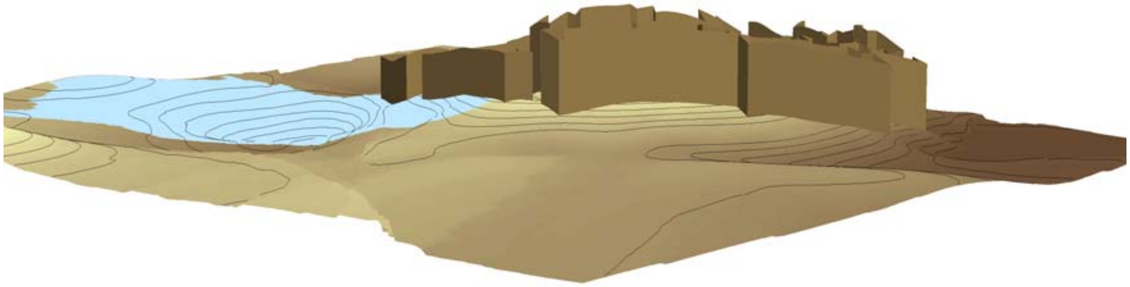
AN INVESTIGATION OF PREHISTORIC WATER MANAGEMENT IN THE CHUPADERA ARROYO BASIN, CENTRAL NEW MEXICO

by
Monica L. Murrell



Prepared for
New Mexico State University
Water Resources Research Institute
Las Cruces, NM

September 2006

ABSTRACT

Pueblo Oso Negro includes a depression located adjacent to the prehistoric habitation structure that was identified as a probable water storage feature, and is suspected to have served as a domestic water supply. The majority of interpretations regarding the presence of water management features are based on assumption rather than being founded on evidence corroborating the presence of water. An explicit methodology was used to examine the geological and biological characteristics of sediments contained in the depression to determine depositional processes and the seasonality of water storage. Analysis of sediments from the feature yielded geological evidence, as well as invertebrate remains consisting of ostracodes and gastropods that are indicative of a past water-rich environment. The hydrological modeling extension for GIS software was used to generate a predictive model designating the contributive watershed and runoff patterns that supplied and replenished the feature with water. Additionally, a subsurface water source was located within the confines of the depression. Geological evidence and invertebrate remains provide corroborating evidence demonstrating that the depression functioned as a water control feature for this prehistoric community.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table Page

INTRODUCTION

Researchers often identify water control features without intensively examining the characteristics of the subsurface deposits to provide accurate interpretation of these features (Crown 1987). There are several lines of evidence that can be used for evaluating the function of artificial depressions: the presence or absence of water-lain sediments, aquatic botanical or faunal remains, artificial inlets or outlets, and an insoluble underlying matrix (Dart 1983; Nials and Fish 1986). The methodological convergence of archaeology and the geosciences provides invaluable technical tools in support of archaeological research. This research involved the application of a geoarchaeological methodology to investigate a probable water management feature in an attempt to understand its paleohydrological role during the twelfth century. While many prehistoric water control features are purported to exist in the archaeological record, in most cases sufficient geological and biological evidence is lacking in support of these interpretations.

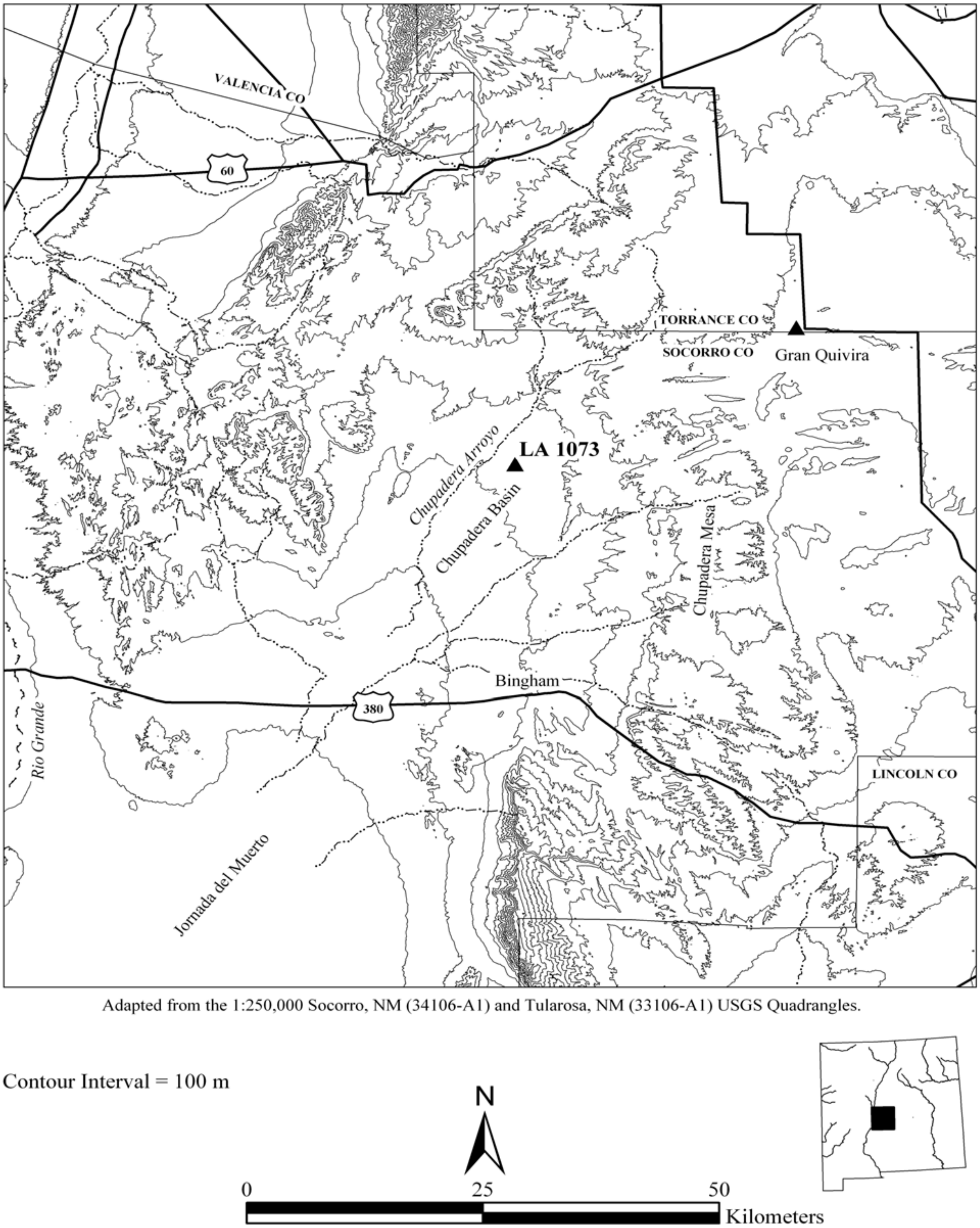
Research Objectives

The primary goal of this research was focused on characterizing the function of an artificial depression associated with Pueblo Oso Negro (site LA 1073), located in the Chupadera Arroyo basin. Due to the relative paucity of data presented to support claims of prehistoric water management, it was realized that extensive examinations of the deposits contained within probable water control features are necessary to substantiate interpretation. Employing a methodology specifically geared toward elucidating the geologic and biological characteristics of formerly water rich environments is essential to produce irrefutable evidence upon which such interpretations are based. The conclusions of this research allow for a reliable interpretation concerning the function of this artificial depression. Only through geoarchaeological research can the natural and/or cultural formation processes that resulted in the creation of this depression be comprehended.

Geological characteristics of the subsurface deposits contained within the features were used to characterize the deposition environment. Additionally, the presence of aquatic flora in sediments recovered from the depression was used to substantiate the presence of a formerly water-rich environment within the feature. Ostracodes have been used in a limited number of archaeological investigations as evidence of past water-rich environments (Jennings 1957; Bayman et al. 2004). Microbotanical evidence and invertebrate remains are lines of evidence that can be used in the determination of the seasonality of water storage. The final goal of this research was to reveal how this depression was supplied and replenished with water. As a topographic basin the nature of the surrounding topography was used to create a predictive model of how water flowed across the landscape to replenish the depression with surface runoff. Geographic information system (GIS) mapping software was used to delineate the contributive area of this watershed and model runoff patterns using digital elevation data.

Research Context

The Chupadera Arroyo basin, located in south central New Mexico (Figure 1), contains some of the largest unexcavated Puebloan sites in the state. Knowledge pertaining to the prehistoric developments that occurred in the Chupadera Basin is limited and to date these sites remain incompletely surveyed and professionally unexcavated (Montgomery and



Adapted from the 1:250,000 Socorro, NM (34106-A1) and Tularosa, NM (33106-A1) USGS Quadrangles.

Figure 1. General project location.

Bowman 1989; Kyte 1988; Montgomery et al. 1985; Stuart and Gauthier 1981:211). During the mid 1980s an archaeological reconnaissance was undertaken by the Agency for Conservation Archaeology (ACA) to accurately record the archaeological resources located within the Chupadera Basin. The outcome of this survey resulted in the detailed documentation of ten Glaze-period archaeological sites located within the basin (Montgomery and Bowman 1989).

Two of the archaeological sites (LA 1070 and LA 1073) recorded during this survey reportedly include depressions, or probable water control features, located adjacent to the prehistoric pueblo ruins (Montgomery and Bowman 1989). Pueblo Oso Negro (LA 1073) is dated to the Pueblo IV period (ca. A.D. 1300 – 1540). This era in prehistory was characterized by widespread population aggregations that resulted in large nucleated settlements throughout the Greater Southwest (Adams and Duff 2004).

The development of water storage features to meet the domestic needs of prehistoric occupations situated at a distance from permanent water sources is well documented in areas adjacent to the Chupadera Basin (Scarborough 1988). Spanish accounts of extant native communities of the area from the mid-1500s through the mid-1600s express recurrent concern about adequate water supplies. Toulouse (1945), who was concerned with the apparent lack of a reliable water source within close proximity to Gran Quivira, documented the presence of an elaborate system of reservoirs, ditches, terraces, and artificial drainage basins to supply water for this community. The concern with potable water at Pueblo Oso Negro is reflected by the effort invested in constructing a water control feature (Montgomery and Bowman 1989). This archaeological site is located 3.6 km from the Chupadera Arroyo, well away from any known permanent water source, and the depression is suspected to have supplied the domestic water needs of this prehistoric community.

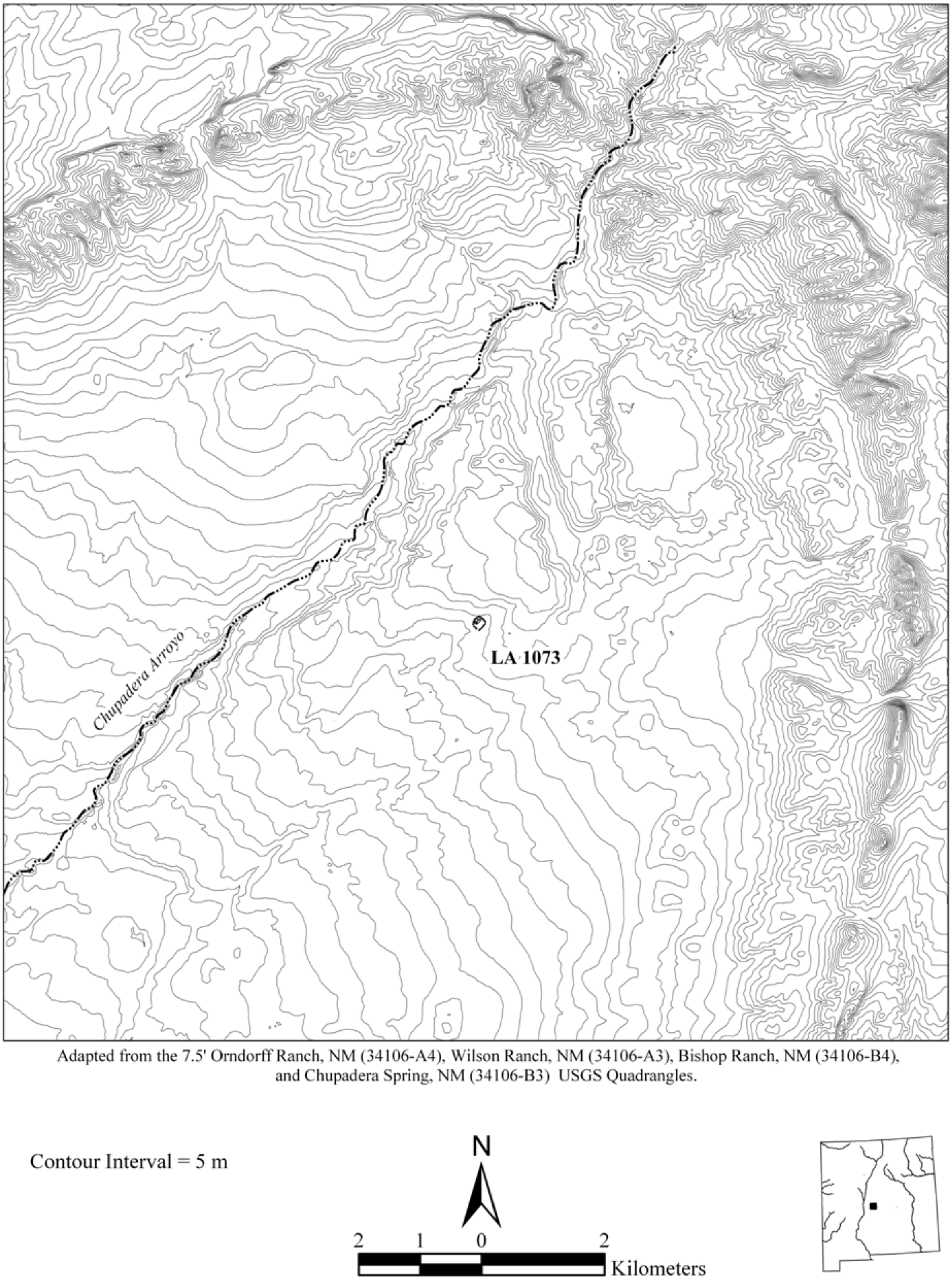
BACKGROUND FOR RESEARCH

The following section provides a detailed description of Pueblo Oso Negro. A brief overview of water management features documented in the Greater Southwest is included in this section. This is followed by a discussion highlighting the geoarchaeology and ecology of lacustrine environments, as well as the ecology of freshwater ostracodes.

Pueblo Oso Negro (LA 1073)

Pueblo Oso Negro is located 3.6 km (2.25 mi) east of the Chupadera Arroyo at an elevation of 1734 m (5690 ft) amsl. Topographically this community is situated on the western face of a north-south trending ridge (Figure 2). Between the western margin of the ridge and the pueblo a subsurface depression is noticeably present on the landscape.

The vegetation distributed across the site is predominately juniper (*Juniperus monosperma*) and sand sage (*Artemisia filifolia*) interspersed with numerous cholla (*Opuntia* sp.) and prickly pear cacti (*Opuntia* sp.) (Montgomery and Bowman 1989). Vegetation growth within the depression is noticeably different from the rest of the site. Thick stands of giant sacaton (*Sporobolus wrightii*) grow in the center of the depression bordered by a concentric distribution of broom snakeweed (*Xanthocephalum sarothrae*). Encircling the perimeter of the snakeweed is a dense sand sage cover. The extent of the snakeweed appears to delineate the horizontal limits of the artificial depression. The area surrounding the site is predominantly vegetated with dense stands of juniper and sand sage intermixed with cholla and prickly pear cacti. The floral community present on the site, excluding the depression, does not differ significantly from the surrounding landscape. Sandstone and shale bedrock outcrops are



Adapted from the 7.5' Orndorff Ranch, NM (34106-A4), Wilson Ranch, NM (34106-A3), Bishop Ranch, NM (34106-B4), and Chupadera Spring, NM (34106-B3) USGS Quadrangles.

Figure 2. Geographic location of LA 1073.

present within the vicinity of the site. These sandstones and shales most likely belong to the Glorieta and Abo Formations. Relatively active dunes are present on the slope of the north-south trending ridge within close proximity to the site (Montgomery and Bowman 1989).

This community consists of seven generally rectangular mounds arranged in a rectangular pattern around two main plazas (Figure 3). Within the exterior rectangle two roughly orthogonal mounds are present (Montgomery and Bowman 1989). The central mound rises over 4 m (13.4 ft) above the present surface and terracing is evident in the construction of this feature. The construction materials were derived from locally available sandstone and small amounts of local shale. A moderate degree of shaping is apparent on the masonry, which is laid in relatively well-formed courses (Montgomery and Bowman 1989). Based on the degree of relief of the mounds, Montgomery and Bowman (1989) estimated that some of the structures within this community were three stories high. The nine roomblocks that comprise the pueblo were estimated to contain approximately 591 rooms. Based on the ceramic assemblage the major occupation of the pueblo dates between A.D. 1350-1650 (Montgomery and Bowman 1989).

The depression to the northeast of the site is approximately 44 m (144 ft) in diameter and roughly 2 m (6.5 ft) deep. Six drainages leading into the depression from upslope to the north and east were recorded during the fieldwork associated with this research. The depression was suspected to originally be natural and subsequently culturally modified by excavation and berming to improve the catchment function of the basin (Montgomery and Bowman 1989). Additionally, it is possible that prehistorically this depression may have acted as a cistern and captured precipitation runoff from structures located adjacent to the depression (Montgomery and Bowman 1989).

Figure 3. Plan view of Pueblo Oso Negro and associated depression.

Water Control Features in the Greater Southwest

Prehistoric constructions designed to concentrate and hold water for domestic or agricultural use occur throughout the Southwest (Crown 1987:209). Water control features persist in the archaeological record throughout prehistoric and historic times, occurring in a variety of morphologically and technologically distinct forms. These water management systems range from large reservoirs capable of holding hundreds of kiloliters of water to cisterns capable of holding only a few liters (Crown 1987). Modifying the landscape to control water availability for domestic use is a technology that allowed human populations to sustain permanent communities located at a distance from permanent water sources.

The locations of 150 water control features are reported in the literature for the Greater Southwest (Figure 4). Crown (1987) differentiated five discrete types of water storage features noted to occur at archaeological sites in the Southwest: wells, walled springs, retention basins, catchment basins, and reservoirs. The typology that Crown (1987) presented was based on the means of water introduction into a feature. This system of classification was created in order to facilitate comparison and analysis of these features, and to provide some measure of standardization for the use of descriptive terms (Crown 1987:211).

The excavation of wells to utilize subsurface water sources remains the earliest documented technique of controlling water availability in the Southwest (Crown 1987; Cordell 1997). Prehistoric wells persist in the archaeological record dating as early as11,500 B.C. at Blackwater Draw on the southern High Plains of eastern New Mexico (Evans 1951; Green 1962; Warnica 1966; Hester 1972:33,70; Meltzer and Collins 1987; Haynes et al. 1999) and 6,000 B.C. at the Lehner site in southern Arizona (Agenbroad and Huckell n.d.). Over 60 Archaic age wells

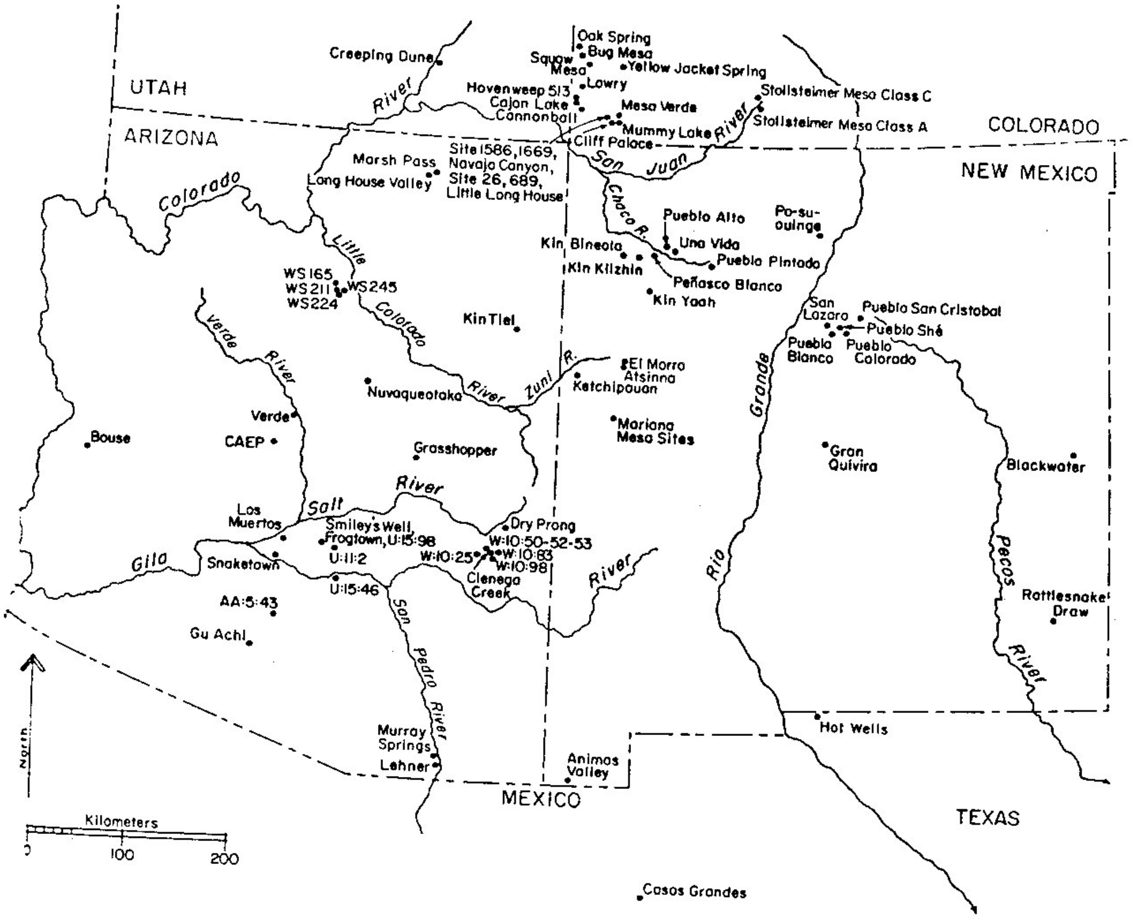


Figure 4. The locations of prehistoric water storage features distributed across the Greater Southwest (Crown 1987:212).

were discovered at Mustang Springs on the southern margin of the Llano Estacado (Hill and Meltzer 1987; Meltzer and Collins 1987; Meltzer 1991).

Other wells existing in preceramic contexts occur at Rattlesnake Draw in southeastern New Mexico (Smith et al. 1966) and at the Cienega Creek site in east-central Arizona (Haury 1957). The features described by Haury (1957) at the Cienega Creek site were pits ranging from 0.6 to 2 m in diameter and less than 4 m deep. In most instances these wells were reportedly excavated into or near drainages. Wells were also noted to occur in association with later ceramic period sites such as Mariana Mesa 616 in northwestern New Mexico (McGimsey 1951:303) and at Casas Grandes in northern Chihuahua (Di Peso et al. 1974:845). The well described at Mariana Mesa was located 2.5 m below the ground surface and included a three-level ramp. At Casas Grandes, a well was excavated down to 12.35 m below the plaza surface. A series of stairs was present leading down to this depth, and the well was reported to extend to over 2 m below the maximum water line (Di Peso et. al 1974:845). The Cinega site, located on the floor of the El Morro Valley, is so-named because of the spring or seep located in the plaza of the pueblo (Kintigh 1985). This feature was described as a seep or possible well that is ringed by a masonry wall (Kintigh 1985; Watson et al. 1980).

In the Point of Pines area, located on the San Carlos Apache Reservation in east-central Arizona, walk-in wells were reported at AZ W:10:98 and AZ W:10:25. These wells were described as small depressions 16 x 20 m in diameter located near stream courses (Wheat 1952). Wheat (1952) suggested that the location of these wells in alluvial fans near ephemeral stream channels indicates that they were dug in an attempt to utilize a probable perennial subsurface flow of water. Another possibility suggested for these wells is that a natural spring was deepened to collect water and store the increased flow. Haury (1976) documented the presence of several walk-in wells at Snaketown. Two types of wells were recognized at Snaketown; ones that were excavated in tubelike penetrations to the water table, and pits with wide mouths and sloping sides resembling an inverted cone (Haury 1976:152). Water in these wells was accessed by walking into them, hence the term walk-in wells.

Martin and Rinaldo (1960) excavated series of archaeological sites along the Upper Little Colorado Drainage in east-central Arizona. Site 31 was described as a Formative age pueblo. A rectangular feature proposed to be a walk-in well was documented in association with this pueblo. The dimensions of this feature are 2.2 x 2.45 m at a maximum depth of 1.52 m below the ground surface. This feature was interpreted as a well based on the lack of evidence that it served as a fire pit or post-hole, and due to its proximity to a streambed. Walk-in wells were also documented to occur within the interior of Pueblo III occupation sites on Mariana Mesa. Danson (1957) noted the presence of several walk-in wells located within the plazas of Site 616 and Site 190.

Walled springs are artificially modified to enhance storage capabilities. Known examples consist of masonry or logs constructed around the spring to impound water. These features appear in the archaeological record after A.D. 700 at Lowry Ruin in southwestern Colorado (Martin 1936), at Kin Tiel in the Little Colorado River drainage (Haury and Hargrave 1931), and at the Creeping Dune site in Glen Canyon, Utah (Sharrock et al. 1951).

Tinajas, or naturally formed rock tanks were used prehistorically and historically as water catchments across the Southwest. Crown (1987) described these features as retention basins filled by slope wash, rainfall, or both and typically consisted of “potholes” in rock surfaces. These features were noted to hold water for variable time periods ranging from hours to weeks (Woosley 1980). Tinajas were used as water catchment features by the prehistoric inhabitants of

Chapin Mesa, Pool Canyon and Soda Canyon in southwestern Colorado (Woosley 1980), as well as at Tinajas Altas in the Sonoran desert of Arizona (Hartmann and Thurtle 2001). At Tinajas Altas a series of 15 water catchments provided a nearly perennial water source for prehistoric occupations (Hartman and Thurtle 2001). Tinaja Ruin, located on a small butte in the El Morro Valley, was noted to include water catchment basins in the outcrop boulders on the site (Kintigh 1985). This type of water storage feature was the primary source of domestic water supply for residents of Acoma Pueblo, in northwestern New Mexico (Office of Indian Affairs 1921).

