ALLUVIAL STRATIGRAPHY AND SOIL FORMATION AT

COX RANCH PUEBLO, NEW MEXICO

By

STEPHANIE VANBUSKIRK

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of STEPHANIE VANBUSKIRK find it satisfactory and recommend that it be accepted.

Chair

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Abstract

by Stephanie VanBuskirk, M.A.
Washington State University
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Chair: Gary Huckleberry

Cox Ranch Pueblo is a 900-year old Anasazi site located in west-central New Mexico, near the southern edge of the Chacoan system. Both sociocultural and environmental factors may have contributed to the abandonment of the pueblo around A.D. 1130. Numerous arroyos provide access to subsurface deposits at and around Cox Ranch Pueblo and insight into past environmental changes. I radiocarbon dated and analyzed alluvial stratigraphy and buried soils in four of these arroyos to gain a better understanding of changes in geomorphic conditions at the site, their possible causes, and their archaeological implications.

Arroyos in the Cox Ranch Pueblo area expose stratigraphic layers representative of episodic deposition on the piedmont over at least the last 8,000 years, as well as previous episodes of arroyo cutting. A buried arroyo predates the occupation of Cox Ranch Pueblo and does not appear to be linked to abandonment. Arroyo formation is likely linked to changes in stream dynamics related to climatic changes. Significantly

moister periods than present are indicated by organic fine-textured paleosols. Fluctuations in soil moisture due to regional climatic variability may have significantly influenced both the development of agriculture in the Cox Ranch Pueblo area during the Early Agricultural period and the abandonment of the pueblo in the twelfth century. Future work should focus on improved temporal control on soil formation and arroyo cutting on the piedmont, thus facilitating correlation to the regional paleoenvironmental record.

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CHAPTER ONE

INTRODUCTION

The mesa and canyon country of the American Southwest uplands is home to numerous ruins that have long intrigued archaeologists. One such ruin is Cox Ranch Pueblo, an eleventh- and twelfth-century community located in the Cibola region of west-central New Mexico, approximately 40 km from the Arizona border. This area is near the boundary between the Anasazi (prehispanic Puebloan) tradition centered to the north in the heart of the Colorado Pleateau, and the Mogollon tradition to the south in the central highlands of eastern Arizona and western New Mexico (Figure 1.1). A major development in the Anasazi world was the rise and fall of a regional system centered on Chaco Canyon in the San Juan Basin of northwestern New Mexico (Cordell 1997:188-192, 305-331). Beginning in the ninth century people in Chaco Canyon built large masonry structures called great houses. During the following century great houses spread throughout the San Juan Basin and beyond. The extent of the Chacoan system has been defined based on the presence of these Chacoan style great houses (Judge 1991). However, the nature of the system and the ties between its communities are highly debated. Cox Ranch Pueblo—located 190 km south of Chaco Canyon on the southern frontier of the system—is one of more than 200 Chacoan great houses now recognized outside of the canyon (Mahoney and Kantner 2000). Its history is tied to events at Chaco Canyon, and also to Mogollon social developments to the south.

Study of Cox Ranch Pueblo may provide additional insight into the nature and organization of the Chacoan system. The Cox Ranch Community Research project led

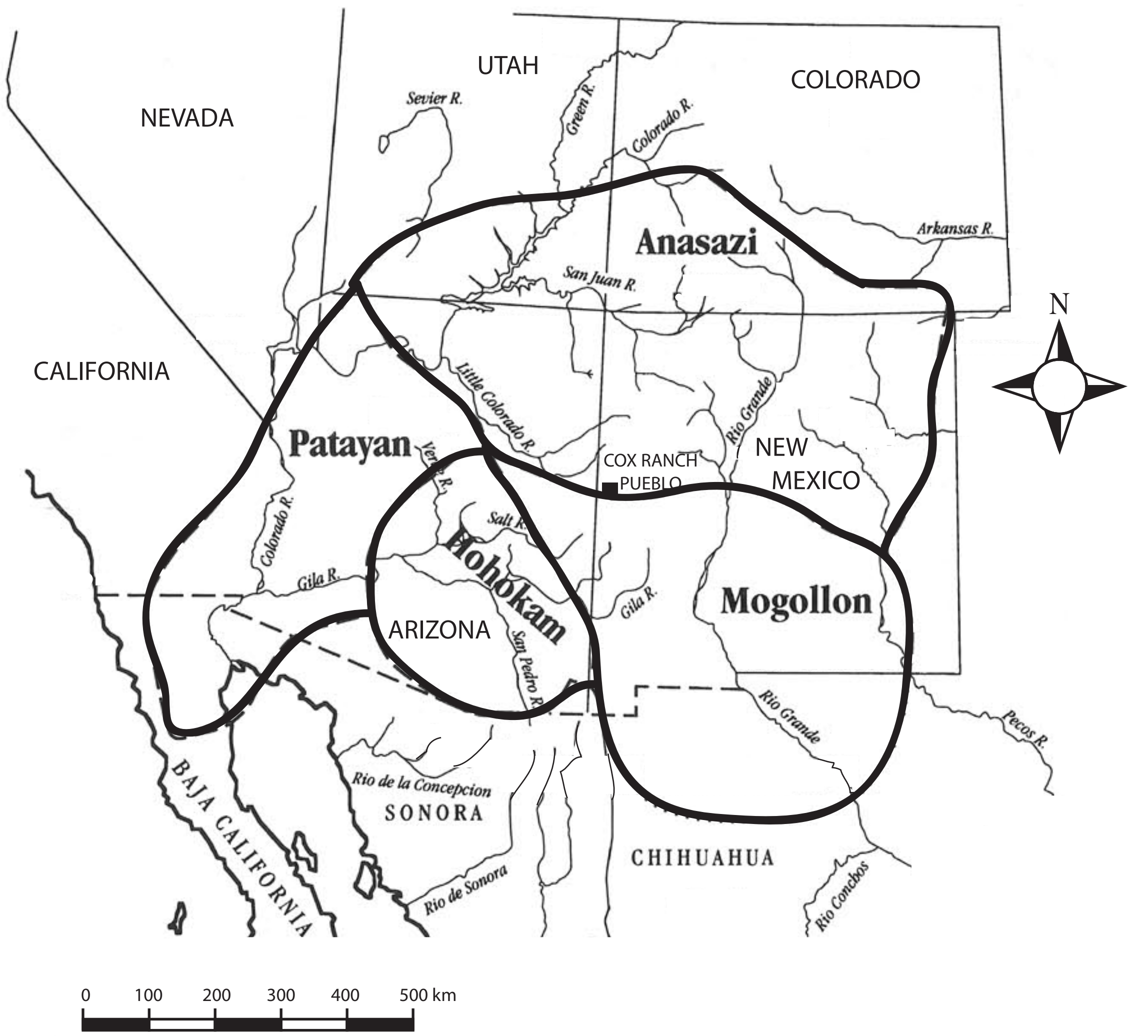

Figure 1.1. Approximate boundaries between cultural traditions in the Southwest and location of Cox Ranch Pueblo (Cordell 1997:Figure 1.7).

by Dr. Andrew Duff at Washington State University has conducted excavations at Cox Ranch Pueblo and survey of the surrounding region. The project's goals include documenting the development and eventual abandonment of the community and gaining a better understanding of community organization and interaction within the regional political and ideological system. To do this, the community must be placed within an environmental context because both sociocultural and environmental processes can contribute to changes in population dynamics and settlement patterns.

Environmental change has long been considered a causal factor in cultural change. This is especially true for the Colorado Plateau (e.g., Bryan 1941; Euler et al. 1979; Petersen 1988), partly because there is abundant paleoenvironmental data available, and also because it is a relatively marginal region for food production. Availability of water is a major limiting factor, which affects the abundance of biotic resources and people's ability to grow crops. Short growing seasons in higher elevations and poor soils in some areas also place constraints on agriculture. The expansion of the Chacoan system in the eleventh century has been tied to generally favorable climatic conditions for agriculture (Dean et al. 1985), and its collapse, with major drought (Van West and Dean 2000). The area around Cox Ranch Pueblo is marginal for growing maize and yet people relied heavily upon it. Minor fluctuations in climate may have had a great impact on local agriculture, either directly through moisture availability and length of growing season, or indirectly through changes in hydrology and stream channel behavior.

Today an arroyo—a vertical-walled channel—cuts through the northern end of the Cox Ranch Pueblo community (Figure 1.2), and numerous other arroyos occur in the area

Figure 1.2. View to the northeast of the northern part of the Cox Ranch Pueblo community showing the great house and arroyo that cuts through the northern end of the site. People are visible on the great house for scale.

around the site. Flood deposits located at the mouth of an arroyo bury an historic homestead with more than 1 m of alluvium, suggesting the current arroyos were formed during the early twentieth century—a time of significant arroyo activity in the Southwest (Cooke and Reeves 1976). The primary cause of these arroyos is uncertain. They may form due to climatic changes, internal stream dynamics, or human activity including introduction of grazing animals and water diversions related to farming. Arroyos create problems for floodwater farming (Bryan 1941) primarily by limiting the ability to divert channelized streamflow onto field areas. Moreover, arroyo cutting is associated with decreased soil moisture and lowered water tables (Dean et al. 1985).

This thesis presents an investigation of landforms and alluvial stratigraphy at Cox Ranch Pueblo and its surrounding area in an attempt to document changes in physical landscape and climate, and to place the community within an environmental context. There are many important questions to be addressed at Cox Ranch Pueblo. What is the current environmental setting at the site and how has it fluctuated in the past? What were the environmental and physical landscape conditions at the time of site occupation? How did environmental change affect the development and practice of agriculture at Cox Ranch Pueblo and in the surrounding region? Was channel-downcutting a problem for the people at Cox Ranch Pueblo? When did arroyo formation take place and what was the cause? How have physical landscape changes influenced the visibility of pre-Pueblo sites? My study seeks to address these questions through geoarchaeological analysis of soils and alluvial stratigraphy in the Cox Ranch Pueblo area.

This thesis is divided into three primary parts. First, I begin with a review of the physical and cultural settings including an overview of the various theories on arroyo formation. Second, I present my field methods and results, including a surficial geologic map of the area and profiles of arroyo stratigraphy with ^{14}C dates. Third, I discuss the results and their implications for environmental change at Cox Ranch Pueblo and what impact it may have had on the local inhabitants.

CHAPTER TWO

PHYSICAL SETTING

The physical environment was not only important to the inhabitants of Cox Ranch Pueblo but also to those who lived before them. Fluctuations in climate during the Holocene likely influenced how people made a living and positioned themselves on the landscape. For example, the development of agriculture may be linked to more favorable climatic conditions for maize production. Differences in alluvial deposits and soil formation are also related to climatic changes and are indirect records of past environments. It is important to review the evidence for climatic change during the Holocene on the Colorado Plateau to better understand how climatic changes have influenced the landscape and inhabitants of the Cox Ranch Pueblo area as well as to determine how well the local record correlates with the regional one.

Geologic Background

Cox Ranch Pueblo is located within the Colorado Plateaus Physiographic Province (Fenneman 1931:274-325; Patton et al. 1991; Thornbury 1965:405-441), also known simply as the Colorado Plateau (Figure 2.1). There are many plateaus comprising the province, named for its principal drainage, the Colorado River. One of the major characteristics of the province is a relatively high elevation. Most of the area is above 1,500 m in elevation, but there is also a considerable amount of relief, with deep canyons dissecting some plateaus, and mountains reaching over 3,600 m. As the region was uplifted approximately 5 million years ago volcanism erupted, especially around the margins, and the plateaus were tilted slightly to the north (Patton et al. 1991). Uplifting

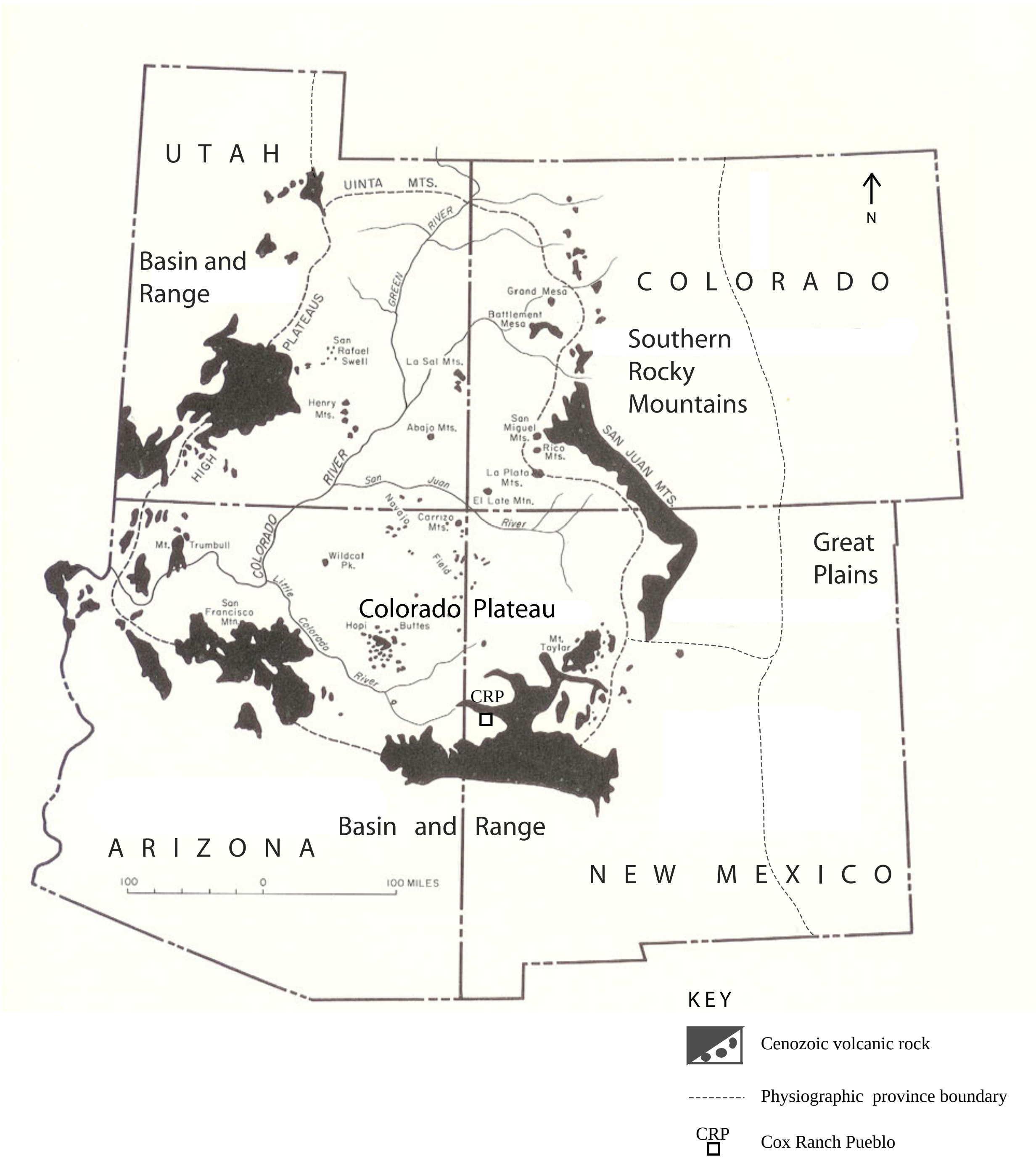

Figure 2.1. Map of the Colorado Plateau and surrounding physiographic provinces with distribution of Cenozoic volcanic rock (adapted from Cordell 1997:Figure 2.1; Thornbury 1965:Figure 22.4).

also caused the major rivers to become deeply entrenched. Other characteristics of the province are nearly horizontal sedimentary rock formations, a semi-arid to arid climate except at high altitudes, and a stepped landscape pattern of mesas and canyons resulting from differential erosion on the nearly horizontal formations. The province is bordered by the Basin and Range Province to the west and south and by the Southern Rocky Mountains to the north and east.

The Colorado Plateau was divided into six sections by Fenneman (1931). Cox Ranch Pueblo is located in the Datil Section on the southeastern edge of the Plateau. This section has numerous Cenozoic volcanic lava flows and plugs. The site also lies within a partially overlapping structural feature termed the Mogollon Slope (Kelley 1957). The region was once a basin and filled with sedimentary and volcanic rocks during the Eocene (58-37 mya) and Oligocene (37-24 mya) (Chamberlin and Cather 1994; Fitsimmons 1959:114). The rocks dip gently to the south, likely as a result of downwarping caused by sediment loading. The Mogollon slope is bordered to the north by strata dipping gently north-northeast (more common to the rest of the Colorado Plateau) and to the south by the San Agustin depression, an arm of the Rio Grande rift (Chamberlin and Cather 1994:6).

Cox Ranch Pueblo lies in the Carrizo Valley, drained by Carrizo Wash-Largo Creek (Figure 2.2) and eventually by the Little Colorado River. There are several significant geological features surrounding the site. A mesa borders the site to the south and west. Part of the Moreno Hill Formation (Mesa Verde Group), it is composed primarily of fine-grained sandstone and shale with small amounts of siltstone and coal. The sediments represent fluvial channel, floodplain, and delta deposits that formed on a

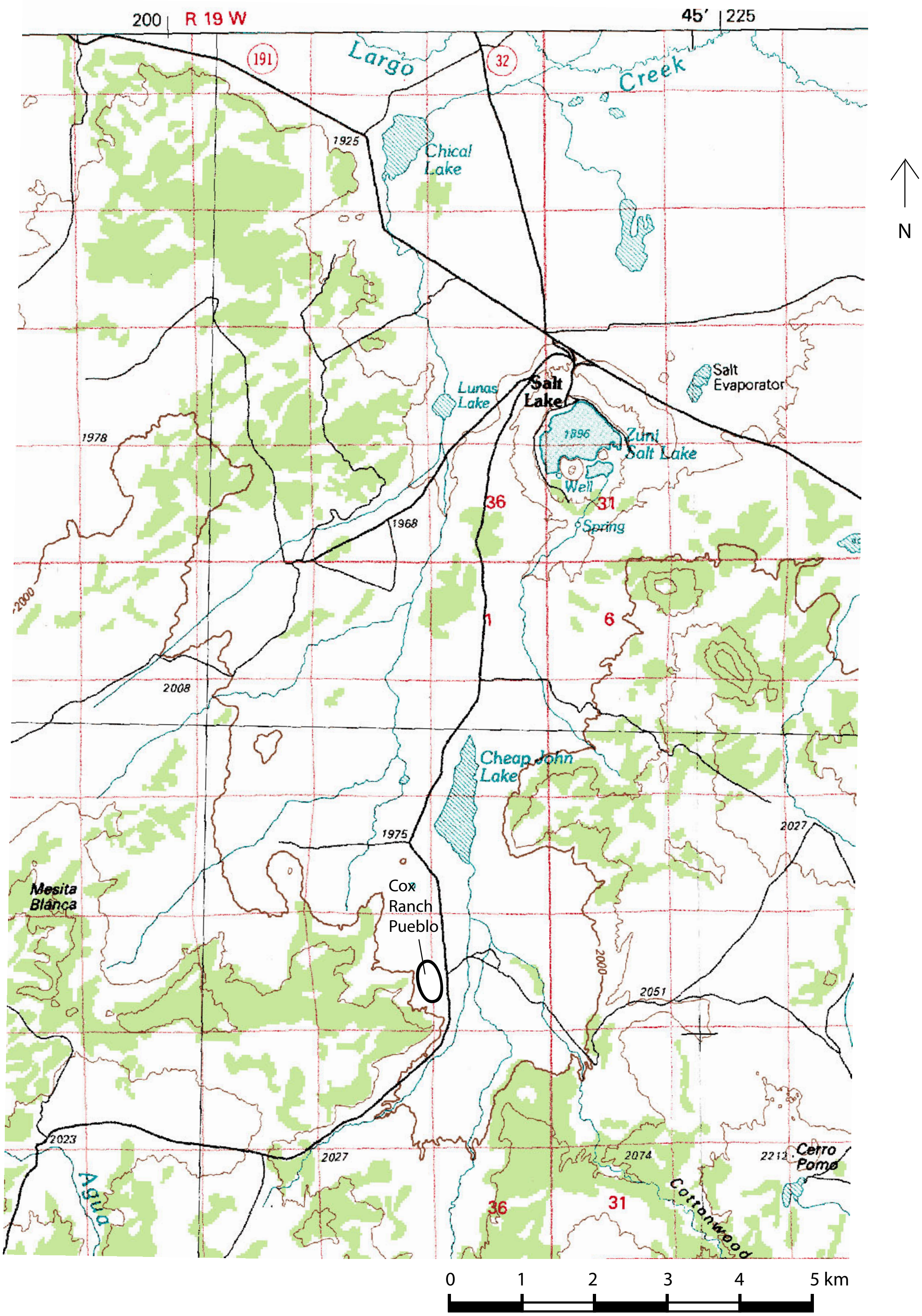

Figure 2.2. Local topography at Cox Ranch Pueblo. Drainage is to the northwest by Largo Creek which becomes Carrizo Wash to the west (USGS 1972: Zuni Salt Lake, N. Mex.).

coastal plain setting during the Late Cretaceous (Anderson 1994:63; Anderson et al. 1994:113). The sediments were likely deposited during a regression and subsequent transgression of the Mancos Seaway. There was a progradation of the coastal plain as the paleoshoreline dropped, but then as it transgressed peat swamps formed parallel to the shoreline resulting in coal seams. Within 10 km of Cox Ranch Pueblo are Cheap John Lake, an approximately 1 km^2 playa that seasonally fills with water, and the Zuni Salt Lake Marr, formed by a volcanic eruption approximately 100,000 years ago (Anderson et al. 1994:114). To the east is Cerro Pomo, a Quaternary cinder cone breached by lava flows on the north side.

Modern Environment

Cox Ranch Pueblo is situated on a piedmont consisting of coalesced alluvial fans. An ephemeral drainage running through the site has cut an arroyo more than 4 m deep, exposing several sequences of alluvial deposits and buried soils. The arroyo becomes shallower downstream and forms a large alluvial fan where it intersects with the valley floor. Several other first- and second-order drainages in the area are also incised. As previously mentioned, an historic homestead, located downslope from the mouth of one of these arroyos, has been buried by about 1 m of alluvium, suggesting the current arroyos were formed within the last 100 years.

The area around Cox Ranch Pueblo is presently used as rangeland. It is in the piñon-juniper savannah vegetation zone (Cepeda and Allison 1994; Roybal et al. 1984). Vegetation on site includes blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), galleta (*Pleuraphis rigida*), rubber rabbitbrush (*Chrysothamnus nauseosus*), alkali sacaton (*Sporobolus airoides*), salt grass (*Distichlis spicata*), and greasewood (*Sarcobatus vermiculatus*). Disturbance species such as broom snakeweed (*Gutierrezia sarothrae*) are present on the alluvial fan east of the site. On the mesa and slopes above the site juniper is present, but it does not occur on the site itself. Piñon pine appears to have begun recolonizing some adjacent mesa areas within the last 100 years.

The modern climate at Cox Ranch Pueblo is semi-arid. Based on weather station records from Fence Lake 30 km to the north and Quemado 30 km to the southeast, the site receives approximately 25-38 cm (10-15 inches) of annual precipitation (Western Regional Climate Center 2004). Approximately 40 percent of the precipitation falls during July and August, and snowfall is common in winter. May and June are the driest months. The average temperature during the warmest month, July, is approximately 21° C (70° F) and during the coolest month, January, approximately 0° C (32° F) (Roybal et al. 1984). Locally temperature and moisture can vary significantly, especially due to changes in elevation. Higher elevations are generally cooler and have more effective moisture. Records also show that there has been a considerable amount of annual variation in precipitation and some variation in temperature during the historic period.

Seasonal changes in precipitation on the Colorado Plateau are greatly influenced by large-scale global circulation patterns (Lamb 1995). Circulation patterns redistribute heat and moisture across the earth's surface. Factors affecting circulation patterns include amount of solar radiation, difference between land and ocean temperatures, and obstructions to overland flow such as mountain ranges (Kutzbach and Webb 1993; Reiter 1963:375-409). As a result, different parts of the Colorado Plateau are affected differently by seasonal shifts in atmospheric circulation. Winter precipitation is more dominant in the western and northern part of the Colorado Plateau. Winter precipitation originates over the Pacific Ocean and is brought eastward by low pressure associated with the polar jet stream. Most of these storms enter the continent in the northwestern U.S. and then move southeast. This pattern generally begins in November but the southern part of the Colorado Plateau does not receive precipitation until December and January when the jet stream begins to dip farther to the south (Tuan et al. 1973:29). For the southern Colorado Plateau to receive significant winter precipitation, a low-pressure trough must form over the western United States creating a subtropical jet over the Gulf of California and allowing moisture to enter the continent over southern California and Mexico (Reiter 1963:226-236). After entering the continent these storms travel northeast bringing more rain to the western part of the Colorado Plateau.

Summer precipitation is more dominant in the southern part of the Colorado Plateau. The southwestern monsoon is related to a shift in the Bermuda High, which directs subtropical moisture from the Gulf of Mexico to the American Southwest. Subsequent heating of the surface lifts the moist air forming localized and often violent convective thunderstorms. Late summer and early fall precipitation can also originate in the Gulf of California or Tropical Pacific. These represent storm cells formed in the tropical Eastern Pacific that every 4 to 5 years are steered into the American Southwest and have brought some of the heaviest recorded precipitation to the Southwest (Sellers 1960).

These seasonal shifts in global atmospheric circulation create a bimodal pattern for the Colorado Plateau with peaks in precipitation in summer and winter separated by two periods of low precipitation in the spring and fall. The bimodality is best expressed in the western and northern part of the plateau. A more unimodal pattern with a prominent peak during the summer months occurs in the southeastern part of the Colorado Plateau. Under this pattern approximately 60 percent of the total annual precipitation falls during July and August. The boundary (Figure 2.3) between these two precipitation patterns is a curved line aligned southwest-northeast that moves slightly from year to year (Dean 1988). Cox Ranch Pueblo is characterized by a more unimodal (summer-dominant precipitation) pattern but it is near the boundary between the two.

