PROYECTO ARQUEOLOGICO Y PALEONTOLOGICO CHIVACABE:

A GEOMORPHIC AND GEOARCHAEOLOGICAL INVESTIGATION

OF LATE QUATERNARY ENVIRONMENTS IN

NORTHWESTERN HIGHLAND GUATEMALA

Presented to the Graduate College of
Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of SCIENCE

by

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San Marcos, Texas
August 2010

ACKNOWLEDGMENTS

There are many people who are owed a big *thank you* for making this thesis project possible and for contributing to this positive educational experience. Dr. Jon Lohse is responsible for making the 2009 field season at Chivacabe happen, and his support and encouragement, academically and professionally, is greatly appreciated. A great debt is owed to my committee members, Drs. David R. Butler, Charles D. Frederick, and Rene DeHon, for their encouragement, support, patience, and time. I am grateful to have had them all a part of my graduate education thus far, and I look forward to continuing to work with them professionally and academically. Special thanks are owed to Dr. Frederick and the rest of his family for opening up their lab and home. I appreciate the support of my family through my graduate endeavors. And of course my dear wife, Layla: she is responsible for inspiration and has been a steady rock throughout. I am much appreciative of all those people whose names are not mentioned and who played a part in PAPCHIV 2009.

This manuscript was submitted on 7 July 2010.

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ABSTRACT

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This thesis presents the description, analysis, and interpretation of sediments and soils encountered at the archaeological and paleontological site, Chivacabe, located in Highlands of northwestern Guatemala. Chivacabe had been investigated and excavated twice previously, but both former projects lacked a systematic and intensive geomorphic and geoarchaeological investigation. Additionally, early investigations at the site resulted in contrasting site formation hypotheses: lacustrine sediment v. volcanically-derived colluvium. Intentions of this component of the 2009 investigations were to systematically

record the sediments associated with the site, and also to provide a substantially supported site formation hypothesis.

As a result of fieldwork and laboratory analyses, three allostratigraphic units within the previously excavated block were identified and described. An additional two profile exposures were described in order to supplement the understanding of the site's sediments. The unit containing the Pleistocene faunal remains was confirmed as colluvially re-worked volcanic ash, and radiocarbon dates frame the deposit between 15,700 and 12,920 yr BP (Cal. 2-sigma). This age range places the Pleistocene fauna beyond the accepted beginning of human presence in the New World. The unit above the re-worked volcanic ash was radiocarbon dated to 10,190 yr BP, minimally. This unit is marked by a prominent Btkb horizon, and could feasibly contain the vestiges of human occupation at the site. The uppermost unit truncates the middle unit, and most likely represents erosion and deposition in the latter portion of the Holocene.

Overarching conclusions from the 2009 geomorphic and geoarchaeological investigations are that 1) sediments containing the Pleistocene bone bed are not lacustrine, 2) the Pleistocene faunal remains are not associated with cultural remains, and 3) evidence of early occupation at this locale is likely in the middle depositional unit, marked by a prominent calcic horizon.

CHAPTER 1

INTRODUCTION

Earth's dynamic landscape and environments have profound effects on each other and on the populations of organisms which they support. As such, investigations of past and present plants and animals should incorporate a physiographic component. Historical geomorphology, an aspect of physiography, is the interpretation of landscape history through morphological mapping and the examination of sedimentary features (Hugget 2007). As a study of landscape morphology, sedimentary features, and their respective formation processes, historical geomorphology has inherent paleoenvironmental implications.

Humans are no different from all other organisms in that they are highly dependent on resources provided by the Earth. It is appropriate, or even necessary then, that investigations of past humans (e.g., archaeology) incorporate geosciences. Emerging from this necessity is a long-running relationship between archaeology and geosciences, or geoarchaeology as it has relatively recently been recognized (Davidson and Shackley 1976; Renfrew 1976; Butzer 1982; Waters 1992; Goldberg and MacPhail 2006). Geoarchaeology uses practical aspects of geomorphology, sedimentology, stratigraphy, pedology, and geochronology to understand past human-environment relationships and site formation processes (Waters 1992; Goldberg and Macphail 2006).

This thesis will present the methods, results, and interpretations of a geomorphological and geoarchaeological investigation of late Quaternary faunal and cultural remains located at a single site in the western Highlands of Guatemala, Chivacabe. The objective of this research is to complement concurrent independent paleontological and archaeological investigations at the site by establishing temporal and environmental context of the faunal and cultural remains.

Chivacabe is situated in a small side valley of the Huehuetenango Valley located in the western Highlands of Guatemala. Previous paleontological and archaeological investigations at Chivacabe, of which there have been two, offered contradicting hypotheses of site formation and paleoenvironments (Hayden and Cocks 1976; Ericastilla 1992; Ericastilla and Garcia 1994; Ericastilla 1996). An initial investigation of the paleontological and archaeological components of the site resulted in a hypothesis of a lacustrine depositional environment (Hayden and Cocks 1976). A later investigation of the site identified faunal and cultural remains within a thick tephra deposit (Ericastilla 1992; Ericastilla and Garcia 1994; Ericastilla 1996). It is clear that an intensive geomorphic or geoarchaological component was not included in either of the two early investigations of Chivacabe.

The current investigation of the site, Proyecto Arqueologico y Paleontologico Chivacabe 2009 (PAPCHIV), included specialists in the fields of Paleoindian archaeology, Pleistocene vertebrate paleontology, and historical geomorphology/geoarchaeology, and was conducted with goals of confirming or denying the previous investigations' hypotheses and increasing the understanding of Pleistocene fauna migration and population dynamics of early Americans. To establish a physiographic, stratagraphic, and temporal context, the historical geomorphic/geoarchaeological component of PAPCHIV addressed the following questions:

1. What is the current setting of the site in terms of local surface morphology?
2. What are the sedimentary and depositional contexts of the Pleistocene faunal remains and cultural artifacts?
3. What is the geomorphic/environmental history of the site?

Pedological, geological, geographical, chemical, and biological analyses will be employed to answer the above proposed questions. And by answering these questions, this research could potentially contribute to a greater understanding of late-Quaternary paleontological and archaeological issues, as well as paleoenvironmental dynamics, of Highland Guatemala.

CHAPTER 2

PROJECT SETTING AND BACKGROUND

Chivacabe is located on the Villatoro family farm, approximately 10 km west of the city Huehuetenango near the Guatemala-Mexico border in the capitol (*cabecera*) of the Departamento Huehuetenango (Figure 2-1). Since its discovery and subsequent archaeological and paleontological investigations, the site has become a public museum with open-air (excavation pit) and enclosed (curation and display) components. As a museum, the site is partially cared for by the Villatoro family and the Instituto de Antropologia e Historia (IDAEH). However, Chivacabe's location relative to boundaries and municipalities, as well as its function as a museum, is peripheral to the current project; more important is the site's setting in terms of natural environment.

Natural Setting

South of the Altos Cuchumatanes, the highest mountain range of northern Central America, Chivacabe (15°18'48" N, 91°32'49" W) is nestled in a small valley in the western Highlands of Guatemala at approximately 1890 m above sea level. The Highlands, located near the intersection of the North American, Caribbean, and the subducting Cocos tectonic plates, were formed by strong folding during periods of increased tectonic activity in the late-Paleozoic era and again during the late-Mesozoic (Maldonado-Koerdell 1964; Pardo and Suarez 1995). Chixoy-Polochic and Motagua

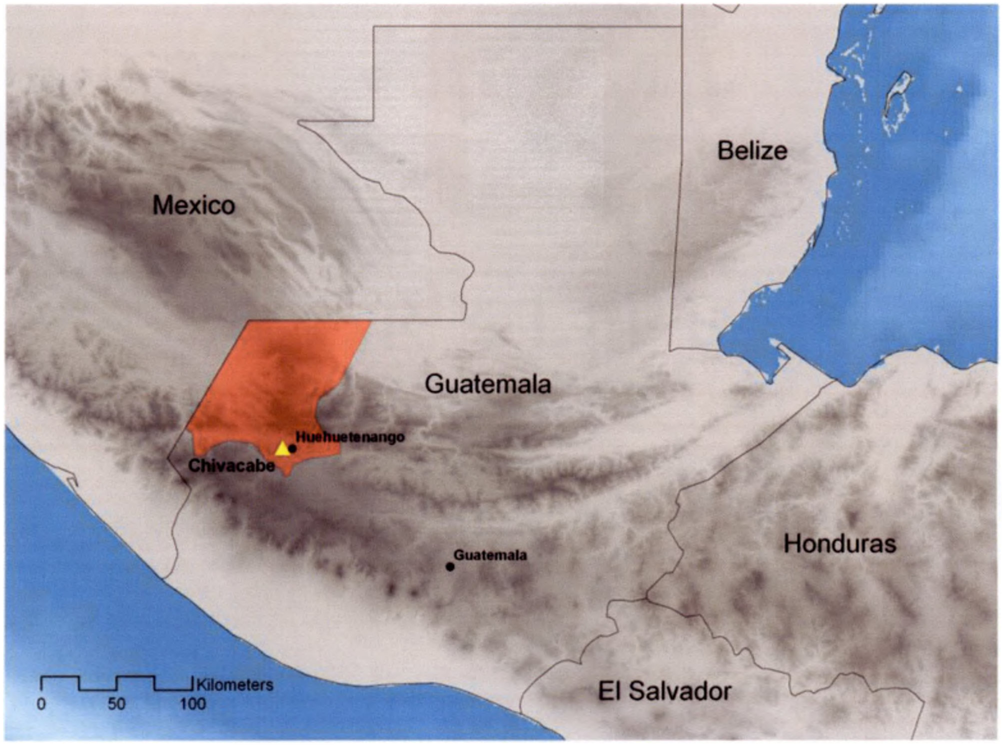

Figure 2-1. Location map of Chivacabe in relation to administrative boundaries and elevation (darker grays represent increasing altitude)(modified from USGS 2008).

Faults associated with these orogenies trend east-west and contribute to complicated bedrock geology (Anderson et al. 1973). Generally, bedrock in the region is composed of pelitic schists, quartzofeldspathic gneisses, migmatites, amphibolites, local quartzites, and minor marble rocks (Alvarado et al. 2007). Bedrock geology in the vicinity of Chivacabe has been mapped by Anderson et al. (1973) as undifferentiated metamorphic rocks and Quaternary alluvium and pumice deposits. Outcrops of schist and gneiss bedrock occur in proximity to the site and are consistent with the plutonic and metamorphic nature of the rocks that characterize the geology of this region. Quaternary alluvium and pumice deposits compose terraces and floodplains along Rio Selegua and its major tributaries to the south, along one of which Chivacabe is situated. Tephra is contributed by the Central American Volcanic Axis. This series of Quaternary volcanoes, which is within 60 km south of Chivacabe, marks the transition from Highlands to Pacific Lowlands, and stretches from western Guatemala to Costa Rica (West 1964).

Climate and weather of the Guatemalan Highlands vary as much as the geology of the region. In terms of temperature in Central America, altitude may be the most influential factor. The elevation at which the site lies is near the boundary of two altitudinal zonations of weather and climate, tierra templada (1000-2000 m) and tierra fria (>2000 m) (Escoto 1964). Temperature of the tierra templada is characterized as temperate and relatively warmer than the tierra fria. Precipitation, however, is in part dependent on relief, and is, too, quite variable in the Highlands. Windward and leeward slopes, as well as ridges and valleys, receive differing amounts of precipitation, the former receiving more than the latter on both accounts (Escoto 1964). Precipitation is also affected by ebb and flow of the intertropical convervgence zones, which seasonally migrate throughout the tropics (Magana et al. 1999). Chivacabe falls within a region that is characterized as having a temperate climate with a distinctly dry winter and wet summer.

Bedrock geology and geomorphology, as well as climate and weather, are limiting factors for flora and fauna. Natural vegetation in the vicinity of Chivacabe would most likely be a pine-oak forest with ferns and shrubs composing the understory (Wagner 1964; Breedlove 1973). Though current land use (e.g., farm and range) obscures the natural vegetation, patches of evergreen and deciduous trees, as well as ferns, are present. Similarly, wildlife in the region has been displaced. Guatemala is currently habitat for myriad species of mammal, bird, reptile, and fish (Stuart 1964). As Chivacabe is a paleontological and archaeological site, perhaps it is important to briefly survey previous paleoenvironmental investigations in the region.

Late Quaternary environmental reconstructions are derived from proxy data, lines of evidence that imply or infer past conditions. These proxy data are put into chronological context by absolute dating techniques, commonly radiocarbon (^{14}C). All of these data are sensitive to pre- and post-depositional environmental conditions, or contexts, and are subject to interpretation. Occasionally, these lines of evidence are not complementary. In northern Central America, much of the paleoenvironmental reconstructions are based on data procured from deep sediment core samples collected in lowland lacustrine settings. As the lowland environments are presumably different than the adjacent highlands, only a vague picture can be painted of the environments at higher elevations.

Glaciers were present on the Altos Cuchumatanes during the late Pleistocene (Hastenrath 2009). Southeast of Mexico City, glacial moraines on Iztaccihuatl provide some insight to fluctuating climates during the Late Quaternary (Vazquez-Selem 2000). Dated by cosmogenic ^{36}Cl, there were two glacial pulses during the late Pleistocene, 19-18 ka and 17-14 ka, followed by glacial retreat through the Holocene with a relatively brief period of glacial stability around 8.7-7.3 ka (Vazquez-Selem 2000). Citing several paleoenvironmental investigations of oxygen isotopes, fossil pollens, and phytoliths throughout Central America lowlands, Piperno (2006) confirms a cooler climate during the late Pleistocene. Precipitation, however, is a point of incongruity (elucidating environmental differences between altitudinal regions) between these records; glaciers require considerable moisture, whereas the lowland proxies indicate dry conditions. Continuing into the early Holocene, many lowland lakes were dry until approximately 9000 BP when conditions became gradually moister and warmer, as indicated by an influx of semi-deciduous forest pollens and chemical signatures of rising lake levels (Curtis et al. 1998; Dunning et al. 1998; Dull 2004; Ruter et al. 2004). Maximum lake levels near 6800 BP are followed by a number of drying events, as marked by gastropods, fossil pollens, and soil mineral ratios (Curtis et al. 1998; Dunning et al. 1998; Dull 2004). After approximately 3500 BP, much of the flux in proxy data is attributed to Maya agricultural practices (Dunning 1998; Dull 2004). Paleoenvironmental investigations of highland settings in Guatemala, however, are lacking.

History of Investigations

Chivacabe was discovered in 1976 when mastodon remains were unearthed by the Villatoro brothers while excavating a well on their farmstead. Subsequently, archaeologists from Simon Frasier University spent two field seasons investigating a suspected archaeological component associated with the Pleistocene megafauna (Hayden and Cocks 1978). The initial excavation began by mechanically excavating 3.5 m of overburden in a 5-by-5 m area to an elevation just above that of the recovered mastodon remains, and then excavations continued by manual excavation of 2-by-2 m units in arbitrary 20 cm levels (Hayden and Cocks 1978). Through the two field seasons, the 5-by-5 m excavation pit was slowly expanded to approximately 6-by-8 m, and an additional two test units (size unknown) were excavated at 30 m and 40 m north of the main excavation pit. Due to tough, clayey texture, only a sample of hand-excavated sediment was passed through ¼" and 1/16" mesh screen. Field analyses of faunal remains and stones were performed, and faunal remains, features, and walls were illustrated as excavated. Charcoal samples were collected, but it is unclear whether or not they were processed and analyzed. At an undisclosed point in the two field seasons, profile exposures were examined. These initial investigations at Chivacabe provided results, however, prehistoric human association with the Pleistocene bone bed was still not confirmed.

In Hayden and Cocks' (1978) report of findings from the two initial field seasons, the authors present an estimated age of 20-30,000 B.P. for the site based on soil development, and they suggest that the sedimentary deposits are possibly lacustrine or colluvial in origin. An initial profile investigation took place in the 5-by-5 m excavation pit, and was admittedly obscured by uneven distribution of moisture and seepage in the profile. A second profile, exposed in one of the northern test units, was examined, and showed differing patterns of deposition. As the differing profiles provided an element of complexity to interpretations, one unspecified profile was chosen for description in the report and differences between the two profiles were briefly described as needed. Unfortunately, Hayden and Cocks' (1978) description of stratigraphy at the site is not supplemented by illustration and uses only relative location to establish depth and sequence to the site's deposits. Nonetheless, the authors describe five depositional units (hereafter abbreviated DU). The lowest unit, which will be referred to as DU 5, contains the Pleistocene bone bed and is interpreted as a paleosol with A, B, and C horizons. The C horizon is composed of lenses of fine sand in clayey silt matrix with fine MnO_2 and Fe_2O_3 concretions and thin beds; the B horizon is bedded/banding silty clay with mycellious carbonates, well developed columnar ped structure, and weak clay coats on ped faces; and the A horizon is also bedded/banded sitly clay with slightly larger columnar structure and more prominent clay coats on ped faces. A description of Depositional Unit 4 (DU 4), and the page on which it was recorded, is missing from the report, but it is clear from the extant description that deposition of DU 4 was terminated by a presumed drainage of the purported lake. Depositional Unit 3 is colluvial in origin, and according to Hayden and Cocks (1978), it may represent or coincide with a "prehistoric shift to permanent field cropping, either in the late classic or post classic" (p. 23). Second from the top, Depositional Unit 2 (DU2) is colluvial, lacks primary soil development, and is truncated by Deposition Unit 1. The authors suggest a correlation between deposition of DU 2 and shifting agricultural strategies. Depositional Unit 1 (DU 1) is silt with some mineral elluviation and no apparent ped structure, and the authors indicate that deposition of this uppermost unit initiated just prior to European contact.

Bedding in DU 5 indicates a lacustrine context of the Pleistocene bone bed to the author, but a second opinion from Al Bryan, in Hayden and Cocks' (1976:19) report, expresses doubt to lacustrine and favor towards a colluvial origin. Another interpretation is very briefly provided in a short article, written by Hayden (1980), reporting the discovery of a fluted projectile point later discovered at the site. In this article, Hayden refers to Gary Gates, a consulting geologist, who interpreted sediments at Chivacabe "to have been deposited by several small, successive volcanic ash flows (Gates n.d.)" (Hayden 1980:702). Unfortunately, Gates' interpretations of the sediments at Chivacabe are not published and remain at large.

In 1991, investigations resumed at Chivacabe, this time performed by archaeologists and paleontologists from Guatemala and Mexico on behalf of

Departamento de Monumentos Prehispanicos y Coloniales, Instituto de Antropologia e Historia de Guatemala and the Centro de Estudios Mexicanos y Centroamericanos Antena Guatemala (Godoy 1992). Investigations returned to the site on account of its significance to the understanding of Pleistocene megafauna in Guatemala, and its potential to contain evidence of early Americans. Excavations in 1991 were limited to a 2-by-2 m unit, which was excavated manually in arbitrary 20 cm levels in the southwest corner of the main excavation pit. Again, investigations were directed toward confirming or denying the human-megafauna association. Field analysis of faunal remains, stones, and profile exposures were also a part of the 1991 investigation.

Ericastilla (1992; 1996) offers slightly different descriptions and interpretations of the stratigraphy at Chivacabe. Fortunately, profile illustrations are provided as supplement to the descriptions, however, descriptions are very general and considerably less detailed than those provided by Hayden and Cocks (1978). The uppermost depositional unit is interpreted as relatively recent deposits. The next lower depositional unit is composed of three lenses of sand and silt overlying six strata of fine sand and abrasive silt with inclusions of volcanic ash and pumice. This depositional unit also contains an approximately four-centimeter-thick, clayey paleosol that is notably different than the adjacent sediment. Beneath the second depositional unit there is a third, consisting of a phosphate-rich zone with a clayey crust. This depositional unit is also interpreted as a paleosol, and lies atop the zone containing the Pleistocene bone bed.

In 2009, archaeologists, paleontologists, and geomorphologists from the United States and Guatemala returned to investigate cultural and natural deposits at Chivacabe. Currently, results from the archaeological and paleontological investigations are pending.

