FIELD GUIDE
TO THE
GEOARCHAEOLOGY
OF THE
MESCALERO SANDS,
SOUTHEASTERN NEW MEXICO

Stephen A. Hall

October 30, 2002

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By

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Prepared for

State of New Mexico Historic Preservation Division

and

New Mexico Bureau of Land Management

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October 30, 2002

Project No. 35-00-15334.11

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INTRODUCTION

The Mescalero Sands is a band of wind-deposited sand and sand dunes that extends north south along the western edge of the Caprock escarpment in southeastern New Mexico (Fig. 1). The name of the sand dunes is for the Mescalero Apache who once hunted in the area (Julyan, 1996). The Caprock escarpment that forms the eastern boundary of the sand sheet is also called the Mescalero Ridge. In an early reference to the area, geologist N. H. Darton observed: "On the east side of the Pecos Valley in southern New Mexico there are very extensive sand hills formed of deposits known as the 'Mescalero Sands'..."(1928, p. 59). In the study area in northeastern Eddy Co., New Mexico, the sand sheet is about 15 miles wide (Fig. 2).

The present investigation was undertaken to evaluate the geomorphic context of the archaeology of the sand sheet and to identify sand bodies that contain or have a potential for containing archaeological sites as well as sand bodies that do not have a potential for containing sites. A further goal of the study has been to establish criteria for evaluating the occurrence and integrity of archaeological sites on the sand sheet. One of the Historic Preservation Division requirements of the study is to compare the results from Mescalero Sands with the findings from the GBFEL-TIE project in the Tularosa Valley.

Fig. 1. Telephoto view of several small areas of active dunes on the Mescalero sand sheet, northeastern Eddy Co., New Mexico; mesquite coppice dune field in the foreground.

ACKNOWLEDGEMENTS

The investigation was sponsored by the State of New Mexico Historic Preservation Division and the Bureau of Land Management; I thank Glenna Dean and Stephen Fosberg for their guidance and support. The study benefited by the helpfulness of the BLM Carlsbad Field Office, especially Michael McGee, Tiffany Sullivan-Owens, Rose Marie Havel, and Doug Melton. Special thanks to Don Clifton for sharing results from archaeological studies and field experience at Bear Grass Draw. Many reviewers made numerous helpful comments on earlier drafts of the *Field Guide* (July 23, 2001; March 8, 2002).

The optically stimulated luminescence ages of the sand sheet were generously provided by Ronald Goble, Department of Geosciences, University of Nebraska-Lincoln. Sediment data were provided by Mary Jo Schabel, Milwaukee Soil Laboratory, Milwaukee, Wisconsin. The radioactive isotope analyses and their interpretation were provided by Hewitt Jeter. Stable isotope data were provided by Geochron Laboratories, Cambridge, Massachusetts. I thank Glenna Dean for providing the identity of Torrey mesquite.

CLIMATE AND VEGETATION

The semiarid climate of the Mescalero Sands places it at the northeastern edge of the Chihuahuan Desert near the transition with the semiarid steppe of the southwestern High Plains. The mean annual precipitation is about 13 to14 inches and the mean annual temperature is about 60 $^{\circ}$F (Table 1). The area is within the region that receives a significant amount of annual precipitation in the summer from the Mexican monsoon. The climate and elevation of the Mescalero Sands are similar to that of the Tularosa basin where a similar late Quaternary sequence of eolian geology occurs, except that the Mescalero Sands receives about 2 to 3 inches of rainfall a year more than does the Tularosa basin.

