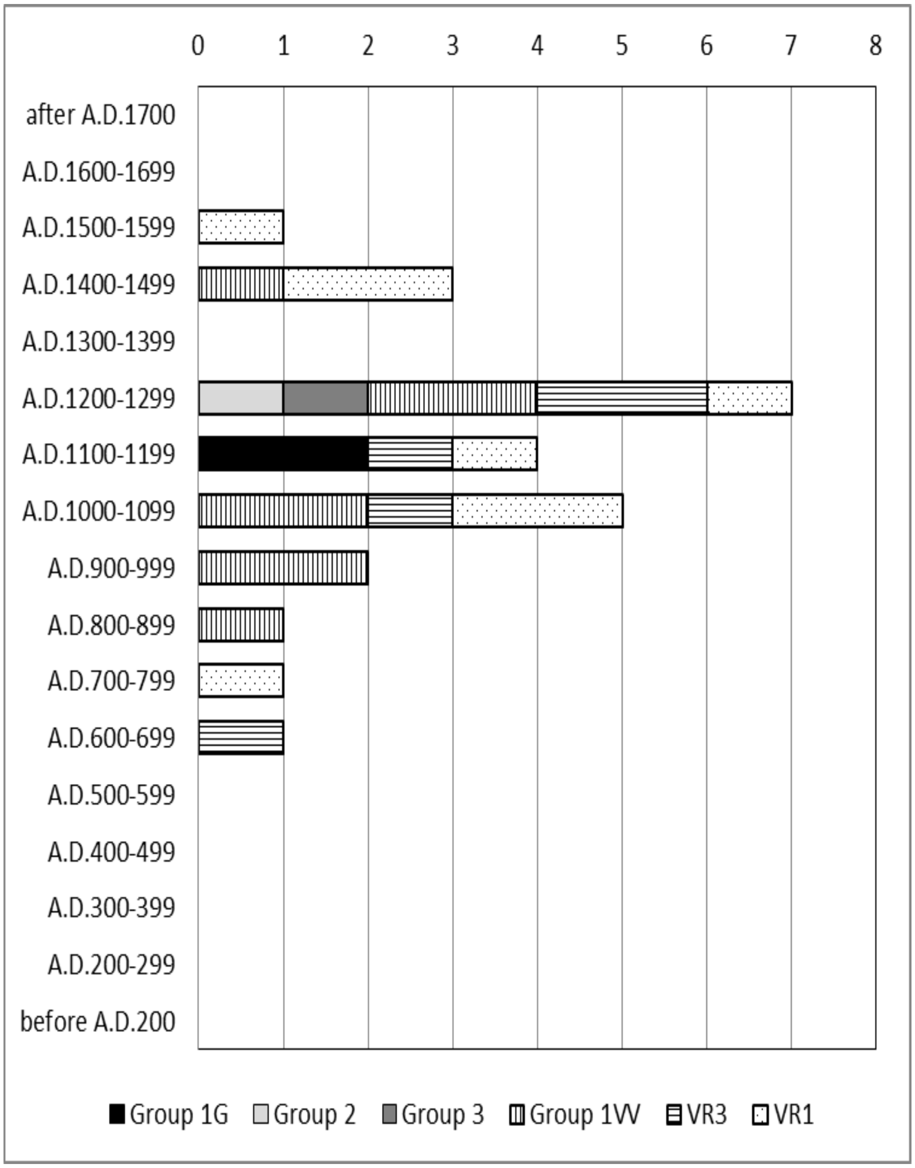


Figure 7.7. Frequency of sand-tempered sherds by time interval and compostional groups (Mt. Trumbull and Lowland Virgin).

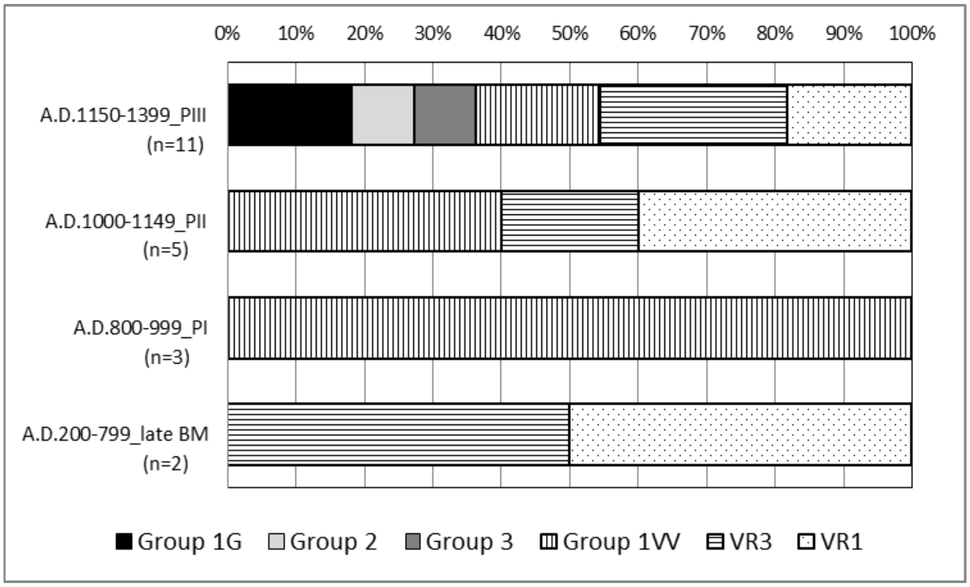


Figure 7.8. Percentage of sand-tempered sherds by time period and compostional group (Mt. Trumbull and Lowland Virgin). Sherds dating after A.D. 1400 and before A.D. 200 are excluded (n = 21).

temper started relatively late in the study area and increased over time, with a peak between A.D. 1200 and 1300, at least with respect to this data set (Figure 7.7). The data also suggest that more clay sources were involved in the later production of sand-tempered ceramics in the study area as a whole (Figure 7.8).

Trends in Ceramic Production and Circulation in Mt. Trumbull

The distribution of OSL dates demonstrated that there are regional trends of the use of the clay resource/recipe and circulation of the ceramics at a macro-regional level. To investigate which social interaction forms were involved in the production and circulation of ceramics, the trend is examined in small geographic scale as discussed above. First I examine the pattern in Mt. Trumbull where the majority of ceramics produced have olivine tempers.

Ceramic Production Pattern in Mt. Trumbull

During the early part of the sequence (Late Basketmaker through Pueblo II), all Mt. Trumbull ceramics were tempered with olivine (Figure 7.9), and sand temper was used only during Pueblo III.

The distribution of OSL dates of the sherds sourced to Mt. Trumbull shows how clay resource use changed over time in Mt. Trumbull (Figure 7.10). The figure suggests increase in the use of optimal clays for ceramic production (Groups 1G and 1VM) between the Pueblo I and Pueblo III periods, as was also recognized in the

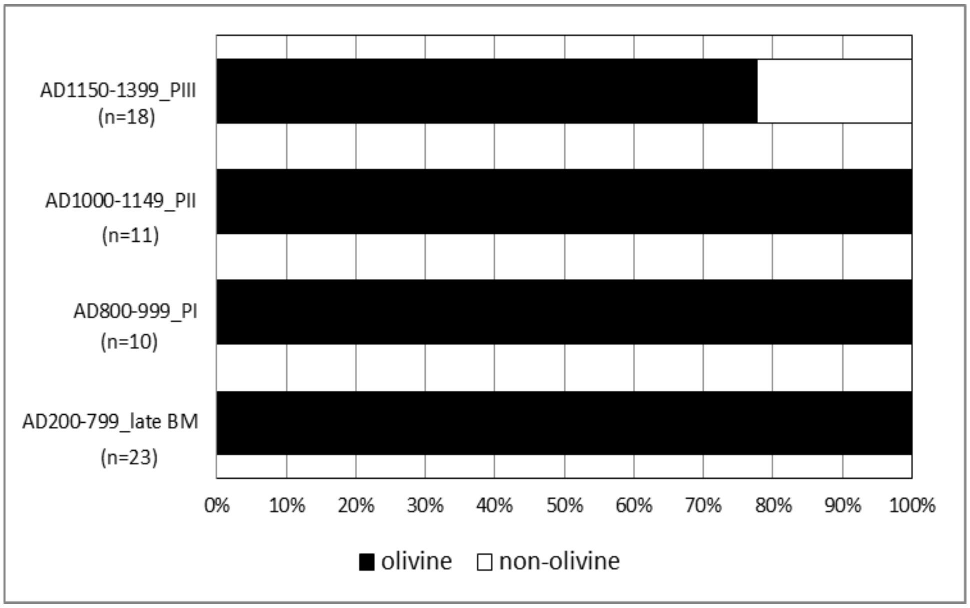


Figure 7.9. Percentage of all sherds produced in Mt. Trumbull Source by time period and temper type. Sherds dating after A.D. 1400 are excluded (n = 62).

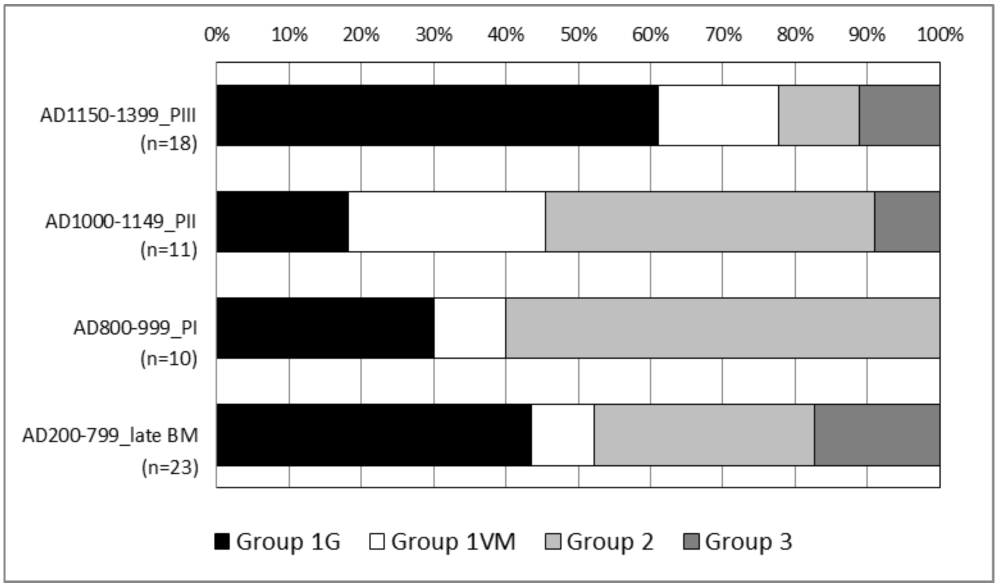


Figure 7.10. Percentage of all sherds produced in Mt. Trumbull (olivine and non-olivine) by time period and compositional group. Sherds dating after A.D. 1400 are excluded (n = 62).

discussion of ceramic production in the entire areas. Group 1G was a dominant clay group early during the Late Basketmaker period and its use decreased thereafter, but it became the single dominant clay group again during the Pueblo III period. The use of Group 1VM increased over time, too. The ceramics in Groups 1G and 1VM seem to be more durable because of better quality clays and/or better clay preparation. These optimal clays were increasingly used for ceramic production in Mt. Trumbull, and almost 80% of the pottery was made with these optimal clays during Pueblo III, regardless of the intended use of the vessels.

The distribution of OSL dates of sherds from Mt. Trumbull sources (Figure 7.10) also shows that all four local clay groups available in Mt. Trumbull were utilized during most time periods, with the exception of Pueblo I. Group 1G is a multiple-purpose clay used for both domestic and traded vessels and for utilitarian and non-utilitarian ware. Group 2 was used for utilitarian ware, and Groups 1VM and 3 were used for only domestic consumption. These observations suggest that clay resource selection was involved in some of the pottery production in Mt. Trumbull. Although Groups 1G and 2 were used for trading and domestic purposes during early times, especially before A.D. 600, only Group 1G was used for the pots transported to the lowland Virgin area, and Group 2 was used for pots consumed domestically. Thus, clay-resource specialization began soon after people began producing ceramics in Mt. Trumbull. On the other hand, clay-resource specialization for pots intended for transport was not emphasized as much later on. During Pueblo I and II, the use of the multiple-purpose clay (Group 1G) decreased, and the use of Groups 2 (for mostly utilitarian ware) and 1VM (exclusively consumed locally) increased. This suggests that clay-resource specialization for trade vessels was less emphasized but that clay-resource specialization for daily use and local consumption was more emphasized.

Ceramic Consumption Patterns in Mt. Trumbull

I will investigate how the ceramic consumption pattern changed in Mt. Trumbull, examining how the source of all ceramics, olivine-tempered ceramics, and sand-tempered ceramics changed independently.

<u>All Ceramics</u>

The distribution of OSL dates for ceramics consumed in Mt. Trumbull suggests that, with the possible exception of Pueblo I, non-local ceramics were always a small proportion of the total (Figures 7.11 and 7.12). Pueblo I is also the time when clay resource specialization for trade ware declined in Mt. Trumbull (Figure 7.10) and when local production in the lowland Virgin area increased (Figure 7.4), as I discussed above. Considering the fluctuating climatic conditions during Pueblo I, increased imports from the lowland Virgin area to Mt. Trumbull are not likely the result of local specialization and exchange, but rather the result of pots moving with migrants from the lowland Virgin area to Mt. Trumbull.

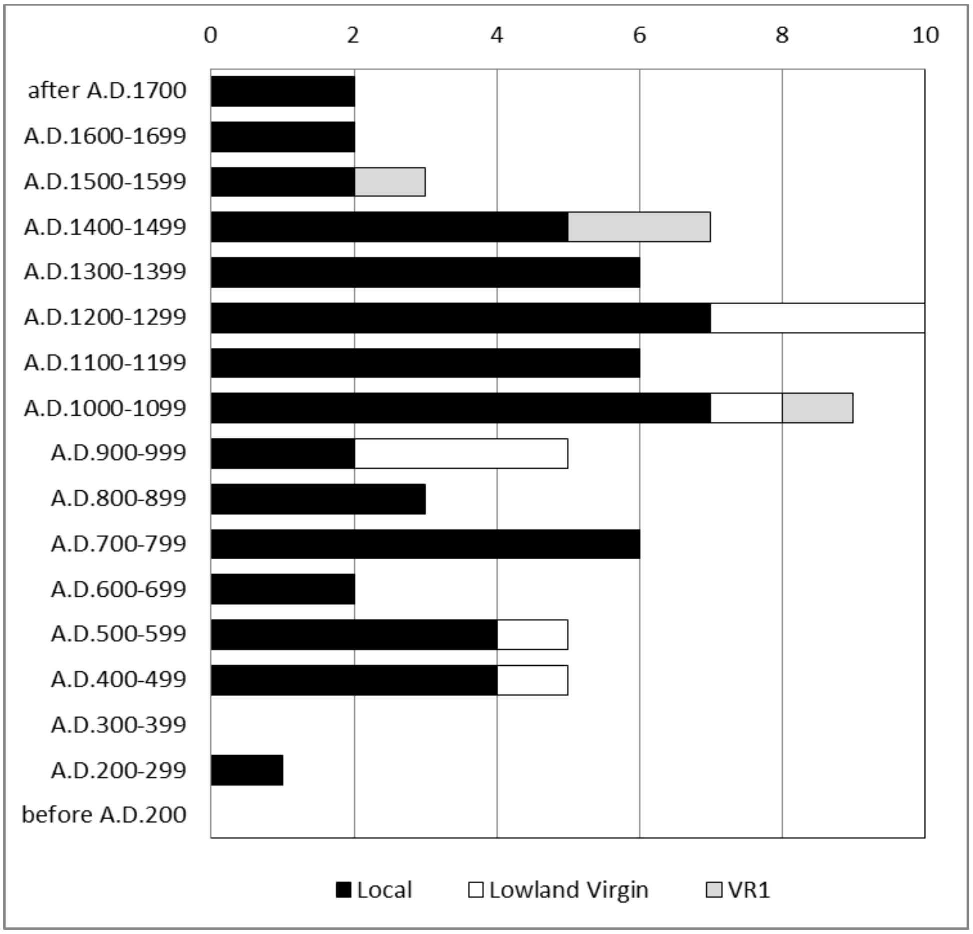


Figure 7.11. Frequency by time interval of local vs. non-local wares represented among sherds from Mt. Trumbull.

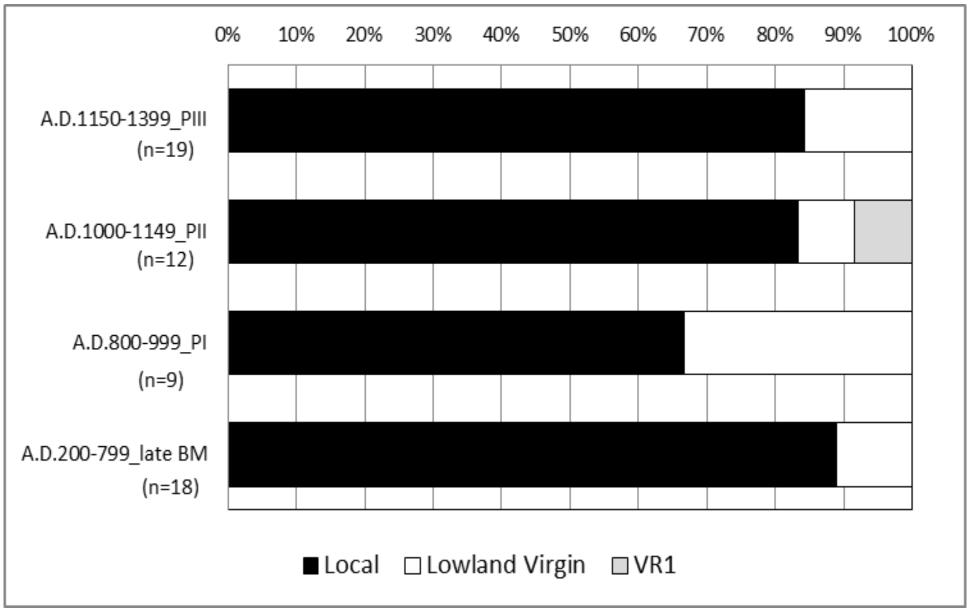


Figure 7.12. Percentage of local vs. non-local wares by time period represented among sherds from Mt. Trumbull. Sherds dating after A.D. 1400 are excluded (n = 58).

The changes in non-local ware (Figure 7.12) suggest that the pots with a lowland Virgin origin were present during all time periods in Mt. Trumbull, while VR1 pots were found only during Pueblo II (A.D. 1000–1150). Considering that Pueblo II was a period of generally wet and favorable climate, especially between A.D. 1050 and 1120 (Figure 7.32), the addition of ceramics from a new source to the Mt. Trumbull assemblage may suggest that trade networks were extended during Pueblo II.

Figures 7.13 and 7.14 show specific source assignments of all ceramics consumed in Mt. Trumbull. The number of compositional groups decreases only during Pueblo I. Six compositional groups were present during the other time periods, but the combination of compositional groups changed.

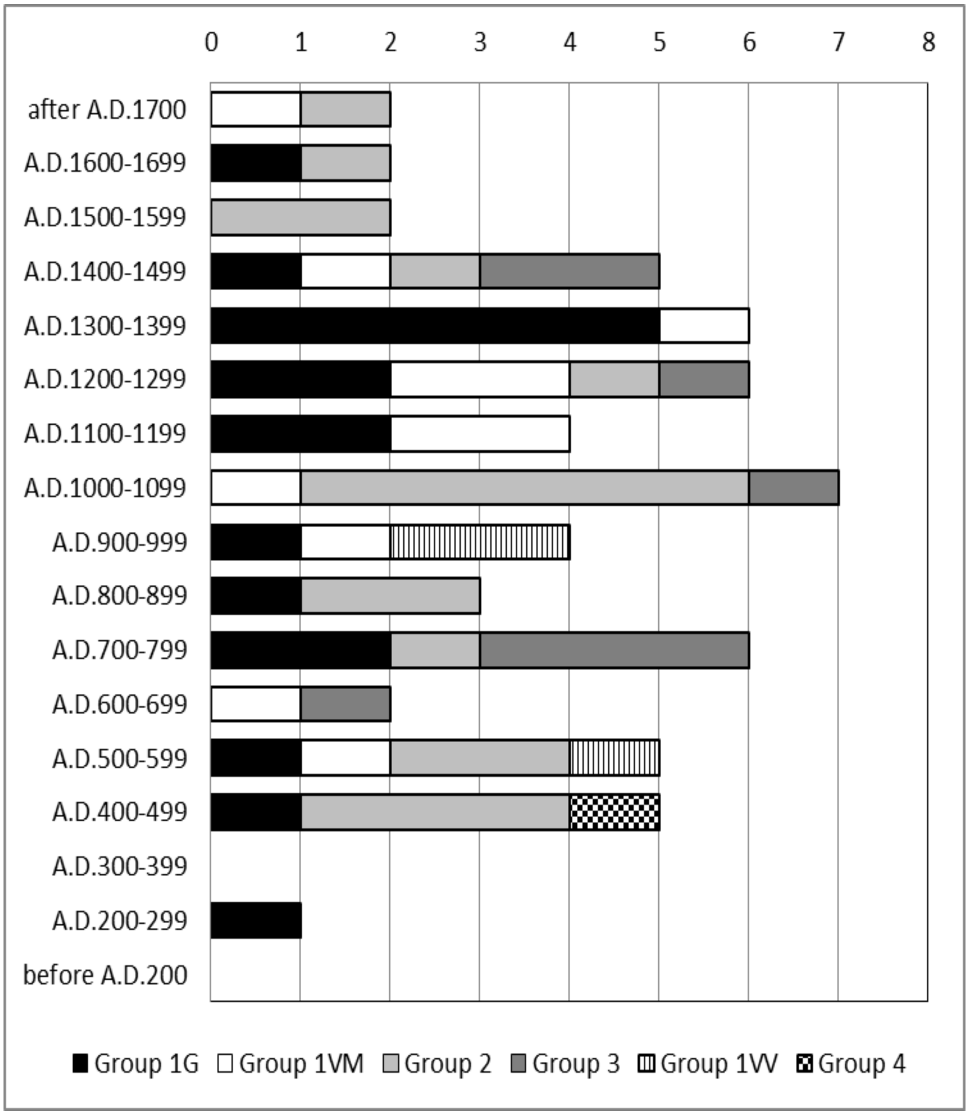


Figure 7.13. Frequency of all Mt. Trumbull sherds (olivine and sand temper) by time interval and compositional group.

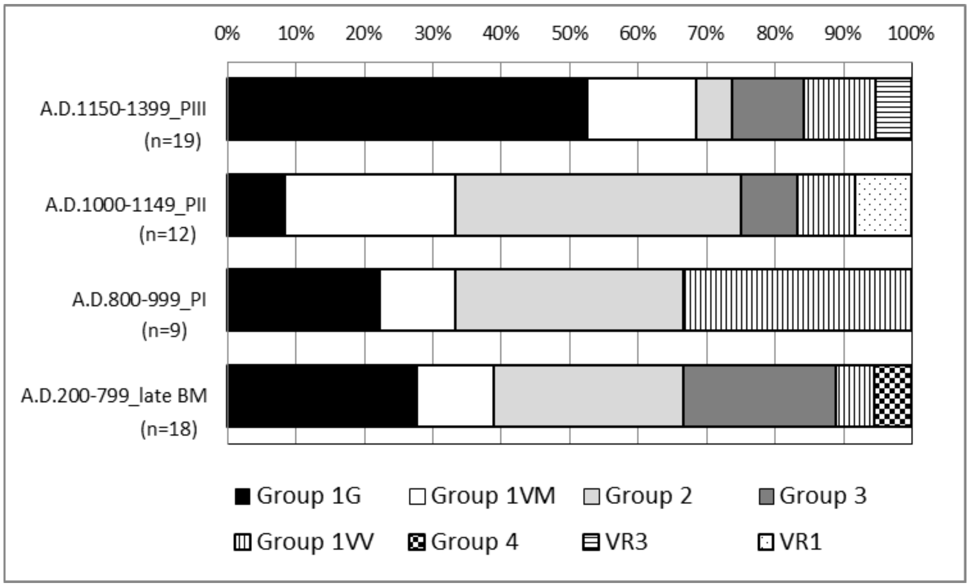


Figure 7.14. Percentage of all Mt. Trumbull sherds (olivine and sand temper) by time period and compositional group. Sherds dating after A.D. 1400 and before A.D. 200 are excluded (n = 58).

<u>Olivine-tempered Ceramics</u>

Figures 7.15 and 7.16 examine changes in the source of olivine-tempered ceramics found in Mt. Trumbull. Olivine-tempered ceramics from non-Mt. Trumbull sources (Groups 1VV and 4) were consumed only during Late Basketmaker and Pueblo I (Figure 7.16). In addition, hardly any sand-tempered pots were transported from the lowland Virgin area to Mt. Trumbull during these periods (four olivine-tempered sherds out of five sherds; Appendix B Table B4). Since olivine was an imported temper in the lowland Virgin area, this observation only makes sense if pots from the lowland Virgin area arrived in Mt. Trumbull with human migrants, not as trading pots. That is, it would have been economically irrational to import olivine

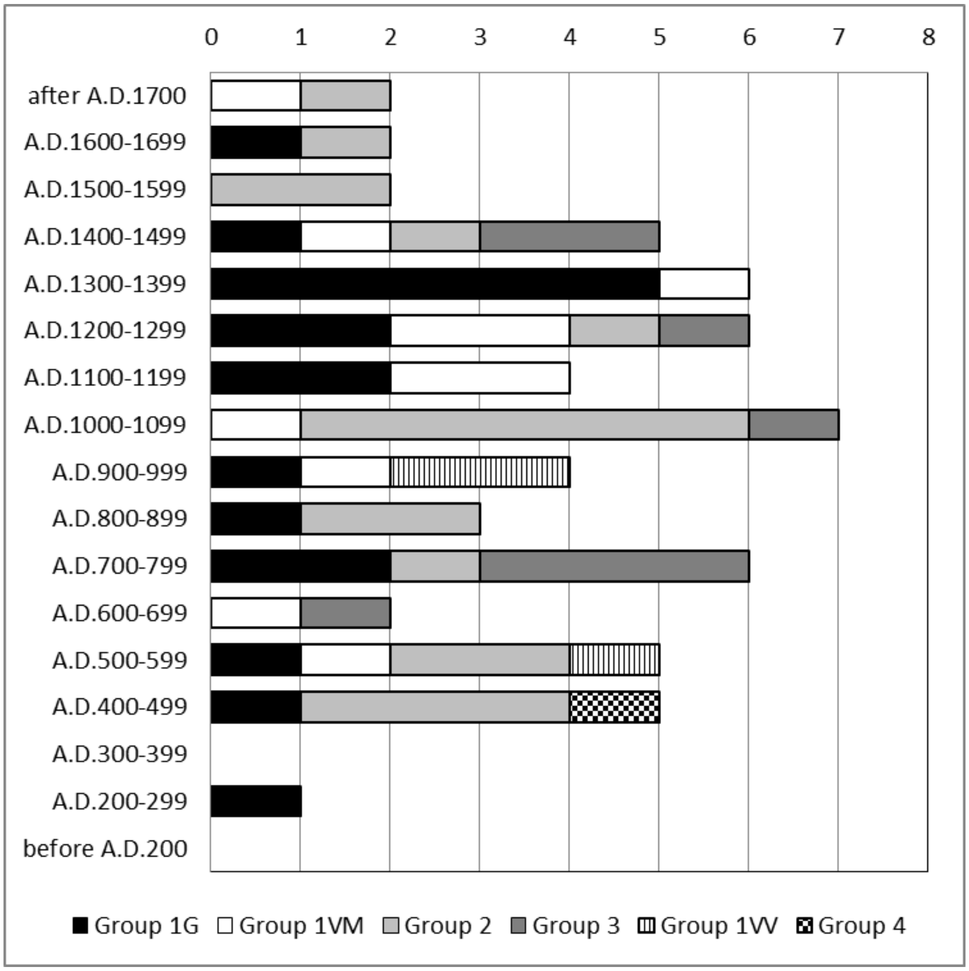


Figure 7.15. Frequency of Mt. Trumbull olivine-tempered sherds by time interval and compositional group.

temper to the lowland Virgin area, make olivine-tempered pots, and then export those pots to Mt. Trumbull, where olivine temper and usable clays are abundant. Later on, black-on-gray wares moved to Mt. Trumbull from the lowland Virgin area, but these black-on-gray imports were tempered exclusively with sand temper. This movement is more compatible with trade than migration, and it also supports the idea that olivine was too expensive to use for the trade pots in the lowland Virgin area. Another observation supporting the migration hypothesis is that all olivine-

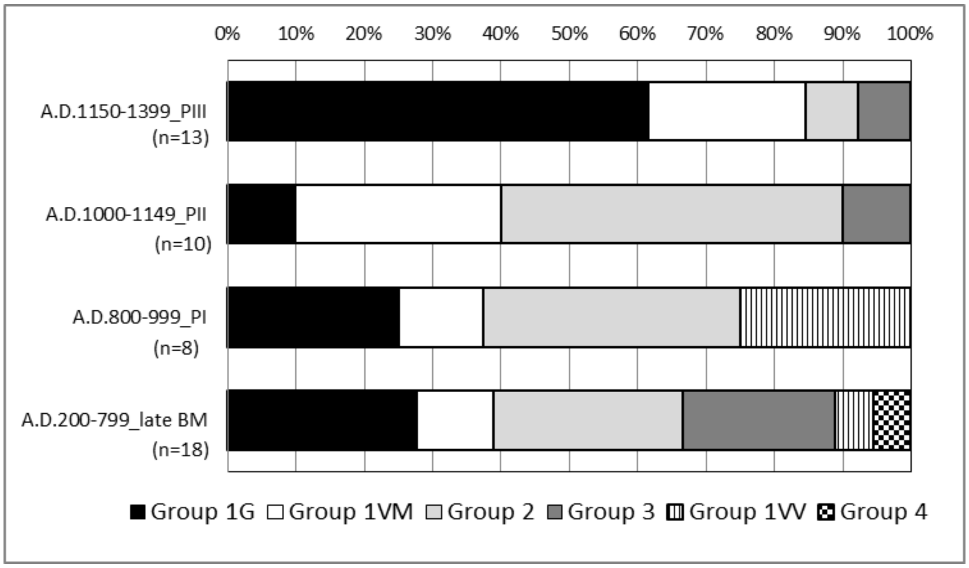


Figure 7.16. Percentage of Mt. Trumbull olivine-tempered sherds by time period and compositional group. Sherds dating after A.D. 1400 are excluded (n = 49).

tempered pots imported to Mt. Trumbull from the lowland Virgin area during the Late Basketmaker and Pueblo I periods were utilitarian wares (three sherds in Group 1VV dating A.D. 800–1000 are either plain or corrugated wares, and two sherds dating A.D. 200–800 in Groups 1VV and 4 are both plain wares) (Appendix B Table B4). All these lines of evidence support the proposition that the olivine-tempered pots from the lowland Virgin area during Late Basketmaker and Pueblo I are the result of human migration. As discussed above, Pueblo I is the only time when pots from a lowland Virgin source increased in Mt. Trumbull, and this is also a period of unfavorable climate. In sum, the ceramic circulation data presented here indicate that Pueblo I people in the lowland Virgin area may have migrated for brief periods to Mt. Trumbull, where more moisture was available due to its higher elevation.

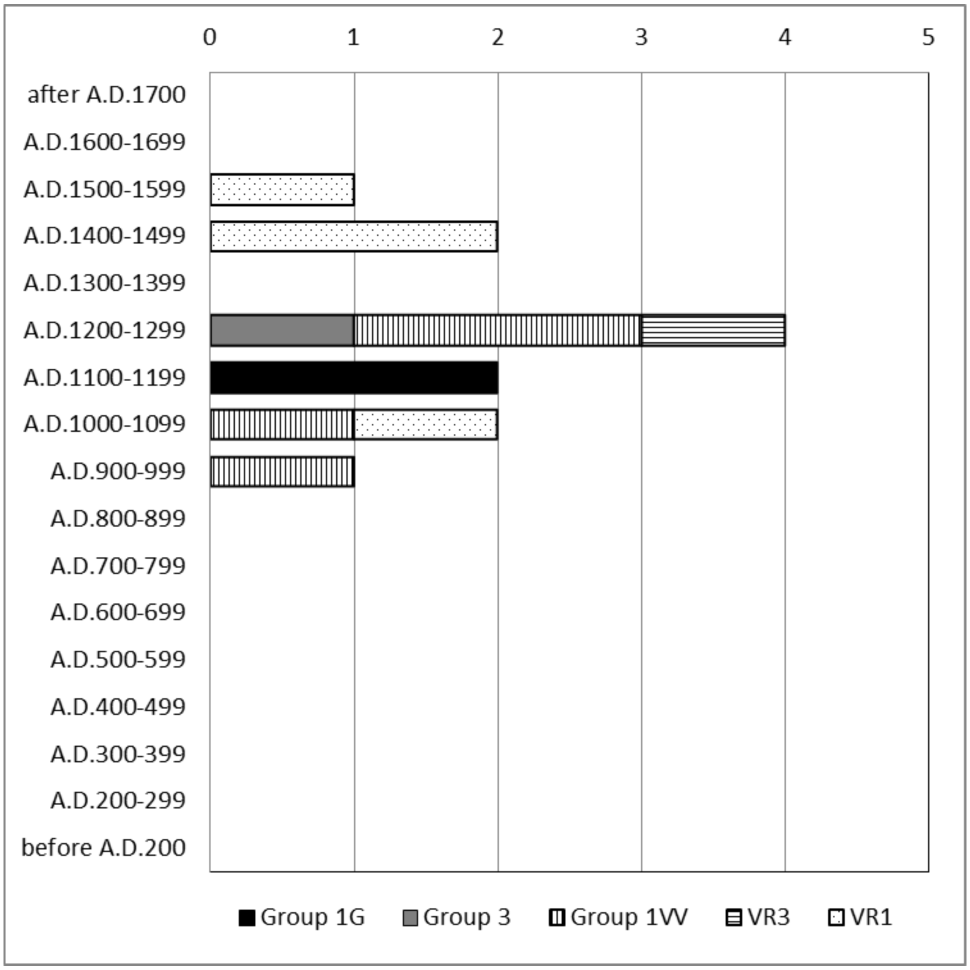


Figure 7.17. Frequency of Mt. Trumbull sand-tempered sherds by time interval and compositional group.