Broad, open reservoirs constructed for the collection and conservation of runoff water are widely distributed among prehistoric and historic Native American settlements in the Southwest (Wheat 1952). Crown (1987) differentiated catchment basins as situated to retain water in surface drainages, while reservoirs store water diverted from a natural source, both of these features can include dams constructed from rocks, dirt, or adobe. Even though Crown made a distinction between these features, they are similar in their retention capabilities. Catchment basin features were reported to appear in the archaeological record around A.D. 900 to 1100 (Olson 1960), and were associated with large, late prehistoric pueblos after A.D. 1200 (Olsen 1982; Wheat 1952). A large number of reservoirs were documented in the archaeological record after A.D. 700 (Rohn 1963). These water storage features appear across the Southwest at Mesa Verde, at Aztec, in Chaco Canyon, in the Galisteo Basin, at Gran Quivira, and particularly in southern Arizona (Toulouse 1945; Wheat 1952; Rohn 1963; Rabb 1975; Turney 1985; Wilshusen et al. 1997; Bayman et al. 2004).

More than 20 probable prehistoric water basins were reported in the literature for the Mesa Verde region (Wilshusen et al. 1997). Mummy Lake includes a large-scale water management system encompassing an area of 25 acres on Chapin Mesa (Rohn 1963). A series of ditches and diversions directed runoff to a shallow gathering basin, where water was channeled into a main feeder ditch that supplied Mummy Lake. This prehistoric reservoir is a circular depression roughly 27 m (90 ft) in diameter, formed by berming on the south and east sides of the feature (Rohn 1963). The interior of this depression was lined with a stone masonry wall, excluding the area of the inlet.

An extensive paleoecological study was conducted for a large reservoir located in the Hohokam periphery of southern Arizona. This reservoir encompassed a shallow basin with an intake channel located north and east of the C-shaped mound. Bayman et al. (2004) incorporated a unique approach towards the identification of prehistoric reservoirs. Ostracodes and cattail pollen, which are indicative of a water-rich environment, were recovered from sediments contained within the prehistoric reservoir. Bayman et al. (2004) integrated the use of ostracodes in this investigation to substantiate the presence of water and indicate seasonality of water storage for this water storage feature.

The Geoarchaeology and Ecology of Lacustrine Environments

Lacustrine environments can be simply defined as bodies of fresh or saline water that occupy topographically closed basins or that are impounded behind natural dams, and include hydrologic features ranging from lakes, ponds, swamps, and bogs (Waters 1992; Rapp and Hill 1998). Clastic, chemical, and carbonaceous sediments accumulate in lacustrine environments, most of which are ultimately derived from the rivers and intermittent streams that drain the surrounding uplands (Waters 1992). Sediment transportation and deposition in lacustrine environments corresponds to potential levels of hydrological energy. Coarser particles are generally deposited in the high-energy regions around the margin of the basin. While fine silt-sized particles will eventually settle to the lake bottom, the finer clay-sized sediments usually remain held in suspension (Waters 1992; Rapp and Hill 1998).

The processes by which particles are set into motion in an aqueous environment directly influence particle size distributions. Water flow velocity and grain size are the primary variables responsible for particle entrainment (Waters 1992). Specific water velocities are needed to move particles of various sizes. Clastic particles in a hydrological environment are transported by the processes of traction, saltation, and suspension depending on their size as well as the speed and turbulence of water (Waters 1992). Fine-grained sediments (clay and silt) are transported in water by the process of suspension. Heavier sand-sized particles are moved by saltation, in which sand-sized grains bounce or hop along the lake bottom or streambed. Saltation is unable to move heavier particles consisting of very coarse sand and gravel, which slide or roll downstream on the lake bottom by a process referred to as traction. Saltation and traction result in the distribution of coarser-grained sediments in the bottom of an aqueous environment, while finer-sized sediments will only settle to the bottom when water velocities are too low to hold these particles in suspension (Waters 1992). These processes result in sediment distributions that are characterized by upward fining, in which the finer-sized sediments settling out of suspension overlie the heavier particles distributed at the lake bottom.

Lacustrine deposits include evaporates, calcareous beds, marls, silts and clays, sands, as well as organic deposits (Butzer 1971). In addition to the clastic deposits contained within lacustrine environments, chemical deposits are also an important constituent. Evaporates form in closed-basin lakes in arid and semi-arid regions, where salts dissolved in the water entering the basin become concentrated into saline brines due to intense evaporation (Waters 1992). Organic sediments are expected to occur along the edges of basins in shallow water marshes, swamps, and bog settings or ponds, and calcite is the dominant chemically deposited mineral in freshwater lakes. Lake sediments can also be created by organisms, mostly invertebrates like pelecypods and gastropods, diatoms, oncolites, and ostracodes (Rapp and Hill 1998). Apart from particle size and chemical analyses (carbonate content, pH, organic matter), biological studies can provide significant paleoecological information (Butzer 1971).

Botanical signatures that are indicative of water-rich environments can produce archaeological evidence of long-term water storage (Bayman et al. 1997). Pollen accumulates at different rates on different surfaces, and the surface receptivity of a lake or bog is far greater than that of a bare rocky surface. Pollen is predominantly studied from restricted areas of active sedimentation, such as water bodies, floodplains, or archaeological sites. Concentric rings of aquatic, semiaquatic, and water-tolerant terrestrial plants will contribute diverse pollen to the accumulating sediment of a lake or bog (Butzer 1982).

Cattail (*Typha* sp.) grows around the margins of wetland environments, and requires permanently damp soil. Turney (1985) noted that cattails can essentially invade reservoirs, consequently reducing their storage volume. The presence of cattail pollen contained in lacustrine sediments can indicate the duration of a moisture-rich environment on a recurring year-round basis (Bayman et al. 2004).

The Ecology of Freshwater Ostracodes

Ostracodes have been used in a limited number of archaeological investigations as evidence suggesting previously water-rich environments. The presence of ostracodes in the sediments analyzed from Danger Cave and Juke Box Cave in the Great Basin indicated that these caves were inundated by Lake Bonneville (Jennings 1957). Bayman et al. (2004) used ostracodes to indicate the presence of a water storage reservoir in the Hohokam periphery in southern Arizona. Ostracode paleoecology has also proven to be a reliable method to reconstruct Hohokam irrigation canal conditions, such as canal water chemistry, intensity of land use, and human impacts on soil (Palacios-Fest 1994, 1997a, 1997b).

Non-marine ostracodes are widely distributed in both fresh and brackish waters, normally under well-oxygenated conditions. They occur in lakes, ponds, springs, and streams (Forester 1983; Delorme 1989; Palacios-Fest 1994). Ostracode species may be eurytopic (i.e., able to tolerate a wide range of environmental conditions) or stenotopic (i.e., tolerant of a restricted range of environmental conditions). Based on their known ecological tolerances, fossil ostracodes can provide preliminary criteria for reconstructing paleoenvironments (Palacios-Fest 1994).

North American freshwater ostracodes are very small, bivalved crustaceans that range from ~ 0.1 to 3 mm in length (Rapp and Hill 1998; Smith 2001). These microcrustaceans are equipped with a calcareous carapace that is shed periodically as the organisms grow, until they reach maturity (Pokorny 1978). Both juvenile and adult carapaces, consisting of two valves attached by a dorsal hinge and a ligament, preserve well in the geologic record (Delorme 1969, 1989; De Dekker and Forester 1988; Palacios-Fest 1994, 1997b). The valves, generally referred to as the “hard parts”, are what is preserved and are taxonomically significant (Delorme 1989). These organisms are largely bottom dwellers, although some species have the ability to swim, ostracodes generally do not live in high-energy environments. Ecologically, ostracodes are considered omnivorous scavengers that subsist on bacteria, molds, algae, fine detritus, and even dead animals (Smith 2001). These crustaceans are commonly found on algae, decaying vegetation, rooted aquatics, and within organic-rich, clay to fine silt textured sediments at the sediment-water interface (Delorme 1989; Rapp and Hill 1989; Smith 2001; Bayman et al. 2004).

The presence of ostracodes in sediments indicates the existence of aquatic habitats in the past that were either freshwater or saline (Delorme 1989; Forester 1991; Rapp and Hill 1998). Ostracodes can also be used as an indicator of the permanency of a body of water (Delorme 1969). The life cycle of ostracodes involve nine stages, during which they molt or shed their valves (Palacios-Fest 1994). Evidence of reproduction is distinguished by an assemblage consisting of both adolescent and adult valves, which indicates that surface water was present for a considerable period of time (Broodbakker 1982, 1983). Recent studies have concluded that these crustaceans are very selective to ecological constraints, and as a result their habitat is a complex product of many environmental variables. This research indicated that certain taxa are only found in temporary water bodies, while others are found only in permanent water bodies (De Dekker and Forester 1988; Forester 1991).

RESEARCH DESIGN AND METHODOLOGY

The principal goals of this research were threefold. First, it was specifically focused on characterizing the depositional environment of the depression associated with Pueblo Oso Negro by implementing a series of geological analyses. The description and analysis of sediments from archaeological sites and the areas surrounding them provide a means of identifying particular depositional processes and environments (Rapp and Hill 1998). In addition to sediment analysis, microbotanical and invertebrate remains can provide significant information regarding water-rich environments. The second goal was to utilize microbotanical and invertebrate evidence to indicate the seasonality of water storage. Certain species of ostracodes are exceptional for indicating paleoecological conditions. As stated previously, botanical signatures that are indicative of water-rich environments can also produce archaeological evidence of long-term water storage. The third goal was to model runoff patterns and delineate the contributive watershed for the depression.

To address these goals, a research design was formed to distinguish the geology and paleoecology of the depression. Methods were chosen based on their ability to provide the data necessary to reconstruct the geological and paleoecological characteristics of the depression. Together, they were designed to collect and organize data relevant to understanding the mechanics of this water management system. Additionally, a series of hypotheses were presented for the purpose of evaluating the results of the data analysis.

Research Design

This research design incorporated a unique methodology for testing water storage features and determining their seasonality. Water-laid sediments are identified by a specific set of geological, biological, and botanical characteristics. The central goal of this research was to characterize the depositional environment of the depression. Thus, indicating the function of this depression as a water storage feature was primarily a geoarchaeological problem, where geological methods can be used to provide archaeological interpretation. The study of the physical and chemical properties of sediments can identify the nature of a sediment source, transportation mechanism, environment of deposition, and post-depositional environment (Stein 1985).

Granulometric analysis of sediments recovered from the depression was used to determine the mode of transport and deposition. The granulometric analysis was necessary for indicating sediment size distributions, surface texture, and particle morphology of the subsurface deposits contained within the depression. Measurements of particle size distribution can be extremely useful in geoarchaeological interpretations of sediment sources and transport agents (Stein 1985). Particle size distributions were used to ascertain the degree of sorting, which plays a specific role in determining the mode of transport and deposition. This analysis was critical for partitioning which natural and/or cultural processes were responsible in the formation of the deposits contained in the depression. Fluvial/alluvial and aeolian processes are better sorting agents, whereas colluvial processes will result in more poorly sorted deposits. Sediment transport can also be the result of human activity, and sediments deposited by humans tend to be poorly sorted. Spring, lake, and marsh sediments commonly exhibit poor to good sorting, due in part to fluctuating energy levels (Rapp and Hill 1998). The sediments contained in lacustrine environments generally grade from coarser and more heterogeneous particles that are deposited in the high-energy regions around the margin of the basin, and finer and more homogenous toward the center.

> An idealized picture of sediment distribution in lakes corresponds to potential levels of hydrological energy, in a scale that ranges from coarse particles around the perimeter in the beach zone, grading into sandy marly muds, and finally grading into muds or deposits high in carbonates [Rapp and Hill 1998:57].

Calcareous silts and clays, referred to as marls, are commonly deposited in lakes and swamps. Plant or inorganic agencies influence lime content, while streams and rainwash will contribute clays and silts to these deposits. Freshwater marl sedimentation is generally confined to comparatively small water bodies and is common in humid and semi-arid landscapes (Butzer 1964:182).

Granulometic analysis also included observations on particle morphology and surface texture. The morphology of a sand grain can be an important indicator of the conditions of sediment transportation and deposition. The sharpness, angularity, or rounded edges of sand grains contained within a deposit reflect the amount and intensity of transportation that particles have undergone (Rapp and Hill 1998). Surface texture refers to the micro-relief of the surface of the particle and is characterized by clarity, polishing, frosting, or pitting. Surface features such as polishing or frosting also indicate the method of transportation. The particle shape of a sand grain is described by its degree of sphericity, which is a measure of how close a grain approximates a sphere (Waters 1992). A measure of roundness is based on the sharpness or smoothness of the corners and edges of a sand grain particle. A hierarchy of categories ranging from very angular to well rounded express the degree of sand grain roundness (Waters 1992). Sediment alterations that occur as a result of lacustrine processes are expected to exhibit characteristics of rounding, high sphericity, and polishing.

Loss-on-ignition is an exceptionally effective analysis for determining the percentages of organics contained in sediment samples. The amount of organic carbon is estimated by measuring weight loss in a sediment sample subsequent to burning at selected temperatures. Carbonate content is determined by measuring the amount of CO_2 produced when $CaCO_3$ is dissolved with a strong acid. Measurements of pH are also useful for indicating the chemical constituents of a geological deposit. Lacustrine deposits include evaporates, calcareous beds, marls, as well as organic deposits (Butzer 1971). Organic sediments are expected to occur along the edges of basins in shallow water marshes and ponds. Calcite is the dominant chemically deposited mineral in freshwater lakes. Calcium carbonate constituents provide clues to the climatic, hydrologic, biologic, and chemical processes that have acted upon a deposit (Rapp and Hill 1998). As stated previously, marls commonly originate as biogeochemical deposits formed in the bottom of lakes and ponds and are characterized by calcareous silts and clays.

In addition to particle size and chemical analyses, biological studies were an important component of this research. Distinguishing among the types of aqueous environments using only sedimentologic data can be difficult in the absence of fossils or other paleoecologic indicators (Rapp and Hill 1998). In shallow basins or around the edges of lakes plant life can be abundant, and consequently microbotanical signatures present in the pollen record can be used as evidence of long-term water storage. Certain species of plants require permanently damp soil and will only persist in aquatic environments. Pollen analysis was necessary to indicate the presence of aquatic flora in the depression.

To indicate the potential of the depression as a probable water storage feature and make suppositions regarding the seasonality of the duration of water storage at Pueblo Oso Negro, a Null hypothesis is posed:

> H_0: There is no significant difference in the species of pollen present in the sediments of the probable water storage feature than in the surrounding sediments.

An alternative hypothesis reads:

> H_1: There is a significant difference in the species of pollen present in the sediments of the probable water storage feature than in the surrounding sediments.

The seasonality of water storage was also explored by the presence of fossil ostracodes and other aquatic invertebrates. To investigate the potential of using ostracodes to indicate that the depression was used as a water storage feature and make inferences regarding the seasonality of the duration of water storage at Pueblo Oso Negro, a Null hypothesis is posed:

> H_0: There is no significant difference in the species and quantity of ostracodes in the sediments of the probable water storage feature than in the surrounding sediments.

An alternative hypothesis reads:

> H_1: There is a significant difference in the species and quantity of ostracodes in the sediments of the probable water storage feature than in the surrounding sediments.

Answering the question of how the depression was supplied with water is related to the geomorphic characteristics of the surrounding landscape. The shape of a surface directly influences the movement of water or runoff patterns. The hydrological modeling analysis extension for ArcGIS software provides the capability to model the movement of water based on the physical characteristics of a surface. This software also includes the capability of delineating a drainage system and quantifying the characteristics of this system using digital elevation models. Geographic Information System (GIS) software is an extremely useful means for creating predictive models. By modeling the movement of water across the topography of the area surrounding the depression the presence of natural watersheds and surface runoff patterns can be determined

Methods

The methods employed in this analysis were selected because of their potential for yielding reliable data sets relevant to answering the research questions presented in the previous section. There are various acceptable methods for each of the analyses used in this research. The methods chosen to determine particle size, organic matter, and calcium carbonate content are discussed in the following section. Additionally, a description of the procedures used for data collection, determining pH, microscopic analyses, and hydrological modeling are presented.

Sample Collection. Sediment samples collected from the hydrologic feature, as well as from control localities were necessary to address the research questions presented in the previous section. Samples were obtained from the depression associated with Pueblo Oso Negro by coring with a bucket auger. Coring and augering are efficient techniques by which subsurface deposits can be readily examined (Stein 1986). It has been demonstrated that coring with a bucket auger can yield accurate information about the depth of archaeological features, as well as recovering sediments for chemical and biological microanalysis (Casteel 1970; Stein 1986). This method of data collection is a highly efficient supplement to excavation in respect to cost and time, as well as providing the means for sampling much larger portions of the feature.

Auger samples were collected during two separate field visits to Pueblo Oso Negro in August of 2005. As stated previously, lacustrine deposits are characterized by differential sediment distributions grading from coarser particles around the margins of the basin to finer silt-sized sediments in the center. In an attempt to characterize these differing sediment distributions two transects were placed across the depression from east to west and north to south. The center auger test location (AC) was judgmentally determined from differences in vegetation cover present within the depression (Figure 5), and four more auger test locations (AN, AS, AW, and AE) were placed ten meters away from the center in all four cardinal directions. Additionally, three control auger columns (ACON1, ACON2, and ACON3) were collected at varying distances from the depression located to the east, northeast, and northwest. Observations on depth, munsell color, soil texture, cultural materials, and organic inclusions were recorded for each auger sample. After recording observations on the sample the sediment was placed in plastic sample bags labeled sequentially from top to bottom. Samples were collected in roughly 10 cm increments.

Pollen samples were judgmentally chosen from stratigraphic levels exhibiting high clay content (Table 1). Clay often acts as a barrier to downward percolation of particulates, which results in an accumulation of materials within this matrix (Holloway 2005). Prior to removing sediments from which a pollen sample was to be collected, the bucket auger was rinsed with a 10% HCl solution and distilled water to prevent contamination. A clean trowel, rinsed with 10% HCl and distilled water, was used to collect pollen samples which were then placed them in sterile whirl-pak sample bags.

During the data recovery process water was encountered water at the bottom of the north, center, and south auger test locations within the depression. The depth of water present in the bottom of the auger holes was measured and recorded. Additionally, water samples were collected from these locations by taping a plastic sample bag around the bucket and inserting the auger down to the bottom of the hole.

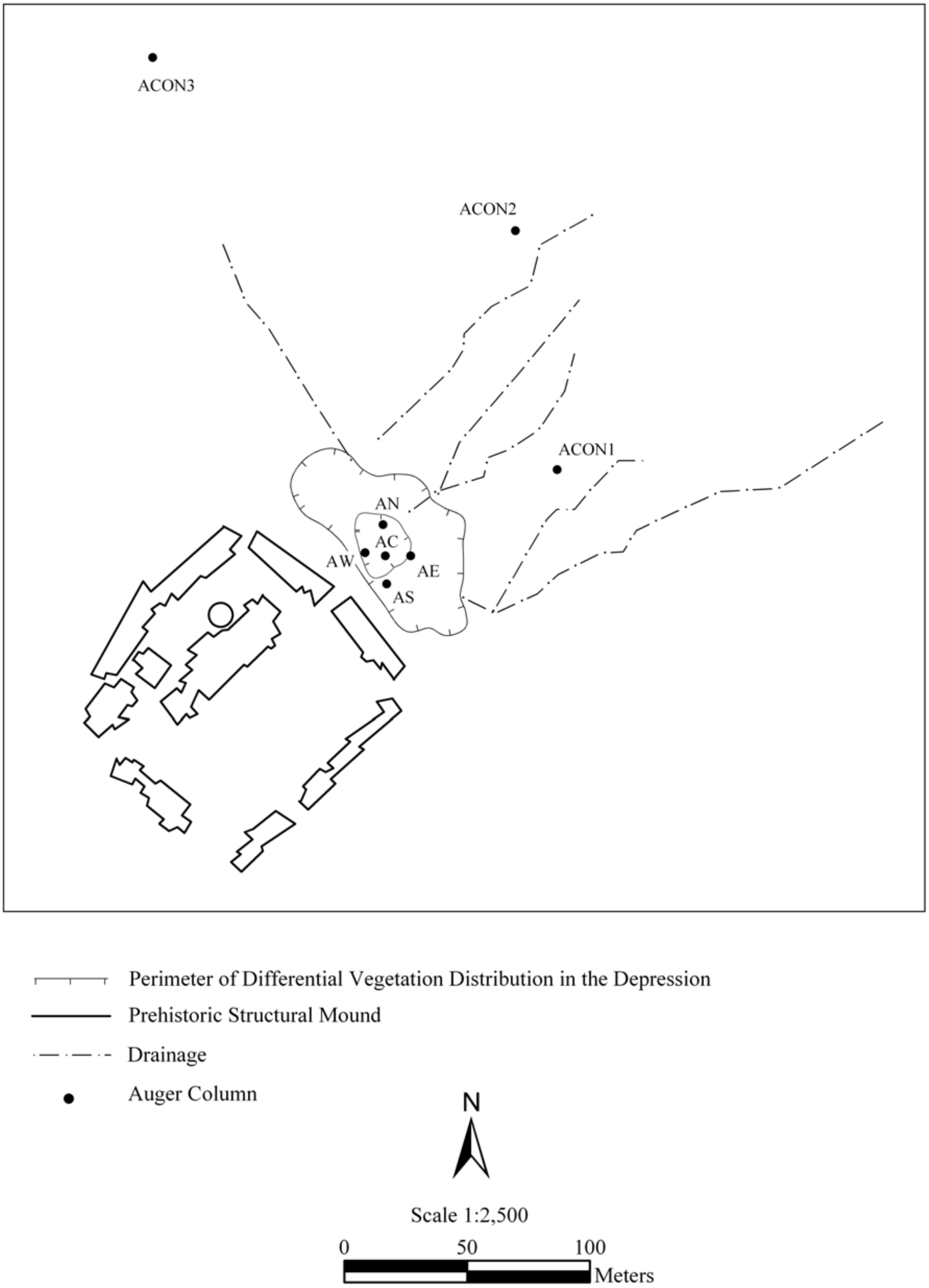


Figure 5. Locations of auger test columns.

Table 1. Description of Auger Column Samples and Analyses Conducted on Each Sample.

Auger Column/ UTM Coordinates	Auger Sample	Depth (cm)	Subsamples (n)	Analyses Conducted
West Auger Column	AW-1	0-13	5	a, b, c, d, e
(AW)	AW-2	13-26	5	a, b, c, d, e
373398E	AW-3	26-38	5	a, b, c, d, e
3776936N	AW-4	38-45	5	a, b, c, d, e
Elev. 1712 m	AW-5	45-59	5	a, b, c, d, e
UTM Zone 13	AW-6	59-75	5	a, b, c, d, e
NAD 1927	AW-7	75-85	5	a, b, c, d, e
	AW-8	85-95	5	a, b, c, d, e
	AW-9	95-104	5	a, b, c, d, e
	AW-10	104-117	5	a, b, c, d, e
	AW-11	117-128	5	a, b, c, d, e
	AW-12	128-139	5	a, b, c, d, e
	AW-13	139-149	5	a, b, c, d, e
	AW-14	149-159	5	a, b, c, d, e
	AW-15	159-171	5	a, b, c, d, e
Center Auger Column	AC-1	0-11	5	a, b, c, d, e
(AC)	AC-2	11-21	5	a, b, c, d, e
373406E	AC-3	21-30	5	a, b, c, d, e
3776935N	AC-4	30-39	5	a, b, c, d, e
Elev. 1712 m	AC-5	39-49	5	a, b, c, d, e
	AC-6	49-58	5	a, b, c, d, e
	AC-7	58-68	5	a, b, c, d, e
	AC-8	68-76	5	a, b, c, d, e
	AC-9	76-84	5	a, b, c, d, e
	AC-10	84-100	5	a, b, c, d, e
	AC-11	100-110	5	a, b, c, d, e
	AC-12	110-125	5	a, b, c, d, e
	AC-13	125-134	5	a, b, c, d, e
	AC-14	134-149	5	a, b, c, d, e
	AC-15	149-165	5	a, b, c, d, e
	AC-16	165-180	5	a, b, c, d, e
	AC-17	180-190	5	a, b, c, d, e
	AC-18	190-202	6	a, b, c, d, e, f
	AC-19	202-215	5	a, b, c, d, e
	AC-20	215-232	6	a, b, c, d, e, f

Note : a = Particle Size Distribution Analysis

b = Particle Morphology and Surface Texture Analysis

c = Organic and Carbonate Content

d = pH Measurement

e = Invertebrate Analysis

f = Pollen Analysis

Table 1. Description of Auger Column Samples and Analyses Conducted on Each Sample (continued).

Auger Column/ UTM Coordinates	Auger Sample	Depth (cm)	Subsamples (n)	Analyses Conducted
	AC-21	232-241	5	a, b, c, d, e
	AC-22	241-251	6	a, b, c, d, e, f
	AC-23	251-263	5	a, b, c, d, e
	AC-24	263-273	5	a, b, c, d, e
	AC-25	273-280	6	a, b, c, d, e, f
	AC-26	280-291	6	a, b, c, d, e, f
	AC-H_2O	268-291	1	d
East Auger Column	AE-1	0-9	5	a, b, c, d, e
(AE)	AE-2	9-21	5	a, b, c, d, e
373417E	AE-3	21-32	5	a, b, c, d, e
3776935N	AE-4	32-41	5	a, b, c, d, e
Elev. 1712 m	AE-5	41-52	5	a, b, c, d, e
	AE-6	52-60	5	a, b, c, d, e
	AE-7	60-71	5	a, b, c, d, e
	AE-8	71-82	5	a, b, c, d, e
	AE-9	82-90	5	a, b, c, d, e
	AE-10	90-103	5	a, b, c, d, e
	AE-11	103-110	5	a, b, c, d, e
	AE-12	110-120	5	a, b, c, d, e
	AE-13	120-129	5	a, b, c, d, e
	AE-14	129-139	5	a, b, c, d, e
	AE-15	139-150	5	a, b, c, d, e
	AE-16	150-160	5	a, b, c, d, e
	AE-17	160-169	5	a, b, c, d, e
	AE-18	169-180	5	a, b, c, d, e
	AE-19	180-192	5	a, b, c, d, e
	AE-20	192-202	5	a, b, c, d, e
	AE-21	202-210	5	a, b, c, d, e
	AE-22	210-221	5	a, b, c, d, e
	AE-23	221-233	5	a, b, c, d, e
	AE-24	233-243	5	a, b, c, d, e
	AE-25	243-253	5	a, b, c, d, e
	AE-26	253-262	5	a, b, c, d, e
	AE-27	262-272	5	a, b, c, d, e
	AE-28	272-283	5	a, b, c, d, e

Note : a = Particle Size Distribution Analysis
b = Particle Morphology and Surface Texture Analysis
c = Organic and Carbonate Content
d = pH Measurement
e = Invertebrate Analysis
f = Pollen Analysis

Table 1. Description of Auger Column Samples and Analyses Conducted on Each Sample (continued).

