AN ABSTRACT OF THE THESIS OF

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Title: Thin-Section Analysis Of Temper In

Patayan Ceramics From Willow Beach, Arizona

Abstract approved:

Prehistoric ceramics along the Lower Colorado River have been difficult to classify, partially due to their lack of decoration. These utilitarian, plain brown wares are best described by the materials used to manufacture them. Five sherds of Patayan ceramics (A.D. 900 - 1150) recovered from Willow Beach, Arizona are examined in thin section. Based on a preliminary examination of surface treatment, color, and temper by another investigator, these five sherds are thought to represent five subgroups of ceramics from the site. Temper is the non-plastic, granular material potters add to clay to prevent a ceramic vessel from excessive shrinking during drying or firing. In this study, a petrographic microscope is used to examine the temper found in one sherd from each of the five subgroups. A thin-section analysis of temper on the five sherds reveals that raw materials used to produce the ceramics were derived from the garnetiferous granite pegmatite outcropping at the site. Furthermore, it is shown that there is no difference in temper used in the five sherds. Therefore, the five sherds do not represent separate subgroups if temper is the sole criterion of analysis.

THIN-SECTION ANALYSIS OF TEMPER IN PATAYAN CERAMICS FROM WILLOW BEACH, ARIZONA

A Thesis

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by

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CHAPTER 1: INTRODUCTION

Problem

Prehistoric ceramics along the Lower Colorado River have been difficult to classify, partially due to their lack of decoration. Ceramics found in the Lower Colorado River region are quite utilitarian and unadorned. There is some controversy on defining Lower Colorado Ceramics as a type and how they relate to other ceramic types. Prehistoric ceramics in the Lower Colorado River, however, have not been well studied. When a ceramic ware lacks paint, glaze, or incisions, temper, the non-plastic, granular material potters add to clay to prevent a ceramic vessel from excessive shrinking during drying or firing, is often used to define a ceramic type. When a temper contains unusual materials distinctive to a certain area or region, temper type can tell us about group mobility as well as trade between groups.

Purpose

Based on a preliminary examination of surface treatment, color, and temper, archaeologist Greg Seymour has preliminarily divided the Patayan ceramics (A.D. 900 - 1150) recovered from Willow Beach, Arizona, into five subgroups. In this study, the mineral temper of one fired pottery sherd from each of the five subgroups recovered from Willow Beach, Arizona is determined by examining sherd thin-sections under a petrographic microscope. The temper between sherds is compared to determine whether they represent subgroups. The mineralogy of the temper is also compared to the local geology to determine whether the sherds were locally produced. Therefore, the purpose of this study is to more fully describe characteristics of sherds from Willow Beach that Schroeder classified as Pyramid Gray.

Hypotheses

The null hypotheses developed to meet the goal of this study are:

H_{01}: There is no significant difference in temper composition among the five sherds.

H_{02}: There is no significant difference between temper used to produce ceramics found at Willow Beach, Arizona and the surrounding geologic units.

Organization of This Thesis

This chapter includes discussion of the study area geography and geology, background on the archaeology of the site and history of the problems in classifying these ceramics.

Chapter 2 provides a background of ceramic petrology and previous studies in temper analysis. Chapters 3, 4, 5, and 6 are the methods; results; discussion; and conclusions, respectively.

Study Area

Geography

Willow Beach is situated in northwestern Arizona approximately 13 km south of Hoover Dam and approximately 40 km southeast of Las Vegas, Nevada, along the eastern bank of the Colorado River (Figure 1-1). Willow Beach and this portion of the Colorado River lie within Black Canyon, with the Eldorado Mountains to the west and the Black Mountains to the east.

The Willow Beach archaeological site is situated on Precambrian garnet-bearing gneiss near a contact with overlying Tertiary Lower Member of the Muddy Creek Formation (Anderson 1978). There are many generally east to west-trending

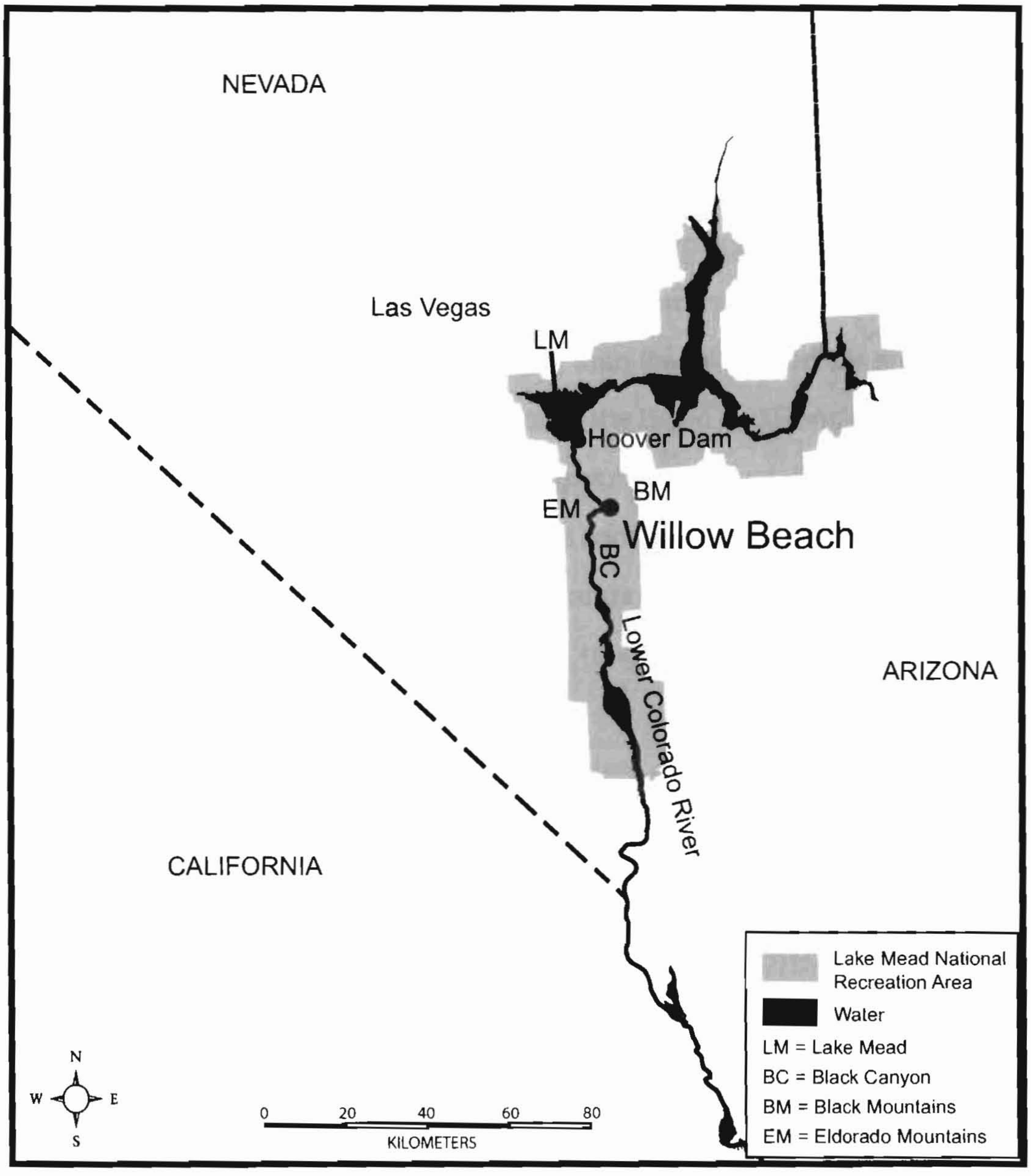

Figure 1-1. Location of Willow Beach, Arizona.

ephemeral washes on the east bank that empty into the Colorado River. The largest of these is Jumbo Wash, which trends southeast-northwest and empties into the Colorado River just below Willow Beach.

Today, the Willow Beach site is covered with a marina, parking lot, and other National Park Service facilities (Figure 1-2). Some of the shore near Willow Beach is covered with rip-rap, large fragments of rock thrown together to prevent erosion by waves or current (Figure 1-2). The area directly across the Colorado River from Willow Beach also lies on Precambrian basement and remains undeveloped. The terrain across the river is much more rugged than the Willow Beach area.

This site is within the southern portion of the Basin and Range physiographic province (Figure 1-3). Basin and Range topography is characterized by north-south trending mountain ranges separated by valleys containing smaller knolls and washes (Feuerbach 1986). Elevations in the vicinity range from 2000 - 3400 ft (610 - 1035 m) within the Black and Eldorado Mountain ranges to 720 ft (220 m) along the valley floor at the Colorado River.

Willow Beach is within the Mojave Desert and receives 13 cm of annual rainfall. Common shrubs in the area include Creosote Bush (*Larrea tridentata*) and Bursage (*Ambrosia dumosa*). The area is also home to the Desert Bighorn (*Ovis canadensis* spp.), Coyote (*Canis lantrans*), and the federally protected Desert Tortoise (*Gopherus agassizi*) as well as numerous other mammal and reptile species.

A marina was built at Willow Beach in the 1940s. Today, Willow Beach is part of the Lake Mead National Recreation Area, which receives 10 million visitors per year (USNPS 2003). It is also the site of the Willow Beach National Fish Hatchery, which stocks fish throughout the Lower Colorado River along the shared borders of California, Nevada and Arizona.

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Photographs of Willow Beach.
(A) Marina at Willow Beach, Arizona;
(B) Rip-rap on east bank of Colorado River near marina; (C) West bank of Colorado River in Nevada as viewed from marina.

Figure 1-2. Photographs of Present Day Willow Beach, Arizona.

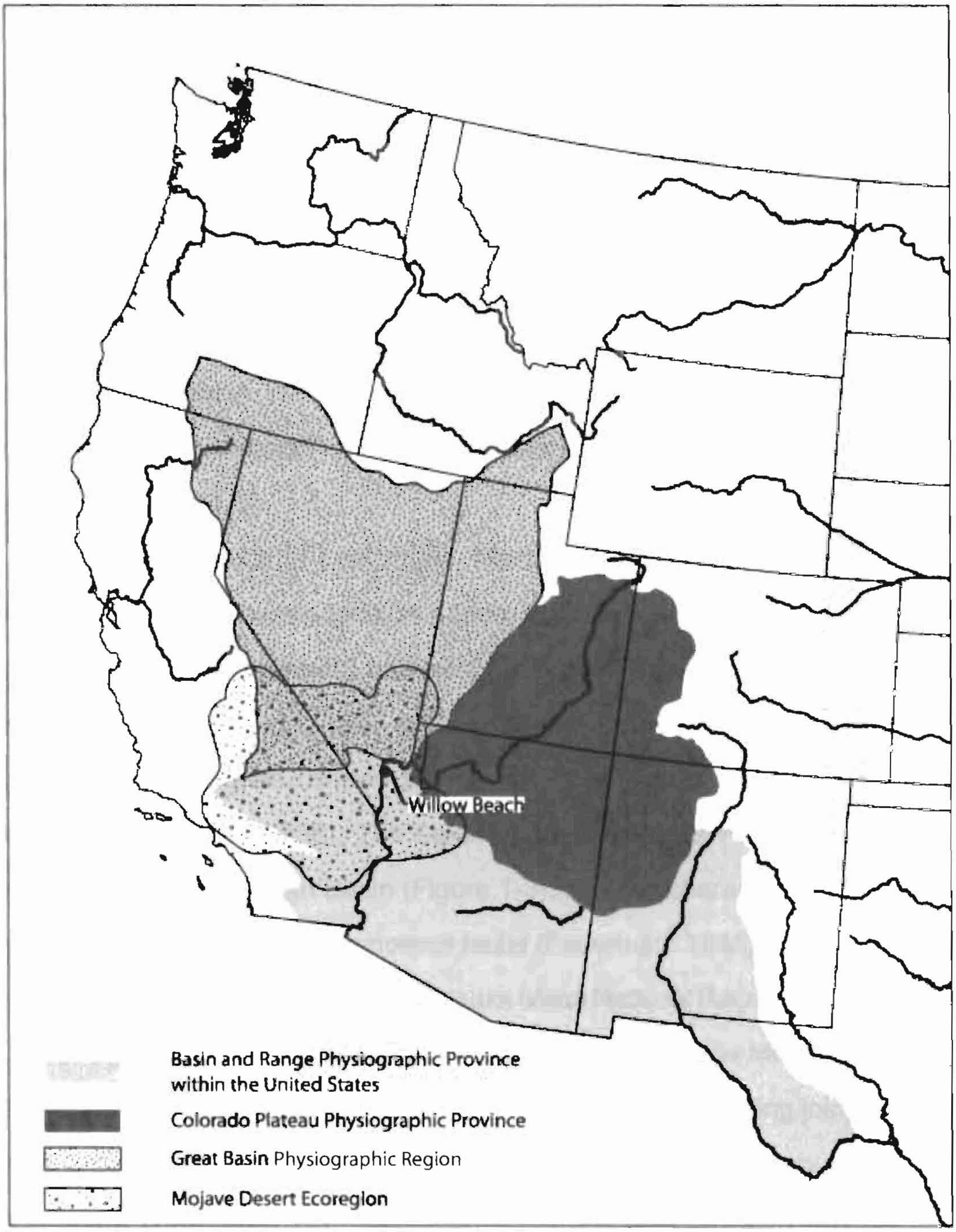


Figure 1-3. Major Physiographic and Ecological Regions in the Vicinity of Willow Beach, Arizona.

Geology

Regional Geologic Setting. Willow Beach lies within the Basin and Range Physiographic Province, south of the Sevier Orogenic Belt, east of the Mesozoic Batholith Belt (Figure 1-4), and west of the Colorado Plateau (Figure 1-3). Willow Beach is situated within the Lower Colorado River Extensional Corridor between the Eldorado Mountains to the west and the Black Mountains to the east (Faulds and others 1988, 1990) (Figure 1-5). West of the Eldorado Mountains lie the McCullough Mountains. The Eldorado Mountains are separated from the McCullough Mountains by the Eldorado Valley. Detrital Valley lies on the east side of the Black Mountains (Figure 1-5).

Near the latitude of Las Vegas, Nevada, the Basin and Range Province narrows. Regionally, the topographic pattern in this area is one of high flanks to the west (Sierra Nevada batholith) and east (Colorado Plateau) enclosing two broad low-lying areas (Pahrump Valley and Las Vegas Valley) separated by a median high (Spring Mountains, Sheep Range, and Las Vegas Range) (Figure 1-5) (Wernicke and others 1988). The Lake Mead–Las Vegas Region lies near the southern edge of the Great Basin (Figure 1-3), an area characterized by Tertiary-aged low-angle and high-angle normal faults (Feuerbach 1986).

North of Willow Beach, within the Lake Mead National Recreation Area (Figure 1-1), lies the junction of the Las Vegas Shear Zone and the Lake Mead Fault System (Figure 1-5). The Lake Mead area lies across a northeast-trending join between a broad area of thick Paleozoic, Mesozoic, and Tertiary sedimentary rocks to the north and a broad area of Precambrian crystalline and Tertiary volcanics to the south (Anderson 1973). The Lake Mead Fault System (a left-lateral strike-slip fault zone) and the Las Vegas Shear Zone (a right-lateral strike slip fault zone) are

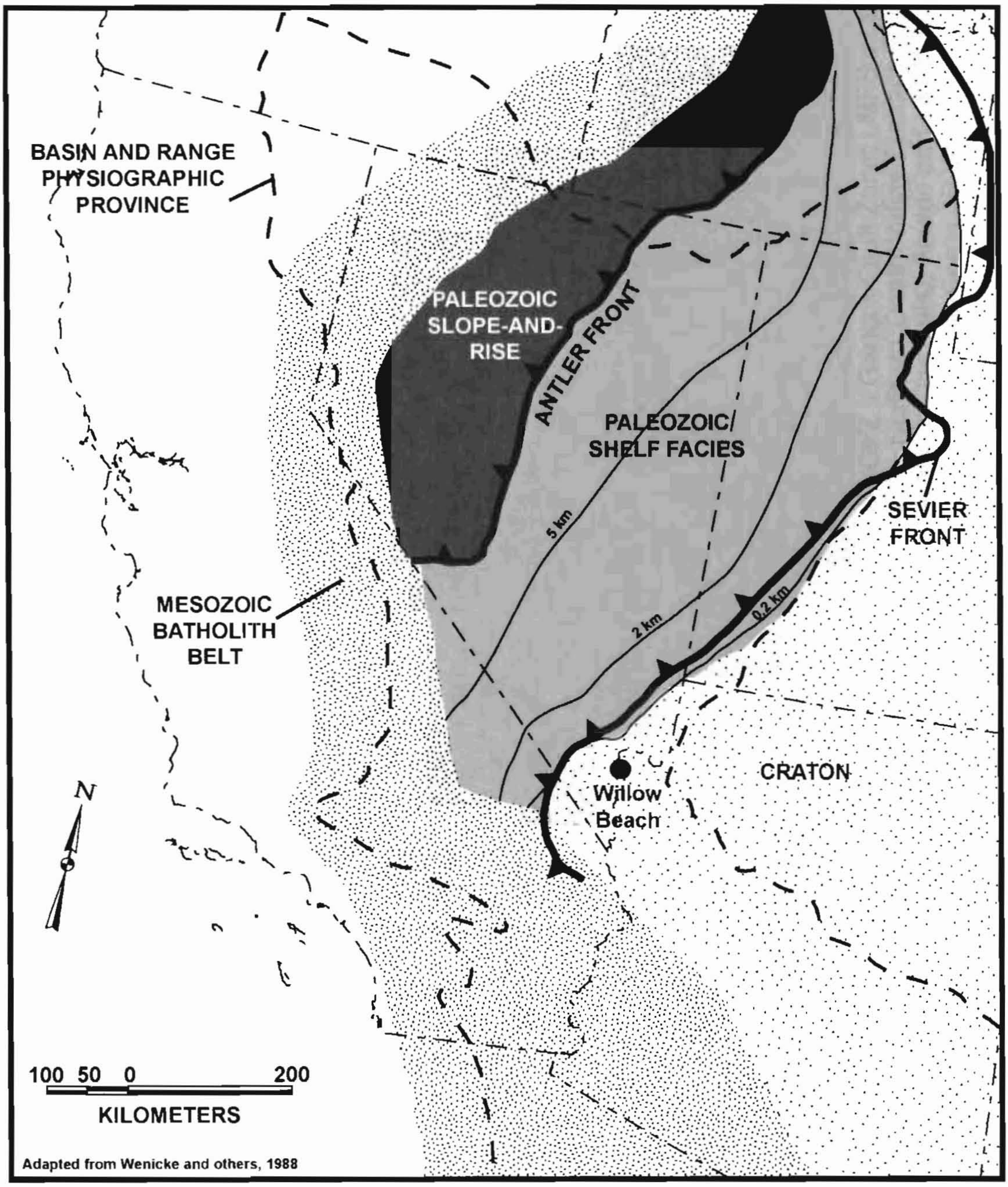


Figure 1-4. Generalized Geologic Setting of the Western United States.

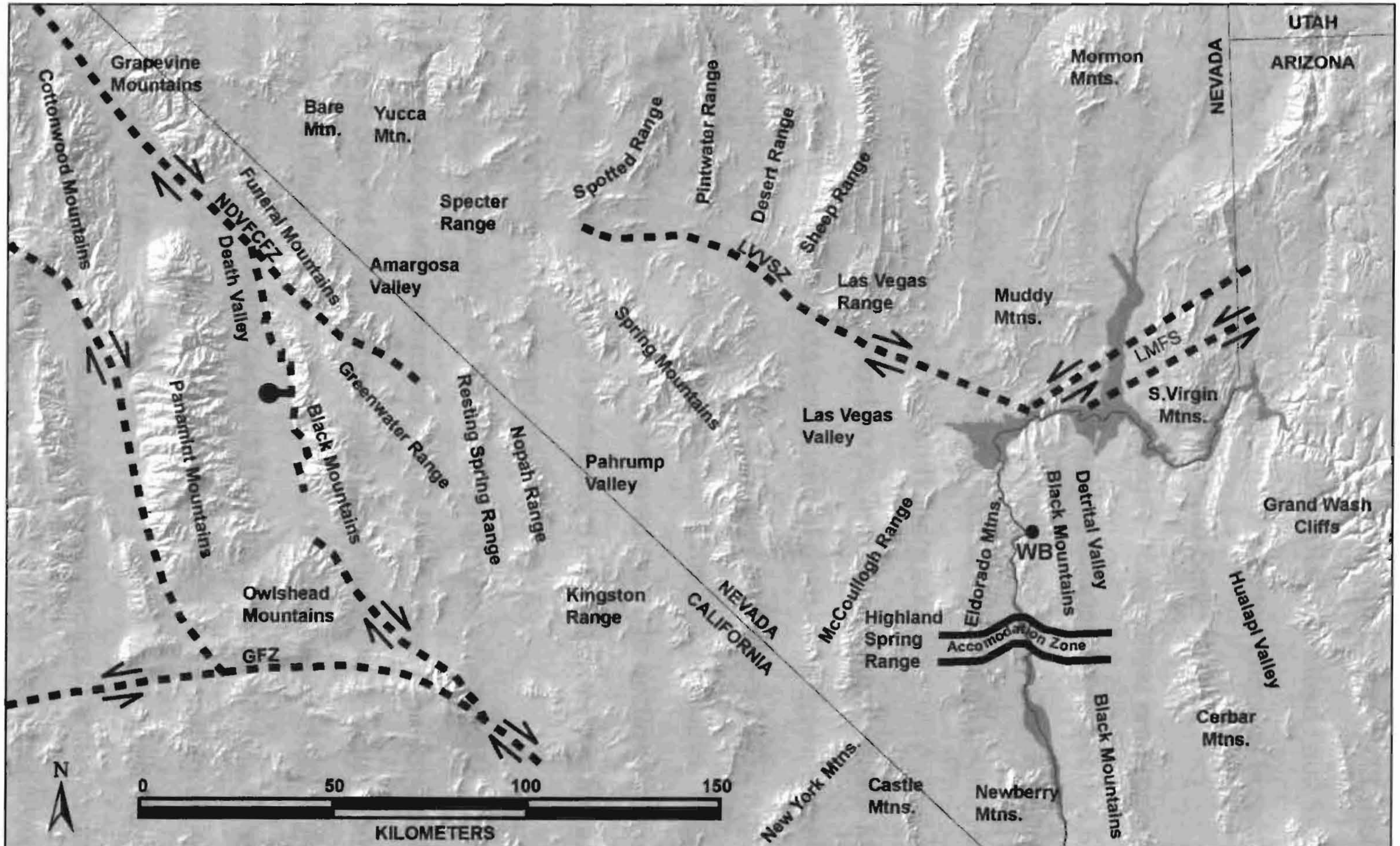


Figure 1-5. Geologic Setting Near the Latitude of Las Vegas, Nevada (GFZ = Garlock Fault Zone; LMFS = Lake Mead Fault System; LVVSZ = Las Vegas Valley Shear Zone; NDVFCFZ = Northern Death Valley-Furnace Creek Fault Zone). Adapted from Applegate and Hodges 1995, Axen and others 1990, Carr 1990, Faulds and others 1990, Guth 1990, Holm and others 1994, Rowland and others 1990, Turner and Glazner 1990, Serpa 1990, Spencer 1990, and Wernicke and others 1988.)

representative of upper plate transfer faults (Anderson 1973, Bohannon 1979, Feuerbach,1986, Weber and Smith 1987). The Lake Mead Fault System is thought to turn to the south into the Eldorado Valley where it changes from strike-slip faults into west-dipping dip-slip faults (Weber and Smith 1987).