<u>Sand-tempered Ceramics</u>

Figures 7.17 and 7.18 examine changes in the compositional groups in the sand-tempered sherds found in Mt. Trumbull. As I noted above, these locally made sand-tempered sherds appeared late at Mt. Trumbull, during the Pueblo III period, and the earlier sand-tempered pots were imports. It is possible that tempering with sand for ceramic production was introduced by potters who emigrated from the lowland Virgin area. Sporadic or short-term population movement from the lowland

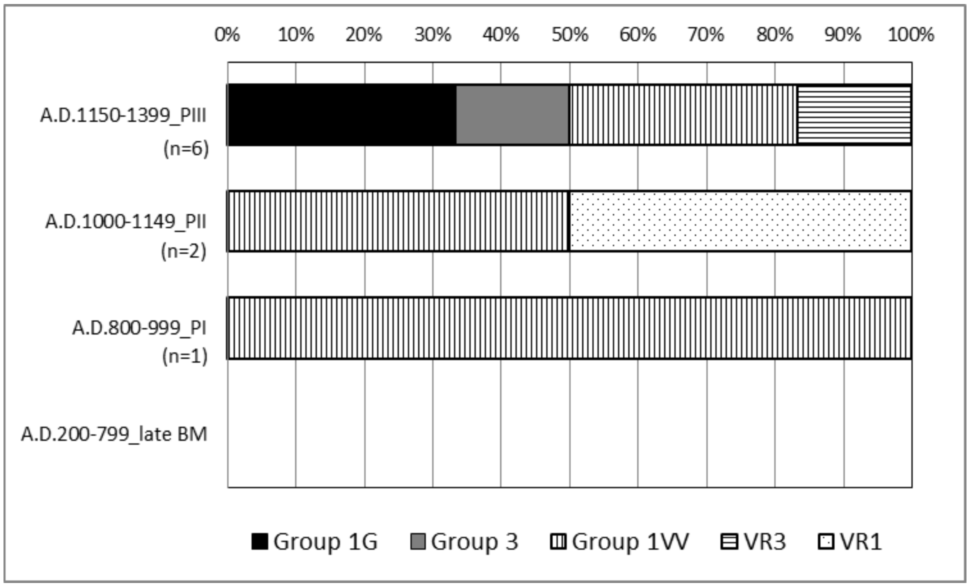


Figure 7.18. Percentage of Mt. Trumbull sand-tempered sherds by time period and compositional group. Sherds dating after A.D. 1400 are excluded (n = 9).

Virgin to Mt. Trumbull could have occurred throughout the Ancestral Pueblo occupation. However, the drought between A.D. 1120 and 1150 would have affected the lowland Virgin area severely, which may have induced part of the population to leave the lowland Virgin area permanently and migrate to Mt. Trumbull, where more moisture was available. Thus, it is possible that these immigrants to Mt. Trumbull started making pottery according to their own ceramic tradition by using sand temper.

Trends in Ceramic Production and Circulation in the lowland Virgin Area

In this section I examine the change in ceramic production and circulation pattern in the lowland Virgin area, where environmental conditions are much different from Mt. Trumbull. I note especially how populations in these two different environments survived differently.

Ceramic Production Pattern in the lowland Virgin area

Figure 7.19 shows the changes in the temper types among the ceramics produced in the lowland Virgin area. This indicates that the use of olivine as temper decreased over time in the lowland Virgin area, and that no olivine was used during Pueblo II period.

Figure 7.20 shows the change in clay use for potters working in the lowland Virgin area. All three lowland Virgin local groups were present in roughly equivalent proportions during Pueblo III. Although three groups were also present

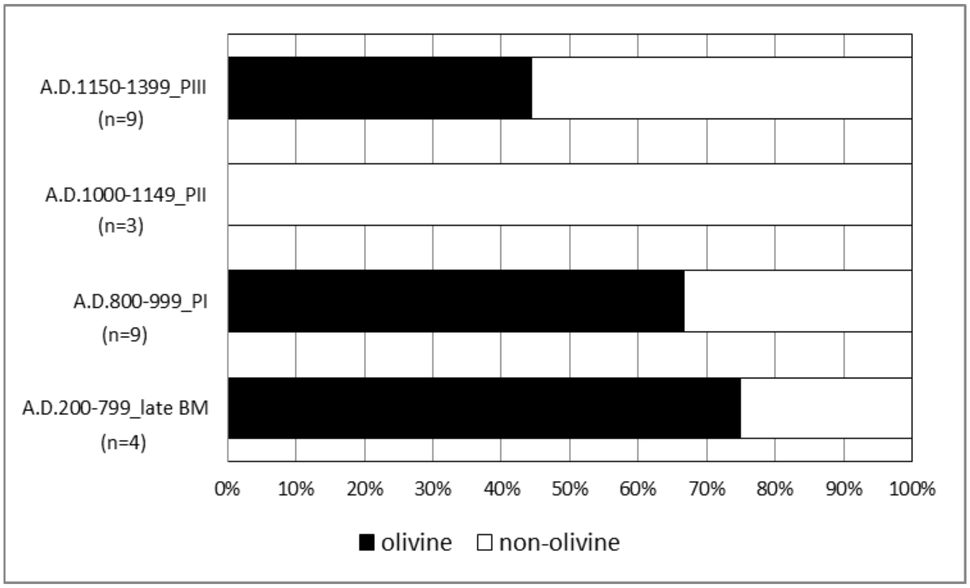


Figure 7.19. Percentage of all sherds produced in the lowland Virgin source by time period and temper type. Sherds dating after A.D. 1400 and before A.D. 200 are excluded (n = 25).

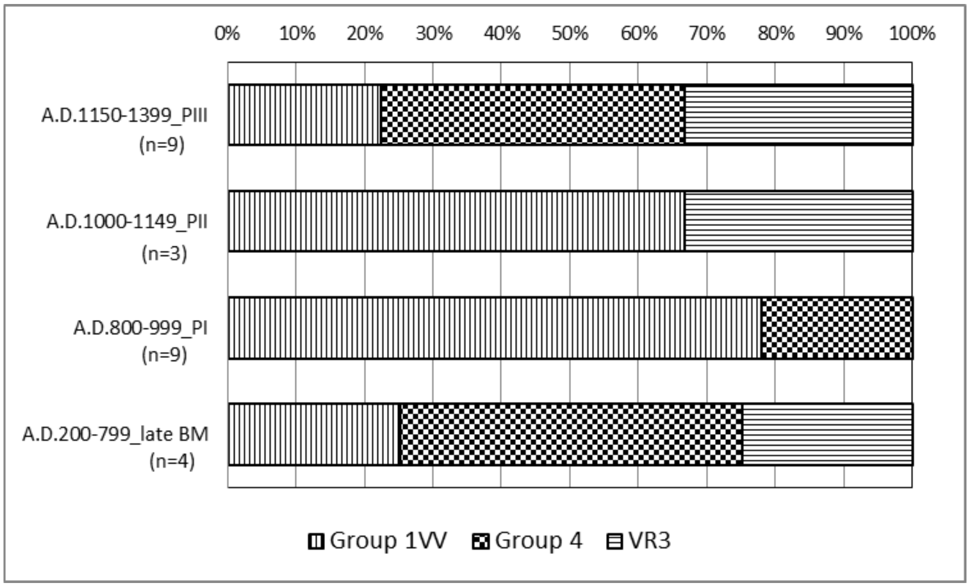


Figure 7.20. Percentage of all sherds (olivine and non-olivine) produced in the Lowland Virgin area by time period and compositional group. Sherds dating after A.D. 1400 and before A.D. 200 are excluded (n = 25).

during the Late Basketmaker period, the small sample size for this period precludes definitive statements about resource use.

Group 1VV is a multiple-purpose clay group used for domestic and trade vessels, both with and without olivine temper. The source clay for this group was utilized during all time periods in the lowland Virgin area. It became the dominant clay group during Pueblo I, but it decreased after that time. By Pueblo III times, Group 4, used with only olivine temper, and VR 3, used only with sand temper, were exploited most heavily based on the available sample (which admittedly is small). Interestingly, Group 1VV was used with both olivine and sand temper early on, but later it was used only with sand temper (Table 7.2). All these changes suggest that

Table 7.2. Frequency of Group 1VV sherds by time period and temper type.

	Olivine temper	Sand temper
A.D. 1150-1399_PIII	0	2
A.D. 1000-1149_PII	0	2
A.D. 800-999_P1	3	4
A.D. 200-799_BIII	1	0

clay resource specialization became more pronounced later, during Pueblo III. Only one clay (Group 4) was used with olivine temper. Olivine is an expensive temper transported from Mt. Trumbull, and it appears that a specific clay, presumably of better quality, was preferred for use with this expensive, imported temper. Such a combination of optimal clay and optimal temper would have reduced production failures. In accord with this suggestion, Group 4 sherds have lighter core colors, and no local clay matches it, possibly indicating that the clay used for Group 4 underwent a special preparation process to increase its quality for ceramic production.

Ceramic Consumption Patterns in the Lowland Virgin Area

I will examine the ceramic consumption patterns in the lowland Virgin area based on all ceramics, as well as on different ceramic types, as a comparison to the ceramic consumption patterns in Mt. Trumbull discussed above.

All Ceramics

The sources of all ceramics found in the lowland Virgin area are shown in Figures 7.21 and 7.22. Although the sample may be biased against locally produced pots, since more olivine-tempered sherds were analyzed than sand-tempered sherds discussed above, the distribution of OSL dates still shows a strong trend toward increased local ceramic production over time (Figure 7.22). Pots from Mt. Trumbull

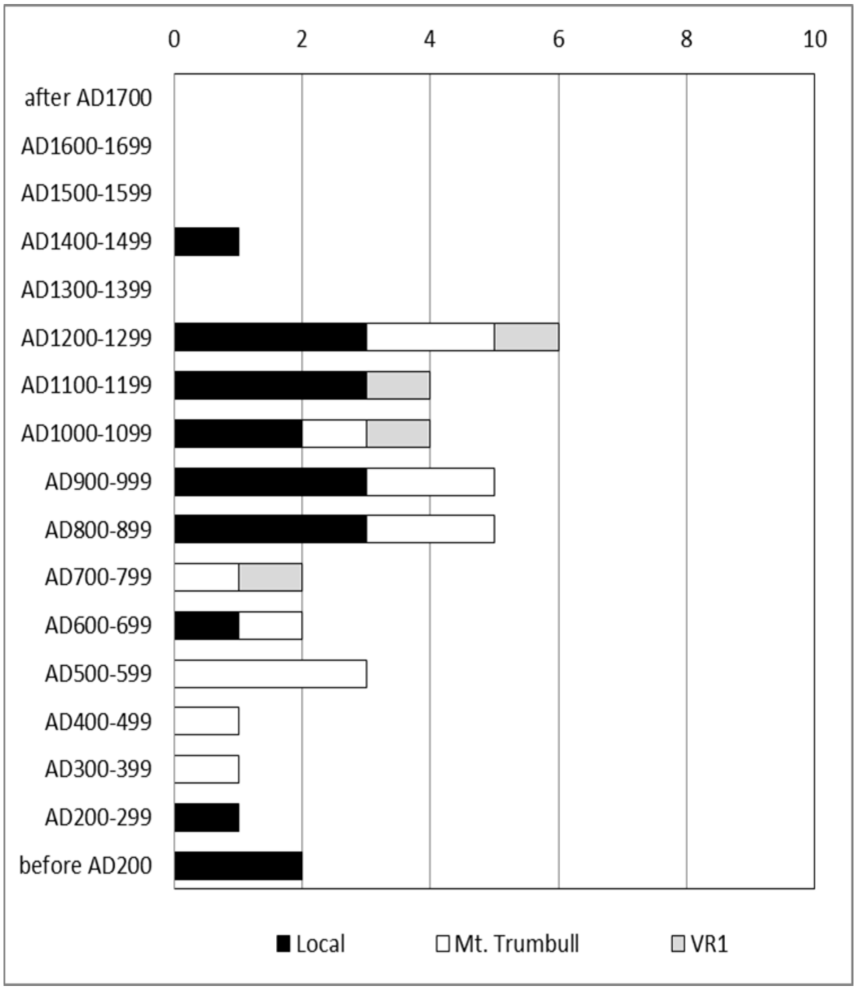


Figure 7.21. Frequency by time interval of local vs. non-local wares represented among sherds from the lowland Virgin area.

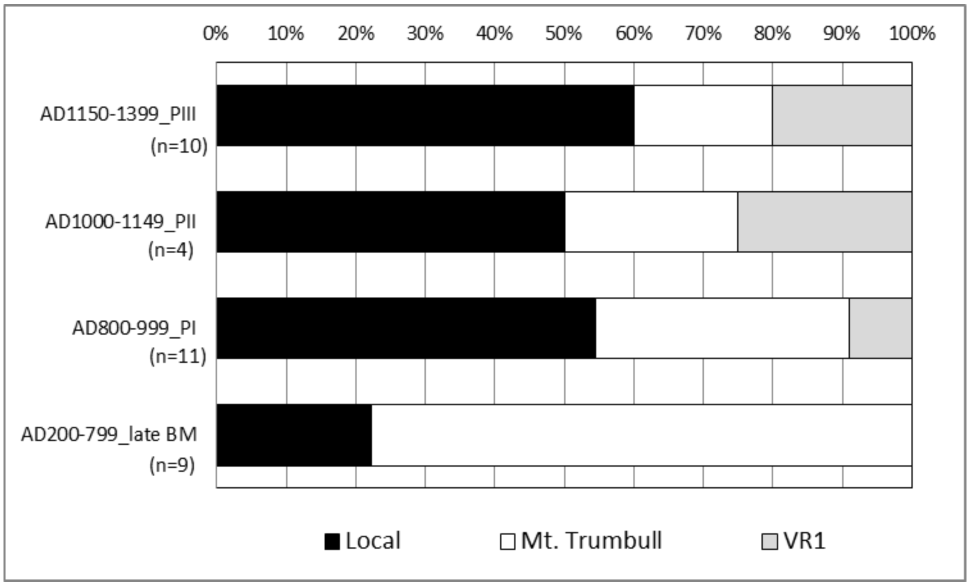


Figure 7.22 Percentage by time period of local vs. non-local wares represented among sherts from the lowland Virgin area. Sherds dating after A.D. 1400 and before A.D. 200 are excluded (n = 34).

were dominant during the Late Basketmaker period and then decreased over time. The early pots were likely brought from Mt. Trumbull to the lowland Virgin area along with human migration to the area, as discussed above. The OSL dates also suggest that VR1 pots started to appear in the lowland Virgin area during Pueblo I, when the population increased in the lowland Virgin area. Apparently the growing population began to consume pots made with clay from a previously unutilized source area associated with VR1. Consumption of VR1 pots then increased over time after Pueblo I, which indicates more intense trading with the VR1 area as time went on.

Another way to examine the relative importance of non-local goods for the lowland Virgin residents is to combine pots made from non-local clays and pots made from local clays but tempered with imported olivine (Figure 7.23). In this

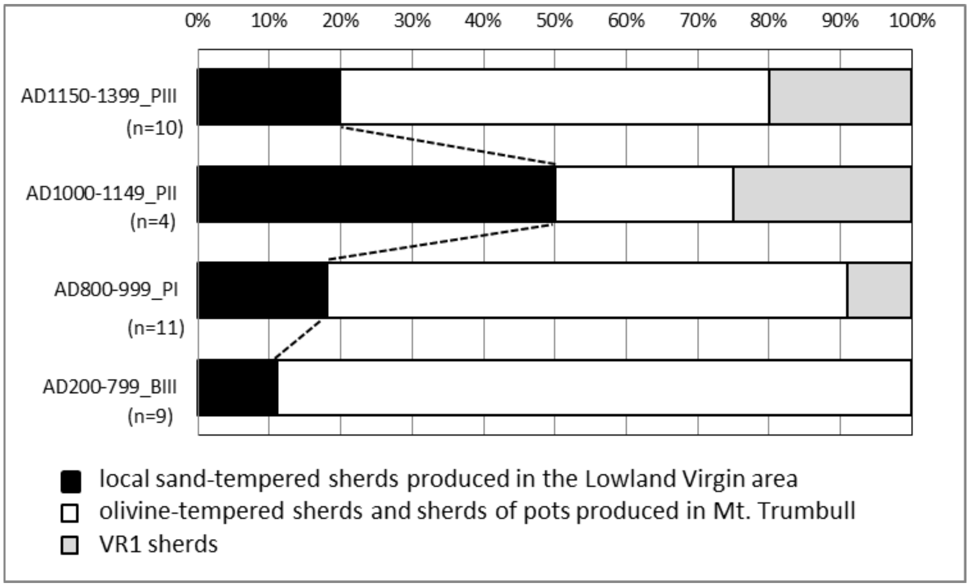


Figure 7.23. Percentage by time period of sherds of which the raw materials are from Mt. Trumbull. The raw materials from Mt. Trumbull includes both clay and olivine temper, thus these sherds are either those of pots produced in Mt. Trumbull or olivine-tempered sherds produced in the lowland Virgin area. The sherds dating after A.D. 1400 and before A.D. 200 are excluded (n = 34).

comparison, samples from Mt. Trumbull include both sherds with a Mt. Trumbull clay source (Groups 1G and 2) and sherds with a lowland Virgin clay source to which imported olivine temper was added (Groups 1VV and 4). Although the previous comparison (Figure 7.22) indicated that ceramic imports from Mt. Trumbull decreased over time as lowland Virgin people produced more local pots, Figure 7.23 highlights the continued importance of external interactions with Mt. Trumbull during Pueblo III. Thus, unlike Mt. Trumbull, the lowland Virgin area always depended on the circulation of goods from outside the region. This difference in circulation patterns between the two areas highlights a point made before, that is, the lowland Virgin residents living in a more marginal environment

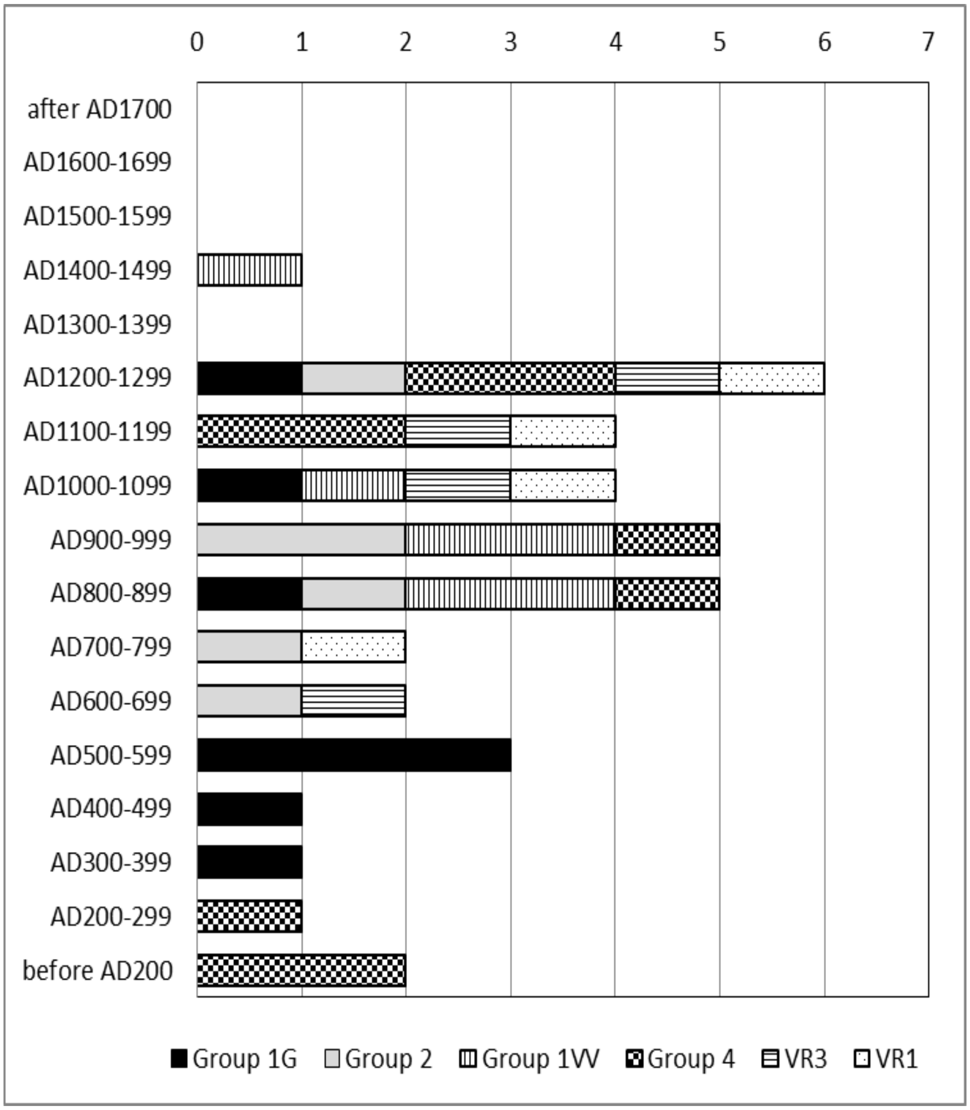


Figure 7.24. Frequency of compositional groups by time interval in the lowland Virgin area (olivine and sand temper).

appear to have depended on population mobility or trading as adaptive strategies to a greater extent than did the Mt. Trumbull residents.

A more detailed picture of changes in ceramic circulation patterns emerges from a consideration of specific sources of sherds found in the lowland Virgin area (Figures 7.24 and 7.25). While these data show an increase in the local production,

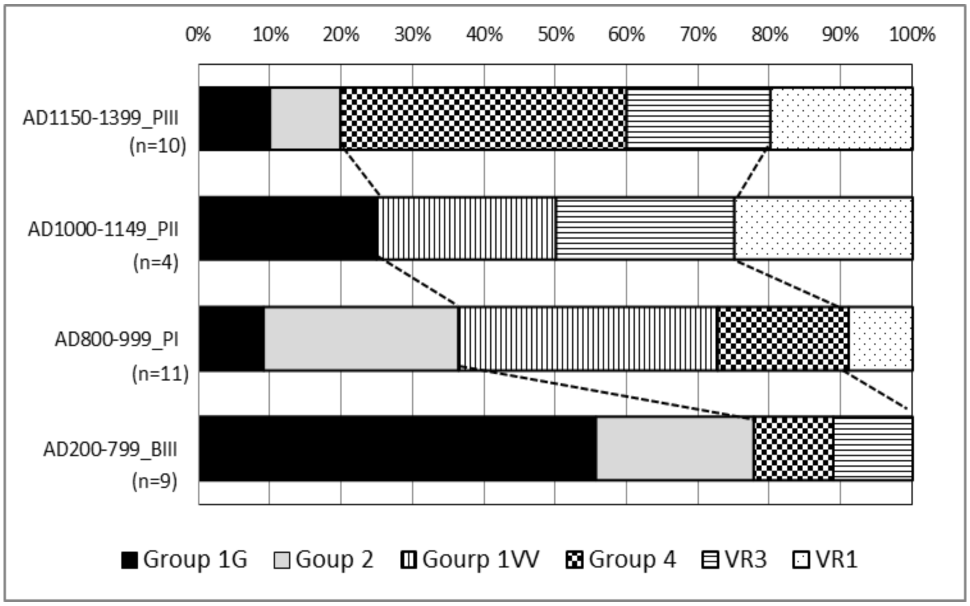


Figure 7.25. Percentage of lowland Virgin area sherds (olivine and sand temper) by time period and compositional group. Groups 1VV, 4 and VR 3 are local groups in the lowland Virgin area. Sherds dating after A.D. 1400 and before A.D. 200 are excluded (n = 34).

they also show that clay resource specialization for the production of domestic use of pots was enhanced during Pueblo III, with some pots tempered exclusively with sand (VR3) and others (Group 4) tempered only with olivine.

Olivine-Tempered Ceramics

Changes in the sources of olivine-tempered ceramics found in the lowland Virgin area are examined in Figures 7.26 and 7.27. The OSL dates show that the majority of olivine-tempered pots were produced in Mt. Trumbull during the Late Basketmaker period, but olivine-tempered pots made with Mt. Trumbull clay sources decreased over time. This supports the idea that the source of olivine-tempered ceramics found in the lowland Virgin area shifted over time from Mt. Trumbull to local lowland Virgin sources, as proposed above. An alternative illustration of the

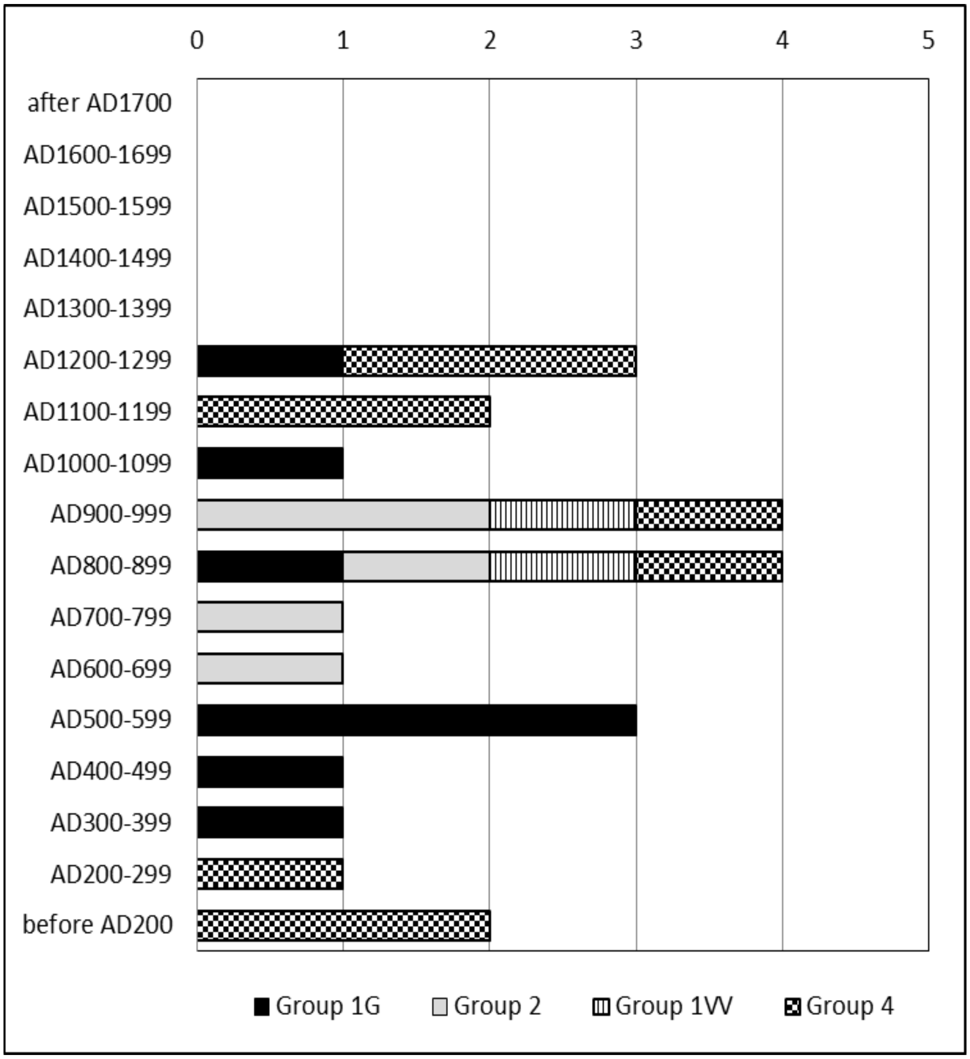


Figure 7.26. Frequency of olivine-tempered sherds from the Lowland Virgin area by time interval and compositional group.

same pattern is shown in Figure 7.28, which shows the individual OSL dates of olivine-tempered sherds from the lowland Virgin area coded according to source. Two extremely early dates are probably erroneous and should be excluded from the analysis: VR7-5 and VR21-22. Based on Figure 7.28, almost all olivine-tempered pots consumed in the lowland Virgin area before A.D. 800 were produced in Mt.

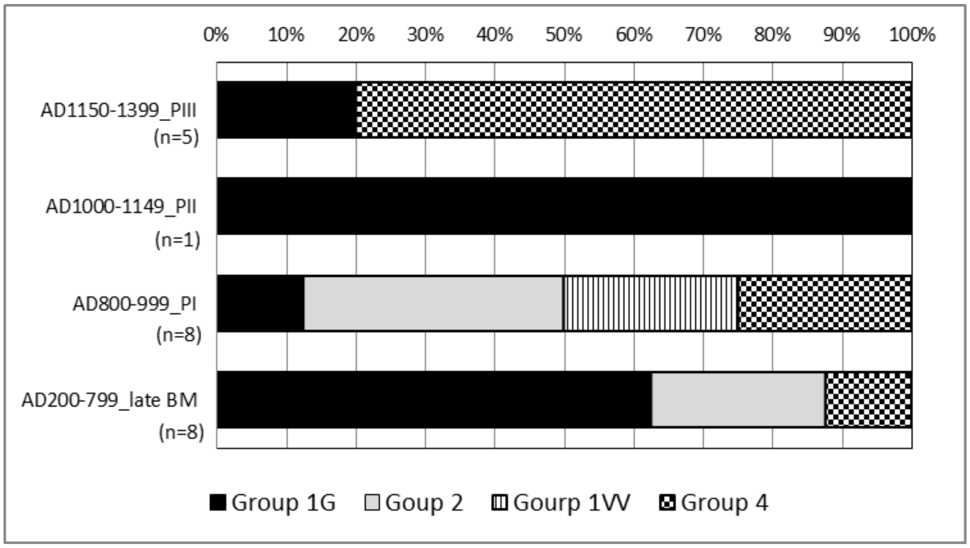


Figure 7.27. Percentage of lowland Virgin olivine-tempered sherds by time period and compositional group. Sherds dating before A.D. 200 are excluded (n = 22).

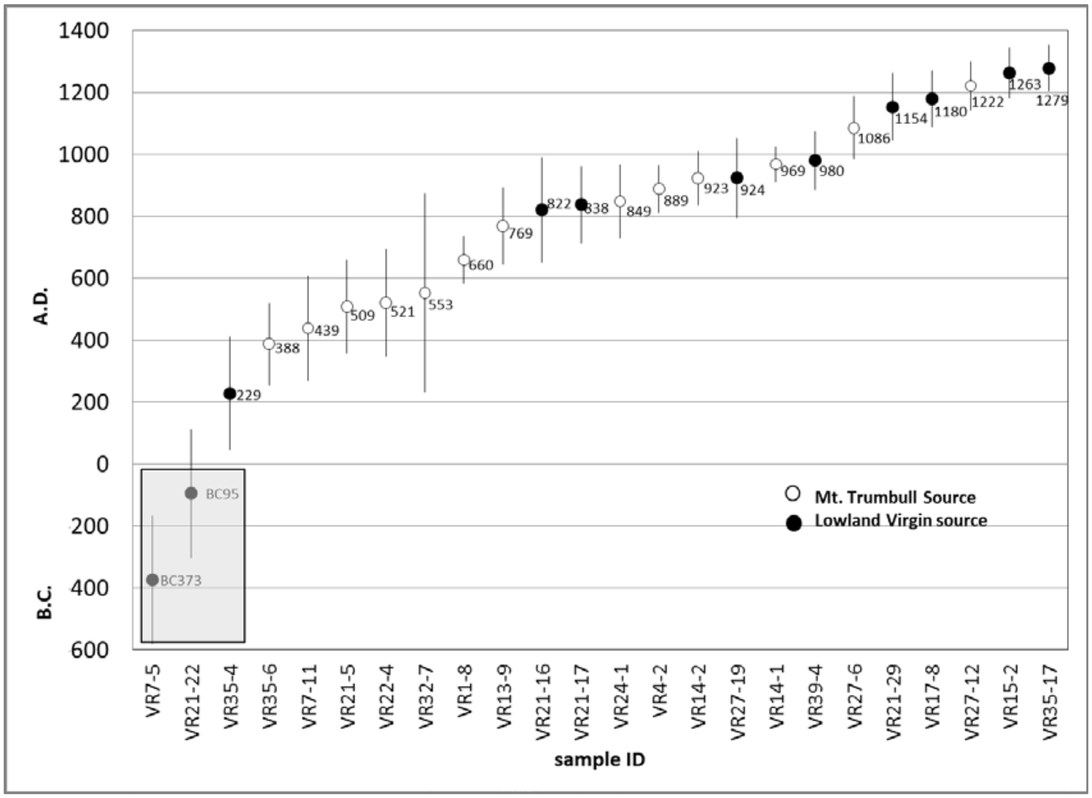


Figure 7.28. Distribution of OSL dates for olivine-tempered sherds from the lowland Virgin area. Sherds with open circles are from pottery made in Mt. Trumbull, and sherds with solid circles are from pottery made in the lowland Virgin area.

Trumbull. Local production of olivine-tempered pots started around A.D. 800, coincident with the dramatic increase in local production of ceramics in the lowland Virgin area. This pattern intensified even more after A.D. 1000, when the majority of the olivine-tempered pots were produced locally.

Sand-Tempered Ceramics

Although the number of sand-tempered sherds analyzed in this study is very small, the available data (Figures 7.29 and 7.30) indicate that production of sand-tempered pots for domestic use started around A.D. 600, and early sand-tempered domestic pots actually predate the shift to local production of olivine-tempered pots, which occurred around A.D. 800.

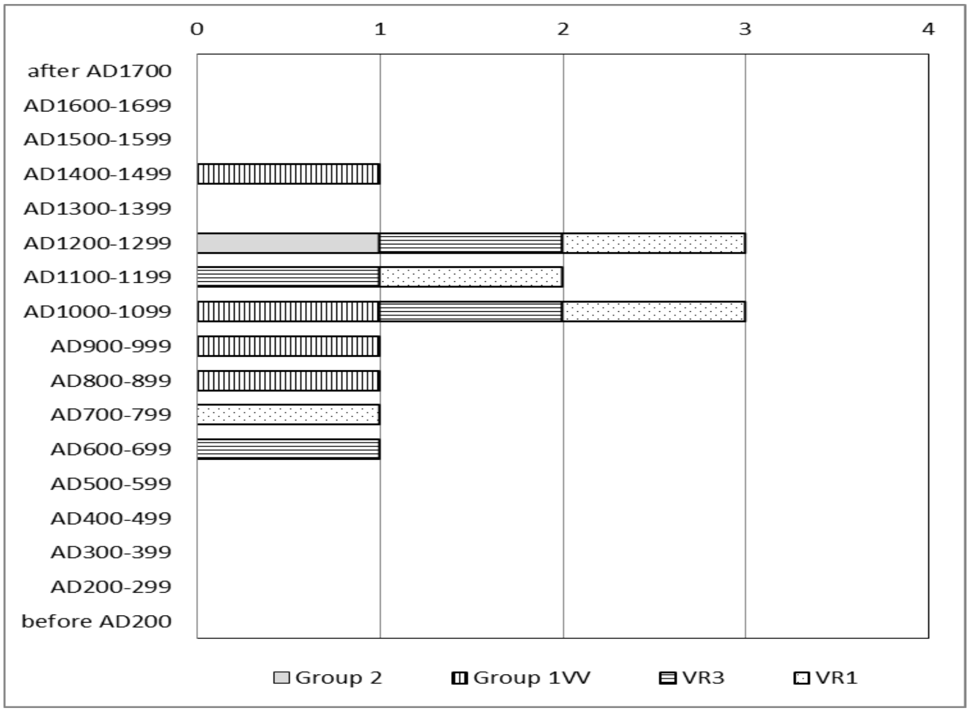


Figure 7.29. Frequency of sherds from the lowland Virgin area by time interval and compositional group.

