AN ANALYTIC STUDY OF OBSIDIAN FROM THE MIDDLE RIO PUERCO VALLEY, NEW MEXICO

A Thesis Presented

to the

Graduate Faculty of Anthropology

Eastern New Mexico University

In Partial Fulfillment

of the Requirements

for the Degree

Master of Arts

by

Kathleen Knapp Bowman

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CERTIFICATE OF ACCEPTANCE

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ABSTRACT

ANALYTIC STUDY OF OBSIDIAN FROM THE
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In this study, 31 obsidian samples from several sites in the Middle Rio Puerco Valley were analyzed. These sites were associated with mean ceramic dates ranging from A.D. 795 to A.D. 1240 and one archaeomagnetic date of A.D. 1275. The main goal of this research was to determine a hydration rate for the obsidians.

This was done by first chemically characterizing the archaeological samples by x-ray fluorescence and comparing them to a previously characterized comparative base of known sources. Results obtained showed that the archaeological samples were derived from three sources relatively close to the project area. The sources were the Rio Grande Pleistocene Terrace Gravels, Cochiti vicinity, Rio Grande Pleistocene Terrace Gravels, Los Lunas vicinity, and San Antonio/No Agua Mt. Through regression analysis a hydration rate was determined for the Rio Grande Pleistocene Terrace Gravels, Cochiti vicinity.

An ancillary goal was to test the validity of macroscopic sorting of obsidians. This was found to be questionable. An experiment was also done which compared the results obtained through discriminant analysis for this study with another similar study.

Finally, several limitations on the results were observed and discussed. These were related to the sample size, time span of the sample, and chronological control problems.

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I. INTRODUCTION

Obsidian, an igneous rock formed by the quick cooling of molten rhyolitic lava, was a widely used raw material source prehistorically. In recent years obsidian has become a valuable source of information for archaeologists. Through obsidian sourcing and obsidian hydration dating, the delineation and study of prehistoric exchange systems (cf. Cobean et al. 1971; Hammond 1972; Asaro et al. 1978; Charlton 1978) and the development of absolute and relative chronologies within specific source areas (cf. Layton 1972; Findlow et al. 1975; Findlow 1977; Hurtado de Mendoza 1981) are possible.

The hydration of obsidian is a natural chemical process that begins soon after the obsidian forms and continues throughout the life-cycle of the obsidian, ending when it has been transformed into perlite. The hydration rim forms as flakes are removed (via many processes) from the surface of the obsidian. Due to its changed refraction, the hydration rim can be seen and measured under high magnification with a petrographic microscope. A hydration rim on a piece of obsidian will hold up to ten times more water than the non-hydration portion of the rock (Clark 1961). Because fresh hydration surfaces are caused when flakes are removed from the obsidian, prehistoric flintworkers created these surfaces. In effect, they were setting a clock, which, due to present scientific techniques, can be read by archaeologists and used to date archaeological sites and assemblages.

Three decades of research has shown that hydration rate is dependent on several factors (cf. Friedman and Smith 1960; Ericson 1975; Findlow et al. 1975; Hurtado de Mendoza 1981). Chemical composition and environmental factors were found to be the most crucial variables affecting the hydration rate of all obsidians (Friedman and Smith 1960). Therefore in determining a hydration rate for a particular obsidian, its geologic source must be determined, environmental factors should be similar for all obsidian samples used, and in addition, strong contextual association with dates obtained through other chronometric techniques are necessary.

Research Goals and Objectives

In this study, obsidian collected from Anasazi sites in the Middle Rio Puerco Valley (Figure 1) are used in determining a hydration rate. The obsidian was recovered through the efforts of Dr. Cynthia Irwin-Williams in this area. According to Brett (1984:2), Irwin-Williams began work in this area in 1970. Initially, only surface survey and collections were done. Later, based on results obtained from that early work, subsurface testing was undertaken at sites in the area (Brett 1984:2).

It is the obsidian artifacts collected from the subsurface testing at these sites that forms the database for this study. A hydration rate for this obsidian will be developed by mathematically correlating

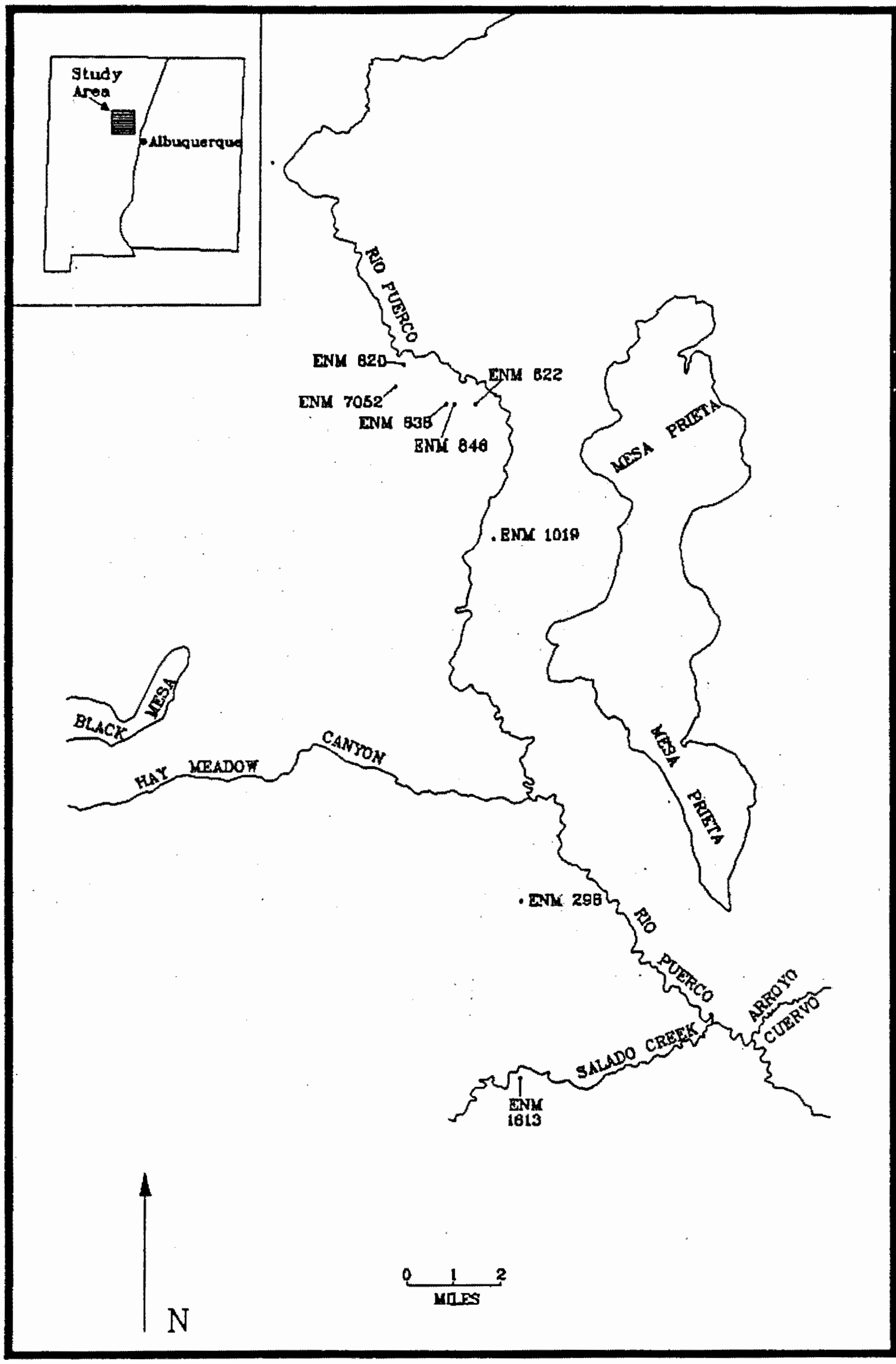

Figure 1. Project area.

hydration rim measurements and associated dates. The associated dates were derived from mean ceramic dates and archaeomagnetic dates obtained for the sites by Irwin-Williams.

This research is based on several explicit and acceptable assumptions. It was assumed that the obsidian found at the sites is in fact associated with the ceramic dates obtained for these sites. This is believed to be an acceptable assumption because all of the obsidian used in this study is from ceramically single component sites and were found in similar stratigraphic contexts. It is also assumed that variation introduced through environmental conditions (e.g., effective temperature and depositional environment) is minimal for the samples under study. This is considered valid because the samples are from an area of relatively slight elevational differences and, more importantly, all were recovered from excavated contexts. Previous research has shown that soil temperature does not vary much on a daily basis in contrast to the variation found in atmospheric temperature (Ambrose 1976). Finally, it is assumed that macroscopically similar obsidian comes from the same geologic source. This assumption was made out of necessity because not all of the obsidian samples could be characterized by x-ray fluorescence. Some were too small to be sub-sampled both for x-ray fluorescence and for hydration rim measurements. Within a given region, it has been demonstrated that some individual obsidian sources can be macroscopically distinct (cf. Findlow et al. 1975; Ammerman 1979).

The first two assumptions could not be tested for validity and were therefore accepted outright. However, the third assumption caused definite uneasiness because others have shown that macroscopic distinctions do not correlate well with chemical source characterization (cf. Frison et al. 1968; Landis and Sappington 1985). As a result, an additional goal of this study was to test the validity of macroscopic sorting. If the test was not successful, the third assumption would be discarded.

Physical Setting of the Study Area

The study area is within the southeastern portion of the San Juan Basin, specifically the Middle Rio Puerco Valley (Figure 2). The bedrock of the valley is composed of Mesozoic shales and sandstones (Durand and Nials 1981:1). As a result of the erosion of tertiary volcanic deposits that previously overlaid the area many dikes and plugs are now exposed. Paralleling the Puerco River and its tributaries is a broad, flat floodplain which resulted from postglacial deposition (Durand and Nials 1981).

The San Juan Basin covers parts of northwestern New Mexico, Arizona, Colorado, and Utah in the Four Corners area of the United States. Marshall et al. (1979:21) define the boundaries of the San Juan Basin as follows: at its northern perimeter are the Hogback monocline and the San Juan Uplift; to the east are the Nacimiento Uplift and the Jemez Mountains Caldera; it is bounded on the south by

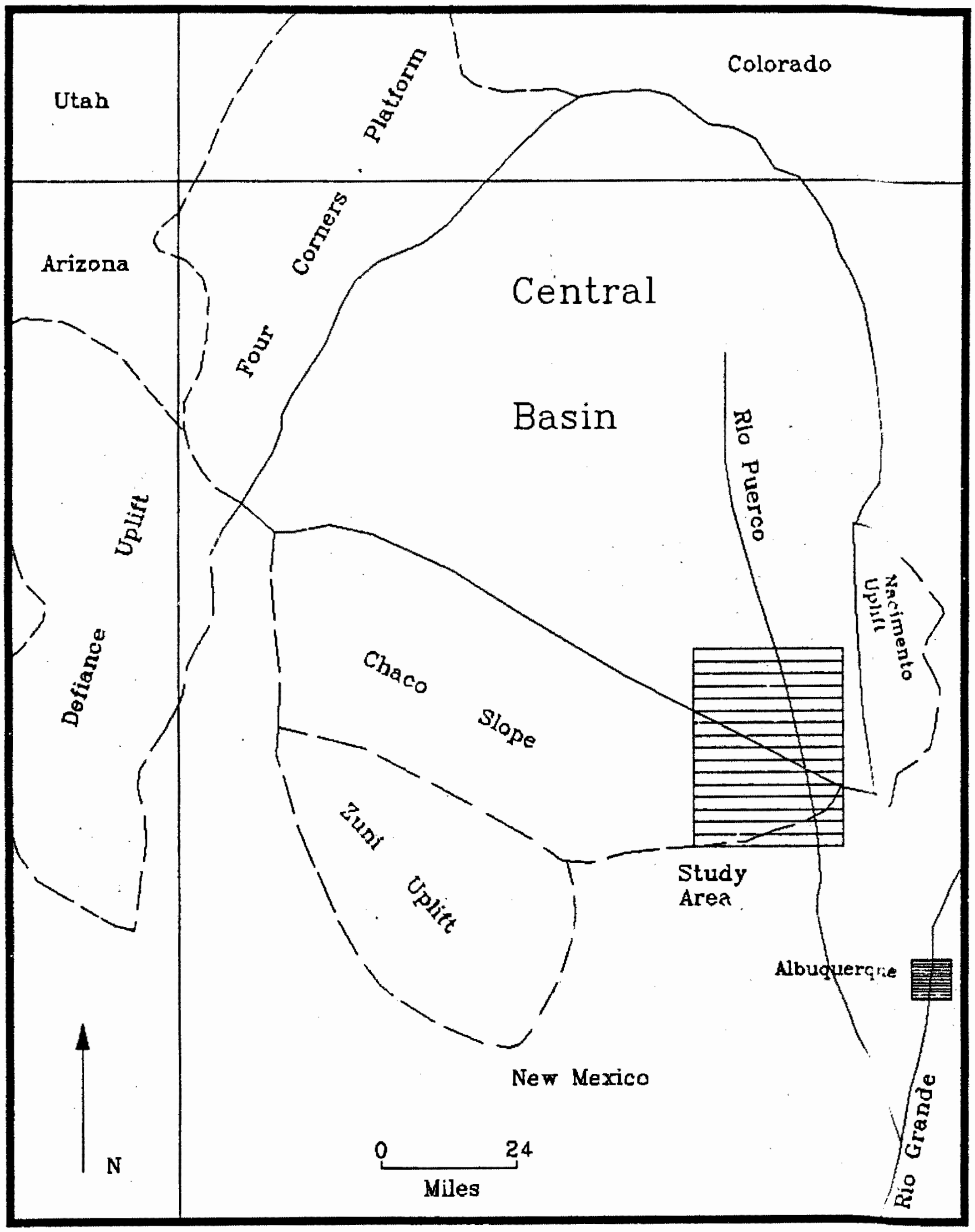

Figure 2. Location of the San Juan Basin (adapted from Little 1957).

the Zuni Uplift and the Chaco Slope; and to the west its boundaries are the Defiance Uplift and the Four Corners Platform (see Figure 2).

The San Juan Basin began forming during the Cretaceous period, over 100 million years ago (Marshall et al. 1979:21). The basin's sedimentary floor is composed of shales, siltstones, and sandstones. Many volcanic intrusions are also present. Also characterizing the basin are Pleistocene terraces, erosional surfaces, floodplains, washes, valleys, alluvial slopes, deep arroyos, dune fields, and numerous mesas and ridges (Marhsall et al. 1979:21).

II. PREHISTORIC CULTURAL BACKGROUND

In the overview of prehistoric cultural development in and around the study area Irwin-Williams' cultural and temporal frameworks are relied upon heavily (1973, 1979). These frameworks are tied into the more general development of the Anasazi in northwestern New Mexico presented by others (Lipe 1978; Cordell 1979, 1984; Stuart and Gauthier 1981). Table 1 presents a summary of the cultural periods and their associated dates used in this study.

Paleoindian

There have been few Paleoindian remains found in northwestern New Mexico (Stuart and Gauthier 1981) and none were recorded in the study area. It has been theorized that this may be due, in part, to the absence of significant erosion in this part of New Mexico (Stuart and Gauthier 1981; Cordell 1984). Most Paleoindian remains are deeply buried and without significant erosion would not be exposed for discovery. The evidence that exists from the Arroyo Cuervo area east of the present study area, supports the existence of Clovis, Folsom, and Cody cultural adaptations (Irwin-Williams 1973).

The earliest Paleoindians were the Plains-based Clovis big-game hunters. They extended into the study area sometime between 9500 and 9000 B.C. (Irwin-WIlliams 1979; Cordell 1984). The lithics associated with this adaptation are typified by the large, lanceolate, fluted

Table 1. Cultural Periods in the Study Area.

Cultural Period		Associated Dates
Pueblo IV		A.D. 1330 - A.D. 1540
Pueblo III		A.D. 1100 - A.D. 1300
Pueblo II		A.D. 900 - A.D. 1100
Pueblo I		A.D. 700 - A.D. 900
Basketmaker III		A.D. 450 - A.D. 750
Oshara	Trujillo	A.D. 400 - 600
	En Medio	800 B.C. - A.D. 400
	Armijo	1800 B.C. - 800 B.C.
	San Jose	3000 B.C. - 1800 B.C.
	Bajada	4800 B.C. - 3200 B.C.
	Jay	5500 B.C. - 4800 B.C.
Paleoindian	Cody	6600 B.C. - 6000 B.C.
	Folsom	9000 B.C. - 7800 B.C.
	Clovis	9500 B.C. - 9000 B.C.

Clovis projectile point. Two well known sites that have contributed greatly to our knowledge of this cultural period are the Blackwater Draw site in eastern New Mexico and the Lubbock Lake site in the Texas Panhandle.

After 9,000 B.C. there is evidence of an overall decrease in effective moisture; a trend that continued, interspersed with few relatively moister periods, to around 5000 B.C., when it is believed that environmental conditions approximated those of today (Irwin-Williams 1979:31-33). The Folsom period, which follows Clovis, is seen as an adaptation to this changing environment. Its lithic assemblage is characterized by smaller, more finely worked, fluted points. At the Lindenmeier site in Colorado, Folsom points are associated with radiocarbon dates around 9000 B.C. (Wilmsen and Roberts 1978:39-40), while at the Lubbock Lake site they are associated with radiocarbon dates of 8800 to 9100 B.C. (Holliday et al. 1983).

The next cultural group found in the area, the Cody, represents an adaptation to a brief increase in effective moisture (Irwin-Williams 1979:33). The Cody Complex is characterized by Eden and Scottsbluff points and the distinctive Cody knives (Willey 1966). At the Hell Gap site in Wyoming this period is associated with a mean date of 6640 B.C. (Willey 1966:47). In the Arroyo Cuervo region, Irwin-Williams (1973:4) dates the Cody Complex from 6600-6000 B.C.