Auger Column/ UTM Coordinates	Auger Sample	Depth (cm)	Subsamples (n)	Analyses Conducted
	AE-29	283-293	5	a, b, c, d, e
	AE-30	293-303	5	a, b, c, d, e
Control Auger Column	ACON3-1	0-16	5	a, b, c, d, e
(ACON3)	ACON3-2	16-29	5	a, b, c, d, e
373312E	ACON3-3	29-42	5	a, b, c, d, e
3777138N	ACON3-4	42-52	5	a, b, c, d, e
Elev. 1721 m	ACON3-5	52-69	5	a, b, c, d, e
	ACON3-6	69-89	5	a, b, c, d, e
	ACON3-7	89-98	5	a, b, c, d, e
	ACON3-8	98-107	5	a, b, c, d, e
	ACON3-9	107-115	5	a, b, c, d, e
	ACON3-10	115-126	5	a, b, c, d, e
	ACON3-11	126-135	5	a, b, c, d, e
	ACON3-12	135-146	5	a, b, c, d, e
	ACON3-13	146-155	5	a, b, c, d, e
	ACON3-14	155-164	5	a, b, c, d, e
	ACON3-15	164-174	5	a, b, c, d, e
	ACON3-16	174-181	5	a, b, c, d, e
	ACON3-17	181-191	5	a, b, c, d, e
	ACON3-18	191-201	6	a, b, c, d, e, f
	ACON3-19	201-210	5	a, b, c, d, e
	ACON3-20	210-220	6	a, b, c, d, e, f
	ACON3-21	220-228	5	a, b, c, d, e
	ACON3-22	228-238	6	a, b, c, d, e, f
	ACON3-23	238-248	5	a, b, c, d, e
	ACON3-24	248-254	6	a, b, c, d, e, f
	ACON3-25	254-265	5	a, b, c, d, e
	ACON3-26	265-275	5	a, b, c, d, e
	ACON3-27	275-285	5	a, b, c, d, e
	ACON3-28	285-294	5	a, b, c, d, e
	ACON3-29	294-303	6	a, b, c, d, e, f

Note : a = Particle Size Distribution Analysis
b = Particle Morphology and Surface Texture Analysis
c = Organic and Carbonate Content
d = pH Measurement
e = Invertebrate Analysis
f = Pollen Analysis

Sample Treatment. All sediment samples were collected in plastic sample bags. Due to the high moisture content of the sediments collected from the depression, the samples were transferred to paper bags and placed them inside of unsealed plastic sample bags. This action was taken in an attempt to absorb moisture and prevent mold growth in the samples. The pollen and water samples were refrigerated until the time of analysis also to prevent mold growth. This was critical for two reasons. The addition of mold to the samples can increase the organic content of the sediments and skew the results of a chemical analysis. Mold is also known to digest pollen grains subsequently removing pollen from a sample (Dimbleby 1957, 1967; Goldstein 1960; King et al. 1975).

Portions of each sediment sample were required for the particle size distribution analysis and characterizing organics and carbonates. Due to the large number of samples collected from the eight auger test locations, analyses were only conducted on the samples collected from AW, AC, AE, and ACON 3 (Table 1 and Figure 5). Before conducting these analyses, the 100 sediment samples chosen for analysis were divided with a riffle splitter to produce two sets of subsamples. Roughly 100 g of sediment was removed from the bulk sediment sample for each analysis and transferred to smaller plastic sample bags. These two sets of subsamples were sent to Texas A&M University and New Mexico Tech for the particle size distribution analysis and the determination organic and carbonate content. The remaining portions of the sediment samples were used for extracting invertebrate remains, as well as determining pH, particle morphology, and surface texture.

Particle Size Analysis

Several acceptable methods exist for conducting a particle size analysis, and many are appropriate for specific types of sediments or sedimentary rock (Kilby 1998). The various methods used for determining the particle size distribution include dry sieving with a mechanical shaker, wet sieving, pipette analysis, and hydrometer analysis. The pipette method requires a substantial amount of time, but is extremely effective for determining the percentages of clays and silts contained within sediments. For this reason, conducting a hydrometer analysis was not necessary to determine silt and clay fractions present within the samples. Dry sieving was also used subsequent to the pipette procedure to partition the resulting bulk sand fraction into Wentworth size classes. Texas A&M Soil Characterization Laboratory in College Station, TX conducted the particle size distribution analysis.

Grain sizes were classified according to the Wentworth classification scale (Table 2). The Wentworth scale is almost universally accepted for classifying particle size units and nomenclature used to describe clastic particles (Waters 1992:21). Particle sizes are roughly divided into five major categories: gravel particles have a diameter of greater than 2 mm, sand particles range from 2 to 0.0625 mm in diameter, silt particles range from 0.0625 to 0.0039 mm in diameter, and clay particles are less than 0.0039 mm in diameter (Waters 1992). Wentworth size classes use grain diameter to further subdivide the major groups into smaller particle categories generally ranging from coarse to very fine, with the exception of gravels, which have named subdividions. Phi categories range from -12 phi (4096 mm) to 14 phi (0.00006 mm) and correspond to Wentworth size classes. The particle size analysis indicated the percentages of gravel (>2 mm), very coarse sand (2.0-1.0 mm), coarse sand (1.0-0.5 mm), medium sand (0.5-0.25 mm), fine sand (0.25-0.10 mm), very fine sand (0.10-0.05 mm), coarse silt (0.05-0.002

Table 2. Wentworth Grain-Size Classification for Sediments.

	U.S. Standard Sieve Mesh	Millimeters	Phi Units	Wentworth Size Class
Gravel		4096	-12	Boulder
		1024	-10	
		256	-8	
		64	-6	Cobble
		16	-4	Pebble
	5	4	-2	Granule
	6	3.36	-1.75	
	7	2.83	-1.5	
	8	2.38	-1.25	
Sand	10	2.00	-1.0	Very coarse sand
	12	1.68	-0.75	
	14	1.41	-0.5	
	16	1.19	-0.25	
	18	1.00	0.0	Coarse sand
	20	0.84	0.25	
	25	0.71	0.5	
	30	0.59	0.750	
	35	0.50	1.0	Medium sand
	40	0.42	1.25	
	45	0.35	1.5	
	50	0.30	1.750	
	60	0.25	2.0	Fine sand
	70	0.210	2.25	
	80	0.177	2.5	
	100	0.149	2.750	
	120	0.125	3.0	Very fine sand
	140	0.105	3.25	
	170	0.088	3.5	
	200	0.074	3.75	
Silt	230	0.0625	4.0	Coarse silt
	270	0.053	4.25	
	325	0.044	4.5	
		0.037	4.750	
		0.0312	5.0	Medium silt
		0.0156	6.0	Fine silt
		0.0078	7.0	Very fine silt
Clay		0.0039	8.0	Clay
		0.0020	9.0	
		0.00098	10.0	
		0.00049	11.0	
		0.00024	12.0	
		0.00012	13.0	
		0.00006	14.0	

mm), fine silt (0.02-0.002 mm), and clay (<0.002 mm) contained in the sediment samples recovered from the depression.

Pipette Method. Prior to conducting the pipette procedure the samples were disaggregated and pre-sorted using a series of graded sieves. All particles greater than 2 mm in diameter were removed from the samples. This fraction was weighed to determine the percentage of gravel, or coarse fragments that comprised the sample. Subsequent to the removal of the <2 mm fraction, 10.0 g of air-dry sample was transferred into a numbered sedimentation bottle. Five milliliters of a 10% sodium hexametaphosphate dispersing agent was added to the sample and the bottle was filled 1/2 to 2/3 full with distilled water. The sample was then placed in a reciprocating shaker for eight hours. The temperature of the suspension must be within 1°C of the water bath before pipetting. After the suspensions were removed from the shaker, soil residues on the stopper and sides of the bottle were carefully washed. The suspension was then brought to a volume of 400 ml with the addition of room temperature distilled water. The volume was determined by the weight of the suspension. It was calculated according to the following formula:

$$400.00 \text{ g for water} + 10 \text{ g soil} = 410.00 \text{ g total weight of suspension.}$$

The temperature of the suspension was determined and the corresponding sedimentation time for 20 μm was established. Next, a spin bar was inserted and stirred for approximately two minutes on a magnetic stirrer. The sample was transferred to a water bath and the sedimentation period timing began. Approximately one minute before the end of the sedimentation period, a clean calibrated 5 ml pipette was lowered 5 cm into the suspension.

At the end of the sedimentation period the pipette was used to remove a 5 ml aliquot, which was transferred to a tared crucible. At the end of the 2 µm sedimentation period the previous two steps were repeated. After the completion of the 2 µm pipetting, the sample was removed from the water bath, stirred for approximately two minutes, and allowed to settle for one to two minutes.

A 25 ml aliquot was removed from about 4 cm below the surface of the suspension and transferred to a 90 ml glass centrifuge tube. Subsequent to collecting eight aliquots, four pairs of tubes were balanced in centrifuge shields and placed into the centrifuge. The centrifugation period was determined for 0.2 µm particles from the temperature of the suspension, and the samples were centrifuged at 2000 rpm for the required time. The centrifuged samples were then pipetted in a manner identical to the 20 µm and 2 µm fractions, with the exception that a 2 cm depth was used in place of the 5 cm depth. The pipetted aliquots were dried overnight at 105°C and weighed to 0.1 mg. The corresponding particle size fractions were calculated according to the following formulae:

$$\%\ \text{fraction} = \frac{(\text{weight of Aliquot - salt factor})(\text{volume factor})(100)}{\text{sample weight}}$$

$$\text{volume factor} = \frac{400.0}{\text{volume of pipette}}$$

After all aliquots were removed from the suspension, the remainder of the sample was passed through a 300 mesh (50 µm) sieve. The residual clay and silt was washed through the sieve and the sand was transferred to a beaker to dry overnight at 105°C. The dry sand was then transferred to a nest of sieves ordered:

#18	1.0 mm
#35	0.5 mm
#60	0.25 mm
#140	0.10 mm
#300	0.05 mm

Each resulting sand fraction was then weighed to 0.01 g. The percentages of sand fractions present in a sample were calculated according to the following formula:

$$\%\ \text{sand fraction} = \frac{(\text{weight of fraction})(100)}{\text{sample weight}}$$

The method of displaying and analyzing granulometric analyses depends on the purpose of the study (Selley 1976). Both graphical and statistical methods of data presentation have been developed. Typically, particle size data are presented in either histograms or as cumulative weight curves to show the relative abundance of size fractions and to allow statistical measures to be derived (Rapp and Hill 1998). Tabulations of the percentages of specific size classes present within a given sample may be displayed graphically as histograms. A more common method of graphic display is the cumulative weight curve. The closer a curve approaches a vertical line the better sorted it is, as a major percentage of sediment occurs in one size class (Selley 1976). Cumulative weight curves can also be used to compare the relative proportion of different size fractions contained in a deposit (Rapp and Hill 1998). For this analysis cumulative weight curves were used to characterize the deposits within the depression and derive measurements used for statistical calculations.

Cumulative weight curves can be drawn on an arithmetic or logarithmic scale. Most sedimentologists agree that the grain size distribution of sediments approaches log normality indicated by plotting single-population sediments (e.g., well sorted beach sands) on a logarithmic scale, which result in a nearly symmetrical Gaussian probability curve (Folk 1966). Krumbein (1934) introduced a logarithmic scale of size classes for particle measurement referred to as the phi scale. This scale of measurement expresses the particle size as the negative logarithm, to the base of two, of the diameter in millimeters. The advantage of using the phi scale is that it gives a simple scale of measurement already converted to logs. Use of the phi scale simplifies the computation of statistical measurements. Because most unimodal sediments have a nearly normal Gaussian distribution when the phi geometrical grain scale is used on the abscissa, they approach a straight line when plotted on probability percentage paper. This method of plotting grain size distributions is considered superior for the interpolation of statistical measurement (Folk 1966).

A variety of statistical methods can be used to describe and interpret sediment distributions. Two main groups of size parameters are used for characterizing grain size distributions, those that define the central tendency of the distribution (median and mean) and those that define the scatter and non-normality of the distribution (sorting, kurtosis, and skewness). The simplest of these statistics is the measurement of central tendency, of which there are three commonly used parameters: the median, the mode, and the mean (Selley 1976:18). The mean grain size reflects the overall average size of the sediment as influenced by supply source and depositional environment (Folk 1966). The mean particle size is related to the current velocity or to the energy of the depositional environment. Sorting or the separation of particles by size is generally a consequence of variations in transport velocity and turbulence, and is an indication of entrainment and transport by water or air currents (Rapp and Hill 1998).

Various statistical measurements can be used express the mean particle size and the degree of sorting from particle size data. Each method has its advantages and drawbacks. The method of moments was the preferred method of computation, due to the fact that the entire distribution is used for calculation rather than a few selected percentiles (Folk 1966). Moment measurements are efficient estimators of the population parameters for normal distributions and are considered to be of great value as practical sediment-size parameters (Friedman 1962; Middleton 1962).

The best measure of the overall average particle size for a given sample is the mean as computed by the method of moments, where the entire size curve enters into the computation (Folk 1966). Sorting can be expressed on a geometric scale as a measure of uniformity, and the standard deviation can be used as a measurement that is indicative of sorting processes (Folk 1966; Lewis and McConchie 1994). The standard deviation is a moment measure that is considered the most suitable statistic for describing sorting characteristics (Friedman 1962). Better-sorted sediments are indicated by a low standard deviation, in which there is less dispersion about the mean. For this analysis a standard deviation of <0.05 represents well sorted sediments, between 0.05 and 1.40 represents moderate sorting, a value between 1.40 and 2.00 represents poorly sorted sediments, and a value of >2.00 represents very poorly sorted sediments (Friedman 1962).

In the method of moments, the first moment calculation is the mean or average grain size. The second moment is a calculation of variance, which is used for the calculation of the standard deviation. The moments were calculated according to the following formulae:

$$\text{mean}^{*} = \frac{\Sigma fd}{N}$$

$$\text{variance} = \Sigma fd^2 - \frac{(\Sigma fd)^2}{N-1}$$

$$\text{standard deviation} = \sqrt{\text{variance}}$$

where:

f = frequency (weight %)
d = log diameter
N = number of measurements (100 when dealing with percents)
* This is a log (phi) mean; the antilog$_2$ gives the millimeter value.

Moment calculations are easily derived from computational programs. Granplots is an excel spreadsheet application template designed to generate moment measures for the mean, standard deviation, skewness, kurtosis, relative dispersion, and frequency plot. This statistical application automatically generates cumulative frequency curves plotted on a probability percentage ordinate (Balsillie et al. 2002). Statistical results were obtained using the Granplots statistical package.

Measuring Organics and Carbonates

There are two primary accepted methods for measuring the organic and calcium carbonate content of a sediment sample, both which are based on measures of weight loss from removing the organic and calcium carbonate from sediments. Chemical methods consist of using a dilute acid leach or ammonium acetate solution to remove carbon. The ignition method removes organics and carbonates from a sample by burning at selected temperatures for specific durations of time. When a dry sample is heated, the organic matter will begin to ignite at 200°C and finish burning when the temperature reaches 550°C (Stein et al. 1984). $CaCO_3$ is removed by evaporating into carbon dioxide (CO_2) gas. Carbonates are vaporized into CO_2 at 800°C, and removed when 850°C is reached. Quantitative gasometric determination of carbonates involves using a strong acid (HCl - $FeCl_2$) to dissolve $CaCO_3$. The acid dissolution of carbonates is summarized by the following reaction:

$$CaCO_3 + 2H+ \rightarrow Ca^{2+} + CO_2 + H_2O$$

The Chittick apparatus measures the amount of CO_2 produced when carbonate is dissolved in acid. The measurement of CO_2 production provides an absolute measure of carbonate content (Loeppert and Suarez 1996). Both of these methods are also comparable in the accuracy of results (Dean 1974). Weight loss-on-ignition is the most efficient procedure for determining organic content. Additionally, measuring carbonates with a Chittick apparatus is a simplistic procedure that yields accurate results. These were the preferred methods used by the New Mexico Tech Soil Science Laboratory to characterize the organic and carbonate content.

Loss-on-Ignition Method. Initially, the samples were ground into a fine power. Prior to conducting the ignition procedure the ceramic crucibles used for the analysis were cleaned by burning in a kiln at 1000°C and placed in a desiccator to cool. The cleaned crucibles were then labeled and weighed to four decimal places. Approximately 3-5 g of sample was placed in each ceramic crucible and weighed again. The crucibles were then placed into a kiln and heated at 90° to 100° C for one hour to dry the sample completely. The crucibles were placed into a desiccator until they equalized with room temperature. After cooling the samples were weighed again. This was the dry weight measure that was used in all calculations. The crucibles were then placed into a kiln preheated to 550°C for exactly one hour. After burning for the duration of an hour the samples were removed and placed into a desiccator to cool and were reweighed.

The dry sample weight difference and the weight after the 550°C burn represents the weight of organic material in the sample. The following formula was used in this calculation:

$$\%\ \text{organics} = \frac{\text{weight of sample after burning at } 550^{\circ}\text{ C}}{\text{dry weight}} * 100$$

Quantitative Gasometric Determination of Carbonates. Prior to conducting the analysis, the Chittick apparatus was calibrated using a fine-grained reagent-grade $CaCO_3$. Subsequent to calibration, approximately 5 g of ground sediment was placed into a decomposition flask. A magnetic stirring rod was inserted and two drops of amyl alcohol were added. The sample flask was then attached to the Chittick apparatus and 25 ml of a $HCl\text{-}FeCl_2$ solution was added to a graduated funnel. The three-way stopcock on the apparatus was opened, and the liquid level of the measuring burette was adjusted to exactly 0 ml by altering the height of the leveling bulb. The apparatus was closed to the atmosphere using the three-way stopcock and the leveling bulb was lowered about 2 cm. Simultaneously, the HCl-$FeCl_2$ solution was added from the graduated funnel to the sample, and the leveling bulb was lowered and kept 1 to 2 cm below the liquid level in the measuring burette. After the sample was moistened, the magnetic stirrer was activated. Subsequent to adding 20 ml of acid, the stopcock on the graduated funnel was closed. When the level in the gas burette ceased to drop, the liquid levels in the leveling bulb and measuring burette were equalized, and the volume of CO_2 produced was measured. Carbonate content was determined according to the following formulae:

$$\text{weight of } CaCO_3 \text{ (in grams)} = {}_{(C)}\,[V\ CO_{2(corr)}]\ \left(\frac{100g\ CaCO_3\ mol\ {-1}}{22.414\ L\ mol\ {-1}}\right)\ x\ \left(\frac{1L}{1000\ ml}\right)$$

where:

$_{(C)}$ = the slope of the correction factor between the actual and calculated $CaCO_3$ determined during calibration

$[V\ CO_{2(corr)}]$ = the corrected CO_2 volume determined from subtracting the average CO_2 volumes for the reagent blanks used during the calibration process

$$CaCO_3 \text{ equivalent, \%} = \left(\frac{W_{CaCO3}\ g}{W_{sample}\ g}\right) * 100$$

pH Measurement. The degree of acidity or alkalinity of a solution expressed on a scale ranging from 0.0 to 14.0 is a measure of pH. Soil or sediment pH measurements are useful for indicating the degree of chemical weathering, as well as the degree of pollen preservation. A pH measurement was determined for all 100 sediment samples analyzed, including the water sample collected from the center auger column, to indicate the levels of alkalinity within in the depression relative to the control samples. Prior to conducting the procedure the beakers were cleaned and rinsed with distilled water. The dilution chosen for this analysis was a 1:10 substrate:solution ratio. A total of 10 g of subsample was measured out and placed into a labeled beaker. Subsequent to this, distilled water was added to the beakers to result in a total of 100 ml of solution. The samples were agitated with a glass stirring-rod, and soaked overnight for 12 hours. The following morning the samples were stirred again and allowed to settle for 10 minutes. After the settling period an electronic probe was inserted into the sample and a reading was taken. Between each pH reading the probe was rinsed with distilled water.

Microscopic Analysis Methods

Microscopic analyses were necessary for extracting invertebrate remains, as well as determining particle morphology and surface texture for the granulometric analysis. Observations on particle morphology were made to complement the particle size data and aid in interpreting sediment transport and depositional processes. Additionally, a scanning electron microscope was used to generate micrographs of the invertebrate remains recovered from the sediment samples.

Particle Morphology. Microscopic observations were used for determining particle roundness, sphericity, and surface texture for the sediment samples. Differing particle sizes that comprise a deposit also vary in their morphology. These observations are subjective and qualitative. Powers (1953) provides a visual chart for guidance in determining the degree of sand grain roundness and sphericity (Figure 6). To quantify this analysis, counts on sand grain sphericity, roundness, and texture were recorded for each sample. Sediments were washed and allowed to dry prior to examination under a low-powered stereomicroscope. All sand grains that fell within a predefined 1x1 cm square were tabulated into the respective categories of the degree of rounding, high or low sphericity, and textural characteristics of frosted, clear, or polished. The resulting counts are presented as percentages of sand grains that were rounded vs. angular,

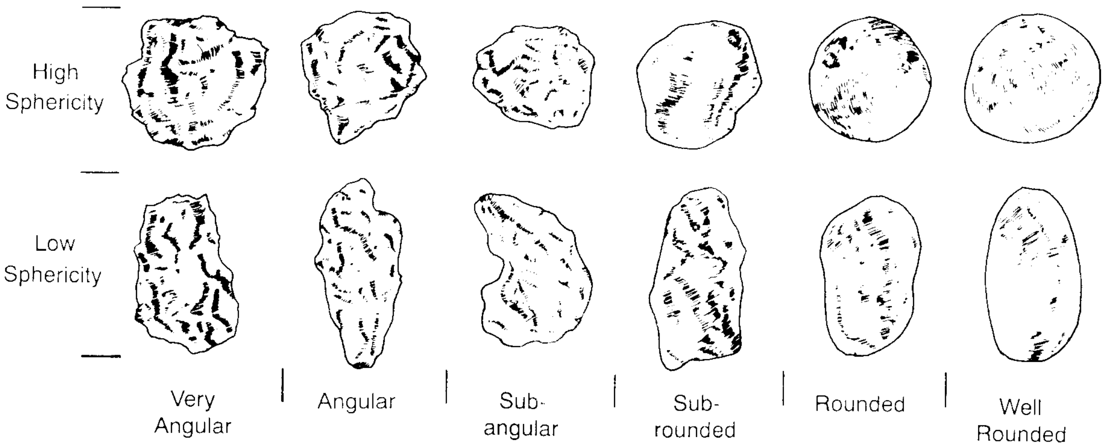


Figure 6. Range of sand grain rounding and sphericty used in the determination of particle morphology (Waters 1992:28).

high vs. low sphericity, and frosted vs. clear. Each sample examined under the microscope contained varying amounts of sand grains within the 1 x 1 cm sample area. Therefore, the calculation of percentages was based on the total amount of grains counted for each sample. Roughly 20 to 30 individual sand grains were counted for each of the 100 samples examined under the microscope.

Ostracode Extraction. All of the samples used for analysis were scanned with a low-magnification stereomicroscope for the presence of invertebrate remains, namely ostracodes. Additionally, samples that contained ostracodes were wet screened using graded sieves to aid in the extraction process. Prior to screening, the samples were soaked in a deflocculent (Calgon) solution to disperse the clay aggregates. The majority of ostracodes recovered from the samples measured approximately 1 mm. To ensure the recovery of ostracodes sediments were washed through a series of nested US Standard Testing Sieves ordered:

# 12	1.70 mm
# 18	1.00 mm
# 50	0.30 mm
#100	0.15 mm

The sediments were washed through the screens and allowed to dry before examination with a microscope to scan for the presence of invertebrates. Ostracodes were removed from the sediments using a camelhair brush saturated in distilled water to prevent damaging the carapace. Additionally, specimens representing three species of gastropods were recovered from the sediment samples during the screening process.

Scanning Electron Microscope. It was necessary to conduct sample preparation procedures prior to viewing specimens with a scanning electron microscope. The shells were soaked overnight in 10% hydrogen peroxide solution to eradicate any biological material, leaving behind the taxonomically identifiable carapace. Before a specimen was mounted, the mounting stubs were cleaned in three ultrasonic baths consisting of two acetone washes and one ethanol wash for a duration of 10 minutes each. The specimens were then mounted using double adhesive mounting media, and coated with a gold-palladium alloy by means of a sputter coater to ensure electrical conductivity. Images of the invertebrates recovered from the sediment samples were produced with a ISI-100B scanning electron microscope. These images were necessary to provide the amount of detail required for species identification of the specimens.

Invertebrate Species Identification. The micrographs generated for the purposes of this research project consisted of both interior and exterior lateral views of the ostracode carapace to illustrate shell morphology, hinge structure, and muscle scars. Ostracode species identification is based on shell features such as morphology, hingement, and muscle scars. The outline or shape of an ostracode is one of the most important criteria in classification (Moore 1961). Muscle scars are important shell features, and until recently their value in classification had been neglected. Based on the characteristics of the ostracodes found in the sediment samples, species identifications were determined from adductor muscle scar patterns present on the exterior of the shell.

Scanning electron micrographs of the gastropods recovered from the depression were also required for taxonomic identification. Micrographs generated of the gastropods illustrate the abapertural vertical axis of the shells. Unfortunately, all of the gastropods collected from the sediment samples were fragmented. Gastropod taxonomy includes a long history of disagreement regarding which features of the soft anatomy and shell are the most useful for classification purposes (Moore 1964). Accepted taxa are based on living forms and fossil shells are fit into these groups based on comparative morphology. This issue also becomes problematic when attempting to identify recent gastropod species based solely on shell morphology. Due to this fact, characteristics of shell morphology such as whorls were used to indicate the probable family affiliation of the gastropods. Whorls consist of the coils of the helicocone, which is the distally expanding coiled tube that forms most gastropod shells (Moore 1964). Specific species determinations of these gastropods are impossible based on the characteristics available for identification.

Pollen Analysis. Dr. Richard Holloway of Quaternary Services Inc, Flagstaff conducted the pollen analysis. Ten samples were used for this analysis: five from the center auger (AC) and five from the control locality (ACON3). As stated previously, pollen samples were removed from stratigraphic units exhibiting high clay content. The Texas A&M Palynology Laboratory conducted the chemical extraction of pollen from the samples using a procedure designed for semi-arid Southwestern sediments. The method used for extraction specifically avoids the use of reagents such as nitric acid and bleach, which are destructive to pollen grains (Holloway 1981).