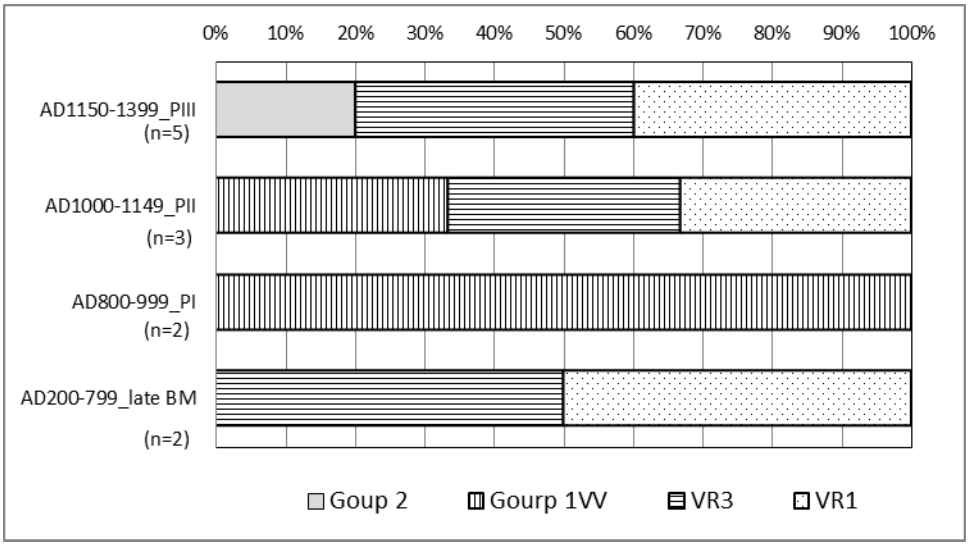


Figure 7.30. Percentage of the lowland Virgin sand-tempered sherds by time period and compositional group. Sherds dating after A.D. 1400 were excluded (n = 13).

Summary of the Observation of Data and Evaluation of Hypotheses

Based on the above observations on changes in ceramic resource use over time, the hypotheses proposed previously will be evaluated in this section according to whether they help explain the patterns detected.

In Chapter III, three hypotheses were proposed. Hypothesis 1 states that under conditions of environmental instability and relatively high population density, social networks as opposed to migration would have been favored as a risk-reducing strategy; the existence of social networks, in turn would have favored clay-resource specialization. I predict that under the condition of environmental instability with low population density during Late Basketmaker and Pueblo I, olivine-tempered pots made with locally available clay in Mt. Trumbull would be expected to move to the lowland Virgin area with human movement. I also predict that olivine-tempered pots during Pueblo II and III, under the condition of environmental instability with high population density, would be expected to have moved between communities as a result of exchange, and clay-resource specialization would be expected to have occurred. This hypothesis implies that all compositional groups should be present during all time periods and that the association between compositional groups and formal attributes should become stronger in the pottery of later periods.

Hypothesis 2 states that under conditions of environmental instability and relatively high population density, social networks as opposed to migration would have been favored as a risk-reducing strategy; the existence of social networks, in turn, would have favored production of olivine-tempered pots outside of Mt. Trumbull. I predict under the condition of environmental instability with low population density during Late Basketmaker and Pueblo I, olivine-tempered pots made in Mt. Trumbull moved along with human movement. I also predict that during Pueblo II and III under the condition of environmental instability with high population density, not only olivine-tempered pots but also olivine itself would be expected to have moved between communities as a result of exchange. As a result, it is expected that potters in the lowland Virgin area would have made pots with olivine using their local clay. For the second hypothesis, observable expectations include an increase in the number of compositional groups over time, stronger associations between compositional groups and the locations where the sherds were found in later assemblages, and greater presence of some compositional groups outside of Mt. Trumbull during the later portion of regional prehistory.

Hypothesis 3 states that under conditions of short-term relative environmental stability and relatively high population density, maintenance of social networks as a risk-buffering strategy would have been selected against; the absence or minimal importance of social networks, in turn, would have favored specialized production of olivine-tempered pots within each community. I predict that during late Pueblo II and Pueblo III, when there were a few episodes of short-term stable climatic condition and population density was high, olivine-tempered pots would have been produced within a community and moved less between communities as a result of exchange, and specialized production of olivine-tempered pots with optimal clay within the community would be expected to have occurred. Observable expectations based on this hypothesis are that the number of compositional groups should decrease during late Pueblo II and Pueblo III, there should be a weak association between compositional groups and formal attributes during later periods in the production center, and the frequencies of sherds made with optimal clays should increase later in time.

In the following section, I will summarize the observations on changes in ceramic compositional groups and evaluate which hypotheses explain most observed changes at the macro-regional and sub-regional scales.

Ceramic Production and Circulation at the Macro-Regional Scale

OSL dates on sherds from Mt. Trumbull and the lowland Virgin area suggest that ceramic production began before A.D. 400 and then increased until A.D. 1200–

1300, interrupted by slight downturns between A.D. 600 and 700 and A.D. 1100 and 1200. These two phases of decrease partially correspond to dry/fluctuating climatic conditions (A.D.600–700 and A.D.1130–1185, respectively). From a broad perspective, these OSL dates support the assumption that ceramic circulation patterns were shaped by selective pressures in the natural environment. Changes in the sources of pots that circulated across the entire study area suggest that during Pueblo II, circulation of pots produced in the lowland Virgin area decreased, while Mt. Trumbull and VR1 area pots increased in frequency. This time period partially overlaps with the time of wet climatic conditions in the study area (A.D. 1050–1120). The favorable climatic conditions would have permitted agricultural intensification in the lowland Virgin area and, as argued here, a reduction in production of ceramics for exchange. In Mt. Trumbull, where a pattern of clay-resource specialization was established early, agricultural intensification was possible without reduced ceramic production, since clay resource specialization lowered the total cost of ceramic production. The increase in the circulation of VR1 pots during the Pueblo II indicates extended trading networks, thus supporting the view that exchange was a vital risk management strategy associated with agricultural intensification.

Considering all analyzed ceramics, the number of compositional groups increased over time within the study area as a whole. This observed pattern supports Hypothesis 2, which predicts that production centers making olivine-tempered pottery should increase over time due to the increased trading under environmental instability with higher population. The reason for this observed macro-regional pattern is that more olivine-tempered ceramics were produced locally in the lowland Virgin area later on. However, it is also true that production of olivine-tempered pots in the lowland Virgin area started relatively early, around A.D. 600. Thus, the data do not fully support Hypothesis 2. In addition, the larger number of compositional group in the Pueblo III assemblage arises not from the production of olivine tempered pots in the lowland Virgin area but from the expansion of trading networks, as indicated by the increased representation of VR1 pots. The enhanced clay-resource specialization involving all three clay sources utilized in the lowland Virgin area during this time also contributed to the increase in the compositional groups. Thus, while Hypothesis 2 may partly capture the macro-regional changes, it is an incomplete explanation.

In fact, the number of compositional groups represented by the olivine-tempered sherds decreased during Pueblo III. This could support Hypothesis 3, in which potters used optimal clay for pots regardless of the intended purpose or function. Understanding how selective pressures acted on populations to cause this change in pottery production requires detailed consideration of environmental as well as social factors such as population density. In other words, changes in the production and circulation of ceramics need to be examined separately for each of the environmental settings represented in this study.

Ceramic Production and Circulation in Mt. Trumbull

The OSL dates demonstrate that all four local clay groups were used for ceramic production in Mt. Trumbull at all times, except between A.D. 800 and 1000, during the Pueblo I period. The OSL dates also show some changes in relative proportions of compositional groups over time in Mt. Trumbull. There are four local ceramic groups present in Mt. Trumbull and all of them have patterned associations with particular ceramic physical attributes and/or provenience. Group 1G is a multiple-purpose clay used for both utilitarian and non-utilitarian pots as well as domestic consumption and trading purposes. Group 2 was predominantly used for utilitarian wares. Groups 3 and 1VM were used only in pots intended for domestic use. Clays used in both Groups 1G and 1VM appear to have been better clays, or they may have been prepared to enhance their mechanical and firing properties. The existence of clay groups associated with different physical characteristics and provenience suggest that clay resource specialization was practiced in ceramic production in Mt. Trumbull to some degree. Interestingly, clay resource specialization seems to have started early in Mt. Trumbull. Especially before A.D. 600, Group 1G was used for pots transported to the lowland Virgin area, while Group 2 was used for domestic ware. Clay-resource specialization for transported pots declined during Pueblo I, since the lesser-quality Group 2 clay began to appear among the pots transported to the lowland Virgin area. However, clay resource specialization continued to characterize ceramic production in Mt. Trumbull to some degree. Group 1G, which is a multiple-purpose clay, was an early dominant clay group during the Late Basketmaker period, but its use decreased between Late Basketmaker and Pueblo II. Data indicate a decrease in the use of multiple-purpose clay and an increase in use in specialized clay (e.g., Group 2 for utilitarian ware, Group 1VM for domestic use) over time until the Pueblo II period. In sum, clay resource specialization started early and increased over time in Mt. Trumbull between Late Basketmaker and Pueblo II.

A slightly different pattern is evident during Pueblo III, when there is a large increase in use of Group 1G after A.D. 1150. This suggests an increase in the use of optimal clay for ceramic production in Mt. Trumbull. This pattern is also evidenced by the increase over time in Group 1VM, another optimal clay group. In all, almost 80% of the pots were made of these optimal clays (Groups 1G and 1VM) during Pueblo III, even for vessels intended to serve domestic and utilitarian functions.

The nature of non-local ceramics in Mt. Trumbull suggests possible mechanisms for the transport of these ceramics from outside the area. Unlike in the lowland Virgin area, non-local wares in Mt. Trumbull were always a small fraction of the pots consumed at Mt. Trumbull, except during Pueblo I (Figure 7.31). Olivine-tempered pots produced in the lowland Virgin area moved to Mt. Trumbull only during the Late Basketmaker and Pueblo I periods. Considering the expense of procuring olivine temper in the lowland Virgin area, these early olivine-tempered pots were almost certainly transported from the lowland Virgin as a result of population movement rather than as trade items. During Pueblo I, the climatic conditions were very unstable. Since the lowland Virgin area is at a much lower

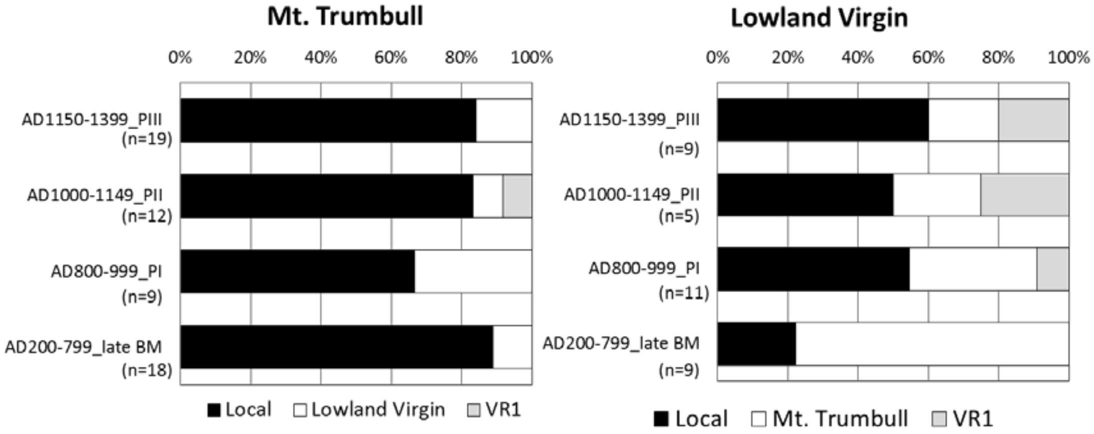


Figure 7.31. Comparison by time period of local and non-local wares represented among sherds from Mt. Trumbull and the lowland Virgin area.

elevation and drier environment which are more marginal for agriculture than Mt. Trumbull, it is likely that the unstable climatic conditions (unpredictable moisture for supporting crops) may have affected the population in the lowland Virgin area more than those in Mt. Trumbull, which may have forced some lowland Virgin residents to move up to Mt. Trumbull.

The non-local ceramic circulation pattern changed during Pueblo II. Interestingly, ceramics from the VR 1 area (source unknown) arrived at Mt. Trumbull only during Pueblo II, while ceramics from the lowland Virgin area were present during all time periods. As argued earlier, this may indicate an expansion of trading networks during Pueblo II, when climatic conditions were relatively wet and stable. An enhanced role for exchange is also suggested by the fact that lowland Virgin pots moving to Mt. Trumbull during Pueblo II and III were tempered with sand, the presumed local lowland Virgin temper, rather than olivine, which would have had to have been imported into the lowland Virgin area.

Sand temper was used as ceramic temper in Mt. Trumbull only during Pueblo III. This change at A.D. 1150 coincides with the extremely severe drought, which would have had a huge impact on agricultural productivity, especially in the lowland Virgin area. This crisis may have forced part of the lowland population to migrate to Mt. Trumbull, where more moisture was available. It is possible that the use of sand as temper may have been introduced by potters who emigrated from the lowland Virgin area. In any case, the population increase in Mt. Trumbull during Pueblo III and the higher population density appear to have entailed the aggregation of the villages.

In sum, the OSL dates suggest that earlier non-local ceramics in Mt. Trumbull were brought there as a result of population movement, and later non-local pots arrived as a result of exchange. Clay resource specialization was practiced by local potters in Mt. Trumbull from the outset, but increased until Pueblo II. The use of optimal clay increased over time, so that by Pueblo III most pots were made from optimal clay regardless of their purpose.

The ceramic production and circulation pattern in Mt. Trumbull between the Late Basketmaker and Pueblo II periods seems to support part of Hypothesis 1, because olivine-tempered ceramics produced in Mt. Trumbull were transported along with population movement early on and later by exchange, and clay-resource specialization increased later on as well. However, Hypothesis 1 also postulates that all olivine-tempered ceramics were produced in Mt. Trumbull, and this is contradicted by the data indicating the production of olivine-tempered ceramics not only in Mt. Trumbull but also in the lowland Virgin area. Thus, Hypothesis 1 is not fully supported by the data presented here for Mt. Trumbull. Hypothesis 2, on the other hand, also proposes an earlier migration and later exchanges as the context in which olivine-tempered pots were transported, but it proposes the existence of multiple production centers of olivine-tempered ceramics later, including in the lowland Virgin area. Not anticipated by this hypothesis is the fact that production of olivine-tempered pots started early in the lowland Virgin area and then increased over time. Thus, the data do not fully support Hypothesis 2. Hypothesis 1 proposes clay-resource specialization by potters later in Mt. Trumbull, but the data demonstrate that clay-resource specialization was observed even in the earlier ceramic assemblages. The data also imply that clay resource specialization was actually not favored in Pueblo III; instead, optimal clays were used for most ceramic production regardless of the intended functions of the pots.

During Pueblo III, the population level was apparently high in the Mt. Trumbull region. Pueblo III was also marked by several episodes of wet climatic conditions, when the population is expected to have grown, supported by successful agriculture under favorable climatic conditions. After A.D. 1150, however, intermittent dry conditions would have forced part of the lowland Virgin population to disperse from the lowland Virgin area and relocate to Mt. Trumbull, where more moisture was expected. An earlier abandonment in the lowland Virgin area (Figure 6.12) also suggests that environmental factors in Mt. Trumbull allowed the population to survive even after two severe drought episodes around A.D. 1150 and

1275. Thus, during Pueblo III, population density in Mt. Trumbull may have been sustained not only by its local growth but possibly also by some immigration. With a growing population, more time/energy would have been devoted to agricultural activities, thus reducing the time for other non-agriculture-related activities, such as pottery production. From this perspective, the use of optimal clays for the production of all vessel classes may have reduced the replacement cost of pottery. Although the procurement of optimal clay may have required more time/energy, the use of better clay would have yielded pots more resistant to breakage, thus reducing efforts to replace pots and leaving more time for agricultural activities during the later time period, assuming that the amount of energy devoted to clay procurement/paste preparation and manufacture of replacement of vessels was less than the earlier time period.

There are two possible ways to explain the trend toward the emphasis on the optimal clays in Mt. Trumbull, resulting in lower energy expenditures during the later time period. One possibility is that pottery production became increasingly specialized. In circumstances where the climatic conditions were favorable for agriculture, the accumulated surplus may have allowed specialized potters to devote more time to pottery production activities, including clay procurement. If specialization within the society in pottery manufacture occurred (i.e., relatively few potters who made pottery for everybody), these specialists presumably were making pottery more efficiently than was the case earlier, when every household made its own pottery, even though they used special clays or paste recipes. Under this scenario, it is expected that potters in Mt. Trumbull would have selected only the clay with better performance characteristics to make better and stronger pots even for daily use, despite the added expense of acquiring better clay. This growing specialization would have freed other segments of the population (non-potters) to devote more time to agricultural production.

Thus, this trend, entailing an increase in the use of the optimal clay over time, seems to support the Hypothesis 3: ceramics were produced by specialized potters under the condition of relative environmental stability with high population density. However, the question remains whether climatic conditions during Pueblo III were favorable and stable enough to accumulate agricultural surpluses to support specialized potters. Between A.D. 1150 and 1400, there were several wet climatic episodes (around A.D. 1195–1215, A.D. 1255–1270, and A.D. 1300–1335; Figure 7.32) based on the PDSI record. However, there were also a few prolonged droughts during Pueblo III (A.D. 1125–1195 for 70 years, A.D. 1215–1255 for 40 years, and A.D. 1270–1300 for 30 years). Thus, Hypothesis 3 still leaves some questions about whether climatic conditions were stable enough to support labor specialization throughout the entire Pueblo III period. Instead, specialized production could have been a temporary strategy adopted whenever the climate allowed, with some individuals spending more time for pottery production to provide pots for the rest of the community and others focusing on agricultural activities. Even though population density is expected to have been high during Pueblo III in Mt. Trumbull, the size of the population was not nearly as high as in Anasazi heartland

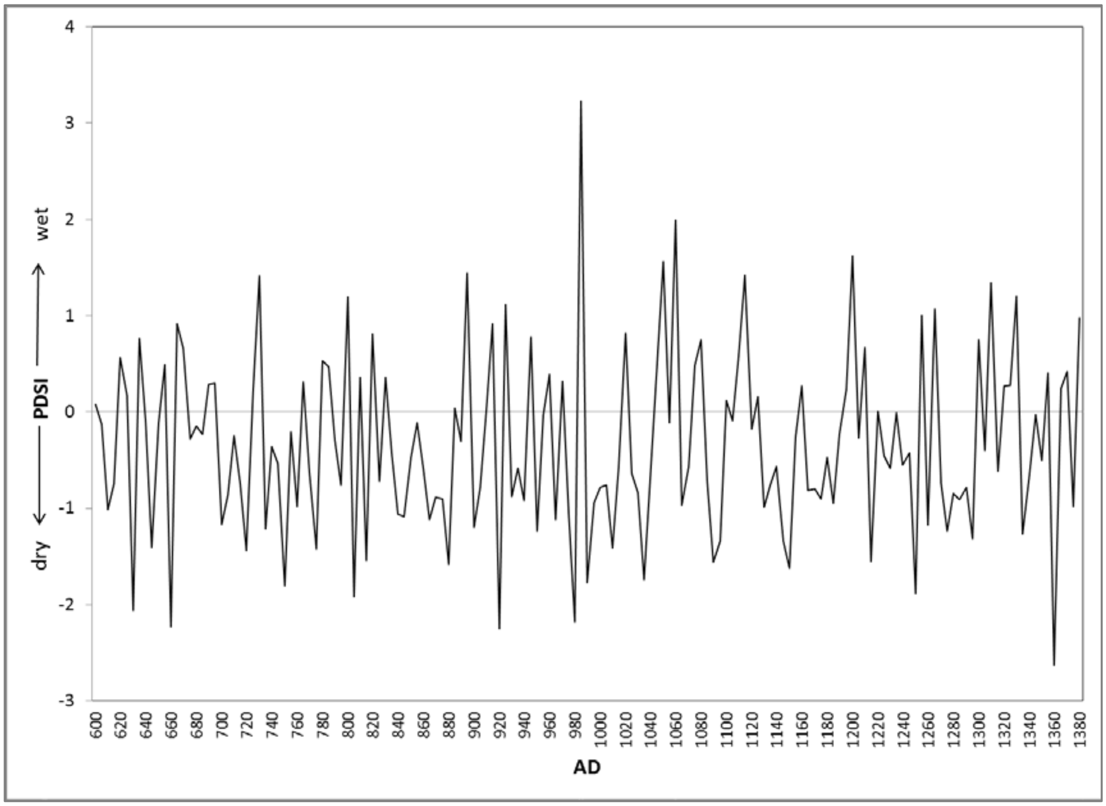


Figure 7.32. Five-year average of the Palmer Drought Severity Index PDSI between A.D. 600 and 1380. The original data were kindly provided by Larson in 2001. The data between A.D. 900 and A.D. 1300 were published (Larson et al. 1996). The data between A.D. 600 and A.D. 1300 was also published (Sakai 2001).

communities such as Mesa Verde, so population size still may have been small enough to allow Mt Trumbull inhabitants to choose between labor specialization and generalized labor depending on the environmental conditions.

There is another possible explanation for the trend toward the emphasis on the optimal clays in Mt. Trumbull, resulting in lower energy expenditures during the later time period. When the population was very high in Mt. Trumbull during Pueblo III, more communication between the villages or potters would be expected. This situation could have stimulated the rapid spread of information and technology, so that all potters in Mt. Trumbull soon knew the source of good clay or preparation techniques to achieve the most mechanically and thermally effective fabrics. These potters may have spent more time procuring these high-quality clays or preparing the clays in special ways, but they would not have spent as much time searching for the better clays as the earlier potters because they would have already known where to find good clay. In this case, the later pots were not made by specialized potters, but by multiple potters who were not specialists but knew the best clays and/or preparation techniques. While the data presented here seem to support Hypothesis 3, they cannot falsify this alternative explanation for the use of the optimal clays during Pueblo III.

In sum, the three hypotheses proposed at the beginning of this study partially fit the data presented here pertaining to changes in ceramic production and consumption patterns in Mt. Trumbull.

In pottery production, two behaviors, clay resource specialization and the use of optimal clay, were proposed to explain the shifts in clay resource use in Mt. Trumbull. Under the condition of environmental instability with increased population density, clay resource specialization was enhanced. Under the condition of environmental stability and/or even higher population density, optimal clay was used for all pottery types by temporary specialized potters or various potters with shared knowledge. The compositional data demonstrate that clay resource specialization started in Mt. Trumbull early and increased over time. Using different clays for different purposes may have been a strategy of a moderate sized population for leaving more time for agriculture and reducing time for non-agricultural activities while still producing attractive trading pots. However, during Pueblo III, a larger population required more labor investment in agriculture, which favored the use of optimal clay for all pottery production to decrease the replacement cost of pots and to increase the value of trading pots discussed above. A few episodes of wet climatic conditions with successful agriculture may have allowed the specialized potters to procure better clay or prepare clay in a special manner to make more resistant pots whenever the climatic condition was stable. Potters from different villages may have also shared the best clay sources and/or techniques to produce resistant pots under a high population density, which would have left more time for agriculture once they produced more resistant pots. Thus, the earlier production of ceramics in Mt. Trumbull is explained by clay resource specialization and later production by the preferential exploitation of optimal clays by temporary specialists or various potters sharing of ideas about the optimal clay.

Ceramic Production and Circulation in the Lowland Virgin Area

The ceramic compositional data suggest that olivine-tempered ceramics found in the lowland Virgin area are not only from Mt. Trumbull, but also from local, lowland Virgin sources. The production of olivine-tempered ceramics in the lowland Virgin area started relatively early, around A.D. 400. The early olivine-tempered ceramics in the lowland Virgin area were from Mt. Trumbull, but olivine-tempered ceramics were produced in the lowland Virgin later, especially after A.D. 800. As seen in the Mt. Trumbull ceramic distribution pattern, the earlier olivine-tempered pots were likely transported with population migration and later pots arrived there as a result of trade.

There are three local clay groups used for the ceramic production in the lowland Virgin area: Group 1VV is a multiple-purpose clay used for olivine-tempered and non-olivine-tempered ceramics, as well as for both domestic and trading purpose; Group 4 was used only with olivine temper; and VR3 was used only with sand temper. During the Late Basketmaker period, these three clay groups were used evenly, but the number of samples analyzed is small. Although the same numbers of clays were used later, the use of Group 1VV decreased over time. The change in ceramic compositional patterns suggests clay resource specialization was enhanced in the lowland Virgin area during Pueblo III which supports Hypothesis 1: Group 1VV was used for trading pots, Group 4 was used only with olivine temper, and VR3 was used only with sand temper. The olivine may be considered as an expensive temper because it was imported from Mt. Trumbull. To reduce the cost of production of olivine-tempered pots by avoiding production failures, it is likely that better clay was procured/prepared.

The majority of pots in the lowland Virgin area were from Mt. Trumbull during earlier times, but local production increased over time, and the local use of imported olivine decreased. Thus, as time went on, lowland Virgin potters increasingly used locally available raw materials. Despite increasing local production, exchange still remained an important risk buffering strategy during

Pueblo II and III. Unlike in Mt. Trumbull, ceramic production and circulation in the lowland Virgin area does not show evidence of an increase in the use of optimal clay for all types of ceramics. Group 4 is a good clay but was used only with olivine temper. Thus, the data do not support Hypothesis 3, the use of optimal clay for all ceramics.

As mentioned, olivine-tempered ceramics found in the lowland Virgin area were from Mt. Trumbull early, but increasingly more olivine-tempered pots found in the lowland Virgin area were produced locally later on. Thus, the change in compositional data partially supports Hypothesis 2 for the production and consumption of pottery in the lowland Virgin area. However, as small numbers of olivine-tempered pots were produced early, the data do not fully support the late production of olivine-tempered pots proposed under Hypothesis 2.

The overall pattern for the early time periods is that population seems to have moved often between the lowland Virgin and Mt. Trumbull areas, perhaps to optimize access to wild resources. Even after starting small-scale agriculture, the population probably moved periodically or seasonally. Under these conditions, olivine-tempered pots apparently were brought to the lowland Virgin area as a byproduct of population movements. When population started to increase in the Arizona Strip and adjacent areas, population mobility would have been increasingly constrained. Residence time in each location would have increased as people turned increasingly to agricultural intensification. However, agriculture would have been precarious, so risk management strategies would have been important, especially during unstable or dry periods. Therefore, olivine-tempered pots likely arrived in the lowland Virgin area as a part of exchange during later times. Around A.D. 800, when the population started to increase in the lowland Virgin area, people increased their local production of pottery, probably to meet growing local demand for daily-use pots and also for exchange transactions that buffered agricultural risk. More olivine-tempered pots were produced in the lowland Virgin area as well, with imported olivine temper added to locally available clay. Clay-resource specialization was emphasized later in the lowland Virgin area to increase the attractiveness and viability of pots for trading and decrease the production cost of daily-use pots. This, in turn, left more time for investment in agricultural activities.

Conclusion

The ceramic compositional analysis and OSL dating reveal changes in ceramic production and circulation patterns in the Arizona Strip and adjacent areas. The ceramic compositional data demonstrate that multiple clay resource and preparation techniques were used for olivine-tempered ceramics distributed in the study area and that different clays were used for different purposes. The ceramic compositional data also suggest that olivine-tempered ceramics found in the lowland Virgin area were not only transported from Mt. Trumbull, but were also produced locally in the lowland Virgin area. The distribution of OSL dates suggests that the local production of olivine-tempered pots in the lowland Virgin area increased over time.

Three hypotheses were proposed to explain the ceramic production and circulation patterns. The change in the ceramic production and circulation patterns did not support any single hypothesis, but instead different hypotheses explain the different components of the pattern in Mt. Trumbull. The circulation of ceramics was largely the result of population migration during earlier time periods, but they arrived later as exchanged items. Clay resource specialization may have been practiced in order to leave more time for agricultural production and also to facilitate risk-buffering exchange until Pueblo II in Mt. Trumbull. During Pueblo III, when population density was much higher than before, clay resource specialization declined in importance; instead, optimal clays were used for the production of all pots perhaps in order to leave more time for agricultural activities. Production of ceramics with the optimal clays could have been used by short-term specialized potters under relative population stability or various potters with widely shared ideas about how to achieve better, more mechanically strong fabrics in high population density.

The ceramic production and circulation patterns in the lowland Virgin area can be explained by Hypotheses 1 and partially by Hypothesis 2. The olivine-tempered ceramics were initially brought from Mt. Trumbull to the lowland Virgin area along with the population movement under the condition of environmental instability with low population density. With high population density, exchange was selected as a risk management strategy instead of migration, which suggests that olivine-tempered pots were brought to the lowland Virgin area as a part of an exchange system. Olivine-tempered ceramics were also produced in the lowland Virgin area, and the local production of olivine-tempered ceramics increased over time. Clay resource selection increased over time as well, quite likely in order to increase the time available for agricultural production.

The data presented here demonstrate that the changes in production and distribution patterns observed in ceramic assemblages in different natural and social environmental settings require different explanations. The small-scale agricultural communities in Mt. Trumbull adapted to the natural and social environments differently than the lowland Virgin people, who had to survive in a more marginal environment. This dissertation suggests that the change in ceramic production and circulation pattern was likely related to population growth and consequent agricultural intensification. Future research might focus on documenting change in agricultural productivity over time in the study area to demonstrate that agricultural productivity increased in response to the change in ceramic production and circulation pattern in marginal environment.

This dissertation is the first attempt to combine chemical compositional analysis and OSL dating of a large collection of sherds to understand changes in ceramic production and distribution in detail. By combining data from these two kinds of analysis, I was able to address the issue of whether migration or trading moved pots from one area to another. This type of study could be used elsewhere to study change in social interaction patterns though the analysis of ceramic production and distribution patterns.

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APPENDIX A: SAMPLE INFORMATION FOR THE LA-ICP-MS ANALYSIS

Database for Laser Ablation ICP-MS (LA-ICP-MS) of all samples and Instrumental Neutron Activation Analysis (INAA) of Mt. Trumbull sherds is available at The Digital Archaeological Record (tDAR) web sites. (https://core.tdar.org/dataset/392879). INAA data of lowland Virgin sherds are available at University of Missouri Research Reactor (MURR) (http://www.murr.missouri.edu).

The appendix A includes two tables listed below. They include the information about the ceramic and clay samples for LA-ICP-MS analysis.

Table A1. Sample Information (Ceramics).
Table A2. Sample Information (Clay).