Geologic History. In the Las Vegas—Lake Mead area rocks from all of the four major divisions of geologic time, Precambrian (from about 4.5 billion to 540 million years ago), Paleozoic (from 540 million to 248 million years ago), Mesozoic (from 248 to 65 million years ago), and Cenozoic (from 65 million years ago to the present) are represented (Tingley and others 2001).

Precambrian. The oldest rocks in the Las Vegas—Lake Mead area are Precambrian basement units comprised of gneiss and schist which date to about 1.7-1.8 billion years ago (Fiero 1986, Tingley and others 2001). Approximately 1.4 billion years ago, large amounts of granitic magma were forced or melted up into the metamorphic basement. It is believed that this occurred during a period of possible continental rifting and widespread igneous activity in the ancestral North American continent (Tingley and others 2001).

Paleozoic. During the Paleozoic (from about 540 to 248 million years ago), southern Nevada and the eastern Great Basin were at the edge of North America and were covered by a shallow tropical sea (Fiero 1986, Tingley and others 2001). The earliest Paleozoic rocks deposited on this continental shelf setting were clastic sedimentary rocks. Beach deposits (Tapeats Sandstone; late Proterozoic, 520 - 600 my) were followed by the deposition of shale containing abundant trilobites (Pioche Shale, Lower Cambrian). However, the Paleozoic in southern Nevada was mainly an era of geologic quiescence and nonclastic sedimentary deposition, marked by slow accumulation of limestone and dolomite in ancient shallow tropical seas that were similar to shallow parts of the present-day Caribbean. During the Permian, sandstone and gypsum deposition predominated. The Toroweap and Kaibab Formations, which mainly consist of limestone with abundant brachiopod and crinoid fossils, also contain sandstone and shale with associated gypsum beds.

Mesozoic. Significant regional tectonic changes occurred during the Mesozoic. In the early Mesozoic, an eastbound oceanic plate began subducting beneath the westerly moving North American Plate. This resulted in intense magmatism which produced the granitic batholiths of the Sierra Nevada Range. The subduction also caused compression of rocks laid down by the Paleozoic sea. During this time, the Las Vegas—Lake Mead Region experienced uplift, large-scale folding, and thrust faulting (Tingley and others 2001).

The sedimentary deposition environment of southern Nevada changed from marine to continental. The Moenkopi Formation (Triassic) contains marine fossils that mark the last time southern Nevada was under the ocean. The Chinle Formation (mainly clastic continental rocks that contain remains of ancient forests) and Aztec Sandstone (thick eolian deposits) followed.

Cenozoic. The Pacific and Farallon oceanic plates continued to subduct beneath the North American Plate during the early part of the Cenozoic (Tingley and others 2001). During this time, North America began undergoing extensional deformation. Rocks were tilted, folded and broken by faults. East-west displacement associated with this tectonic activity is estimated to be about 200 km in southern Nevada.

Then during the late Cenozoic, the Pacific oceanic lithosphere changed its movement from collision and subduction to right-lateral shearing. This oblique movement signaled the beginning of extensional deformation in the area west of the Colorado Plateau. This area began to be literally pulled apart. The rocks were tilted, folded, and broken by faults during this deformation. This shearing resulted in extensional forces that produced the mountain ranges and intervening valleys that are characteristic of the present-day Basin and Range Province. This crustal extension resulted in the deposition of clastic and non-clastic sedimentary rocks in fault-bounded basins in the area between about 17 and 10 mya. Between about 17 and 5 mya, volcanic activity occurred in the Las Vegas—Lake Mead region as magma rose from deeper in the crust and upper mantle into the thinned crust.

Rock Units in the Vicinity of Willow Beach. To aid in determining whether temper found in Willow Beach ceramics is locally derived, it is necessary to become familiar with rock units in the vicinity. These units include Precambrian metamorphics, Tertiary igneous units, Tertiary sedimentary units, and Quaternary alluvium (Figure 1-6). The units displayed in Figure 1-6 and described below have been adapted from Anderson 1978; Reynolds 1988; and Stewart and Carlson 1978.

> **Qa -Quaternary Alluvium.** Older surficial deposits (Pleistocene and late Pliocene)—Alluvium with minor talus and eolian deposits. Playa deposits (Holocene and Pleistocene). Playa, marsh, and alluvial-flat deposits consisting of silt, clay, salt, and sand; locally include lacustrine deposits. Surficial deposits (Holocene and Pleistocene)—Alluvium, colluvium, lake, and terrace deposits; locally includes sand and glacial deposits. On east flank of Black Mountains predominantly sheet form

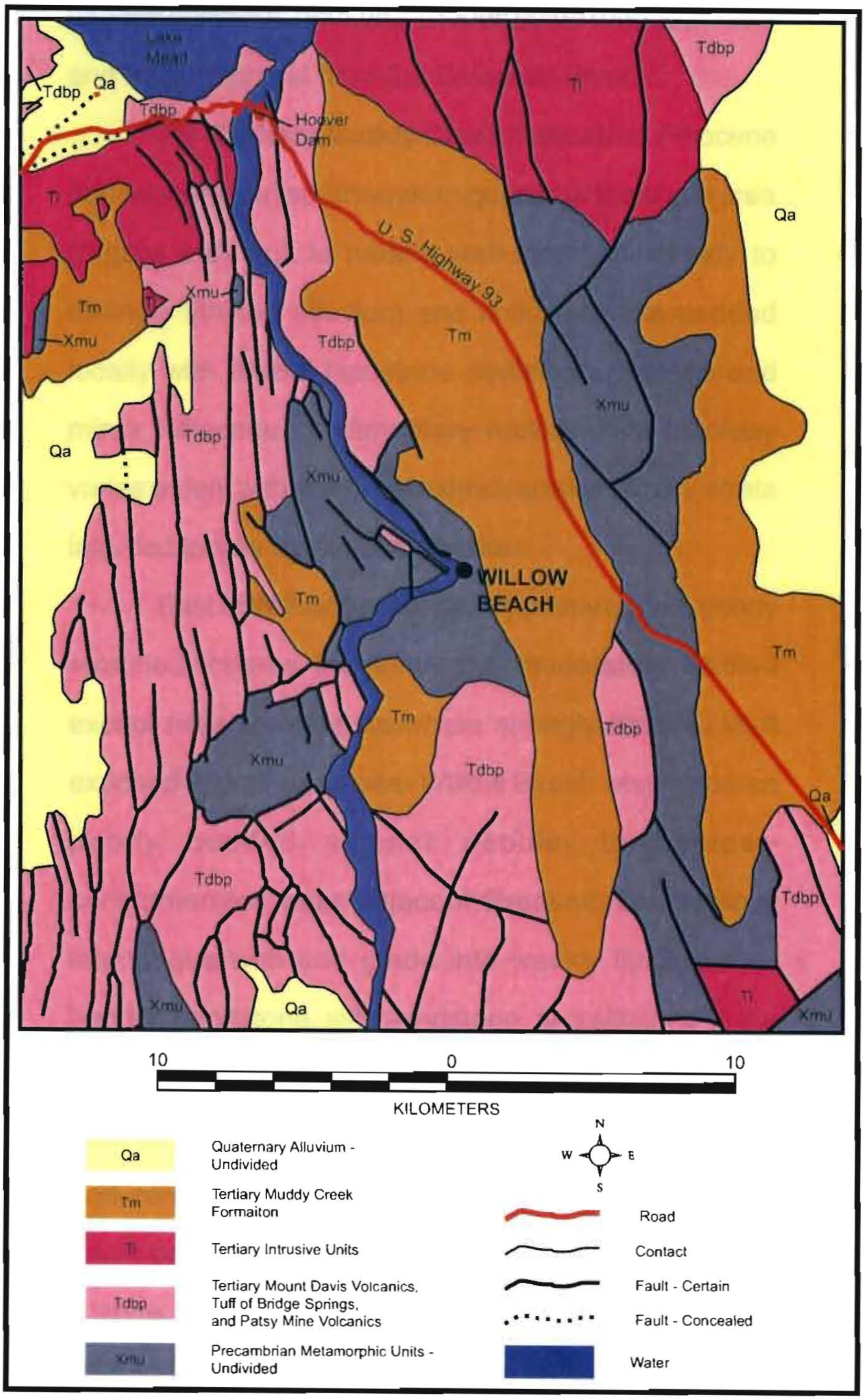


Figure 1-6. Generalized Geologic Map of Willow Beach Vicinity (Adapted from Anderson 1978; Reynolds 1988; and Stewart and Carlson 1978).

bedded unlithified detritus, includes some rounded clasts and beds of gravel from the Colorado River.

Tm -Tertiary Muddy Creek Formation (Pliocene and Miocene). In southwestern quarter of the study area (Figure 1-6) unit is mostly well-stratified weakly to strongly lithified alluvium and colluvium interbedded locally with friable lacustrine sedimentary rocks and minor tuffaceous sedimentary rocks); clast lithology varies widely with adjacent bedrock source terrain, strata intruded locally by sandstone dikes.

East of Willow Beach, mostly poorly sorted, poorly stratified, coarse fanglomerate, moderately lithified except near some faults where strongly lithified. Well exposed in drainages near Willow Beach where coarse poorly bedded angular pebble- to boulder-conglomerates near adjacent Precambrian bedrock intertongue with and grade into weakly lithified thin-bedded sandstone, silty sandstone, and siltstone to the east; fine-grained sedimentary rocks predominate in outcrop area; they include minor thin beds of gypsum and carbonate. Near Willow Beach, the contact with upper part of the Muddy Creek Formation is marked by a zone of very coarse Precambrian rubble, probably related to the emplacement of the megabreccia mass. Megabreccia masses described by Longwell (1951, 1963), the main mass in northwestern part of they study area (Figure 1-6), about 1.5 km north of Willow Beach, is composed of Precambrian landslide debris stripped from the Black Mountains. Southwest of Willow Beach, megabreccia masses that were probably derived from west lie at base of Muddy Creek Formation; the northern mass there consists of landslide lens of Precambrian megabreccia overlain by a lens consisting of Tertiary volcanic megabreccia. Fortification Basalt Member:

Lavas intercalated with and overlying the sedimentary rocks of the Muddy Creek Formation; mostly thin flows of dark-gray to black olivine basalt having typical oxidized and brecciated contact zones. Thin flows are commonly glassy and vesiculated throughout. Flows in which olivine phenocrysts predominate are especially common in younger; olivine is sparse in some flows, augite and olivine are in subequal amounts in some.

Ti - Tertiary Intrusive Units (Miocene)

Intrusive rocks (Miocene and Oligocene): Aphanitic, porphyritic, and coarsely granular rocks ranging in composition from diorite to granite. Granitoid plutons (Miocene to latest Eocene; 14 to 38 Ma)—Mostly granite and granodiorite.

Plutonic rocks: Exposures in northwest corner of study area (Figure 1-6) are part of large composite Boulder City pluton (Anderson 1969). They include about equal amounts of medium-grained granodiorite of diverse mineral composition and complex fine-grained to aphanitic border facies of predominantly andesitic composition. Exposures in north-central part of quadrangle are part of large composite Wilson Ridge pluton (Anderson and others 1972); rocks range from sparse very light-gray leucocratic biotite granite through abundant gray faintly foliated hornblende-biotite granodiorite to sparse dark gray pyroxene-biotite diorite; mafic rocks contain as much as 30 percent dark minerals and are most abundant near margins of pluton along with siliceous aplites and pegmatites. Accessory minerals vary widely in abundance and include iron oxides, sphene, allanite, apatite, and zircon; abundant accessory yellow sphene grains are visible megascopically in many rocks.

Dikes: Undifferentiated dikes ranging from rhyolite to basalt. Most are probably equivalent to extrusive rocks of Fortification Basalt Member of Muddy

Creek Formation and Mount Davis Volcanics but some may be older.

Tdbp: Tertiary Volcanics including Mount Davis Volcanics, Tuff of Bridge Spring, and Patsy Mine Volcanics

Mount Davis Volcanics (Miocene):

Mafic lavas and flow brecicas: Gray, dark-gray, and purplish-gray olivine-bearing basalt and basaltic andesite, mostly thin flows 10-30 feet (3-9 m) thick but locally as much as 250 feet (76 m) thick, some thick flows have well-developed crystalline interiors.

Rhyodacite and dacite lava and flow breccia: Gray, yellowish-gray, brown, and reddish-gray massive cliff-forming biotite- and hornblende-bearing lavas generally having pale-yellow, light-gray, or beige vitric or zeolithized slope-forming lower parts that are commonly brecciated. Some flows contain gray vitrophyre zones. Unit locally includes tuffaceous sedimentary rocks.

Tuff of Bridge Spring (Miocene):

Isolated masses of faulted and brecciated, welded to nonwelded, quartz-free rhyolitic ash-flow tuff; mostly gray to pale-red rock having about 20 percent phenocrysts and common purplish-gray andesitic lithic inclusions.

Patsy Mine Volcanics (Miocene):

Upper part: Dark-purplish-gray pyroxene-olivine andesite lava exposed only southwest of Malpais Flattop Mesa. Middle part: Rhyolite lavas and tuffaceous sedimentary rocks undivided, mapped east of Copper Basin. Together with its subdivided units the rocks are probably direct correlatives with the middle part of Patsy Mine Volcanics in type locality northwest of Nelson, Nevada (Anderson 1971).

Rhyolite lava of middle part: Lobate and lenticular bodies of rhyolite lava that form brown to dark-brown cliffs and bold knobs. Core zones are massive resistant gray to reddish-gray devitrified or crystalline porphyritic rock that grades outward in all directions to envelopes of yellowish-gray weakly resistant crumbly weathering zeolithized rhyolite that is commonly brecciated. Zones of gray to dark-gray vitrophyre commonly separate the crystalline core zone from the zeolithized base. Entire mass is zeolitized at the distal ends. Most rock is crystal-poor quartz-free two-feldspar rhyolite but includes biotite-hypersthene-augite rhyodacite or dacite.

Sedimentary rocks of middle part: Predominantly pale-yellow highly lithified zeolitized tuffaceous sedimentary rocks that contain sparse to abundant pumice lapilli and volcanic lithic clasts, probably mostly of rhyolithic composition. Unit includes minor tuffaceous sandstone and pebble- and cobble-conglomerate. Light-gray to white vitric tuffs are very sparse.

Lower Part: Numerous flows of dark-purplish-gray andesite lava and breccia. Basal contact with Precambrian metamorphic rocks (Xmu) generally complicated by faults, but locally a few tens of feet (meters) of prevolcanic clastic rocks separate the volcanic and metamorphic rocks. Unit contains some strata that are probably laharic or mudflow breccia. Most flows are pyroxene-olivine andesite.

Volcanic rocks undivided: Almost wholly andesitic lava and breccia generally similar to and in most areas probably correlative with rocks of lower part. As with lower part the basal contact is generally complicated by faults but locally is marked by a few tens of feet (meters) of prevolcanic clastic rocks. Rocks in south-central and southeast parts of quadrangle are probably parts of a single lava pile separated by fault displacements; although mostly andesitic they are lighter colored, more siliceous (biotite- and hornblende-bearing rocks are common), contain fewer breccias, and are more varied texturally and mineralogically than rocks of lower part to the west with which they are probably coeval.

Xmu -Precambrian metamorphics – undivided:

Variagated metamorphic rocks: Predominantly biotite-garnet gneiss and schist and garnetiferous granite pegmatite, some rocks contains sillimanite or hornblende. Mostly segregated into bands of gray granite gneiss and schist a few feet (meters) to many tens of feet (meters) thick that alternate with bands of massive pink to white coarse- to medium-grained granite pegmatite and dark-gray, dark-greenish-gray, or black mafic segregations. Hornblende is common in mafic segregations but sparse in most gneiss.

Schistose and phyllitic rocks: Greenish-brown, greenish-gray, and gray banded to highly foliated biotite or biotite-hornblende schist, augen schist, and phyllonite.

Hornblende-biotite gneiss: Mostly medium-gray evenly foliated or banded gneiss containing conspicuous hornblende and little or no garnet. Contains pods, lenses, and layers of granite pegmatite and amphibolite in highly variable amounts. Stippled overprint indicates where unit is predominantly granite pegmatite. Similar map-unit rocks occur elsewhere but are not mapped separately.

Archaeology

Cultural Traditions of the Southwest United States

The oldest archaeology in the southwest dates to the end of the last major Pleistocene glaciation. These groups are known to archaeologists as Paleoindians and were among the first inhabitants of the Americas (Cordell 1984). The climate of the southwest during the terminal Pleistocene was much more temperate than it is today. There are few cultural remains left by the Paleoindians. Archaeologists, however, have been able to determine from their tool technologies that they were hunter-gatherers and that they are likely the ancestors of later Southwestern peoples (Cordell 1984).

By the end of Pleistocene to about A.D. 100, Southwestern peoples began cultivating domestic crops to supplement their hunting and gathering. Archaeologists refer to these people as living in the Archaic period. Archaeologists working in the southwest United States have defined three major cultural traditions and a few minor ones, that follow the Archaic period. The three major archaeological traditions are Anasazi, Hohokam, and Mogollon (Figure 1-7; Cordell 1984). The Patayan tradition, the culture that produced ceramics found at Willow Beach, lies to the west of these, and is less well known.

The Patayan tradition is represented by sites along the lower Colorado River, from the Grand Canyon to the Gulf of California and adjacent upland areas (Figure 1-5). Patayan ceramics were finished by paddle and anvil techniques, and most were unpainted (Cordell 1984). Patayan ceramics were apparently somewhat casually fired, and surface colors range from buff to gray. Most archaeologists agree that, in a general way, the Patayan tradition was ancestral to the modern Yuman-speaking peoples (Cordell 1984).

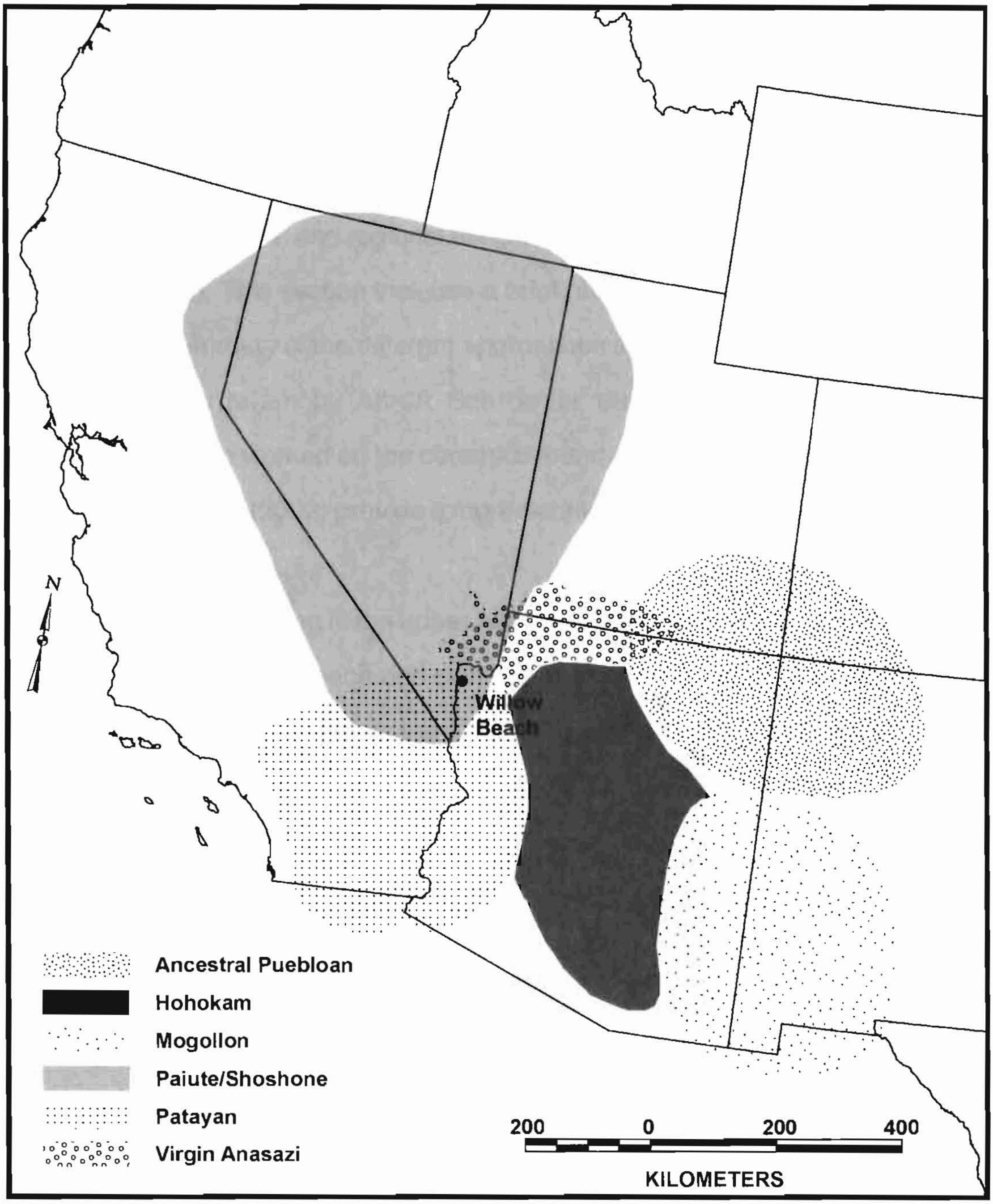


Figure 1-7. Selected Prehistoric Ceramic Cultures of the Southwestern United States (After Rager 2003).