Two tablets of concentrated *Lycopodium* spores were added as marker grains to each 20 g subsample of sediment, in order to permit calculation of pollen concentration values and indicate the accidental destruction of pollen during the extraction procedure. The samples were then treated with 3% HCl overnight to remove carbonates and release the *Lycopodium* spores from their matrix. The acid was neutralized with distilled water and the samples were allowed to settle for at least three hours prior to removing the supernatant liquid. Additional amounts of distilled water were added to the supernatant, stirred, and allowed to settle for 10 seconds. The liquid was poured off and saved in a second beaker. This procedure was repeated three times to ensure that all pollen was freed from the matrix in the original beaker. Any sand and small rocks remaining in the beaker were discarded. The matrix was placed in to a 50 ml centrifuge tube with a detergent solution, and the sample was sonicated in a Delta D-9 Sonicator for 15 seconds to remove any remaining clay particles. Subsequent to sonciation, the contents of the centrifuge tube were placed in a beaker. The suspended fine fraction was saved and decanted through a 150 µm sieve. The material passing through the screen was concentrated into a second beaker using a centrifugation mesh screen. This procedure was repeated three times to remove lighter materials, including pollen grains, from the heavier fractions (Holloway 2005).

The fine fraction was treated overnight with 48% Hydrofluoric Acid (HF) to remove silicates. After neutralizing the acid with distilled water, the samples were treated with a concentrated HCl wash to remove any potential fluorosilicates that formed during the HF wash. The HCl wash was repeated several times until the solution remained clear subsequent to centrifugation. The samples were then washed twice with distilled water (Holloway 2005).

The samples were dehydrated in a glacial acetic acid in preparation for acetolysis. The acetolysis solution (acetic anahydride: concentrated sulfuric acid in 9:1 ratio) was added to each sample and heated in a heating block at 180°F for approximately eight minutes and then washed to remove the solution. The sample was then centrifuged at 2000 rpm for 90 seconds. Heavy density separation using zinc bromide ($ZnBr_2$), with a specific gravity of 2.00, was used to remove the remaining detritus from the pollen sample. The sample was centrifuged for 10 minutes at 2000 rpm, and the light fraction was removed and diluted with 95% ethanol solution, centrifuged, and washed with distilled water until neutral. The residues were rinsed in a 5% potassium hydroxide (KOH) solution for less than one minute to remove alkaline soluble humates, followed by a concentrated HCl wash. The samples were repeatedly washed with distilled water until the solution was clear. Residues were rinsed in ethanol stained with safranin-O, and transferred to 1-dram vials with ethanol. A small quantity of glycerin was added to the samples to evaporate the remaining ethanol overnight (Holloway 2005).

A drop of the polliniferous residue was mounted on a microscope slide and sealed with fingernail polish under an 18 x 18 mm cover slip. The slide was examined using either a 200X or 100X magnification with an aus-Jen Laboval 4 compound microscope. Additionally, pollen grains were examined using a 400X or 1000X oil immersion to obtain positive identification to the family or genus level. Abbreviated microscopy was preformed on each sample for either 20% of the slide (approximately four transects at 200X) or until a minimum of 50 marker grains were counted (Holloway 2005). Samples warranting full microscopy were counted to a minimum of 200 pollen grains per sample. All transects were completely counted, resulting in various numbers of grains counted beyond 200. Pollen taxa encountered on the uncounted portion of the slide during the low magnification scan were tabulated separately. The total pollen concentration was calculated for all taxa found in the pollen assemblage. Additionally, the percentage of indeterminate pollen was also counted. The pollen data are reported as pollen concentration values calculated according to the following formula (Holloway 2005):

$$PC = \frac{K * \Sigma_p}{\Sigma_L * S}$$

where: PC = Pollen Concentration
K = *Lycopodium* spores added
Σ_p = Fossil pollen counted
Σ_L = *Lycopodium* spores counted
S = Sediment weight

Pollen grains were identified to the lowest taxonomic level possible and the majority of the identifications conformed to existing levels of taxonomy with a few exceptions. Cheno-am is an artificial pollen category that includes pollen from the family Chenopodiaceae (goosefoot) and the genus *Amaranthus* (pigweed), which are indistinguishable from each other (Martin 1963). All members are wind pollinated (anemophilous) and produce very large quantities of pollen. This taxon often dominates the pollen assemblage of many sediment samples from the American Southwest. Pollen from the Asteraceae (Sunflower) family was divided into four groups. The low spine and high spine groups are identified on the basis of spine length. High spine Asteraceae contains grains with a spine length of greater than or equal to 2.5µm, while the low spine group has a spine less than 2.5µm in length (Bryant 1969; Martin 1963). *Artemisia* pollen is identifiable to the species level due to its unique morphology. Pollen grains in the family Liguliflorae are distinguished by their fenestrate morphology and grains of this type are restricted to the tribe Cichoreae, which includes genera as *Taraxacum* (dandelion) and *Lactuca* (lettuce) (Holloway 2005). Pollen grains of the family Poaceae (grass) are generally indistinguishable below the family level with the exception of *Zea mays*.

Clumps of four or more pollen grains were tabulated as single grains to avoid skewing the pollen counts. Grains that were in the final stages of disintegration that retained identifiable features were assigned to the Indeterminate category. A severely deteriorated grain closely resembles many spores without distinguishing features. The Indeterminate category contains a minimum estimate of degradation for any assemblage. If this percentage is between 10 -20%, relatively poor preservation is inferred, whereas counts in excess of 20% indicate severe deterioration. Samples containing total pollen concentration values approximately at or below 1000 grains/g, with a 20% or greater percentage of indeterminate pollen, were not counted past the abbreviated microscopy phase. Additionally, for samples containing a low species diversity counting ceased after abbreviated microscopy, even in the case of pollen concentrations exceeding 1000 grains/g (Holloway 2005).

GIS Hydrological Modeling

As stated previously, the shape of a surface directly influences the movement of water or runoff patterns. The hydrological modeling extension for GIS software was used to predict the movement of water based on the physical characteristics of a surface. This extension is capable of delineating a drainage system and quantifying the characteristics of this system using digital elevation models.

The data used for this analysis consist of seamless digital elevation model downloaded from the USGS Seamless Data Distribution System, Earth Resources Observation and Science (EROS) website. During the data collection process a Trimble GeoXT GPS unit was used to obtain UTM coordinates for the perimeter of the depression, roomblocks, auger column locations, and six drainages found leading into the depression. These data were necessary for pinpointing these features on the digital elevation model obtained for the analysis. Additionally, provenience information for the auger column localities as well as topographic data was collected with a Sokkia Set 3F total station, and was used to generate a fine scale digital elevation model of the depression and surrounding landscape.

Prior to modeling the movement of water across a surface, the source of water and its path were determined by calculating flow directions and accumulations with the hydrological modeling extension. The analysis of flow directions was used to establish the direction of flow from every cell within the digital elevation model grid to aid in deriving other hydrologic characteristics for the surface in this area. The direction of flow was determined by finding the direction of the steepest descent, or maximum drop, from each cell. This calculation was derived from the following equation:

$$\text{maximum drop} = \frac{\text{change in z value}}{\text{distance}}$$

The flow accumulation analysis calculated the accumulated flow as the amassed weight of all cells flowing into each downslope cell in the output raster. This analysis can be simply described as the number of upslope cells that flow into each cell. The resulting output raster from the flow accumulation analysis provided the data necessary to delineate stream networks.

The stream network analysis works by applying a threshold value to the results of the flow accumulation, which was performed in two steps. A threshold was described as the minimum number of cells that flow into a cell that constitute a flowing stream. The stream network was first linked within the accumulation raster grid, and then this network vectorized the raster grid to create a feature dataset of lines that represent stream networks. The vectorization algorithm was designed primarily for the vectorization of stream networks, or any other raster linear network for which directionality is known. The arcs present in these vectorized lines point downstream.

Delineating watersheds is the term used to identify the contributing watershed to a specified point, referred to as the pour point. The location of the center auger column (AC) was identified as the pour point for the watershed delineation analysis. The watershed was determined by identifying the cell of the highest flow accumulation within the neighborhood of the pour point. The identified neighborhood is ten times the cell size. The resulting watershed is interpreted as the area that will concentrate runoff from the surrounding topography. Runoff patterns were determined using the raindrop interactive modeling tool, which traces how a water drop will travel through the landscape with respect to the natural topography. The results of the raindrop analysis display a line that defines the route of runoff from a specified point.

RESULTS

In this section, the results of the analyses of the three auger test columns located in an east-west transect across the proposed water control feature used to characterize the depositional environment and paleoecology of the depression are presented (Figure 7). Additionally, samples analyzed from an off-site control locality are compared against the results obtained from the depression. The results of the various analyses are arranged to first address depositional processes before paleoecological information obtained from the samples is presented and the hypotheses relating to paleoecological data are evaluated. Lastly, the hydrological models generated for the area surrounding the depression are discussed.

The surface elevations of the auger column locations within the depression vary slightly. The surface of the AW auger column locality was the highest in elevation relative to the locations of AC and AE. AC was located 31 cm lower in elevation than AW and 10 cm lower than AE. AE was located 20 cm lower than AW and 10 cm above the AC. The control auger column was located on a sandy ridge 225 m northwest of the depression, and roughly 9 m (29.5 ft) above the base level of auger column AC. To facilitate a comparison of the results for these varying depths, one measurement of depth based on the surface of the AW locality was used to present the results of all samples analyzed from the depression. The results from the control locality are presented in a measurement of depth based on the surface of ACON3. This system for presenting the results for the depression was used to establish a comparable scale to observe changes in sediment distributions, chemical signatures, and biological remains at a specific depth below the ground surface.

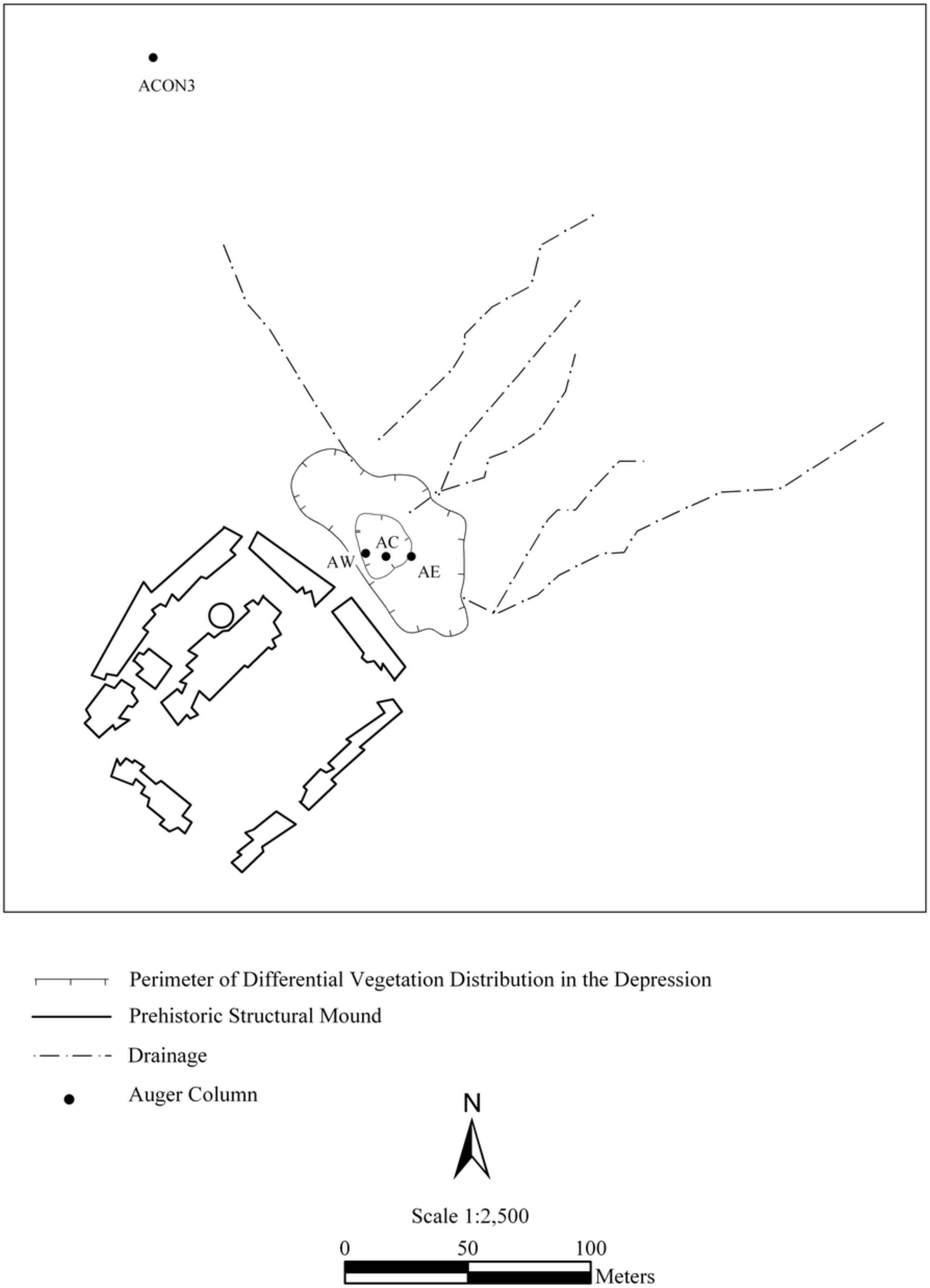


Figure 7. Locations of analyzed auger test columns.

Depositional Environment

The results of the geoarchaeological analyses are discussed for each auger column analyzed. Figure 8 presents average cumulative weight curves generated for each auger column. Soil texture classifications are provided for the sediment samples in Table 3. Table 4 presents the mean particle sizes from the particle size distribution analysis. For practical reasons, these results are converted from the phi scale of measurement to millimeters. Table 5 displays the standard deviation calculations that are used to indicate the degree of sorting for the sediment samples. Figures 9 through 11 display the results of the observations recorded for particle morphology and surface texture. The results of the organic, carbonate, and pH analyses are presented as line graphs in Figures 12 and 13.

West Auger Column (AW). The average cumulative weight curve for AW is consistent with standard curves that were generated from sediments collected from the delta foreslope of Lake Geneva (Figure 8). Typically, deposits formed around the margin of a lacustrine basin consist of fine sands and silt, with sand increasing from bottom to top (Reineck and Singh 1975:216).

Depositional processes responsible for the formation of the sedimentary deposit present in AW can be attributed to a combination of lacustrine, cultural, and colluvial factors. The amalgamation of both geological and biological evidence undoubtedly indicates the presence of water-laid sediments in this column. A synthesis of the particle size results, particle morphology and surface texture, as well as organic and carbonate content reveals a rather young depositional history for this column.

The very minute carbonate content of sediments recovered from this column denotes a fairly young deposit that has been subject to disturbance (Figure 12). A substantial peak

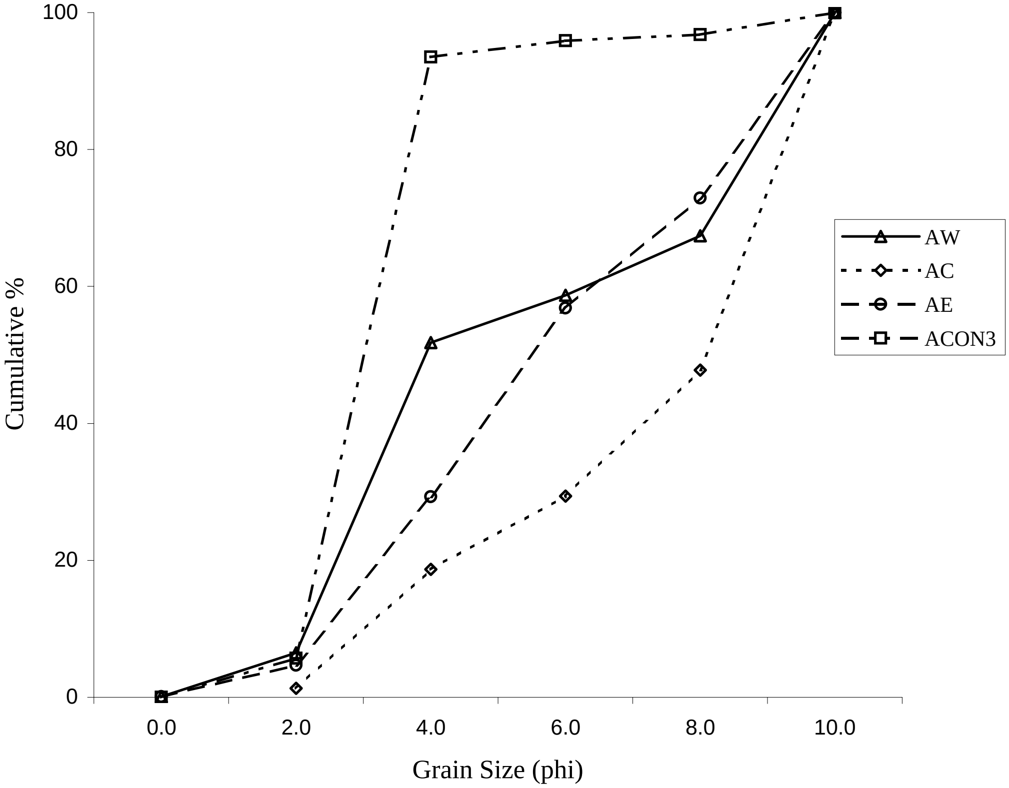


Figure 8. Average cumulative weight curve of each auger column.

Table 3. Soil Texture Classification of Sediments Analyzed from the Auger Columns.

Depth	Soil Texture Class			
(cm)	AW	AC	AE	ACON3
0	SCL	-	-	FS
10	LFS	-	-	FS
20	LFS	-	SCL	FS
30	LFS	C	LFS	FS
40	LFS	C	LFS	FS
50	LFS	C	LFS	FS
60	LFS	C	FS	FS
70	LFS	C	FS	FS
80	FSL	CL	FSL	FS
90	FSL	CL	SC	LFS
100	FSL	SCL	C	FSL
110	LFS	SC	C	FSL
120	FSL	SCL	C	FSL
130	FSL	SCL	C	SCL
140	SCL	SCL	C	C
150	SCL	SCL	SiC	C
160	SCL	SCL	SiC	SiCL
170	-	SCL	SiCL	SiCL
180	-	FSL	SiCL	SiCL
190	-	FSL	SiCL	SiCL
200	-	FSL	SiCL	SiCL
210	-	SCL	SiCL	SiCL
220	-	CL	SiL	SiCL
230	-	FSL	SiL	SiL
240	-	FSL	SiL	SiCL
250	-	FSL	SiL	SiCL
260	-	FSL	SiL	SiCL
270	-	SCL	SiL	SiCL
280	-	SCL	SiL	SiCL
290	-	SCL	SiL	SiCL
300	-	SCL	SiL	SiCL
310	-	SCL	SiL	-
320	-	SCL	SiL	-

Note : FS = Fine sand SC = Sandy clay SiC = Silty clay CL = Clay loam
FSL = Fine sandy loam SCL = Sandy clay loam SiCL = Silty clay loam
LFS = Loamy fine sand SiL = Silty loam C = Clay

Table 4. Mean Particle Size Results Calculated from Moment Measures.

Depth	Mean Particle Size (mm)			
(cm)	AW	AC	AE	ACON3
0	0.0652	-	-	0.1517
10	0.1278	-	-	0.1425
20	0.1259	-	0.0550	0.1425
30	0.1217	0.0161	0.1249	0.1407
40	0.1174	0.0159	0.1294	0.1355
50	0.1174	0.0167	0.1330	0.1393
60	0.1157	0.0191	0.1456	0.1443
70	0.1120	0.0249	0.1365	0.1443
80	0.0963	0.0295	0.0732	0.1392
90	0.0982	0.0382	0.0360	0.1301
100	0.0983	0.0474	0.0216	0.0977
110	0.1213	0.0396	0.0215	0.0956
120	0.0813	0.0494	0.0204	0.1011
130	0.0813	0.0660	0.0178	0.0866
140	0.0651	0.0673	0.0190	0.0281
150	0.0429	0.0406	0.0193	0.0233
160	0.0515	0.0688	0.0192	0.0240
170	-	0.0688	0.0205	0.0238
180	-	0.1053	0.0215	0.0220
190	-	0.0947	0.0233	0.0210
200	-	0.0947	0.0235	0.0215
210	-	0.0412	0.0236	0.0200
220	-	0.0315	0.0253	0.0213
230	-	0.0920	0.0284	0.0232
240	-	0.0810	0.0281	0.0207
250	-	0.0810	0.0272	0.0218
260	-	0.0762	0.0275	0.0212
270	-	0.0620	0.0263	0.0216
280	-	0.0734	0.0269	0.0221
290	-	0.0778	0.0285	0.0198
300	-	0.0383	0.0278	0.0187
310	-	0.0383	0.0273	-
320	-	0.0597	0.0273	-

Table 5. Sorting Index Results Calculated from Moment Measures.

Depth	Standard Deviation (phi)			
(cm)	AW	AC	AE	ACON3
0	2.22	-	-	1.08
10	1.63	-	-	1.09
20	1.66	-	2.30	1.09
30	1.71	1.92	1.71	1.23
40	1.77	1.91	1.60	1.30
50	1.77	2.01	1.57	1.28
60	1.84	2.11	1.47	1.24
70	1.85	2.27	1.28	1.24
80	2.02	2.27	2.13	1.33
90	2.02	2.41	2.57	1.60
100	2.04	2.41	2.42	2.06
110	1.84	2.44	2.35	2.13
120	2.19	2.46	2.26	2.20
130	2.19	2.31	1.98	2.40
140	2.32	2.30	2.01	2.50
150	2.41	2.41	1.87	2.16
160	2.40	2.22	1.86	1.84
170	-	2.22	1.90	1.94
180	-	2.01	1.75	1.87
190	-	2.02	1.78	1.52
200	-	2.02	1.83	1.46
210	-	2.43	1.69	1.55
220	-	2.34	1.53	1.48
230	-	2.07	1.37	1.47
240	-	2.22	1.33	1.42
250	-	2.22	1.34	1.61
260	-	2.21	1.29	1.44
270	-	2.22	1.58	1.67
280	-	2.29	1.32	1.57
290	-	2.31	1.39	1.48
300	-	2.45	1.26	1.47
310	-	2.45	1.25	-
320	-	2.39	1.25	-

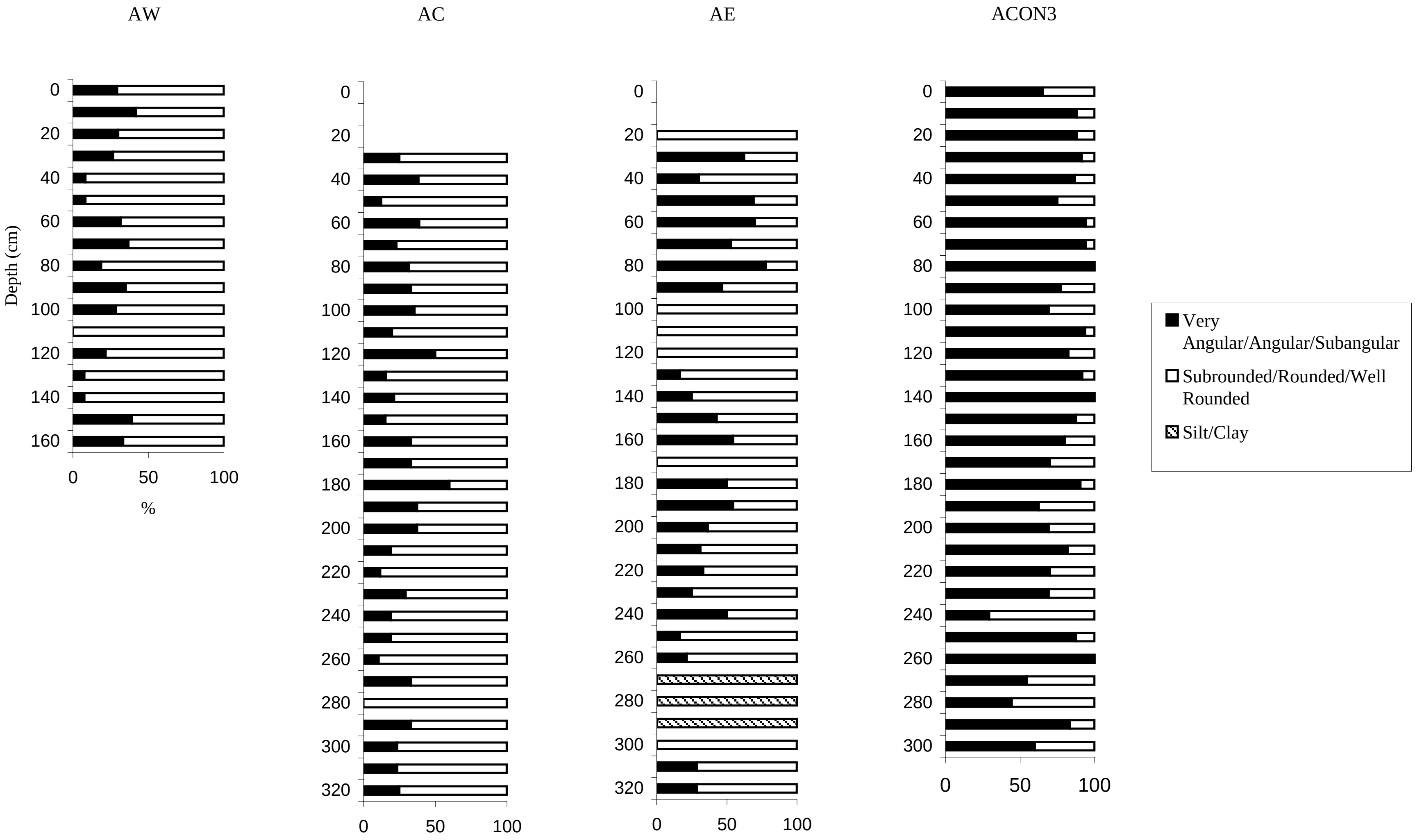


Figure 9. Percentage of rounded and angular sand grains.