Note on Abbreviation

Table A1

Group

1G = Group 1G
1VM = Group 1VM
1VV = Group 1VV
G2 = Group 2
G3 = Group 3
G4 = Group 4
VR1 = VR1
VR3 = VR3

Provenience

TP = Test Pit
SCU = Surface Collection Unit
L = Level
S = Surface

Types

MP = Moapa Plain
MPF = Moapa Plain Fugitive Red
MC = Moapa Corrugated
MBG = Moapa Black-on-gray
TP = Tusayan Plain
TPF = Tusayan Plain Fugitive Red
TC = Tusayan Corrugated

TBC = Tusayan Black-on-gray
SNP = Shinarump Pain
SVP = Shivwits Plain
SVC = Shivwits Corrugated
TO = Tegi Orange Ware
SJR = San Juan Red Ware
SNR = Shinarump Red Ware
RED = Other red ware
POL = Polychrome

Surface Treatment

P = Plain
C = Corrugated
BG = Black-on-gray
BG_C = Black-on-gray and Corrugated
RED = Red
BR = Black-on-red
POLY = Polychrome

Table A2

Region

MT = Mt. Trumbull
VR = Lowland Virgin
TW = Tuweep
SV = Shivwits Plateau

Clay Type

VOL = Volcanic
Sed = Sedimentary
Sec = Secondary

Group

G1G = Group 1G
G2 = Group 2
G1VV = Group 1VV

Appendix A: Table A1. Sample Information (Ceramics)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
131-2	G2	Mt. Trumbull	131 BLM	SCU A-1	olivine	MP	P
131-3		Mt. Trumbull	131 BLM	SCU A-1	olivine	MP	P
131-4	1VV possible	Mt. Trumbull	131 BLM	SCU A-1	sand	TP	P
131-9	1G	Mt. Trumbull	131 BLM	SCU A-2	olivine	MP	P
131-11	1VV	Mt. Trumbull	131 BLM	SCU A-2	sand	TP	P
131-14	G2	Mt. Trumbull	131 BLM	SCU A-3	olivine	MP	P
131-19	1G	Mt. Trumbull	131 BLM	SCU A-3	olivine	MP	P
131-26	1G	Mt. Trumbull	131 BLM	SCU A-3	sand	TP	P
131-30	G2	Mt. Trumbull	131 BLM	SCU A-3	olivine	MC	C
131-32		Mt. Trumbull	131 BLM	SCU A-3	olivine	MC	C
131-45	G2	Mt. Trumbull	131 BLM	SCU A-7	olivine	MP	P
131-53	G2	Mt. Trumbull	131 BLM	SCU A-7	olivine	MP	P
131-59	1VM	Mt. Trumbull	131 BLM	SCU A-7	olivine	MC	C
131-70	1G	Mt. Trumbull	131 BLM	SCU A-11	olivine	MP	P
131-74	1G	Mt. Trumbull	131 BLM	SCU A-11	olivine	MP	P
131-80	1VM	Mt. Trumbull	131 BLM	SCU A-11	olivine	MP	P
131-84	1G	Mt. Trumbull	131 BLM	SCU A-11	olivine	MP	P
131-96	1G	Mt. Trumbull	131 BLM	SCU B-1	olivine	MP	P
131-103		Mt. Trumbull	131 BLM	SCU A-8	olivine	MP	P
131-119		Mt. Trumbull	131 BLM	SCU A-3	olivine	MBG	BG
131-136	1G	Mt. Trumbull	131 BLM	SCU A-8	olivine	MBG	BG
131-160	VR1	Mt. Trumbull	131 BLM	surface general	sand	TBG	BG_C
131-167	1G	Mt. Trumbull	131 BLM	surface general	olivine	MBG	BG
131-168	1VM	Mt. Trumbull	131 BLM	surface general	olivine	MBG	BC_C
131-172	1G possoble	Mt. Trumbull	131 BLM	surface general	olivine	MBG	BG
131-188		Mt. Trumbull	131 BLM	surface general	olivine	MP	P
131-189		Mt. Trumbull	131 BLM	surface general	sand	TP	P
131-236	1VV	Mt. Trumbull	131 BLM	TP-1 L3	sand	TP	P
131-237	1G	Mt. Trumbull	131 BLM	TP-3 L7	olivine	MBG	BG
131-238	1G	Mt. Trumbull	131 BLM	TP-3 L2	olivine	MBG	BG
131-239	1G	Mt. Trumbull	131 BLM	TP-1 L2	olivine	MBG	BG
131-240	1G	Mt. Trumbull	131 BLM	TP-3 L1	olivine	MBG	BG_C
131-241	1G	Mt. Trumbull	131 BLM	TP-2 L3	olivine	MBG	BG
131-242	1VV possible	Mt. Trumbull	131 BLM	TP-3 L1	sand	TBG	BG
131-243	1G possoble	Mt. Trumbull	131 BLM	TP-3 L7	olivine	MPF	P
131-244	1G	Mt. Trumbull	131 BLM	TP-3 L7	sand	TBG	BG
131-245	G2	Mt. Trumbull	131 BLM	TP-1 L3	sherd_olivine	MBG	BG
131-247	1VV	Mt. Trumbull	131 BLM	TP-1 L7	sand	TBG	BG
131-248		Mt. Trumbull	131 BLM	TP-2 L1	olivine	MBG	BG
131-249	1G	Mt. Trumbull	131 BLM	TP-1 L6	olivine	MBG	BG
131-250	1G	Mt. Trumbull	131 BLM	TP-2 L1	olivine	MBG	BG
131-251	1G	Mt. Trumbull	131 BLM	TP-3 L6	olivine	MBG	BG
131-252		Mt. Trumbull	131 BLM	TP-3 L6	olivine	MPF	P
131-253	1G	Mt. Trumbull	131 BLM	TP-3 L4	olivine	MP	P
131-254	1G	Mt. Trumbull	131 BLM	TP-3 L1	olivine	MP	P
131-255		Mt. Trumbull	131 BLM	TP-3 L1	sand	TP	P
131-256		Mt. Trumbull	131 BLM	TP-3 L1	sand	TC	C
131-257	1G	Mt. Trumbull	131 BLM	TP-3 L1	olivine	MC	C
131-258		Mt. Trumbull	131 BLM	TP-3 L2	olivine	MP	P
131-259		Mt. Trumbull	131 BLM	TP-3 L2	olivine	MP	P
131-260	1VV	Mt. Trumbull	131 BLM	TP-3 L2	sand	TP	P
131-261		Mt. Trumbull	131 BLM	TP-3 L2	sand	TP	P
131-262		Mt. Trumbull	131 BLM	TP-3 L2	sand	SNP	P
131-263	1G	Mt. Trumbull	131 BLM	TP-3 L3	olivine	MP	P
131-264		Mt. Trumbull	131 BLM	TP-3 L5	olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
131-265		Mt. Trumbull	131 BLM	TP-3 L5	olivine	MP	P
131-266	1G	Mt. Trumbull	131 BLM	TP-3 L6	olivine	MP	P
131-267	1G	Mt. Trumbull	131 BLM	TP-3 L7	olivine	MP	P
131-268		Mt. Trumbull	131 BLM	TP-3 L7	olivine	MP	P
131-269		Mt. Trumbull	131 BLM	TP-3 L7	sand	SNP	P
131-270	1VV	Mt. Trumbull	131 BLM	TP-3 L7	sand	TP	P
131-271	1G possoble	Mt. Trumbull	131 BLM	TP-3 L8	olivine	MPF	P
131-272	1G	Mt. Trumbull	131 BLM	TP-3 L8	olivine	MP	P
131-273	1G possoble	Mt. Trumbull	131 BLM	TP-3 L8	olivine	MP	P
131-274	G2	Mt. Trumbull	131 BLM	TP-3 S	olivine	MP	P
131-275	G2	Mt. Trumbull	131 BLM	TP-1 S	olivine	MP	P
131-276	1G	Mt. Trumbull	131 BLM	TP-1 S	sand	SNP	P
131-277	G2	Mt. Trumbull	131 BLM	TP-1 S	olivine	MC	C
131-278	1G	Mt. Trumbull	131 BLM	TP-1 L1	olivine	MP	P
131-279	1VV	Mt. Trumbull	131 BLM	TP-1 L1	sand	TP	P
131-280	1VV	Mt. Trumbull	131 BLM	TP-1 L2	sand	TP	P
131-281	1G	Mt. Trumbull	131 BLM	TP-1 L2	olivine	MP	P
131-282	1G possoble	Mt. Trumbull	131 BLM	TP-1 L3	olivine	MP	P
131-283	1G	Mt. Trumbull	131 BLM	TP-1 L3	sand	TP	P
131-284	1G	Mt. Trumbull	131 BLM	TP-1 L4	olivine	MP	P
131-285	1G	Mt. Trumbull	131 BLM	TP-1 L4	olivine	MP	P
131-286	1VV	Mt. Trumbull	131 BLM	TP-1 L4	sand	TP	P
131-287	1G	Mt. Trumbull	131 BLM	TP-2 L5	olivine	MP	P
131-288	1G	Mt. Trumbull	131 BLM	TP-2 L5	olivine	MP	P
131-289	1VV	Mt. Trumbull	131 BLM	TP-2 L5	sand	TP	P
131-290	1G	Mt. Trumbull	131 BLM	TP-3 L5	olivine	MP	P
131-291	1G	Mt. Trumbull	131 BLM	TP-1 L6	olivine	MP	P
131-292	1G	Mt. Trumbull	131 BLM	TP-1 L7	olivine	MP	P
131-293	1G	Mt. Trumbull	131 BLM	TP-2 S	olivine	MP	P
131-294	G2 possible	Mt. Trumbull	131 BLM	TP-2 S	sherd_olivine	SVP	P
131-295	1VV	Mt. Trumbull	131 BLM	TP-2 S	sand	SNP	P
131-296	1VV	Mt. Trumbull	131 BLM	TP-2 S	sand	TP	P
131-297	1G	Mt. Trumbull	131 BLM	TP-2 L6	olivine	MP	P
131-298	1G	Mt. Trumbull	131 BLM	TP-2 L2	olivine	MP	P
131-299	1G	Mt. Trumbull	131 BLM	TP-2 L2	olivine	MP	P
131-300	1VV	Mt. Trumbull	131 BLM	TP-2 L2	sand	TP	P
131-301	1G	Mt. Trumbull	131 BLM	TP-2 L4	olivine	MP	P
131-302	G2	Mt. Trumbull	131 BLM	TP-2 L3	olivine	MP	P
131-303	1G	Mt. Trumbull	131 BLM	TP-2 L1	olivine	MPF	P
131-304		Mt. Trumbull	131 BLM	TP-2 L1	olivine	MBG	BG
131-305	1G	Mt. Trumbull	131 BLM	TP-2 L5	olivine	MP	P
131-306	1G	Mt. Trumbull	131 BLM	TP-2 L7	olivine	MP	P
131-307	1G	Mt. Trumbull	131 BLM	TP-2 L3	olivine	MP	P
131-308	1G	Mt. Trumbull	131 BLM	TP-2 L7	sand	TP	P
131-310	1G	Mt. Trumbull	131 BLM	TP-2 L5	olivine	MPF	P
131-311	1G	Mt. Trumbull	131 BLM	TP-3 L7	olivine	MP	P
131-312	1VV possible	Mt. Trumbull	131 BLM	TP-2 L3	sand	TP	P
131-313		Mt. Trumbull	131 BLM	TP-2 L3	olivine	MP	P
131-314	VR1	Mt. Trumbull	131 BLM	TP-2 L3	sand	TBG	BG
131-315	VR1	Mt. Trumbull	131 BLM	TP-2 L3	sand	TP	P
131-316	1G	Mt. Trumbull	131 BLM	TP-2 L3	olivine	MP	P
131-317	1G	Mt. Trumbull	131 BLM	TP-2 L3	olivine	MC	C
131-318	1VV	Mt. Trumbull	131 BLM	TP-2 L6	olivine	MPF	P
131-319	1G	Mt. Trumbull	131 BLM	TP-3 L7	olivine	MP	P
131-320	1G	Mt. Trumbull	131 BLM	TP-3 L7	olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
131-321	1G	Mt. Trumbull	131 BLM	TP-1 L4	olivine	MP	P
131-322	1G	Mt. Trumbull	131 BLM	TP-3 L1	olivine	MP	P
131-323	1G	Mt. Trumbull	131 BLM	TP-1 L3	olivine	MP	P
131-324		Mt. Trumbull	131 BLM	TP-1 L3	olivine	MP	P
131-325	G2	Mt. Trumbull	131 BLM	TP-3 L4	sand	TP	P
131-326	1G	Mt. Trumbull	131 BLM	TP-3 L8	olivine	MPF	P
131-327		Mt. Trumbull	131 BLM	TP-1 S	sherd_olivine	SVP	P
131-328		Mt. Trumbull	131 BLM	TP-1 L1	olivine	MP	P
131-329	1G	Mt. Trumbull	131 BLM	TP-2 L1	olivine	MP	P
131-330	1G	Mt. Trumbull	131 BLM	TP-2 L1	olivine	MP	P
131-331	1G	Mt. Trumbull	131 BLM	TP-2 L1	olivine	MP	P
131-332	1G	Mt. Trumbull	131 BLM	TP-2 L5S	olivine	MP	P
131-333	1G	Mt. Trumbull	131 BLM	TP-3 L5	olivine	MPF	P
131-334	1G	Mt. Trumbull	131 BLM	TP-3 L5	olivine	MP	P
131-335	1G	Mt. Trumbull	131 BLM	TP-3 L6	olivine	MP	P
131-336	1G	Mt. Trumbull	131 BLM	TP-3 L6	olivine	MP	P
131-337	G2	Mt. Trumbull	131 BLM	TP-2 L3N	olivine	MP	P
131-338	1G	Mt. Trumbull	131 BLM	TP-2 6S	olivine	MP	P
131-339	1G	Mt. Trumbull	131 BLM	TP-2 L2	olivine	MP	P
131-340	1G	Mt. Trumbull	131 BLM	TP-2 L5N	olivine	MP	P
131-341	1G	Mt. Trumbull	131 BLM	TP-2 L3S	olivine	MP	P
131-342	G2	Mt. Trumbull	131 BLM	TP-3 L2	olivine	MP	P
131-343	1G	Mt. Trumbull	131 BLM	TP-3 L2	olivine	MPF	P
131-344	1G	Mt. Trumbull	131 BLM	TP-2 L4N	olivine	MP	P
131-345		Mt. Trumbull	131 BLM	TP-3 L3	olivine	MP	P
131-346	1G	Mt. Trumbull	131 BLM	TP-3 L3	olivine	MP	P
131-347	1G	Mt. Trumbull	131 BLM	TP-2 S	olivine	MP	P
131-348	1G	Mt. Trumbull	131 BLM	surface general	olivine	MP	P
131-349	1G	Mt. Trumbull	131 BLM	TP-3 L7	olivine	MPF	P
131-350		Mt. Trumbull	131 BLM	TP-2 L4	olivine	MC	C
131-351	1G	Mt. Trumbull	131 BLM	TP-2 L3	olivine	MP	P
131-352	1VV	Mt. Trumbull	131 BLM	TP-3 L5	olivine	MP	P
131-353	1G	Mt. Trumbull	131 BLM	TP-3 L5	olivine	MP	P
131-354	1G	Mt. Trumbull	131 BLM	TP-3 L6	olivine	MP	P
131-355	1VV possible	Mt. Trumbull	131 BLM	TP-2 L1	sand	TP	P
131-356	1G	Mt. Trumbull	131 BLM	TP-2 L6	olivine	MP	P
131-357	1G	Mt. Trumbull	131 BLM	TP-1 L1	olivine	MP	P
131-358	1G	Mt. Trumbull	131 BLM	TP-3 L8	olivine	MP	P
131-359	1G	Mt. Trumbull	131 BLM	TP-3 L4	olivine	MP	P
131-360	1G possoble	Mt. Trumbull	131 BLM	TP-1 L4	olivine	MP	P
131-361	1G	Mt. Trumbull	131 BLM	TP-1 S	olivine	MP	P
131-362	1G	Mt. Trumbull	131 BLM	TP-3 L1	olivine	MP	P
131-363	1G	Mt. Trumbull	131 BLM	TP-3 L7	olivine	MP	P
131-364	1G	Mt. Trumbull	131 BLM	TP-2 L5	olivine	MP	P
131-365	1G	Mt. Trumbull	131 BLM	TP-3 S	olivine	MP	P
131-366		Mt. Trumbull	131 BLM	TP-2 S	olivine	MP	P
131-367	1G	Mt. Trumbull	131 BLM	TP-3 L2	olivine	MP	P
131-368	1G	Mt. Trumbull	131 BLM	TP-1 L3	olivine	MP	P
131-369	G2	Mt. Trumbull	131 BLM	TP-2 L5	olivine	MP	P
136-7	1G possoble	Mt. Trumbull	136 ASM	surface general	olivine	MC	C
136-9	G2	Mt. Trumbull	136 ASM	surface general	olivine	MC	C
136-16	G2	Mt. Trumbull	136 ASM	surface general	olivine	MP	P
136-18	1G	Mt. Trumbull	136 ASM	surface general	olivine	MP	P
136-25		Mt. Trumbull	136 ASM	surface general	olivine	MP	P
136-26	G2	Mt. Trumbull	136 ASM	surface general	olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
136-27	G2	Mt. Trumbull	136 ASM	surface general	olivine	MP	P
136-31		Mt. Trumbull	136 ASM	surface general	sherd	RED	RED
136-32		Mt. Trumbull	136 ASM	surface general	sand_andesite	SJR	RED
136-34	1VM	Mt. Trumbull	136 ASM	surface general	olivine	MBG	BG
136-35		Mt. Trumbull	136 ASM	surface general	olivine	MBG	BG
136-36	1VV	Mt. Trumbull	136 ASM	surface general	sand	TBG	BG
136-38		Mt. Trumbull	136 ASM	surface general	olivine	MC	C
136-56		Mt. Trumbull	136 ASM	surface general	olivine	MBG	BG
136-57		Mt. Trumbull	136 ASM	surface general	sand	TBG	BG
136-58	1G	Mt. Trumbull	136 ASM	surface general	olivine	MBG	BG
136-59	G2	Mt. Trumbull	136 ASM	surface general	olivine	MBG	BG
136-63	1VV	Mt. Trumbull	136 ASM	surface general	sand	TBG	BG
136-64	G2	Mt. Trumbull	136 ASM	surface general	sherd_olivine	MBG	BG
136-67		Mt. Trumbull	136 ASM	surface general	olivine	MBG	BG
136-71		Mt. Trumbull	136 ASM	surface general	sand	SNR	BR
136-72	G2	Mt. Trumbull	136 ASM	surface general	olivine	MBG	BG
136-74		Mt. Trumbull	136 ASM	surface general	sand	TBG	BG
136-75	1VM	Mt. Trumbull	136 ASM	surface general	olivine	MBG	BG_C
136-76	1VM	Mt. Trumbull	136 ASM	surface general	olivine	MBG	BG_C
136-82		Mt. Trumbull	136 ASM	surface general	sherd_sand	SNR	BR
136-218	1VV	Mt. Trumbull	136 ASM	TP-2 L4	sherd_sand	TBG	BG
136-219		Mt. Trumbull	136 ASM	TP-2 L6	sand	TBG	BG
136-220		Mt. Trumbull	136 ASM	surface general	sand	TP	P
136-221	1VV	Mt. Trumbull	136 ASM	TP-2 L7	sand	SNR	RED
136-223	G2	Mt. Trumbull	136 ASM	TP-3 L1	olivine	MP	P
136-224	1VV	Mt. Trumbull	136 ASM	TP-3 L1	sand	TP	P
136-225		Mt. Trumbull	136 ASM	TP-3 L1	olivine	MC	C
136-226	1G	Mt. Trumbull	136 ASM	TP-3 L1	sand	TC	C
136-227		Mt. Trumbull	136 ASM	TP-3 L1	sherd_sand	TC	C
136-228	G2 possible	Mt. Trumbull	136 ASM	TP-3 L2	sherd_olivine	SVP	P
136-229		Mt. Trumbull	136 ASM	TP-3 L2	sherd_olivine	SVP	P
136-230		Mt. Trumbull	136 ASM	TP-3 L2	olivine	MC	C
136-231	G2 possible	Mt. Trumbull	136 ASM	TP-3 L2	sherd_olivine	SVC	C
136-232	1VM	Mt. Trumbull	136 ASM	TP-1 L1	olivine	MC	C
136-233	1G	Mt. Trumbull	136 ASM	TP-1 L2	olivine	MP	P
136-234		Mt. Trumbull	136 ASM	TP-1 L3	olivine	MP	P
136-235	1G	Mt. Trumbull	136 ASM	TP-1 L2	sherd_olivine	MC	C
136-236	G2	Mt. Trumbull	136 ASM	TP-1 L2	olivine	MP	P
136-237	1VV	Mt. Trumbull	136 ASM	TP-1 L2	sand	TP	P
136-238	1G	Mt. Trumbull	136 ASM	TP-3 L3	olivine	MP	P
136-239	G2	Mt. Trumbull	136 ASM	TP-3 S	sherd_olivine	MC	C
136-240	G2	Mt. Trumbull	136 ASM	TP-3 S	olivine	MP	P
136-241		Mt. Trumbull	136 ASM	TP-1 L3	olivine	MC	C
136-242	G2	Mt. Trumbull	136 ASM	TP-1 L1	olivine	MP	P
136-243	1VM possible	Mt. Trumbull	136 ASM	TP-1 L2	olivine	MC	C
136-244	G2	Mt. Trumbull	136 ASM	TP-1 L1	olivine	MP	P
136-245	G2	Mt. Trumbull	136 ASM	TP-1 S	olivine	MP	P
136-246	1G	Mt. Trumbull	136 ASM	TP-1 L3	olivine	MP	P
136-247	G2	Mt. Trumbull	136 ASM	TP-1 L13	olivine	MP	P
136-248		Mt. Trumbull	136 ASM	TP-1 L3	olivine	MC	C
136-249		Mt. Trumbull	136 ASM	TP-1 L5	olivine	MP	P
136-250	G2	Mt. Trumbull	136 ASM	TP-1 L6	olivine	MP	P
136-251	G2	Mt. Trumbull	136 ASM	TP-1 L4	olivine	MP	P
136-252		Mt. Trumbull	136 ASM	TP-1 L4	sand	TP	P
136-253	G2	Mt. Trumbull	136 ASM	TP-1 L5	sherd_olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
136-254	1VM	Mt. Trumbull	136 ASM	TP-2 L6	olivine	MC	C
136-255	1G	Mt. Trumbull	136 ASM	TP-2 S	olivine	MP	P
136-256	G2	Mt. Trumbull	136 ASM	TP-2 L13	olivine	MP	P
136-257		Mt. Trumbull	136 ASM	TP-2 L4	sand	TP	P
136-258	1VM	Mt. Trumbull	136 ASM	TP-2 L4	olivine	MC	C
136-259		Mt. Trumbull	136 ASM	TP-2 L13	olivine	MC	C
136-260	G2	Mt. Trumbull	136 ASM	TP-2 L2	olivine	MP	P
136-261		Mt. Trumbull	136 ASM	TP-2 L3	olivine	MC	C
136-262	G2	Mt. Trumbull	136 ASM	TP-2 L5	olivine	MP	P
136-263	G2	Mt. Trumbull	136 ASM	TP-2 L1	olivine	MP	P
136-264	1G	Mt. Trumbull	136 ASM	TP-2 L11	olivine	MPF	P
136-265	1G	Mt. Trumbull	136 ASM	TP-2 L5	olivine	MC	C
136-266	G2	Mt. Trumbull	136 ASM	TP-2 L3	olivine	MP	P
136-267	1VV	Mt. Trumbull	136 ASM	TP-2 L10	sand	TP	P
136-268	G2	Mt. Trumbull	136 ASM	TP-2 L9	olivine	MP	P
136-269	G2	Mt. Trumbull	136 ASM	TP-2 L6	olivine	MP	P
136-270		Mt. Trumbull	136 ASM	TP-2 L3	olivine	MC	C
136-271	1VM	Mt. Trumbull	136 ASM	TP-2 L3	olivine	MC	C
136-272		Mt. Trumbull	136 ASM	TP-2 L2	sand	TC	C
136-273	G2	Mt. Trumbull	136 ASM	TP-2 L12	olivine	MP	P
136-274		Mt. Trumbull	136 ASM	TP-2 L8	olivine	MP	P
136-275	1VM	Mt. Trumbull	136 ASM	TP-2 L2	olivine	MC	C
136-276	1VV	Mt. Trumbull	136 ASM	TP-2 L2	sand	TP	P
136-277		Mt. Trumbull	136 ASM	TP-2 L8	olivine	MP	P
136-278	1G	Mt. Trumbull	136 ASM	TP-2 L9	olivine	MBG	BG
136-279	1G	Mt. Trumbull	136 ASM	TP-2 L8	olivine	MBG	BG
136-280		Mt. Trumbull	136 ASM	TP-2 L12	olivine	MP	P
136-281	G2	Mt. Trumbull	136 ASM	TP-2 L13	olivine	MP	P
136-282		Mt. Trumbull	136 ASM	TP-2 L6	sherd	POL	POLY
136-283		Mt. Trumbull	136 ASM	TP-2 L6	olivine	MC	C
136-284		Mt. Trumbull	136 ASM	TP-2 L6	olivine	MP	P
136-285		Mt. Trumbull	136 ASM	TP-2 L5	sand	TP	P
136-286	1G	Mt. Trumbull	136 ASM	TP-2 L8	olivine	MC	C
136-287	1G possoble	Mt. Trumbull	136 ASM	TP-2 L3	olivine	MC	C
136-288	1G	Mt. Trumbull	136 ASM	TP-2 L5	olivine	MP	P
136-289		Mt. Trumbull	136 ASM	TP-2 L1	olivine	MP	P
136-290	G2	Mt. Trumbull	136 ASM	TP-2 L2	olivine	MP	P
136-291	G2	Mt. Trumbull	136 ASM	TP-2 L3	olivine	MP	P
136-292	1G	Mt. Trumbull	136 ASM	TP-2 L13	olivine	MPF	P
136-293	G2	Mt. Trumbull	136 ASM	TP-2 L2	olivine	MP	P
136-294	G2	Mt. Trumbull	136 ASM	TP-2 L10	olivine	MP	P
136-295		Mt. Trumbull	136 ASM	TP-2 L8	olivine	MP	P
136-296	G2	Mt. Trumbull	136 ASM	TP-2 L4	olivine	MP	P
136-297	G2	Mt. Trumbull	136 ASM	TP-2 L6	olivine	MP	P
136-298	1G	Mt. Trumbull	136 ASM	TP-2 L9	olivine	MPF	P
136-299	G2	Mt. Trumbull	136 ASM	TP-2 L8	olivine	MP	P
136-300	G2	Mt. Trumbull	136 ASM	TP-2 L12	olivine	MP	P
136-301	G2	Mt. Trumbull	136 ASM	TP-2 S	olivine	MP	P
136-302	1VM	Mt. Trumbull	136 ASM	TP-2 L6	olivine	MP	P
136-303		Mt. Trumbull	136 ASM	TP-2 L6	olivine	MP	P
136-304		Mt. Trumbull	136 ASM	TP-3 L6	olivine	MP	P
136-305		Mt. Trumbull	136 ASM	TP-3 L6	olivine	MP	P
136-306		Mt. Trumbull	136 ASM	TP-3 L6	olivine	MP	P
136-307	G2	Mt. Trumbull	136 ASM	TP-2 L12	olivine	MP	P
136-308	1G	Mt. Trumbull	136 ASM	TP-2 L12	olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
136-309		Mt. Trumbull	136 ASM	TP-2 L14	sherd	RED	RED
136-310		Mt. Trumbull	136 ASM	TP-2 L8	olivine	MBG	BG
136-311	G2 possible	Mt. Trumbull	136 ASM	TP-2 L7	olivine	MP	P
136-312		Mt. Trumbull	136 ASM	TP-4 L2	olivine	MP	P
136-313		Mt. Trumbull	136 ASM	TP-4 L4	olivine	MP	P
136-314	1VM	Mt. Trumbull	136 ASM	TP-4 L1	olivine	MP	P
136-315		Mt. Trumbull	136 ASM	TP-4 S	olivine	MP	P
136-316	1G	Mt. Trumbull	136 ASM	TP-4 L3	olivine	MP	P
136-317		Mt. Trumbull	136 ASM	TP-4 L4	sand	TC	C
136-318	G2	Mt. Trumbull	136 ASM	TP-4 L4	olivine	MP	P
136-319	G2	Mt. Trumbull	136 ASM	TP-4 L7	olivine	MP	P
136-320		Mt. Trumbull	136 ASM	TP-4 L1	olivine	MC	C
136-321		Mt. Trumbull	136 ASM	TP-4 L2	olivine	MC	C
136-322	1VM	Mt. Trumbull	136 ASM	TP-4 L1	olivine	MC	C
136-323		Mt. Trumbull	136 ASM	TP-4 L6	olivine	MPF	P
136-324		Mt. Trumbull	136 ASM	TP-4 L3	olivine	MC	C
136-325	1VM	Mt. Trumbull	136 ASM	TP-4 L1	olivine	MP	P
136-326		Mt. Trumbull	136 ASM	TP-4 L2	sand	SNP	P
136-328	1G	Mt. Trumbull	136 ASM	TP-2 L9	olivine	MP	P
136-329	G2	Mt. Trumbull	136 ASM	TP-2 L3	olivine	MP	P
136-330	G2	Mt. Trumbull	136 ASM	TP-2 L6	olivine	MPF	P
136-331	G2	Mt. Trumbull	136 ASM	TP-2 L5	olivine	MP	P
136-332		Mt. Trumbull	136 ASM	TP-2 L2	olivine	MC	C
136-333		Mt. Trumbull	136 ASM	TP-2 L2	olivine	MP	P
136-334	1G	Mt. Trumbull	136 ASM	TP-2 L8	olivine	MPF	P
136-335	G2	Mt. Trumbull	136 ASM	TP-2 L12	olivine	MP	P
136-336	1VV	Mt. Trumbull	136 ASM	TP-2 L4	sand	TP	P
136-337	G2	Mt. Trumbull	136 ASM	TP-3 L1	olivine	MP	P
136-338		Mt. Trumbull	136 ASM	TP-2 L4	olivine	MC	C
14-6	1G possoble	Mt. Trumbull	14 MNA	SCU 5	olivine	MBG	BG_C
14-28	1G possoble	Mt. Trumbull	14 MNA	ROOM1 fill	olivine	MP	P
14-34		Mt. Trumbull	14 MNA	ROOM1 fill	olivine	MC	C
14-70	1G	Mt. Trumbull	14 MNA	ROOM2 fill	olivine	MP	P
14-71		Mt. Trumbull	14 MNA	ROOM2 fill	olivine	MP	P
14-74		Mt. Trumbull	14 MNA	ROOM2 fill	olivine	MC	C
14-83	G2	Mt. Trumbull	14 MNA	ROOM2 fill	olivine	MC	C
14-92		Mt. Trumbull	14 MNA	ROOM2 fill	olivine	MBG	BG
14-106	1G	Mt. Trumbull	14 MNA	ROOM3 fill	olivine	MC	C
14-116	G2	Mt. Trumbull	14 MNA	ROOM3 fill	olivine	MP	P
14-120	1G	Mt. Trumbull	14 MNA	ROOM3 fill	olivine	MBG	BG
14-140	G2	Mt. Trumbull	14 MNA	SCU 5	olivine	MP	P
14-152	G2	Mt. Trumbull	14 MNA	SCU 3	olivine	MP	P
14-203	1G	Mt. Trumbull	14 MNA	TP-14 L5	olivine	MBG	BG
14-204		Mt. Trumbull	14 MNA	TP-7 L4	olivine	MBG	BG_C
14-205	1G possoble	Mt. Trumbull	14 MNA	TP-7 L5	sand	TBG	BG
14-206		Mt. Trumbull	14 MNA	TP-13 L2	sand	TBG	BG_C
14-207		Mt. Trumbull	14 MNA	TP-13 L2	olivine	MBG	BG
14-208	1G	Mt. Trumbull	14 MNA	TP-7 L3	sherd_olivine	MBG	BG
14-209		Mt. Trumbull	14 MNA	TP-L S	sherd	TO	BR
14-210	1G	Mt. Trumbull	14 MNA	TP 3 L3	olivine	MBG	BG_C
14-211	1VV possible	Mt. Trumbull	14 MNA	TP-12 L2	sand	TBG	BG
14-212	VR1	Mt. Trumbull	14 MNA	TP-7 L2	sand	TBG	BG
14-213	1G	Mt. Trumbull	14 MNA	TP-14 L3	olivine	MC	C
14-214		Mt. Trumbull	14 MNA	TP-14 L6	olivine	MC	C
14-215	G2	Mt. Trumbull	14 MNA	TP-14 L7	sherd_olivine	SVC	C