The paleontology and archaeology of Chivacabe can potentially contribute to the understanding of the natural history of northern Central America. Not in dispute between previous investigations, and making Chivacabe particularly interesting and potentially important, is the presence of Pleistocene proboscideans (i.e. mammoth and mastodon) and pre-Maya cultural artifacts. Central America's role as a land bridge for intercontinental megafauna migration has excited the interest of paleontologists (e.g., Roy et al. 1996; Pearson 2005; MacFadden 2006) but it is Arroyo-Cabrales et al. (2007) that articulate a lack of evidence for Pleistocene proboscedeans in Guatemala. In terms of cultural material, a fluted projectile point, characteristic of Paleoindian culture, discovered at Chivacabe indicates an early human occupation (ca. 12,000 BP to 9,000 BP) of the small highland valley (Hayden 1980). Paleoindian sites have been documented in Guatemala; however, the quality and quantity of sites are low, which leaves record of Paleoindian subsistence strategies and distribution in Guatemala unclear (Gruhn and Bryan 1977; Brown 1980). Therefore, Chivacabe has the potential to both contribute to the record of human occupation of Guatemala during the late Pleistocene and to the spread of fluted point technology (Hayden 1980).

CHAPTER 3

METHODS

In the spirit of starting afresh on a site that has been previously excavated during four discontinuous field seasons, it is necessary to be aware of the preceding literature, but it is more important to make primary observations. Especially in this case where general *interpretations* have been provided but where there is a dearth of primary *observations* that support them. Accordingly, field methods were directed towards obtaining an understanding of the site in the context of the surrounding landscape and narrowing observations to the context of the Pleistocene bone bed within the excavated block (the 1976 Simon Frasier University excavation). The following methods will detail field and lab processes used to address research issues.

Field Methods

Reconnaissance and Mapping

Prior to arriving in the field, satellite images of the site and the surrounding area—the small side valley in which the site is located— were obtained through the application Google Earth. Though useful for their depiction of vegetation and the location of structures and roads, the satellite images do not meaningfully illustrate topography. Nonetheless, these images are an introduction to the area. Through reconnaissance and observation, a field map illustrating the geomorphology of the valley in direct proximity to the site was illustrated directly on one of the printed satellite images (Figure 4-1) using a combination of methods described by Goudie (1981), Gardiner and Dackombe (1983), and Schoeneberger et al. (2002). Reconnaissance and the subsequent geomorphological map are the first step in understanding the context of Chivacabe.

Precise three dimensional data for two transects, which dissect the small valley and the excavated block, add to geomorphological mapping. The spatial data were collected using a Sokkia Total Data Station (TDS), and provide cross sections of the valley.

Sediment Profile Description

Through reconnaissance and geomorphological mapping of the small side valley, three profile exposures representing depositional processes across the valley were identified and described. One discontinuous profile exposure, Columns A and B, adjacent to the Pleistocene bone bed within the excavation pit was recorded; another profile exposure, a cutbank, containing contact between a tephra deposit and underlying sediments was recorded; and a third profile exposure, a roadcut, was recorded for its presumed oldest age (Figure 4-2). Depth below datum and below surface and thickness, color, texture, structure, calcium carbonate morphology, percent gravel, and pedological features were recorded for each of the three profiles. The smallest units of the profile exposures are termed *zones*, and multiple zones compose allostratigraphic units, termed *depositional units*. Comparison of the three profiles provides a basic understanding of the soil geomorphology and past geomorphological processes of the valley, thus providing insight to the context of the Pleistocene bone bed.

Samples

Following description of the three profiles, a variety of samples were collected to establish geochronology of the observed sediments and to support and provide descriptive statistics for field profile descriptions of soil properties. A suite of Optically Stimulated Luminescence (OSL) and bulk humate radiocarbon samples were collected for dating within and outside of the excavation block. Within the excavated block, two columns were selected for intense sampling. A bulk sediment sample (approximately 10 cm wide and 5 cm deep) was collected from each column at 10 cm increments, where zones exceeded 10 cm in thickness, or by zone boundaries, where zones were less than 10 cm in thickness. A total of 65 bulk column samples were collected, providing the necessary amount of sediment to analyze particle size, calcium carbonate equivalent, magnetic susceptibility, organic carbon, and stable carbon isotopic analyses in the laboratory. Additionally, 20 block sediment samples, targeting pedological features and prominent stratigraphic interfaces (i.e., boundary between allostratigraphic units) were collected from the two profile exposures within the excavated pit for micromorphological analysis.

Laboratory Methods

The physical properties of the sedimentary matrix of the site were documented from within the excavated pit. For each bulk sediment sample the texture (or particle size distribution), calcium carbonate content, magnetic susceptibility, organic carbon content, and stable carbon isotopic composition were determined. Each of the 20 block sediment samples, representing a suite of pedological features and stratigraphic boundaries, were prepared for thin section and soil micromorphological analysis. The details of the analytical methods employed are described below.

Particle Size Analysis (texture)

Texture analysis was performed using the hydrometer-sieve method (cf. ASTM 1985). Samples were first weighed moist and then gently passed through a 2 mm sieve. When more than 200 g of <2 mm sediment was obtained, the remainder of the sample was transferred to a 100 ml beaker and a 5% sodium hexametaphosphate solution was added to break down the clays and to permit separation of the >2 mm gravels. After soaking for two days, during which time the samples were agitated on occasion without regard for strict regimen, the samples were wet sieved through a 2 mm sieve and the coarse fraction separated and dried. Coarse material caught on the 2 mm sieve, if detrital sediment, was then sieved at a 1 phi interval and the mass on each sieve recorded. A split of the <2 mm size material (roughly 40 g) was then soaked in 50 ml of a 5% sodium hexametaphosphate solution overnight, and then mixed in a mechanical mixer for five minutes before being diluted to one liter with distilled water. This mixture was placed in a one liter settling jar, mechanically agitated for one minute, and then set on a table, after which point hydrometer readings were made at intervals (specifically 1, 3.5, 15, 45, 300, and 1440 minutes). Measurement of a hexametaphosphate solution was made at intervals throughout the analysis to permit calibration of the hydrometer. A small split of the <2 mm soil was also oven dried to determine the moisture content and to correct the sample mass used in the hydrometer analysis (hygroscopic moisture correction). After 24 hours, the contents of the hydrometer jar were wet sieved through a 37 micron sieve, and the sand retained on the sieve was transferred to a beaker and oven dried at 105° C. This sand, once dried, was sieved at 0.5 phi intervals, and the mass retained on each sieve was recorded. From these data, the percentage of gravel, sand, silt, and clays, as well as various descriptive statistics were calculated for the grain size distribution using a spreadsheet.

Calcium Carbonate Content (CCE)

A small split (1.7 g) of the ground <2 mm fraction of each soil sample was used to determine the calcium carbonate equivalent by means of a Chittick apparatus (Dreimanis 1962; Machette 1986). This sample was finely ground (to pass a 0.075 mm sieve), and then weighed, and placed into a small (250 ml) Erlenmeyer flask. Once attached to the Chittick apparatus, the liquid level in the measuring burette was set to -10 ml, the stopcock was closed so no gas can leave the system, and the leveling bulb was dropped in order to establish a vacuum inside the sample chamber. At this point the barometric pressure and temperature in the room were recorded. Then 10 ml of 50% hydrochloric acid was delivered to the sample flask, which was agitated intermittently until the reaction has ceased (usually 1-2 minutes). At this point, the leveling bulb was raised to the point that the liquid level inside of it was equal in elevation to the liquid in the burette, and the volume of gas evolved was then measured and the calcium carbonate equivalent calculated.

Organic Carbon and Stable Carbon Isotopic Analysis

In order to determine the carbon content of each sample, splits of the <2 mm size fraction were submitted to the Stable Isotope Research Unit, Department of Crop and Soil Sciences at Oregon State University. The carbon content was determined on Europa Scientific ANCA SL Roboprep system equipped with a Dumas combustion/reduction apparatus. Details of the procedures used in the process may be found on the institute's web page (http://cropandsoil.oregonstate.edu/siru). Prior to submission, calcium carbonate was removed from the samples by treating an approximately 2 g split of the <2 mm size soil with hydrochloric acid. The samples were allowed to sit five hours or until the supernatant was clear, and then decanted and subsequently rinsed with distilled water three times in order to remove all traces of acid. After the third rinse, the decanted sample was dried at 105° C and finely ground.

Magnetic Susceptibility

Dry sediment samples that have been sieved to remove the >2 mm size material were packed into 2.5 cm plastic cubes, weighed, and then the low frequency (470 Hz) and high frequency (4700 Hz) magnetic susceptibility (kappa) were measured on the 0.1 setting on a Bartington MS2 meter and an MS2b sensor. The mass corrected magnetic susceptibility (X1f) and coefficient of frequency dependency (Xfd) were then calculated. The coefficient of frequency dependency is the percent difference in magnetic susceptibility measured at low and high frequencies (calculated as: Xfd = ((X1f – Xhf)/X1f) *100). Mass corrected measurements of magnetic susceptibility elucidate the total amount of potentially magnetic particles within a given sample, and frequency dependent measurements elucidate the amount of ultrafine (<0.03 μm) superparamagnetic ferromagnetic particles, which are crystals produced by biochemical processes involved with soil formation, within the sample (Dearing 1999). Thus, magnetic susceptibility provides insights to parent material and pedogenesis.

Petrography/Pedography

Petrography is the description of sediments and stratigraphy, whereas pedography is the description of soils; and, the two methods can be applied to elucidate depositional and post-depositional processes and environments (Brewer 1976; Courty et al. 1989). Examining and describing sedimentary and pedogenetic features in thin section provides a finer scale analysis of the matrix at Chivacabe.

Small blocks of sediment cut from the excavation wall were oven dried at low temperature (50°C) and then vacuum embedded with polyester resin and subsequently cut into slabs when hardened. The slabs were first scanned on a flatbed scanner, and then blanks for thin section were selected, cut to size, and then submitted to National Petrographic Inc. (Houston, Texas) for thin section preparation. The thin sections were subsequently examined at a range of magnifications. Low magnification examination was performed with the aid of a flat bed scanner and the slides were scanned at 1200 dpi using transmitted light (slide mode). Full page color laser prints of the slides are used to perform the first pass assessment of each slide. Areas of interest were then identified and examined with a Leica S8 APO binocular microscope fitted with transmitted light base and polarizing filters. Higher magnification examination employed a Leica DMEP polarizing light microscope.

Observed under magnification, the relative sequence of secondary minerals precipitated minerals and colloidal laminae provide insight to disparate depositional environments and pedogenic processes. This component of the analysis is strictly qualitative, and it will be used to supplement and support quantitative analyses of particle size, calcium carbonate content, organic carbon content, stable carbon isotopes, and magnetic susceptibility. Descriptions are based on methods set out by Bullock et al. (1985), however, some terminology is borrowed from Brewer (1976). For example, Brewer (1976) provides the term *cutan* for coats, whereas terms for abundance of the features (rare, <2%; occasional, 2-5%; many 5-10%; abundant, 10-20%; very abundant, >20%) is taken from Bullock et al. (1985).

Geochronology

In order to provide temporal context to the sediment and soil characteristics investigated at Chivacabe, four bulk humate samples were submitted for radiocarbon dating. The measurement of age for bulk humates is dependent upon radioactive 14C in soil organic matter, which begins decaying at death for plants and animals—therefore, it can be attributed to the time soils are buried, as they are cutoff from the addition of fresh organic matter at that point (Matthews 1980; Schaetzl and Anderson 2005). The actual accuracy and utility of soil organic matter-derived radiocarbon dates, however, have been the subject of debate for the last 40 years. Some research has shown that radiocarbon dates from soil organic matter can be quite variable and not representative of soil development (Martin and Johnson 1995; Wang et al. 1996); whereas other research has shown that soil organic matter yields generally accurate dates, which are only unreliable when disturbed (Matthews 1980; Haas et al. 1986). Accuracy of this method is likely contingent upon application, process, and environment.

Results of bulk humate radiocarbon analysis from sediments at Chivacabe appear to yield accurate dates for bracketing depositional units and soil development (Table 4-2). The following ages will be described in calibrated (2 Sigma) years before present (BP), or circa 1950. Taken from a muddy stratum beneath the tephra and gravelly deposit exposed in the Cut Bank profile, a sample marking the maximum age of the tephra deposit yields an age range of 15,400 +/- 300 yr BP. A sample taken from the top of Zone XII in Column A, just below the boundary of Deposition Units 2 and 3, yields a date of 13,065 +/- 145 yr BP. This date effectively dates a minimum age for soil development in Depositional Unit 3 and a maximum age for the onset of Depositional Unit 2. From Zone VIII at the top of Depositional Unit 2 in Column A, a sample representing the minimum age of this phase of soil development dates to 10,235 +/- 45 yr BP. A fourth date, 8,790 +/- 200 yr BP, was yielded from a sample extracted from a 2-by-1 m unit excavated on the south side of the excavation block. It was collected after the current investigation, and it's provenience in terms of depositional units is unclear. Lohse et al. (2009) note that it is from the first buried soil, 50 cmbs, however, the investigated north face of the excavation block contains no buried soil at this depth. This date of ca. 8,790 yr BP could possibly represent a more accurate time of soil development in Depositional Unit 2, as the truncating channel gravels present in the bottom of Depositional Unit 1 in Column A are absent in the south face of the excavation block; or, it could represent an age for soil development of the older A horizon in Depositional Unit 1. In any event, dates of 15,400 +/- 300 yr BP, 13,065 +/- 145 yr BP, and 10,235 +/- 45 yr BP effectively bracket Depositional Units 2 and 3 and provide a maximum age for the onset of Depositional Unit 1.

Additionally, a suite of four optically stimulated luminescence (OSL) samples were collected from Columns A and B within the excavation block. Only one of these samples was submitted for analysis. The date of 11.91 +/- 2.1 ka (solar years) provided by this sample did not fit well into the framework provided by radiocarbon dates (e.g., it

Table 3-1. Results of radiocarbon analysis.

Sample ID	Age (2 Sigma Calibration)	Provenience
Beta-257571	Cal BP 8,990-8,590	Uppermost buried soil (~0.50 m below surface on south side of excavation block)
Beta-257569	CAL BP 10,280-10,190	Top of Depositional Unit 2, Column A (~99.98 m arbitrary elevation)
Beta-257568	Cal BP 13,210-12,920	Top of Depositional Unit 1, Column A (~98.20 m arbitrary elevation)
Beta-257570	Cal BP 15,700-15,100	Below tephra deposit in Cut Bank profile (~5.05 m below surface)

is several thousand years younger than the deposit as framed by radiocarbon dates), and this was attributed to the sample being collected from an exposure which has been open to the elements for more than 30 years.

Diatom and Ostracodes

A total of 28 diatom samples and 11 ostracode samples were collected for analysis, however, no samples have been submitted. Diatoms and ostracodes are sensitive biological indicators of environmental, or hydrological, conditions.

CHAPTER 4

RESULTS

Understanding context of the late Pleistocene fauna and archaeological material at Chivacabe is the objective of this investigation. As such, results of all components, including reconnaissance and geomorphic mapping, sediment profile descriptions and illustrations, and a multitude of lab analyses, will be described in the following paragraphs.

Reconnaissance and Geomorphic Mapping

Reconnaissance and geomorphic mapping composes the first phase of investigation; it is a necessary component in gaining an understanding of valley-wide formation, depositional, and environmental processes; and it was useful in identifying profile exposures that provide insight to the story of bone and artifact deposition, which is ultimately the goal of the project. Through hiking, observing, and mapping, a number of features on the landscape, which are characteristic of varying modes of erosion, transportation, and deposition, were identified (Figures 4-1 and 4-2).

Generally, the excavation pit and museum at Chivacabe are situated on a terrace long ago abandoned by the valley's main drainage, which is a deeply incised stream lying approximately 175 m south of the site. This terrace slopes gently to the east and is more or less bisected by a shallow perennial stream channel. To the north of this stream

Figure 4-1. Geomorphic map illustration on Google Earth image.

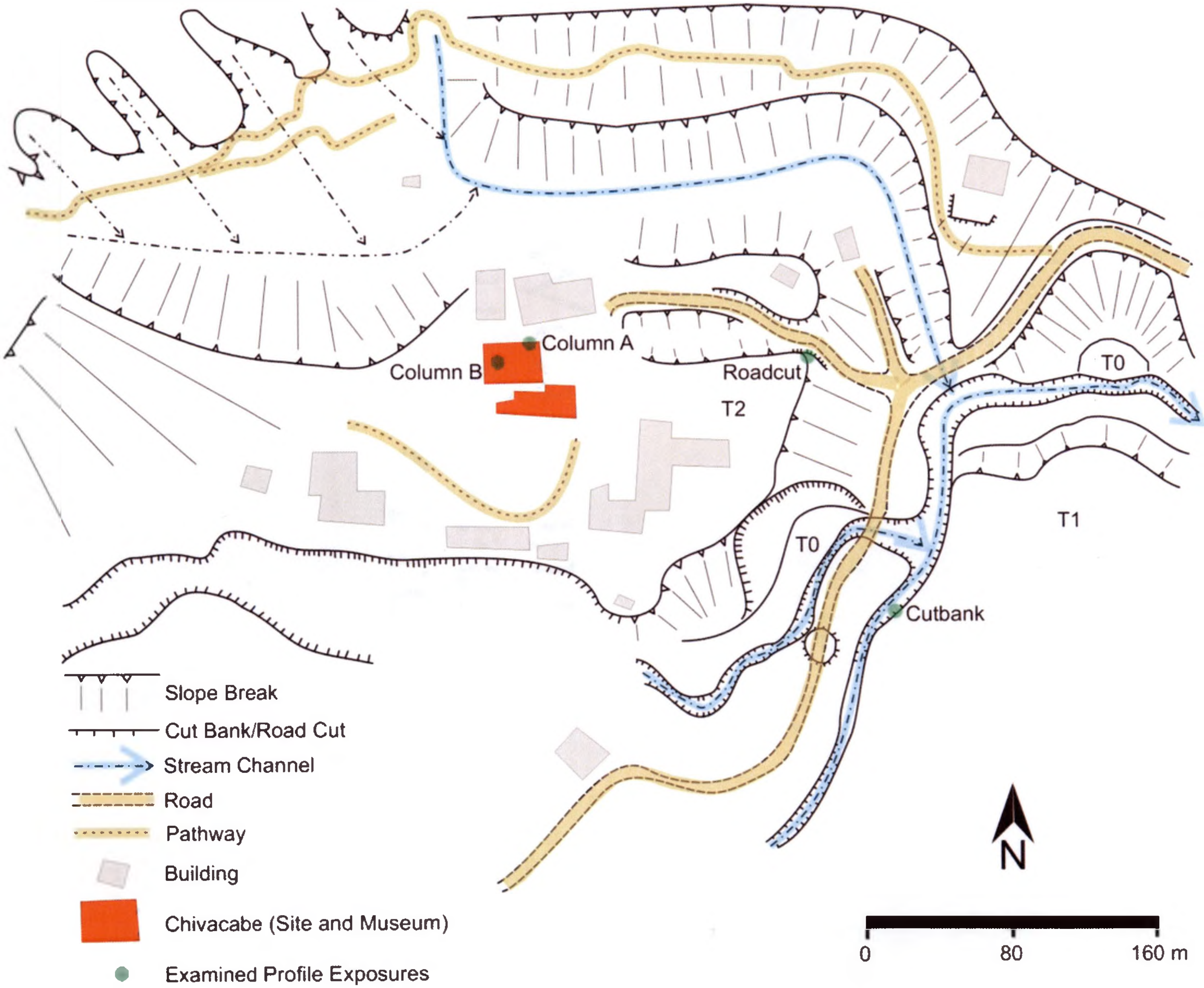

Figure 4-2. Geomorphic map illustration with locations of examined profile exposures.

channel, and of the site, the slope substantially increases towards the top of hills that define the north side of the valley. The footslopes of these hills are marked by alternating convex lobes and concave drainages, which may be vestiges of ancient gullies. At the peak of the dry season, when field work was performed at Chivacabe, the concave drainages contained markedly greener vegetation, indicating preferential flow and retention of groundwater (Figure 4-3). The alternating convexities and concavities are also indicative of colluvial processes, which will be an important theme presented in the presentation of results from sediment profiles within the excavated pit. Currently, however, sediment from the hillside presumably enters the shallow ephemeral stream channel between the northern hills and site.

Figure 4-3. Overview of Chivacabe with alternating convexity-concavity-convexity in foreground and the site in the background (photographed facing southeast).

