

# APPLICATION OF QUANTIFIABLE METHODOLOGIES IN CERAMIC ANALYSIS: PETROGRAPHIC AND GEOCHEMICAL ANALYSIS OF CERAMICS FROM RIVERSIDE COUNTY, CALIFORNIA

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## ABSTRACT

Petrographic and geochemical techniques were applied in a sample of Luiseño pottery sherds from 3 Riverside County sites. These methods enabled the analyst to distinguish quantitatively between Tizon Brown Ware and Buff Ware based on both mineral composition and abundances. The mineralogy of the Tizon Brown Ware suggests a localized production, and the Buff Ware appears to be intrusive. Two unclassified sherds did not fit into either Tizon Brown Ware or Buff Ware, and their source was not conclusively determined. These methodologies provide a more precise temper identification that can develop a better classification system once a data base is established in southern California.

## INTRODUCTION

Archaeologists involved in ceramic studies have proposed different typologies or classification schemes to give order to the paddle-and-anvil ceramic wares found in western Arizona and southern California. Presently, there is no well-defined taxonomic structure for the classification of prehistoric southern California paddle-and-anvil pottery (Lyneis 1988). Ceramic vessels and sherd fragments are generally put into 1 of the 2 major "wares" categories, either "Tizon Brown Ware" or "Lower Colorado Buff Ware". These classifications are based on a buff-brown dichotomy, or a light-dark dichotomy, further described by a less-grainy/more-grainy differentiation in the clays (Lyneis 1988:149). These determinations are made typically by hand-lens or binocular microscope evaluation. Even though these characteristics are generalized, due to the considerable variation of surface color and temper texture between the 2 wares, the sherds are not always easily classified by this method. The need for a formal structure in ceramic ware analysis is important in order to develop temporal, spatial, and cultural relationships for paddle-

and-anvil ware producers in the Southwest and southern California.

This research entails the petrographic and geochemical analyses of prehistoric ceramics from 3 archaeological sites near Murrieta, in southwestern Riverside County, California: RIV-1864, RIV-722, and RIV-2229. The purpose of this study was to define a ware classification system, based on petrographic evaluation of the paste and temper mineralogy and geochemical evaluation of the bulk sherd composition. These 2 analytical techniques can be used to distinguish between wares. In addition, petrographic data may indicate possible source areas for temper and suggest whether the ceramics were produced locally or were intrusive.

## PREVIOUS CERAMIC STUDIES

### Malcolm J. Rogers

In 1928, Malcolm J. Rogers pioneered studies in Southern California paddle-and-anvil-constructed ceramic wares. Rogers' (n.d.) unpublished notes from the San Diego Museum of Man indicate that his criteria for

ceramic evaluation emphasized the importance of temper and surface color. He considered the natural environment to be important in ceramic manufacture. The geological environment defined the composition of the temper and, therefore, provides critical information for inferences about the sources of ceramics. Rogers (1945:181) also promoted the hypothesis of local manufacture and noted (Rogers 1936:4):

It may be possible, eventually, to identify distinguishing constituents in the inclusions of clays from specific localities, which in turn can be identified in the pottery.

### Analysis Criteria

Since Rogers, many ceramic studies in southern California followed Southwestern criteria which emphasized descriptive aspects of ceramics including rim and vessel form (Harner 1957; Euler and Dobyns 1958; Waters 1982). These criteria deemphasized temper and quantitative mineralogical analysis. The problem in southern California is that few rim or vessel forms are found in the archaeological record. Body sherds, which constitute most of the ceramic collections, have limited interpretative value.

Evaluating the temper can provide useful information about the geological source. This kind of analysis can give a better description of sherd composition, mineral abundances, and consistency between sherds. Specific data from temper analysis can provide distinctive information about the source rock, which can be beneficial to studies of the source material and possibly trade or migration patterns. The emphasis on the vessel form and function can provide some cultural inferences, but because the percentage of recovery is limited in southern California, identifying source material may provide more valuable information. Geochemical analysis of the bulk sherd compositions can also provide data to further characterize the wares and additionally provide sourcing information.

## ARCHAEOLOGY

### Site Location

The 3 study sites are located on the

northeast border of Luiseño territory. Luiseño territory encompasses over 1,500 square miles of coastal southern California and is described by Bean and Shippek (1978:550-551) as follows:

Along the coast it extended from about Agua Hedionda Creek on the south to near Aliso Creek on the northwest. The boundary extended inland to Santiago Peak, then across to the eastern side of the Elsinore Fault valley, then southward to the east of Palomar Mountain, then around the southern slope above the valley of San Jose. From there the boundary turned west and returned to the sea along the Agua Hedionda Creek.

### San Luis Rey Complexes

The major distinguishing cultural remains separating San Luis Rey I (A.D. 1400-1700) and San Luis Rey II (A.D. 1750-1850) cultural phases in Luiseño territory is the presence of pottery in the later phase (Meighan 1954). The introduction of pottery into this area was generally considered to be late (True et al. 1974). Meighan (1954) characterized the San Luis Rey I complex as having grinding implements, small triangular projectile points with concave base, stone pendants, *Olivella* sp. disc and spire-topped beads, quartz crystals, and bone tools. He described (ibid.:1954:223) the San Luis Rey II phase as substantial duplication of the earlier complex, with the significant addition of pottery vessels, tubular clay pipes, pictographs, glass beads, knives, and grooved steatite arrow straighteners.

### Significance of Pottery

The presence of pottery at the 3 study sites gives insight into the cultural behavior of the Luiseño people who are believed to have lived there. The use of pottery reflects aspects of their subsistence and settlement activities. It implies the Luiseño relied on storage capabilities for a year-round supply of food and water in a more permanent settlement. Although the Luiseño did not practice agriculture, they had many of the characteristics found in a sedentary agricultural subsistence pattern, which sets them apart from typical hunters and gatherers. Since pottery is considered to be a late development and a part of the San Luis Rey II

complex defined for the area, its presence indicates a temporal context for the sites. The study of pottery can be used to understand a region's historical context, i.e., if there had been interaction between cultural spheres. The ceramic remains of Tizon Brown Ware, Buff Ware, and variations between these wares suggest a spatial context, implying interactions with other cultural groups.

## GEOLOGICAL SETTING

### Regional Geology

The Peninsular Ranges province encompasses a region characterized by a series of northwest-trending mountain ranges and intervening valleys. The southern California batholith constitutes the majority of this province. The study area (Figure 1) lies within the Perris Block of the Peninsular Ranges province. The Perris block is a down-faulted structural block bounded by the Elsinore fault zone along its western side and the San Jacinto fault zone along its eastern side. The Elsinore fault zone is closest to the study area with Mesozoic metamorphic and plutonic rocks, and Cenozoic sedimentary and volcanic rocks complexly faulted along most of its length (Kennedy 1977).

### Rock Types in Study Area

Plutonic rocks (Kp) exposed within the study area include gabbro, tonalite, and granodiorite (Figure 2). All of these are intrusive igneous rock types; gabbro is a mafic rock, and tonalite and granodiorite are more felsic (feldspar and quartz-rich) and are considered granitoids. Gabbro is composed chiefly of plagioclase, clinopyroxene, and minor olivine. Tonalite and granodiorite are widespread batholithic rocks and are composed of plagioclase, quartz, biotite, and hornblende. Granodiorite, however, contains more than 10% K-feldspar. The presence of K-feldspar serves to distinguish granodiorite from tonalite and quartz diorite. Even though biotite is more common in granodiorite, its presence or absence in temper materials may be more dependent on weathering, sediment transport, and temper preparation than on abundances in the source rock type.

Metamorphic rock types, both low-grade (pKy) and high grade (pKo) metasedimentary rocks, are also found in the study area. These rocks were metamorphosed by intrusion of the southern California batholith. The low-grade rocks have minerals such as chlorite or muscovite, albite, and quartz. High-grade rocks contain minerals such as hornblende, biotite, and muscovite in addition to quartz.

The Quaternary alluvium (Qal) and nonmarine terrace (Qn) deposits are composed of poorly to moderately consolidated sandstone, conglomeratic sandstone, and conglomerate. These deposits are derived from the erosion of older intrusive, volcanic, and metasedimentary rocks, and therefore reflect the mineralogy of the parent rocks from which they were eroded. These rocks and/or their weathering products are potential sources of temper observed in the ceramic thin sections. They would be expected to contain weathering products from a variety of rock types and would be far more mineralogically complex than material derived from outcrops of a single parent rock type or from active streams in small drainage basins.