Paleoenvironment

There have been many major and minor fluctuations in climate in the Southwest during the Holocene that are likely linked to changes in global circulation patterns. Climatic models have been developed to simulate change in circulation and precipitation patterns during and after the last glacial period based on the location of ice and variations in solar radiation (Kutzbach et al. 1993). There has also been an attempt to match these predictions with evidence from paleoclimatic indicators (Thompson et al. 1993). Some of the proxy evidence used to reconstruct climate in the Southwest include tree rings, pollen, packrat middens, speleothems (growth bands on stalagmites), and lacustrine, eolian, and alluvial stratigraphy. Although some of the general patterns of climate change are recognizable, there is still much debate regarding the timing and magnitude of past changes in precipitation and temperature. Moreover, various subregions have changed in different ways, making inferences and correlations based on adjacent subregions problematic. Nonetheless, an improved picture of post-glacial climate change in the Southwest is emerging.

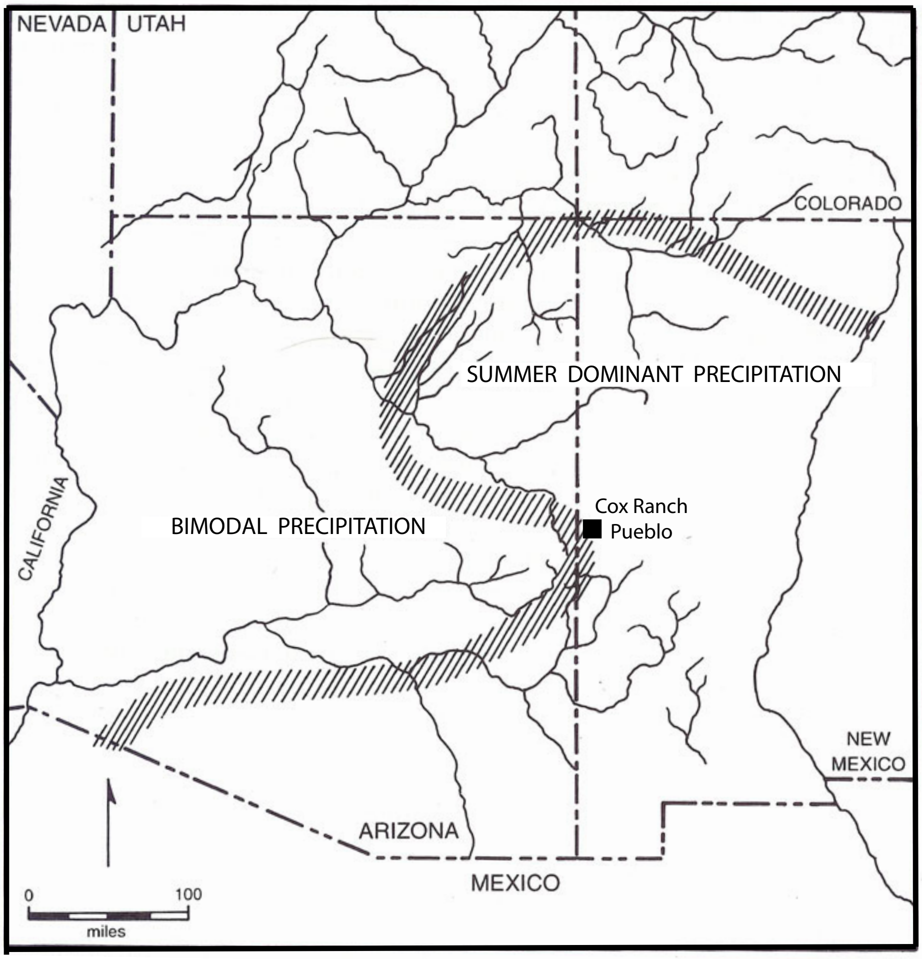

Figure 2.3. Cox Ranch Pueblo and boundary between bimodal and unimodal precipitation patterns (adapted from Cordell 1997:Figure 2.2; Dean 1988:Figure 5.1). The boundary moves somewhat from year to year and is shown as a wide dashed line.

Early Holocene (11,000 – 9,000 BP)[1]

The early Holocene appears to have been transitional between late-glacial conditions and warmer conditions in the middle Holocene. At approximately 12,000 BP on the Colorado Plateau subalpine and montane conifers remained at lower elevations than present, but by 9000 BP many species had retreated to higher elevations (Betancourt 1990; Thompson et al. 1993). Packrat middens in the Grand Canyon record evidence of Douglas-fir, white fir, and Utah juniper well below their modern distribution during the early Holocene (Cole 1982). Cole (1982, 1990) suggests temperatures were similar to today or slightly warmer, and there was increased summer precipitation based on the spread of ponderosa pine and Gambel oak north of their present distribution.

Packrat middens from the Southwestern deserts also indicate the early Holocene was a transitional time period with increased precipitation. Woodlands remained at lower elevations during the beginning of the period in the Sonora Desert suggesting cooler temperatures and increased precipitation (Van Devender 1990a). Van Devender (1990a) argues there was consistent summer precipitation only in the eastern part of the region because species requiring summer rain are only found in this area. A subtropical grass species found in a midden dated to 8200 BP much farther north of its present location indicates increasing temperatures between 9000 and 8000 BP and a continuation of high summer precipitation. Van Devender (1990a) suggests temperatures increased and precipitation continued to be greater than today into the middle Holocene.

The climatic model developed by Kutzbach et al. (1993) predicted increased precipitation and increasing temperatures during the early Holocene due to greater

[1] All ages presented in ^{14}C years unless otherwise specified. The Early Holocene is traditionally placed between 10,000 and 7000 BP, but I use Van Devender's (1990a) division of 11,000 to 9000 BP based on changes in vegetation.

amounts of summer solar radiation at 9000 BP. Data from packrat middens appear to support the model. Increased precipitation around 9000 BP is also supported by evidence of higher lake levels. Willcox Playa in southern Arizona was filled with water at approximately 8900 BP or slightly before (Waters 1989). A lake was also present at this time in the San Agustin Plains (Markgraf et al. 1984) of western New Mexico, approximately 100 km southeast of Cox Ranch Pueblo.

Middle Holocene (9000-4000 BP)

Paleoclimatic conditions during the middle Holocene are much more controversial and yet important to our understanding of the shift to agriculture in the Southwest ca. 4000 BP. All indications support a warmer middle Holocene but some argue it was a very dry period and others that it was a period of increased precipitation. Ernst Antevs (1955) first proposed a period of increased temperature and aridity called the Altithermal between approximately 7000 and 4500 BP in the western U.S. Martin (1963) developed a counter argument working with palynological data from southeastern Arizona, suggesting warmer temperatures would have increased summer precipitation. Haynes (1966) and Mehringer (1966) discredited the data that Martin used to support his hypothesis by showing that the middle Holocene was not represented in the pollen sequence. However, the general theory of increased precipitation during warmer periods has remained in the literature supported primarily by those analyzing packrat middens (e.g., Betancourt 1990; Van Devender 1990a, 1990b). A majority of evidence based on other paleoclimatic indicators seems to indicate the middle Holocene was in fact drier.

Based on packrat middens in the Sonoran and Chihuahuan deserts and Colorado Plateau, Van Devender (1990a, 1990b) and Betancourt (1990) argue for wetter conditions during the middle Holocene (9000-4000 BP). There may have been less winter precipitation, but they believe an increase in summer precipitation due to increased temperatures would have increased the total precipitation. The evidence from the desert plants may be somewhat misleading because many are limited by summer precipitation and minimum temperatures but not substantially by winter precipitation. It is also possible that these areas did receive increased overall precipitation during the middle Holocene because summer precipitation is a greater percentage of the annual total than in regions to the north. However, Spaulding (1991) points out that the arguments for greater precipitation during the middle Holocene are based primarily on packrat middens older than 7500 BP and younger than 5500 BP and may be missing the period of maximum aridity. The few samples from the Sonoran desert that are dated to this period lack ironwood, palo verde and catclaw acacia, all indicators of a warm wet climate (Spaulding 1991).

Betancourt (1990) bases his argument of a wetter middle Holocene for the Colorado Plateau on the expansion of Ponderosa pine and Gambel oak between 10,000 and 6000 BP into areas no longer occupied by these species. However, there are few samples dating to around 7000 BP, perhaps the driest part of the middle Holocene. Based on packrat evidence from the Grand Canyon, Cole (1990) suggests effective moisture decreased during the middle Holocene. He found piñon-juniper woodland was displaced upward in elevation between 8500 and 6800 BP. He suggests that perhaps precipitation remained high but effective moisture did not because of greater evaporative stress.

One of the packrat midden sequences used in Betancourt's (1990) summary was from Chaco Canyon, New Mexico, 190 km north of Cox Ranch Pueblo, where several pollen analyses have also been done. Again, researchers have interpreted the mid-Holocene proxy evidence differently. Based on four packrat midden samples dated between 5550 and 4480 BP, Betancourt and Van Devender (1981) argue there was a piñon-juniper woodland in the canyon during the middle Holocene, indicating increased moisture. Based on the pollen sequence, however, Hall (1985) argues there were not a significant number of pine trees in the canyon during the middle Holocene. He suggests the piñon found in the midden samples is representative only of isolated trees on the rocky slopes and does not characterize the rest of the area in the canyon. There is also a large time gap in these midden samples between 9460 and 5550 BP.

Evidence of a drier middle Holocene is also supported by speleothems and lacustrine and eolian stratigraphy. Waters (1989) found evidence of two high lake stands at the end of the middle Holocene in the Wilcox basin of southern Arizona, but for most of the middle Holocene the basin was only intermittently filled with shallow lakes. Lake levels in the Estancia basin of central New Mexico, 250 km east of Cox Ranch Pueblo, also support a drier middle Holocene (Menking and Anderson 2003). During wetter periods the basin contained more than 80 playas, but during drier times the playas dried and blowouts were cut into the lacustrine sediments. Menking and Anderson (2003) argue that there were two main episodes of deflation caused by drought dating to sometime between 7000 and 5400 BP. During the middle Holocene there was also little to no growth in stalagmites found in caves of the Guadalupe Mountains in southern New Mexico, 400 km southeast of Cox Ranch Pueblo. Since growth is limited by effective moisture this also indicates a drier middle Holocene (Polyak and Asmerom 2001).

The majority of the evidence for the middle Holocene points to drier conditions than at present at Cox Ranch Pueblo, at least during the middle of the period. There may in fact have been increased precipitation in summer as hypothesized by Martin (1963) and others. However, higher temperatures and decreased winter precipitation would likely counteract increases in summer precipitation.

Late Holocene (4000 BP – Present)

The proxy data for the late Holocene climate on the Colorado Plateau comes from speleothem, tree-ring, and pollen sequences and is of better quality for the last 2,000 years. The stalagmites in the caves of the Guadalupe Mountains began to grow again at approximately 4000 BP, signaling a change to wetter conditions (Polyak and Asmerom 2001). The stalagmites contain yearly couplets of light and dark bands, which are thinner when there is less effective moisture. Polyak and Asmerson (2001) suggest the period from 4000 to 3000 BP was generally wetter than at present and from 3000 to 1700 BP it was significantly wetter. Conditions from 1700 to 800 BP were slightly wetter than at present followed by drier conditions after 800 BP, except for a 300-year period between 460 and 170 BP in which conditions were slightly wetter. Polyak et al. (2001) also examined microarthropods preserved in the stalagmites dating from approximately 3200 to 800 BP. The species found do not match the species found in and around the cave today and more closely match those found in wetter and cooler climates. Polyak and Asmerom (2001) note that the earliest evidence for growing of corn in the southwestern U.S. is near the beginning of the first period of increased wetness in the Holocene. Additionally, the collapse of the Chacoan regional system in the mid-twelfth century (including the abandonment of Cox Ranch Pueblo) occurred at the end of this relatively moist period.

Whereas the speleothem data from the Guadalupe Mountains provides insight into long-term trends in climate, southeastern New Mexico is less influenced by winter cyclonic systems from the Pacific. Hence, more local proxy records are needed. One of the longest dendroclimatic reconstructions comes from El Malpais National Monument, which is only 80 km northeast of Cox Ranch Pueblo. Grissino-Mayer's (1995:Figures 3.9 and 3.10, 1996) reconstruction from 136 B.C. to A.D. 1992 is based upon tree-ring widths from Douglas-fir and ponderosa pine calibrated with historic records from 1896 to 1992 (Figure 2.4A). Major centennial trends in precipitation include above-average precipitation between A.D. 81-257, 521-660, 1024-1398, and 1791-1992 and below-average precipitation between A.D. 258-520, 661-1023, and 1399-1790. A shorter period of below-average precipitation from approximately A.D. 1125-1175 may have affected the people at Cox Ranch Pueblo. When the time series is fitted to a 10-year smoothing spline, it shows more of the annual to decadal variation (Figure 2.4B). A major decrease in precipitation is apparent on this graph shortly after A.D. 1200 that may have also affected people at Cox Ranch Pueblo if it was still occupied during this time. Grissino-Mayer (1996) compared the trends evident in his data with the sequences developed by Dean et al. (1985) from alluvial, pollen, and tree-ring data from across the Colorado Plateau and found that they conformed fairly well (Figure 2.5).

In summary, a variety of proxy climate records suggest that the area surrounding Cox Ranch Pueblo was witness to Holocene climatic variability. The early Holocene (11,000-9000 BP) was a transitional period between the last glacial period and the middle

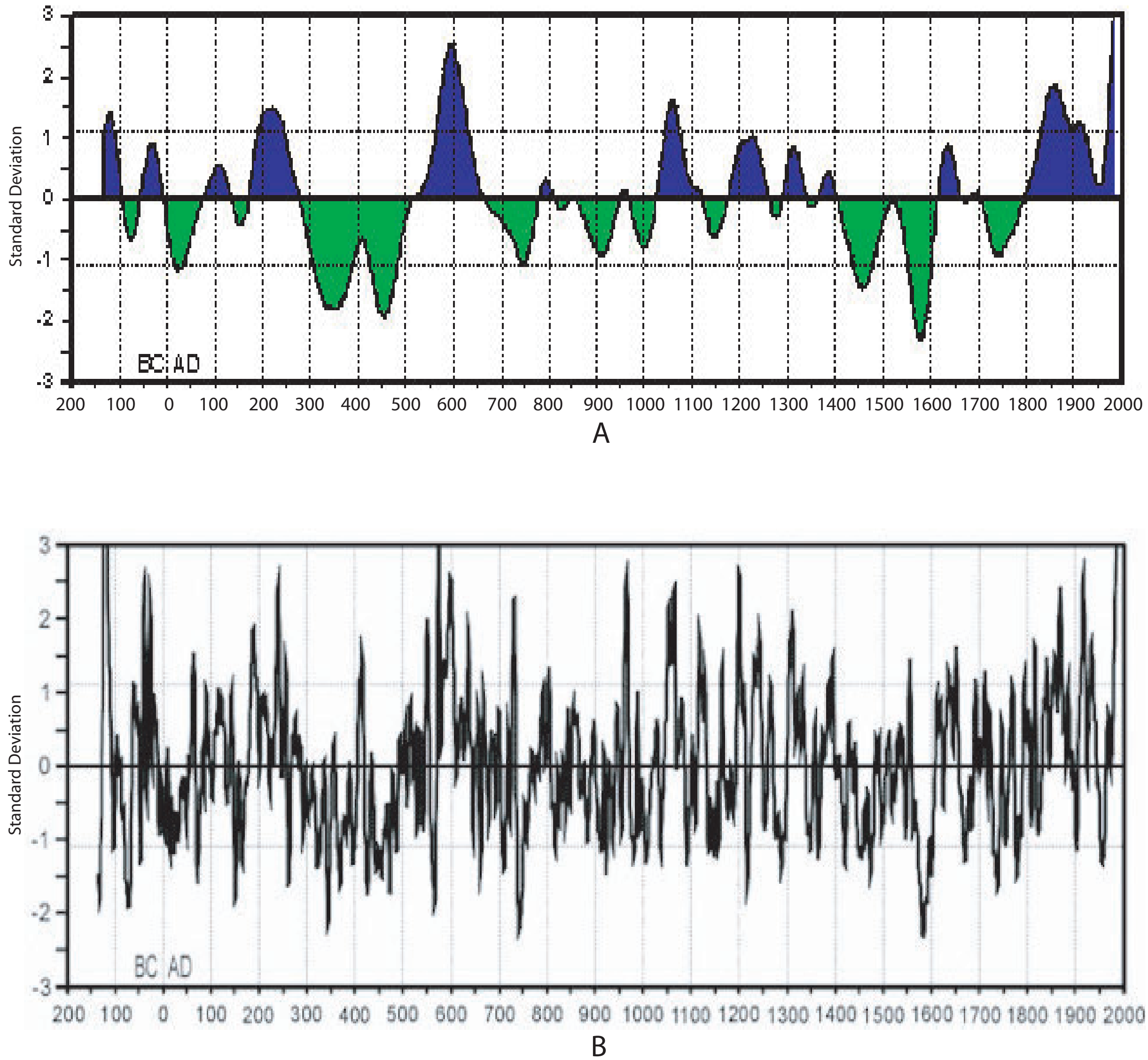

Figure 2.4 Grissino-Mayer's (1995:Figure 3.9 and 3.10) 2,129-year reconstruction of precipitation in northwestern New Mexico from tree rings in El Malpais National Monument. The 100-year spline (A) shows large scale trends; the 10-year spline (B) highlights annual to decadal variation. The center line is the average for the entire period.

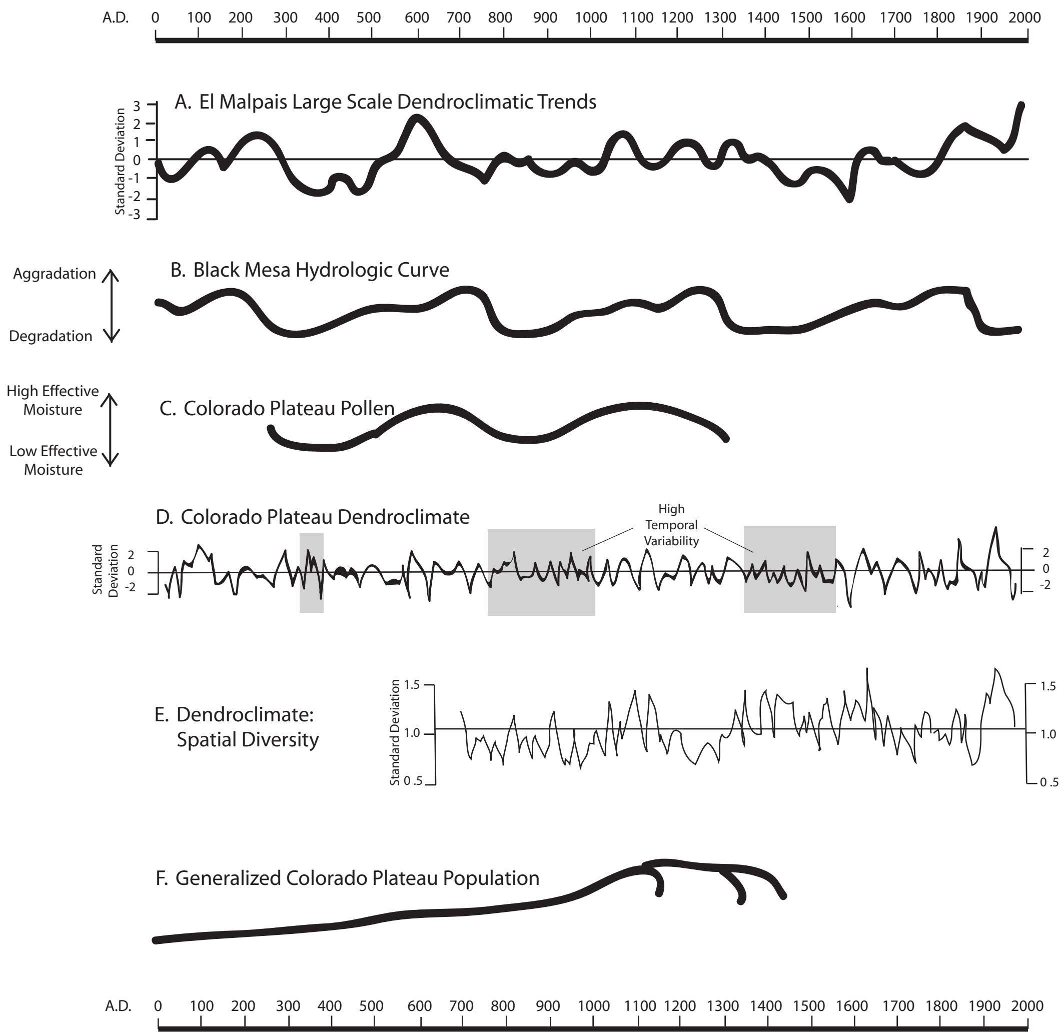

Figure 2.5. Comparison of Grissino-Mayer's (1995) dendroclimatic reconstruction from El Malpais National Monument and other environmental and demographic data from across the Colorado Plateau (adapted from Dean et al. 1985:Figure 1). A. El Malpais century-scale tree-growth departures. B. Black Mesa hydrologic curve of floodplain aggradation and degradation based on inferred water-table levels. C. Effective moisture based on pollen data from the Colorado Plateau. D. Decadal tree-growth departures from the southern Colorado Plateau. E. Spatial diversity in southern Colorado Plateau dendroclimate. F. Generalized population reconstruction for the Colorado Plateau.

Holocene with temperatures apparently cooler than at present during the beginning of the period and increasing thereafter. Effective moisture appears to have decreased through the period although summer precipitation likely increased. The middle Holocene (9000-4000 BP) was a period of increased temperatures but there is still much debate over the level of effective moisture. Much of the evidence suggests effective moisture was high at the beginning and end of the period but low during the middle of the period. The late Holocene (after 4000 BP) appears to have been wetter and cooler than the middle Holocene, especially during the first half of the period.

Possible Responses to Environmental Change

Given that the Colorado Plateau has experienced Holocene climatic change, how did it impact prehistoric life-ways? Dean et al. (1985) summarize paleoenvironmental and populational data for the Colorado Plateau in an attempt to model human behavior. They use alluvial sequences in the Black Mesa region, pollen sequences from 13 sites primarily in the Four Corners region, and tree-ring sequences from the southern Colorado Plateau including several sites in the region around Cox Ranch Pueblo to reconstruct paleoclimate and relate it to demographic and behavioral changes (Figure 2.5). They predicted no significant behavioral shifts in response to climate change before about A.D. 1000 because the population was low until this time. Population increased and there was increased community interaction from A.D. 1050 to 1150. Dean et al. (1985) suggest that the development of the Chacoan regional system during this time was due to overall favorable conditions for agriculture but high spatial diversity in climate. People in areas with lower crop yields could have traded other goods in exchange for food. They also argue the period from A.D. 1150 to 1200 was unfavorable for agriculture due to alluvial degradation, i.e., arroyo cutting, and a major drought evident in the tree-ring record. They expected to see major changes in the archaeological record, such as occurred with the collapse of the Chacoan regional system. Another period of high impact was predicted for the period from A.D. 1275 to 1300 because of a dense population and unfavorable climatic conditions. This matches the widespread abandonment of the Four Corners region and relocation seen in the archaeological record from this time period.

In a study area less than 20 km northeast of Cox Ranch Pueblo, Patrick Hogan (1987) used available data on alluvial stratigraphy, paleoclimate, growth requirements of *Zea mays*, and types of strategies used by historic Hopi and Zuni farmers to predict what types of agricultural strategies would have been practiced between A.D. 900 and 1350. The only major difference between Hogan's study area and the Cox Ranch Pueblo area is that it is located along a larger, although still ephemeral drainage.

Hogan focused on two factors that place well-defined limits on corn growth: length of the growing season and precipitation. Pollen, tree-rings and alluvial stratigraphy from other sites on the Colorado Plateau (e.g., Dean and Robinson 1977; Euler et al. 1979; Hall 1983**;** Hevly 1964**;** Karlstrom et al. 1976; Rose et al. 1982) were used to make inferences for the Fence Lake Study Area. Hogan (1987) suggested cooler conditions between A.D. 900 and 1000 would have decreased crop yields at lower elevations and made higher elevations in the study area risky. He predicts both floodplain and ak chin fields would have been used at this time. More favorable conditions for crop production followed with warmer temperatures between A.D. 1000 and 1100, although the amount of summer rainfall was probably marginal until A.D. 1040. Hogan suggests people would have relied mainly on small-catchment floodwater fields and some ak chin fields during this time because the larger drainages were likely entrenched[2]. The period from A.D. 1100 to 1130 was characterized by a return to cooler temperatures making higher elevation fields again risky. Hogan predicts a severe drought from A.D. 1130 to 1150 may have led to temporary abandonment. He believes precipitation became adequate again between A.D. 1150 and 1250 but that cooler temperatures would have restricted good yields to lower elevations[3]. The period from A.D. 1250 to 1300 was warmer but summer rainfall was marginal, probably forcing many groups to abandon the area.