Oshara

Following the Cody Complex, the archaeological record becomes less clear. Archaeologists such as Stuart and Gauthier (1981) see the Jay phase occurring as a transitional period into the Archaic in this area. However, Irwin-Wiliams' (1973) believes that there was an occupational hiatus of the area following the Cody and that the Jay materials represent the earliest Archaic adaptation in this area, the Oshara. For the purposes of this study Irwin-Williams' interpretation is used.

The Oshara, defined by Irwin-Williams (1973), represents the Archaic adaptations in the study area. Irwin-Williams (1973) developed the cultural sequence for this period based on her work in the Arroyo Cuervo region just east of the study area. She found that it can generally apply to much of northwestern New Mexico, including the present study area. The following summary of the Oshara/Archaic tradition is based upon Irwin-Williams research (1973). Other discussion of Irwin-Williams' work may be found in Cordell (1984).

The earliest phase of this cultural tradition dates between 5500 B.C. and 4800 B.C. and is termed the Jay Phase (Irwin-Williams 1973). This is the earliest Archaic adaptation that can be "directly connected with the development of Anasazi (Pueblo) culture" (Irwin-Williams 1973:4). Cultural adaptations at this time are based on a mixed hunting and gathering subsistence, characterized by seasonal camps usually located near permanent water resources and other special activity areas. Sites dated to this phase are generally small. Of the lithic assemblage associated with the Jay Phase, Irwin-Williams states "the tool assemblage of these earliest Archaic cultures differs so greatly in technology, typology, and functional classes from the preceding Cody, and other Paleoindian phases, that there is evidently no generic connection between them" (1973:4). Some archaeologists view the Jay phase as a transitional period between the Paleoindian and Archaic, while Irwin-Williams sees a hiatus between these phases (see Cordell 1984:158.) Lithic items associated with this phase include large projectile points, lanceolate bifaces, and side scrapers.

The next phase defined by Irwin-Williams (1973) is the Bajada Phase and has been dated from 4800 B.C. to 3200 B.C. During this phase there is an overall continuity in cultural adaptation from the preceding Jay Phase except for minor technological changes and a postulated slight increase in population. Hunting and gathering continues as the major subsistence activity. Settlement patterns are similar to the Jay Phase, however, sites become more numerous. It is this increase in the number of sites that is interpreted as a population increase (Irwin-Williams 1973:6). Lithic items are basically the same as the Jay Phase, however the trend towards decreasing projectile point size begins.

The San Jose Phase, dating from 3000 B.C. to 1800 B.C., succeeds the Bajada Phase. This phase was reported on earlier by Agogino and Hester (1953, 1956) as the Santa Ana pre-ceramic sites. Agogino (1960a, 1960b) identified many sites in and near the study area that contained point types similar to those of the San Jose phase. He obtained radiocarbon dates ranging from 3300-2900 B.P. (Agogino

1960a:19). This adaptation is a response to several changes in the environment. These include an increase in effective moisture, stabilization of dunes, and the formation of soils (Irwin-Williams 1973). This phase is characterized by an increase in the number and size of sites. Base camps are larger and there is evidence of seasonal occupation of the same sites. Archaeological evidence also indicates the use of temporary structures. Subsistence shifts to one of mixed foraging. Shallow, basin grinding slabs have been found at sites attributed to this phase. There is a continuity in projectile point form from preceding phases, however there is a decrease in overall size.

During the next phase, Armijo (1800-800 B.C.), there is the first appearance of limited maize agriculture and a concurrent shift in land use patterns to accommodate this shift. There is also the fist appearance of seasonal population aggregation as evidenced by large, dense sites with multiple living floors (e.g., Armijo Shelter). There is an increase in groundstone tools and the overall tool kit is a continuation of the previous phase with the addition of religious items (Irwin-Williams 1973).

Irwin-Williams (1973) places the En Medio (800 B.C. to A.D. 400) and subsequent Trujillo (A.D. 400-600) phases following the Armijo phase. These are transitional phases to the later Basketmaker III and Puebloan adaptations. Of the En Medio phase Irwin-Williams states "it included the earliest recognizable Anasazi-Pueblo materials, generally termed Basketmaker II" (1973:11). The Trujillo phase is part of the Basketmaker III adaptation. Both of these phases are similar to the preceding Armijo phase. Notable differences include an increased use of groundstone and, during the Trujillo phase, the addition of ceramics and the bow and arrow. Basic settlement and subsistence patterns, however, apparently did not change.

Basketmaker III

Dating from A.D. 450/500 to A.D. 750/900 this period encompasses what Irwin-Williams (1981) has termed the dispersed state. She states that this "forms the essential basic component subsystem for all higher Pueblo organizations" (Irwin-Williams 1981:2). This adaptation shows a shift in settlement patterns with sites occurring near deep, well-watered soils both in alluvial valleys and uplands (Lipe 1978). In general, this period is characterized by "villages of irregular, shallow pithouses, numerous interior and exterior storage pits and cists, and widespread occurrence of ceramics, all of which are interpreted as indicative of sedentism" (Cordell 1979:134). According to ceramic seriation groups used by Baker et al. (1981) for sites in the immediate study area, this period ends in A.D. 813. During this period sites are located "on flat-topped interfluve environments, mesa edge environments, steep colluvial slopes, and shallow colluvial slopes" (Baker et al. 1981:2-3).

This period is also marked by the introduction of domesticated beans, completing the triad of maize, squash, and beans typical of most Greater Southwestern cultural adaptations. Wild plants present include pinon and Indian rice grass. Hunting continues possibly with a shift from the atlatl to the bow and arrow, as evidenced by the decreasing size of projectile points. Faunal remains include cottontail, jackrabbit, deer, antelope, and Rocky Mountain bighorn sheep. Trough metates and grinding slabs also occur.

Ceramics of this period include Sambrito Brown, Tallahogan Red, and Lino Gray, the latter of which is considered diagnostic of this period (Cordell 1979). Lino gray is produced in a reducing atmosphere, a trademark of the Anasazi (Cordell 1979). At sites in the Albuquerque area, Mogollon ceramics, indicative of trade, are found. Other trade items found include marine shell, found both as whole beads and as pendants. Other items of material culture associated with this cultural adaptation include coiled baskets, sandals, cloud-blower pipes, and turquoise pendants (Lipe 1978; Cordell 1979).

Villages are common, although small, with no obvious plan to the arrangement of structures in the villages (Cordell 1979; Irwin-Williams 1981). Kivas begin to show specialized architectural details in the Albuquerque and San Juan areas around A.D. 500-700 and in the Cimarron area around A.D. 750-900. Houses show a great deal of subregional variation in pithouse shape and interior features (Cordell 1979).

Puebloan Adaptations

Pueblo I

With the advent of this cultural adaptation (A.D. 700-900) we see the beginning of the "aggregated state" as defined by Irwin-WIlliams (1981). She sees the evolution from dispersed state to aggregated state as a "response to changing environmental conditions, technology, and/or other socioeconomic pressures" (Irwin-Williams 1981:4). This period is characterized by changes in architecture and ceramic variation with a great deal of variability in the rate of change from area to area (Cordell 1979). Population shifts occurred, causing a less uniform distribution of populations (Lipe 1978).

There are also changes in the use of structures. Pithouses changed from domestic structures to "kivas" and used as the focus of ceremonial activity. Surface structures were became larger and used both for habitation and storage (Lipe 1978; Cordell 1979). Village location was also changed. In the beginning of this period, site location was generally the same as in the preceding period, but toward the later part populations began expanding into the colluvial slopes of the more mountainous portions of the area (Baker et al. 1981; Cordell 1979).

During this period ceramic manufacture becomes more refined and diversified. In addition to utility wares, decorated vessels become more common (Lipe 1978; Cordell 1979). Painted wares include Rosa Black-on-white, Kiatuthlana Black-on-white, Abajo Red-on-orange, and La Playa Black-on-red (Cordell 1979). Forms used include jars, bowls, ollas, and ladles, which were traded from area to area. Kana'a Gray is considered the diagnostic ceramic type for this period (Cordell 1979).

Cotton is added to the list of domesticated plants and loom weaving appears (Lipe 1978). Evidence from burials shows that flattening of infant skulls through cradleboarding was practiced (Lipe 1978; Cordell 1979). Other archaeological evidence, specifically stockaded settlements, may indicate the existence of warfare at this time (Cordell 1979).

Pueblo II

This cultural period is dated from A.D. 900 to A.D. 1100/1150 and is characterized by sizeable shifts in populations (Cordell 1979). Previously unoccupied and abandoned areas were settled and maximum geographic distribution and population size occurred (Lipe 1978). During the early part of Pueblo II development, site size increased and settlement locations became more diversified (Baker et al. 1981). It was also during this period that the initial development of the "nucleated state" (Irwin-Williams 1981) is seen at Chaco Canyon.

Ceramic manufacture differs from the preceding Pueblo I period in the increasing variation and complexity seen in painted designs (Lipe 1978). Diagnostic ceramics for this time period include banded utility wares (early) and corrugated wares (late). Red Mesa Black-on-white is the diagnostic painted ware (Cordell 1979).

Subsistence is now based on farming, partly a response to favorable climatic conditions (Lipe 1978). Pithouses and surface structures are used for habitation. Masonry structures are more common. Kivas begin to exhibit typical features (e.g., sipapus and wall niches) for which they are traditionally noted (Cordell 1979).

Variation in settlement types and population size exists from region to region during this period. For example, in the Navajo Reservoir area (Cordell's terminology) there is a disappearance of stockaded settlements after A.D. 900 (Cordell 1979). Sites are found at higher elevations. Trade items are seen to derive from Mesa Verde. Also in this region it is postulated that there is a decrease in farming and an increase in hunting. This is based on a decrease in groundstone implements and an increase in flaked stone (Cordell 1979).

This particular area is abandoned in A.D. 1050 and it is speculated that population moved north to the Mesa Verde area (Cordell 1979). In other areas, specifically Chaco Canyon and Cebolleta Mesa, there is an increase in population. In the Albuquerque area no changes area noted and pithouses are still the dominant domestic structure form.

Pueblo III

This period in Puebloan development dates from A.D. 1100/1150 to A.D. 1300 (Lipe 1978; Cordell 1979). There is an aggregation of populations into fewer, larger pueblos and a shift in settlement patterns from open locations to shelters and ledges in canyon walls possibly for defensive purposes (Lipe 1978). Cultural development at Chaco Canyon peaks during this time and events there dominate Eastern Anasazi development during this period (Cordell 1979). Chaco Canyon is now fully a "nucleated state" as defined by Irwin-Williams (1981). The nucleated state is characterized by a "dramatic growth in size and complexity of the cultural system", however it also "lacks flexibility and is more easily disrupted than either the aggregated or dispersed states" (Irwin-Williams 1981:6).

During this period, ceramic manufacture reaches its peak in technical and artistic quality (Lipe 1978). There is an increase in the use of black pigment. Many ceramic types now reflect Chaco influence. These types include Chaco Corrugated, Gallup Black-on-white, and Chaco Black-on-white (Cordell 1979). One Mesa Verdean ware, McElmo Black-on-white, also begins to appear more frequently.

By A.D. 1300, much of the original plateau lands inhabited by the Anasazi were abandoned. It is postulated that Anasazi groups moved to the south and southeast margins of the area (Lipe 1978). In the Middle Rio Puerco valley abandonment occurred by A.D. 1300. This occurred after major fluctuations in populations and settlement location. During the early part of this period (A.D. 1125-1208), a drought caused an apparent dispersal of populations (Baker et al. 1981). Following this dispersal, site size increased and more variety is seen in the types of environments settled. By the latter portion of this period, there is a population aggregation and decline, and finally in A.D. 1300 abandonment (Baker et al. 1981).

Pueblo IV

This period which lasts from A.D. 1300 to A.D. 1540 (Historic Contact) is characterized by population aggregation into a few large communities located mostly in the eastern and southern portions of the Anasazi area and frequent abandonment of these areas (Cordell 1979). Cliff dwellings become less common and populations moved away from canyon areas (Lipe 1978). The Rio Grande area has an increase and aggregation of population for the first time. In this area, many large sites were abandoned prior to historic contact and the historically known and modern eastern Pueblos were founded (Cordell 1979).

Summary

The preceding pages have provided a brief overview of the cultural setting in and surrounding the study area. General trends in the development of the Anasazi culture in northwest New Mexico and its subsequent decline area seen throughout this sequence and include an increasing reliance on agriculture as a subsistence base and concomitant formation of larger, more aggregated populations and sites.

III. LITERATURE REVIEW

Over the last three decades, obsidian hydration dating has been researched and refined by many archaeologists. The main attraction of this method has been that it is relatively inexpensive and less time consuming than other chronometric techniques and samples are more easily obtained. From early work in the 1960s until the present, obsidian hydration has become more and more reliable. The following pages detail its development as a viable dating method.

The Early Years

The first serious research into obsidian hydration as a useful dating technique for archaeologists began in the late 1950s and early 1960s. Friedman and Smith (1960) published one of the first articles detailing the technical aspects of obsidian hydration dating and have been called the "fathers" of the method (Clark 1961). Also in 1960, Evans and Meggars, two archaeologists working with Friedman and Smith, published an article detailing the archaeological applications of obsidian hydration dating (Evans and Meggars 1960).

Friedman and Smith's research focused on developing hydration rates for various regions throughout the world (1960). They accomplished this with the help of several absolutely dated archaeological assemblages that they obtained from Evans and Meggars. They examined the major sources of variation in the hydration process and established guidelines for future research in obsidian hydration dating.

Friedman and Smith (1960) began their research by evaluating several factors thought to influence the hydration rate of all obsidians. They observed that temperature, chemical composition, burning, and erosion all had some effect on the hydration rate. They believed that temperature had the greatest effect on the rate. This conclusion was supported by their experiments which determined that obsidian in cold, frozen environments, such as the Arctic, hydrated more slowly than obsidian from temperate or tropical environments. Likewise, they observed that buried obsidian hydrated slower than obsidian from surface contexts. Chemical composition was also observed to influence the hydration rate. In their work with Egyptian obsidian they found that trachytic (basaltic) glass hydrated at a different rate than rhyolitic (obsidian) glass. Burning was found to seriously alter hydration rate. They also observed that both chemical and mechanical processes of erosion could alter the hydration rate, as well as alter the existing hydration rim. Common mechanical weathering processes, such as wind and water abrasion, could wipe out existing hydrations rims and create new ones (Friedman and Smith 1960:481-483).

Another major contribution of Friedman and Smith's research was the guidelines they set forth for preparing slides and taking hydration rim measurements (Friedman and Smith 1960:478-481). With the exception of a few minor modifications, the general procedure they described is still in practice: a thin section is cut at right angles to the obsidian sample, it is ground down to a thickness of 0.002 to 0.003 inch, and then examined under a high power transmitted light microscope. The measurement of the hydration rim is made with a filar and calibrator, moving the filar from the inner boundary of the rim to the outer boundary.

Their final results were plotted on graphs with time (in years) and the thickness of the hydration rim (in microns) as the axes. In this way missing parts of the curves were estimated and future sample readings could be properly oriented and given a date without the necessity of being tied to absolutely dated contexts. Their research resulted in the formulation of several hydration rates for various regions of the world.

Widespread archaeological applications of Friedman and Smith's (1960) work were considered by Evans and Meggars (1960). They reported that many samples from a well established archaeological context were necessary for obsidian hydration dating to be successful. Archaeologists had to be reasonably sure that the obsidian samples they were using were firmly associated with absolute dates. They also cautioned that the method was still in its exploratory stages. They pointed out how several of the curves developed by Friedman and Smith (1960) did not fit with dates obtained from other methods and that hydration rates would apply only to the areas they were developed for (Evans and Meggars 1960).

Continuing these lines of research, Clark (1961) developed a hydration rate for central California obsidians. He also began research into the development of regional hydration rates. He noted that the hydration rim would expand until reaching a thickness of approximately 50 microns at which point it would spall off and the process would begin anew. He points out that this probably gives obsidian hydration dating a range of close to 200,000 years (Clark 1961). In his article, Clark also requested archaeological obsidian samples from the world over so that regional hydration rates could be established. At this point it was still believed that climate (temperature) was the variable exerting the most influence over the rate of hydration.

Research continued in the following years, and in 1967 J.W. Michels published an article in which he states "many of the difficulties associated with the technique [obsidian hydration dating] have been solved" (1967:211). However, this point was really still many years away. While agreeing to its value for relative dating (Michels 1967, 1969; Friedman and Evans 1968), archaeologists were still debating its value as an accurate absolute chronometric method.

This debate is seen clearly in the numerous hydration equations developed during these early years. Friedman, Smith, and Long (1966) developed the $X^2 = Kt$ equation, where $\underline{X}$ is the depth of water penetration (in microns), $\underline{K}$ is the effective temperature constant, and $\underline{t}$ is time in years. Michels (1967) supported this equation. However, Meighan et al. (1968) found that this didn't work with their West Mexican obsidian samples, and developed the linear model, $X = Kt$. Clark (1961) had previously developed the equation, $X = Kt^{3/4}$ for the central California obsidian in his study. Johnson (1969), working with obsidian from the Klamath Basin of California and Oregon, developed still another rate.

Other research during these early years focused on obsidian sourcing and its significance for studying prehistoric exchange systems (Stross et al. 1968; Frison et al. 1968; Gordus et al. 1968). Frison et al. (1968) used neutron activation analysis and the ratios of percents of the elements Na to Mn to source obsidian. Their work focused on sources in the northwestern United States. They observed that while some obsidians could be sorted macroscopically, others could look the same and yet be very different geochemically (Frison et al. 1968:214). Gordus et al. (1968) also used neutron activation analysis and Na to Mn ratios. They noted that other elements useful in differentiating geologic sources included Sc, La, and Sm (Gordus et al. 1968:223). Stross et al. (1968) used x-ray fluorescence values for their work, except for values of Mn, which were derived through neutron activation analysis. They analyzed artifacts from Mexico, Guatemala, Honduras, California, and Nevada.