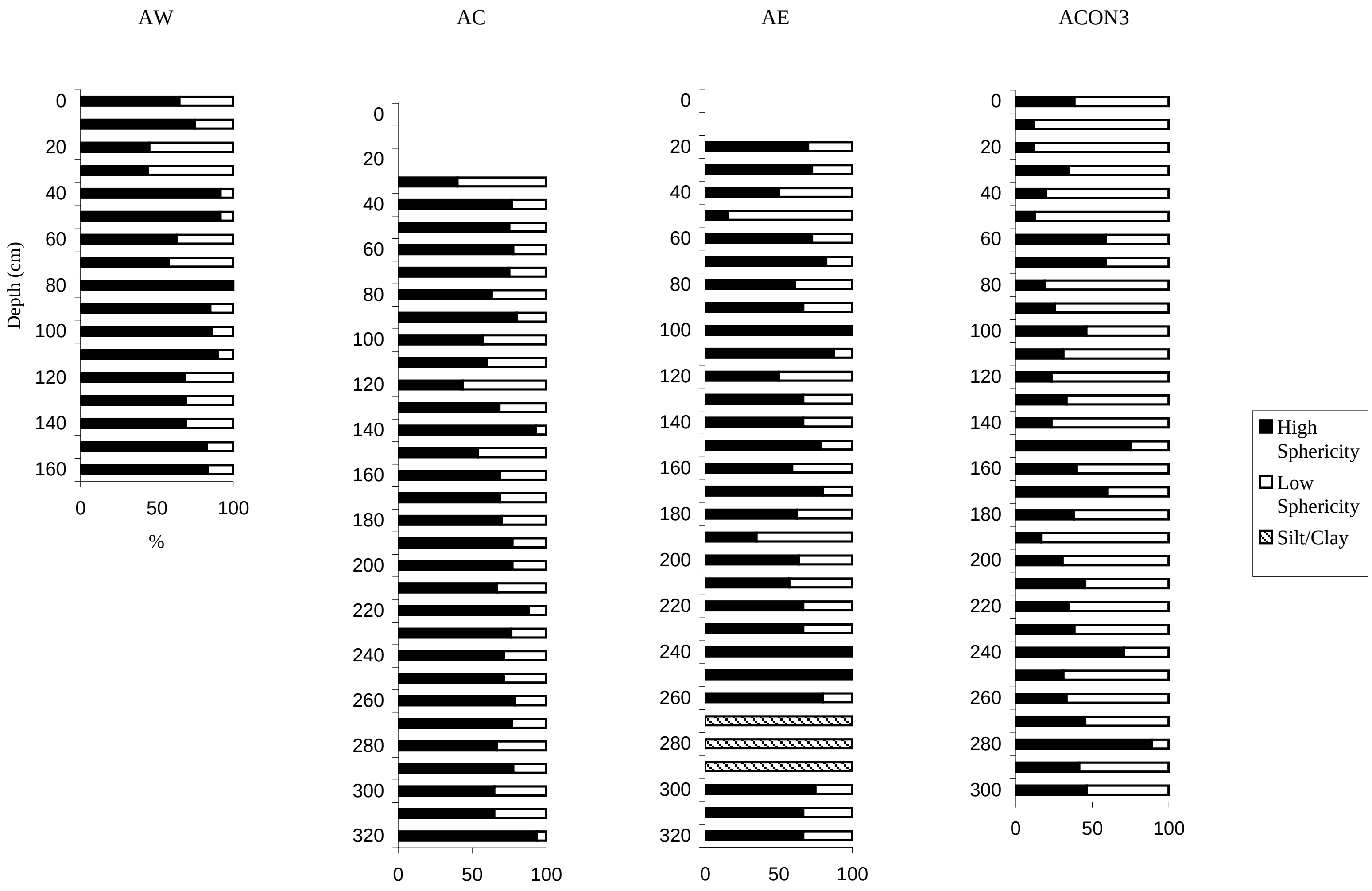


Figure 10. Percentage of sand grains exhibiting high and low sphericity.

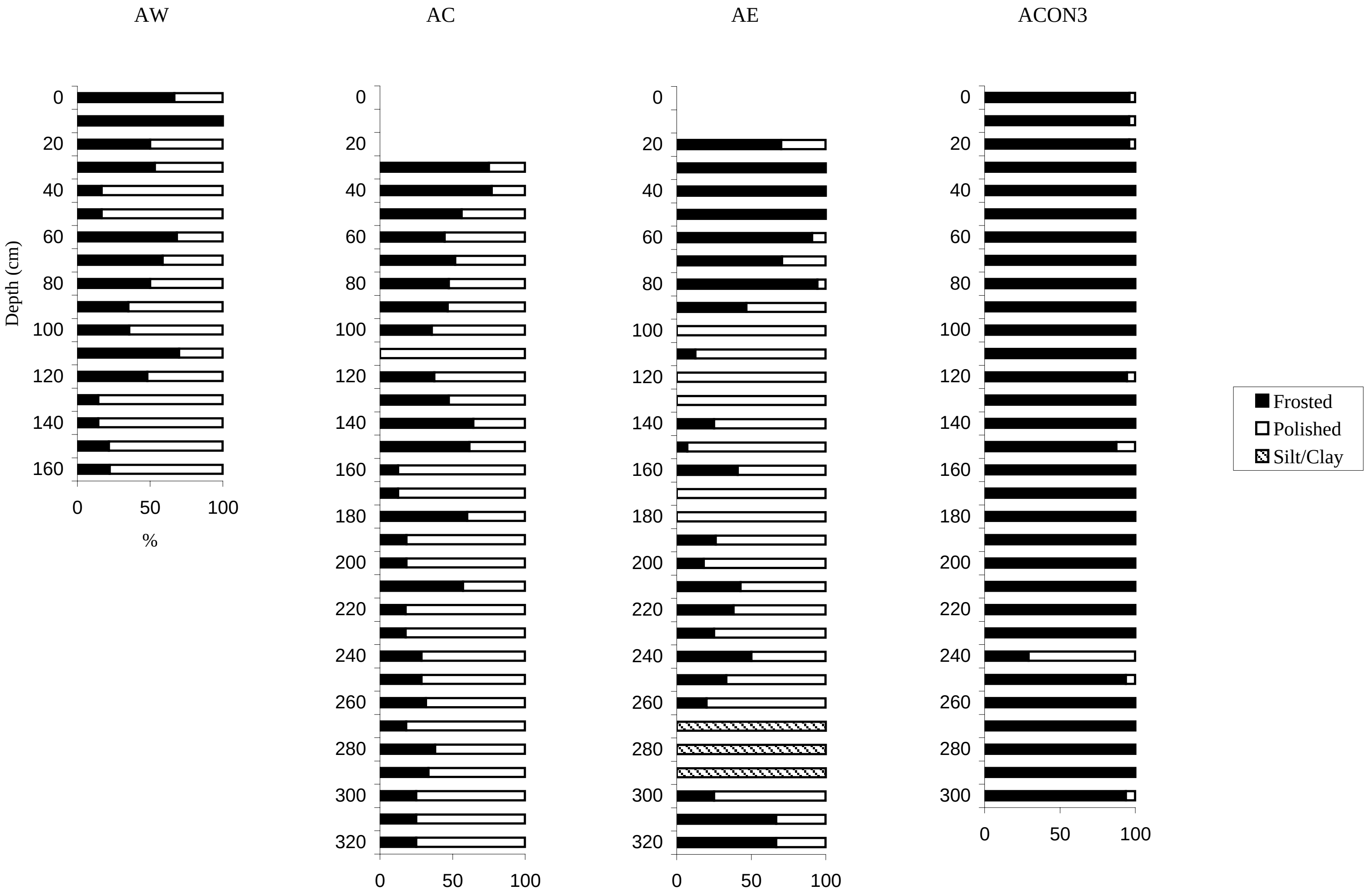


Figure 11. Percentage of frosted and polished sand grains.

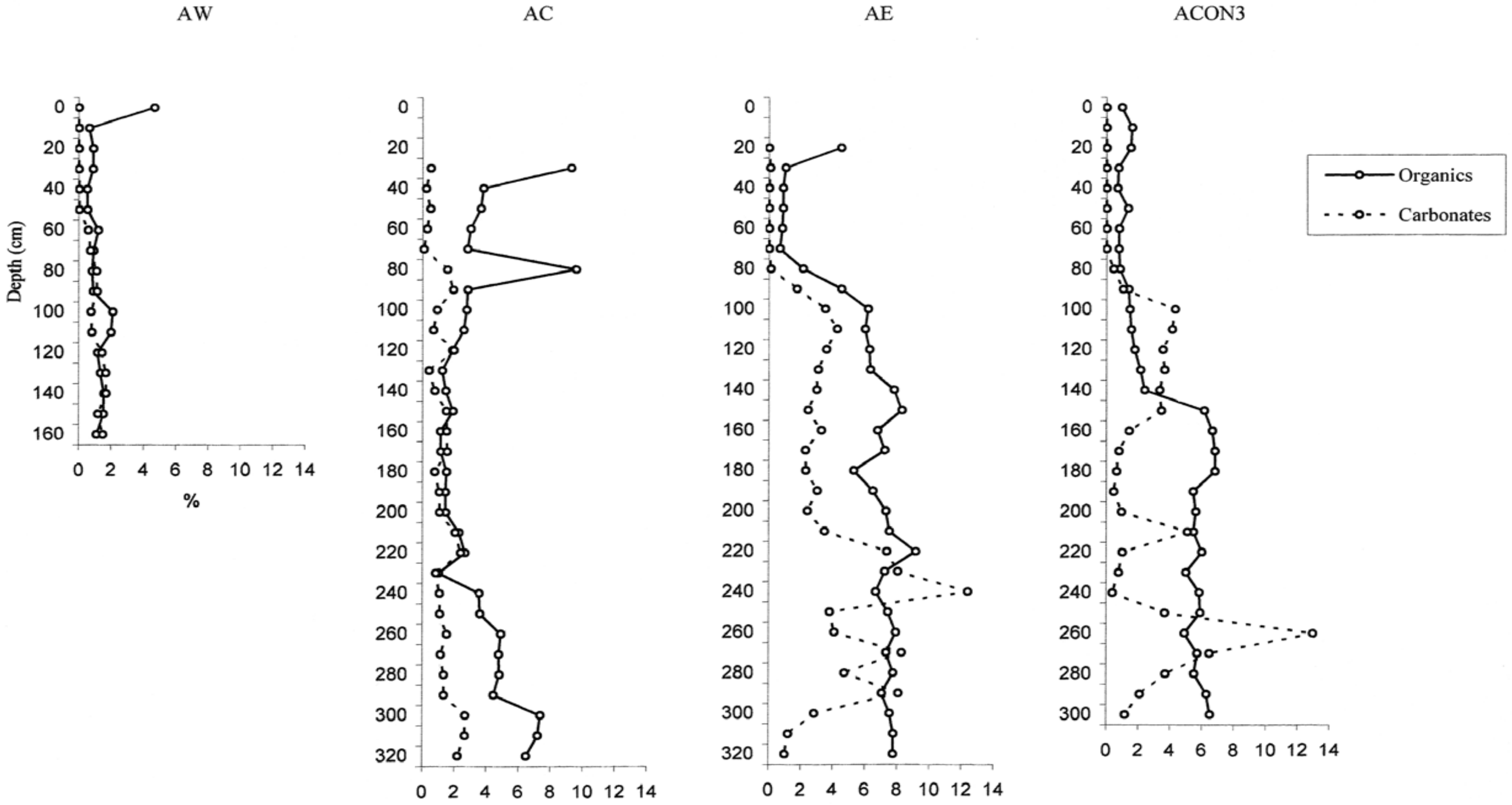


Figure 12. Organic and carbonate content of sediments analyzed from the auger columns.

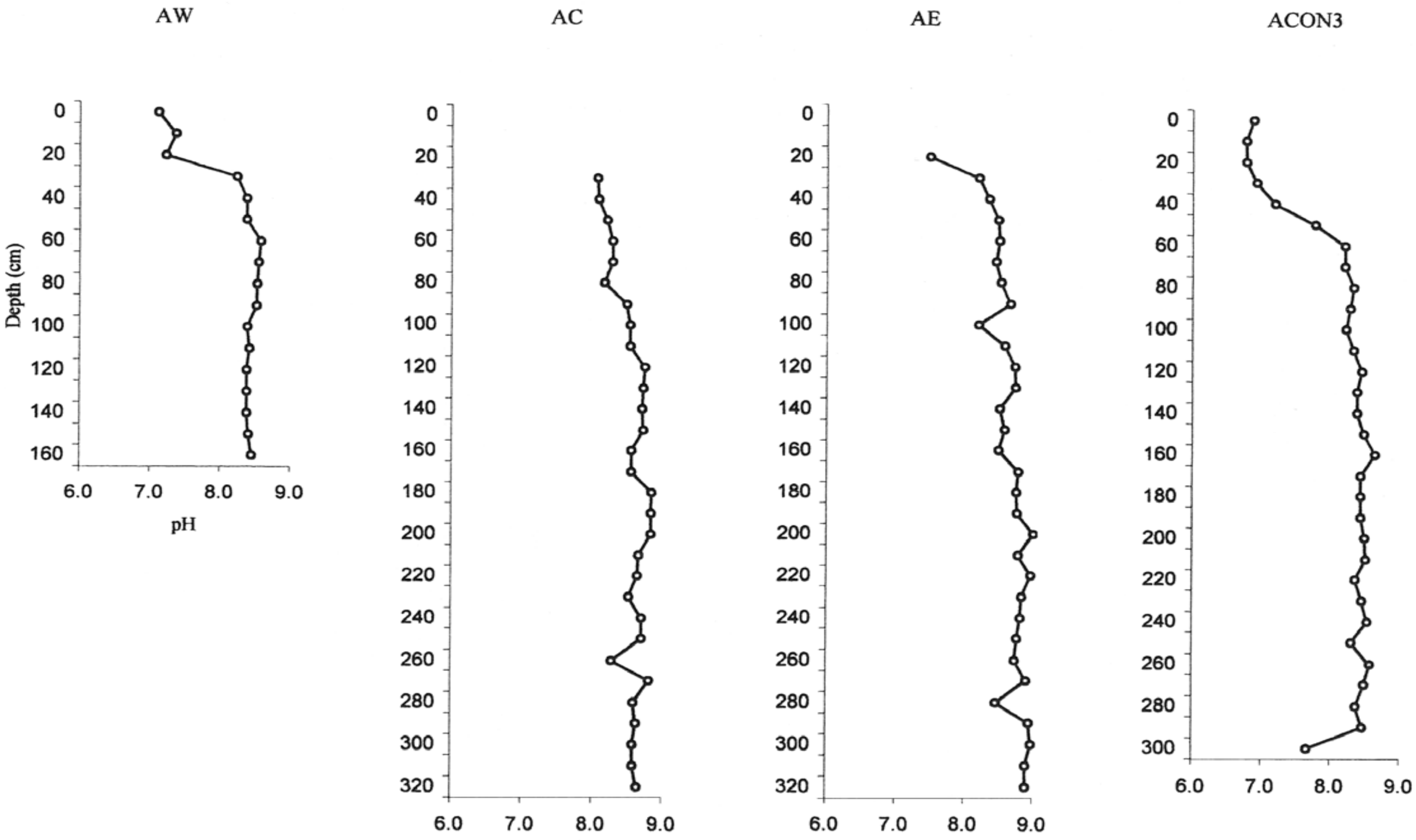


Figure 13. Results of the pH measurements.

in organic content from the uppermost sample analyzed from this auger is attributed to recent pedogenic activity. Pedogenesis or the development of soil profiles is indicated by a specific set of characteristics in chemical signatures and particle size distributions. Natural soil development is characteristic of the accumulation of organic matter in the upper horizon, while carbonates and fine-grained particles translocate down into the lower horizons or along contact with an impermeable layer (Waters 1992). The organic content of this sample is similar to the percentages noted for the surficial samples collected from both AC and AE. These chemical signatures indicate the recent development of an A soil horizon, in which decomposed matter and humus has accumulated. Modern ponding episodes within the depression likely resulted in this substantial increase in organics. There are two other slight peaks in organic content present at 60 and 100 cm that are not typical of natural soil development, but are attributed to hydrodynamic processes. Carbonates were not detected in sediments recovered from this column until a depth of 60 cm.

Sandy clay loam characterizes the uppermost sample recovered from AW, which is noted to occur at the very bottom of this column as well as at the bottom of AC (Table 3). This reversal in stratigraphy indicates cultural modifications, which were likely performed to maintain the storage capacity of the feature. Artifacts were recovered from sediments throughout the column, ranging from the uppermost sample to a depth of 150 cm. Charcoal infused sediments were also present from a depth of 40 cm to the bottom of the column. Poorly sorted sediments are generally the result of colluvial or cultural processes. Cultural modifications to the depression such as excavation and berming can be a contributing factor to the poorly sorted sediments recovered from this column (Table 5). Colluvial processes likely contributed sediments to this deposit given its position at the base of a prehistoric structural rubble mound.

Stratigraphically underlying the sandy clay loam, soil textures are characterized by loamy fine sand and sandy fine loam to a depth of 130 cm. Particle size data indicates two small episodes of fining upward from a depth of 80 to 110 cm and 150 to 160 cm (Table 4). This pattern indicates that hydrological processes aided in the formation of this deposit. Underlying the fine sands is a deposit of coarse silt that included prehistoric artifacts. Silt deposits are generally the result of settling in an aqueous environment or by translocation during pedogenesis. In a lacustrine environment, fines that are usually held in suspension in moving water environments eventually settle to the bottom (Waters 1992). This process is responsible for the accumulation of silts within the statigraphy of this auger column.

Observations on particle morphology and surface texture indicate primarily rounded sand grains that are highly spherical with polished textural modifications (Figures 9 through 11). Sediments modified by transport in an aqueous environment are typically rounded and clear, and vary in particle size distributions according to potential levels of hydraulic energy. Spring environments also create highly spherical and highly polished sand grains (Waters 1992). Polished sand grains predominate from a depth of 130 to 160 cm, corresponding to very poorly sorted sediments and a stratum comprised of coarse silt. The lower wave energy in lakes and the fluctuation of water level also results in sediments that are mixed in size or poorly sorted (Rapp and Hill 1998).

Invertebrate remains, notably a single ostracode carapace and fragmented gastropod shells, were present in sediments from a depth of 70 cm to the termination of the column. Shells appeared in this column as a result of the former aqueous environment and redeposition. The column terminated at a maximum depth of 160 cm below ground surface, where a large rock or bedrock was encountered.

Center Auger Column (AC). The average cumulative weight curve generated for this column is characteristic of standard weight curves that represent sediment distributions in the central plain and lateral slopes of a lacustrine environment (Figure 8). Deposits formed in the lateral slope and central plain are characterized by accumulations of silt and clay with minor sand intercalations (Reineck and Singh 1975).

Lacustrine and cultural modifications resulted in the sedimentary deposit present in AC. The distribution of organics and carbonates in the AC column are not characteristic of natural soil development (Figure 12). The natural weathering of organics is typified by decreasing percentages of organic matter with increasing depth. The low percentages of carbonates in this column indicate that these sediments are fairly young and have not been stabilized for a substantial period of time. The significant peak in organics from the uppermost sample is indicative of recent pedogenic activity resulting in the formation of an A soil horizon. Other substantial peaks noted in the distribution of organics are characteristic of hydrodynamic processes.

Soil textures within the column are dominated by clay and silt-sized particles (Table 3). The average particle sizes of AC are generally finer than the sands and coarse silts that dominate AW (Table 4). The average particle sizes indicate three distinct episodes of upward fining in the deposit from a depth of 200 cm to the surface, 260 to 210 cm, and 290 to 270 cm. These particle size distributions are characterized by coarse and fine silt deposits intercalated with very fine sand strata. Hydrodynamic processes are typified by these sediment distributions. These sediment distributions represent three episodes of fairly turbid water influx in the sedimentary history of the depression. Accumulations of silts and clays are the result of either translocation during pedogenesis or settling in an aqueous environment. The distinct episodes of fining up and textural modifications of the sediments indicate hydrodynamic processes. The silt and clay deposits are the result of settling in an aqueous environment. Observations on particle morphology and surface texture correlate with modifications noted in an aqueous environment. The majority of sediments examined from this column are well rounded and polished with a high sphericity, which is indicative of sediments modified in a spring environment (Figures 9 through 11).

Significant increases in the distribution of organics from AC roughly correlate with the episodes of upward fining in sediment distributions. The substantial peak in organic content and increase in carbonates at a depth of 80 cm corresponds to the appearance of invertebrate remains in sediments from this column. Sediment distributions within AC are also reversed in comparison to AE, with clays dominating the upper strata in the column. A reversal in stratigraphy points toward cultural modification or maintenance of the depression. Artifacts were recovered from a depth of 90 to 320 cm within this column. Sediments from a depth of 90 cm to the termination of the column were also heavily infused with charcoal. Corn pollen appeared in relatively high concentrations at varying depths throughout AC, ranging from 220 to 320 cm, with substantial concentration values at a depth of 300 cm. Lacustrine and cultural processes were responsible for the very poorly sorted sediments that are ubiquitous throughout this column (Table 5).

Water appeared at the bottom of the column during sample collection. Sediments recovered from this column were saturated with water around 190 cm below ground surface. At 268 cm water began to fill the bottom of the column. This column filled with 30 cm of water during sample recovery. The water sample collected from this column is alkaline, with a pH measurement of 7.84. The presence of water at a depth of 268 cm (8.7 ft) below the surface suggests that this was a prime location for water storage, indicating that a subsurface water source is present within this feature. Perched springs or seeps are common in the Southwest and occur where an impermeable layer outcrops beneath a water-bearing permeable stratum. Textural modifications of polishing are indicative of alteration in a spring environment (Waters 1992:216). The exploitation of an underground water source will definitely result in cultural modification of the depression contributing to the mixing that is apparent in this column. As was the case in the evaluation of the AW, the presence of a large rock at the bottom of the AC column prevented augering to a greater depth. The rock located at the bottom of this column was pushed down into the waterlogged sediments with the auger, indicating that bedrock was not encountered.

East Auger Column (AE). The average cumulative weight curve generated for AE is consistent with standard curves characteristic of the lateral slope and central plain of a lacustrine environment (Figure 8). Deposits formed in this area of a lacustrine basin generally consist of silt and clay-sized sediments that include minor sandy intercalations (Reineck and Singh 1975).

A combination of aeolian, lacustrine, and pedogenic processes contributed to the formation of the deposit in AE. The uppermost stratum within this column consists of a sandy clay loam that includes a substantial peak in organic content (Table 3 and Figure 12). This distribution, as in the case of AW and AC, is indicative of recent pedogenic activity that resulted in the formation of an A soil horizon.

From the surface to a depth of 80 cm fine sands dominate the particle size distributions (Table 4). Sediments recovered from this depth in the column are generally angular, with a high degree of sphericity and frosting (Figures 9 through 11). They also include a very low organic and carbonate content. These sands are characteristic of aeolian deposition.

Aeolian deposition generally produces well sorted silt and sand-sized deposits with sand grains that are characteristically rounded, frosted, and highly spherical. Similar to alluvial/fluvial depositional processes, particles transported in an aeolian environment are also deposited by wind in suspension, by saltation, or by surface creep (Waters 1992). The initiation of particle movement in an aeolian environment is contingent upon wind velocity and particle size. Silt and clay-sized particles are transported in suspension. These fine-grained sediments become airborne as a result of impact by saltating grains and are then buoyed to great heights by wind turbulence (Waters 1992). Saltation transports fine- to medium-sized particles downwind by hopping or skipping along the ground. After sediments become airborne, the free-fall velocity of the particle exceeds the velocity of the wind, resulting in the grain falling and colliding with the ground. Upon impact with the ground, sand grains will either rebound or set other particles into motion. Saltation is the dominant mechanism by which wind transports sediment (Waters 1992). Surface creep occurs when saltating grains strike the surface and roll or move heavier particles without displacing them vertically, and is the dominant mechanism that is responsible for the movement of coarse sands (Waters 1992).

During aeolian sediment transport, the collision of sand grains results in a frosted, and sometimes pitted, textural modification. The process of attrition results in the removal of small chips and fragments that protrude from shape corners causing sand grains to become well rounded. However, fine sands and particles finer than 0.05 mm (coarse silt) tend to remain angular (Briggs 1977). Windblown materials often become incorporated into many different deposits, especially in closed basin settings that tend to act as a sediment trap (Feibel 2001).

The depositional sequence noted in uppermost strata of the column represents the post-abandonment filling of the depression via aeolian processes. Dunal deposits were either redeposited by runoff and slopewash or by direct aeolian infilling of the depression. The sorting indices of sediments within these strata range from very poor to poorly sorted, suggesting that slopewash and runoff likely redeposited dunal materials into the depression (Table 5). Likewise, the hydrological modeling analysis and gullies leading into the depression indicate that runoff patterns lead into the feature from the east.

Organic and carbonate content begins to progressively increase at a depth of 90 cm with several substantial peaks that occur in the distribution. Increases in organic content correspond with the appearance of clay and clay loams and a pattern of upward fining in the sediment distributions to a depth of 240 cm. The range of sorting index values for sediments from a depth of 90 to 240 cm are all characterized as poorly sorted sediments. Observations on particle morphology indicate predominately rounded sediments with a high sphericity, and textural modifications consisting of highly polished/clear sand grains. These strata exhibit characteristics of alteration in a lacustrine environment.

A synthesis of the data indicates the presence of a paleosol underlying the lacustrine deposit in this column. Stratigraphically below the lacustrine deposit, a pattern of downward fining is noted in sediment distributions. This deposit primarily consists of a silty loam. From this depth, sorting index values become progressively smaller indicating moderately well sorted sediments. The organic content of sediments from a depth of 250 to 320 cm holds steady and does not include any substantial increases, while carbonate content is characterized by two substantial peaks in the distribution. This silty loam stratum represents a buried B soil horizon, in which illuvial accumulations have resulted in the concentration of fine particles, organics, and carbonates.

Control Auger Column (ACON3). The average cumulative weight curve generated for the control auger column includes a substantial aeolian hump (Figure 8). The particle size distributions indicated from this curve are typical of standard curves that characterize dune sands (Rapp and Hill 1998:39).

The sedimentary history of the control auger is rather straightforward in comparison to the columns analyzed from the depression. The results of particle size distribution and particle morphology analyses indicate that differential depositional processes are responsible for the formation of the deposits within the depression than in the control locality. Sediments recovered from the uppermost 90 cm of this column are much coarser than any of the columns located within the depression.

Aeolian sands dominate the depositional sequence within the upper half of this column (Table 3). This is noted from the fine and very fine sands that predominate the particle size distributions (Table 4). Observations of particle morphology and surface texture on sediments recovered from the depression contrast the textural modifications of sediments collected from the control samples. Sediments recovered from the control locality are generally more angular, have a low sphericity, and are frosted (Figures 9 through 11). These characteristics indicate that aeolian processes were primarily responsible for the formation of this deposit.

The aeolian sands represented in the uppermost strata of this column have been stabilized for a substantial period of time, resulting in the development of a soil. A distinct pattern of downward fining is apparent in the sediment distributions within these strata, coupled with the presence of moderately well sorted sediments (Table 5). The distribution of organics and carbonates is characteristic of natural soil development, with a decrease in organics and an increase in carbonates from the surface to a depth of 140 cm (Figure 12). The slight increase in organic content at a depth of 10-20 cm represents an A horizon of the modern soil in this column, where decomposed organic matter or humus has accumulated. Stratigraphically underlying the A horizon, an illuvial B horizon is present from a depth of 90-140 cm. This soil horizon is characterized by the illuvial concentration of carbonates and clays that can be seen in both soil texture and chemical signatures. Carbonate nodules characteristic of soil formation are also present within this horizon from a depth of 90-120 cm.

The paleosol present in the lower part of AE is also present in ACON3 from a depth of 150 cm to the termination of the column at 300 cm. Organic and carbonate distributions are very similar between the lowermost portions of both AE and ACON3. Chemical signatures in ACON3 are distinguished by a slight decrease in distribution of organics, while carbonate content includes two substantial peaks that progressively increase with depth.