Hogan (1987) finds it difficult to compare his expectations with the archaeological record because occupation periods based on ceramics do not conform exactly to changes in environmental conditions. However, the patterning in the archaeological record did seem to generally fit the model. One discrepancy was a greater number of small-catchment fields and fewer ak chin fields in the archaeological record than predicted by the model. Ak chin fields are a type of floodwater field found at the mouth of arroyos where floodwaters spread out. Hogan (1987:71) defines small-catchment fields as slope-wash, arroyo bottom, or trinchera (check-dam) floodwater fields associated with small streams or arroyos. The discrepancy found may be due to either a failure to identify ak chin fields or an over-estimation of their importance. If Hogan's model is correct, the periods of favorable and unfavorable conditions for agriculture should be the same for Cox Ranch Pueblo, and occupation of the pueblo can be compared to these environmental fluctuations. Likewise, Late Archaic (Early

[2]Hogan adopted the model of Dean et al. (1985) and Karlstrom (1988) that drought resulted in lower water tables, which in turn was correlated with valley entrenchment and arroyo formation.
[3]This is contrary to Dean et al. (1985). They argue there was a major drought during the last half of the twelfth century.

Agricultural) occupations of the area may also relate to similar environmental fluctuations between 4000 and 2000 BP. Alluvial stratigraphy and soils at Cox Ranch Pueblo may provide additional insights into these environmental changes.

CHAPTER THREE

CULTURAL SETTING

The mesa and canyon topography of the Colorado Plateau has changed little since people first set foot in the region at the end of the Pleistocene, however climate has changed significantly. As noted in the previous chapter, there have been many climatic fluctuations in the Southwest during the Holocene that in turn have an effect on the landscape and what resources are available to people. The degree to which environmental changes affect people is largely dependent upon their subsistence strategy and population size. Thus, it is important to consider the culture history of the Cox Ranch Pueblo area in order to gain a better understanding of how people might have been impacted by environmental change.

Pre-Pueblo

Clovis and Folsom points found throughout the American Southwest indicate people have occupied the area for at least 11,000 years (Cordell 1997). Paleoindian sites have been reported on the Plains of San Agustin, 100 km southeast of Cox Ranch Pueblo (Beckett 1980; Berman 1979), in the central Rio Grande area, 220 km to the east (Judge 1973), in Chaco Canyon, 190 km to the north (Judge 1982), and near St. Johns, Arizona, 60 km to the northwest (Longacre and Graves 1976). Isolated points have also been found in the local area (Hogan 1985). There are likely many more Paleoindian sites that are not visible because they have been deeply buried or destroyed by erosion.

Clovis and Folsom points are often found with the remains of mammoths and other big game suggesting Paleoindians were mobile hunter/gatherers with a primary focus on large mammals (Amick 2000; Haury et al. 1956; Kelly and Todd 1988; Martin 1973; Meltzer et al. 2002). There is also documented use of wild plant foods by Paleoindians (e.g., Johnson 1987; Meltzer 1993) but it is difficult to determine what proportion of the diet came from these.

Following the Paleoindian period in the Southwest is the Archaic. The Archaic refers to both the time period and subsistence economy (Cordell 1997:101-102). Archaic people continued to hunt but focused on smaller animals. The beginning of the Archaic period is marked by ground stone seed milling equipment found throughout the Southwest by 8000 to 8500 BP indicating there was also a greater reliance on plants (Huckell 1996a). As noted in the previous chapter, temperatures were likely increasing and effective moisture was relatively high at the beginning of the Archaic but decreased over the next 1000 years. Maize was introduced as early as 4000 BP and people began to experiment with agriculture, although they did not rely on it as heavily as in the following period. Effective moisture was also relatively high between 4000 and 2000 BP when this experimentation began. The end of the Archaic is defined by archaeologists as coinciding with the appearance of pottery between 2000 and 1500 BP (Huckell 1996a).

The Archaic period can be broken up in a number of different ways. Irwin-Williams (1979) suggested there were four interacting cultural traditions in the Southwest during the Archaic that were ancestral to later traditions. These include the Oshara tradition, ancestral to the Anasazi, and the Cochise tradition, ancestral to the Mogollon. She also broke traditions into phases representing different time periods.

Huckell (1996a) divides the Archaic into three periods: Early Archaic, Middle Archaic, and Late Archaic/Early Agricultural. He suggests that there is variability in artifacts such as projectile points in different regions during the Early Archaic (8500-5500 BP) but those differences tend to disappear during the Middle Archaic (5500-3500 BP). The first evidence of domestic structures in the Southwest is during the Middle Archaic. These are shallow pithouses that are roughly circular and range between 2.0 and 4.5 m in diameter (Huckell 1996a; Irwin-Williams 1973). Huckell also refers to the Late Archaic as the Early Agricultural (3500-1500 BP) because people were beginning to experiment with agriculture following the introduction of maize as early as 4000 BP. Features present at Early Agricultural sites in northwestern New Mexico include shallow pithouses, bell-shaped pits, and slab-lined cists indicating food storage (Huckell 1996a).

There are a number of sites dating to the Archaic period in the region around Cox Ranch Pueblo (Hogan 1985; Westfall 1981). Projectile points diagnostic of both the Oshara and Cochise traditions and spanning the entire Archaic period were found in the Fence Lake Project area, approximately 15 km north of Cox Ranch Pueblo. The immediate area around Cox Ranch Pueblo was recently surveyed as part of the Cox Ranch Community Research Project (Duff 2003). Several projectile points and fragments dating to the Early and Middle Archaic were collected and a number of lithic scatters with no temporally diagnostic material were noted.

Evidence for early use of maize also comes from the nearby Fence Lake Project area. Maize dating between 3400 and 3700 ^{14}C yr. BP—near the transition between the Middle Archaic and Late Archaic/Early Agricultural—was recovered (Van West 2004). What is not completely understood is the level of reliance on corn during this time period, but evidence suggests it may have been substantial. Damp et al. (2002) documented irrigation canals dating between approximately 3000 and 1000 BP at two sites in the Zuni area, approximately 75 km north of Cox Ranch Pueblo. Maize remains recovered from nearby habitation sites and maize pollen recovered from buried soils supports the interpretation that these were agricultural canals.

Pueblo

The beginning of the Pueblo period is marked by the appearance of pottery. There was also a much greater reliance on maize and increased storage associated with this. Four major cultural traditions follow the Archaic in the Southwest. Cox Ranch Pueblo is located in the Cibola region near the boundary between the Anasazi tradition centered to the north and the Mogollon tradition centered to the south (Figure 1.1). The Mogollon culture is often distinguished by brown ware ceramics and square kivas whereas the Anasazi culture is distinguished by gray ware ceramics and circular kivas (Cordell 1997; Fowler 1991; Reed 1950; Rinaldo 1962). A major development in the Anasazi world was the rise and fall of the Chacoan system.

There are many different schemes for dividing up the Pueblo traditions into time periods (Figure 3.1). The Pecos Classification Scheme (Pueblo I, Pueblo II, Pueblo III, and Pueblo IV), or a modified version of it, is often used to discuss Anasazi occupation. Different phase sequences are usually used for different areas within the Mogollon region. In the Cibola region major changes in settlement patterns are marked by Chacoan occupation and the eventual collapse of the Chacoan system, and so a more useful division of time for this region is Early Pueblo Occupation (ca. A.D. 500-1050),

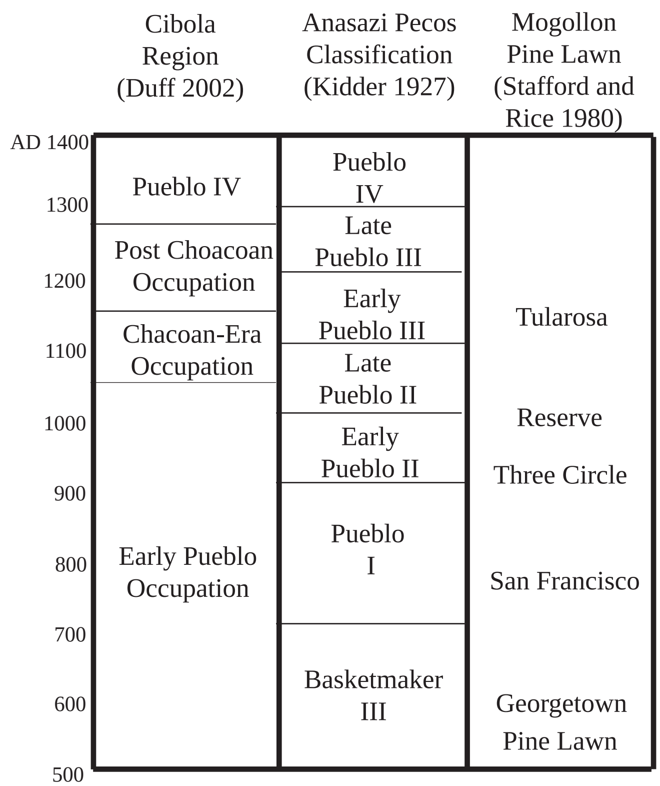

Figure 3.1. Pueblo phase sequences for the Cibola region, general Anasazi, and the Pine Lawn branch of the Mogollon tradition.

Chacoan-Era Occupation (ca. 1050-1150), Post-Chacoan Occupation (A.D. 1150-1275), and Pueblo IV (A.D. 1275-1400) (Duff 2002).

Early Pueblo Occupation (ca. A.D. 500-1050)

Masonry structures and painted ceramics first appeared during this period but are more frequent after about A.D. 900 (Duff 2002). Based on the number of visible sites, population of the region appears to have been fairly limited (Beeson 1966; Danson 1957; Hogan 1985; Longacre 1962). However, there are a number of sites in the Mariana Mesa area (Danson 1957; Whalen 1984), approximately 45 km east of Cox Ranch Pueblo, and several large villages were reported near Quemado (Danson 1957), approximately 30 km southeast of Cox Ranch Pueblo. Only one residential site likely dating to this time period was found in the immediate project vicinity; a seven-room pueblo located a few hundred meters west of Cox Ranch Pueblo.

Chacoan-Era Occupation (ca. A.D. 1050-1150)

Chaco Canyon is located approximately 190 km north of Cox Ranch Pueblo. Beginning in the late ninth century people in Chaco Canyon began to build large multistoried masonry structures that grew into what are called great houses. Great houses in Chaco Canyon were planned structures with geometrical designs that included blocked-in kivas and enclosed plazas (Lekson 1984). The largest were at least four stories high with more than 500 rooms in their final stages, much larger than any contemporary buildings. Particularly large storage rooms and great kivas are also found in Chaco Canyon.

Great houses began appearing outside of Chaco Canyon in the late tenth or early eleventh century (Mahoney and Kantner 2000; Figure 3.2). Roads also appeared in

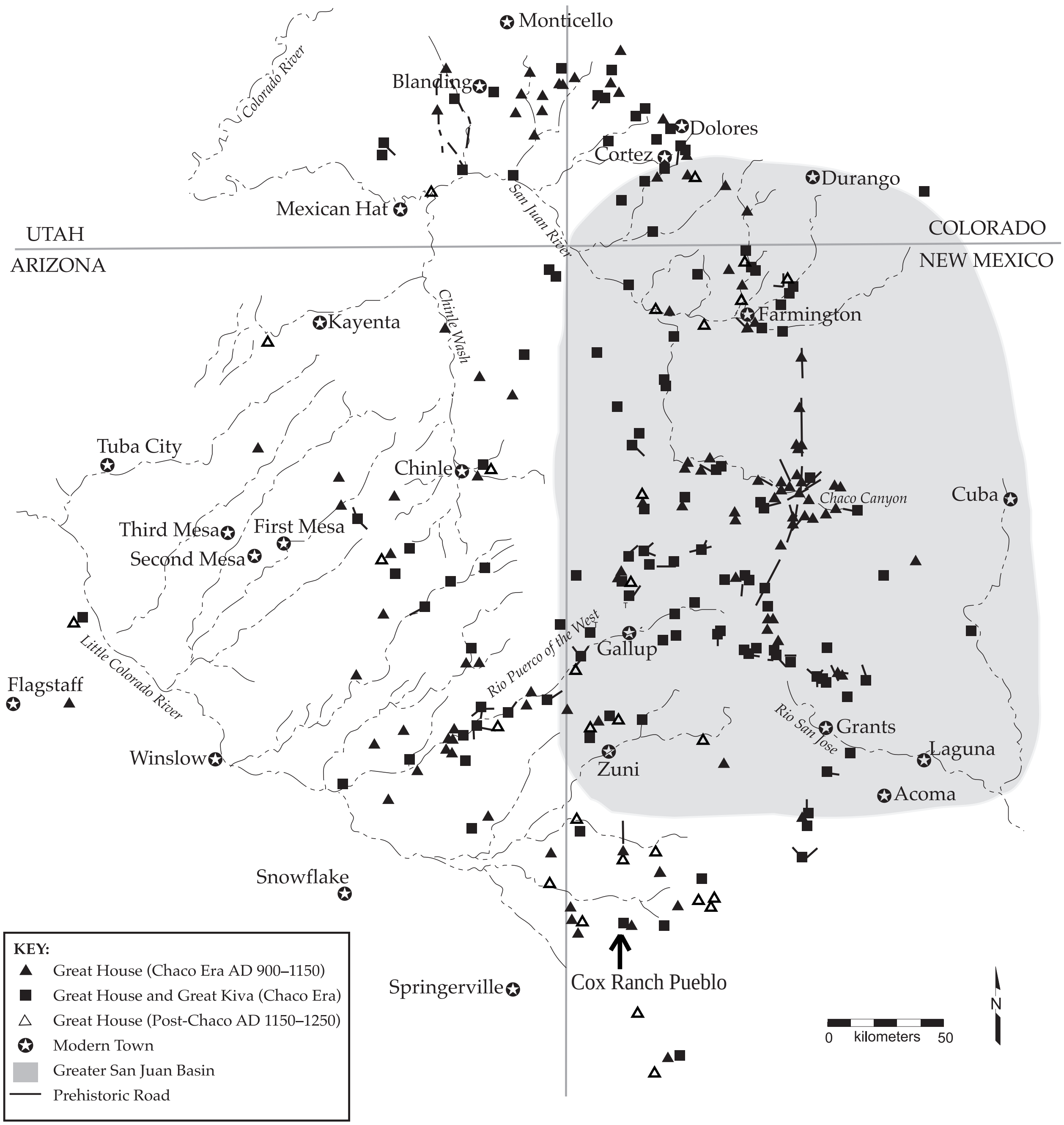

Figure 3.2. Four Corners map with locations of recorded Chacoan great houses, great kivas, post-Chacoan great houses, and confirmed Chacoan roads (adapted from Kantner 2004). An arrow points to Cox Ranch Pueblo near the southern limit of great houses.

outlying areas connecting some great houses with each other or with Chaco Canyon. More than 200 great houses are now recognized outside of Chaco Canyon. As previously mentioned, this organization of great houses is often referred to as the Chaco Phenomenon or Chacoan system, and archaeologists debate the nature of the system and the strength of the socioeconomic ties between communities.

The system probably served both economic and religious purposes. Items found at Chaco Canyon include pottery from throughout the San Juan Basin as well as Hohokam and Mimbres pottery, turquoise, macaws, copper bells, and shells from the Gulf of California (Toll 1991). Many see its main function as a redistribution center and focus on the large quantity of utilitarian items found in comparison to exotics (Earle 2001; Judge et al. 1981; Marshall et al. 1979; Stuart 2000; Toll 1991). In contrast, Sebastian (1991, 1992) argues the system was an elite network built on surplus production. She maintains that settlement patterns, amount of labor investment, material culture, and burial differences are evidence of institutionalized leadership. Others believe Chaco Canyon's prominence was related to its function as a religious center (Judge 1989; Renfrew 2001). In this model people visited Chaco Canyon on regular pilgrimages but the number of people living there year round was fairly low.

One major question is the level of power that Chaco Canyon had over the outlying communities. At one extreme it has been viewed as the center of a system with the power to establish control over the region and extract tribute (Kane 1993; Turner and Turner 1999; Wilcox 1993). In this model outposts were established through force in outlying communities. In contrast, others argue that outlying communities copied the architecture and styles of Chaco Canyon but retained a relatively high level of independence (Herr 2001; Kantner 1996; Van Dyke 2000). Great houses and great kivas may have been a form of competition among outlying communities aimed at attracting and pooling labor (Herr 2001; Kendrick and Judge 2000; Van Dyke 1999, 2000). Recent studies have shown that many of the outlying Chacoan communities traded with other nearby communities but probably had limited interaction with Chaco Canyon itself (Gilpin and Purcell 2000; Jalbert and Cameron 2000; Kantner et al. 2000). However it is viewed, the Chacoan system impacted people in a very large region, including those at Cox Ranch Pueblo.

There is a dramatic increase in the number of sites in the region around Cox Ranch Pueblo during this period (Hogan 1985), likely as a result of migration (Duff 2002). Populations in the period prior were higher both to the north and south than they were in the Cox Ranch Pueblo area, and both Anasazi gray wares and Mogollon brown wares are found at many sites in the region including Cox Ranch Pueblo (Stuart and Gauthier 1988:167-169). Most of the new sites are small pueblos with two to six rooms but a few have 20 rooms or more (Hogan 1985; Hogan, ed. 1987).

Cox Ranch Pueblo is one such settlement. It contains approximately 300 rooms in multiple roomblocks and is much larger than any contemporary settlements in the region (Stuart and Gauthier 1988:163). It includes a Chacoan great house, 19 additional roomblocks, one great kiva-like feature, a walk-in well, and 18 midden areas (Figure 3.3). The great house is D-shaped with distinctive Chacoan masonry and encloses an elevated plaza, 50 ground-story rooms, and one kiva. The site appears to have been occupied primarily between about A.D. 1030/1050 and 1130 based on excavated ceramics (Duff and Nauman 2004).

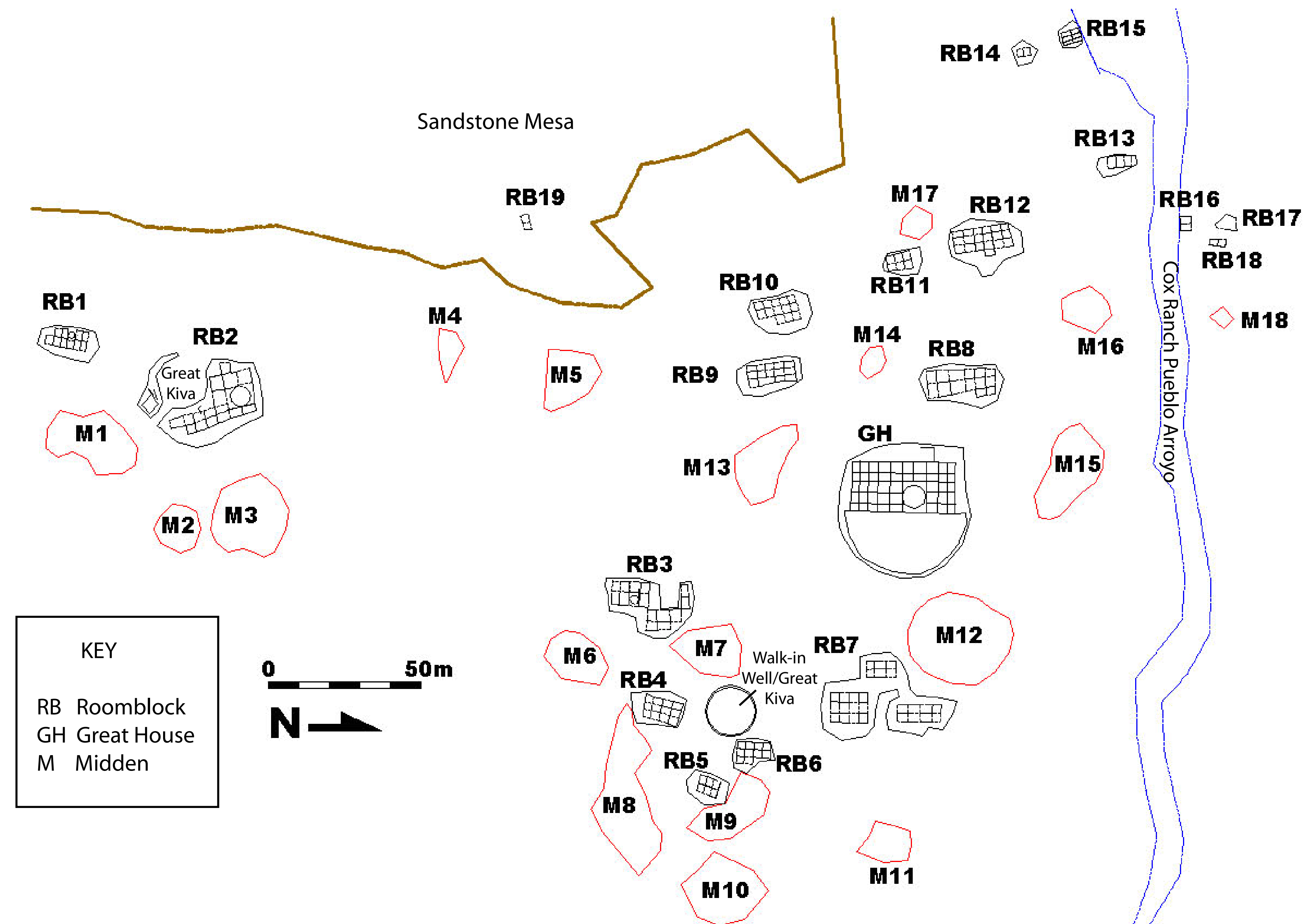

Figure 3.3. Map of Cox Ranch Pueblo (Duff and Nauman 2004:Figure 2).

Approximately 20 field houses and several residential settlements occur within 1 km of Cox Ranch Pueblo (Duff 2003). These appear to be contemporaneous and were probably part of a community associated with Cox Ranch Pueblo. Another Chacoan great house (Cerro Pomo) is located 4 km southeast of Cox Ranch Pueblo and it appears to have had a community surrounding it, although it was much smaller (Duff 2003).

Post-Chacoan Occupation (A.D. 1150-1275)

By A.D. 1150 settlement patterns in the region had changed dramatically (Kintigh 1994, 1996; LeBlanc 1978, 1989). Across the Colorado Plateau there is aggregation into larger sites at this time (Kintigh 1996; Varien et al. 1996). Some sites in the Zuni region grew to contain more than 500 rooms (Duff 1994; Kintigh 1994; Kintigh et al. 1996). New great houses were constructed at these sites and were often connected to Chacoan-era great houses by roads or paths (Fowler et al. 1987; Stein and Fowler 1996). Great kivas also changed during this time. They became larger, were probably unroofed, and lacked the floor features common in Chacoan-era kivas. Kintigh (1994) argues changes in the Zuni region are representative of a smaller-scale, socio-political system that replaced the Chacoan system when it collapsed. This system included architectural features reminiscent of Chaco but was focused more around local centers.

South of Zuni and closer to Cox Ranch Pueblo the settlement pattern is different. Larger sites are present but so too are smaller sites more representative of the Mogollon settlements from this time period (e.g., Lekson 1996; Martin et al. 1956, 1957; Rinaldo 1959). These sites typically contain 35 to 50 rooms and a square kiva. No sites in the immediate vicinity of Cox Ranch Pueblo date to this time period. The majority of the population seems to have shifted towards the Mariana Mesa area, 45 km to the east, where there are several large sites (Fowler et al. 1987; Hogan 1985; McGimsey 1980).

Pueblo IV Period (A.D. 1275-1400)

At around A.D. 1275 another major change in settlement pattern and site layouts occurred in the region. Great houses were replaced by plaza-pueblos in the Zuni region and near Quemado (Kintigh 1985; Lekson 1996; Roney 1996). These were very large, rectangular pueblos oriented around a communal plaza. Pueblos west of Cox Ranch Pueblo in the Little Colorado River area are more similar to Mogollon sites; they consist of large residential blocks with attached or adjacent square great kivas (Duff 2002). Production of glaze-painted ceramics began during this time period and differences in material culture between the Anasazi and Mogollon became less apparent (Reed 1948, 1950). Many sites occupied during the previous period were abandoned and settlements shifted to areas along major rivers (Duff 2002; Kintigh 1985) and near springs (Danson 1957; McGimsey 1980). No sites dating to this period were found in the immediate area around Cox Ranch Pueblo. By A.D. 1400 most sites were abandoned and the population became concentrated at Hopi, Zuni, Acoma, or the Rio Grande.

Historic Period

The first contact between pueblo people in the area and Europeans was in 1540 when the Coronado expedition reached Zuni (Cordell 1997:429-431). Spanish explorers and settlers had a large negative impact on pueblo people by exposing them to disease and attempting to change their religious beliefs. During the historic period there is little evidence for Native American use of the immediate area around Cox Ranch Pueblo. Use of Zuni Salt Lake, approximately 10 km to the north, is recorded, however, and the Zuni continue to use it today (Hogan 1985).

Ranching began in the region in the 1880s when the price of cattle and sheep rose due to increased rail links into New Mexico, but an economic decline in the 1890s caused many ranches to go under (Baydo 1970). Prices increased during World War I but soon fell during the worldwide recession following the war. The majority of early ranchers were Hispanics raising sheep, but eventually Anglo-European cattle ranchers took over. Historic sites around Cox Ranch Pueblo related to ranching include a masonry house to the south and a partially buried cabin to the east. The Bureau of Land Management currently administers Cox Ranch Pueblo, and the area is currently used as rangeland for cattle.

Summary

West-central New Mexico has witnessed several important changes in population, subsistence, and material culture over the past 11,000 years. Hunter/gatherers lived in the region for 7,000 years but eventually came to be dependent on maize agriculture. The artifacts and architecture they left behind also changed. Population in the Carrizo Valley area appears to have been fairly low until the Chacoan era when occupation increased dramatically. The rise of the Chacoan system and its eventual collapse affected many people including those at Cox Ranch Pueblo. Environmental change may have played a key role in this cultural event. The rise of the system has been associated with an especially favorable climate for maize agriculture and the fall with extensive drought (Dean 1992, 1996; Van West and Dean 2000). Use and abandonment of Cox Ranch

Pueblo may also relate to environmental factors affecting crop production such as moisture, temperature, and local hydrology.