To sum up these early years in obsidian hydration studies, we see many pioneering studies geared at creating regional hydration rates. It had not yet been discovered that hydration rates need to be source-specific, based on variation in chemical composition. It was recognized that gross variations in chemical compositions, such as that between rhyolitic and trachytic flows, could affect hydration but minor chemical variations were not considered (Friedman, Smith, and Clark 1969; Johnson 1969). Good techniques for measuring hydration rims were developed (Friedman and Smith 1960), and the use of obsidian hydration as a relative chronology to sort mixed and reused artifacts (Michels 1967, 1969) was realized. Obsidian sourcing was being explored as an avenue for studying prehistoric exchange systems. All of these early studies created the foundation for the future avenues of research that obsidian hydration dating would take.

The Middle Years

In the early 1970s research efforts were still focused on debates over hydration rates and on the use of obsidian hydration measurements for relative sequencing of artifacts from stratigraphically mixed contexts. Layton (1972, 1973) experimented a great deal with the development of relative chronologies through obsidian hydration rim measurements. He developed a relative chronology for points in the Great Basin (Layton 1973). In another experiment, utilizing surface projectile points and excavated points (of the same type) from two different sites, he found that although surface obsidian hydrated at a faster rate that the buried obsidian (almost twice as fast), the ratio of band width from older to younger remained the same (Layton 1973).

By the mid 1970s archaeologists were beginning to realize that chemical composition of obsidian played a major role in the determination of hydration rate. Ericson and Berger (1974) were among some of the first researchers to point this out. Their research focused on the Mostin site, near the Borax Lake site in northern California. Human bones were found in direct association with obsidian artifacts. Radiocarbon dates derived from the bones provided absolute chronological correlations for the obsidian. They state that it was apparent that two sources of obsidian were being utilized and could be seen based on the macroscopic appearance of the obsidian (Ericson and Berger 1974:824). They used neutron activation analysis and x-ray fluorescence to chemically characterize the two obsidian sources.

In another work, Ericson (1975) discusses the need for source specific rates. He used neutron activation analysis and x-ray fluorescence in conjunction with stepwise discriminant analysis to determine source specific rates. Findlow et al. (1975) supported these methods in their work with the Government Mountain-Sitgreaves Peak (in Arizona) obsidian source. This was an obsidian source heavily exploited in the Southwest prehistorically. Findlow et al. (1975:345) observed that this obsidian could be separated from others macroscopically, but with a high error level. Therefore it was recommended that sources be chemically characterized for more accurate results. The hydration rate they developed was different from models formulated by others (e.g., Friedman and Smith 1960; Clark 1961). Findlow et al. (1975) stress the fact that this rate can only be applied to the Government Mountain-Sitgreaves Peak source within the time frame spanned by their samples. Findlow (1977) later revised this rate. Kimberlin (1976) also researched the relationship of chemical composition to rate. He believed that no one rate was possible, but that each chemically distinct source would need its own rate (Kimberlin 1976).

Friedman and Long (1976) further examined the relationship of hydration rate to temperature and chemical composition of obsidian. They calculated hydration rates based on factors such as silica content of the obsidian, refractive index, chemical index, and the effective temperature at which the hydration process occurred. This temperature was estimated from weather records or else actual measurements were taken. Ambrose (1976) also researched the use of temperature in determining hydration rates. However, in contrast to Friedman and Long (1976), Ambrose did not believe an accurate temperature constant could be determined from records on mean annual temperature. Instead he supported the use of a thermal cell placed in the ground at archaeological sites and monitored throughout the course of a year to determine an accurate temperature constant.

Also during this decade, a great deal of research focused on obsidian sourcing and its relevance to establishing prehistoric exchange networks. Charlton (1978) examined trade networks and their importance to the development of Teotihuacan in Mexico. Ammerman (1979) researched obsidian exchange in Italy. He noted that some obsidian could be macroscopically sorted. In a blind test between two Italian sources, students correctly identified them on the basis of macroscopic variables (Ammerman 1979:99). Asaro et al. (1978) studied obsidian sources in Guatemala using neutron activation analysis and x-ray fluorescence. These researchers emphasized that a source must be sampled well enough to support homogeneity or to demonstrate significant heterogeneity (Asaro et al. 1978:436). Many other studies focused on the use of x-ray fluorescence analysis and neutron activation analysis for geochemical characterization of obsidian (cf. Ward 1974; Nelson et al. 1975; Nelson et al. 1977; Stross et al. 1977; Nelson and Holmes 1979). They also called for standardization of analytic and reporting techniques.

Sample size also continued to be scrutinized during this decade. As first mentioned by Johnson (1969), Meighan (1976) theorized that the confusion with hydration rate could be the result of small sample size. When a small sample spanning a short time period is analyzed a linear rate may be determined when in actuality the rate may be curvilinear. Friedman and Trembour (1978) also noted this in their review of the state of the art and its applications both to geological and archaeological problems.

Several monographs on archaeological dating techniques published in the 1970s include lengthy sections on obsidian hydration as a dating technique (Michael and Ralph 1971; Michels 1973; Fleming 1976). In all of these instances, the process and technique of the method are described in varying detail. A major monograph, Advances in Obsidian Glass Studies, was devoted solely to obsidian hydration techniques, applications, and geochemical characteristics of the obsidians (Taylor 1976). All of these publications support the fact that obsidian hydration dating was becoming a viable dating method valuable to archaeologists.

Current Research

In the early 1980s many reviews of obsidian hydration dating and sourcing and critiques of the current state of the art were published (e.g., Michels and Tsong 1980; Friedman and Trembour 1983; Meighan 1983). A dichotomy also began to develop between those researchers who pursued obsidian sourcing for use in delineation of exchange patterns and those who pursued obsidian hydration dating. A great deal of work was done with Mexican obsidians and sourcing. Nelson and Voorhies (1980) used x-ray fluorescence to analyze obsidian from Chiapas, Mexico and assign samples to sources. Rice et al. (1985) used x-ray fluorescence and neutron activation analysis for sourcing obsidians from Guatemala. Findlow and Bolognese (1982) worked with New Mexico obsidians to describe prehistoric and historic exchange patterns. Overall, there was a desire (and a true need) among researchers to provide comparative trace elemental data. This trend occurred not only in obsidian research in the areas mentioned above but in other parts of the world as well.

Obsidian hydration laboratories begin to focus more on induced hydration and developing hydration rates for various geological obsidian sources. The most prolific of these labs is Mohlab operated by J. W. Michels. Induced hydration is done by placing a geologic obsidian sample in a thermoregulated reaction bomb with deionized water and heating it at high temperatures (cf. Michels 1983). This speeds up the hydration process. After a period of days the samples are then prepared for hydration rim measurements. These measurements are the used to determine the hydration rate for the sample. Between 1983 and 1986 Michels generated rates for over 17 New Mexican obsidian sources. Most of these are various groups of gravels collected up and down the Rio Grande. In each of his reports Michels uses geologic obsidian samples, provided by various persons, for induced hydration and subsequent determination of hydration rate constants (e.g., Michels 1983; 1984; 1985). Stevenson (1985a, 1985b) also used induced hydration to develop rates for various New Mexico obsidians. Shelley and Montgomery (1985) also characterized various New Mexico obsidians for use in sourcing unknown archaeological samples.

Other trends evident in the last few years involve increasing interest in perfecting hydration rim measuring and sourcing techniques. Most recently Stevenson et al. (1987) have reported on the increased accuracy of hydration rim measurements when a gypsum (1/4 wave red tint) plate is used in conjunction with a high power light transmitted microscope. Clark (1984) discusses various problems with obsidian hydration dating of obsidians found in the Arctic and possible solutions.

Summary

Obsidian hydration dating has now been available to archaeologists for almost 30 years. Throughout these years there has been intense research aimed at perfecting the methods and techniques involved in hydration rate determination. There is also another avenue of research, obsidian sourcing, that has been consistently part of research into obsidian and its various geochemical properties. This chapter has presented some of the more important strides being made in this field.

IV. DATABASE AND ANALYTIC METHODS

Important to all archaeological research is the context of the artifacts being studied and the methods used to analyze them. Presented in this chapter is the necessary contextual information of the artifacts and project specific methods used for the analysis in this study.

Database

The database for this study consisted of 31 obsidian samples collected from eight prehistoric archaeological sites in the Middle Rio Puerco valley, New Mexico (see Figure 1). These obsidian artifacts were all from excavated contexts, primarily structured and unstructured trash middens. This terminology is used as defined by Irwin-Williams and Shelley (1980). All of these are flaked stone debitage. Appendix I provides illustrations of the artifacts prior to analysis. Presented below are descriptions of each site and the obsidian artifacts associated with them. Table 2 summarizes this information. All of the site descriptions were summarized from Brett (1984:Appendix 1).

ENM 7052

This site consists of a small two room structure located on a shallow colluvial slope. The southwestern edge of the site is dissected by a small arroyo. The structure has slab-lined rooms with

Table 2. Sample Numbers Listed by Site.

Sample Number	Site Number	Sample Number	Site Number
1.1	ENM 7052	13.5	ENM 1613
1.2	ENM. 7052	13.6	ENM 1613
2.0	ENM 7052	13.7	ENM 1613
3.0	ENM 1019	14.1	ENM 846
4.0	ENM 1019	14.2	ENM 846
5.0	ENM 1019	15.0	ENM 846
6.0	ENM 298	16.1	ENM 846
7.0	ENM 298	16.2	ENM 846
8.0	ENM 838	17.0	ENM 820
9.0	ENM 838	18.1	ENM 820
10.0	ENM 838	18.2	ENM 820
11.0	ENM 622	19.1	ENM 820
12.0	ENM 622	19.2	ENM 820
13.1	ENM 1613	19.3	ENM 820
13.2	ENM 1613		
13.3	ENM 1613		
13.4	ENM 1613		

jacal walls. Total site area, including the structure, is approximately 4,370 m^2. Occupation of the site spans from A.D. 813 to A.D. 900. Three obsidian samples were collected from this site (numbers 1.1, 1.2, and 2). The mean ceramic date associated with these samples is A.D. 860, placing them in the Pueblo I period (Hurst and Durand 1981).

ENM 1019

This site is located on a large Pleistocene terrace to the east of the Rio Puerco. It consists of a 14-room "C" shaped pueblo with one exterior kiva. The pueblo is constructed of sandstone, basalt, and quartzite. Total site area, including the structure, is approximately 1,521 m^2. This site is attributed to the Pueblo III period with occupation dating from A.D. 1236 to A.D. 1300. Several sites dating to Basketmaker III/Pueblo I have been found nearby. Three obsidian samples (numbers 3, 4, and 5) were collected from this site. Their associated mean ceramic date is A.D. 1240 (Hurst and Durand 1981).

ENM 298

This site, located on an isolated mesa, covers 3300 m^2 and includes a large irregularly-shaped 60-room pueblo. It is constructed of shaped and unshaped sandstone blocks. This site reportedly represents and intrusion of Mesa-Verdean culture into the San Juan region (Brett 1984). Two obsidian samples (numbers 6 and 7) were recovered from this site. They are associated with an archaeomagnetic date of A.D. 1275 (Brett 1984).

ENM 838

This site is known as Guadalupe Ruin, a Chacoan outlier. It is located on an isolated mesa overlooking the Rio Puerco floodplain. The site, including the structure, covers 3,000 m^2. The structure is an irregularly-shaped linear pueblo constructed of shaped sandstone slabs. This pueblo is composed of 29 rooms, six exterior kivas, one interior kiva, and one cist. Two occupations have been attributed to this site. The first dates from A.D. 975 to A.D. 1125. Then, following a short period of abandonment, the site was reoccupied around A.D. 1200. Samples 8, 9, and 10 were recovered at this site and are associated with a mean ceramic date of A.D. 940 (Hurst and Durand 1981).

ENM 622

This site is located on an alluvial terrace overlooking the Rio Puerco floodplain. The site consists of a small, four-room pueblo constructed of shaped and unshaped basalt. The site covers approximately 288 m^2. The pueblo dates to A.D. 1208 and was probably abandoned around A.D. 1250. However, the pueblo may have been built on an earlier Pueblo I site, as ceramics were found which date from A.D. 813 to A.D. 850. Obsidian samples 11 and 12 are from this site and are associated with a mean ceramic date of A.D. 795 (Hurst and Durand 1981).

ENM 1613

This site represents one of the earliest major Anasazi occupations in the project area (Brett 1984). It is located on a colluvial slope overlooking a tributary of Salado Creek. It consists of a nine-room linear pueblo constructed of sandstone. One possible kiva was recorded. The site covers a total area of approximately 340 m^2. It dates from A.D. 1090 to A.D. 1125 or 1208. Seven obsidian samples (numbers 13.1 through 13.7) are from this site and are associated with a mean ceramic date of A.D. 1100 (Hurst and Durand 1981).

ENM 846

This site is located on an erosional remnant at the base of Guadalupe Mesa. It consists of an L-shaped, 13-room pueblo constructed of shaped and unshaped sandstone and basalt blocks. The site covers a total of 408 m^2. It is dated from A.D. 900 to A.D. 1250. Obsidian samples 14.1, 14.2, 15, 16.1, and 16.2 were found at this site and are associated with a mean ceramic date of A.D. 940 (Hurst and Durand 1981).

ENM 820

This is a small linear pueblo located on Gonzales Mesa. The pueblo and associated trash scatter are attributed to the Pueblo II period. However, a possible pithouse located under the trash scatter is attributed to Basketmaker III/Pueblo I period and is dated from A.D. 813 to A.D. 875. Five obsidian samples (numbers 17, 18, 19.1, 19.2, and 19.3) were found at this site and are associated with a mean ceramic date of A.D. 795 (Hurst and Durand 1981).

In summary, it should be noted that the 31 obsidian samples are associated with an approximate 500 year time span ranging from A.D. 795 to A.D. 1275. All of these dates were derived from the ceramic seriation for this area developed through Irwin-Williams' work in the Middle Rio Puerco valley (Hurst and Durand 1981).

Analytic Methods

The methods used in this study encompass several different steps. Briefly these steps are: 1) macroscopic sorting of the sample; 2) x-ray fluorescence (XRF) analysis of the sample; 3) statistical comparison of the XRF data with known source area sample; 4) preparation of the microscope slides; and 5) measurement of the hydration rim. The methods used are important as they are the foundation from which the results are obtained. The specific methods used in this study are described fully in the pages that follow.

Macroscopic Sort

As mentioned previously, a dichotomy exists in the literature over the validity of macroscopic sorting for distinguishing obsidian sources (cf. Ammerman 1969; Landis and Sappington 1985). The samples used in this study were macroscopically sorted to test this hypothesis. The samples were placed into nine visually distinct groups based on translucency, presence and absence of inclusions, and the presence and absence of several other compositional attributes.

Before proceeding further in this discussion, it is necessary to define the terms used to express the physical characteristics of the obsidian. The definitions used are quoted from the Dictionary of Geological Terms (American Geological Institute [AGI] 1976).

> dendrite: a branching figure resembling a shrub or tree, produced on or in a rock by crystallization of a foreign mineral [AGI 1976:114].
>
> vug: a cavity, often with a mineral lining of different composition from that of the surrounding rock [AGI 1976:458].
>
> inclusion: a crystal fragment of another substance or a minute cavity filled with gas or liquid enclosed in a crystal; a fragment of older rock enclosed in an igneous rock [AGI 1976:224].
>
> translucent: admitting the passage of light, but not capable of being seen through [AGI 1976:440].
>
> flowlines: a structure of igneous rocks...in which the stream or flowlines of the magma are revealed by alternating bands or layers of differing composition [AGI 1976:168].

The above definitions were used to divide the obsidian samples into the groups described below. [Table 2 correlates the sample numbers with the sites]:

> Group 1: Obsidian in this group is very translucent and has some small, dark inclusions. This group consists of samples 13.3, 13.4, 15, 1.2, 16.1, 16.2, 14.1, 3, and 4.
>
> Group 2: Obsidian in this group is translucent mostly around the edges and looks gray and white in color. It has no inclusions. This group consists of samples 9 and 13.5.
>
> Group 3: Obsidian in this group is very translucent and has dark flowlines. It includes samples 12, 13.7, and 8.
>
> Group 4: Obsidian in this group is not translucent and is very black in color. This groups consists of samples 19.1, 19.3, and 2.

Group 5: Obsidian in this group is translucent, dendritic, and has dark inclusions. It consists of samples 13.1 and 7.

Group 6: Obsidian in this group is translucent, has dark inclusions, and is lightly dendritic. It consists of samples 5, 13.2, 17, 18.1, and 19.2.

Group 7: Obsidian in this group is translucent, has dark inclusions, is mossy, and has large vugs. It includes samples 1.1 and 10.

Group 8: Obsidian in this group is very translucent and clear showing no inclusions, flowlines, or vugs. It includes samples 11, 6, and 13.5.

Group 9: Obsidian in this group is translucent, has dark inclusions, and flowlines. Samples in this group are 14.2 and 18.2.

X-Ray Fluorescence Analysis

Current researchers in obsidian hydration use several methods for determining the trace element composition of obsidian. Those used most often are neutron activation analysis, x-ray fluorescence analysis and atomic absorption. All have been used successfully (e.g., Ericson 1975; Nelson et al. 1975; Nelson et al. 1977; Ammerman 1979; Michels 1983, 1984; Cameron and Sappington 1984). For this study, x-ray fluorescence was used.

X-ray fluorescence is a rapid, non-destructive method that is less costly than neutron activation analysis. It is done by irradiating an obsidian sample with x-rays generated, usually, by a tungsten-anode, x-ray tube. This causes excitation of the atoms present in the sample. The atoms reemit the radiation in the form of measurable wavelengths. These wavelengths are individually separated out and measured in counts per second (see Goffer 1980:45-48).