Lower Colorado Buff Ware and Excavations at Willow Beach

Historically, there have been two opposing approaches to building a workable typology for Lower Colorado Buff Ware (Seymour 1997). Each approach attempted to define primary variables in assigning ceramics to meaningful types. The history of categorizing prehistoric ceramics in the Lower Colorado River region is anchored in politics, personalities, and regional allegiance to ideas (Seymour 1997, Seymour and Rager 2002). This section includes a brief history of excavations conducted at the site and a summary of the different approaches and interpretations of the Willow Beach ceramics taken by Albert Schroeder and Malcolm Rogers, the two archaeologists who worked on the ceramics found at this site. Seymour (1997) and Seymour and Rager (2002) provide a more detailed account of the dispute between Schroeder and Rogers.

Because of flooding in the upper reaches of the Lower Colorado River during the early 1930s, Willow Beach and several other archaeological sites south of the Hoover Dam were excavated by the Civilian Conservation Corps (Seymour 1997). Mark Harrington excavated the site in 1936 (Figure 1- 8). In 1947, Gordon Baldwin excavated the site. Baldwin dug a 2.3 m^2 area adjacent to Harrington's excavation (Figure 1-8). Baldwin first attempted to define the site's stratigraphy. Unfortunately, Baldwin's field notes were incomplete and neither he nor Harrington ever wrote up the results of their research (Seymour 1997).

In 1950, Albert Schroeder (1950a, 1950b, 1950c) excavated two large trenches adjacent to the previous excavations of Harrington and Baldwin (Figure 1-8). His research may be considered as a pioneering effort in this region of the southwestern United States (Seymour 1997). Schroeder synthesized results from the two previous investigations and concluded that Willow Beach was a campsite

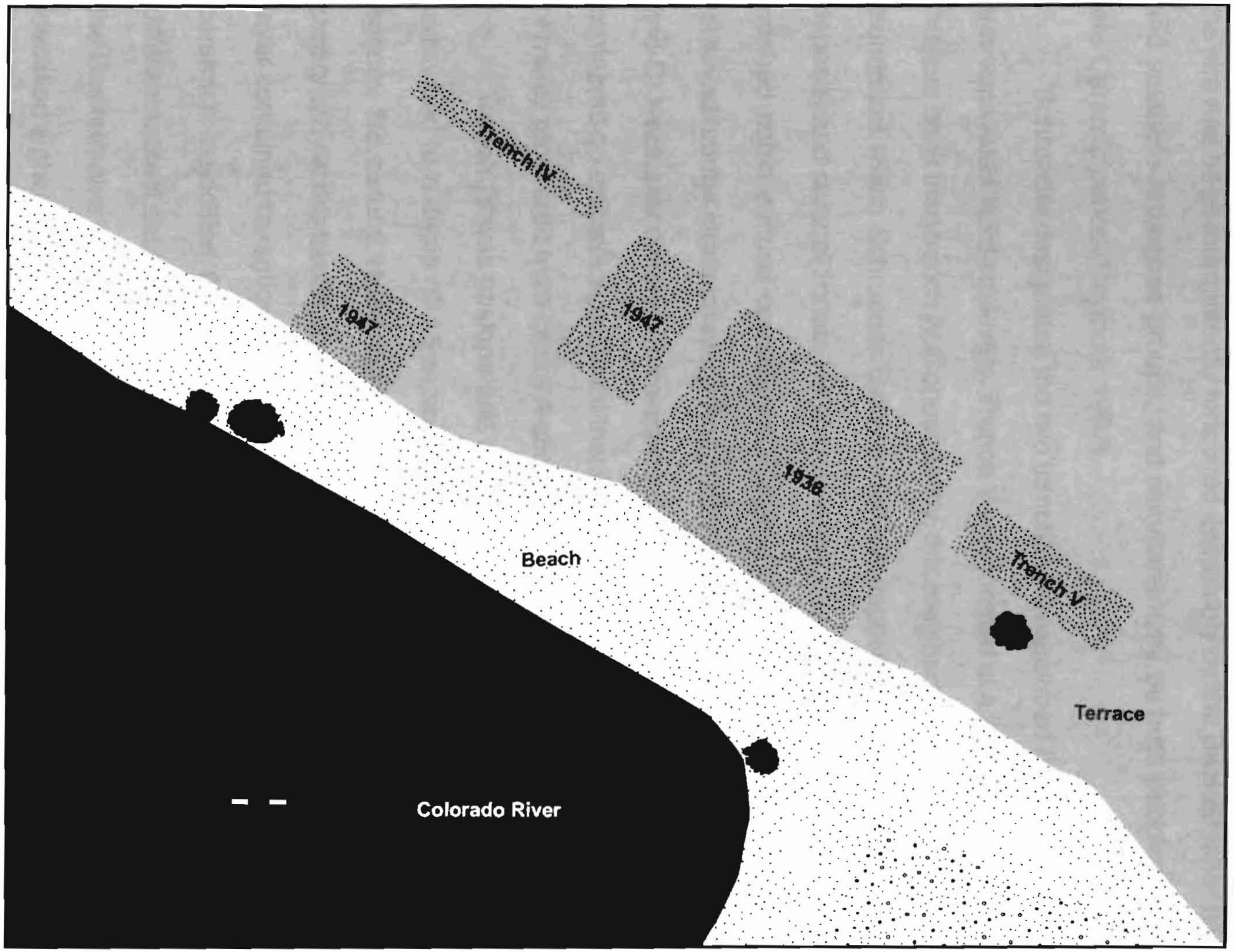


Figure 1-8. Excavations at Willow Beach, Arizona (Adapted from Schroeder 1950a).

during the Archaic and Ceramic Periods located along a travel corridor linking the southern Great Basin area to the Mojave Desert (Figure 1-2). According to Schroeder, the site had been intermittently inhabited separately by the Basketmaker II people and southern Amargosa groups, and simultaneously by both peoples during the late Ceramic period (Seymour 1997).

Schroeder designated the two trenches he excavated IV and V. Each trench was excavated in 25-cm levels. Trench V was located at a lower elevation closer to the river bank than trench IV. Consequently, this area had been subjected to periodic inundation which Schroeder believed left silt deposits that sealed some cultural deposits and cultural zones. He also believed that the periodic flooding may have washed some cultural components away at this location. Within each level, he removed natural strata in layers designated A through O. The top three layers (A, B, and C) were associated with ceramics. All other layers were either preceramic or contained no artifacts. A buffware that Schroeder designated as Pyramid Gray was primarily recovered from layers A and B in Trench V.

Trench IV was upslope and not subject to period flooding. This trench was excavated to a depth of 1.5 m and contained a homogeneous matrix from top to bottom. No natural stratigraphy was present in this trench. Despite the lack of stratigraphy at this trench, Schroeder identified two cultural layers. The upper cultural layer contained ceramics and lithics while the lower layer contained lithics and no ceramics. In addition, the upper and lower horizons of Trench IV contained distinctly different artifact assemblages. Schroeder believed the distinctions were related to the Basketmaker II/Archaic and ceramic period occupations. Although Schroeder identified eight ceramic wares affiliated with several cultural groups, he focused his studies on Pyramid Gray.

Schroeder believed ceramic types can be linked to specific ethnic groups. Schroeder identified Pyramid gray ceramics at Willow Beach and linked them to the Hakataya. He defined Hakataya as separate from Hohokom and included Yuman and non-Yuman speaking peoples in this group. Schroeder (1952) attributed the prehistoric Lower Colorado Buff Ware ceramic complex to the Laquish branch of Patayan Culture. Schroeder (1958) later split Patayan culture into two branches identified as Upland and Lowland Branches of the Hakataya Culture. The Lowland Branch included the Lower Colorado River. Schroeder suggested that this branch be further subdivided. He referred to areas south of Blythe as the Palo Verde Branch. Willow Beach lies within the area north of Blythe and south of the Hoover Dam which Schroeder referred to as the Amacaua Branch. Schroeder confined the term "Patayan" to the Upland Patayan of western Arizona.

Based on his excavations at Willow Beach, Schroeder (1952, 1958) came to the conclusion that ceramics in the region were first manufactured in southern Nevada. This conclusion was based on intrusive sherds recovered from Willow Beach found in association with Pyramid Gray. These sherds were found in levels assigned to the end of the Willow Beach phase dating to A.D. 900 - 1150. Schroeder classified ceramics based on temper. Based on the ceramics he found at Willow Beach, he believed ceramic production along the Lower Colorado River began here.

In the 1950s, Malcolm Rogers worked at the Museum of Man in San Diego, California (Cordell 1984). He did work on tens of thousands of sherds and complete vessels from the western deserts of the United States and in Mexico. He believed that ceramic types could be linked to specific chronologic periods by comparing spatial relationships of sherds to trail segments and excavation data . After studying the ceramics excavated by Schroeder, Rogers came to different conclusions concerning their typology and significance (1966).

He identified late prehistoric complex in the Lower Colorado River region as Yuman. He divided Yuman cultures into three periods: Yuman I (A.D. 800 - 1050), Yuman II (A.D. 1050 - contact with the Spanish), and Yuman III (~A.D. 1600 - present). Furthermore, he believed the cultural attributes of Yuman and Patayan peoples were derived from a Mexican root. Rogers categorized ceramics based on vessel form and manufacture technique. He believed that ceramics along the Lower Colorado River began in Yuma.

Rogers (1945) believed that the ceramics along the Lower Colorado River were first introduced during the Yuman I period. He believed that Yuman II ceramics were made by local populations in the Mojave and that the Yuman II and III periods were marked by an increase in the paddle and anvil buff ware. Rogers also believed that the Mojave River was a trade route between the Lower Colorado River and the southern California coast.

CHAPTER 2: BACKGROUND

Introduction

At the most basic level, ceramic studies should include a description of components of a ceramic body (Vince 1999). Ceramic petrology may be conducted to describe, classify, and source ceramics. Petrology is the study of rocks and minerals and is based on the identification of minerals and their associations. Ceramic petrology is a specialized subdiscipline that uses the same techniques and knowledge to study prehistoric ceramics (Vince 1999). Ceramic petrology can be used to study clay and temper preparation, which is an important part of ceramic production (Shepard 1985, Vince 1999). Furthermore, ceramic petrology can be used to test the hypothesis that ceramics from two separate archaeological sites were obtained from the same source (Vince 1999). In some cases, it can be used to pinpoint the source of the raw materials.

The focus of this thesis is the petrology of temper used in Patayan ceramics found at Willow Beach, Arizona. Therefore, this chapter describes the purpose of temper analysis, temper analysis methods, interpretation of data yielded from such studies, and some previous studies dealing with temper analysis.

The Purpose of Temper

All pottery is made from a mixture of clay minerals and other particles smaller than 0.1 mm, which form a paste and temper. Temper is a non-plastic granular material, generally greater than 0.1 mm in diameter, added to paste by a potter. The essential role of temper is to counteract shrinkage during drying and firing (Shepard 1985).

When clay is fired, the clay minerals undergo vitrification, a process that gives the vessel strength. Temper actually weakens a vessel. Despite this drawback, temper is used because it reduces shrinkage and facilitates drying, resulting in reduced strain and risk of cracking during the firing process.

Selection of Temper

Primitive potters used a wide range of inorganic and organic materials for temper (Shepard 1985). Inorganic materials used as temper include sand, rock fragments, and crushed potsherds. Organic materials used as temper include shell, diatomaceous earth, sponge spicules, silica from burned bark, plant fibers, and feathers. Because ceramics from Willow Beach contain mineral and rock temper, the remainder of this chapter will deal with that type of temper.

Despite the abundance of sand, it is not used as temper as often as one might suppose (Shepard 1985). The bonding of clay and temper has a direct effect on the strength of the vessel body. Clay forms a stronger bond with temper that has rough surfaces. The result is that temper with a smooth surface, for example windblown sand, will weaken a vessel.

Whereas smooth sand is seldom used as temper, all three major classes of rocks are crushed and sorted for use as temper (Shepard 1985). Igneous rocks, including andesites, diorites, trachytes, basalts, tuff, and unconsolidated volcanic ash, are especially common. Common sedimentary rocks used as temper include sandstone, limestone, and dolostone. Common metamorphics are schist and gneiss.

Processing of Clay and Temper

Primitive potters processed mined clay by grinding it and separating inclusions and coarser particles (Shepard 1985). Clay was prepared in a variety of ways, but all primitive potters took care to remove coarse particles, which may cause a vessel to crack during drying or firing. Common methods for removing coarse particles include hand picking or grinding of clay in a mortar or metate. Temper and clay may have been ground together or separately.

According to Shepard (1985), the method of preparation of non-plastics is dictated largely by the nature of the material. Among primitive potters, there were many methods of preparing and adding temper. Clay shrinkage varies widely according to clay mineral composition and determines the amount of temper to be added. Primitive potters consider the color and stickiness of the clay paste when determining the amount of temper needed. The proportions of clay and temper are not precisely measured.

The Effects of Heat on Mineral Temper

Patayan ceramics were fired under primitive conditions at temperatures between 500 and 700° C (Lyneis 2001). The effect of heat on a material is an important factor in the choice of temper material (Shepard 1985). Some materials are stable at primitive firing temperatures while others undergo changes that weaken ceramic vessels. When minerals are heated during the firing stage they undergo physical and chemical changes including dehydration, oxidation, reduction, inversion, decomposition, and fusion. Dehydration occurs in the lower temperature ranges and may be accompanied by swelling as water is converted to steam. Oxidation and reduction are controlled by the firing atmosphere and may have an important effect on color. These processes occur at a wide range of temperatures. Inversion is a physical change in atomic structure that takes place at different temperatures and varies with mineralogy. Decomposition also occurs over a wide temperature range and varies with mineralogy. Fusion, or melting, of temper occurs only at the highest firing temperatures. A discussion of the changes that occur in several common types of minerals during firing follows.

Feldspars are the most common minerals that are stable at the temperatures achieved under primitive firing conditions (Shepard 1985). Two varieties of feldspar undergo inversion at 900° C, but this temperature is well outside the range of firing temperatures obtained by the Patayan. Quartz, a major constituent of common tempers, is stable during firing. Quartz has three reversible inversion points (Shepard 1985). One of these inversion points is at about 572° C, which is within the range of primitive firing temperatures seen at Willow Beach. Volcanic glass is a common temper that undergoes no change during firing (Shepard 1985). Dehydration of muscovite during firing is accompanied by swelling. This swelling occurs well within the range of primitive firing temperature. However, flakes of muscovite are usually not large or numerous enough to weaken a vessel.

In addition to temper and paste, ceramics often contain voids. A void is an empty space in a ceramic vessel wall. Voids in a vessel are usually treated as a form of inclusion and, in many cases, are actually left when an original mineral inclusion has dissolved or disintegrated (Vince 1999). Lenticular voids never contain inclusions and are a byproduct of the clay preparation process. These voids are laminae between aligned clay particles in the vessel wall (Lyneis 2001). They may be relicts of the original stratification of the clay bed or created by the folding in of air during the preparation stage (Vince 1999).

Temper Analysis and Ceramic Sourcing

There are three ways temper analysis can reveal the source of ceramics (Vince 1999). The first and simplest method is when the sampled sherd or vessel contains a distinctive rock or mineral type that occurs naturally in a small area. The second method is to demonstrate that a sherd or vessel contains rocks or minerals that do not occur naturally in the area where the artifact was discovered. This situation usually results in a range of possible source locations and may be an indication that the ceramics in question were traded. The third method is to compare the temper of wares from a known kiln source with the temper from a consumer site. The problem with this method is that it generally cannot confirm that ceramics from a consumer site were produced at the kiln site. This method can only show that the ceramics may have been manufactured at the kiln site in question.

Temper Analysis Methods

Ideally, ceramic petrographic studies involve a hierarchical approach. Initially a relatively large number of sherds are surveyed by looking at the mineralogy of temper with a hand lens along the edge of sherds or the cut edge of a vessel. The vessels and sherds are then preliminarily classified and samples are selected from each group for more detailed petrographic analysis.

These new groups are examined in more detail using a binocular microscope. In some circumstances a binocular microscope may be inadequate for fully describing the mineralogy of the temper. In this case, a petrographic microscope is used. During analysis, ceramic classes may be redefined and vessels and sherds may be reclassified. Before proceeding with the discussion of ternper analysis methods, a description of the basic operation and capabilities of a petrographic scope is required.

Petrographic Microscope

From bottom to top, a petrographic microscope (Figure 2-1) consists of an illuminator, substage assembly, stage, objective lenses, upper polar, Betrand lens, and oculars (Nesse 1991). The sub-stage assembly consists of the lower polar, condensor lens, auxilliary condensor, Iris diaphragm, and sub-stage centering screw.

The light generated by the illuminator is ordinary light. Ordinary light (e.g., sunlight or light from a light bulb) is unpolarized, meaning it vibrates in all directions at right angles to the light's direction of propagation (Nesse 1991). Before the light reaches the stage, it passes through the lower polar. The lower polar usually consists of a piece of optical-quality polarizing film and functions to produce plane polarized light. In plane polarized light, the light wave is transformed into a single sine wave with the vibrational direction lying within the plane of polarization.

Plane polarized light passes through minerals in thin section resting on the stage, then through the objectives, and is viewed through the oculars (Figure 2-1). The vibrational direction of the upper and lower polars are at right angles to each other. The position of the upper polar is controlled by the petrographer. When the upper polar is engaged, the polars are crossed.

Thin Sections

When viewed under crossed polars, minerals appear completely dark in some positions as the stage is rotated. This dark appearance is referred to as extinction

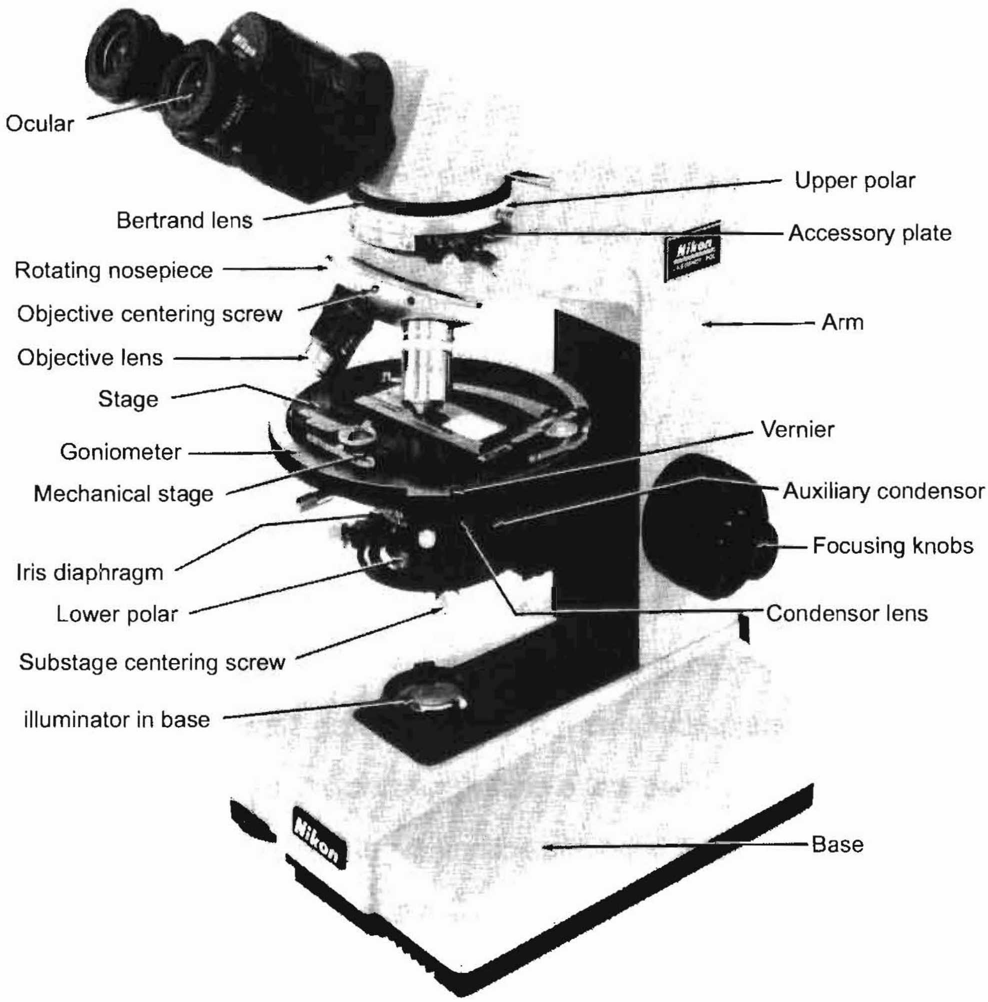


Figure 2-1. Petrographic Microscope Adapted from Nesse (1991).

and is an important optical property in identifying minerals. Under crossed polars, isotropic and anisotropic materials can be easily distinguished.