CHAPTER FOUR

ARROYO FORMATION AND PREHISTORIC FARMING

There have been several attempts to determine the types of environmental conditions favorable or unfavorable to past Puebloan farmers and the many possible human responses to environmental change. One environmental change that may have affected farmers at Cox Ranch Pueblo is arroyo cutting and filling. Arroyos are steep-sided, entrenched channels that are common today in the Southwest (Antevs 1952; Bull 1997; Cooke and Reeves 1976; Waters 1991). Buried channels exposed in the walls of the modern arroyos indicate that such floodplain entrenchment also occurred at times in the past. Many arroyos in the Southwest are dry during most of the year but fill with water during heavy rainfall episodes, usually in the summer. Many are also discontinuous, with alternating entrenched and unentrenched segments, although larger streams may be continuously entrenched for several tens of kilometers. Arroyos are formed by predominantly vertical channel erosion occurring at a nick point or headcut, that then migrates upstream. For discontinuous arroyos the channel is deepest at the nick point, and channel walls decrease in height downslope until eventually they intersect with the channel bottom (Bull 1997). An alluvial fan forms at the intersection point because the water is no longer confined to a channel and its stream power—its ability to transport sediment—decreases. For continuously entrenched arroyos, downstream changes in channel depth and areas of deposition are more irregular in space and time.

Effect of Arroyo Formation on Prehistoric Farmers

Kirk Bryan (1929) suggested that arroyo formation would have created problems for floodwater farmers in the Upland Southwest because it would have confined floods within narrow channels, thus decreasing the amount of land that could be irrigated. He considered channel entrenchment a possible cause for local abandonment of pueblos. Following this idea, Dean et al. (1985) integrated tree-ring, pollen, and geological data to argue that channel entrenchment and falling water tables created major problems for floodwater farming in the Black Mesa region of northern Arizona while floodplain stability or aggradation during relatively moist or stable climates created favorable conditions. Waters (1991) found evidence of similar environmental and cultural changes in the lower deserts of the Southwest. He argues that the location of late prehistoric Hohokam settlements in southern Arizona was closely related to the condition of drainages. In areas of discontinuous arroyos, large villages were abandoned after episodes of major drainage entrenchment, and settlements moved in tandem with arroyo-mouth fans so that they were positioned in areas suitable for floodwater farming.

Not only have scholars argued that past floodplain dynamics influenced agricultural productivity and settlement location, but some have linked riverine processes to the adoption and spread of agriculture in the Southwest. Huckell (1996b) notes that the alluvial stratigraphic records in southern Arizona reveal a major episode of degradation sometime before 4000 BP in the upper San Pedro Valley, the Cienega Valley, and the Tucson Basin reach of the Santa Cruz Valley. This was followed by a shift to aggradation sometime between 4000 and 3000 BP, coinciding with the arrival and spread of maize. Huckell (1996b:36) argues this shift would have created "excellent conditions for floodplain agriculture, and such an opportunity seems to have been quickly taken by Late Archaic cultivators…”.

The degree to which arroyo formation would have deleterious impacts on Puebloan farmers depends on demographic and socioeconomic factors, as well as the nature of the valley entrenchment. Huckleberry and Billman (1998) argue that arroyos may not have impacted Puebloan farmers as much as has been predicted by others. They do not dispute that entrenchment may have caused some problems, but counter that flexible agricultural strategies may have minimized the impact, especially if arroyos were discontinuous. Ak chin fields on arroyo-mouth fans may have been utilized more in response. These fields were common at historic Pueblos (Hack 1942) and are rich in nutrients because nitrogen, phosphorous, and sediment are added to the soil along with each flood (Nabhan 1986). Water may also have been diverted from unentrenched segments. Huckleberry and Billman (1998) suggest that large habitation sites may have stayed in the same locations while small field camps moved with the position of arroyo-mouth fans.

Primary Cause of Arroyo Formation

Arroyo cutting undoubtedly had some impact on prehistoric farmers but the extent is unclear. There is also considerable debate over the ultimate cause of arroyo formation. There are many factors that may affect the geomorphic condition of drainages including slope, water table levels, tectonics, lithology, sediment yield, vegetation cover, rainfall amounts, and human land use (Bull 1991). Theories on the primary cause of arroyo formation fall into three general categories: human disturbance, climate changes, and internal stream dynamics.

Human Disturbance

The first major historic episode of arroyo cutting in the Southwest began in the late nineteenth century. Initiation of arroyo cutting occurred at different times in different areas, but many drainages became entrenched in the period between 1880 and 1900 (Thornthwaite et al. 1942). Introduction of large numbers of cattle and sheep just prior to this major cutting episode led many researchers to believe that human disturbance was the primary cause of arroyo formation (e.g., Dodge 1902; Duce 1918; Leopold 1921). Cattle not only reduce vegetation, but also create paths, reduce moisture in the upper layers of the soil, and promote shrub growth over grasses (Cook and Reeves 1976). Other forms of human disturbance that may play a part in arroyo formation include logging, mining, cultivation, and construction of roads, trails, ditches, canals, bridges and embankments, all of which can affect sediment yield and the concentration of runoff.

Evidence of prehistoric arroyos exposed in the walls of modern arroyos led many to question human disturbance as the primary factor in arroyo formation. However, others (e.g., Antevs 1952; Bailey 1935; Bryan 1928; Cook and Reeves 1976; Thornthwaite et al. 1942) still stressed human disturbance as the primary factor or trigger mechanism in historic arroyo formation, but hypothesized that prehistoric arroyos were a result of climate change. They believed that the major change resulting in arroyo formation was a decrease in vegetation, which can be caused by either human disturbance or climate change.

Prehistoric human disturbance may also have played a role in arroyo formation. Waters (1991) suggests that prehistoric farmers may have increased the frequency of arroyo entrenchment by removing vegetation, concentrating runoff, constructing ditches, and creating compacted paths. He argues that all of these actions would have increased erosion and velocity of water flow over the floodplain. He studied an area in southern Arizona occupied by the Hohokam where streamflow was typically diverted into canal systems and found arroyo entrenchment was more common in late prehistoric settlements after occupation intensified. However, he does not suggest that human disturbance is the primary cause of arroyo formation.

Climate

Most researchers focus on climate as the primary factor in arroyo formation. Since climate is a regional phenomenon, those who focus on it emphasize correlations of arroyo formation over large areas (e.g., Bryan 1941; Haynes 1968; Knox 1983), though they also recognize that local geomorphic factors can modify the timing of entrenchment (McFadden and McAuliffe 1997). However, the specific climatic conditions that trigger arroyo formation are a matter of dispute. There are two somewhat contradictory hypotheses. Antevs (1952) and Bryan (1925, 1941) hypothesized that drought conditions initiated arroyo cutting because they decrease the amount of vegetation holding sediment in place. Recent work on the Great Plains supports this model. Hall (1990) studied 15 well-dated alluvial sequences in Texas and Oklahoma and found evidence of synchronous downcutting in all of the floodplains at approximately 1000 BP, an episode of cutting that he argues was initiated by a change to a drier climate. This is supported by a recurrent pattern of paleo-arroyo cutting through an organic-rich soil representative of an earlier wetter time period as indicated by pollen, fauna, and sedimentary structures. He also found very few deposits dating between 7000 to 5000 BP and argues this is because it was a hot and dry climatic period (i.e., the Alithermal) resulting in deep down cutting.

The geological evidence used by Dean et al. (1985) to link arroyos and Puebloan settlement shifts also supports the drought-arroyo model. Karlstrom (1988) analyzed more than 40 alluvial sequences on large drainages in the Black Mesa area and found synchronous cutting episodes. He uses Schumm's (1977) threshold concept, arguing that the key relationship determining whether a stream aggrades or degrades is the ratio between discharge and sediment supply, but unlike Schumm, Karlstrom argues this ratio is dependent on climatic change. During wetter periods there is a greater volume of water but the ratio of discharge to sediment supply is decreased, because greater precipitation on valley slopes results in higher sediment yields. This leads to stream overloading and deposition on the valley floor. During drier periods there is less water, but it is confined to narrower channel cross sections and thus has greater erosive power. Moreover, reduced vegetative cover on hill-slopes accelerates surface runoff. As water tables lower, there is a decrease in the length of permanent-flow reaches and discharge becomes greater than sediment supply, initiating down cutting. From his work on Black Mesa, Karlstrom developed a hydrologic curve of aggradation/degradation cycles that correlates well with pollen and tree-ring data from across the southern Colorado Plateau (Dean et al. 1985; Grissino-Mayer 1996).

Others have argued that rather than extended periods of below and above average precipitation, it is the intensity of rainfall or occurrence of large floods that is the primary factor in arroyo initiation (e.g., Balling and Wells 1990; Graf et al. 1991; Hereford 2002; Leopold 1951; Martin 1963; Tuan 1966). Graf et al. (1991), Hereford (2002), and Tuan

(1966) point out that historic arroyo formation is often associated with high-intensity precipitation and large floods. What is not entirely clear from their work is the effect, if any, of annual precipitation totals on aggradation and degradation. Annual precipitation and flood magnitude on lower order streams where arroyos often occur are not strongly correlated.

Hereford (2002) argues aggradation in south-central Utah in the Paria River basin between ca. A.D. 1400 to 1880 is correlated with the Little Ice Age epoch and a period of decreased large flood events in the Upland Southwest. Evidence of arroyo cutting is present both before and after this period. His alluvial chronology for the Paria River correlates with other sequences on the southern Colorado Plateau. Like Karlstrom (1988) he argues that it is a reduction in the discharge to sediment ratio that promotes aggradation. However, Hereford suggests the ratio would be higher during periods with high intensity precipitation and large floods. Arroyo formation correlated with large floods produced by tropical storms during the historic period in the Paria River basin, however it did not correlate with an increase or decrease in annual precipitation (Graf et al. 1991).

Closer to the Cox Ranch Pueblo study area, Balling and Wells (1990) studied arroyo activity and precipitation patterns for the historic period in the Zuni River drainage basin. They recognized that hydrologic conditions vary with the size of the drainage and grouped drainages into three classes based on total drainage area. They found arroyo cutting was dominant in small- and intermediate-sized drainages during a period with frequent high-intensity summer storms and high annual precipitation totals.

The two climatic arguments for arroyo formation during periods of drought or high intensity precipitation are not necessarily contradictory. Summer storms, although usually intense, do not necessarily occur during wetter periods. Large floods can occur during periods of below average precipitation, especially on low order (small) drainages. Although Balling and Wells (1990) found a correlation in the historic period between arroyo cutting and high annual precipitation totals, other researchers have not (Hereford 2002; Leopold 1951; Tuan 1966). The difference may be due to the fact that the Zuni region, where Balling and Wells performed their study, is in an area where summer rainfall accounts for a relatively high percentage of the annual precipitation (approximately 40 percent). Hence, the largest floods tend to occur in summer and are more likely to correlate with high annual precipitation. This does not, however, preclude the importance of looking at the general trend in longer periods as in Karlstrom's hydrologic curve. Karlstrom (1988) suggested that during drier periods larger floods would erode more than smaller ones, so his model is not necessarily inconsistent with the others.

Waters and Haynes (2001) studied alluvial stratigraphy representing the last 15,000 years in the Santa Cruz and San Pedro River Basins of southern Arizona and argue it is the transition from dry to wet conditions that causes arroyo formation. They found the first occurrence of arroyos only after 7500 BP, with an increase in arroyo frequency after 4000 BP when the modern climatic regime was established. They see evidence of synchronous arroyo cutting at ca. 4000, 2500, 2000, 1000, 500 BP, and near the turn of the century in both river valleys, indicating the cutting episodes are caused by an external mechanism such as climate. Waters and Haynes (2001) suggest drought causes a lowering of the water table and a reduction in vegetation, which makes sediment more easily erodible when intense storms and flooding do occur.

Internal Stream Dynamics

Although many scholars link arroyos and climate change, there remain differences in opinion regarding what specific type of climate change results in arroyos. Furthermore, there is another group of researchers that link arroyo activity more to intrinsic geomorphic controls than external climatic factors (Gellis and Elliott 2001; Patton and Schumm 1975, 1981; Schumm and Hadley 1957). Schumm and Hadley (1957) first suggested gullies and arroyos developed on oversteepened slopes within floodplains. They argued alluvial fill builds up to a certain point until slope reaches a critical value, and the channel responds by downcutting. They focused on discontinuous gullies in Wyoming and New Mexico, emphasizing the cycle of erosion and aggradation within a drainage basin. Sediment eroded upstream is deposited downstream on a channel fan until it becomes unstable and down cutting is initiated, so the location of cutting and filling is constantly changing within the drainage basin. Patton and Schumm (1975, 1981) also studied gully and arroyo development in small valleys and found a significant relationship between slope and initiation of arroyo downcutting. However, the critical slope varies between drainages because it is dependent on other factors such as vegetation, runoff, discharge, and drainage basin area. They emphasize instantaneous discharge as an important part of the equation. The higher the discharge the lower the critical slope value needed to initiate down cutting. Climate may trigger arroyo formation in some cases because flood magnitude is linked to large-scale atmospheric and oceanic cycles that change through time, but cutting and filling can also take place without climatic changes or other external forcing mechanisms.

Some have combined the climate and internal stream dynamics arguments. Gellis and Elliott (2001) argue that synchronous downcutting episodes documented in many Southwestern drainage basins suggest climate plays a major role in arroyo formation. However, they hypothesize that the condition of the channel before the climate change is also important; the channel must reach a critical slope before climatic changes can trigger arroyo initiation. The farther removed from the critical slope, the larger the discharge needed to initiate downcutting. Whether or not a channel entrenches its floodplain depends on stream power exceeding the resistance of sediment to be entrained, and stream power is the product of slope and discharge. Based on precipitation records in New Mexico, Gellis and Elliott (2001) expected downcutting to have occurred after 1967 because rainfall intensity increased and has remained relatively high since. Instead they found the Rio Puerco and tributaries of the Zuni River have continued to aggrade since about 1940. They hypothesize that arroyo formation is triggered by climatic changes but that aggradation is controlled primarily by internal stream dynamics.

Arroyo Studies in the Carrizo Valley

In a local study, about 10 km north of Cox Ranch Pueblo, Jill Onken (2004) recorded alluvial stratigraphy in the Fence Lake project area, along Carrizo Wash and its tributaries. If the timing of arroyo downcutting at Cox Ranch Pueblo was synchronous with degradation in the Fence Lake project area it would suggest that climate played a dominant role. Differences in timing between the two areas may indicate that climate was not a major factor and that local geomorphic parameters were more important.

Despite their proximity the Fence Lake project area and Cox Ranch Pueblo area do have significant geomorphic differences. The arroyos studied at Cox Ranch Pueblo are located on upper piedmont surfaces whereas the arroyos studied by Onken are in higher order drainages along the valley bottom. The Cox Ranch drainages have steeper slopes but smaller catchment areas. Also, the Fence Lake project area has a fairly continuous arroyo system today formed by Carrizo Wash and its tributaries whereas the arroyos in the Cox Ranch Pueblo study area are part of a discontinuous system.

Onken distinguished six alluvial units deposited in the Carrizo Valley during the Holocene (Table 4.1) based on stratigraphy with 23 ^{14}C dates and some ceramic age control for the younger units. None of the deposits exposed in the modern arroyo walls and in their backhoe trenches date older than 6400 BP. Alluviation in Carrizo Wash and its tributaries was episodically halted by periods of arroyo cutting and soil formation on terrace treads. Of interest are three episodes of prehistoric arroyo cutting at approximately 4000, 1000, and 500 BP (Figure 4.1). Onken (2004) found the alluvial history in the Fence Lake project area to be similar to alluvial chronologies in other areas in the Southwest, particularly those of Karlstrom (1988) on Black Mesa, Hall (1983) at Chaco Canyon, and Waters and Haynes (2001) for southern Arizona.

Onken follows Waters and Haynes (2001) suggesting that the increase in the frequency of arroyo formation after about 5000 BP is due to an increase in El Niño events and alternating wet and dry conditions. She uses a modified version of Karlstrom's (1988) model hypothesizing that arroyos form when water tables are low and there is a climate shift towards an increased frequency of high-intensity storms. She uses this model and some regional paleoclimatic data to infer the geomorphic conditions at Fence

Table 4.1. Alluvial Chronology for Carrizo Wash and Tributaries (Onken 2004)

Depositional History	Approximate Age ^{14}C yr. BP	Sedimentology
Historic Arroyo Cutting		
Qha 6	500-100	Graded coarse to fine, pebbly sand or sand to sandy silt, sandy loam, or clayey silt
Arroyo Cutting	500	
Qha 5	1000-500	Graded coarse to fine, sandy to clayey; capped by weak soil
Arroyo Cutting	1000	
Qha 4	4000-1000	Graded coarse to fine, bedded sands or laminated mud to clay; capped by weak soil
Arroyo Cutting	4000	
Qha 3	4500-4000	Graded coarse to fine, silty sand or clayey silt to clay or silty clay; capped by weak soil
Qha 2	4900-4500	Graded coarse to fine, sand or silty sand to clay; capped by weak soil
Qha 1	6400-5500	Fine grained alluvial, clay, silty clay, and clayey silt; capped by weak soil

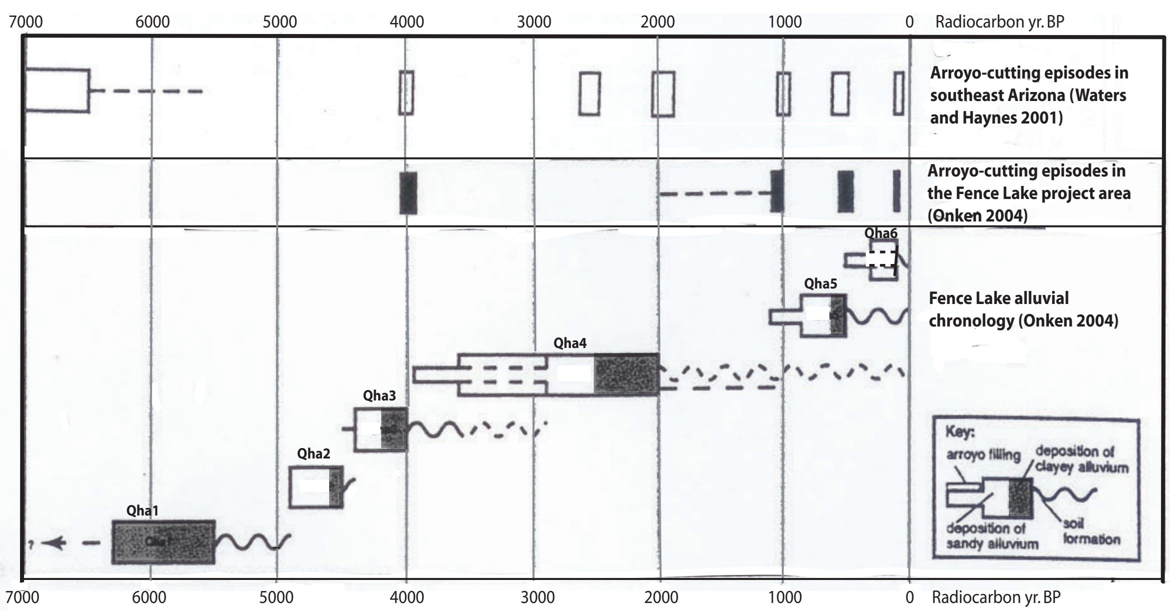

Figure 4.1. Comparison of regional and local arroyo-cutting episodes and a schematic of the alluvial chronology in the Fence Lake project area (adapted from Onken 2004:Figure 1.3).

Lake between 7000 BP and the present. She argues that the region was relatively dry and warm from approximately 7000 to 5000 BP, in line with the concept of a mid-Holocene Altithermal. The late Holocene was cooler and moister but with greater variance in precipitation and flooding leading to episodes of downcutting and backfilling in many floodplains. Arroyos thus occurred in response to episodes of increased flooding along Carrizo Wash at approximately 4000, 1000, and 500 BP, and in the late 1800s. However, the timing of arroyo formation in other drainages on the Colorado Plateau may be offset by several hundred years due to local environmental factors.

Summary

The complex interaction of many different variables makes it difficult to discern the primary or ultimate cause of arroyo formation. The cause may actually be different in different drainage basins, or at least local geomorphic controls may make arroyo activity more or less likely during any given climate change. It seems likely that both climate and internal stream dynamics play a role in the formation of many arroyos including those at Cox Ranch Pueblo. Human land disturbance may also trigger arroyo formation but it is unlikely the primary cause. Both climate and local geomorphic factors have to be considered in addressing the history and cause of arroyo formation at Cox Ranch Pueblo.

CHAPTER FIVE

METHODS AND RESULTS

An examination of alluvial stratigraphy and soil formation in arroyos at Cox Ranch Pueblo may provide insight into what factors are most important in local arroyo activity, and whether or not it is linked to past community abandonment. If buried channels exist at Cox Ranch Pueblo and correlate in time to arroyos identified along Carrizo Wash or elsewhere in the region, then it is likely that climate change is the driving force. If buried channels exist but are asynchronous with regional paleoarroyos, then a combination of climate and local geomorphic factors may be responsible. If buried channels at Cox Ranch Pueblo date to the twelfth century, then arroyo formation may have contributed to local abandonment, regardless of the cause of channel incision. The only way to identify past arroyos at Cox Ranch Pueblo is to examine the alluvial stratigraphy and buried soils exposed in the walls of modern arroyos. In addition to searching for evidence of past arroyo activity, buried soils may also provide insight into past environmental changes. If paleosols differ from modern soils and can be dated, then local evidence of environmental change can be presented and correlated to local and regional cultural changes. Hence, it is important to document, describe, analyze, and if possible, date the sedimentary deposits lying beneath the surface.

Methods

Geoarchaeological fieldwork at Cox Ranch Pueblo included reconnaissance of local arroyos, stratigraphic profiling, soil description, and sediment sampling. Aerial photographs were also used to identify and map landforms. Entrenched and non-entrenched segments of drainages in the area around the pueblo are shown in Figure 5.1 as identified in the field and on aerial photographs.

I selected four localities in three different arroyos for stratigraphic profiling during the 2003 field season (Figure 5.1). One locality is where an arroyo transects Cox Ranch Pueblo. I also focused on two arroyos in Section 22 (T 2N; R 19W), northwest of Cox Ranch Pueblo. These two arroyos are also situated on a piedmont beneath the same mesa as Cox Ranch Pueblo, although drainage direction differs. I profiled two localities in one arroyo located in the eastern half of Section 22 and one locality in another arroyo located in the western half of Section 22. Both arroyos drain a north-facing embayment cut into the mesa. Two additional stratigraphic localities profiled by Gary Huckleberry and Andrew Duff during the 2004 field season are included here. One of these is in the arroyo at Cox Ranch Pueblo (Profile 2 in Figure 5.1) located upslope from the 2003 profile (Profile 1). The other is in an arroyo located a few hundred meters south of Cox Ranch Pueblo in Section 23 (T 2N; R 19W).

I mapped and distinguished stratigraphy based on physical properties such as color, texture, and soil structure. Soil profile descriptions were also made for Cox Ranch Arroyo, Profile 1 and East Arroyo Section 22, Profiles 1 and 2 (Appendix A) based on field methods described in Schoeneberger et al. (1998). I used the ribbon method to estimate the USDA textural class, a Munsell book for color, and a 1N HCl solution to estimate calcium carbonate content. I sampled sediment from these three localities by soil horizon. Several A and B horizons were combined at Section 22, East Arroyo, Profile 1 due to their thinness. Material was also collected from all eight profiles for ^{14}C dating and this included bulk soil samples from organic soil horizons, individual charcoal

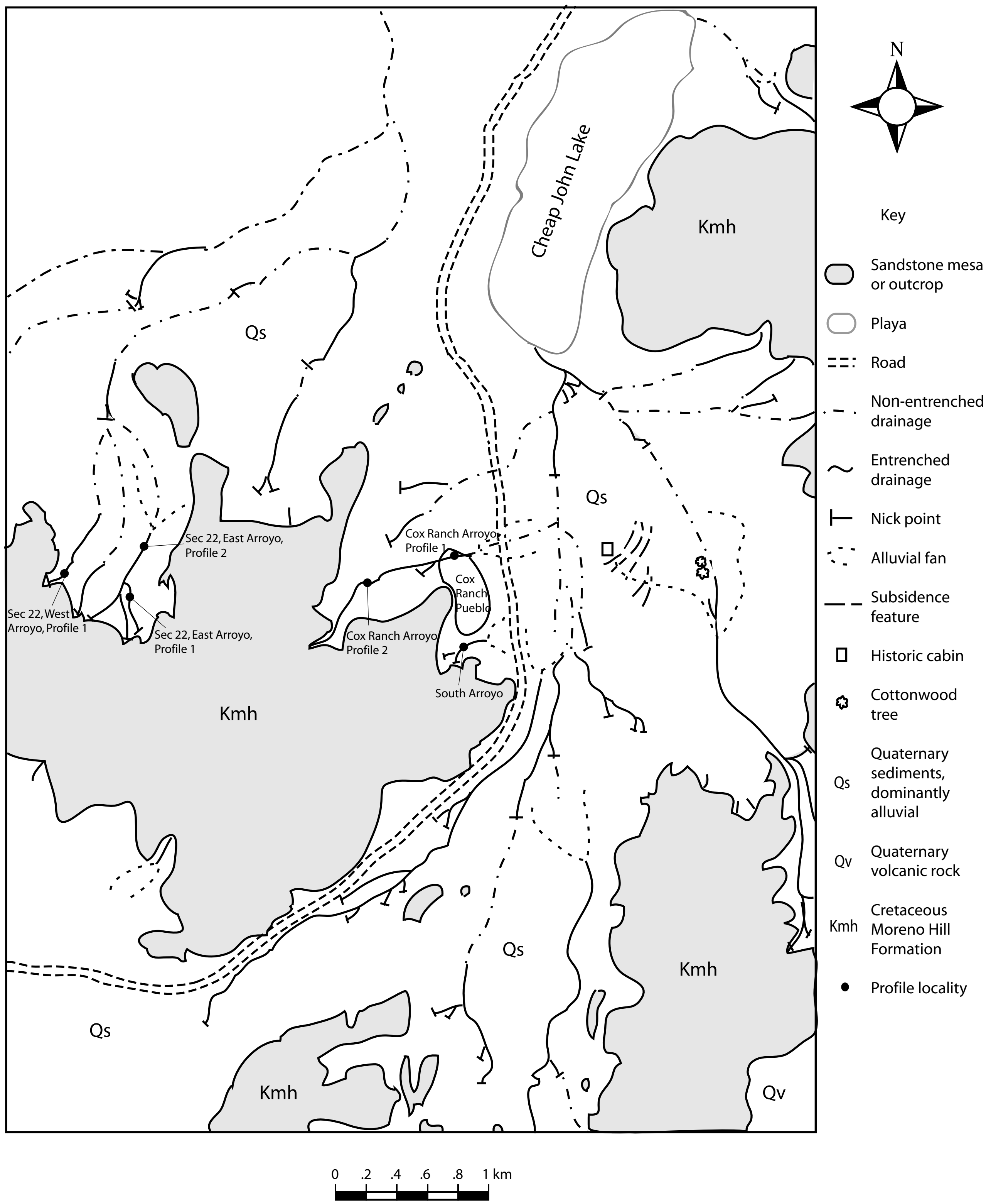

Figure 5.1. Landform map of the area surrounding Cox Ranch Pueblo including entrenched and non-entrenched segments of drainages and location of profiles.

pieces, and combined charcoal and sediment samples from lenses with dispersed charcoal. Six ^{14}C samples were submitted to Beta Analytic for analysis.

