3 Pedology in Arid Lands Archaeological Research: An Example from Southern New Mexico–Western Texas

H. Curtis Monger

New Mexico State University
Las Cruces, New Mexico

ABSTRACT

Pedology is a key component of arid lands archaeological research, providing information about landscape evolution, the stratigraphic context of artifacts, and environmental change. As an example, a pedologic study was conducted for archaeologists at the Fort Bliss Military Installation, which covers slightly >445 000 hectares of the northern Chihuahuan desert in southern New Mexico and western Texas. Part one of the study consisted of (i) mapping geomorphic surfaces and (ii) mapping deflated areas. Maps of geomorphic surfaces reveal the age and evolution of the arid landscape, and where archaeological sites might be buried. Deflation maps reveal areas where soils are deflated, stable, or recently buried. Artifact visibility is highest in deflated areas, but the stratigraphic integrity is generally lost. Areas buried by eolian sands, on the other hand, are most likely to contain artifacts with stratigraphic integrity, but artifact visibility is low. Part two of the study focused on paleoenvironmental changes. The most useful paleoenvironmental information was obtained from erosion–sedimentation history, fossil pollen preserved in buried soils, and $\delta^{13}C$ and $\delta^{18}O$ signatures in soil carbonates. Erosion, pollen, and isotopes all revealed a major period of desertification beginning at the middle Holocene about the time Paleoindians gave way to people of the Archaic period.

More than 10 000 archaeological sites have been recorded on Fort Bliss based on surveys conducted by the Fort Bliss Environmental Management Office (e.g., Whalen, 1977, 1978; Carmichael, 1986). These archaeological sites span the time from Paleoindian to Historic periods. Paleoindians (≈8000 B.P. and older) in the northern Chihuahuan desert, as elsewhere, were highly mobile and specialized large-game hunters (Camilli et al., 1988). They were followed by people of the Archaic period (8000 B.P.–200 A.D.) who, in response to an apparent increase in aridity and megafauna extinctions, adopted a lifestyle consisting of general-

Pedological Perspectives in Archeological Research. SSSA Special Publication 44.

ized plant gathering and dependence on medium to small animals. About 2000 yr ago the Formative period began, which in this region is termed Jornada Mogollon (≈200–1450 A.D.), with the widespread use of ceramics and domesticated crops, such as maize (*Zea mays* L.), bean (*Phaseolus* sp.), and squash (*Cucurbita* sp.; Camilli et al., 1988). Little archaeological record exists for the Protohistoric, a time between the Formative and Historic periods, although early Spanish travelers noted the presence of natives along the Rio Grande, as well as Apaches in the uplands (Carmichael, 1986). The Historic period, beginning in 1540 A.D., consisted of sparse Spanish settlements beginning along the Rio Grande, which was an important northward route for Spanish explorers and missionaries. Beginning in the late-1800s, large numbers of Anglos from the eastern USA moved into the region (Stone, 1988).

The primary understanding of soil-geomorphic processes in the region was developed by Ruhe (1967), Hawley and Kottlowski (1969), and Gile et al. (1981). Early geomorphic investigations on Fort Bliss were undertaken by Pigott (1977; 1978) who correlated settlement patterns with soil types in both the western Hueco Bolson and McGregor Range, as well as identified droughts at ≈1100, 1300, and 1890 A.D. Building on their research, Blair et al. (1990) conducted a geoarchaeology study on the White Sands Missile Range, which borders Fort Bliss to the north. They recognized several important features, including (i) buried A horizons preserved beneath coppice dunes that record the topography of the prehistoric land surfaces, (ii) the eolian stratum that is most likely to contain buried artifacts, (iii) and lag strata in Holocene deposits that indicates earlier periods of landscape instability. A few years earlier, Davis and Nials (1988) working near the USA and Mexican border west of El Paso recognized that artifacts visible on the ground surface are usually out of stratigraphic context, and artifacts in stratigraphic context are usually buried and therefore invisible. In response to Davis and Nials' observation, Camilli et al. (1988) commented that although the vertical layering of artifacts may be destroyed in deflated areas, their horizonal relationships may be preserved, and that a composite site (one used repeatedly) would appear similar to a deflated site.

Increased usage of Fort Bliss has put pressure on archaeologists to mitigate larger areas of land for desert military training. In order to assist archaeologists of the Environmental Management Office at Fort Bliss, soil-geomorphic studies were conducted (Monger, 1993). The purpose of the studies was to help archaeologists understand why sites are located where they are as a function of prehistoric geomorphology and paleoenvironmental phenomena, and to evaluate the present condition of the archaeologic sites. This chapter summarizes the techniques and findings of those studies.

MATERIALS AND METHODS

The study area occupies a portion of the northern Chihuahuan Desert and is dominated by desert shrub species, mainly creosote [*Larrea tridentata* (Sessé & Mocino ex DC) Cov.], mesquite [*Prosopis juliflora* (Sw.) DC.], and various C4 grasses. Mean annual rainfall averages ≈20 cm, with ≈70% of the total falling in the summer; evaporation is >10 times the annual precipitation (Gile et al., 1981). Mean annual temperatures range around 15°C, although winter freezes are common. Soils are predominantly Aridisols and Entisols, with Mollisols occurring in the higher elevations where grasses are more plentiful.

The locations of study sites are illustrated in Fig. 3–1. Routine soil characterization for classification was conducted at each site and included particle-size analysis (Gee & Bauder, 1986), organic C (Nelson & Sommers, 1982), and Ca carbonate (Soil Survey Staff, 1982). Stable isotopes were analyzed at the Oak Ridge National Lab, Oak Ridge, TN, and by Beta Analytic Inc., Miami, FL. Pollen was analyzed by Quaternary Palynology Research, Rio Rancho, NM. Radiocarbon ages were determined by Beta Analytic, Miami, FL.

RESULTS AND DISCUSSION

Part 1: Soil-Geomorphic Mapping

The pedologic aspects that proved most useful were (i) mapping geomorphic surfaces and (ii) deflation mapping. In addition, soil-geomorphic mapping techniques were used to disprove the potential existence of a pluvial paleolake (Khresat, 1993). Airborne radar images produced by the U.S. Geological Survey also were analyzed as a potential method for exploring subsurface features. The radar imagery, however, proved to be a function of land surface roughness rather than subsurface features (Kipp,1993).

