THESIS

OBSIDIAN HYDRATION ANALYSIS ON ARTIFACTS FROM THE RIO GRANDE NATIONAL FOREST

Submitted by

George R. Burns

Department of Anthropology

In partial fulfillment of the requirements

for the Degree of Master of Arts

Colorado State University

Fort Collins, Colorado

Summer, 1981

ABSTRACT OF THESIS

OBSIDIAN HYDRATION ANALYSIS ON ARTIFACTS

FROM THE RIO GRANDE NATIONAL FOREST

One hundred twenty two obsidian artifacts collected during the 1975 to 1979 field seasons from surface surveys conducted in the Rio Grande National Forest were analyzed using obsidian hydration dating and X-ray Fluorescence spectrometry. The goal was to develop a working chronology for the mountains of southern Colorado. Previous work in the Rio Grande National Forest and the San Luis Valley, which the forest surrounds, revealed a period of occupation ranging from Paleo-Indian times to the historic era. This area as a whole retains the status of an archaeological region in its own right but as yet has not had a chronology established based strictly on locally obtained data. Typological information used to establish the present chronology has been based almost exclusively on diagnostic ~~arrowheads~~ projectile points whose times of utilization were inferred from three surrounding cultural areas: the Southwest, Great Basin and Great Plains. No independent dating techniques applied to artifacts recovered from the Rio Grande National Forest had produced usable results. Chronologic ordering of artifacts within the forest, therefore, followed chronologies borrowed from these surrounding regions. This present study was the first application of an independent dating technique specific to the forest.

The lack of site specific climatic data, information on elements vital to the hydration process and the use of surface finds precluded the establishment of an absolute chronology at this time. Relative

ages derived within the two source locality clusters provided by computer aided cluster analysis of chemical fingerprinting results confirmed the established chronologic ordering of the artifacts. An anomalous hydration reading on a single artifact was the only stumbling block to an otherwise orderly pattern of hydration rim depths.

This thesis is the genesis of a complete understanding of obsidian sources exploited and the cultural processes by which the obsidian was transported to this region of southern Colorado.

George R. Burns
Department of Anthropology
Colorado State University
Fort Collins, Colorado 80523
Summer, 1981

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

LIST OF FIGURES

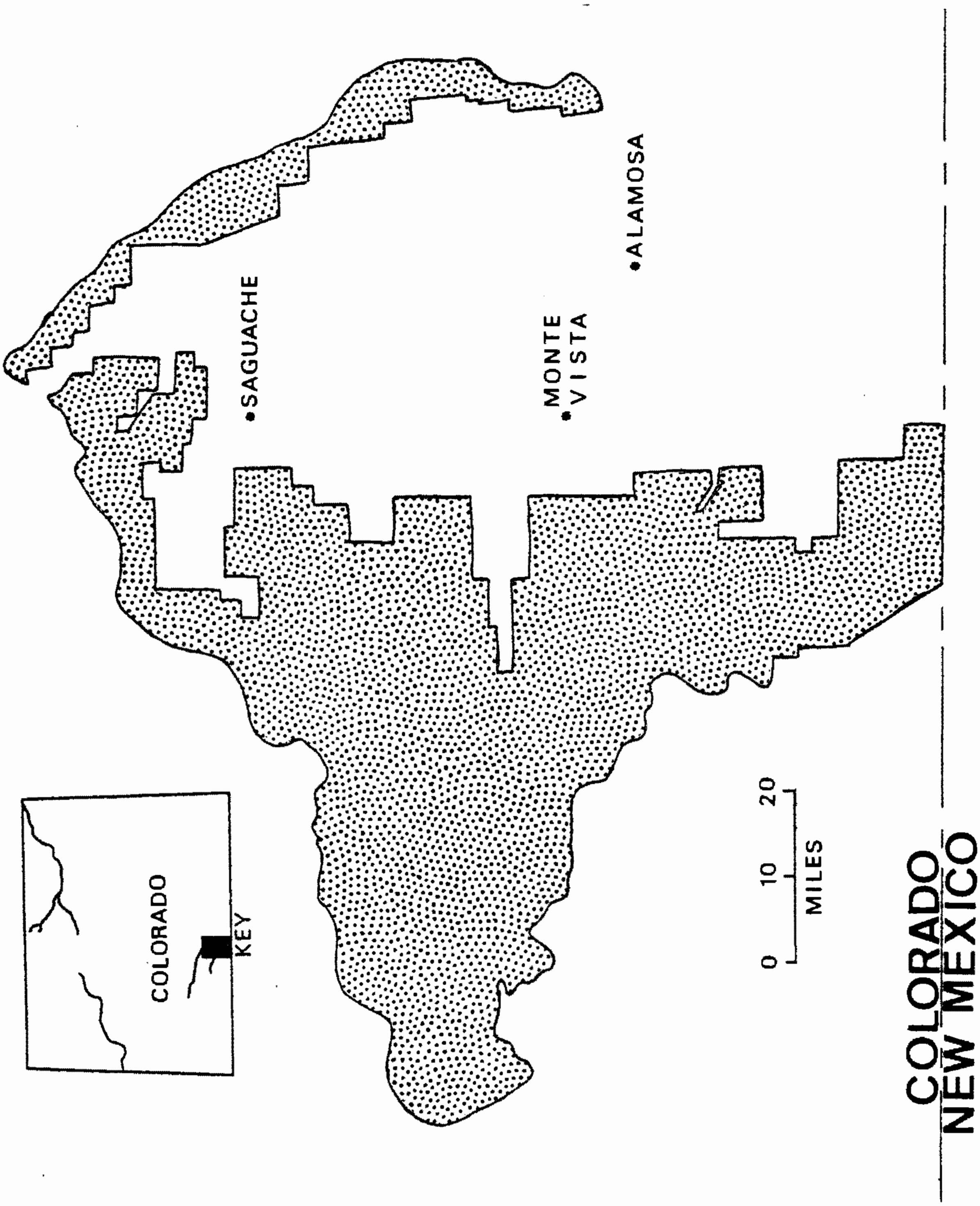
CHAPTER I

INTRODUCTION

The Rio Grande National Forest (RGNF) is a 1.9 million acre forest located on the eastern slope of the Continental Divide in south-central Colorado. Two mountain ranges are partially located within the forest: the eroding volcanic San Juans lying to the west and the actively faulting Sangre de Cristos to the east. The ranges encircle the 7500 ft high San Luis Valley (SLV) which is drained to the south by the Rio Grande River, the headwaters of which are located high in the San Juans. Portions of five counties are included within forest boundaries: Alamosa, Conejos, Hinsdale, Mineral, Rio Grande and Saguache (Figure 1). The SLV and RGNF are located adjacent to three culture areas, the Great Basin, the Southwest and Great Plains, suggesting the likelihood that Indians from each area visited the Valley to exploit its natural resources. The possibility of such visits leads to the belief that a complex series of cultural events were at work there.

Government agencies have for some time now noted a growing public interest in cultural systems and our national heritage by increased usage of national parks and monuments featuring remnants of prehistoric activity. The U. S. Forest Service recognizes that the forests contain remote areas that often are rich in cultural resources. Forests are among the last areas where nonrenewable cultural resources can be found

Figure 1. Map of the Rio Grande National Forest (stippled area).


SAGUACHE
MONTE VISTA
ALAMOSA
COLORADO
KEY
0 10 20
MILES
COLORADO
NEW MEXICO

in a relatively undisturbed state. With increasing public use of the forests, the cultural resources are in eminent danger of being removed and their value as research tools being forever lost to the scientific community.

Since 1906 when the Antiquities Act was established, the government has attempted to curtail illegal and often malicious collecting and destruction of cultural resources. Recently, additional laws providing for protection and research on artifacts have surfaced in the attempt to preserve information about our past and orient current as well as future generations to the importance of the past. It was recognized that a strong and continued effort was needed to ensure preservation. As part of that effort, Forest Service policy (U. S. Government 1974) provided for the use of cultural properties for public educational and scientific purposes. It was this policy that allowed the present study to be undertaken.

CHAPTER II

BACKGROUND ARCHAEOLOGY OF THE RIO GRANDE NATIONAL FOREST

A review of existing literature revealed that several papers and reports dealing with the archaeology of the upper Rio Grande Valley have been published, but relatively few have concentrated on the Rio Grande National Forest. Research in the San Juan Mountains revealed them to be a discrete archaeological area within the larger archaeological picture of the region, yet they were largely ignored in reports save those on the forest itself. Most reports on the region have dealt with archaeology of the adjacent San Luis Valley. The present review and summary will, therefore, be centered on archaeological manifestations in the Valley with mention made of forest archaeology whenever possible.

The Upper Rio Grande area received much attention in the 1940s with work done mostly by E. B. Renaud, C. T. Hurst and the Huschers. Reports generated from their work described specific sites or artifact styles found mainly on the valley floor while the surrounding mountains received little attention. Between the 1940s and 1975, when the Forest Service implemented an in-house archaeology program to comply more effectively with federal regulations, little archaeology was done either in the Valley or the mountains. Since that time, however, the RGNF has been the source of several reports and evaluations dealing with archaeological findings (Shafer 1978; Nickens 1979; Spero 1978; Gooding and Kreuser 1980 and others).

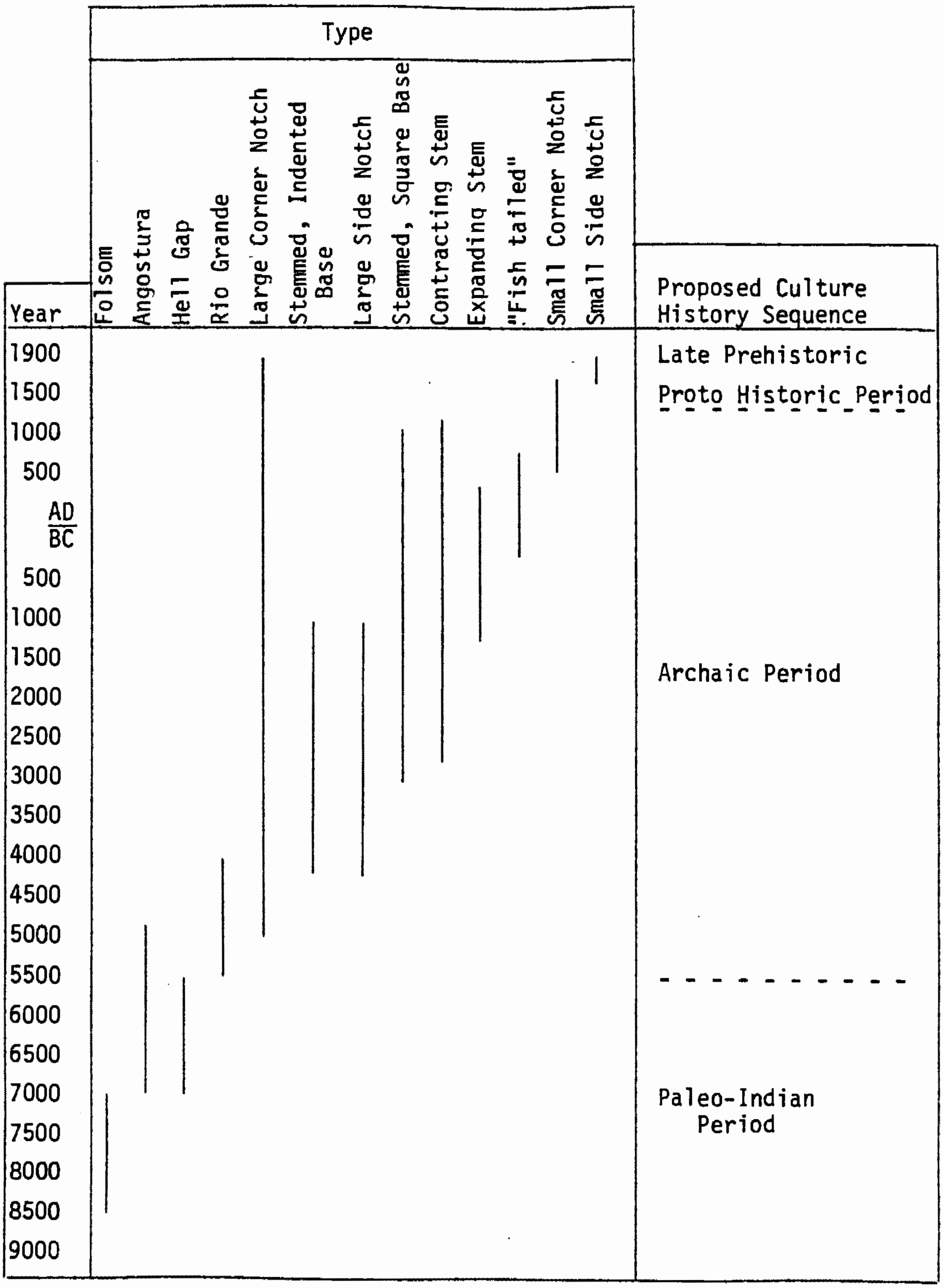
San Juan mountain research revealed a rich area with diverse types of cultural resources. The reason for this diversity can be attributed to the fact that the SLV and surrounding mountains lie at the juncture of three major culture areas: the Southwest, Great Plains and Great Basin. At various times over the past 10,000 years, people from each of these areas visited the valley, a fact reflected in the archaeological record.

PALEO-INDIAN (11,500-7500 BP)

(Chronology follows Frison 1978:83)

The earliest people to visit the RGNF and SLV were of the Paleo-Indian tradition evidenced by the presence of Sandia, Clovis, Folsom, Angostura and Hell Gap points (Table 1) (Wilson 1971:12; Dangler et al. 1978:44; Nickens 1979:67). Most of the points were isolated finds or from private collections so information on context was either limited or lost. Thus, little has been learned about the culture of Paleo-Indians in the area. The Folsom occupation has provided the most information on the Paleo-Indian tradition in the Valley. The Linger (Hurst 1941, 1943) and Zapata (Wormington 1957:29-30) sites were found along the foothills of the Sangre de Cristo Mountains, excavated, and between them produced over 30 Folsom points and much of the tool assemblages. Another documented Paleo-Indian site in the valley produced a single Folsom point base and related tools and flakes (Dangler et al. 1978). This site, located in the mountains west of Creede, has not been excavated but testing showed a soil depth of at least .5 meter (Nickens 1979:37), leaving open the

Table 1. Temporal Distribution of Projectile Point Types (After Nickens 1979)



possibility of subsurface material. Combined, these early man artifacts have made the SLV, and especially Alamosa County, the best represented area in the state for Paleo-Indian occupation (Nickens 1979:17). The relative density of Paleo-Indian material from the SLV appears to indicate repeated and intensive use rather than visitation by an occasional hunting expedition.

EARLY ARCHAIC (7750-5000 BP)

Following the Paleo-Indian tradition, the RGNF experienced a cultural hiatus. Shafer (1978:1) commented on the lack of Early Archaic from this area as well as the surrounding mountains. In contrast, Benedict and Olsen (1978), working farther north, in Rocky Mountain National Park, noted no lack of material from this period with occupation of the Mount Albion site beginning about 5800 BP. The paucity of Early Archaic material in southern Colorado could be due simply to a small sample of artifacts or it could indeed reflect less utilization of the southern Rocky Mountains during those years. Based on personal experience with the cultural resource base in the mountains of southern Colorado, the latter appears to be the case. A clue might lie in the fact that the Early Archaic coincided with the Altithermal (7000-5500 BP), a warmer and drier climatic period when animals, and consequently man travelled farther north in search of greener pastures (Benedict and Olsen 1978:v).

Around 5000 BC, people traveling from the south introduced a new point style along the Rio Grande Valley. Dr. E. B. Renaud, writing in the early 1940s, was the first to comment on this new industry. After several years of surveying along the Rio Grande River Renaud produced a group of 54 similar and previously uncategorized projectile points which he designated "Rio Grande Points" for their presence mainly along and in areas drained by the Rio Grande River (Renaud 1942).

The main features distinguishing these points are a relatively long stem, a concave or straight base (ground), small obliquely cut shoulders, and a body which is generally shorter and broader than the base. The points are commonly percussion flaked out of locally obtained basalt but some made from rhyolite and obsidian have also been found (Renaud 1942, 1944).

The range of diversity Renaud noted in his original sample of Rio Grande points prompted him to divide them into a typical style and two subtypes (Renaud 1942). The variation present within the style caused considerable confusion and encouraged a reclassification in which Renaud's Subtype 1 was redefined as the typical style (Honea 1969:65). Types Renaud originally designated as Rio Grande points but excluded as such in the more recent classification include Lake Mojave and Pinto Basin points, both possessing too much variation to be called Rio Grande points. They are believed to be earlier or later transitional representatives of the same Paleo to Archaic continuum that produced Rio Grande points (Beardsley 1976:63).

Evidence as to temporal position of Rio Grande points has been consistent, revealing the Archaic as the time of manufacture for the points. Stratigraphically, Rio Grande points were found below Pueblo occupation levels, prompting archaeologists to refer to them as pre-Pueblo (Renaud 1942:36; 1944:37) and pre-Ceramic (Honea 1969:61, 66).

Honea (p. 65) also called them proto-Archaic based on Krieger's definition (Krieger 1964:59), since some were associated with grinding stones. Radiocarbon dates produced from strata containing Rio Grande points indicated a range of use from 4300 BC to AD 1 (Dick 1965:19; Irwin-Williams 1967:454; Honea 1969:66; Nickens 1979:16).

Knowledge of point types that replaced Rio Grande points remains an uncertain issue. Specimens from upper levels of Bat Cave, called Bat Cave points (Dick 1965:29, fig. 23), date to the Chirachahua stage of the Cochise culture and are stylistically similar to Rio Grande points. These may represent the introduction of points representative of the ancestral Mogollon culture, but this change remains speculative since Bat Cave is the only known site containing Bat Cave points. More work is needed to identify earlier and later forms of Rio Grande points.

Whatever their true temporal position, Rio Grande points are almost certainly a member of a complex of stemmed-indented points with lanceolate blades representative of the Early Archaic period known as the Picosa, which appears to have developed in New Mexico and spread northward along the Rio Grande River into southern Colorado (Irwin-Williams 1967). In the present study area a single Rio Grande point (LPD-IF-01) presents the only evidence of forest resource utilization during this period.

SAN LUIS VALLEY BLADES

One other artifact type was given a local name and was thought to be indicative of a particular phase in the area. San Luis Valley blades, so named because they were found in or near the SLV had a characteristic notch near their distal ends (Williams 1951).

The notch appeared on a variety of artifact styles, including a parallel flaked Paleo-Indian point, large stemmed points, and a small side notched point and oval bifaces. This variety of artifacts has made temporal placement of the trait difficult. Additional information also emerged to further complicate the issue. Grinding stones found indirectly associated with one of the blades indicated a possible Archaic manufacture, but the further presence of bones believed to be from the extinct Bison taylori added uncertainty to the Archaic placement. Considering the broad temporal span indicated for utilization of the notch, the possibility of a purely utilitarian use (i.e. a fingerhold for better grip on the tool) should be considered. The trait may not have been established during a particular period and the tools discussed may simply represent an occasional use of the notch. An alternate hypothesis is that the notch was introduced at a late date and its presence on the parallel flaked point represented reuse of the artifact.

MIDDLE ARCHAIC (5000-3200 BP)

Much evidence for Middle Archaic occupation of the RGNF has been found, the principal representatives being members of the McKean complex, which encompassed the period from 3600 to 3200 BP. Other point styles, simply referred to by their morphological characteristics, i.e. stemmed indented base, large side notch, stemmed square base, also represented this period.

LATE ARCHAIC (3200-1500 BP)

The most commonly used point style in the RGNF was the large corner notched type. Although Nickens (1979:55) indicated a temporal span of almost 7000 years for this style, Shafer (1978:16) restricted it further to the Late Archaic. If Shafer was right, this period was by far the best represented in the chronology, but considering the utility of large points as spear points, a longer period of use than 1700 years seems reasonable. Additional representatives of the Late Archaic include contracting stem points (Nickens 1979:55).

LATE PREHISTORIC (1500 BP to Historic times)

The RGNF saw heavier utilization during the Late Prehistoric period than the previous periods with the possible exception of the Late Archaic. A reason for the high representation during the Late Prehistoric was the presence of Ute Indians, who frequented the SLV after their arrival in southern Colorado. The Utes of southern Colorado lived in three bands, only one of which visited the Valley regularly. The Capote band hunted in the Valley, while the Wiminuche and Moache bands remained as peripheral Valley occupants (Schroeder 1965:54). Ute presence in the SLV is well documented in both archaeological records (Hurst 1939; Boyd 1940; Huscher and Huscher 1943; Hamilton 1974) and ethnohistorical sources (Schroeder 1965; Bean 1964) and their dominance of the area would seem to explain the better representation of Late Prehistoric material.

Some of the supposed Ute material may actually have come from nomadic Plains tribes such as the Arapahoes, Comanches, Apaches, Cheyennes, Sioux or Kiowas who also visited the SLV in search of game (Wilson 1971:16). Several aspects of Plains Indian tool assemblages were similar to Ute assemblages and this overlap has caused some confusion as to the exact source of the materials (Beardsley 1976: 63).

Considerable evidence of Pueblo contact with people of the SLV during the Late Prehistoric also exists. Evidence includes artifacts found near Saguache (Hurst 1939) and occurrences of Pueblo pottery found southeast of Alamosa (Bandelier Black-on-grey dated to between 1395 and 1500 AD; Breternitz 1966:70 in Nickens 1979:20), in the Dry Lakes area near the Great Sand Dunes along the Rio Grande (Pearsall 1939:9) and near Rock Creek at the foot of the San Juan Mountains (Wilson 1971:15). Other ceramics have been found at various locations in the SLV and RGNF but their cultural affiliations remain conjectural (Hurst 1939; Nickens 1973; Irwin-Williams and Irwin 1966:214; Beardsley 1976).

This, then, outlines the major cultural and chronological divisions represented in the archaeological record of the RGNF and SLV. Most of the divisions were established by the 1960s from survey and evaluative work done in the area up to that time. Subsequent work in the RGNF and SLV has served to reinforce rather than contradict these early findings. Although reinforced, the chronology has not been substantially refined, and, currently, archaeologists utilize available information as a guide for more recent finds.

RECENT ARCHAEOLOGICAL WORK

Recent archaeological work in the RGNF and SLV has been of a different nature than the older work. Rather than simply report on the findings, the thrust has changed, and researchers have concentrated more on proposals for mitigation of impact on sites. This is both a sign of our changing times and a move of necessity, for many of the sites will soon be lost to construction activities if not attended to.

The basis for much of the new work in the RGNF was the establishment of an in-house Forest Service capability which began in 1975 with the hiring of archaeological technicians to survey areas of proposed impact. The program was implemented to comply more effectively with several pieces of historic preservation legislation including: The Antiquities Act of 1906, The Historic Sites Act of 1935, The Reservoir Salvage Act of 1960, The National Historic Preservation Act of 1966, The National Environmental Policy Act of 1969, Executive Order 11593 and The Historical Conservation Act of 1974. Additionally, Colorado legislation including The Colorado Antiquities Act of 1973 and The Colorado Land Use Act of 1974 has been fulfilled by these surveys (Beardsley 1976:57).

Typically, survey areas in the forest were designated by the Forest Service and included timber sales ranging from 500 to 10,000 acres. Other survey areas included road rights of way, recreation area improvement, land exchanges, etc. From 1975 until the end of 1978, when the first evaluative work was begun on the collected material, 133 prehistoric and historic sites were recorded. Of these, 107 were prehistoric or proto-historic aboriginal (Nickens 1979:7), the latter term encompassing Late Prehistoric material deposited after white contact.

In 1978, a contract was awarded to Centuries Research for the purpose of evaluating the significance of the 133 sites recorded to that time. Under the terms of the contract, sites were to be placed in one of three categories according to their perceived significance. These categories were: I. Sites needing no further action, II. Sites qualifying for nomination to the National Register and III. Sites needing additional exploration (Nickens 1979:10). Under specifications of the contract, all but one of the 107 sites was placed in category III. This single site, a wickiup, possibly of Ute origin, was determined as meeting the criteria for nomination to the National Register. Nine sites were recommended for further testing and final disposition of the remaining 97 sites remains unresolved.