Rock types located in the study area are within the travel distances proposed by Arnold (1985) for the procurement of ceramic resources. The preferred travel distance for temper sources averaged 1 km or less, with the maximum range within 6-9 km (Arnold 1985:32-52). Within this range of distances, quartz diorite and tonalite are the most abundantly exposed rocks and their minerals would be expected to be abundant in the temper if it was locally derived.

## ANALYTICAL METHODS

### Typing of Sherds and Sample Selection

Twenty-four representative samples were selected for petrographic and geochemical analysis out of more than 400 sherds recovered from the sites. They were divided into 3 ware categories: Lower Colorado Buff Ware, Tizon Brown Ware, and unclassified wares. These initial placements were made after inspection by hand lens or binocular microscope, and were intended only as a

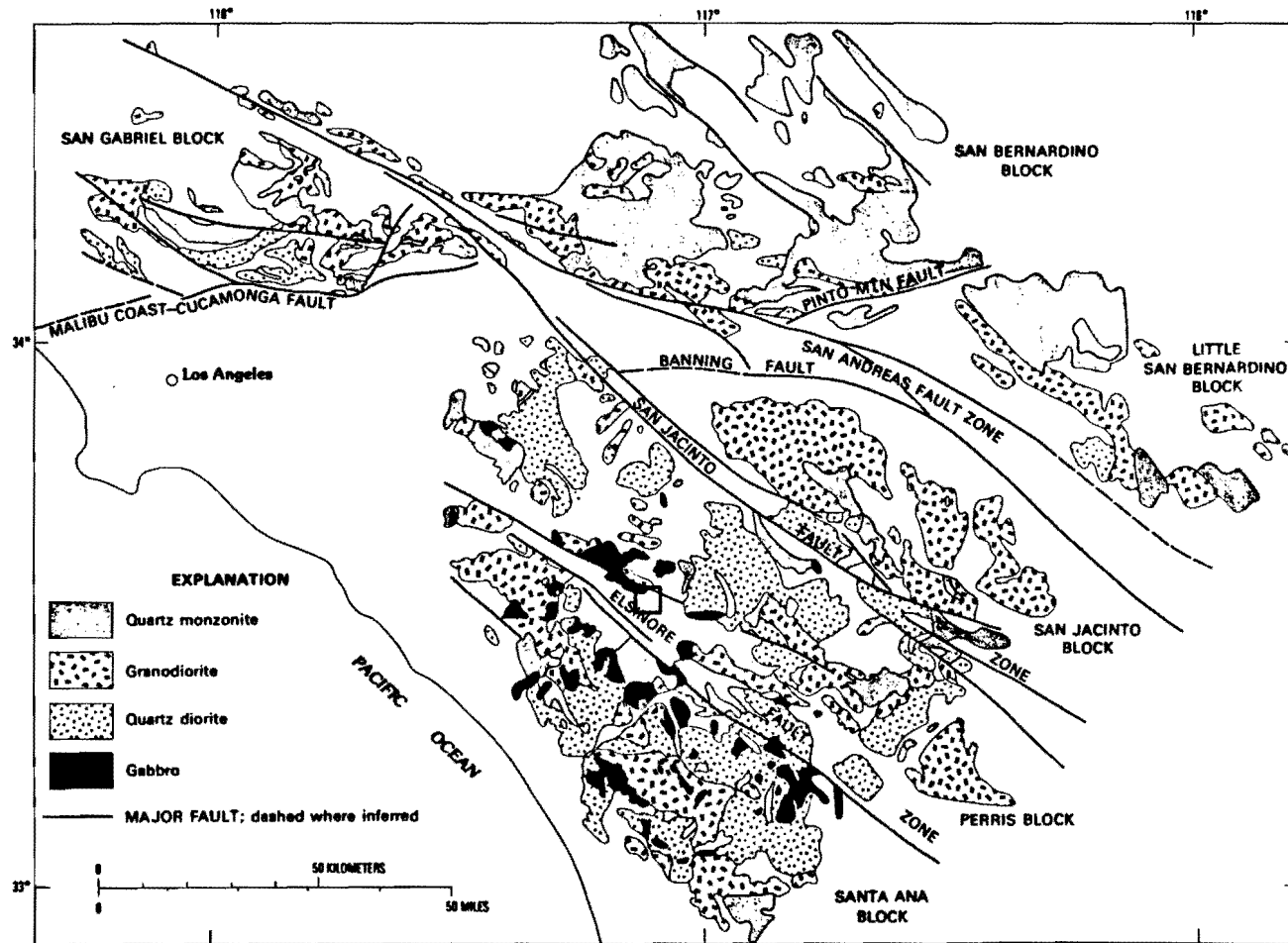


Figure 1. Generalized map for the Mesozoic plutonic rocks of Northern Peninsular and Transverse Ranges provinces, California. Fault-bounded structural blocks are indicated. [From Baird and Miesch 1984.]

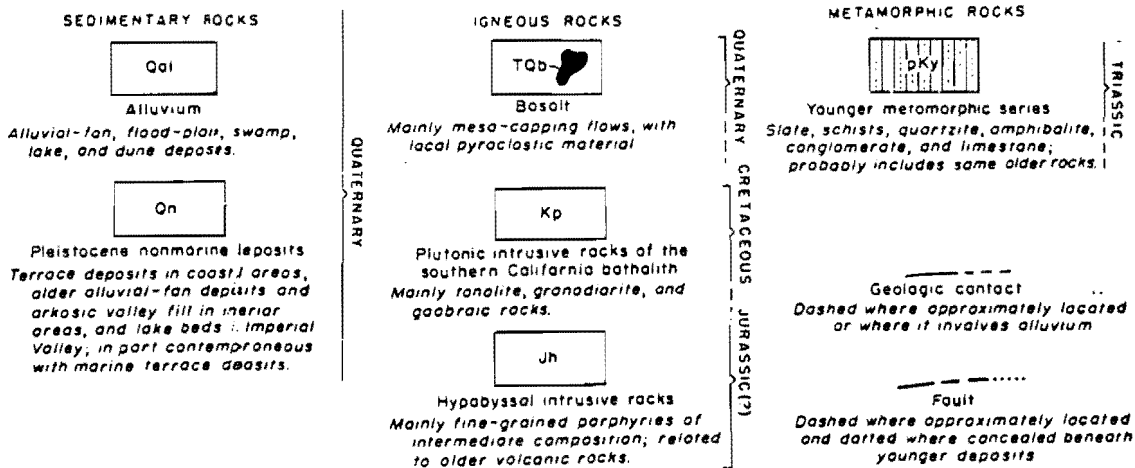
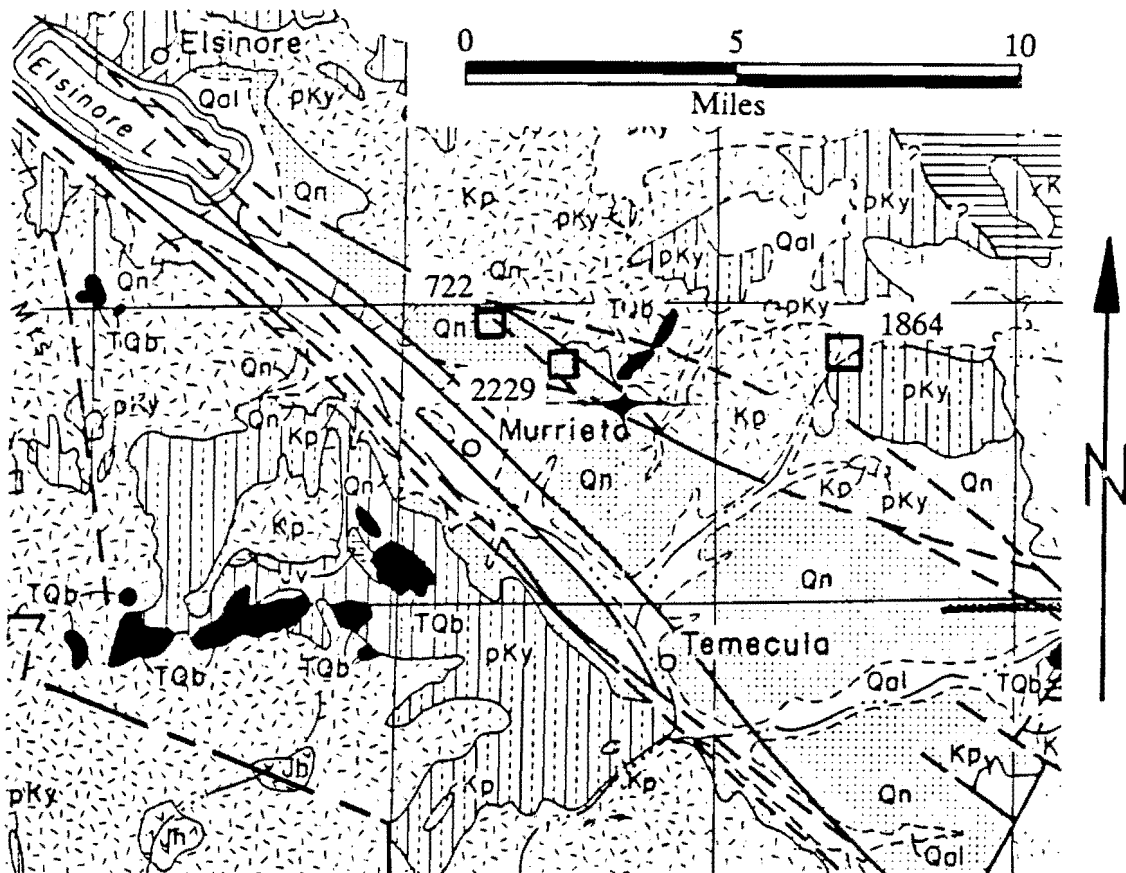