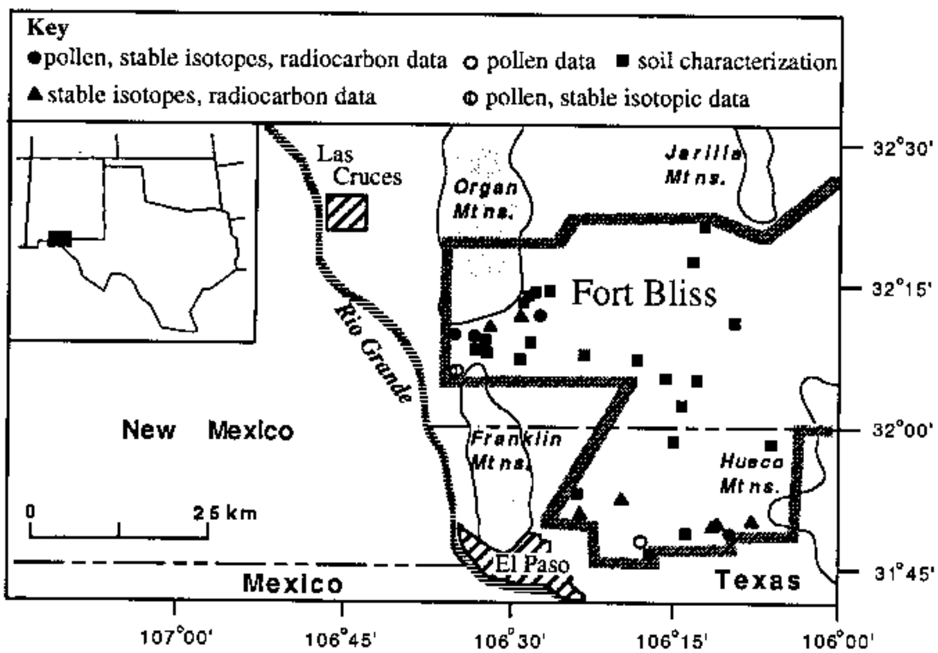

Fig. 3–1. Location map showing western, northern, and southern boundaries of Fort Bliss and study sites. See Monger (1993) for details.

Geomorphic Surfaces Applied to Arid Archaeological Research

Geomorphic surfaces were mapped to provide archaeologists with the big picture of soil-geomorphic and paleoclimatic processes on Fort Bliss. First, maps of geomorphic surfaces provide a picture of Quaternary landscape evolution. In southern New Mexico, erosion and sedimentation are thought to correspond to arid interglacial periods, whereas landscape stability and soil formation correspond to glaciopluvial periods (Hawley et al., 1976). Thus, many geomorphic surfaces in this region, especially on the fan-piedmonts of mountains, probably formed in this and previous interglacial periods. Second, geomorphic surface maps provide a method for subdividing landforms according to age. This information can be particularly useful to archaeologists because it identifies areas that may contain buried sites that are stratigraphically intact. Moreover, geomorphic surface maps locate areas, such as middle Pleistocene alluvial fan surfaces, where archaeological stratification is unlikely to occur (i.e., artifacts of various ages exist on the same surface). Names of geomorphic surfaces used in this study are the same as those developed for the neighboring USDA-SCS Desert Soil-Geomorphology Project, a 400-square mile study area joining Fort Bliss to the west (Ruhe, 1967; Hawley & Kottlowski, 1969; Gile & Grossman, 1979; Gile et al., 1981).

As defined by Daniels and Hammer (1992), a geomorphic surface is two-dimensional, a *plane* or *area* of land that has a development history related in space and time, and does not include the soils or sediments that underlie the surface. As used in this study, however, a geomorphic surface does include the underlying soils, which are diagnostic for their identification. The age of a geomorphic surface and its soils is considered to be the same (Gile et al., 1981). On a constructional (depositional) surface, for example, both the surface and the associated soil would date from the approximate time that sedimentation stopped and soil development started. The term morphostratigraphic unit refers to the geomorphic surface combined with its soil and underlying sediment (Gile et al., 1981). The concept of geomorphic surfaces provides a way to subdivide the major land-forms, such as the fan-piedmont and La Mesa basin floor, into smaller components based on their age (Fig. 3–2).

The fan-piedmont landform, for example, was subdivided into four geomorphic surfaces (Fig. 3–3). The oldest geomorphic surfaces are topographically highest, with progressively younger surfaces inset below them. Basinward, younger geomorphic surfaces bury older surfaces (Fig. 3–3). The oldest surface is the Jornada I surface. In addition to its highest topographic position, it can be identified by its well-developed soil, which includes a reddish Bt, if uneroded, and Stage III to IV carbonate morphology (Gile et al., 1981). Jornada I also has a steeper gradient than younger surfaces, parallel drainage, and highly weathered boulders (Seager, 1981). The Jornada I surface is estimated to be 250 000 to 400 000 yr old (Gile et al, 1981). On the other extreme, the Organ geomorphic surface, which is estimated to be less than ≈7000 yr old (Gile, 1975), has weak soil development characterized by Stage I carbonate filaments and/or pebble coatings (Gile et al., 1966), a braided-channel pattern, and occupies the lowest geomorphic position, which is graded very close to the modern arroyo system (Seager,

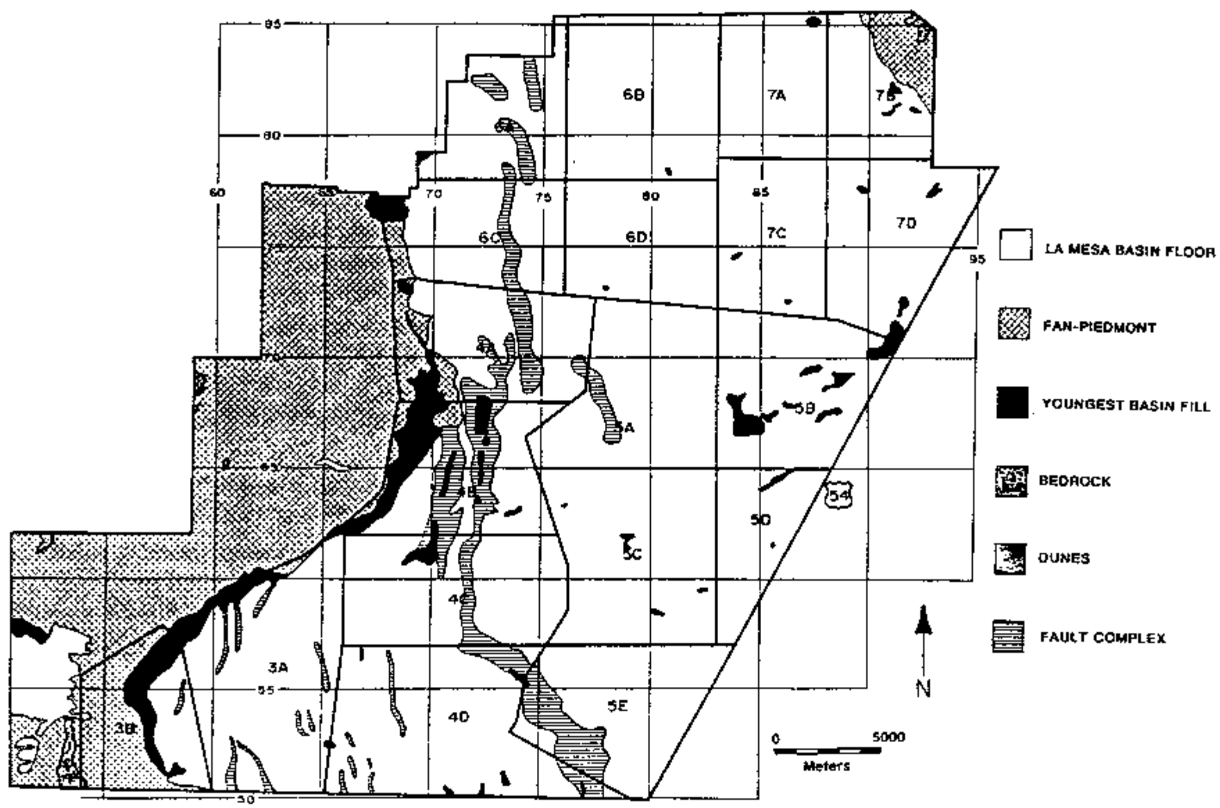

Fig. 3–2. Landform map of a northern portion of Fort Bliss. The La Mesa basin floor of middle Pleistocene age contains the fault complex characterized by normal faults and youngest basin fill deposits composed of late Pleistocene and Holocene alluvium. The fan-piedmont landform is made up of alluvial fans, coalescent fans, and interfan valleys. Although coppice dunes occur across most of Fort Bliss, a few areas contain several meters of sand with sparse interdune vegetation and were designated as the dunes landform (from Monger, 1993).