The typological evaluation Centuries completed on diagnostic projectile points provided much of the information on prehistoric occupation of the RGNF as discussed earlier. Some of the point styles examined were indicative of specific cultural episodes and defined forest utilization with a fair degree of accuracy. For example, points representative of the Small Point Tradition (Fenega 1953:317), or those weighing less than 3.5 grams, have been identified as arrow points that came into use around 500 AD. Based on that date, they were used for less than 1500 years. Other points, especially some members of the Large Point Tradition (p. 318), consisting of points weighing more than 3.5 grams, present more of an enigma. Large points were used with the atl-atl and spear, whose combined span of use covered over 10,000 years. Given the present state of knowledge concerning the use of some styles of large points, the styles may have been introduced at almost any time during that span of years. Large points are, therefore, difficult to assign temporally.

As an ancillary study, Nickens had obsidian hydration analysis done on 10 flakes, and found that the oldest specimen was 7.8 times older than the youngest (Nickens 1979:45). This finding was based on the Relative Age Factor (RAF), which was derived as the direct proportion of the hydration depth, in microns squared (μm^2), to the squared hydration depth of the artifact with the least hydration. Nickens' results cannot be considered as accurate representations of age, however, because no chemical characterization was done to determine similarity of chemical composition. Relative percentages of certain elements in obsidian are critical to the rate of hydration and unless two artifacts can be shown to possess the same percentages of these elements, they cannot be accurately compared. Perhaps owing to the knowledge of that fact, no attempt was made to correlate the relative ages with diagnostic artifacts, although three of the samples were found in association with diagnostics.

During Forest Service sponsored surveys since the contract was awarded, technicians recorded an additional 50 prehistoric sites and 36 prehistoric isolated finds (Burns and Spero 1979; Spero and Mruzik-Doering 1980). Initial typologies were completed for this subsequent collection but additional evaluative work has yet to be completed.

Several other archaeological projects contracted to outside organizations have been completed within forest boundaries. The largest of these was the 1978 survey and evaluation of sites along Highway 160 on the east side of Wolf Creek Pass (Shafer 1978). During this project, 24 prehistoric sites and 27 isolated finds were recorded. Of these sites, three were determined as meeting criteria for nomination to the National Register and one needed additional testing to determine its disposition. The remainder were deemed insignificant. As part of the evaluation, several obsidian samples were subjected to hydration analysis. As was the case with Nickens' study, no chemical analysis of the obsidian was completed so, once again, results were inconclusive.

In addition to these projects done in the forest, several other projects were completed in the RGNF and SLV that reinforced the existing chronology without adding appreciably to a more detailed understanding of the regional archaeology (Van Elsacker 1972; Dick 1975, 1976; Martin and Bell 1976; Jones 1977; Spero 1978; Gooding and Kreuser 1980).

CHAPTER III

PROBLEM

The major problem confronting further elaboration of the archaeological record of the Rio Grande National Forest has been touched on briefly. The chronology, although established, is based on typological evidence from surrounding regions and in some aspects is unnecessarily broad. If the San Juan Mountains are indeed a separate and peripheral cultural area, as they are treated in the literature, they need a chronology based on local archaeology, not the archaeology of other cultural areas. To establish such a chronology requires the use of a dating technique independent of typological considerations; a technique specific to the region.

To date, independent techniques have been used sparingly and incompletely. Shafer, in her 1978 study, had obsidian hydration analysis done on several artifacts from a limited area of the forest and provided relative age estimates for only a few sites. Nickens, in his 1979 evaluation, also had hydration analysis completed on several artifacts, but again, the relative age estimates were of little use.

The reason for the lack of utility of these studies is twofold. First, both studies represent too small a sample to be of value toward the establishment of a working relative chronology. Even when combined, they contribute little since a major fault exists with both analyses. This fault, being the second reason, lies with the fact that the analyses were not carried through to completion. The hydration rim was simply measured and the comparison between rims was used to establish relative ages of the artifacts.

Without knowledge that two given pieces of obsidian are chemically similar, their hydration rims cannot be validly compared. Obsidian of different chemical composition hydrates at different rates and to compare hydration on obsidian samples without first confirming chemical similarity is inappropriate.

The problem with the present typological sequence does not lie in its validity. It has been developed through examination of existing knowledge of the point styles represented in the collection and although broad in some respects, it accurately reflects current knowledge about those styles. What the present paper is concerned with is contributing more exact information to the chronology for the purpose of refining the sequence.

Large corner notched points epitomize the problem. According to the existing chronology, these points were utilized for almost 7000 years, much too long a time span to be of use to the researcher interested in more delimited periods of forest resource utilization. The popularity of large corner notched points in the procurement of game is evident by their relative abundance in the collection. They comprise 45% of the total collection of points collected from the RGNF. It may well be that the makers of these points visited the area periodically throughout the time span suggested. It may also be that they came during a much more limited span of years. At present, no concrete evidence exists to substantiate either speculation.

The point styles indicative of long periods of utilization are of greatest concern because they give the most general information and need to have more exact temporal parameters placed around them. The presence of points that serve as horizon markers, like McKean complex, and small corner and side notches, do not pose a large problem since their periods of use have been determined with some precision. Knowledge of their temporal spans, in fact, may serve in solving the problem of the general cultural sequence suggested by more imprecisely dated styles. For example, if a number of large corner notched points can be shown to have been introduced at approximately the same time as a more temporally defined type, the temporal presence of those large corner notches will become more meaningful. More specific knowledge of the introduction of certain point styles could prove very beneficial in formation of a more complete picture of the cultural processes at work in the RGNF. Through more thorough research, it is hoped to generate information necessary to fill existing gaps in knowledge about ambiguous placement of point styles and produce a more substantive data base on which to evaluate the chronology of the RGNF.

CHAPTER IV

RESEARCH DESIGN

The solution to the problem just described lies in the application of dating techniques that operate independently of typological information to evaluate the chronology. The choice of methods is extremely limited in this case. No known hearths occur with the artifacts for obtaining archaeomagnetic dates, no decaying organic material to date by C-14 is known, no wood for tree-ring dates is associated with diagnostics, and only a few sites exist with diagnostic pot sherds. In short, only the artifacts themselves provide evidence of when prehistoric visitors used the forest.

The San Juan Mountains, as mentioned earlier, are of volcanic origin, as are several other ranges in the Southwest. One product of vulcanism is obsidian, a natural glass long used by the Indians whose natural ability to absorb water makes it a valuable tool in dating. As a consequence of the proximity of the RGNF to volcanic areas, obsidian is a common tool material in the area, providing the potential for obsidian hydration dating. It is proposed then, to use obsidian hydration dating in the attempt to refine the RGNF chronology.

After determining a general course of action, a cooperative agreement is to be prepared between the Forest Service and CSU (Appendix A) and under its terms, the necessary artifacts removed from curation for analysis at CSU (Appendix B). Not only is cooperation from the Forest Service essential, but research plans are contingent on the availability of lab facilities to conduct the necessary analysis.

The artifacts to be used for analysis are a portion of those found during surveys conducted in the RGNF between 1975 and 1979. Since the research deals with cultural chronology and obsidian hydration dating, only diagnostic projectile points and non-diagnostic obsidian artifacts found in association with diagnostics are useful. Those without diagnostic association cannot contribute useful information since they imply no temporal or cultural position.

Of the 298 potentially usable artifacts, 122 or 40.9% are made of obsidian. All those found suitable will undergo obsidian hydration analysis and chemical fingerprinting. The results should contribute to a workable relative chronology to compare future artifacts for a more accurate interpretation of forest occupation and resource utilization.

HYDRATION THEORY

The utility of volcanic glass as a datable material lies in the fact that as part of the natural weathering process, it absorbs atmospheric water (hydration) at a measurable rate. With a known rate, the amount of hydration will tell how long the present surface has been exposed. At formation, obsidian normally contains 0.1 to 0.3% water, but as it absorbs water, it undergoes a mineralogical transformation, evolving into perlite, the hydrated form of obsidian, now containing 3.5% water, or about ten times the original amount (Friedman and Smith 1960:482).

The hydration process begins at the surface of a freshly fractured piece of obsidian and as the unaltered obsidian evolves into perlite, the change becomes microscopically visible when the layer reaches about .5 micron (μm) in depth. Given suitable environmental conditions, this can take as little as 30 years (p. 491). The hydration can be distinguished by the presence of a sharply contrasted interface between the hydrated and nonhydrated layers. The reason for the sharp distinction is due to strain birefringence (the power of double refraction) which is the result of the combined effects of a higher refractive index caused by increased density and a mechanical strain on the hydrated portion due to the added volume of water (Michels and Bebrich 1971:174; Tite 1972:157). At this depth, measurement of the advancing perlite is possible in microns, thus forming the basis for the dating technique. It is highly accurate and under ideal conditions measurement error can be kept to ± 1 μm, or about ± 10% of the true calendar date (Friedman and Long 1976:347). Not only is the hydration visible under white light, but under polarized light as well. Here, the birefringence causes the rim to stand out as a luminous white band against a black background. This feature allows the researcher to confirm the presence of hydration (Friedman and Trembour 1978:45).

Accuracy in measuring the hydration rim is best under the relatively low magnification of a light microscope. When viewed under an electron microscope, there is no sharp distinction at the interface. Instead, the true nature of the hydration is revealed as a series of parallel fractures extending from the surface into the body of the artifact. They appear irregular in length so the identification of a distinct layer of hydration is impossible. Inherent qualities of the light microscope give it an advantage to the researcher in this case (Michels and Bebrich 1971:176).

The zone of hydration was noted as early as 1877 by T. G. Bonney, a scientist working with volcanic glasses. At the time, however, he had no idea of what caused the effect (Kimberlin 1976:63). In time, research revealed that the phenomenon was caused by stress from the bonding of water to the obsidian. The underlying principles behind hydration were worked out by the late 1950s, and the early 1960s brought hope that the rate of hydration may provide the basis for a new method of chronometric dating. After preliminary research, the extent of microenvironmental influence on hydration rates was realized and the hopes for an independent absolute dating technique were dealt a severe blow. The effects of the immediate environment were found to be too great for absolute dates to be calculated on just general climatic information. Even lacking the necessary data for deriving absolute dates, however, obsidian hydration was still used successfully to derive relative estimates of age (Michels and Bebrich 1971:167).

The lack of all necessary data allows only relative dates to be attained with the present research problem as well. General climatic information from several locations around the SLV is available for the past 40 years, but is of little help in determining prehistoric microenvironmental conditions. Even the establishment of a relative chronology, however, would prove useful in the comparisons of sites and assemblages exhibiting similar attributes.

ADVANTAGES OF OBSIDIAN DATING

Obsidian dating has several advantages over other available techniques. First, it is largely a nondestructive technique. All that is required for analysis is the removal of a small section from the edge of the specimen. Contrast this to C-14 which requires between 25 - 300 grams of material for accurate dating.

Secondly, because it is the flaked surface of the artifact that is being dated, the date obtained is that of a cultural event: the actual manufacture and use of a tool. This advantage contrasts with dendrochronology which dates a natural event: the death of a tree, and provides only circumstantial evidence of the cultural use of the tree (Bannister and Smiley 1955).

Third, it is theoretically possible through obsidian dating to identify successive periods of artifact reuse. Since hydration begins anew with exposure of a fresh surface, subsequent reshaping should be evident by the existence of a smaller rim in addition to the original (if a portion of the original rim is still intact). In comparison, consider archaeomagnetism, which dates the last time a hearth was fired, an event which erases evidence of previous firings. This same feature makes obsidian conducive to fracture analysis. An artifact (point) may have broken at the time of use due to impact with an animal or other immovable object. Measurements taken on both the broken and flaked surfaces should be similar if this is the case. A shallower rim on the broken edge would indicate a later breakage, the cause of which could stem from a number of reasons.

Fourth, time and cost are additional benefits of this technique. It is a very fast and inexpensive way to date artifacts. Proficiency comes quickly with practice and in a short time it is possible to prepare and measure several artifacts per hour. Cost is minimal compared to other methods. For the price of processing one C-14 sample, 50 or more obsidian samples can be examined (Michels and Bebrich 1971:167).

Fifth, since it is possible to get several dates from a site containing obsidian artifacts, the statistical probability of establishing an accurate mean date for that site becomes much greater. The range of rim widths obtained from a given single component site should be small since the environmental conditions at work on a site will have a similar effect on all obsidian present.

Sixth, obsidian dating provides a method for cross-checking the accuracy of other dating techniques. A typological chronology should be confirmed by successively deeper hydration rims on older artifacts.

On obsidian, hydration begins as soon as a fresh surface is exposed and continues until the strain becomes too great and the rim spalls off. The effect has been likened to peeling a layer of onion skin. Typically, obsidian will tolerate about 50μm of hydration before the pressure exceeds the bonding strength. This has little bearing on archaeological applications though since depending on the determining factors, spalling takes from 100,000 to .5 million years to occur (Michels and Bebrich 1971:175).

APPLICATIONS

To fully appreciate the advantages of hydration dating, a few examples will be helpful. Probably the most obvious application lies in the ability to establish a chronology of artifact types and tool kits by measurement and comparison of hydration rims. Deeper rims theoretically indicate older artifacts, and both vertical and horizontal stratigraphy can be established through comparison. Not only is the association of an artifact to a period of time possible but the duration and intensity of occupation can be determined as well (Robinson 1951:293; Brainerd 1951:301). Typological information can serve the same function but in its absence, hydration rims can be compared to determine the sequence. Chronological ordering is possible with mixed sites, midden deposits, surface finds (although tenuously) and in cases of otherwise unreliable stratigraphy through comparison of the hydration rims.

Once the sequence of a site or area is established, cultural processes at work there may also be revealed. A break in trading with a group that formerly provided obsidian may be seen by the appearance of a period of artifact reuse when formerly, artifacts were made from fresh material. The introduction of a new innovation or style in the tool kit can be temporally placed by measurement of hydration on the artifact(s) exhibiting the trait. Presence of such a trait could signal the opening of new trade relations or the influx of a new group of people (Michels 1967:214). Application of chemical fingerprinting mentioned previously could verify whether the idea is manifest in a physically intrusive artifact or simply a mimic of a neighboring style on local material. The relative percentages of elements present in obsidian are unique to particular volcanic sources or source locality complexes (Hurtado de Mendoza and Jester 1978). Knowledge of the chemical composition of the artifact as well as the composition of local and neighboring sources may allow correlation of the artifact with a particular source, thereby identifying the direction and area of influence. A more detailed discussion of the role of chemical composition will be given in another section of this paper.

OBSIDIAN AS A CHRONOMETRIC DATING TOOL

In the applications suggested above, the dating of artifacts implies merely a measurement of the hydration rim, while the requirements that must be met in order to develop the chronology are only mentioned in passing. The establishment of absolute dates, i.e., duration and intensity of site occupation, is of course a major objective of obsidian dating, but it requires that certain information be learned about the obsidian since hydration rates vary from less than one to over $20 \mu m^2/1000$ years (Friedman and Trembour 1978:47). With knowledge of the rate, accuracy is possible to within ± 10% of the true calendar date (Friedman and Long 1976:352).

Several formulas for determining rates have been proposed since Friedman and Long published their original dates in 1960. Based on experiments involving obsidian from six major temperature zones, Friedman and Long found that hydration proceeds according to the standard diffusion equation:

$$x^2 = kt \qquad (1)$$

where x = depth of hydration in microns, k = a constant for the hydration rate at a fixed temperature (estimated hydration temperature or EHT), and t = elapsed time in years (Friedman and Long 1976:347; Ambrose 1976:90; Friedman and Trembour 1978:46). It can be seen that the original findings propose an exponential rate of absorption where the hydration proceeds as the square root of time. In addition, Friedman and Long found two areas (Egypt and Mexico) where the two major types of obsidian used by man, trachytic and rhyolitic, hydrated at very different rates when exposed to the same climatic conditions. This discovery led to the knowledge of the role chemical composition plays in the hydration process (Friedman and Smith 1960:485; Michels and Bebrich 1971:167).

Although the standard rate has been found applicable to many situations (Friedman and Evans 1968:813), its use is by no means universal and hydration specialists debate the "right" formula. Refinement of the technique for more accurate derivation of absolute dates has been the subject of ongoing research since the time it was developed. Subsequent proposed rates have differed from the original in that rather than suggesting that the hydration depth is equal to the square root of time, as Friedman and his coauthors proposed (Friedman and Smith 1960; Friedman et al. 1966; Friedman and Long 1976), some researchers proposed a faster rate on the order of depth = time 1/3 or depth = time 3/4. Others proposed a linear rate with the depth of hydration directly proportional to the elapsed time. Possible causes of the divergence in rate determinations include the belief that research has involved studies of too short of duration in which the true exponential nature of the growth curve was not allowed to develop, while other opponents of the subsequent rates say the differences may be due to the use of obsidian with different chemical composition than was assumed (Friedman and Trembour 1978:46). The presence of conflicting rates serves to stress the importance of empirically determining a rate for each area under study.

Despite the added uncertainty, this subsequent research revealed the influence of the microenvironment in causing variation in the hydration rate for an area and the unsuitability of applying a rate to an area without first examining the variables at work there. Due to the complexity of the variables involved, it seems doubtful that a single constant rate can be derived. Obsidian dating may be forever doomed to dependence on other dating techniques for absolute age estimates.

VARIABLES IN RATE DETERMINATION

The disparity in hydration rates results from several variables. One of the most important begins with the initial formation of the glass. Obsidian is a complex combination of elements whose presence and quantity are a function of the chemical processes at work during the time of volcanic activity. Essentially, obsidian is an alumino-silicate, as is all glass, with aluminum and silicon comprising up to 80% of a typical sample (Griffin et al. 1969:2). The major elements (those over .01%) in the composition of rhyolitic obsidian include silicon (72-76%), aluminum (10-15%), sodium (3-5%), potassium (1-7%), calcium (1-3%), iron (1-3%), titanium (0-.5%), magnesium (0-.4%), hydrogen (.2-.9%), and manganese (0-.1%) (Michels and Bebrich 1971: 171; Ambrose 1976:83; Nelson et al. 1977:210; Michels 1980:3). In addition, more than two dozen minor and trace elements have been noted in varying amounts depending on the volcanic area and moment (Griffin et al. 1969:2). Most elements present in obsidian do not influence the rate but combinations of a few have been shown to almost completely determine the rate in some places. Conflicting data make it difficult to specify the ones that determine the rate (Griffin et al. 1969:2; Jack and Carmichael 1969:20; Tite 1972:310), but generally the major components have the most effect on the hydration process. Silicon (Si) especially, as well as sodium (Na) and potassium (K) tend to accelerate the rate; while water (H_2O), calcium (Ca), iron (Fe) and magnesium (Mg) retard it (Friedman and Long 1976:347; Ambrose 1976:83, Friedman and Trembour 1978:46). The reason for these effects lies in the energy required to induce the structural transfer of water. Na and K require much less energy than do Fe, Ca and Mg, and therefore allow faster transfer of water into the interior of the glass.

As water is absorbed, it becomes part of the chemical structure of obsidian and impedes the transfer of additional water molecules. The constant addition of water causes the rate to slow with time because existing water inhibits additional hydration. Thus the decaying exponential rate (Ambrose 1976:85; Friedman and Trembour 1978:46).

The necessity for determining the chemical composition of artifacts in chronological studies can be seen more clearly when one realizes the two objectives of chemical fingerprinting. The first objective is to aid in determination of the hydration rate, and for this, quantification of those major elements discussed above is necessary. These major elements are always present in obsidian and while their quantification is necessary for rate determination, knowledge of their relative amounts contributes only partial information toward the second goal, that of associating the artifact with other chemically similar artifacts and ultimately, with the flow source itself. Interflow variation of major elements is often minimal and knowledge of their presence alone is not sufficient to group artifacts. The importance of identifying minor and trace elements enters here. Although they do not contribute appreciably, if at all, to the hydration rate, the presence of these minor and trace elements in varying amounts will often serve to associate chemically similar artifacts or the artifact to its source. All minor and trace elements are not present in all flows, so the presence of even a single element, if unique enough, can be used to differentiate between flow sources.

A second major variable in the hydration rate involves the effect of temperature, with higher temperatures having been found to appreciably accelerate the rate (Tite 1972:155). For example, obsidian in tropical regions may hydrate up to $20\mu m^2$/1000 years as compared to $1\mu m^2$/1000 years in Arctic regions (Friedman and Trembour 1978:47). In general, the rate decreases with northward location. The speed at which obsidian hydrates in warmer climates makes measurement and interpretation easier than in the Arctic since rims grow faster there (Meighan et al. 1968:1072).

The key to finding a rate for a region is to solve the hydration equation (1) for the temperature constant "k". Several variables influence this component alone, temperature and chemical composition again, being two of the major ones. Friedman et al. (1966) determined under controlled conditions that the relation is best expressed by the Arrhenius equation:

$$k=Ae^{E/RT} \tag{2}$$

where k = diffusion rate at temperature "T", A = a constant based on chemical properties, e = 2.71828 (the base of natural logarithms), E = activation in kcal/mole, R = 1.987 cal/mole/°K (the universal gas constant) and T = the effective hydration temperature (EHT) (Michels and Bebrich 1976:179; Friedman 1976:173). Field research in the highlands of Equador provided different figures for A and E (Bell 1977). Rather than invalidating the equation, the highland Equador studies indicated the intricacies involved in the technique and served to stress the effect of chemical composition on the rate.

To further specify the effect of temperature, accuracy in rate determination depends on the calculation of the EHT (Ambrose 1976:91), a difficult task in some climatic zones. For tropical and Arctic environments, deriving the EHT is relatively easy because diurnal and seasonal temperature fluctuations are minimal and in many cases a single temperature can be used. For temperate areas, however, identification of the EHT is more difficult because of extreme seasonal temperature fluctuations. Variable temperature conditions lead to more burdensome derivation of the EHT since each variation must be considered in the calculation. The temperature pattern, especially the extremes, for each site's microenvironment must be identified to calculate the EHT. With such specific requirements, no across the board temperature data will apply toward rate determination (Minor 1977:67).

Another microenvironmental consideration, even for obsidian within a single temperature zone, is the depth of burial. A change in ground temperature of 1°C can change the rate by as much as 10% (Friedman and Long 1976:351; Friedman and Trembour 1978:47). When obsidian is buried below about 10 meters, hydration proceeds at a relatively slow and constant rate because effects from fluctuations in surface temperatures are negligible. In this case, a single temperature can be used to calculate the rate. At shallower depths, up to about .5 meter, diurnal temperature fluctuations are shielded but about a third of the seasonal variations penetrate, resulting in a faster and more variable rate (Friedman and Long 1976:348). Even this small variation necessitates calculation of the EHT by combining and averaging the seasonal variations rather than using a single figure.

At depths less than .5 meter, not only do the seasonal temperature variations increase but the daily fluctuations begin to play a role as well. In such cases the amount of data necessary to derive the Arrhenius equation makes finding a rate extremely difficult.

With surface finds, additional factors must be considered. Effects of direct solar heating, a factor seriously affecting the rate, must be added. Dates derived from surface finds have always been considered tenuous (Trembour 1980:personal communication), a fact largely due to direct solar radiation. Obsidian is generally formed of dark colors which, because they absorb and retain heat, tend to hydrate faster. Thus, surface finds, especially, are subject to inflated readings, possibly up to five times the normal rate (Friedman 1976:178). This is true especially in desert and mountain regions where insolation is most intense. This factor is difficult to control when measuring the hydration rim. The EHT is also more difficult to calculate, if not impossible, since the artifact is affected directly by temperature changes. In large climatically homogeneous areas it may be possible to assume that all surface finds have been exposed to the same conditions and therefore can be treated the same vis-à-vis each other, but results should still be considered tenuous because of other factors.

Frost heaving, rodent activity and other forms of mixing further complicate the treatment of surface finds. Unless a site is excavated and found to have little or no depth, it is difficult to speculate on how long a particular artifact has lain on the surface. This is especially true with isolated finds. Jim Benedict has spent a considerable amount of time studying periglacial geologic processes in mountainous regions and found that mixing is indeed a problem on archaeological sites there (Benedict and Olsen 1978:94). The presence of vegetation providing shade for an artifact lying on the surface will slow the rate by shielding the direct rays of the sun, introducing yet aunother unknown factor to the hydration rate. Comparison on an equal basis becomes still more difficult since the length of time the artifact has been shaded cannot be determined.