Figure 2. Generalized geological map of the Peninsular Ranges Province, southern California, in the study area. [From Jahns 1954.]

cursorry method of classification following the buff-brown classification dichotomy previously cited. Tizon Brown Ware fits the general criteria established for this category, having a darker color and a coarse temper grain texture. The Lower Colorado Buff Ware samples also were considered to have the described characteristics of the general ware category. It was hoped that the unclassified sherds could be classified through petrography or geochemical analysis when compared to the other wares.

#### Petrographic Analysis

Thin sections were prepared professionally by Glenn Striegler of the Rock Lab in Sherman Oaks, California, and Frank Padilla of U.S.A. Professional Petrographics of Ontario, California. All samples were impregnated and mounted with clear epoxy to compensate for the friability of the ceramic material. Thin sections were ground to the standard thickness of 30 microns, and a cover slip was mounted to preserve the sample.

Petrographic examination of the ceramic temper revealed that it consisted of mineral grains, rock fragments, and sherd fragments. Mineral fragments were identified using standard petrographic techniques; the mineralogy of the rock fragments, an agglomerate of 2 or more mineral grains, were determined and further subdivided into metamorphic, plutonic, and volcanic rock types. Plutonic igneous rocks were classified by the IUGS Classification System (Dietrich and Skinner 1979:116). Sherd fragments were identified by their darker matrix color, shrinkage voids around the edges of the sherd fragments, and fine-grained inclusions. Abundances of temper constituents were estimated by comparison to visual estimation charts. The abundance of temper materials differ among the 3 wares and also among sherds within the same ware classification. These constituent variations relate to different temper sources and possibly the use of different manufacturing techniques.

Grain texture characteristics were evaluated and described by using various geological standards -- grain rounding, sorting, and size (Compton 1962:212, 214, 215). These characteristics were analyzed to determine if further distinction could be made between

the wares.

#### Geochemical Analysis

Geochemistry was used to further characterize and define the sherd composition. Ceramic samples were pulverized, prepared, and analyzed at the ACME Laboratory in Vancouver, British Columbia. Major and trace element abundances were determined by Inductively Coupled Plasma (ICP) spectroscopy. Two types of preparation were used for ICP analyses: a  $\text{LiBO}_2$ -fusion method for element abundances of major oxides and some trace elements, and an acid-leach method for additional major and trace element abundances.

$\text{LiBO}_2$ -fusion analysis used a 0.2000-g sample fused with 1.2 g of  $\text{LiBO}_2$  and dissolved in 100 ml of 5%  $\text{HNO}_3$ . All elemental abundances reported for the  $\text{LiBO}_2$ -fusion technique are quantitative (fully measured) in percentages (%) and parts per million (ppm). The acid-leach analysis used a 0.5000 g sample digested with 3 ml 3-2-1- $\text{HCl-HNO}_3\text{-H}_2\text{O}$  @ 95° C for 1 hour, diluted to 10 ml with water. The acid-leach analysis resulted in total analysis for Mo, Cu, Pb, Zn, Ag, Ni, Co, As, U, Au, Th, Cd, Sb, Bi and V; partial analysis for Mn, Fe, Sr, Ca, P, La, Cr, Mg, Ba, Ti, B, and W; and limited analysis for Na, K, and Al.

## PETROGRAPHIC RESULTS

### Description of Wares

After petrographic analysis, the ceramics were divided into 3 ware categories, Buff Ware, Tizon Brown Ware, and unclassified. The Buff Ware sherds are not referred to as "Lower Colorado Buff Ware" because they did not have all the characteristics described by Lyneis (personal communication, 1991): "light color; clean clay matrix; lack of/or very fine temper or inclusions; matrix supported". Buff Ware is herein defined as: light color; fine clay matrix; with temper characteristics intermediate between Lower Colorado Buff Ware and Tizon Brown Ware. This Buff Ware is potentially a variant of the Lower Colorado Buff Ware, but more petrographic analysis of ceramic collections is needed to determine if this interpretation is correct. Tizon Brown Ware fits the general

criteria established for this category, having a dark color and a coarse temper grain texture. The unclassified wares remained in this category, as their characteristics did not neatly fall into either of the previous categories.

#### Buff Ware Temper

Four Buff Ware sherds were analyzed from sites RIV-722 and RIV-2229. No representative Buff Ware sherds were found at RIV-1864. Buff Ware samples contained 9-20% of their volume as temper; quartz (6-14%) was the dominant mineral; plagioclase (1-4%), biotite (1-2%), K-spar (trace-1%) were less abundant but always present; and trace amounts of muscovite, sphene, zircon, and epidote were present. Three samples contained sherd fragments (3-13%) as temper. One sherd contained a trace amount of sillimanite in feldspar grains. Three sherds had volcanic rock fragments (<1-2%).

The rounding, sorting, packing, and size of grains in the Buff Ware temper was examined. The grain rounding of 3 sherds ranged from angular to subrounded with 1 sherd containing grains ranging from subangular to rounded. Three were well sorted; 1 was moderately sorted. Packing of all 4 sherds was matrix supported. The grain size ranged from fine to coarse sand.

#### Tizon Brown Ware Temper

Eighteen Tizon Brown Ware sherds were analyzed from the 3 sites. The mineral composition of the temper was homogeneous with the total temper mineral abundance ranging from 23 to 33%. Quartz was the most abundant mineral (10-25%), followed by plagioclase (1-10%), and hornblende (ranging from trace to 12%), and these 3 minerals were present in all samples. Biotite was present (trace-4%) in all samples and pyroxene (trace-4%) in some samples. Accessory minerals that were present include muscovite and sphene (trace), zircon (trace-1%), and epidote (trace-2%). Three sherds contained traces of sillimanite in feldspar, and 1 sherd contained a trace of rutile.

The IUGS igneous rock classification system was utilized to identify rock types based on rock fragments and/or relative

abundances of quartz, plagioclase, and K-feldspar. Twelve sherds contained mineral abundances that are suggestive of tonalite source rock; 4 a quartz diorite source rock; and 1, a granodiorite source rock. Two sherds having evidence of potentially 2 different rock sources have both quartz diorite fragments/mineral abundances, with 1 sherd additionally having a quartz gabbro source rock, and the other had a grain resembling a metasedimentary argillaceous source rock.

The rounding, sorting, packing, and size of grains in each thin section was evaluated. The temper grain rounding of 5 sherds is subangular to subrounded and of 3 sherds is angular to subrounded. The grain rounding of 10 sherds is angular to subangular. Nine sherds are poorly sorted and 9 sherds are moderately sorted. Four sherds have abundant temper material and are considered grain supported. The other 14 sherds are matrix supported. The grain size for all Tizon Brown Ware sherds is medium to coarse sand.

#### Unclassified Ware Temper

Two sherds were not classified during the initial sorting/selection process because they did not fit into either ware classification. Both sherds were from RIV-722. The temper contained a total mineral abundance from 9 to 10%. Quartz (4-5%) was the dominant mineral followed by plagioclase (1%). Biotite (trace-2%) was the principal characterizing mineral and the only accessory mineral was muscovite (trace-1%). One sherd had a trace of hornblende and 15% sherd fragments. Both sherds had volcanic rock fragments (1-3%).