Realizing that the value of macroscopic sorting may be questionable, almost all of the archaeological obsidian samples used in this study were submitted for x-ray fluorescence analysis. Unfortunately sample numbers 2, 3, 13.3, and 19.1 were too small to be cut both for x-ray fluorescence and hydration rim measurement, so they were not sent for x-ray fluorescence analysis. It was hoped that there would be a strong correlation between the macroscopic sourcing and the actual source determination so that these four samples could be assigned to a source. The rest of the samples had small pieces cut from them and were sent for x-ray fluorescence analysis. The analysis was performed by Dr. Jerry Hoffer, University of Texas at El Paso. The samples were x-rayed with a tungsten source for 200 seconds and their relative intensities were recorded. This is a standard technique used for energy dispersive x-ray fluorescence analysis (see Hoffer 1985).

Source Determination

One non-statistical method used in source determinations is the ternary graph (tripoled grid). This method compares relative proportions of three elements, usually rubidium (Rb), strontium (Sr), and zirconium (Zr) by plotting them on a three-cornered graph. This method works well when there are strong differences between the trace element compositions of the sources being analyzed. When sources being compared are similar, one problem with this method arises: plots will be similar and it is difficult to distinguish between them (Hughes 1986:50). Another drawback to this method is that the same measurement units must always be used to collect trace element data. It has been found that if the trace element data for the same sample are collected differently (i.e., parts per million and peak counts) and then plotted, the two plots may not give the same results (Hughes 1986:54). This has become a problem in recent years due to the number of laboratories performing x-ray fluorescence analysis. The data collected are not always comparable from laboratory to laboratory.

Realizing that there are some problems with ternary graphs, a statistical method was chosen for source determinations of the samples used in this study. All x-ray fluorescence data were analyzed using an IBM mainframe computer and Statistical Analysis System (SAS) stepwise discriminant function analysis. This procedure has been used successfully in determining the geologic source of unknown obsidian samples by many other researchers (Ward 1974; Ericson 1975; Cameron and Sappington 1984; Shelley and Montgomery 1985). As defined in Doran and Hodson (1976:209) "discriminant analysis is intended basically to discover and emphasize those attributes which discriminate between known groups, and to assign fresh, ungrouped units to one or other using this knowledge." In this study, the stepwise procedure was used to determine which trace elements (based on XRF values) were the best discriminators for several previously characterized sources. This is done by adding variables (the elements) one at a time until it is found that adding more variables will not discriminate significantly better (Manly 1986:96).

The selected elements were then used to classify known sources which each other to see how accurately these elements would discriminate between the sources. This is also dependent upon the heterogeneity of the sources. In some cases it may not be possible to distinguish between two sources as they may be very similar chemically. Next, the archaeological obsidian samples (the unknowns) were analyzed against the known sources to determine which source(s) the unknowns might have derived from. This is where one drawback of discriminant analysis is obvious. The analysis will fit the unknown into one of the known groups (Manly 1986:86). Therefore, in this particular study, if the true source of the unknowns was not included in the analysis, the unknowns would still be classified to a known source even though it is not the true source. A check on this is the posterior probability of groups membership generated by the statistical routine. This probability is a whole number between 0.0 and 1.0; the closer to 1.0 the stronger the probability that the unknown has been sourced correctly classified (Hughes 1986:77-78).

Preparation of Slides

All samples were prepared generally by methods used successfully by other researchers (cf. Michels and Tsong 1980; Michels and Bebrich 1971). The first step in the procedure was the application of isotropic epoxy to the surface of the obsidian. The obsidian was then heated in a kiln at 140°F (60°C) for two hours to insure maximum cure. The epoxy protects the hydration surface of the obsidian during sawing (Katsui and Kondo 1976).

The next step involved cutting a wedge from each sample. This was done by making two parallel cuts perpendicular to the edge of the artifact. All sawing was done using an oil-cooled Raytech Trimsaw with a 4-inch diamond edge blade. Next, using an "X-acto" knife the wedge was removed from the artifact and then cleaned with ethyl alcohol and rinsed to remove any remaining traces of oil.

The initial grinding phase began by mounting the wedge onto a glass microscope slide. Lakeside thermoplastic (quartz) cement was used as a mounting medium. The sample number was etched onto the slide to maintain provenience information. The wedge was ground to approximately half of its original thickness using a slurry of water and fine-grained corrundum grit. All grinding was done by hand on a glass plate using a "figure-8" motion.

After the wedge was ground halfway, the slide was cleaned to remove any traces of grit. A pencil line was drawn on the sample to indicate its hydrated surface and the wedge was turned over and remounted. A new slide was used for the remounting. Once again, Lakeside thermoplastic (quartz) cement was used for the mounting. The sample number was etched onto the new slide. Using the slurry of fine-grained corrundum grit and water, the wedge was then ground (in the same manner as described above) to an approximate thickness of .003 inch to maximize the optical qualities of the obsidian under the microscope.

The final step in sample preparation was the application of the cover slip. Cover slips are applied using heated Canada Balsam. The Canada Balsam creates less air bubbles thus making a clearer slide and more accurate readings.

Measurement of the Hydration Rim

All hydration rims were measured using a Nikon Labophot POL petrographic microscope with polarized light (X-Nichols) and 1/4 wave/red tint plate at 600 diameters. The 1/4 wave/red tint plate creates a dark background upon which the hydration rim appears blue due to the difference in biorefringence. This helps to better define the interior of the hydration rim and has been demonstrated to improve the accuracy of the measurements (Stevenson 1987).

All measurements were made with a filar eyepiece interfaced with a TI-50 calculator for automatic data recording. Prior to taking measurements the optics of the microscope were calibrated against a standard to account for changes in barometric pressure and temperature. Measurements were taken by the author and another independent observer. An effort was made to find the widest and narrowest portions of the hydration rim. In cases where it was apparent that there were two rims, indicating possible artifact reuse, each rim was measured separately. Each observer made five measurements at five different locations. These ten measurements were recorded and averaged to calculate the mean depth (in microns) and the standard deviation of the hydration rim.

V. RESULTS AND INTERPRETATIONS

Source Determination

Seven spatially and chemically distinct New Mexico obsidian sources were chosen for comparison with the obsidian samples used in this study. These sources were selected based on a review of the previous work in the general vicinity and their proximity to the present study area. Research by Brett (1984) with non-obsidian lithic collections from these same sites have shown that the populations were using locally acquired lithic raw materials in most instances. Therefore, it was logical to assume the obsidian may have also been derived locally.

The sources selected have been characterized previously by the obsidian hydration laboratory at Eastern New Mexico University (Shelley and Montgomery 1985). In all instances no less than 10 specimens were used for chemical characterization. The source names are used as described by others (see Shelley and Montgomery 1985; Cameron and Sappington 1984). These sources are Grants Ridge, Jemez, Polvadera Peak, San Antonio/No Agua Mt., Red Hill, Rio Grande Pleistocene Terrace Gravels, Cochiti vicinity, and Rio Grande Pleistocene Terrace Gravels, Los Lunas vicinity (hereafter termed Cochiti river gravels and Los Lunas river gravels). Figure 3 illustrates the locations of these sources and their relation to the Middle Rio Puerco valley.

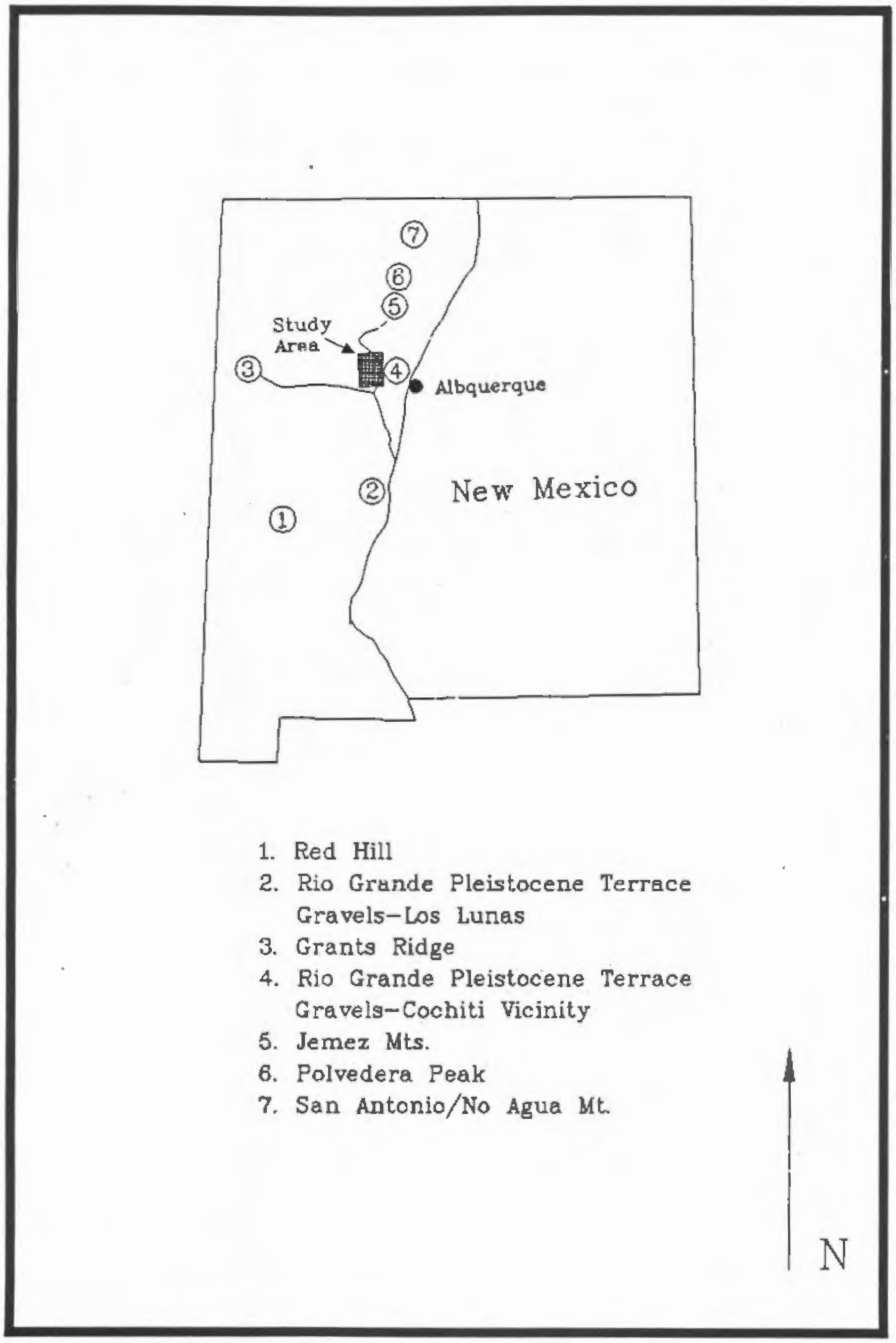

Figure 3. Location of obsidian sources used in this study (adapted from Shelley and Montgomery 1985).

Stepwise discriminant analysis resulted in the selection of 20 elements as the best discriminators to distinguish between these sources. The elements are magnesium (Mg), aluminum (Al), potassium (K), calcium (Ca), titaniun (Ti), manganese (Mn), copper (Cu), germanium (Ge), selenium (Se), rubidium (Rb), silicon (Si), barium (Ba), chromium (Cr), zinc (Zn), francium (Fr), actinium (Ac), thorium (Th), bismuth (Bi), cesium (Cs), and yterrbium (Yb). Discriminant function analysis of the <u>known</u> sources using the ratios of these 20 trace elements to iron (Fe) resulted in a 98.75% correct classification (Table 3). One known Jemez sample was misclassified to the Cochiti river gravels source. This is understandable as some studies have hypothesized that the some of the Rio Grande river gravel obsidians are derived from Jemez (see Michels 1984).

Twenty-seven of the 31 obsidian samples under study were analyzed by x-ray fluorescence analysis to determine their trace element compositions. The data derived from that analysis are presented in Appendix II. Results of the discriminant analysis of these artifacts are summarized in Table 4. Seventy percent (n=19) of the samples were classified to the Cochiti river gravels source, 26% (n=7) were classified to the Los Lunas river gravels source, and 4% (n=1) were classified to the San Antonio/No Agua Mt. source. Posterior probabilities of membership into the source groups are quite strong; almost all were 1.000. It is inferred from these results that the populations from the sites used in this study were using relatively local obsidian.

Table 3. Classification Results For Known Sources.

Known Source	Classified Source	Posterior Probability of Membership in Source						
		Cochiti River Gravels	Grants Ridge	Jemez	Los Lunas River Gravels	Poluadera Peak	Red Hill	San Antonio /No Agua Mt
Jemez	Jemez	0.0004	0.0000	0.9996	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0003	0.0000	0.9997	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0059	0.0000	0.9941	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0001	0.0000	0.9999	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0005	0.0000	0.9995	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0005	0.0000	0.9995	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
Jemez	Cochiti River Gravels	0.9728	0.0000	0.0272	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0060	0.0000	0.9940	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0092	0.0000	0.9908	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0038	0.0000	0.9962	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0132	0.0000	0.9868	0.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0047	0.0000	0.9953	0.0000	0.0000	0.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0008	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000

Table 3. (continued).

		Posterior Probability of Membership in Source						
Known Source	Classified Source	Cochiti River Gravels	Grants Ridge	Jemez	Los Lunas River Gravels	Poluadera Peak	Red Hill	San Antonio /No Agua Mt
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	0.0000	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	0.0000	1.0000	0.0000	0.0001	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	0.0000	0.9999	0.0000	0.0016	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	0.0000	0.9999	0.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	0.0000	0.9984	0.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Poluadera Peak	Poluadera Peak	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Poluadera Peak	Poluadera Peak	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Poluadera Peak	Poluadera Peak	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Poluadera Peak	Poluadera Peak	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Poluadera Peak	Poluadera Peak	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Poluadera Peak	Poluadera Peak	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Poluadera Peak	Poluadera Peak	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Poluadera Peak	Poluadera Peak	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Poluadera Peak	Poluadera Peak	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Poluadera Peak	Poluadera Peak	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
Cochiti River Gravels	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 3. (continued).

Known Source	Classified Source	Posterior Probability of Membership in Source: Cochiti River Gravels	Grants Ridge	Jemez	Los Lunas River Gravels	Poluadera Peak	Red Hill	San Antonio /No Agua Mt
Cochiti River Gravels	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Cochiti River Gravels	Cochiti River Gravels	0.9996	0.0000	0.0034	0.0000	0.0000	0.0000	0.0000
Cochiti River Gravels	Cochiti River Gravels	0.9430	0.0000	0.0570	0.0000	0.0000	0.0000	0.0000
Cochiti River Gravels	Cochiti River Gravels	0.9997	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000
Cochiti River Gravels	Cochiti River Gravels	0.9999	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Cochiti River Gravels	Cochiti River Gravels	0.9979	0.0000	0.0021	0.0000	0.0000	0.0000	0.0000
Cochiti River Gravels	Cochiti River Gravels	0.9993	0.0000	0.0007	0.0000	0.0000	0.0000	0.0000
Cochiti River Gravels	Cochiti River Gravels	0.9983	0.0000	0.0017	0.0000	0.0000	0.0000	0.0000
Cochiti River Gravels	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Los Lunas River Gravels	Los Lunas River Gravels	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Los Lunas River Gravels	Los Lunas River Gravels	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
Los Lunas River Gravels	Los Lunas River Gravels	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
Los Lunas River Gravels	Los Lunas River Gravels	0.0004	0.0000	0.0000	0.9986	0.0000	0.0000	0.0000
Los Lunas River Gravels	Los Lunas River Gravels	0.0000	0.0036	0.0000	0.9964	0.0000	0.0000	0.0000
Los Lunas River Gravels	Los Lunas River Gravels	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
Los Lunas River Gravels	Los Lunas River Gravels	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
Los Lunas River Gravels	Los Lunas River Gravels	0.0000	0.0004	0.0000	0.9999	0.0000	0.0000	0.0000
Los Lunas River Gravels	Los Lunas River Gravels	0.0000	0.0001	0.0000	0.9999	0.0000	0.0000	0.0000
Los Lunas River Gravels	Los Lunas River Gravels	0.0000	0.0001	0.0000	0.9999	0.0000	0.0000	0.0000

Table 4. Classification Results of Archaeological Samples with Known Sources.

Sample Number	Classified Source	Posterior Probability of Membership in Source: Cochiti River Gravels	Grants Ridge	Jemez	Los Lunas River Gravels	Polvadera Peak	Red Hill	San Antonio /No Agua Mt.
1.1	Cochiti River Gravels	0.7224	0.0000	0.0000	0.2776	0.0000	0.0000	0.0000
1.2	Los Lunas River Gravels	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
4.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
7.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
10.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13.1	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13.2	Los Lunas River Gravels	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
13.4	Los Lunas River Gravels	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
13.5	Cochiti River Gravels	0.9999	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000
13.6	Cochiti River Gravels	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
13.7	San Antonio/No Agua Mt.	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
14.1	Los Lunas River Gravels	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
14.2	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
15.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16.1	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16.2	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
17.0	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18.1	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
18.2	Los Lunas River Gravels	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
19.1	Los Lunas River Gravels	1.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
19.2	Cochiti River Gravels	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

These results were a bit surprising when compared with other studies in northwestern New Mexico. Cameron and Sappington (1984) have sourced obsidian from Chaco Canyon (north of the Middle Rio Puerco Valley). It has been postulated that obsidian exchange was occurring both locally and on a long-distance level between Chaco Canyon and other sites (Cameron and Sappington 1984). One of the sites in this study, Guadalupe Ruin, is a Chacoan outlier and there are others nearby. Therefore, it was expected that the results of the source analysis would be somewhat similar to previous research such as Cameron and Sappington's (1984), as interaction would be expected between Chaco Canyon and these sites. However, as a comparison of the current results with Cameron and Sappington's (1984) data shows, this is not true.