Isotropic materials include gases, liquids, glasses, and rock forming minerals in the isometric system (e.g., garnet). An optically isotropic material is one that shows the same velocity of light in all directions (Nesse 1991). Under crossed polars, isotropic materials appear completely dark, or extinct, at all angles of stage rotation.

Anisotropic rock forming minerals include minerals in the tetragonal, hexagonal, orthorhombic, monoclinic, and triclinic systems. Anisotropic minerals are distinguished from isotropic materials because the velocity of light passing through them varies depending on the direction the light passes through the mineral (Nesse 1991). Most of the light that enters anisotropic minerals is split into two rays with different velocities, called a fast and slow ray. When viewed under crossed polars, anisotropic minerals exhibit extinction when rotated on the microscope's stage. Unless the optical axis of the mineral happens to be vertical in relation to the stage, anisotropic minerals go extinct between crossed polars once in every 90°. This extinction may be sharp (occuring within a few degrees) or gradual (occuring over a relatively wide angle). If the extinction of a grain follows an irregular or wavy pattern, it is called undulatory extinction.

Another important optical property of minerals is pleochroism. When viewed in plane polarized light (upper polar out), many colored minerals (e.g., biotite) exhibit a change of color as the stage is rotated. This change, called pleochroism, is produced because fast and slow rays of light are absorbed differently by the colored mineral and therefore produce different colors (Nesse 1991).

Pottery may be examined with a petrographic microscope in thin section or in powdered form. Thin sections have many advantages over powdered form. Thin sections show the texture of paste and temper, the size and shape of grains, the proportions of paste to temper, and the proportions of minerals within the temper.

When using the petrologic microscope a distinction is made between temper and the paste. Paste is composed of clay minerals and other materials. For practical purposes, paste is generally considered to consist of clay minerals and other materials less than 0.1 mm in diameter.

In some cases it may be desirable to supplement microscopic techniques with microchemical studies. Such techniques include x-ray diffraction and neutron activation analysis. A discussion of these techniques is beyond the scope of this study.

Sampling Design

According to Glascock (2003), the number of samples to submit to petrographic analysis largely depends on the goals of the project. When the goal of the study is to search for subgroups within a ceramic type, a large number of analyses is required. This is because, for each subgroup to be large enough for statistical description, the data set as a whole has to be large. As a rough rule-of-thumb, ceramics projects of this type usually involve between 100 and 500 analyses. Raw materials (clay and temper) should be collected and analyzed if at all possible.

In contrast, Vince (1999) argued that no definite rules can be applied for the number of samples or how they should be taken for sourcing or characterization studies. Instead, he believes it is more important to know the archaeological and geological context of any work before settling on a sampling strategy. For example, Vince states that if a site is located in an area with a unique rock type, a single thin-section might be sufficient to demonstrate that a pot was tempered with rocks from that local source. In contrast, if ceramics found at a kiln site are being compared to those found at a consumer site, a minimum of five samples may be required from each site to fully describe the range of inclusions found to demonstrate a relationship between the two sites.

Previous Temper Analysis Studies in the Lower Colorado River Region

Ceramics along the Lower Colorado River are not well studied. After reviewing the literature, only two studies dealing with temper analysis of ceramics from archaeological sites near Willow Beach, Arizona were found. There studies were conducted by Colton (1939) and Tuohy and Strawn (1986).

Colton (1939) examined 13 sherds (#5570 - #5582) of Willow Beach ceramics with a hand lens. He characterized the temper used as abundant, large to medium, subangular and rounded quartz sand exhibiting bits of biotite mica and rare pieces of obsidian (glass).

Tuohy and Strawn (1986) conducted thin-section analysis on 35 potsherds from various parts of Nevada, Idaho, California, and the Baja Peninsula of Mexico. Twenty-eight of these sherds are from sites in Nevada. Three of the sherds from Nevada were recovered from sites north of Lake Mead in the Virgin River Valley. All sherds were thin-sectioned and examined under a petrographic microscope. Both black and white photomicrographs and 35 mm color sides were made of each thin section. In some cases, 35 mm slides were made under cross-polarized light as well. Tuohy and Strawn recorded the mineral constituents comprising the temper on 5- x 8-inch index cards. Tuohy and Strawn also noted whether the temper was very angular, angular, subangular, subrounded, rounded, or very rounded following Power's (1953) chart for visual estimation of roundness. Tuohy and Strawn also recorded temper size (in mm). Using a comparison chart for estimating percentage composition (Terry and Chilingar 1955), they estimated percentage of temper. Finally, on each index card they made note of the nature of the mineral inclusions visible in the thin section.

Tuohy and Strawn (1986) listed all the mineral constituents found in each sherd. They subdivided the sherds three groups: (1) sherds with volcanic temper, (2) sherds with granitic temper, and (3) sherds with temper other than volcanics or granite. Tuohy and Strawn noted that no single attribute measured or described for plain brown wares has been diagnostic. Several attributes, including temper, must be considered to separate ceramics into types. They also came to a conclusion frequently derived from thin-section analysis that the ceramic materials used by early people of the region reflect the local geology. Three of the four ceramic sherds from the Virgin River Valley analyzed by Tuohy and Strawn (1986) had volcanic temper (NSM 119, NSM 120, and NSM 121) while the fourth had granitic temper (NSM 114).

CHAPTER 3: METHODS

Introduction

In the 1950s, Albert Schroeder conducted excavations at Willow Beach. He integrated the findings from studies conducted by Harrington and Baldwin during the 1930s and 1940s into his own and published them in 1958. Schroeder classified a gray colored Buff Ware dating to AD 900-1150 as Pyramid Gray. Descriptions of Pyramid Gray are vague and consequently have long created confusion among researchers in the Southwest. This chapter includes a description of the methods used to analyze and describe the temper used in these ceramics.

Background

Archaeologists with the Lake Mead National Recreation Area recovered the Willow Beach ceramic collections from storage in the Western Archeological & Conservation Center (WACC) in Tucson, Arizona. The sherds had been recataloged by National Park Service (NPS) staff, but still retained the original type designations assigned by Schroeder in 1952. Greg Seymour, an archaeologist with the Las Vegas Valley Water District examined approximately 1,000 sherds that Schroeder classified as Pyramid Gray. Seymour collected some standard descriptive information on the sherds (e.g. color, temper, surface treatment) (Seymour and Rager 2002). After quantifying the information, Seymour determined that, in general, there were five overlapping broad groups in those sherds. Next, Seymour selected one sherd from each of the five groups that most typified that group (Seymour and Rager 2002).

Preparation of Thin Sections

Under the direction of the NPS personnel, the five sherds selected by Greg Seymour were sent to Quality Thin Sections (QTS) in Tucson, Arizona to be made into thin sections. Personnel at Quality Thin Sections cut each sherd so that the thin section would be a viewed tangential to the vessel wall rather than across the vessel wall. One half of each thin section was stained with a combination feldspar stain.

The combination feldspar stain includes a pink plagioclase stain and a greenish-yellow alkali feldspar stain. The intensity of the pink plagioclase stain is proportional to the amount of calcium in the molecule: Albite/oligoclase will stain lighter than a more calcic plagioclase. Pure Na-albite will not take up any of the rhodizonate stain (QTS 2003). Alkali feldspars are stained greenish-yellow. The accuracy of the stains decreases according to grain size: with finer grained specimens, the pink stain tends to pervade the surface and obscure the quartz grains (QTS 2003). Reagents in the combination feldspar stain include potassium rhodizonate (0.01g K-rhodizonate in 30ml distilled water), sodium cobaltinitrite (saturated solution; about 50g per 100ml distilled water) and barium chloride (5% solution in distilled water).

Thin Section Analysis

The five thin sections were examined using a Nikon petrographic microscope at the Department of Geosciences, University of Nevada, Las Vegas. Percentages of temper and paste were estimated to the nearest 5% for each thin section. Terry and Chilingar's (1955) comparison chart for estimating percent composition was used to estimate modal mineralogy (percent composition) of the temper for each thin section (Figure 3-1). Following Power's (1953) chart for visual estimation of roundness, the temper shape was described as very angular, angular, subangular, subrounded, rounded, or very rounded (Figure 3-2). Several 35 mm color photomicrographs were taken of each slide at 20X (plus a 10X optic), in plane polarized light and with crossed polarization. Crossed polarization enables the petrographer to determine the mineral's extinction angle (the angle relative to the mineral's long axis [or c axis] through which polarized light does not pass) and thus aid in mineral identification.

The general procedures used to describe temper of Willow Beach ceramics were modified from the methods of analysis employed by Tuohy and Strawn (1986) and described in Chapter 2. The ceramics studied by Tuohy and Strawn included buff wares found in the Las Vegas Valley and north of Lake Mead in the Virgin River Valley. One reason for following Tuohy and Strawn's general procedures is to facilitate future comparisons between ceramics they studied and ceramics found at Willow Beach.

Tuohy and Strawn estimated percent composition and roundness from photomicrographs of each thin section. In this study, percent composition of paste and inclusions as well as percent composition of each mineral within the temper were estimated while looking through the petrographic microscope at the entire thin section.

The percent paste and percent inclusions found in each sherd were recorded. Inclusions were defined as mineral temper and voids greater than 0.2 mm in diameter. As discussed in Chapter 2, voids are spaces within a vessel's wall which may represent a location of a disintegrated or dislodged piece of temper when round (Vince 1999) or a shrinkage void when lenticular (Vince 1999, Lyneis 2001). In the

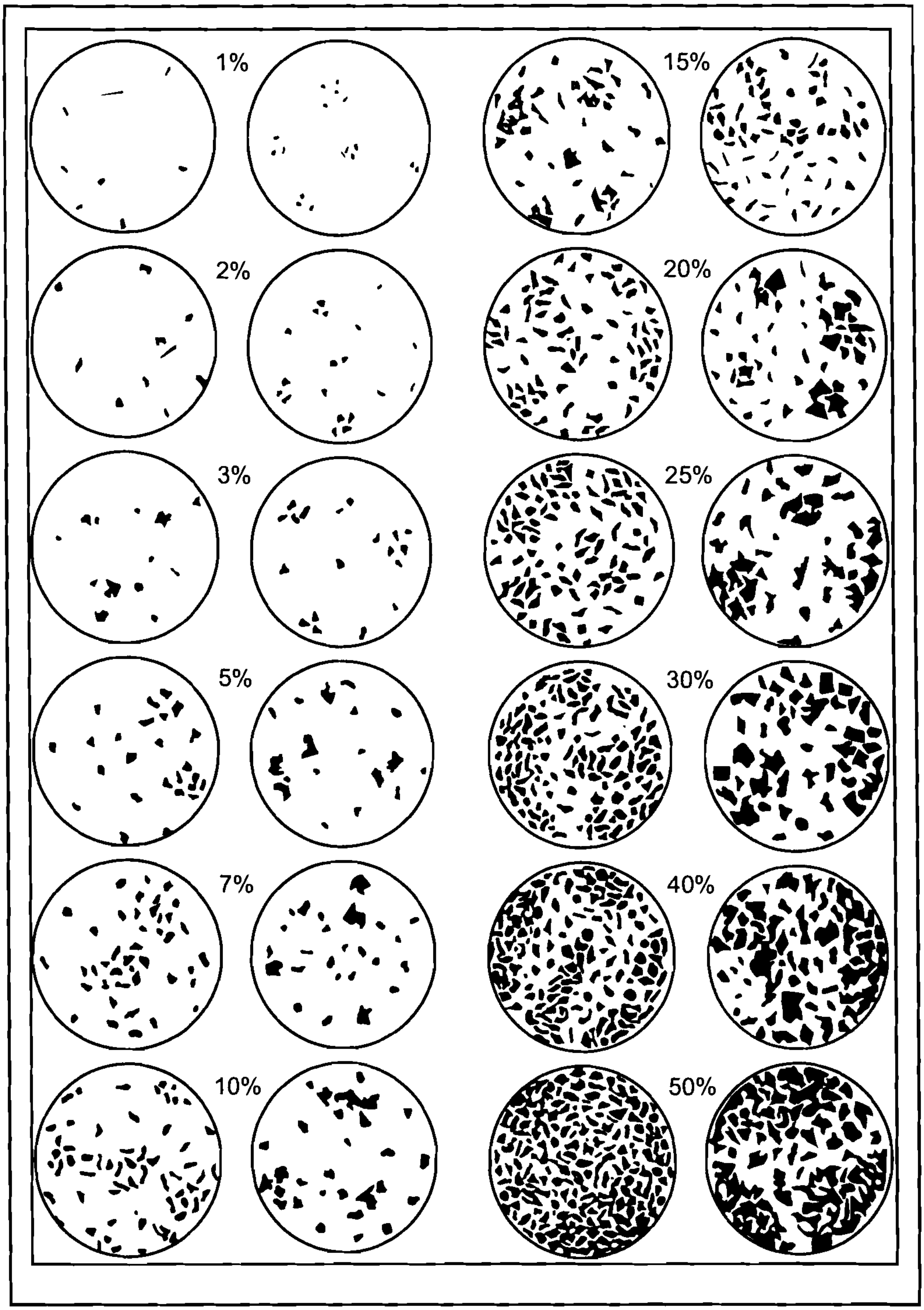


Figure 3-1. Comparison chart for estimating percentage composition used for estimating percent composition of paste and temper in Patayan ceramics recovered from Willow Beach, Arizona. Adapted from Terry and Chilingar (1955).

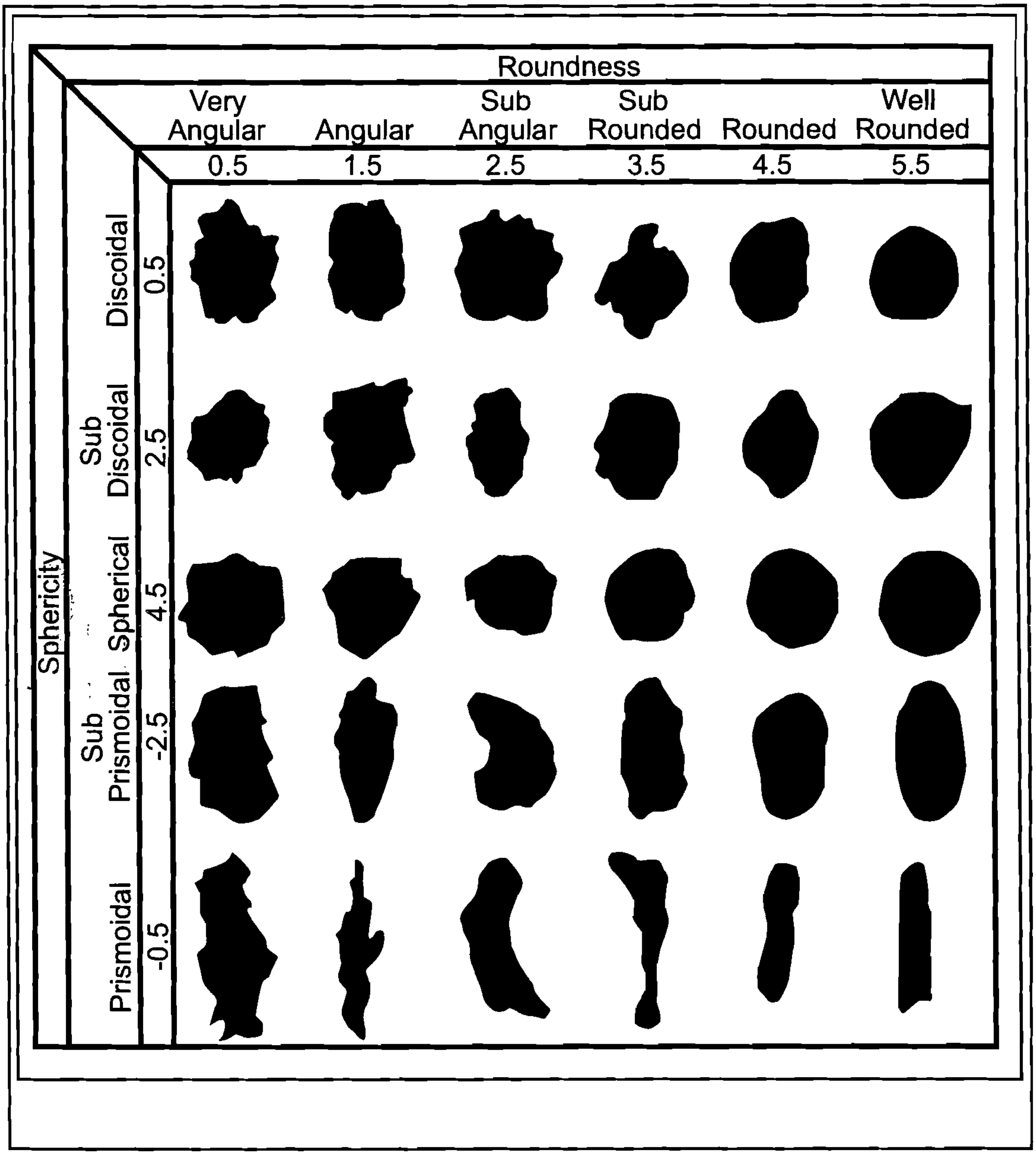


Figure 3- 2. Standard images of roundness used to describe roundness of temper grains in Patayan ceramics recovered from Willow Beach, Arizona. Adapted from Powers (1953).

absence of any standards on distinguishing voids from shrinkage voids based on roundness or any other factor, no attempt was made to quantify percent composition of these two types of voids.

During thin-section analysis of the sherds, it was noted that some of the temper particles were composed of rock fragments. These rock fragments consist of two or more phenocrysts of two or more mineral types. The mineral composition, size, and roundness of these rock particles were also noted.

Percent composition of paste and inclusions found in each sherd is presented in the following chapter. The amount of mineral temper and voids comprising inclusions is also presented. Modal mineralogy (percent composition) for temper in each sherd is presented. A table of rock fragment size, shape, and composition is also presented. Photomicrographs taken of each sherd in plane polarized light and in crossed polars are also presented.

CHAPTER 4: RESULTS

Table 4-1 summarizes the types of mineral constituents of the Willow Beach sherd temper found during thin-section analysis using a petrographic microscope. Minerals found include quartz, plagioclase, microcline, biotite, garnet, and orthoclase. Quartz is recognized in thin-section by its lack of cleavage, clear color, and undulatory extinction in crossed polars. Plagioclase is identified in thin section by its multiple (polysynthetic) twinning (alternating dark and light bands observed in crossed polars). However, twinning may be absent in small grains, particularly in metamorphic rocks (Nesse 1991). Tartan twinning is the most distinguishing characteristic of microcline in thin section. Biotite is distinguished in thin section by its brown color, perfect cleavage, and pleochroism. Garnet is recognized by its high relief, isotropic character, and equant crystal shape. Orthoclase greatly resembles quartz or sanidine in thin section. However, orthoclase shows negative relief, is biaxial, and is often slightly clouded due to incipient alteration (Nesse 1991). Unidentified trace minerals were found in thin sections taken from sherds #6866 and #6889. These minerals may be olivine, sphene, or zircon. Small amounts of oxides were found in thin sections for sherds #6859, #6866, and #6869.

In addition to separate mineral grains, some rock fragments were found. These rock fragments are composed of one or more mineral grains. They may be clusters of the same mineral or contain two or more minerals. Rock fragments constitute some of the larger pieces of temper (generally 1-3 mm diameter) found in the sherds.

Voids, spaces within a vessel's wall, were also found. In many cases voids are actually spaces left when an original mineral inclusion has dissolved or

Table 4-1. Mineral Constituents of the Temper of Willow Beach Potsherds (adapted from Coale 1963; and Tuohy and Strawn 1986).

	Minerals†							
Sherd #	Qtz	Plag	Micro	Bio	Grnt	Ortho	trace	ox
6859	x	x	x	x		x		x
6863	x	x		x		x		
6866	x	x		x	x	x	x	x
6869	x	x		x	x			x
6889	x	x	x	x	x		x	

†Qtz = Quartz
Plag = Plagioclase
Micro = Microcline
Bio = Biotite
Grnt = Garnet
Ortho = Orthoclase
trace = trace mineral (zircon or sphene)
ox = oxides

disintegrated (Vince 1999). When this is the case, voids in a pot fabric are usually treated as a form of inclusion. Shrinkage voids never contained any inclusions (Lyneis 2001). These lenticular-shaped voids are a byproduct of the mixing process created by the folding in of air during the preparation stage.

Because the voids are empty spaces within the vessel wall, light from the petrologic microscope passes through only the glass of the thin section's slide. The isotropic properties of glass caused the voids to appear black at all angles in crossed-polars. These voids could easily be distinguished from isotropic minerals (for example garnet) by their lack of cleavage or relief. In this study, the percent composition of voids is estimated. Because there are no guidelines for classifying voids, no attempt is made to distinguish shrinkage voids from voids that may have contained temper.

The following sections include discussion of the temper found in the thin sections of each sherd. Photomicrographs taken of each sherd in plane polarized light and with crossed polars are shown in Figures 4-1 through 4-20.

Sherd Descriptions

Sherd #6859

Sherd #6859 consists of 78% paste and 22% inclusions (Table 4-2). Inclusions are comprised of 90.9% temper and 9.1% voids. Six photomicrographs were taken of the thin section of sherd #6859 (Figures 4-1 through 4-6). Minerals in the temper for this sherd include quartz (55%), orthoclase (15%), plagioclase (15%), biotite (8%), and microcline (4%). A small amount of oxides (3%) were also found (Tables 4-1 and 4-2).

Quartz temper ranges from 0.2 to 2 mm in diameter and is rounded to angular. Orthoclase temper grains are 0.4 to 3 mm and are subangular to angular. Plagioclase

Table 4-2. Pyramid Gray (Willow Beach, Arizona) Thin-Section Analysis.