The unclassified sherds were evaluated for rounding, sorting, packing and size. The temper grain rounding of one ranges from subangular to subrounded; the other ranges from angular to subangular. Both sherds are well sorted. The packing of both sherds is matrix supported, and the grain size is fine sand.

#### Petrography Discussion

The petrographic analysis showed mineralogical and textural feature distinctions between the wares (Table 1). Although only

Table 1

Mineral Abundance Ranges Estimated From Thin Sections  
of Tizon Brown Ware, Buff Ware, and Unclassified Ceramics

Minerals/other inclusions	Tizon Brown Ware	Buff Ware	Unclassified
Total Temper	23-33%	9-20%	9-10%
Quartz	10-25%	6-14%	4-5%
Plagioclase	1-10%	1-4%	1%
K-spar	Trace-2%	Trace-1%	
Biotite*	Trace-4%	1-2%	Trace-2%
Hornblende*	Trace-12%	Trace	
Pyroxene*	Trace-4%		
Muscovite+	Trace	Trace	Trace-1%
Sphene+	Trace	Trace	
Zircon+	Trace-1%	Trace	
Epidote+	Trace-2%	Trace	
Sherd	Trace-2%	3-13%	0-15%
Rock	1-3%		
Volcanic Rock		1-2%	1-3%
Other	Sillimanite = Trace Augite = Trace Opaques = TR-2% Metamorphic = Trace Sericite = TR-1% Fibrolite = TR Hematite = TR	Sillimanite = Trace Opaques = TR-1%	Rutile = Trace
* = Characterizing Mineral		+ = Accessory Mineral	

4 Buff Ware sherds were analyzed, they showed a high degree of variability. Some general characteristics are similar: the amount of temper is moderate (10-20%); the mineral abundance shown on Table 1 indicates that quartz, plagioclase, and biotite are most abundant. K-feldspar is present in

all sherds. The Buff Ware temper consists of minerals, sherds, and volcanic fragments. The characterizing minerals are hornblende and sphene for all; zircon for 3 sherds; and epidote for 3. Sherd fragments are found in 3. The grains are more rounded and well sorted compared to the Tizon Brown Ware.



The matrix clay grains are more transparent, and have a higher birefringence than those in Tizon Brown Ware.

In spite of the fact that far more Tizon Brown Ware sherds were analyzed, they had less variation than the 4 Buff Ware sherds. The overall abundance of the Tizon Brown Ware temper abundance ranges from moderate to heavy (23-33%) and the mineral abundances are greater for all minerals. Quartz and plagioclase are dominant, with hornblende as the most abundant characterizing mineral in these sherds. Rock fragments are more characteristic of the Tizon Brown Ware than the other wares, as they are present in 15 of the 18 sherds. The grains are moderately to poorly sorted; all temper grains are angular. The matrix is darker in color and has discernible grain when viewed under cross-polarized light.

The unclassified sherds are petrographically distinct from the 2 described wares and from one another. Although they have similar mineral compositions, (abundant quartz and plagioclase along with characterizing biotite), the total mineral abundance is less than either Tizon Brown Ware or Buff Ware. The sherds do not have the rock fragments characteristic of Tizon Brown Ware, and 1 has an abundance (15%) of sherd fragments, a characteristic of Buff Ware. The unclassified sherd grains have sorting, rounding, and packing characteristics that are more similar to Buff Ware.

#### Sourcing Inferences

The Buff Ware may have been locally made; however, the mineral abundances and textural characteristics suggest that Buff Ware could have been derived from outside the study area. The presence of K-feldspar in the Buff Ware sherds is suggestive of a source east of the San Jacinto mountains. K-feldspar may be present in the study area but is more abundant in rocks to the east. The distinct rounding, sorting, and packing in Buff Ware could indicate a different manufacturing technique from the Tizon Brown Ware.

The mineral composition of the Tizon Brown Ware can be directly related to rocks exposed near the sites. The most abundant

plutonic rocks in the site area have mineral and textural features that are very similar to temper grains in the Tizon Brown Ware sherds. The large amount of quartz, plagioclase and hornblende and the small amount of K-feldspar and biotite suggest that Tizon Brown Ware temper materials were derived from gabbro, quartz diorite, or tonalite sources. Each of these crop out extensively near the sites. The most abundant rock type of the Perris Block is tonalite (Kp), which is considered to be a very likely source of temper grains in Tizon Brown Ware. The additional minerals identified include sillimanite, sphene, and rutile. Sillimanite is a mineral that typically occurs in metasedimentary rocks in contact with plutonic rocks. Rutile could be from metasedimentary or mafic plutonic rocks. Sphene is an abundant accessory mineral in tonalite. The relative scarcity of these minerals is consistent with a dominantly plutonic source that may have minor inclusions of metamorphic rocks.

The distinctive nature of the unclassified sherds suggests that their source was not from the local area nor from the source area of Buff Ware. Their mineral abundances are distinctively different from the Buff Ware and Tizon Brown Ware, and their relation to the study area's geology is inconclusive. Further investigation is needed to verify a potential source area for these sherds.

## GEOCHEMICAL RESULTS

The data resulting from the geochemical analysis did not provide as clear a distinction between the wares as did petrographic analysis. The chemical composition for all ware types was, in general, very similar based on raw elemental abundances. Therefore, major and trace element abundance variation as a function of other elemental abundances was used to distinguish between wares. Three general types of plots were used: binary diagrams plotting major elements in silica variation diagrams; ternary diagrams plotting the relative abundances of 3 major elements; and binary diagrams plotting trace elements in silica or calcium variation diagrams. Variation diagrams of this type are commonly used in geochemical

analysis when the ratio of elements to each other is more informative than absolute abundances.

#### Binary Major Element Diagrams

Major element oxides of aluminum, iron, magnesium, calcium, sodium, and potassium were plotted on silica variation diagrams. Of these diagrams plotted, only the aluminum oxide, calcium oxide, and potassium oxide results appear useful in distinguishing between the wares (Figures 3-5). The other oxides show significant overlap in the abundance fields and are not considered useful. The results indicate that  $Al_2O_3$  is lower for Buff Ware at a given silica content, and  $CaO$  is higher for Buff Ware, possibly due to different clay sources.  $K_2O$  is higher in Buff Ware particularly at low silica content. The higher abundance of  $K_2O$  may be due use of temper materials from rocks east of the study area which are known to have higher K-feldspar (Baird and Miesch 1984).

#### Ternary Major Element Diagrams

Ternary diagrams, where 3 elements (or element sums) are plotted relative to one another, help demonstrate significant chemical variations between sample groups. This technique is commonly used in igneous petrology and was used here in an attempt to distinguish between different wares.  $CaO$ ,  $FeO$ , and  $MgO$  data were plotted relative to one another for each sample (Figure 6). The results indicate that the Buff Ware and unclassified sherds plot within a field that is enriched in  $CaO$  relative to  $FeO$  when compared to Tizon Brown Ware. One Buff Ware sherd sample plots outside the Buff Ware field probably due to a high iron content in the hematite (sample was deep-red due to an abundance of hematite).