I analyzed the sediment in the Geoarchaeological and Pollen laboratories at the Department of Anthropology, Washington State University in Pullman (see Appendix B for detailed results of sediment analysis). Grain size analysis was conducted to determine the percentage of sand, silt, and clay in each sample (Janitzky 1986). The coarse fraction (>.5 mm) was sorted into size grades using nested sieves in a Ro-Tap machine, and hydrometer analysis was conducted on the fine fraction (<.5 mm). I measured pH using an electrometric pH meter on a 1:2 soil-water paste. Calcium carbonate was determined using a Chittick apparatus (Machette 1986), and the Walkley-Black (1934) method was used to determine organic matter content. Magnetite was removed from the samples by hand with a magnet before analysis to minimize error caused by extraneous oxidation of iron.

Organic matter and calcium carbonate are both indicators of soil pedogenesis. Organic matter is added to soil by decaying plants and other material. Calcium carbonate can be delivered to soil by a number of sources and accumulates in the B horizon during pedogenesis when there is inadequate water to leach it from the soil profile (Schaetzl and Anderson 2005). Soil pH is less a measure of pedogenesis as it is a measure of soil fertility. Neutral to slightly alkaline soils contain more base cations such as calcium, magnesium, phosphorous, and potassium than do acidic soils and are the most fertile for crop production (Schaetzl and Anderson 2005). However, pH can be indirectly related to pedogenesis. For example, organic matter is commonly associated with lower pH and thus pH generally generally increases with depth. Dramatic shifts in pH with depth may indicate buried soil horizons or organic cultural deposits. Differences in pH, organic matter, and calcium carbonate between soil horizons may relate to changing environmental conditions, length of pedogenesis, or use of the land.

Results

Numerous arroyos in the area around Cox Ranch Pueblo provide access to subsurface deposits. These arroyos are discontinuous—they do not extend through the valley bottom and are not integrated with Largo Creek to the north (Figure 2.2). Several drainages have repeated patterns of alternating entrenched and non-entrenched segments. Although discontinuous, several of the arroyos located along the major valley axes are greater than 2 km in length (Figure 5.1). The arroyos on the upper piedmont are shorter in length, generally less than 1 km, but expose many layers of past depositional events, separated by periods of surface stability (represented by soil formation). They also reveal previous episodes of arroyo activity similar to today.

Cox Ranch Pueblo Arroyo, Profile 1 is located on the southern wall of the arroyo near the northern boundary of the site (Table 5.1, Figure 5.1). The arroyo exposes 3.7 m of deposits (measured vertically) at this locality, and the area profiled measures 1.8 m in width (Figure 5.2 and 5.3). The profile contains 14 separate strata (labeled I – XIV from top to bottom) most of which are fine textured, representing relatively low energy alluvial deposition. The units range from loamy sand to clay and only three contain any gravel. A snail shell was found in Stratum III and a ceramic sherd was found at the boundary between Strata II and III. The pueblo occupation appears to post-date or is coeval with Stratum II. On the bank opposite of Profile 1 the arroyo cuts and exposes a room block associated with Cox Ranch Pueblo that lies in, and on top of the soil developed in

Stratum II (2ABwb). Thus the sherd located at the base of Stratum II is believed to be intrusive. The profile also contains seven other paleosols of various thickness and development. Decalcified sediment samples from the top of horizons 5Akb (104-118 cm) and 9Akb (276-285 cm) dated to 5070 $\pm$ 40 BP and 6150 $\pm$ 40 BP, respectively (Table 5.2). Soil horizons 5Akb (104-157cm) and 8Akb (235-263 cm) contain greater than 40 percent clay, and horizon 6ABkb (180-212 cm) contains more than 30 percent clay (Figure 5.4; Appendix B). Most of the clay, however, is likely inherited from the shale units of the Moreno Hill formation, although clay skins do suggest some translocation and pedogenesis. Organic matter and calcium carbonate accumulation in the B horizon are better indicators of pedogenesis at Cox Ranch Pueblo. Organic matter is highest in soil horizons 5Akb (104-157 cm), 6ABkb (180-212 cm), and 7Akb (212-224 cm). There are six peaks in calcium carbonate in soil horizons 2ABwb (11-31 cm), 3Bkb (40-63 cm), 4Bkb (78-104 cm), 5Ckb (157-180 cm), 7Akb (212-224 cm), and 9Ckb (295-355 cm). Except for the 7Akb horizon, calcium carbonate tends to be leached from the A horizons and/or enriched in the B and C horizons. The soils are slightly alkaline; pH generally increases with depth from 7.1 in the first unit to 7.7 in the last unit. This is not surprising given the amount of calcium carbonate present in the soils.

Table 5.1: Profile UTM Locations

Profile	UTM location (Zone 12)
Cox Ranch Arroyo, 1	3,806,858 m N, 702,951 m E
Section 22, East Arroyo, 1	3,806,593 m N, 700,896 m E
Section 22, East Arroyo, 2	3,806,965 m N, 700,968 m E
Section 22, West Arroyo, 1	3,806,917 m N, 700,531 m E

Table 5.2: Radiocarbon Samples, Dates, and $^{13}C/^{12}C$ Ratios

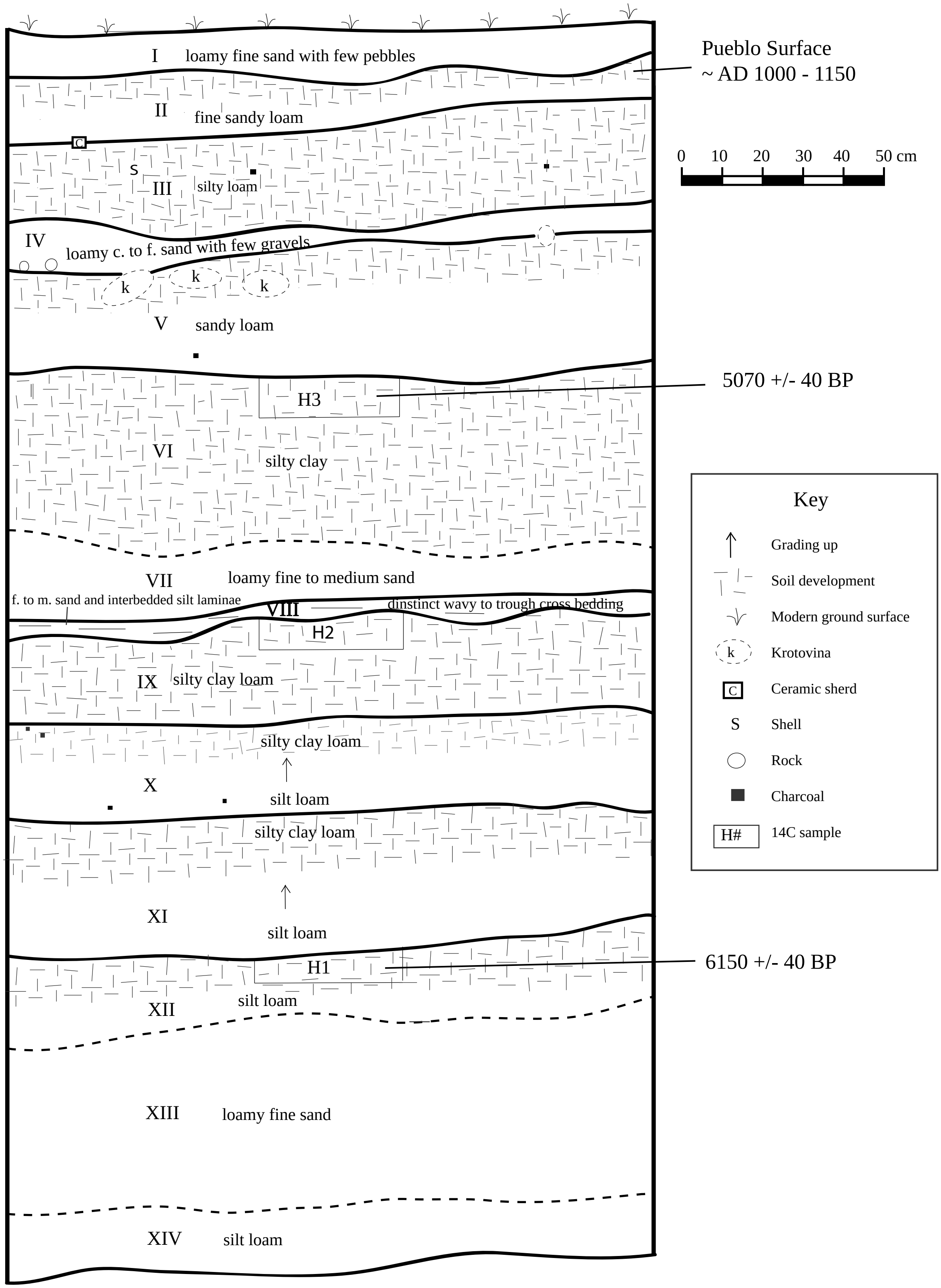

Figure 5.2. Cox Ranch Arroyo, Profile 1. (Profile drawn by S. VanBuskirk and G. Huckleberry 6/03.)

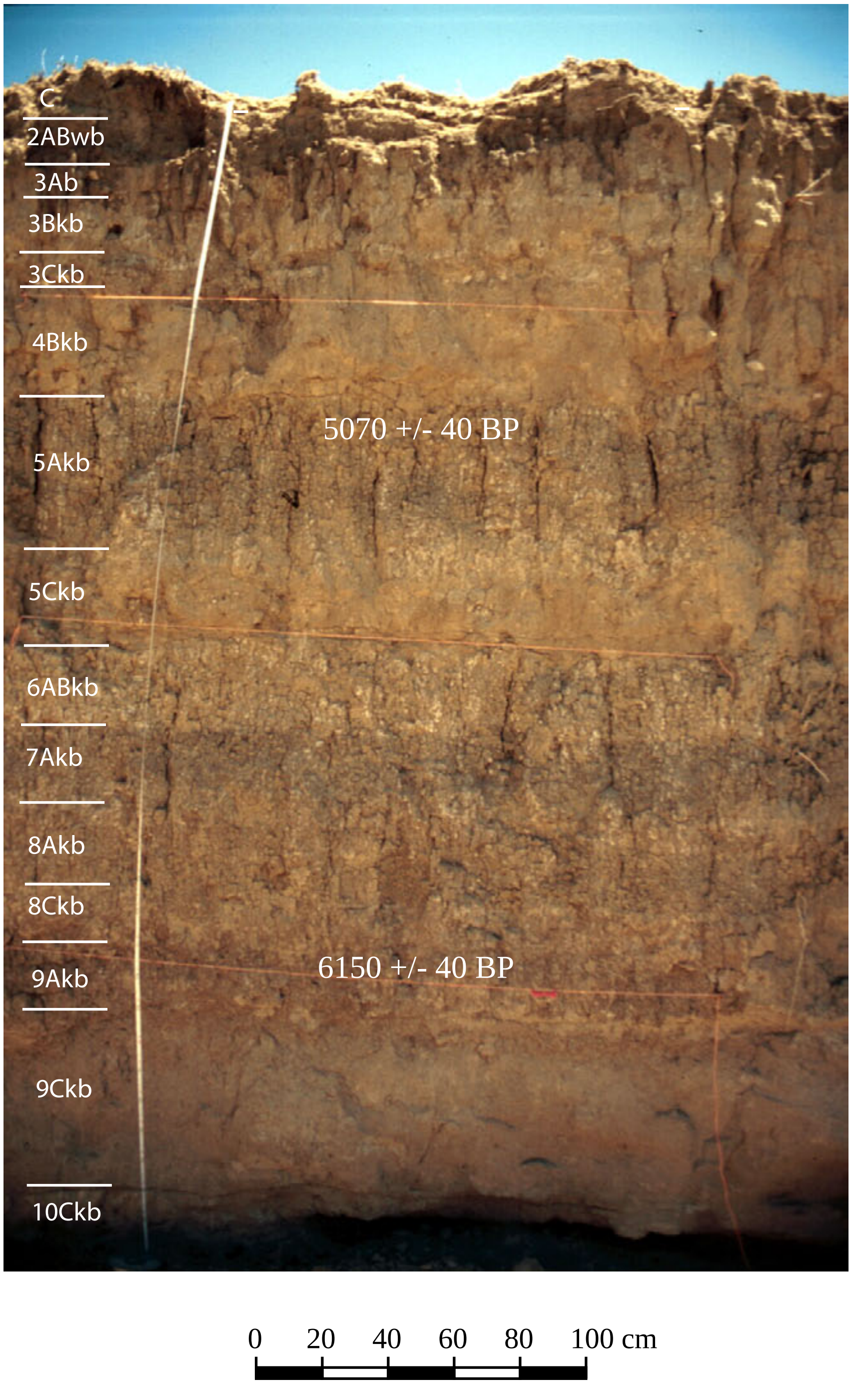

Figure 5.3. Cox Ranch Arroyo Profile 1 with soil horizon designations.

Note: INTCAL98 was used for radiocarbon age calibration (Stuiver et al. 1998)

Sample	Beta Lab #	Profile (Sec 22)	Depth (cm)	Material	^{14}C age BP	$\delta^{13}C$ ($^0/_{00}$)	Calibrated Age BP (2σ)
920	183331	Sec 22, West 1	640	Charcoal	8690 $\pm$ 50	-24.3	9880-9540
936	183332	Sec 22, East 1	390	Stem	2630 $\pm$ 40	-15.1	2970-2780
945	183333	Sec 22, East 2	32-55	Decalcified sediment	770 $\pm$ 40	-14.2	940-760
958	183334	Sec 22, East 2	145-155	Charcoal	3150 $\pm$ 40	-20.2	3550-3370
910	196286	Cox Ranch 1	276-285	Decalcified sediment	6150 $\pm$ 40	-16.6	7280-7170
912	196287	Cox Ranch 1	104-118	Decalcified sediment	5070 $\pm$ 40	-17.7	6000-5900

Cox Ranch Pueblo Arroyo Profile 2 is located approximately 500 m upslope from Profile 1 (Figure 5.1). The arroyo exposes 5 to 6 m of deposits (measured vertically) and the area profiled is approximately 25 m in length (Figure 5.5). Most of the strata at this locality are fine-textured deposits but there are also several gravelly sandy units. A paleoarroyo was identified at this locality, the base of which is traceable across most of the profile. The lower portion of the paleochannel has been filled with gravels, cobbles, and sand with low angle planar cross bedding. The soil underlying architectural features at Cox Ranch Pueblo is traceable upslope along the arroyo and is developed into the fill of the paleochannel, so the paleoarroyo must predate the Chacoan-era occupation of the site. Moreover, the paleosol developed into the 5Akb horizon at Profile 1 and ^{14}C dated at 5190 $\pm$ 40 BP is traceable upslope and truncated by this paleochannel, thus providing a maximum age for the event. There is also possible evidence of a second, earlier

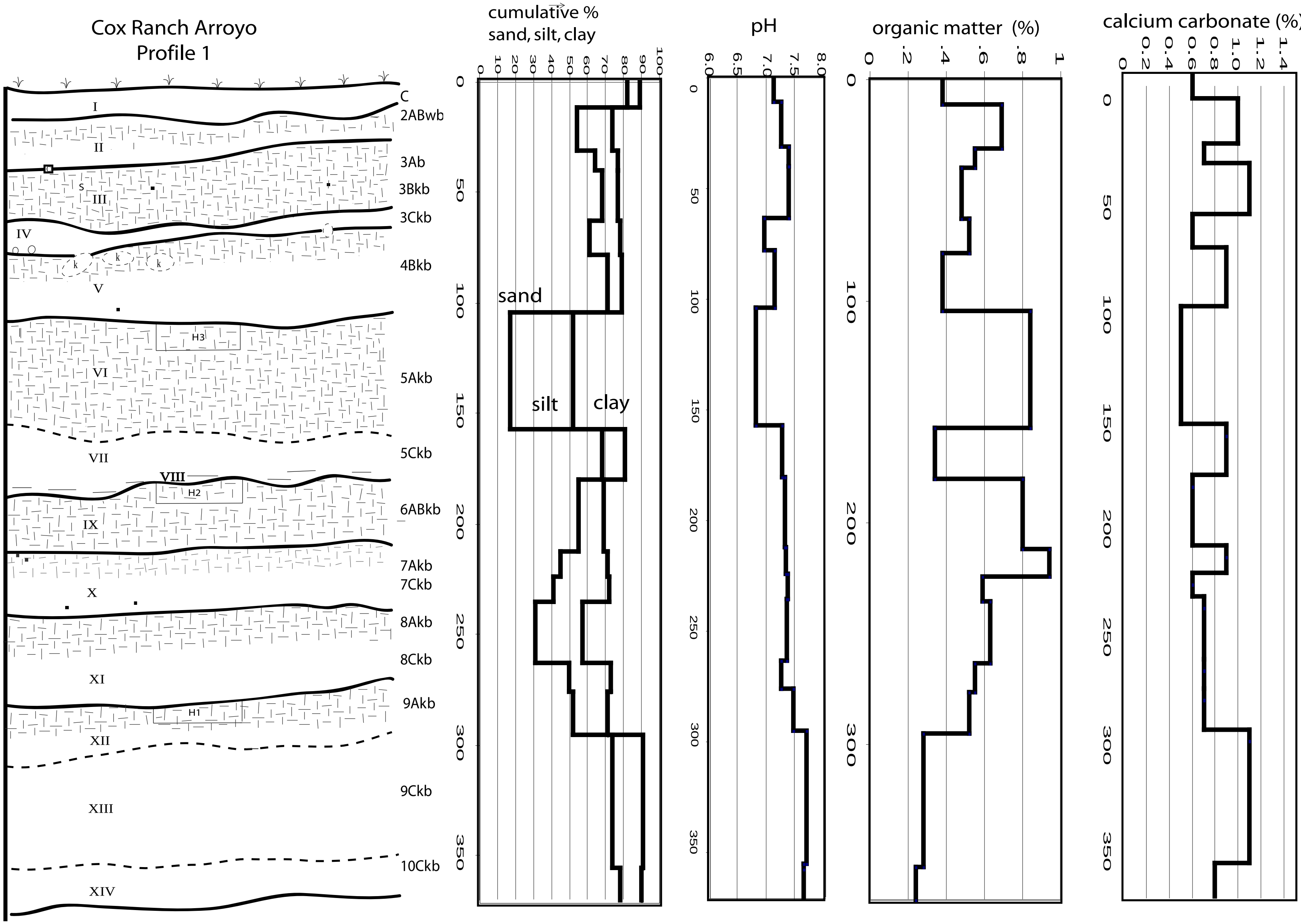

Figure 5.4. Cox Ranch Arroyo, Profile 1 sediment data including grain size, pH, organic matter, and calcium carbonate by sample.

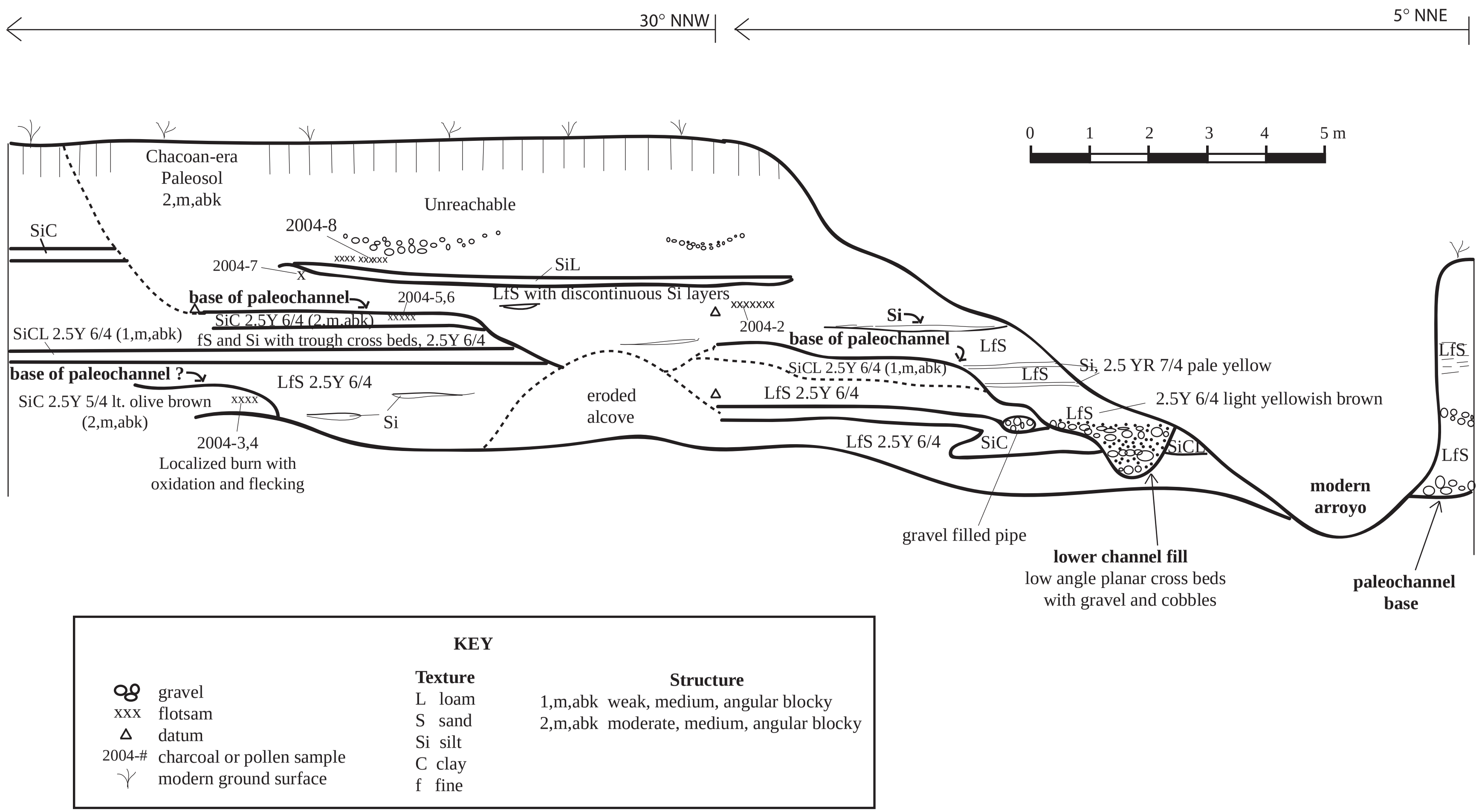

Figure 5.5. Cox Ranch Arroyo, Profile 2. (Profile drawn by G. Huckleberry and A. Duff 7/04.)

paleochannel marked by a truncated paleosol, but the geometry of this channel could not be defined.

Section 23, South Arroyo, Profile 1 is located a few hundred meters south of Cox Ranch Pueblo (Figure 5.1). The arroyo exposes 4 m of deposits at this locality and the area profiled is 9 m in length (Figure 5.6). A paleochannel was also found at this locality, the base of which has been filled with gravelly sand. This paleochannel also likely predates the Chacoan-era occupation of the site. The channel fill is beneath a soil that underlies the remains of a fieldhouse believed to be coeval with Cox Ranch Pueblo.