Particle size distributions also follow a successive pattern of fining downward from this depth. From a depth of 150-180 cm, a buried A horizon is signified by an accumulation of organic matter. Stratigraphically underlying this stratum is an illuvial B horizon typified by the concentration of carbonates from a depth of 190-300 cm. This paleosol characterizes the ancient topography of this area, which is present at a depth of 150 cm in ACON3 and at 240 cm in AE. The difference in elevation between the paleosol present in AE and ACON3 is roughly 9 m, suggesting that the paleosurface is comparable to the modern topography. However, the A horizon is absent from the paleosol present in the bottom of the AE column indicating that this surface was slightly higher in elevation.

Pollen

The results of the pollen analysis are presented in Figures 14 and 15. A total of 10 pollen samples were analyzed: five from the center auger column (AC) and five from the control locality (ACON3) (Table 1). Pollen samples recovered from AC contained fairly well preserved assemblages throughout the column indicated by the pollen concentration values. Samples analyzed from the center of the depression include arboreal pollen species consistent with the presence of a Piñon-juniper community. This includes ponderosa pine (*Pinus ponderosa*), piñon pine (*Pinus edulis*), juniper (*Juniperus*), and oak (*Quercus*) pollen. Elevated concentration values of *Quercus* were present, which is a common understory component of the Piñon-juniper plant community. A single grain of elm (*Ulmus*) was present in a single sample. *Ulmus* is not native, but was introduced historically to the area and is most likely the result of recent contamination (Holloway 2005).

The non-arboreal pollen component included generally high concentrations of grasses (Poaceae) high and low spine Asteraceae, and sagebrush (*Artemisia*). High spine Asteraceae includes plants such as ragweed and cocklebur, while low spine Asteraceae consists of aster, rabbitbrush, snakeweed, and sunflower. Cheno-am was present in varying concentrations throughout the column. Cheno-am is an artificial pollen morphological category which includes pollen of the family Chenopodiaceae (goosefoot) and the genus *Amaranthus* (pigweed) (Martin 1963). Cactaceae and cholla (Cylindropuntia) were also well represented. These taxa are insect pollinated plants and produce relatively fewer pollen grains (Holloway 2005). Consequently, cactus pollen is rarely incorporated into sedimentary deposits. Pollen concentration values for globe mallow (*Sphaeralcea* spp.) and corn (*Zea mays*) were also high throughout the center auger column (Holloway 2005). The high concentration values of pollen in the depression were

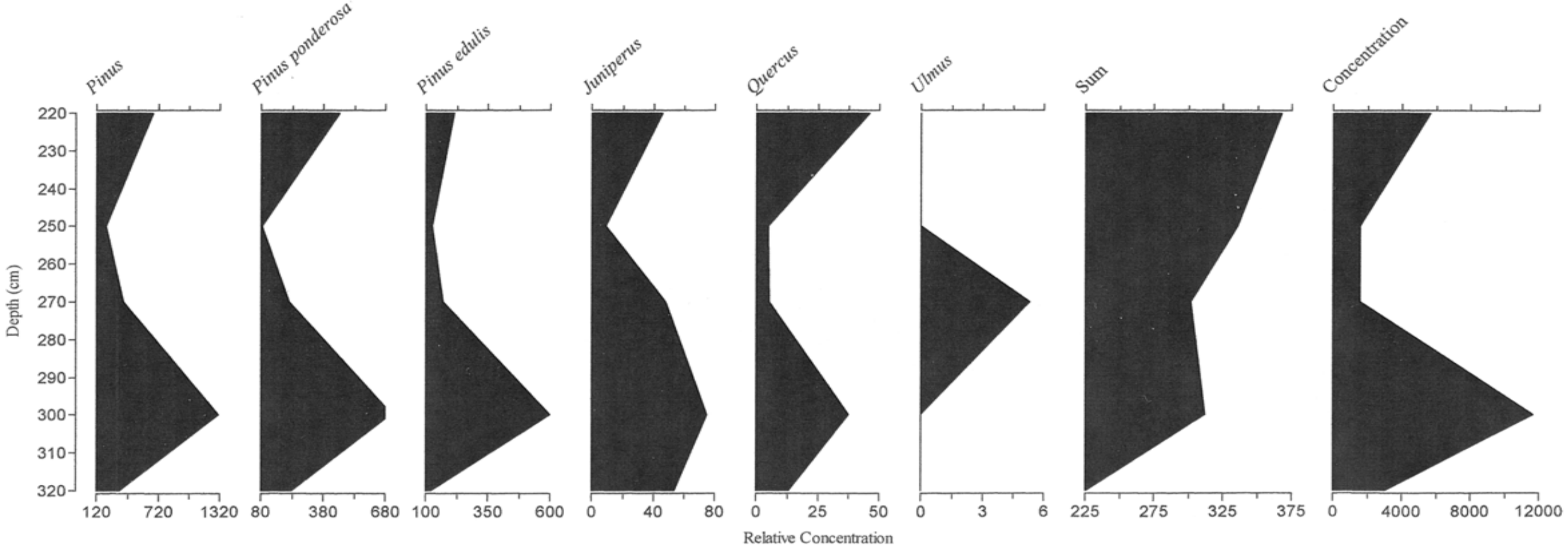


Figure 14. Arboreal pollen species recovered from the depression.

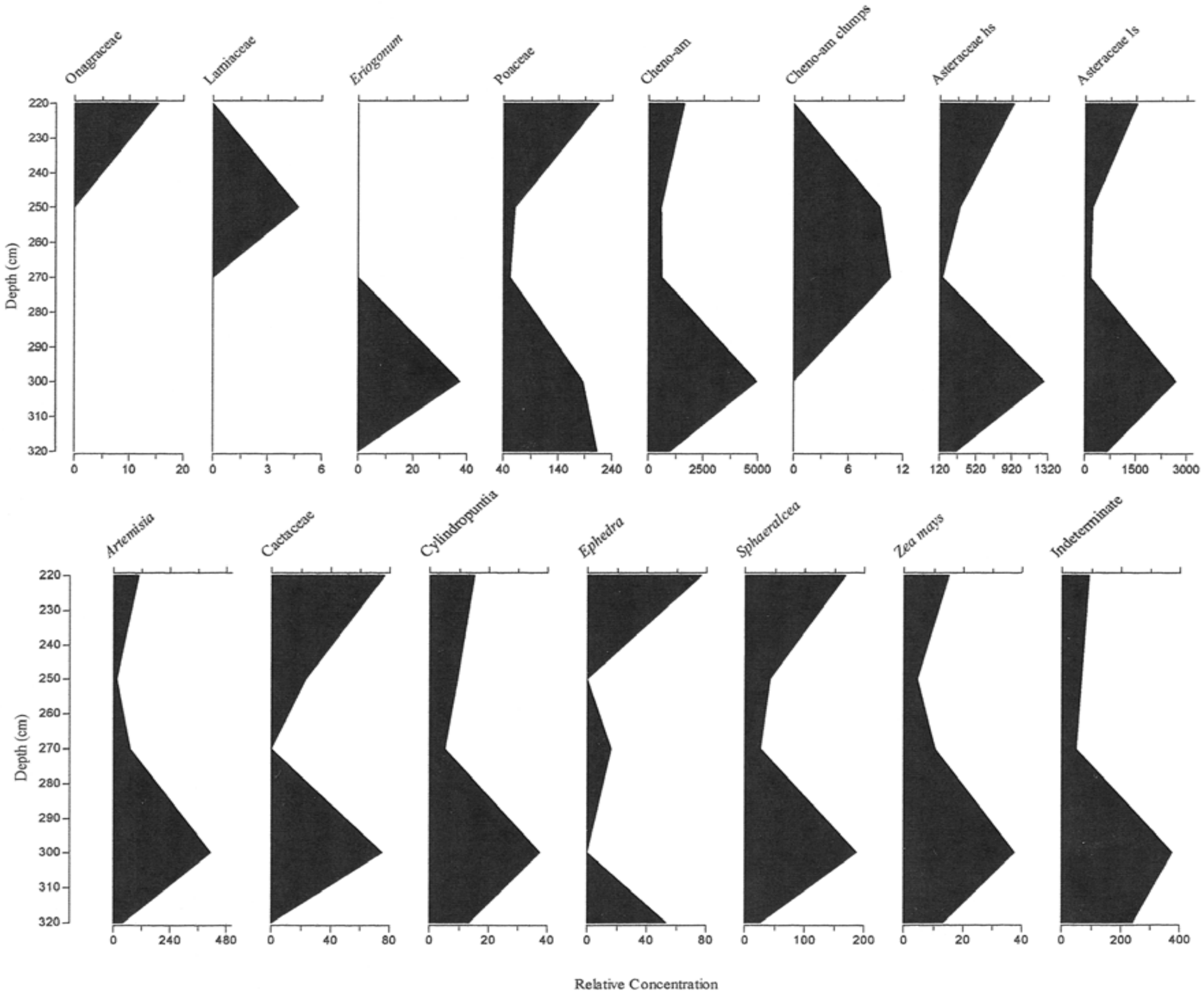


Figure 15. Non-arboreal pollen species recovered from the depression.

due to the water body functioning as a pollen trap. A trace amount of Mormon tea (*Ephedra*) pollen was also represented in the assemblage.

Several economic taxa were identified in the assemblage: evening-primrose family (Onagraceae), mint family (Lamiaceae), buckwheat (*Eriogonum*), Cactaceae, cholla, globe mallow, and corn (Holloway 2005). There were no aquatic taxa represented in the pollen assemblage recovered from the depression. Cattail (*Typha* sp.) pollen did not appear in any of the samples. The pollen assemblage represented in samples recovered from the feature does not differ substantially from the present vegetation community around Pueblo Oso Negro.

The control samples did not yield any pollen, except for a few trace amounts of various local taxa (Holloway 2005). The Texas A&M Palynology Laboratory conducted the extraction process twice for the control samples to ensure that the absence of pollen was not the result of laboratory procedures. Neither extraction procedure for the control samples produced any pollen for analysis. Sediments recovered from the control locality consist of aeolian sand deposits that have weathered into a soil. This unconsolidated sandy matrix includes intracellular spaces that likely accommodated the removal of pollen by the percolating action of precipitation (Holloway 2005).

In the previous section a set of hypotheses were presented to evaluate the results of the pollen analysis. The null hypothesis stated that there is no significant difference in the species of pollen present in the sediments of the probable water storage feature than in the surrounding sediments. The alternative hypothesis asserted that there is a significant difference in the species of pollen present in the sediments of the probable water storage feature than in the surrounding sediments. Pollen was not present in samples recovered from the control locality, therefore, the null hypothesis is rejected indicating that there is a significant difference in the species of pollen present in the sediments of the probable water storage feature than in the surrounding sediments. Due to the absence of pollen in the control samples direct comparisons between the pollen assemblage of the depression and control samples cannot be made.

Invertebrate Remains

Sediments collected from the AW and AC auger columns, located within the probable water control feature, yielded invertebrate remains. The presence of invertebrates within sediment samples collected from the auger columns is illustrated in Figure 16. The faunal assemblage includes invertebrates from the Phylum Arthropoda (ostracodes) and the Phylum Mollusca (gastropods). Additionally, an abundance of unidentified shell fragments were present in numerous samples collected from the depression. These remains were too fragmented to allow for specific identification; however, they appeared to be broken gastropod shells. Invertebrates belonging to the subclass Ostracoda are confined to aquatic environments, while animals belonging to the class Gastropoda can inhabit both terrestrial and aquatic environments.

Ostracodes. Ostracode valves were present in three samples collected from the center auger column and one sample from the west auger column (Figure 16). Dr. Alison Smith with the Department of Biological Sciences, Kent State University, identified the ostracodes as juvenile forms of either *Candona rawsoni* or *Candona patzcuaro* (Figure 17).

All of the ostracodes recovered from the sediment samples were in the juvenile stage of development. Throughout the life cycle of ostracodes the carapace is shed up to eight times (Smith 2001) and the valves do not appear in the adult form until the final molt. This presented a problem with identifying species due to the lack of distinguishing characteristics in shell morphology. Species identification was based on adductor muscle scars present on the exterior

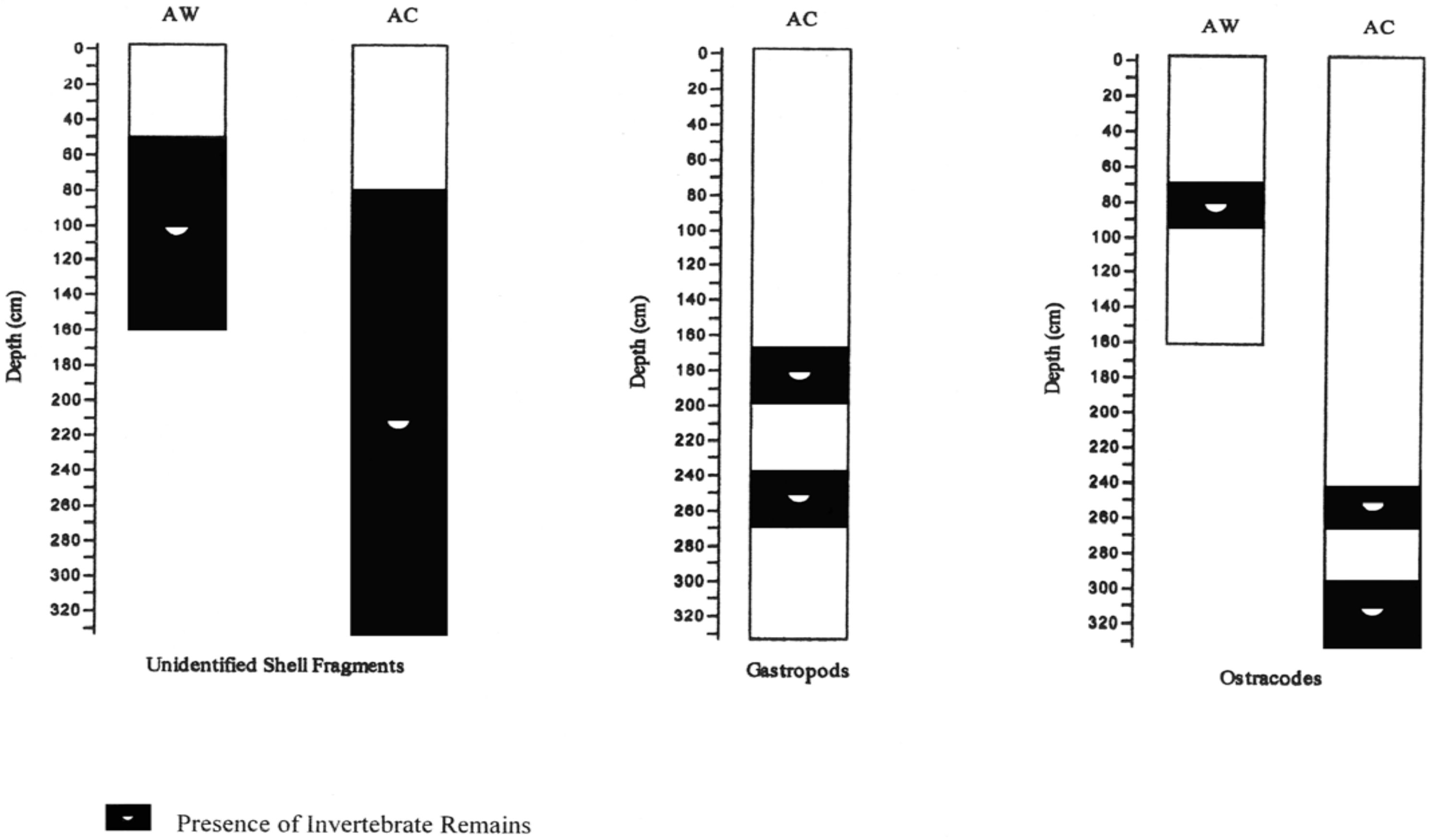


Figure 16. Distribution of invertebrate remains in auger columns located within the depression.

Figure 17. Scanning electron micrograph of the exterior lateral view of a selected *Candona* specimen at a magnification of 180X. Line scale is equal to 10 µm.

lateral view of the carapace (Figure 18). These two species of ostracodes are indistinguishable in their juvenile stages and close to identical in the adult stage (Delorme 1970:1114). Both of these ostracode species belong to the same taxonomic subfamily and genus. In the absence of adult forms, identification to the species level was not possible. Both of these species are very tolerant of variable conditions of salinity (fresh/saline) and drought, and consequently are common in prairie potholes, southwestern playas, and wetlands (Dr. Alison Smith, personal communication 2006). However, *C. patzcuaro* is more commonly distributed in semi-arid regions (Delorme 1970).

Characteristics of the ostracodes recovered from the depression include a whitish carapace with distinctive pore canals. The shell is elongated with the height equaling one half the width. The juvenile Candoninae specimen shown in the scanning electron micrograph measures 0.589 x 0.029 mm (Figure 17). The muscle scar pattern of the Candoninae specimen is analogous to patterns characteristic of both *Candona rawsoni* and *C. patzcuaro.*

Candona p*atzcuaro* is differentiated by an elongated carapace. The height of the shell is slightly greater than one-half the width and includes rounded ends (Tressler 1954). Valves are smooth and sparsely hairy. The carapace of this species is a whitish color and includes pore canal features. The average length and width of the shell is 1.30 x 0.68 mm (Tressler 1954).

Candona rawsoni is characterized by an elongated carapace, with a maximum height equaling about one-half the length (Tressler 1957). The dorsal margin and the anterior ends of both valves are rounded. The average length of this species is 1.26 x .72 mm (Tressler 1957). The adductor muscle scar patterns of *C. patzcuaro* and *C. rawsoni* are indistinguishable.

In the previous section a set of hypotheses were presented to evaluate the potential of using ostracodes to indicate that the depression served as a prehistoric water storage feature. The

Figure 18. Scanning electron micrograph of the adductor muscle scar pattern of a selected *Candona* specimen at a magnification of 910X. Line scale is equal to 10 µm.

null hypothesis stated that there is no significant difference in the species and quantity of ostracodes in the sediments of the probable water storage feature than in the surrounding sediments. The alternative hypothesis asserted that there is a significant difference in the species and quantity of ostracodes in the sediments of the probable water storage feature than in the surrounding sediments. Ostracode shells were only recovered from the AW and AC auger columns located within the depression. Ostracodes were not present in any of the sediment samples from AE or ACON3. Due to this fact the null hypothesis is rejected and the alternative hypothesis is accepted. The presence of aquatic fauna in sediments collected from the depression leads to the implication that water was in fact present in the depression. Paleoecological implications of the species of ostracodes recovered from the feature are discussed in the following section.

Gastropods. Three species of gastropods were recovered from sediment samples collected from the depression. Representative specimens recovered from the feature are presented in Figures 19 through 21. These specimens were present in two samples recovered from AC (Figure 16). Additionally, an abundance of unidentified shell fragments present in both AW and AC were assumed to be fragmented gastropod remains. Gastropod species determination is based on both the soft (internal anatomy) and hard (shell) parts, and taxonomic classifications to the species level cannot be determined merely from shell features. The shells also exist in a somewhat fragmented state. The identification of shells is usually based on the characteristics of the aperture, and this feature was absent from every specimen recovered from the depression.

All of the gastropods recovered from the depression belong to the subclass Pulmonata. Pulmonate gastropods are widespread on land and in fresh waters (Moore 1964; Hyman 1967).

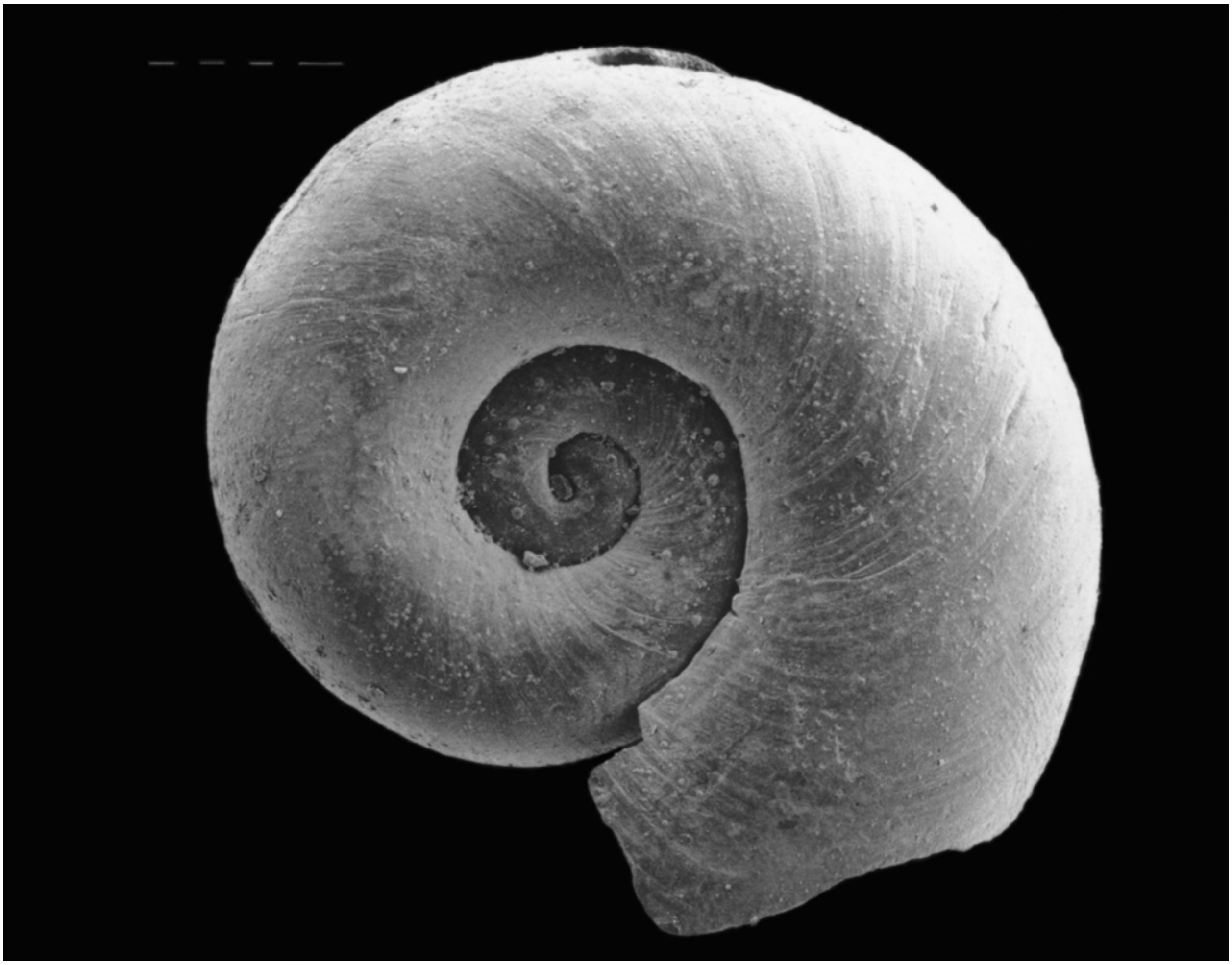


Figure 19. Scanning electron micrograph of the abapertural vertical axis of a selected Planorbidae specimen at a magnification of 42X. Line scale is equal to 100µm.

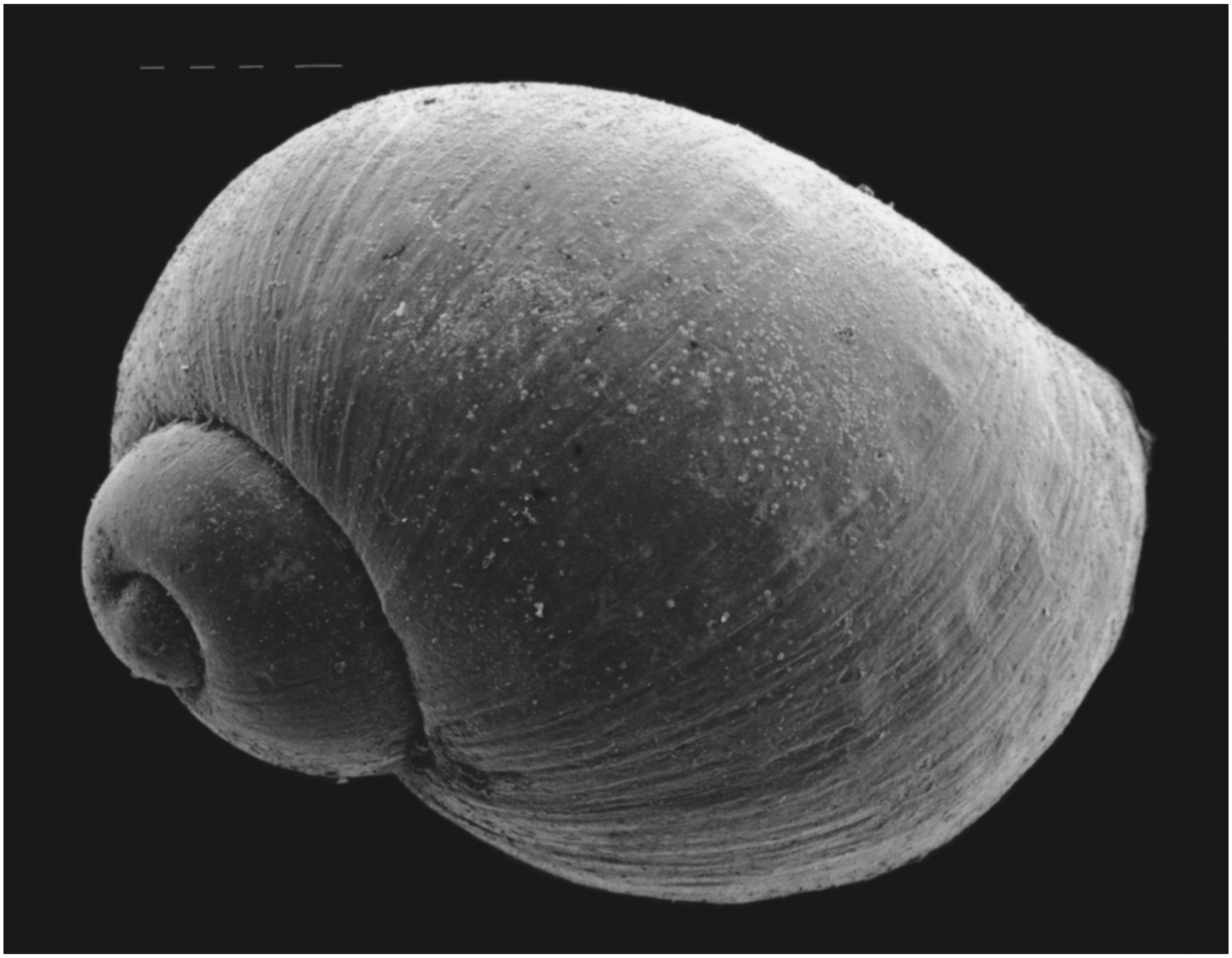


Figure 20. Scanning electron micrograph of the abapertural vertical axis of a selected Lymnaeidae specimen at a magnification of 50X. Line scale is equal to 100µm.