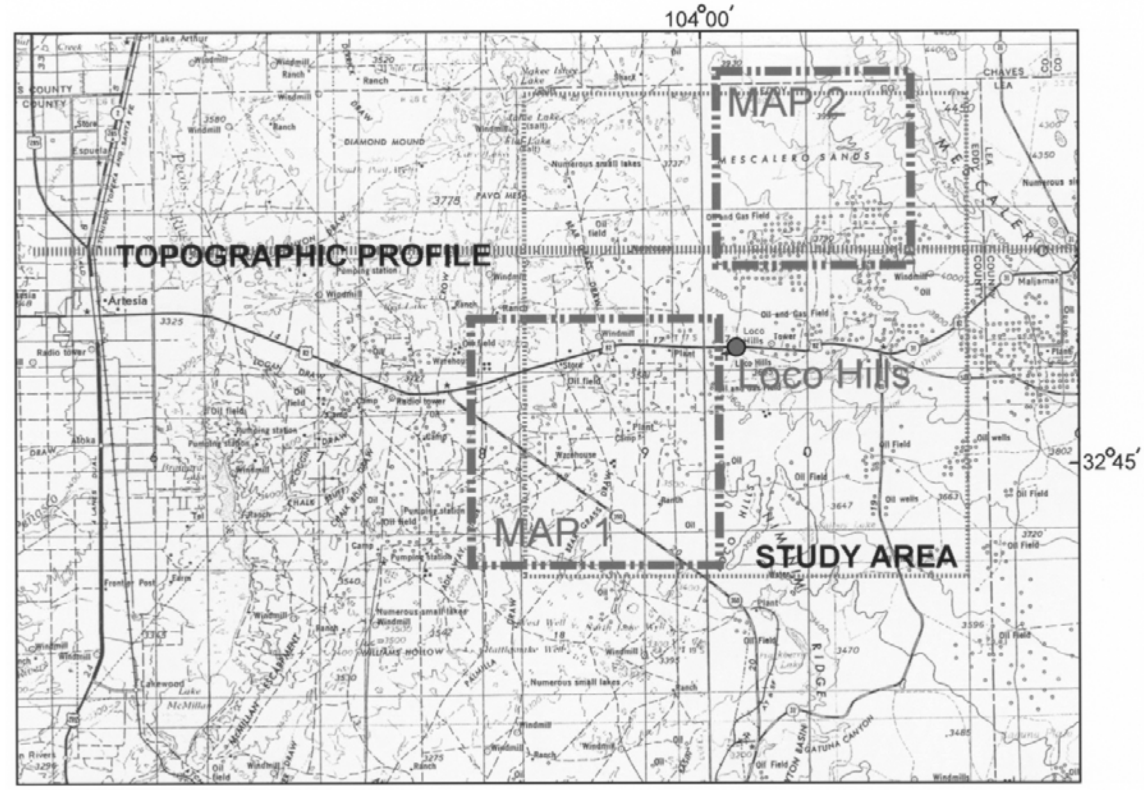

Fig. 2. Topographic map of northeastern Eddy Co., New Mexico; map scale 1:250,000.

Even though the climate of the Mescalero Sands and Tularosa basin are somewhat similar, the treeless shrub vegetation is very different in species composition, related to substrate: quartz sands at Mescalero and gypsiferous sands at Tularosa. The plant community that characterizes the Mescalero sand sheet is unique to eolian sands in the region. The dominant shrub is shin oak (*Quercus havardii*) that thrives in the sand as well as serving as a sand trap in parabolic dunes, aiding in the stability of the central core of the sand sheet, especially where the sand exceeds two meters in thickness. Subdominants include sand sagebrush (*Artemisia filifolia*), yucca (*Yucca campestris*), and occasional stands of western soapberry (*Sapindus drummundii*). At the margins of the sand sheet where the sand is thin, generally less that one meter thick, Torrey mesquite (*Prosopis glandulosa torreyana*) recently expanded its range and increased its abundance; mesquite forms the nucleus for numerous recent coppice dunes in its newly established population throughout the region far beyond the Mescalero Sands (Peterson and Boyd, 1998; Dick-Peddie, 1993).

Table 1. Climatological data from Mescalero Sands area and Tularosa basin, New Mexico (from NOAA, Climatological Data, Annual Summary, New Mexico, 2000, v. 103, no. 13).