At first, differences in the rates were also thought to be due in part to differences in relative humidity. This was proved false, however, when obsidian from relatively dry caves was found to have hydrated at much the same rate as obsidian from more humid areas of the same temperature zone. The hydration process is so slow that as long as enough atmospheric water exists to keep the surface saturated, hydration will proceed at a normal rate (Tite 1972:155). Conversely, high humidity, even total immersion in water does not increase the rate since diffusion is time dependent and cannot proceed faster than the other factors allow (Michels and Bebrich 1971:181).

Accurate obsidian dating, then, involves detailed knowledge of internal characteristics of the obsidian as well as environmental conditions that have acted upon it to influence the hydration process. With this in mind, it must be noted that the seven rates proposed by Friedman and Smith (1960:492) cannot be used for even similar regions and should be seen as simply a demonstration of variability due to both internal and external factors.

For the various reasons discussed above, it should be clear that establishing absolute dates for the RGNF material will be impossible through the obsidian hydration method. Lack of temperature data is the most critical factor. It was found that the mean annual temperature for the years 1941 to 1975 atop 10,800 ft Wolf Creek Pass was 40.7°F (National Weather Service 1980:personal communication). This is the closest approximation of a constant figure for the RGNF, but cannot be applied to the artifacts in the RGNF collection because the artifacts were found in disparate terrain with differing climatic trends and up to 70 miles from the Wolf Creek station.

No other data to further specify the microenvironmental conditions exists. This fact, then, precludes use of the formulas given for rate calculation. The potential error involved is too great to allow this to be done.

Despite the absence of some of the critical information just discussed, some controls over estimating the hydration rate do exist. All these controls are dependent on other chronometric scales if one exists for the collection. In the absence of an independent chronometric scale, it is still possible to roughly estimate a rate by correlation with typologically similar data (Michels and Bebrich 1971:183-188).

Unfortunately, these "backup methods" are not applicable to the RGNF, where the major reason for attempting obsidian hydration analysis is the lack of other suitable chronometric methods. The final method mentioned, that of correlating the hydration with typological information, may be used, but to do so involves circular reasoning since it is ultimately the lithic chronology in question. The hydration information should be used to refine the chronology rather than use of the chronology to verify the hydration. Lacking the information necessary to calculate a hydration rate, it should still be possible to specify the chemical composition of the obsidian artifacts and assign relative dates to them.

CHEMICAL FINGERPRINTING

Fortunately, chemical composition is one area over which some control exists. Determination of the composition involves the application of a chemical fingerprinting technique, a method to identify the elemental structure of the sample. Several methods of chemical fingerprinting are available; X-ray fluorescence spectrometry (XRF) being the most accessible. This then is the method to be used in fingerprinting the artifacts to determine groups for direct comparison. The researcher needs to know that the obsidian being compared is chemically similar and therefore will react the same way to comparable environmental conditions.

In fingerprinting artifacts, it is necessary to operate under three assumptions. The first of these is that the sources in a given area of the world are confined to a limited number of volcanic flows, so fingerprinting should reveal a limited number of chemical combinations. The truth of this assumption can only be ascertained through analysis of the fingerprinting results. In addition, the outward distribution of material from the sources would be expected to diminish as the distance from the source increases. To demonstrate in more significant terms the heavier utilization of volcanic material in the southern end of the forest, which is closer to volcanic sources, a count was made by county of all artifacts (including flakes) recorded from the 1975 through 1979 field seasons. Table 2 shows the number of artifacts and flakes recorded in each county in south to north order of location in the forest. The low number of artifacts in Alamosa County is a reflection of both few projects in the area and the presence of steeper and more heavily timbered terrain.

Table 2. Breakdown of Artifact Material by County

County	Basalt	Obsidian	Other Material	Total
Conejos	1684	1035	3286	6005
Alamosa	0	0	5	5
Rio Grande	925	87	1426	2438
Mineral	20	7	244	271
Hinsdale	34	33	485	552
Saguache	135	140	4145	4420
Totals	2798	1302	9591	13691

It is suggested that the amount of volcanic material in Conejos and Rio Grande Counties is a reflection of their proximity to volcanic sources and the localized use of that material. Both of the latter counties either contain or are located very near to a volcanic source.

The second assumption is that since obsidian is formed from a molten state, the chemical composition should be relatively homogeneous throughout the flow (Tite 1972:309; Nelson et al. 1977:210). This assumption holds true for the most part but some exceptions are to be expected, especially within a widespread formation. Tests on chemical composition at widely separated portions of a single flow have shown considerable differences in the quantity of elements present (Asaro et al. 1978:436; Leudtke 1979:746). This intraflow variation has limited researchers to restrict statements of association between samples or between a sample and an assumed parent flow to a degree of statistical probability of the presence of selected elements (Leudtke 1979:747).

The third assumption is that each volcanic moment creates a unique combination of elements and each flow should be chemically distinct from all others. In a 1978 study, Hurtado de Mendoza and Jester found this assumption not to be as definite a statement as it appears. A regional analysis of artifact obsidian in Guatemala revealed that geologic processes may produce chemically similar obsidian at separate but nearby locations, so similarities may not be as indicative of a single location as previously believed. They called the associated extrusions "source locality complexes" in recognition of the chemical similarities.

In order to operate most comfortably under the three assumptions just presented, quantification of as many elements of the flow as possible is necessary, especially the minor and trace elements. Kowledge of several elements will decrease the chance of overlap or exclusion of elements that may be characteristic of an individual flow. Considering the implications of the last two assumptions, it should be pointed out that research has shown that differences in chemical composition between flows or locality complexes tends to be greater than the differences within flows or locality complexes (Michels and Bebrich 1971:165).

Matching an artifact to its source through chemical fingerprinting then is not as simple as matching a fingerprint to a person. Elemental variations within the source prohibit matching with certainty. Through quantification of as many elements as possible, the identification of artifacts from common sources should be possible.

Color is sometimes used to judge the origin of obsidian but use of color alone can be misleading because of extreme variation even within a single flow. Obsidian from Obsidian Cliff in Yellowstone Park, for example, occurs in all color gradations from clear to black (Griffin et al. 1969:2). The variation in color may be indicative of different chemical composition but also may be due to different cooling rates in separated sections of the same flow (Michels and Bebrich 1971:173). Color difference, then, is not a reliable criterion for evaluation of similarity and associations made on the basis of color alone can be very misleading.

THEORETICAL CONSTRUCT OF X-RAY FLUORESCENCE

X-ray Fluorescence is a highly precise method of chemical finger-printing, able to detect elements in concentrations ranging from 100% to less than 0.1 ppm (Tite 1972:202). Through quantification of selected elements in an obsidian sample with an X-ray spectrometer, a chemical spectrum is formed that is unique to the sample being tested (Woldseth 1973:3.15). The more elements that are identified, the more precise the spectrum becomes, and a more characteristic spectrum leads to more accurate information on the number and character of the sources being dealt with. The more elements the researcher is able to identify, then, the better, especially when dealing with an unknown number of sources. Minor and trace elements, or those present in quantities less than .01%, tend to be more characteristic of a flow than major components so their identification is vital to producing reliable results.

In XRF spectrometry, the sample being analyzed is irradiated with primary X-rays, exciting the inner orbit electrons and displacing them from their orbits. Electrons from the outer orbits then fill the vacated inner orbits, and in doing so, emit characteristic secondary X-rays, or fluorescence. Each element fluoresces at a particular wavelength depending on the atomic number. These secondary X-rays are separated into their characteristic wavelengths and the intensity of each can be measured to provide an estimate of the concentration of that element within the sample (Tite 1972:267; Nelson et al. 1977:211; Fleming 1976:217).

ADVANTAGES AND LIMITATIONS

XRF chemical analysis has advantages over other techniques. One major advantage is that XRF is a fast and inexpensive way to obtain chemical information. Instruction in the use and programming of the spectrometer and basic theoretical constructs of the method can be given in about an hour's time. A second advantage is that XRF is a non-destructive method of analysis. Although powdering the sample to increase the surface area may result in a slightly more accurate reading, the increased accuracy is not worth destroying the sample.

When analyzing a complete sample, its condition is important to obtaining accurate information. A regular surface should be exposed to the X-rays because the equipment is calibrated to detect flat surfaces and a difference of even .5 mm between high and low points on the surface of an artifact can reduce the accuracy by as much as 45%. This reduction is due to the short distance covered by the low level radiation. The normal range of X-ray penetration into the body of a sample is between 50 - 100 μm. The depth of penetration can vary, however, from more than 200 μm to as little as 20 μm depending on the density of the chemical structure. X-rays are strongly absorbed by matter so the denser the material, the shallower will be the depth of penetration (Tite 1972:270). This essentially surfacial exploration of the artifact dictates that care should be taken to prepare as clean a surface as possible for irradiation. The detection of remnant paint or ink from artifact identification labels can throw the reading off considerably.

Air as well as dense material absorbs the X-rays. To increase the chance of optimum readings, the sample should cover the entire width of the primary X-ray beam, which is about 1 cm in diameter. Samples smaller than this may show less of the selected elements since the beam will be larger than the surface exposed to it (Tite 1972:271).

The X-ray absorbing property of air means that the accuracy of XRF can decrease by as much as 20% with each successive decrease in atomic number below that of the radioactive source. The loss of accuracy is due to the increased lengths of the wavelengths emitted by elements at this lower end of the chemical spectrum.

The use of an analogy will best serve to describe the increasing loss of accuracy. Consider each decreasing element in the Periodic Table as a lower note in a musical scale. For each lower note, a complete cycle, consisting of a peak and a valley, takes longer to pass a given point. When the sample is bombarded with primary X-rays, displacing the electrons from their orbits, it takes progressively longer for each lower element to reestablish its position in the elemental structure. The characteristic secondary X-rays, or fluorescence, produced by each element while their component electrons move back into the inner orbits, may be likened to the musical notes. Lower elements are detected less than higher ones because the wavelength cycles of the lower elements travel at a slower rate and are not detected as quickly as the higher ones.

The loss of accuracy is most pronounced in the quantification of elements with atomic numbers below 19, that of potassium (Peterman 1980:personal communication). When attempting to read elements with atomic numbers below 19, the readings tend to be obscured by the low level background radiation. Elements below potassium in the Periodic Table can be quantified but the use of a special vacuum or helium filled spectrometer is required. Even then, identification is only possible for elements down to magnesium, with an atomic number of 12 (Tite 1972:271).

Identification of as many elements as possible is important because the ratio of two or more may vary so as to be diagnostic of individual flows. One ratio that is often used and in some areas has become a standard for trace element analysis is that of rubidium (Rb):strontium (Sr) (Peterman 1980:personal communication). A third element, zirconium (Zr) is sometimes added to these (Jack and Carmichael 1969:20). Other ratios that have provided significant enough differences to identify individual sources include: Mn:Ba:K, Ma:Mn, Ba:Zr, and Fe:Ba:Mn (Griffin et al. 1969:2; Tite 1972:310; Stross et al. 1977:116; Nelson et al. 1977:241). Jack and Carmichael (1969) expanded on the idea of ratios and provided a useful nine element comparison by correlating the combined ratios of three groups of three elements: Sr,Ba,Y:Zr,Ti,Nb:Rb,Mn,Pb. Although the above ratios provide proof of the possibility of successful fingerprinting based on a limited number of elements, it is best when dealing with an unknown number of sources to quantify as many elements as possible because of the possible problems with overlapping chemical compositions and conflicting results as discussed earlier. In addition, a priori assumptions of significant elements should not be made without prior knowledge of the geologic history of the area.

DETERMINATION OF SOURCE CLUSTERS

After gathering all necessary data concerning hydration depth and chemical composition, computer aided cluster analysis was used to evaluate the chemical information and establish groups of artifacts based on the similarities.

CHAPTER V

METHODOLOGY

ARTIFACT PHOTOGRAPHY

Obsidian hydration analysis, although largely a non-destructive method of dating, does require removal of a small section from each artifact to be studied. To preserve their integrity for future reference, the artifacts of this study were photographed prior to analysis. The numbering system used for cataloging consisted of the roll number and the photo number as indicated by the negative. For example, photo 1-5 refers to the fifth frame of the first roll. The photo record can be found in Appendix C.

HYDRATION ANALYSIS

Preparation of the obsidian samples for hydration analysis involved several steps, the first being the removal of a small piece from the edge of each artifact for preparation of a thin section. This was done by making two parallel cuts about 2mm apart and 4mm deep into the edge of each artifact with a water-cooled geologic saw. The chip broken out was large enough to handle easily with tweezers and possessed an edge with enough hydration along it to provide an accurate measurement. When making the cuts, it was important to stay within 10° of a 90° angle to the edge of the artifact. Angles beyond this can produce an indistinct or fuzzy image whose measurement, if possible at all, may be too distorted to be of any use.

Careful consideration was given to the placement of the cuts. In order to maximize the number of hydrated surfaces available for measurement on broken artifacts, the sections were removed from the broken edge so the rim on that surface as well as that on the flaked surface could be measured. The purpose of this was to tell if the artifact, especially a projectile point, was broken on impact or at a later date. Fracture analysis isn't included in the present thesis but the data is now available for a future study.

With the cuts completed and the resultant chip removed from the body of the artifact, the chips were in turn mounted on glass microscope slides that had been etched with the respective artifact number to prevent mixing. Mounting was done by placing a small piece of Canada balsam on the slide and melting it by placing the slide with the balsam on a hot plate. A temperature setting of 100° F was sufficient to liquify the balsam quickly. The chip was then placed in the melted balsam and pressed down with a blunt pencil tip until contact was made between the chip and the slide. This ensured a solid mount to prevent the chip from being pulled away during grinding.

GRINDING

The balsam generally took 3-4 minutes to harden, allowing time to complete the step on the other chips being prepared at the same time. For expediency, at least six slides were prepared together. Once hardened, and with the chip securely in place, grinding was begun. Two calibrated holders were used in turn to hold each slide during grinding. With the slide mounted in the first holder, each sample was ground to .015 in on a steel lap wheel rotating at 125 rpm.

Water mixed with 9.5μm aluminum silicate grit was used as an abrasive to speed the process. The application of light to moderate pressure while moving the holder clockwise against the counterclockwise motion of the wheel also speeded the grinding.

After reaching .015 in, a pencil mark made on the ground side identified it as being completed. The slide was then reheated, melting the balsam, and the chip turned over and reset for grinding of the other side. This proceeded in the manner just described by using the second holder, calibrated to .003 in. The result was a chip of uniform thickness with hydration on two edges, or three if the chip was removed from a broken edge of the artifact. At this thickness, even the darkest obsidian became transluscent and the hydration rim was visible under magnification.

As the final step in the preparation of the thin section, another piece of balsam was melted atop the chip, and a cover slip applied to protect the chip and hold it in place.

Eighteen of the original 122 obsidian artifacts were deemed unacceptable for mounting and measurement. Four of these were too small to remove a workable size chip from the edge without shattering the artifact. Two of the four were small projectile points; 5CN17-107, small corner notch and 5CN125-01, expanding stem, whose hydration rims certainly would have contributed useful information. The other two were flakes, associated with diagnostic artifacts but too small to cut. The remaining 14 were neither diagnostic nor associated with a diagnostic. Measurement of the hydration rim on these would not have contributed useful information to the study so they were excluded from this step. All artifacts and flakes were fingerprinted however since fingerprinting is independent of hydration and none were smaller than the minimum size required for this analysis. For more detailed explanations of laboratory procedures see Michels and Bebrich (1971: 202-208) and Friedman and Smith (1960:478).

MEASUREMENT OF HYDRATION RIMS

To expedite the analysis, thin sections for all artifacts were prepared before beginning actual measurements. Measurements were done with a polarizing binocular microscope equipped with a 10x Vickers image splitting eyepiece and calibrated readout drum. Using white light under 10x magnification, the edge of the artifact was located. Upon location, the polarized light was switched on to confirm the presence of a hydration rim. As explained earlier, strain birefringence is seen as a luminous band under the polarized light. It can be distinguished from other similar looking phenomena by rotating the microscope platform 45° in either direction. Hydration alternately appears and disappears (lightens and darkens) with each 45° of rotation. Contrast this with remnant paint or ink on the artifact which, although similar to hydration in appearance, remains visible while rotating the platform.

After confirmation of hydration, the white light was again used and magnification increased to 40x to locate a portion of the edge suitable for measurement. Attention to two points increases the chance for an accurate measurement at this stage. The first, and a requisite, is the presence of distinct parallel lines marking the advancing hydration and the edge of the artifact. If no inner boundary exists, the sample was either prepared improperly or the artifact has insufficient hydration, and cannot be analyzed. A second feature, not a requisite but helpful, is the presence of a small impurity or inclusion on or near the inner boundary of hydration. Such an impurity, usually on the order of one micron in diameter, provides an excellent reference point to observe the movement of the images during measurement.

When a suitable point along the edge was located for measurement, the function of the microscope was switched from the binocular to the image-splitting eyepiece. Refocusing now assured definition of a sharp inner boundary line and the inclusion(s) that had been chosen for observation.

Operation of the Vickers eyepiece is based on a calibrated dial mounted on the side of the eyepiece. With the scale set to zero shear, a single image is seen when looking through the eyepiece. Turning the dial causes the image to separate so two images can be seen, one remaining stationary while the other image moves across the stationary one perpendicular to the edge of the specimen. When the reference point on the inner boundary aligns with the outside edge, or in the same place relative to the edge as in the original observation, the width of hydration has been traversed and the value can be read off the scale.

This procedure was repeated at least three times on each of three points of measurement for a minimum of nine measurements on each hydrated edge of the specimen. The resultant values for each point were averaged to achieve one value for each edge. The final averaged value was multiplied by the conversion factor of .145 to determine the depth of hydration in microns.

Several factors can contribute to possible error during measurement, including the resolution power of the microscope, precision of the eyepiece used in measurement, observer error, and variability in hydration depth within a single specimen (Minor 1977:616). The first two factors are of course beyond the control of the researcher, but consistent results are possible if the same instrument is used throughout the experiment. Tests have shown the Vickers image splitting eyepiece to be accurate to within 0.01 μm (Michels and Bebrich 1971:213) so precision of the optics is not a major consideration. The latter two factors can be controlled to a certain extent through care in sample preparation, choice in measurement locations and again, consistency in measurement. Studies into observer error have revealed that the extent to which an individual researcher will vary in making measurements is also of minor consequence (Michels 1967:213).

CHEMICAL FINGERPRINTING

The importance of quantifying as many elements influencing the hydration rate as possible was detailed in the previous chapter. Knowledge of the hydration depth alone is not sufficient to chronologically order a collection of artifacts. Even to establish relative dates, comparison of artifacts without first determining whether they are of similar chemical composition is a misapplication of the dating technique.

Chemical composition was determined through X-ray fluorescence spectrometry using radioactive silver (atomic number 48) as the source material. Each sample was irradiated for 200 seconds, a standard amount of time which allows enough exposure to detect even minute quantities of all elements selected for analysis.

The elements tested were: Gallium (Ga, atomic number 31), Zinc (Zn, 30), Potassium (K, 19), Calcium (Ca, 20), Iron (Fe, 26), Rubidium (Rb, 37), Strontium (Sr, 38), Yttrium (Y, 39), Zirconium (Zr, 40), Niobium (Nb, 41), Scandium (Sc, 21), Manganese (Mn, 25), Lead (Pb, 82), and Titanium (Ti, 22). A quick inspection of these reveals that only five are major components (K, Ca, Fe, Mn, Ti) and of these only three (K, Ca, Fe) are believed to influence the hydration rate.

The choice of elements was limited by the detection limits of the silver source. Efforts could have been made to quantify other elements critical to the hydration process but since the establishment of a hydration rate was impossible without more accurate temperature data, the trace elements selected for analysis were felt to be sufficient to discriminate between sources, which was the goal of the fingerprinting.

In order to measure the amounts of the selected elements, the spectrometer was programmed to count the frequency of occurrence of each element within a 9-channel wide "window," spanning a range of 320 kiloelectronvolts (Kev). Each element emits a characteristic peak of energy in the spectrum when its constituent electrons are excited and the replacement process takes place. This peak can be isolated and a window formed around it by calling a series of programs in the spectrometer. The first of these is the Marker program which locates on the viewing screen the primary peak, and the secondary peak as well if one exists for the desired element. The Window Select program is then called to form a window around the peak(s) for the element and lock it into the spectrometer. This was completed for each of the 14 elements and the background radiation level. Since XRF analysis does not provide absolute values for the elements, a window must be inserted to measure the Compton's, or backscatter peak. This peak is formed by the combined frequencies of all elements with atomic numbers below that of the (silver) source, including the source material itself. Due to the immensity of this peak in relation to the others, only a 5 channel wide window spanning 178 Kev is required.

It is only necessary to enter the elements once since the spectrometer retains the information until reprogrammed. The Link program, which begins exposure to the radioactive source in order to quantify the elements however, must be initiated for each sample analyzed.

Once implemented, the program is automatic. The program terminates at the end of 200 seconds and a printout is provided giving the results of the reading (Figure 2). The artifact number appears as the first piece of information on the output. This can be typed across the top of the sheet before the Link program terminates. Below that, the date appears. The date can be entered through use of a separate code when programming the spectrometer. Results of the fingerprinting are then provided in two forms, the first a listing, in numerically ascending order of window location according to Kev, of the observed frequency of the element contained within each window. Below the frequency counts is a second list,

```
5CN17-124
11-26-80        00
      200 SEC                              446 INT
0      EV  -  0      EV          0              INT
3120   EV  -  3440   EV          866            INT
3520   EV  -  3840   EV          464            INT
3920   EV  -  4240   EV          261            INT
4320   EV  -  4640   EV          338            INT
5720   EV  -  6040   EV          472            INT
6240   EV  -  6560   EV          3370           INT
8440   EV  -  8760   EV          540            INT
9080   EV  -  9400   EV          565            INT
10360  EV  -  10680  EV          620            INT
11240  EV  -  11560  EV          446            INT
13200  EV  -  13520  EV          2786           INT
13960  EV  -  14280  EV          484            INT
14760  EV  -  15080  EV          1304           INT
15560  EV  -  15880  EV          2178           INT
16400  EV  -  16720  EV          1998           INT
20360  EV  -  20520  EV          50683          INT

WINDOW RATIO
11-26-80        00
W:0

 0 1.000000
 1 1.114772E-02
 2 1.065446E-02
 3 1.708660E-02
 4 9.154945E-03
 5 6.649172E-02
 6 5.496912E-02
 7 9.549554E-03
 8 2.572855E-02
 9 4.297299E-02
10 3.942150E-02
11 5.149655E-03
12 9.312788E-03
13 1.223290E-02
14 6.668903E-03
15 8.799795E-03
```

Figure 2. Sample of XRF output

printed in the order in which the windows were entered, showing the percentage of each frequency count to the backscatter peak. The frequency count of Compton's peak is not constant between samples or even on successive readings of the same sample so the percentage provides the best data for relative comparisons between samples. The percentages which formed the basis for subsequent cluster analysis may be found in Appendix D.

In addition to the 122 artifacts, ten obsidian samples from known sources were fingerprinted in hopes of identifying the parent stock of some of the artifacts. Nine samples were provided by Dr. Irving Friedman, who collected one from Obsidian Cliff in Yellowstone Park, Wyoming and the remainder from flows in New Mexico, including Bland Canyon, Arroyo Canyon (2 samples), Frazer Canyon, Arroyo Hondo (3 samples) in the Jemez Mountains, and Tres Piedres in the San Juan Mountains. The tenth sample was an Apache Tear collected from a source in the Del Norte district of the RGNF, which was located in 1977 during timber sale reconnaissance near Wolf Creek Pass. Apache Tears, or "float obsidian," can be found some distance from the actual flow (Michels and Bebrich 1971:169) and the small size of these nodules (they average about 2 cm in diameter) indicated that this may be true in this case as well. Although those observed appeared too small for suitable artifacts, larger pieces undoubtedly exist in the area. These additional samples brought the total population for fingerprints to 132.