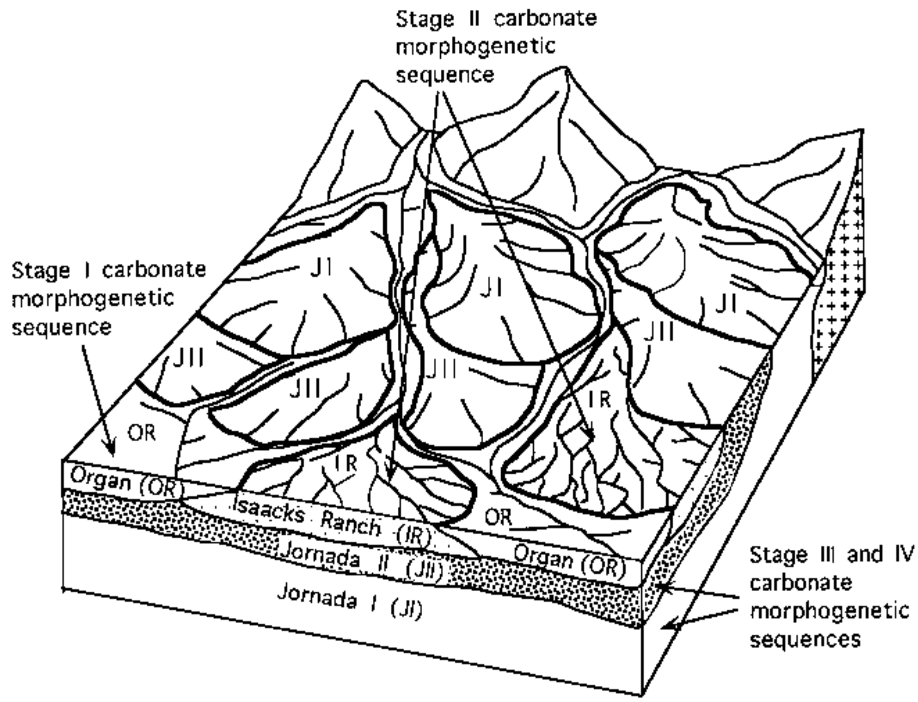

Fig. 3–3. Block diagram showing the stratigraphic relationships of geomorphic surfaces and diagnostic carbonate morphogenetic sequences.

1981). The Organ unit, which is delineated in Fig. 3–4, is of interest to archaeologists because it is young enough to contain buried artifacts with stratigraphic integrity.

Deflation Maps Applied to Arid Archaeological Research

The climate in the southern New Mexico region has alternated between wetter and drier conditions many times in the Quaternary based on soil-geomorphic, paleolake, paleofloral, and paleofaunal evidence (Hawley et al., 1976; Harris, 1987; Holliday, 1989; Waters, 1989; Van Devender, 1990). Thus, unburied soils of pre-Holocene age have polygenetic soil profiles resulting from a combination of glaciopluvial and arid climates (Hawley, 1975). Of primary interest to archaeologists, however, are the alterations to soil mantles that have occurred since humans inhabited Fort Bliss (i.e., latest Pleistocene and Holocene).

In archaeological research, the soil mantle is a useful concept. The soil mantle is the layer of pedogenically altered material, which can include a single soil profile or multiple soil profiles (Catt, 1986), and is equivalent to stacks of buried sola or sequa used by the Soil Survey Staff (1993). The alterations that most directly impact Fort Bliss archaeological sites are complex erosional and depositional sequences of the La Mesa basin floor (Fig. 3–2). Maps of wind erosion and sedimentation provide information about where artifact visibility is probably good, and where archaeological stratigraphy is probably intact (Davis & Nials, 1988).

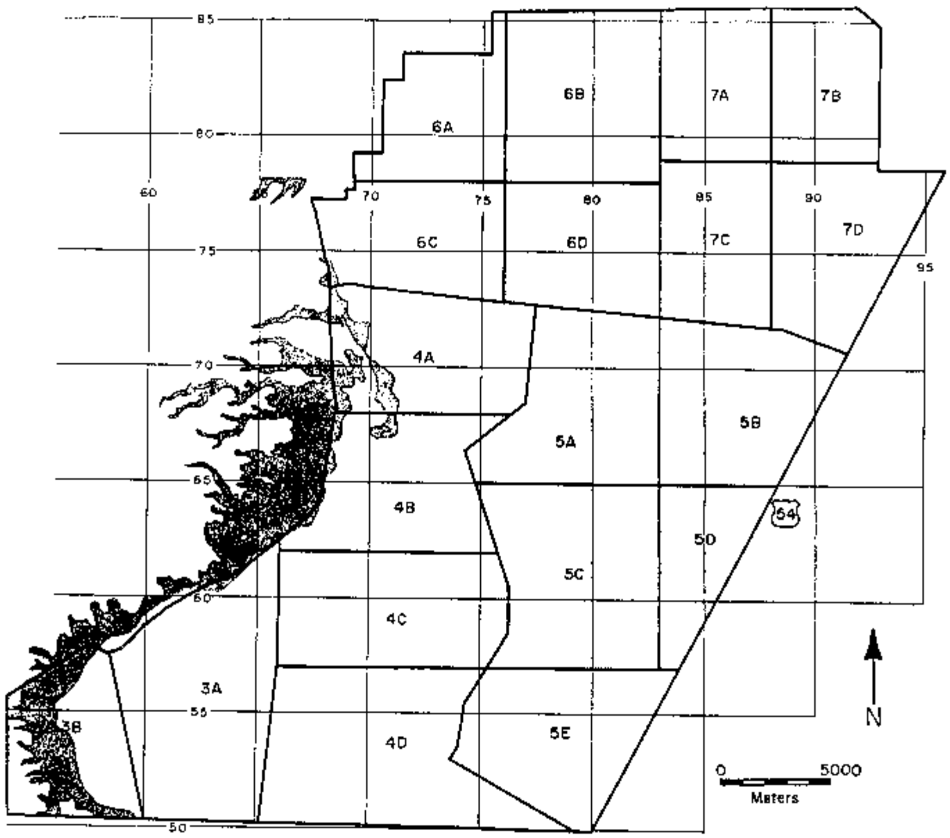

Fig. 3–4. Map of Organ alluvium, which is less than ≈7000 yr old, and potentially contains buried archaeological sites. The upper shaded unit that has a straight line oriented east-west is the border between the Fort Bliss and White Sands reservations.