A standard igneous rock Alkali-Iron-Magnesium (AFM) diagram that measures the relative proportion of alkalis ( $Na_2O + K_2O$ ), iron ( $FeO$ ), and magnesium ( $MgO$ ), was plotted (Figure 7). The AFM plot showed distinctions between the 2 wares because of the relatively high iron content either from hematite or hornblende in Tizon Brown Ware as compared to Buff Ware. Differences in clay composition may also contribute to a higher iron content. The Buff Ware and unclassified sherds are more

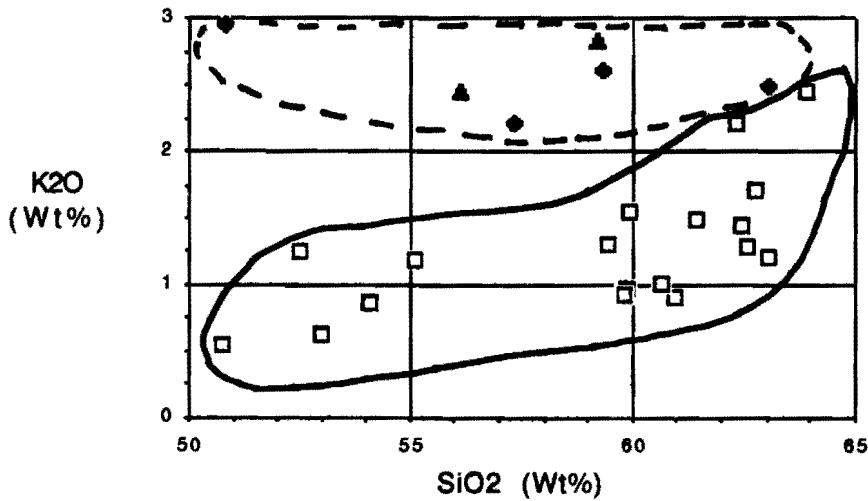
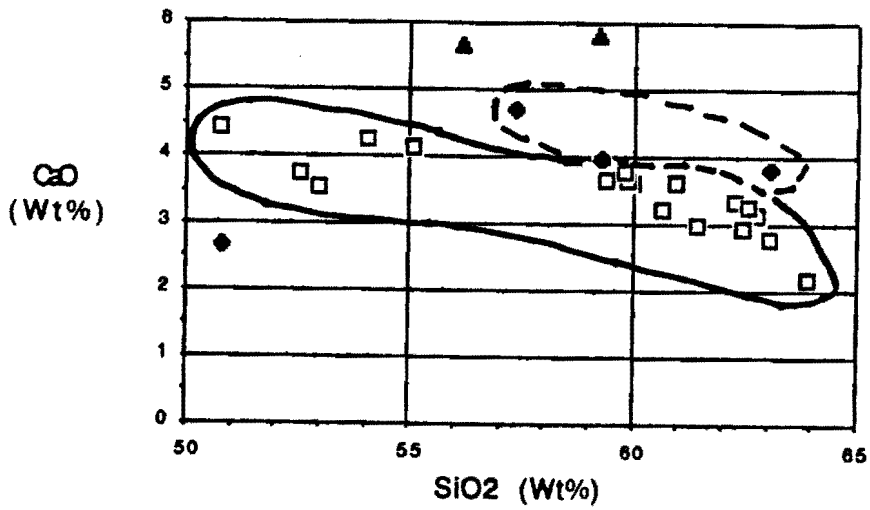
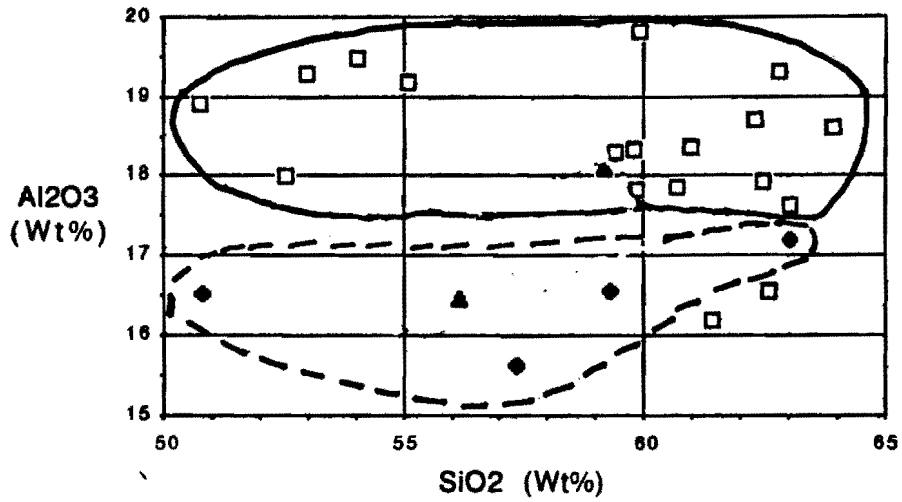
similar in composition and plot in the same field, with the exception of a deep-red hematite-rich sherd which plots with relatively high iron content.

Major element oxides  $Na_2O$ ,  $K_2O$  and  $CaO$  were plotted (Figure 8) relative to one another for each ceramic sample. The results show that the Buff Ware and unclassified sherds fall within the same field showing a higher potassium oxide and calcium oxide content relative to sodium oxide. This higher  $K_2O$  content may be related to the clay composition and relatively more K-feldspar in these samples.

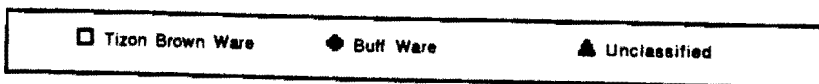
#### Binary Trace Element Diagrams

Trace element compositions were compared to distinguish between sherds of similar major element chemistry. Many of the trace element data were not used in this study because of their overlapping ranges. Those elements disregarded include: Pb, Cu, Zn, Ni, Co, As, Th, Ti, Cd, Cr, Ag, La, Zr, Ce, and Y. Some elements (Mo, U, Bi, Au, Nb, and Ta) had similar abundances in all samples and were not used in this study. Three trace elements were found to effectively separate the 2 wares: boron, vanadium, and strontium. These trace elements were plotted on binary silica variation diagrams. Results of these diagrams indicate the following:

The boron-silica variation diagram (Figure 9) allows for the separation of Tizon Brown Ware from 3 out of 4 Buff Ware. The ceramic samples from site RIV-722 contain significantly more boron than wares from the other sites. The reason for the higher boron abundances from this site is not known. The unclassified sherds fall within the 2 Buff Ware fields. Figure 10 shows that vanadium has a higher abundance in the Tizon Brown Ware with overlap between the 2 fields. The unclassified sherds fall in both fields, one in the Buff Ware, the other within the Tizon Brown Ware range. A binary silica variation diagram was constructed for strontium (Figure 11). This figure illustrates that the Buff Ware has a generally higher strontium content than Tizon Brown Ware. There is, however, obvious overlap in their ranges.



Figures 3-5.  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{K}_2\text{O}$  silica variation diagrams. Abundance fields shown with a solid line for Tizon Brown Ware and a dashed line for Buff Ware.