STATION	ELEV. (FEET)	AVE. ANN. PRECIP. (INCHES)	AVE. ANN. TEMP. (°F)	AVE. JAN. PRECIP. (INCHES)	AVE. JULY PRECIP. (INCHES)	AVE. JAN TEMP. (°F)	AVE. JULY TEMP. (°F)
MESCALERO SANDS							
Artesia	3320	12.32	59.5	0.34	1.40	38.8	79.3
Maljamar	4000	14.93	60.2	0.37	2.19	40.1	78.9
TULAROSA BASIN							
Orogrande	4182	11.40	61.9	0.46	1.85	42.4	81.0
White Sands Natl. Mon.	3995	11.40	59.3	0.46	1.51	39.4	80.3

STRATIGRAPHY

The stratigraphic sequence of the Mescalero sand sheet consists of two prehistoric eolian sand units, each accumulating during discrete periods of sand deposition. Recent deflation and eolian sand accumulation has resulted in the formation of parabolic and coppice dunes, together comprising a third eolian sand unit that may be wholly historic in age. The entire sand sheet is underlain by the Mescalero paleosol, a largely eroded calcic soil that formed over the broad region on weathered Permian and Triassic bedrock and older Quaternary deposits prior to the origin of the Mescalero Sands.

Mescalero Paleosol

The caliche that occurs everywhere beneath the Mescalero Sands is the Bk petrocalcic horizon of the Mescalero paleosol. The secondary carbonates form a layer about 40 to 80 cm thick that is continuous, moderately hard, with thin laminae at the top in a few exposures. The Bk horizon is characterized by about 50 to 70% carbonates and is developed directly on the Santa Rosa Sandstone and Chinle Formation (Dockum Group, Triassic) in the study area (Pl. I-A) and on the Rustler Formation (Permian) and the Gatuña Formation (Middle Pleistocene) elsewhere in the area. The quartz sand, silt, and clay content and occasional chert clasts in the caliche reflect the texture of the Triassic bedrock parent material in which the soil formed. Exposures of caliche occur at various elevations and topographic position throughout the region, indicating that the local topography is bedrock controlled and is only nominally related to thickness of the sand sheet. The paleosol and its occurrence in southeastern New Mexico are reported by Bachman (1976) who refers to it informally as the Mescalero caliche.

The degree of secondary carbonate accumulation in the paleosol is equivalent to stage III or weak stage IV soil development in the soil chronosequence described from south-central New Mexico, indicating a broad period of potential development extending from 25,000 to <400,000 years (Gile et al., 1981). The age of formation of the Mescalero paleosol also is poorly constrained. The paleosol occurs at the top of the Gatuña Formation, indicating that the paleosol is younger than the age of the Gatuña. While the geologic age and correlation of the Gatuña Formation are yet unresolved (reviewed by Hawley, 1993), the discovery of the Lava Creek-B volcanic ash, dated about 0.6 Ma, in the upper part of the Gatuña Formation (Bachman, 1980; Powers and Holt, 1993) indicates that the deposition of the Gatuña extended into the Middle Pleistocene. In the Mescalero Sands area, the Mescalero sand sheet, the earliest unit of which began to accumulate about 90,000 years ago, overlies the Mescalero paleosol. Thus, the Mescalero paleosol developed during the broad period of time between 90,000 and 600,000 years ago. The age of the paleosol may be further constrained by the paleoclimatic history of the region: it is likely that the petrocalcic horizon of the soil formed during one period or multiple periods of dry climate instead of during periods of wetter climate. The latest period of time that could be represented by the Mescalero paleosol is the warm dry climate of the Sangamon and early Eowisconsin, about 100,000 to 130,000 years ago. Whether the Mescalero paleosol is Sangamonian or formed during one or more earlier interglacial-age periods of aridity remains to be determined.