Figure 21. Scanning electron micrograph of the abapertural vertical axis of a selected Pupillidae specimen at a magnification of 62X. Line scale is equal to 100µm.

Typically the shells of pulmonate gastropods are spiral and range in size from 1 to 160 mm (Hyman 1967; Thiele 1992). This subclass of gastropods is divided into two orders: Basommatophora and Stylommatophora. Terrestrial pulmonates ("true" land snails) are in the order Stylommatophora, while the freshwater pulmonates are placed in the order Basommatophora (Moore 1964; Dillon 2000).

The Basommatophora comprise shelled aquatic pulmonates that have one pair of tentacles with an eye at their base. Four major freshwater pulmonate families belong to the order Basommatophora (Dillon 2000). Stylommatophora pulmonates contain many species exploiting a great range of habitats on land. These terrestrial pulmonates are characterized by two pairs of tentacles, with the eyes borne on the tips of the posterior pair (Moore 1964; Hyman 1967). Although all are in the subclass Pulmonata, the freshwater pulmonate snails are not closely related to the land snails. Gastropods recovered from the depression belong to both Basommatophora and Stylommatophora. Three distinct families of gastropods were present in the faunal assemblage: Planorbidae, Lymnaeidae (Basommatophora), and Pupillidae (Stylommatophora).

The first of the three species of gastropods recovered from the probable water control feature belongs to the family Planorbidae (Figure 19). The planorbids, commonly known as ramshorn snails, are aquatic pulmonates distributed in mud bottoms rich in decaying matter of river pools, lakes, or ponds (Dillon 2000). Planorbid shells are generally planispiral or disk-shaped (Thiele 1992). These shells are coiled in a single plane, with symmetrical sides and a small aperture (Moore 1964).

Gastropods belonging to the family Lymnaeidae were also present in sediments recovered from the depression (Figure 20). Lymnaeids include a large family of freshwater aquatic pulmonates (Hyman 1967). These snails are widely distributed in freshwater ponds, lakes, and marshes. The Lymnaeidae have conical dextral shells. The shell shape is highly variable but the body whorl is usually expanded with a wide aperture. Lymnaeidae shells are commonly thin and characterized by a more or less high spire (Hyman 1967). Sinistral (left-handed) shells are described by an aperture on the observers left when the shell apex is directed upward, while the aperture of dextral shells opens to the right (Smith 2001).

The final type of gastropod recovered from the depression belongs to the order Stylommatophora and family Pupillidae (Figure 21). This is a large family of small or minute snails, that comprise over 40 genera and nearly 700 species that are distributed over all the continents and most islands (Pilsbry 1948). These are terrestrial pulmonates that commonly inhabit open woodland, gardens, borders of marshes, ditches, canals, and other similar habitats where humid niches may be found. Gastropods belonging to the family Pupillidae are distinguished by an enlongate shell (ovate to cylindric), rimate or umbilicate, and a rounded aperture (Pilsbry 1948). Umbilicus is a morphological term that describes the cavity or depression formed around the shell axis between the whorls where these do not coalesce to form a solid collumella (Moore 1964).

Artifacts Recovered from the Depression

Artifacts recovered from the depression primarily consist of ceramic sherds and flaked-stone debitage (Table 6). Artifacts were only recovered from samples collected from AC and AW located within the depression. Characteristics of the sherds recovered from a depth of 60 cm and lower within the depression included rounded edges indicating modification by hydrodynamic processes. Skibo and Schiffer (1987) conducted an experimental study to

Table 6. Artifacts and Ecofacts Recovered from Auger Columns Located within the Depression.

Depth (cm)	Unidentified Black-on-red	Unidentified Black-on-white	Smudged Plainware	Plain Redware	Plain Whiteware	Plain Grayware	Flaked Stone	Bone
0	1[w]	-	-	-	-	-	1[w]	-
60	-	-	-	-	-	1[w]	-	-
90	-	-	-	-	-	-	-	1[c]
110	1[w]		3[w]	-	-	-	-	-
120	1[w]	1[c]	-	-	-	-	4[w]	-
130	2[w]	-	-	-	-	-	-	-
150	1[w]	-	-	-	-	-	-	-
160	-	1[c]	-	-	-	-	1[w]	-
220	-	-	-	-	-	-	1[c]	-
280	-	-	-	-	-	-	1[c]	-
290	-	-	-	1[c]	-	-	-	-
300	-	-	-	-	1[c]	-	-	-
320	1[c]	-	-	-	-	-	-	-

Note: [w] = west auger column (AW)
[c] = center auger column (AC)

examine the effects of water abrasion on ceramic sherds in the context of both natural and cultural formation processes. Skibo (1987) suggested that abrasion by water movement results in sherds that exhibit distinctive set of attributes, most notably among them is edge rounding.

All of the decorated wares recovered from the depression exist in fragmented state that prevented type-specific identification. The majority of the assemblage consists of unidentified black-on-red decorated wares. These sherds included decorated concavities characteristic of bowl vessel forms. A few unidentified black-on-white sherds were recovered from varying depths in the center auger column. Other ceramic types noted in the assemblage consist of smudged plainwares, plain redwares, plain whitewares, and plain graywares. Lithic artifacts recovered from the depression include sandstone, limestone, chert, and quartzite flaked-stone debitage. A large sandstone flake recovered from AW was either the result of groundstone maintenance or a fragment of a shaped building stone. Two pieces of limestone debitage recovered from the feature are intact flakes that include all the characteristics of flake morphology. A single ecofact was recovered from AC consisting of a lagomorph metacarpal. Additionally, charcoal infused sediments were ubiquitous throughout the samples collected from a depth of 40 cm to the bottom of AW and from a depth of 90 cm to the bottom of AC, indicating heavily culturally modified deposits.

Absolute chronometric dates were not obtained from the feature to indicate the contemporaneity of the depression and the pueblo occupation. However, artifacts were only recovered from auger columns located within the depression. A relatively high concentration of *Zea Mays* was present at a depth of 300 cm in the center of the depression. Corn appeared in the pollen assemblage at varying depths from 220-320 cm. This evidence indicates that the depression was present prehistorically. The sediments collected from AW and AC included a considerable amount of cultural material. Ceramic sherds and corn pollen were recovered to a maximum depth of 320 cm below the ground surface from the AC column. The occurrence of artifacts and ecofacts at this depth in the center auger locality suggests that prehistorically the depth of this depression was comparable to at least 320 cm below ground surface.

Hydrological Modeling

During the data collection phase of this project a subsurface water source was located in the center of the probable water control feature that undoubtedly supplied the depression with water. In addition to this underground water supply, the topographic location of the feature was situated in a prime location for the contribution of surface runoff. The hydrological modeling analysis resulted in the identification of the contributive watershed and runoff patterns for the feature. The watershed is interpreted as the total area that contributes runoff to a specified pour point. The location of AC was identified as the pour point for both of the hydrological models generated from this analysis. Predictive models were generated for both the USGS digital elevation model and the fine scale digital elevation model created from topographic data collected with an EDM.

The watershed and runoff patterns determined from the USGS digital elevation model are presented in Figure 22. This watershed encompasses a total area of 5.18 km^2. The pueblo and associated depression are topographically located at the southwestern base of a north-south trending ridge. The contributive watershed indicated by the hydrological modeling analysis is located on the southwestern slope of this ridge. This indicates that runoff patterns flow to the southwest from the ridge to the depression. A certain degree of ground-truthing was conducted for this model during the field visits to the site. The presence of six natural gullies from upslope

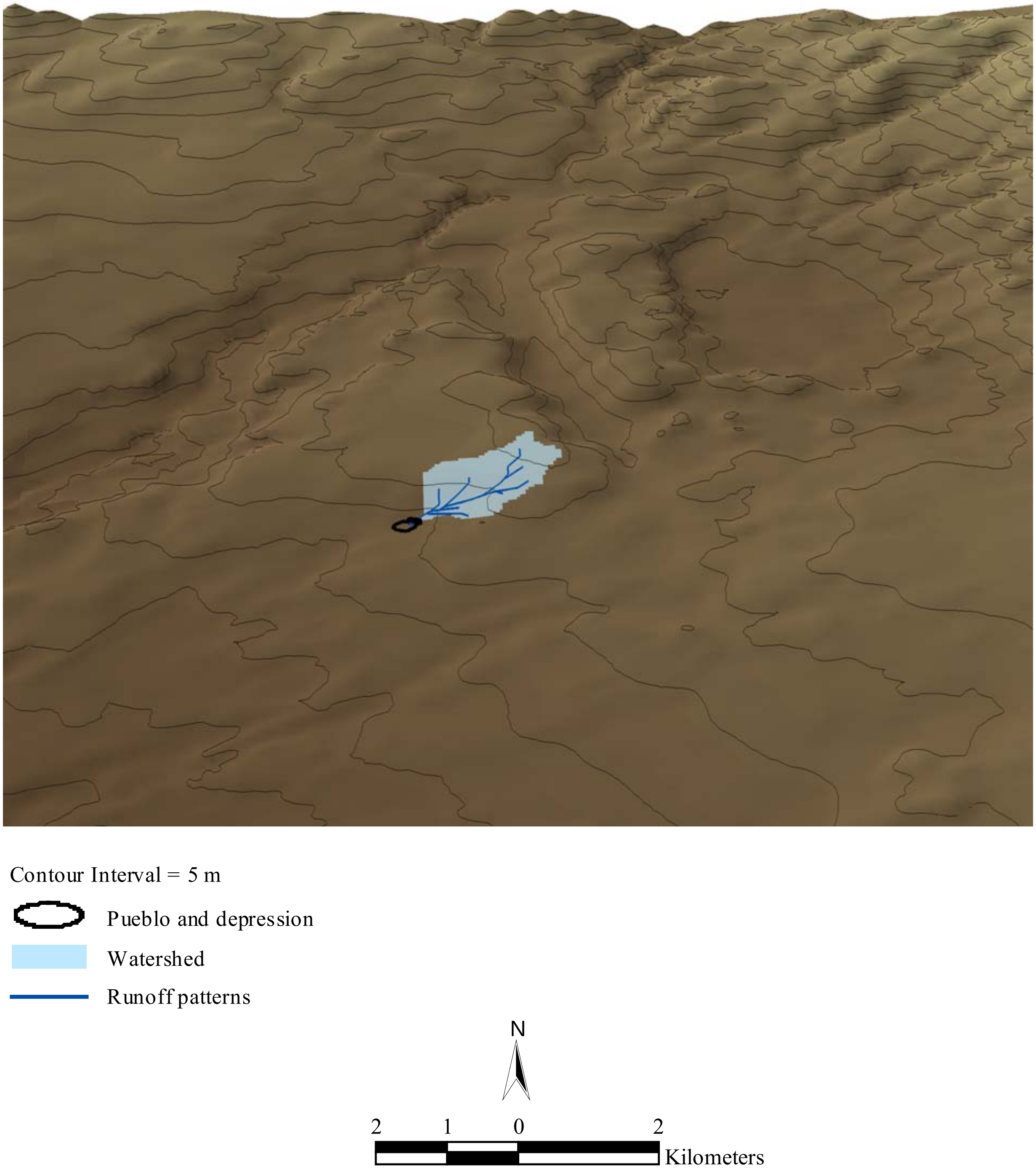


Figure 22. Results of the watershed delineation and runoff pattern analysis for the USGS digital elevation model.

to the north, east, and northeast were located leading directly into the depression (Figure 7). These gullies are generally located in the areas that are identified to concentrate runoff in this model.

Figure 23 illustrates the contributive watershed identified for the fine-scale digital elevation model. This model was generated to indicate the probability of the depression to act as a cistern that concentrated precipitation runoff from the pueblo. Topographic data collected during the archaeological reconnaissance conducted by ACA and during fieldwork associated with this research was used to interpolate a surface of the immediate site area. This three dimensional model of the site topography includes a reconstruction of the pueblo structure. This was accomplished by vertically exaggerating the height of the structure to illustrate the potential of the pueblo to contribute precipitation runoff into the depression.

The watershed identified from this digital elevation model indicates that runoff from the west was also contributing to the depression. It is clear from this model that the location of the depression relative to the pueblo was situated in a prime position to collect runoff from the structure, in addition to runoff supplying the depression from the north and east.

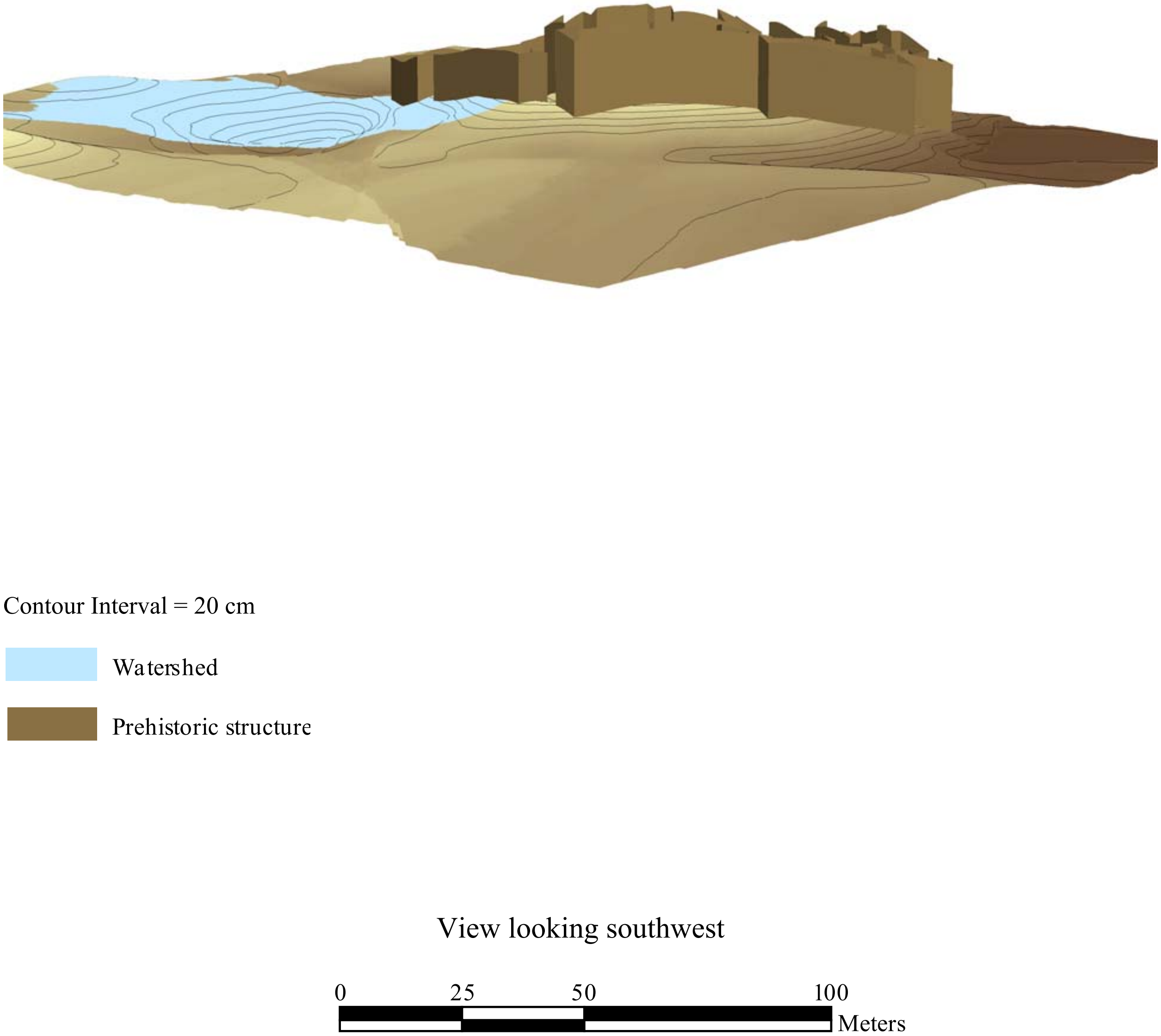


Figure 23. Results of the watershed delineation analysis for the fine-scale digital elevation model.

DISCUSSION AND CONCLUSION

This section provides a discussion of the results obtained from the various geoarchaeological analyses as well as the implications of the paleoecological data obtained from the artificial depression associated with Pueblo Oso Negro. This is followed by concluding remarks and implications for future research in this area of study.

Geoarchaeology of the Artificial Depression

Lakes or ponds can be simply described as standing-water bodies that are mostly filled with freshwater. Sediment deposition in lacustrine environments depends on a number of variables. A lake or pond is usually described in terms of its shape, expressed as length, breadth, and depth or in terms of its shape in plane view. Lakes can be circular, elliptical, half-moon shaped, dissected, rectangular, triangular, or irregular, and the shape of a lake may be in a state of constant fluctuation (Reineck and Singh 1975). Thus, the geometry of lacustrine deposits can be extremely variable.

Climate is also a very important parameter that affects the characteristics of lacustrine deposits. Climate controls the amount of precipitation and evaporation, the nature of weathering, and the nature of soil in the catchment area and its vegetation. The amount of clastic sediments deposited into a lacustrine basin also depends on seasonal fluctuations in runoff contribution (Reineck and Singh 1975).

Clastic lake deposits are generally characterized by an outer belt of beach pebbles, followed by a zone of sand, an inner zone of sandy marly mud, with mud dominating the central region of the basin. This zoning corresponds to the zone-like distribution of hydraulic energy in large lake settings and there are many variants of this idealized picture (Reineck and Singh 1975). Sediments and rocks dominated by a particle diameter less than 0.0625 mm are considered mud and mudstone (Rapp and Hill 1998). A lake or pond is filled by the deposition of silt and clay across the lake, and especially within the central basin. Suspended sediment is separated into a coarser fraction (sand) that sinks down to the bottom, while the finer fractions (mud) remain held in suspension. Muddy sediments with intercalations of fine sand layers characterize the lateral slope and central basin of lacustrine environments (Reineck and Singh 1975).

Coarser sandy sediments dominate the strata within the AW column. Sediment distributions within this column represent the sandy zone characteristic of the margin of a lacustrine basin. Mud or fine-grained sediments that display a pattern of upward fining in particle size distributions characterize the two lowermost samples collected from this column. These sediments are also highly rounded, spherical, and polished. Ostracodes and a large amount of broken gastropod shells were also present in sediments recovered from this column.

Sediment distributions present in AC include very fine-sized sediments that are intercalated with very fine sands. These particle size distributions are typical of the lateral slopes and central plain of a lacustrine environment. Although this auger column is located in the current center of the depression, this may not be the actual center of the feature that was present in prehistoric times. The distribution of organic matter in the AC column is characteristic of the prominent organic component that is commonly incorporated into lacustrine sediment. At a depth of 80 cm, there is an increase in carbonate content that is coupled with the presence of carbonates and invertebrate remains. These signatures are characteristic of marl development, in which carbonate clasts and shells accumulate.

The AE column is located on the present-day eastern margin of the depression. Underlying the aeolian sands in the uppermost strata of AE, silts and clays characteristic of lacustrine deposition dominate sediment distributions. Stratigraphically below the aeolian sands there are substantial increases in organic content. Carbonaceous sediments that include considerable increases in organic content are expected to occur around the margins of lacustrine environments. The carbonate content of sediments recovered from AE is typical of freshwater marl sedimentation. Marls are biogeochemical deposits present in lakes and ponds, and are described as detrital muds that contain significant amounts of calcium carbonate. Marls are commonly created near the shoreline in freshwater and brackish lakes (Waters 1992). The very high carbonate and organic content of sediments collected from AE represents the gradation of lacustrine chalk or marl to mixed organic-calcareous oozes in the semiterrestrial (shore) zone of the basin.

Discussion. From a sedimentological perspective, well-developed lake deposits are of only minor importance in ancient stratigraphic records, most likely due to the fact that lacustrine deposits are not easily identifiable (Reineck and Singh 1975). The rate of deposition in lakes is not very high and a lacustrine environment must have existed over a long period of time, i.e., over several million years, to produce a thick extensive sequence of lake sediments (Reineck and Singh 1975). Therefore, paleoentological evidence is extremely valuable for distinguishing lacustrine deposits.

Invertebrates are commonly accepted as valuable evidence for differentiating between terrestrial and aquatic environments (Delorme 1969). From the middle Paleozoic times gastropods are known to have lived in lake environments (Reineck and Singh 1975). Most of the macrobenthonic (bottom dwelling) fauna of lakes live in water depths of less than 10 m. Plant life is also abundant on the bottom of lakes in shallow water, as well as on the water surface. Several species of flora present in lakes, some algae, *Potamogeton*, *Elodea*, and other submerged plants produce carbonate, and during the process of decomposition they are known to produce lake chalk (Reineck and Singh 1975). Gastropods also contribute to the carbonate content of lake sediments.

Biological evidence consisting of invertebrate remains recovered from the depression supports the interpretation of a formerly water-rich environment within the feature associated with Pueblo Oso Negro. There are four distinct species of invertebrates that were present in sediments examined from the depression: one species of ostracodes and three species of gastropods. These aquatic invertebrates were not present in any samples collected from the AE and ACON3 auger columns. The presence of invertebrate remains in sediments recovered from the depression corroborates with the geological evidence indicating aqueous environmental characteristics in the sedimentary history of the feature. This combination of biological and geological evidence offers substantive proof that the depression associated with Pueblo Oso Negro served as a water control feature for this prehistoric community.

Paleoecology of the Water Control Feature

Another goal of this research was the use of microbotanical evidence and invertebrate remains to indicate the paleoecology and seasonality of water storage for the feature associated with Pueblo Oso Negro.

Pollen. Botanical signatures that are indicative of water-rich environments can produce archaeological evidence of long-term water storage (Bayman et al. 1997). Cattail (*Typha* sp.) grows around the margins of wetland environments, and requires permanently damp soil. In an attempt to address this question, microbotanical samples were collected from both the feature and control locality to search for the presence of aquatic flora in the fossil pollen record. The presence of cattail pollen in sediments recovered from the depression would have provided ample proof that this feature functioned as a perennial water supply for the prehistoric community. Unfortunately, the pollen assemblage present in sediments recovered from the depression was devoid of *Typha* sp. as well as any other species of aquatic flora. Therefore, microbotanical remains recovered from the feature do not provide the evidence necessary to indicate the seasonality of water storage.

Ostracodes. Invertebrate remains, notably ostracodes, can also be used as an indicator of the permanency of a body of water (Delorme 1969). Certain species of ostracodes are exceptional for indicating paleoecological conditions, and based on their known ecological tolerances fossil ostracodes can provide preliminary criteria for reconstructing paleoenvironments (Palacios-Fest 1994). Due to their preservation, relative abundance in sediments, and rapid means of dispersal by aeolian deposition, ostracodes are ideally suited as a means for paleoecological interpretation (Delorme 1969).

A suite of geological, hydrological, botanical, and climatic factors controls the environments ostracodes inhabit. In most cases ostracodes can endure a wide range of ecological conditions. However, some species exhibit sensitivity to a very narrow range of temperatures and chemical concentrations. The presence and/or absence of ostracodes in aquatic habitats can be controlled by a number of factors such as the total dissolved solids, solute composition, dissolved oxygen, pH, depth of water, and the availability of food (Delorme 1969).

Species belonging to the genus *Candona* are generally eurytopic and are able tolerate a wide range of environments (Delorme 1969). Generally, species belonging to this genus are widespread in both lakes and ponds. However, Forester (1991) suggested that *Candona* occur in both spring-seep and lacustrine environments.

Delorme (1989) provided the parameters of environmental conditions affecting *C. rawsoni* as between 10-10000 total dissolved solids mg L^{-1}, and a pH ranging between 7.5-12.5. This species of ostracodes is primarily confined to pond and lake habitats. *Candona rawsoni* can tolerate water of moderately high salinity and is noted to occur in both ephemeral and permanent water sources (Delorme 1969). The environmental parameters of *C. patzcuaro* are provided from a study conducted on Hohokam irrigation canals (Palacois-Fest 1994, 1997b). *Candona patzcuaro* is eurythermic or tolerant of a wide range of temperatures. This species is also able to inhabit aquatic environments with a salinity index between 200-5000 ppm, which ranges from low salinity to hypersaline conditions. *C. patzcuaro* is noted to occur in lakes or ponds that are either permanent or ephemeral, with a life cycle that ranges from 10-16 weeks (Palacois-Fest 1994, 1997b).

Gastropods. Major ecological determinates that affect the distributions of freshwater snails are notably water hardness and pH. A great majority of species and the largest numbers of individuals occur in alkaline waters (Smith 2001). Generally, snails are uncommon in lakes and streams with an acidic pH. Freshwater pulmonates are common in slightly alkaline water to a maximum pH of 8.5 (Hyman 1967). Other environmental factors to be considered include temperature, light, currents, salinity, calcium carbonate, and desiccation. Alkaline waters are attributed to the presence of calcium carbonate, which is essential for the well being of freshwater snails. Snails inhabiting temporary waters that are subject to successive stages of drying burrow into the mud bottoms or secrete a membrane across the aperture and enter into a state of estivation or hibernation (Hyman 1967). Dissolved oxygen is an important limiting factor of snail distribution. Aquatic pulmonates include gilled species of snails that require rather high oxygen concentrations. Thus, a great majority of species and individuals are distributed in shallow waters, especially water less than 3 m deep (Smith 2001). Due to their physiology, pulmonates are better dispersers than prosobranchs, and many pulmonate species appear before any others when artificial habitats (e.g., reservoirs and quarry ponds) are formed (Smith 2001).

Freshwater pulmonates of the families Lymnaeidae and Planorbidae are common in lakes, ponds, ditches, and other kinds of standing waters, but usually do not occur in rapidly flowing water (Hyman 1967; Thorp and Covich 2001). Both of the Basommatophora gastropods present in the faunal assemblage are common freshwater snails distributed across North America, and many species are found in shifting and ephemeral habitats. Planorbids are found in almost any body of freshwater ranging from the largest lakes to the smallest ponds. Due to their ability to breath fresh air, lymnaeids and planorbids are able to withstand unfavorable environmental conditions including extreme alkalinity and salinity, as well as water containing sewage (Baker 1945). The third species of gastropod recovered from the depression is a terrestrial pulmonate belonging to the family Pupillidae. Although land pulmonates generally require a humid atmosphere, some shelled species can endure arid conditions. Water relations are of paramount importance to the life of terrestrial pulmonates (Hyman 1967).

Discussion. Microbotanical evidence recovered from the depression would have served as the primary line of evidence to indicate the seasonality of water storage. The absence of *Typha* sp. in the pollen assemblage denotes the likelihood of an ephemeral water source. However, the lack of cattail in the pollen assemblage does necessarily indicate that this floral species was not present around the perimeter of the feature.