Four mapping units were developed to portray soil mantle alteration (Fig. 3–5). Mapping Unit no. 1 is characterized by extensively eroded interdune areas. This unit was further subdivided into dunes taller than 1 m, <1 m, or eroded non-dune areas. The dunes are composed of Historical blow sand, which are primarily Torripsamments of loamy sand texture. Mapping Unit no. 2 contains dunes with interdune sheet deposits. The alteration underlying the sandy sheet deposits ranges from buried deflational surfaces to buried soils that contain intact, well-developed sola. At the present time, there is no way to determine from examining the land surface if the subsurface contains collapsed or intact archaeological strata. Mapping Unit no. 3 is of sandy eolian sheet deposits of at least 50 cm thick without dunes. This mapping unit ranges from Torripsamments that bury erosional surfaces to accretionary eolian soils (Fig. 3–5). Mapping Unit no. 4 is of soils that have experienced little, if any, alteration since human inhabitation. These soils occur on stable alluvial fan surfaces protected by desert pavement, and in depressions that contain clayey textured soils resistant to deflation. Figure 3–6 is an example of a deflation map.

Archaeological expectations in these mapping units are as follows. The visibility of artifacts should be high in Mapping Unit no. 1, but the archaeologi-

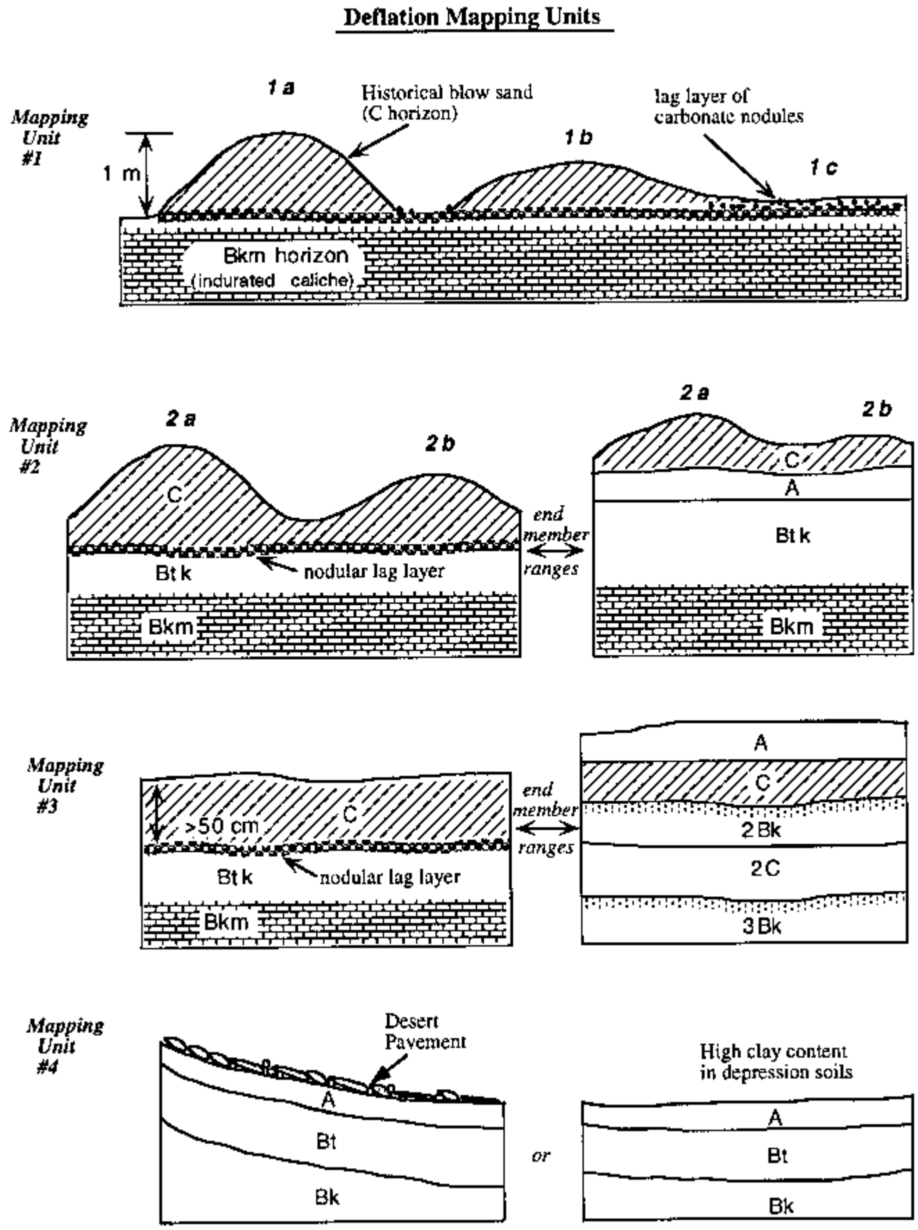

Fig. 3–5. Profiles of deflation mapping units. Mapping unit no. 1 is an eroded unit readily identifiable from aerial photography. In contrast, Mapping units no 2 and 3 contain a range of profiles illustrated by their two end members. Mapping unit no. 4 is little affected by eolian activity. Horizon symbols follow Soil Survey Staff (1993). Because of the mobile nature of the uppermost C horizon, its frequent thinness, and young age (less than ≈150 yr old), no *b* designation was placed on horizons beneath the C horizon.

cal stratigraphy has probably collapsed as the result of deflation. In contrast, the visibility of artifacts in Mapping Units no. 2 and no. 3 is apt to be low, but the likelihood of finding intact archaeology strata is increased. The stable land sur-