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
14-216	1VV	Mt. Trumbull	14 MNA	TP-14 L8	sand	TP	P
14-217	G2	Mt. Trumbull	14 MNA	TP-14 L5	olivine	MP	P
14-218	1G possoble	Mt. Trumbull	14 MNA	TP-14 L5	sand	TP	P
14-219	1G	Mt. Trumbull	14 MNA	TP-14 L5	olivine	MC	C
14-220	G2	Mt. Trumbull	14 MNA	TP-14 L5	sherd_olivine	SVC	C
14-221	G2 possible	Mt. Trumbull	14 MNA	TP-2 L7	olivine	MC	C
14-222		Mt. Trumbull	14 MNA	TP-14 L6	olivine	MC	P
14-223	1G	Mt. Trumbull	14 MNA	TP-14 S	olivine	MP	P
14-224	1G	Mt. Trumbull	14 MNA	TP-14 L2	olivine	MC	C
14-225	1VM possible	Mt. Trumbull	14 MNA	TP-14 L4	olivine	MP	P
14-226		Mt. Trumbull	14 MNA	TP-14 L4	olivine	MP	P
14-227	G2	Mt. Trumbull	14 MNA	TP-14 L4	olivine	MP	P
14-228	G2	Mt. Trumbull	14 MNA	TP-14 L2	sherd_olivine	SVP	P
14-229		Mt. Trumbull	14 MNA	TP-14 L2	olivine	MP	P
14-230		Mt. Trumbull	14 MNA	TP-14 L4	olivine	MP	P
14-231		Mt. Trumbull	14 MNA	TP-14 L4	olivine	MP	P
14-232	1G	Mt. Trumbull	14 MNA	TP-14 L1	olivine	MP	P
14-233	1G	Mt. Trumbull	14 MNA	TP-14 L1	olivine	MP	P
14-234	G2	Mt. Trumbull	14 MNA	TP-14 L3	olivine	MP	P
14-235	1G	Mt. Trumbull	14 MNA	TP-14 L3	olivine	MP	P
14-236	1G	Mt. Trumbull	14 MNA	TP-14 L3	olivine	MP	P
14-237	1G	Mt. Trumbull	14 MNA	TP-14 L1	olivine	MP	P
14-238	1G possoble	Mt. Trumbull	14 MNA	TP-14 L1	sand	TP	P
14-239	1VV possible	Mt. Trumbull	14 MNA	TP-2 L1	sand	TBG	BG_C
14-240		Mt. Trumbull	14 MNA	surface general	sand	POL	POLY
14-241	G2	Mt. Trumbull	14 MNA	TP-5 L4	olivine	MP	P
14-242	G2	Mt. Trumbull	14 MNA	TP-14 L5	olivine	MC	C
14-243		Mt. Trumbull	14 MNA	TP-7 L6	olivine	MBG	BG
14-244		Mt. Trumbull	14 MNA	TP-3 L2	olivine	MC	C
14-245	G2	Mt. Trumbull	14 MNA	TP-5 L3	sherd_olivine	SVP	P
14-246	G2	Mt. Trumbull	14 MNA	TP-7 L8	sherd_olivine	SVP	P
14-247		Mt. Trumbull	14 MNA	TP-7 L6	olivine	MC	C
14-248	G2	Mt. Trumbull	14 MNA	TP-13 S	olivine	MP	P
14-249		Mt. Trumbull	14 MNA	TP-13 L5	olivine	MP	P
14-250	1G	Mt. Trumbull	14 MNA	TP-13 L5	olivine	MC	C
14-251		Mt. Trumbull	14 MNA	TP-13 L4	olivine	MC	C
14-252	1G possoble	Mt. Trumbull	14 MNA	TP-13 L2	olivine	MC	C
14-253	1G	Mt. Trumbull	14 MNA	TP-13 L2	olivine	MC	C
14-254	1G	Mt. Trumbull	14 MNA	TP-13 L8	olivine	MP	P
14-255	G2	Mt. Trumbull	14 MNA	TP-13 L3	sherd_olivine	SVP	P
14-256	1G	Mt. Trumbull	14 MNA	TP-13 L3	olivine	MP	P
14-257	1G	Mt. Trumbull	14 MNA	TP-13 L6	olivine	MC	C
14-258	1G	Mt. Trumbull	14 MNA	TP-13 L2	olivine	MP	P
14-259	G2	Mt. Trumbull	14 MNA	TP-13 L2	sherd_olivine	SVP	P
14-260		Mt. Trumbull	14 MNA	TP-13 L3	sand	TC	C
14-261	1G	Mt. Trumbull	14 MNA	TP-13 L3	olivine	MC	C
14-262	1G	Mt. Trumbull	14 MNA	TP-13 L4	olivine	MP	P
14-263	1G	Mt. Trumbull	14 MNA	TP-13 L4	olivine	MC	C
14-264	1G	Mt. Trumbull	14 MNA	TP-13 S	olivine	MC	C
14-265	G4	Mt. Trumbull	14 MNA	TP-13 L7	olivine	MC	C
14-266	G2	Mt. Trumbull	14 MNA	TP-13 L1	olivine	MP	P
14-267	G2	Mt. Trumbull	14 MNA	TP-7 L5	olivine	MP	P
14-268	1G	Mt. Trumbull	14 MNA	TP-7 L8	olivine	MC	C
14-269	1G possoble	Mt. Trumbull	14 MNA	TP-7 L4	olivine	MC	C
14-270	G2	Mt. Trumbull	14 MNA	TP-7 L9	sherd_olivine	SVP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
14-271		Mt. Trumbull	14 MNA	TP-7 L9	sand	TP	P
14-272		Mt. Trumbull	14 MNA	TP-7 L3	olivine	MP	P
14-273	1G	Mt. Trumbull	14 MNA	TP-7 L7	olivine	MC	C
14-274	1G possoble	Mt. Trumbull	14 MNA	TP-7 S	olivine	MC	C
14-275	G2	Mt. Trumbull	14 MNA	TP-7 L7	sherd_olivine	SVC	C
14-276	1G	Mt. Trumbull	14 MNA	TP-7 L2	olivine	MP	P
14-277	G2	Mt. Trumbull	14 MNA	TP-7 L7	sand	SNP	P
14-278	1G	Mt. Trumbull	14 MNA	TP-7 L7	olivine	MP	P
14-279		Mt. Trumbull	14 MNA	TP-7 L6	olivine	MP	P
14-280	1G possoble	Mt. Trumbull	14 MNA	TP-7 L6	olivine	MC	C
14-281		Mt. Trumbull	14 MNA	TP-7 L1	olivine	MC	C
14-282	G2	Mt. Trumbull	14 MNA	TP-7 L1	sherd_olivine	SVC	C
14-283	G2	Mt. Trumbull	14 MNA	TP-7 L1	olivine	MP	P
14-284	G2	Mt. Trumbull	14 MNA	TP-7 L8	sherd_olivine	SVP	P
14-285		Mt. Trumbull	14 MNA	TP-7 L6	sand	TP	P
14-286	1G	Mt. Trumbull	14 MNA	TP-7 L6	sand	TC	C
14-287		Mt. Trumbull	14 MNA	TP-7 L6	olivine	MC	C
14-288		Mt. Trumbull	14 MNA	TP-7 L4	olivine	MP	P
14-289		Mt. Trumbull	14 MNA	TP-7 L3	olivine	MC	C
14-290		Mt. Trumbull	14 MNA	TP-3 L2	olivine	MC	C
14-291		Mt. Trumbull	14 MNA	TP-3 L2	sand	TC	C
14-292		Mt. Trumbull	14 MNA	TP-7 S	sherd_olivine	SVP	P
14-293	G2 possible	Mt. Trumbull	14 MNA	TP-7 L5	olivine	MC	C
14-294	G2	Mt. Trumbull	14 MNA	TP-7 L5	olivine	MC	C
14-295	1G possoble	Mt. Trumbull	14 MNA	TP-7 L2	olivine	MP	P
14-296	1VV	Mt. Trumbull	14 MNA	TP-7 L1	sherd	RED	R
14-297	VR3	Mt. Trumbull	14 MNA	TP-1 L1	sand	RED	R
14-298		Mt. Trumbull	14 MNA	TP-1 L5	olivine	MBG	BG
14-299		Mt. Trumbull	14 MNA	TP-3 L2	sherd_andesite	SJR	R
14-300	G2	Mt. Trumbull	14 MNA	TP-6 L2	sand	TP	P
14-301	G2	Mt. Trumbull	14 MNA	TP-6 L2	olivine	MP	P
14-302		Mt. Trumbull	14 MNA	TP-6 S	olivine	MC	C
14-303	1G	Mt. Trumbull	14 MNA	TP-6 L4	olivine	MP	P
14-304	1G	Mt. Trumbull	14 MNA	TP-6 L3	olivine	MC	C
14-305	1G	Mt. Trumbull	14 MNA	TP-6 L3	olivine	MPF	P
14-306	G2	Mt. Trumbull	14 MNA	TP-6 L1	sherd_olivine	SVC	C
14-307		Mt. Trumbull	14 MNA	TP-6 L1	olivine	MC	C
14-308	1G	Mt. Trumbull	14 MNA	TP-6 L1	olivine	MP	P
14-309	G2	Mt. Trumbull	14 MNA	TP-6 S	olivine	MP	P
14-310		Mt. Trumbull	14 MNA	TP-9 L2	olivine	MC	C
14-311	G2	Mt. Trumbull	14 MNA	TP-9 L2	olivine	MP	P
14-312		Mt. Trumbull	14 MNA	TP-9 L5	olivine	MP	P
14-313		Mt. Trumbull	14 MNA	TP-9 L3	olivine	MC	C
14-314	1G	Mt. Trumbull	14 MNA	TP-9 L1	olivine	MP	P
14-315	1G	Mt. Trumbull	14 MNA	TP-9 S	olivine	MP	P
14-316		Mt. Trumbull	14 MNA	TP-9 L1	olivine	MC	C
14-317	1G	Mt. Trumbull	14 MNA	TP-9 S	olivine	MC	C
14-318		Mt. Trumbull	14 MNA	TP-9 L4	sherd_olivine	SVP	P
14-319		Mt. Trumbull	14 MNA	TP-9 L4	olivine	MP	P
14-320	G2	Mt. Trumbull	14 MNA	TP-9 L3	olivine	MP	P
14-321		Mt. Trumbull	14 MNA	TP-12 L2	olivine	MC	C
14-322	1G	Mt. Trumbull	14 MNA	TP-12 L4	olivine	MC	C
14-323	G2	Mt. Trumbull	14 MNA	TP-12 L3	olivine	MP	P
14-324	1G	Mt. Trumbull	14 MNA	TP-12 L2	sherd_olivine	MP	P
14-325	G2	Mt. Trumbull	14 MNA	TP-12 L2	sand	SNP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
14-326	G2	Mt. Trumbull	14 MNA	TP-12 S	olivine	MP	P
14-327	1G	Mt. Trumbull	14 MNA	TP-12 L3	olivine	MC	C
14-328		Mt. Trumbull	14 MNA	TP-12 L1	olivine	MC	C
14-329		Mt. Trumbull	14 MNA	TP-12 L1	olivine	MP	P
14-330	G2	Mt. Trumbull	14 MNA	TP-12 L4	olivine	MP	P
14-331	G2	Mt. Trumbull	14 MNA	TP-6 L2	olivine	MC	C
204-1	G2	Mt. Trumbull	204 BLM	SCU A2	olivine	MP	P
204-2	1G	Mt. Trumbull	204 BLM	SCU A4	olivine	MP	P
204-3	G2	Mt. Trumbull	204 BLM	SCU A5	olivine	MP	P
204-4	G2	Mt. Trumbull	204 BLM	SCU A6	olivine	MP	P
204-7	G2	Mt. Trumbull	204 BLM	SCU A8	olivine	MP	P
204-8	G2	Mt. Trumbull	204 BLM	SCU A8	olivine	MP	P
204-9		Mt. Trumbull	204 BLM	SCU A8	olivine	MBG	BG
204-10	G2	Mt. Trumbull	204 BLM	SCU B8	olivine	MP	P
204-11	G2	Mt. Trumbull	204 BLM	SCU B3	olivine	MP	P
204-12	G2	Mt. Trumbull	204 BLM	SCU B3	olivine	MP	P
204-13	G2	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-14		Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-15	G2	Mt. Trumbull	204 BLM	surface general	sand	TP	P
204-16	G2	Mt. Trumbull	204 BLM	surface general	sherd_olivine	MP	P
204-20	1VV	Mt. Trumbull	204 BLM	SCU A8	sand	TP	P
204-21	1VM possible	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-23		Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-24	G2 possible	Mt. Trumbull	204 BLM	surface general	sand	TP	P
204-25	G2	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-27		Mt. Trumbull	204 BLM	surface general	olivine	MBG	BG
204-28	1G possoble	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-31	1VM	Mt. Trumbull	204 BLM	TP-3 L1	olivine	MP	P
204-32	1VM	Mt. Trumbull	204 BLM	TP-3 L2	olivine	MP	P
204-33	1VM	Mt. Trumbull	204 BLM	TP-1 L1	olivine	MP	P
204-34	1VM possible	Mt. Trumbull	204 BLM	TP-3 S	olivine	MP	P
204-35	G2	Mt. Trumbull	204 BLM	TP-2 L2	olivine	MP	P
204-36	1G	Mt. Trumbull	204 BLM	TP-3 S	olivine	MP	P
204-37	G2	Mt. Trumbull	204 BLM	TP-2 S	olivine	MP	P
204-38		Mt. Trumbull	204 BLM	TP-1 S	sand	TP	P
204-39		Mt. Trumbull	204 BLM	TP-2 L3	sand	TP	P
204-40		Mt. Trumbull	204 BLM	TP-3 L2	sand	TP	P
204-41	G3	Mt. Trumbull	204 BLM	TP-3 S	olivine	MP	P
204-42	G3	Mt. Trumbull	204 BLM	TP-3 L1	olivine	MP	P
204-43		Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-44	G2	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-45	1G	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-46	1G	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-47		Mt. Trumbull	204 BLM	surface general	sand	TP	P
204-48		Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-49	G2	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-50		Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-51	G2	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-52	1G	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-53	1VM	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-54	1VV possible	Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-55	1VM possible	Mt. Trumbull	204 BLM	TP-3 L1	olivine	MP	P
204-56		Mt. Trumbull	204 BLM	TP-3 L1	sand	TP	P
204-57		Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-58	G2	Mt. Trumbull	204 BLM	surface general	olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
204-59		Mt. Trumbull	204 BLM	surface general	olivine	MP	P
204-60		Mt. Trumbull	204 BLM	surface general	olivine	MP	P
214-1	IVV	Mt. Trumbull	214 ASM	TP-2 L1	sand	TP	P
214-2	1VV possible	Mt. Trumbull	214 ASM	TP-2 S	sand	TC	C
214-3		Mt. Trumbull	214 ASM	TP-5 L1	olivine	MC	C
214-4	G2	Mt. Trumbull	214 ASM	TP-2 L2	olivine	MP	P
214-5	G2	Mt. Trumbull	214 ASM	TP-5 L1	olivine	MP	P
214-6	1VM	Mt. Trumbull	214 ASM	TP-1 L1	olivine	MC	C
214-7	1VM possible	Mt. Trumbull	214 ASM	TP-1 L1	olivine	MP	P
214-8	1VM	Mt. Trumbull	214 ASM	TP-3 L1	olivine	MC	C
214-9		Mt. Trumbull	214 ASM	TP-3 L1	olivine	MP	P
214-10		Mt. Trumbull	214 ASM	TP-2 S	olivine	MP	P
214-11	1VM	Mt. Trumbull	214 ASM	TP-1 L2	olivine	MC	C
214-12		Mt. Trumbull	214 ASM	TP-1 S	olivine	MC	C
214-13	G2	Mt. Trumbull	214 ASM	TP-2 L1	olivine	MP	P
214-14	1VV possible	Mt. Trumbull	214 ASM	TP-2 S	olivine	MP	P
214-15		Mt. Trumbull	214 ASM	TP-1 S	olivine	MC	C
214-16		Mt. Trumbull	214 ASM	TP-2 S	sand	TC	C
214-17		Mt. Trumbull	214 ASM	TP-1 L1	sand	TC	C
214-18	1G	Mt. Trumbull	214 ASM	TP-1 L2	sand	TBG	BG
214-19	1VV possible	Mt. Trumbull	214 ASM	TP-3 L1	sand	TBG	BG
214-20	1VV possible	Mt. Trumbull	214 ASM	TP-3 S	sand	TBG	BG
214-21	G2	Mt. Trumbull	214 ASM	TP-2 S	olivine	MP	P
214-22		Mt. Trumbull	214 ASM	SCU A2	olivine	MC	C
214-23	G2	Mt. Trumbull	214 ASM	SCU A12	olivine	MP	P
214-24		Mt. Trumbull	214 ASM	SCU A12	sand	TP	P
214-25	G2 possible	Mt. Trumbull	214 ASM	TP-2 L1	olivine	MP	P
214-26		Mt. Trumbull	214 ASM	SCU A6	olivine	MC	C
214-27		Mt. Trumbull	214 ASM	TP-2 L1	olivine	MP	P
214-28	G2	Mt. Trumbull	214 ASM	TP-2 L1	olivine	MP	P
214-29	1VM	Mt. Trumbull	214 ASM	SCU A3	olivine	MP	P
214-30		Mt. Trumbull	214 ASM	SCU A3	olivine	MC	C
214-31	G2	Mt. Trumbull	214 ASM	SCU A4	sherd_olivine	SVP	P
214-32		Mt. Trumbull	214 ASM	SCU A12	sand	TC	C
214-33		Mt. Trumbull	214 ASM	TP-2 S	olivine	MC	C
214-34	G2	Mt. Trumbull	214 ASM	SCU A1	sherd_olivine	SVP	P
214-35		Mt. Trumbull	214 ASM	SCU A10	olivine	MP	P
214-36		Mt. Trumbull	214 ASM	SCU A10	olivine	MC	C
30-1		Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-7	G2	Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-9		Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-10	1G	Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-11	1VM possible	Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-16	1G	Mt. Trumbull	30 BLM	surface general	olivine	MBG	BG
30-17	G2	Mt. Trumbull	30 BLM	surface general	olivine	MC	C
30-22		Mt. Trumbull	30 BLM	surface general	olivine	MC	C
30-25	1VV possible	Mt. Trumbull	30 BLM	surface general	sherd_sand	TP	P
30-31		Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-36	1VM	Mt. Trumbull	30 BLM	surface general	olivine	MBG	BG
30-37	1G	Mt. Trumbull	30 BLM	surface general	olivine	MBG	BG
30-40	1G	Mt. Trumbull	30 BLM	surface general	olivine	MBG	BG
30-46	1G	Mt. Trumbull	30 BLM	surface general	olivine	MBG	BG
30-47		Mt. Trumbull	30 BLM	surface general	sand	TBG	BG
30-60		Mt. Trumbull	30 BLM	surface general	olivine	MBG	BG
30-63	IVV	Mt. Trumbull	30 BLM	surface general	sand	TBG	BG

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
30-64		Mt. Trumbull	30 BLM	surface general	sand_andesite	SJR	BR
30-77	VR1	Mt. Trumbull	30 BLM	surface general	sand	TBG	BG
30-79		Mt. Trumbull	30 BLM	surface general	sand	TP	P
30-80	G3	Mt. Trumbull	30 BLM	surface general	olivine	MC	C
30-81	G3	Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-82	G3	Mt. Trumbull	30 BLM	surface general	sand	TP	P
30-86		Mt. Trumbull	30 BLM	surface general	olivine	MPF	P
30-87		Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-88	1G	Mt. Trumbull	30 BLM	surface general	olivine	MPF	P
30-146		Mt. Trumbull	30 BLM	TP-3 L8	olivine	MBG	BG
30-147		Mt. Trumbull	30 BLM	TP-1 L4	olivine	MBG	BG
30-148		Mt. Trumbull	30 BLM	surface general	olivine	MBG	BG
30-149	1G	Mt. Trumbull	30 BLM	surface general	olivine	MBG	BG
30-150		Mt. Trumbull	30 BLM	surface general	sand	POL	POLY
30-151	1VM	Mt. Trumbull	30 BLM	TP-2 L3	olivine	MP	P
30-152	G2	Mt. Trumbull	30 BLM	TP-1 L5	olivine	MP	P
30-153		Mt. Trumbull	30 BLM	TP-1 L6	olivine	MP	P
30-154	G2	Mt. Trumbull	30 BLM	TP-1 L3	olivine	MP	P
30-155	1G	Mt. Trumbull	30 BLM	TP-3 L3	olivine	MC	C
30-156	G2	Mt. Trumbull	30 BLM	TP-3 L5	olivine	MP	P
30-157	G2	Mt. Trumbull	30 BLM	TP-3 L8	olivine	MP	P
30-158	G2 possible	Mt. Trumbull	30 BLM	TP2 L7	sherd_olivine	SVP	P
30-159	1VM	Mt. Trumbull	30 BLM	TP2 L6	olivine	MP	P
30-160	1VM possible	Mt. Trumbull	30 BLM	TP-2 L1	olivine	MP	P
30-161		Mt. Trumbull	30 BLM	TP-1 L1	olivine	MP	P
30-162	1G	Mt. Trumbull	30 BLM	TP-3 L12	olivine	MPF	P
30-163	G2	Mt. Trumbull	30 BLM	TP-3 L6	olivine	MP	P
30-164	1G	Mt. Trumbull	30 BLM	TP-2 L5	olivine	MC	C
30-165		Mt. Trumbull	30 BLM	TP-1 L2	olivine	MP	P
30-166	1VM	Mt. Trumbull	30 BLM	TP-3 L5	olivine	MC	C
30-167	1VM possible	Mt. Trumbull	30 BLM	TP-2 L5	olivine	MP	P
30-168	1VM	Mt. Trumbull	30 BLM	TP-3 L2	olivine	MP	P
30-169	1G	Mt. Trumbull	30 BLM	TP-3 L4	olivine	MP	P
30-170	1VM possible	Mt. Trumbull	30 BLM	TP-3 L1	olivine	MP	P
30-171	G2	Mt. Trumbull	30 BLM	TP-3 S	olivine	MP	P
30-172		Mt. Trumbull	30 BLM	TP-3 L9	olivine	MP	P
30-173	1VV possible	Mt. Trumbull	30 BLM	TP-3 L6	sherd_sand	TC	C
30-174		Mt. Trumbull	30 BLM	TP-12 2	olivine	MP	P
30-175		Mt. Trumbull	30 BLM	TP-3 L10	sherd	TP	P
30-176	G2	Mt. Trumbull	30 BLM	TP-2 L8	olivine	MP	P
30-177	1G	Mt. Trumbull	30 BLM	TP-2 L9	sherd_olivine	MP	P
30-178	G2	Mt. Trumbull	30 BLM	TP-3 L3	olivine	MP	P
30-179	G2	Mt. Trumbull	30 BLM	TP-1 L4	olivine	MP	P
30-180		Mt. Trumbull	30 BLM	TP-2 L4	olivine	MP	P
30-181		Mt. Trumbull	30 BLM	TP-3 L1	olivine	MC	C
30-182	1G	Mt. Trumbull	30 BLM	TP-1 L6	olivine	MC	C
30-183	1G	Mt. Trumbull	30 BLM	TP-2 L1	olivine	MC	C
30-184		Mt. Trumbull	30 BLM	TP-3 L7	sherd_olivine	SVP	P
30-185	1G	Mt. Trumbull	30 BLM	TP-3 L11	olivine	MPF	P
30-186	1G	Mt. Trumbull	30 BLM	TP-3 S	olivine	MC	C
30-187		Mt. Trumbull	30 BLM	TP-1 L2	olivine	MC	C
30-188		Mt. Trumbull	30 BLM	TP-1 L3	olivine	MC	C
30-189	1VM possible	Mt. Trumbull	30 BLM	TP-3 L2	olivine	MC	C
30-190	1G	Mt. Trumbull	30 BLM	TP-2 S	olivine	MP	P
30-191	1G	Mt. Trumbull	30 BLM	TP-1 L1	olivine	MC	C

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
30-192	G2	Mt. Trumbull	30 BLM	TP-2 L6	sherd_olivine	MC	C
30-193		Mt. Trumbull	30 BLM	TP-3 L4	olivine	MC	C
30-194		Mt. Trumbull	30 BLM	TP-1 S	olivine	MP	P
30-195	G2	Mt. Trumbull	30 BLM	TP-2 L12	sherd_olivine	MP	P
30-196		Mt. Trumbull	30 BLM	TP-2 L2	olivine	MC	C
30-197		Mt. Trumbull	30 BLM	TP-2 L6	olivine	MBG	BG
30-198	1G	Mt. Trumbull	30 BLM	TP-2 L2	olivine	MBG	BG
30-199		Mt. Trumbull	30 BLM	TP-2 L6	olivine	MBG	BG
30-200	1G	Mt. Trumbull	30 BLM	TP-1 L4	olivine	MBG	BG
30-201	VR1	Mt. Trumbull	30 BLM	TP-2 L6	sand	TBG	BG
30-202		Mt. Trumbull	30 BLM	TP-2 L3	sand_andesite	SJR	RED
30-203	1G	Mt. Trumbull	30 BLM	TP-2 L10	olivine	MBG	BG
30-204	G2	Mt. Trumbull	30 BLM	TP-2 L6	olivine	MP	P
30-205	G2	Mt. Trumbull	30 BLM	TP-2 S	olivine	MP	P
30-206		Mt. Trumbull	30 BLM	TP-2 L8	olivine	MP	P
30-207		Mt. Trumbull	30 BLM	TP-2 S	olivine	MC	C
30-208		Mt. Trumbull	30 BLM	TP-2 L2	olivine	MPF	P
30-209		Mt. Trumbull	30 BLM	TP-2 L7	olivine	MP	P
30-210	1G	Mt. Trumbull	30 BLM	TP-2 L3	olivine	MC	C
30-211	G2	Mt. Trumbull	30 BLM	TP-2 L11	olivine	MP	P
30-212	1G	Mt. Trumbull	30 BLM	TP-2 L9	olivine	MP	P
30-213	1G	Mt. Trumbull	30 BLM	TP-2 L4	olivine	MP	P
30-214	1G	Mt. Trumbull	30 BLM	TP-2 L3	olivine	MC	C
30-215	1G	Mt. Trumbull	30 BLM	TP-2 L2	olivine	MC	C
30-216	G2	Mt. Trumbull	30 BLM	TP-2 L7	sherd_olivine	SVC	C
30-217	G2	Mt. Trumbull	30 BLM	TP-2 L1	olivine	MP	P
30-218		Mt. Trumbull	30 BLM	TP-2 L1	sand	TP	P
30-219	1G	Mt. Trumbull	30 BLM	TP-2 L10	olivine	MC	C
30-220		Mt. Trumbull	30 BLM	TP-2 L3	olivine	MP	P
30-221	IVV	Mt. Trumbull	30 BLM	TP-2 L6	sand	TC	C
30-222		Mt. Trumbull	30 BLM	TP-2 L6	olivine	MC	C
30-223	1G	Mt. Trumbull	30 BLM	TP-2 L8	olivine	MC	C
30-224	1G possoble	Mt. Trumbull	30 BLM	TP-2 L12	olivine	MP	P
30-225	G2	Mt. Trumbull	30 BLM	TP-2 L10	olivine	MP	P
30-226	1G	Mt. Trumbull	30 BLM	TP-2 L13	olivine	MP	P
30-227		Mt. Trumbull	30 BLM	TP-2 L5	olivine	MP	P
30-228	1G	Mt. Trumbull	30 BLM	TP-2 L4	olivine	MC	C
30-229		Mt. Trumbull	30 BLM	TP-2 L1	olivine	MC	C
30-230	1G	Mt. Trumbull	30 BLM	TP-2 L5	olivine	MC	C
30-231	IVV	Mt. Trumbull	30 BLM	TP-3 L9	sand	TP	P
30-232	VR3	Mt. Trumbull	30 BLM	TP-2 L11	sand	RED	R
30-233	IVV	Mt. Trumbull	30 BLM	TP-2 L6	sherd	TO	R
30-234	1VV possible	Mt. Trumbull	30 BLM	TP-3 L2	sand	TBG	BG
30-235		Mt. Trumbull	30 BLM	TP-2 L4	olivine	MC	C
30-236		Mt. Trumbull	30 BLM	TP-2 L7	olivine	MC	C
30-237		Mt. Trumbull	30 BLM	TP-2 L6	sand	TP	P
30-238		Mt. Trumbull	30 BLM	TP-2 L6	olivine	MP	P
30-239		Mt. Trumbull	30 BLM	TP-2 L1	olivine	MC	C
30-240		Mt. Trumbull	30 BLM	TP-2 S	olivine	MPF	P
30-241	1G	Mt. Trumbull	30 BLM	TP-2 L6	olivine	MC	C
30-242	G2	Mt. Trumbull	30 BLM	TP-2 L8	olivine	MP	P
30-243	1VM possible	Mt. Trumbull	30 BLM	TP-2 L8	olivine	MP	P
30-244		Mt. Trumbull	30 BLM	TP-2 L3	olivine	MP	P
30-245	G2	Mt. Trumbull	30 BLM	TP-2 L5	sherd_olivine	MP	P
30-246		Mt. Trumbull	30 BLM	TP-2 L5	olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
30-247	1G	Mt. Trumbull	30 BLM	TP-2 L1	olivine	MPF	P
30-248	1G	Mt. Trumbull	30 BLM	TP-2 L4	olivine	MP	P
30-249		Mt. Trumbull	30 BLM	TP-2 L4	sand	TP	P
30-250		Mt. Trumbull	30 BLM	TP-2 L7	olivine	MP	P
30-251	1VV possible	Mt. Trumbull	30 BLM	TP-2 L9	sand	TP	P
30-252	1VM	Mt. Trumbull	30 BLM	TP-3 L2	olivine	MP	P
30-253	G2	Mt. Trumbull	30 BLM	TP-3 L2	olivine	MP	P
30-254		Mt. Trumbull	30 BLM	TP-3 L5	olivine	MP	P
30-255		Mt. Trumbull	30 BLM	TP-3 L5	olivine	MP	P
30-256	G2	Mt. Trumbull	30 BLM	TP-2 L7	olivine	MP	P
30-257		Mt. Trumbull	30 BLM	TP-3 L1	olivine	MP	P
30-258	1G	Mt. Trumbull	30 BLM	TP-2 L4	olivine	MP	P
30-259		Mt. Trumbull	30 BLM	TP-3 L3	olivine	MC	C
30-260	G2	Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-261	1G	Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-262	1G	Mt. Trumbull	30 BLM	surface general	olivine	MP	P
30-263	1G	Mt. Trumbull	30 BLM	surface general	olivine	MBG	BG
30-264		Mt. Trumbull	30 BLM	surface general	sand	SNR	BR
30-265		Mt. Trumbull	30 BLM	surface general	sand	TBG	BG
30-266	VR1	Mt. Trumbull	30 BLM	surface general	sand	TBG	BG
30-267		Mt. Trumbull	30 BLM	surface general	olivine	MBG	BG
71-1	IVV	Mt. Trumbull	71 ASM	surface general	sand	TBG	BG
71-7	G3	Mt. Trumbull	71 ASM	surface general	sand	TBG	BG
71-8	G3	Mt. Trumbull	71 ASM	surface general	sand	TBG	BG
71-9		Mt. Trumbull	71 ASM	surface general	sand	TBG	BG
71-10		Mt. Trumbull	71 ASM	surface general	sand	TBG	BG
71-11		Mt. Trumbull	71 ASM	surface general	olivine	MBG	BG
71-16	1G	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-17		Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-18	1G	Mt. Trumbull	71 ASM	surface general	olivine	MC	C
71-19		Mt. Trumbull	71 ASM	surface general	olivine	MC	C
71-20	G2	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-21	1G	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-22		Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-23		Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-24	G2	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-25		Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-26		Mt. Trumbull	71 ASM	surface general	olivine	MBG	BG
71-27	1VM	Mt. Trumbull	71 ASM	TP-4 L1	olivine	MP	P
71-28		Mt. Trumbull	71 ASM	TP-4 L1	olivine	MP	P
71-29	G2	Mt. Trumbull	71 ASM	TP-1 L2	olivine	MP	P
71-30	G2	Mt. Trumbull	71 ASM	TP-1 L1	olivine	MP	P
71-31	G2 possible	Mt. Trumbull	71 ASM	TP-3 S	olivine	MP	P
71-32	G2	Mt. Trumbull	71 ASM	TP-3 L1	olivine	MP	P
71-33	1VM	Mt. Trumbull	71 ASM	TP-4 S	olivine	MP	P
71-34	1VM	Mt. Trumbull	71 ASM	TP-4 L2	olivine	MP	P
71-39	G2	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-40	G2	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-41	G4	Mt. Trumbull	71 ASM	TP-4 L2	olivine	MP	P
71-42		Mt. Trumbull	71 ASM	TP-4 L2	olivine	MP	P
71-43	G2	Mt. Trumbull	71 ASM	TP-2 L3	olivine	MP	P
71-44	G3	Mt. Trumbull	71 ASM	TP-4 S	olivine	MP	P
71-45	G3	Mt. Trumbull	71 ASM	TP-2 L1	olivine	MP	P
71-46	G3	Mt. Trumbull	71 ASM	TP-1 L2	olivine	MP	P
71-47	G3	Mt. Trumbull	71 ASM	TP-4 L1	olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
71-48	G3	Mt. Trumbull	71 ASM	TP-3 S	olivine	MP	P
71-49	G3	Mt. Trumbull	71 ASM	TP-3 L1	olivine	MP	P
71-50	G3	Mt. Trumbull	71 ASM	TP-3 L1	olivine	MP	P
71-51	G3	Mt. Trumbull	71 ASM	TP-3 S	olivine	MP	P
71-52	G3	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-53	G3	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-54	G3	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-55	G3	Mt. Trumbull	71 ASM	surface general	olivine	MBG	BG
71-56	G3	Mt. Trumbull	71 ASM	surface general	olivine	MBG	BG
71-57	G3	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-58	G3	Mt. Trumbull	71 ASM	surface general	olivine	MP	P
71-59	G3	Mt. Trumbull	71 ASM	surface general	olivine	MBG	BG_C
71-60	G3	Mt. Trumbull	71 ASM	TP-4 L1	olivine	MP	P
71-61	1VM	Mt. Trumbull	71 ASM	TP-4 L3	olivine	MP	P
71-62		Mt. Trumbull	71 ASM	TP-3 S	olivine	MP	P
71-63		Mt. Trumbull	71 ASM	TP-4 S	olivine	MP	P
71-64	G4	Mt. Trumbull	71 ASM	TP-4 L1	olivine	MP	P
71-65	G4	Mt. Trumbull	71 ASM	TP-4 L1	olivine	MP	P
71-66		Mt. Trumbull	71 ASM	TP-4 L1	olivine	MP	P
71-67	1VM	Mt. Trumbull	71 ASM	TP-4 S	olivine	MP	P
71-68	G2	Mt. Trumbull	71 ASM	TP-1 S	olivine	MP	P
71-69		Mt. Trumbull	71 ASM	SCU A8	olivine	MP	P
71-70	1G	Mt. Trumbull	71 ASM	SCU A1	sand	TP	P
71-71	1VM	Mt. Trumbull	71 ASM	SCU A1	olivine	MP	P
71-72		Mt. Trumbull	71 ASM	SCU B6	olivine	MP	P
71-73		Mt. Trumbull	71 ASM	SCU A7	olivine	MP	P
71-74		Mt. Trumbull	71 ASM	SCU D5	olivine	MP	P
71-75	G2	Mt. Trumbull	71 ASM	SCU C5	olivine	MP	P
71-76	1VV possible	Mt. Trumbull	71 ASM	SCU A2	olivine	MP	P
71-77		Mt. Trumbull	71 ASM	SCU A4	olivine	MP	P
71-78		Mt. Trumbull	71 ASM	SCU A4	sherd	TP	P
71-79	G2	Mt. Trumbull	71 ASM	SCU B16	olivine	MP	P
71-80	1VM	Mt. Trumbull	71 ASM	SCU A10	olivine	MP	P
71-81	1VM	Mt. Trumbull	71 ASM	SCU A9	olivine	MP	P
71-82		Mt. Trumbull	71 ASM	SCU A5	olivine	MP	P
71-83		Mt. Trumbull	71 ASM	SCU B15	sand	TP	P
TW26	1VM possible	Tuweep	GC895	surface	olivine	MP	P
TW47	G2	Tuweep	GC666	surface	olivine	MP	P
TW93	1VV possible	Tuweep	GC695	surface	sand	TC	C
TW101	1VM	Tuweep	GC913	surface	olivine	MC	C
TW118	1VM possible	Tuweep	GC663	surface	olivine	MC	C
TW119	1G	Tuweep	GC663	surface	olivine	MC	C
TW124	G2	Tuweep	GC671	surface	sherd_olivine	SVC	C
TW128		Tuweep	GC888	surface	olivine	MPF	P
TW130		Tuweep	GC888	surface	olivine	MP	P
TW135		Tuweep	GC671	surface	sand	SNP	P
TW136	IVV	Tuweep	GC689	surface	sand	TP	P
TW139		Tuweep	GC666	surface	sand	TP	P
TW142	1VM	Tuweep	GC671	surface	olivine	MBG	BG
TW143	1VM	Tuweep	GC671	surface	olivine	MBG	BG
TW151		Tuweep	GC663	surface	olivine	MBG	BG
TW154		Tuweep	GC671	surface	olivine	MBG	BG
TW156	G2	Tuweep	GC663	surface	olivine	MBG	BG
TW159	1VM	Tuweep	GC671	surface	olivine	MBG	BG
TW183	1VV possible	Tuweep	GC671	surface	sand	TBG	BG

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
TW185		Tuweep	GC671	surface	sand	TBG	BG
VR1-1	IVV	lowland Virgin	VR1	surface	sand	TBG	BG
VR1-2	1VV possible	lowland Virgin	VR1	surface	sand	TP	P
VR1-3	IVV	lowland Virgin	VR1	surface	sand	TP	P
VR1-4	1VV possible	lowland Virgin	VR1	surface	sand	TBG	BG
VR1-5	G2	lowland Virgin	VR1	surface	olivine	MP	P
VR1-6		lowland Virgin	VR1	surface	olivine	MP	P
VR1-7	G2	lowland Virgin	VR1	surface	olivine	MP	P
VR1-8	G2	lowland Virgin	VR1	surface	olivine	MP	P
VR1-9	G2	lowland Virgin	VR1	surface	olivine	MP	P
VR4-1	G2 possible	lowland Virgin	VR4	surface	olivine	MP	P
VR4-2	G2	lowland Virgin	VR4	surface	olivine	MP	P
VR4-3		lowland Virgin	VR4	surface	olivine	MP	P
VR6-1		lowland Virgin	VR6	surface	sherd_olivine	SVP	P
VR6-2	1VV possible	lowland Virgin	VR6	surface	olivine	MBG	BG
VR6-3		lowland Virgin	VR6	surface	olivine	MP	P
VR6-4	1VV possible	lowland Virgin	VR6	surface	olivine	MP	P
VR6-5	IVV	lowland Virgin	VR6	surface	olivine	MP	P
VR6-6	IVV	lowland Virgin	VR6	surface	olivine	MP	P
VR6-7	IVV	lowland Virgin	VR6	surface	olivine	MP	P
VR7-1		lowland Virgin	VR7	surface	olivine	MP	P
VR7-2	VR3	lowland Virgin	VR7	surface	sand	TC	C
VR7-3	VR3	lowland Virgin	VR7	surface	sherd_sand	RED	BR
VR7-4		lowland Virgin	VR7	surface	olivine	MP	P
VR7-5	G4	lowland Virgin	VR7	surface	olivine	MBG	BG
VR7-6	1G	lowland Virgin	VR7	surface	olivine	MC	C
VR7-7	IVV	lowland Virgin	VR7	surface	olivine	MBG	BG_C
VR7-8	G4	lowland Virgin	VR7	surface	olivine	MP	P
VR7-9	IVV	lowland Virgin	VR7	surface	olivine	MP	P
VR7-10	1VV possible	lowland Virgin	VR7	surface	olivine	MP	P
VR7-11	1G	lowland Virgin	VR7	surface	olivine	MP	P
VR8-1	1VV possible	lowland Virgin	VR8	surface	olivine	MP	P
VR13-1	G2	lowland Virgin	VR13	surface	olivine	MP	P
VR13-2	G2	lowland Virgin	VR13	surface	olivine	MP	P
VR13-3	VR3	lowland Virgin	VR13	surface	sand	TP	P
VR13-5	IVV	lowland Virgin	VR13	surface	sand	TP	P
VR13-6	G2	lowland Virgin	VR13	surface	olivine	MP	P
VR13-7	G2	lowland Virgin	VR13	surface	olivine	MP	P
VR13-8	G2	lowland Virgin	VR13	surface	olivine	MP	P
VR13-9	G2	lowland Virgin	VR13	surface	olivine	MP	P
VR13-10		lowland Virgin	VR13	surface	olivine	MP	P
VR14-1	G2 possible	lowland Virgin	VR14	surface	olivine	MP	P
VR14-2	G2	lowland Virgin	VR14	surface	olivine	MP	P
VR15-1	IVV	lowland Virgin	VR15	surface	olivine	MP	P
VR15-2	G4	lowland Virgin	VR15	surface	olivine	MBG	BG
VR17-1	VR1	lowland Virgin	VR17	surface	sand	TBG	BG
VR17-2	IVV	lowland Virgin	VR17	surface	sand	TBG	BG
VR17-3		lowland Virgin	VR17	surface	olivine	MP	P
VR17-4		lowland Virgin	VR17	surface	olivine	MP	P
VR17-5	VR1	lowland Virgin	VR17	surface	sand	TBG	BG
VR17-6		lowland Virgin	VR17	surface	olivine	MBG	BG
VR17-7		lowland Virgin	VR17	surface	olivine	MP	P
VR17-8	G4	lowland Virgin	VR17	surface	olivine	MBG	BG
VR17-9	VR1	lowland Virgin	VR17	surface	sand	TBG	BG
VR17-10	IVV	lowland Virgin	VR17	surface	olivine	MBG	BG