Section 22, East Arroyo, Profile 1 is located on the eastern wall of the arroyo (Table 5.1, Figure 5.1). The arroyo has exposed 4.6 meters of deposits here, and the area profiled is 1.2 m wide at the top and 2 m wide at the bottom (Figure 5.7 and 5.8). The profile contains 12 separate strata most of which are fine alluvial deposits but there are also several gravelly sandy units with trough cross bedding. Several thermal features were found near the bottom of the profile between Strata IX and XII (Figure 5.9). These features have abundant charcoal and oxidized zones around them distinguished by a reddish brown color indicating an in situ burn. Several samples were taken from these features for ^{14}C dating. A plant stem taken from the largest feature at a depth of approximately 3.9 m below the surface yielded a date of 2630 $\pm$ 40 BP (Table 5.2). The profile also contains nine paleosols. Horizons 3Akb (176-181 cm), 3Bktb (181-188 cm), 8Akb (320-326 cm), and 9Akb (356-374 cm) contain over 30 percent clay (Figure 5.10, Appendix B). Organic matter is highest in soil horizons 2Ab (60-70 cm), 3Akb (176-181), 3Bktb (181-188 cm), 4Akb (188-193 cm), 4Bktb (193-202 cm), 5ABtb (202-207 cm), 5Btb (207-215 cm), and 9Akb (356-374 cm). Calcium carbonate has two major

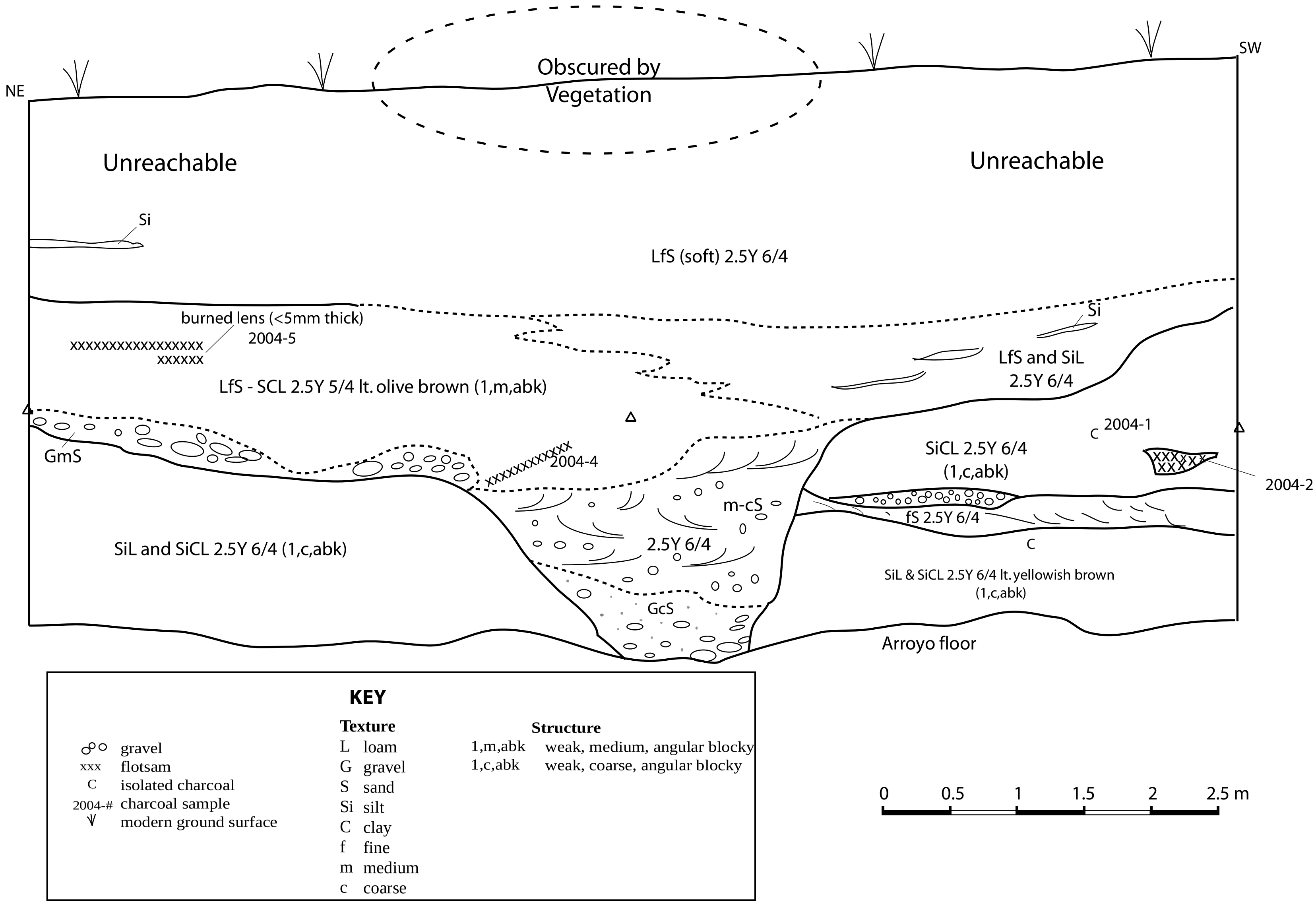

Figure 5.6. Section 23, South Arroyo, Profile 1. (Profile drawn by G. Huckleberry and A. Duff 7/04.)

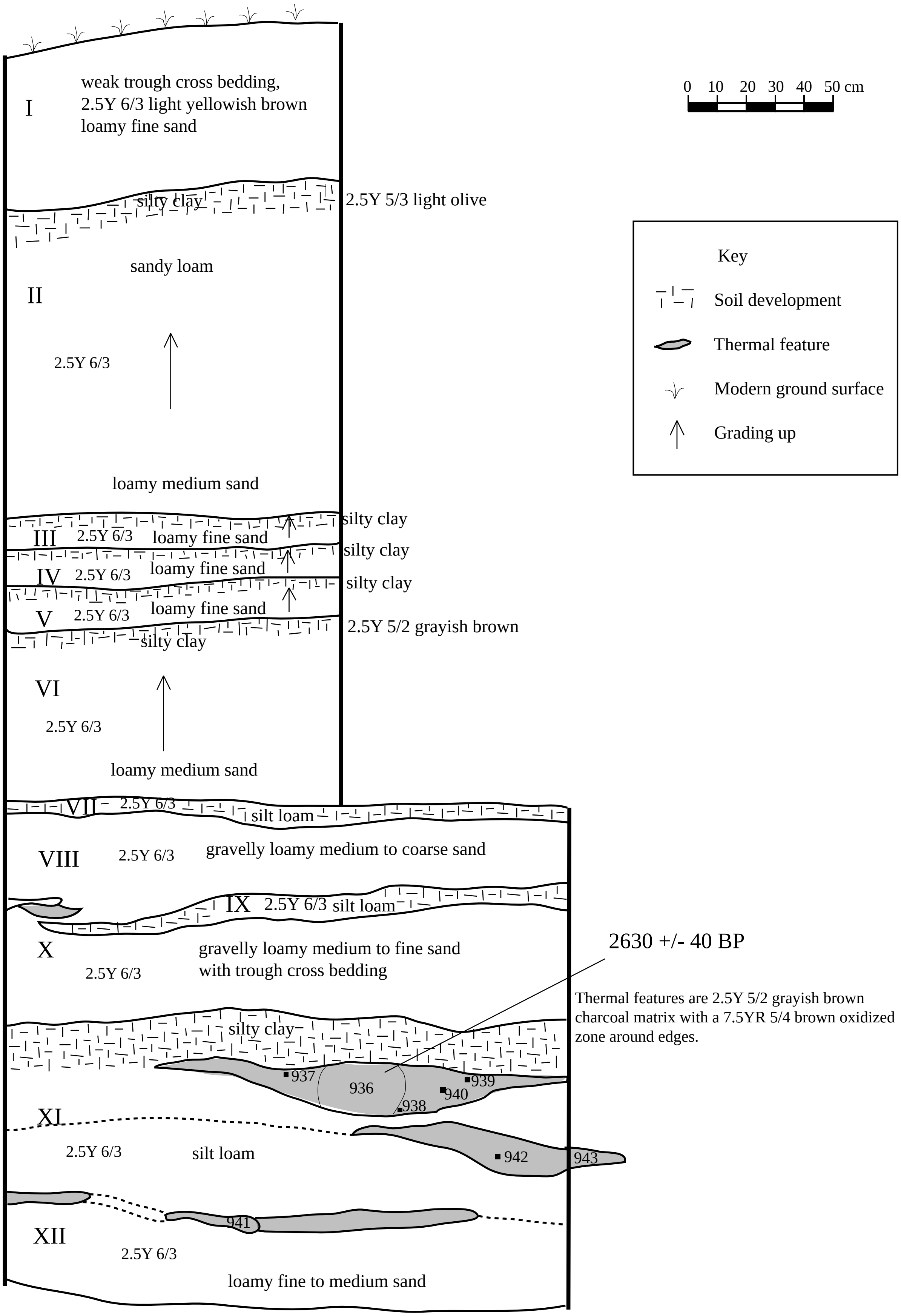

Figure 5.7. Section 22, East Arroyo, Profile 1. (Profile drawn by S. VanBuskirk and G. Huckleberry 6/03.)

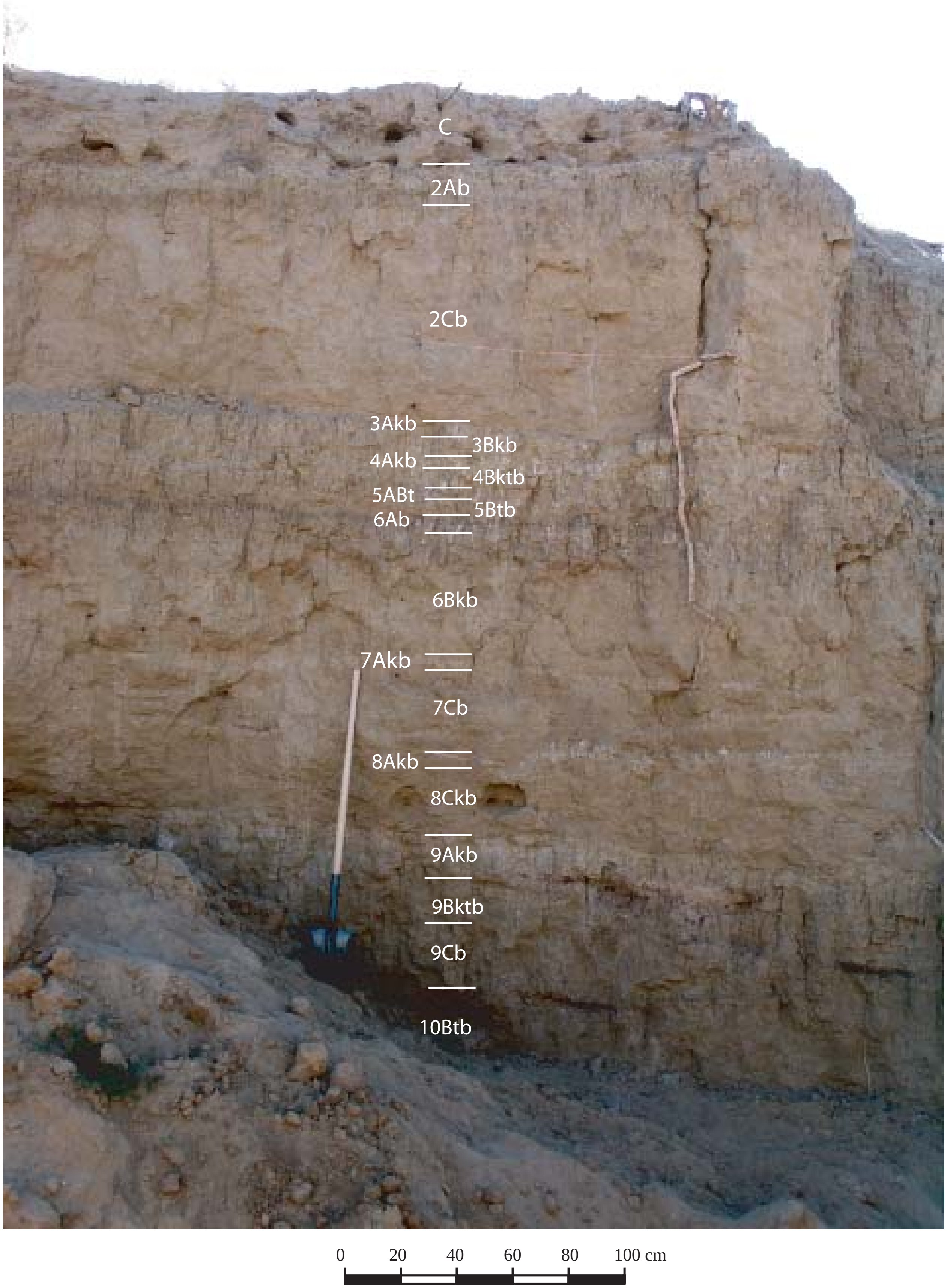

Figure 5.8. Section 22, East Arroyo, Profile 1 with soil horizon designations.

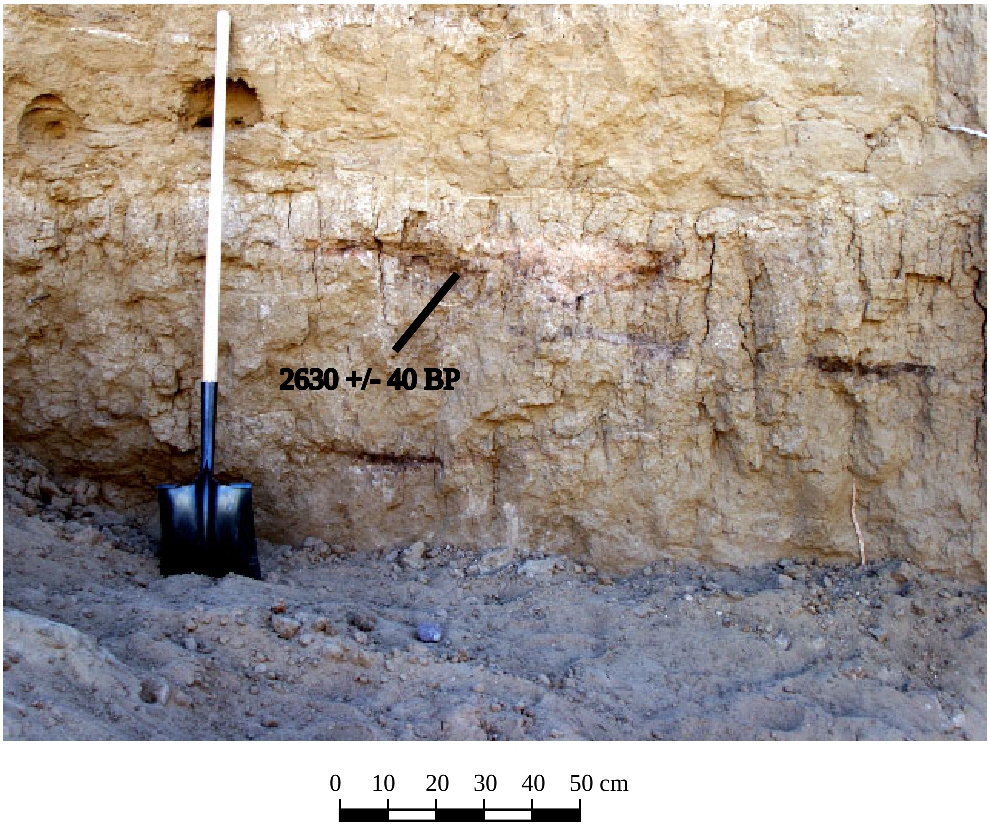

Figure 5.9. Bottom of Section 22, East Arroyo, Profile 1 showing charcoal features and location of charcoal sample used for dating.

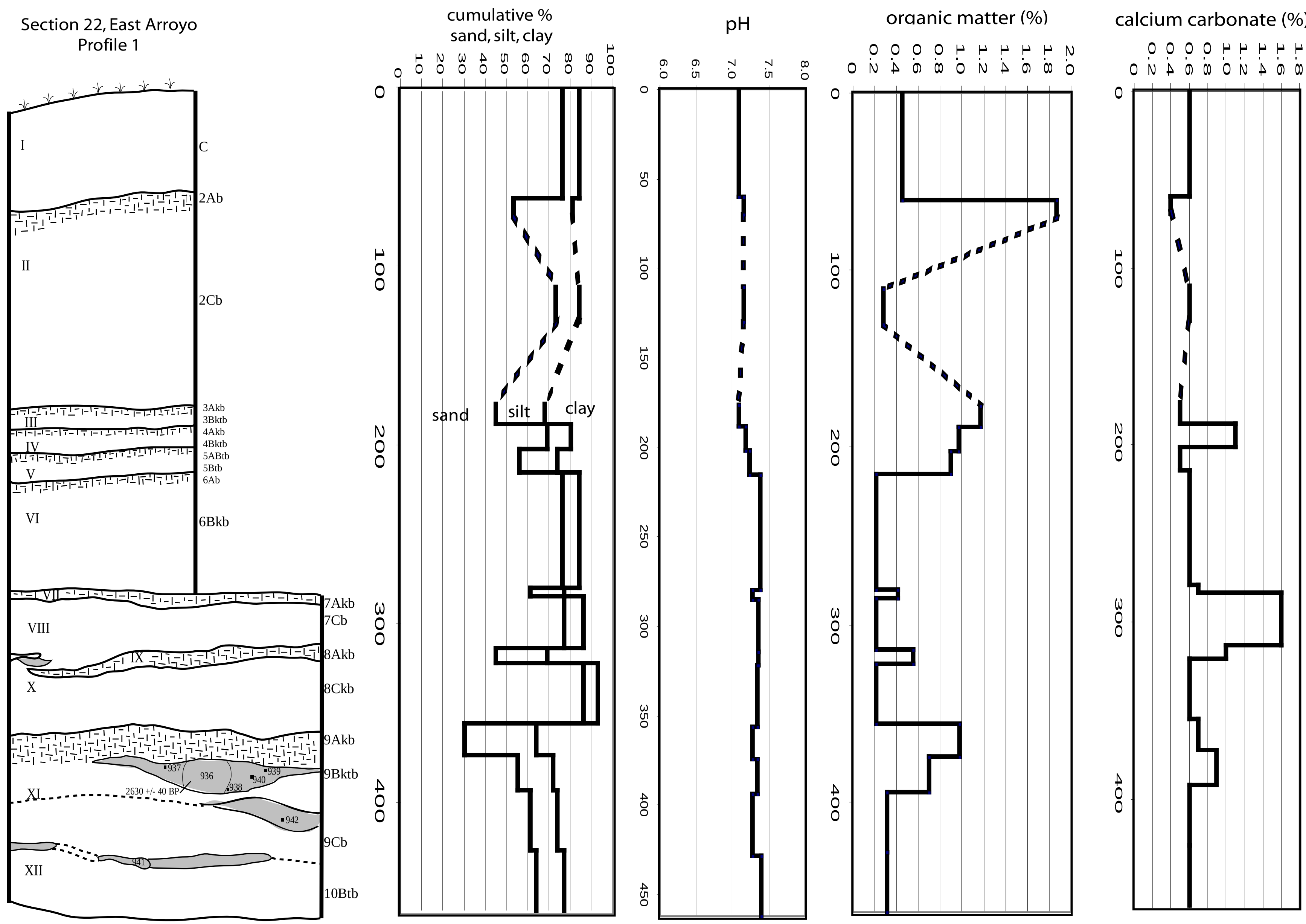

Figure 5.10 Section 22, East Arroyo, Profile 1 sediment data including grain size, pH, organic matter, and calcium carbonate by sample.

peaks in soil horizons 4Akb and 4Bktb (188-202 cm) and in 7Ckb (285-320 cm) and a smaller peak in horizon 9Bktb (374-394 cm). Soil pH generally increases with depth from 7.1 in the first unit to 7.4 in the last unit.

Section 22, East Arroyo, Profile 2 is located downslope from Profile 1 on the western wall of the arroyo (Table 5.1, Figure 5.1). The arroyo has exposed 2.8 m of deposits and the area profiled is 1.8 m wide (Figure 5.11 and 5.12). The profile contains eight separate strata representing alluvial deposits and four paleosols. Stratum V contains abundant charcoal and fire cracked rock. One small chert flake was also found just upslope from the profile in this unit. Charcoal from near the bottom of the unit dated to 3150 $\pm$ 40 BP (Table 5.2). Decalcified sediment from horizon 2Ab (32-55 cm) dated to 770 $\pm$ 40 BP. As in the other profiles, the A horizons are relatively fine textured; the 3ABktb and 6ABtb contain 40 and 28 percent clay, respectively (Figure 5.13, Appendix B). The highest organic matter is in horizon 4Ckb (136-148 cm), which has abundant charcoal. Horizons 2Ab (32-55 cm) and 3ABtkb (88-106 cm) were also high in organic matter. Soil pH generally increases from 7.0 at the top of the profile to 7.4 at the bottom of the profile. Calcium carbonate percentages were highest in horizons 2Bkb (55-88 cm), 3Bkb (106-127 cm), and the bottom half of 5Ckb (180-217 cm).

Section 22, West Arroyo, Profile 1 is located near the base of the mesa on the east wall of the arroyo (Table 5.1, Figure 5.1). The arroyo has downcut approximately 7 m at this locality, making access to the upper deposits difficult. As a result, only lithostratigraphy was recorded although soil development was estimated visually by dark, fine-textured layers. The area profiled is 80 cm wide at the top and 1.6 m wide at the bottom (Figure 5.14 and 5.15). Sixteen separate strata, ranging in texture from loamy

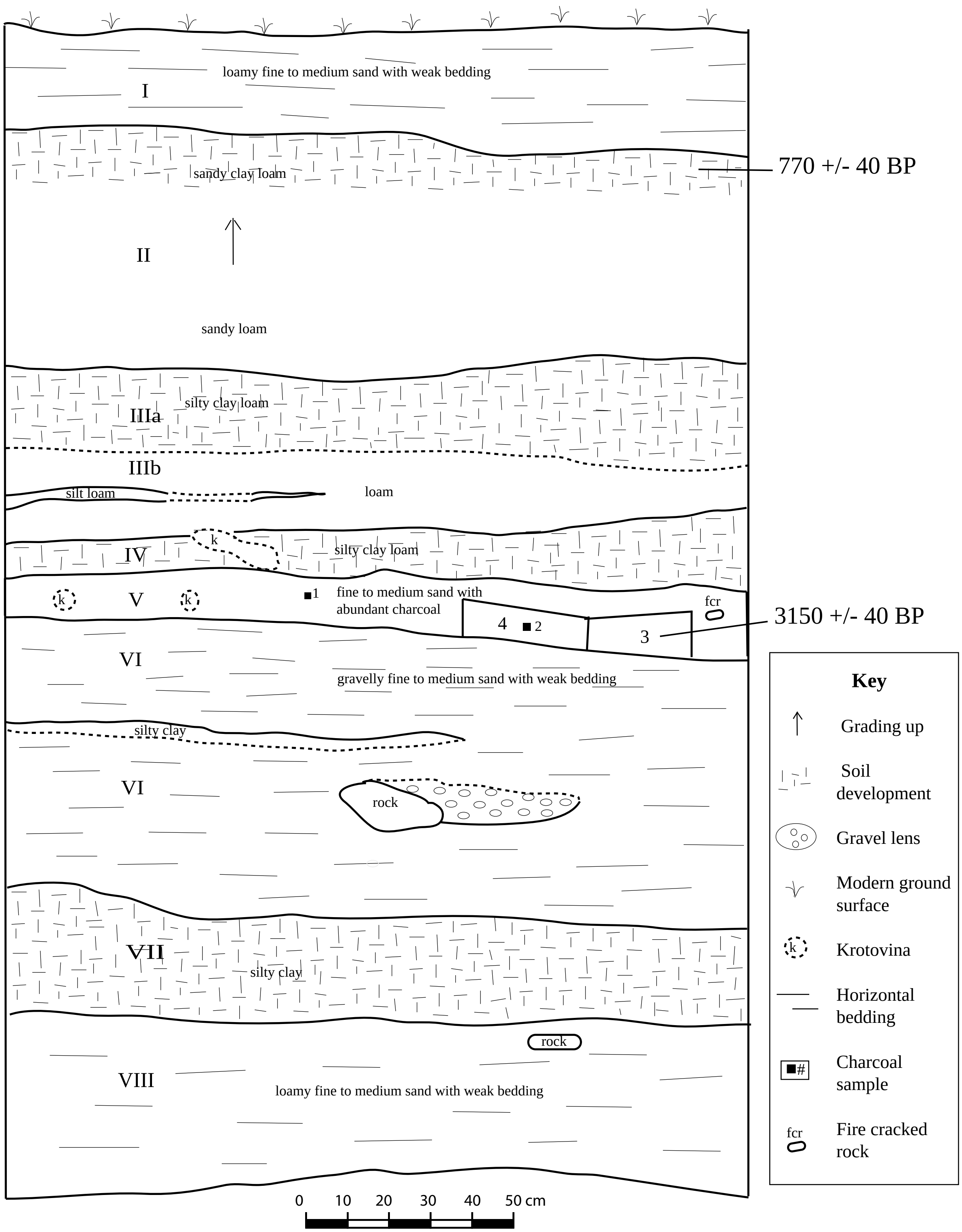

Figure 5.11. Section 22, East Arroyo, Profile 2. (Profile drawn by S. VanBuskirk and G. Huckleberry 6/03.)