The ephemeral stream that drains the hillside begins approximately 200 m west of the site. A cross-section of the feature approximately 70 m west of the site shows that the channel is broad but shallowly concave, changing three meters in elevation over approximately 80 m perpendicular to flow. To the east of the site where the channel is fed by hillside drainages, affected by bovid trampling, and drops in elevation to the level of the valley's primary drainage, there is a distinct change in channel morphology. The only accessible portion of the drainage in this area was relatively dramatically incised.

The valley's primary drainage currently resides in a channel approximately 20 m below the surface elevation of the site and museum. This stream appears responsible for the formation of the alluvial terraces found within the valley, however, a survey of the entire valley was restricted by divisions of property. Chivacabe's excavated pit and museum is situated upon the second terrace (T2), which is the highest and oldest of the terraces in the immediate vicinity of the site. Approximately seven meters above the stream channel and 13 m below the elevation of the T2 terrace is the first terrace (T1). Approximately two meters above the stream channel is a floodplain (T0). Morphology of the primary drainage, which is generally meandering and greatly incised, and its history, as observed in terracing, provide for opportunities to observe sediments not present within the excavated pit. Accordingly, one profile from a cut bank of the primary drainage and a profile exposed in a road cut for the farm's drive, in addition to two columns, forming a discontinuous profile, within the excavation pit, were analyzed to varying degrees. Whereas all of the profile exposures were described and illustrated, profile exposures within the excavation block were extensively sampled and analyzed in order to provide finer resolution for contexts of faunal and cultural remains.

Profile Exposures

Four profile exposures, composed of various sediments and characteristic of different periods in the valley's history, were identified for analysis. Two profile exposures within the excavation pit, combined form a single discontinuous profile framing the Pleistocene faunal remains, were analyzed intensively. A profile exposure in the cutbank of the valley's primary drainage provides a glimpse of tephra deposit exposed in the T1 terrace. A fourth profile, a roadcut a short distance east of the block excavation (approximately 80 m), shows what lies beneath the tephra deposit on the T2 terrace. The latter two profiles were described, photographed, and selectively sampled. Together, these profiles represent the period of time within which bones and artifacts were deposited at Chivacabe.

All of the following profile descriptions' depths will be discussed in terms of centimeters below surface (cmbs). The units described below were also recorded in meters relative to Datum A, an exercise which ties all elevations into a single point. Datum A, which was used as an anchor for elevation data, is located in the southeast corner of the fenced-in area adjacent to the excavated pit, and the ground surface at this point is considered 100.000 m. The reason for arbitrarily recording depths is because not all profiles examined and described were able to be measured from the surface. All datum-based depths were acquired with a Sokkia SET Series total data station.

Excavation Block Profiles: Columns A and B

Within the Simon Frasier University excavation block, two profile exposures were examined, Columns A and B (Figures 4-4 and 4-5, respectively). Column A is located on the north wall in the northeast corner of the excavation block. This location

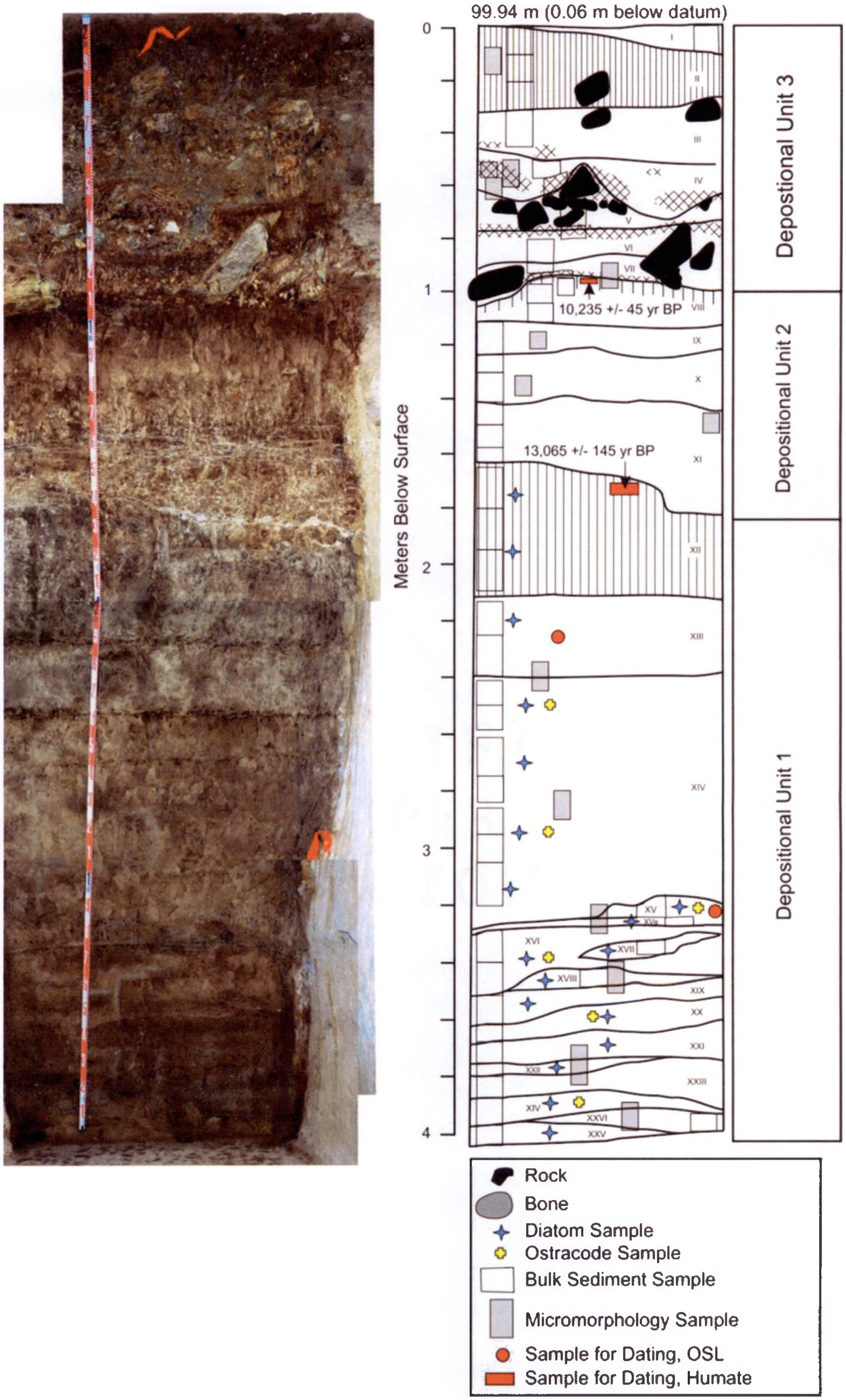

Figure 4-4. Photo-mosaic and illustration of Column A.

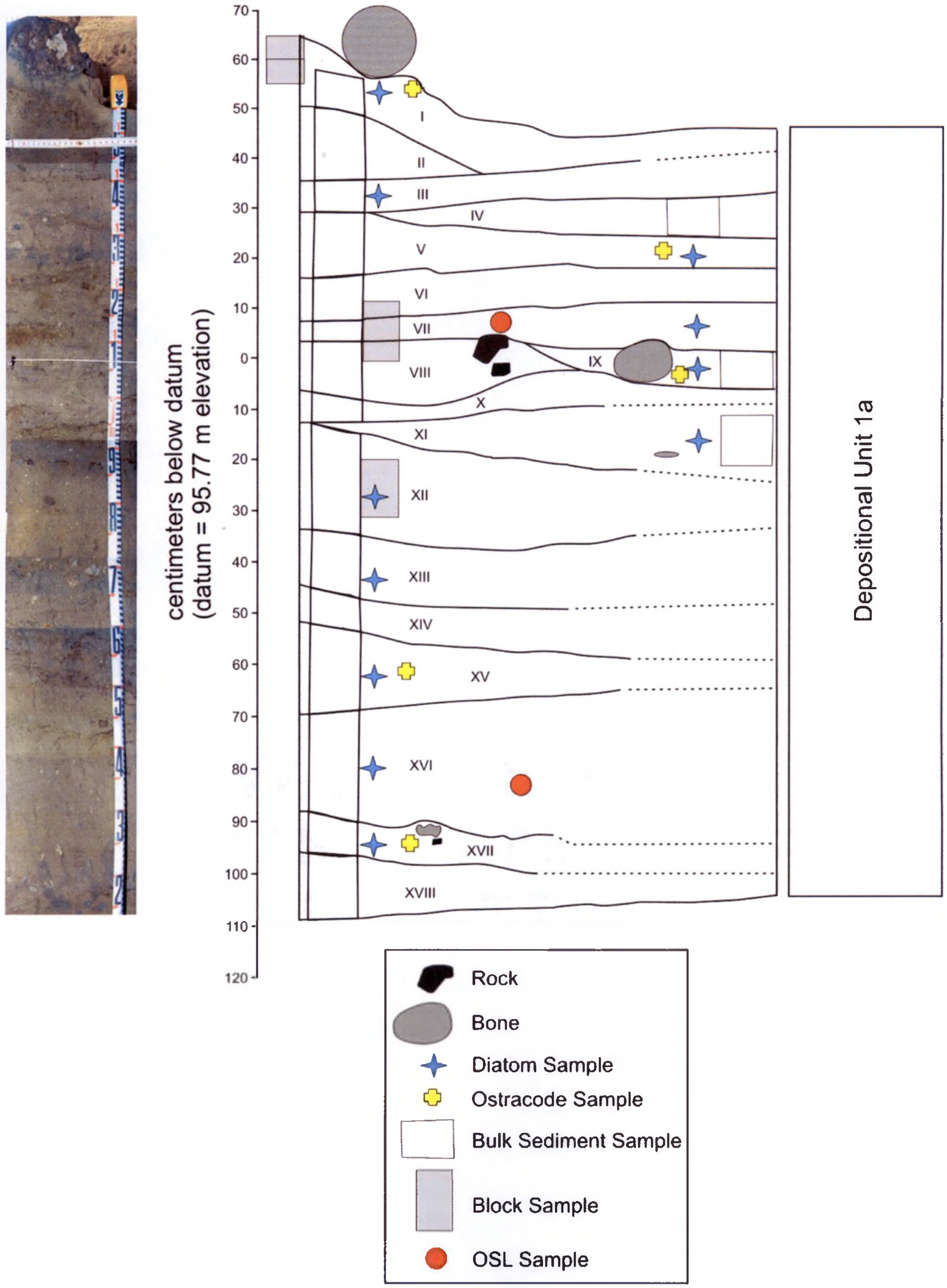

Figure 4-5. Photo-mosaic and illustration of Column B.

was chosen due to its distance from the late Pleistocene bone bed and the necessity of having to excavate approximately 20 cm off the face that has been exposed for more than 30 years. Column B is the south face of the hand-excavated well, adjacent to the bone bed, that was excavated by the Villatoro brothers in the mid-1970s. This exposure was chosen not only because it extends below the elevation of the exposed bone bed, but also because of its proximity to the faunal remains. Using depth below datum and loosely correlating stratigraphy across the approximately six-meter gap between the columns, the sediments exposed and examined in Columns A and B frame the faunal remains of Chivacabe.

A continuous column of bulk sediment samples was collected from each profile (Columns A and B) in order to more accurately and quantifiably record characteristics of the stratigraphy associated with the site. While the strata are anchored by field observations, descriptions of their characteristics are based on the results of tests performed in the laboratory. Results of Columns' A and B particle size analysis are presented in Table 4-1; results of soil analyses are presented in Table 4-2; pedogenic structure, features, and their respective formation conditions are presented in Tables 4-3 and 4-4; and a combination of particle size and proxy data are plotted and presented in Figure 4-6. As the two profiles are separated by a number of meters and they form a somewhat overlapping and continuous stratigraphic record, they will be described together. Primary field descriptions in their raw form are presented in Appendix A.

In all, three allostratigraphic depositional units were identified in the combined five-meter tall profile. The lowest unit, which contains tephra throughout, is further divided into two subunits based on trends in thickness of deposits. These units will be referred to as, from lower to upper, Depositional Units 1a (DU1a), 1b (DU1b), 2 (DU2), and 3 (DU3).

Depostional Unit 1

Depostional Unit 1 is framed by the dates 15,450 +/-300 years BP, obtained from below the tephra deposit exposed in the Cutbank Profile (described below), and 13,165 +/-145 years BP, from the top of Depositional Unit 1. The lower two meters of DU1 are considered DU1a, and they are composed of 30 medium to thick beds with varying amounts of gravel spanning Column B and the lower portion of Column A. The upper 1.5 m of DU1 is considered DU1b, and this subdivision is composed of three strata, Zones XII, XIII, and XIV within Column A. It should be noted that between Columns A and B there are approximately 30 cm of overlapping elevation (highlighted in yellow in the above tables), and it is therefore likely that 20-25 beds is a more realistic count of the strata composing DU1a. For upper and lower elevations of zones, one can refer to either profile illustrations or Tables 4-3 and 4-4. Nonetheless, in terms of sedimentary characteristics, these zones have much in common. Zones XXII (Column A), VII (Column B), and XVIII (Column B) contain 44.4, 42.06, and 29.6 percent coarse fragments, respectively, and have the highest percentages of gravels. The remaining zones' gravel contents range from 6.5 to 21.95 percent. Aside from the aforementioned peaks in gravel content, there is no distinct patterning (i.e., grading or fining upwards) to the matrix-supported coarse fragments. The matrix of DU1a is commonly sandy loam, and ped structure throughout DU1a ranges from weak, fine subangular blocky in the upper 15 zones to weak, medium subangular blocky in the lower 14 zones. Subangular blocky ped structures are the result of shrink-swell processes associated with variable soil

Table 4-1. Results of particle size analysis for Columns A (top) and B (bottom). Note that the highlighted rows are overlapping elevations.

DU	Sample ID	Zone	Elevation cmbs	Elevation m	% gravel	% sand	% silt	% clay	mean	sd	skew	kurt	Textural Class
DU3	1015-46	I	0-12	99.856	4.3	45.4	28.5	21.7	5.90	4.73	0.40	0.44	LOAM
	1015-45	II	12-31	99.846	18.1	38.6	18.9	24.4	4.79	6.23	0.27	0.31	GRAVELLY SANDY CLAY LOAM
	1015-44	II		99.781	15.0	43.4	16.2	25.4	4.85	5.68	0.36	0.40	GRAVELLY SANDY CLAY LOAM
	1015-43	II		99.626	19.7	43.0	16.2	21.1	4.42	6.18	0.37	0.39	GRAVELLY SANDY CLAY LOAM
	1015-42	III	31-53	99.541	34.0	38.6	11.6	15.8	2.80	5.60	0.32	0.47	GRAVELLY SANDY CLAY LOAM
	1015-41	IV	53-64	99.386	24.5	43.8	14.6	17.1	3.92	4.89	0.49	0.30	GRAVELLY SANDY CLAY LOAM
	1015-40	IV		99.326	35.5	44.5	8.2	11.8	2.07	4.69	0.39	0.72	VERY GRAVELLY SANDY LOAM
	1015-39	V	64-76	99.226	54.1	29.6	9.0	7.3	-0.30	4.56	0.31	n/a	VERY GRAVELLY SANDY LOAM
	1015-38	VI	76-88	99.151	27.3	51.4	10.3	11.0	2.20	4.18	0.31	0.78	GRAVELLY SANDY LOAM
	1015-37	VI		99.096	17.6	58.3	8.9	15.3	3.56	4.70	0.58	0.58	GRAVELLY SANDY LOAM
	1015-36	VII	86-100	99.016	63.3	23.1	6.6	7.1	-0.81	4.01	0.50	n/a	EXTREMELY GRAVELLY SANDY LOAM
	1015-35	VII		98.986	44.9	32.2	9.5	13.5	2.02	5.34	0.40	0.54	VERY GRAVELLY SANDY CLAY LOAM
DU2	1015-34	VIII	95-114	98.921	0.2	20.6	31.0	48.3	8.10	4.37	-0.09	0.29	CLAY
	1015-33	VIII		98.851	1.1	28.2	38.1	32.7	7.07	4.53	0.17	0.10	CLAY LOAM
	1015-32	IX	112-125	98.756	6.2	31.9	36.4	25.5	5.88	4.93	0.05	0.46	CLAY LOAM
	1015-31	X	123-145	98.656	7.7	28.5	40.0	23.8	5.82	4.64	-0.05	0.55	LOAM
	1015-30	X		98.571	21.6	36.3	28.9	13.2	3.36	4.89	0.07	0.52	GRAVELLY LOAM
	1015-29	XI	140-182	98.471	25.1	39.7	26.3	8.9	2.76	4.42	0.18	0.58	GRAVELLY SANDY LOAM
	1015-28	XI		98.381	26.6	33.1	30.0	10.3	2.80	4.84	0.01	0.55	GRAVELLY LOAM
	1015-27	XI		98.321	26.3	34.0	29.7	10.0	2.89	4.78	0.10	0.58	GRAVELLY LOAM
DU1b	1015-26	XII	165-212	98.211	24.3	31.5	32.4	11.9	3.20	4.91	0.01	0.49	GRAVELLY LOAM
	1015-25	XII		98.051	19.3	32.6	35.7	12.3	3.45	4.83	-0.07	0.50	GRAVELLY LOAM
	1015-24	XII		97.901	28.2	24.1	36.8	10.8	2.96	4.96	-0.15	0.47	GRAVELLY SILT LOAM
	1015-23	XIII	212-239	97.736	9.2	34.5	44.4	12.0	5.26	2.72	0.25	0.94	LOAM
	1015-22	XIII		97.606	7.7	37.2	41.6	13.5	4.67	3.41	0.05	1.02	LOAM
	1015-21	XIV	239-325	97.471	11.1	32.3	39.5	17.1	5.03	4.47	0.07	0.61	LOAM
	1015-20	XIV		97.381	15.8	30.7	43.1	10.4	3.47	4.40	-0.19	0.59	GRAVELLY SILT LOAM
	1015-19	XIV		97.246	7.1	38.6	43.0	11.3	4.59	3.29	0.10	1.02	LOAM
	1015-18	XIV		97.131	9.8	37.7	40.4	12.1	4.41	3.56	0.07	1.01	LOAM
	1015-17	XIV		97.021	2.4	45.6	37.5	14.5	5.22	3.20	0.26	0.90	LOAM
	1015-16	XIV		96.936	7.9	45.2	36.4	10.5	4.22	3.23	0.13	1.07	LOAM
	1015-15	XIV		96.801	10.8	35.7	41.1	12.3	4.30	3.58	0.03	0.68	LOAM
DU1a	1015-14	XV	315-325	96.721	9.2	72.8	15.9	2.1	2.27	1.84	-0.02	1.35	LOAMY SAND
	1015-13	XVa	325-330	96.651	14.9	40.7	35.9	8.5	3.39	3.76	-0.06	0.78	LOAM
	1015-12	XVI	328-350	96.581	6.5	45.2	40.3	8.0	4.25	2.94	0.12	1.08	LOAM
	1015-11	XVII	332-340	96.566	14.1	46.4	32.9	6.7	3.14	3.45	-0.03	0.90	SANDY LOAM
	1015-10	XVI	328-350	96.466	10.8	51.9	31.2	6.2	3.38	2.99	0.11	1.04	SANDY LOAM
	1015-09	XVIII	343-350	96.456	9.9	56.5	28.5	5.1	3.24	2.58	0.09	1.06	SANDY LOAM
	1015-08	XIX	350-360	96.356	9.5	45.7	37.0	7.8	3.89	3.05	0.08	1.07	LOAM
	1015-07	XX	355-365	96.271	9.8	49.8	32.3	8.1	3.76	3.00	0.13	1.19	SANDY LOAM
	1015-06	XXI	365-375	96.201	17.3	47.8	28.3	6.6	2.61	3.79	-0.05	0.73	GRAVELLY SANDY LOAM
	1015-05	XXII	375-380	96.146	44.4	36.0	15.7	4.0	0.90	3.42	0.17	0.45	VERY GRAVELLY SANDY LOAM
	1015-04	XXIII	375-390	96.086	18.9	42.5	29.7	8.8	2.76	4.24	-0.05	0.73	GRAVELLY SANDY LOAM
	1015-03	XXIV	386-390	95.996	18.2	46.6	28.2	7.0	2.48	3.83	-0.08	0.80	GRAVELLY SANDY LOAM
	1015-02	XXVI	397-405	95.961	11.3	59.3	24.1	5.3	2.95	2.83	0.13	0.93	SANDY LOAM
	1015-01	XXV	392-400	95.911	8.7	42.9	37.4	11.0	4.23	3.28	0.10	1.06	LOAM