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
VR17-11	G4	lowland Virgin	VR17	surface	olivine	MP	P
VR17-12		lowland Virgin	VR17	surface	olivine	MP	P
VR17-13	VR3	lowland Virgin	VR17	surface	sand	TP	P
VR17-14		lowland Virgin	VR17	surface	sand	TP	P
VR17-15	VR3	lowland Virgin	VR17	surface	sand	TP	P
VR19-1		lowland Virgin	VR19	surface	olivine	MP	P
VR19-2		lowland Virgin	VR19	surface	olivine	MP	P
VR19-3	IVV	lowland Virgin	VR19	surface	olivine	MBG	BG
VR19-4	VR1	lowland Virgin	VR19	surface	sand	TBG	BG
VR19-5		lowland Virgin	VR19	surface	olivine	MP	P
VR19-6		lowland Virgin	VR19	surface	sand	TBG	BG
VR19-7	G4	lowland Virgin	VR19	surface	olivine	MP	P
VR19-8	IVV	lowland Virgin	VR19	surface	olivine	MP	P
VR19-9		lowland Virgin	VR19	surface	olivine	MP	P
VR19-10		lowland Virgin	VR19	surface	olivine	MP	P
VR19-11	IVV	lowland Virgin	VR19	surface	olivine	MP	P
VR19-12		lowland Virgin	VR19	surface	olivine	MP	P
VR19-13		lowland Virgin	VR19	surface	olivine	MP	P
VR19-14	IVV	lowland Virgin	VR19	surface	olivine	MP	P
VR19-15	G4	lowland Virgin	VR19	surface	olivine	MP	P
VR19-16		lowland Virgin	VR19	surface	olivine	MP	P
VR19-17	1VV possible	lowland Virgin	VR19	surface	olivine	MP	P
VR19-18		lowland Virgin	VR19	surface	olivine	MP	P
VR19-19		lowland Virgin	VR19	surface	olivine	MBG	BG
VR19-20	IVV	lowland Virgin	VR19	surface	olivine	MC	C
VR19-21		lowland Virgin	VR19	surface	olivine	MP	P
VR19-22	IVV	lowland Virgin	VR19	surface	olivine	MBG	BG
VR19-23	IVV	lowland Virgin	VR19	surface	olivine	MBG	BG
VR19-24	1VV possible	lowland Virgin	VR19	surface	olivine	MBG	BG
VR19-25		lowland Virgin	VR19	surface	olivine	MBG	BG
VR19-26	1VV possible	lowland Virgin	VR19	surface	olivine	MBG	BG
VR19-27	VR3	lowland Virgin	VR19	surface	sand	TP	P
VR19-28	IVV	lowland Virgin	VR19	surface	sand	TC	C
VR20-1	IVV	lowland Virgin	VR20	surface	olivine	MP	P
VR21-1	VR1	lowland Virgin	VR21	surface	sand	TBG	BG
VR21-2		lowland Virgin	VR21	surface	sand	MP	P
VR21-3		lowland Virgin	VR21	surface	olivine	MP	P
VR21-4	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR21-5	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR21-6		lowland Virgin	VR21	surface	olivine	MBG	BG
VR21-7	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR21-8	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR21-9	IVV	lowland Virgin	VR21	surface	olivine	MC	C
VR21-10	IVV	lowland Virgin	VR21	surface	sand	TC	C
VR21-11	VR1	lowland Virgin	VR21	surface	sand	TBG	BG
VR21-12		lowland Virgin	VR21	surface	sand	TP	P
VR21-13		lowland Virgin	VR21	surface	sherd_sand	TP	P
VR21-14	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR21-15		lowland Virgin	VR21	surface	olivine	MP	P
VR21-16	G4	lowland Virgin	VR21	surface	olivine	MP	P
VR21-17	IVV	lowland Virgin	VR21	surface	olivine	MP	P
VR21-18	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR21-19	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR21-20	1VV possible	lowland Virgin	VR21	surface	sand	TC	C
VR21-21	G4	lowland Virgin	VR21	surface	olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
VR21-22	G4	lowland Virgin	VR21	surface	olivine	MP	P
VR21-23	G4	lowland Virgin	VR21	surface	olivine	MP	P
VR21-24	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR21-25	IVV	lowland Virgin	VR21	surface	olivine	MP	P
VR21-26		lowland Virgin	VR21	surface	olivine	MP	P
VR21-27	G4	lowland Virgin	VR21	surface	olivine	MP	P
VR21-28	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR21-29	G4	lowland Virgin	VR21	surface	olivine	MP	P
VR21-30	G4	lowland Virgin	VR21	surface	olivine	MP	P
VR21-31	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR21-32	1G	lowland Virgin	VR21	surface	olivine	MP	P
VR22-1	IVV	lowland Virgin	VR22	surface	olivine	MP	P
VR22-2	VR3	lowland Virgin	VR22	surface	sand	TP	P
VR22-3		lowland Virgin	VR22	surface	olivine	MP	P
VR22-4	1G	lowland Virgin	VR22	surface	olivine	MP	P
VR22-5	IVV	lowland Virgin	VR22	surface	olivine	MP	P
VR22-6		lowland Virgin	VR22	surface	olivine	MBG	BG
VR22-7	IVV	lowland Virgin	VR22	surface	olivine	MP	P
VR22-8	IVV	lowland Virgin	VR22	surface	olivine	MP	P
VR22-9	1VV possible	lowland Virgin	VR22	surface	olivine	MP	P
VR22-10	1VV possible	lowland Virgin	VR22	surface	olivine	MP	P
VR22-11	IVV	lowland Virgin	VR22	surface	olivine	MP	P
VR22-12	IVV	lowland Virgin	VR22	surface	olivine	MP	P
VR22-13	IVV	lowland Virgin	VR22	surface	olivine	MP	P
VR22-14		lowland Virgin	VR22	surface	olivine	MP	P
VR23-1	IVV	lowland Virgin	VR23	surface	sand	TBG	BG
VR23-2		lowland Virgin	VR23	surface	olivine	MP	P
VR23-3	G2	lowland Virgin	VR23	surface	olivine	MP	P
VR23-4	VR3	lowland Virgin	VR23	surface	sand	TBG	BG
VR23-5	1G	lowland Virgin	VR23	surface	olivine	MP	P
VR23-6	1VV possible	lowland Virgin	VR23	surface	sand	TP	P
VR24-1	1G	lowland Virgin	VR24	surface	olivine	MP	P
VR24-2		lowland Virgin	VR24	surface	olivine	MBG	BG
VR24-3		lowland Virgin	VR24	surface	olivine	MP	P
VR24-4	IVV	lowland Virgin	VR24	surface	olivine	MBG	BG
VR24-5	VR3	lowland Virgin	VR24	surface	sherd_sand	RED	R
VR26-1	IVV	lowland Virgin	VR26	surface	olivine	MP	P
VR26-2		lowland Virgin	VR26	surface	sherd_olivine	SVP	P
VR27-1		lowland Virgin	VR27	surface	olivine	MP	P
VR27-2	G4	lowland Virgin	VR27	surface	olivine	MP	P
VR27-3	VR3	lowland Virgin	VR27	surface	sand	TC	C
VR27-4	IVV	lowland Virgin	VR27	surface	sand	TBG	BG
VR27-5	1G	lowland Virgin	VR27	surface	olivine	MP	P
VR27-6	1G	lowland Virgin	VR27	surface	olivine	MP	P
VR27-7		lowland Virgin	VR27	surface	sand	TBG	BG
VR27-8		lowland Virgin	VR27	surface	sand	TBG	BG
VR27-9		lowland Virgin	VR27	surface	olivine	MP	P
VR27-10		lowland Virgin	VR27	surface	olivine	MP	P
VR27-11		lowland Virgin	VR27	surface	olivine	MP	P
VR27-12	1G	lowland Virgin	VR27	surface	olivine	MBG	BG
VR27-13		lowland Virgin	VR27	surface	olivine	MBG	BG
VR27-14		lowland Virgin	VR27	surface	olivine	MBG	BG
VR27-15	IVV	lowland Virgin	VR27	surface	olivine	MP	P
VR27-16		lowland Virgin	VR27	surface	olivine	MP	P
VR27-17		lowland Virgin	VR27	surface	olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
VR27-18	1VV possible	lowland Virgin	VR27	surface	olivine	MP	P
VR27-19	G4	lowland Virgin	VR27	surface	olivine	MP	P
VR27-20	1G	lowland Virgin	VR27	surface	olivine	MBG	BG
VR27-21	IVV	lowland Virgin	VR27	surface	olivine	MP	P
VR27-22	IVV	lowland Virgin	VR27	surface	olivine	MP	P
VR27-23	IVV	lowland Virgin	VR27	surface	olivine	MP	P
VR27-24	IVV	lowland Virgin	VR27	surface	olivine	MP	P
VR27-25	IVV	lowland Virgin	VR27	surface	olivine	MP	P
VR27-26	IVV	lowland Virgin	VR27	surface	olivine	MP	P
VR28-1		lowland Virgin	VR28	surface	sand	TP	P
VR28-2	VR3	lowland Virgin	VR28	surface	sand	TP	P
VR28-3	VR1	lowland Virgin	VR28	surface	sand	TBG	BG
VR28-4		lowland Virgin	VR28	surface	olivine	MP	P
VR28-5	IVV	lowland Virgin	VR28	surface	olivine	MBG	BG
VR28-6	IVV	lowland Virgin	VR28	surface	olivine	MBG	BG
VR28-7		lowland Virgin	VR28	surface	olivine	MBG	BG
VR28-8		lowland Virgin	VR28	surface	olivine	MP	P
VR29-1	1VV possible	lowland Virgin	VR29	surface	sand	TP	P
VR29-2	VR3	lowland Virgin	VR29	surface	sherd_andesite	SJR	BR
VR29-3	VR3	lowland Virgin	VR29	surface	sand	TBG	BG
VR29-4		lowland Virgin	VR29	surface	olivine	MP	P
VR29-5		lowland Virgin	VR29	surface	sherd_olivine	SVP	P
VR29-6	VR3	lowland Virgin	VR29	surface	sand	TP	P
VR29-7	VR1	lowland Virgin	VR29	surface	sand	TBG	BG
VR29-8	IVV	lowland Virgin	VR29	surface	olivine	MP	P
VR29-9	IVV	lowland Virgin	VR29	surface	olivine	MPF	P
VR29-10		lowland Virgin	VR29	surface	olivine	MP	P
VR30-1	IVV	lowland Virgin	VR30	surface	olivine	MP	P
VR30-2		lowland Virgin	VR30	surface	olivine	MP	P
VR31-1	VR3	lowland Virgin	VR31	surface	sand	TP	P
VR32-1		lowland Virgin	VR32	surface	sherd_olivine	SVP	P
VR32-2	VR3	lowland Virgin	VR32	surface	sand	TP	P
VR32-3	VR1	lowland Virgin	VR32	surface	sand	TBG	BG
VR32-4	VR1	lowland Virgin	VR32	surface	sand	TBG	BG
VR32-6		lowland Virgin	VR32	surface	sherd_olivine	SVP	P
VR32-7	G1	lowland Virgin	VR32	surface	olivine	MP	P
VR32-8		lowland Virgin	VR32	surface	olivine	MP	P
VR32-9	VR1	lowland Virgin	VR32	surface	sand	TBG	BG
VR32-10		lowland Virgin	VR32	surface	sherd_olivine	SVP	P
VR32-11	IVV	lowland Virgin	VR32	surface	sand	TBG	BG
VR32-12	IVV	lowland Virgin	VR32	surface	sherd_sand	TO	RED
VR32-13	IVV	lowland Virgin	VR32	surface	olivine	MP	P
VR33-1	VR1	lowland Virgin	VR33	surface	sand	TBG	BG
VR33-2	VR3	lowland Virgin	VR33	surface	sand	TP	P
VR33-3		lowland Virgin	VR33	surface	olivine	MP	P
VR33-4		lowland Virgin	VR33	surface	olivine	MP	P
VR33-5	IVV	lowland Virgin	VR33	surface	olivine	MP	P
VR33-6		lowland Virgin	VR33	surface	olivine	MP	P
VR33-7	IVV	lowland Virgin	VR33	surface	olivine	MP	P
VR33-8	1VV possible	lowland Virgin	VR33	surface	olivine	MP	P
VR33-9	1VV possible	lowland Virgin	VR33	surface	sand	TP	P
VR33-10	VR3	lowland Virgin	VR33	surface	sand	TC	C
VR33-11		lowland Virgin	VR33	surface	olivine	MP	P
VR33-12		lowland Virgin	VR33	surface	olivine	MP	P
VR33-13	IVV	lowland Virgin	VR33	surface	olivine	MP	P

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
VR33-14	1VV possible	lowland Virgin	VR33	surface	olivine	MP	P
VR33-15	IVV	lowland Virgin	VR33	surface	olivine	MP	P
VR33-16		lowland Virgin	VR33	surface	olivine	MP	P
VR33-17	IVV	lowland Virgin	VR33	surface	olivine	MP	P
VR33-18	1G	lowland Virgin	VR33	surface	olivine	MP	P
VR33-19		lowland Virgin	VR33	surface	olivine	MP	P
VR33-20		lowland Virgin	VR33	surface	olivine	MP	P
VR34-1	IVV	lowland Virgin	VR34	surface	olivine	MBG	BG
VR34-2	VR1	lowland Virgin	VR34	surface	sand	TBG	BG
VR34-3		lowland Virgin	VR34	surface	sand	TP	P
VR34-4		lowland Virgin	VR34	surface	olivine	MP	P
VR34-5	IVV	lowland Virgin	VR34	surface	olivine	MP	P
VR34-6		lowland Virgin	VR34	surface	olivine	MP	P
VR34-7	IVV	lowland Virgin	VR34	surface	olivine	MP	P
VR34-8		lowland Virgin	VR34	surface	olivine	MP	P
VR34-9		lowland Virgin	VR34	surface	olivine	MP	P
VR34-10	IVV	lowland Virgin	VR34	surface	olivine	MBG	BG
VR34-11	IVV	lowland Virgin	VR34	surface	olivine	MP	P
VR34-12		lowland Virgin	VR34	surface	olivine	MP	P
VR34-13	VR3	lowland Virgin	VR34	surface	sand	TP	P
VR34-14	VR1	lowland Virgin	VR34	surface	sand	TP	P
VR34-15	IVV	lowland Virgin	VR34	surface	olivine	MBG	BG
VR34-16	IVV	lowland Virgin	VR34	surface	olivine	MP	P
VR35-1	IVV	lowland Virgin	VR35	surface	olivine	MP	P
VR35-2		lowland Virgin	VR35	surface	olivine	MBG	BG
VR35-3		lowland Virgin	VR35	surface	sand	TP	P
VR35-4	G4	lowland Virgin	VR35	surface	olivine	MP	P
VR35-5	G4	lowland Virgin	VR35	surface	olivine	MP	P
VR35-6	1G	lowland Virgin	VR35	surface	olivine	MBG	BG
VR35-7	1G	lowland Virgin	VR35	surface	olivine	MBG	BG
VR35-8	IVV	lowland Virgin	VR35	surface	olivine	MP	P
VR35-9		lowland Virgin	VR35	surface	olivine	MP	P
VR35-10	IVV	lowland Virgin	VR35	surface	olivine	MP	P
VR35-11	IVV	lowland Virgin	VR35	surface	sand	TBG	BG
VR35-12		lowland Virgin	VR35	surface	sand	TBG	BG
VR35-13	IVV	lowland Virgin	VR35	surface	sand	TBG	BG
VR35-14	IVV	lowland Virgin	VR35	surface	sand	TBG	BG
VR35-15	IVV	lowland Virgin	VR35	surface	olivine	MBG	BG
VR35-16		lowland Virgin	VR35	surface	olivine	MBG	BG
VR35-17	G4	lowland Virgin	VR35	surface	olivine	MBG	BG
VR35-18		lowland Virgin	VR35	surface	olivine	MBG	BG
VR36-1		lowland Virgin	VR36	surface	olivine	MP	P
VR36-2		lowland Virgin	VR36	surface	olivine	MPF	P
VR36-3	IVV	lowland Virgin	VR36	surface	olivine	MP	P
VR36-4		lowland Virgin	VR36	surface	sherd_olivine	SVP	P
VR36-5		lowland Virgin	VR36	surface	olivine	MP	P
VR36-6		lowland Virgin	VR36	surface	olivine	MP	P
VR36-7		lowland Virgin	VR36	surface	olivine	MP	P
VR36-8	IVV	lowland Virgin	VR36	surface	olivine	MP	P
VR36-9		lowland Virgin	VR36	surface	olivine	MP	P
VR36-10		lowland Virgin	VR36	surface	olivine	MP	P
VR36-11		lowland Virgin	VR36	surface	olivine	MBG	BG
VR36-12		lowland Virgin	VR36	surface	olivine	MP	P
VR36-13	IVV	lowland Virgin	VR36	surface	olivine	MP	P
VR37-1	IVV	lowland Virgin	VR37	surface	sherd_sand	TO	BR

Appendix A: Table A1. Sample Information (Ceramics)(continued)

ID	Group	Region	Site	Provinience	Temper	Type	Surface
VR37-2	1VV possible	lowland Virgin	VR37	surface	sherd_sand	TO	BR
VR37-3	IVV	lowland Virgin	VR37	surface	olivine	MC	C
VR38-1	IVV	lowland Virgin	VR38	surface	olivine	MP	P
VR38-2		lowland Virgin	VR38	surface	olivine	MP	P
VR38-3	IVV	lowland Virgin	VR38	surface	olivine	MC	c
VR38-4	VR3	lowland Virgin	VR38	surface	sand	TP	P
VR38-5	G2	lowland Virgin	VR38	surface	sand	TP	P
VR38-6	1G	lowland Virgin	VR38	surface	olivine	MP	P
VR38-7	VR1	lowland Virgin	VR38	surface	sand	TBG	BG
VR38-8	IVV	lowland Virgin	VR38	surface	olivine	MP	P
VR39-1	1VV possible	lowland Virgin	VR39	surface	olivine	MP	P
VR39-2	IVV	lowland Virgin	VR39	surface	sand	TP	P
VR39-3		lowland Virgin	VR39	surface	olivine	MP	P
VR39-4	IVV	lowland Virgin	VR39	surface	olivine	MBG	BG
VR39-5	IVV	lowland Virgin	VR39	surface	olivine	MBG	BG
VR40-1		lowland Virgin	VR40	surface	olivine	MP	P
VR40-2		lowland Virgin	VR40	surface	sherd_olivine	SVP	P
VR40-3		lowland Virgin	VR40	surface	sherd_olivine	SVP	P
VR40-4	1VV possible	lowland Virgin	VR40	surface	olivine	MBG	BG
VR40-5	IVV	lowland Virgin	VR40	surface	olivine	MBG	BG
VR40-6		lowland Virgin	VR40	surface	sherd_olivine	SVP	P
VR40-7	IVV	lowland Virgin	VR40	surface	olivine	MP	P
VR40-8	IVV	lowland Virgin	VR40	surface	olivine	MP	P
VR40-9	1VV possible	lowland Virgin	VR40	surface	olivine	MBG	BG

Appendix A: Table A2. Sample Information (Clay)

ID	Region	Note	Clay Type	Group
MT6C	MT		vol	
MT6PC	MT	prepared	vol	
MT7C	MT		vol	G2
MT7PC	MT	prepared	vol	G1G, G2
MT17C	MT		sec	G2
MT17PC	MT	prepared	sec	
MT22C	MT		sec	G2
MT22PC	MT	prepared	sec	G2
MT23C	MT		sec	
MT23PC	MT	prepared	sec	
MT24C	MT		sec	
MT24PC	MT	prepared	sec	
MT25C	MT		sec	
MT25PC	MT	prepared	sec	
MT28C	MT		sec	G2
MT28PC	MT	prepared	sec	
MT33C	MT		vol	
MT33PC	MT	prepared	vol	
MT37C	MT		sed	
MT37PC	MT	prepared	sed	
MT44C	MT		vol	
MT44PC	MT	prepared	vol	
MT47C	MT		vol	
MT47PC	MT	prepared	vol	
MT49C	MT		vol	
MT49PC	MT	prepared	vol	
MT52C	MT		sed	
MT53C	MT		sec	
MT53PC	MT	prepared	sec	
MT63C	MT		sec	G1G
MT63PC	MT	prepared	sec	
MT71C	MT		sec	G2
MT71PC	MT	prepared	sec	
MT72C	MT		vol	G2
MT72PC	MT	prepared	vol	
MT73C	MT		vol	
MT73PC	MT	prepared	vol	
MT74C	MT		vol	
MT74PC	MT	prepared	vol	
MT75C	MT		vol	
MT75PC	MT	prepared	vol	
MT80C	MT		vol	
MT80PC	MT	prepared	vol	
MT81C	MT		sed	
MT81PC	MT	prepared	sed	
MT82C	MT		vol	
MT86C	MT		sed	
MT86C	MT		sed	
MT87C	MT		sed	
MT87PC	MT	prepared	sed	
MT88C	MT		vol	G2
MT88PC	MT	prepared	vol	
MT89C	MT		vol	
MT89PC	MT	prepared	vol	
MT90C	MT		sec	
MT90PC	MT	prepared	sec	
MT91C	MT		vol	
MT91PC	MT	prepared	vol	
MT92C	MT		sec	G2
MT93C	MT		sec	
MT93PC	MT	prepared	sec	
MT95C	MT		sed	
MT95PC	MT	prepared	sed	G2
MT97PC	MT	prepared	vol	
MT98C	MT		vol	
MT98PC	MT	prepared	vol	G2
MT99C	MT		vol	G2
MT99PC	MT		vol	
MT100C	MT		sed	
MT100PC	MT	prepared	sed	
MT101C	MT		sed	
MT101PC	MT	prepared	sed	
MT102C	MT		sed	
MT102PC	MT	prepared	sed	
MT103C	MT		sed	
MT103PC	MT	prepared	sed	
MT104C	MT		sed	
MT104PC	MT	prepared	sed	
MT105C	MT		sec	G2
MT105PC	MT	prepared	sec	G1G, G2
MT106C	MT		sec	
MT106PC	MT	prepared	sec	G2
MT109C	MT		sed	
MT109PC	MT	prepared	sed	
MT110C	MT		sed	
MT110PC	MT	prepared	sed	
MT111C	MT		sed	
MT111PC	MT	prepared	sed	
MT112C	MT		sed	
MT112PC	MT	prepared	sed	
MT115C	MT		sed	
MT116C	MT		vol	
MT116PC	MT	prepared	vol	G2
MT117C	MT		sed	
MT117PC	MT	prepared	sed	
MT118PC	MT	prepared	sec	
MT119C	MT		sed	
MT119PC	MT	prepared	sed	
MT123C	MT		sed	
MT123PC	MT	prepared	sed	
MT124C	MT		sed	
MT124PC	MT	prepared	sed	
MT125C	MT		sed	
MT126PC	MT	prepared	sed	
MT127C	MT		sed	
MT127PC	MT	prepared	sed	
MT131PC	MT	prepared	sed	
MT132C	MT		sed	
MT134C	MT		sed	
MT134PC	MT	prepared	sed	

Appendix A: Table A2. Sample Information (Clay)(continued)

ID	Region	Note	Clay type	Group
MT135C	MT		sed	
MT136PC	MT	prepared	sed	
MT138C	MT		sed	
MT138PC	MT	prepared	sed	
MT139C	MT		sed	
MT139PC	MT	prepared	sed	
MT141C	MT		sed	
MT141PC	MT	prepared	sed	
MT142C	MT		sed	
MT142PC	MT	prepared	sed	
MT144PC	MT	prepared	sed	
MT146C	MT		vol	
MT146PC	MT	prepared	vol	
MT147C	MT		sed	
MT147PC	MT	prepared	sed	
MT148C	MT		vol	G2
MT148PC	MT	prepared	vol	
MT149PC	MT	prepared	sed	
MT150PC	MT	prepared	sed	
MT151PC	MT	prepared	sed	
MT181C	MT			
MT197C	MT			
VR2C	VR		sed	
VR2PC	VR	prepared	sed	
VR3C	VR		sed	
VR3PC	VR	prepared	sed	
VR4C	VR		sed	
VR4PC	VR	prepared	sed	
VR6C	VR		sec	
VR6PC	VR	prepared	sec	
VR7C	VR		sed	
VR7PC	VR	prepared	sed	
VR9PC	VR	prepared	sec	
VR10C	VR		sed	
VR10PC	VR	prepared	sed	
VR11PC	VR	prepared	sed	
VR13C	VR		sed	
VR14C	VR		sed	
VR14PC	VR	prepared	sed	G1VV
VR17C	VR		sed	
VR18C	VR		sed	
VR18PC	VR	prepared	sed	
VR19C	VR		sed	
VR19PC	VR	prepared	sed	
VR22C	VR		sed	G1VV
VR24C	VR		sec	
VR24PC	VR	prepared	sec	
VR25C	VR		sec	
VR25PC	VR	prepared	sec	
VR26C	VR		sec	
VR26PC	VR	prepared	sec	
VR28PC	VR	prepared	sec	
VR29C	VR		sec	G1VV
VR29PC	VR	prepared	sec	
VR30C	VR		sec	
VR30PC	VR	prepared	sec	
VR31C	VR		sec	
VR31PC	VR	prepared	sec	
VR34C	VR		sec	
VR34PC	VR	prepared	sec	
VR35C	VR		sed	
VR35PC	VR	prepared	sed	
VR37PC	VR	prepared	sec	
CH2-2COMP	other		sec	
CH2C	other		sec	
CH2PC	other	prepared	sec	
JC2PC	other	prepared	sed	
JC3C	other		sed	
JO1C	other		sed	
JO1PC	other	prepared	sed	
JO2C	other		sed	
JO3PC	other	prepared	sed	
MP1C	other			
MP1PC	other	prepared		
QC10C	other		sed	
QC10PC	other	prepared	sed	
QK1C	other		sed	
QK1PC	other		sed	
SV9C	SV		vol	G2
SV9PC	SV		vol	
TW40C	TW			
TW40PC	TW			
TWP1C	TW		sec	G2
TWP1PC	TW		sec	

APPENDIX B: OSL DATING DATA

Table B1. The equivalent doses used for the OSL dating.

Table B2. Dose rate information for OSL dating.

Table B3. Locational information, thickness and water absorption of the sample for OSL dating.

Table B4. Summary of OSL dates.

Appendix B: Table B1. The equivalent doses used for the OSL dating.