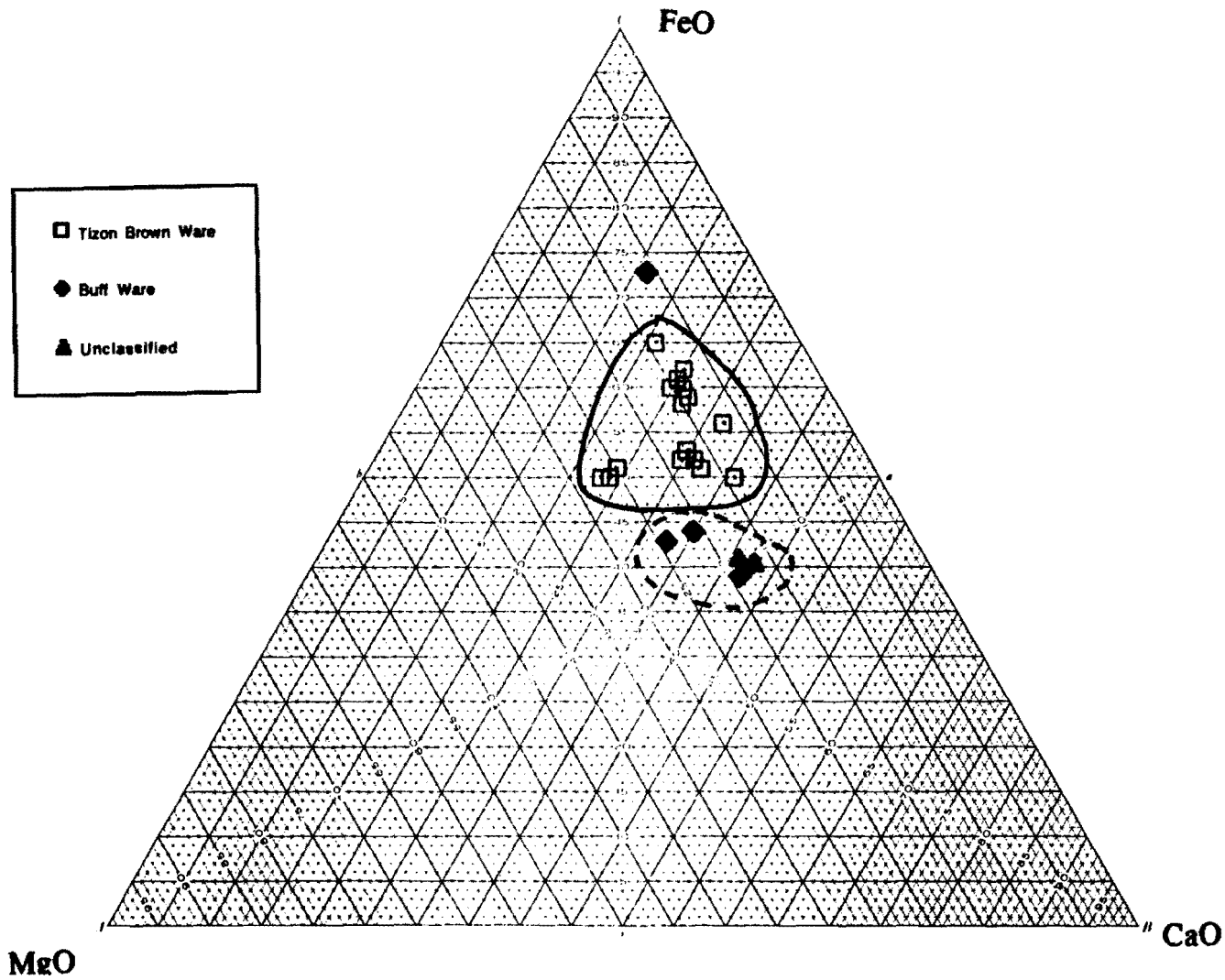


Figure 6. CaO, FeO, MgO Ternary Diagram. Abundance fields shown with a solid line for Tizon Brown Ware and a dashed line for Buff Ware.

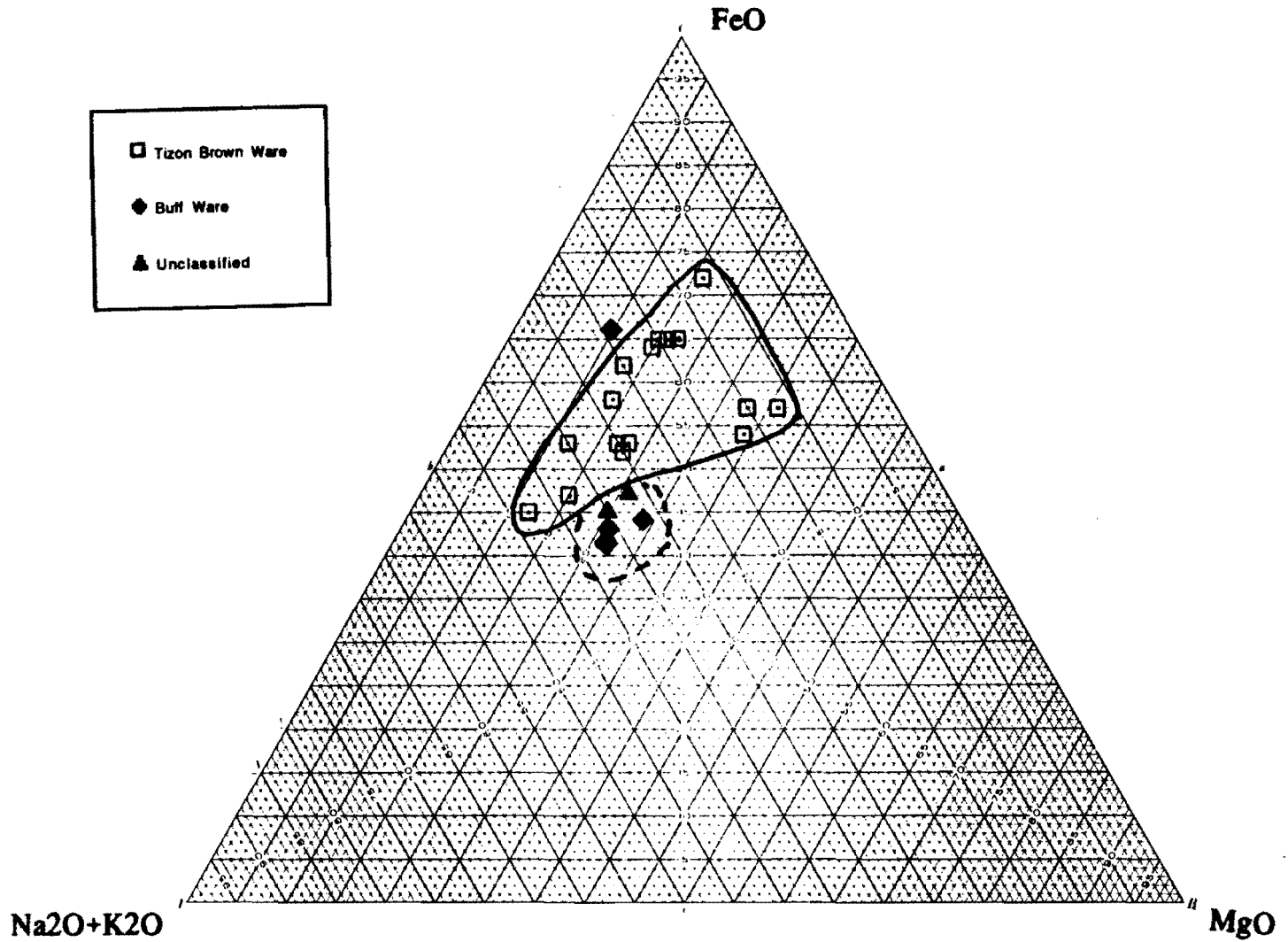


Figure 7. AFM ( $\text{Na}_2\text{O} + \text{K}_2\text{O}$ , FeO, MgO) Ternary Diagram. Abundance fields shown with a solid line for Tizon Brown Ware and a dashed line for Buff Ware.