Sherd	% Paste	% Inclusions[†] Temper/Voids	Temper Composition	% Temper Composition	Size (mm)	Shape
6859	78	20(90.9)/2(9.1)	quartz	55	0.2 - 2	rounded,subrounded, subangular, angular
			orthoclase	15	0.4 - 3	subrounded,subangular, angular
			plagioclase	15	0.4 - 2	subrounded,subangular, angular
			biotite	8	0.2 - 1	subrounded
			microcline	4	0.5 - 0.8	subrounded
			oxides	3	0.2	rounded
6863	65	30(85.7)/5(14.3)	quartz	88	0.5 - 2	rounded, subrounded
			biotite	4	0.2 - 0.4	subangular,angular
			orthoclase	4	0.4 - 1	subrounded
			plagioclase	4	0.2 - 0.3	subrounded,subangular
6866	60	30(75)/10(25)	quartz	82	0.2 - 3	rounded,subrounded, subangular,
			garnet	5	0.5 - 0.8	rounded
			biotite	5	0.2 - 1	subrounded, subangular
			orthoclase	3	0.2 – 0.5	subangular
			plagioclase	3	0.5 - 1	subrounded, subangular
			trace minerals (zircon or sphene)	1	0.2	angular
			oxides	1	0.2	rounded
6869	74	22(84.6)/4(15.4)	quartz	62	0.2 - 2	rounded, subrounded
			garnet	22	0.5 – 2.5	rounded,angular
			biotite	11	0.2 - 1	subrounded,subangular,angular
			plagioclase	3	0.2 - 0.5	subangular
			oxides	2	0.2	rounded
6889	67	28(84.8)/5(15.2)	quartz	52	0.2 - 2	rounded, subrounded,subangular
			biotite	22	0.2 - 0.8	subrounded, subangular,angular
			garnet	22	0.8 – 1.5	rounded, subangular, angular
			plagioclase	2	0.2 - 1	subangular
			microcline	1	0.2 – 0.5	rounded,subrounded
			trace mineral (olivine)	1	0.2	rounded

[†]Percent composition of sherd. Percent composition of inclusions in parentheses.

grains are 0.4 to 2 mm and are subrounded to angular. Some plagioclase grains exhibited alteration (Figure 4-1). Biotite grains are approximately 0.2 to 0.4 mm and are subrounded. Microcline is subrounded and about 0.5 to 0.8 mm in size.

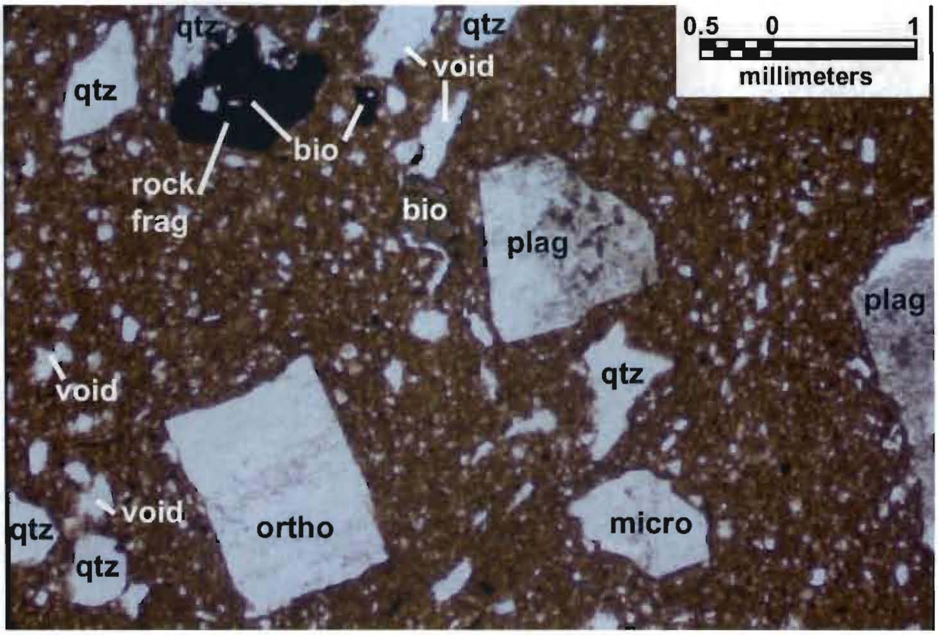
Rock fragments (Table 4-3; Figures 4-1, 4-2, 4-3, 4-5 and 4-6) are composed of quartz; biotite and quartz; and biotite, plagioclase, and quartz. Rock fragments, which are temper particles composed of one or more phenocrysts of one or more minerals, ranged in size from 1 to 2 mm and are subrounded to angular. One rock fragment (Figure 4-3) of quartz, plagioclase, and biotite has myrmekite. Myrmekite is an intergrowth of dendritic quartz in plagioclase. Myrmekite is formed during the later stages of consolidation in an igneous rock or during a subsequent period of plutonic activity.

Sherd #6863

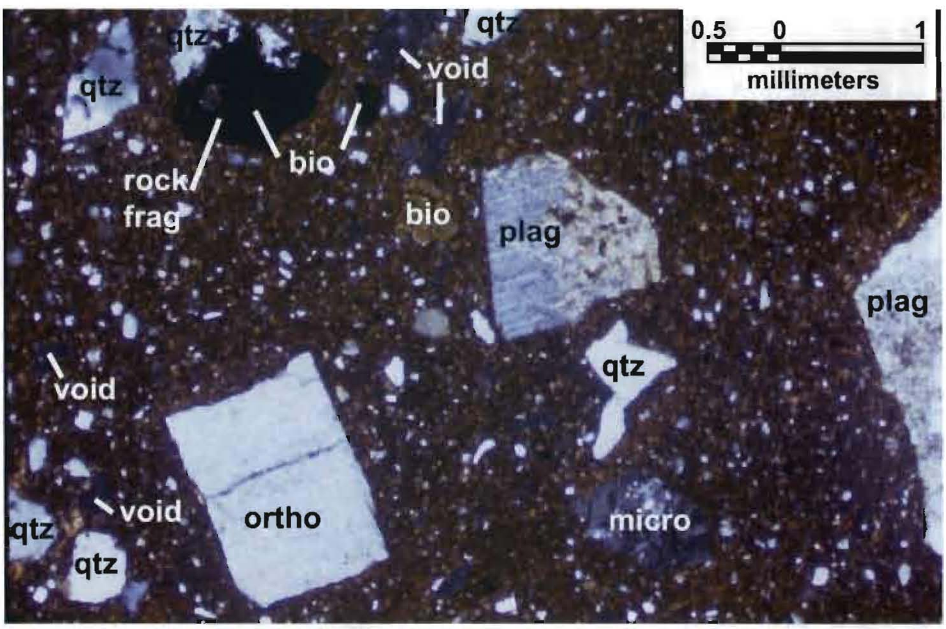
Sherd #6863 consists of 65% paste and 35% inclusions (Table 4-2). Inclusions are comprised of 85.7% temper and 14.3% voids. Two photomicrographs were taken of the thin section of sherd #6863 (Figures 4-7 and 4-8). Mineral temper includes quartz (88%), biotite (4%), orthoclase (4%), and plagioclase (4%) (Tables 4-1 and 4-2).

Quartz temper is rounded to subrounded and 0.5 to 2 mm. Biotite is 0.2 to 0.3 mm and subangular to angular. Orthoclase is subrounded and 0.2 to 1 mm in size. Plagioclase is subrounded to subangular and 0.2 to 0.3 mm.

Rock fragments in this sherd are composed only of quartz (Figures 4-7 and 4-8; Table 4-3). These multi-grain temper particles are subrounded to angular and are about 1.4 to 2 mm in diameter.

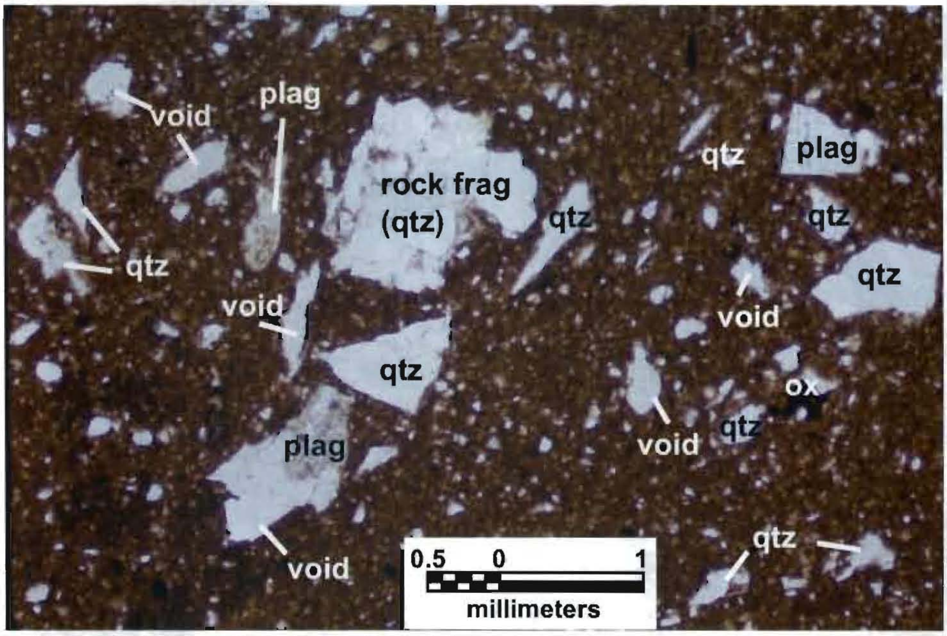


Sherd #6859: Plain Polarized Light; No Stain

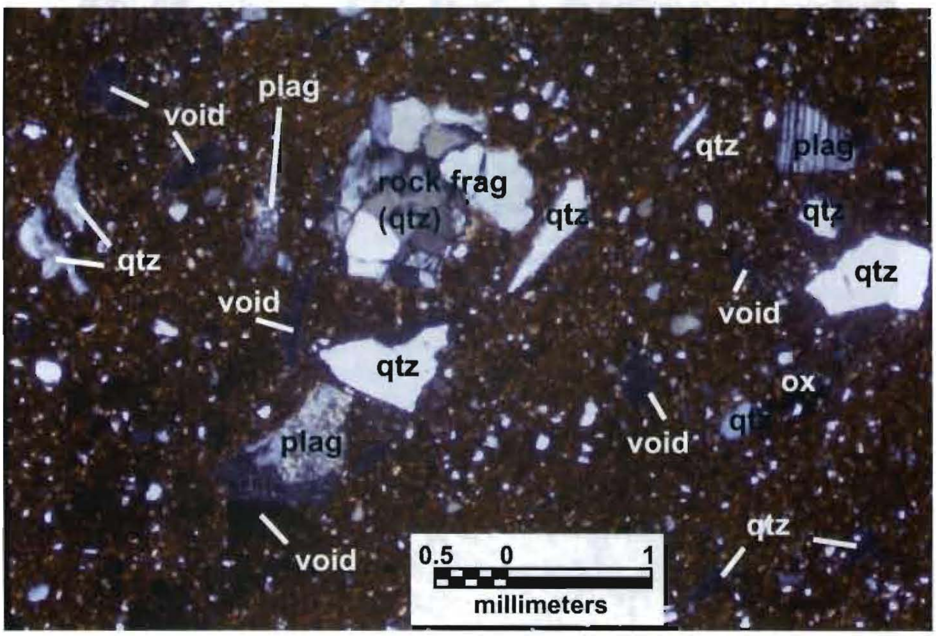


Sherd #6859: Cross Polars; No Stain

Figure 4-1. Photomicrographs of sherd #6859.

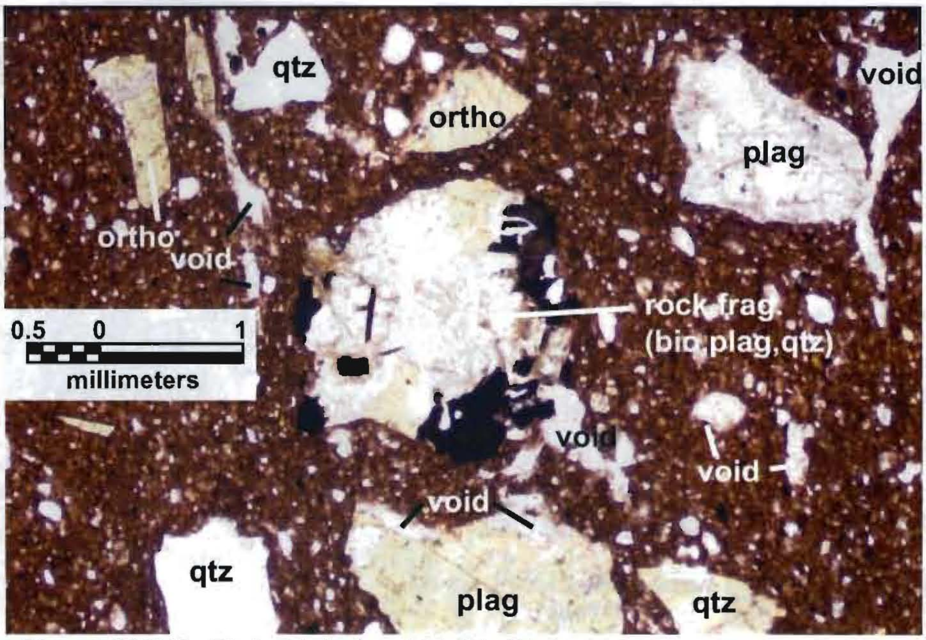


Sherd #6859; Plain Polarized Light; No Stain

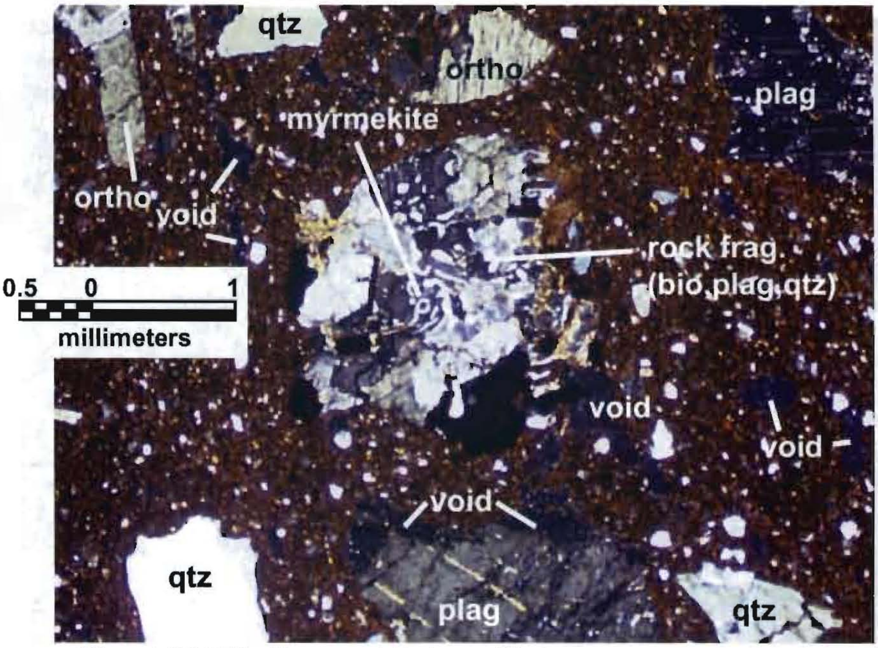


Sherd #6859; Crossed Polars; No Stain

Figure 4-2. Photomicrographs of sherd #6859.

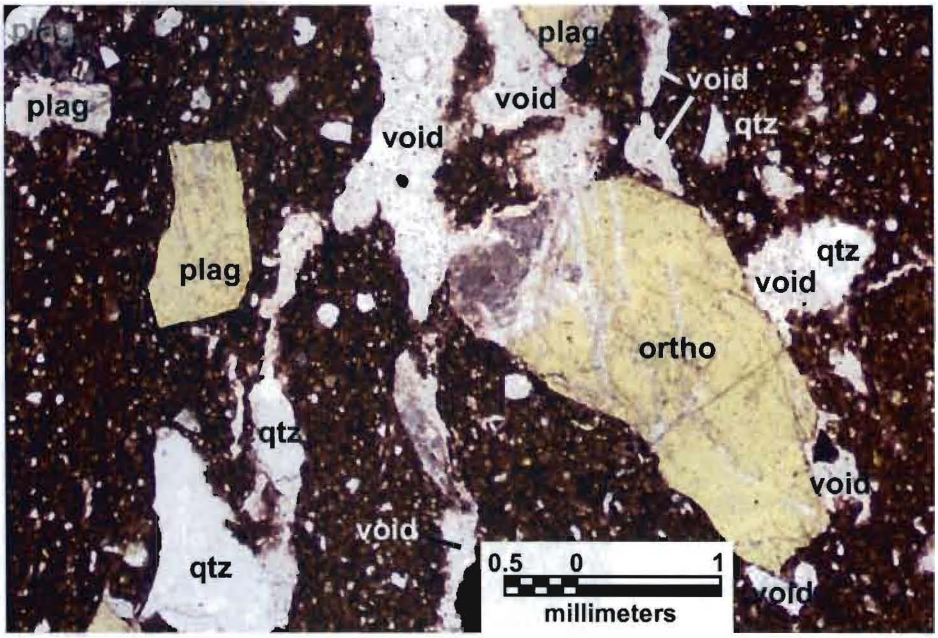


Sherd #6859; Plain Polarized Light; Stain

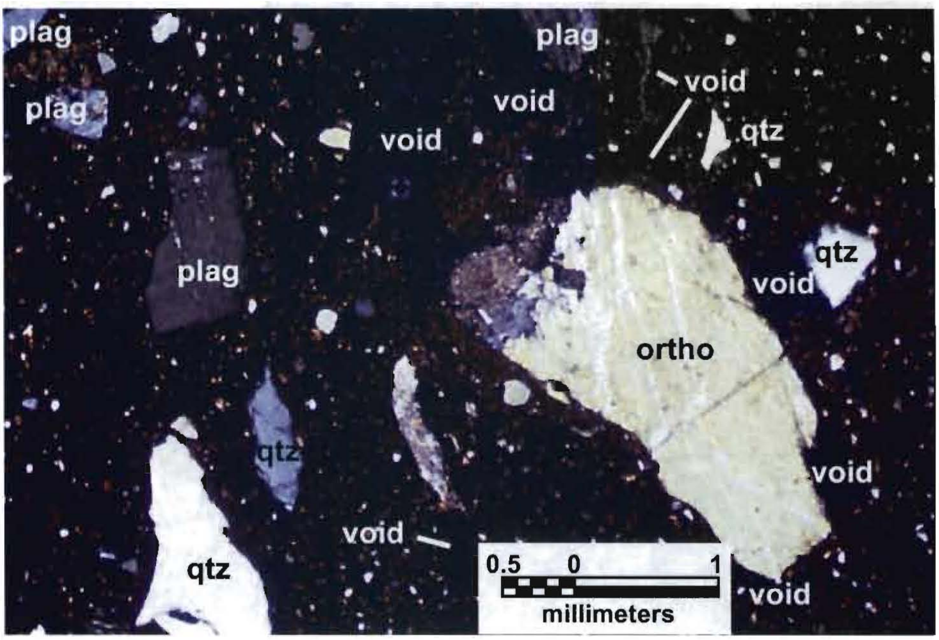


Sherd #6859; Crossed Polars; Stain

Figure 4-3. Photomicrographs of sherd #6859.

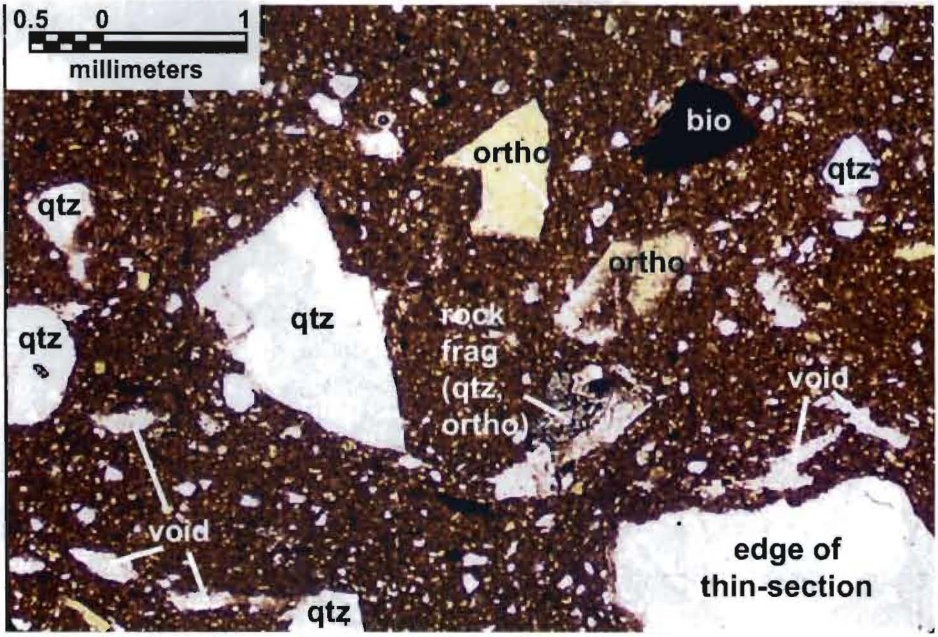


Sherd #6859; Plain Polarized Light; Stain

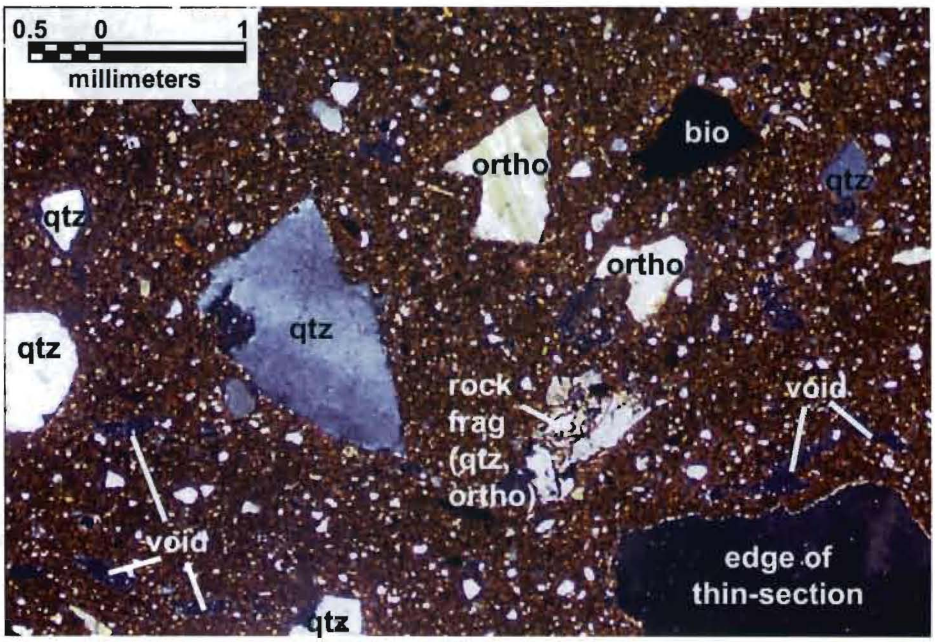


Sherd #6859; Crossed Polars; Stain

Figure 4-4. Photomicrographs of sherd #6859.