CLUSTER ANALYSIS

The appropriate statistic for evaluation of the trace element data was found in the BMDP2M "Cluster Analysis of Cases" computer program (Dixon and Brown 1979:633). Comparison of the relative frequencies of each element was done through use of sum of squares analysis. Prior to computation of the Euclidean distance between samples (cases), the frequency data for each element were normalized to Z-scores so that equal weight would be given to all variables. Otherwise, large standard deviations in distances between cases would be weighted more than distances with small standard deviations, thereby providing clusters according to absolute, rather than relative, values.

At each step of the amalgamation process, the relative amount of each element was compared to the mean of that element in the total population. The standard deviation of the value was determined and samples exhibiting similar sets of standard deviations in all elements were joined to form a cluster. The averages of the elements in the newly formed cluster then became the centroids to which subsequent cases were compared and joined.

CHAPTER VI

RESULTS AND DISCUSSION

RESULTS OF HYDRATION

Results of the hydration analysis are illustrated in Table 3. In this table, no attempt has been made to separate the artifacts into groups according to chemical composition. It merely presents the hydration rim depth(s) for each artifact analyzed. In cases where more than one edge was examined, the edge with the deepest hydration is listed first. This is the one used for dating purposes since it is presumably the originally flaked surface and therefore the oldest of the visible rims. Shallower measurements are listed below this in parentheses. Hydration depths of the 108 artifacts ranged from 1.27 to 12.35μm, but it was found that all cannot be compared together.

FORMATION OF SOURCE CLUSTERS

In order to understand the archaeological implications of the hydration results, an understanding of the cluster analysis performed on the results of the chemical fingerprinting must first be gained. The analysis indicates the degree of similarity in terms of distance coefficients of every artifact to every other artifact that was analyzed. Eight degrees of association are used to represent the similarity between artifacts based on Euclidean distances between the means of chemical values (derived from XRF) of the samples

Table 3. Artifacts and Associated Hydration Depths

Site/Artifact Number	Artifact Type	Hydration Depth µm	Hydration Depth µm²
5CN17-19	Point	4.65	21.82
-21	Large side notch	4.12	16.97
		(3.62)	(13.10)
-25	Expanding stem	2.88	8.29
		(2.44)	(5.95)
-27	Stemmed indented	4.67	21.80
-106	Stemmed indented	4.05	16.40
-107	Small corner notch	*	*
-124	Stemmed indented	3.77	14.21
		(3.10)	(9.61)
5CN18-65	Expanding stem	5.21	27.14
		(5.05)	(25.50)
-69	Small corner notch	1.54	2.37
-349	Flake	6.23	38.81
5CN19-97	Stemmed square base	3.28	10.75
-899	Flake	5.51	30.36
-903	Flake	4.55	20.70
CS-IF-03	Basal Notch	2.93	8.58
		(2.75)	(7.56)
-15	Large corner notch	4.02	16.16
-17	Large corner notch	4.81	23.16
-32	Stemmed indented	5.56	30.91
-54	Point fragment	*	*
-116a	Flake	*	*
-116b	Flake	*	*
-120	Small corner notch	3.91	15.28
5CN20-10	Flake	3.81	14.51
5CN22-30a	Small corner notch	1.85	3.42
-31	Expanding stem	3.34	11.18
		(3.07)	(9.42)
-33	Small side notch	3.01	9.06
		(1.61)	(2.59)
-35	Biface	2.1	4.41
		(1.72)	(2.95)
-55	Point	3.77	14.21
		(2.94)	(8.64)
5CN24-02	Biface	3.09	9.54
		(2.85)	(8.12)

Table 3. (cont'd)

Site/Artifact Number	Artifact Type	Hydration Depth µm	Hydration Depth µm^2
DL-IF-04	Stemmed square base	2.05 (1.43)	4.20 (2.04)
5CN24-83	Flake	3.41 (2.99)	11.62 (8.94)
-85	Stemmed square base	4.34 (2.78)	18.83 (7.72)
5CN25-88	Expanding stem	4.53	20.53
FC-IF-10	Biface	*	*
-24	Stemmed square base	3.10	9.16
-57	Stemmed indented	3.58	12.81
-70	Small corner notch	1.91 (1.24)	3.64 (1.53)
5CN26-89	Biface	*	*
5CN31-38	Flake	2.29	5.24
5CN35-03	Large corner notch	4.24 (3.35)	17.97 (11.22)
5CN40-03	Biface	*	*
-04	Biface	*	*
5CN42-01	Stemmed square base	4.97 (4.73)	24.70 (22.37)
-05	Expanding base	2.89 (1.87)	8.35 (3.27)
5CN45-01	Stemmed square base	3.78 (2.73)	14.28 (7.45)
5CN48-06	Flake	3.70 (3.41)	13.69 (11.62)
-13	Biface	5.45 (4.91)	29.70 (24.10)
5CN77-02	Expanding stem	6.50 (6.16)	42.25 (37.94)
-06	Stemmed square base	5.05 (4.35)	25.52 (18.94)
-08	Flake	2.01	4.04
OR-IF-06	Drill	*	*
5CN78-02	Small side notch	1.27	1.61
-03	Point	3.50	12.25
-05	Biface	3.96 (3.84)	15.68 (14.74)

Table 3. (cont'd)

Site/Artifact Number	Artifact Type	Hydration Depth µm	Hydration Depth µm^2
5CN78-08	Biface	1.66	2.75
		(1.61)	(2.59)
-18	Flake	2.21	4.90
BR-IF-02	Small corner notch	3.59	12.88
		(2.89)	(8.35)
5CN80-01	Stemmed indented	*	*
5CN81-02	Expanding stem	5.49	30.14
		(5.30)	(28.09)
5CN83-03	Scraper	1.86	3.45
		(1.38)	(1.90)
5CN87-01	Stemmed square base	4.13	17.05
		(4.09)	(16.72)
-05	Biface	3.67	13.46
		(3.65)	(13.32)
GS-IF-05	Small corner notch	4.59	21.06
-15	Expanding stem	*	*
5CN94-05b	Biface	4.46	19.89
-12	Large corner notch	2.97	8.82
		(2.63)	(6.91)
5CN97-08	Biface	*	*
5CN101-03	Scraper	4.18	17.47
-09	Flake	4.45	19.80
-13	Flake	3.41	11.62
-50	Flake	3.67	13.46
		(3.33)	(11.08)
-51	Flake	4.41	19.44
-52	Flake	4.96	24.60
-53	Flake	2.69	7.23
-63	Flake	3.23	10.43
-64	Flake	4.60	21.16
-65	Flake	*	*
-82	Flake	4.23	17.89
		(4.12)	(16.97)
-83	Flake	2.90	8.43
		(2.41)	(5.80)
-84	Flake	4.02	16.16
-124	Flake	3.68	13.54
-127	Flake	*	*

Table 3. (cont'd)

Site/Artifact Number	Artifact Type	Hydration Depth µm	$µm^2$
5CN101-128	Flake	5.28	27.87
5CN103-05	Large corner notch	4.58 (4.19)	21.02 (17.55)
-07	Flake	4.35 (4.08)	19.05 (16.64)
-10	Contracting stem	4.76	22.65
-11	Point fragment	*	*
5CN125-01	Expanding stem	*	*
-02	Flake	*	*
5CN94-25	Flake	3.22	10.40
HC-IF-04	Large corner notch	2.99 (2.94)	8.95 (8.64)
RH-IF-01	Expanding stem	4.22 (3.65)	17.80 (13.32)
LPD-IF-01	Rio Grande Point	4.86 (4.70)	23.66 (22.09)
5HN9-09	Small corner notch	4.25	18.06
-F1	Flake	3.35	11.22
-F2	Flake	5.30	28.09
-F3	Flake	5.75	33.06
-F4	Flake	3.59	12.92
5HN61-01	Small corner notch	insufficient hydration	
5HN63-02	Scraper	3.63	13.21
5HN71-09	Drill	5.28 (4.46)	27.87 (19.93)
5ML02-7	Flake	5.21	27.14
5ML7	Flake	3.51	12.32
5ML10-17	Flake	5.55 (4.94)	30.84 (20.40)
5RN75-03	Stemmed indented	5.50 (1.64)	30.25 (2.68)
-04	Flake	6.46 (4.39)	41.73 (19.27)

Table 3. (cont'd)

Site/Artifact Number	Artifact Type	Hydration Depth µm	Hydration Depth µm^2
5RN86-D1	Small corner notch	3.54 (1.59)	12.56 (2.52)
5RN93-01	Point fragment	2.51 (2.01)	6.30 (4.04)
-02	Contracting stem	2.94	8.64
5RN95-02	Stemmed square base	4.22 (4.18)	17.80 (17.47)
-04	Scraper	4.17 (3.49)	17.38 (12.18)
-13	Flake	3.56	12.67
-15	Scraper	2.0	4.0
-17	Expanding base	2.72 (2.5)	7.39 (6.25)
CD-02	Point base	*	*
RC-01	Hell Gap Point	12.35 (10.0)	152.52 (100.0)
5SH54-16	Biface	5.08 (3.76)	25.85 (14.13)
5SH261-16	Flake	5.89	34.75
5SH262-05	Flake	5.44 (5.41)	29.59 (29.26)
5SH264-15	Flake	2.76	7.64
5SH326-02	Stemmed square base	7.70	59.29
5SH328-06	Drill	4.57 (2.23)	20.88 (4.97)
KA-IF-02	Angostura point	1.52 (1.33)	2.31 (1.78)

*Denotes artifact not tested-too small, not diagnostic or not associated with a diagnostic.

within the cluster. The highest level of association represents a distance coefficient of 2.031 or less. The levels range downward through seven gradations: 2.031 to 2.901, 2.901 to 3.597, 3.597 to 4.293, 4.293 to 5.048, 5.048 to 5.976, 5.976 to 7.543, to a distance coefficient of 7.543 or greater. The higher the coefficient, the fewer the similarities between two artifacts.

Source locality clusters were interpreted as those artifacts joined at the 2.031 (or highest) level. Discrete clusters showing no overlap of artifacts between clusters were formed at this level. Based on utilization of the 2.031 level, four discrete clusters, accounting for 114 of the cases (artifacts or source samples) emerged. In addition, 18 artifacts were found to be chemically unlike any others and mayhave originated at different and presently unidentified sources. The chemical characterizations that differentiate the four clusters are presented in Table 4. Through examination of each cluster, the archaeological as well as analytical implications of the chemically derived clusters may be more fully understood.

CLUSTER #1

The cluster designated as Cluster #1 contains 24 samples, including the sample from Bland Canyon. This canyon is located in the Jemez Mountains about 30 miles west of Santa Fe, New Mexico, and drains in a southeasterly direction into the Rio Grande River, which probably served as the avenue for the northward distribution of the obsidian. Legal location of the canyon is T.18N., R.4E., S.23, 24, 25, NMPM. It may be found on the 7.5' Bland, N.M. topographic map.

Table 4. Elemental composition of clusters in terms of standard deviations from the mean of each element in the total population.

Element		Cluster #1	Cluster #2	Cluster #3	Cluster #4
Gallium	(Ga)	.924	-.064	-.237	.089
Zinc	(Zn)	1.076	-.177	-.178	.307
Potassium	(K)	.701	.231	.645	.294
Calcium	(Ca)	.572	.171	.370	.946
Iron	(Fe)	1.616	.010	-.194	-.173
Rubidium	(Rb)	.682	.067	-.516	3.056
Strontium	(Sr)	.044	-.064	3.859	-.227
Yttrium	(Y)	1.271	-.037	-.546	2.427
Zirconium	(Zr)	1.715	-.070	.036	-.151
Niobium	(Nb)	.956	.057	-.104	2.740
Scandium	(Sc)	.552	.103	.291	.558
Manganese	(Mn)	.824	-.105	-.050	3.126
Lead	(Pb)	.989	.026	-.214	-.121
Titanium	(Ti)	.390	.005	-.061	.347

Vulcanism in this area of the Jemez Mountains of New Mexico occurred during the Eocene epoch of the Tertiary Period, or between 25 and 55 million years ago (Smith et al. 1970).

Table 4, in illustrating the standard deviations that differentiate the clusters, indicates the amount of homogeniety between samples in the clusters. Cluster #1 contains no elements falling below their respective means, but shows considerable deviation above the mean in most elements. This deviation suggests the inclusion of samples that may be peripherally joined to the cluster in terms of chemical composition.

To further test the internal consistency of the cluster, the twenty four samples contained in Cluster #1 were run through the cluster analysis by themselves, without the remainder of the samples. Three subclusters were indicated, containing fourteen, four and three samples. In addition, three samples, including the one from Bland Canyon proved to be poor relations to all other samples. Based on the presence of the subclusters, the initial formation of Cluster #1 could be viewed as a statistical artifact of the cluster analysis and not a true indication of a common source for artifacts contained in the cluster. Therefore, it might be more reasonable to consider source locality complex (Hurtado de Mendoza and Jester 1972) as having produced these artifacts rather than a single flow.

As explained earlier, the amount of variation between sources or source locality complexes is greater than that within the sources, so for purposes of the present analysis artifacts in Cluster #1 were treated as possessing the same hydration rate and were compared together. A note of caution should be observed in the comparison, however, since subrates probably are in operation here.

Hydration depths of the 19 artifacts in Cluster #1 that were found acceptable for hydration analysis range from 2.29μm to 12.35μm (Table 5). Diagnostic artifacts contained in Cluster #1 are illustrated in Figure 3. The oldest artifact, according to both hydration depth and typological information is a Hell Gap point (RC-01), and the youngest artifact is a flake (5CN31-38) that was found in association with a large corner notched point and a metate, the only artifacts suggestive of the temporal position of the flake. The association of these artifacts suggests a time of manufacture ranging from the Early Archaic to historic times, so they are of little help in establishing specific temporal parameters for the manufacture of the flake.

Without a definite base date from which to work, little besides speculative guesses can be made concerning chronologic positions of other artifacts in the source cluster. Going beyond solid inference, some speculation on the relationship between hydration depth and chronology can be made. The relationships are based on relative age factors of the artifacts whichare to be used only as rough guides of age since important temperature data are not considered in their derivations.

If the suggested temporal parameters of 7500 to 9000 BP for the Hell Gap point are correct, the age of manufacture of the flake (5CN31-38) would fall between 300 and 350 years BP, which is not an unreasonable estimate given the associated tool assemblage.

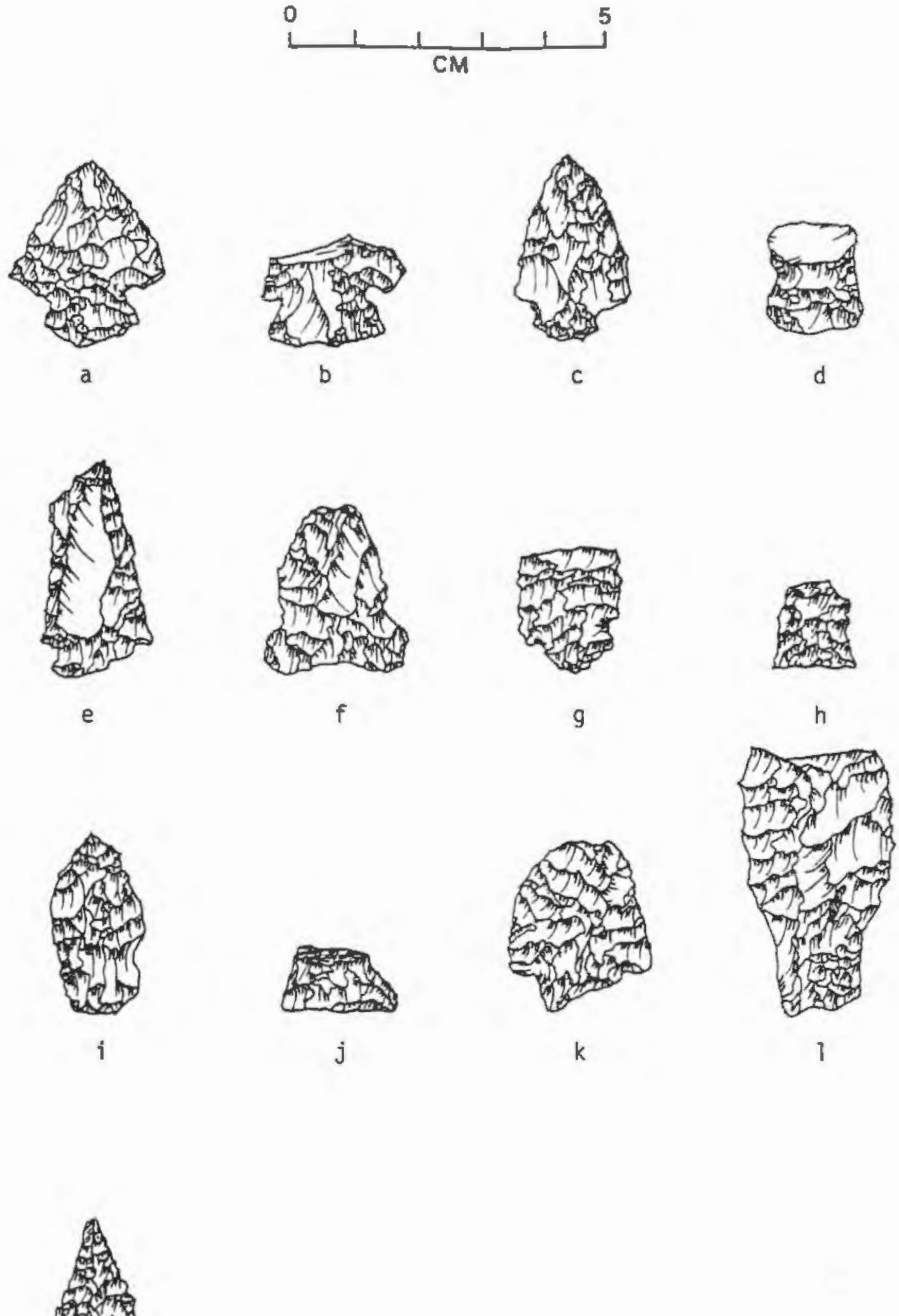
Table 5. Samples contained in Cluster #1

Site/Artifact Number	Hydration Depth µm	Hydration Depth μm^2	Relative Age Factor
5CN31-38	2.29	5.24	1.0
5CN94-12	2.97	8.82	1.68
HC-IF-04	2.99	8.95	1.7
FC-IF-24	3.1	9.16	1.74
5CN19-97	3.28	10.75	2.05
5ML7	3.51	12.32	2.35
5RN95-13	3.56	12.67	2.41
5CN17-21	4.12	16.97	3.23
5CN25-88	4.53	20.53	3.91
5CN17-19	4.65	21.62	4.12
5CN42-01	4.97	24.70	4.71
5CN77-06	5.05	25.52	4.87
5ML2-07	5.21	27.14	5.17
5HN9-F2	5.30	28.09	5.36
5CN48-13	5.45	29.70	5.66
5CN18-349	6.23	38.81	7.4
5CN77-02	6.5	42.25	8.06
5SH326-02	7.7	59.29	11.31
RC-01	12.35	152.52	29.10
FC-IF-10	*	*	N/A
CS-IF-54	*	*	N/A
BLACAN2	*	*	N/A
5CN26-89	*	*	N/A
5HN61-01	*	*	N/A

*Denotes no hydration analysis or insufficient hydration.

Figure 3. Diagnostic artifacts in Cluster #1

a: 5CN94-12	b: HC-IF-04	c: FC-IF-24	d: 5CN19-97
e: 5CN17-21	f: 5CN25-88	g: 5CN17-19	h: 5CN42-01
i: 5CN77-06	j: 5CN77-02	k: 5SH326-02	l: RC-01
m: 5HN61-01			


0
5
CM
a
b
c
d
e
f
g
h
i
j
k
l
m

Use of this suggested base date, however, produces ambiguous results when attempting to reproduce the ages of certain other point styles whose indicated dates of manufacture fall between those of the Hell Gap point and the flake (Table 1). For example, 5CN17-21, a large side notch, is thought to have been utilized from 4200 to 1000 BC. Its hydration depth, however, is only 4.12. According to the speculated base date of the flake, an RAF of 3.23 for 5CN17-21 indicates that the point was made no earlier than AD 1830, almost 2000 years after its suggested period of use. A similar time of utilization is suggested for 5CN77-D6, a stemmed square base point, whose 5.05 microns of hydration and RAF of 4.87 indicate that it was manufactured at least 1000 years later than its typologically suggested dates. Other diagnostic points in this cluster enjoyed popularity over such long periods of time that their hydration depths are acceptable indicators of their manufacture dates. 5CN17-21 and 5CN77-06 are both included in the large subcluster within Cluster #1, so external factors probably influenced the hydration rate.

Two noticable gaps exist in the otherwise orderly progression of hydration rims in Cluster #1. The first gap is between two large corner notched points: 5CN77-02, possessing 6.5 microns of hydration, and 5SH326-02, with a hydration depth of 7.7. Based on the speculated base date of 300-350 BP, this gap could represent a span of over 1000 years that people visiting the RGNF failed to use obsidian from Bland Canyon. The gap does not appear to coincide with the theorized early altithermal hiatus. The two artifacts bounding the gap were found in widely separated areas of the forest so the difference may be the function of differing external factors such as climate or solar intensity, or it may indeed reflect the lack of forest utilization during those years.

The second gap is much larger and involves the latter discussed large corner notch (5SH326-02) and the Hell Gap point (RC-01), which has 12.35 microns of hydration. RC-01 was found closer to 5SH326-02 than was 5CN77-02 but the two were still widely separated. Climatic differences were probably a factor in this gap as well, but the difference is, no doubt, also a reflection of the age of the Hell Gap point in relation to the large corner notch.

CLUSTER #2

The value of examining chemical compositions to distinguish between clusters becomes more clear when comparing chemical values in Cluster #1 to those in Cluster #2. The quantities of all 14 elements hover much closer around the mean than those in Cluster #1, suggesting a higher degree of homogeniety within the cluster

To test the homogeneity of Cluster #2, its component samples were run through the cluster analysis together, as were those of Cluster #1. Cluster #2 did indeed prove to be largely homogeneous with 75 of the 85 artifacts contained in it showing a high degree of similarity.

Three additional subclusters containing two samples each were also revealed. Four samples fell outside of all clusters. A source locality complex (Hurtado de Mendoza and Jester 1978) once again is suggested, but the internal consistency in Cluster #2 suggests the probability of a single source having contributed the bulk of the samples contained in it. If this is the case, comparison of hydration depths of artifacts in Cluster #2 may be regarded as more accurately representing the ages of the artifacts than those of Cluster #1.

Cluster #2 contains none of the identified source samples so there is only the available typological information to indicate direction of distribution of artifacts in the cluster. Artifacts in Cluster #2 are listed in Table 6 and Figure 4 illustrates diagnostic artifacts contained in the cluster. Of the 75 artifacts found in this cluster that were found acceptable for hydration analysis, a small side notched point, 5CN78-02, was found to have the least amount of hydration. The artifact with the most hydration is a flake, 5RN75-04, with a hydration depth of 6.46μm. Hydration depths proceed with regularity from the youngest to the oldest artifact with no large grouping that would indicate a major influx of people and no large gaps in the continuum to indicate a temporary lack of utilization.

The small hydration rim present on 5CN78-02 is seemingly consistent with its typologically suggested dates of use: AD 1200 to the late 1800s. Two of the next three youngest artifacts as indicated by hydration are small corner notches, also consistent with typological information. The third of these, and the next oldest to 5CN78-02 according to its hydration depth is an Angostura point, KA-IF-02, typologically the oldest obsidian point collected from the forest. Its 1.52μm of hydration is an extremely inconsistent finding relative to the other results. The lack of hydration on this artifact could be the result of several factors.