Cameron and Sappington (1984) analyzed 665 obsidian samples from Chaco Canyon using methods similar to those employed in this study. All of their obsidian samples were analyzed by x-ray fluorescence to determine their trace element compositions. Then using the stepwise discriminant procedure they selected iron (Fe), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), niobium (Nb), tin (Sn), barium (Ba), lanthanum (La), and cerium (Ce) as the best discriminators between their sources. They used several known sources from New Mexico, Arizona, Utah, and Colorado. <u>However, they did not use the Cochiti or Los Lunas river gravel sources</u>. Through discriminant analysis they found that over 50% of their obsidian samples classified as Jemez, 25% classified as Red Hill, and the remaining 25% classified to several other sources, none of which exceeded 10%. The discriminant analysis of their known sources resulted in a 96% correct classification (Cameron and Sappington 1984:158). None of the archaeological samples analyzed as part of this research project sourced to either Jemez or Red Hill, although both of these sources were included in the discriminant analysis.

As an experiment, the Cochiti and Los Lunas river gravel sources were removed from the known sources and the discriminant analysis performed again. The stepwise procedure resulted in the selection of 16 elements as the best discriminating variables. They were manganese (Mn), potassium (K), titanium (Ti), rubidium (Rb), zinc (Zn), bismuth (Bi), calcium (Ca), copper (Cu), lead (Pb), magnesium (Mg), silicon (Si), aluminum (Al), nickel (Ni), cesium (Cs), thallium (Tl), and cadmium (Cd). Most of these are different than the elements used by Cameron and Sappington (1984); however, the results obtained from the discriminant analysis were not. Sixty-seven percent (n=18) of the obsidian samples were classified to the Jemez source, 19% (n=5) were classified to the Red Hill source, 7% (n=2) were classified to the Grants Ridge source, and 7% (n=2) were classified to the San Antonio/No Agua Mt. source. Classification of the known sources resulted in a 100% correct solution. Further, of those samples previously classified as Cochiti river gravels, all but one classified as Jemez. The samples classified as Los Lunas were classified to Red Hill, Grants Ridge, or San Antonio/No Agua Mt. One sample (number 13.7) classified as San Antonio/No Agua Mt. in both analyses. Data tables summarizing these results may be found in Appendix III.

Interpretation of these results is difficult at best. There could be several explanations for the difference in results obtained through the omission of the river gravels. The primary reason, hypothesized here, for this difference may be that the Cochiti river gravels are in fact redeposited Jemez obsidians. As mentioned ealier work by others (cf. Michels 1984) have postulated this. If the posterior probabilities for both sets of analysis are examined closely several interesting patterns emerge (Tables 3 and 4; Appendix III).

In the initial analysis 17 of the 19 samples classifiying to the Cochiti river gravels source have posterior probabilities of 1.0000. Of the other two, one has a posterior probability of 0.7224 and the other has a posterior probability of 0.9999 for classification in the Cochiti source. Both of these posterior probabilities are still relatively strong and indicate a good classification. All seven of the samples classified to Los Lunas river gravels source have posterior probabilities of 1.0000. The one sample classified as San Antonio/No Agua Mt. also has a posterior probability of 1.0000. By themselves, these probabilities simply imply a strong correlation between the known sources and the unknown samples classified to them indicating that the sources have most likely been sourced correctly. However, examining and comparing these with the posterior probability data for the second analysis reveals an interesting occurrence.

With one exception, all of the samples now classifying as Jemez, had posterior probabilities of 1.0000. The one that did not, split between Jemez and Red Hill with posterior probabilities of 0.5394 and 0.4606, respectively. The one sample that classified as San Antonio/No

Agua Mt. again, also had a posterior probability of 1.000 again. None of the samples classifying as Red Hill or Grants Ridge had posterior probabilities of 1.000. They all were split between the two sources (see Appendix III).

Recall that almost all of the samples previously sourced as Cochiti classified to the Jemez source during the second analysis. All of the samples previously sourced to the Los Lunas river gravels were now classified to the Red Hill and Grants Ridge sources. Also remember that discriminant analysis will force all unknown samples into a known source group, even if the correct source is not included in the analysis, and this occurrence is usually revealed by inspecting the posterior probabilities. This information was interpreted to indicate that in the second analysis, without the river gravels, the statistical routine could not find very good matches for the Los Lunas samples and therefore forced them into the Red Hill and Grants Ridge sources. These two sources may be very similar chemically. The fact that none of them had posterior probabilities of 1.0000 would seem to support this interpretation. The one San Antonio/No Agua Mt. sample was classified as San Antonio/No Agua Mt. both times, with a 1.0000 posterior probability, indicating that this sample has a high probability of being derived from the San Antonio/No Agua Mt. source.

The case of the samples classifying to the Cochiti river gravels source the first time and to the Jemez source the second, with very high posterior probabilities both times, indicates that the computer had no problem placing the unknowns into these source groups. This also indicates that the two sources are probably very similar chemically. However, recall that in the initial discriminant analysis of known sources, including the river gravels, only one Jemez source was misclassified as Cochiti. This result indicates that although they may be similar, they are still distinct chemically. This leads to the conclusion that perhaps the Cochiti river gravels are, in fact, derived from the Jemez source. However, of the known source examples used in this study, perhaps the collected Cochiti river gravels are from a different Jemez flow than those examples collected from the Jemez source itself. Of course, this is only a tentative conclusion based on the current analysis. Further research would be necessary to prove or disprove this hypothesis. Perhaps it would even be necessary to re-analyze the 665 samples used by Cameron and Sappington (1984) with the addition of the river gravel sources used in this study to that database.

One other comparison between Cameron and Sappington's results and those presented here can be made. At Chaco Canyon, they observed a change in patterns of obsidian exploitation through time. Prior to A.D. 700 they note a higher relative frequency of Red Hill obsidian; after this date they see a higher relative frequency of Jemez obsidian with a concomitant decline in the relative frequency of Red Hill obsidian (Cameron and Sappington 1984:166). Once again the presence of a Chacoan outlier in the study area would lead one to think that there may be similarities in results. However, no evidence of temporal variation of obsidian sources was observed. This is most likely the result of the small sample size under analysis. Variation may exist; however, based on only 31 samples, it could not be discerned.

Macroscopic Sorting

Previous obsidian sourcing studies have experimented with macroscopic identification of obsidian sources based on various observable attributes. Research by Ammerman (1979) with obsidian from Italy found that in a blind test 20 students could successfully distinguish between two sources based on macroscopic attributes of the obsidian. Findlow et al. (1977) say that Government Mountain obsidian is macroscopically very distinct from other sources. However, others disagree with the accuracy of macroscopic sourcing. Early research by Frison et al. (1968) discovered that it was not always possible to separate sources visually. Recent research by Landis and Sappington (1985) also resulted in poor correlations between macroscopically created groups and actual trace element composition.

Results of the present study also indicate that obsidian cannot be sourced successfully on the basis of visual attributes alone. Nine distinct macroscopically sorted groups were defined for the obsidian samples under study. However, the macroscopic findings differ greatly from the results of the discriminant analysis (Table 5). Overall, it was observed that nine macroscopically-distinct groups actually represented only three different obsidian sources. In most cases, each visually-defined group was found to contain examples from different sources. For example, the seven samples in Group 1 were classified to both the Los Lunas river gravels source (43%) and the Cochiti river gravels source (57%). The two samples in Group 2 split between the Cochiti and Los Lunas river gravels sources. Sixty-seven percent of

Table 5. Comparison of Macroscopic Sort Groups with Actual Source Results.

Macroscopic Sort Group	Sample Number	Classified Source
Group 1	1.2	Los Lunas River Gravels
	3.0	Not Sent
	4.0	Cochiti River Gravels
	13.3	Not Sent
	13.4	Los Lunas River Gravels
	14.1	Los Lunas River Gravels
	15.0	Cochiti River Gravels
	16.1	Cochiti River Gravels
	16.2	Cochiti River Gravels
Group 2	9.0	Cochiti River Gravels
	13.6	Los Lunas River Gravels
Group 3	8.0	Cochiti River Gravels
	12.0	San Antonio/No Agua Mt.
	13.7	Cochiti River Gravels
Group 4	2.0	Not Sent
	19.1	Los Lunas River Gravels
	19.3	Not Sent
Group 5	7.0	Cochiti River Gravels
	13.1	Cochiti River Gravels
Group 6	5.0	Cochiti River Gravels
	13.2	Los Lunas River Gravels
	17.0	Cochiti River Gravels
	18.1	Cochiti River Gravels
	19.2	Cochiti River Gravels
Group 7	1.1	Cochiti River Gravels
	10.0	Cochiti River Gravels
Group 8	6.0	Cochiti River Gravels
	11.0	Cochiti River Gravels
	13.5	Cochiti River Gravels
Group 9	14.2	Cochiti River Gravels
	18.2	Los Lunas River Gravels

the three samples in Group 3 sourced as Cochiti river gravels and 33% sourced as San Antonio/No Agua Mt. The two samples in Group 5 classified 100% to the Cochiti river gravels source. Of the remaining groups, 7 and 8 were 100% Cochiti, and 6 and 9 had samples which classified as either Los Lunas or Cochiti river gravels (see Table 5). In conclusion, it seems clear that the value and reliability of macroscopic sorting, at least for the sources in this study, is rather limited at best. Therefore, the four samples not included in the x-ray fluorescence analysis, were not assigned to any of the known sources.

Correlation of Rim Depth and Associated Dates

Measurement of hydration rims on all 31 obsidian samples was carried out as described in the previous chapter. Four samples were found not to have measurable hydration rims. Therefore, they are excluded from further analysis. Measurement results are presented in Table 6. They have been sorted and grouped into geochemical source groups because hydration rate is affected by chemical composition. Samples that derive from the Cochiti river gravels source were the most numerous (n=19). The rest of this analysis is focused solely upon them. It was felt that the remaining sources were represented by too few samples to allow for an accurate determination of hydration rate.

Hydration rim measurements were obtained for 18 of the 19 Cochiti river gravel samples. Sample 11 was one of the aforementioned samples found to lack a hydration rim. It was prepared twice and a hydration rim was not observed on either slide. Therefore, it was excluded from the rest of the analysis.

Table 6. Hydration Rim Measurements for All Samples Arranged by Source.

Sample Number	Source	Rim Depth (in microns)	Standard Deviation
1.2	Los Lunas River Gravels	3.9	0.4
13.2	Los Lunas River Gravels	2.1	0.2
13.4	Los Lunas River Gravels	---	---
13.6	Los Lunas River Gravels	---	---
14.1	Los Lunas River Gravels	3.6	0.4
18.2	Los Lunas River Gravels	2.4	0.3
19.1	Los Lunas River Gravels	---	---
13.7	San Antonio/No Agua Mt.	2.1	0.4
1.1	Cochiti River Gravels	2.4	0.4
4.0	Cochiti River Gravels	3.3	0.5
5.0	Cochiti River Gravels	3.3	0.4
6.0.	Cochiti River Gravels	3.7	0.8
7.0	Cochiti River Gravels	1.9	0.3
8.0	Cochiti River Gravels	2.1	0.4
9.0	Cochiti River Gravels	3.8	0.9
10.0	Cochiti River Gravels	4.3	0.6
11.0	Cochiti River Gravels	---	---
12.0	Cochiti River Gravels	3.9	0.3
13.1	Cochiti River Gravels	3.6	0.6
13.5	Cochiti River Gravels	2.4	0.4
14.2	Cochiti River Gravels	2.6	0.5
15.0	Cochiti River Gravels	2.6	0.7
16.1	Cochiti River Gravels	3.1	0.3
16.2	Cochiti River Gravels	4.4	0.7
17.0	Cochiti River Gravels	3.4	0.4
18.1	Cochiti River Gravels	3.8	0.6
19.2	Cochiti River Gravels	3.7	0.4

To begin to establish a hydration rate, hydration rim measurements (in microns) and associated dates (in years B.P.) were plotted on graph paper. The resulting scatter plot (Figure 4) showed an apparent random distribution of points, seemingly unrelated to each other. There appeared to be no relative relationship between the rim measurements and their associated dates. Several ideas were proposed to explain this occurrence. The first and easiest to test was the possibility that there were errors made during the measuring process. Therefore 14 samples, chosen because of the high standard deviations associated with their rim measurements, were re-measured. If this did not help to solve the problem, other ideas included re-grinding the samples and re-running the x-ray fluorescence and disciminant analyses.

During the course of re-measuring these samples, it was discovered that three of them (numbers 6, 9, and 15) showed evidence of possible reworking. Under close scrutiny, two hydration rims were revealed on each of these slides. Two separate micron measurements were determined for each of these samples, one for the thinner rim and another for the thicker one. It is possible that these originated from Basketmaker sites located in and around the project area and were then re-used by later Puebloan inhabitants. As mentioned in the site descriptions, several Basketmaker sites were found in the area and in some cases Puebloan-age sites were built on top of them, although, these specific samples were not from those sites.

Table 7 presents a summary of the re-measured rim depths arranged chronologically. It may be noticed that in most cases re-measuring resulted in smaller standard deviations. These measurements were also

Table 7. Rim Depths (in Microns) for Samples Classifying to Rio Grande Pleistocene Terrace Gravels, Cochiti Vicinity.

Sample Number	Site Number	Associated Date	Rim Depth (in microns)	Standard Deviation
11	ENM 622	1155 B.P.	---	---
12	ENM 622	1155 B.P.	3.9	0.3
17	ENM 820	1155 B.P.	3.4	0.4
18.1	ENM 820	1155 B.P.	4.2	0.4
19.2	ENM 820	1155 B.P.	3.9	0.7
1.1	ENM 7052	1090 B.P.	2.6	0.4
8	ENM 838	1010 B.P.	2.1	0.4
9*	ENM 838	1010 B.P.	2.2	0.3
10	ENM 838	1010 B.P.	3.2	0.2
14.2	ENM 846	1010 B.P.	2.7	0.4
15*	ENM 846	1010 B.P.	2.8	0.5
16.1	ENM 846	1010 B.P.	3.2	0.3
16.2	ENM 846	1010 B.P.	2.9	0.4
13.1	ENM 1613	850 B.P.	2.5	0.4
13.5	ENM 1613	850 B.P.	2.0	0.4
4	ENM 1019	710 B.P.	2.3	0.4
5	ENM 1019	710 B.P.	2.0	0.4
6*	ENM 298	675 B.P.	1.1	0.3
7	ENM 298	675 B.P.	1.9	0.3

*possible re-worked samples

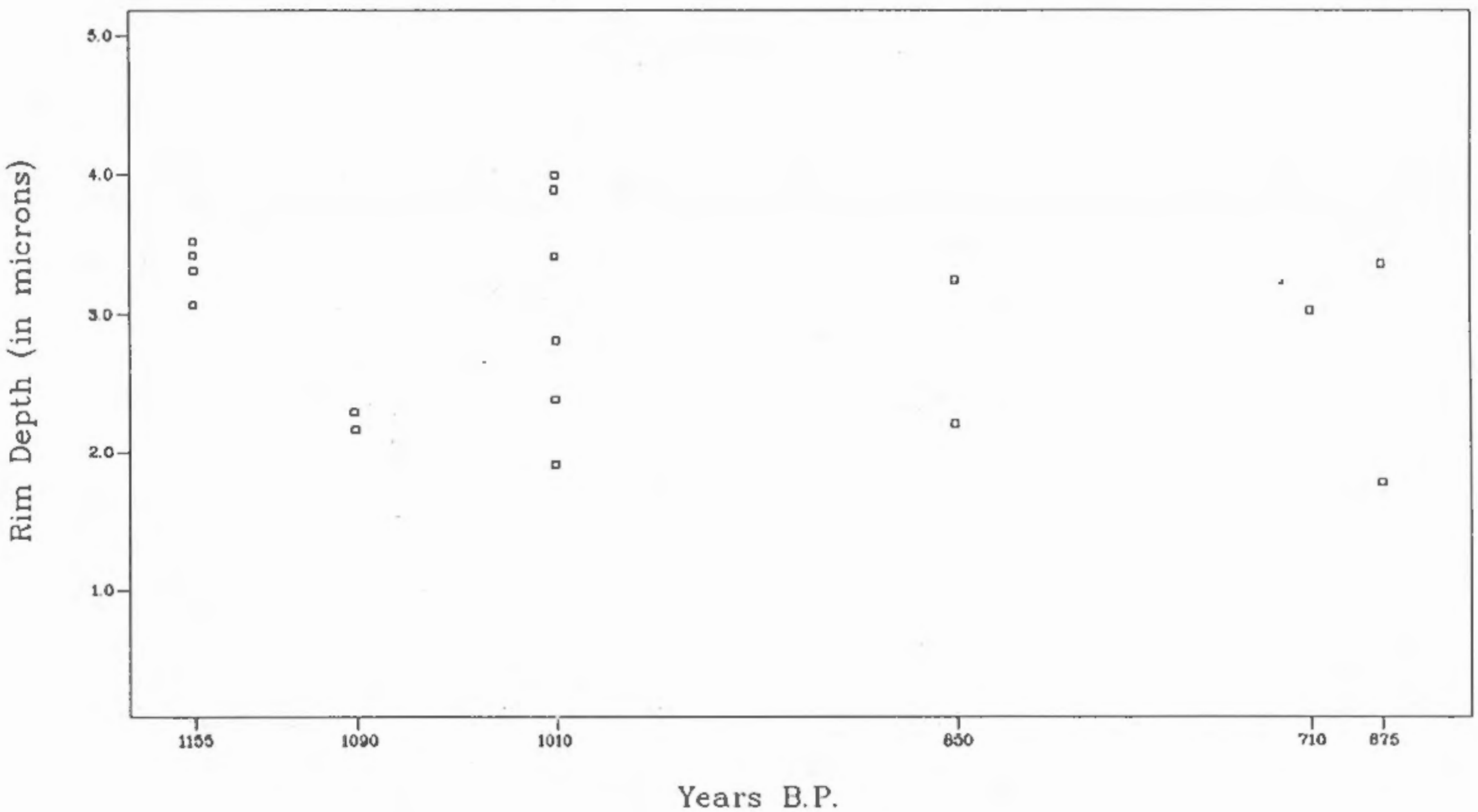

Figure 4. Original hydration rim measurements plotted against time.

plotted on graph paper (Figure 5). A strong correlation between rim depth and time was still difficult to establish, although a general relationship was more apparent. To help smooth out the data, a decision was made to average the rim depths for all samples for each particular site. This is a common practice for smoothing data and has been used before in both obsidian hydration rate determination and in other chronological techniques (Hurtado de Mendoza 1981; Long and Rippetau 1974). Measurements were averaged on a site-specific basis to help control for any environmental factors. In most cases obsidian from a particular site was found in the same contextual association. There were two cases where a time period was represented by only one sample and so there was no need for averaging; however, all of the measurements are referred to collectively as averages in this discussion. A scatter plot of the averaged rim depths shows a much clearer picture of their possible correlation with the associated dates (Figure 6). Therefore, the averaged rim depths were used for the rest of this analysis.