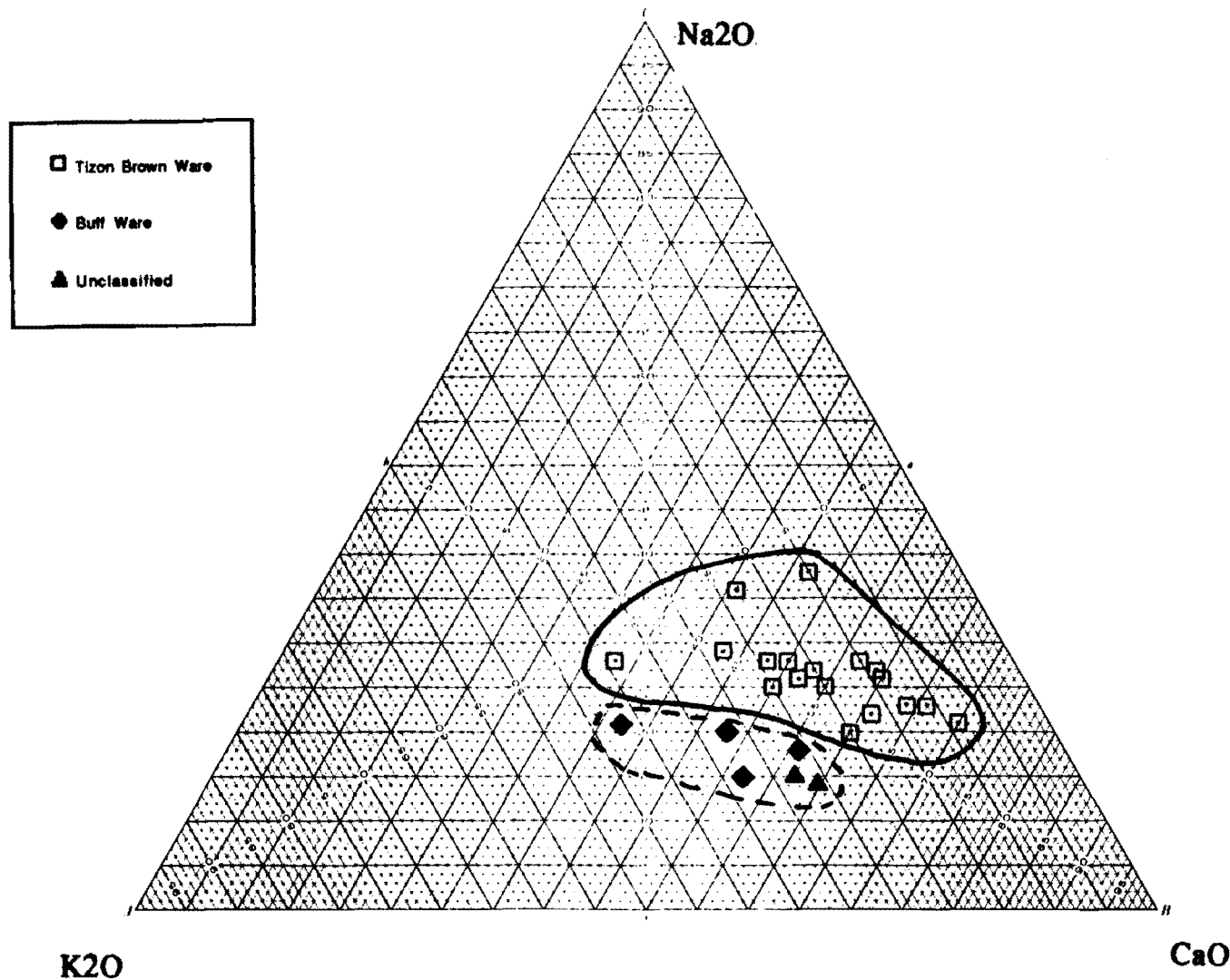
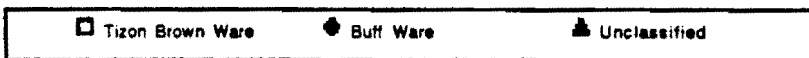
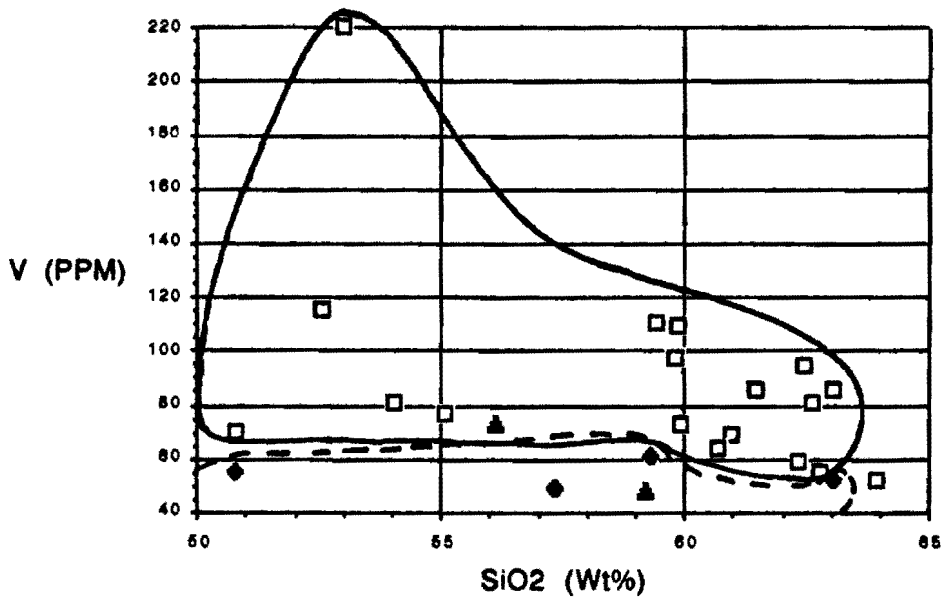
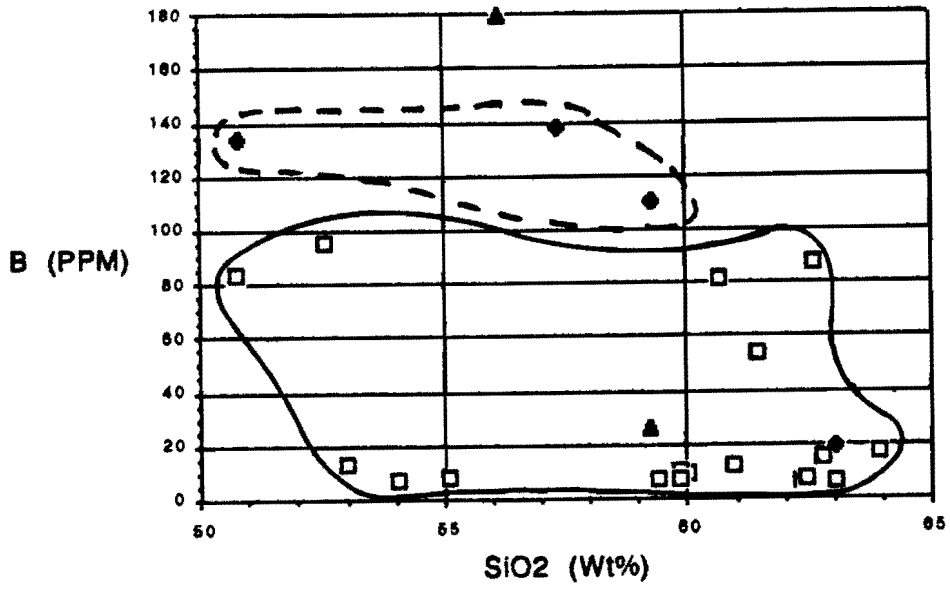


Figure 8. Na<sub>2</sub>O + K<sub>2</sub>O, CaO Ternary Diagram. Abundance fields shown with a solid line for Tizon Brown Ware and a dashed line for Buff Ware.



Figures 9-10. Boron and vanadium silica variation diagrams. Abundance fields shown with a solid line for Tizon Brown Ware and a dashed line for Buff Ware.

In addition to the above trace elements, a strontium and calcium oxide binary plot (Figure 12) indicates a relatively higher amount of these elements in Buff Ware as compared to Tizon Brown Ware. The unclassified sherds fall close together in the Buff Ware field, exhibiting similar abundances.

### Geochemistry Discussion

Major and trace elements abundance variations allowed some discrimination between wares. The geochemical differences between wares are summarized in Table 2. Ranges of major and trace element abundances were not useful by themselves for distinguishing between wares. Major element-silica variation diagrams, however, indicate there is considerable variation of major element abundances as a function of silica content. Trace element-silica variation diagrams are generally not useful for separating wares; however boron, vanadium, and strontium variations with silica content are different for the 2 wares and allow their chemical distinction. Buff Ware has higher abundances of boron and strontium while Tizon Brown Ware exhibits a higher vanadium content. The ternary diagrams that measure ratios in the major elements further characterize the wares. These show Buff Wares having higher potassium and calcium oxides relative to iron oxide, whereas iron oxide is greater in Tizon Brown Ware. This results in separate abundance fields on CaO-MgO-FeO (calcium oxide-magnesium-oxide-iron oxide), AFM (alkali-iron-magnesium), NaO-K<sub>2</sub>O-CaO (sodium oxide-potassium oxide-calcium oxide) diagrams.

The abundance fields are better defined for Tizon Brown Ware because of the relatively large number of samples. The Buff Ware abundance fields are poorly defined because only 4 samples were analyzed. Of these 4, only 2 had plutonic rock temper. More samples of plutonic-rock-tempered Buff Ware are required to better define abundance fields and to clearly establish similarities or differences between the 2 types of ceramic wares.

Unclassified sherds had major and trace elements abundances that were not conclu-

sively like either the Tizon Brown Ware or Buff Ware. For some major (Fe<sub>2</sub>O<sub>3</sub> (iron oxide), K<sub>2</sub>O (potassium oxide) and minor (V-vanadium and Sr-strontium) elements, unclassified sherds were most like Buff Ware; however other major element (Al<sub>2</sub>O<sub>3</sub>-aluminum oxide) and minor element (B-boron) characteristics were similar to both Tizon Brown Ware and Buff Ware. The unclassified samples were unlike either ware on calcium-silica variation diagrams. Geochemical data alone are not able to classify the unknown wares as 1 of the 2 types; rather they may be distinct types of their own.