One, it may be of much more recent manufacture than its morphology indicates. It may be a copy of an older point by a master flintknapper

Table 6. Samples contained in Cluster #2

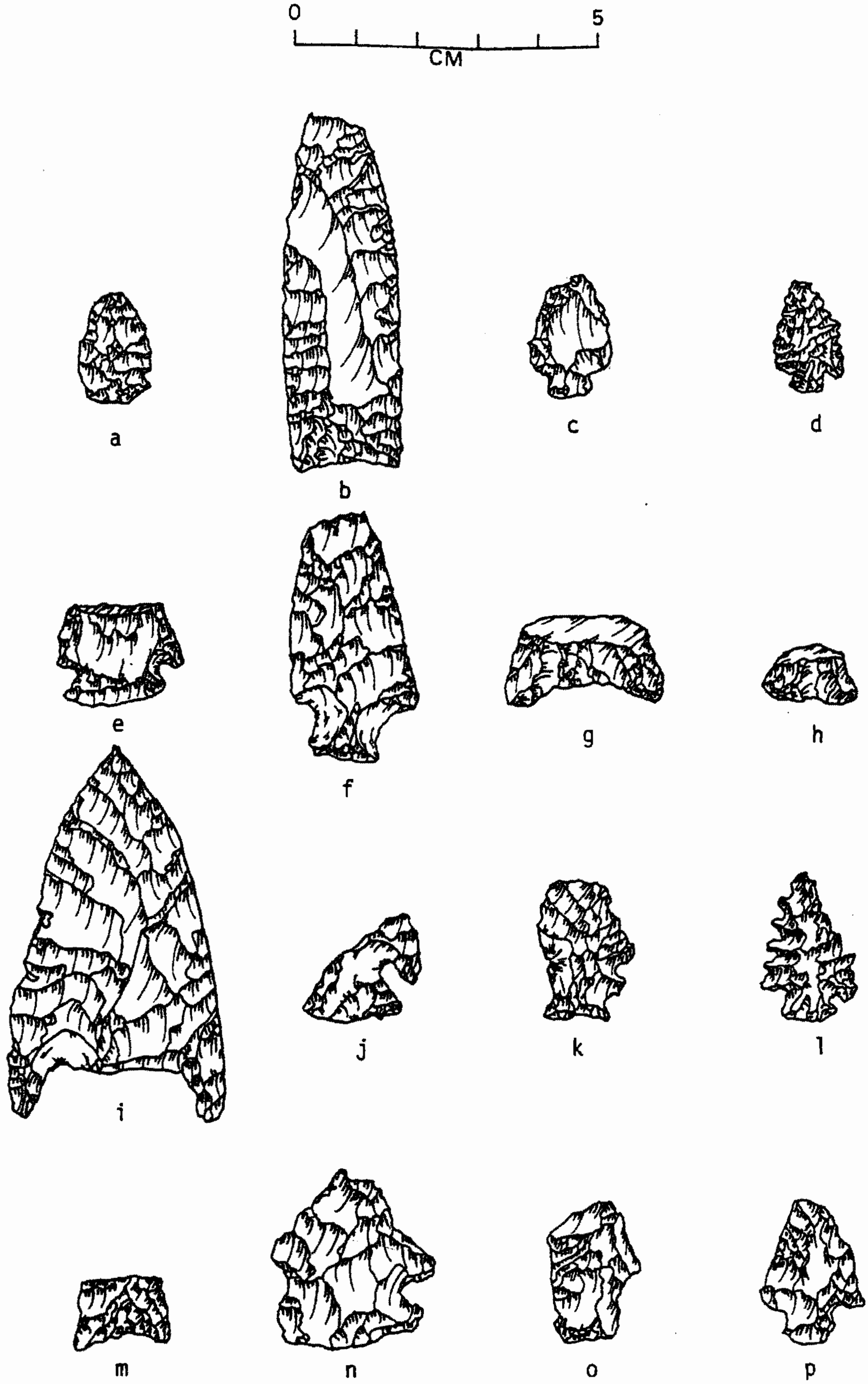
Site/Artifact Number	Hydration Depth μm	Hydration Depth μm^2	Relative Age Factor
5CN78-02	1.27	1.61	1.0
KA-IF-02	1.52	2.31	1.43
5CN18-69	1.54	2.37	1.47
5CN22-30a	1.85	3.42	2.12
5CN83-03	1.86	3.45	2.14
FC-IF-70	1.91	3.64	2.26
5RN95-15	2.0	4.0	2.48
DL-IF-04	2.05	4.2	2.6
5CN22-35	2.1	4.41	2.73
5CN78-18	2.21	4.90	3.04
5CN101-53	2.69	7.23	4.49
5CN17-25	2.88	8.29	5.14
5CN42-05	2.89	8.35	5.18
5CN101-83	2.90	8.43	5.23
CS-IF-03	2.93	8.58	5.32
5CN22-33	3.01	9.06	5.62
5CN24-02	3.09	9.54	5.92
5CN101-63	3.23	10.43	6.47
5CN22-31	3.34	11.18	6.94
5HN9-F1	3.35	11.22	6.96
5CN24-83	3.41	11.62	7.21
5CN101-13	3.41	11.62	7.21
5CN78-03	3.5	12.25	7.6
5RN86-01	3.54	12.56	7.8
BR-IF-02	3.59	12.88	8.0
5HN9-F4	3.59	12.92	8.02
5HN63-02	3.63	13.21	8.2
5CN87-05	3.67	13.46	8.36
5CN101-50	3.67	13.46	8.36
5CN101-124	3.68	13.54	8.4
5CN48-06	3.70	13.69	8.5
5CN17-124	3.77	14.21	8.82
5CN22-55	3.77	14.21	8.82
5CN45-01	3.78	14.28	8.86
5CN20-10	3.81	14.51	9.01
CS-IF-120	3.91	15.28	9.49
5CN78-05	3.96	15.68	9.73
5CN101-84	4.02	16.16	10.03
CS-IF-15	4.02	16.16	10.03
5CN17-106	4.05	16.40	10.18
5CN87-01	4.13	17.05	10.59
5RN95-04	4.17	17.38	10.79
5CN101-03	4.18	17.47	10.85
5RN95-02	4.22	17.80	11.05
RH-IF-01	4.22	17.80	11.05
5CN101-82	4.23	17.89	11.11

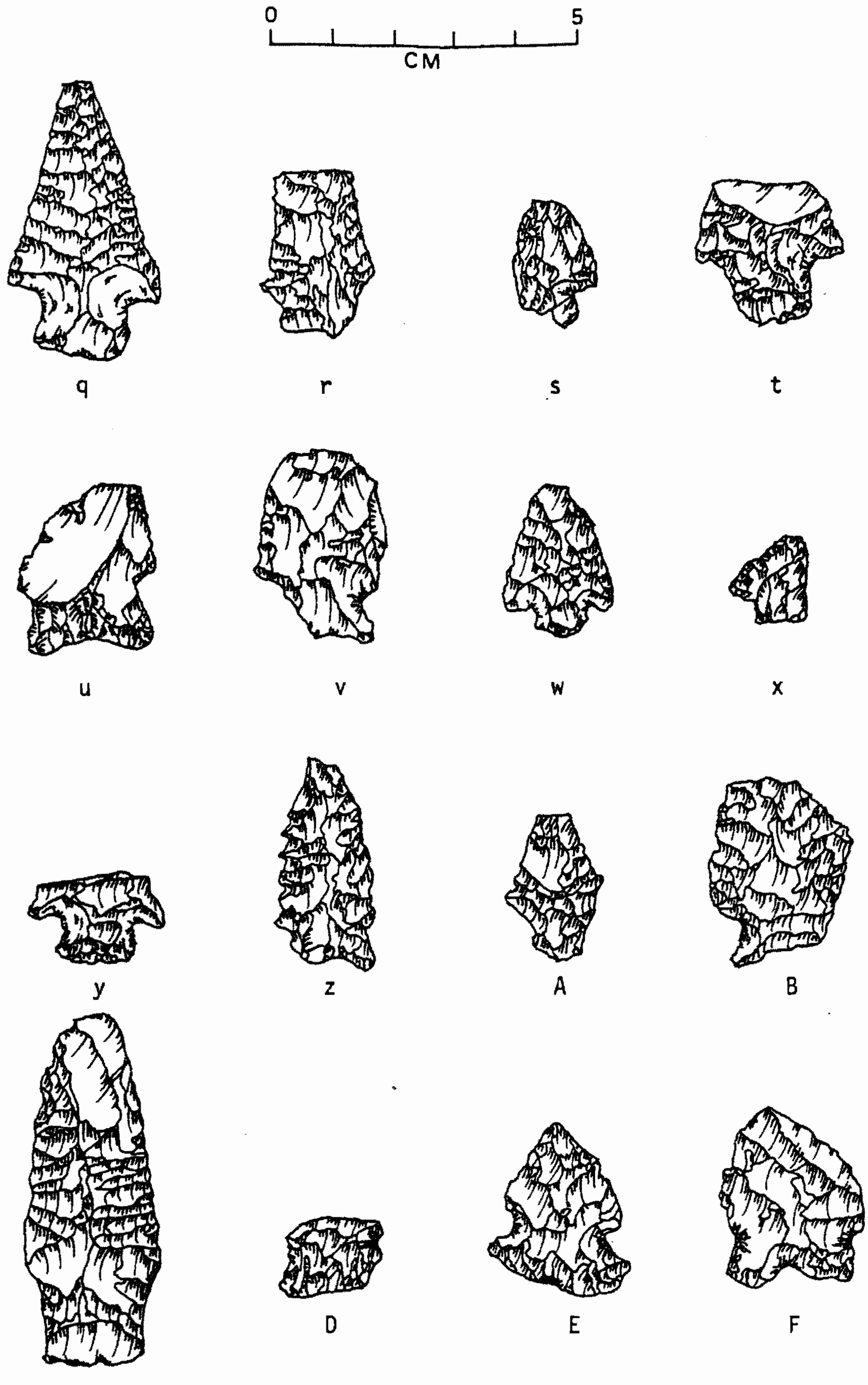
Table 6. (cont'd)

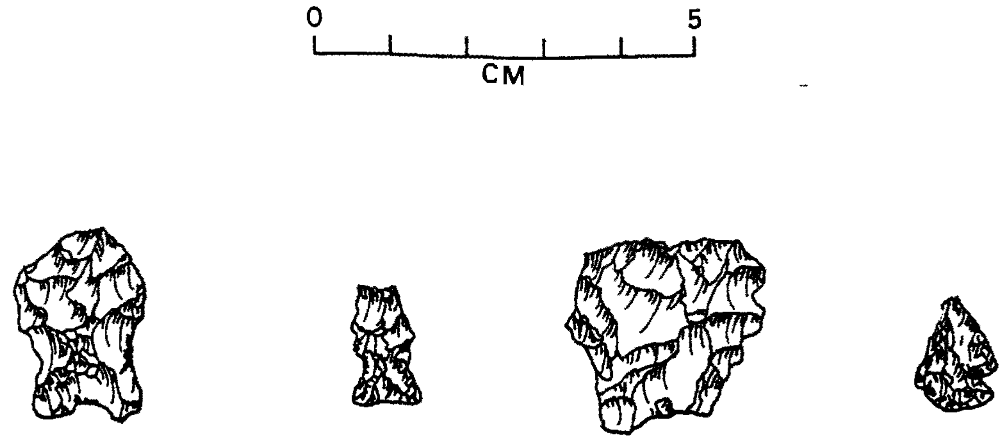
Site/Artifact Number	Hydration Depth μm	Hydration Depth $μm^2$	Relative Age Factor
5CN35-03	4.24	17.97	11.16
5HN9-09	4.25	18.06	11.21
5CN24-85	4.34	18.83	11.69
5CN103-07	4.36	19.05	11.83
5CN101-51	4.41	19.44	12.07
5CN101-09	4.45	19.80	12.29
5CN94-05b	4.46	19.89	12.35
5CN19-903	4.55	20.70	12.85
5SH328-06	4.57	20.88	12.96
5CN103-05	4.58	21.02	13.05
5CN101-64	4.60	21.16	13.14
5CN17-27	4.67	21.80	13.54
5CN103-10	4.76	22.65	14.06
CS-IF-17	4.81	23.16	14.38
LPD-IF-01	4.86	23.66	14.69
5CN101-52	4.96	24.60	15.27
5SH54-16	5.08	25.85	16.0
5CN18-65	5.21	27.14	16.85
5CN101-128	5.28	27.87	17.03
5HN71-09	5.28	27.87	17.03
5SH262-05	5.44	29.59	18.37
5CN81-02	5.49	30.14	18.72
5RN75-03	5.50	30.25	18.78
5CN19-899	5.51	30.36	18.85
5ML10-17	5.55	30.84	19.15
CS-IF-32	5.56	30.91	19.19
5HN9-F3	5.75	33.06	20.53
5SH261-16	5.89	34.75	21.58
5RN75-04	6.46	41.73	25.91
CD-02	*	*	N/A
GS-IF-15	*	*	N/A
CS-IF-116b	*	*	N/A
5CN40-03	*	*	N/A
5CN40-04	*	*	N/A
5CN17-107	*	*	N/A
5CN97-08	*	*	N/A
5CN101-127	*	*	N/A
5CN103-11	*	*	N/A
5CN125-02	*	*	N/A

Figure 4. Diagnostic artifacts in Cluster #2

a: 5CN78-02	b: KA-IF-02	c: 5CN18-69	d: 5CN22-30a
e: FC-IF-70	f: DL-IF-04	g: 5CN17-25	h: 5CN42-05
i: CS-IF-03	j: 5CN22-33	k: 5RN86-01	l: BR-IF-02
m: 5CN17-124	n: 5CN22-55	o: 5CN45-01	p: CS-IF-20
q: CS-IF-15	r: 5CN17-106	s: 5CN87-01	t: 5RN95-02
u: RH-IF-01	v: 5CN35-03	w: 5HN9-09	x: 5CN24-85
y: 5CN103-05	z: 5CN17-27	A: 5CN103-10	B: CS-IF-17
C: LPD-IF-01	D: 5CN18-65	E: 5CN81-02	F: 5RN75-03
G: CS-IF-32	H: GS-IF-15	I: CD-02	J: 5CN17-107


0
5
CM
a
b
c
d
e
f
g
h
i
j
k
l
m
n
o
p


0
5
CM
q
r
s
t
u
v
w
x
y
z
A
B
C
D
E
F



G H I J

of the Late Prehistoric or Proto-Historic era. The second possibility is that the dense trees in which it was found could have shielded out the sun's rays over the millenia, thus drastically reducing the hydration rate. Third, it may have been buried for most of the years since its manufacture, shielding climatic fluctuations and reducing the rate even further.

The first of these possibilities provides the most reasonable solution given the present state of knowledge. The latter two possibilities cannot be substantiated without further research, nor can they be eliminated as possible reasons for the anomalous reading. In order to substantiate the second possibility, information on the length of time the present tree cover has existed and its density would have to be obtained. This would be difficult, and substantiation of the third alternative would be equally difficult since there is no way to determine if the artifact was buried, and if it was, how deep it was deposited and for how long. Unless it was buried at a shallow depth, it would have presumably remained buried until excavated or brought to the surface by rodents. If it was buried only a short distance below the surface, hydration would have proceeded at only a slightly slower rate than if it had been lying on the surface. The point was an isolated find, so no information on context other than that involving the surrounding ecozone exists.

In addition to the Angostura point, two other points possess hydration depths that seem inconsistent with their suggested dates of utilization. 5RN75-03, with 5.5μm of hydration, and CS-IF-32, with 5.56μm of hydration are both stemmed indented points belonging to the McKean Complex. They have the two deepest hydration rims of the cluster, suggesting an earlier introduction than even the Rio Grande point, LPD-IF-01. Due to the long span of utilization of the remainder of the points in the cluster, chronologic placement of the McKean points in the cluster is not possible, but they should at least have fallen at a later date than LPD-IF-01. In thier present position, they are of little use in refining the dates of points with broad temporal placements.

Cluster #2 contains several large corner notched points, principal targets of this research. Hydration depths on this style range from 1.91 to 4.81μm with no large groupings that would indicate a new introduction of the style or increased utilization. This point style does predate small arrowpoints and postdate the Rio Grande point, a finding consistent with typological data but more specific temporal placement is not possible at this time.

Several sites included in Cluster #2 are represented by a number of artifacts. 5CN101 is the best represented in the cluster, containing 14 flakes. The recorders of the site determined that four separate concentrations of obsidian flakes were present on the site. Each concentration is represented in the cluster and each possesses a range of hydration depths that indicate either multicomponency or the presence of differing external factors influencing the hydration rate.

Flake Concentration 1 (FC 1) contains four flakes that underwent hydration analysis. Hydration rims range from 2.69 to 4.96μm, too large a difference to indicate a single component or to be attributed to observer measurement error. FC 2 is represented by two flakes, one with 3.23μm of hydration and the other with 4.6μm. FC 4 has three flakes with hydration ranging from 2.9 to 4.23μm. FC 5 also contains three flakes, two of which underwent hydration analysis, revealing hydration depths of 3.68 and 5.28μm. All four flake concentrations contain so much variance as to strongly suggest that the flake concentrations were arbitrarily assigned and not individually representative of site reoccupation that took place over many years. They do represent the complexity of the site, but not in the manner that they were recorded.

The single point found on 5CN101 is basally notched, a type which is of no use in determining the age of the site because its temporal position remains unknown in this area (Nickens 1979:58). Two other obsidian tools from the site, both utilized flakes, were tested for hydration and fingerprinted and found to fall within Cluster #2. Hydration depths of these are 3.41 and 4.45μm, figures falling within the range of the 11 flakes discussed above and providing further indications of site reoccupation. External factors would presumably have affected all obsidian present on the site equally since all artifacts are chemically similar so the range of hydration depths must represent reoccupation.

Two other sites in the cluster are represented by five artifacts. 5CN17 contains four points or point fragments, three classified as stemmed indented and one classified as an expanding stem. Hydration depths for the stemmed indented points are 3.77, 4.05 and 4.67 microns. When using the temporal distribution suggested by Nickens (1979), the relative ages of these points seem consistent with that of the fourth point, the expanding stem point, with 2.88μm of hydration. Stemmed indented points do indeed fall into an earlier time frame than expanding stem points. The fifth artifact from 5CN17 is a small corner notched point that was too small to remove a section for hydration analysis without shattering the artifact. The relative ages of the four artifacts that were tested indicate multiple occupation of the site.

5CN22 is the other site in Cluster #2 represented by five artifacts. Their span of hydration ranges from 1.85 to 3.77μm, a range also indicative of multicomponency. Typologically, the points include a small corner notch and two large corner notches, styles which also suggest multicomponency.

The next best represented site in Cluster #2 is 5HN9, containing four obsidian artifacts including three flakes and a small corner notched point. The point has 4.25 microns of hydration, while hydration depths on the three flakes are 3.35, 3.59 and 5.75μm. As was the case with 5CN101, these depths vary too much to be attributed to environmental factors or observer error. Again, multicomponency is suggested.

In addition to this site, one other is represented by four artifacts. The only diagnostic artifact is a small side notched point, so little can be said about 5CN78 except that the range of hydration depths, 1.27 to 3.96μm indicate multicomponency for the same reasons cited above.

Inferences as to direction of travel, trade, cultural affiliation and age of the artifacts in the RGNF ultimately fall back on existing knowledge of the chronological positions as indicated by point typologies. The number of artifacts contained in Cluster #2 indicates a heavily exploited obsidian source at a still unidentified location. Points contained in this cluster indicate influence from at least two surrounding cultural regions. The Southwest most likely contributed what has been classified as a Rio Grande point (LPD-IF-01) and several small side notched points can be attributed either to the Utes, the late prehistoric and early historic inhabitants of the Valley, or to Great Plains tribes. The Great Plains may also be represented by what looks like a Woodland point (5CN18-69).

Obsidian attributed to Cluster #2 was found in all counties located in the forest except Alamosa County, indicating widespread trade and/or travel within the RGNF. Knowledge of the source(s) of this obsidian would help considerably in the identification of the travel route(s) and cultural processes that brought it to the RGNF.

The hydration depths of points included in Cluster #2 seem consistent with their estimated dates of utilization, with the Angostura and McKean points producing the only anomalous results. The vast majority of artifacts in Clsuter #2 are flakes or other undiagnostic artifacts whose diagnostic associations appear consistent with the hydration depths of the undiagnostic artifacts. This type of association of an undiagnostic artifact with a diagnostic artifact located on the same site is a tenuous one at best given the large amount of multicomponency suggested by hydration thicknesses. Apparently, archaeological sites in mountain environments were often occupied several times through the years due to a lack of suitable site locations, a fact that surface remains may not indicate. The artifactual evidence from 5CN101 exemplifies the fact that unless a site has been excavated or dated and is known to represent a single occupation, artifacts should be assumed to be unrelated.

CLUSTER #3

Cluster #3 contains three samples: TRES11, TRES12, and ARRHON, all source samples. Based on the lack of associated artifacts, these sources do not appear to have contributed artifactual material to the RGNF collection. TRES11 and TRES12 originated at the same source, a flow located in the Tres Piedras area, near the foothills of the San Juan Mountains in northern New Mexico. The ARRHON sample came from Arroyo Hondo, also in northern New Mexico, but in the Sangre de Cristos about 20 miles east of Tres Piedras. Apparently, the migration/trade patterns of the region did not include routes that led past these two sources since neither source is represented by artifactual remains. An alternative possibility is that artifacts from these sources are present in the RGNF, but simply are not represented in this collection.

This cluster clearly contains samples representative of a source locality complex (Hurtado de Mendoza and Jester 1978). While the previous two clusters contain diversity believed to represent locality complexes, Cluster #3 actually contains samples from different flows, thereby confirming the presence of a complex.

Elemental composition of these three samples is relatively close to the mean with the exception of strontium, whose extremely high + 3.859 standard deviations make it a characteristic element in the cluster.

CLUSTER #4

Cluster #4 contains two artifacts, 5CN77-08 and OR-IF-06, only one of which underwent hydration analysis. Neither artifact is diagnostic (Table 7). This cluster exhibits very high concentrations

Table 7. Samples contained in Cluster #4

Site/Artifact Number	Hydration Depth μm	Hydration Depth μm^2	Relative Age Factor
5CN77-08	2.01	4.04	1.0
OR-IF-06	*	*	N/A

of four elements: manganese and rudibium at more than +3.0 standard deviations and niobium and yttrium, present in more than + 2.0 standard deviations. The presence of these four elements in such high concentrations isolates this cluster rather markedly.

NONASSOCIATED ARTIFACTS

The remainder of the artifacts and source samples, 18 in number, have too little in common to cluster at a significant level with any other samples. All were ultimately clustered, but with associations too weak to make determinations as to the elemental composition that prevented stronger association. Having been excluded from clusters, relative ages cannot be assigned to any of these artifacts, even though 13 have distinct hydration rims. Nonassociated samples are listed in Table 8 and diagnostic artifacts are illustrated in Figure 5.

Two source samples in this group deserve special mention. APACHE, an Apache Tear taken from the obsidian source above Poage Lake in the RGNF, having no chemically similar artifacts associated with it, did not contribute any artifact material to this collection of artifacts. This is an unexpected result considering the location of the source. The people who visited the forest either did not know of the existence of this source or preferred to use material obtained from other sources. At any rate, obsidian used in the RGNF was carried in from outside sources. Likewise, neither did any artifacts cluster with the sample from Obsidian Cliff in Yellowstone Park, Wyoming. This outcome was expected given the geographical distance between northern Wyoming and southern Colorado. The seasonal migration patterns apparently did not reach that far.