Turney (1985) noted that cattails can essentially invade reservoirs, consequently reducing their storage volume, and maintenance to the feature may have resulted in the removal of cattail from the perimeter of the depression. Ethnographic evidence also suggests that cattail was an economically valuable plant that was extensively used as fiber and food (Dunmire and Tierney 1995). Woven sleeping mats composed of cattail fibers have been recovered from Arroyo Hondo Pueblo, and cattail stems are also useful in the construction of roofs as lathing over the vigas and thatch to support the mud or adobe cover. All parts of this plant are edible and ethnographic evidence indicates that pueblo people incorporated cattail into their diet, especially during times when food supplies ran low (Dunmire and Tierney 1995). Consequently, the absence of cattail from the pollen assemblage could be due to maintenance activities in addition to procurement for economic purposes. This feature may have also been used for agricultural as well as domestic purposes, resulting in water being drawn out of the depression and diverted to fields for irrigation. Pollen grains are carried in water by the process of suspension and will only settle down to the bottom in calm waters (Davis and Brubaker 1973). As a result, the diversion of water from the feature would have created fairly turbid waters and prevented much of the pollen from settling to the bottom of the depression.

Invertebrate remains recovered from the depression include taxa that exhibit a wide range of environmental tolerances. All of the ostracodes and gastropods recovered from the feature are overall very common and are incorporated into many different environmental settings. Nevertheless, all of the ostracodes recovered from the depression were present in the juvenile stage of development. This suggests the successful reproduction of these species, indicating that water was present in the feature for at least the duration of their life cycle of two and a half to four months.

Substantive evidence concerning the seasonality of water storage for this feature was not obtained from this analysis. Runoff and groundwater undoubtedly supplied the depression with water, and precise paleoclimatic data for this geographic area would be useful to aid in determining seasonality based on prehistoric weather patterns. Unfortunately, paleoclimatic data for the Chupadera Basin proper is not available. This is a distinctive landform that is topographically isolated from the surrounding areas for which paleoclimate information exists. Consequently, historical climate records from adjacent areas could used to denote the probability of when seasonal precipitation contributed runoff and replenished the source of groundwater that supplied the feature.

A definitive groundwater source is noted from the presence of water at the bottom of the AC column. Groundwater is generally recharged from snowfall precipitation, while rainfall precipitation contributes to the supply of runoff available for the feature. Historic climate data from Gran Quivira and Bingham indicates that rainfall precipitation is most abundant in the early spring thru early fall, with snowfall dominating precipitation patterns in the late fall thru early spring. These precipitation records suggest that in the months of April through October rainfall contributed runoff to the feature and groundwater supplies were replenished from snowfall that dominates precipitation patterns in the months of November through March.

Hydrological Modeling

The final goal of this research was to generate a predictive model of how water supplied and replenished the feature. The discovery of water located at a shallow depth within the boundary of the depression identified a subsurface water supply for the feature. Textural modifications to sediments examined from the depression exhibit a high degree of polishing, which is usually attributed to spring activity. Springs are defined as areas where groundwater emerges at the surface through natural openings in lithified rock or unconsolidated sediment (Waters 1992). Perched springs or seeps are common in the Southwest and occur where an impermeable layer outcrops beneath a water-bearing permeable stratum. The occurrence of water within the depression suggests the presence of a perched spring within the feature, indicating that groundwater supplied the depression in addition to the contribution of surface runoff.

The hydrological modeling analysis resulted in the definition of a contributive watershed for the depression encompassing an area of over 5 km^2. Topographically the feature is situated near the southwestern base of a north-south trending ridge. The contributive watershed identified from this model suggests that rainfall precipitation contacting the slope of the ridge will travel downslope from the north, northeast, and east into the depression. The network of runoff patterns indicated by the model exist within the limits of the contributive watershed and course from the north, northeast, and east until they coalesce into a single drainage flowing westward into the feature. Gullies located and mapped during fieldwork associated with this research provide a certain degree of ground-truthing for this model. The six gullies that were located leading to the feature generally conform to the runoff patterns identified from the model, indicating that runoff supplies the depression from the north, northeast, and east.

The model generated for the immediate site topography was intended to illustrate the potential of the depression to act as a cistern and concentrate runoff directly from the pueblo. A three dimensional reconstruction of Pueblo Oso Negro and the surrounding topography indicates the likelihood that runoff from the structure contributed to the water supply contained by feature.

The pueblo is topographically situated on the margin of the depression, suggesting that the structure supplied runoff to the feature.

Conclusion

Water was a critical resource necessary for prehistoric populations to sustain life in the arid and often unpredictable environment of the Southwest, and the amount of available water supplies continually affects the modern populations living in this region. Climate regimes in the Southwest are fairly erratic in an environmental setting that initially contains limited water resources. A wide array of innovative water management systems were established by countless prehistoric populations that occupied the Southwest. This is a recurring theme in Southwestern prehistory, dating as far back as the late Pleistocene (Haynes et al. 1999).

Water management systems constructed by both the prehistoric and historic occupants of the Greater Southwest incorporated low-level technological solutions in order to create predictable water supplies. A simple earthen construction was used to sustain the water needs for this prehistoric community. The engineering skills integrated into the development of the water storage feature at Pueblo Oso Negro required only a basic understanding of both surface runoff patterns and groundwater sources in order to supply water for the prehistoric occupants residing in the community.

The water table within the Chupadera Basin is extremely low and there are few instances of springs that are documented in this area. The archaeological reconnaissance conducted by ACA resulted in the identification of at least one other prehistoric pueblo (LA 1070) located in the Chupadera Basin that included a depression suspected to be a possible water management feature (Montgomery and Bowman 1989). There are reportedly nine other large pueblo communities present within the area that include similar associated depressions (Foreman of the Orona Ranch, personal communication 2005). These depressions are also likely the remnants of prehistoric water management systems constructed and maintained by the occupants of these prehistoric pueblos. This pattern suggests that this area was attractive to prehistoric populations, most likely due to abundant water supplies that were located within the basin. The location of Pueblo Oso Negro was likely initially selected due to the presence of this spring.

A large number of prehistoric water control features are identified in the literature pertaining to the archaeology of the Southwest and the majority of these interpretations are purely based on conjecture. In many cases, these features are identified on the assumption that they stored and distributed water for prehistoric communities. Few of these interpretations are founded on evidence that corroborates the presence of water. There are numerous lines of evidence that can be used to evaluate the function of water control features: the presence or absence of water-lain sediments, aquatic botanical or faunal remains, artificial inlets or outlets, and an insoluble underlying matrix (Dart 1983; Nials and Fish 1986). Thus, defining the function of probable water management features requires an understanding of geological processes and rests within the realm of geoarchaeological investigation. The results of this analysis have revealed that the methods employed in this research are exceptional for illuminating the function of probable water control features.

A combination of geological and biological evidence obtained from the artificial depression associated with Pueblo Oso Negro provides substantive proof of a formerly water-rich environment in the sedimentary history of the feature. In addition to geological and biological evidence recovered from the feature, the presence of culturally modified sediments, ecofacts, and artifacts present to a great depth within the depression indicates that this feature was present and maintained prehistorically. The results of this investigation reveal that the depression in fact served as a prehistoric water management feature.

While this investigation has provided evidence corroborating the notion that the feature served in a water storage capacity, there remain many implications for future research. This research has accomplished the task of revealing a basic understanding of the use of the feature. Geological, biological, and microbotanical evidence necessary to clarify feature function was easily obtained with a bucket auger and resulted in a minimal degree of disturbance to the feature. However, the conclusions of this analysis warrant further attention. Extensive excavation is necessary to produce exact stratigraphic profiles of the depression. This information is paramount to gain a complete comprehension of the depositional history of the depression and its full potential as a water storage feature.

Due to the proximity of the depression to Pueblo Oso Negro, it is assumed that this feature served as the domestic water supply for this community. Pueblo Oso Negro is a substantial structure that supported a large community over a span of three hundred years (Montgomery and Bowman 1989). This feature could range in function from a walk-in well providing water for domestic of the community to a large reservoir capable of supplying water for agricultural purposes. The exact spatial extent of this feature is unknown, while the possibility of artificial inlets and outlets not readily apparent on the surface may yet remain to be discovered.

REFERENCES CITED

Adams, E. Charles, and Andrew I. Duff

2004 Settlement Clusters and the Pueblo IV Period. In *The Protohistoric Pueblo World, A.D. 1275-1600*, pp. 3-16, edited by Charles Adams and Andrew Duff. The University of Arizona Press, Tucson.

Agenbroad, Larry D., and Bruce Huckell

n.d. New Discoveries at the Lehner Site: 1974-1975 and 1980. In *Clovis Hunters in the San Pedro Valley, Arizona*, edited by Vance Haynes. Ms. On file, Department of Anthropology, University of Arizona, Tucson.

Baker, Frank Collins

1945 *The Molluscan Family Planorbidae*. The University of Illinois Press, Urbana, Illinois.

Balsillie, James H., Joseph F. Donoghue, Kenji M. Butler, and Jennifer L. Koch

2002 Plotting Equation for Gaussian Percentiles and a Spreadsheet Program for Generating Probability Plots. *Journal of Sedimentary Research* 72: 929-943.

Bayman, James M., Manuel R. Palacios-Fest, Suzanne K. Fish, and Lisa W. Huckell

2004 The Paleoecology and Archaeology of Long-Term Water Storage in a Hohokam Reservoir, Southwestern Arizona, U.S.A. *Geoarchaeology* 19: 119-140.

Bayman, James M., Manuel R. Palacios-Fest, and Lisa W. Huckell

1997 Botanical Signatures of Water Storage Duration in a Hohokam Reservoir. *American Antiquity* 62: 103-111.

Briggs, David

1977 *Sources and Methods in Geography*: Sediments. Butterworth & Co., Boston.

Broodbakker, N.W.

1982 The genus *Heterocypris* (Crustacea, Ostracoda) in the West Indies. Part I. Taxonomic Characters. *Bijdragen tot de Dierkunde* 52: 207-227.

1983 The genus *Heterocypris* (Crustacea, Ostracoda) in the West Indies. Part II. Carapace length, ecology, and zoogeography. *Bijdragen tot de Dierkunde* 53: 115-134.

Bryant, Vaughn M. Jr

1969 Pollen analysis of late-glacial and post-glacial Texas sediments. Ph.D. dissertation, Department of Anthropology, The University of Texas, Austin.

Butzer, Karl W.

1964 *Environment and Archaeology: An Introduction to Pleistocene Geography*. Aldine Publishing, Chicago.

1971 *Environment and Archaeology*: *An Ecological Approach to Prehistory*. Aldine-Atherton, Chicago.

1982 *Archaeology as Human Ecology*. Cambridge University Press.

Casteel, Richard W.
1970 Core and Column Sampling. *American Antiquity* 35: 465-467.

Cordell, Linda S.
1997 *Archaeology of the Southwest*. 2nd ed. Academic Press, New York.

Crown, Patricia L.
1987 Water Storage in the Prehistoric Southwest. *Kiva* 52: 209-228.

Danson, Edward Bridge
1957 *An Archaeological Survey of West Central New Mexico and East Central Arizona*. Papers of the Peabody Museum of Archaeology and Ethnology, Harvard University, Vol. 44, No. 1. Cambridge.

Dart, Allen
1983 Agricultural Production in the Salt-Gila Project Area. In *Specialized Activity Sites*, edited by Lynn S. Teague and Patricia L. Crown, pp. 345-574. Hohokam Archaeology along the Salt-Gila Aqueduct, Central Arizona Project, Vol. 3. Arizona State Museum Archaeological Series, No. 150. University of Arizona, Tucson.

Davis, Margaret Bryan, and Linda B. Brubaker
1973 Differential Sedimentation of Pollen Grains in Lakes. *Limnology and Oceanography* 18: 635-646.

Dean, Walter E.
1974 Determination of Carbonate and Organic matter in Calcareous Sediments and Sedimentary Rock by Loss on Ignition: Comparison with Other Methods. *Journal of Sedimentary Petrology* 44: 242-248.

De Dekker, P., and R.M. Forester
1988 The Use of Ostracodes to Reconstruct Continental Paleoenvironmental Records. In *Ostracoda in the Earth Sciences,* pp.176-199.

Delorme, L.D.
1969 Ostracodes as Quaternary Paleoecological Indicators. *Canadian Journal of Earth Sciences* 6: 1471-1476.

1970 Freshwater Ostracodes of Canada, Part III Family Candonidae. *Canadian Journal of Zoology* 48: 1099-1127.

1989 Methods in Quaternary Ecology #7. Freshwater Ostracodes. *Geoscience Canada* 16(2): 85-90.

Dillon, Robert T., Jr.
2000 *The Ecology of Freshwater Mollusks*. Cambridge University Press, New York.

Dimbleby, G. W.
1957 Pollen Analysis of Terrestrial Soils. *New Phytologist* 56: 12-28.

1967 *Plants and Archaeology*. John Baker, London.

Di Peso, Charles C., John B. Rinaldo, and Gloria J. Fenner
1974 *Architecture*. Casas Grandes, A Fallen Trading Center of the Gran Chichimeca, Vol. 5. The Amerind Foundation, Inc., Series No. 9. Dragoon, Arizona.

Dunmire, William W., and Gail D. Tierney
1995 *Wild Plants of the Pueblo Province: Exploring Ancient and Enduring Uses*. Museum of New Mexico Press, Santa Fe.

Evans, Glen L.
1951 Prehistoric Wells in Eastern New Mexico. *American Antiquity* 17: 1-9.

Feibel, Craig S.
2001 Archaeological Sediments in Lake Margin Environments. In *Sediments in Archaeological Context* edited by Julie K. Stein and William R. Farrand, pp. 127-148. The University of Utah Press, Salt Lake City.

Folk, Robert L.
1966 A Review of Grain Size Parameters. *Sedimentology* 6: 73-93.

Forester, R.M.
1983 Relationship of Two Lacustrine Ostracode Species to Solute Composition and Salinity: Implications for Paleohydrochemisty. *Geology* 11: 435-438.

1991 Ostracode Assemblages from Springs in the Western United States: Implications for Paleohydrology. *Memoirs of the Entomological Society of Canada* No. 155: 181-201.

Friedman, Gerald M.
1962 On Sorting Coefficients and the Lognormality of the Grain-Size Distribution of Sandstones. *Journal of Geology* 70: 737-756.

Goldstein, Solomon
1960 Degradation of Pollen by Phycomyetes. *Ecology* 41: 453-545.

Green, F. E.
1962 Additional Notes on Prehistoric Wells at the Clovis Site. *American Antiquity* 28: 230-234.

Hartmann, Gayle Harrison, and Mary Charlotte Thurtle
2001 The Archaeology of Tinajas Altas, A Desert Waterhole in Southwestern Arizona. *Kiva* 66: 489-518.

Haury, Emil W.
1957 An Alluvial Site on the San Carlos Indian Reservation, Arizona. *American Antiquity* 23: 2-27.

1976 *The Hohokam, Desert Farmers and Craftsmen: Excavations at Snaketown, 1964-1965*. The University of Arizona Press, Tucson.

Haury, Emil W., and Lyndon L. Hargrave
1931 *Recently Dated Pueblo Ruins in Arizona*. Smithsonian Miscellaneous Collections, Vol. 82, No. 11. Smithsonian Institution, Washington.

Haynes C. Vance, Dennis J. Stanford, Margaret Jodry, Joanne Dikenson, John L. Montgomery, Phillip H. Shelley, Irwin Rovner, and George A. Agogino
1999 A Clovis Well At The Type Site 11,500 B.C. The Oldest Prehistoric Well in America. *Geoarchaeology* 14: 455-470.

Hester, James J.
1972 *Blackwater Locality No. 1: A Stratified Early Man Site in Eastern New Mexico*. Fort Burgwin Research Center Publication No. 8. Ranchos de Taos, New Mexico.

Hill, C., and D. J. Meltzer
1987 Late Pleistocene to Middle Holocene Depositional Environments at Mustang Springs, Southern Llano Estacado. *Current Research in the Pleistocene* 4: 127-130.

Holloway, Richard G.
1981 Preservation and Experimental Diagenesis of the Pollen Exine. Ph.D. dissertation, Department of Anthropology, Texas A&M University, College Station.

2005 *Pollen Analysis of Samples from LA 1073, Oso Negro, A Suspected Pueblo IV Period Reservoir, Socorro County, New Mexico*. Submitted to Monica L. Enke, Eastern New Mexico University. Copies available from the author.

Hyman, Libbie Henrietta
1967 *The Invertebrates, Volume IV Mollusca I: Aplacophora, Polyplacophora, Monoplacophora, Gastropoda*. McGraw-Hill Book Company, New York.

Jennings, Jesse
1957 *Danger Cave*. University of Utah Press, Salt Lake City.

Kilby, D.
1998 A Geoarchaeological Analysis of Ten Pueblo III Pit Structures in the Sand Canyon Locality, Southwest Colorado. Unpublished Master’s thesis, Department of Anthropology and Applied Archaeology, Eastern New Mexico University, Portales.

King, James E., Walter E. Klippel, and Rose Duffield
1975 Pollen Preservation and Archaeology in Eastern North America. *American Antiquity* 40: 180-190.

Kintigh, Keith W.
1985 *Settlement, Subsistence, and Society in Late Zuni Prehistory*. Anthropological Papers of the University of Arizona 44. Tucson.

Krumbein, W.C.
1934 Size Frequency Distributions of Sediments. *Journal of Sedimentary Petrology* 4: 65-77.

Kyte, Michael A.
1988 *A Ceramic Sequence from the Chupadera Arroyo Basin, Central New Mexico*. Unpublished MA thesis, Department of Anthropology and Applied Archaeology, Eastern New Mexico University, Portales.

Lewis, Douglas W., and David McConchie
1994 *Analytical Sedimentology*. Chapman and Hall, New York.

Loeppert, Richard H., and Donald L. Suarez
1996 Carbonate and Gypsum. In *Methods of Soil Analysis Part 3. Chemical Analysis*, edited by Donald L. Sparks, pp. 437-474. Soil Science Society of America Book Series Number 5. American Society of Agronomy, Madison, WI.

Martin, Paul S.
1936 *Lowry Ruin in Southwestern Colorado*. Field Museum of Natural History, Anthropological Series, Vol. 23, No. 1. Chicago.

1963 *The last 10,000 years*. University of Arizona Press, Tucson.

Martin, Paul S., and John B. Rinaldo
1960 *Excavations in the Upper Little Colorado Drainage, Eastern Arizona*. Fieldiana: Anthropology Vol. 51, No. 1. Field Museum of Natural History, Chicago.

McGimsey, Charles R., III
1951 Peabody Museum Upper Gila Expedition – Pueblo Division Preliminary Report, 1950 Season. *El Palacio* 58(10): 299-312.

Meltzer, David J.
1991 Altithermal Archaeology and Paleoecology at Mustang Springs, on the Southern High Plains of Texas. *American Antiquity* 56: 236-267.

Meltzer, David, and M. B. Collins
1987 Prehistoric Wells on the Southern High Plains: Clues to Altithermal Climate. *Journal of Field Achaeology* 14: 9-28.

Middleton, Gerard V.
1962 On Sorting, Sorting Coefficients, and the Lognormality of the Grain-Size Distribution of Sandstones: A Discussion. *Journal of Geology* 70: 754-756.

Montgomery, John, and Kathleen Bowman (editors)
1989 *Archaeological Reconnaissance of the Chupadera Arroyo Drainage, Central New Mexico*. Agency for Conservation of Archaeology, Report CD89.1, Eastern New Mexico University, Portales. Ms. on file with the Department of Anthropology and Applied Archaeology, ENMU.

Montgomery, John, Daniel Landis, and Phillip Shelley
1985 *A Proposed Archaeological Reconnaissance of the Chupadera Arroyo Drainage, Central New Mexico*. Agency for Conservation of Archaeology, Eastern New Mexico University, Portales. Ms. on file with the Department of Anthropology and Applied Archaeology, ENMU.

Moore, Raymond C. (editor)
1961 *Treatise on Invertebrate Paleontology*. *Part Q Arthropoda 3 Crustacea Ostracoda*. Geological Society of America and University of Kansas Press, Lawrence, Kansas.

1964 *Treatise on Invertebrate Paleontology Part I Mollusca 1*. Reprinted. Originally published 1960. Geological Society of America and University of Kansas Press, Lawrence, Kansas.

Nials, Fred, and Suzanne K. Fish
1986 Canals and Related Features. In *The Site and Its Features*, edited by David A. Gregory. Excavations at Las Colinas, Phoenix, Arizona, Vol. 2. Arizona State Museum Archaeological Series, No. 162. The University of Arizona, Tucson.

Office of Indian Affairs
1921 Primitive Agriculture of the Indians. *Office of Indian Affairs Bulletin* 1: 1-5.

Olsen, Stanley J.
1982 Water Resources and Aquatic Fauna at Grasshopper Pueblo. In *Multidisciplinary Research at Grasshopper Pueblo, Arizona*, edited by William A. Longacre, Sally J. Holbork, and Michael W. Graves, pp. 61-63. Anthropological Papers of the University of Arizona, No. 40. The University of Arizona Press, Tucson.

Olson, Alan P.
1960 The Dry Prong Site, East Central Arizona. *American Antiquity* 26: 185-204.

Palacios-Fest, Manuel R.
1994 Nonmarine Ostracode Shell Chemistry from Ancient Hohokam Irrigation Canals in Central Arizona: A Paleohydrochemical Tool for the Interpretation of Prehistoric Human Occupation in the North American Southwest. *Geoarchaeology* 9:1-29.

1997a Paleoenvironmental Reconstruction of Human Activity in Central Arizona Using Shell Chemistry of Hohokam Canal Ostracodes. *Geoarchaeology* 12: 211-226.

1997b Continental Ostracode Paleoecology from the Hohokam Pueblo Blanco Area, Central Arizona. *Journal of Archaeological Science* 24: 965-983.

Pilsbry, Henry A.
1948 *Land Mollusca of North America (North of Mexico)*. Monograph No. 3. The Academy of Natural Sciences of Philadelphia, Philadelphia.

Pokorny, V.
1978 Ostracodes. In *Introduction to Marine Micropaleontology*. Elsevier, Amsterdam.

Powers, M.C.
1953 A New Roundness Scale for Sedimentary Particles. *Journal of Sedimentary Petrology* 23:117-119.

Rabb, Mark L.
1975 A Prehistoric Water Reservoir from Santa Rosa Wash, Southern Arizona. *Kiva* 40:295-307.

Rapp, George Jr., and Christopher L. Hill
1998 *Geoarchaeology: The Earth Science Approach to Archaeological Interpretation*. Yale University Press, New Haven.

Reineck, H. E., and I. B. Singh
1975 *Depositional Sedimentary Environments*. Springer-Verlag, New York.

Rohn, Arthur H.
1963 Prehistoric Soil and Water Conservation on Chapin Mesa, Southwestern Colorado. *American Antiquity* 28: 441-455.

Scarborough, Vernon L.
1988 A Water Storage Adaptation in the American Southwest. *Journal of Anthropological Research* 44: 21-40.

Selley, R. C.
1976 *An Introduction to Sedimentology*. Academic Press, New York.

Sharrock, Floyd W., David S. Dibble, and Keith M. Anderson
1951 The Creeping Dune Irrigation Site in Glen Canyon, Utah. *American Antiquity* 27: 188-202.

Skibo, James M
1987 Fluvial Sherd Abrasion and the Interpretation of Surface Remains on Southwestern Bajadas. *North American Archaeologist* 8:125-141.

Skibo, James M, and Michael B. Schiffer
1987 The Effects of Water on Processes of Ceramic Abrasion. *Journal of Archaeological Science* 14:83-96.

Smith, Douglas Grant
2001 *Pennak's Freshwater Invertebrates of the United States: Porifera to Crustacea*. John Wiley and Sons, Inc., New York.

Smith, Calvin B., John Runyon, and George Agogino
1966 A Progress Report on a Pre-ceramic Site at Rattlesnake Draw, Eastern New Mexico. *Plains Anthropologist* 11: 302-313.

Stein, Julie K.
1985 Interpreting Sediments in Cultural Settings. In *Archaeological Sediments in Context* edited by Julie K. Stein and William R. Farrand, pp. 5-19. Peopling of the Americas Edited Volume Series Vol. 1, Center for the Study of Early Man Institute for Quaternary Studies University of Maine, Orono.

1986 Coring Archaeological Sites. *American Antiquity* 51: 505-527.

Stein, Julie K., Robin L. Burgess, and Leon Jacobson
1984 News and Short Contributions. *Journal of Field Archaeology* 11; 233-246.

Stuart, David E., and Rory P. Gauthier
1981 *Prehistoric New Mexico: Background for Survey*. New Mexico Historic Preservation Office, Santa Fe.

Thiele, Johannes
1992 *Handbook of Systematic Malacology: Part 2 Gastropoda: Opisthobranchia and Pulmonata*. Smithsonian Institution Libraries and The National Science Foundation, Washington, D.C.

Thorp, James H., and Alan P. Covich (editors)
2001 *Ecology and Classification of North American Freshwater Invertebrates*. 2nd ed. Academic Press, New York.

Toulouse, Joseph H. Jr.
1945 Early Water Systems at Gran Quivera National Monument. *American Antiquity* 10: 362-372.

Tressler, Willis L.
1954 Fresh-water Ostracoda from Texas and Mexico. *Journal of the Washington Academy of Sciences* 44: 138-148.

1957 The Ostracoda of Great Slave Lake. *Journal of the Washington Academy of Sciences* 47: 415-423.

Turney, William F.
1985 Prehistoric Water Reservoirs: The Southwest. In *Southwester Culture History: Papers in Honor of Albert H. Schroeder*, edited by Charles H. Lange, pp. 43-57, The Archaeological Society of New Mexico, Vol. 10, Albuquerque.

Warnica, James M.
1966 New Discoveries at the Clovis Site. *American Antiquity* 31: 345-357.

Waters, Michael R.
1992 *Principles of Geoarchaeology: A North American Perspective*. The University of Arizona Press, Tucson.

Watson, Patty Jo, Stephen A. LeBlanc, and Charles L. Redman
1980 Aspects of Zuni Prehistory: Preliminary Report on Excavations and Survey in the El Morro Valley of New Mexico. *Journal of Field Archaeology* 7: 201-218.

Wheat, Joe Ben
1952 Prehistoric Water Sources of the Point of Pines Area. *American Antiquity* 17: 185-196.

Wilshusen, Richard H., Melissa J. Churchill, and James M. Potter
1997 Prehistoric Reserviors and Water Basins in the Mesa Verde Region: Intensification of Water Collection Strategies During the Great Pueblo Period. *American Antiquity* 62: 664-681.

Woosley, Anne I.
1980 Agricultural Diversity in the Prehistoric Southwest. *Kiva* 45: 317-33.