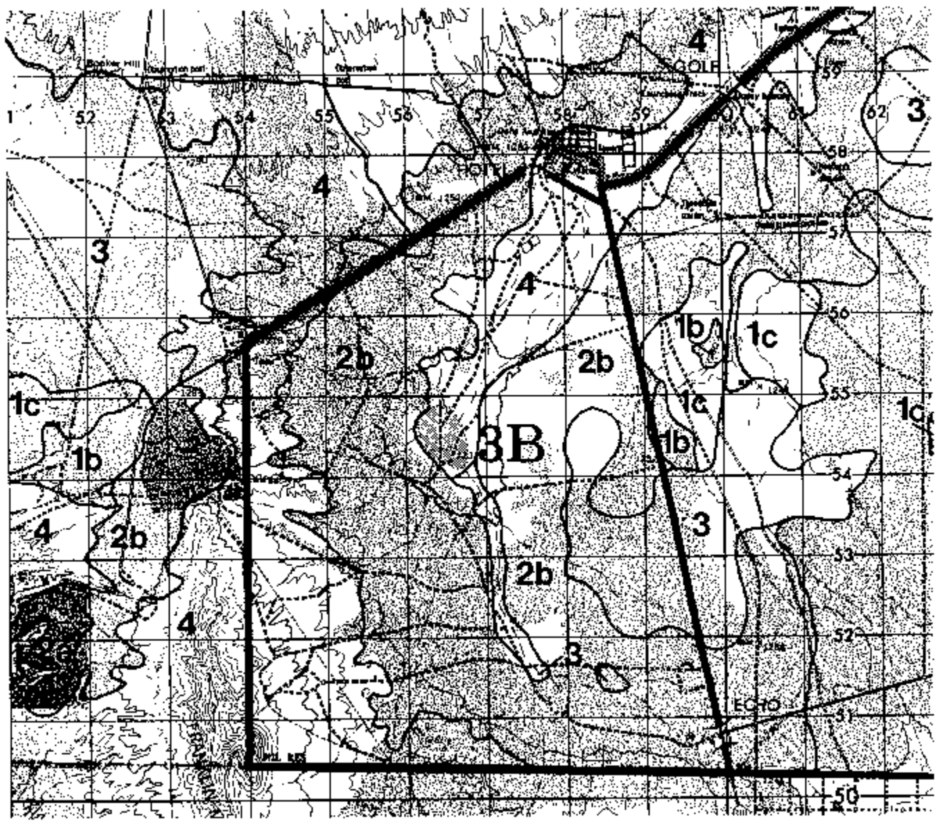

Fig. 3–6. Example of a deflation map. The large "B" is a Maneuver area symbol on the base map. The other symbols correspond to the mapping units illustrated in Fig. 3–5.

faces of Mapping Unit no. 4 should contain high artifact visibility, but no archaeological stratigraphy, especially the fans covered with desert pavement. The fine-textured soils of the depressions may, or may not, contain buried artifacts depending on the nature of the individual sedimentary environments.

Part 2: Paleoenvironmental Reconstruction

Three approaches that proved most successful for paleoenvironmental reconstruction were erosion–sedimentation history, pollen analysis, and stable isotope analysis. Phytoliths also were investigated, but the lack of a key for identification (Buck, 1993) and their scarcity (Cummings, 1993) limits their usefulness as paleoenvironmental indicators at this time.

Erosion–Sedimentation History

The erosion–sedimentation history provides an understanding of paleoenvironmental conditions based on the premise that increased erosion and sedimentation occur in response to some environmental change. The main environmental changes that affect erosion–sedimentation are climate (rainfall and temperature) and, more recently, overgrazing (Bull, 1991). In addition, increasing atmospheric CO_2 may have a direct effect on C4 desert grasslands (Mayeux et al., 1991; Cole & Monger, 1994). Since erosion–sedimentation are related to geomorphic surfaces, knowing the ages of the geomorphic surfaces provides a history of landscape stability and instability (Hawley et al., 1976). A good example of this is the Organ geomorphic surface, which began forming ≈7 000 yr ago in response to the Altithermal desertification (Gile, 1975).

Pollen Analysis

Pollen analysis was conducted at six sites on Fort Bliss (Fig. 3–1) containing a total of 44 samples (Gish, 1993). Many samples had insufficient pollen for analysis, such as buried Torripsamment soils in the basin floor and petrocalcic horizons; however, ample pollen occurred in one basin fill site and two buried soil sites on the fan-piedmont.

The basin fill site, termed the Old Coe Lake Site, occurs just east of the fan-piedmont in the northwestern portion of Fort Bliss at approximately 32° 12'N lat, 106° 26'W long (Fig. 3–1). The site is composed of Petts Tank alluvium overlain by Lake Tank alluvium overlain by coppice dune deposits (Fig. 3–7). Carbon-14 ages are of carbonate nodules and indicate that most of the alluvium is early Holocene-latest Pleistocene in age. The nodules appear to be in situ because they have diffuse boundaries and show no signs of having been rotated or concentrated into layers by erosion. Four pollen types dominate: Cheno-am (Chenopodiaceae and Amaranthaceae), Gramineae, High-spine Compositae, and Low-spine Compositae (Gish, 1993). The proportions of pollen change in a zigzag pattern throughout the 238 cm of sediment (Fig. 3–7). There are two possibilities for why the pollen did not drastically change through time. The first is that the vegetation did not change; that this fine-textured soil, having a high water holding capacity, could buffer the effects of climate change and support a similar plant community through periods of aridity. Second, the pollen could be stratigraphically out of place. Since the alluvium is clayey (mostly clay loams and sandy clay loams), cracks might provide a route for modern pollen to be transported downward.

The best samples for pollen analysis found on Fort Bliss were from buried Haplargid soils on the fan-piedmont sites on the western portion of Fort Bliss at 32° 9' lat (Fig. 3–1). The two sites (Booker Hill Gully site and Pedon 90-1) contained similar pollen profiles characterized by dramatic increases in Cheno-am pollen from Jornada II to Organ alluvium (Fig. 3–7). Similar pollen taxa were found in Organ alluvium east of Las Cruces (Freeman, 1972). Freeman interpreted the high Cheno-am:Gramineae ratio to reflect the arid Altithermal (Antevs, 1955). The increased Cheno-am pollen, which generally reflects saltbush shrubs (*Atriplex* sp.; Gish, 1986, 1993), and concurrent decline in Gramineae pollen appears to represent the onset of desertscrub vegetation. The decline of vegetation density associated with desertscrub would account for increased erosion and sedimentation resulting in the burial of the Jornada II geomorphic surface by Organ alluvium.