The last scatter plot (Figure 6) shows an almost linear correlation between the rim depths and time. However, it has been established over the years that the hydration rate of obsidian is often not linear; it tends to decrease through time. However, a consensus does not exist as to what form the actual hydration equation should take. With this in mind, stepwise polynomial regression was chosen to determine the best-fitting equation for the data under study.

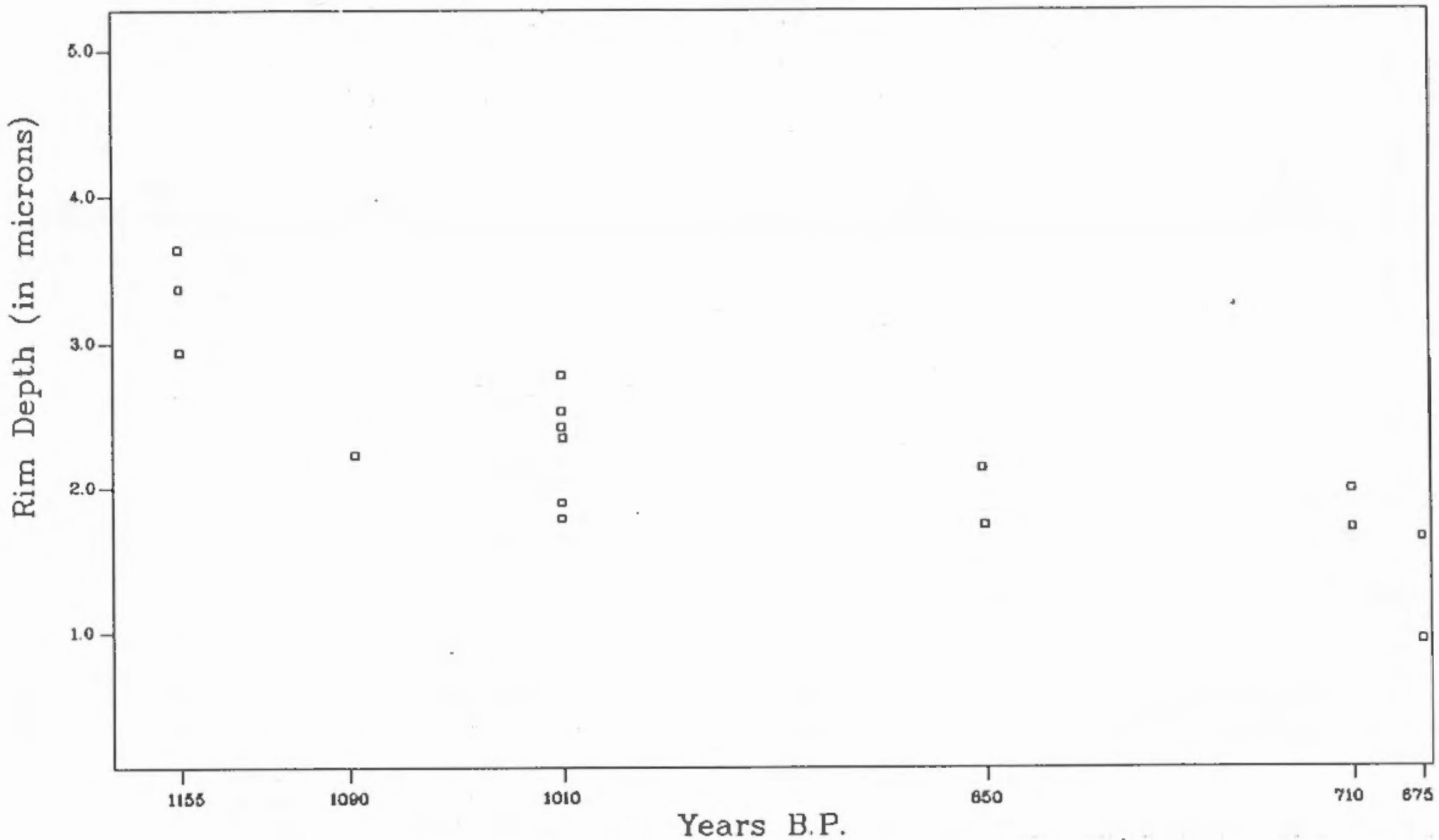

Figure 5. Second rim measurements plotted against time.

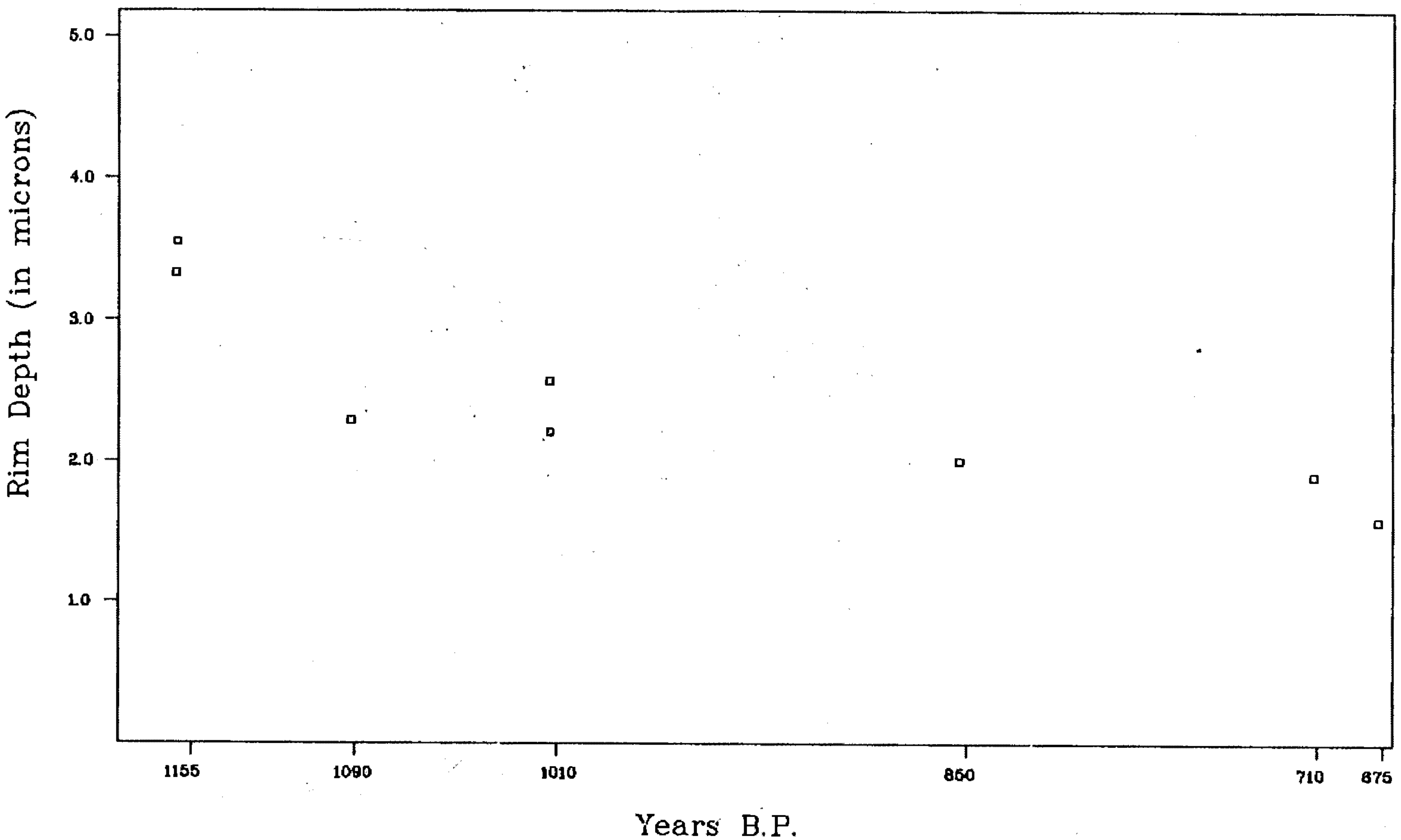

Figure 6. Averaged rim measurements plotted against time.

Stepwise polynomial regression is described by Zar (1974:268-273). Stepwise polynomial regression is a type of multiple regression in which increasing polynomial equations are tested on the data until the best fit is reached. For this study, the independent variable, x, was assigned to years B.P. and the dependent variable, y, was assigned to the obtained rim depths (in microns). Regression was performed at the linear, quadratic, and cubic levels. Results of these analyses are presented in Tables 8, 9, and 10. These results indicate that the linear equation is the best fit for this data. This conclusion is based on the results of the Student's t test on the ccrrelation coefficient obtained for each level of regression. Although graphs of the quadratic and cubic regression lines appear to "fit" the data better, this cannot be confirmed statistically (Figures 7, 8, and 9).

Based on these results the linear equation, $y = mx + b$, was used to determine a hydration rate for the Cochiti river gravels source. In this equation, y is the rim depth (in microns), x is the associated date in years B.P., m is the slope coefficient, and b represents the y-intercept. Solving the equation for $x = 1000$ and using the slope coefficient and y-intercept obtained from the computer analysis, results in an obtained y value of 2.86 microns. The resulting hydration rate would therefore take the form 2.86 microns/1000 years. The micron value is not reported as microns^2 because it represents a linear relationship in this analysis.

Many hydration studies have pointed out that small sample spanning a short time period (usually <500 years) will most likely result in a linear hydration rate (e.g., Friedman and Trembour 1978; Friedman and

Table 8. Results of Linear Regression.

Rim Depth (Y)	Years B.P. (X)
3.9	1155
3.8	1155
2.6	1090
2.5	1010
2.9	1010
2.25	850
2.15	710

Regression Output:	
Constant	-0.9378293485
Std Err of Y Est	0.4119429714
R Squared	0.7826719167
No. of Observations	8
Degrees of Freedom	6
X Coefficient	0.0038017812
Std Err of Coefficient	0.0008178611

Critical Value of $t_{0.05(6)} = 1.943$

t score = 4.75

H_o : significant

Table 9. Results of Quadratic Regression.

Rim Depth (Y)	Years B.P. (X)
3.9	1155
3.8	1155
2.6	1090
2.5	1010
2.9	1010
2.25	850
2.15	710

Regression Output:

Constant		5.7751452985
Std Err of Y Est		0.3872536245
R Squared		0.8399515799
No. of Observations		8
Degrees of Freedom		5
X Coefficients	-0.0114514006	0.0000083208
Std Err of Coefficient	0.0114284876	0.0000062202

Critical Value of $t_{0.05(5)} = 2.015$

t score = 1.34

H_o : not significant

Table 10. Results of Cubic Regression.

Rim Depth (Y)	Years B.P. (X)
3.9	1155
3.8	1155
2.6	1090
2.5	1010
2.9	1010
2.25	850
2.15	710

Regression Output:	
Constant	-57.5535681320
Std Err of Y Est	0.3094675964
R Squared	0.9182324924
No. of Observations	8
Degrees of Freedom	4

X Coefficients	0.2014517893	-0.0002250803	0.00000000837
Std Err of Coef.	0.1091791295	0.0001193747	0.00000000428

Critical Value of $t_{0.05(4)} = 2.132$

t score = 1.95

H_o : not significant

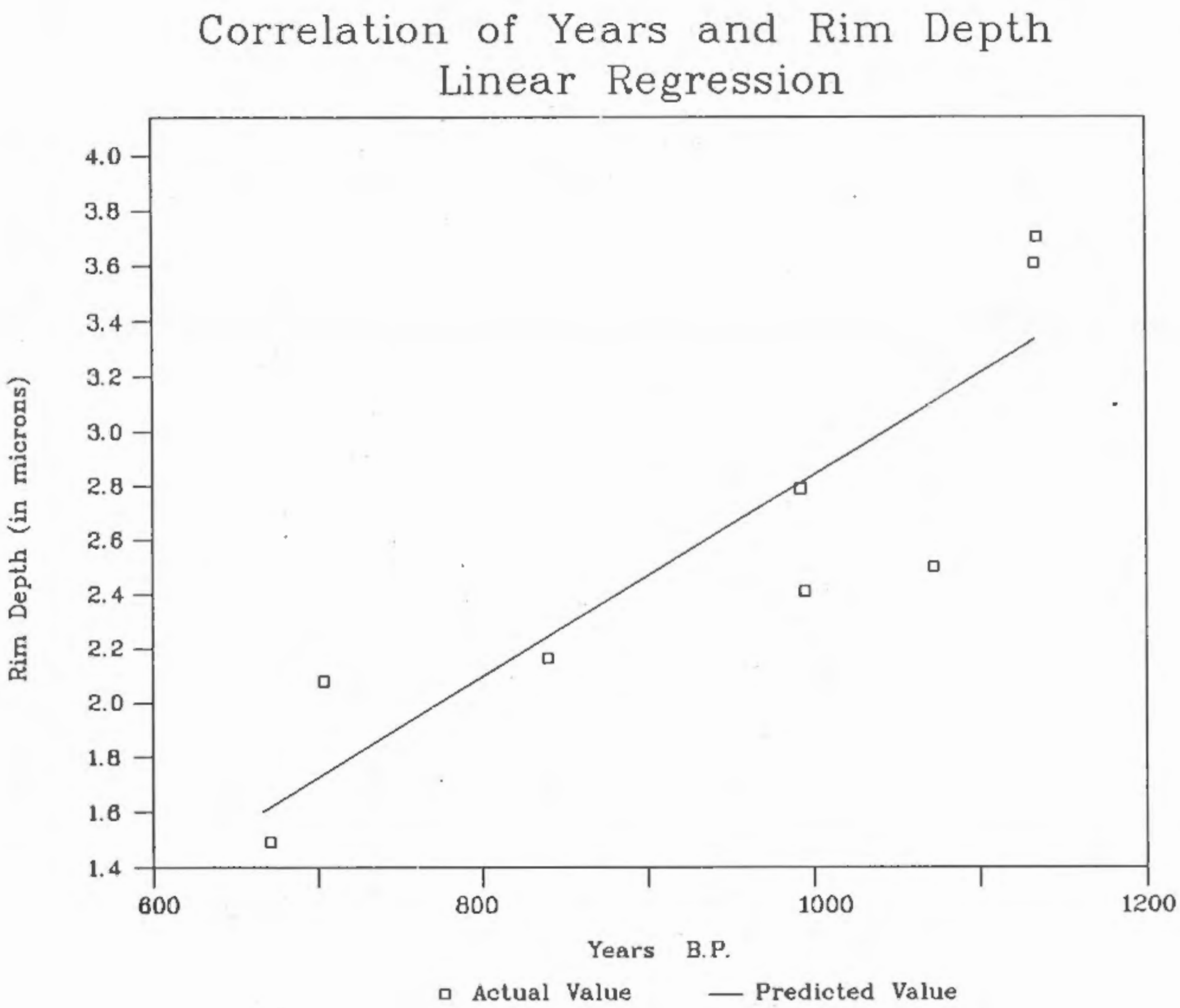

Figure 7. Linear regression results.

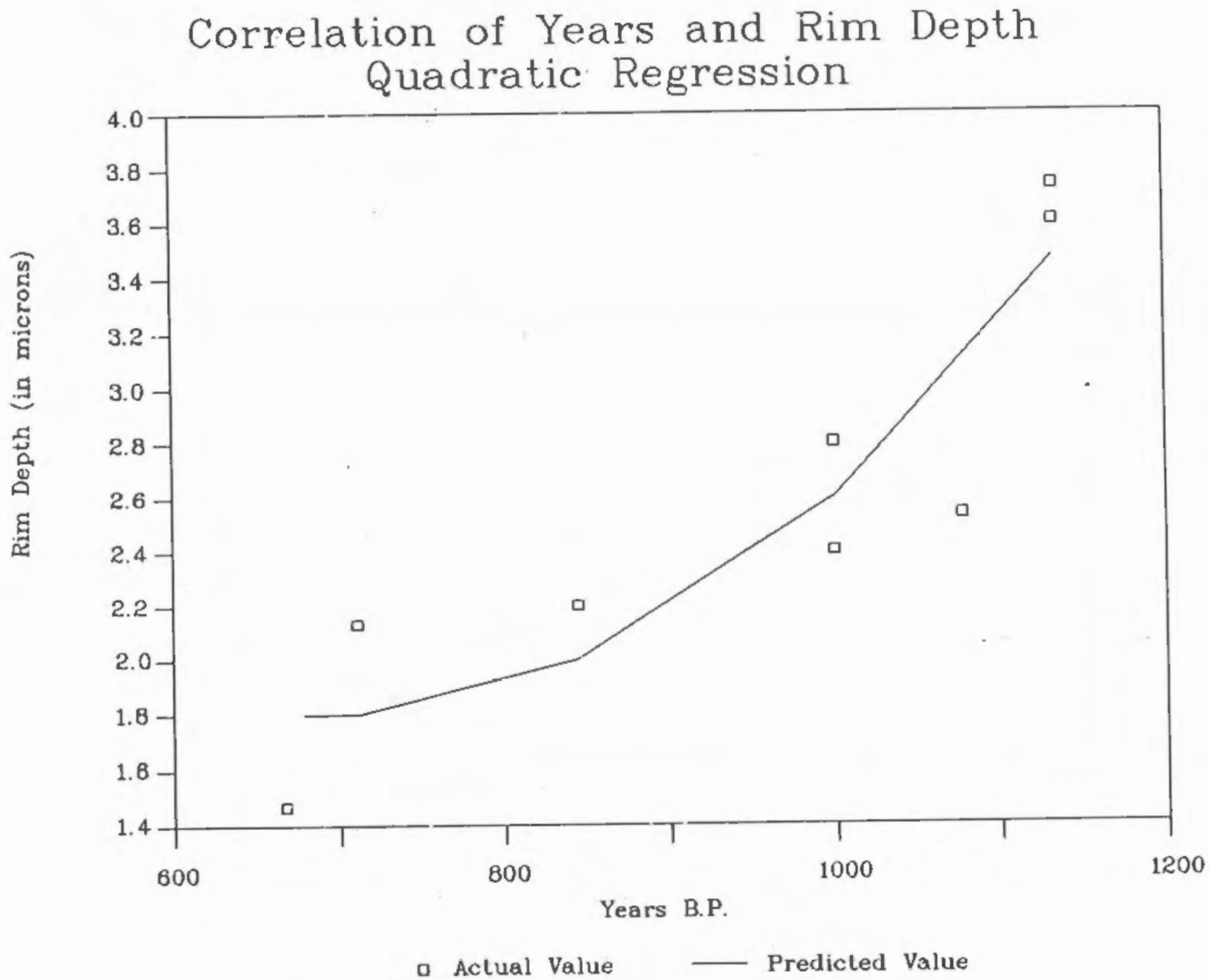

Figure 8. Quadratic regression results.