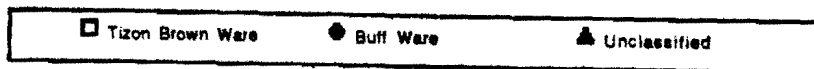
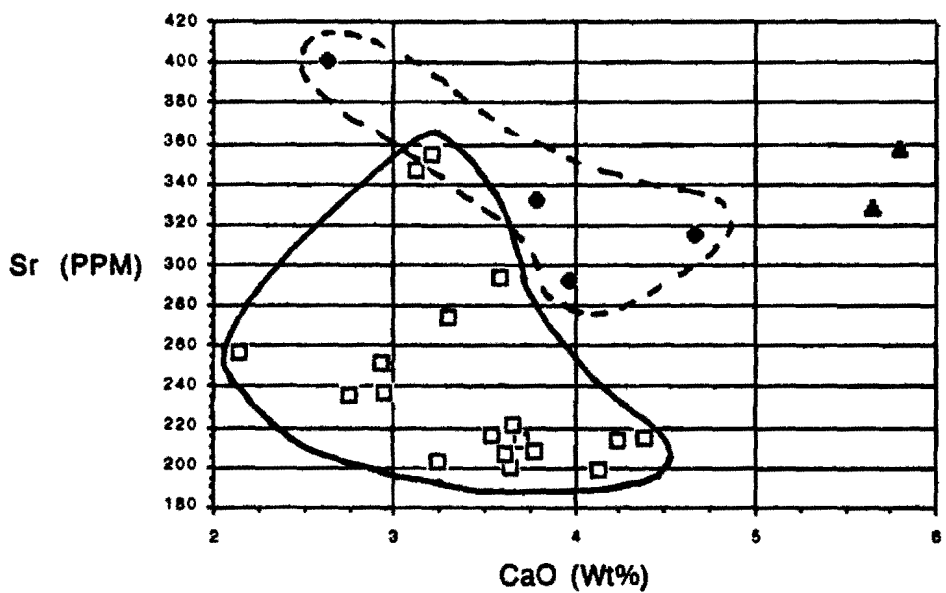
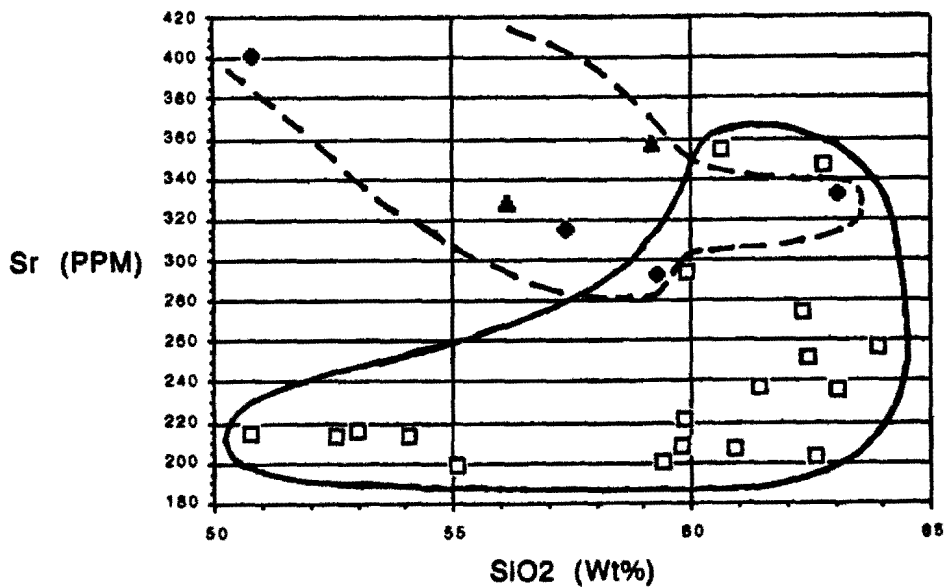
## CONCLUSIONS

Previous ceramic studies have not developed an adequate taxonomic system for ceramics found in the southern California area. These studies have not used consistent criteria or analytical techniques and have attempted to place southern California pottery in the Southwestern ceramic classification system. Because this descriptive system does not work for the mostly fragmentary, undecorated southern California ceramics, the analysis criteria must rely instead on temper and chemical composition.

This study applies quantitative analytical techniques - petrography and geochemistry - to characterize the 2 prominent southern California wares found in Riverside County, Tizon Brown Ware and a potential variant of Lower Colorado Buff Ware. This kind of study provides data that are not only consistent but also quantifiable. The wares are defined using more precise analytical methods for the classification criteria. The results of these analytical techniques can be verified, unlike previous descriptive methods of analysis.

Petrography verified the distinctions between the wares by characterizing each ware based on mineral abundance, temper composition, grain texture, and sorting. Tizon Brown Ware samples were homogeneous in mineral composition, mineral abundance, and textural features. Quartz, plagioclase, and hornblende were the most abundant characterizing minerals, and the textural features included coarse texture,





Figures 11-12. Strontium silica variation diagram and strontium-calcium oxide variation diagram. Abundance fields shown with a solid line for Tizon Brown Ware and a dashed line for Buff Ware.

Table 2. Summary of Geochemical Results

Figure	Buff Ware	Tizon Brown Ware	Unclassified
Major Element Binary Figures 3-5	Al <sub>2</sub> O <sub>3</sub> lower CaO lower K <sub>2</sub> O higher	Al <sub>2</sub> O <sub>3</sub> higher CaO higher K <sub>2</sub> O lower	Same as Buff Ware range
Ternary Element Diagrams Figure 6	Less FeO relative to CaO, MgO	More FeO relative to CaO, MgO	Same as Buff Ware range
AFM Figure 7	Less FeO relative to Na <sub>2</sub> O+K <sub>2</sub> O, MgO	More FeO relative to Na <sub>2</sub> O+K <sub>2</sub> O, MgO	Same as Buff Ware range
Figure 8	K <sub>2</sub> O higher relative to CaO, Na <sub>2</sub> O	K <sub>2</sub> O lower relative to CaO, Na <sub>2</sub> O	Same as Buff Ware range
Binary Trace Element Diagrams Boron vs SiO <sub>2</sub> Figure 9	Higher abundance range	Lower range	Buff Ware range with overlap
Vanadium vs SiO <sub>2</sub> Figure 10	Less abundant relative to SiO <sub>2</sub> content	More abundant	Buff Ware range with overlap
Strontium vs SiO <sub>2</sub> Figure 11	More abundant relative to SiO <sub>2</sub> content	Less abundant	Buff Ware range with overlap
Strontium vs Calcium Figure 12	More abundant relative to CaO content	Less abundant	In separate field More abundant High CaO content

moderate to poorly sorted, and grain supported. Buff Ware samples, considered a variant of Lower Colorado Buff Ware, have a fine texture, well sorted, and matrix supported. The distinctive nature of the unclassified wares' temper and matrix features set them apart from the other 2 wares, but also from one another. One sample has chiefly sherd fragments, while the other had fine grained plutonic fragments. These sherds had similar textural features to the Buff Ware, i.e., temper abundance, mineralogy, sorting, and rounding, although they remained distinct both petrographically and geochemically and are considered to represent different wares.

In addition to defining the ceramic wares quantitatively, this research also tested Rogers' hypothesis of local manufacture. Potential source inferences were made, based on the mineral abundance and rock fragment composition in the ceramic temper. The Tizon Brown Ware sherds showed a significant correlation with the local geology, whereas the Buff Ware and unclassified sherds did not exhibit mineral composition or abundances indicative of a local source. The presence of K-feldspar in the Buff Ware is suggestive of a source east of the San Jacinto mountains. The unclassified sherds' distinctive nature suggest that they are not from the local area or from the source area

of the Buff Ware. Further investigation is needed to verify a potential source area for these sherds.

Although this study shows that geochemical analysis can discriminate between the 2 wares, the samples are a limited data set; therefore the fields on the plots are not conclusively defined, especially for Buff Ware. Even so, geochemical separation of the wares was suggested by the data. The major element diagrams indicate Tizon Brown Ware had a higher aluminum oxide and iron oxide content than the Buff Ware and unclassified, whereas Buff Ware had a higher content of calcium oxide and potassium oxide. The minor elements measured found a relatively higher vanadium content in Tizon Brown Ware, and Buff Ware had higher abundances of boron, strontium vs.  $\text{SiO}_2$  and strontium vs. calcium. More extensive geochemical analyses on ceramic collections would be desirable to better establish composition fields and the degree of overlap between compositions of the 2 ceramic wares found extensively in the archaeological record in the Riverside County area.

This ceramic study was based on a limited collection; therefore, the ware characteristics are not well defined. Because of the high variability of the Buff Ware sherds and small sample size, more samples need to be studied in order to define the ware. In addition, further sampling needs to be done regionally in order to compare ceramic collections within the Riverside County area. With more data for comparison, it will be possible to develop a working classification for Tizon Brown Ware and Buff Ware as well as other wares potentially found in this area. Once established, these ceramic ware characteristics can then be compared to a larger regional data base. These studies can suggest temper sources by studying the regional geology and its associations with the ceramics. The quantifiable data derived from ceramic studies of this kind can contribute to a more accurate interpretation of the prehistory of this region.

## NOTES

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