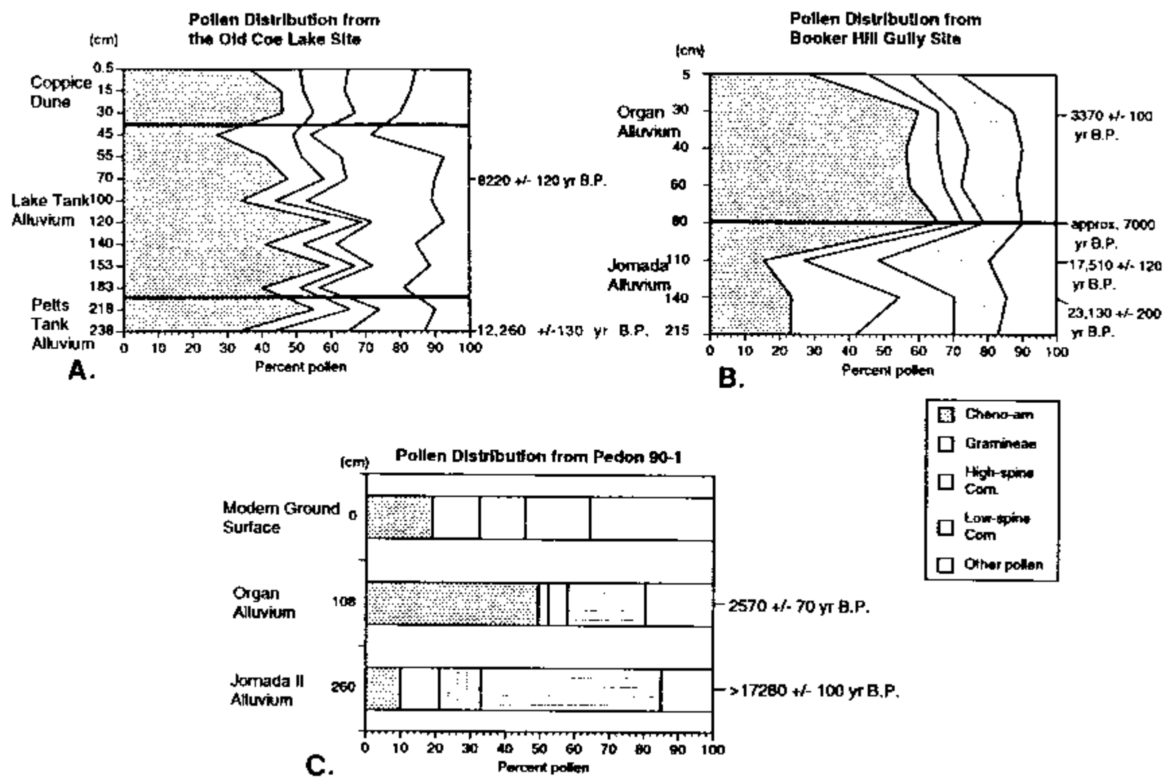

Fig. 3–7. Relative proportions of major pollen types, alluvial deposits, and ^{14}C ages from three soil locations: (A) Old Coe Lake Site, (B) Booker Hill Gully Site, and (C) Pedon 90-1. Petts Tank alluvium refers to the morphostratigraphic unit described by Gile et al. (1981); Lake Tank was defined by Ruhe (1967). Organ and Jornada II units are illustrated in Fig. 3–3.

Stable Isotope Analysis

Since pedogenic carbonates are ubiquitous in soils of arid regions (Hendricks, 1992), their stable isotopic signatures (i.e., $\delta^{13}C$ and $\delta^{18}O$) can provide important paleoenvironmental information, provided the carbonates precipitated in situ (Cerling, 1984; Amundson et al., 1989; Quade et al., 1989; Kelly et al., 1991). In ideal situations, pedogenic carbonate crystals provide a record of plant communities and mean annual temperatures that occurred when the crystals formed.

The $\delta^{13}C$ values of pedogenic carbonates reflect the isotopic composition of soil CO_2 which in turn, is determined by the relative abundance of plants with C4, C3, or CAM photosynthetic pathways (Cerling, 1984; Quade et al., 1989). Most plants, including most desertscrub vegetation, are C3 plants; whereas tropical and subtropical grasses are almost exclusively C4 grasses, while CAM plants include many Cactaceae and Euphorbiaceae (Boutton, 1991). C3 plants respire isotopically light CO_2, which becomes incorporated into the calcite crystal via bicarbonate, producing crystals with light isotopic values, around −12‰ (Pee Dee Belemnite, PDB; Boutton, 1991). On the other hand, C4 plants produce isotopically heavy CO_2 and thus generate heavy carbonate, around +2‰ (PDB). The isotopic values of CAM plants overlap with C4 and C3 values and are generally intermediate between the two (Quade et al., 1989). Thus $\delta^{13}C$ of pedogenic carbonates provide a method for estimating the relative proportions of C4–C3 biomass (Fig. 3–8).

The $\delta^{18}O$ values of pedogenic carbonates are inherited from meteoric water (Cerling, 1984). Since the isotopic signature of meteoric water is related to mean annual temperature (Dansgaard, 1964), carbonate crystals may record paleotemperatures. Hays and Grossman (1991) presented a model that quantita-

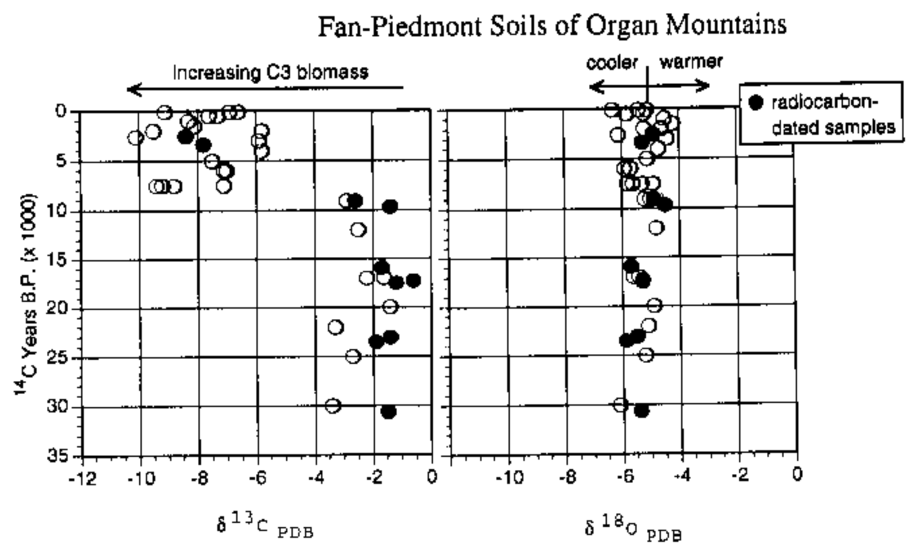

Fig. 3–8. Stable isotope values versus time for samples from four fan-piedmont soils on the southeast slopes of the Organ Mountains (Fig. 3–1). Ages are interpolated based on their stratigraphic position between radiocarbon-dated samples.

tively relates $\delta^{18}O$ values of meteoric carbonates to mean annual temperatures; however, because $\delta^{18}O$ values vary seasonally (Yurtsever & Gat, 1981; Wang et al., 1993), are dependent on air mass stability (Grootes, 1993), and because $\delta^{18}O$ enrichment may occur in the soil due to evaporation (Schlesinger et al., 1989), $\delta^{18}O$ values are used here only to indicate possible warmer or cooler conditions (Fig. 3–8).

The results of $\delta^{13}C$ and $\delta^{18}O$ values for four fan-piedmont soils indicate a major increase in the amount of C3 biomass ≈8000 ^{14}C yr B.P. (Fig. 3–8). This corresponds with the dramatic increase in Cheno-am pollen on the same fan-piedmont area at the Booker Hill Gully site (Fig. 3–7). Since the desertscrub vegetation of the area is dominated by C3 plants, such as creosote (*Larrea* sp.) and mesquite (*Prosopis* sp.), and the grasses of the area are predominately C4 (Syvertsen et al., 1976), the isotopic shift supports the interpretation of a grassland decline and increased desertscrub around the beginning of the middle Holocene. This environmental change must have been largely due to reduced effective moisture possibly supplemented by the effects of increased atmospheric CO_2 (Mayeux et al., 1991; Cole & Monger, 1994), because $\delta^{18}O$ values indicate little temperature change (Fig. 3–8).

SUMMARY

Two categories of pedogenic research, soil-geomorphic mapping and paleoenvironmental reconstruction, were employed in arid lands archaeological investigations on the Fort Bliss Military Reservation in the northern Chihuahuan Desert. Soil-geomorphic mapping was composed of two mapping endeavors. The first endeavor was geomorphic surface mapping, which disclosed the ages of soils and their potential for containing stratified archaeologic sites, or unstratified sites on stable land surfaces. The second mapping endeavor was to identify where wind erosion had increased artifact visibility (i.e., deflated areas), and where archaeological stratigraphy was probably intact (i.e., dune and sand sheets areas).