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
G2	LB0097	204-13	A.D.490 ± 110	1	5.07 ± 0.21	Single aliquot
1VM	LB0098	30-36	A.D.1091 ± 321	summary	2.88 ± 0.97	Central age (47.4)
				1	4.65 ± 0.28	
				2	1.79 ± 0.11	
G2	LB0099	136-27	A.D.1656 ± 32	summary	1.16 ± 0.07	Central age (8.1)
				1	1.07 ± 0.01	
				2	1.26 ± 0.01	
1G	LB0101	131-9	A.D.739 ± 125	summary	4.18 ± 0.08	Central age (2.3)
				1	4.08 ± 0.04	
				2	4.30 ± 0.06	
G3	LB0106	30-80	A.D.1255 ± 80	summary	2.67 ± 0.15	Common age (NA)
				1	2.67 ± 0.20	
				2	2.68 ± 0.22	
G3	LB0107	30-81	A.D.1472 ± 84	summary	1.89 ± 0.28	Central age (19.4)
				1	1.56 ± 0.07	
				2	2.38 ± 0.24	
G3	LB0108	30-82	A.D.1264 ± 45	summary	2.39 ± 0.08	Common age (NA)
				1	2.39 ± 0.08	
				2	2.11 ± 0.66	
G2	LB0119	71-39	A.D.587 ± 85	1	3.14 ± 0.13	Single aliquot
G2	LB0120	71-40	A.D.895 ± 193	summary	2.20 ± 0.37	Central age (22.7)
				1	1.73 ± 0.13	
				2	2.77 ± 0.13	
1G	LB0123	30-88	A.D.804 ± 140	summary	2.53 ± 0.24	Central age (15.1)
				1	2.68 ± 0.19	
				2	3.00 ± 0.21	
				3	2.01 ± 0.15	
1G	LB0126	204-28	A.D.1683 ± 93	1	0.63 ± 0.18	Single aliquot
G2	LB0129	131-14	A.D.476 ± 115	1	4.58 ± 0.25	Single aliquot
G2	LB0130	131-45	A.D.1085 ± 80	summary	2.69 ± 0.18	Central age (13.1)
				1	2.95 ± 0.09	
				2	3.10 ± 0.07	
				4	2.57 ± 0.11	
				3	2.20 ± 0.07	
G2	LB0131	136-16	A.D.1730 ± 17	summary	0.89 ± 0.01	Common age (NA)
				1	0.96 ± 0.08	
				2	0.89 ± 0.01	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
G2	LB0133	204-4	A.D.1581 ± 33	summary	1.35 ± 0.06	Central age (4.6)
				1	1.45 ± 0.09	
				2	1.25 ± 0.02	
G2	LB0135	30-17	A.D.1984 ± 10	1	0.61 ± 0.01	Single aliquot
G2	LB0136	30-7	A.D.493 ± 137	summary	5.03 ± 0.36	Central age (8.7)
				1	4.60 ± 0.18	
				2	5.66 ± 0.38	
G2	LB0137	14-140	A.D.590 ± 203	summary	4.33 ± 0.57	Central age (18.4)
				1	3.58 ± 0.14	
				2	5.20 ± 0.05	
1G	LB0138	14-70	A.D.1313 ± 304	summary	2.84 ± 1.22	Central age (60.1)
				1	1.55 ± 0.14	
				2	5.18 ± 0.28	
1G	LB0139	131-96	A.D.1350 ± 64	summary	2.27 ± 0.08	Common age (NA)
				1	2.74 ± 1.57	
				2	2.27 ± 0.08	
1G	LB0140	30-10	A.D.769 ± 199	1	3.71 ± 0.50	Single aliquot
1G	LB0141	136-18	A.D.436 ± 127	summary	4.49 ± 0.05	Common age (NA)
				1	4.83 ± 0.21	
				2	4.47 ± 0.05	
1G	LB0144	14-106	A.D.1309 ± 60	summary	2.15 ± 0.02	Common age (NA)
				1	2.10 ± 0.08	
				2	2.15 ± 0.02	
1G	LB0145	14-120	A.D.1375 ± 62	summary	1.86 ± 0.08	Common age (NA)
				1	1.92 ± 0.13	
				2	1.83 ± 0.10	
1G	LB0146	30-40	A.D.205 ± 205	1	4.07 ± 0.34	single aliquot
1G	LB0148	136-7	A.D.1655 ± 28	summary	1.03 ± 0.01	Common age (NA)
				1	1.05 ± 0.05	
				2	1.03 ± 0.01	
1VM	LB0149	136-34	A.D.1264 ± 61	summary	2.04 ± 0.07	Common age (NA)
				1	1.76 ± 0.16	
				2	2.09 ± 0.08	
G2	LB0258	136-9	A.D.1592 ± 30	summary	1.14 ± 0.05	Central age (9.2)
				1	1.18 ± 0.01	
				2	1.01 ± 0.01	
				4	1.03 ± 0.03	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
G2	LB0258	136-9		3	1.26 ± 0.02	
				6	1.26 ± 0.03	
G2	LB0260	136-26	A.D.833 ± 81	summary	3.73 ± 0.13	Common age (NA)
				1	3.62 ± 0.17	
				2	3.84 ± 0.18	
1G	LB0262	30-16	A.D.1410 ± 54	summary	1.93 ± 0.01	Common age (NA)
				1	1.93 ± 0.01	
				3	1.93 ± 0.01	
				4	1.91 ± 0.02	
				5	1.90 ± 0.02	
1G	LB0263	30-37	A.D.1177 ± 123	summary	2.33 ± 0.30	Central age (12.9)
				1	2.79 ± 0.06	
				2	1.94 ± 0.03	
1G	LB0264	14-6	A.D.1312 ± 104	summary	2.49 ± 0.27	Central age (10.7)
				1	3.13 ± 0.03	
				2	2.47 ± 0.02	
				3	1.99 ± 0.04	
G2	LB0268	14-83	A.D.1002 ± 52	summary	3.00 ± 0.02	Common age (NA)
				1	2.99 ± 0.02	
				2	3.21 ± 0.10	
G2	LB0270	14-116	A.D.1282 ± 45	summary	2.50 ± 0.02	Central age (0.8)
				1	2.48 ± 0.01	
				2	2.54 ± 0.02	
G2	LB0271	14-152	A.D.1067 ± 85	summary	3.36 ± 0.12	Central age (11.3)
				1	2.87 ± 0.02	
				2	2.77 ± 0.03	
				3	3.40 ± 0.03	
				6	3.52 ± 0.03	
				7	3.19 ± 0.03	
				8	3.40 ± 0.03	
				9	3.35 ± 0.02	
				10	4.28 ± 0.02	
				11	3.56 ± 0.04	
				12	3.43 ± 0.04	
G2	LB0275	131-53	A.D.830 ± 73	summary	2.98 ± 0.04	Central age (1.3)
				2	3.02 ± 0.02	
				3	2.91 ± 0.04	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
1G	LB0276	131-74	A.D.599 ± 123	summary	4.32 ± 0.15	Central (3.4)
				1	4.73 ± 0.07	
				2	4.37 ± 0.08	
				3	4.25 ± 0.08	
				4	3.85 ± 0.15	
1G	LB0279	204-2	A.D.977 ± 109	summary	3.41 ± 0.15	Central age (4.5)
				1	3.67 ± 0.02	
				2	3.08 ± 0.01	
				3	3.10 ± 0.01	
				4	4.04 ± 0.02	
				5	3.49 ± 0.02	
				6	2.84 ± 0.01	
				7	3.81 ± 0.02	
1VM	LB0586	214-8	A.D.1465 ± 43	1	1.65 ± 0.05	Single aliquot
G2	LB0588	214-5	A.D.1049 ± 53	summary	2.95 ± 0.09	Central age (5.4)
				1	2.98 ± 0.03	
				2	2.75 ± 0.02	
				3	3.15 ± 0.05	
G2	LB0599	30-260	A.D.1461 ± 52	summary	2.13 ± 0.04	Central age (1.7)
				1	2.37 ± 0.01	
				2	2.58 ± 0.01	
				3	2.37 ± 0.01	
				4	2.46 ± 0.01	
				5	2.33 ± 0.01	
				6	2.25 ± 0.02	
				7	2.11 ± 0.01	
				8	2.22 ± 0.01	
				9	1.99 ± 0.01	
				10	2.06 ± 0.01	
				11	2.18 ± 0.01	
1G	LB0600	30-261	A.D.1130 ± 96	summary	2.54 ± 0.17	Central age (16.9)
				1	2.71 ± 0.12	
				2	3.42 ± 0.18	
				3	2.76 ± 0.14	
				4	2.27 ± 0.11	
				5	2.17 ± 0.07	
				6	2.83 ± 0.16	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
1G	LB0600	30-261		8	1.97 ± 0.07	
1G	LB0601	30-262	A.D.1250 ± 65	summary	2.14 ± 0.09	Central age (4.2)
				1	2.32 ± 0.02	
				2	2.14 ± 0.01	
				3	2.26 ± 0.02	
				4	1.87 ± 0.01	
G2	LB0616	30-158	A.D.1132 ± 63	summary	2.13 ± 0.06	Central age (7.1)
				1	2.24 ± 0.04	
				2	2.05 ± 0.03	
				3	2.10 ± 0.05	
				4	2.10 ± 0.05	
				5	2.22 ± 0.03	
				6	1.86 ± 0.03	
				7	2.47 ± 0.08	
				8	2.12 ± 0.04	
1G	LB0624	VR21-5	A.D.509 ± 151	summary	4.50 ± 0.19	Central age (15.5)
				1	4.63 ± 0.19	
				2	3.93 ± 0.15	
				3	3.87 ± 0.13	
				4	4.92 ± 0.22	
				5	3.73 ± 0.15	
				6	4.57 ± 0.21	
				7	4.22 ± 0.16	
				8	5.82 ± 0.18	
				9	4.71 ± 0.14	
				10	5.68 ± 0.18	
				11	4.89 ± 0.19	
				12	4.64 ± 0.16	
				13	4.15 ± 0.18	
				14	5.40 ± 0.19	
				15	3.18 ± 0.14	
1G	LB0641	131-307	A.D.1236 ± 90	summary	2.22 ± 0.17	Central age (12.6)
				1	1.91 ± 0.03	
				2	2.59 ± 0.03	
				4	2.23 ± 0.12	
1VV	LB0650	30-173	A.D.1253 ± 59	summary	2.48 ± 0.02	Central age (2.2)
				3	2.53 ± 0.01	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
1VV	LB0650	30-173		4	2.40 ± 0.01	
				5	2.49 ± 0.02	
				6	2.42 ± 0.02	
				7	2.13 ± 0.26	
				8	2.64 ± 0.08	
				11	2.51 ± 0.06	
				12	2.49 ± 0.07	
1VV	LB0655	131-236	A.D.1275 ± 63	summary	3.84 ± 0.17	Central age (12.8)
				1	3.98 ± 0.03	
				2	3.83 ± 0.04	
				3	4.47 ± 0.05	
				4	4.40 ± 0.04	
				5	3.34 ± 0.04	
				6	3.37 ± 0.04	
				7	3.50 ± 0.06	
				8	4.67 ± 0.07	
				11	3.26 ± 0.15	
G3	LB0661	204-41	A.D.798 ± 86	summary	3.54 ± 0.13	Central age (9.1)
				1	3.41 ± 0.07	
				2	3.76 ± 0.08	
				3	3.89 ± 0.07	
				4	3.20 ± 0.10	
				5	3.74 ± 0.12	
				8	3.83 ± 0.07	
				9	2.90 ± 0.14	
1VM	LB0673	30-166	A.D.1146 ± 74	summary	1.97 ± 0.08	Central age (9.5)
				1	1.82 ± 0.07	
				2	1.90 ± 0.03	
				3	2.38 ± 0.11	
				4	1.74 ± 0.05	
				5	1.95 ± 0.08	
				6	2.24 ± 0.10	
				8	1.89 ± 0.08	
G2	LB0674	VR14-1	A.D.969 ± 57	summary	3.17 ± 0.06	Central age (5.2)
				1	3.30 ± 0.03	
				2	2.91 ± 0.02	
				4	3.12 ± 0.03	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
G2	LB0674	VR14-1		5	3.12 ± 0.06	
				6	3.22 ± 0.04	
				7	3.48 ± 0.03	
				8	3.07 ± 0.04	
1G	LB0676	VR7-11	A.D.439 ± 169	summary	4.53 ± 0.32	Central age (15.1)
				1	3.42 ± 0.08	
				2	4.46 ± 0.25	
				3	5.09 ± 0.21	
				4	4.96 ± 0.39	
				5	5.07 ± 0.22	
1VV	LB0679	VR17-2	A.D.1478 ± 93	summary	3.10 ± 0.40	Central age (39.9)
				2	5.17 ± 0.09	
				3	5.01 ± 1.54	
				4	2.85 ± 0.35	
				5	2.30 ± 0.15	
				7	1.43 ± 0.62	
				8	2.93 ± 0.16	
				10	4.06 ± 0.41	
				11	4.35 ± 0.55	
				12	4.87 ± 0.31	
				13	2.18 ± 0.25	
				14	1.47 ± 0.13	
G3	LB0868	71-48	A.D.606 ± 83	summary	3.98 ± 0.15	Central age (8.4)
				1	4.47 ± 0.10	
				2	4.14 ± 0.07	
				3	3.45 ± 0.07	
				6	3.86 ± 0.11	
				5	4.06 ± 0.08	
G3	LB0870	71-57	A.D.1467 ± 37	summary	1.33 ± 0.07	Central age (10.1)
				1	1.25 ± 0.09	
				2	1.51 ± 0.09	
				3	1.07 ± 0.09	
				4	1.18 ± 0.11	
				5	1.48 ± 0.06	
				11	1.40 ± 0.07	
1G	LB0875	VR24-1	A.D.849 ± 118	summary	2.84 ± 0.22	Central age (18.9)
				1	2.81 ± 0.25	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
1G	LB0875	VR24-1		2	3.83 ± 0.21	
				3	3.30 ± 0.35	
				4	2.55 ± 0.35	
				5	3.31 ± 0.29	
				6	2.14 ± 0.16	
				7	2.29 ± 0.18	
1VM	LB0878	30-168	A.D.1141 ± 70	summary	2.03 ± 0.04	Central age (3.8)
				1	2.12 ± 0.03	
				2	2.04 ± 0.03	
				3	1.91 ± 0.03	
				5	2.12 ± 0.04	
1VM	LB0878	30-168		6	1.98 ± 0.03	
VR1	LB1071	131-314	A.D.1080 ± 66	summary	4.04 ± 0.19	Central age (13.2)
				1	4.26 ± 0.21	
				2	4.49 ± 0.10	
				3	3.53 ± 0.10	
				4	3.68 ± 0.10	
				5	3.99 ± 0.14	
				6	3.83 ± 0.11	
				7	3.52 ± 0.08	
				8	5.41 ± 0.19	
VR1	LB1072	VR32-3	A.D.1099 ± 78	summary	4.69 ± 0.29	Central age (13.6)
				1	4.98 ± 0.07	
				2	3.98 ± 0.08	
				3	4.37 ± 0.13	
				4	6.07 ± 0.31	
				5	4.44 ± 0.11	
G4	LB1073	VR27-19	A.D.924 ± 129	summary	1.85 ± 0.16	Central age (19.6)
				1	1.58 ± 0.02	
				2	1.71 ± 0.02	
				3	1.51 ± 0.02	
				4	2.58 ± 0.05	
				5	2.06 ± 0.04	
VR3	LB1074	VR33-2	A.D.1282 ± 52	summary	2.54 ± 0.08	Central age (8.7)
				1	2.48 ± 0.02	
				4	2.32 ± 0.03	
				5	2.32 ± 0.02	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
VR3	LB1074	VR33-2		6	2.46 ± 0.03	
				7	2.99 ± 0.03	
				8	2.65 ± 0.02	
				9	2.36 ± 0.02	
				10	2.80 ± 0.03	
G4	LB1075	VR21-16	A.D.822 ± 170	summary	2.91 ± 0.33	Common age (NA)
				3	2.17 ± 0.48	
				5	3.11 ± 0.81	
				7	2.83 ± 0.54	
				9	4.14 ± 1.02	
1G	LB1076	VR27-12	A.D.1222 ± 79	summary	2.10 ± 0.07	Central age (10.9)
				2	2.09 ± 0.02	
				3	2.44 ± 0.03	
				5	1.70 ± 0.02	
				6	2.29 ± 0.07	
				7	2.05 ± 0.05	
				8	2.37 ± 0.06	
				9	1.82 ± 0.05	
				10	2.09 ± 0.04	
				13	1.97 ± 0.08	
				14	2.38 ± 0.06	
				15	2.06 ± 0.10	
1G	LB1077	VR35-6	A.D.388 ± 132	summary	4.78 ± 0.08	Central age (3.5)
				2	4.65 ± 0.08	
				3	4.77 ± 0.08	
				4	5.04 ± 0.13	
				5	4.80 ± 0.14	
				6	5.16 ± 0.15	
				7	4.75 ± 0.27	
				8	4.70 ± 0.11	
				9	4.24 ± 0.18	
1G	LB1078	VR22-4	A.D.521 ± 172	2	3.72 ± 0.34	Single aliquot
1G	LB1079	VR32-7	A.D.553 ± 319	summary	3.63 ± 0.73	Central age (53.1)
				1	5.96 ± 0.68	
				2	6.68 ± 1.32	
				3	5.50 ± 0.51	
				4	3.51 ± 0.56	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
1G	LB1079	VR32-7		5	0.35 ± 0.29	
				6	1.39 ± 0.20	
				7	3.86 ± 0.28	
				8	4.11 ± 0.46	
1G	LB1080	VR27-6	A.D.1086 ± 101	1	3.06 ± 0.12	Single aliquot
VR3	LB1084	14-297	A.D.1299 ± 45	summary	3.06 ± 0.09	Central age (7.7)
				1	2.93 ± 0.03	
				2	3.06 ± 0.04	
				3	2.92 ± 0.03	
				5	2.99 ± 0.05	
				6	3.70 ± 0.14	
				8	2.71 ± 0.07	
				9	3.01 ± 0.06	
				10	3.31 ± 0.05	
VR3	LB1086	VR7-3	A.D.1073 ± 73	summary	2.69 ± 0.14	Central age (4.7)
				1	2.85 ± 0.10	
				2	2.63 ± 0.35	
				3	2.92 ± 1.62	
				4	2.16 ± 0.30	
				6	1.21 ± 0.50	
VR3	LB1087	VR23-4	A.D.602 ± 121	summary	4.66 ± 0.22	Central age (15.4)
				1	4.15 ± 0.12	
				2	5.70 ± 0.15	
				3	4.47 ± 0.12	
				4	4.05 ± 0.11	
				5	5.47 ± 0.12	
				6	4.45 ± 0.16	
				7	5.57 ± 0.11	
				8	4.26 ± 0.13	
				9	3.51 ± 0.12	
				10	5.76 ± 0.15	
				11	4.43 ± 0.10	
VR3	LB1090	VR28-2	A.D.1156 ± 95	summary	2.20 ± 0.22	Central age (25.4)
				1	1.51 ± 0.03	
				2	1.84 ± 0.04	
				4	2.28 ± 0.06	
				3	3.41 ± 0.07	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
VR3	LB1090	VR28-2		5	2.32 ± 0.09	
				6	2.66 ± 0.08	
				7	1.74 ± 0.34	
VR1	LB1092	VR21-11	A.D.790 ± 238	summary	6.53 ± 1.22	Central age (23.5)
				3	5.09 ± 0.52	
				4	8.65 ± 1.20	
VR1	LB1093	30-266	A.D.1494 ± 62	summary	2.81 ± 0.28	Common age (NA)
				1	3.18 ± 0.70	
				4	3.34 ± 0.66	
				5	2.46 ± 0.34	
VR1	LB1094	30-77	A.D.1402 ± 81	2	4.14 ± 0.50	Single aliquot
VR1	LB1096	VR38-7	A.D.1238 ± 54	summary	3.89 ± 0.10	Central age (8.9)
				1	4.28 ± 0.10	
				2	4.09 ± 0.12	
				3	3.44 ± 0.08	
				5	3.69 ± 0.14	
				7	3.83 ± 0.15	
				8	4.09 ± 0.21	
				9	4.05 ± 0.23	
				10	3.41 ± 0.12	
				11	3.89 ± 0.17	
				12	3.52 ± 0.23	
				13	4.65 ± 0.11	
				14	3.64 ± 0.18	
				15	3.61 ± 0.12	
				16	4.44 ± 0.18	
VR1	LB1097	30-201	A.D.1529 ± 48	summary	2.62 ± 0.21	Common age (NA)
				1	2.85 ± 0.30	
				2	2.39 ± 0.50	
				3	2.31 ± 0.35	
VR1	LB1098	VR17-5	A.D.1188 ± 107	summary	4.90 ± 0.55	Central age (28.6)
				1	2.80 ± 0.11	
				2	5.39 ± 0.15	
				3	4.64 ± 0.47	
				5	7.97 ± 0.46	
				6	4.59 ± 0.42	
				7	4.91 ± 0.21	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
VR1	LB1098	VR17-5		8	5.45 ± 0.46	
G4	LB1099	71-64	A.D.468 ± 148	summary	4.28 ± 0.14	Central age (9.6)
				1	4.35 ± 0.10	
				2	4.36 ± 0.14	
				3	4.38 ± 0.14	
				4	4.24 ± 0.26	
				5	3.77 ± 0.21	
				6	4.26 ± 0.25	
				8	5.02 ± 0.19	
				9	5.07 ± 0.33	
				10	3.47 ± 0.15	
				11	4.08 ± 0.24	
G4	LB1100	VR21-22	B.C.95 ± 207	summary	4.48 ± 0.23	Central age (14.9)
				1	5.67 ± 0.17	
				2	4.49 ± 0.20	
				3	4.15 ± 0.16	
				4	4.37 ± 0.12	
				5	4.75 ± 0.16	
				6	4.44 ± 0.17	
				8	3.13 ± 0.12	
				9	5.12 ± 0.12	
				10	4.57 ± 0.14	
G4	LB1101	VR17-8	A.D.1180 ± 90	summary	1.74 ± 0.08	Central age (15.9)
				1	1.91 ± 0.04	
				2	1.54 ± 0.03	
				3	1.89 ± 0.04	
				4	1.46 ± 0.03	
				5	1.96 ± 0.06	
				6	1.90 ± 0.02	
				7	1.40 ± 0.03	
				8	1.72 ± 0.04	
				9	1.59 ± 0.05	
				10	1.64 ± 0.06	
				11	2.61 ± 0.09	
				12	1.59 ± 0.05	
G4	LB1102	VR7-5	B.C.373 ± 206	summary	4.08 ± 0.10	Central age (6.9)
				1	3.54 ± 0.05	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
G4	LB1102	VR 7-5		2	4.45 ± 0.09	
				4	4.15 ± 0.08	
G4	LB1102	VR7-5		5	4.31 ± 0.13	
				6	4.05 ± 0.14	
				7	3.88 ± 0.15	
				8	4.39 ± 0.15	
				9	4.23 ± 0.15	
				10	3.83 ± 0.17	
G4	LB1103	VR15-2	A.D.1263 ± 80	summary	1.95 ± 0.04	Central age (5.0)
				1	2.03 ± 0.02	
				2	1.98 ± 0.02	
				3	1.98 ± 0.02	
				4	1.99 ± 0.03	
				5	1.99 ± 0.04	
				6	1.72 ± 0.04	
G4	LB1105	VR35-17	A.D.1279 ± 74	summary	1.82 ± 0.07	Central age (10.5)
				1	1.60 ± 0.02	
				2	1.99 ± 0.02	
				3	1.84 ± 0.03	
				4	1.57 ± 0.02	
				5	2.09 ± 0.03	
				6	2.01 ± 0.02	
				7	1.71 ± 0.02	
G4	LB1106	VR35-4	A.D.229 ± 183	summary	4.41 ± 0.14	Central age (5.0)
				4	4.40 ± 0.15	
				6	3.92 ± 0.19	
				8	4.49 ± 0.14	
				9	4.80 ± 0.20	
G4	LB1107	VR21-29	A.D.1154 ± 110	summary	2.17 ± 0.18	Central age (9.1)
				2	2.59 ± 0.29	
				7	1.99 ± 0.10	
1VM	LB1109	30-151	A.D.1304 ± 109	summary	2.00 ± 0.26	Central age (21.2)
				1	1.50 ± 0.09	
				2	2.11 ± 0.16	
				3	2.56 ± 0.19	
1VM	LB1111	136-76	A.D.1815 ± 32	summary	0.49 ± 0.07	Common age (NA)

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
1VM	LB1111	136-76		1	0.45 ± 0.08	
				3	0.56 ± 0.18	
				4	0.58 ± 0.19	
1VM	LB1112	136-271	A.D.941 ± 109	summary	3.03 ± 0.19	Central age (6.3)
				1	3.22 ± 0.30	
				2	2.72 ± 0.22	
				3	2.86 ± 0.48	
				4	2.04 ± 0.67	
				6	4.16 ± 0.68	
1VM	LB1113	131-168	A.D.696 ± 105	1	3.34 ± 0.07	Single aliquot
1VM	LB1114	TW143	A.D.569 ± 149	summary	3.52 ± 0.23	Common age (NA)
				1	3.28 ± 0.46	
				2	2.92 ± 0.41	
				3	4.15 ± 1.11	
				4	2.87 ± 0.77	
				5	4.59 ± 1.26	
				6	3.35 ± 0.96	
				7	5.54 ± 1.45	
				8	3.99 ± 0.68	
				9	3.52 ± 0.69	
1VM	LB1115	TW101	A.D.1275 ± 82	summary	1.84 ± 0.14	Central age (9.6)
				2	1.89 ± 0.17	
				4	2.23 ± 0.26	
				5	1.86 ± 0.23	
				6	1.34 ± 0.20	
G3	LB1117	71-58	A.D.748 ± 90	summary	3.36 ± 0.16	Central age (11.5)
				1	3.00 ± 0.02	
				2	3.16 ± 0.02	
				3	3.83 ± 0.02	
				4	3.78 ± 0.02	
				5	3.66 ± 0.02	
				7	2.84 ± 0.11	
G3	LB1118	71-56	A.D.1055 ± 94	summary	3.02 ± 0.19	Central age (19.6)
				1	2.99 ± 0.13	
				2	4.13 ± 0.23	
				3	3.72 ± 0.17	
				4	2.91 ± 0.11	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
G3	LB1118	71-56		5	1.96 ± 0.08	
				6	2.45 ± 0.09	
				7	2.86 ± 0.18	
				8	3.36 ± 0.26	
				9	3.16 ± 0.27	
				10	3.37 ± 0.12	
G3	LB1119	71-47	A.D.758 ± 110	summary	3.38 ± 0.10	Central age (10.2)
				1	3.20 ± 0.14	
				2	2.68 ± 0.07	
				3	3.84 ± 0.19	
				4	3.44 ± 0.08	
				5	3.39 ± 0.10	
				6	3.04 ± 0.10	
				7	3.36 ± 0.11	
				8	4.04 ± 0.13	
				9	3.14 ± 0.14	
				10	3.64 ± 0.11	
				11	3.30 ± 0.13	
				12	3.70 ± 0.12	
1VV	LB1120	VR39-2	A.D.1094 ± 74	summary	2.45 ± 0.11	Central age (12.2)
				2	2.56 ± 0.01	
				4	2.26 ± 0.01	
				4	2.94 ± 0.02	
				6	2.12 ± 0.02	
				7	2.59 ± 0.10	
				8	2.84 ± 0.09	
				12	2.02+-/0.05	
				13	2.45 ± 0.05	
1VV	LB1121	VR26-1	A.D.866 ± 108	summary	3.13 ± 0.11	Central age (6.3)
				2	3.44 ± 0.20	
				4	2.89 ± 0.09	
				6	3.52 ± 0.24	
				7	2.71 ± 0.27	
				8	3.20 ± 0.29	
				11	3.26 ± 0.20	
				12	2.68 ± 0.35	
1VV	LB1122	204-20	A.D.982 ± 106	summary	3.40 ± 0.23	Central age (20.4)

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
1VV	LB1122	204-20		1	2.43 ± 0.08	
				2	5.32 ± 0.13	
				3	3.95 ± 0.11	
				4	3.17 ± 0.08	
				5	3.36 ± 0.09	
				6	3.48 ± 0.09	
				7	3.33 ± 0.09	
				10	2.80 ± 0.05	
				11	3.39 ± 0.11	
1VV	LB1123	136-63	A.D.1063 ± 89	summary	3.45 ± 0.15	Central age (11.9)
				1	3.53 ± 0.03	
				2	3.00 ± 0.03	
				3	4.30 ± 0.05	
				4	3.58 ± 0.06	
				5	2.96 ± 0.03	
				6	3.85 ± 0.05	
				7	3.40 ± 0.05	
				8	3.17 ± 0.04	
1VV	LB1124	VR35-11	A.D.940 ± 88	summary	2.97 ± 0.10	Central age (10.0)
				1	2.83 ± 0.04	
				2	2.80 ± 0.03	
				3	3.51 ± 0.04	
				4	2.72 ± 0.04	
				5	3.53 ± 0.03	
				6	2.67 ± 0.03	
				7	2.86 ± 0.04	
				8	2.78 ± 0.05	
				9	3.13 ± 0.06	
1VV	LB1125	131-318	A.D.569 ± 154	summary	3.84 ± 0.30	Central age (15.1)
				2	3.59 ± 0.29	
				3	4.62 ± 0.46	
				4	2.89 ± 0.21	
				7	4.19 ± 0.41	
				12	4.35 ± 0.42	
1VV	LB1127	214-11	A.D.938 ± 83	summary	4.51 ± 0.22	Central age (11.6)
				3	4.85 ± 0.03	
				4	4.92 ± 0.04	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
1VV	LB1127	214-11		5	5.05 ± 0.04	
				6	4.68 ± 0.04	
				7	4.11 ± 0.06	
				8	3.60 ± 0.10	
1VV	LB1128	VR39-4	A.D.980 ± 94	summary	2.74 ± 0.11	Central age (10.1)
				1	2.80 ± 0.04	
				2	2.70 ± 0.03	
				3	3.12 ± 0.04	
				4	2.62 ± 0.04	
				5	3.20 ± 0.06	
				6	2.50 ± 0.04	
				7	2.36 ± 0.05	
1VV	LB1129	VR21-17	A.D.838 ± 124	summary	2.98 ± 0.18	Central age (16.7)
				1	3.90 ± 0.12	
				2	3.37 ± 0.11	
				3	3.40 ± 0.33	
				4	2.99 ± 0.21	
				5	2.31 ± 0.04	
				6	2.24 ± 0.11	
				12	2.99 ± 0.28	
				13	3.03 ± 0.21	
				14	3.03 ± 0.11	
1VV	LB1130	136-336	A.D.923 ± 148	summary	3.48 ± 0.42	Central age (30.5)
				2	5.44 ± 0.09	
				3	2.99 ± 0.08	
				5	2.55 ± 0.06	
				6	2.80 ± 0.09	
				8	4.71 ± 0.10	
				9	4.71 ± 0.11	
				11	2.34 ± 0.18	
1G	LB1150	131-308	A.D.1152 ± 79	summary	2.78 ± 0.09	Central age (10.4)
				2	2.82 ± 0.05	
				3	2.54 ± 0.06	
				4	2.51 ± 0.09	
				5	3.04 ± 0.16	
				6	3.09 ± 0.14	
				7	3.15 ± 0.09	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
1G	LB1150	131-308		8	2.68 ± 0.09	
				9	2.82 ± 0.08	
				10	2.61 ± 0.09	
				11	2.20 ± 0.10	
				12	3.26 ± 0.10	
1G	LB1151	131-244	A.D.1179 ± 83	summary	2.58 ± 0.12	Central age (10.4)
				2	2.29 ± 0.02	
				3	2.82 ± 0.04	
				4	2.32 ± 0.04	
				5	2.97 ± 0.06	
				7	2.56 ± 0.11	
G2	LB1153	VR14-2	A.D.923 ± 87	summary	3.35 ± 0.20	Central age (15.4)
				1	3.44 ± 0.02	
				2	2.40 ± 0.01	
				3	3.85 ± 0.03	
				4	3.80 ± 0.03	
				5	3.64 ± 0.03	
				6	3.55 ± 0.05	
				11	3.05 ± 0.10	
G2	LB1154	VR1-8	A.D.660 ± 76	summary	4.23 ± 0.07	Central age (2.9)
				4	4.41 ± 0.03	
				5	4.14 ± 0.03	
				6	6.64 ± 1.05	
G2	LB1156	VR4-2	A.D.889 ± 76	summary	3.38 ± 0.13	Central age (6.3)
				1	3.68 ± 0.05	
				2	3.15 ± 0.03	
				3	3.33 ± 0.04	
G2	LB1157	VR38-5	A.D.1236 ± 70	summary	2.52 ± 0.15	Central age (15.3)
				1	2.40 ± 0.02	
				2	2.19 ± 0.02	
				3	2.78 ± 0.05	
				4	2.35 ± 0.07	
				5	3.15 ± 0.08	
				6	3.00 ± 0.05	
				7	1.99 ± 0.09	
G2	LB1158	VR13-9	A.D.769 ± 124	summary	3.54 ± 0.29	Central age (16.1)
				1	3.19 ± 0.04	

Appendix B: Table B1. The equivalent doses used for the OSL dating (continued).

Group	LB#	Sample ID	Date	Disc#	Equivalent Dose (Gy)	Age model (overdispersion %)
G2	LB1158	VR13-9		2	3.08 ± 0.03	
				3	4.64 ± 0.07	
				4	3.45 ± 0.05	

Appendix B Table B2. Dose rate information for OSL dating.

ID	Cat#	Sherd (ppm)			Sediment Sample ID		Surrounding Sediments (ppm)		
		K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)		Distance to sherds	K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)
LB0097	204-13	20403.51	11.66	0.83	LB133 r1, LB133 r2	< 40 m	13554.14	7.14	0.76
LB0098	30-36	8778.57	17.21	2.21	LB135 r1, LB135 r2	< 40 m	13014.19	8.38	0.86
LB0099	136-27	15502.20	14.40	1.01	LB131 r1, LB131 r2	< 40 m	13554.14	9.79	1.12
LB0101	131-9	10084.38	21.21	1.32	LB129 r1, LB129 r2	< 40 m	17177.71	6.90	0.92
LB0106	30-80	6986.41	16.60	4.16	LB105 r1	< 30 m	13385.90	10.93	0.79
LB0107	30-81	21145.88	10.21	0.90	LB105 r1	< 30 m	13385.90	10.93	0.79
LB0108	30-82	17646.12	7.71	1.23	LB105 r1	< 30 m	13385.90	10.93	0.79
LB0119	71-39	16762.77	1.73	0.23	LB119 r1	< 20 m	13006.61	3.44	0.80
LB0120	71-40	13466.42	2.16	0.19	LB119 r1	< 20 m	13006.61	3.44	0.80
LB0123	30-88	6646.35	5.51	1.33	LB135 r1, LB135 r2	< 40 m	13014.19	8.38	0.86
LB0126	204-28	8880.86	3.56	0.46	LB133 r1, LB133 r2	< 40 m	13554.14	7.14	0.76
LB0129	131-14	17415.41	7.39	0.95	LB129 r1, LB129 r2	< 40 m	17177.71	6.90	0.92
LB0130	131-45	15613.02	7.45	1.09	LB129 r1, LB129 r2	< 40 m	17177.71	6.90	0.92
LB0131	136-16	16148.05	10.85	1.10	LB131 r1, LB131 r2	< 40 m	13554.14	9.79	1.12
LB0133	204-4	16934.16	9.34	1.49	LB133 r1, LB133 r2	< 40 m	13554.14	7.14	0.76
LB0135	30-17	22091.81	9.43	1.63	LB135 r1, LB135 r2	< 40 m	13014.19	8.38	0.86
LB0136	30-7	19926.04	9.43	1.14	LB135 r1, LB135 r2	< 40 m	13014.19	8.38	0.86
LB0137	14-140	19255.73	8.65	0.97	LB137_r1	< 30 m	14620.10	5.21	0.60
LB0138	14-70	12685.00	19.52	3.77	LB138_r1	< 30 m	18255.38	10.71	1.09
LB0139	131-96	8433.19	17.84	3.12	LB129 r1, LB129 r2	< 40 m	17177.71	6.90	0.92
LB0140	30-10	8565.51	14.95	2.04	LB135 r1, LB135 r2	< 40 m	13014.19	8.38	0.86
LB0141	136-18	7569.40	13.10	1.93	LB131 r1, LB131 r2	< 40 m	13554.14	9.79	1.12

Appendix B Table B2. Dose rate information for OSL dating (continued).

ID	Cat#	Sherd (ppm)			Sediment Sample ID		Surrounding Sediment (ppm)		
		K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)		Distance to sherds	K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)
LB0144	14-106	7488.25	13.06	3.24	LB138 r1, LB137 r1	< 40 m	16437.74	7.96	0.84
LB0145	14-120	6983.90	15.09	2.47	LB138 r1, LB137 r1	< 40 m	16437.74	7.96	0.84
LB0146	30-40	4854.47	9.24	1.61	LB135 r1, LB135 r2	< 40 m	13014.19	8.38	0.86
LB0148	136-7	7390.22	12.40	2.21	LB131 r1, LB131 r2	< 40 m	13554.14	9.79	1.12
LB0149	136-34	7390.22	10.04	2.27	LB131 r1, LB131 r2	< 40 m	13554.14	9.79	1.12
LB0258	136-9	12490.22	7.78	1.18	LB131 r1, LB131 r2	< 40 m	13554.14	9.79	1.12
LB0260	136-26	16397.53	10.50	0.95	LB131 r1, LB131 r2	< 40 m	13554.14	9.79	1.12
LB0262	30-16	9094.36	18.24	2.17	LB135 r1, LB135 r2	< 40 m	13014.19	8.38	0.86
LB0263	30-37	10226.26	11.53	1.68	LB135 r1, LB135 r2	< 40 m	13014.19	8.38	0.86
LB0264	14-6	10667.81	24.78	2.19	LB137_r1	< 30 m	14620.10	5.21	0.60
LB0268	14-83	18844.62	6.52	0.85	LB138 r1, LB137 r1	< 40 m	16437.74	7.96	0.84
LB0270	14-116	18930.03	12.13	1.63	LB671 r1, LB900 r1, LB1084 r1	< 40 m	15976.87	7.50	0.90
LB0271	14-152	18397.03	19.59	0.75	LB137 r1	< 30 m	14620.10	5.21	0.60
LB0275	131-53	12619.78	8.47	0.57	LB129 r1, LB129 r2	< 40 m	17177.71	6.90	0.92
LB0276	131-74	10055.37	14.79	1.92	LB129 r1, LB129 r2	< 40 m	17177.71	6.90	0.92
LB0279	204-2	11078.00	21.06	1.54	LB133 r1, LB133 r2	< 40 m	13554.14	7.14	0.76
LB0586	214-8	8114.17	11.08	2.75	LB586 r1	0 m	16847.94	13.25	1.06
LB0588	214-5	17416.30	5.09	0.92	LB588 r1	0 m	13630.85	12.86	1.80
LB0599	30-260	8101.48	13.17	6.00	LB599 r1	0 m	14519.67	8.54	1.03
LB0600	30-261	5233.02	10.70	3.71	LB600 r1	< 10 m	13639.68	9.08	0.81
LB0601	30-262	7764.45	11.00	2.24	lb601 r1	< 5 m	14017.87	9.66	1.06
LB0616	30-158	12074.20	9.56	0.98	LB616 r1	0 m	14148.50	4.84	0.76

Appendix B Table B2. Dose rate information for OSL dating (continued).