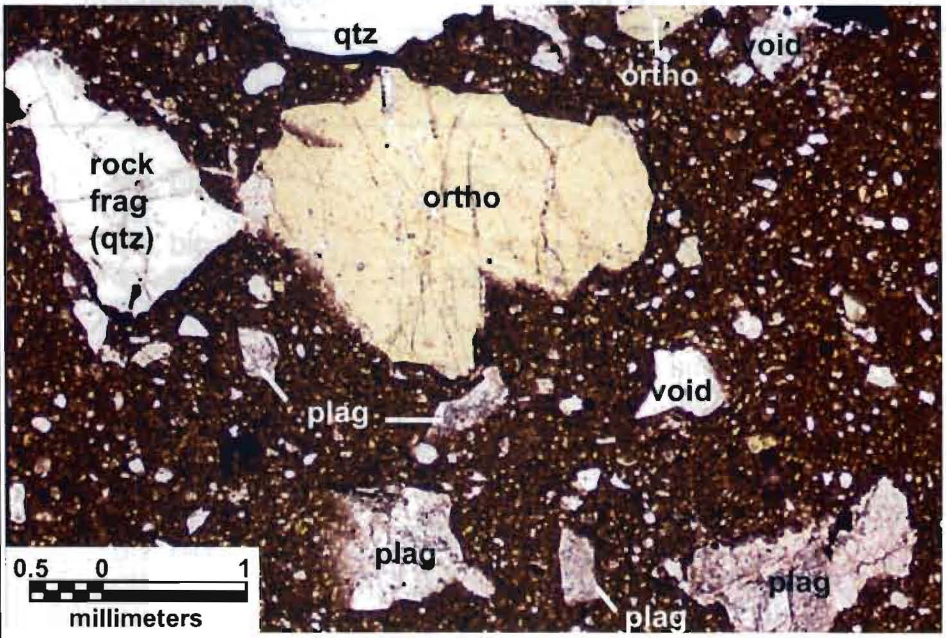


Sherd #6859; Plain Polarized Light; Stain

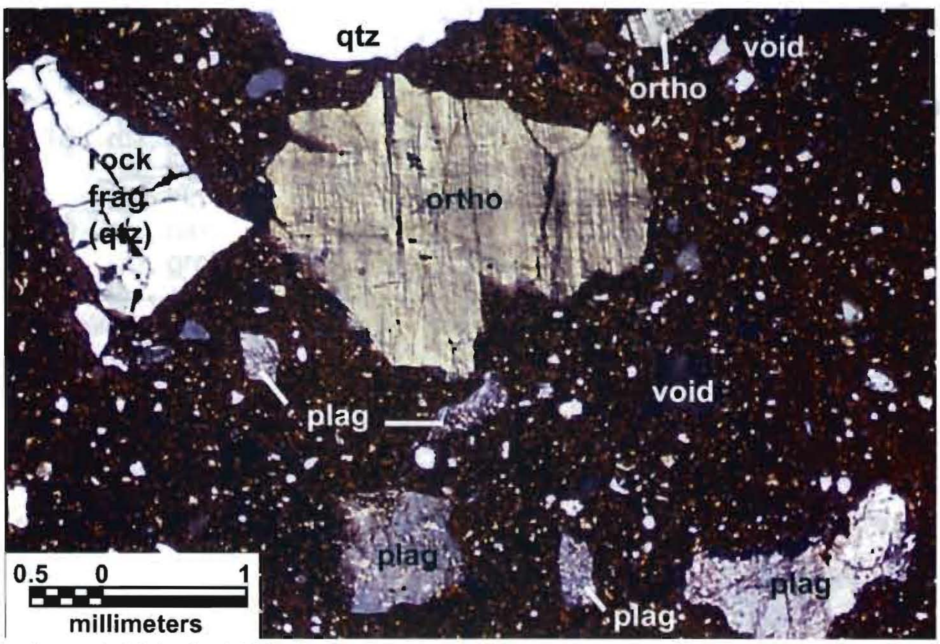


Sherd #6859; Crossed Polars; Stain

Figure 4-5. Photomicrographs of sherd #6859.



Sherd #6859; Plain Polarized Light; Stain



Sherd #6859: 20X; Crossed Polars; Stain

Figure 4-6. Photomicrographs of sherd #6859.

Table 4-3. Description of Rock Fragments found in Willow Beach Sherds.

Sherd	Figure	Minerals in Rock Fragment†	Size of Rock Fragment (mm)	Roundness of Rock Fragment
6859	4-1	qtz, bio	1 x 1.2	subrounded
	4-2	qtz	1.5	subangular
	4-3	qtz, bio, plag	2	subrounded
	4-5	qtz, ortho	0.8 x 1	subangular, angular
	4-6	qtz	1 x 2	subangular, angular
6863	4-7	qtz	1.5 x 2.5	subrounded
		qtz	1.5 x 2	subrounded
	4-8	qtz	1.4 x 2	angular
6866	4-10	qtz, grnt	1.2	subrounded, subangular
	4-11	qtz, plag	1.5 x 2	subangular
	4-12	qtz, plag	2	subangular, angular
6869	4-13	qtz, bio	1.5 x 2	subrounded, subangular
		qtz, bio	0.7 x 1	subrounded
		qtz, bio	1.5	subrounded
	4-14	qtz, bio	1.2 x 1.6	subangular
		qtz, bio	1.5	subangular
	4-15	qtz, bio	0.4 x 0.8	angular
	4-16	qtz, bio	2.5 x 3	subangular
		qtz, bio	1.5 x 1.8	subangular, angular
	4-17	qtz, bio, grnt	1.4	subangular
		qtz, grnt	2 x 2.5	subangular
		qtz, bio	1.5	rounded, subrounded
6889	4-18	qtz, grnt	1.2	rounded
		qtz, bio	1 x 1.5	subangular
		qtz, bio	0.5	subrounded
	4-19	qtz, bio	1.2	subangular
	4-20	qtz, grnt	1.1 x 1.5	subrounded, subangular

†bio = biotite grnt = garnet ortho = orthoclase plag = plagioclase qtz = quartz

Sherd #6866

Sherd #6866 consists of 60% paste and 40% inclusions (Table 4-2). Inclusions are comprised of 75% temper and 25% voids. Four photomicrographs were taken of the thin section of sherd #6866 (Figures 4-9 through 4-12). Temper in this sherd is comprised of quartz (82%), garnet (5%), biotite (5%), orthoclase (3%), and plagioclase (3%) (Tables 4-1 and 4-2). A very small amount of trace minerals (1% zircon or sphene) and oxides (1%) were also found.

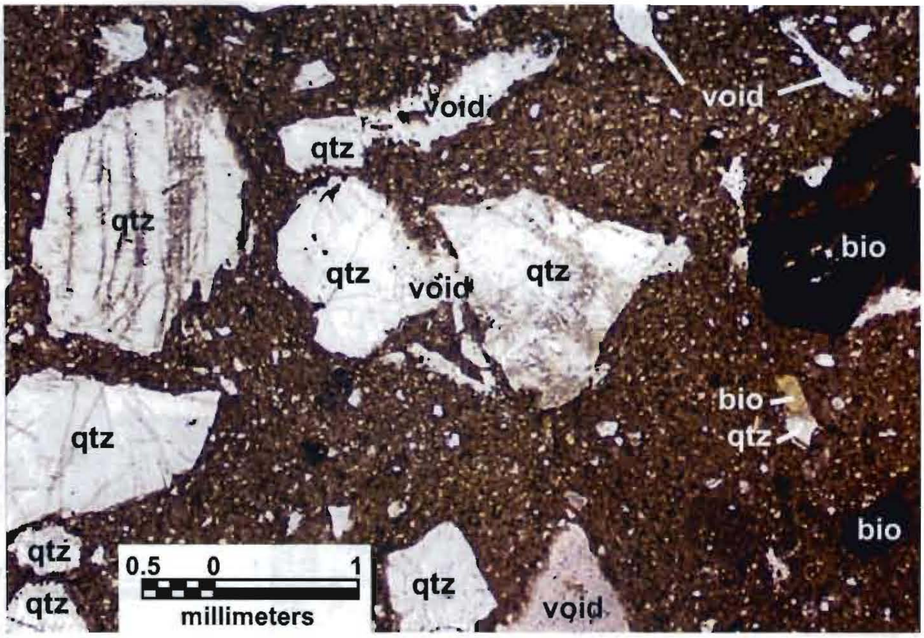
Quartz temper is rounded to subangular, ranging in size from 0.2 to 3 mm. Garnet is rounded and about 0.5 to 0.8 mm. Subrounded and subangular biotite grains are 0.2 to 1 mm. Orthoclase is 0.4 to 1 mm and is subrounded. Plagioclase grains are 0.5 to 1 mm and is subrounded to subangular.

Rock fragments (Table 4-3; Figures 4-10, 4-11, and 4-12) are composed of quartz and garnet (Figure 4-10) quartz and feldspar (Figures 4-11 and 4-12). The rock fragment in Figure 4-11 contains myrmekite.

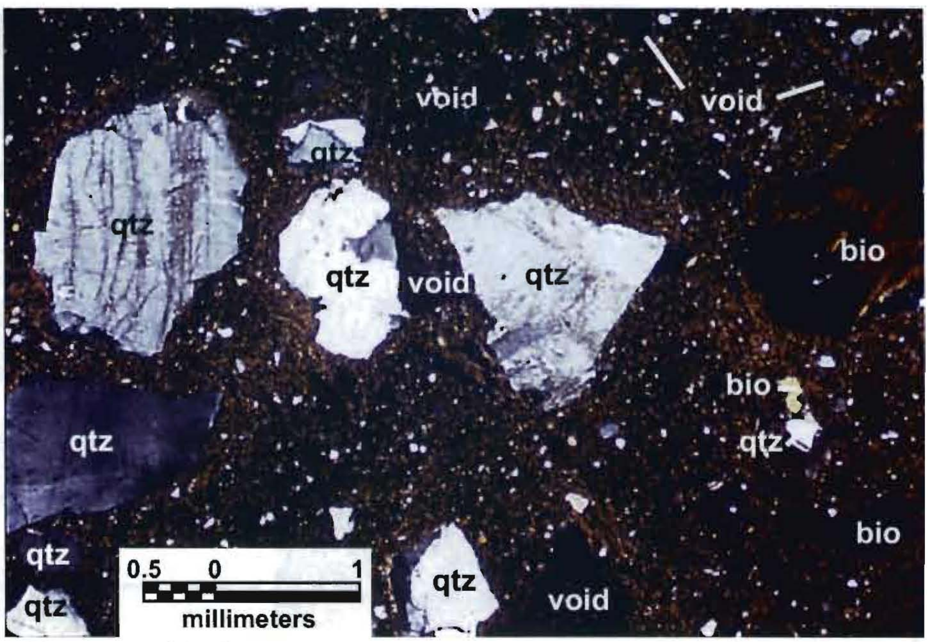
Sherd #6869

Sherd #6869 consists of 74% paste and 26% inclusions (Table 4-2). Inclusions are comprised of 84.6% temper and 15.4% voids. Five photomicrographs were taken of the thin section of sherd #6869 (Figures 4-13 through 4-17). Temper in this sherd is composed of quartz (62%), garnet (22%), biotite (11%), and plagioclase (3%) (Tables 4-1 and 4-2). A small amount of oxides were also present (2%).

Quartz temper ranges in size from 0.2 – 2 mm and is rounded to subrounded. Garnet is rounded to angular and is 0.5 to 2.5 mm in size. Biotite is subrounded to angular and 0.2 to 1 mm. Plagioclase grains are about 0.2 to 0.5 mm and are subangular.

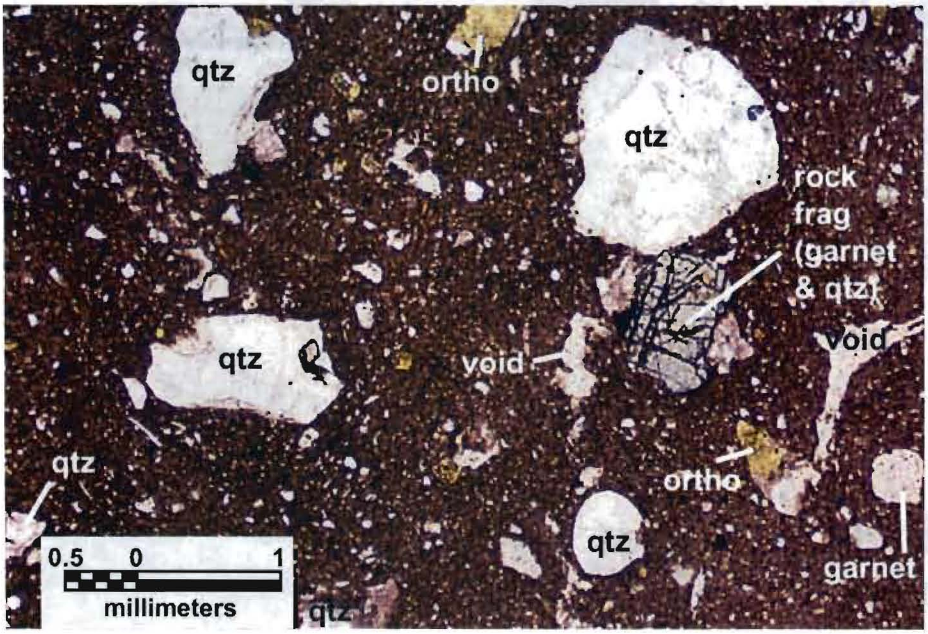


Sherd #6866; Plain Polarized Light; No Stain

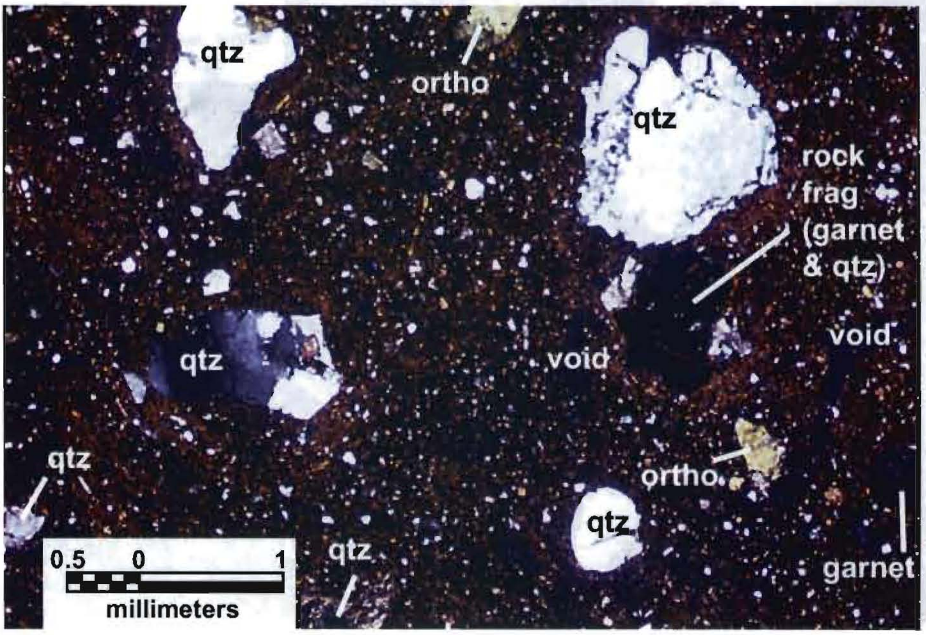


Sherd #6866; Crossed Polars; No Stain

Figure 4-9. Photomicrographs of sherd #6866.

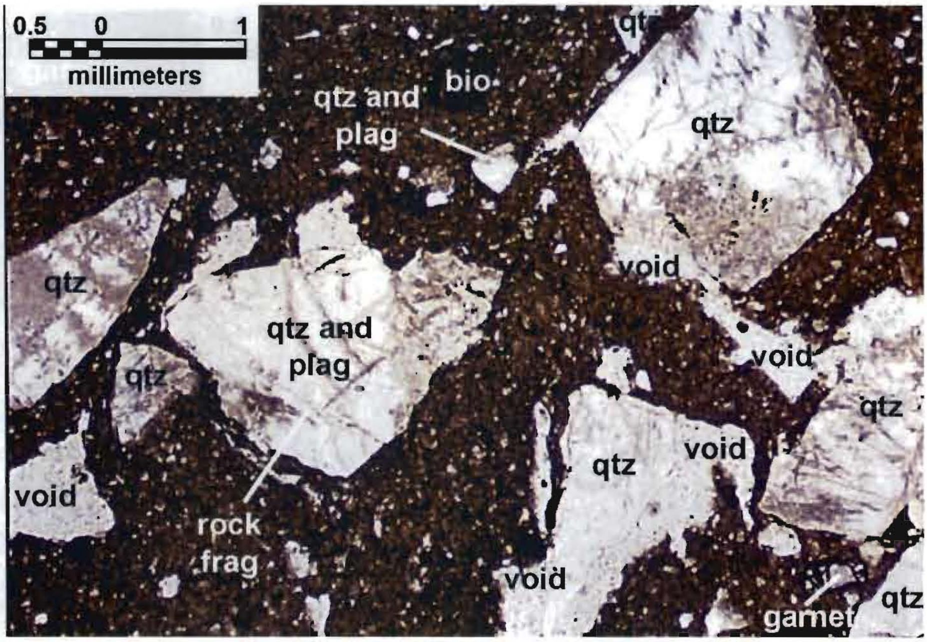


Sherd #6866; Plain Polarized Light; Stain

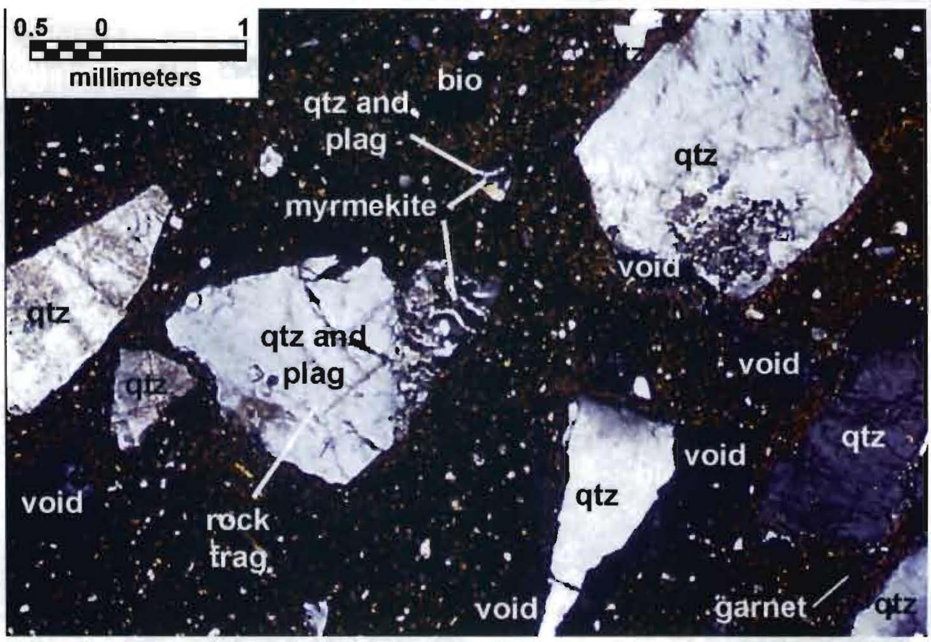


Sherd #6866; Crossed Polars; Stain

Figure 4-10. Photomicrographs of sherd #6866.