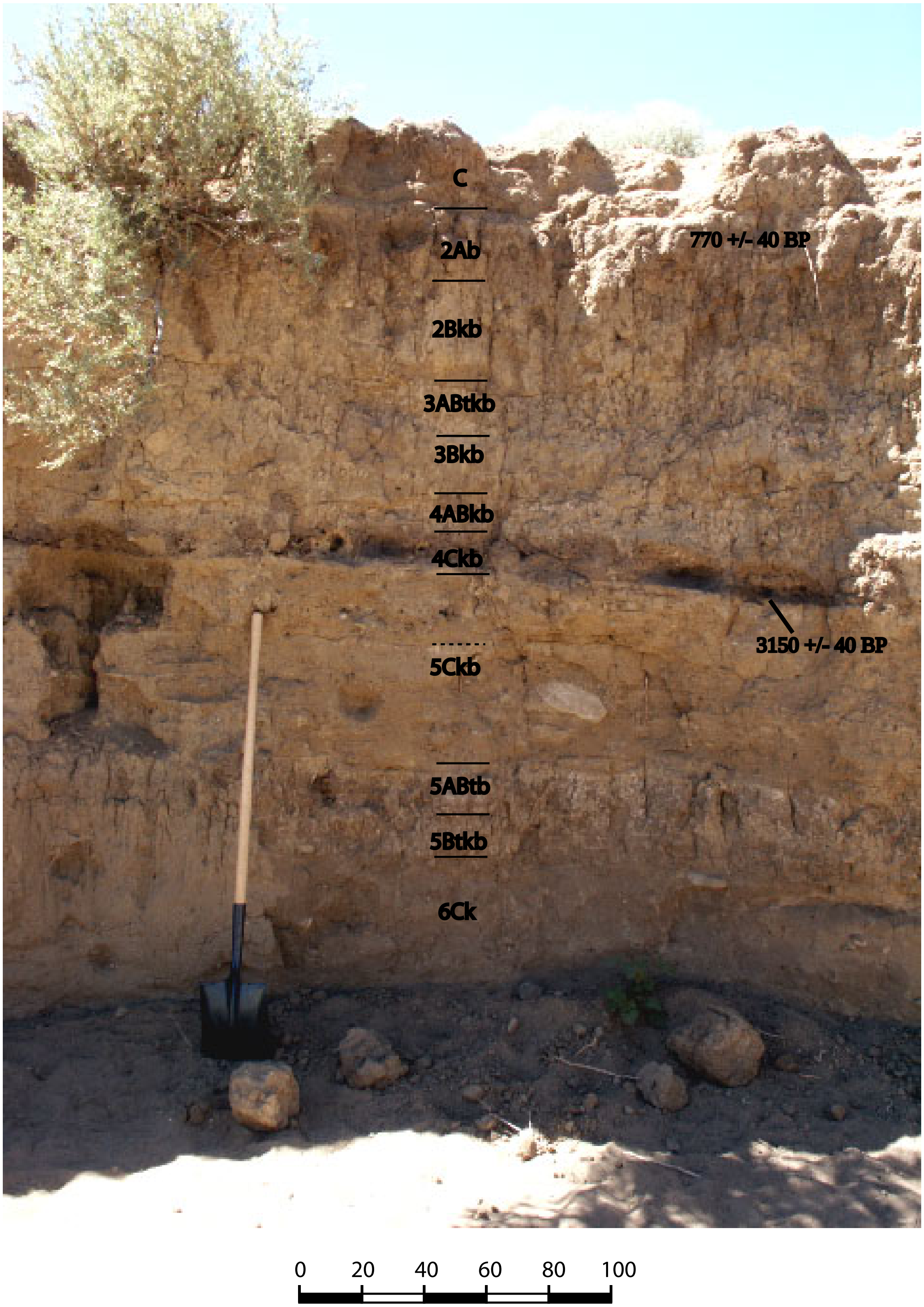

Figure 5.12. Section 22, East Arroyo, Profile 2 with soil horizon designations.

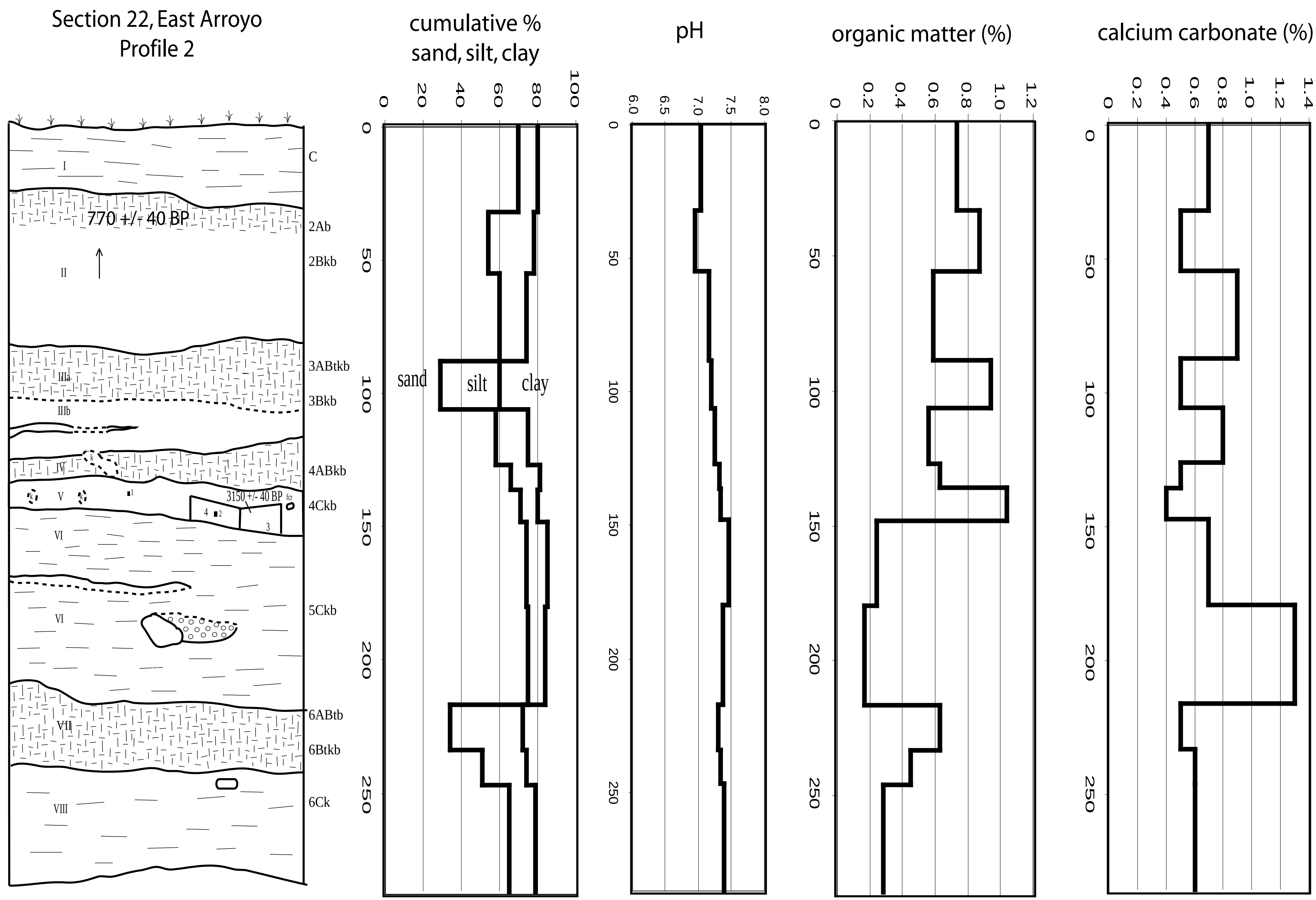

Figure 5.13. Section 22, East Arroyo, Profile 2 sediment data including grain size, pH, organic matter and calcium carbonate by sample.

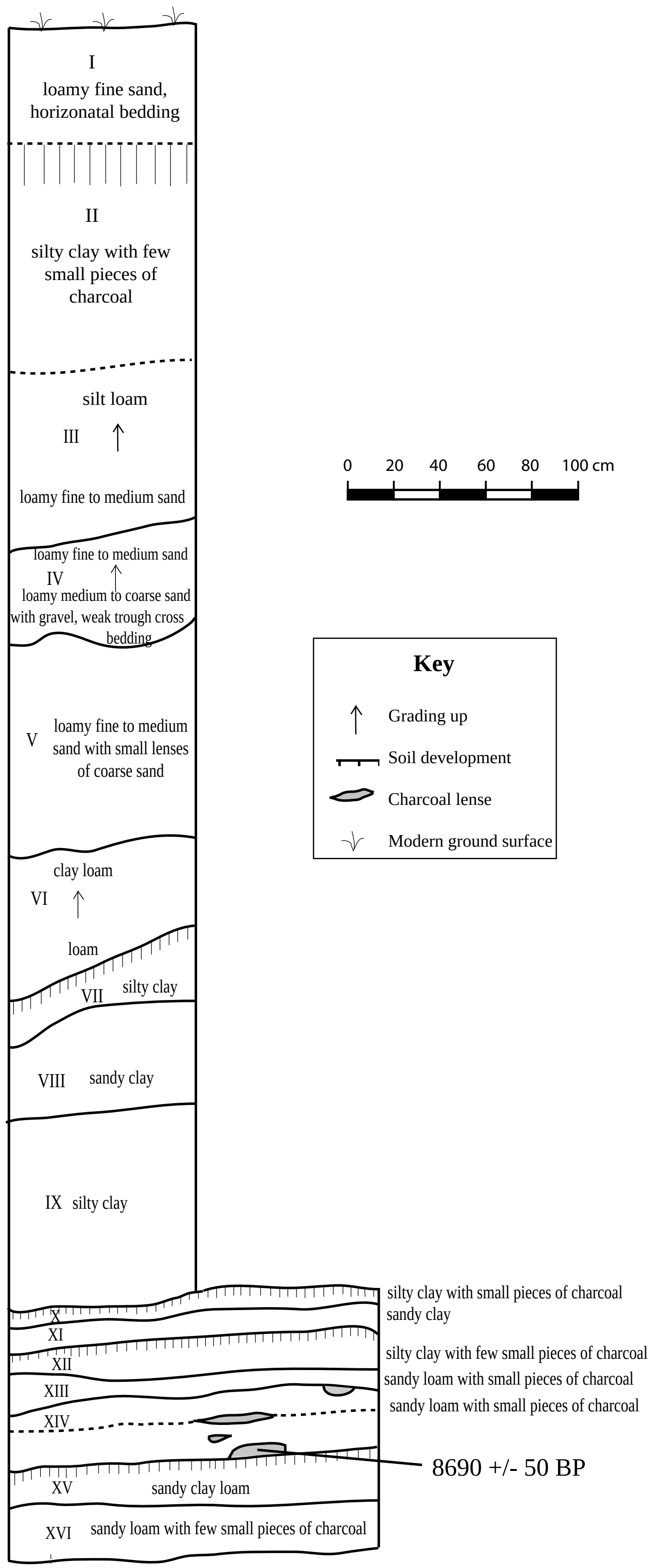

Figure 5.14. Section 22, West Arroyo, Profile 1. The first three unit boundaries are approximate because they could not be reached with a ladder. (Profile drawn by S. VanBuskirk and F. Arakawa 6/03.)

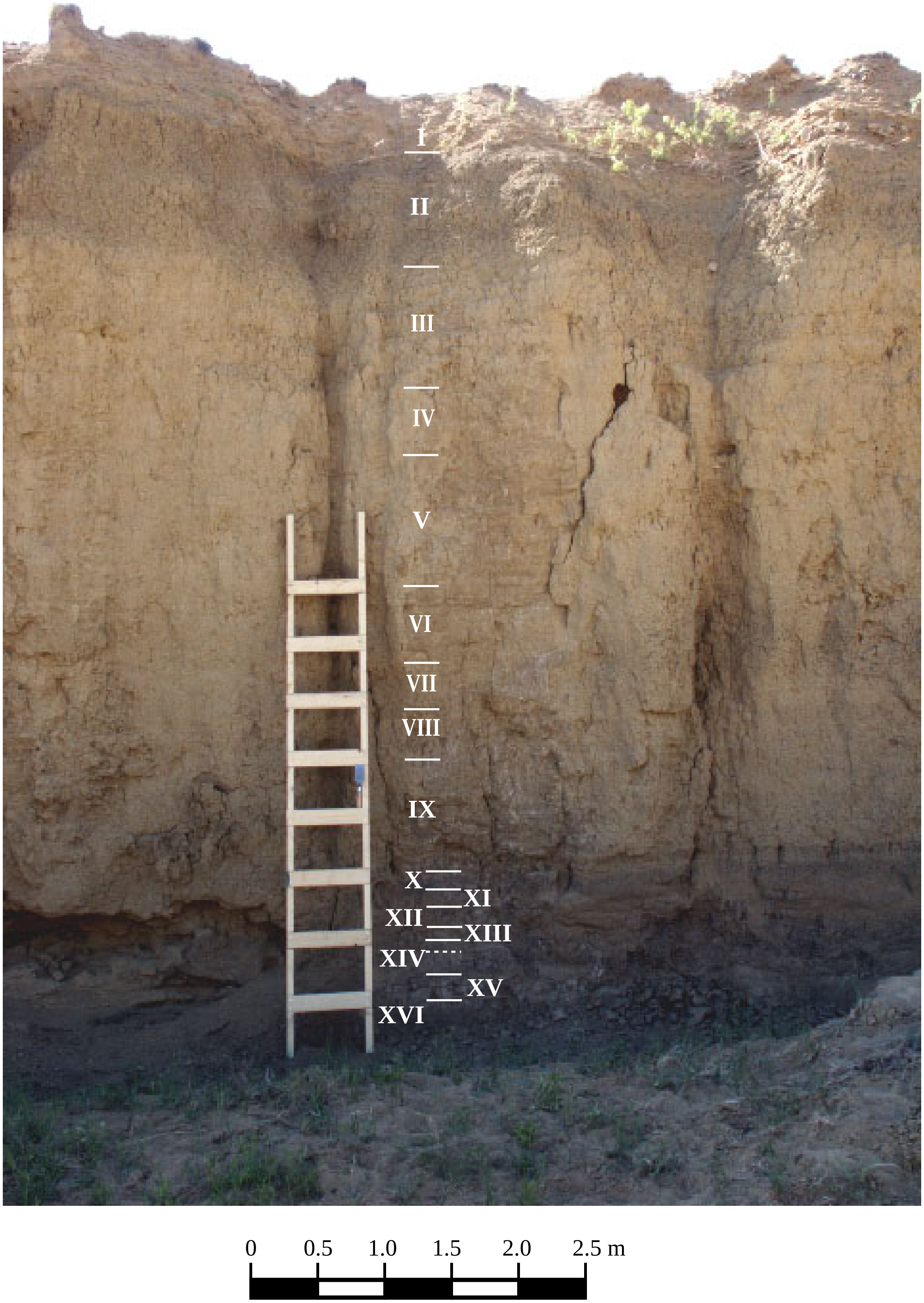

Figure 5.15. Section 22, West Arroyo, Profile 1 with stratigraphic designations.

sand with gravel to silty clay, were identified. Five presumed paleosols were identified in Strata II, VII, X, XII, and XV. Stratum XIV contained four charcoal lenses surrounded by oxidized burned zones suggesting in situ burning (Figure 5.16). Charcoal from the deepest lens (approximately 6.4 m below modern ground surface) yielded a ^{14}C date of 8690 $\pm$ 50 BP (Table 5.2). Other laboratory analyses were not performed on these sediments.

Figure 5.16. Bottom of Section 22, West Arroyo, Profile 1 showing charcoal features and radiocarbon sample location.

CHAPTER SIX

DISCUSSION

Although arroyos and other erosional channels are not viewed positively by environmentalists and land managers, they are advantageous for historical scientists who seek to understand the past. Arroyos in the Cox Ranch Pueblo area expose alluvial deposits and soils that reveal changing environmental and geomorphic conditions. Buried organic soil horizons indicative of moister conditions than today reveal episodes of environmental fluctuation and landform stability from the early to late Holocene. Buried paleoarroyo channels are indicative of changing geomorphic conditions possibly related to climate and vegetation changes. These arroyos also expose archaeological evidence that would not otherwise be seen.

The arroyo at Cox Ranch Pueblo exposes a series of flood deposits and buried soils that extend discontinuously down the piedmont below the mesa. The lower locality (Profile 1, Figure 5.1) in the Cox Ranch Pueblo Arroyo reveals eight previous episodes of soil formation including one contemporaneous with occupation of Cox Ranch Pueblo. Based on ^{14}C dates from two paleosols at this locality, the average deposition rate between approximately 6200 and 5100 BP was 12.5 cm per 100 years but slowed considerably over the last 5100 years to only 1.8 cm per 100 years. Moreover, at least one paleochannel formed by a previous arroyo is recorded at Profile 2 that post-dates 5190 $\pm$ 40 BP and predates Cox Ranch Pueblo. Because soils and alluvial deposits are horizontally discontinuous, piedmont deposition, erosion, and surface stability is spatially variable, thus limiting long distance correlations of stratigraphy.

Major stratigraphic differences are also evident between the two localities in the East Arroyo of Section 22 (Figure 5.1). The upper locality contains evidence of eight soil formation episodes, whereas the lower locality only contains four paleosols with older deposits near the surface. Episodes of surface stability and consequent soil formation at the lower locality appear to have been longer than at the upper locality. Only one ^{14}C date is available from the upstream locality and two from the downstream locality, but they reveal that deposition rates are higher on the upper piedmont. During the last 2,600 years the average deposition rate at the upper locality was approximately 15 cm per 100 years. The average deposition rate at the lower locality is estimated at 5 cm per 100 years based on a date from near the middle of the profile, and 4 cm per 100 years based on a date from the uppermost buried soil horizon. High deposition rates on the upper piedmont reduced the duration of soil-forming intervals resulting in numerous Fluvents (Soil Survey Staff, 1975:187) with weak A over C horizonation.

The locality studied in the West Arroyo of Section 22 is also located on the upper piedmont (Figure 5.1). Charcoal from a depth of 7 m below the surface, near the bottom of the profile, returned a date of 8690 $\pm$ 50 BP. The average deposition rate based on this date is approximately 8 cm per 100 years. This falls between the deposition rates for the upper and lower localities in the East Arroyo. Hence, overall deposition rates are greater as one approaches the toe slope beneath the mesa. However, over such a long span of time, deposition rates likely fluctuated on both the upper and lower piedmont in response to climate changes between the early and late Holocene.

Variability in the frequency and magnitude of Holocene deposition experienced by first and second order drainages on the piedmont implies that there is probable variation in geological processes throughout the larger hydrologic basin. In upper Carrizo Wash, only 15 km to the north of Cox Ranch Pueblo, Onken (2004) mapped and dated alluvial deposits exposed in arroyo walls and archaeological test trenches (refer to Figure 4.1). She identified several episodes of floodplain entrenchment including arroyo events at 4000 BP, ~1100 BP, and 500 BP. She correlates these events to other documented paleoarroyos in the Southwest (e.g., Waters and Haynes 2001) and believes they were driven by climatic changes (increased moisture and large flood frequency). On lower Carrizo Wash, 40 km northwest of Cox Ranch Pueblo, Anderson and Edwards (2004) performed a similar stratigraphic study and documented a significant episode of floodplain entrenchment between 6130 and 4250 BP, and several possible smaller downcutting events at 4250-3780 BP, 2410 BP, and 700 BP. They do not provide a climatic explanation for these events, but do note that some of the paleoarroyos correlate in time with those documented by Waters and Haynes (2001) in southern Arizona (who link arroyo activity to increased El Niño-Southern Oscillation activity).

Carrizo Wash and its tributaries are currently part of a fairly continuous arroyo system. In contrast, the arroyos presently found on piedmonts in the Cox Ranch area are discontinuous, and were discontinuous in the past based on paleosol and alluvial deposit discontinuity revealed in the walls of modern arroyos. Differences in the number of paleosols and rates of deposition between stratigraphic localities in the Cox Ranch Pueblo area suggest that local hillslope processes and internal stream dynamics play an important role in arroyo formation in piedmont settings. The importance of local geomorphic factors in the behavior of small ephemeral drainages is well documented in the semiarid west (McFadden and McAuliffe 1997; Patton and Schumm 1975, 1981; Schumm and

Hadley 1957). Patton and Schumm (1981) argued slope and discharge are the key factors influencing arroyo formation on these types of streams; as slope and/or discharge increase, so does the probability of arroyo cutting. The slopes of entrenched and unentrenched drainage segments located in the Cox Ranch Pueblo area were measured by Huckleberry with a total station and digital elevation software (personal communication 2004). Whereas piedmont slope alone did not appear to correlate with entrenched segments, entrenched streams were associated with a combination of relatively steep piedmont slopes and large catchment areas. Both increased slope and catchment area size contribute to larger instantaneous discharges during heavy rainfall, which provide the energy to downcut into the piedmont floor.

If arroyos in the Cox Ranch Pueblo area are controlled by local geomorphic variables like slope and drainage basin area, does climate have any influence? It is likely that climate does play a role because it influences the frequency and magnitude of rainfall events, which help determine peak instantaneous discharge. Balling and Wells (1990) argue that precipitation intensity is a major factor in arroyo formation in the Zuni area. High-intensity summer storms correlate with arroyo incision of small- and intermediate-sized drainages during the historical period. The largest instantaneous discharges on these smaller streams coincide with localized summer storms, and the larger the discharge, the greater the stream power and erosion.

With only six ^{14}C dates, it is difficult to know exactly when past arroyo activity occurred at Cox Ranch Pueblo. Cox Ranch Arroyo Profile 2 (the upper locality) reveals two paleochannels and Section 23, South Arroyo Profile 1 reveals one paleochannel. The younger channel at Profile 2 dates sometime between 5190 ± 40 BP (4050-3950 B.C.)

and ca. A.D. 1100—the occupation of Cox Ranch Pueblo. The paleochannel at South Arroyo Profile 1 also predates occupation of Cox Ranch Pueblo because the soil associated with occupation of the pueblo occurs above the channel fill. These paleo-arroyos may or may not correlate with the 4000 BP and 1000 BP events identified along Carrizo Wash (Onken 2004). However, it does appear unlikely that arroyo formation and lowered water tables contributed to the abandonment of Cox Ranch Pueblo. Some of the other piedmont streams in the area may have been entrenched in the twelfth century, but there is no evidence for any major degradation event coinciding with local abandonment.

If arroyos were present on the landscape when people occupied the site, it is uncertain how much effect they would have had on local agriculture. As explained above, paleoarroyos on the piedmont were likely discontinuous with localized channelized segments and distributary fans where the channel bottom merges with the valley floor. Such a configuration is well suited to ak chin farming (Hack 1942; Huckleberry and Billman 1998). Waters (1991) argues that prehistoric farmers in southeastern Arizona favored areas dominated by arroyo mouth fans and accordingly moved their settlements to take advantage of these fluvial features. At Cox Ranch Pueblo, distributary fans found at the end of entrenched segments would have been good areas for growing maize. Upslope entrenchment would help concentrate runoff from hillslopes and increase the amount of streamflow to localized areas on the distributary fan. Numerous field houses are found in the area around Cox Ranch Pueblo; use of these may have shifted along with any fans if they were present. The only deleterious impact from discontinuous entrenchment of the upper piedmont would be localized lowering of water tables along the channelized segments. This could limit soil moisture and reduce opportunities for dry farming.

If arroyos alone are an unlikely cause for abandonment of Cox Ranch Pueblo, then there were likely other environmental or sociocultural factors at work. Primary occupation of the site appears to end by A.D. 1130 based on ceramics (Duff and Nauman 2004). The timing of abandonment coincides with a decrease in precipitation that occurred between A.D. 1125 and 1175 in the region (Grissino-Mayer 1996). The area around Cox Ranch Pueblo is marginal for growing maize. The two primary constraints on corn growth are precipitation and length of the growing season (Hogan 1987). Thus, the drought from A.D. 1125 to 1175 would have had a large impact on the community by reducing dry farming capacity and remains a likely factor contributing to the abandonment of the pueblo. As noted previously, there was a major shift in regional settlement patterns at around A.D. 1150. Settlements moved upslope to higher elevations where precipitation is greater, so drought is a likely cause for regional population movements as well.

Alternating with drought were extended periods of above-average precipitation. Past episodes of increased moisture may have made the pinon-juniper woodland/grassland ecotone ideal for dry farming corn. Paleosols exposed in the modern arroyos on the piedmont appear to represent a wetter environment than is present at Cox Ranch Pueblo today. The buried A horizons documented at each locality are darker in color and most contain higher levels of organic matter than modern surface horizons (Figure 5.4, 5.10, 5.13). The modern surface horizons ranged between .4 and .7 percent organic matter whereas the buried A horizons ranged between .4 and 1.9 percent with a mean of .8 percent (n=18) (Appendix B). These are relatively high organic matter levels considering that some of these horizons have been buried for several thousand years. Many of these buried A horizons are thick and typical of grassland vegetation. Moreover, they are fine textured (silt and clay) suggesting low energy deposition through sheetwash or overbank floodflow adjacent to a piedmont channel. Several contained snail shells, further evidence of moister conditions.

Two of the buried A horizons at the lower locality in the Cox Ranch Pueblo Arroyo (Profile 1, Figure 5.1) were ^{14}C dated to 5070 $\pm$ 40 and 6150 $\pm$ 40 BP. It is possible that there may be some contamination from coal in the Moreno Hill formation but the dates are internally consistent. These dates fall within the Altithermal (7000-4500 BP) as proposed by Antevs (1955). Five soil formation episodes are represented between these two dates (Figure 5.2) suggesting that effective moisture fluctuated somewhat but was generally high during the last 2000 years of the middle Holocene at Cox Ranch Pueblo. The area appears to have been particularly moist during the formation of the paleosol dating to 5070 $\pm$ 40 BP. This soil is the thickest, most fine-grained (48 percent clay), had the least amount of calcium carbonate (.5 percent), lowest pH (6.8) and second highest amount of organic matter (.8%) of all the soils exposed at the same locality (Figure 5.4). Regional evidence suggests effective moisture was low between 7500 and 5500 BP (Cole 1990; Menking and Anderson 2003; Spaulding 1991) and Onken (2004) suggests the period between 7000 and 5000 BP was dry locally. Evidence from Cox Ranch Pueblo suggests that if the region was overall dry during the middle Holocene, there were local microenvironments that were relatively moist, at least to support semimesic grassland. Alternatively, it is possible that the period of low effective moisture ended prior to 6150 BP.

Current conditions are not amenable to formation of fine-textured organic-rich soil horizons such as those seen in arroyo walls in the Cox Ranch Pueblo area. Today the area is relatively dry and has been heavily grazed. Grass cover is thin and discontinuous, soil moisture is relatively low, and surface runoff tends to be characterized by high-energy flow either in shallow distributary channels or in incised gullies. Recent lowering of water tables is suggested not only by the presence of arroyos, but also by the concentric subsidence cracks located at SW ¼, NE ¼, Sec. 24, T 2N, R 19W near the half-buried, historic homestead (Figure 5.1). The area has definitely experienced a recent change toward less effective moisture.