The late Pleistocene Mescalero soil profile may have been two meters thick. Subsequent to its development, erosion removed the A horizon and the upper part of the B horizon, probably an argillic Bt. The erosional contact is sharp in some exposures with a 1 to 2 cm thick zone of sand that may represent a residuum of leaching at the caliche-eolian sand interface (Fig. 3). The lower Bt and upper part of the Bk horizon are partly preserved at locality 10. At the time of development of the Mescalero soil, an eolian sand sheet was not present in the study area.

The Mescalero paleosol carbonates are well exposed in numerous caliche pits in the study area (Pl. I-B). However, the investigator should be aware that the locations of caliche pits are selected by drill testing of caliche for hardness and suitability for road surfacing material. While caliche pits provide valuable information on paleosol carbonates, pit locations may not be representative of Bk horizon morphologic variability. Also, the upper part of the Bk horizon and overlying eolian sand are generally disturbed around caliche pits and may of limited use for stratigraphic investigations.

Unit 1 Eolian Sand

Unit 1 is the basal eolian sand body in the stratigraphic sequence in the study area and represents the first period of eolian sand accumulation in the Mescalero Sands. Prior to the deposition of unit 1, the sand sheet did not exist in the study area. The fine to very fine quartz sand is subangular-subrounded and yellowish red to red (5YR 5/8, 2.5YR 5/8); redder color is generally closer to the Bt paleosol at the top of the unit. The sand lacks bedding, probably due to bioturbation, and rests unconformably on the eroded surface of the Mescalero paleosol. The sand accumulated to a thickness of 3 meters or more in some areas of the sand

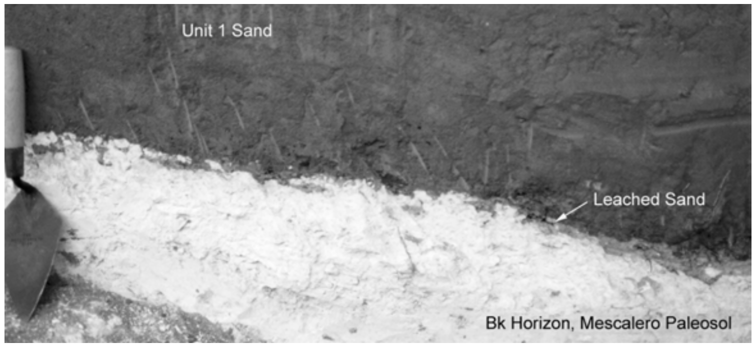

Fig. 3. Eroded surface of Mescalero paleosol petrocalcic horizon overlain by red unit 1 eolian sand at loc. 4; thin irregular zone of leached sand occurs at contact; similar record of eroded caliche at loc. 6; evidence of widespread erosion after the development of the calcic paleosol and before the deposition of unit 1 eolian sand.

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sheet. However, in most areas where the sand unit is preserved, the sand was either deposited as a thin layer only 40 to 60 cm thick, or the sand was severely eroded immediately following its deposition and prior to its stability and subsequent soil development.

Based on optically stimulated luminescence (OSL) ages of two horizons (Table 4) and accompanying sedimentation rates at the Valley Gas Road sand pit (locality 1, Pl. I-C), unit 1 sand accumulated during an interval of 14,700 years between about 70,000 to 90,000 years ago during the warm late Eowisconsinan (oxygen isotope stage 5A) and the Early Wisconsinan (stage 4).