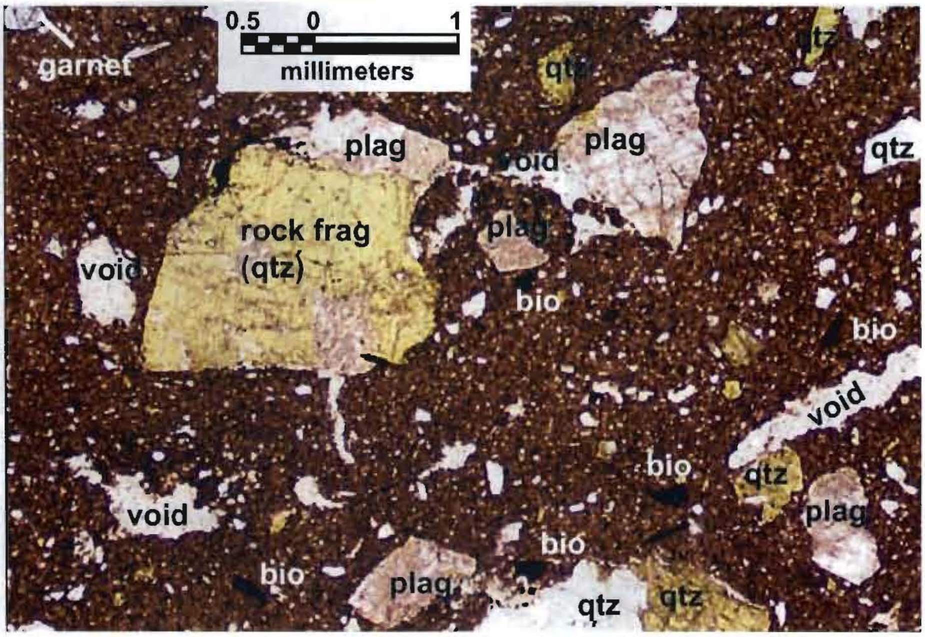


Sherd #6866; Plain Polarized Light; No Stain

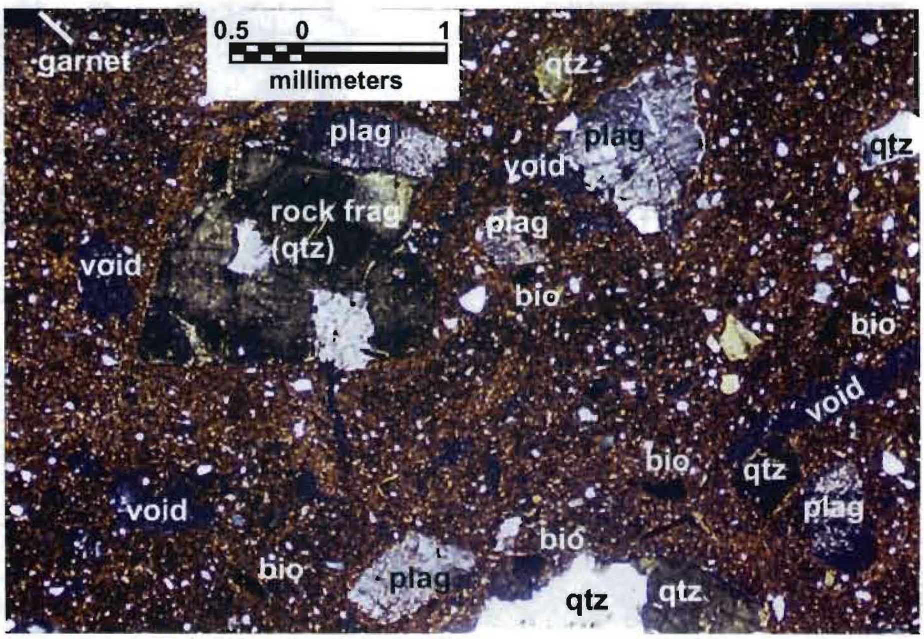


Sherd #6866; Crossed Polars; No Stain

Figure 4-11. Photomicrographs of sherd #6866. Myrmekite visible under crossed polars.

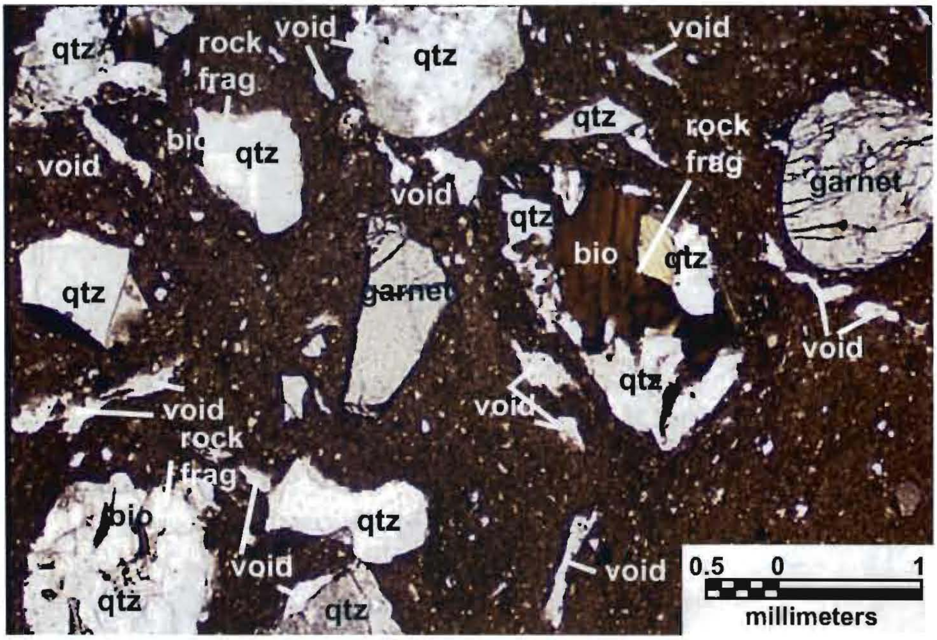


Sherd #6866; Plain Polarized Light; Stain

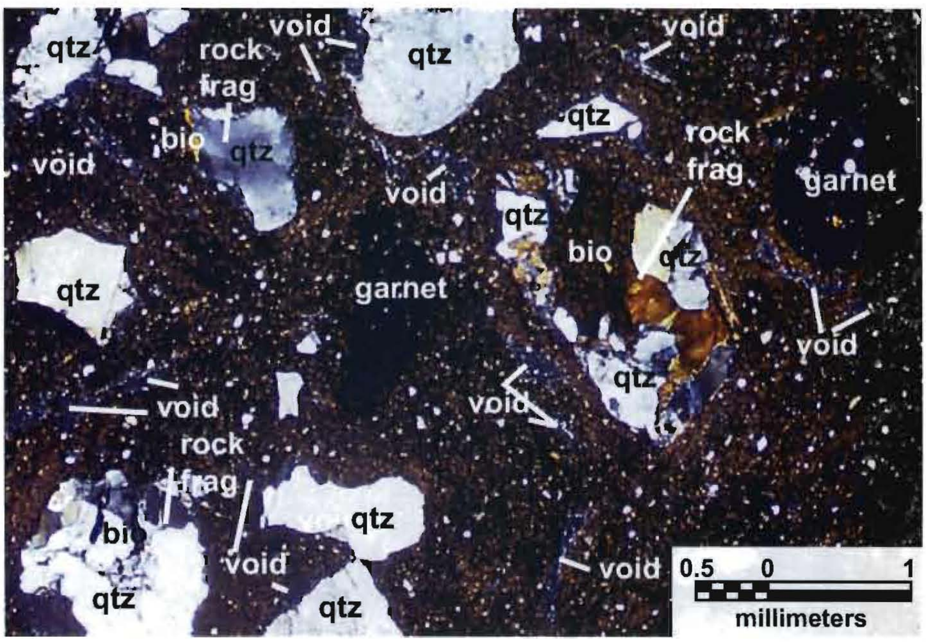


Sherd #6866; Crossed Polars; Stain

Figure 4-12. Photomicrographs of sherd #6866.

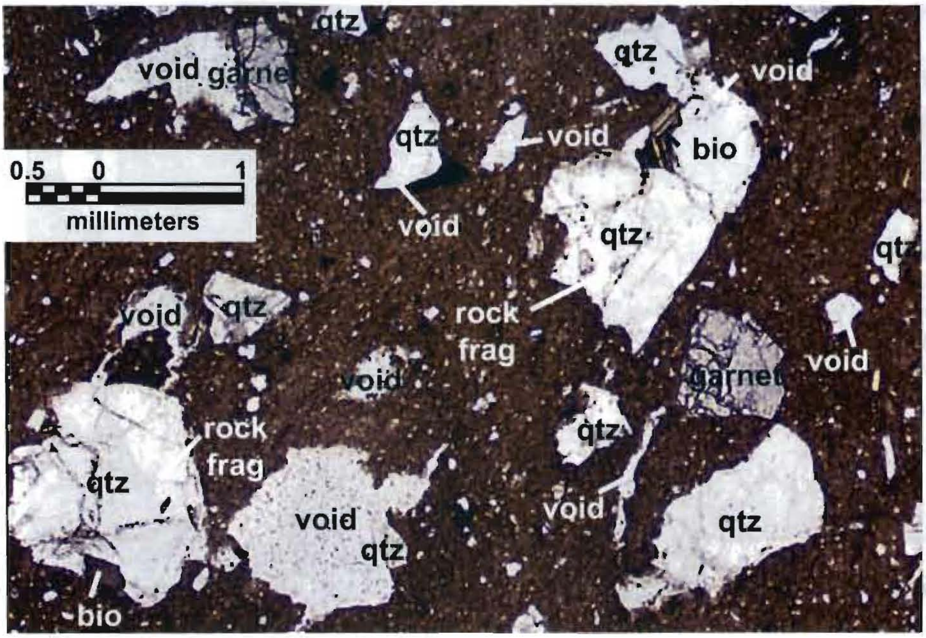


Sherd #6869; Plain Polarized Light; No Stain

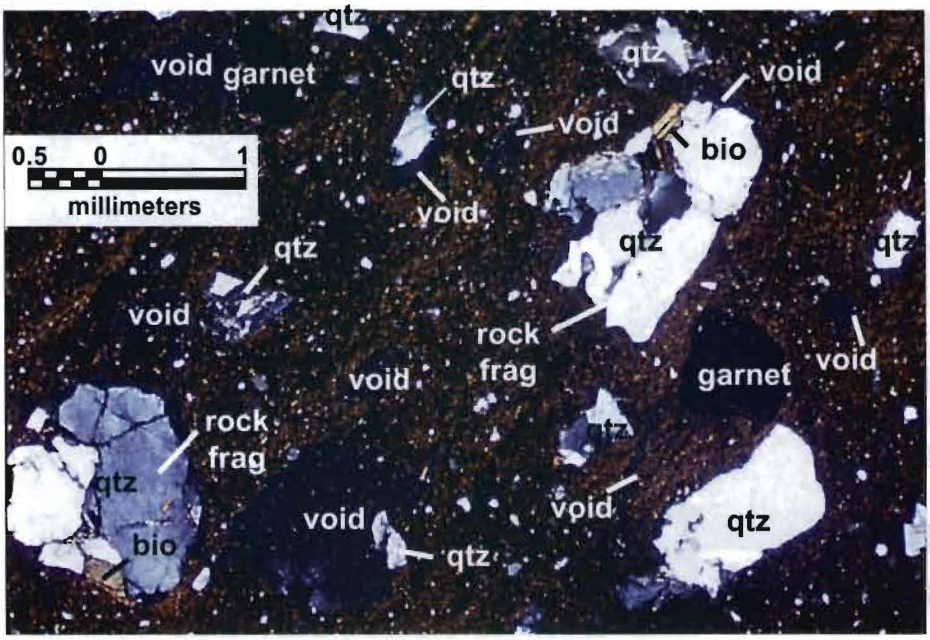


Sherd #6869; Crossed Polars; No Stain

Figure 4-13. Photomicrographs of sherd #6869.

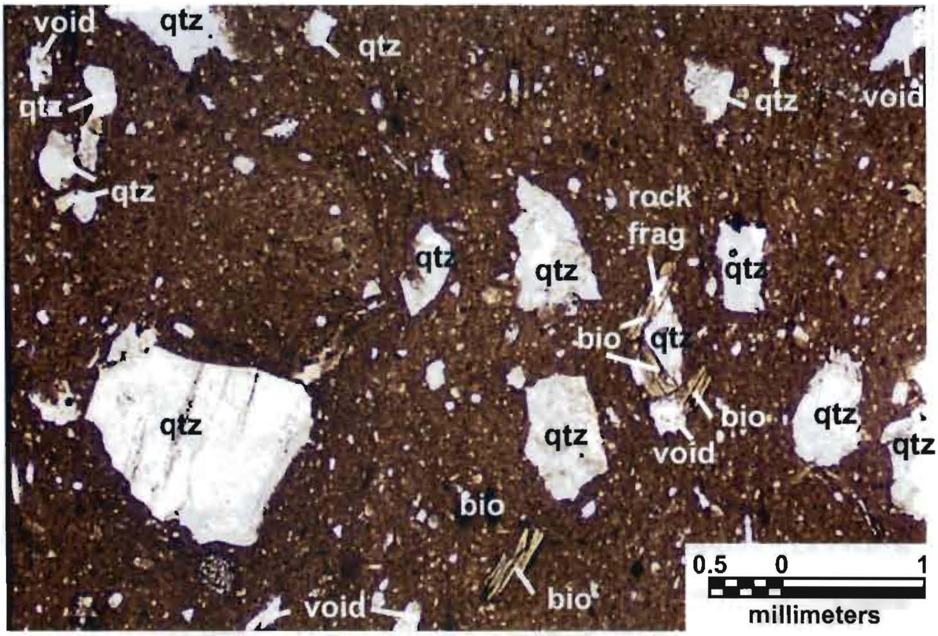


Sherd #6869; Plain Polarized Light; No Stain

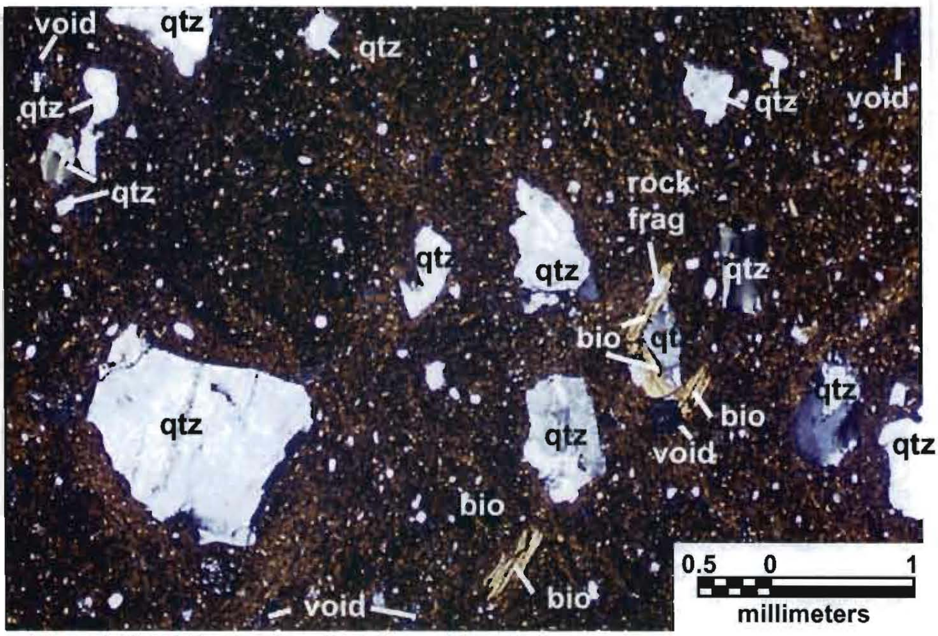


Sherd #6869; Crossed Polars; No Stain

Figure 4-14. Photomicrographs of sherd #6869.

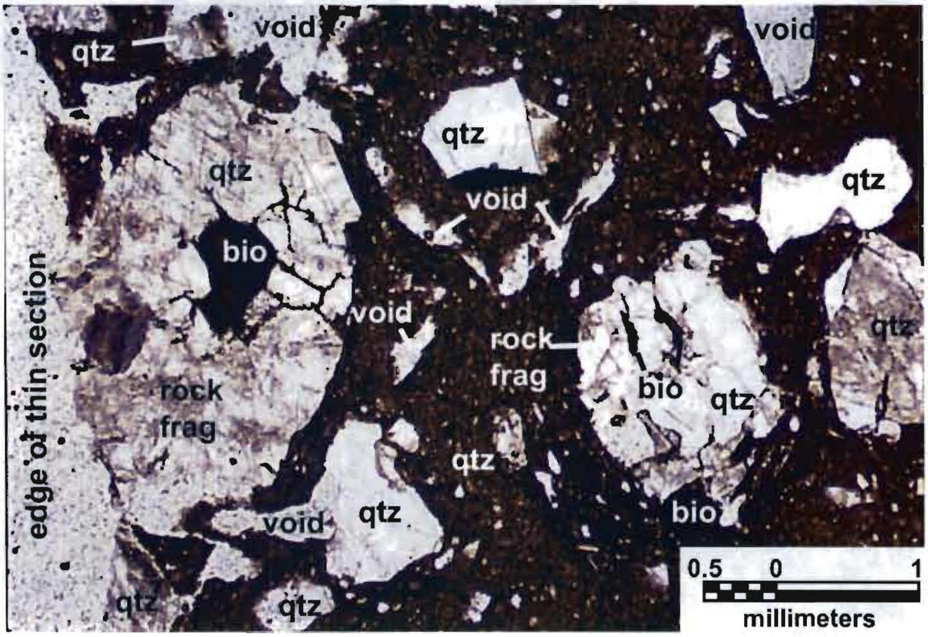


Sherd #6869; Plain Polarized Light; No Stain

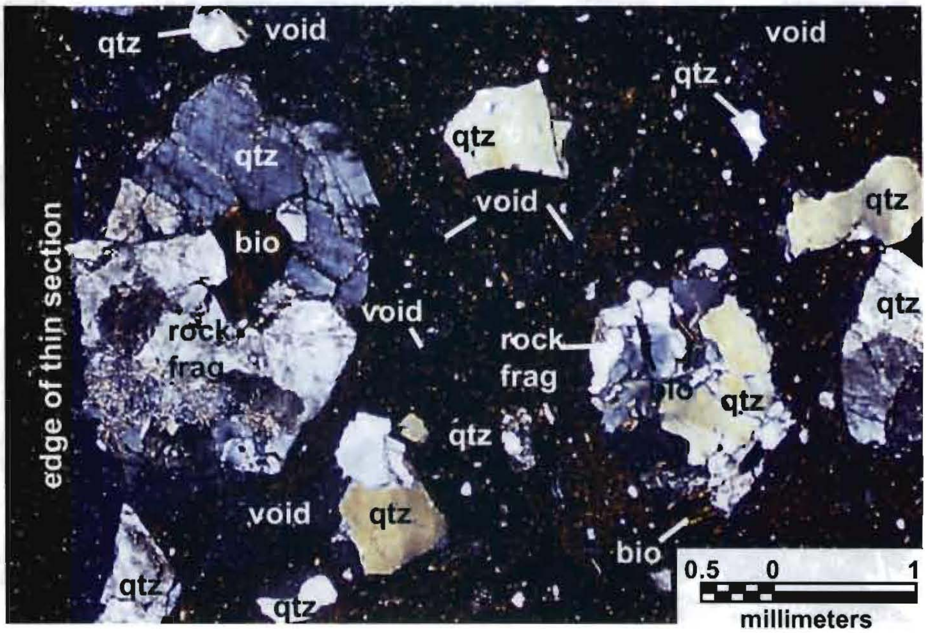


Sherd #6869; Crossed Polars; No Stain

Figure 4-15. Photomicrographs of sherd #6869.

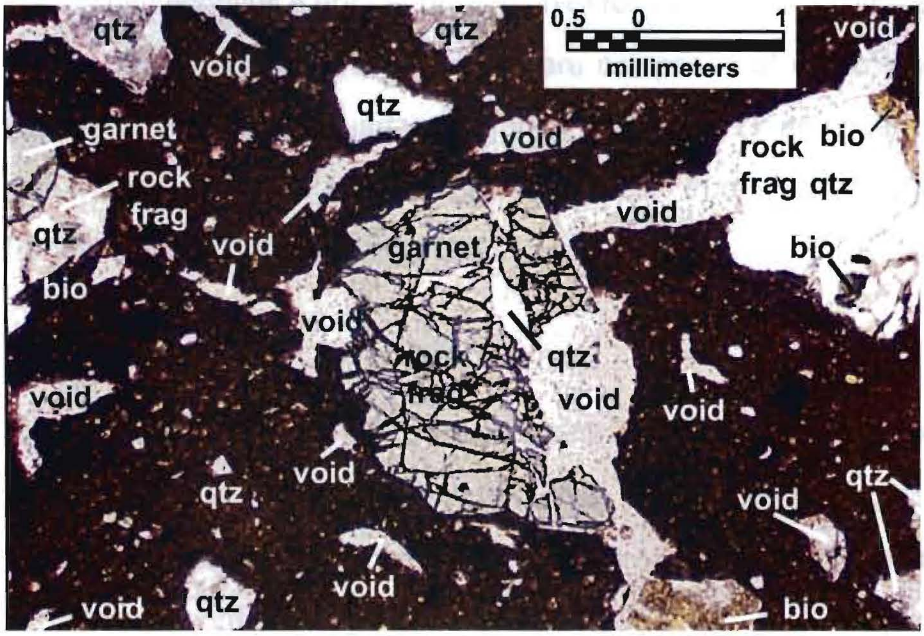


Sherd #6869; Plain Polarized Light; No Stain

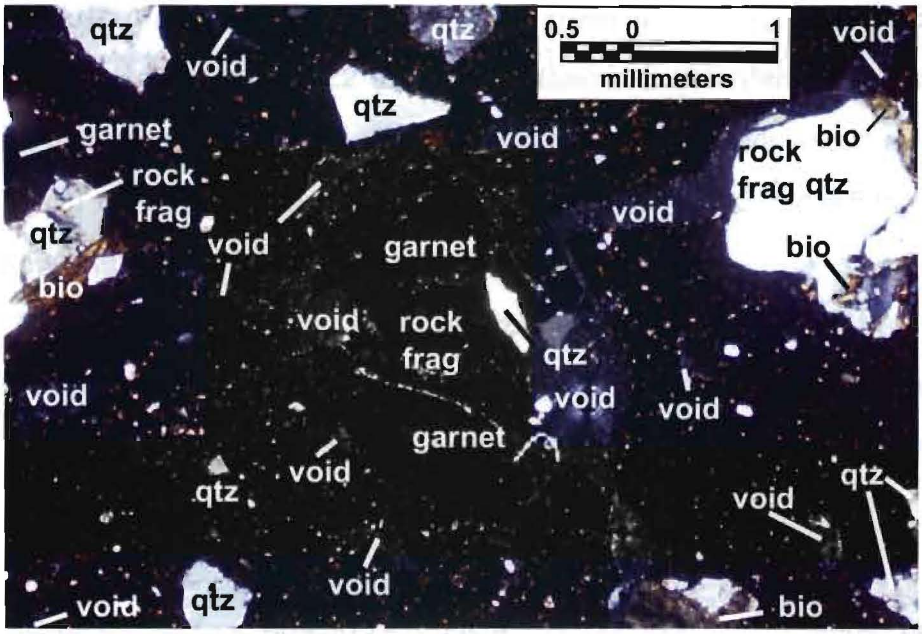


Sherd #6869; Crossed Polars; No Stain

Figure 4-16. Photomicrographs of sherd #6869.