DU	Sample ID	Zone	Elevation cmbs	Elevation m	% gravel	% sand	% silt	% clay	mean	sd	skew	kurt	Textural Class
DU1a	1022-1	I	0-20	96.305	8.78	49.9	25.3	16.0	4.81	4.16	0.35	0.72	SANDY LOAM
	1022-2	II	5-20	96.195	8.48	48.52	25.7	17.3	5.15	4.24	0.38	0.71	SANDY LOAM
	1022-3	III	20-26	96.09	14.09	50.72	21.9	13.3	3.40	3.85	0.14	0.96	SANDY LOAM
	1022-4	IV	26-33	96.025	12.27	45.75	26.4	15.6	4.59	4.24	0.27	0.85	SANDY LOAM
	1022-5	V	26-39	95.96	10.01	45.85	28.3	15.8	5.51	3.38	0.57	0.33	LOAM
	1022-6	VI	39-47	95.885	19.58	50.61	19.3	10.5	2.68	4.17	0.07	0.74	GRAVELLY SANDY LOAM
	1022-7	VII	47-55	95.82	42.06	38.63	12.5	6.9	0.83	3.98	0.06	0.83	VERY GRAVELLY SANDY LOAM
	1022-8	VIII	52-65	95.78	20.49	44.19	23.3	12.0	2.80	4.66	0.02	0.73	GRAVELLY SANDY LOAM
	1022-9	IX	55-63	95.73	20.76	59.25	12.2	7.7	1.74	3.21	-0.03	1.08	GRAVELLY SANDY LOAM
	1022-10	X	59-68	95.665	21.95	43.4	22.6	12.0	2.45	4.57	-0.04	n/a	GRAVELLY SANDY LOAM
	1022-11	XI	66-78	95.59	19.26	49.49	19.4	11.8	2.61	4.10	0.03	0.80	GRAVELLY SANDY LOAM
	1022-12	XII	70-93	95.53	12.73	54.15	22.0	11.1	3.35	3.36	0.19	1.09	SANDY LOAM
	1022-13	XIII	89-105	95.365	21.63	44.38	22.6	11.4	2.48	4.64	-0.02	0.74	GRAVELLY SANDY LOAM
	1022-14	XIV	100-113	95.275	20.2	43.67	24.2	11.9	3.02	4.62	0.08	0.70	GRAVELLY SANDY LOAM
	1022-15	XV	107-125	95.16	12.07	51.02	28.1	8.9	3.54	3.38	0.14	0.67	SANDY LOAM
	1022-16	XVI	120-148	94.885	8.75	45.74	32.3	13.2	4.53	3.47	0.24	1.01	LOAM
	1022-17	XVII	145-153	94.85	18.3	42.27	28.1	11.3	3.01	4.40	-0.01	0.72	GRAVELLY LOAM
	1022-18	XVIII	153+	94.75	29.6	25.6	36.3	8.5	2.00	5.01	-0.22	0.51	GRAVELLY SILT LOAM

Table 4-2. Results of CCE, magnetic susceptibility, organic carbon, and stable carbon isotope analyses for Columns A (top) and B (bottom). Note that the highlighted rows represent overlapping elevation.

DU	Sample ID	Zone	Elevation		%CCE	Xfd	Xlf	% C	13C
			cmbs	m					
DU3	1015-46	I	0-12	99.856	0.7	1.381215	31.28781331	0.638	-15.96
	1015-45	II	12-31	99.846	0.6	1.057402	29.24028269	0.598	-15.84
	1015-44	II		99.781	0.1	1.286174	26.20050548	0.456	-14.31
	1015-43	II		99.626	0.6	0.806452	25.59867878	0.389	-16.64
	1015-42	III	31-53	99.541	0.7	1.528384	19.67353952	0.337	-17.01
	1015-41	IV	53-64	99.386	0.4	0.235294	18.06972789	0.231	-19.13
	1015-40	IV		99.326	0.7	0.285307	59.76129582	0.139	-19.38
	1015-39	V	64-76	99.226	0.9	1.196411	42.42808799	0.114	-21.83
	1015-38	VI	76-88	99.151	0.7	1.092896	196.6115702	0.109	-17.70
	1015-37	VI		99.096	0.7	1.377953	80.0000000	0.115	-17.10
	1015-36	VII	86-100	99.016	0.6	1.284585	84.68619247	0.106	-19.18
	1015-35	VII		98.986	0.7	1.150252	114.0163934	0.149	-22.74
DU2	1015-34	VIII	95-114	98.921	0.9	1.439458	55.08395522	0.265	-18.55
	1015-33	VIII		98.851	0.6	1.376721	75.80645161	0.265	-16.03
	1015-32	IX	112-125	98.756	0.6	1.559454	69.19964029	0.172	-20.03
	1015-31	X	123-145	98.656	0.3	1.267351	78.30812854	0.178	-18.28
	1015-30	X		98.571	1.2	1.264368	88.7755102	0.236	-19.37
	1015-29	XI	140-182	98.471	6.1	1.727862	93.53535354	0.227	-19.71
	1015-28	XI		98.381	5.2	1.773455	87.05179283	0.203	-17.97
	1015-27	XI		98.321	5.7	1.467505	48.57433809	0.254	-18.89
DU1b	1015-26	XII	165-212	98.211	2.1	0.670391	45.06545821	0.209	-16.73
	1015-25	XII		98.051	0.7	0.536193	38.1390593	0.245	-17.65
	1015-24	XII		97.901	0.7	0.692521	37.25490196	0.230	-17.63
	1015-23	XIII	212-239	97.736	0.6	0.769769	74.19522326	0.164	-17.85
	1015-22	XIII		97.606	0.5	0.604839	82.30088496	0.148	-17.44
	1015-21	XIV	239-325	97.471	0.9	0.95986	64.89241223	0.189	-18.82
	1015-20	XIV		97.381	0.5	0.538793	53.08924485	0.229	-19.02
	1015-19	XIV		97.246	0.5	0.350877	76.53061224	0.223	-19.17
	1015-18	XIV		97.131	0.6	0.566038	85.7605178	0.185	-18.10
	1015-17	XIV		97.021	0.5	0.298507	75.7918552	0.181	-18.33
	1015-16	XIV		96.936	0.5	0.296209	91.73913043	0.169	-18.77
	1015-15	XIV		96.801	0.3	0.448096	76.25284738	0.172	-17.85
DU1a	1015-14	XV	315-325	96.721	0.3	0.137489	180.9286899	0.053	-19.27
	1015-13	XVa	325-330	96.651	0.3	0.311111	114.7959184	0.144	-19.36
	1015-12	XVI	328-350	96.581	0.3	0.247117	128.6016949	0.122	-18.66
	1015-11	XVII	332-340	96.566	0.3	0.347343	135.8018868	0.112	-20.32
	1015-10	SVI	328-350	96.466	0.3	0.52795	154.3624161	0.122	-20.48
	1015-09	XVIII	343-350	96.456	0.3	0.407925	165.9574468	0.087	-19.98
	1015-08	XIX	350-360	96.356	0.3	-0.12255	130.0743889	0.118	-19.60
	1015-07	XX	355-365	96.271	0.3	0.50077	126.7578125	0.112	-18.06
	1015-06	XXI	365-375	96.201	0.3	0.408024	139.7813688	0.105	-18.74
	1015-05	XXII	375-380	96.146	0.5	0.510204	168.2023487	0.101	-20.29
	1015-04	XXIII	375-390	96.086	0.5	0.50077	131.7766497	0.156	-20.79
	1015-03	XXIV	386-390	95.996	0.5	0.58309	134.6418057	0.098	-19.53
	1015-02	XXVI	397-405	95.961	0.3	0.468975	118.3603757	0.081	-20.83
	1015-01	XV	392-400	95.911	0.3	-0.07342	72.52396166	0.146	-20.11

DU	Sample ID	Zone	Elevation		%CCE	Xfd	Xlf	% C	13C
			cmbs	m					
DU1a	1022-1	I	0-20	96.305	0.3	0.207039	93.06358382	0.104	-19.67
	1022-2	II	5-20	96.195	0.3	0.996885	87.32317737	0.132	-18.41
	1022-3	III	20-26	96.09	0.3	1.340616	91.87956204	0.095	-19.57
	1022-4	IV	26-33	96.025	0.3	0.24108	105.7084608	0.126	-19.33
	1022-5	V	26-39	95.96	0.3	1.148796	88.73786408	0.113	-17.39
	1022-6	VI	39-47	95.885	0.3	0.634391	134.3049327	0.110	-20.45
	1022-7	VII	47-55	95.82	0.3	1.132686	158.5970915	0.084	-19.52
	1022-8	VIII	52-65	95.78	0.2	0.99723	89.80099502	0.102	-19.23
	1022-9	IX	55-63	95.73	0.3	0.657534	154.6610169	0.067	-18.91
	1022-10	X	59-68	95.665	0.3	1.298701	58.5106383	0.106	-18.48
	1022-11	XI	66-78	95.59	0.2	0.930233	59.39226519	0.113	-19.18
	1022-12	XII	70-93	95.53	0.2	0.989011	85.44600939	0.095	-19.93
	1022-13	XIII	89-105	95.365	0.3	1.088435	72.98907646	0.104	-18.49
	1022-14	XIV	100-113	95.275	0.3	1.045016	64.32264736	0.105	-21.34
	1022-15	XV	107-125	95.16	0.0	0.685453	62.4643197	0.096	-21.60
	1022-16	XVI	120-148	94.885	0.2	0.883534	64.50777202	0.095	-20.27
	1022-17	XVII	145-153	94.85	0.0	0.488998	57.22947761	0.115	-22.26
	1022-18	XVIII	153+	94.75	0.0	1.100244	44.12081985	0.146	-21.55

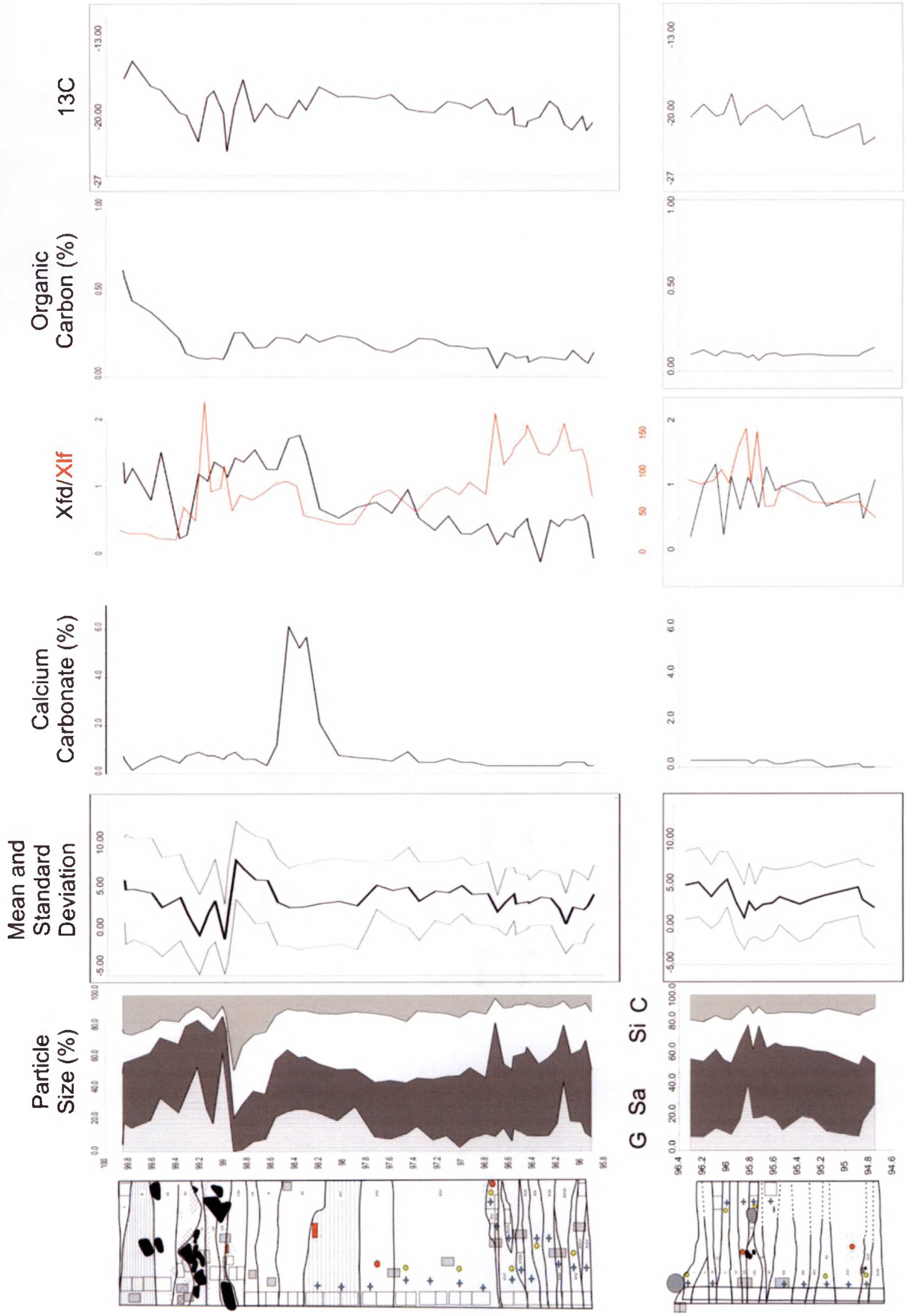

Figure 4-6. Plotted results of lab analyses for Columns A (top/left) and B (bottom/right).

Table 4-3. Column A, pedogenic characteristics and features and associated formation conditions.

Depositional Unit	Zone	Elevation m (cmbs)	Structure	Pedofeatures	Conditions
3	I	99.80-99.93 (0-12)	Strong, medium subangular blocky	Distinct mottles	Variable soil moisture, oxidizing and reducing conditions
	II	99.61-99.93 (12-31)	Strong, coarse angular blocky to strong, fine subangular blocky	Faint clay films between grains	Variable soil moisture
	III	99.61-99.47 (31-53)	Moderate, fine to medium subangular blocky	Distinct clay films on ped faces	Variable soil moisture
	IV	99.29-99.41 (53-64)	Moderate, fine to medium subangular blocky	Faint clay films on ped faces	Variable soil moisture
	V	99.17-99.27 (64-76)	Moderate, fine to medium subangular blocky	Prominent clay films on grains and ped faces	Variable soil moisture
	VI	99.03-99.17 (76-88)	Weak to moderate, fine subangular blocky	Distinct clay films covering and between grains	Variable soil moisture
	VII	98.97-99.03 (86-100)	Weak to moderate, fine subangular blocky	Distinct clay films covering and between grains	Variable soil moisture
2	VIII	98.81-98.95 (95-114)	Strong, medium prismatic to strong, medium angular blocky	Prominent clay films on ped faces and in pores	Extremely variable soil moisture (e.g., dehydrated--adequate)
	IX	98.69-98 81 (112-125)	Strong, coarse prismatic to strong, medium to coarse angular blocky	Prominent clay films on ped faces	Extremely variable soil moisture (e.g., dehydrated--adequate)
	X	98.51-98.68 (123-145)	Strong, coarse prismatic to strong, medium to coarse angular blocky	Faint clay films on ped faces	Extremely variable soil moisture (e.g., dehydrated--adequate)
	XI	98 29-98.51 (140-182)	Strong, very coarse prismatic	Prominent carbonate coats on all sides of peds	Prominent dehydration (Arid)
1b	XII	97.82-98.29 (165-212)	Strong, coarse prismatic		Extremely variable soil moisture (e.g., dehydrated--adequate)
	XIII	97.53-97.79 (212-239)	Moderate, coarse prismatic to moderate, coarse angular blocky	Distinct Mn films on ped faces and prominent Mn/Fe irregular masses	Extremely variable soil moisture (e g., dehydrated--adequate), oxidizing and reducing conditions
	XIV	96.72-97.51 (239-325)	Moderate, coarse columnar	Distinct mottles, distinct Mn films on ped faces, and prominent Mn/Fe irregular masses	Extremely variable soil moisture (e.g., dehydrated--adequate), oxidizing and reducing conditions
1a	XV	96.67-96.76 (315-325)	Weak, fine to medium subangular blocky	Distinct Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	XVA	96.63-96.66 (325-330)	Weak, fine subangular blocky	Distinct Mn films on ped faces and prominent Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	XVII	96.53-96.59 (332-340)	Weak, fine subangular blocky	Distinct Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	XVIII	96.41-96.49 (343-350)	Weak, fine subangular blocky		Variable soil moisture
	XVI	96.40-96.63 (328-350)	Weak, fine subangular blocky	Distinct Mn and Ferriargillan coats on ped faces and between grains	Variable soil moisture, oxidizing and reducing conditions
	XIX	96.30-96.40 (350-360)	Weak, fine subangular blocky	Distinct Mn films on ped faces and prominent Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	XX	96.23-96.30 (355-365)	Weak, fine subangular blocky	Distinct Mn films on ped faces and prominent Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	XXI	96.16-96.23 (365-375)	Weak, fine subangular blocky	Distinct Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	XXII	96.12-96.16 (375-380)	Weak, fine subangular blocky	Distinct Mn and Ferriargillan coats on ped faces and between grains	Variable soil moisture, oxidizing and reducing conditions
	XXIII	96.04-96.12 (375-390)	Weak, fine subangular blocky	Distinct Mn and Ferriargillan coats on ped faces and between grains	Variable soil moisture, oxidizing and reducing conditions
	XXIV	95.94-96.04 (386-390)	Weak, fine subangular blocky	Distinct Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions

Table 4-4. Column B pedogenic structure and features and associated formation conditions.

Depositional Unit	Zone	Elevation m (cmbs)	Structure	Pedofeatures	Conditions
1a	I	96.27-96.34 (0-20)	Weak, very fine subangular blocky	Distinct ferriargillan coats in pores	Variable soil moisture, oxidizing and reducing conditions
	II	96.12-96.27 (5-20)	Weak, fine subangular blocky	Faint sandy films on ped faces and in channels	Variable soil moisture, oxidizing and reducing conditions
	III	96.06-96.12 (20-26)	Weak, fine subangular blocky	Prominent mottles located at boundaries	Variable soil moisture, oxidizing and reducing conditions
	IV	95.99-96.06 (26-33)	Weak, fine to medium subangular blocky	distinct mottles	Variable soil moisture, oxidizing and reducing conditions
	V	95.93-95.99 (26-39)	Moderate, very fine platy	Faint sandy films on ped faces	Possible freeze-thaw origin or cementing-induced structure, variable soil moisture
	VI	95.84-95.93 (39-47)	Weak Medium subangular blocky	Distinct Mn coats on ped faces	Variable soil moisture, oxidizing and reducing conditions
	VII	95.80-95.84 (47-55)	Weak Medium subangular blocky	Distinct Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	VIII	95.76-95.80 (52-65)	Weak Medium subangular blocky	Faint clay films on ped faces	Variable soil moisture, oxidizing and reducing conditions
	IX	95.69-95.76 (55-63)	Weak Medium subangular blocky	Distinct Mn/Fe irregular masses and nodules	Variable soil moisture, oxidizing and reducing conditions
	X	95.64-95.69 (59-68)	Weak Medium subangular blocky	Distinct Mn coats in pores and distinct Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	XI	95.54-95.64 (66-78)	Weak, fine to medium subangular blocky	Distinct Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	XII	95.44-95.62 (70-93)	Weak Medium subangular blocky	Distinct Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	XIII	95.29-95.44 (89-105)	Weak Medium subangular blocky	Distinct Mn/Fe irregular masses	Variable soil moisture, oxidizing and reducing conditions
	XIV	95.24-95.31 (100-113)	Weak, fine to medium subangular blocky	Distinct Mn and ferriargillan coats on ped faces and in channels	Variable soil moisture, oxidizing and reducing conditions
	XV	95.08-95.24 (107-125)	Weak, fine to medium subangular blocky	Distinct ferriargillan coats in pores and on ped faces	Variable soil moisture, oxidizing and reducing conditions
	XVI	94.89-95.08 (120-148)	Weak Medium subangular blocky		Variable soil moisture
	XVII	94.81-94.89 (145-153)	Weak Medium subangular blocky	Distinct Mn and ferriargillan coats on ped faces	Variable soil moisture, oxidizing and reducing conditions
	XVIII	94.69-94.81 (153+)	Weak Medium subangular blocky	Prominent mottles located at upper boundary	Variable soil moisture, oxidizing and reducing conditions

moisture (Birkeland 1999). At the transition between fine to medium sized peds, Zone V (Column B) has a very fine platy structure. Platy structure may be the result of parent material orientation, freeze-thaw processes, or cementing (Birkeland 1999); it is likely the case that Zone V's platy structure is due to a combination of cementing and parent material orientation. Ferruginous and manganiferous clay films and nodules are common throughout DU1a, and are the result of a fluctuating oxidizing and reducing environment, which is capable of weathering, transporting, and precipitating the mineral constituents (Birkeland 1999; Schaetzl and Anderson 2005). These iron- and manganese mineral-rich clay films are present on ped faces and on and between coarse fragments.