Table 8. Nonassociated Artifacts

Site/Artifact Number	Hydration Depth μm	Hydration Depth μm^2	Relative Age Factor
CS-IF-116a	*	*	N/A
CF-IF-57	3.58	12.81	N/A
5CN78-08	1.66	2.75	N/A
5CN80-01	*	*	N/A
GS-IF-05	4.59	21.06	N/A
5CN125-01	*	*	N/A
5CN94-25	3.22	10.40	N/A
5RN93-01	2.51	6.30	N/A
5RN93-02	2.94	8.64	N/A
5RN95-17	2.72	7.39	N/A
5SH264-15	2.76	7.64	N/A
APACHE	*	*	N/A
FRAZCAN	*	*	N/A

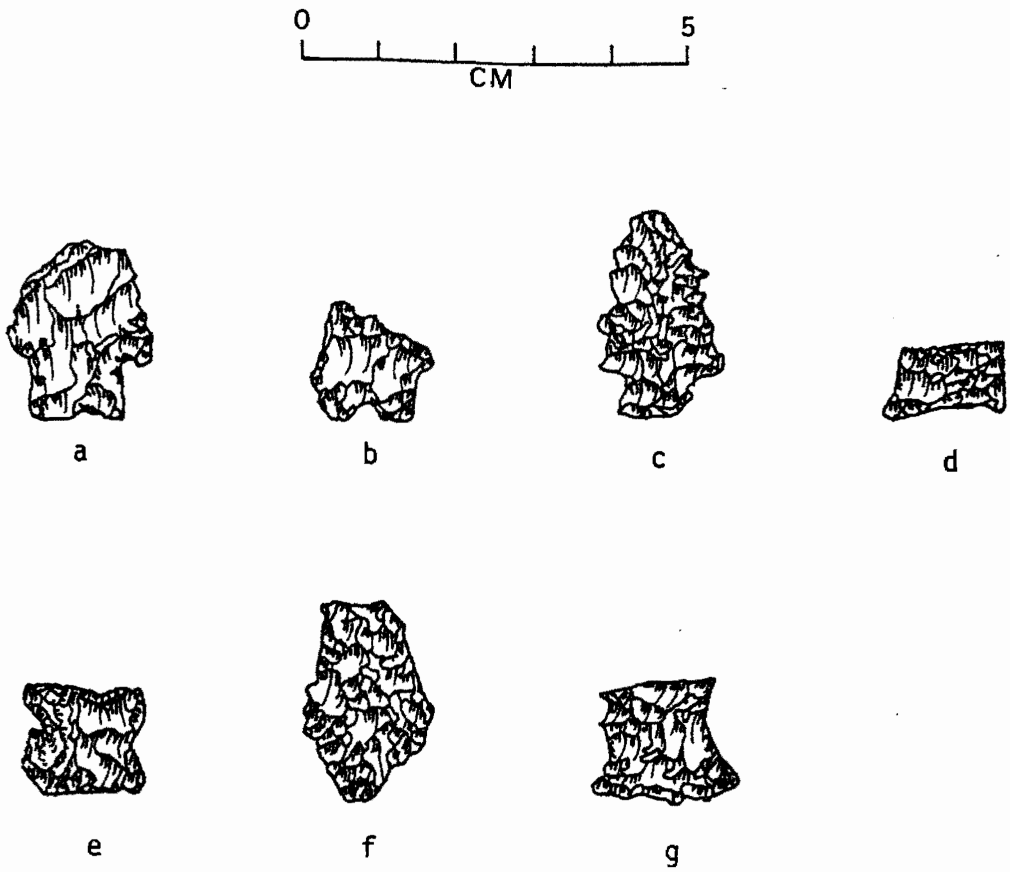


Figure 5. Diagnostic nonassociated artifacts

a: FC-IF-57 b: 5CN80-1 c: GS-IF-05 d: 5CN125-01
e: 5RN93-01 f: 5RN93-02 g: 5RN95-17

CHAPTER VII

CONCLUSIONS

Obsidian hydration analysis was completed on 104 obsidian artifacts in the attempt to refine a working relative chronology for the Rio Grande National Forest. In order to control for elemental variation in the hydration rate, it was necessary to find which artifacts were chemically similar.

Trace element analysis of 14 elements and computer clustering of the results indicated two principal groups of artifacts exhibiting similar chemical composition were present in the collection. Artifacts clustering together were assumed to have originated at the same volcanic flow or source locality complex (Hurtado de Mendoza and Jester 1978). All external environmental factors being equal, these artifacts should have hydrated at approximately the same rate. Relative ages could be assigned to chemically similar artifacts based on their hydration depths, but the lack of other information, particularly microenvironmental temperature data, precluded establishment of an absolute hydration rate.

For the most part, hydration depths and corresponding relative age estimates obtained for artifacts within clusters produced in this study appeared consistent with typologically suggested chronologic positions.

The use of surface finds projected uncertainty into the results of the hydration analysis because of the influence of extremes in temperature fluctuations and solar intensity. The hydration depths obtained may or may not be accurate reflections of the true ages of the artifacts. The only way to know is through additional research using site specific data concerning climatic conditions and preferably to use artifacts obtained through excavation rather than surface surveys. Studies done within the confines of these two research requirements will ensure more accurate results and lend more credence to obsidian hydration dates obtained.

The 24 artifacts and/or source samples contained in Cluster #1 were run through the cluster analysis alone as a test of the internal consistency of the cluster. The presence of three subclusters suggested that all artifacts did not originate at a single flow but that a source locality complex (Hurtado de Mendoza and Jester 1978), consisting of at least three separate but chemically similar flows, contributed artifacts to the cluster. A single source sample, from Bland Canyon in the Jemez Mountains of New Mexico, was included in Cluster #1, suggesting the possibility that some artifacts in the collection may have originated here. In order to know the likely sources for Cluster #1 obsidian, however, it would be necessary to test other flows of the region.

In Cluster #1, the oldest artifact, a Hell Gap point, was found to have a relative age factor of 29.1, a figure seemingly consistent with its suggested temporal placement. The RAFs of other artifacts in the cluster seemed consistent with their temporal placements as well.

Cluster #2 contained 85 artifacts, the oldest of which had an RAF of 25.9. The RAFs of all but three of the diagnostic points in this source cluster indicated that typological information has led to correct relative chronological ordering of the points. One anomalous reading came from an Angostura point, typologically the oldest obsidian artifact in the present collection. The hydration depth of this point indicated a much more recent date of manufacture than that indicated by its typological identity. It was bracketed by three small side or corner notched points, all of which have been attributed to the Late Prehistoric or Proto-Historic period, ranging from AD 500-1880, the early date coinciding with the introduction of the bow and arrow. This Angostura point may not be an original, but a more recent reproduction of an original.

The other anomalous readings came from two McKean points. Hydration depths indicated the same time of manufacture for both points but an earlier time than was previously suggested. Their manufacture predated even the Rio Grande point. All three of the points with questionable temporal placement had distinct hydration rims so observer error in measurement would not have produced such anomolous results.

Cluster #2 was also run through the cluster analysis alone to test the internal consistency. It was found that while this cluster was largely homogeneous, subclusters were present, indicating that a source locality complex (Hurtado de Mendoza and Jester 1978) was represented in it as well. The source of artifacts in this cluster remains unidentified at this time.

Cluster #3 contained three samples from volcanic flows with documented locations. Two of these samples originated at the same flow, but the third came from a flow located about 20 miles from the other one. This grouping indicated a source locality complex (p. 424) and more obviously so since separate flows were represented.

Cluster #4 consisted of two artifacts, only one of which had its hydration rim analyzed. The source of these artifacts also remains unknown.

Twelve artifacts failed to cluster with other artifacts or source samples. In addition, six source samples did not contribute to the artifacts analyzed in this study. All stood alone in terms of their chemical composition and appeared to have originated at separate sources. The possibility exists that the flows that produced some or all of these unassociated artifacts are located in the San Juan Mountains of southern Colorado and northern New Mexico or the Jemez Mountains of northern New Mexico, both ranges being of volcanic origin.

This work, involving the use of obsidian hydration and XRF studies, has contributed to the better understanding of the prehistoric occupation and utilization of resources in the RGNF. Although neither the obsidian hydration nor the chemical fingerprinting provided completely conclusive temporal data, several positive results did emerge from the study:

1) Hydration rim thicknesses ranged from 1.27 to 12.35 microns and these measurements were used to arrange 104 artifacts into relative chrnological order. The distribution of rim measurements within two principle clusters indicated virtually continual utilization of forest resources for 10,000 years or more. No major influxes of people were noted and only two apparent gaps in forest utilization were noted.

2) Typologically assigned times of artifact manufacture, although relatively accurate, should be correlated with a second, independent dating technique before making final conclusions as to the age of an artifact.

3) Differences in hydration depths were present not only between sites but within them as well that indicated multicomponency in a number of sites. These differences may be used to develop a more exact chronology for the region. More diagnostic obsidian artifacts are needed for this development as it is not known to which period a nondiagnostic artifact in a multicomponent site is associated.

4) All available obsidian artifacts, and samples from several documented sources, including one local obsidian source from the RGNF were fingerprinted. The latter source, a flow located in the mountains east of Wolf Creek Pass, did not appear to have contributed to the archaeology of the RGNF. Northern New Mexico, especially the Jemez Mountains appears to have been a contributor. The presence of trade and/or travel between the two areas along the Rio Grande River has been documented (Pearsall 1939). Several unidentified sources appear to have contributed artifact material to the RGNF as well.

5) Chemicals identified as major components of obsidian are not always present in higher quantities than those designated as minor and trace elements. Obsidian flows may be comprised of large amounts of minor elements as well as, or rather than, major elements. Minor elements that appeared in quantities greater than one standard deviation from the mean included zinc, rubidium, strontium, yttrium, zirconium and niobium. Often, the quantity of these elements was greater than that of elements designated as major elements.

6) Additional obsidian studies in the area should focus on two problems. First, a concentrated study should be made of surrounding

obsidian sources in the attempt to correlate them with artifacts whose sources remain unknown. Temperature data and quantification of those elements vital to the hydration process should be more accurately ascertained in order to establish a hydration rate for the Rocky Mountains of southern Colorado. Second, a rate could not be established at this time because of the lack of certain chemical and temperature data. Quantification of those elements vital to the hydration process and calculation of necessary temperature data should be accomplished in order to establish a hydration rate for the Rocky Mountains of southern Colorado.

REFERENCES CITED

Ambrose, Wallace
1976 Intrinsic hydration rate dating of obsidian. In Advances in obsidian glass studies, edited by R. E. Taylor, pp. 81-105. Noyes Press, Park Ridge, New Jersey.

Asaro, F., H. V. Michel, R. Sidrys and F. Stross
1978 High precision chemical characterization of major obsidian sources in Guatemala. American Antiquity 43(3):436-443.

Bannister, B. and T. L. Smiley
1955 Dendrochronology. University of Arizona Bulletin 26(2): 177-195.

Bean, Luther
1964 Land of the blue sky people. The Monte Vista Journal. Monte Vista, Colorado.

Beardsley, John
1976 Report on the archaeology of the Rio Grande National Forest, 1975. In Cultural resource inventory of the Rio Grande National Forest, 1975-1976. Report No. 1, U.S.D.A. Forest Service, edited by Terry Dangler, pp. 54-64. Rio Grande National Forest, Colorado.

Bell, Robert E.
1977 Obsidian hydration studies in Highland Equador. American Antiquity 42(1):68-78.

Benedict, James B. and Byron L. Olson
1978 The Mount Albion complex. Center for Mountain Archaeology, Ward, Colorado.

Boyd, Henrietta
1940 Saguache antelope traps. Southwestern Lore 6(2):28-34.

Brainerd, George W.
1951 The place of chronological ordering in archaeological analysis. American Antiquity 16(4):301-313.

Breternitz, David A.
1966 An appraisal of tree-ring dated pottery in the Southwest. Anthropological Papers of the University of Arizona, No. 10.

Burns, George and Vincent Spero
1979 Cultural resource inventory of the Rio Grande National Forest, 1978. Report No. 3, U.S.D.A. Forest Service. Rio Grande National Forest, Colorado. Ms. on file, Rio Grande National Forest, Monte Vista, Colorado.

Dangler, Terry, George Burns, Sharon Kyle, Wayne Williams, Michael Wanner, Marilyn Armagast and Vincent Spero
1978 Cultural resource inventory of the Rio Grande National Forest, 1977. Report No. 2, U.S.D.A. Forest Service. Rio Grande National Forest, Colorado. Ms. on file, Rio Grande National Forest, Monte Vista, Colorado.

Dick, Herbert
1965 Bat Cave. The School of American Research, Monograph 27. Santa Fe, New Mexico.

1975 A surface survey of Indian camps on the Blanca Wildlife Refuge, San Luis Valley, Colorado. Ms. on file, Department of Anthropology, Adams State College, Colorado.

1976 Archaeological clearance of a road cut, Rio Grande National Forest, Mineral County, Colorado. Rio Grande National Forest, Colorado.

Dixon, W. J. and M. B. Brown
1979 BMDP-79 biomedical computer programs P-series. University of California Press, Berkeley.

Fenega, Franklin
1953 The weights of chipped stone points: a clue to their functions. Southwestern Journal of Anthropology 9:309-323.

Fleming, Stuart
1976 Dating in archaeology. St. Martins Press, New York.

Friedman, Irving
1976 Calculations of obsidian hydration rates from temperature measurements. In Advances in obsidian glass studies, edited by R. E. Taylor, pp. 173-180. Noyes Press, Park Ridge, New Jersey.

Friedman, Irving and Robert L. Smith
1960 A new dating method using obsidian. Part I, the development of the method. American Antiquity 25(4):476-493.

Friedman, Irving, R. L. Smith and W. D. Long
1966 The hydration of glass and the formation of perlite. Bulletin of the Geologic Society of America 77:323-330.

Friedman, Irving and Clifford Evans
1968 Obsidian dating revisited. Science 162(3855):813-874.

Friedman, Irving and William Long
1976 Hydration rate of obsidian. Science 191:347-352.

Friedman, Irving and Fred Trembour
1978 Obsidian: the dating stone. American Scientist 66(1):44-51.

Frison, George
1978 Prehistoric hunters of the high Plains. Academic Press, New York.

Gooding, John and Susan Kreuser
1980 An archaeological survey of Forest Highway 7. Colorado Department of Highways Project No. RS0149(5). Highway Salvage Report No. 31.

Griffin, James B., A. A. Gordus and G. A. Wright
1969 Identification of the sources of Hopewellian obsidian in the middle West. American Antiquity 34(1):1-14.

Hamilton, Alice L.
1974 Carnero Creek pictographs, La Garita, Colorado. Southwestern Lore 40(4):75-82.

Honea, Kenneth
1969 The Rio Grande complex and the northern Plains. Plains Anthropologist 14(43)57-70.

Hurst, Clarence T.
1939 A Ute shelter in Saguache County, Colorado. Southwestern Lore 5(3):57-64.

1941 A Folsom location in the San Luis Valley, Colorado. Southwestern Lore 7(2):31-33.

1943 A Folsom site in a Colorado mountain valley. American Antiquity 8(3):250-253.

Hurtado de Mendoza, Luis and William A. Jester
1978 Obsidian sources in Guatemala: a regional approach. American Antiquity 43(3):424-435.

Huscher, Elizabeth and Harold Huscher
1943 The hogan builders of Colorado. Southwestern Lore 9(2):1-92.

Irwin-Williams, Cynthia
1967 Picosa: the elementary Southwest culture. American Antiquity 32(4):441-457.

Irwin-Williams, Cynthia and H. J. Irwin
1966 Excavations at Magic Mountain: a diachronic study of Plains-Southwest relations. Proceedings, No. 12. Denver Museum of Natural History.

Jack, R. N. and I. S. E. Carmichael
1969 The chemical fingerprinting of acid volcanic rocks. California Division of Mines and Geology Special Report 100:17-30.

Jennings, Jesse D. and Edward Norbeck
1964 Prehistoric man in the new world. University of Chicago Press, Chicago, Illinois.

Jones, Kevin T.
1977 Archaeological test excavations at the Blanca Wildlife Refuge in the San Luis Valley, Colorado. Reports of the Laboratory of Public Archaeology, No. 12. Colorado State University.

Kimberlin, Jerome
1976 Obsidian hydration rate on chemically characterized samples. In Advances in obsidian glass studies, edited by R. E. Taylor, pp. 63-80. Noyes Press, Park Ridge, New Jersey.

Krieger, A. D.
1964 Early man in the new world. In Prehistoric man in the new world, edited by J. D. Jennings and E. Norbeck, pp. 51-69. University of Chicago Press, Chicago, Illinois.

Leudtke, Barbara
1979 The identification of sources of chert artifacts. American Antiquity 44(4):744-756.

Lister, Robert H.
1953 The stemmed indented base point, a possible horizon marker. American Antiquity 18(3):264-265.

Martin, Curtis and Patti Bell
1976 The archaeological survey of selected bypass routes through Alamosa. Colorado State Highway Department Project No. U160-2(14). Report No. 15. Ms. on file, Colorado Department of Highways, Boulder, Colorado.

Meighan, Clement W., Leonard J. Foote and Paul V. Aiello
1968 Obsidian dating in west Mexican archaeology. Science 160 (3832):1069-1975.

Michels, Joseph W.
1967 Archaeology and dating by hydration of obsidian. Science 159(3798):211-213.

1980 Bulk element composition versus trace element composition in the reconstruction of obsidian source systems. American Antiquity, in press.

Michels, Joseph W. and Car. A. Bebrich
1971 Obsidian hydration dating. In Dating techniques for the archaeologist, edited by Michael and Ralph, pp. 63-80. The MIT Press, Cambridge, Massachusetts.

Minor, Rick
1977 An obsidian hydration for the Lower Columbia River Valley. American Antiquity 42(4):616-619.

National Weather Service
1980 Personal communication.

Nelson, Fred W., Kirk K. Nielson, Nolan F. Mangelson, Max W. Hill, and Ray T. Matheny
1977 Preliminary studies of the trace element composition of obsidian artifacts from northern Campeche, Mexico. American Antiquity 42(2):209-225.

Nickens, Paul R.
1973 Archaeological reconnaissance of a proposed construction area. Blanca Wildlife Refuge, Alamosa County, Colorado. Ms. on file, Department of Anthropology, University of Colorado.

1979 Prehistoric cultural resources of the Rio Grande National Forest south-central Colorado. Centuries Research, Inc. USDA Forest Service Contract No. 53-82AK-8-01151.

Pearsall, Al
1939 Evidences of Pueblo culture in the San Luis Valley. Southwestern Lore 5(1):7-9.

Peterman, Zell
1980 Personal communication.

Renaud, Etienne Bernardeau
1942 The Rio Grande points. Southwestern Lore 8(3):33-36.

1944 The upper Rio Grande culture. Southwestern Lore 10(3): 35-37.

Robinson, W. S.
1951 A method for chronologically ordering archaeological deposits. American Antiquity 16(4):293-301.

Schroeder, Albert H.
1965 A brief history of the southern Utes. Southwestern Lore 30(4):53-78.

Shafer, Judy Ann
1978 An archaeological survey of Wolf Creek Pass east. Colorado Department of Highways Project No. FC 160-2(21). Highway Salvage Report No. 26.

Smith, R. L., R. A. Bailey and C. S. Ross
1970 Geologic map of the Jemez Mountains, New Mexico. Department of the Interior. U.S. Geologic Survey. Miscellaneous Geologic Investigations Map I-571.

Spero, Vincent
1978 A discriminant analysis of stylistically derived groups of isolated finds of projectile points found on the Rio Grande

National Forest, Colorado - using locational attributes to distinguish among the groups. Ms. on file, Department of Anthropology, University of Northern Colorado.

Spero, Vincent and Mary Mruzik-Doering
1980 Cultural resource inventory of the Rio Grande National Forest, 1979. Report No. 4 U.S.D.A. Forest Service. Rio Grande National Forest, Colorado. Ms. on file, Rio Grande National Forest, Monte Vista, Colorado.

Stross, F. H., H. V. Michel, F. Asaro, and R. Gruhn
1977 Sources of some obsidian flakes from a Paleo-Indian site in Guatemala. American Antiquity 42(1):114-118.

Tite, M. S.
1972 Methods of physical examination in archaeology. Seminar Press, New York.

Trembour, Fred
1980 Personal communication.

U.S. Government Printing Office
1974 Forest Service manual. Title 2300 recreation management. U.S. Government Printing Office, Washington, D.C.

Van Elsacker, Diana
1972 Magnasite survey. Ms. on file, University of Colorado Museum, Boulder, Colorado.

Williams, Jack R.
1951 The San Luis Valley blade. Southwestern Lore 17(1):8-12.

Wilson, Dorothy
1971 They came to hunt. San Luis Valley Historian 3(3):12-18.

Woldseth, Rolf
1972 All you ever wanted to know about X-ray energy spectrometry. Kevex Corporation.

Wormington, H. M.
1957 Ancient man in North America. Denver Museum of Natural History, Popular Series, No. 4.

APPENDICES

Appendix A

MEMORANDUM OF UNDERSTANDING BETWEEN THE RIO GRANDE NATIONAL FOREST, U.S. FOREST SERVICE, AND COLORADO STATE UNIVERSITY

WHEREAS, Colorado State University desired to do research on finds artifacts on land administered by the Rio Grande National Forest. These artifacts were found during calendar 1975, 1976, 1977, 1978, and 1979.

WHEREAS, the United States Forest Service is desirous of making available to Colorado State University for scientific and research purposes, artifacts which were found on National Forest land. This Memorandum of enderstanding is entered into under the authority provided in Executive Order 11593 of May 13, 1971 (36 FR 8921).

NOW, THEREFORE, The United States Forest Service, acting by and through the Forest Supervisor, Rio Grande National Forest, Monte Vista, Colorado, and Colorado State University, by and through the Chairperson, College of Sociology, Department of Anthropology, agree as follows:

A. The U.S. Forest Service will:

1. Make available to Colorado State University artifacts which were found on land administered by the Rio Grande National Forest.

B. Colorado State University:

1. Agrees that the artifacts will remain the property of the U.S. Forest Service, and that the Rio Grande National Forest may borrow them at any time.

2. Agrees to accept full responsibility for security when the artifacts are in their custody.

3. Will make artifacts available for examination to all bonafide researchers who have clearance in writing from the Forest Supervisor of the Rio Grande National Forest.

4. Agrees to provide the Rio Grande National Forest a copy of any research paper or report developed from the study of these artifacts.

5. Agrees to return artifacts and other materials to the Rio Grande National Forest Supervisors Office in Monte Vista, Colorado, on or before January 5, 1981.

C. The U.S. Forest Service and Colorado State University mutually agree:

1. That there will be a complete inventory made of all artifacts and materials released to Colorado State University.

This inventory will be prepared in writing and signed by a representative of the Rio Grande National Forest and Colorado State University prior to release of the artifacts. This inventory will also be checked and signed upon return of the artifacts.

2. That the authorization herein granted will have no force or effect until this Memorandum of Understanding is accepted and signed by the Forest Supervisor, Rio Grande National Forest, Monte Vista, Colorado, and the Chairperson of the College of Sociology, Department of Anthropology of Colorado State University.

3. No member or delegate to Congress, or Resident Commissioner, shall be admitted to any share of this agreement, or to any benefit that may arise therefrom; but this provision shall not be construed to extend to this agreement if made with a corporation for its general benefit.

4. The extension of benefits under the provisions of this agreement shall be without discrimination as to race, color, creed, sex, or national origin.

5. That none of the conditions of this Memorandum of Understanding as set forth herein can be varied or modified except through a written modification of the Memorandum acceptable to the U.S. Forest Service and Colorado State University.

6. The liability of the parties under this Memorandum is contingent upon the necessary appropriation and reservation of funds being made therefore.

In witness whereof the parties hereto have signed this Memorandum:

August 12, 1980 Date	[signed] Dan Peters [for] Forest Supervisor Rio Grande National Forest
14 August 1980 Date	[signed] Robert J. Theodoratus Chairperson College of Sociology Department of Anthropology Colorado State University

ADDITIONAL ARTIFACTS AND MATERIALS TAKEN

1975 Cold Springs Timber Sale: CS-10, 5CN17-25, 5CN18-65, CS116 a,b, 5CN19-97.

Fox Creek Timber Sale: 5CN20-10, 5CN22-29, 30a, 30b, 31, 33, 35, 52. 5CN24-83, 85.

1977 Fence Creek Timber Sale: 5SH54-16.

Tiny Beaver Timber Sale: 5RN75-04.

Black Mountain Timber Sale: 5HN63-02

Obsidian flakes: 5CN18-349, 5CN19- 899, 903, 5CN-31-38, 5ML02-07, 5ML7.

also

Cultural Resource Inventory Reports for 1975, 1976, 1979, and the following Reports from 1977: Black Mountain Timber Sale- 5HN09, 55, 56, 60, 61, and 63.
Apache Timber Sale- 5CN35, 36, 38, 40, 42, 45, and 46.
Conaboy Timber Sale- 5CN48, 49, and 50.
Neff Mountain Timber Sale- 5RN63.
Campo Molino Timber Sale- 5RN63.
Five Mile Park Timber Sale- 5RN64.
Tiny Beaver Timber Sale- 5RN75.
Fence Creek Timber Sale- 5SH54.
Spanish Bear Timber Sale- 5SH65 and 5SH71.