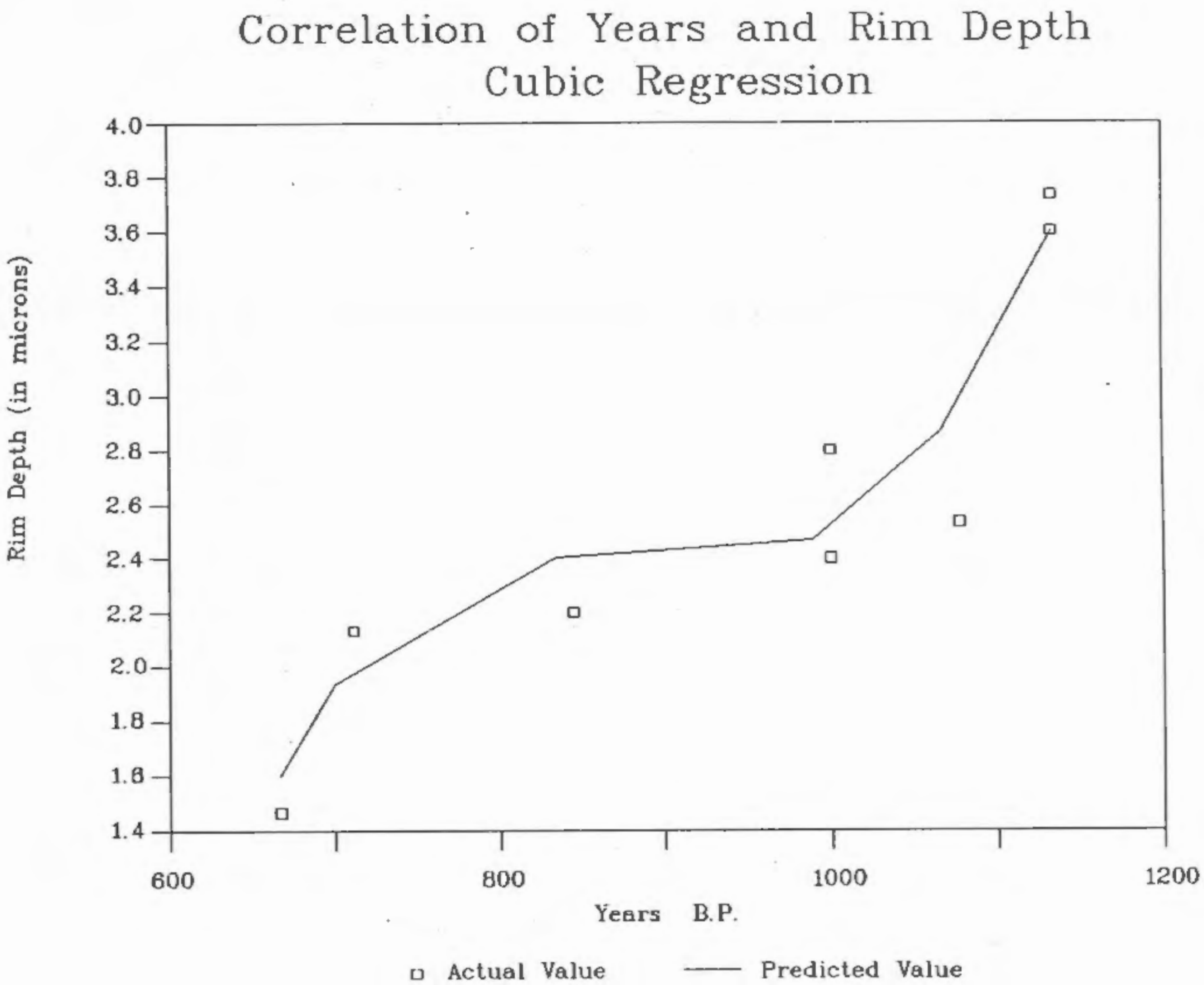

Figure 9. Cubic regression results.

Evans 1968). Therefore, the linear rate obtained from this analysis could be questioned, as only 31 samples spanning only 500 years was used. Realizing that this linear quality might be artificial, another test was used to develop a rate. This one was based on curvilinear regression.

In a study of Mexican obsidians, the curvilinear regression equation $y = mx^b$ [first proposed by Friedman and Smith (1960)] is transformed into the logarithimic equation $\log y = \log m + b(\log x)$ and used to determine a hydration rate for the obsidian source being studied (Hurtado de Mendoza 1981:160). In both of these cases, the alpha designations (y, m, x, and b) represent the same values as described earlier.

There were many parallels noted between that study and the current one, notably the small sample size and the short time span. As a test, encouraged by the seeming success of that study, the current data were analyzed using the logarithmic equation. All data were transformed into logarithmic form and tested with linear regression. Table 11 summarizes the results. A Student's t test of the correlation coefficient for these results produced a higher t-score, showing this equation to be slightly more significant statistically than the original linear equation (indicating that perhaps the relationship is linear). Figure 10 illustrates the line fitted to the data based on the logarithmic equation.

Solving the logarithmic equation for $x = 1000$ and , using the slope coefficient and y-intercept obtained from the computer analysis, results in $y = 2.82$ microns, which is very similar to the 2.86 microns

Table 11. Results of Linear Regression on Logarithmically Transformed Data.

Rim Depth (Y)	Years B.P. (X)
0.5912	3.063
0.5798	3.063
0.4150	3.037
0.3979	3.004
0.4624	3.004
0.3521	2.929
0.3324	2.851
0.1761	2.829

Regression Output:	
Constant	-3.5067765110
Std Err of Y Est	0.0642594378
R Squared	0.8073067038
No. of Observations	8
Degrees of Freedom	6
X Coefficient	1.3188020222
Std Err of Coefficient	0.2630377026

Critical Value of $t_{0.05(6)} = 1.943$

t score = 5.01

H_o : significant

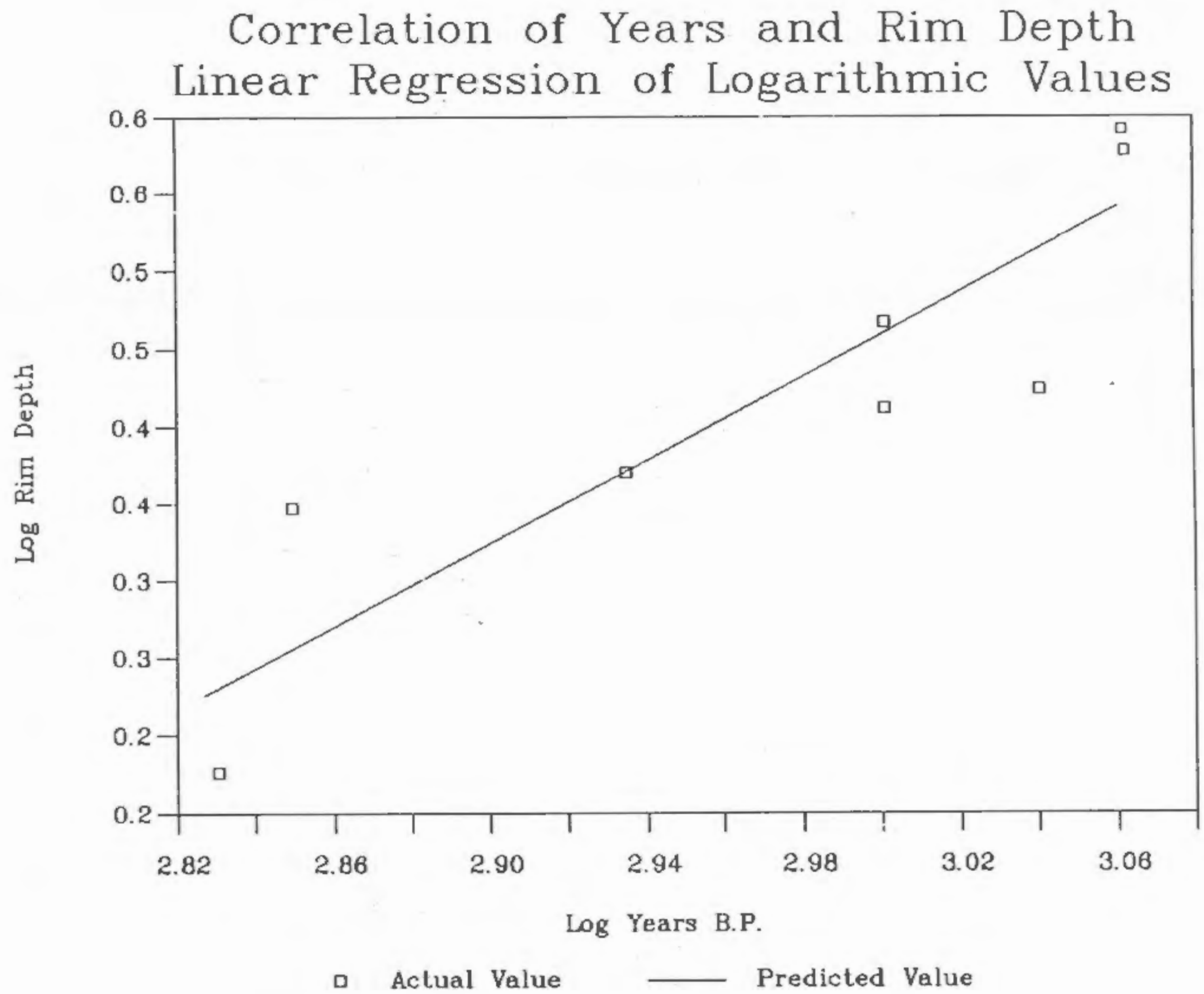

Figure 10. Linear regression results of logarithimic data.

obtained from the original linear regression. The obtained rate from the curvilinear regression analysis is represented as 7.93 $microns^2$/1000 years.

To test the validity of these rates, some of the micron measurements obtained during this study were "plugged into" the rate. However, neither the 2.86 microns/1000 years nor the 7.93 $microns^2$/1000 years rate seemed to work very well with the data. Therefore their validity may be questionable. If either of these rates were valid, one would expect that by inserting some of the micron measurements obtained for the samples under study the resultant dates would be close to the dates associated with the samples.

This chapter has summarized the analytic results of the sourcing and hydration rate determinations for the samples under study. Interpretations were made about the obtained results. It is realized that there are several limitations to these interpretations based on the small sample size and the chronological controls.

VI. SUMMARY AND CONCLUSIONS

The preceding chapters have described each step of the analysis of 31 obsidian samples used to develop a hydration rate for the Cochiti river gravels. These samples were part of previous collections made during subsurface testing of several sites in the Middle Rio Puerco Valley. These samples were associated with mean ceramic dates ranging from A.D. 795 to A.D. 1240, and an archaeomagnetic date of A.D. 1275.

Initial analysis of these samples was to determine their geologic sources. Stepwise discriminant analysis revealed that 70% of the samples were from the Rio Grande Pleistocene Terrace Gravels, Cochiti vicinity, 26% were from the Rio Grande Pleistocene Terrace Gravels, Los Lunas vicinity, and 4% were derived from San Antonio/No Agua Mountain. Comparison of this data with previous research near the study area prompted the second discriminant analysis of the data without the river gravel sources. Results of this analysis implied that many of the samples may have been derived from the Jemez and Red Hill sources.

Correlation of rim measurements for the samples classified to the Cochiti river gravels source was done using polynomial regression. According to the regression analysis a linear equation was the best fit for the data. A hydration rate of 2.86 microns/1000 years was obtained for the Cochiti river gravels using this equation. A second analysis, based on the curvilinear equation $y=mx^b$, suggested a hydration rate of 7.93 $microns^2$/1000 years for the Cochiti river gravels. Both of these rates suggest a linear relationship between the rim measurements and associated dates.

Other analyses included a test of the validity of macroscopic sorting for distinguishing obsidian sources. It was demonstrated that this method is often not successful. This result supports the work of others such as Landis and Sappington (1985). Because of these results, the third assumption described in the introduction was found to be unacceptable and the four samples affected by it were excluded from the analysis.

Conclusions

Based on the results obtained from the initial discriminant analysis, it is concluded that prehistoric populations in the study area were using locally acquired obsidians in lithic manufacture. This conclusion is similar to that of Brett (1984). In her analysis of non-obsidian lithic collections from these same sites she found that, in most cases, locally derived lithic sources were being exploited. Another implication of these results involved speculated exchange between Chaco Canyon and various Chacoan outliers in the area. At least at Guadalupe Ruin, the one Chacoan outlier included in this study, there was no evidence of obsidian exchange with Chaco Canyon. However, this conclusion is tentative as a very small sample was analyzed in this study. Future research in this direction should include analysis of a larger sample of obsidian from this site and other Chacoan outliers in the area to test the hypothesized exchange.

The results of the second discriminant analysis were very different. This leads to several possible conclusions. First, it points out one of the problems with discriminant analysis. This procedure will classify all unknown obsidian samples into the known source groups used for comparison, even if the correct source is not included in the comparative base. This problem is difficult to resolve, as it would be next to impossible to always have every possible known source included in the database for discriminant analysis. As this research has shown, leaving out only two possible sources results in a whole different set of data and possible interpretations. Future research to solve this problem may involve compiling a comparative base of geochemical characterization information that would be accessible by many researchers. This would give one access to the data, without necessarily having to collect it oneself. Also, as more archaeologists do more and more research, the database would always grow. Perhaps standardization of elements used as discriminating variables will also be achieved. Recent research (Newman and Nielsen 1985) has already embarked upon this possibility.

Another problem pointed out in the second discriminant analysis is one that has been inherent in the source determination of the various Rio Grande Terrace gravels. All of these obsidians are found in secondary deposits along the Rio Grande. While this made them easily accessible to prehistoric populations, it also makes it difficult to derive their ultimate source. As work by others have shown (cf. Shelley and Montgomery 1985; Michels 1984) all of these obsidians are very similar chemically. I think the idea postulated in this study about the derivation of the Cochiti river gravels needs to be explored more fully. Perhaps intensive survey and collection from the Jemez area and trace element characterization of the samples will reveal sources matching the Cochiti river gravels. Until such time when this task can be accomplished, it is important to include trace element information of the river gravels in analyses. As demonstrated here, if they had not been included, interpretations of the whole study would have been different. Along these lines another future goal may be to re-analyze the samples from Cameron and Sappington's (1984) study and see if the results change significantly. They may not, especially if populations were exploiting easily obtained local raw materials. Chaco Canyon is closer (ca. 80 mi [128 km]) to the Jemez source than it is to the various river gravels sources (ca. 115-140 mi [185-225 km]).

Results of the macroscopic sorting demonstrate clearly that visual distinctions between obsidians does not always imply chemical distinctions. As pointed out in some studies, such as Ammerman's (1979) study with obsidian from Italy, this can be done successfully; however, others (cf. Landis and Sappington 1985) have been equally unsuccessful. The major implication of this is that chemical characterization of obsidian samples is important to both the study of exchange systems and hydration rate determinations. Future research should include as many samples as possible for trace element analysis.

Correlation of rim depths and associated dates provided the most problems with this study. It was very difficult to even achieve a relative chronological relationship for these samples. This is unusual, as others (cf. Findlow et al. 1975; Layton 1972, 1973; Michels

1969) have not had this problem. I think this arises from several limitations inherent in the data. The sample used in this study was very small. With only 31 samples, although statistically significant results can be achieved, there is the possibility of sampling error. Also, the time span represents only a very small period, 500 years. Better results could have been obtained with the inclusion of samples from the earlier end of the time scale. Unfortunately, none were available at the time this research was done. Future research in this study area should attempt to obtain a well rounded sample representing a significant time span.

Aside from small sample size and time span problems, most importantly is the problem with actual chronological control. The mean ceramic dates used for correlations were derived using South's (1977) formula. In actuality, these dates are not averages but medians. In some cases, the ceramic date obtained does not even fall within the occupational span of the site. For example, samples 1.1, 1.2, and 2 are from site ENM 7052 and associated with a mean ceramic date of A.D. 795. However, other data suggests the site was actually occupied from A.D. 813 to A.D. 900. This is a potentially significant difference. Through the use of average micron measurements with the mean ceramic dates for each site, it is hoped that most of the variability was accounted for.