Though containing a considerable amount of tephra, DU1b is quite distinct from the lower portion. DU1a is composed of highly stratified thin beds, whereas DU1b consists of just three much thicker beds. Gravels compose just under 10 percent of Zones XIV and XIII and just over 20 percent of Zone XII. Textural class of these three strata is consistently loamy. Ped structure, however, varies among the zones of DU1b: Zone XIV is composed of medium, coarse columnar peds; Zone XIII contains medium, coarse prismatic to subangular blocky peds; and, Zone XII has strongly developed, coarse prismatic ped structure. Both columnar and prismatic ped structures are the result of soil moisture deficiencies, and the rounded top of columnar peds is characteristic of erosion and expanding centers (Birkeland 1999). The lower two zones of DU1b contain pedofeatures, but the upper stratum, Zone XII, markedly lacks pedofeatures. Zone XIV contains distinct, irregular red mottles of less than 76 mm in size; prominent iron- and manganese mineral-rich irregular spherical masses of approximately two to five mm in size; and prominent manganese clay films on ped faces and in pores. Zone XIII also contains similar manganese clay coats and masses, but lacks the mottles present in the underlying zone. The upper and lower boundaries of Zone XIII are delineated by bands of iron- and manganese mineral-rich material, which will be further described in thin section below. Less developed bands of iron and manganese minerals are irregularly spaced throughout Zone XIV as well. These bands can be followed almost continuously around the excavation block, and they appear to dip towards the southwest corner. In addition to iron- and manganese mineral-rich bands, there are bands that appear to be cemented by silica. Boundaries of these zones are abrupt, and the upper boundary of Zone XII is wavy and characteristic of an erosional surface.

In terms of soil development, DU1b contains evidence of being a paleosol. Zone XII, while being truncated to an unknown extent, appears to be the relic of an A horizon, and has been designated 3ABb. It is darker in color than the underlying sediments, has a slight increase in organic carbon content, and it lacks pedofeatures. The underlying deposits all contain pedofeatures that are characteristic of mobilized (illuvial) minerals, however, there is no distinct B horizon. Iron- and manganese-rich clay films and masses, as well as mottles, described above, are redoximorphic features, which are characteristic of alternating oxidation and reduction (Schaetzl and Anderson 2005). Clay films are characteristic of particle translocation by water through voids within the sediments, e.g. clay illuviation (Brewer 1976; Retallack 1988). Presence of these pedofeatures increasing with depth is characteristic of variable soil moisture and water table elevation. The most prominent redoximorphic features (e.g., mottles) present in the lower stratum indicates that this deposit was more dramatically over- and under-saturated than the overlying deposit. Silica cementation (described in more detail below) is the result of silica precipitating out of ground water solution moving upwards or downwards through the profile, and they are common in volcanically-derived soils and in arid to semi-arid environments with adequate sources of silica (Birkeland 1999; Schaetzl and Anderson 2005).

Depositional Unit 2

Depositional Unit 2, spanning 95-182 cmbs and observed only in Column A, is composed of four strata, Zones VIII to XI. This unit is framed by the dates 13,165 +/-145 years BP, from the top of Depositional Unit 1, and 10,235 +/-45 years BP, at the top of Depositional Unit 2. Generally, the particle size of this unit exhibits a fining upwards, or normally graded, sequence. Gravel content decreases from approximately 25 percent in Zone XI to less than one percent in Zone VIII. Textural classes changing from loam in the lower strata to clay in the upper stratum are also characteristic of the fining-up nature of the deposit. Pedogenic structure varies throughout Depositional Unit 2: Zone XI is strongly developed, coarse prismatic; Zones X and IX are composed of strong, coarse prismatic to strong, medium to coarse angular blocky peds; and Zone VIII has strong, medium prismatic to strong medium angular blocky ped structure. Faint to prominent reddish brown clay films occur on ped faces and in pores in Zones X, IX, and VIII. While clay films are not present in Zone XI, this zone contains carbonate coats on more than 90 percent of ped faces. This abundance and distribution of carbonate coats forms a reticulate pattern, or boxwork carbonate.

In terms of soil development, an 2ABb-2Btb-2Bwb-2bkb soil has formed within DU2, and the presence of this calcareous deposit, referred to the 2Bk horizon, is peculiar and important. Bk horizons develop as calcium carbonate is precipitated out of solution from soil moisture. This process can occur by *in situ* dissolution and reprecipitation, by capillary flow of calcium-rich groundwater (*per ascensum*), by percolating calcium-rich water (*per descensum*), or biogenically (Schaetzl and Anderson 2005). The first two processes are contingent upon calcareous parent material, and as this is not the case at

Chivacabe, the third process of formation, *per descensum*, is most likely the origin of calcium carbonates in Zones V and VI. In any event, calcic horizons are the result of conditions when calcium content exceeds the soil water's capacity, which is most common in regions where evaporation exceed precipitation, i.e., arid-semi to arid climates or humid environments with clay-rich soils (Birkeland 1999; Schaetzl and Anderson 2005). As the parent material is not calcareous, the location of carbonate source is unclear. Though not absolute, it is probable that this calcium carbonate was derived from airborne dust that was subsequently translocated down the profile by meteoric water to a point of precipitation at a perched water table, sitting atop the interface between Depositional Units 1 and 2. Additionally, the boxwork structure of this Bk horizon indicates that pedogenic structure had formed prior to calcium carbonate precipitation and that water flow was greatest down the planar spaces between peds. Increasing strength and structure of the peds downward through the zones of Depositional Unit 2 is characteristic of diminishing soil moisture with depth. Above this horizon is a 2Bw (Zone X), 2Bt (Zone IX), and an AB (Zone VIII). The 2Bw and 2Bt horizons contain illuvial clays, and the AB horizon is very thin, darkly colored and obviously truncated relic of an A horizon, and it also contains vestiges illuvial clays, which are visible in thin section (discussed below).

Depositional Unit 3

Depositional Unit 3 occupies the uppermost meter of Column A (0-92 cmbs). This unit is composed of seven zones, Zones I through VII, representing the most recent accumulation of sediments and soil formation. A maximum age of this unit is 10,235 +/- 45 years BP, the date yielded from a sample at the top of Depositional Unit 2.

Depositional Unit 3 is distinct from the underlying units due to the presence of cobble-sized clasts. But it was apparent in the field that Column A sampled a channel facies of DU1, and most of the DU1 deposits in the excavation block were not this coarsely textured. Depositional Unit 3 also exhibits a generally fining upwards sequence. Gravel content in the lower three strata ranges from approximately 25 to 55 percent, but decreases to slightly less than five percent in Zone I. Additionally, textural classes change from sandy loam in Zone VII to loam in Zone I as clay content increases from 13.5 percent to more than 20 percent, respectively. Coarse fragments of Zones V-VII include clasts of gneiss that are up to approximately 20 cm along their greatest axes. Much of these coarse fragments are clast supported. Zones II and III also contain relatively large clasts of gneiss, reaching approximately 10 cm in diameter. These cobble-size clasts, however, are subangular to subround in shape and are mostly matrix supported. As their transportation and deposition would have required a relatively great amount of energy, their presence is characteristic of an abandoned channel, likely of the drainage at the base of the hillslopes to the north. Ped structure in Zones III to VII is weakly to moderately developed, fine to medium subangular blocky; whereas Zone II contains strong, coarse angular blocky to fine subangular blocky peds, and Zone I contains strong, medium subangular blocky peds. Zones II-VII all contain common, distinct to prominent clay films on pedfaces and between grains, and additionally, illuvial clay can be observed in the form of lamellae in Zones III-VII. These pedofeatures are gray and red, and coat 50-90 percent of pedfaces and grains where the illuvial clay is present. Textural analysis of lamellae and adjacent deposits lacking illuvial clay suggests that the lamellae contain between about four percent and 7 percent illuvial clay. Although the lamellae were apparent in the field, their micromorphologic expression was spectacularly clear in thin section (discussed below).

Soil development in Depositional Unit 1 consists of a modern AC (Zone I), and an older A (Zone II)-Bw (Zone III)-Bt/C (Zones IV-VII) soil. The modern AC horizon pinches out to the west within the exposure of Column A. As such, the older A horizon is present at the surface in the western third of the exposure. It is characterized by a considerable increase in organic carbon content. The Bw and Bt/C horizons both contain a relatively high amount of illuvial clay, and the distinction between the two horizons is the greater amount and size of coarse fragments in the latter. Additionally, Depositional Unit 3 contains lamellae, which have a highly questionable and debated origin (Rawling 2000).

Micromorphology

A total of 20 block sediment samples were collected for thin-sectioning and micromorphological analysis from Columns A and B within the excavation block at Chivacabe. Sixteen of these samples were selected for micromorphological analysis; though visually scanned, four thin sectioned samples were omitted from analysis due to replication and their inability to provide further data. Seven of the 16 samples, including two from Depositional Unit 1, two from Depositional Unit 2, and four from Depositional Unit 3, were described in terms of microstructure, mineral components, and pedofeatures, whereas the remaining nine thin sections were reviewed only for supplemental data and features.

Depositional Unit 1

The lowest-most thin section comes from Zone I of Column B, at an elevation of approximately 96.37 m. This sample was collected from a position adjacent to a proboscidean tusk and represents the context of the exposed bone bed. Type, size and grade of aggregate have either been obscured through the 30-plus years that the sediment has been exposed or due to the nature of the somewhat massive loamy sand deposit. Voids consist of approximately 75 percent vughs and 25 percent channels, and they are no greater than 100 μm in diameter. The microstructure of this sample is considered vughy to massive. At a coarse/fine limit of 10 μm, the poorly sorted material is approximately 60 percent coarse and 40 percent fine. Identifiable mineral grains in the coarse component include metamorphic quartz, plagioclase, potassium feldspar, and pumice. These grains reach sizes in excess of 300 μm, although the very abundant, vesicular volcanic glass is not observed greater than 300 μm in size (Figure 4-7). In addition to mineral grains, there are opaque minerals, iron and manganese, that are present in sizes less than 100 μm. Textural and amorphous pedofeatures are present in this sample. The rare to occasional silans, or siliceous clay coats, are no greater than 5μm in size, have a grainy/silty texture, and are speckled in color. Amorphous pedofeatures consist of iron halos and iron and manganese mineral nodules. Iron halos, occasional to many in abundance, are monomorphic in nature and have widths of no greater than 20 μm. Iron and manganese mineral typic nodules, which are also occasional to many in abundance, are polymorphic and no greater than 200 μm in diameter. Silca precipitation is commonly a result of mildy alkaline and reducing conditions, and iron and manganese mineral nodules and masses are typically formed in oxidizing and reducing environments

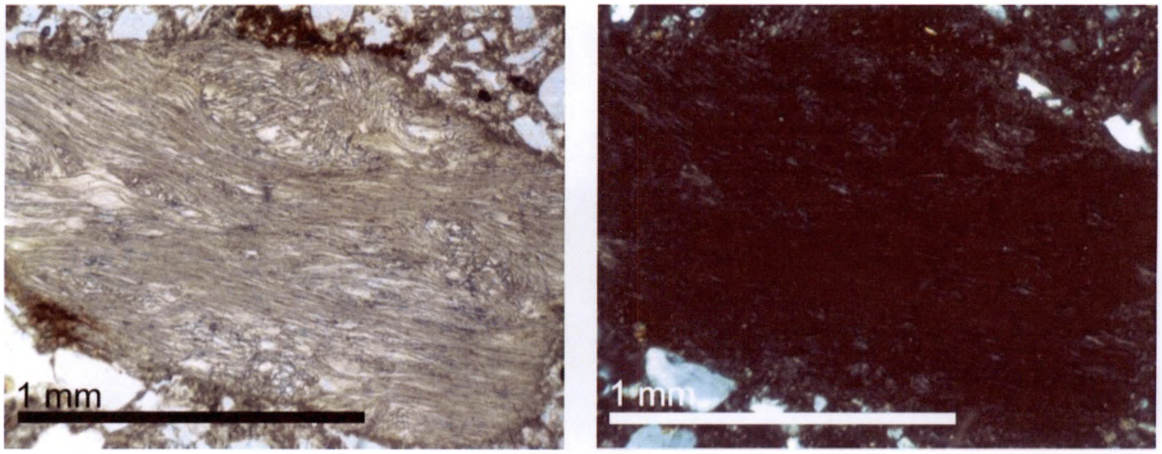

Figure 4-7. 4X photomicrograph of pumice in plain light (left) and in crossed-polarized light (right).

(Schaetzl and Anderson 2005). Accordingly the presence of these pedofeatures represent fluctuating availability of soil moisture and a ready source of soluble silica such as the volcanic glass.

At the upper boundary of DU1a, an elevation of approximately 96.67 m, the next thin section spans a coarse to fine strata interface. As such, the two components were analyzed separately. The lower, coarse component contains vughs and channel voids thatare no greater than 50 μm in diameter. Aggregate type, size, and grade, as well as type of microstructure, are not apparent in this sample. With a coarse/fine ratio limit of 10 μm, the sample consists of poorly sorted 60 percent coarse and 40 percent fine materials. Identifiable minerals include fragments of plagioclase, potassium feldspar, metamorphic quartz, and pumice that reach no more than 300 μm in diameter. Additionally, there are many opaque black minerals that are no greater than 25 μm in size. Pumice is very abundant and reaches sizes in excess of 50 μm. Pedofeatures observed include cutans (i.e., clay films in macro-morphology descriptions) and nodules. Silans are many in abundance, have a grainy/silty texture, are speckled in color, and are approximately five to 10 μm in thickness. There are also argillans, which occur rarely to occasionally. The argillans are non-laminated, are approximately 5 μm in width, have limpid texture, and are highly birefringent. Nodules in this coarse component of the thin section are polymorphic, consisting of iron and manganese minerals. They are many in abundance, are typic to digitate, and occur in excess of 75 μm in diameter. The upper, fine fraction of this thin section contains strong, subangular blocky aggregates of more than two cm in size. Voids include approximately 66 percent channels and 33 percent vughs of less than 25 μm in diameter. The microstructure in this portion of the sample is spongy to prismatic. At a coarse/fine ratio limit of 10 μm, this well sorted material is composed of approximately 20 percent coarse and 80 percent fine grains. Identifiable mineral grains include metamorphic quartz, plagioclase, potassium feldspar, pumice, magnetite, and hematite, all reaching sizes of no greater than 30 μm. There are many less than 30 μm-diameter pumice fragments, however, they are much more abundant in sizes less than one μm in size. Magnetite and hematite grains are occasional to many in abundance. Within the fine fraction of this sample, there are cutans and nodules. Silans are equivalent to those found in the coarse-grained portion of this sample, and digitate nodules are polymorphic in nature. They are occasional to many in abundance and can be greater than 75 μm in size. A contrast in the amount and variety of pedofeatures between the coarse and fine portions of this sample is a function of porosity; the coarser portion contains larger voids capable of translocating more colloidal material, whereas the finer portion has limited access via capillary flow.

The uppermost sample collected from Depositional Unit 1 comes from approximately 97.52 m, in the middle of Zone XIII, DU1a. Aggregates, whose extents are greater than the slide, are strong and subangular blocky. Void types include channels and vughs that are less than 100 μm in diameter. At a coarse/fine ratio limit of 10 μm, the sample is composed of approximately 40 percent coarse and 60 percent fine, poorly to moderately sorted material. Identifiable mineral grains include a considerable amount of pumice, metamorphic quartz, and gneiss that reach greater than 50 μm in size. Textural and amorphous pedofeatures are present and include, ferri-argillans, argillans, silans, digitate bands, and typic nodules. Ferri-argillans range in size from five to 15 μm, are non-laminated, have limpid texture, are reddish brown, and occur occasionally. Argillans are less than five μm thick, are non-laminated, have limpid texture, are highly birefringent, and are rarely present. Silans are five to 15 μm thick, are grainy/silty in texture, are speckled in color, and are many in abundance. A near-continuous band around the excavation block is polymorphic in thin section, and it is composed of iron and manganese minerals. Monomorphic typic nodules are present and composed only of iron minerals. These nodules occur rarely to occasionally, and they are no larger than 50 μm in size.

Three other thin sections from Depositional Unit 1, spanning DU1a and DU1b, confirm the ubiquity of volcanic glass and mobile silica in this unit. These samples, however, do not have any additional unique characteristics.

Depositional Unit 2

From the bottom of Depositional Unit 2 within the Btk horizon, a thin-sectioned sample reveals strong, subangular blocky aggregates of one to two μm in size. Voids present within this sample are channels, planar, and vughs, reaching no greater than 500 μm in diameter. Microstructure of this sample is prismatic. With a 10 μm coarse/fine ratio limit, the material is composed of 50 percent coarse and 50 percent fine, moderate to well sorted grains. Identifiable framework grains include metamorphic quartz, plagioclase, potassium feldspar, and gneiss. These mineral grains reach sizes of greater than 200 μm. Of particular interest in this sample are complex cutans. Complex cutans consist of multiple overlapping coats, indicative of changing environmental conditions during which each of the cutan types form. Arigllans, silans, and calcitans are present, and in some places they are superimposed. Argillans are micro-laminated, approximately 5 μm thick, limpid in texture, and highly birefringent. Silans reach 10 μm in thickness, are grainy/silty in texture, and speckled. Calcitans reach thicknesses of greater than 100 μm, are hypidiotopic, and are birefringent. All of these cutans are many to abundant, and where they are stratified, argillans are at the base, calcitans are above argillans, and silans lie atop calcitans (Figure 4-8). Stratification of these cutans is indicative of the differential rates of mineral weathering as well as past climatic conditions. The deposition of argillans first is indicative of adequate soil moisture and illuvial processes, and the following precipitation of carbonate and silica is characteristic of soil moisture deficiency (Schaetzl and Anderson 2005). Typic nodules composed of iron, manganese, or iron and manganese are also present, albeit rarely, in diameters no greater than 100 μm. In an adjacent micromorphological thin section, floral remains and a vesicular fragment of volcanic glass (< 125 μm-diameter) were observed.

A sample was collected from Zone VIII in the top of Depositional Unit 2, and this sample contains strong, subangular block aggregates that are one to three-plus cm in size. Voids present within the sediment include approximately 75 percent channels and 25 percent vughs, reaching diameters of no greater than 125 μm. The microstructure of the

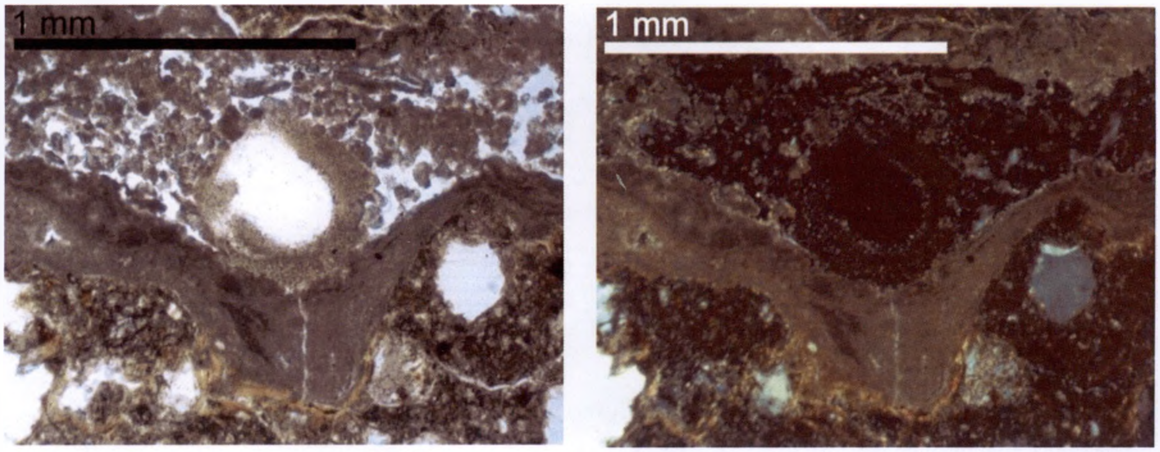

Figure 4-8. 4X photomicrograph of compound cutan in plain light (left) and in cross-polarized light (right).