Sherd #6869; Plain Polarized Light; Stain



Sherd #6869; Crossed Polars; Stain

Figure 4-17. Photomicrographs of sherd #6869.

This sherd contains a greater proportion of rock fragments compared to the other sherds. Rock fragments in this sherd are composed of quartz and biotite (Figures 4-13 through 4-17); quartz and garnet (Figure 4-17); and quartz, biotite, and garnet (Figure 4-17). Rock fragments range in size from about 0.8 to 3 mm in diameter and are rounded to angular.

Sherd #6889

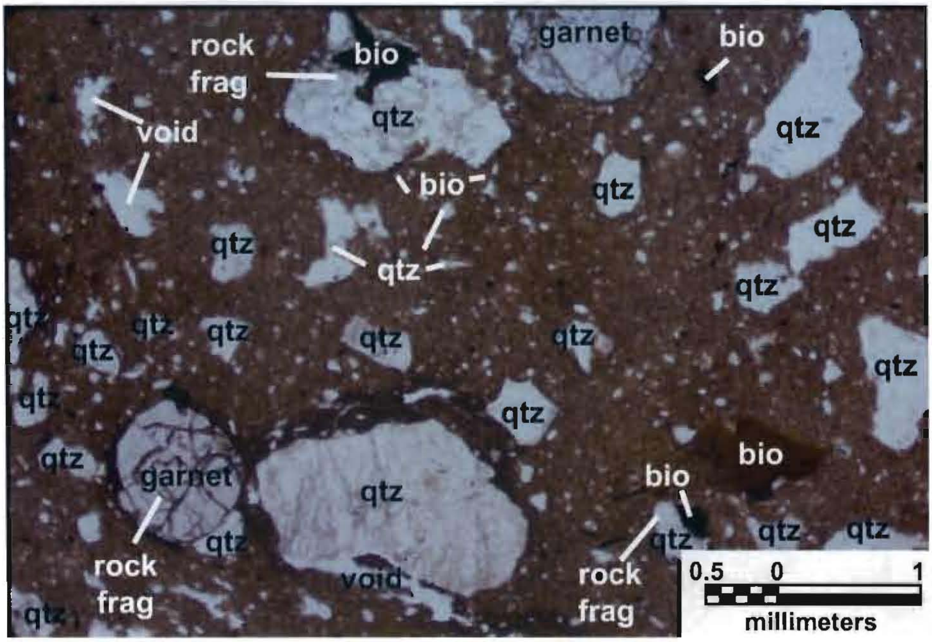
Sherd #6889 consists of 67% paste and 33% inclusions (Table 4-2). Inclusions are comprised of 84.8% temper and 15.2% voids. Three photomicrographs were taken of the thin section of sherd #6889 (Figures 4-18 through 4-20). Minerals in this sherd's ternper consist of quartz (52%), biotite (22%), garnet (22%), plagioclase (2%), microcline (1%), and olivine (1%) (Tables 4-1 and 4-2).

Quartz grains are rounded to subangular and 0.2 to 2 mm. Biotite is subrounded to angular and 0.2 to 0.8 mm. Garnet is rounded, subangular, and angular. Garnets are about 0.8 to 1.5 mm in diameter. Plagioclase is subangular and 0.2 to 1 mm. Microcline is rounded to subrounded and 0.2 to 0.5 mm. Olivine (not shown) is rounded and about 0.2 mm in diameter.

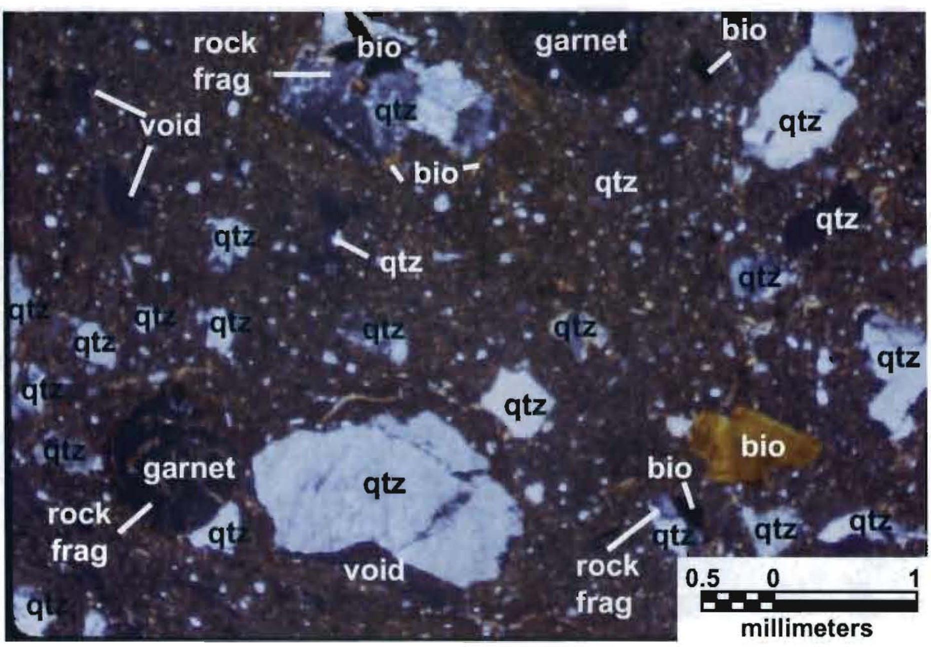
Rock fragments in this sherd are rounded, subrounded, and subangular. These temper grains are composed of quartz and biotite (Figures 4-18 through 4-20); and quartz and garnet (Figures 4-18 and 4-20). Rock fragments in this sherd are about 0.5 to 1.5 mm in diameter.

Summary

Sherds contained 60% to 78% paste and 22% to 40% inclusions (Table 4-2). Temper comprised 20% to 30% of the sherds (Table 4-2). Temper from all five thin sections contained quartz, plagioclase, and biotite (Table 4-2). Three sherds (#6859,

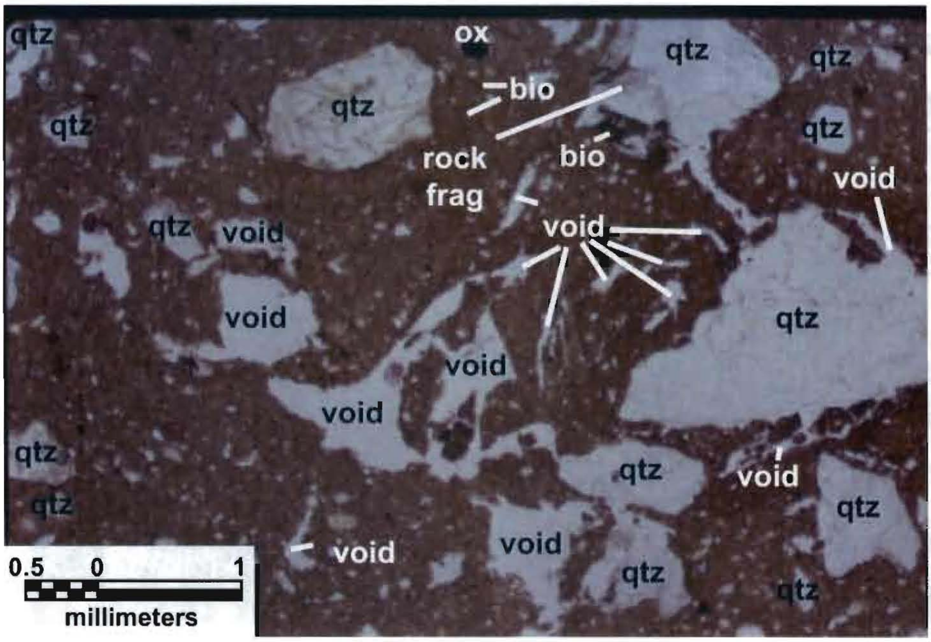


Sherd #6889; Plain Polarized Light; No Stain

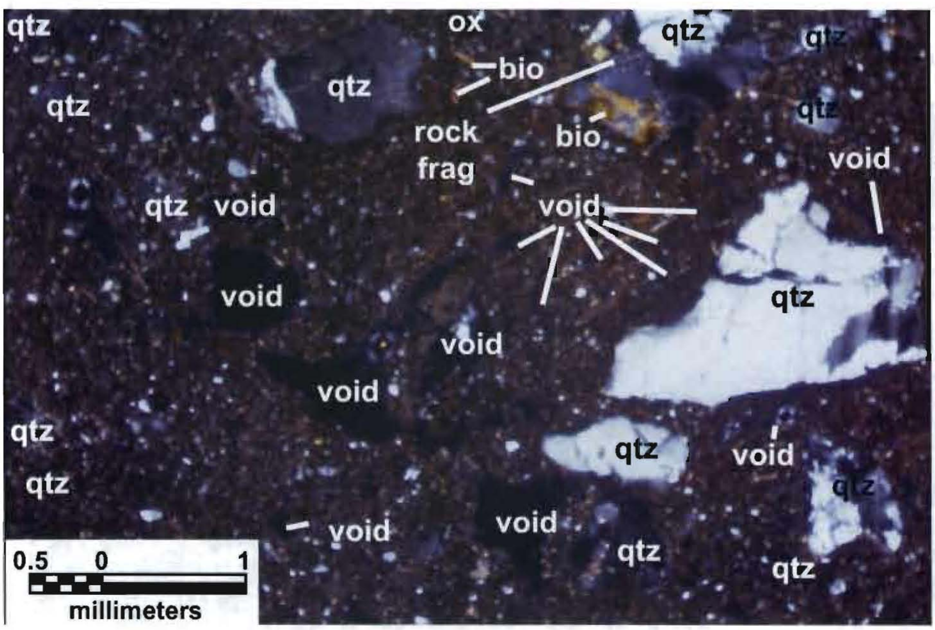


Sherd #6889; Crossed Polars; No Stain

Figure 4-18. Photomicrographs of sherd #6889.

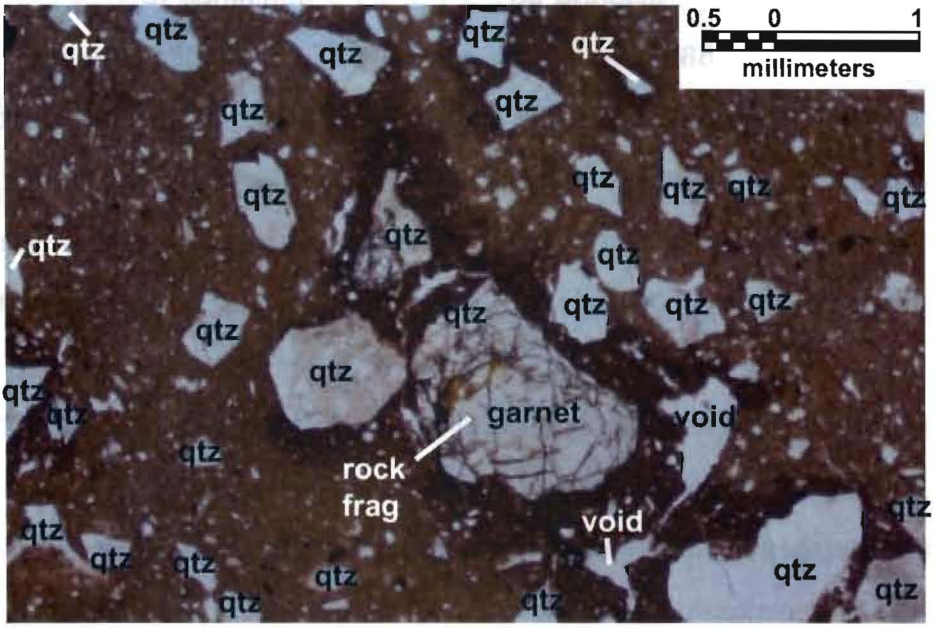


Sherd #6889; Plain Polarized Light; Stain

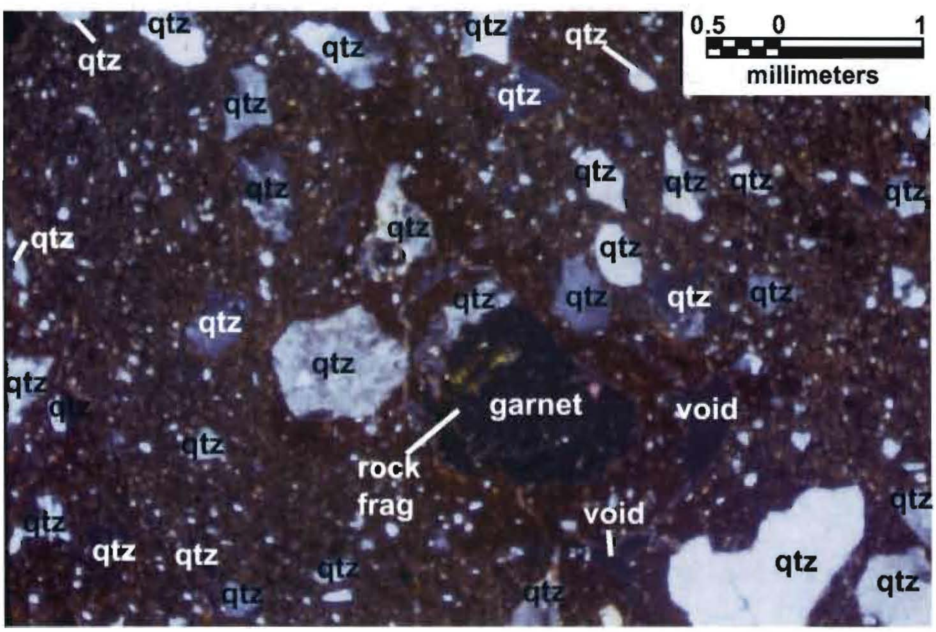


Sherd #6889; Crossed Polars; Stain

Figure 4-19. Photomicrographs of sherd #6889.



Sherd #6889; Plain Polarized Light; No Stain



Sherd #6889; Crossed Polars; No Stain

Figure 4-20. Photomicrographs of sherd #6889.

#6863, and #6866) contained orthoclase. The orthoclase in sherd #6859 had a perthitic texture (Smith 2000). Two sherds, #6859 and #6889, contained less than 4% microcline (Table 4-2). Three sherds (#6866, #6869, and #6889) contained garnet. Temper in all sherds was composed of mineral grains and small rock fragments. Temper composed of a single mineral grain were generally 0.2 to 1.5 mm, while small rock fragments composed of one or more mineral types were usually larger.

Smaller (0.2 to 1 mm) single-mineral temper grains tended to be rounder than larger (>1 mm) single temper mineral grains and rock fragments. Rock fragments were about 0.7 to 3 mm in diameter (Table 4-3). These larger, multi-grain temper particles were consisted of mostly subrounded to subangular particles. Rock fragments found in sherd #6863 were composed only of quartz. However, rock fragments in the temper of the other sherds were generally composed of biotite and quartz and, occasionally, plagioclase. In sherds #6869 and #6889, rock fragments also contained garnet. Sherd #6869 contained the most rock fragments (Table 4-3). Rock fragments in sherds 6859 (Figure 4-3) and 6866 (Figure 4-11) contained myrmekite.

CHAPTER 5: DISCUSSION

Interpretation of Results

Thus far, the mineral temper characteristics of Patayan ceramics (A.D. 900-1150) found at Willow Beach, Arizona has been described, and it has been determined if the temper was derived from a local source. To meet these goals, thin-section analysis of five sherds from Willow Beach was undertaken. Minerals found in the temper include quartz, plagioclase, alkali feldspar (orthoclase and microcline), biotite, and garnet. Bedrock at Willow Beach consists of predominantly garnetiferous granite pegmatite. Other units in the vicinity include the Muddy Creek Formation, a Tertiary conglomerate, and various Tertiary volcanic units (Figure 1-6).

All five sherds examined contained quartz, plagioclase, and biotite. One of the five sherds contained microcline and orthoclase, one contained garnet and orthoclase, one contained microcline and garnet, one contained orthoclase, one orthoclase with no microcline or garnet, and one contained garnet with no orthoclase or microcline (Table 4-1). Most temper pieces were subangular to sub-rounded (Table 4-2), indicating that, despite the abundance of sand on banks of the Colorado River and in nearby washes, the Patayan did not use this sand as temper. This is consistent with Shepard's (1985) observation that rounded sand is not often used as temper due to its poor ability to adhere to the clay matrix.

The plain brown wares recovered from Willow Beach are utilitarian, unadorned wares. To expedite the production of these utilitarian wares, it is most likely that a local clay source was used as raw material. Clay forms from the weathering of bedrock. Consequently, the locally obtained clay probably contained natural inclusions derived from the weathered bedrock. Further studies may be undertaken to verify that a local clay source was used and to determine whether crushed rocks were added to sifted clay or if was clay was minimally processed such that natural inclusions acted as temper.

Colton (1939) examined thirteen sherds (#5570 - #5582) of Willow Beach ceramics with a hand lens. He characterized the temper used as abundant, large to medium, subangular and rounded quartz sand exhibiting bits of biotite mica and rare pieces of obsidian. There are several Tertiary volcanic units near Willow Beach (Figure 1-6). Therefore, it is possible that this type of temper was used to produce some ceramics at this site. In this study, however, volcanic glass was not identified within the temper (Table 4-1).

As previously noted, ceramics found at Willow Beach contain garnet. Besides the garnetiferous granite pegmatite and garnet-bearing gneiss outcropping at or near Willow Beach, the nearest source for garnet is north of Lake Mead in the Virgin River Valley, approximately 80 km to the north. As described in Chapter 2, Tuohy and Stawn (1986) examined three sherds from this area. They found no garnet in the temper used to manufacture these cerarnics.

Implications of Results

The similarity between the mineral temper found in the five thin sections to the local bedrock suggests that the raw materials for manufacturing these ceramics were locally derived. It is not surprising that the ceramics were derived from local resources. Tuohy and Strawn (1986) have previously noted that a common conclusion derived from thin-section analysis is that the materials used in ceramics by prehistoric people are closely related to local geology. Ceramics along the Lower

Colorado River have not been well studied. This study serves as a baseline in describing the ceramics found at Willow Beach. The information derived from this study helps to better describe ceramics from one site along the Lower Colorado River. This description may help to identify interactions among groups if ceramics with temper similar to that found in Willow Beach ceramics are found in other areas.

Additional questions have been raised during this study. These questions include:

1. How were ceramics at Willow Beach manufactured?
    a. Were rocks crushed and added to clay paste?
    b. Were natural inclusions found in clay used as temper?
2. What is the clay source for Willow Beach ceramics?
    a. Was a nearby clay source used?
    b. Did the Patayan go out of their way to choose a higher quality clay source?
3. Were volcanic rocks crushed and used as temper in ceramics found at Willow Beach as indicated by Colton's study (1939)?

It is possible that the sample size of five sherds is too small to characterize the ceramics. Seymour (1997) has noted that ceramics along the Colorado River represent a continuum of types. Perhaps a larger, randomly selected sample size would show a larger variety of temper used to produce ceramics at Willow Beach. Indeed, this type of study should be undertaken to more fully characterize the ceramics in the Lower Colorado River Region and to identify potential subgroups.

CHAPTER 6: CONCLUSIONS

In this study, thin section analysis of temper was undertaken on five Patayan ceramic sherds (A.D. 900 - 1150) recovered from Willow Beach, Arizona. Based on a preliminary analysis of color, surface treatment and temper, the five sherds were defined as five subgroups within the Willow Beach ceramics by another investigator.

Thin section analysis of these sherds reveals that there is no significant difference in temper among the five sherds. The mineral assemblage of the Willow Beach temper consists of quartz, plagioclase, biotite, alkali feldspar, and garnet. Not all thin sections contain all minerals in the temper assemblage. All sherds analyzed contained quartz, plagioclase, and biotite. Two of the five thin sections (#6859 and #6863) contained alkali feldspar but no garnet. Two of the five thin sections (#6866 and # 6889) contained both garnet and alkali feldspar. And one of the five thin sections (#6869) contained garnet and no alkali feldspar. Because a thin section is only a sample of an entire vessel, statistically, some minerals in the vessels temper may avoid detection. However, there is enough overlap in minerals to indicate there is no significant difference in temper used in manufacturing the five vessels. Therefore, on the basis of temper alone, the five sherds do not represent five subgroups within the ceramic assemblage recovered from Willow Beach, Arizona. The first null hypothesis that there is no difference between the temper found in the five sherds examined is accepted.

Petrographic composition of temper in ceramic artifacts included mineral grains and rock fragments composed of the mineral assemblage described in the previous paragraph. This composition appears to correspond with locally available raw materials. Bedrock at Willow Beach consists predominantly of garnetiferous granite pegmatite. The only other garnet in the vicinity is found north of Lake Mead, approximately 80 km away.

In addition to garnet, minerals in the granite pegmatite include quartz, plagioclase, biotite and alkali feldspar. The scarcity of garnet in the region and the occurrence of garnet within a relatively confined area near Willow Beach indicate that the raw materials used in production of the Willow Beach ceramics were most likely derived from a local source. Therefore, the second null hypothesis that there is no difference between temper found in the five sherds and the local bedrock is also accepted.

That the ceramics at Willow Beach were locally produced using local materials is not surprising. Because garnet does not commonly occur in the area, its presence in Willow Beach ceramics helps define this ware as a type. Garnet temper is a diagnostic feature of Willow Beach ceramics which may help identify interaction between groups of prehistoric people when ceramic vessels containing garnet in their temper are found at other sites.

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