Another factor possibly adding to this problem, is the density of occupations in the project area. Many Basketmaker and Puebloan sites are found within this area. In many cases Puebloan sites are constructed on top of previous Basketmaker sites. It is logical to assume that re-use of old lithics would have occurred. Three of the samples in this study showed clear evidence of this; they had two hydration rims, one which fits well with Basketmaker dates and one that fits well with later Puebloan dates. This phenomenon was not observed on other samples. However, if a previously made lithic was used by a later occupant, but not reworked, such as is the case in many instances with expedient tools, the re-use would not appear in the hydration rim measurement. This may have been occurring with samples used in this study.

Finally, the regression analyses used to determine the hydration rates presented in the preceding chapter were based on sound statistical methods. The fact that a linear rate was supported by the data may indicate that it is probably a result of the small sample used. Others have identified this same problem (cf. Meighan et al. 1968). Future attempts a determining a rate for this source should be based on a larger sample.

The research presented in this thesis represents an attempt to determine a hydration rate for some obsidians from the Middle Rio Puerco Valley, New Mexico. In the course of its development, other hypotheses and assumptions were attempted. I believe that the most significant contribution of this research is not the hydration rate, but rather the information gained on sourcing problems and the problems associated with macroscopic sorting. Future research in obsidian hydration both in this area and others should develop a sound comparative base for sourcing from which other avenues of research may proceed.

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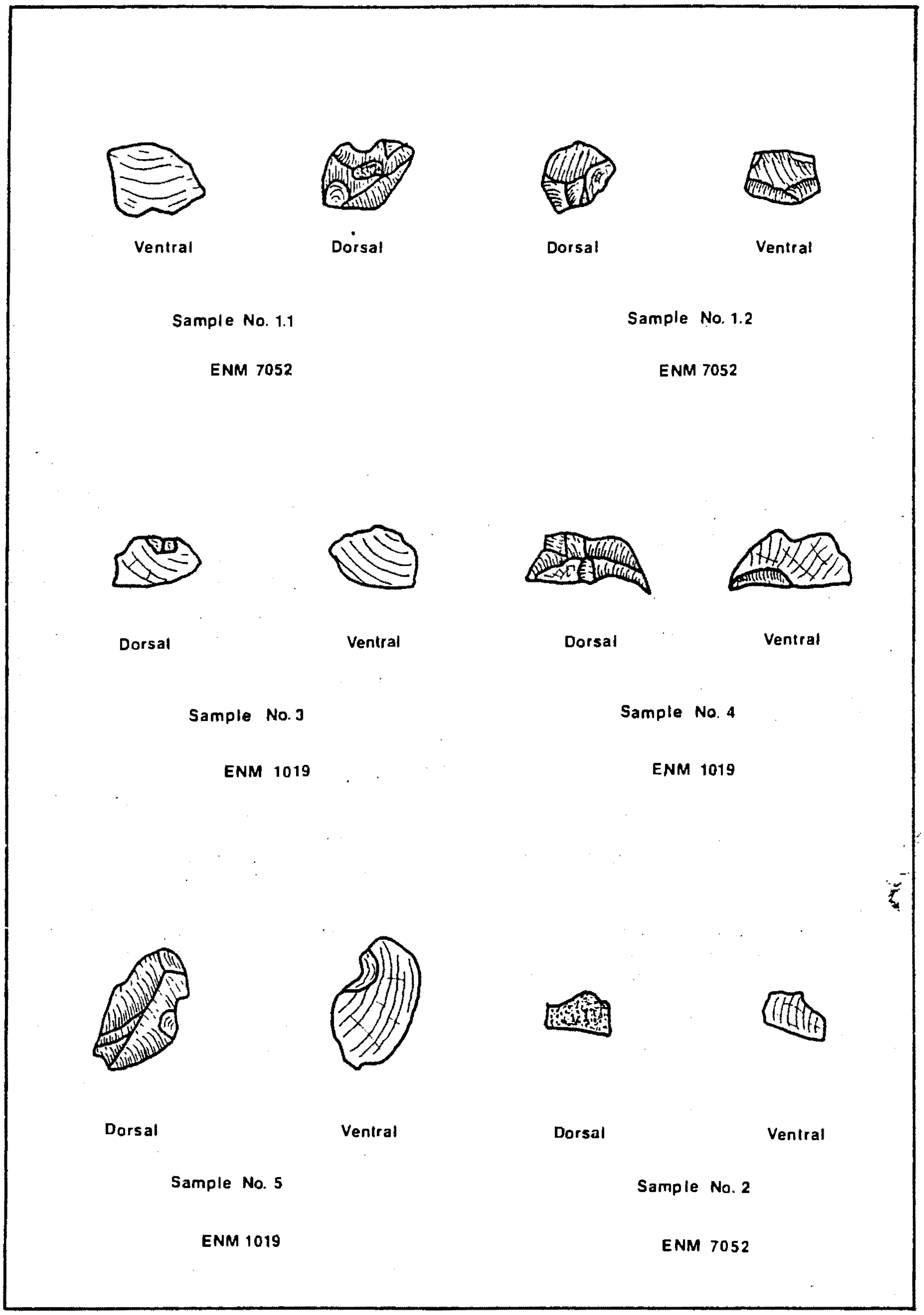
APPENDIX I

ARTIFACT SKETCHES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Dorsal
Ventral
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Dorsal
Ventral
Sample No. 3
ENM 1019
Sample No. 4
ENM 1019
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Ventral
Dorsal
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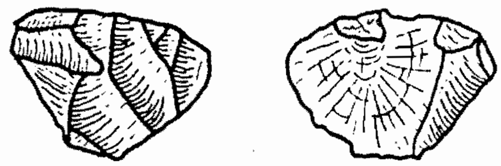
Sample No. 2
ENM 7052

Ventral Dorsal

Sample No. 6

ENM 298



Dorsal Ventral

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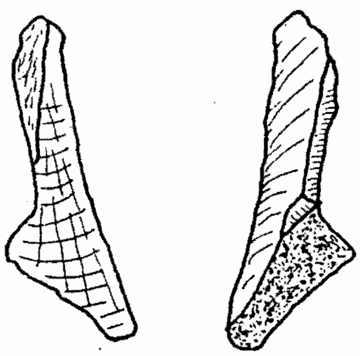

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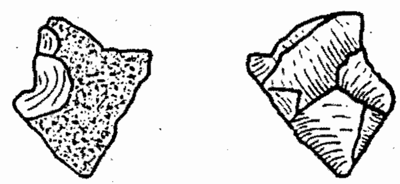

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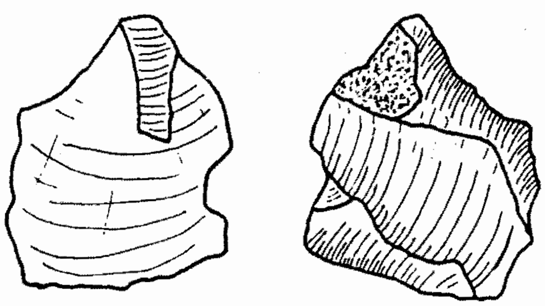

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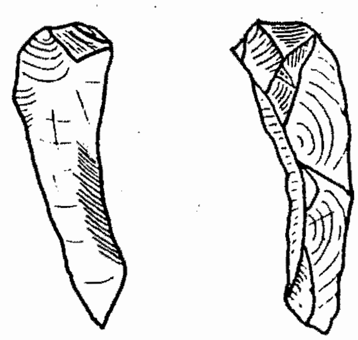

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Sample No. 9

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Ventral Dorsal

Sample No. 13.3

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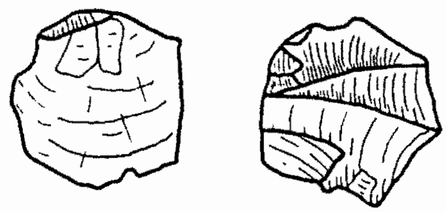

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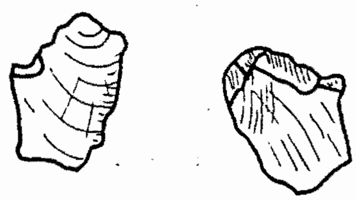

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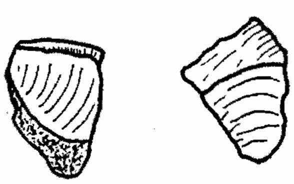

Dorsal Ventral

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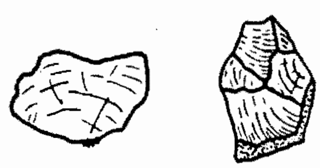

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Reverse Obverse

Sample No. 13.6

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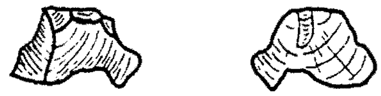

Dorsal Ventral

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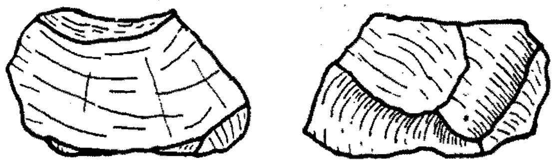

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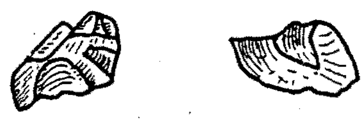


Dorsal Ventral

Sampla No. 16.1

ENM 846

Ventral Dorsal

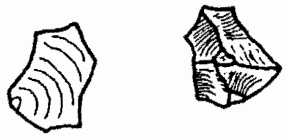
Sample No. 15

ENM 846

Obverse Reverse

Sample No. 14.1

ENM 846



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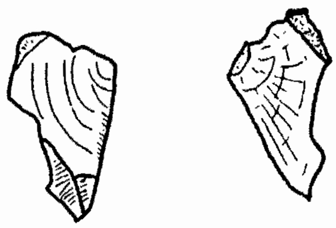

Dorsal Ventral

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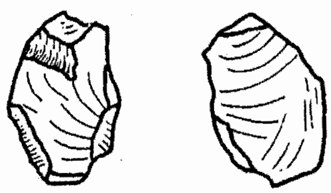

Dorsal Ventral

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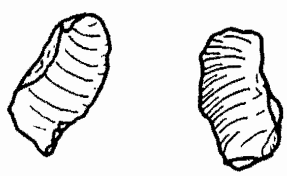

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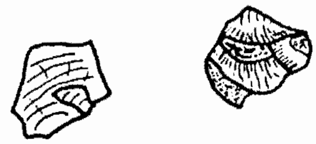

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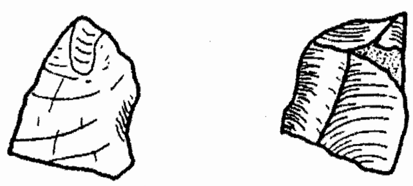

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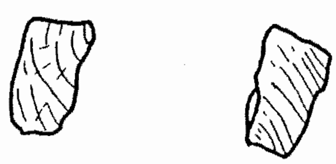

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ENM 820

APPENDIX II

X-RAY FLUORESCENCE DATA

X-Ray Fluorescence Data for Trace Elements in Counts Per Second.

Sample Number	Element																					
	Al	Si	P	Ag	K	Ca	Ti	Mn	Fe	Ni	Cu	Zn	Ga	Se	Rb	Zr	Cr	Ge	S	Cl	Co	Pb
1.1	1	5	2	8	19	4	6	3	90	6	11	9	-	-	10	16	-	-	-	-	-	-
1.2	1	3	3	10	17	9	3	7	65	-	11	6	-	-	-	-	-	10	-	-	-	-
4	1	3	2	14	28	10	8	11	126	-	17	17	-	18	-	22	6	31	-	-	-	-
5	1	4	4	12	38	25	7	12	186	-	25	12	-	18	23	26	-	-	6	-	28	16
6	3	8	-	23	114	23	17	33	543	48	38	-	-	59	52	68	-	81	-	-	-	-
7	4	11	4	26	93	24	13	32	500	-	56	51	-	48	64	60	-	-	-	-	-	-
8	7	16	17	42	170	49	33	66	976	58	91	94	95	76	79	111	-	-	22	-	-	-
9	3	9	4	16	57	19	10	19	261	-	42	32	42	-	23	-	-	50	10	-	-	25
10	6	14	7	21	92	28	18	24	426	24	42	38	39	46	40	51	-	-	-	-	-	-
11	2	4	6	12	25	9	6	14	152	8	21	15	-	22	-	-	-	30	-	-	-	-
12	3	10	9	15	69	27	11	22	372	18	42	30	51	43	42	-	-	51	9	-	-	-
13.1	6	4	6	12	63	20	12	20	296	15	43	27	46	32	32	35	-	56	-	-	-	19
13.2	1	2	1	5	14	5	1	4	38	-	10	5	10	6	4	7	-	7	-	-	-	-
13.4	1	4	1	8	12	7	4	6	45	5	11	5	-	-	-	-	-	10	-	-	11	-
13.5	1	2	3	5	16	8	3	5	62	7	21	7	12	10	10	10	-	-	5	-	-	-
13.6	5	12	10	31	110	51	26	39	335	-	49	34	-	51	51	47	-	105	-	-	-	-
13.7	1	2	1	10	19	6	4	7	43	-	9	9	10	5	6	7	-	13	-	-	-	-
14.1	-	1	-	8	4	3	1	2	17	-	2	2	-	-	-	-	-	3	-	-	-	3
14.2	7	28	-	26	218	45	25	54	763	-	83	63	-	94	70	88	-	142	22	-	-	-
15	3	7	3	23	50	9	11	14	219	-	38	19	35	23	-	28	5	-	-	5	-	-
16.1	1	2	2	7	12	3	4	4	47	-	16	5	12	-	7	-	-	13	-	-	-	-
16.2	1	4	6	14	28	11	8	8	156	-	19	15	20	21	-	20	-	42	-	-	-	-
17	2	6	6	17	69	19	11	13	263	-	21	13	33	30	-	29	10	-	-	-	-	-
18.1	4	8	5	19	65	17	9	12	234	-	36	27	33	25	-	26	-	-	-	-	-	-
18.2	3	2	3	10	13	9	4	8	69	-	17	11	14	10	9	12	-	21	-	-	-	12
19.1	3	4	3	12	42	10	5	24	186	15	29	22	-	25	33	25	-	40	-	-	-	19
19.2	2	22	7	14	65	13	8	18	228	-	34	24	30	24	23	31	7	-	8	-	-	21

APPENDIX III

RESULTS OF SECOND DISCRIMINANT ANALYSIS

Table III-1. Discriminant Analysis Results for Known Sources Without the River Gravels.

Known Source	Classified Source	Posterior Probability of Membership in Source: Grants Ridge	Jemez	Polvadera Peak	Red Hill	San Antonio /No Agua Mt.
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Jemez	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0008	0.0000	0.0000	0.9992	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	1.0000	0.0000
Red Hill	Red Hill	0.0000	0.0000	0.0000	1.0000	0.0000

Table III-1. (Continued).

Known Source	Classified Source	Grants Ridge	Jemez	Polvadera Peak	Red Hill	San Antonio /No Agua Mt.
		Posterior Probability of Membership in Source				
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
San Antonio/No Agua Mt.	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
Grants Ridge	Grants Ridge	1.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	1.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	1.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	1.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	1.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	1.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	1.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	1.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	1.0000	0.0000	0.0000	0.0000	0.0000
Grants Ridge	Grants Ridge	1.0000	0.0000	0.0000	0.0000	0.0000
Polvadera Peak	Polvadera Peak	0.0000	0.0000	1.0000	0.0000	0.0000
Polvadera Peak	Polvadera Peak	0.0000	0.0000	1.0000	0.0000	0.0000
Polvadera Peak	Polvadera Peak	0.0000	0.0000	1.0000	0.0000	0.0000
Polvadera Peak	Polvadera Peak	0.0000	0.0000	1.0000	0.0000	0.0000
Polvadera Peak	Polvadera Peak	0.0000	0.0000	1.0000	0.0000	0.0000
Polvadera Peak	Polvadera Peak	0.0000	0.0000	1.0000	0.0000	0.0000
Polvadera Peak	Polvadera Peak	0.0000	0.0000	1.0000	0.0000	0.0000
Polvadera Peak	Polvadera Peak	0.0000	0.0000	1.0000	0.0000	0.0000
Polvadera Peak	Polvadera Peak	0.0000	0.0000	1.0000	0.0000	0.0000
Polvadera Peak	Polvadera Peak	0.0000	0.0000	1.0000	0.0000	0.0000

Table III-2. Classification Results of Archaeological Samples Without the River Gravels.

Sample Number	Classified Source	Posterior Probability of Membership in Source				
		Grants Ridge	Jemez	Polvadera Peak	Red Hill	San Antonio /No Agua Mt.
1.1	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
1.2	Red Hill	0.0211	0.0000	0.0000	0.9789	0.0000
4.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
5.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
6.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
7.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
8.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
9.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
10.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
11.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
12.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
13.1	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
13.2	Red Hill	0.2738	0.0000	0.0000	0.7262	0.0000
13.4	San Antonio/No Agua Mt.	0.0126	0.0000	0.0000	0.0157	0.9717
13.5	Jemez	0.0000	0.5394	0.0000	0.4606	0.0000
13.6	Red Hill	0.0070	0.0000	0.0000	0.9930	0.0000
13.7	San Antonio/No Agua Mt.	0.0000	0.0000	0.0000	0.0000	1.0000
14.1	Red Hill	0.0015	0.0000	0.0000	0.9985	0.0000
14.2	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
15.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
16.1	Red Hill	0.0019	0.0000	0.0000	0.9981	0.0000
16.2	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
17.0	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
18.1	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000
18.2	Grants Ridge	0.9038	0.0000	0.0000	0.0962	0.0000
19.1	Grants Ridge	0.9996	0.0000	0.0000	0.0004	0.0000
19.2	Jemez	0.0000	1.0000	0.0000	0.0000	0.0000