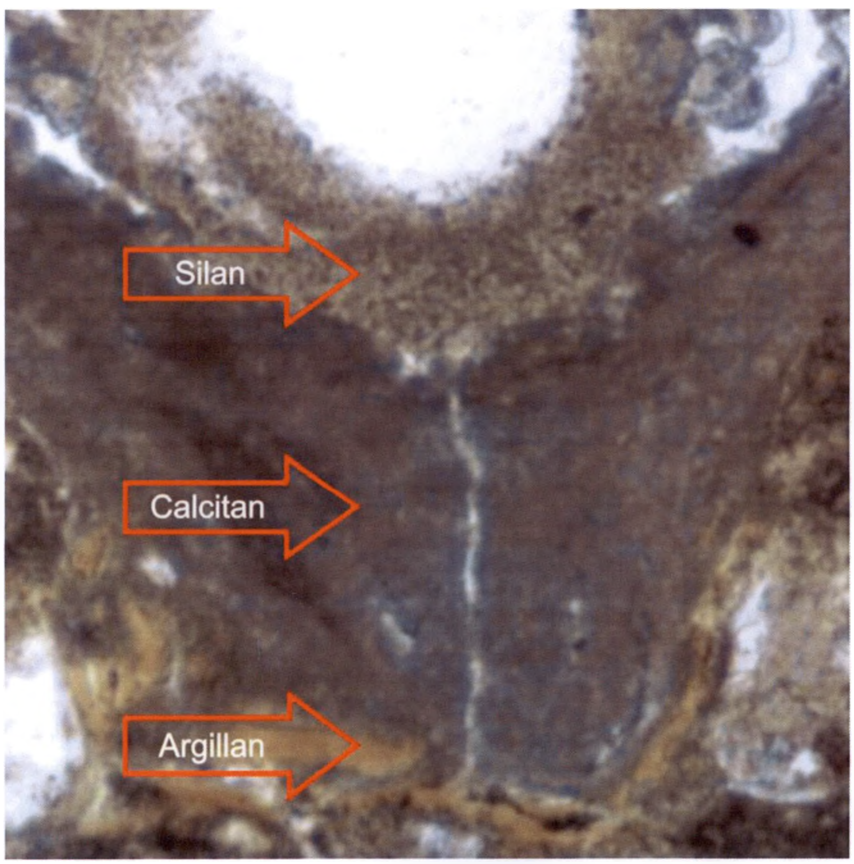

Figure 4-9. Magnification of compound cutan (see Figure 4-8) in plain light.

sediment is prismatic. With a coarse/fine ratio limit of 10 µm, the sample contains approximately 20 percent coarse and 80 percent, moderate to well sorted grains. Identifiable mineral grains include metamorphic quartz, plagioclase, potassium feldspar, and micas. These grains are no larger than 25 µm. Pedofeatures include cutans and nodules. Silans are less than 10 µm in size, have grainy/silty texture, and are speckled. There are also argillans, which measure less than 50 µm in thickness, are micro-laminated, have limpid texture, and are highly birefringent. Similar to the thin section from the base of Depositional Unit 2 described above, this sample contains complex cutans, however, there are no calcitans. In this slide, silans lie directly atop argillans where they are found together. Although there are no calcitans, the juxtaposition of argillans and silans imply similar changing conditions to the previous sample. Nodules in this thin section are identical to those described in the above thin section. On rare occasion, small sherds of volcanic glass are identified, but unlike Depositional Unit 1, they do not form a considerable part of the matrix's constituency.

Depositional Unit 3

In the middle of Depositional Unit 3, a sample for thin sectioning was collected from Zone IV. No aggregate type, size, or grade is apparent in this sample, however, the microstructure ranges from spongy to chamber. Void types present include chambers, vughs, and channels, and these voids exceed 150 µm in diameter. Minerals identified within this sample include potassium feldspar, metamorphic quartz, gneissic rock fragments and micas, all no larger than 250 µm in diameter. Pedofeatures consist of ferri-argillans, argillans, and silans (Figure 4-9). Iron-rich argillans are less than 15 µm thick, are reddish brown, and rarely to occasionally occur. Argillans observed are less than 50 µm thick, micro-laminated, limpid in texture, birefringent, and very abundant. Silans are less than 15 µm in thickness, speckled, and occur rarely. This specimen also contains iron, manganese, and iron and manganese mineral typic nodules. Nodules composed of only iron or manganese minerals are less than 200 µm in size, whereas nodules composed of both elements reach greater than 300 µm in diameter. These nodules are occasional to many.

At approximately 99.82 m, near the top of Depositional Unit 3, a single thin section sample reveals strong to moderate subangular blocky aggregates that are greater than 2 cm in diameter. Microstructure is classified as spongy to chamber. Using a 10 µm coarse/fine ratio limit, the materials present in this thin section are approximately 60 percent coarse and 40 percent fine grains. These grains are moderately to poorly sorted. Within the coarse-grained component, minerals that can be identified include metamorphic quartz, potassium feldspar, and gneissic rock fragments ranging in size from less than 10 µm to greater than 3 µm. Textural and amorphous pedofeatures are present within this sample; similar to the above described thin section, cutans consist of ferriargillans, argillans, and silans. Ferriargillans are greater than 10 µm in thickness, have a yellowish brown limpid texture, and are occasional to many in abundance. Silans are also more than 10 µm in thickness, have grainy/silty texture, are speckled, and are rare in occurrence. Argillans are approximately one µm in thickness, micro-laminated, limpid in texture, highly birefringent, and are occasional to many in abundance. Also present in this sample are very abundant, disjointed, polymorphic typic iron nodules. Ferriargillans and argillans, as well as typic iron nodules, are present in the remaining micromorphological samples collected from Depositional Unit 3. Markedly not present,

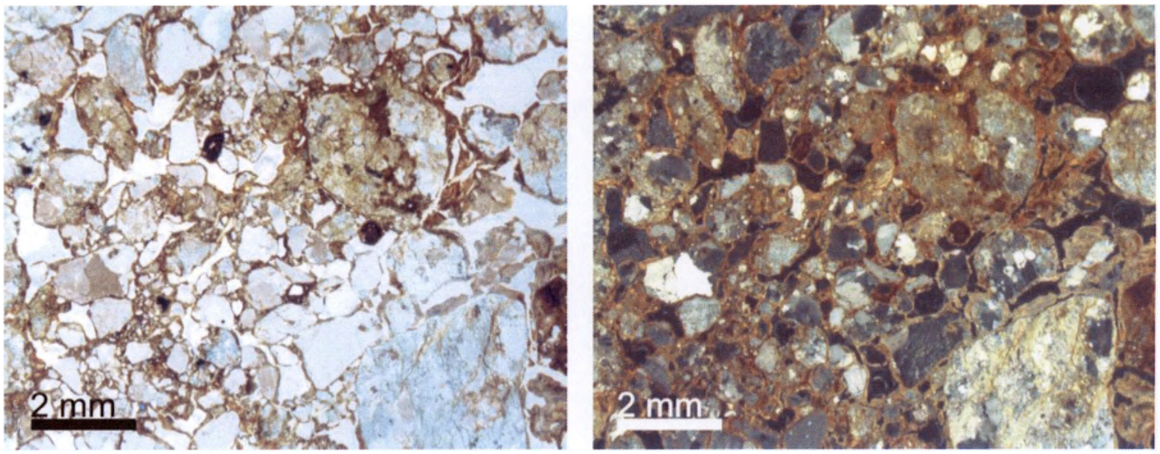

Figure 4-10. 1.2X photomicrograph of very abundant cutans in plain light (left) and in cross-polarized light (right).

however, is volcanically-derived glass.

Pedofeatures

Descriptions of soil thin sections collected from Columns A and B within the excavation block at Chivacabe provide paleoenvironmental insight at a much finer resolution than the macro-observations and subsequent descriptions. Pedofeatures encountered and described above, as well as the varying mineralogical constituency of the samples, are characteristic of depositional processes and fluctuating environmental conditions.

In the suite of samples collected from Chivacabe, cutans are composed of clay minerals, iron-rich clay minerals, silica, and calcium carbonate. The material, orientation, and distribution of these features suggest that they are all illuvial in nature. Though translocative properties of clay minerals, iron, and silica are variable, warm and wet-dry climates, as such is the currently the regime at Chivacabe, mobilize and deposit these minerals quite effectively (Birkeland 1999; Schaetzl and Anderson 2005). Nodules present at the site are composed of iron and manganese, and Bullock et al. (1985:128) note that "nodules are the most common form of ferruginous and manganiferous pedofeatures." These nodules of various shapes and sizes not only represent translocation of minerals throughout the profile, but also are indicative of the environments necessary for chemical precipitation.

Of particular note is the presence of the calcium carbonate ped coats and the Bk horizon at the bottom of Depositional Unit 2. The parent material of this buried soil is not carbonate-rich, nor is the valley's geology. Birkeland (1999) and Schaetzl and Anderson (2005) note that during climatically dry periods, calcium carbonate can become airborne and deposited during precipitation events. Ferruginous and manganiferous nodules require an alternating wet-dry climatic regime and fluctuating ground water elevation to form (Schaetzl and Anderson 2005), and they are present below and above, as well as within, Depositional Unit 2. The juxtaposition of these pedofeatures indicates a fluctuation in climatic regime toward the drier during the period of time that the buried soil in Depositional Unit 2 formed.

Mineral Component

Though it was not quantitatively analyzed, the changing lithology in the profile provides some indication of depositional environments. More specifically, the increasing presence of volcanic glass toward the bottom of the profile is characteristic of the adjacent hillsides shedding their tephra deposits. This trend of volcanically-derived material increasing with depth is clear in comparison of thin sections. The ubiquitous presence of the constituents of gneiss and schist (i.e., metamorphic quartz and feldspars), indicates a colluvial nature for much of the exposed strata. And the presence of volcanically-derived clasts through the top of Depositional Unit 1 indicates that during that period of time, the valley sidewalls were blanketed in tephra. It is important to note that sediments of DU1 contained not only volcanic ash, but gneissic rock fragments as well, indicating colluvial processes once at work.

Stable Carbon Isotopes

Paleoenvironmetal signatures provided by stable carbon isotopes ($\delta^{13}C$) are contingent upon photosynthetic pathways and are thus reflections of past climatic regimes (Cerling et al. 1989). Flora fix carbon in three ways: C_3, C_4, and CAM. The CAM (crassulacean acid metabolism) pathway is characteristic of desert-dwelling, as well as some tropical, cacti and succulents (Schaetzl and Anderson 2005). Employed by woody vegetation and many grasses, C_3 is the most common form of photosynthesis (Schaetzl and Anderson 2005; Pollard et al. 2007). C_4 photosythesis is considerably less common, however, it is more efficient and successful in increasingly warm and arid environments (Teeri and Stowe 1976; Ehleringer and Monson 1993). From a survey of 650 species of grass, Cerling (1984) calculated widely acceptable average $\delta^{13}C$ production values of -27‰ for C_3 and 13‰ for C_4 plants (cf. Boutton et al. 1994; Kelly et al. 1998; Nordt et al. 2002). Though $\delta^{13}C$ content in soils may be obscured by imprints of swift climatic swings and anthropogenic perturbations, it has the potential to remain unaffected for millions of years (Cerling et al. 1989).

Results from $\delta^{13}C$ analysis of samples split out of the bulk sediment column samples from Columns A and B indicate three general trends in C_3 to C_4 production. In DU1a, $\delta^{13}C$ values shift from -21.55‰ in Zone XVIII (lowest stratum in Column B) to -19.27‰ in Zone XV (upper-most stratum in DU1a). Assuming 20‰ to be an approximate equilibrium (50% C_4 plant contribution to soil organic matter), DU1a exhibits a shift from vegetation slightly dominated by C_3 to slightly dominated by C_4 photosynthetic pathways. In DU1b, $\delta^{13}C$ values increased from an average of -18.58‰ in Zone XIV to -17.34‰ in Zone XII, suggesting a slight shift towards more C4 vegetation. $\delta^{13}C$ content in DU2 decreases from approximately -18.80‰ in Zone XI to -20.03 in Zone IX, and then it increases to -17.20‰ at the top of DU2 in Zone VIII. $\delta^{13}C$ values in DU2 are characteristic of an environment changing from C_4 dominated vegetation to approximate equilibrium and back. DU3 $\delta^{13}C$ values ranges from -22.74‰ at the bottom of the unit to -15.96‰ at the surface. The range of $\delta^{13}C$ values in DU3 clearly shows a shift from C_3 dominated vegetation to C_4. High $\delta^{13}C$ values near and at the surface can likely be attributed to agricultural maize, which follows a C_4 photosynthetic pathway, in the region.

Magnetic Susceptibility

Magnetic susceptibility is the measurement of magnetized iron-based mineral particles, formed as a result of pedogenesis, in sediments, and thus, it can be a valuable paleoenvironmental proxy (Birkeland 1999; Schaetzl and Anderson 2005). Conditions that promote the genesis of ferromagnetic minerals, such as magnetite and maghemite, are warm with alternating wet-dry precipitation, while excessively arid or wet conditions or acidic soils decrease the production of these magnetically susceptible minerals (Maher 1998). Xfd and Xlf are measures of magnetic susceptibility, and they are dependent upon the size of ferromagnetic grains (Maher 1998; Liu et al. 2007). And though Zhou et al. (1990) and Liu et al. (2007) correlate paleosols in China's loess plateau with Xfd values between five and 10 percent, Maher (1998) notes that there can be great time-, parent material-, biological-, relief-, or aspect-derived variability in Xfd values across a relatively small area.

Though Xfd values of samples from Chivacabe Columns A and B do not exceed 1.77 percent, they loosely correspond with trends seen in $\delta^{13}C$ values. DU1a Xfd values contain a modest amount of variation, oscillating between just below and just above one percent. A best-fit line might show, however, that these values are more-or-less consistent. Xfd values of DU1b exhibit an increasing trend. From a peak at the base of DU2, Xfd values generally decrease, whereas Xfd values in DU1 generally increase. Keep in mind that these shifts are on the order of a fraction of a percent. These low values are likely attributable to magnetic depletion caused by the formation of iron into iron-oxide/hydroxides rather than ferrimagnetic minerals (Maher 1998).

Where Xfd values are a frequency-dependent measure and used to elucidate the abundance of superfine magnetic materials, Xlf is a measure of the total amount of magnetic material per sample (Dearing 1994). Xlf values for Columns A and B loosely correspond with and support other proxy data. DU1a shows a great amount of fluctuation yet consistently high Xlf values. This is likely due to variable water table elevation, i.e., wet-dry intervals. Xlf values decrease as elevation increases through DU1b with the exception of a peak at the top of the unit, which supports the identification and designation of the buried soil. In DU2, Xlf values tend to increase with depth, a trend that repeats in DU3. DU3 contains an anomalous peak near its bottom, and the reason for this high Xlf value is not clear. This peak in Xlf might be attributable to grain size or mineral content and not because of pedogenesis, as the value was obtained from a zone (Zone VI) containing channel gravels. Similar to the Xfd values, Xlf values are quite possibly obscured by the formation of iron-oxide/hydroxides and the translocation of ferromagnetic minerals.

Road Cut Profile

Approximately 100 m east of the excavated pit and museum, the farm's drive was once cut into the eastern edge of the T2 terrace. The resulting four-meter-tall profile exposure lacks a tephra deposit, and as such, is presumed to contain sediments underlying tephra deposits elsewhere on the T2 terrace. This is important because excavations in the block never reached below tephra deposits. In the road cut profile there were a total of 15 zones identified and recorded.

The lowest two zones, XIV and XV, ranging from 297-300 cmbs, contain a relic soil horizon designated as 3B/C. The sediments are brown to dark yellowish brown loams with weak prismatic parting to subangular blocky structure. Zone XIV contains no coarse fragments, whereas Zone XV is mostly clast supported and somewhat imbricated coarse fragments reaching 20 cm in diameter. Both of these zones contain prominent black clay films in voids and on clasts and peds where present. Zones XI through XIII also contain a relic soil horizon, though this overlying pedological unit is designated 2B/C. The bottom most stratum of the 2B/C, Zone XIII, is composed of approximately 70 percent coarse fragments reaching 10 cm in diameter. This gravelly stratum represents a high energy event capable of eroding the upper portion of the 3B/C soil sequence, and thus, it represents a younger stage of soil development. Zones XI and XII contain considerably less coarse fragments, 10-30 percent and 3-5 percent respectively. Ped structure in these two strata is primarily moderate medium subangular blocky, and neither zone is calcareous. Zones XI through XIII all contain clay films, which bridge clasts and are discontinuous yet present on peds.

The uppermost soil consists of Zones I through X and exhibits an A-AB-Bt-Btk-BC-C sequence. Zones VII through X, which compose the BC and C horizons, are brown loams with alternating amounts of 15-20 percent and less than one percent coarse fragments. Ped structure parts from moderate medium subangular blocky to massive with depth. Much like the underlying zones, Zones VII through X contain illuvial clay coats on clasts and peds, where structure permits. Above BC and C horizons, there is a Btk horizon composed of Zones V and VI. These two zones contain dark brown clays with coarse prismatic structure. Calcium carbonate coats ped faces in these two zones, similar to but less distinct than the boxwork Bk horizon in Column A. An absence of radiometric dates associated with the Bk horizon present in the roadcut profile makes renders the correlation of the two similar horizons unreasonable. Nonetheless, similar processes of inadequate soil moisture and calcium carbonate translocation contributed to the formation of this horizon. Above the Bk horizon is a reddish brown Bt horizon composed of two strata, Zones III and IV. The lower of these two zones contains less than 10 percent coarse fragments, whereas the upper contains no coarse fragments. Ped structure ranges from strong medium prismatic in Zone III to moderate coarse subangular blocky in Zone IV. Both of these zones contain illuvial clay. Above the Bt horizon is modern topsoil formation, represented by an AB horizon in Zone II and an A horizon in Zone I. Zone II contains 15-20 percent coarse fragments, and Zone I contains no coarse fragments. Both strata are brown, loamy, and have weak medium subangular blocky structure. Zone I, however, does not contain illuvial clay or minerals.

Without the range of data that was collected from Columns A and B, it is not possible to correlate much of the Roadcut Profile's sediments with vegetation and climate. Zones containing more coarse fragments, especially near the bottom of the profile where coarse fragments approach 20 cm in diameter, do however indicate relatively high energy alluvial transportation.

Cut Bank Profile

A single profile, approximately 120 m east-southeast of the excavation block, in a cut bank of the valley's primary drainage was examined due to the presence of contact between the tephra deposit and underlying sediments (Figure 4-10 and 4-11). As will be discussed in upcoming paragraphs, the intensely examined profiles within the excavation block contained reworked tephra, and so the opportunity to record the base of the tephra deposit could contribute greatly to the understanding of the valley's depositional history. Due to difficulties in describing an approximately seven-meter-tall profile without a very tall ladder or ropes and harnesses, only the lower 3.5 m were recorded, but this was enough to include a bulk of the tephra deposit. In the section of the profile that was recorded, there were 17 zones, including three allostratigraphic units (AU), identified and described.

From the base of the profile to approximately 585 cmbs, there is a poorly sorted gravel and cobble deposit. This stratum was not designated a zone identification, nor was it described further, however, it is clear that it is a relic stream channel. Above this rocky stratum is the bottom most described AU, which extends from 490-585 cmbs. This AU is composed of seven alternating deposits of fine-grained material and gravels. The fine-grained strata are roughly 25 cm thick, whereas the gravelly strata are as much as five

Figure 4-11. Photo-mosaic of Cut Bank profile with red arrow pointing to interface between gravelly deposit below tephra.