August 12, 1980
Date

[Received by] [signed] George R. Burns
Colorado State University

8/12/80
Date

[signed] Dan Peters

Appendix B

LIST OF ARTIFACTS REMOVED FROM CURATION

Smithsonian Artifact Number	Project Name	Year	Ranger District	County	Artifact Material	Artifact Type
5CN17-19	Cold Spgs.	1975	Conejos	Conejos	Obsidian	Point
-21	T.S.				Obsidian	Point
-23					Basalt	Point
-25					Obsidian	Point
-27					Obsidian	Point
-29					Chert	Point
-33					Basalt	Point
-34					Basalt	Point
-106					Obsidian	Point
-107					Obsidian	Point
-108					Basalt	Point
-121					Basalt	Point
-124					Obsidian	Point
5CN18-65	Cold Spgs.	1975	Conejos	Conejos	Obsidian	Point
-69	T.S.				Obsidian	Point
-72					Basalt	Point
-78					Obsidian	Point
-81					Chert	Point
-86					Basalt	Point
-88					Basalt	Point
-89					Basalt	Point
-91					Basalt	Point
-119					Basalt	Point
-349					Obsidian	Flake
5CN19-37	Cold Spgs.	1975	Conejos	Conejos	Basalt	Point
-43	T.S.				Basalt	Point
-46					Basalt	Point
-93					Chert	Point
-95					Chert	Point
-96					Jasper	Point
-97					Obsidian	Point
-100					Basalt	Point
-103					Chalcedony	Point
-899					Obsidian	Flake
-903					Obsidian	Flake
-03-79	Cold Spgs. T.S.	1979	Conejos	Conejos	Chert	Point
CS-IF-01	Cold Spgs.	1975	Conejos	Conejos	Basalt	Point
-02	T.S.				Basalt	Point
-03					Obsidian	Point
-09					Basalt	Point
-10					Basalt	Point
-15					Obsidian	Point
-17					Obsidian	Point

Smithsonian Artifact Number	Project Name	Year	Ranger District	County	Artifact Material	Artifact Type
CS-IF-32	Cold Spgs. T.S.	1975	Conejos	Conejos	Obsidian	Point
-51					Chert	Point
-52					Basalt	Point
-54					Obsidian	Point
-56					Basalt	Point
-57					Chert	Point
-59					Basalt	Point
-61					Basalt	Point
-62					Basalt	Point
-110					Basalt	Point
-115					Chert	Point
-116a					Obsidian	Flake
-116b					Obsidian	Flake
-118					Basalt	Point
-120					Obsidian	Point
5CN20-01,02	Fox Creek T.S.	1975	Conejos	Conejos	Chert	Point
-04					Basalt	Point
-05					Basalt	Point
-07					Basalt	Point
-08					Jasper	Point
-10					Obsidian	Point
5CN21-12					Basalt	Point
5CN22-29					Chert	Point
-30a					Obsidian	Point
-30b					Basalt	Point
-31					Obsidian	Biface
-33					Obsidian	Point
-35					Obsidian	Biface
-48					Basalt	Point
-49a,b					Basalt	Point
-51					Basalt	Point
-52					Basalt	Point
-55					Obsidian	Point
-56					Rhyolite	Point
-60					Quartzite	Point
-68					Basalt	Point
5CN24-83					Obsidian	Flake
-84					Basalt	Point
-85					Obsidian	Point
5CN25-88					Obsidian	Point
FC-IF-10	Fox Creek T.S.	1975	Conejos	Conejos	Obsidian	Biface
-15					Basalt	Point
-18					Basalt	Point
-19					Basalt	Point
-24					Obsidian	Point
-26					Basalt	Point
-57					Obsidian	Point

Smithsonian Artifact Number	Project Name	Year	Ranger District	County	Artifact Material	Artifact Type
FC-IF-58	Fox Creek T.S.				Basalt	Point
-70					Obsidian	Point
-72					Basalt	Point
-76					Chert	Point
5CN26-89	Osier Tree Plant	1975	Conejos	Conejos	Obsidian	Point
5CN31-38	Cat Creek T.S.	1975	Alamosa	Conejos	Obsidian	Flake
Point-01	Didde Site	1975	Creede	Mineral	Quartzite	Point
5ML02-7	Upper Pass Cr.	1975	Del Norte	Mineral	Obsidian	Flake
CD-02					Obsidian	Point
CD-03					Chert	Point
P-IF-06	Piedrosa T.S.	1976	Alamosa	Rio Grande	Chert	Point
SM-IF-01	Sargents Mesa	1976	Saguache	Saguache	Chert	Point
5RN18-04	Rock Creek T.S.	1976	Alamosa	Rio Grande	Chert	Point
RC-01					Obsidian	Point
IF-(No#)					Basalt	Point
WC-IF-01	Willow Cr. T.S.	1976	Del Norte	Rio Grande	Basalt	Point
5HN53-point	Pearl Lakes	1976	Creede	Mineral	Basalt	Point
RH-IF-01	Rito Hondo	1976	Conejos	Conejos	Obsidian	Point
5HN9 -01	Black Mtn. T.S.	1977	Creede	Hins-dale	Chert	Point
-06					Opal	Point
-08					Chert	Point
-09					Obsidian	Point
-11					Chert	Point
-15					Jasper	Point
-21					Quartzite	Point
-F1					Obsidian	Flake
-F2					Obsidian	Flake
-F3					Obsidian	Flake
-F4					Obsidian	Flake
5HN55-01					Jasper	Point
5HN56-02					Chert	Point
5HN60-02					Chert	Point

Smithsonian Artifact Number	Project Name	Year	Ranger District	County	Artifact Material	Artifact Type
5HN61-01					Obsidian	Point
5HN63-01					Chert	Point
-02					Obsidian	Biface
5HN71-09					Obsidian	
BM-IF-03					Chert	Point
5CN35-01	Apache T.S.	1977	Conejos	Conejos	Basalt	Point
-03					Obsidian	Point
5CN36-02					Chal	Point
5CN38-01					Flint	Point
5CN40-03					Obsidian	Point
-04					Obsidian	Point
5CN42-01					Obsidian	Point
-04					Basalt	Point
-05					Obsidian	Point
5CN45-01					Obsidian	Point
5CN46-03					Chert	Point
5CN48-02	Conoboy T.S.	1977	Conejos	Conejos	Chal	Point
-04					Basalt	Point
-06					Obsidian	Biface
-13					Obsidian	Point
-16					Basalt	Point
5CN49-01					Basalt	Point
5CN50-01					Basalt	Point
5CN62-02	Neff Mtn. T.S.	1977	Conejos	Conejos	Chal	Point
LPD-IF-01	Los Pinos Div.	1977	Conejos	Conejos	Obsidian	Point
M -IF-01	Massey T.S.	1977	Conejos	Conejos	Chal	Point
-02					Basalt	Point
5RN63-01	Campo Molino T.S.	1977	Del Norte	Rio Grande	Basalt	Point
5RN64-02	Five Mile Park	1977	Del Norte	Rio Grande	Chert	Point
IF-01					Chert	Point
IF-02					Basalt	Point
IF-03					Chert	Point
5RN75-01	Tiny Beaver T.S.	1977	Del Norte	Rio Grande	Quartzite	Point
-03					Obsidian	Point
-04					Obsidian	Flake
MR-IF-01	Million Res.	1977	Del Norte	Rio Grande	Basalt	Point

Smithsonian Artifact Number	Project Name	Year	Ranger District	County	Artifact Material	Artifact Type
PW-IF-02	Poage West T.S.	1977	Del Norte	Rio Grande	Chert	Point
MCME-IF-01	Mid. Cr. Mining	1977	Creede	Mineral	Chert	Point
5SH54-16	Fence Creek T.S.	1977	Saguache	Saguache	Obsidian	Biface
-18					Jasper	Point
5SH65-01	Spanish Bear	1977	Saguache	Saguache	Chalcedony	Point
-05					Chert	Point
-17					Rhyolite	Point
5SH71-05					Chert	Point
KA-IF-02	Kerber Antero	1977	Saguache	Saguache	Obsidian	Point
LM-IF-01	Lookout Mtn. T.S.	1977	Saguache	Saguache	Quartzite	Point
5CN22-01	Dry Lake T.S.	1978	Conejos	Conejos	Basalt	Point
5CN24-01					Chalcedony	Point
-02					Obsidian	Biface
DL-IF-01					Basalt	Point
-02					Basalt	Point
-04					Obsidian	Point
-05					Basalt	Point
-06					Basalt	Point
-07					Chert	Point
-08					Basalt	Point
5CN77-02	Osier Rd. Reloc.	1978	Conejos	Conejos	Obsidian	Point
-06					Obsidian	Point
-08					Obsidian	Flake
OR-IF-01					Basalt	Point
-05					Basalt	Point
-06					Basalt	Drill
5CN78-02	Bighorn Reveg.	1978	Conejos	Conejos	Obsidian	Point
-03					Obsidian	Point
-04					Quartzite	Point
-05					Obsidian	Point
-08					Obsidian	Knife
-18					Obsidian	Flake
BR-IF-02					Obsidian	Point
HC-IF-04	Bighorn Contour	1978	Conejos	Conejos	Obsidian	Point

Smithsonian Artifact Number	Project Name	Year	Ranger District	County	Artifact Material	Artifact Type
5CN79-02	Gomez Sp. T.S.	1978	Conejos	Conejos	Basalt	Point
5CN80-01					Obsidian	Point
5CN81-02					Obsidian	Point
5CN82-01					Basalt	Point
-06					Basalt	Point
-09					Basalt	Point
5CN83-02					Basalt	Point
-03					Obsidian	Scraper
5CN84-01					Basalt	Point
5CN87-01					Obsidian	Point
-03					Chert	Point
-04					Basalt	Point
-05					Obsidian	Biface
GS-IF-01	Gomez Sp. T.S.	1978	Conejos	Conejos	Chert	Point
-02					Chert	Point
-03					Basalt	Point
-05					Obsidian	Point
-06					Chert	Point
-09					Basalt	Point
-10a,b					Basalt	Point
-11					Basalt	Point
-12					Basalt	Point
-14					Basalt	Point
-15					Obsidian	Point
5SH259-01	S Carnero Rd	1978	Conejos	Conejos	Chert	Point
-02					Basalt	Point
-11					Chert	Point
5SH260-01					Chert	Point
5SH261-07	Cochetopa T.S.	1978	Saguache	Saguache	Chert	Point
-08					Chert	Point
-16					Obsidian	Flake
5SH262-01					Chert	Point
-05					Obsidian	Flake
-08					Obsidian	Flake
5SH263-09					Quartzite	Point
5SH264-02					Quartzite	Point
-15					Obsidian	Flake
5SH267-07					Chert	Point
B- IF- 01	Browns T.S.	1978	Saguache	Saguache	Quartzite	Point
-02					Chert	Point
-04					Chert	Point

Smithsonian Artifact Number	Project Name	Year	Ranger District	County	Artifact Material	Artifact Type
5ML10 -03	Deep Cr Ad Site	1978	Creede	Mineral	Chert	Point
-04					Basalt	Point
-17					Obsidian	Flake
H- IF-01	Hilman T.S.	1978	Alamosa	Conejos	Chert	Point
5CN94 -02	Globe Cr. T.S.	1978	Alamosa	Conejos	Quartzite	Point
-03					Basalt	Point
-05b					Obsidian	Point
-06					Basalt	Point
-08					Basalt	Point
-12					Obsidian	Point
-25					Obsidian	Flake
5CN97 -08	Conejos R. Imp.	1979	Conejos	Conejos	Obsidian	Point
-13					Felsite	Point
5CN101-03					Obsidian	Scraper
-08					Chert	Point
-09					Obsidian	Flake
-13					Obsidian	Flake
-50					Obsidian	Flake
-51					Obsidian	Flake
-52					Obsidian	Flake
-53					Obsidian	Flake
-63					Obsidian	Flake
-64					Obsidian	Flake
-65					Obsidian	Flake
-82					Obsidian	Flake
-83					Obsidian	Flake
-84					Obsidian	Flake
-124					Obsidian	Flake
-127					Obsidian	Flake
-128					Obsidian	Flake
5CN103-05					Obsidian	Point
-07					Obsidian	Flake
-10					Obsidian	Point
-11					Obsidian	Point
-12					Basalt	Point
5CN125-01					Obsidian	Point
-02					Obsidian	Flake
5CN126-01					Basalt	Point
CRI-IF-07					Basalt	Point
5RN86 -01	Difficult T.S.	1979	Del Norte	Rio Grande	Obsidian	Point
D - IF-01					Chalcedony	Point
-07					Basalt	Point
-08					Quartzite	Point
-09					Quartzite	Point

Smithsonian Artifact Number	Project Name	Year	Ranger District	County	Artifact Material	Artifact Type
5RN93 -01	Five Mile Park	1979	Del Norte	Rio Grande	Obsidian	Point
-02					Obsidian	Point
-03					Chert	Point
5RN94 -01					Basalt	Point
5RN95 -01					Basalt	Point
-02					Obsidian	Point
-04					Obsidian	Scraper
-13					Obsidian	Flake
-15					Obsidian	Scraper
-17					Obsidian	Point
5SH325-01	B.S. Stone Cir.	1979	Saguache	Saguache	Chert	Point
-06					Chert	Point
IF-01					Chert	Point
5SH326-02	Cave Cr. T.S.	1979	Saguache	Saguache	Obsidian	Point
-05					Felsite	Point
-07					Chalcedony	Point
5SH328-01					Chert	Point
-02					Basalt	Point
-06					Obsidian	Drill
5SH335-13					Basalt	Point
ML -IF-01	Mtn. Lion T.S.	1979	Saguache	Saguache	Chalcedony	Point
5ML12 -01	Didde Land Ex.	1979	Creede	Mineral	Chalcedony	Point
5ML18 -01	Bellows T.S.	1979	Creede	Mineral	Chert	Point
5ML19 -01					Chert	Point
5HN71 -01	Lost Trail C.G.	1979	Creede	Hinsdale	Chert	Point
-09					Obsidian	Point

Appendix C

ARTIFACT PHOTO RECORD

Roll/Frame	Project Name and Artifact Number				
1-1	Difficult Timber Sale				
	Top L-R	5RN86-01	IF-01	IF-07	
	Bot L-R		IF-08	IF-09	
1-2	Cochetopa T.S.				
	Top L-R	5SH261-07	5SH261-08	5SH262-01	
	Bot L-R	5SH262-05	5SH262-08	5SH261-16	
1-3	Cochetopa T.S.				
			5SH264-02		
	L-R	5SH263-09		5SH267-07	
			5SH264-15		
1-4	Tiny Beaver T.S.		5RN75-		
	Top L-R	03		01	
	Bot L-R		04		
1-5	Black Mountain T.S.				
	Top L-R	5HN55-01	5HN56-02	5HN60-02	
	Bot L-R	5HN63-01	5HN63-02	5HN61-01	BM-IF-03
1-6	Black Mtn. T.S.		5HN9-		
	Top L-R	01	06	08	09
	Bot L-R	11	15	21	F1 F2
					F4 F3
1-7	Rock Creek T.S.				
	Top L-R		IF-(No #)		
	Bot L-R	5RN18-04		RC-01	
1-8	Rito Hondo Sagebrush		IF-01		
1-9	Upper Pass Cr. T.S.		IF-		
	L-R	03	02		
1-10	Deep Creek Administration Site			5ML10-	
	Top L-R		03		
	Bot L-R	04		17	
1-11	Osier Tree Plantation		5CN26-89		
1-12	Cave Cr. T.S.				
	Top L-R	5SH328-01	5SH328-02		
	Bot L-R	5SH328-06	5SH335-13		

Roll/Frame	Project Name and Artifact Number						
1-13	Apache T.S.						
	Top L-R			5CN36-02			
	Bot L-R	5CN35-01			5CN35-03		
1-14	Apache T.S.						
	Top L-R	5CN38-01		5CN40-03			
	Bot L-R	5CN40-04		5CN46-03			
1-15	Apache T.S.						
	Top L-R	5CN42-01		5CN42-04			
	Bot L-R	5CN42-05		5CN45-01			
1-16	Bighorn Revegetation			5CN78-			
	Top L-R	02		03	04	05	
	Bot L-R	08		18	IF-02	HC-IF-04	
1-17	L-R Kerber Antero T.S. IF-02 Los Pinos Divide T.S. IF-01						
1-18	Cold Springs T.S.			5CN17-			
	Top L-R	19		21	23	25	
	Bot L-R	29		27	33	34	
1-19	Cold Springs T.S.			5CN17-			
	Top L-R	106		107	108		
	Bot L-R		121	124			
1-20	Cold Springs T.S.			5CN18-			
	Top L-R	65	69	72	78	81	
	Bot L-R	86	88	89	91	119	
1-21	Cold Springs T.S.			5CN19-			
	Top L-R	37	43	46	93	95	
	Bot L-R	96	97	100	103	03-79	
1-22	Cold Springs T.S.			CS-IF-			
	Top L-R	01	02	03	09	10	15
	Bot L-R	17	32	51	52	54	
1-23	Cold Springs T.S.			CS-IF-			
	Top L-R	56	57	59	61	62	
	Bot L-R	110	115	116a	118	120	
				116b			
1-24	Fox Creek T.S.			5CN20-			
	Top L-R	01, 02		04	05	07	
	Bot L-R	08		10	5CN21-12		
1-25	Fox Creek T.S.			5CN22-			
	Top L-R	55		31	29	30a	
	Bot L-R		30b	33	35		

Roll/Frame	Project Name and Artifact Number				
2-1	Fox Cr. T.S.		5CN22-		
	Top L-R	48	49a,b	51	52
	Bot L-r	56	60	68	
2-2	Fox Cr. T.S.		5CN24-		
			83		
	L-R	85		84	
			5CN25-88		
2-3	Fox Cr. T.S.		FC-IF-		
	Top L-R	10	15	18	
	Bot L-R	19	24		
2-4	Fox Cr. T.S.		FC-IF-		
	Top L-R	26	57	58	
	Bot L-R	70	72	76	
2-5	L-R	Didde Site Point-01		Didde Land Exchange 5ML12-01	
2-6	Conejos River Stream Improvement				
	Top L-R	5CN101-03	5CN101-08	5CN101-09	
	Bot L-R	5CN101-13	5CN97-08	5CN97-13	
2-7	Conejos R. Stream Imp.		5CN101-		
	Row 1	(FC 1)	50	51	52	53
	Row 2	(FC 2)	63	64	65	
	Row 3	(FC 4)	82	83	84	
	Row 4	(FC 5)	124	127	128	
2-8	Conejos R. Stream Imp.		5CN103-		
	Top L-R	05	07	10	
	Bot L-R	11	12		
2-9	Conejos R. Stream Imp.				
	Top L-R	5CN125-01	5CN125-02		
	Bot L-R	5CN126-01	CRI-IF-07		
2-10	Five Mile Park T.S.				
	Top L-R	5RN93-01	5RN93-02		
	Bot L-R	5RN93-03	5RN94-01		
2-11	Five Mile Park T.S.		5RN95-		
	Top L-R	01	02	04	
	Bot L-R	13	15	17	
2-12	Gomez Springs T.S.				
	Top L-R	5CN79-02	5CN80-01	5CN81-02	
	Bot L-R	5CN82-01	5CN82-06	5CN82-09	

Roll/Frame	Project Name and Artifact Number				
2-13	Gomez Sp. T.S.				
	Top L-R	5CN83-02	5CN83-03	5CN84-01	5CN87-01
	Bot L-R	5CN87-03	5CN87-04	5CN87-05	
2-14	Gomez Sp. T.S.		GS-IF-		
	Top L-R	01	02	03	
	Bot L-R	05	06		
2-15	Gomez Sp. T.S.		GS-IF-		
	Top L-R	09	10a,b	11	
	Bot L-R	12	14	15	
2-16	Globe Creek T.S.		5CN94-		
	Top L-R	02	03	05b	
	Bot L-R	06	08	12	25
2-17	Dry Lake T.S.				
	Top L-R	5CN22-01	5CN24-01		
	Bot L-R	5CN24-02			
2-18	Dry Lake T.S.		DL-IF-		
	Top L-R	01	02	04	
	Bot L-R	05	06	07	08
2-19	Osier Road Relocation				
	Top L-R	5CN77-02	5CN77-06	5CN77-08	
	Bot L-R	OR-IF-01	OR-IF-05	OR-IF-06	
2-20	Conoboy T.S.				
	Top L-R	5CN48-02	5CN48-04	5CN48-06	5CN48-13
	Bot L-R	5CN48-16	5CN49-01	5CN50-01	
2-21	Cave Creek T.S.		5SH326-		
	Top L-R	05			
	Bot L-R	02	07		
2-22	Big Spring Stone Circle				
	Top L-R	5SH325-01	IF-01		
	Bot L-R	5SH325-06			
2-23	Lost Trail Campground		5HN71-		
	L-R	01	09		
2-24	Fence Creek T.S.		5SH54-		
	L-R	16	18		
2-25	Spanish Bear T.S.				
	Top L-R	5SH65-01	5SH65-05		
	Bot L-R	5SH65-17	5SH71-05		

Roll/Frame	Project Name and Artifact Number
3-1	S. Carnero Road R.O.W. Top L-R 5SH259-01 5SH259-02 Bot L-R 5SH259-11 5SH260-01
3-2	Five Mile Park T.S. Top L-R 5RN64-02 FMP-IF-01 Bot L-R FMP-IF-02 FMP-IF-11
3-3	Browns T.S. BC-IF- Top 02 Bot L-R 01 04
3-4	Massey T.S. M-IF- Top L-R 01 Neff Mtn. T.S. 5CN62-02 Bot 02
3-5	L-R Poage West T.S. IF-02 Million Res. IF-01 Campo Molino T.S. 5RN63-01
3-6	Bellows T.S. L-R 5ML18-01 5ML19-01
3-7	L-R Middle Cr. Mining Exploration IF-01 Sargents Mesa IF-01
3-8	L-R Willow Cr. T.S. IF-01 Pearl Lakes 5HN53-point
3-9	L-R Piedrosa T.S. IF-06 Lookout Mtn. T.S. IF-01
3-10	L-R Hilman Lake T.S. IF-01 Mtn. Lion T.S. IF-01