Three methods that proved most valuable for investigating paleoenvironmental changes were erosion–sedimentation history, pollen, and stable isotopes. The setting that provided the most complete record of paleoenvironmental changes was buried soils on fan-piedmont landforms. Both pollen and stable isotopes revealed a major environmental change around the beginning of the middle Holocene, involving a decline in C4 grass cover closely followed by increased erosion–sedimentation. This change, which probably represents the classically-envisioned Altithermal (Antevs, 1955; Holliday, 1989), left a larger geomorphic record than any environmental change following it, except for Historical desertification beginning in the late-1800s.

ACKNOWLEDGMENTS

This project was funded primarily by the US-ARMY Environmental Management Office, Fort Bliss, TX. Contributions of Human Systems Research, Tularosa, NM, and the New Mexico State University Agricultural Experiment are greatly appreciated. The author thanks David R. Cole for stable isotope analysis and interpretation. Gratitude is expressed to Jannifer W. Gish for pollen analysis; Mohammad Nash for field and laboratory assistance; Glen DeGarmo and John Hawley for initiating the study; John Kipp for drafting Fig. 3–2 and 3–4; Leland H. Gile, Jeff Leach, and Raymond Mauldin for valuable discussions.

REFERENCES

Amundson, R.G., O.A .Chadwick, J. M.Sowers, and H.E. Doner. 1989. The stable isotope chemistry of pedogenic carbonates at Kyle Canyon, Nevada. Soil Sci. Soc. of Am. J. 53:200–210.

Antevs, E. 1955. Geologic-climatic dating in the West. Am. Antiq. 20:317–335.

Blair, T.C., J.S. Clark, and S.G. Wells. 1990. Quaternary continental stratigraphy, landscape evolution, and application to archeology: Jarilla piedmont and Tularosa graben floor, White Sands Missile Range, New Mexico. Geol. Soc. Am. Bull. 102:749–759.

Boutton, T.W. 1991. Stable carbon isotope ratios of natural materials: II. Atmospheric, terrestrial, marine, and freshwater environments. p. 173–186. *In* D. Coleman and B. Fry (ed.) Carbon isotope techniques. Academic Press, New York.

Buck, B.J. 1993. Phytolith analysis of buried soils in the Fort Bliss reservation, El Paso, Texas. p. 117–128. *In* H.C. Monger (ed.). Soil-geomorphic and paleoclimatic characteristics of the Fort Bliss maneuver areas, southern New Mexico and western Texas. Historic and Nat. Resour. Rep. no. 10. Environmental Management Office, Fort Bliss, TX.

Bull, W.B. 1991. Geomorphic responses to climatic change. Oxford Univ. Press, New York.

Camilli, E.L., L.Wandsnider, and J.I. Ebert. 1988. Distributional survey and excavation of archaeological landscapes in the vicinity of El Paso, Texas. Las Cruces District Office of the Bur. of Land Manage. BLM-NM-GI-88-024-3120. Tucson, AZ.

Carmichael, D.L. 1986. Archaeological survey in the southern Tularosa basin of New Mexico. Historic and Nat. Resour. Rep. no. 3. Environmental Management Office, Fort Bliss, TX.

Catt, J.A. 1986. Soils and quaternary geology: A handbook for field scientists. Oxford Univ. Press, Oxford.

Cerling, T.E. 1984. The stable isotopic composition of modern soil carbonate and its relationship to climate. Earth Planet. Sci. Lett. 71:229–240.

Cole, D.R., and H.C. Monger. 1994. Influence of atmospheric CO_2 on the decline of C4 plants during the last deglaciation. Nature (London) 368:533–536.

Cummings, L.S. 1993. Phytolith analysis of three locations on the Fort Bliss military reservation, New Mexico: A feasibility study. p. 129–131. *In* H.C. Monger (ed.) Soil-geomorphic and paleoclimatic characteristics of the Fort Bliss maneuver areas, southern New Mexico and western Texas. Historic and Nat. Resour. Rep. no. 10. Environmental Management Office, Fort Bliss, TX.

Daniels, R.B., and R.D. Hammer. 1992. Soil geomorphology. John Wiley & Sons, New York.

Dansgaard, W. 1964. Stable isotopes in precipitation. Tellus 16:436–468.

Davis, J.O., and F. Nials. 1988. Geomorphology of the study area. p. 7–22. *In* J.C. Ravesloot (ed.) Archaeological resources of the Santa Teresa study area, south-central New Mexico. BLM-NM-GI-88-023-3120. Cultural Resour. Manage. Div., Arizona State Museum, Univ. of Arizona, Tucson.

Freeman, C.E. 1972. Pollen study of some Holocene alluvial deposits in Dona Ana County, southern New Mexico. Texas J. Sci. 24:203–220.

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. p. 383–411. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Gile, L.H. 1975. Holocene soils and soil-geomorphic relations in an arid region of southern New Mexico. Quat. Res. (NY) 5:321–360.

Gile, L.H., and R.B. Grossman. 1979. The desert project soil monograph. Document no. PB80-135304. National Technical Information Service, Springfield, VA.

Gile, L.H., J.W. Hawley, and R.B. Grossman. 1981. Soils and geomorphology in the Basin and Range area of southern New Mexico—Guidebook to the desert project. New Mexico Bur. of Mines and Mineral Resour. Memoir 39. New Mexico Bur. of Mines and Mineral Resour., Socorro, New Mexico.

Gile, L.H., F.F. Peterson, and R.B.Grossman. 1966. Morphological and genetic sequences of carbonate accumulation in desert soils. Soil Sci. 101:347–360.

Gish, J.W. 1986. Palynology of Picacho Reservoir, Arizona. p. 279–298. *In* F.E. Bayham et al. (ed.) Prehistoric hunter–gathers of south central Arizona: The Picacho Reservoir Archaic Project. Anthropological Field Studies no. 13. Arizona State Univ., Tempe.

Gish, J.W. 1993. Pollen results from three study localities on the Fort Bliss military reservation, New Mexico. p. 93–115. *In* H.C. Monger (ed.). Soil-geomorphic and paleoclimatic characteristics of the Fort Bliss maneuver areas, southern New Mexico and western Texas. Historic and Nat. Resour. Rep. no. 10. Environmental Management Office, Fort Bliss, TX.

Grootes, P.M. 1993. Interpreting continental oxygen isotope records. p. 37–46. *In* P.K. Swart et al. (ed.) Climate change in continental isotopic records. Geophysical Monogr. 78. Am. Geophysical Union, Washington, DC.

Harris, A.H. 1987. Reconstruction of mid-Wisconsin environments in southern New Mexico. Natl. Geograph. Res. 3:142–151.

Hawley, J.W. 1975. Quaternary history of Dona Ana County region, South-central New Mexico. p. 139–150. *In* W.R. Seager et al. (ed.) New Mexico Geol. Soc. Guidebook. 26th Field Conf., Las Cruces Country. Las Cruces, NM. 13–15 Nov. 1975. New Mexico Bur. of Mines and Mineral Resour., Socorro.