Currently the top layer present at all of the stratigraphic localities is a loamy sand. In the Cox Ranch Arroyo, this overlies a paleosol coeval with occupation of the pueblo, primarily between A.D. 1030 and 1130 based on ceramics. This occupation correlates with an extended period of above average precipitation based on local tree rings (Grissino-Mayer 1996). This buried soil horizon is not as high in organic matter as some of the older buried soil horizons, which may have formed during periods that were slightly wetter or persisted longer prior to burial. However, the differences may also be a result of prehistoric land use. Native grasses input more organic matter into soil than does maize, which was cultivated in the Cox Ranch Pueblo area at the time the upper paleosol formed. In a soil study conducted in the Mimbres and Sapillo Valleys of southwest New Mexico, Sandor (1992) found prehistorically cultivated A horizons contained up to 40 percent less organic matter and nitrogen and were more compacted than uncultivated A horizons. Unfortunately, water control structures, rock alignments, and other visible indicators of prehistoric fields were not present at Cox Ranch Pueblo, and thus the specific field locations remain unknown.

It is worth noting that physical landscape changes have greatly influenced the visibility of archaeological sites in the area around Cox Ranch Pueblo. Deposition rates appear to have been especially high on the upper piedmont in the Late Holocene. Most Paleoindian, Archaic and perhaps even early Pueblo occupations on the piedmont are likely buried by sediment. While the population increase at about A.D. 1050 is probably real, Archaic occupation of the area is likely greatly underestimated. During examination of the East Arroyo in Section 22, a chert flake and pieces of fire-cracked rock were found approximately 1.5 m below the surface. Charcoal from the same layer was dated to 3150 $\pm$ 40 BP. We know that maize was already present in the Fence Lake Project area 15 km north of Cox Ranch Pueblo by this time, and 140 km southeast at Bat Cave. Early agriculturalists may have focused on the valley bottoms for agricultural purposes and used the surrounding upland areas for hunting and gathering. However, there is no reason that horticultural strategies like ak chin floodwater farming would not have been employed early in the history of maize agriculture in the Southwest. If so, pre-Pueblo agricultural sites may exist in the piedmont subsurface.

This study identified evidence of both recent and prehistoric environmental change at Cox Ranch Pueblo. Today the area is relatively dry as is represented in the modern soil—a sandy loam with little organic matter. However, past periods of increased moisture are indicated by buried, fine-textured, organic soil horizons. Arroyo and paleoarroyo channels reflect changes in internal stream dynamics likely related to climatic changes associated with the Southwestern Monsoon. Abandonment of the community does not appear to be related to arroyo formation but it does correlate with a persistent drought. Future work should focus on refining the chronology of soil formation and arroyo cutting and filling on the piedmont, thus facilitating correlation to the regional paleoenvironmental record.

CHAPTER SEVEN

CONCLUSIONS

This geoarchaeological study presents the results of an alluvial stratigraphic investigation at Cox Ranch Pueblo, a 900-year old Anasazi site, and the surrounding area where numerous arroyos expose past episodes of erosion, deposition, and soil formation. Six stratigraphic localities were profiled in four different arroyos and three of these were sampled for sediment and ^{14}C analysis in order to gain a better understanding of changing environmental and geomorphic conditions in the area. It is important to define past environmental conditions because they would have had a large impact on people's use of the land.

Cox Ranch Pueblo sits on a surface of coalescing alluvial fans below a sandstone mesa. The mesa has shed sediments onto the lower piedmont slopes and valley floor throughout the Holocene. Today the piedmont contains a series of discontinuous arroyos, most of which are less than 1 km in length. A total of six ^{14}C dates provide limited age control for local alluvial deposits and paleosols exposed in the arroyos. A majority of the deposits exposed in arroyos appear to date to the late Holocene but deposits at the lower locality in the Cox Ranch Pueblo Arroyo date to the middle Holocene and deposits near the bottom of the Section 22, West Arroyo date to the early Holocene.

People have been in the region for at least 11,000 years, and agriculture in the Carrizo Valley may date to as early as 2000 B.C. (Van West 2004). No evidence of agricultural use prior to the Pueblo period has been found in the immediate vicinity of Cox Ranch Pueblo, however, deposition rates on the piedmont indicate that any evidence is likely buried and Archaic populations are underestimated. Numerous lithic scatters—

some with diagnostic artifacts dating to the Archaic—are found on mesa tops and many more are likely buried beneath sediments on the piedmont. A 3150 ± 40 ^{14}C yr BP buried cultural feature exposed in the east arroyo in Section 22 may be part of an Early Agricultural period occupation. Future survey work in the local area should include arroyo channels where earlier deposits are exposed.

Regional paleoenvironmental studies indicate some major and many minor fluctuations in climate in the Southwest during the Holocene were linked to changes in global circulation patterns. Changes in effective moisture in the Cox Ranch Pueblo area are revealed by buried organic soil horizons with freshwater snail shells, indicative of periods with greater moisture than today. Dates from two of these paleosols suggest that effective moisture was locally high during at least the last 2000 years of the Middle Holocene (6000-4000 BP) contrasting with some of the regional paleoenvironmental data from this time period. Today the Cox Ranch Pueblo area is relatively dry with patchy grass cover. A recent decrease in effective moisture and a lowering of water tables is evidenced by the presence of historic arroyos and modern subsidence cracks in the valley bottom.

Primary occupation of Cox Ranch Pueblo (ca. A.D. 1030/1050 – A.D. 1130) coincides with a period of high effective moisture and abandonment (ca. A.D. 1130) with low effective moisture based on regional tree-ring records (Grissino-Mayer 1996). A soil that had begun forming prior to occupation of the pueblo continued to develop while the site was occupied, but it is lower in organic matter than earlier paleosols due either to relatively less effective moisture or reduced length of time of soil formation. The area is marginal for growing maize because of the constraints placed by precipitation and length of the growing season (Hogan 1987), so drought is a plausible explanation for the cause of abandonment. However, it is unlikely that piedmont entrenchment by arroyos forced the Cox Ranch Pueblo inhabitants to abandon the area. Paleoarroyo channels identified in the modern arroyos at Cox Ranch Pueblo have not yet been dated, but occurred prior to human occupation of the site based on stratigraphic relationships.

Major differences were noted in the number of paleosols and rates of deposition between stratigraphic localities in the Cox Ranch Pueblo area suggesting that internal stream dynamics play an important role in formation of these arroyos, and that not all piedmont surfaces were entrenched at one time. Theories of arroyo formation based on changes in internal stream dynamics are usually viewed as contrastive to those based on climatic changes. However, peak discharge is a major factor in the internal stream dynamics model whereby a critical volume of flow exceeds a local threshold for erosion. Peak discharge is closely related to precipitation levels, and thus, climate still plays a major role in this model of arroyo formation. However, local geomorphic conditions dictate that variability will occur in the timing of past arroyo events, at least for lower order tributaries such as those investigated in the Cox Ranch Pueblo vicinity.

Future work should focus on refining the chronology and the extent of environmental change at Cox Ranch Pueblo. Paleosols should be analyzed for microbotanical evidence of past enhanced moisture in order to complement inferences made from soil morphology. More of the paleosols should also be ^{14}C dated to see how well they correlate with regional periods of high effective moisture. High spatial diversity in climate is common in the Southwest (Dean et al. 1985), and the study presented here suggests that there is also high spatial diversity in stream channel behavior and surface stability on the upper piedmont. Further ^{14}C and tree-ring dating would also help in determining how closely regional and local climatic changes correspond. This is especially important in the Cox Ranch Pueblo area, because it is near the boundary between the two different precipitation patterns (bimodal and more unimodal) found in the Southwest (Dean 1988:Figure 5.1). Episodes of arroyo cutting and filling should also be dated to determine whether or not they coincide with identifiable climatic changes or episodes of floodplain entrenchment along Carrizo Wash (Anderson and Edwards 2004; Onken 2004). Historical arroyo formation has been tied to increases in high-intensity summer storms (Balling and Wells 1990; Graf et al. 1991; Hereford 2002) but these may not be evident in the paleoclimatic record of tree rings, packrat middens, and pollen.

The Cox Ranch Pueblo area has seen numerous changes in environmental and geomorphic conditions during the Holocene, and there was spatial diversity in arroyo activity and surface stability at any one time. The local surface at Cox Ranch Pueblo was stable during human occupation as evidenced by soil formation. Occupation of the pueblo coincides with regional increases in precipitation and abandonment with drought. This is not surprising given the marginal nature of the area for maize production. However, the impact of earlier environmental changes on people in the area is unclear. Effective moisture likely played a role in the development of agriculture in the region, but the reliance on maize was not as great during the Late Archaic/Early Agricultural period as in the subsequent Pueblo period. Population levels were also significantly lower prior to the Pueblo period, so environmental changes like drought may not have had the same level of impact. Improved understanding of population changes through time during the Early Agricultural and Pueblo periods and social interaction between communities, especially during the Chacoan period, should be combined with an improved local paleoenvironmental chronology based on multiple proxy records, including paleosols and buried arroyos. Improved temporal precision in determining when and where these phenomena occurred would aid in placing environmental changes on a scale more relevant to modeling human occupation and use of the area.

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APPENDIX A

SOIL PROFILE DESCRIPTIONS

Table A.1: Cox Ranch Pueblo Arroyo, Profile 1, Soil Profile Description

Location: Catron County, NM; UTM Zone 12, 3,806,858 m N, 702,951 m E; South bank
Physiographic Position: Piedmont
Topography: 2.5% slope
Drainage: Very well drained
Vegetation: Various grasses and forbs
Parent material: Fine-textured alluvium
Sampled by: S. VanBuskirk and G. Huckleberry, Date 6/24/03

C	0 to 11 cm; gravelly loamy sand; weak fine subangular blocky structure; soft, nonsticky and nonplastic; abrupt wavy boundary.
2ABwb	11 to 31 cm; gravelly sandy loam; moderate very coarse angular blocky structure; very hard, sticky and plastic; abrupt wavy boundary.
3Ab	31 to 40 cm; silty loam; moderate coarse to very coarse angular blocky structure, extremely hard, sticky and plastic; gradual straight boundary.
3Bkb	40 to 63 cm; silty loam; moderate very coarse prismatic parting to angular blocky strucutre; xtremely hard, sticky and plastic; effervescent; abrupt straight boundary.
3Ckb	63 to 78 cm; gravelly loamy sand; massive structure; extremely hard, nonsticky and nonplastic; strongly effervescent; abrupt wavy boundary.
4Bkb	78 to 104 cm; sandy loam; strong medium subangular blocky structure; slightly hard, slighty sticky and slightly plastic; strongly effervescent; abrupt wavy boundary
5Akb	104 to 157 cm; silty clay; strong medium subangular blocky structure; extremely hard, sticky and very plastic; strongly effervescent; common faint clay films on ped faces; clear abrupt boundary.
5Ckb	157 to 180 cm; loamy sand; massive structure; slightly hard, slightly sticky and slightly plastic; effervescent; abrupt wavy boundary.
6ABkb	180 to 212 cm; sand; strong fine t medium angular blocky structure; extremely hard, sticky and very plastic; effervescent; very few faint clay films on ped faces; abrupt straight boundary.
7Akb	212 to 224 cm; silty clay; strong fine to medium angular blocky structure; extremely hard, very sticky and very plastic; effervescent; very few faint clay films on ped faces, clear abrupt boundary.

7Ckb	224 to 235 cm; silty loam; moderate fine to medium angular blocky structure; extremely hard, sticky and plastic, effervescent; clear abrupt boundary.
8Akb	235 to 263 cm; silty clay; strong fine angular blocky structure; extremely hard, very sticky and very plastic; effervescent; very few faint clay films on ped faces; clear wavy boundary.
8Ckb	263 to 276 cm; silty clay; massive structure; very hard, sticky and plastic; strongly effervescent; gradual wavy boundary.
9Akb	276 to 295 cm; silty loam; moderate medium to coarse angular blocky structure; very hard, sticky and plastic; effervescent; clear wavy boundary.
9Ckb	295 to 355 cm; loamy sand; massive structure; soft, nonsticky and nonplastic; strongly effervescent; abrupt wavy boundary.
10Ckb	355 to 370 cm; silty loam; massive structure; soft, slightly sticky and slightly plastic; effervescent.

Table A.2: Section 22, East Arroyo, Profile 1, Soil Profile Description

Location: Catron County, NM; UTM Zone 12, 3,806,593 m N, 700,896 m E; East bank
Physiographic Position: Piedmont
Topography: 4% slope
Drainage: Very well drained
Vegetation: Various grasses and forbs
Parent material: Fine-textured alluvium
Sampled by: S. VanBuskirk and F. Arakawa, Date 6/28/03

C	0 to 60 cm; light yellowish brown (2.5Y 6/3) loamy sand; aggregate structure; loose, nonsticky and nonplastic; abrupt straight boundary.
2Ab	60 to 70 cm; light olive brown (2.5Y 5/3) sandy loam; moderate medium angular blocky structure; hard, slightly sticky and slightly plastic; clear wavy boundary.
2Cb	70 to 176 cm; light yellowish brown (2.5Y 6/3) loamy sand; aggregate structure; loose, nonsticky and nonplastic; abrupt straight boundary.
3Akb	176 to 181 cm; light yellowish brown (2.5Y 6/3) silty clay; strong medium prismatic parting to angular blocky structure; extremely hard, sticky and plastic; strongly effervescent; clear wavy boundary.
3Bktb	181 to 188 cm; light yellowish brown (2.5Y 6/3) loamy sand; strong medium angular blocky structure; hard, slightly sticky and slightly plastic; very few faint clay films on ped faces; angular straight boundary.
4Akb	188 to 193; light yellowish brown (2.5Y 6/3) silty clay; strong coarse prismatic parting to angular blocky structure; extremely hard, sticky and plastic; strongly effervescent; clear wavy boundary.
4Bktb	193 to 202; light yellowish brown (2.5Y 6/3) loamy sand; strong coarse prismatic parting to angular blocky strucutre; hard, slightly sticky and slight plastic; strongly effervescent; very few faint clay films on ped faces; abrupt straight boundary.
5ABtb	202 to 207; light yellowish brown (2.5Y 6/3) silty clay; strong coarse prismatic parting to angular blocky structure; extremely hard, sticky and plastic; very few faint clay films on ped fces; clear wavy boundary.
5Btb	207 to 215 cm; light yellowish brown (2.5Y 6/3) loamy sand; strong coarse prismatic parting to angular blocky structure; hard, slightly sticky and slightly plastic; very few faint clay films on ped faces; abrupt straight boundary.

6Ab 215 to 220 cm; light yellowish brown (2.5Y 6/3) silty clay; strong medium prismatic parting to angular blocky structure; extremely hard, sticky and plastic; effervescent; clear wavy boundary.

6Bkb 220 to 280 cm; grayish brown (2.5Y 5/2) sandy loam; strong coarse prismatic parting to angular blocky strucutre; hard, slightly sticky and slightly plastic; strongly effervescent; clear wavy boundary.

7Akb 280 to 285 cm; light yellowish brown (2.5Y 6/3) silty loam; strong medium angular blocky structure; very hard, sticky and slightly plastic; strongly effervescent; clear straight boundary.

7Cb 285 to 320 cm; light yellowish brown (2.5Y 6/3) gravelly loam; aggregate boundary; loose, nonsticky and nonplastic; abrupt straight boundary.

8Akb 320 to 326 cm; light yellowish brown (2.5Y 6/3) silty loam; medium coarse angular blocky structure; very hard, nonsticky and nonplastic; strongly effervescent; abrupt wavy boundary.

8Ckb 326 to 356 cm; light yellowish brown (2.5Y 6/3) gravelly loamy sand; aggregate structure; loose, nonsticky and nonplastic; effervescent; abrupt wavy boundary.

9Akb 356 to 374 cm; light yellowish brown (2.5Y 6/3) silty clay; strong medium angular blocky structure; very hard, sticky and plastic; strongly effervescent; gradual wavy boundary.

9Bktb 374 to 394 cm; light yellowish brown (2.5Y 6/3) silty loam; moderate coarse prismatic parting to angular blocky structure; hard, sticky and plastic; strongly effervescent; very few faint clay films on ped faces, gradual wavy boundary.

9Cb 394 to 428 cm; light yellowish brown (2.5Y 6/3) sandy loam; aggregate structure; loose, nonsticky and slightly plastic; clear wavy boundary.

10Btb 428 to 462+ cm; light yellowish brown (2.5Y 6/3) loamy sand; medium coarse angular blocky structure; slightly hard, nonsticky and slightly plastic; very few faint clay films on ped faces.

Table A.3: Section 22, East Arroyo, Profile 2, Soil Profile Description

Location: Catron County, NM; UTM Zone 12, 3,806,965 m N, 700,968 m E; West bank
Physiographic Position: Piedmont
Topography: 3% slope
Drainage: Very well drained
Vegetation: Various grasses and forbs
Parent material: Fine-textured alluvium
Sampled by: S. VanBuskirk and G. Huckleberry, Date 6/26/03

C	0 to 32 cm; light yellowish brown (2.5Y 6/3) loamy sand; aggregate structure; loose to soft; nonsticky and nonplastic; abrupt wavy boundary.
2Ab	32 to 55 cm; light olive brown (2.5Y 5/3) sandy clay loam; moderate medium prismatic parting to angular blocky structure; very hard, slightly sticky and slightly plastic; clear wavy boundary.
2Bkb	55 to 88 cm; light yellowish brown (2.5Y 6/3) gravelly sandy loam; weak coarse prismatic parting to angular glocky structure; hard, slightly sticky and slightly plastic; strongly effervescent, stage I calcium carbonates; abrupt straight boundary.
3ABtkb	88 to 106 cm; light yellowish brown (2.5Y 6/3) silty clay; strong medium prismatic parting to angular glocky structure; very hard, sticky and plastic; strongly effervescent, disseminated calcium carbonates; very few faint clay films on ped faces; clear wavy boundary.
3Bkb	106 to 127 cm; light yellowish brown (2.5Y 6/3) gravelly loam; weak coarse prismatic parting to angular blocky structure; hard, nonsticky and slightly plastic; strongly effervescent, disseminated calcium carbonates; abrupt straight boundary.
4ABkb	127 to 136 cm; light yellowish brown (2.5Y 6/3) silty clay; moderate medium angular blocky structure; very hard, sticky and plastic; strongly effervescent, disseminated calcium carbonates, depositional structure; clear wavy boundary.
4Ckb	136 to 148 cm; light brownish gray (2.5Y 6/2) gravelly sand (upper) and grayish brown (2.5Y 5/2) gravelly sand (lower); aggregate structure; loose, nonsticky and nonplastick; strongly effervescent, disseminated calcium carbonates; thermal feature; abrupt straight boundary.
5Ckb	148 to 217 cm; light yellowish brown (2.5Y 6/3) gravelly sand; aggregate structure; loose, nonsticky and nonplastic; strongly effervescent; abrupt wavy boundary.

6ABtb 217 to 234 cm; light yellowish brown (2.5Y 6/3) gravelly silty clay; strong medium prismatic parting to angular blocky structure; hard, sticky and plastic; few faint clay films on ped faces; clear wavy boundary.

6Btkb 234 to 247 cm; light yellowish brown (2.5Y 6/3) silty clay; moderate coarse prismatic parting to angular blocky structure; hard, sticky and plastic; effervescent; very few faint clay films on ped faces; abrupt wavy boundary.

6Ck 247 to 287+ cm; light yellowish brown (2.5Y 6/3) gravelly loam; aggregate structure; loose, nonsticky and nonplastic; strongly effervescent.

APPENDIX B

RESULTS OF SEDIMENT ANALYSIS

Table B.1: Results of Grain Size Analysis by Sample

Sample	Horizon Designation	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Graphical Mean (phi)	USDA Textural Class
Cox Ranch Arroyo, Profile 1							
894	C	0-11	82	7	11	2.8	LS
895	2ABwb	11-31	54	20	26	5.3	SCL
896	3Ab	31-40	64	13	23	4.9	SL
897	3Bkb	40-63	68	9	23	5.0	SCL
898	3Ckb	63-78	61	17	22	4.6	SCL
899	4Bkb	78-104	71	8	21	4.8	SCL
900	5Akb	104-157	17	35	48	8.2	C
901	5Ckb	157-180	68	13	19	4.6	SL
902	6ABkb	180-212	55	14	31	5.6	SCL
903	7Akb	212-224	45	26	29	5.9	CL
904	7Ckb	224-235	41	31	28	5.7	CL
905	8Akb	235-263	31	26	43	7.0	C
906	8Ckb	263-276	50	23	27	5.7	SCL
907	9Akb	276-295	52	19	29	5.6	SCL
908	9Ckb	295-355	74	17	9	3.6	SL
909	10Ckb	355-370	78	12	10	3.3	SL
Section 22, East Arroyo, Profile 1							
921	C	0-60	76	8	16	3.9	SL
922	2Ab	60-70	53	28	19	5.3	SL
923	2Cb	110-130	73	11	16	4.0	SL
924	3Akb/3Bktb	176-188	45	23	32	5.9	CL
925	4Akb/4Bktb	188-202	69	11	20	4.5	SCL
926	5ABtb/5Btb	202-215	56	18	26	4.9	SCL
927	6Ab/6Bkb	215-280	76	8	16	4.1	SL
928	7Akb	280-285	61	16	23	4.8	SCL
929	7Cb	285-320	77	9	14	3.5	SL
930	8Akb	320-326	45	24	31	6.1	CL
931	8Ckb	326-356	86	7	7	2.7	LS
932	9Akb	356-374	30	34	36	6.6	CL
933	9Bktb	374-394	55	17	28	5.0	SCL
934	9Cb	394-428	61	13	26	4.8	SCL
935	10Btb	428-462+	64	13	23	4.7	SCL

Sample	Horizon Designation	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Graphical Mean (phi)	USDA Textural Class
Section 22, East Arroyo, Profile 2							
944	C	0-32	70	10	20	4.5	SL
945	2Ab	32-55	54	24	22	5.0	SCL
946	2Bkb	55-88	60	14	26	4.8	SCL
947	3ABtkb	88-106	29	31	40	7.1	C
948	3Bkb	106-127	58	17	25	5.0	SCL
949	4ABkb	127-136	66	15	19	5.1	SL
950	4Ckb	136-148	71	9	20	4.2	SL
951	5Ckb	148-180	74	11	15	3.0	SL
952	5Ckb	180-217	75	9	16	3.6	SL
953	6ABtb	217-234	34	38	28	5.8	CL
954	6Btkb	234-247	51	23	26	5.2	SCL
955	6Ck	247-287	65	14	21	4.4	SCL

Note: LS = loamy sand, SL = sandy loam, SCL = sandy clay loam, CL = clay loam, and C = clay.

Table B.2: pH, Organic Matter, and Calcium Carbonate by Sample

Sample	Horizon Designation	Depth (cm)	pH	Organic Matter	Calcium Carbonate
Cox Ranch Arroyo, Profile 1					
894	C	0-11	7.1	0.4	0.6
895	2ABwb	11-31	7.3	0.7	1.0
896	3Ab	31-40	7.4	0.6	0.7
897	3Bkb	40-63	7.4	0.5	1.1
898	3Ckb	63-78	7.0	0.5	0.6
899	4Bkb	78-104	7.2	0.4	0.9
900	5Akb	104-157	6.8	0.8	0.5
901	5Ckb	157-180	7.3	0.3	0.9
902	6ABkb	180-212	7.3	0.8	0.6
903	7Akb	212-224	7.3	0.9	0.9
904	7Ckb	224-235	7.4	0.6	0.6
905	8Akb	235-263	7.4	0.6	0.7
906	8Ckb	263-276	7.3	0.6	0.7
907	9Akb	276-295	7.5	0.5	0.7
908	9Ckb	295-355	7.7	0.3	1.1
909	10Ckb	355-370	7.7	0.2	0.8
Section 22, East Arroyo, Profile 1					
921	C	0-60	7.1	0.5	0.6
922	2Ab	60-70	7.2	1.9	0.4
923	2Cb	110-130	7.2	0.3	0.6
924	3Akb/3Bktb	176-188	7.1	1.2	0.5
925	4Akb/4Bktb	188-202	7.2	1.0	1.1
926	5ABtb/5Btb	202-215	7.2	0.9	0.5
927	6Ab/6Bkb	215-280	7.4	0.2	0.6
928	7Akb	280-285	7.3	0.4	0.7
929	7Cb	285-320	7.4	0.2	1.6
930	8Akb	320-326	7.4	0.6	1.0
931	8Ckb	326-356	7.3	0.2	0.6
932	9Akb	356-374	7.3	1.0	0.7
933	9Bktb	374-394	7.3	0.7	0.9
934	9Cb	394-428	7.3	0.3	0.6
935	10Btb	428-462+	7.4	0.3	0.6

Sample	Horizon Designation	Depth (cm)	pH	Organic Matter	Calcium Carbonate
Section 22, East Arroyo, Profile 2					
944	C	0-32	7.0	0.7	0.7
945	2Ab	32-55	6.9	0.9	0.5
946	2Bkb	55-88	7.2	0.6	0.9
947	3ABtkb	88-106	7.2	0.9	0.5
948	3Bkb	106-127	7.2	0.6	0.8
949	4ABkb	127-136	7.3	0.6	0.5
950	4Ckb	136-148	7.3	1.0	0.4
951	5Ckb	148-180	7.5	0.2	0.7
952	5Ckb	180-217	7.4	0.2	1.3
953	6ABtb	217-234	7.3	0.6	0.5
954	6Btkb	234-247	7.3	0.5	0.6
955	6Ck	247-287	7.4	0.3	0.6