Figure 4-12. Photograph of Cut Bank profile featuring interface between tephra (above) and gravelly deposit (near center of image).

centimeters thick. Zone XVII is the lowest most of the these seven fine-grained strata,and is composed of brown sandy loam with ped structure ranging from moderate coarse prismatic to strong medium angular blocky. Zone XV consists of loamy clay with weakly developed coarse columnar to moderate subangular blocky ped structure. Zone XIII is composed of clay loam and has weakly to moderately developed coarse prismatic structure. And, Zone XI is composed of clay loam with a ped structure ranging from strong fine granular to moderate coarse subangular blocky. All of these fine-grained strata contain less than one percent coarse fragments, and all have strong brown to black, prominent clay films in pores and channel voids. Additionally, these strata appear to contain relatively increased organic carbon content. As such, the uppermost and suitable of these fine-grained zones, Zone XIII, was sampled for radiocarbon dating. A date of 15,400 +/- 300 yr BP was returned, and marks the maximum date of the overlying tephra deposit.

Found between the fine-grained zones are three thin gravelly deposits. Zones XII, XIV, and XVI contain greater than 35 percent gravel, have brown loamy matrix, contain no ped structure, and are no greater than approximately six centimeters thick. These thin gravelly zones all contain strong brown, prominent clay films on clasts and in voids.

The middle AU is a gravelly unit composed of eight strata, Zones III through X. Except for the lowest two strata, Zones IX and X, which are composed of silty clay and clayey loam, respectively, the matrix of this unit is generally very sandy. Within this AU, Zones VII and IX are particularly gravelly, containing approximately 80 percent coarse fragments that range in size from 0.02 cm to 30 cm. Zones IV, VI, VII, IX and X all contain more than 60 percent coarse fragments, whereas Zones III, V, and VIII contain less than 15 percent gravels. Other than Zone V, which has weak medium prismatic peds, and Zone IX, which has weakly developed medium to coarse subangular blocky peds, ped structure is inhibited or obscured by gravel content. Uncommon and irregular clay coats were observed on clasts in Zones VII, IX and X. Despite the illuvial clay present within this AU, its entirety is considered a C horizon. It is clear that this unit represents channel deposits of the valley's primary drainage.

Above the gravelly unit are two strata of possibly reworked tephra. It should be noted, however, that the profile exposure extends at least two meters above this AU, but as previously mentioned, the upper two meters were inaccessible and thus unexamined. It is speculated that the tephra deposits continue approximately one meter above the AU. Zone II contains five to seven percent coarse fragments and is composed of brown loam. There is moderately developed coarse subangular blocky ped structure with distinct strong brown clay coats on ped faces and in voids. Zone I is separated from Zone II by a clear smooth boundary, and Zone I contains less than one percent coarse fragments. This stratum is also composed of brown loam, but it has a strongly developed coarse to very coarse prismatic structure with faint, strong brown clay films in pore spaces. On account of their moderate to strongly developed ped structure and the presence of illuvial clays, this AU is considered a BC horizon.

Cut Bank Samples

Two bulk sediment samples were collected from the cut bank profile. One sample, previously discussed, was collected for radiocarbon dating. Another bulk sediment sample was collected from the cut bank profile, this one from the middle of Zone I in the upper AU. This is a sample of the tephra deposit, and it was taken with the idea that if analyzed it could 1) securely correlate the tephra deposit observed within the excavation block with tephra deposits exposed in cut banks of the valley's primary drainage, and 2) potentially be a marker bed to which other, regional tephra deposits could be correlated. At this moment, however, chemical analysis of this tephra deposit is beyond the scope and budget of this project.

CHAPTER 5

DISCUSSION

Context of late Pleistocene faunal remains at Chivacabe has previously been ambiguous in terms of depositional processes and paleoenvironments. Additionally, the cultural remains associated with the site lack secure provenience, and as such, are not well understood. Results from the multi-scalar field and lab investigation of geomorphology, sediments, and soils reveal trends in and insights to past environments and depositional processes in this small valley that contains Chivacabe.

Depositional Unit 1, which contains Chivacabe's Pleistocene bone bed, is bracketed by dates of 15,400 +/- 300 yr BP and 13,065 +/- 145 yr BP. The earlier date comes from a muddy stratum below the truncating channel gravels that directly underlie the tephra in the Cut Bank profile, indicating that the onset of tephra deposition is younger than the date suggests. However, tephra observed in the Cut Bank profile and within the excavation block is reworked, and despite the younger age yielded from soil organic matter at the top of Depositional Unit 1, the tephra could in fact be older. Koch and McLean (1975) mapped an extensive ash and pumice deposit, likely originating from the Lake Atitlan area, as far northwest as the Huehuetenango valley. This deposit, however, is dated to greater than 40,000 yr BP, and it is therefore not likely the same deposit investigated at Chivacabe.

Environmental insights gleaned from results of $\delta^{13}C$ and Xfd values, despite zone-by-zone variation in DU1a, generally show a mixed vegetation regime dominated by C3 and C4 photosynthetic pathways in alternating strata. Values are less variable and trend towards C4-dominated vegetation through DU1b. A shift from C3- to C4-dominated vegetation suggests that the climate in this region was increasingly warm and arid. Xfd values, though quite low, complement this trend throughout Depositional Unit 1. Additionally, the shift in pedogenic structure from generally subangular blocky in DU1a to prismatic/columnar in DU1b corresponds with increasing aridity. This trend in increasing warmth also corresponds with the last period of deglaciation, Bolling-Allerod. Weaver et al. (2003) correlate warm Northern Hemisphere temperatures with a glacial meltwater pulse into the north Atlantic around at least 14,235 +/-100 yr BP. Leventer et al. (1982) and Marchitto and Wei (1995) recognize that some meltwater from the Laurentide Ice Sheet was diverted into the Gulf of Mexico during the Older Dryas, which dates between approximately 12,100 and 11,600 years ago, and Hodell et al. (2008) remark that dryer conditions characterize the Older Dryas in lowland Guatemala. Without dates from DU1a and the interface between DU1a and DU1b, trends in $\delta^{13}C$ and Xfd values derived from samples at Chivacabe cannot be absolutely correlated to meltwater in the Gulf of Mexico. However, the variable $\delta^{13}C$ and Xfd values of DU1a generally fall close to the median between C3 and C4 production values, whereas $\delta^{13}C$ values of DU1b are characteristic of an increasingly warm and arid environment, i.e., greater C4 production. Additionally, DU1a is composed of highly stratified sediments with little evidence of soil development, which could be attributed to increased precipitation and subsequent depositional rates. Three strata composing DU1b, with parent material consistent with DU1a, are relatively thicker and contain a developed soil—these characteristics could be attributed to slower rates of deposition and a more suitable environment for the development of C4-photosynthesizing vegetation. Therefore, the sediments examined in DU1a could represent increasingly warm and precipitous conditions, and the climatic reversal to cool and arid characteristic of the Older Dryas in DU1b. Below DU1a, as observed in the Cut Bank profile, is an abandoned channel of the valley's primary drainage that has a maximum age of 15,400 +/- 300 yr BP. These channel gravels are noted to have truncated the underlying sediments, and the date is derived from a stratum below the gravels.

It is not clear how these trends affected the once living animals that now compose the Pleistocene bone bed at Chivacabe. The Pleistocene faunal remains span at least nine zones within DU1b. Unfortunately, the faunal remains were leached of organic carbon, and were generally in less-than-optimal condition for obtaining radiometric dates. Arrangement of the remains is not significantly patterned (i.e., size-sorted, oriented), though they are clustered, and additionally, the remains present at the site represent portions of many disparate individuals. These two attributes of the bone bed indicate that the remains were 1) not deposited in alluvium (e.g., neither size-sorted nor oriented), and 2) deposited in secondary context (e.g., not where the individuals deceased). Considering the matrix-supported remains to be similar to matrix-supported gravels, in terms of depositional processes, this poorly-sorted deposit is characteristic of viscous flow, or colluviation (Gale and Hoare 1991). Though it is clear that the faunal remains have been transported, the lack of considerable abrasion on proximal and distal ends of individual elements suggests that they did not move far.

With dates of 13,065 +/- 145 yr BP to 10,235 +/- 45 yr BP, Depositional Unit 2 exhibits a general trend in decreased relative C4 production and decreased Xfd values. These data suggest that during the formation of this unit, the environment was increasingly cool and increasingly mesic. These trends are consistent with the response of Central America's environments to the Younger Dryas. While a cooler temperature in Central America during the Younger Dryas is debated, precipitation has been shown to have generally increased (Leyden 1995; Hodell et al. 2008). Somewhat perplexing, however, is the formation of the prominent Bk horizon at the base of Depositional Unit 2. Parent materials of the soil and bedrock geology within the valley are not calcareous, which makes the source of calcium carbonate mysterious. Precipitation of calcium carbonate requires the amount of calcium carbonate to exceed the soil moisture's capacity (Birkeland 1999; Schaetzl and Anderson 2005); and as mentioned above, the environment represented by stable carbon isotopes in Depositional Unit 2 trends towards mesic, suggesting an adequate water supply. Furthermore, boxwork structure of the Bk horizon indicates that pedogenic structure was formed prior to precipitation of calcium carbonate, and the presence of illuvial clay beneath carbonate coats supports the framework. A possible explanation of the Bk's presence is a dry period, represented by a peak in $\delta^{13}C$ value less than 20 cm below the top of the unit. Retallack (2005) has used depth to Bk and depth range of carbonate nodules to deduce paleoprecipitation and paleoclimate, however, nature of the truncated unit and the absence of carbonate nodules render these inferential methods inapplicable. The truncated nature of this unit also suggests that the depositional sequence observed is not complete, i.e., evidence of a more arid period, possibly, is not preserved in these deposits. The cause of this peak in aridity remains unclear.

Although no faunal or cultural remains were observed in this unit, Depositional Unit 2 is likely the origin of the fluted projectile point recovered at Chivacabe. The age range of fluted projectile point technology, as per Hayden (1980), is approximately 12,000 to 8000 yr BP. The lack of secure context for the projectile point results in an unclear picture of the origin, however, if Depositional Unit 2, marked by a basal, boxwork Bk horizon, can be identified elsewhere in the valley, the site from which the artifact originated could potentially be found and investigated. A controlled excavation of the site from the ground surface through the top of Depositional Unit 1 could also prove invaluable.

Depositional Unit 3, with a maximum date of 10,235 +/- 45 yr BP, represents sedimentation and soil formation during the Holocene. The fourth radiocarbon date of 8,790 +/- 200 yr BP could potentially represent either a minimum age of Depositional Unit 2 or a more accurate maximum age of Depositional Unit 3. Due to this sample's ambiguous origin, Depositional Unit 3 is considered to have the older maximum date of 10,235 +/- 45 yr BP. $\delta^{13}C$ values have a sharp increase followed by sharp decrease in the bottom of the unit. This indicates that, amidst a mesic climate, there was a period of punctuated aridity—this pattern is similar to that described above in Depositional Unit 2 (i.e., the possible cause of Bk formation). Above this oscillation, there is a trending increase in relative C4 prodution, and therefore, aridity. Xfd values are more variable, but follow the same general trends of $\delta^{13}C$ values. Relatively large clasts in the bottom of Depositional Unit 1 represent an abandoned channel, and though no dates are available to correlate $\delta^{13}C$-inferred climate to depositional processes, the presence of these clasts are likely the result of increased precipitation. More specifically, they indicate that flow off the hill to the north is no longer just colluvial, but rather, channelized and making its way down to the valley's primary drainage. Pedogenic features such as lamellae and other illuvial clay in the deposits containing these clasts, support the conclusion that these strata were deposited under mesic conditions.

As the geomorphological/geoarchaeological component of the 2009 field season at Chivacabe was conducted partially on account of conflicting site formation process hypotheses, it may be valuable to compare results among previous and current investigations. Initial investigations of Chivacabe were performed by Hayden and Cocks during a maximum of three summers during the latter half of the 1970s (Hayden and Cocks 1976). Hayden and Cocks (1976) hypothesize that the late Pleistocene faunal remains were deposited in a lacusterine environment, but opinions of Al Bryan (Hayden and Cocks 1976) and Gary Gates (n.d.; Hayden 1980) suggest colluvial or ash flow deposition, respectively. Ericastilla (1992, 1996) also recognized volcanic ash parent material and the past development of now buried soils, however, his conclusions do not include depositional processes.

Though they appear conjectural, Bryan's and Gates' conclusions are supported by our results and interpretations. Faunal remains present at Chivacabe are located within relatively thin colluvial volcanic ash deposits. The wavy boundaries and appearance of cross bedding indicate that these deposits were likely small-scale colluviation of volcanic ash. An argument of lacustrine-originated sediments can easily be nullified by the comparison, or contrast, among the four examined profiles described in the previous chapter and the poorly sorted nature of the bone-bearing deposits. Most notably, the gravel content is most problematic for a slack water deposit like a lake. Cultural remains, on the other hand, remain ambiguous, however, on the basis of the radiocarbon ages obtained they can almost certainly be associated with Depositional Unit 2 or reworked in Depositional Unit 3. In addition to confirming site formation processes, the current project contributes maximum and minimum ages of 15,400 +/- 300 yr BP and 13,065 +/- 145 yr BP to the faunal remains, and also provides a glimpse into paleoenvironmental conditions.

CHAPTER 6

CONCLUSIONS

Located in western Highland Guatemala, Chivacabe is a site composed of late Pleistocene faunal remains and scattered relics of human occupation, including a fluted projectile point. Because of the site's components and potential to contain valuable cultural and biological information, it has been investigated by three disparate groups of scientists. The most recent effort, of which this geomorphological/geoarchaeological component is a part, had goals of assessing the nature and association of faunal and cultural remains and providing depositional, paleoenvironmental, and geochronological contexts for the site's components. In order to address the latter objectives, geomorphological/geoarchaeological field and lab methods were employed.

As a result, three depositional units were identified, dated, and examined. The lowest most depositional unit contains the late Pleistocene faunal remains, and it dates from at most 15,400 +/- 300 yr BP to at least 13,065 +/- 145 yr BP. The age range of this unit does not necessarily void human occupation of the site, however, it is beyond the age range of fluted projectile point technology. Sediments composing this unit are colluvial in origin and compare tephra, which originates outside this basin, and gneissic materials eroded from the surrounding valley slopes. The lower, highly stratified portion of the unit is the result of mesic conditions, while the upper portion of the unit was deposited under more arid conditions. Vegetation during these periods appears to have ranged from mixed photosynthetic pathways in the former to C4-dominated pathways in the latter. The middle depositional unit is also colluvial in origin, and ithas maximum and minimum ages of 13,065 +/- 145 yr BP to 10,235 +/- 45 yr BP. If the radiocarbon ages obtained are accurate depositional ages, then this middle allostratigraphic unit likely contains the early archaeological component of the site; however, secure provenience of artifacts renders the origin of cultural materials ambiguous. On the basis of the radiocarbon ages, it seems clear that the cultural material is not associated with the main bone bed within Depositional Unit I. Paleoenvironments inferred for this unit trend towards decreasing relative C4 productivity, indicating increasingly mesic conditions, but it also contains a well-developed calcic horizon, characteristic of soil moisture deficiency in comparison to calcium carbonate content. The development of the calcic horizon could possibly correspond with an outlying peak in C4 productivity near the top of the unit. The uppermost unit spans the Holocene, and exhibits a higher energy mode of transportation. Basal gravels in this unit are characteristic of channelized flow typical of a stream, most likely of the ephemeral drainage north of the site. Similar to the top of the underlying unit, the bottom of this upper unit contains a punctuated peak in relative C4 plant productivity. Above this outlying peak, relative C4 plant productivity generally increases, implying an increasingly arid environment through the Holocene. Agricultural maize may also be accountable for increased C4 markers in the late Holocene sediments.

Further field research at Chivacabe could increase the understanding of the site. At present, the cause of death for the Pleistocene fauna present at the site is not understood, and cultural remains have not been systematically documented in secure contexts. Accepting the middle depositional unit as the artifact bearing unit could increase the potential of finding the archaeological site if a valley-wide survey were to take place. This depositional unit could be recognized by the prominent Bk horizon or the top of the tephra-rich deposit. Further analysis of the tephra deposit could identify a unique chemical signature, and thus could be mapped regionally, contributing to the region's tehprachronology. And although paleoenvironmental conditions were inferred from stable carbon isotopes and frequency-dependent magnetic susceptibility, further investigations could elucidate more plant-specific information.

The intentions of geomorphic and geoarchaeological research at Chivacabe during the 2009 Proyecto Arqueologico y Paleontologico investigation were to begin to build a systematic understanding of the valley formation and context of faunal and cultural remains. Although this component was limited in scope to the excavation block and nearby profile exposures, it succeeded in documenting the geological and pedological context of the site. More widespread documentation of the fluvial deposits in the valley would surely provide a more complete story than this, however, the above description, analysis, and interpretation is a foundation from which others may expand.

APPENDIX

Profile Exposure Descriptions

Column A

Location: N5007.38 E4998.29 Datum nail

Geologic Units: Three depositional units encountered and described (DUs 1, 2, and 3).

Comments: The datum nail used to record the location of the profile is tied into the site grid. In relative terms, the profile exposure is located on the north wall in the northeast corner of the excavation block.