Hawley, J.W., G.O. Bachman, and K. Manley. 1976. Quaternary stratigraphy in the Basin and Range and Great Plains provinces, New Mexico and western Texas. p. 235–274. *In* W.C. Mahaney (ed.) Quaternary stratigraphy of North America. Dowden, Hutchinson, & Ross, Stroudsburg, PA.

Hawley, J.W., and F.E Kottlowski. 1969. Quaternary geology of the south-central New Mexico border region. p. 89–115. *In* F.E. Kottlowski and D.V. LeMone (ed.) Border Stratigraphy Symposium, El Paso, TX. 30 Apr. 1968. New Mexico Bur. of Mines and Mineral Resour. Circ. 104. Socorro.

Hays, P.D., and E.L Grossman. 1991. Oxygen isotopes in meteoric calcite cements as indicators of continental paleoclimate. Geology 19:441–444.

Hendricks, D.M. 1991. Genesis and classification of arid region soils. p. 33–80. *In* J. Skujins (ed.) Semiarid lands and deserts: Soil resource and reclamation. Marcel Dekker, New York.

Holliday, V.T. 1989. Middle Holocene drought on the Southern High Plains. Quat. Res. (NY) 31:74–82.

Kelly, E.F., R.G. Amundson, B.D. Marino, and M.J. DeNiro. 1991. Stable carbon isotopic composition of carbonate in Holocene grassland soils. Soil Sci. Soc. Am. J. 55:1651–1658.

Khresat, S.A. 1993. Geomorphic investigation of a possible paleolake on McGregor range. p. 41–67. *In* H.C. Monger (ed.) Soil-geomorphic and paleoclimatic characteristics of the Fort Bliss maneuver areas,southern New Mexico and western Texas. Historic and Nat. Resour. Rep. no. 10. Environmental Management Office, Fort Bliss, TX.

Kipp, J. 1993. Radar analysis of the Fort Bliss study area. p. 69–72. *In* H.C. Monger (ed.) Soil-geomorphic and paleoclimatic characteristics of the Fort Bliss maneuver areas, southern New Mexico and western Texas. Historic and Nat. Resour. Rep. no. 10. Environmental Management Office, Fort Bliss, TX.

Mayeux, H.S., H.B. Johnson, and H.W. Polley. 1991. Global change and vegetation dynamics. p. 62–74. *In* L.F. James (ed.) Noxious range weeds. Westview Press, Boulder, CO.

Monger, H.C. 1993. Soil-geomorphic and paleoclimatic characteristics of the Fort Bliss maneuver areas, southern New Mexico and western Texas. Historic and Nat. Resour. Rep. no. 10. Environmental Management Office, Fort Bliss, TX.

Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon and organic matter. p. 539–579. *In* A. Page (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Pigott, J.D. 1977. Reconnaissance geology: Implications for the analysis of human occupation. p. 97–158. *In* R.D. Kenmotsu and J.D. Pigott (ed.) A cultural resource inventory and assessment of McGregor guided Missile Range, Otero County, New Mexico. Res. Rep. 65. Part III. Bot. and Geol. Stud., Texas Archeol. Surv., Univ. of Texas, Austin.

Pigott, J.D. 1978. Pedology and paleopedology of the western Hueco Bolson for the past two thousand years: A tool for the analysis of aboriginal settlement patterns. p. 209–229. *In* M.E. Whalen (ed.) Settlement patterns of the western Hueco Bolson. Publ. in Anthropol. 6. El Paso Centennial Museum, Univ. of Texas, El Paso.

Quade, J., T.E. Cerling, and J.R. Bowman. 1989. Systematic variations in carbon and oxygen isotopic composition of pedogenic carbonate along elevation transects in the southern Great Basin, United States. Geol. Soc. Am. Bull. 101:464–475.

Ruhe, R.V. 1967. Geomorphic surfaces and surficial deposits in southern New Mexico. New Mexico Bur. of Mines and Mineral Resour. Memoir 18. New Mexico Bur. of Mines and Mineral Resour., Socorro, NM.

Schlesinger, W.H., G.M. Marion, and P.J. Fonteyn. 1989. Stable isotope ratios and the dynamics of caliche in desert soils. p. 309–317. *In* P.W. Rundel et al. (ed.) Ecological Studies Vol. 68. Stable isotopes in ecological research. Springer-Verlag, New York.

Seager, W.R. 1981. Geology of Organ Mountains and southern San Andres Mountains, New Mexico. New Mexico Bur. of Mines and Mineral Resour. Memoir 36. New Mexico. New Mexico Bur. of Mines and Mineral Resour., Socorro, NM.

Soil Survey Staff. 1982. Soil survey laboratory methods and procedures for collecting soil samples. Soil Survey Invest. Rep. 1. U.S. Gov. Print. Office, Washington, DC.

Soil Survey Staff. 1993. Soil survey manual. USDA Handb. 18. U.S. Gov. Print. Office, Washington, DC.

Stone, L.M. 1988. Historic period resources and research goals. p. 44–48. *In* J.C. Ravesloot (ed.) Archaeological resources of the Santa Teresa study area, south-central New Mexico. BLM-NM-GI-88-023-3120. Cultural Resour. Manage. Div., Arizona State Museum, Univ. of Arizona, Tucson.

Syvertsen, J.P., G.L. Nickell, R.W. Spellenberg, and G.L. Cunningham. 1976. Carbon reduction pathways and standing crop in three Chihuahuan Desert plant communities. Southwest Nat. 21:311–320.

Van Devender, T.R. 1990. Late Quaternary vegetation and climate of the Chihuahuan Desert, United States and Mexico. p. 104–133. *In* J.L. Betancourt et al. (ed.) Packrat Middens: The last 40,000 years of biotic change. Univ. of Arizona Press, Tucson.

Wang, Y., T.E. Cerling, J. Quade, J.R. Bowman, G.A. Smith, and E.H. Lindsay. 1993. Stable isotopes of paleosols and fossil teeth as paleoecology and paleoclimate indicators: An example form the St. David Formation, Arizona. p. 241–248. *In* P.K. Swart et al. (ed.) Climate change in continental isotopic records. Geophys. Monogr. 78. Am. Geophys. Union, Washington, DC.

Waters, M.R. 1989. Late Quaternary lacustrine history and paleoclimatic significance of pluvial Lake Cochise, southeastern Arizona. Quat. Res. (NY) 31:1–11.

Whalen, M.E. 1977. Settlement patterns of the eastern Hueco Bolson. Anthropol. Pap. 4. Univ. of Texas, El Paso.

Whalen, M.E. 1978. Settlement patterns of the western Hueco Bolson. Publ. in Anthropol. 6. El Paso Centennial Museum, Univ. of Texas, El Paso.

Yurtsever, Y., and J.R. Gat. 1981. Atmospheric waters. p. 103–142. *In* J.R. Gat and R. Gonfiantini (ed.) Stable isotope hydrology—Deuterium and oxygen-18 in the water cycle. Tech. Rep. Ser. No.210. Int. Atomic Energy Agency, Vienna.