ID	Cat#	Sherd (ppm)			Sediment Sample ID		Surrounding Sediment (ppm)		
		K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)		Distance to sherds	K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)
LB0624	VR21-5	6164.43	15.32	3.14	LB619 r1-4 (east bank average)	< 10 km	15857.00	6.78	0.57
LB0641	131-307	7076.41	15.64	2.26	LB641 r1	0 m	19025.06	6.52	0.77
LB0650	30-173	16079.80	15.66	1.85	LB650 r1	0 m	12767.89	4.92	0.65
LB0655	131-236	22539.20	17.65	5.27	LB655 r1	0 m	15685.48	12.89	1.47
LB0661	204-41	15993.87	9.98	1.05	LB661 r1	0 m	15565.63	5.91	0.79
LB0673	30-166	7628.57	9.01	1.86	LB650 r1	0 m	12767.89	4.92	0.65
LB0674	VR14-1	18562.70	7.62	0.97	LB619 r1	0 m	13612.46	7.14	0.75
LB0676	VR7-11	9145.80	12.67	2.20	LB614 r1-4, LB684 r1-4 (east and west bank average)	< 20km	13712.55	6.86	0.55
LB0679	VR17-2	11338.60	27.89	10.18	LB614 r1-4, LB684 r1-4, r7, r8 (average all except LB684 r5&6 with high Th)	< 10 km	10590.59	5.08	0.44
LB0868	71-48	17790.86	3.77	0.86	LB868 r1	0 m	17237.03	6.43	1.12
LB0870	71-57	16370.84	3.33	0.68	LB119 r1	< 20 m	13006.61	3.44	0.80
LB0875	VR24-1	10550.10	4.50	2.32	LB684 r1-4 (west bank average)	< 1 km	11568.10	6.94	0.54
LB0878	30-168	6715.38	5.91	3.01	LB878 r1	0 m	13443.01	5.23	0.56
LB1071	131-314	30864.20	10.10	2.38	LB1071 r1	0 m	15850.91	5.01	0.71
LB1072	VR32-3	36024.20	14.44	3.41	LB684 r1-4 (west bank average)	<12 km	11568.10	6.94	0.54
LB1073	VR27-19	2937.93	7.22	1.14	LB619 r2	2.5 km	14579.78	4.51	0.55
LB1074	VR33-2	18791.00	12.20	1.77	LB684 r1-4 (west bank average)	<11 km	11568.10	6.94	0.54
LB1075	VR21-16	4606.55	13.32	1.84	LB619 r1-4 (east bank average)	< 10 km	15857.00	6.78	0.57

Appendix B Table B2. Dose rate information for OSL dating (continued).

ID	Cat#	Sherd (ppm)			Sediment Sample ID		Surrounding Sediment (ppm)		
		K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)		Distance to sherds	K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)
LB1076	VR27-12	4774.97	12.23	3.38	LB619 r2	2.5 km	14579.78	4.51	0.55
LB1077	VR35-6	9387.65	12.88	2.50	LB684 r1-4 (west bank average)	<11 km	11568.10	6.94	0.54
LB1078	VR22-4	9602.27	8.78	1.76	LB684 r1-4 (west bank average)	<1 km	11568.10	6.94	0.54
LB1079	VR32-7	6183.42	11.07	2.35	LB684r1-4 (west bank average)	<12 km	11568.10	6.94	0.54
LB1080	VR27-6	6747.70	19.47	3.85	LB619 r2	2.5 km	14579.78	4.51	0.55
LB1084	14-297	29814.00	14.14	1.23	LB1084 r1	0 m	15344.66	7.09	0.99
LB1086	VR7-3	16435.10	7.54	1.68	LB614 r1-4, LB684 r1-4, r7, r8 (average all except LB684 r5&6 with high Th)	< 20 km	10590.59	5.08	0.44
LB1087	VR23-4	18314.40	14.79	1.32	LB684 r1-4 (west bank average)	<1 km	11568.10	6.94	0.54
LB1090	VR28-2	16619.30	5.91	0.83	LB619 r2	<5 km	14579.78	4.51	0.55
LB1092	VR21-11	39903.00	14.75	2.48	LB619 r1-4 (east bank average)	< 10 km	15857.00	6.78	0.57
LB1093	30-266	32932.60	16.50	4.63	LB135 r1, LB135 r2	< 40 m	13014.19	8.38	0.86
LB1094	30-77	48442.00	17.99	4.26	LB135 r1, LB135 r2	< 40 m	13014.19	8.38	0.86
LB1096	VR38-7	31281.00	16.86	3.48	LB684 r1-4 (west bank average)	<13 km	11568.10	6.94	0.54
LB1097	30-201	37406.70	17.10	3.27	LB880 r1	0 m	14526.89	5.58	0.55
LB1098	VR17-5	36537.70	17.81	5.02	LB614 r1-4, LB684 r1-4, r7, r8 (average all except LB684 r5&6 with high Th)	< 10 km	10590.59	5.08	0.44
LB1099	71-64	3603.18	12.59	2.37	LB866 r1	0 m	28021.76	6.77	0.86

Appendix B Table B2. Dose rate information for OSL dating (continued).

ID	Cat#	Sherd (ppm)			Sediment Sample ID		Surrounding Sediment (ppm)		
		K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)		Distance to sherds	K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)
LB1100	VR21-22	3011.90	9.93	1.84	LB619 r1-4 (east bank average)	< 10 km	15857.00	6.78	0.57
LB1101	VR17-8	3011.23	11.40	1.89	LB614 r1-4, LB684 r1-4, r7, r8 (average all except LB684 r5&6 with high Th)	< 10 km	10590.59	5.08	0.44
LB1102	VR7-5	3024.56	7.28	1.31	LB614 r1-4, LB684 r1-4, r7, r8 (average all except LB684 r5&6 with high Th)	< 20 km	10590.59	5.08	0.44
LB1103	VR15-2	3395.86	12.96	3.21	LB619 r2	< 0.5 km	14579.78	4.51	0.55
LB1105	VR35-17	3965.04	11.90	2.89	LB684 r1-4 (west bank average)	<11 km	11568.10	6.94	0.54
LB1106	VR35-4	3174.44	14.47	2.37	LB614 r1-4, LB684 r1-4 (east and west bank average)	< 20km	13712.55	6.86	0.55
LB1107	VR21-29	4329.45	14.75	2.48	LB619 r2	< 2.5 km	14579.78	4.51	0.55
LB1109	30-151	7013.58	11.12	3.48	LB1109 r1	0 m	13274.99	7.28	0.58
LB1111	136-76	7065.99	9.01	1.62	LB131 r1, LB131 r2	< 40 m	13554.14	9.79	1.12
LB1112	136-276	6047.87	12.57	2.23	LB590 r1	0 m	15555.93	12.73	0.87
LB1113	131-168	6062.57	9.43	2.27	LB129 r1, LB129 r2	< 40 m	17177.71	6.90	0.92
LB1114	TW143	5602.89	10.52	2.00	LB1114 r1	< 1 km	18300.90	5.76	0.81
LB1115	TW101	5864.88	10.06	2.49	LB1115 r1	< 2 km	16137.12	5.83	0.42
LB1117	71-58	16326.60	6.26	0.89	LB119 r1	< 20 m	13006.61	3.44	0.80
LB1118	71-56	8787.45	11.09	2.59	lb1118 r1	< 30 m	29285.91	6.06	0.89
LB1119	71-47	3492.04	10.51	2.61	LB866 r1	0 m	28021.76	6.77	0.86
LB1120	VR39-2	13048.60	9.62	1.79	LB614 r1-4, LB684 r1-4, r7,r8 (average all except LB684 r5&6 with high Th)	< 20 km	10590.59	5.08	0.44

Appendix B Table B2. Dose rate information for OSL dating (continued).

ID	Cat#	Sherd (ppm)			Sediment Sample ID		Surrounding Sediment (ppm)		
		K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)		Distance to sherds	K-39 (XRF)	Th-236 (ICP-MS)	U-238 (ICP-MS)
LB1121	VR26-1	6180.76	12.26	3.02	LB684 r1-4 (west bank average)	<1 km	11568.10	6.94	0.54
LB1122	204-20	14596.10	15.86	1.57	LB133 r1, LB133 r2	< 40 m	13554.14	7.14	0.76
LB1123	136-63	14314.30	19.64	1.66	LB131 r1, LB131 r2	< 40 m	13554.14	9.79	1.12
LB1124	VR35-11	11287.30	12.48	1.49	LB614 r1-4, LB684 r1-4 (east and west bank average)	< 20km	13712.55	6.86	0.55
LB1125	131-318	6341.62	10.57	1.89	LB1150 r1	0 m	15749.27	13.61	0.81
LB1127	214-11	24305.70	14.60	1.88	LB656 r1	0 m	17197.76	10.66	1.26
LB1128	VR39-4	9138.49	12.04	2.37	LB614r1-4, LB684r1-4, r7, r8 (average all except LB684 r5&6 with high Th)	< 20 km	10590.59	5.08	0.44
LB1129	VR21-17	5876.05	11.33	2.80	LB619 r2	< 2.5 km	14579.78	4.51	0.55
LB1130	136-336	14134.20	12.15	1.43	LB590 r1	0 m	15555.93	12.73	0.87
LB1150	131-308	7538.21	17.16	2.12	LB1150 r1	0 m	15749.27	13.61	0.81
LB1151	131-244	7191.00	16.30	2.58	LB589 r1	0 m	17078.71	7.49	1.23
LB1153	VR14-2	18745.60	8.75	0.83	LB619 r1	0 m	13612.46	7.14	0.75
LB1154	VR1-8	18621.80	8.54	1.04	LB619 r3	< 50 m	16934.57	6.42	0.59
LB1156	VR4-2	17565.90	9.38	0.99	LB619 r3	< 50 m	16934.57	6.42	0.59
LB1157	VR38-5	17826.90	13.74	1.41	LB684 r1-4 (west bank average)	<13 km	11568.10	6.94	0.54
LB1158	VR13-9	16261.60	9.61	0.77	LB619 r3	< 50 m	16934.57	6.42	0.59

Appendix B: Table B3. Locational information, thickness and water absorption of the sample for OSL dating.

ID	Cat#	Latitude	Longitude	Altitude (m)	Burial Depth (m)	Thickness (cm)	Water absorption
LB0097	204-13	36.362	-113.106	1868	0	0.70	0.090
LB0098	30-36	36.3586	-113.124	1908	0	0.50	0.096
LB0099	136-27	36.359	-113.123	1917	0	0.70	0.105
LB0101	131-9	36.396	-113.175	1962	0	0.70	0.090
LB0106	30-80	36.3586	-113.124	1908	0	0.62	0.095
LB0107	30-81	36.3586	-113.124	1908	0	0.63	0.086
LB0108	30-82	36.3586	-113.124	1908	0	0.82	0.076
LB0119	71-39	36.401	-113.245	1889	0	0.50	0.080
LB0120	71-40	36.401	-113.245	1889	0	0.58	0.075
LB0123	30-88	36.3586	-113.124	1908	0	0.50	0.109
LB0126	204-28	36.362	-113.106	1868	0	0.50	0.060
LB0129	131-14	36.396	-113.175	1962	0	0.50	0.075
LB0130	131-45	36.396	-113.175	1962	0	0.45	0.059
LB0131	136-16	36.359	-113.123	1917	0	0.50	0.086
LB0133	204-4	36.362	-113.106	1868	0	0.40	0.063
LB0135	30-17	36.3586	-113.124	1908	0	0.50	0.109
LB0136	30-7	36.3586	-113.124	1908	0	0.48	0.075
LB0137	14-140	36.391	-113.153	1987	0	0.50	0.087
LB0138	14-70	36.391	-113.153	1987	0.5	0.50	0.087
LB0139	131-96	36.396	-113.175	1962	0	0.42	0.072
LB0140	30-10	36.3586	-113.124	1908	0	0.47	0.070
LB0141	136-18	36.359	-113.123	1917	0	0.55	0.080
LB0144	14-106	36.391	-113.153	1987	0.5	0.52	0.067
LB0145	14-120	36.391	-113.153	1987	0.5	0.55	0.092
LB0146	30-40	36.3586	-113.124	1908	0	0.57	0.088
LB0148	136-7	36.359	-113.123	1917	0	0.73	0.074
LB0149	136-34	36.359	-113.123	1917	0	0.63	0.093
LB0258	136-9	36.359	-113.123	1917	0	0.55	0.094
LB0260	136-26	36.359	-113.123	1917	0	0.50	0.063
LB0262	30-16	36.3586	-113.124	1908	0	0.50	0.093
LB0263	30-37	36.3586	-113.124	1908	0	0.40	0.103
LB0264	14-6	36.391	-113.153	1987	0	0.50	0.107
LB0268	14-83	36.391	-113.153	1987	0.3	0.50	0.075
LB0270	14-116	36.391	-113.153	1987	0.3	0.45	0.094
LB0271	14-152	36.391	-113.153	1987	0	0.50	0.081
LB0275	131-53	36.396	-113.175	1962	0	0.48	0.120

Appendix B: Table B3. Locational information, thickness and water absorption of the sample for OSL dating (continued).

ID	Cat#	Latitude	Longitude	Altitude (m)	Burial Depth (m)	Thickness (cm)	Water absorption
LB0276	131-74	36.396	-113.175	1962	0	0.48	0.088
LB0279	204-2	36.362	-113.106	1868	0	0.51	0.116
LB0586	214-8	36.356	-113.115	1893	0.1	0.42	0.116
LB0588	214-5	36.356	-113.115	1893	0.1	0.61	0.088
LB0599	30-260	36.3586	-113.124	1908	0	0.77	0.079
LB0600	30-261	36.3586	-113.124	1908	0	0.55	0.108
LB0601	30-262	36.3586	-113.124	1908	0	0.83	0.097
LB0616	30-158	36.3586	-113.124	1908	0.7	0.50	0.105
LB0624	VR21-5	36.646	-114.307	395	0	0.60	0.092
LB0641	131-307	36.396	-113.175	1962	0.3	0.40	0.118
LB0650	30-173	36.3586	-113.124	1908	0.6	0.56	0.104
LB0655	131-236	36.396	-113.175	1962	0.3	0.50	0.074
LB0661	204-41	36.362	-113.106	1868	0.1	0.40	0.098
LB0673	30-166	36.3586	-113.124	1908	0.5	0.50	0.090
LB0674	VR14-1	36.7199	-114.235	451	0	0.60	0.077
LB0676	VR7-11	36.6585	-114.314	497	0	0.60	0.092
LB0679	VR17-2	36.658	-114.314	415	0	0.45	0.130
LB0868	71-48	36.401	-113.245	1889	0	0.50	0.095
LB0870	71-57	36.401	-113.245	1889	0	0.70	0.092
LB0875	VR24-1	36.62959	-114.328	394	0	0.60	0.091
LB0878	30-168	36.3586	-113.124	1908	0.2	0.75	0.110
LB1071	131-314	36.396	-113.175	1962	0.3	0.50	0.074
LB1072	VR32-3	36.54666	-114.34	371	0	0.40	0.114
LB1073	VR27-19	36.6512	-114.305	425	0	0.55	0.084
LB1074	VR33-2	36.54665	-114.34	373	0	0.80	0.091
LB1075	VR21-16	36.646	-114.307	395	0	0.60	0.092
LB1076	VR27-12	36.6512	-114.305	425	0	0.50	0.095
LB1077	VR35-6	36.55582	-114.34	370	0	0.45	0.099
LB1078	VR22-4	36.63169	-114.326	393	0	0.50	0.076
LB1079	VR32-7	36.54666	-114.34	371	0	0.65	0.094
LB1080	VR27-6	36.6512	-114.305	425	0	0.45	0.110
LB1084	14-297	36.391	-113.153	1987	0.1	0.50	0.104
LB1086	VR7-3	36.6585	-114.314	497	0	0.43	0.098
LB1087	VR23-4	36.63165	-114.326	398	0	0.50	0.138
LB1090	VR28-2	36.63605	-114.31	400	0	0.45	0.100
LB1092	VR21-11	36.646	-114.307	395	0	0.70	0.102

Appendix B: Table B3. Locational information, thickness and water absorption of the sample (continued).

ID	Cat#	Latitude	Longitude	Altitude (m)	Burial Depth (m)	Thickness (cm)	Water absorption
LB1093	30-266	36.3586	-113.124	1908	0	0.45	0.119
LB1096	VR38-7	36.5332	-114.342	371	0	0.50	0.076
LB1097	30-201	36.3586	-113.124	1908	0.6	0.55	0.061
LB1098	VR17-5	36.658	-114.314	415	0	0.60	0.065
LB1099	71-64	36.401	-113.245	1889	0.1	0.65	0.108
LB1100	VR21-22	36.646	-114.307	395	0	0.50	0.107
LB1101	VR17-8	36.658	-114.314	415	0	0.50	0.118
LB1102	VR7-5	36.6585	-114.314	497	0	0.43	0.098
LB1103	VR15-2	36.67505	-114.296	421	0	0.35	0.094
LB1105	VR35-17	36.55582	-114.34	370	0	0.40	0.108
LB1106	VR35-4	36.55582	-114.34	370	0	0.40	0.114
LB1107	VR21-29	36.646	-114.307	395	0	0.70	0.102
LB1109	30-151	36.3586	-113.124	1908	0.3	0.75	0.110
LB1111	136-76	36.359	-113.123	1917	0	0.50	0.097
LB1112	136-276	36.359	-113.123	1917	0.3	0.50	0.097
LB1113	131-168	36.396	-113.175	1962	0	0.48	0.088
LB1114	TW143	36.22824	-113.147	1645	0	0.60	0.095
LB1115	TW101	36.3364	-112.965	1815	0	0.60	0.101
LB1117	71-58	36.401	-113.245	1889	0	0.60	0.069
LB1118	71-56	36.401	-113.245	1889	0	0.60	0.136
LB1119	71-47	36.401	-113.245	1889	0.1	0.70	0.121
LB1120*	VR39-2	36.55582	-114.34	370	0	0.60	0.108
LB1121	VR26-1	36.63293	-114.325	393	0	0.60	0.108
LB1122	204-20	36.362	-113.106	1868	0	0.45	0.098
LB1123	136-63	36.359	-113.123	1917	0	0.50	0.104
LB1124	VR35-11	36.55582	-114.34	370	0	0.50	0.110
LB1125	131-318	36.396	-113.175	1962	0.6	0.50	0.107
LB1127	214-11	36.356	-113.115	1893	0.1	0.70	0.128
LB1128*	VR39-4	36.55582	-114.34	370	0	0.45	0.100
LB1129	VR21-17	36.646	-114.307	395	0	0.60	0.101
LB1130	136-336	36.359	-113.123	1917	0.4	0.40	0.108
LB1150	131-308	36.396	-113.175	1962	0.25	0.50	0.074
LB1151	131-244	36.396	-113.175	1962	0.25	0.50	0.074
LB1153	VR14-2	36.7199	-114.235	451	0	0.40	0.087
LB1154	VR1-8	36.80418	-114.01	497	0	0.60	0.092
LB1156	VR4-2	36.73183	-114.217	451	0	0.40	0.099

Appendix B: Table B3. Locational information, thickness and water absorption of the sample (continued).

ID	Cat#	Latitude	Longitude	Altitude (m)	Burial Depth (m)	Thickness (cm)	Water absorption
LB1157	VR38-5	36.5332	-114.342	371	0	0.50	0.119
LB1158	VR13-9	36.5332	-114.342	451	0	0.45	0.110

*LB1120 and LB1128: exact provenience information is not available for these two samples.

Appendix B: Table B4. Summary of OSL dates.

Group 1G (n = 29)

Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
30-40	LB0146	4.07 ± 0.34	A.D.	205 ± 205	11.3%	1	single	NA	C	B/G	olivine
VR35-6	LB1077	4.78 ± 0.08	A.D.	388 ± 132	8.1%	8	central	3.5%	A	B/G	olivine
136-18	LB0141	4.49 ± 0.05	A.D.	436 ± 127	8.1%	2	common	NA	A	plain	olivine
VR7-11	LB0676	4.53 ± 0.32	A.D.	439 ± 169	10.7%	5	central	15.1%	A	plain	olivine
VR21-5	LB0624	4.50 ± 0.19	A.D.	509 ± 151	10.0%	15	central	15.5%	A	plain	olivine
VR22-4	LB1078	3.72 ± 0.34	A.D.	521 ± 172	11.5%	1	single	NA	C	plain	olivine
VR32-7	LB1079	3.63 ± 0.73	A.D.	553 ± 319	21.8%	8	central	53.1%	C	plain	olivine
131-74	LB0276	4.32 ± 0.15	A.D.	599 ± 123	8.7%	4	central	3.4%	A	plain	olivine
131-9	LB0101	4.18 ± 0.08	A.D.	739 ± 125	9.8%	2	central	2.3%	A	plain	olivine
30-10	LB0140	3.71 ± 0.50	A.D.	769 ± 199	16.0%	1	single	NA	D	plain	olivine
30-88	LB0123	2.53 ± 0.24	A.D.	804 ± 140	11.6%	3	central	15.1%	A	plain	olivine
VR24-1	LB0875	2.84 ± 0.22	A.D.	849 ± 118	10.1%	7	central	18.9%	A	plain	olivine
204-2	LB0279	3.41 ± 0.15	A.D.	977 ± 109	10.5%	7	central	4.5%	A	plain	olivine
VR27-6	LB1080	3.06 ± 0.12	A.D.	1086 ± 101	10.9%	1	single	NA	C	plain	olivine
30-261	LB0600	2.54 ± 0.17	A.D.	1130 ± 96	10.9%	7	central	16.9%	A	plain	olivine
131-308	LB1150	2.78 ± 0.09	A.D.	1152 ± 79	9.2%	11	central	10.4%	A	plain	sand
30-37	LB0263	2.33 ± 0.30	A.D.	1177 ± 123	14.7%	2	central	12.9%	A	B/G	olivine
131-244	LB1151	2.58 ± 0.12	A.D.	1179 ± 83	10.0%	5	central	10.4%	A	B/G	sand
VR27-12	LB1076	2.10 ± 0.07	A.D.	1222 ± 79	10.0%	11	central	10.9%	A	B/G	olivine
131-307	LB0641	2.22 ± 0.17	A.D.	1236 ± 90	11.6%	3	central	12.6%	A	plain	olivine
30-262	LB0601	2.14 ± 0.09	A.D.	1250 ± 65	8.5%	4	central	4.2%	A	plain	olivine
14-106	LB0144	2.15 ± 0.02	A.D.	1309 ± 60	8.5%	2	common	NA	A	COR	olivine
14-6	LB0264	2.49 ± 0.27	A.D.	1312 ± 104	14.8%	3	central	10.7%	A	B/G_COR	olivine

Appendix B: Table B4. Summary of OSL dates (continued).

Group 1G (n = 29) (continued)

Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
14-70	LB0138	2.84 ± 1.22	A.D.	1313 ± 304	43.4%	2	central	60.1%	C	plain	olivine
131-96	LB0139	2.27 ± 0.08	A.D.	1350 ± 64	9.7%	2	common	NA	A	plain	olivine
14-120	LB0145	1.86 ± 0.08	A.D.	1375 ± 62	9.7%	2	common	NA	A	B/G	olivine
30-16	LB0262	1.93 ± 0.01	A.D.	1410 ± 54	9.0%	4	common	NA	A	B/G	olivine
136-7	LB0148	1.03 ± 0.01	A.D.	1655 ± 28	7.8%	2	common	NA	A	COR	olivine
204-28	LB0126	0.63 ± 0.18	A.D.	1683 ± 93	28.2%	1	single	NA	D	plain	olivine

Group 1VM (n = 11)

Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
TW143	LB1114	3.52 ± 0.23	A.D.	569 ± 149	10.3%	9	common	NA	A	B/G	olivine
131-168	LB1113	3.34 ± 0.07	A.D.	696 ± 105	8.0%	1	single	NA	C	B/G_COR	olivine
136-271	LB1112	3.03 ± 0.19	A.D.	941 ± 109	10.2%	5	central	6.3%	A	COR	olivine
30-36	LB0098	2.88 ± 0.97	A.D.	1091 ± 321	34.8%	2	central	47.4%	C	B/G	olivine
30-168	LB0878	2.03 ± 0.04	A.D.	1141 ± 70	8.0%	5	central	3.8%	A	plain	olivine
30-166	LB0673	1.97 ± 0.08	A.D.	1146 ± 74	8.5%	7	central	9.5%	A	COR	olivine
136-34	LB0149	2.04 ± 0.07	A.D.	1264 ± 61	8.1%	2	common	NA	A	B/G	olivine
TW101	LB1115	1.84 ± 0.14	A.D.	1275 ± 82	11.1%	4	central	9.6%	A	COR	olivine
30-151	LB1109	2.00 ± 0.26	A.D.	1304 ± 109	15.4%	3	central	21.2%	B	plain	olivine
214-8	LB0586	1.65 ± 0.05	A.D.	1465 ± 43	7.8%	1	single	NA	C	COR	olivine
136-76	LB1111	0.49 ± 0.07	A.D.	1815 ± 32	16.2%	3	common	NA	B	B/G_COR	olivine

Appendix B: Table B4. Summary of OSL dates (continued)

Group 1VV (n = 13)

Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
131-318	LB1125	3.84 ± 0.30	A.D.	569 ± 154	10.7%	5	central	15.1%	A	plain	olivine
VR21-17	LB1129	2.98 ± 0.18	A.D.	838 ± 124	10.6%	9	central	16.7%	A	plain	olivine
VR26-1	LB1121	3.13 ± 0.11	A.D.	866 ± 108	9.4%	7	central	6.3%	A	plain	sand
136-336	LB1130	3.48 ± 0.42	A.D.	923 ± 148	13.6%	7	central	30.5%	B	plain	sand
214-11	LB1127	4.51 ± 0.22	A.D.	938 ± 83	7.7%	6	central	11.6%	A	COR	olivine
VR35-11	LB1124	2.97 ± 0.10	A.D.	940 ± 88	8.2%	9	central	10.0%	A	B/G	sand
VR39-4	LB1128	2.74 ± 0.11	A.D.	980 ± 94	9.1%	7	central	10.1%	A	B/G	olivine
204-20	LB1122	3.40 ± 0.23	A.D.	982 ± 106	10.3%	9	central	20.4%	A	plain	olivine
136-63	LB1123	3.45 ± 0.15	A.D.	1063 ± 89	9.4%	8	central	11.9%	A	B/G	sand
VR39-2	LB1120	2.45 ± 0.11	A.D.	1094 ± 74	8.1%	8	central	12.2%	A	plain	sand
30-173	LB0650	2.48 ± 0.02	A.D.	1253 ± 59	7.8%	8	central	2.2%	A	COR	sherd_sand
131-236	LB0655	3.84 ± 0.17	A.D.	1275 ± 63	8.5%	9	central	12.8%	A	plain	sand
VR17-2	LB0679	3.10 ± 0.40	A.D.	1478 ± 93	17.4%	11	central	39.9%	C	B/G	sand

Group 2 (n = 26)

Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
131-14	LB0129	4.58 ± 0.25	A.D.	476 ± 115	7.5%	1	single	NA	C	plain	olivine
204-13	LB0097	5.07 ± 0.21	A.D.	490 ± 110	7.2%	1	single	NA	C	plain	olivine
30-7	LB0136	5.03 ± 0.36	A.D.	493 ± 137	9.0%	2	central	8.7%	A	plain	olivine
71-39	LB0119	3.14 ± 0.13	A.D.	587 ± 85	6.0%	1	single	NA	C	plain	olivine
14-140	LB0137	4.33 ± 0.57	A.D.	590 ± 203	14.3%	2	central	18.4%	A	plain	olivine
VR1-8	LB1154	4.23 ± 0.07	A.D.	660 ± 76	5.6%	3	central	2.9%	A	plain	olivine
VR13-9	LB1158	3.54 ± 0.29	A.D.	769 ± 124	10.0%	4	central	16.1%	A	plain	olivine

Appendix B: Table B4. Summary of OSL dates (continued)

Group 2 (n = 26) (continued)

Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
131-53	LB0275	2.98 ± 0.04	A.D.	830 ± 73	6.2%	2	central	1.3%	A	plain	olivine
136-26	LB0260	3.73 ± 0.13	A.D.	833 ± 81	6.9%	2	common	NA	A	plain	olivine
VR4-2	LB1156	3.38 ± 0.13	A.D.	889 ± 76	6.8%	3	central	6.3%	A	plain	olivine
71-40	LB0120	2.20 ± 0.37	A.D.	895 ± 193	17.3%	2	central	22.7%	B	plain	olivine
VR14-2	LB1153	3.35 ± 0.20	A.D.	923 ± 87	8.0%	7	central	15.4%	A	plain	olivine
VR14-1	LB0674	3.17 ± 0.06	A.D.	969 ± 57	5.6%	7	central	5.2%	A	plain	olivine
14-83	LB0268	3.00 ± 0.02	A.D.	1002 ± 52	5.1%	2	common	NA	A	COR	olivine
214-5	LB0588	2.95 ± 0.09	A.D.	1049 ± 53	5.5%	3	central	5.4%	A	plain	olivine
14-152	LB0271	3.36 ± 0.12	A.D.	1067 ± 85	9.0%	10	central	11.3%	A	plain	olivine
131-45	LB0130	2.69 ± 0.18	A.D.	1085 ± 80	8.6%	4	central	13.1%	A	plain	olivine
30-158	LB0616	2.13 ± 0.06	A.D.	1132 ± 63	7.2%	8	central	7.1%	A	plain	sherd_olivine
VR38-5	LB1157	2.52 ± 0.15	A.D.	1236 ± 70	9.0%	7	central	15.3%	A	plain	sand
14-116	LB0270	2.50 ± 0.02	A.D.	1282 ± 45	6.2%	2	central	0.8%	A	plain	olivine
30-260	LB0599	2.13 ± 0.04	A.D.	1461 ± 52	9.4%	11	central	1.7%	A	plain	olivine
204-4	LB0133	1.35 ± 0.06	A.D.	1581 ± 33	7.6%	2	central	4.6%	A	plain	olivine
136-9	LB0258	1.14 ± 0.05	A.D.	1592 ± 30	7.1%	5	central	9.2%	A	COR	olivine
136-27	LB0099	1.16 ± 0.07	A.D.	1656 ± 32	9.0%	2	central	8.1%	A	plain	olivine
136-16	LB0131	0.89 ± 0.01	A.D.	1730 ± 17	6.0%	2	common	NA	A	plain	olivine
30-17	LB0135	0.61 ± 0.01	A.D.	1984 ± 10	34.5%	1	single	NA	D	COR	olivine

Group 3 (n = 9)

Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
71-48	LB0868	3.98 ± 0.15	A.D.	606 ± 83	5.9%	5	central	8.4%	A	plain	olivine

Appendix B: Table B4. Summary of OSL dates (continued)

Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
Group 3 (n=9) (continued)											
71-58	LB1117	3.36 ± 0.16	A.D.	748 ± 90	7.1%	6	central	11.5%	A	plain	olivine
71-47	LB1119	3.38 ± 0.10	A.D.	758 ± 110	8.8%	12	central	10.2%	A	plain	olivine
204-41	LB0661	3.54 ± 0.13	A.D.	798 ± 86	7.1%	7	central	9.1%	A	plain	olivine
71-56	LB1118	3.02 ± 0.19	A.D.	1055 ± 94	9.8%	10	central	19.6%	A	B/G	olivine
30-80	LB0106	2.67 ± 0.15	A.D.	1255 ± 80	10.6%	2	common	NA	A	COR	olivine
30-82	LB0108	2.39 ± 0.08	A.D.	1264 ± 45	6.0%	2	common	NA	A	plain	sand
71-57	LB0870	1.33 ± 0.07	A.D.	1467 ± 37	6.8%	6	central	10.1%	A	plain	olivine
30-81	LB0107	1.89 ± 0.28	A.D.	1472 ± 84	15.5%	2	central	19.4%	B	plain	olivine
Group 4 (n=10)											
Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
VR7-5	LB1102	4.08 ± 0.10	BC	373 ± 206	8.6%	9	central	6.9%	A	B/G	olivine
VR21-22	LB1100	4.48 ± 0.23	BC	95 ± 207	9.8%	9	central	14.9%	A	plain	olivine
VR35-4	LB1106	4.41 ± 0.14	A.D.	229 ± 183	10.3%	4	central	5.0%	A	plain	olivine
71-64	LB1099	4.28 ± 0.14	A.D.	468 ± 148	9.6%	10	central	9.6%	A	plain	olivine
VR21-16	LB1075	2.91 ± 0.33	A.D.	822 ± 170	14.3%	4	common	N/A	A	plain	olivine
VR27-19	LB1073	1.85 ± 0.16	A.D.	924 ± 129	11.8%	5	central	19.6%	A	plain	olivine
VR21-29	LB1107	2.17 ± 0.18	A.D.	1154 ± 110	12.8%	2	central	9.1%	A	plain	olivine
VR17-8	LB1101	1.74 ± 0.08	A.D.	1180 ± 90	10.8%	12	central	15.9%	A	B/G	olivine
VR15-2	LB1103	1.95 ± 0.04	A.D.	1263 ± 80	10.7%	6	central	5.0%	A	B/G	olivine
VR35-17	LB1105	1.82 ± 0.07	A.D.	1279 ± 74	10.1%	7	central	10.5%	A	B/G	olivine

Appendix B: Table B4. Summary of OSL dates (continued)

Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
VR1 (n=8)											
VR21-11	LB1092	6.53 ± 1.22	A.D.	790 ± 238	19.5%	2	central	23.5%	B	B/G	sand
131-314	LB1071	4.04 ± 0.19	A.D.	1080 ± 66	7.1%	8	central	13.2%	A	B/G	sand
VR32-3	LB1072	4.69 ± 0.29	A.D.	1099 ± 78	8.5%	5	central	13.6%	A	B/G	sand
VR17-5	LB1098	4.90 ± 0.55	A.D.	1188 ± 107	13.0%	7	central	28.6%	B	B/G	sand
VR38-7	LB1096	3.89 ± 0.10	A.D.	1238 ± 54	7.0%	14	central	8.9%	A	B/G	sand
30-77	LB1094	4.14 ± 0.50	A.D.	1402 ± 81	13.3%	1	single	N/A	C	B/G	sand
30-266	LB1093	2.84 ± 0.28	A.D.	1494 ± 62	11.9%	3	common	N/A	A	B/G	sand
30-201	LB1097	2.62 ± 0.21	A.D.	1529 ± 48	9.9%	3	common	N/A	A	B/G	sand
VR3 (n=5)											
Cat#	ID	Equivalent Dose (Gy)		Date	Error term*	#	Age model	Over-dispersion	Evaluation	Surface	Temper
VR23-4	LB1087	4.66 ± 0.22	A.D.	602 ± 121	8.6%	11	central	15.4%	A	B/G	sand
VR7-3	LB1086	2.69 ± 0.14	A.D.	1073 ± 73	7.8%	5	central	4.7%	A	B/R	sherd_sand
VR28-2	LB1090	2.20 ± 0.22	A.D.	1156 ± 95	11.1%	7	central	25.4%	B	plain	sand
VR33-2	LB1074	2.54 ± 0.08	A.D.	1282 ± 52	7.1%	8	central	8.7%	A	plain	sand
14-297	LB1084	3.06 ± 0.09	A.D.	1299 ± 45	6.3%	8	central	7.7%	A	RED	sherd_sand

* Error term is on the years before present. Overdispersion rate indicate the ratio of aliquots beyond t2 standard deviation based on the averaged value. Cut-off to pass the criteria for number of aliquot is more than two, error term is set 15% and for overdispersion is 25%. The based on three criteria, the dates were ranked with A as most reliable date. If the sample passes all three, A is assigned. B is assigned for the sample that passes two, and C for the sample that passes just one. If the sample does not passes any of the criteria, D is assigned.