Depositional Unit	Zone	Horizon	Depth: cm below surface	Depth: m (relative to datum – 100 m)	Description
DU3	I	AC	0-12		Dark grayish brown (10YR 4/2, m) sandy loam, friable, strong medium subangular blocky structure, abrupt smooth lower boundary, non-effervescent, <5% coarse fragments, fewer gravels than underlying zone, distinct mottles.
DU3	II	A-Bt	2-31		Pale brown (10YR 6/3, d) to grayish brown (10YR 5/2, d) sandy clay, very hard, strong coarse angular blocky parting to strong fine subangular blocky structure, clear wavy lower boundary, non-effervescent, 5-7% coarse fragments, coats lining pores and grains, ferriargilans, some gravel in deposit is heavily weathered gneiss.
DU3	III	Bw	31-53		Grayish brown (2.5Y 5/2-5/3, d) loam, hard to very hard, moderate fine to medium subangular blocky, clear wavy lower boundary, non-effervescent, <30% coarse fragments, <10% yellowish brown mottles, Mn coats on ped faces.
DU3	IV	Bt-C	53-64		Weak red (10YR 6/2, d) sandy loam, hard to very hard, moderate fine to

					medium subangular blocky structure, clear wavy lower boundary, non-effervescent, <30% coarse fragments, faint clay coats on ped faces.
DU3	V	Bt-C	64-76		Pale brown (10YR 6/3, d) loam, hard to very hard, moderate fine to medium subangular blocky structure, abrupt smooth lower boundary, non-effervescent, >50% coarse fragments, prominent clay films.
DU3	VI	C	76-88		Brown (10YR 5/3, d) sandy loam, hard, weak to moderate fine subangular blocky structure, abrupt smooth lower boundary, non-effervescent, >50% coarse fragments, distinct clay films abundant.
DU3	VII	C	86-100		Pale brown (10YR 6/3, d) sandy loam, hard, weak to medium fine subangular blocky structure, abrupt smooth lower boundary, non-effervescent, >50% coarse fragments, pedofeatures same as Zone VI.
DU2	VIII	2A-2Bt	95-114		Pale brown (10YR 6/3, m and d) silty clay loam, firm, strong medium prismatic parting to strong medium angular blocky structure, clear smooth lower boundary, non-effervescent, <3% coarse fragments, few Mn coats (uncommon, fine, distinct).
DU2	IX	2Bt	112-125		Brown (10YR 7/3, m; 10YR 5/3, d) silty clay loam, firm, strong coarse prismatic parting to strong medium to coarse angular blocky structure, clear wavy lower boundary, non-effervescent, <5% coarse fragments, prominent clay films on ped faces.
DU2	X	2Bw	123-145		Pale brown (10YR 6/3, m; 10YR 4/2, d) sandy loam, firm, strong coarse prismatic parting to strong medium to coarse angular blocky structure, abrupt wavy lower boundary, non-effervescent, <5% coarse fragments, very small and patchy Mn coats.
DU2	XI	2Bk	140-182		Very dark grayish brown (10YR 3/2, m; 10YR 4.5/3, d) loam, very hard to extremely firm, strong very coarse platy structure, abrupt irregular lower boundary, violently effervescent ped faces, $CaCO_3$ coats on ped faces, <10% coarse fragments.
DU1b	XII	3A	165-212		Dark gray (2.5Y 4/1, m; 2.5Y 6/2, d) loam, extremely firm, strong coarse prismatic structure, abrupt smooth lower boundary, non-effervescent, <5% coarse fragments, no pedofeatures present.
DU1b	XIII	3Bt	212-239		Brown (7.5YR 4/2, m) loam, friable,

					moderate coarse prismatic parting to moderate coarse angular blocky structure, abrupt smooth lower boundary, non-effervescent, <3% coarse fragments, Mn coats and masses in clusters on ped faces and in matrix.
DU1b	XIV	3Bt-3C	239-325		Light olive brown (2.5Y 5/3, m; 2.5Y 7/1, d) loam, friable, moderate coarse columnar structure, abrupt wavy lower boundary, non-effervescent, <7% coarse fragments, Mn concretions, non-calcareous white-ish coats on ped faces and in pores.
DU1a	XV	3C	315-325		Grayish brown (2.5Y 5/2, m; 2.5Y 5/3, d) sandy loam, friable, weak fine to medium subangular blocky structure, abrupt smooth lower boundary, non-effervescent, <15% coarse fragments, clear bed (pinches and swells), redox masses in matrix
DU1a	XVa	3C	325-330		Dark grayish brown (10YR 4/2, m; 10YR 4/3, d) loam, friable, weak fine subangular blocky structure, clear wavy lower boundary, non-effervescent, <5% coarse fragments, Mn coats, very thin stratum with Mn band upper boundary.
DU1a	XVI	3C	328-350		Dark grayish brown (10YR 4/2, m; 10YR 5/3, d) loam, friable, weak fine subangular blocky structure, clear wavy lower boundary, non-effervescent, <5% coarse fragments, Mn concretions, stratum surrounds Zone XVII.
DU1a	XVII	3C	332-340		Grayish brown (10YR 5/2, m; 10YR 5/3, d) loam, friable, weak fine subangular blocky structure, clear wavy lower boundary, non-effervescent, <5% coarse fragments, sandy bed appears to be isolated within Zone XVI, Fe concretions.
DU1a	XVIII	3C	343-350		Dark grayish brown (10YR 4/2, m; 10YR 5/3, d) sandy loam, friable, weak fine subangular blocky structure, clear smooth lower boundary, non-effervescent, <5% coarse fragments, sandy bed, no pedofeatures present.
DU1a	XIX	3C	350-360		Dark grayish brown (10YR 4/2, m; 10YR 5/3, d) loam, friable, weak fine subangular blocky structure, clear wavy lower boundary, non-effervescent, <15% coarse fragments, Fe concretions, Mn coats on gravels.
DU1a	XX	3C	355-365		Grayish brown (10YR 5/2, m; 10YR 5/3, d) loam, friable, weak fine subangular blocky structure, clear wavy lower

					boundary, non-effervescent, <7% coarse fragments, ferriargillans between grains, Fe masses.
DU1a	XXI	3C	365-375		Grayish brown (10YR 5/2, m; 10YR 5/3, d) loam, friable, weak fine subangular blocky structure, clear wavy lower boundary, non-effervescent, <10% coarse fragments, non-calcareous white masses and small veins.
DU1a	XXII	3C	375-380		Dark grayish brown (10YR 4/2, m; 10YR 5/3, d) loam, firm, weak fine subangular blocky structure, clear wavy lower boundary, non-effervescent, 15-20% coarse fragments including gravel up to 2 cm diameter, Fe and Mn coats on gravel, stratum pinches out to east.
DU1a	XXIII	3C	375-390		Dark grayish brown (10YR 4/2, m; 10YR 4/3, d) loam, friable, weak fine subangular blocky structure, clear wavy lower boundary, non-effervescent, 7-10% coarse fragments, Fe and Mn masses, nodules, and coats.
DU1a	XXIV	3C	386-395		Dark grayish brown (10YR 4/2, m; 10YR 5/2, d) loam, friable, weak fine subangular blocky structure, clear smooth lower boundary, non-effervescent, <7% coarse fragments, Fe masses.
DU1a	XXV	3C	392-400		Dark grayish brown (10YR 4/2, m; 10YR 5/4, d) loam, friable, weak fine subangular blocky structure, unknown lower boundary, non-effervescent, <7% coarse fragments, upper boundary is Fe/Mn band.
DU1a	XXVI	3C	397-405		Olive brown (2.5Y 4/3, m; 2.5Y 5/3, d) sandy loam, friable, weak fine subangular blocky structure, clear wavy lower boundary, non-effervescent, 7-10% coarse fragments, mottles present, upper boundary is Fe/Mn band.

Column B

Location: N5004.04 E4992.81 Datum nail

Geologic Units: One depositional unit described (DU 1).

Comments: The datum nail, for which the location is provided, is in the center of the profile exposure in the bone bed. This point ties Column B into the site grid. Depths below surface are measured from the top of the exposure, which has been excavated to the level exposing the Pleistocene bone bed.

Depositional Unit	Zone	Horizon	Depth		Description
			cm below surface	m (relative to datum – 100 m)	
DU1a	I	3C	0-20		Olive brown (2.5Y 4/3, m; 2.5Y 6/3, d) sandy loam, very friable, weak very fine subangular blocky structure, clear wavy lower boundary, non-effervescent, <7% coarse fragments, exposed bone bed may be in or on top of this stratum, distinct ferriargillans in pore spaces.
DU1a	II	3C	5-20		Brown (10YR 4/3, m; 10YR 6/3, d) sandy loam, very friable, weak fine subangular blocky structure, clear smooth lower boundary, non-effervescent, <5% coarse fragments, sand/silica coats on ped faces and in channels.
DU1a	III	3C	20-26		Brown (10YR 4/3, m; 10YR 6/3, d) loam, very friable, weak fine subangular blocky structure, clear smooth lower boundary, non-effervescent, 7-10% coarse fragments, mottles present.
DU1a	IV	3C	26-33		Dark grayish brown (2.5Y 4/2, m; 2.5Y 5/4, d) loam, very friable, weak fine to medium subangular blocky structure, clear smooth lower boundary, non-effervescent, <10% coarse fragments, mottles present.
DU1a	V	3C	26-39		Dark grayish brown (10YR 4/2, m; 2.5Y 5/3, d) loam, friable, moderate very fine platy structure, clear smooth lower boundary, non-effervescent, <10% coarse fragments, sandy coats on ped faces.
DU1a	VI	3C	39-47		Dark grayish brown (2.5Y 4/2, m; 2.5Y 6/4, d) sandy loam, friable, weak medium subangular blocky structure, clear smooth lower boundary, non-effervescent, <7% coarse fragments, Mn coats on gravel.
DU1a	VII	3C	47-55		Light olive brown (2.5Y 5/3, m; 2.5Y 6/3, d) sandy loam, very friable, weak medium subangular blocky structure, clear wavy lower boundary, non-effervescent, <10% coarse fragments, yellowish brown masses/mottling.
DU1a	VIII	3C	52-65		Brown (10YR 4/3, m; 10YR 7/3, d) loam, friable, weak medium subangular blocky structure, clear wavy lower

					boundary, non-effervescent, 5-7% coarse fragments, Fe mottles.
DU1a	IX	3C	55-63		Dark grayish brown (10YR 4/2, m; 10YR 7/3, d) sandy loam, friable, weak medium subangular blocky structure, abrupt smooth lower boundary, non-effervescent, <10% coarse fragments, contains masses/mottles and UID bone fragment (left *in situ*).
DU1a	X	3C	59-68		Dark grayish brown (10YR 4/2, m; 10YR 6/3, d) loam, very friable, weak medium subangular blocky structure, clear wavy lower boundary, non-effervescent, 7-10% coarse fragments, black Mn coats and masses.
DU1a	XI	3C	66-78		Brown (10YR 5/3, m; 10YR 6/2, d) sandy loam, very friable, weak fine to medium subangular blocky structure, clear wavy lower boundary, non-effervescent, <7% coarse fragments, Fe masses/mottling more abundant on east side of profile.
DU1a	XII	3C	70-93		Brown (10YR 4/3, m; 10YR 6/3, d) loam, friable, weak medium subangular blocky structure, clear smooth lower boundary, non-effervescent, <7% coarse fragments, Fe masses, relatively thicker stratum compared to over- and underlying zones.
DU1a	XIII	3C	89-105		Dark grayish brown (10YR 4/2, m; 10YR 4/2, d) clayey loam, friable, weak medium subangular blocky structure, clear wavy lower boundary, non-effervescent, <5% coarse fragments, masses and coats present.
DU1a	XIV	3C	100-113		Brown (10YR 4/3, m; 10YR 5/3, d) loam, friable, weak fine to medium subangular blocky structure, clear smooth lower boundary, non-effervescent, 7-10% coarse fragments, Mn/Fe coats on ped faces and gravels.
DU1a	XV	3C	107-125		Olive brown (2.5Y 4/4, m; 2.5Y 5/3, d) sandy loam, friable, weak fine to medium subangular blocky, clear smooth lower boundary, non-effervescent, <5% coarse fragments, Fe coats on peds and gravels, Mn masses/nodules.
DU1a	XVI	3C	120-148		Dark grayish brown (2.5Y 4/2, m; 2.5Y 5/3, d) loam, friable, weak medium subangular blocky structure, clear wavy lower boundary, non-effervescent, <10% coarse fragments, no pedofeatures present.
DU1a	XVII	3C	145-153		Light olive brown (2.5Y 5/4, m) loam,

					friable, weak medium subangular blocky structure, clear wavy lower boundary, non-effervescent, <10% coarse fragments, bone and laminated quartz present, Mn/Fe coats and masses.
DU1a	XVIII	3C	153+		Light olive brown (2.5Y 5/4, m) silty loam, friable, weak medium subangular blocky structure, unknown lower boundary, <7% coarse fragments, mottles/masses, extends below excavation.

Roadcut Profile

Location: UTM Zone 15P 0656061E 1693505N NAD83

Geologic Units: Three depositional units are present.

Comments: These geologic units have not been positively correlated with those described in Columns A and B within the excavation block; however, the presence of a Btk horizon in both profiles could be a link.

Depositional Unit	Zone	Horizon	Depth		Description
			cm below surface	m (relative to datum – 100 m)	
	I	A	0-35	94.63-94.28	Brown (7.5YR 4/3, m; 7.5YR 5/3, d) loam, loose, weak medium subangular blocky structure, angular wavy lower boundary, non-effervescent, no noted coarse fragments, no pedofeatures.
	II	AB	35-47	94.28-94.18	Brown (7.5YR 4/3, m; 7.5YR 6/4, d) sandy loam, loose, weak medium to coarse subangular blocky structure, abrupt smooth lower boundary, non-effervescent, 10-15% coarse fragments, clay films on ped faces and between grains.
	III	Bt	47-63	94.18-93.95	Reddish brown (5YR 4/3, m; 7.5YR 2/4, d) loamy clay, friable, strong medium prismatic structure, clear smooth lower boundary, non-effervescent, no coarse fragments, clay films on ped faces.
	IV	Bt	63-75	93.95-93.85	Reddish brown (5YR 5/4, m; 7.5YR 6/3, d) gravelly clayey loam, friable, moderate coarse subangular blocky

					structure, abrupt smooth lower boundary, non-effervescent, 5-10% coarse fragments, clay films between grains.
	V	Btk1	75-125	93.85-93.38	Reddish brown (5YR 4/3, m; 7.5YR 5/4, d) clay, firm, strong coarse prismatic structure, clear smooth lower boundary, violently effervescent, $CaCO_3$ coats on peds, no coarse fragments, clay film on ped faces.
	VI	Btk2	125-150	93.38-93.13	Dark brown (7.5YR 3/4, m; 7.5YR 6/4, d) silty clay, firm, strong coarse prismatic structure, clear smooth lower boundary, weakly effervescent, $CaCO_3$ coats on peds, no coarse fragments, clay film between grains.
	VII	BC	150-160	93.13-93.03	Brown (7.5YR 4/3, m) gravelly loam, friable, weak fine to medium subangular blocky structure, abrupt wavy lower boundary, non-effervescent, 15-20% coarse fragments, clay film on ped faces.
	VIII	C	160-173	93.03-92.93	Dark brown (7.5YR 3/4, m; 7.5YR 5/4, d) sandy loam, friable, moderate coarse subangular blocky structure, abrupt smooth lower boundary, non-effervescent, <1% coarse fragments, clay film on ped faces.
	IX	C	173-183	92.93-92.75	Brown (7.5YR 4/3, m; 10YR 5/4, d) sandy loam, friable, massive structure, abrupt smooth lower boundary, non-effervescent, 5-20% coarse fragments, clay film between grains and on clasts, contains two cycles of gravelly sedimentation.
	X	C	183-203	92.75-92.58	Brown (7.5YR 5/3, m; 7.5YR 5/6, d) sandy clay, loose, massive parting to weak medium subangular blocky structure, abrupt irregular lower boundary, non-effervescent, <1% coarse fragments, clay film between grains and on clasts, no clear macrostructure.
	XI	2BC	203-265	92.58-91.98	Dark yellowish brown (10YR 4/4, m; 10YR 5/4, d) loamy clay, friable, moderate medium to coarse subangular blocky structure, abrupt wavy lower boundary, non-effervescent, 10-30% coarse fragments, clay film on ped faces and in pores, gravelly/sandy, crudely fines upwards, horizontally bedded.
	XII	2BC	265-285	91.98-91.78	Yellowish red (5YR 4/6, m; 10YR 4/4, d) sandy loam, friable, weak coarse prismatic parting to moderate medium subangular blocky structure, abrupt wavy lower boundary, non-effervescent, 3-5% coarse fragments, clay film on ped faces

					and in channels.
	XIII	2BC	285-297	91.78-91.65	Dark yellowish brown (10YR 3/4, m; 7.5YR 5/6, d) gravelly clay, loose, clast supported structure, gravels range 0.02-10 cm diameter, abrupt wavy lower boundary, non-effervescent, 70% coarse fragments, clay film between grains and on clasts.
	XIV	3BC	297-320	91.65-91.43	Brown (7.5YR 4/4, m; 10YR 4/6, d) loamy clay, friable, moderate to strong coarse prismatic parting to moderate medium angular blocky structure, abrupt wavy lower boundary, non-effervescent, no coarse fragments, clay film on ped faces and in channels.
	XV	3BC	320-400	91.43-90.63	Dark yellowish brown (10YR 3/4, m; 10YR 5/6, d) sandy loam, friable, weak to moderate fine to medium subangular blocky structure, abrupt smooth lower boundary, non-effervescent, 40-60% coarse fragments, clasts are mostly clast supported and imbricated and range in size from 0.02-20 cm diameter, clay film on ped faces and clasts.

Cutbank Profile

Location: UTM Zone 15P 0656088E 1693435N NAD83

Geologic Units: Three depositional units are present within this profile exposure.

Comments: The depositional units described below are not present in Columns A and B within the excavation block. This exposure was chosen due to the presence of the base of the tephra deposit. A sample was collected from the tephra for chemical composition, and another sample, beneath the gravelly unit, was collected for radiocarbon dating. The tape measure used for description was dropped from a tree root, approximately one meter from the top of the cutbank face—measurements below surface are not hyper-accurate.

Deposi-tional Unit	Zone	Horizon	Depth		Description
			cm below surface	m below datum	
	I	C	280-340	86.32-85.72	Brown (10YR 4/3, m; 10YR 6/3, d) loam, very firm, strong coarse to very coarse prismatic structure, clear smooth lower boundary, non-effervescent, <1% coarse fragments, very thin clay film in

					pores, structure is almost wedge-shaped, stream-worked tephra, tephra sample (1029-3) taken from this zone.
	II	C	340-385	85.72-85.27	Brown (10YR 4/3, m; 10YR 6/3, d) loam, firm, moderate coarse subangular blocky structure, abrupt smooth lower boundary, non-effervescent, 5-7% coarse fragments, clay film on ped faces and in pores, matrix supported gravels fining upwards, stream-worked tephra.
	III	C	385-390	85.27-85.22	Reddish yellow (7.5YR 6/6, d) coarse loamy sand, very friable, granular structure, abrupt wavy lower boundary, non-effervescent, 5-7% coarse fragments, no pedofeatures, uppermost zone of gravelly unit.
	IV	C	390-395	85.22-85.17	Too coarse for matrix color, gravelly sand, loose, granular structure, abrupt irregular lower boundary, non-effervescent, 50-60% coarse fragments <3 cm diameter, no pedofeatures.
	V	C	395-405	85.17-85.10	Pale brown (10YR 6/3, d) loamy sand, very friable, weak medium prismatic structure, abrupt wavy lower boundary, non-effervescent, <3% coarse fragments, no pedofeatures.
	VI	C	405-410	85.10-85.04	Brown (7.5YR 4/4, d) gravelly sand, loose, granular structure, abrupt irregular lower boundary, non-effervescent, >60% coarse fragments <3 cm diameter, no pedofeatures.
	VII	C	410-460	85.04-84.77	Yellowish brown (10YR 5/8, d) extremely gravelly sand, loose, granular structure, abrupt irregular boundary, non-effervescent, 80% coarse fragments <30 cm diameter, enormous clay coats.
	VIII	C	430-455	84.77-84.57	Light yellowish brown (10YR 6/4, d) loamy sand, loose, granular structure, abrupt irregular lower boundary, non-effervescent, 15% coarse fragments <2 cm diameter, no pedofeatures.
	IX	C	450-480	84.57-84.32	Light brownish gray (2.5Y 6/2, d) silty clay, slightly hard, weak medium to coarse subangular blocky parting to massive structure, abrupt irregular lower boundary, non-effervescent, 80% coarse fragments, average clast size is 15 cm diameter, few mottles, fine grain texture is obscured by gravel.
	X	C	480-490	84.32-84.22	Reddish brown (5YR 4/4-5/4, d) clayey loam, slightly hard, massive structure, abrupt smooth lower boundary, non-effervescent, <60% coarse fragments <5 cm diameter, uncommon clay coats.

	XI	2AC	490-497	84.22-84.16	Brown (10YR 4/3, m; 10YR 5/4, d) clay loam, friable, moderate coarse subangular blocky parting to fine granular structure, abrupt smooth lower boundary, non-effervescent, <1% coarse fragments, very prominent clay film on ped faces in channels and pores, mud beneath bottom-most channel gravel.
	XII	2C	497-502	84.16-84.10	Brown (7.5YR 4/4, m; 10YR 4/4, d) loam, firm, granular structure, abrupt smooth lower boundary, non-effervescent, >35% coarse fragments, clay films on ped faces and in pores, gravelly deposit between muddy strata.
	XIII	3AC	502-515	84.10-83.95	Brown (10YR 4/3, m; 10YR 6/4, d) clayey loam, friable, weak to moderate coarse prismatic structure, abrupt smooth lower boundary, non-effervescent, <1% coarse fragments, clay film on ped faces and pores, second stratum of mud beneath channel gravels, bulk humate sample (1026-8) collected for radiocarbon dating.
	XIV	3C	515-520	83.95-83.91	Brown (7.5YR 4/4, m; 10YR 4/4, d) loam, firm, granular structure, abrupt smooth lower boundary, non-effervescent, >35% coarse fragments, clay films, gravelly deposit between muddy strata.
	XV	4AC	520-555	83.91-93.55	Brown (10YR 4/3, m; 2.5Y 5/3, d) loamy clay, friable, weak coarse columnar parting to moderate medium subangular blocky structure, abrupt smooth lower boundary, non-effervescent, <1% coarse fragments, prominent clay film in channels and pores, third stratum of mud beneath channel gravels.
	XVI	4C	555-560	83.55-83.52	Brown (7.5YR 4/4, m; 10YR 4/4, d) loam, firm, granular structure, abrupt smooth lower boundary, non-effervescent, >35% coarse fragments, prominent clay films in pores, gravelly deposit between muddy strata.
	XVII	4C	560-585	83.52-83.27	Brown (7.5YR 4/3, m; 2.5Y 5/3, d) sandy loam, friable, moderate extremely coarse prismatic parting to strong medium angular blocky structure, abrupt smooth lower boundary, non-effervescent, <1% coarse fragments, clay films, sandy stratum just above coarse gravel-cobble (channel) deposit.

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