Red Bt Paleosol

A red argillic non-calcic Bt paleosol occurs at the top of unit 1 sand. The paleosol color is red to dark red (2.5YR 4/8, 2.5YR 3/6). The strong red color of the sand is due to secondary iron oxides and clays (15 to 20 %) that coat the sand grains, giving the clear quartz grains their red color. In areas of thick accumulation of unit 1 eolian sand, the red soil is 50 to 70 cm thick and grades at depth into massive yellow sand with filamentous carbonates but lacking a discernable Bk horizon. More commonly, where the unit 1 eolian sand has a thickness of only 30 to 50 cm, the paleosol has formed in the entire thickness of the unit 1 sand and into sand wedges in pipes in the underlying petrocalcic horizon of the Mescalero paleosol. The modest clay content of unit 1 eolian sand noted by Bachman (1976) is due to secondary clay buildup in the Bt paleosol. While the red sand and paleosol appear to be massive and undisturbed, close inspection shows that the sand and red paleosol have been severely bioturbated. Because of the absence of burrow fills from the overlying younger eolian sand unit 2, the strong degree of bioturbation likely occurred throughout the period of argillic soil development during the Wisconsinan prior to its burial by the younger sand.

The red argillic paleosol formed after the deposition and erosion of unit 1 sand and before the deposition of the overlying unit 2 sand. Thus, the development of the red paleosol occurred between about 15,000 and 60,000 years ago during the Wisconsinan over an interval of no more than about 45,000 years. The non-calcic, argillic character of the paleosol indicates that it developed in a mesic environment in strong contrast to the arid environment in which the underlying calcic Mescalero paleosol developed.

Unit 2 Eolian Sand

The unit is composed of fine to very fine quartz sand, reddish yellow (5YR 6/6), grains subrounded to rounded, and noncalcareous. The sand body lacks bedding, probably due to bioturbation. The sand accumulated to a thickness of 4 to 5 meters in the central portion of the sand sheet while at the margins of the sand sheet it is less than 1 meter in thickness.

The chronology of unit 2 eolian sand deposition is between about 5000 to 9000 years BP, based on two OSL ages (Table 4) and net sedimentation rates of unit 2 sand at the Booger Langston Road sand dunes (locality 8; Pl. II-D). The unit 2 sand may have accumulated during a time interval of about 3700 years. The early to mid-Holocene age of the sand coincides in part with a period of climatic drying and aridity. Most of the archaeology in the study area occurs on the stable surface of the unit 2 sand and in the accompanying Loco Hills soil that mantles the sand unit. The sand body does not contain a soil or buried paleosol.

Clay bands. In areas of the sand sheet where unit 2 sand is thick, clay bands occur between about 1.5 and 3.0 meters depth (Pl. II-D; Pl. V-M). Each band is about 5 mm thick and consists of sand that is indurated by clays (6%) and iron oxides, resulting in a slightly darker color than the surrounding sand. The clay-band sands are leached of carbonates. The bands are discontinuous, each one extending laterally no more than about a meter. The clay bands are visible in areas of active dunes where unit 2 sand is thick and exposed by deflation. The bands may be a result of leaching of clays and minerals from the surface by organic acids found in shin oaks that inhabit on the sand sheet. As waterfronts infiltrate the sand, organic acids from the oaks are incorporated with the water, increasing the amount of mineral translocation in the thick column of eolian sand. The clay bands are secondary features in unit 2 sand and formed in the past 5000 years, subsequent to the accumulation of the sand sheet. Clay bands are not found in unit 1 sand.

Clay bands are reported from most of the Holocene eolian sand deposits on the Texas High Plains, including the Muleshoe dunes (Gile, 1985), the Lea-Yoakum dunes, and the Monahans dunes (summarized by Holliday, 2001). Higher numbers of clay bands are generally related to greater antiquity of the sand, older eolian sand containing stronger band development than occurring in younger sand.

Loco Hills Soil

The Loco Hills soil is named for its occurrence in the vicinity of the Loco Hills community in Eddy Co., New Mexico. It is an A horizon soil about 10 to 30 cm thick and lacks evidence of B-horizon development; the soil is generally noncalcareous. The organic-matter content of the A horizon is low, ranging from 0.2 to 0.4% (Appendix A). The soil's color is reddish brown to reddish yellow to yellowish red (5YR 4/4, 5YR 6/6, 5YR5/6). The Munsell color of the soil commonly keys to the same color as that of the underlying eolian sand. In the field, however, the soil is distinct in appearance due to its slightly darker color value. The sediment matrix of the A horizon is silty, very fine to fine quartz sand, grains subrounded to rounded. Although the Loco Hills soil occurs on substrates of different ages (unit 1, unit 2, late Holocene alluvium and colluvium), the texture of the A horizon sand is similar to that of unit 2 sand, indicating that the surface of unit 2 sand was locally deflated during the period of soil development.