Appendix D

Table 9.
Relative Percentages of Elements as Indicated by Trace Element Analysis

(1) Artifact Number	(2) GA	(3) ZN	(4) K	(5) CA	(6) FE	(7) RB	(8) SR	(9) Y
SCN1719	.01524	.01559	.02107	.01161	.1168	.06533	.01054	.04092
SCN1721	.01425	.01535	.01853	.01021	.1092	.06193	.09344	.03996
SCN1725	.01392	.01292	.01697	.01060	.06701	.06100	.01037	.02896
SCN1727	.01259	.01227	.01797	.01071	.06973	.05994	.01003	.03061
SCN17106	.01337	.01351	.01732	.01156	.07531	.05757	.01055	.02924
SCN17107	.01409	.01296	.01561	.008682	.05789	.04867	.008205	.02412
SCN17124	.01115	.01065	.01709	.009155	.06649	.05497	.009550	.02573
SCN1865	.01910	.01637	.01845	.01007	.06434	.06033	.009645	.02813
SCN1869	.01557	.01447	.01792	.01003	.06151	.05898	.009912	.02883
SCN18349	.009692	.01166	.01757	.008942	.1066	.06216	.01016	.04062
SCN1997	.01742	.01822	.02111	.01138	.1103	.06118	.01024	.04133
SCN19899	.01402	.01207	.01925	.01020	.06536	.06277	.01042	.03066
SCN19903	.009815	.009637	.01834	.01032	.06664	.05810	.01067	.03037
CSIF03	.01941	.01800	.02026	.01122	.06069	.05974	.01122	.03008
CSIF15	.01853	.01678	.01944	.01196	.06492	.06357	.01138	.03085
CSIF17	.01797	.01740	.01971	.01146	.08154	.06065	.01097	.03031
CSIF32	.01813	.01624	.02098	.01185	.08654	.06343	.01157	.03060
CSIF54	.01965	.01877	.01889	.01122	.1145	.06418	.01068	.04140
CSIF116A	.01567	.02128	.01106	.006916	.03348	.03336	.007580	.01774
CSIF116B	.02004	.01683	.01880	.01116	.06479	.05965	.009881	.02952
CSIF120	.01794	.01619	.01958	.01109	.06259	.06042	.01054	.03023
SCN2010	.01755	.01588	.01782	.009970	.05590	.05742	.01021	.02831
SCN2230A	.01380	.01368	.008050	.005325	.02893	.02432	.006496	.01313
SCN2231	.01673	.01443	.01866	.01065	.06118	.05923	.009532	.02749
SCN2233	.01523	.01437	.01005	.006976	.05890	.03152	.008189	.02141
SCN2235	.01722	.01526	.01968	.01100	.06304	.06195	.01039	.02955
SCN2255	.01832	.01660	.02072	.01235	.07382	.06515	.01145	.03051
SCN2402	.01755	.01653	.01834	.01115	.06180	.06475	.01017	.03040
OLIF04	.01834	.01652	.01894	.01185	.05969	.06102	.01058	.03137
SCN2483	.01625	.01510	.01514	.009044	.05157	.04993	.009583	.02559
SCN2485	.01596	.01495	.01087	.007505	.04038	.03557	.008499	.01775
SCN2588	.01862	.01797	.01880	.01050	.1186	.06505	.01093	.04173
FCIF10	.01788	.01765	.01962	.01073	.1141	.06407	.01083	.04054
FCIF24	.01811	.01752	.01950	.01089	.1223	.06510	.01063	.04111
FCIF57	.01923	.01757	.02251	.01311	.08271	.06998	.01257	.03414
FCIF70	.01669	.01603	.01566	.009824	.05814	.04887	.009941	.02417
SCN2689	.01379	.01481	.01606	.009251	.09561	.04782	.008662	.03303
SCN3138	.01111	.01277	.01967	.01002	.1174	.06155	.009621	.03993
SCN3503	.01608	.01480	.01964	.01108	.06336	.06382	.01129	.03146
SCN4003	.01556	.01479	.01815	.01072	.06260	.06038	.009435	.02950
SCN4004	.01545	.01430	.01844	.01012	.06293	.06158	.01001	.02894
SCN4201	.01359	.01624	.01636	.009723	.09954	.05636	.008656	.03571
SCN4205	.01178	.01094	.01643	.009481	.05269	.05341	.008563	.02541
SCN4501	.01387	.01285	.01729	.01132	.07195	.05821	.009919	.02340
SCN4806	.01820	.01683	.02228	.01108	.05920	.06065	.01092	.02821
SCN4813	.008559	.01032	.01856	.009953	.1152	.05982	.01004	.03831
SCN7702	.01361	.01501	.01700	.008719	.09633	.05221	.008782	.03302
SCN7706	.01272	.01351	.01864	.009732	.1080	.05979	.009817	.03866
SCN7708	.01474	.01501	.01781	.01176	.06661	.1016	.009695	.05098
ORIF06	.01542	.01581	.01871	.01162	.06369	.1031	.009644	.05277
SCN7802	.01771	.01534	.01321	.008682	.04085	.04297	.008893	.02142
SCN7803	.01799	.01696	.01539	.009502	.05051	.05106	.009761	.02606
SCN7805	.008973	.009148	.01658	.009429	.05564	.05631	.01052	.02962
SCN7808	.007651	.009338	.01630	.009005	.09711	.05615	.009652	.03516
SCN7818	.01640	.01541	.01524	.009386	.04869	.04935	.009404	.02476
BRIF02	.01765	.01635	.01794	.01085	.06493	.06155	.01062	.02872
SCN8001	.01580	.01755	.01675	.009722	.1092	.07249	.007456	.04933
SCN8102	.01719	.01585	.01945	.01155	.06263	.06172	.01064	.03083
SCN8303	.01862	.01713	.02111	.01299	.06436	.06298	.01070	.03021
SCN8701	.01551	.01480	.01786	.01073	.06069	.06014	.009473	.02875
SCN8705	.01504	.01398	.01754	.009594	.05849	.05322	.009712	.02489
GSIF05	.01847	.01924	.01881	.01112	.06081	.1036	.008839	.05143
GSIF15	.01593	.01460	.01683	.009239	.05763	.05095	.008614	.02463
SCN9405B	.01554	.01411	.01230	.007680	.03343	.03584	.008347	.01789
SCN9412	.01858	.01646	.01877	.01034	.1113	.06675	.01092	.04171
SCN9708	.01480	.01348	.01119	.007055	.03129	.03000	.007556	.01634
SCN10103	.01506	.01521	.01760	.01057	.05846	.06021	.009789	.02859
SCN10109	.01534	.01505	.01550	.009342	.05391	.05255	.009150	.02540
SCN10113	.01475	.01298	.01933	.01162	.06676	.06645	.01081	.03035
SCN10150	.01586	.01518	.01734	.01042	.07204	.06022	.01069	.02985
SCN10151	.01433	.01381	.01757	.01073	.05722	.05703	.009994	.02709
SCN10152	.01388	.01259	.01264	.009575	.04738	.04616	.009205	.02372
SCN10153	.01444	.01432	.01409	.008327	.04347	.04395	.008957	.02223
SCN10163	.01264	.01141	.01255	.008843	.03930	.04000	.008988	.02047
SCN10164	.01272	.01569	.01261	.007680	.03720	.03504	.008464	.01949
SCN10165	.008592	.007399	.01336	.008407	.04816	.04804	.009229	.02388
SCN10182	.01508	.01467	.01666	.01064	.05877	.05955	.009823	.02864
SCN10183	.01453	.01301	.01477	.008526	.04710	.04817	.009459	.02487
SCN10184	.01340	.01247	.01254	.008046	.03936	.03955	.008498	.01947
SCN101124	.01259	.01729	.008446	.006210	.02641	.02628	.007700	.01428
SCN101127	.01162	.01846	.007632	.005542	.02193	.02036	.006828	.01246
SCN101128	.01197	.01548	.01219	.007164	.03512	.03640	.008112	.01881
SCN10305	.01374	.01318	.01835	.01008	.05804	.05749	.009159	.02695
SCN10307	.01508	.01388	.01752	.009560	.05499	.05741	.009717	.02812
SCN10310	.01497	.01454	.01966	.01079	.06214	.05854	.01067	.02975
SCN10311	.01662	.01520	.01714	.009293	.05554	.05588	.009585	.02743
SCN12501	.01438	.01388	.01484	.009802	.05849	.04877	.008502	.02383
SCN12502	.01459	.01451	.01646	.01027	.06202	.05542	.009163	.02634
SCN9425	.006059	.005890	.01506	.009256	.05064	.04899	.007720	.02375
HCIF04	.01734	.01763	.01863	.01019	.1119	.06214	.009880	.04014
RHIF01	.01731	.01607	.01867	.01186	.07334	.06389	.01058	.03093
LPOIF01	.01944	.01769	.01914	.01264	.06260	.06065	.01063	.02852
SHN909	.01562	.01500	.01785	.01037	.05861	.05489	.01012	.02683
SHN9F1	.01453	.01407	.01818	.009737	.06239	.05669	.008426	.02803
SHN9F2	.01521	.01498	.01847	.01036	.1018	.05898	.009860	.03780

Table 9. (cont'd)

SHN9F3	.01476	.01462	.01748	.01021	.06352	.05803	.009410	.02805
SHN9F4	.01224	.01366	.01481	.008975	.05412	.04840	.008360	.02308
SHN6101	.01346	.01396	.01617	.009245	.08831	.04897	.008150	.03258
SHN6302	.01503	.01417	.01820	.01020	.06164	.05808	.008898	.02870
SHN7109	.01549	.01597	.01219	.007589	.06651	.03721	.008858	.02490
SML207	.01187	.01241	.02062	.01107	.1186	.06691	.01093	.04347
SML7	.01335	.01329	.02010	.01162	.1128	.06388	.01011	.03930
SML1017	.01768	.01563	.01636	.009736	.05688	.05272	.009756	.02673
SRN7503	.01432	.01289	.01986	.01078	.06313	.06127	.01092	.02962
SRN7504	.01100	.01017	.01714	.009644	.06323	.05861	.009982	.02944
SRN8601	.01494	.01447	.01922	.01118	.05974	.05777	.009891	.02879
SRN9301	.008201	.01039	.01773	.009549	.06183	.1095	.009614	.05572
SRN9302	.007995	.009204	.01683	.009435	.05653	.1034	.008558	.05107
SRN9502	.009462	.008728	.01787	.009909	.05711	.06228	.01122	.03038
SRN9504	.008842	.009179	.01908	.01062	.05906	.06225	.01127	.03125
SRN9513	.006596	.008675	.01794	.009587	.09551	.05710	.008887	.03343
SRN9515	.08429	.08297	.01916	.01043	.05830	.05774	.01093	.02954
SRN9517	.006319	.007252	.01655	.009065	.05402	.05594	.008850	.02732
CD02	.01927	.01719	.02020	.01117	.06095	.06222	.01107	.03026
RC01	.005866	.007957	.01846	.009436	.1078	.05777	.008450	.03718
SSH5416	.01455	.01357	.01813	.01026	.06593	.05814	.01016	.02714
SSHZ6116	.01671	.01566	.01807	.01123	.06815	.05775	.01010	.02820
SSH26205	.01588	.01421	.01851	.01021	.06180	.06107	.009931	.02968
SSH26415	.01715	.01711	.02076	.01238	.08703	.08577	.01053	.03531
SSH32602	.01104	.01145	.01869	.01012	.1103	.06347	.01155	.04212
SSH32806	.01127	.01118	.01746	.01108	.06846	.05934	.01086	.02862
KAIF02	.01731	.01614	.01815	.01146	.05909	.06092	.01004	.02992
APACHE	.009560	.01323	.01587	.01029	.05223	.06562	.01237	.02522
OBSCLIF	.02279	.02270	.02392	.01449	.1315	.09553	.01243	.06452
BLACAN2	.02095	.02004	.02089	.01296	.1165	.07097	.01194	.04533
FRAZCAN	.01954	.01764	.01885	.01042	.06679	.04724	.01556	.02847
TRES11	.01368	.01329	.01753	.01087	.06315	.05116	.02238	.02768
TRES12	.01419	.01421	.02084	.01078	.06790	.05182	.02095	.02648
ARRHON	.01460	.01418	.02026	.01039	.07042	.05114	.02325	.02721
TRES363	.01828	.01732	.02326	.01583	.08015	.06536	.02726	.03442
LUDMA	.02040	.02367	.02127	.01369	.1900	.06240	.01292	.04632
ARRCAN	.01345	.01424	.01878	.01098	.05689	.04593	.01714	.02158
SAMPLE SIZE	132	132	132	132	132	132	132	132
MEAN	.01477	.01450	.01744	.01019	.07016	.05796	.01032	.03072
STAN.DEV	.003373	.002965	.002923	.001569	.02572	.01398	.002747	.008556
MAX	.02279	.02367	.02392	.01583	.1900	.1095	.02726	.06452
MIN	.005866	.005890	.007632	.005325	.02193	.02036	.006496	.01246

Table 9. (cont'd)

Artifact Number	(10) ZR	(11) NB	(12) SC	(13) MN	(14) PB	(15) TI	(16) Percent of Elements Detected (Columns 2-15)	(17) Other 17 Elements
SCN1719	.1121	.05241	.006279	.01147	.01461	.07578	.501547	.498453
SCN1721	.1076	.04979	.005585	.01087	.01355	.006808	.433017	.566983
SCN1725	.04733	.04405	.005688	.009492	.01358	.006029	.303869	.696131
SCN1727	.04650	.04448	.005464	.01018	.01368	.006482	.350636	.649364
SCN17106	.05080	.04502	.006128	.01011	.01290	.007951	.361339	.638661
SCN17107	.03924	.03373	.004862	.008596	.01376	.005991	.296406	.703594
SCN17124	.04297	.03942	.005150	.009313	.01223	.006669	.320487	.679513
SCN1865	.04766	.04241	.005949	.01131	.01630	.006103	.356176	.643824
SCN1869	.04724	.04186	.005392	.009860	.01733	.005846	.32683	.67317
SCN18349	.1030	.04876	.005160	.009326	.01063	.006188	.450468	.549532
SCN1997	.1069	.04918	.005384	.01041	.01441	.006653	.484117	.515883
SCN19899	.04858	.04353	.005674	.009807	.01276	.006617	.351718	.648282
SCN19903	.04717	.04346	.005385	.009346	.01211	.006258	.337621	.662379
CSIF03	.04807	.04420	.006489	.01179	.01706	.007511	.36574	.63426
CSIF15	.04854	.04361	.006674	.01198	.01669	.008381	.376005	.623995
CSIF17	.04842	.04513	.006538	.01179	.01697	.007125	.385983	.614017
CSIF32	.05203	.04513	.006249	.01141	.01935	.007706	.401215	.598785
CSIF54	.1111	.05415	.006392	.01129	.01874	.007532	.508494	.491506
CSIF116A	.02831	.02580	.004390	.008244	.01340	.004506	.231736	.768264
CSIF116B	.04764	.04381	.005980	.01145	.01703	.007074	.360055	.639945
CSIF120	.04983	.04350	.006730	.01137	.01621	.006183	.362403	.637597
SCN2010	.05192	.04188	.006250	.01009	.01537	.006488	.344878	.655122
SCN2230A	.02049	.01960	.003558	.006012	.01113	.004166	.178687	.821313
SCN2231	.04718	.04413	.005116	.01043	.01579	.006440	.346988	.653012
SCN2233	.05242	.02714	.003842	.007001	.01280	.004486	.274334	.725666
SCN2235	.05138	.04532	.005229	.01086	.01582	.005929	.362628	.637372
SCN2255	.05199	.04525	.006196	.01147	.01751	.008074	.38941	.61059
SCN2402	.05178	.04561	.006825	.01190	.01877	.007034	.372609	.627391
DLIF04	.04958	.04489	.006558	.01120	.01744	.006858	.364836	.635164
SCN2483	.04108	.03693	.005394	.009008	.01487	.005862	.305351	.694649
SCN2485	.02794	.02660	.004693	.008193	.01224	.005380	.23653	.76347
SCN2588	.1126	.05322	.006570	.01152	.01816	.007726	.511996	.488004
FCIF10	.1091	.05095	.006063	.01169	.01689	.007285	.497198	.502802
FCIF24	.1124	.05127	.006315	.01138	.01774	.007376	.511641	.488359
FCIF57	.05698	.05052	.006928	.01325	.01875	.008637	.426885	.573115
FCIF70	.03935	.03777	.005540	.009339	.01535	.005640	.312314	.687686
SCN2689	.08677	.04191	.005389	.009709	.01368	.006131	.402622	.597378
SCN3138	.1084	.05018	.004869	.008926	.01182	.005630	.471896	.528104
SCN3503	.05220	.04707	.006355	.01135	.01536	.007278	.374143	.625857
SCN4003	.05090	.04322	.005321	.01033	.01376	.006611	.351277	.648723
SCN4004	.04934	.04532	.005883	.01049	.01495	.006419	.354172	.645828
SCN4201	.09628	.04487	.005570	.01048	.01149	.006443	.431312	.568688
SCN4205	.04172	.03920	.004431	.008563	.01166	.007106	.301384	.698616
SCN4501	.04770	.04339	.005775	.009676	.01464	.006850	.35184	.64816
SCN4806	.04785	.04262	.005368	.01161	.01581	.006834	.357462	.642538
SCN4813	.1076	.04959	.004811	.008872	.01004	.006136	.457811	.542189
SCN7702	.08905	.04475	.005583	.009890	.01163	.006796	.41238	.58762
SCN7706	.1035	.04936	.005788	.009817	.01356	.007820	.460714	.539286
SCN7708	.05428	.07028	.006354	.01632	.01385	.007607	.456896	.543104
ORIF06	.05557	.07023	.006041	.01733	.01368	.006883	.460498	.539502
SCN7802	.03440	.03101	.004966	.007838	.01524	.004982	.267511	.732489
SCN7803	.04243	.03801	.005216	.009864	.01616	.005836	.314569	.685431
SCN7805	.04769	.04443	.004960	.008973	.01146	.006379	.320112	.679888
SCN7808	.09480	.04602	.004689	.007592	.009770	.009221	.412458	.587542
SCN7818	.04044	.03653	.004946	.009369	.01520	.006060	.301185	.698815
BRIF02	.04911	.04363	.005801	.01076	.01632	.006482	.360713	.639287
SCN8001	.1065	.07239	.005713	.01272	.01557	.006101	.517292	.482708
SCN8102	.04929	.04531	.006452	.01128	.01588	.006644	.364716	.635284
SCN8303	.04891	.04500	.008321	.01279	.01682	.008895	.378836	.621164
SCN8701	.04617	.04168	.005801	.01021	.01495	.006438	.343202	.656798
SCN8705	.04472	.03936	.005541	.01053	.01449	.006089	.323196	.676804
GSIF05	.05492	.07206	.005652	.01710	.01703	.005958	.465039	.534961
GSIF15	.04046	.03627	.005735	.01014	.01370	.005193	.309921	.690079
SCN94058	.03096	.02849	.004859	.008268	.01287	.007308	.237892	.762108
SCN9412	.1131	.05320	.006186	.01097	.01659	.006984	.50186	.49814
SCN9708	.02669	.02477	.003713	.007297	.01303	.004327	.211538	.788462
SCN10103	.04869	.04298	.005877	.01038	.01416	.006317	.343893	.656107
SCN10109	.04437	.03839	.005743	.009214	.01318	.005743	.364569	.635431
SCN10113	.05463	.04814	.006374	.01110	.01510	.006994	.375388	.624612
SCN10150	.04961	.04404	.005314	.01032	.01446	.007150	.362494	.637506
SCN10151	.04670	.04368	.005711	.01003	.01326	.006199	.333354	.666646
SCN10152	.03796	.03419	.005272	.008393	.01312	.005713	.279798	.720202
SCN10153	.03505	.03238	.004633	.009221	.01309	.005043	.310898	.689102
SCN10163	.03290	.03047	.004177	.007812	.01119	.005461	.246211	.753789
SCN10164	.03063	.02835	.005025	.007145	.01081	.005235	.236089	.763911
SCN10165	.03825	.03315	.003576	.008016	.009907	.004810	.264776	.735224
SCN10182	.04677	.04285	.005734	.01048	.01296	.006735	.339362	.660638
SCN10183	.03847	.03649	.005003	.008205	.01256	.004955	.286118	.713882
SCN10184	.03154	.02985	.004402	.007686	.01251	.004947	.244269	.755731
SCN101124	.02299	.02134	.003823	.005934	.01165	.003850	.188793	.811207
SCN101127	.01714	.01755	.003575	.005925	.009463	.003515	.161998	.838002
SCN101128	.03003	.02776	.003997	.007086	.01247	.004854	.231443	.768557
SCN10305	.04866	.04110	.005448	.01054	.01251	.006112	.331359	.668641
SCN10307	.04604	.04160	.005468	.01053	.01421	.006704	.330829	.669171
SCN10310	.04843	.04326	.006610	.01101	.01578	.006677	.352827	.647173
SCN10311	.04356	.03969	.005280	.01036	.01512	.006098	.326796	.673204
SCN12501	.03849	.03567	.005581	.008962	.01170	.01118	.304077	.0695923
SCN12502	.04305	.04054	.005039	.01039	.01305	.005467	.326309	.673691
SCN9425	.04111	.03839	.003829	.007216	.007468	.009256	.274634	.725366
HCIF04	.1085	.04943	.005832	.01168	.01503	.007032	.485354	.514646
RHIF01	.05315	.04712	.006836	.01173	.01700	.007044	.38553	.61447
LPOIF01	.04912	.04373	.007787	.01341	.01821	.008933	.37218	.62782
SHN909	.04625	.04081	.005445	.009765	.01478	.005945	.332285	.667715
SHN9F1	.04718	.04085	.005820	.01004	.01439	.006123	.337356	.662644
SHN9F2	.09676	.04723	.006365	.01011	.01464	.006794	.448849	.551151

Table 9. (cont'd)

SHN9F3	.04497	.04020	.005850	.01039	.01465	.006798	.338938	.661062
SHN9F4	.03662	.03401	.005092	.009611	.01180	.005707	.286485	.713515
SHN6101	.08771	.04013	.005538	.008686	.01286	.005984	.391753	.608247
SHN6302	.04398	.04118	.005533	.009515	.01385	.006661	.335637	.664363
SHN7109	.06403	.03256	.004725	.008379	.01301	.005388	.3169598	.6830402
SML207	.1168	.05459	.005495	.01009	.01285	.006474	.502179	.497821
SML7	.1067	.05119	.005946	.01011	.01261	.006609	.477615	.522385
SML1017	.04368	.03918	.004671	.01043	.01608	.007430	.326963	.673037
SRN7503	.04965	.04481	.005978	.01008	.01533	.007513	.356151	.643849
SRN7504	.04742	.04281	.004771	.008950	.01216	.004957	.330284	.669716
SRN8601	.04676	.04156	.005656	.01017	.01444	.007542	.342129	.657871
SRN9301	.06048	.07595	.004710	.01549	.01038	.005652	.455196	.544804
SRN9302	.05716	.07378	.005098	.01437	.009303	.01986	.442593	.557407
SRN9502	.05085	.04447	.005585	.009015	.009988	.005920	.332787	.667213
SRN9504	.05089	.04551	.005568	.009439	.01033	.005782	.33907	.66093
SRN9513	.1039	.04906	.005515	.008102	.008335	.005493	.42313	.57687
SRN9515	.04806	.04538	.005849	.008610	.009678	.007098	.327501	.672499
SRN9517	.04646	.04066	.004847	.008114	.007306	.004919	.297622	.702378
COO2	.04873	.04473	.006718	.01163	.01806	.006971	.369169	.630831
RC01	.1030	.04891	.004675	.007957	.008042	.006121	.431624	.568376
SSH5416	.04549	.04140	.005723	.01023	.01452	.005995	.341238	.658762
SSH26116	.05004	.04430	.006162	.01136	.01448	.006694	.358906	.641094
SSH26205	.04611	.04179	.005382	.01025	.01421	.005915	.344948	.655052
SSH26415	.08609	.03559	.006775	.01579	.01600	.007718	.454003	.545997
SSH32602	.1121	.05182	.005726	.009383	.01346	.006175	.477404	.522596
SSH32806	.04515	.04167	.005259	.01003	.01400	.006129	.340508	.659492
KAIF02	.04984	.04368	.007048	.01159	.01814	.007048	.360376	.639624
APACHE	.04883	.03176	.005870	.008449	.01161	.006143	.317052	.682948
OBSCLIF	.1161	.04912	.009367	.01282	.02106	.01014	.606487	.393513
BLACAN2	.1196	.05407	.006594	.01282	.02002	.008531	.541215	.458785
FRAICAN	.06127	.03182	.006972	.01158	.01681	.007854	.360516	.639484
TRES11	.05284	.03613	.005544	.01100	.01378	.005798	.344832	.655168
TRES12	.06446	.04640	.005913	.01038	.01405	.006725	.375098	.624902
ARRHON	.06905	.04651	.005869	.01048	.01407	.007043	.384472	.615528
TRES363	.06249	.04230	.008394	.01500	.01717	.008098	.435332	.564668
LUDMA	.2031	.04437	.09629	.01440	.01737	.01203	.691569	.308431
ARRCAN	.05498	.03780	.006401	.008692	.01217	.006603	.325636	.674364
SAMPLE SIZE	132	132	132	132	132	132		
MEAN	.05970	.04301	.005657	.01029	.01409	.006670		
STAN.DEV	.02867	.009640	.0009838	.002047	.002638	.001712		
MAX	.2031	.07595	.009629	.01733	.02106	.01986		
MIN	.01714	.01755	.003558	.005925	.007306	.003513		