Five radiocarbon ages have been obtained on fine organic matter from the Loco Hills soil A horizon: 370 $\pm$ 40, 330 $\pm$ 40, 150 $\pm$ 40, and two modern assays (the two modern ages are probably spurious and are due to the presence of large amounts of modern rootlets in the samples that were radiocarbon dated). The late Holocene period of time, the last 5000 years, is generally not represented by deposits and soils in the Mescalero Sands, except for the late-developing Loco Hills soil about 100 to 500 years ago. The Loco Hills A horizon soil occurs regionally and is documented in the Tularosa basin where it is called the Q3A unit with a single radiocarbon age of 160 $\pm$ 90 ^{14}C yr BP (Swift, 1991b).

The Loco Hills soil mantles the landscape, occurring at the top of eolian sand units 1 and 2 as well as in the upper portion of late Holocene alluvium and in colluvial-slope wash deposits in the study area. The Loco Hills soil is regarded as a distinct stratigraphic unit that is separate from the eolian sand units. The A horizon soil represents a period of landscape stability in both eolian, fluvial, and slope geomorphic environments. The stability of the sand sheet and formation of the A horizon may indicate more mesic conditions and the regional establishment of desert grassland vegetation. The Loco Hills soil is eroded in areas of active deflation but preserved where buried by historic parabolic and coppice dunes (Pl. II-E, Pl. III-G, -I).

PARABOLIC DUNES

Parabolic dunes cover most of the central part of the sand sheet (Pl. V-O). The parabolic dunes are small and sub-circular, averaging 23 meters long, 20 meters wide, and 3 meters high at the crest above the floor of the deflation basin. The dunes are oriented north 70-90° east, formed by west and west-southwest winds. A mantle of shin oak (*Quercus havardii*) vegetation protects the sand sheet from erosion. Shin oak is a low shrub that today occurs on sandy soils in the southwestern plains. However, persistent deflation removes sand from the surface, exposing the roots of the shinnery. Shin oaks with exposed roots and stems generally die, facilitating further deflation of the underlying sand. Occasionally, exposed stems will survive as small trees. The parabolic dunes have not been directly dated, although they occur on the eroded surface of the Loco Hills soil and, consequently, are less than 100 years old.

COPPICE DUNES

Coppice dunes are small circular mounds of eolian sand formed around the base of shrubs where saltating sand grains accumulate because of reduced wind velocity. The sand-capturing shrubs in the Mescalero

Sands are Torrey mesquite (*Prosopis glandulosa torreyana*) and, in a small area in the northeastern corner of the study area, javelina bush (*Condalia ericoides*). Most of the coppice dunes in the study area and in the broader region of the northern Chihuahuan Desert are formed around Torrey mesquite.

Coppice dunes are found throughout the Mescalero sand sheet where unit 2 sands are no more than about one meter thick. The restriction of coppice dunes to areas of thinner sand may be related to the ecology of mesquite, whereby mesquite thrives in areas of thin sand. Dune height ranges from about 40 to 180 cm, averaging about 100 cm, above the pre-dune surface that, in most places, is the Loco Hills soil (Pl. II-F). The coppice dunes consist of fine to very fine silty quartz sand that is yellowish red to light yellowish brown (5YR 4/6, 10YR 6/4). The color of coppice-dune sand generally mimics the color of adjacent sand from which the coppice dune is derived, indicating that the sand that makes up the coppice dunes has not traveled far and is of local origin, although the sand grains are generally subrounded to rounded, a slightly greater degree of rounding than observed in older sand.

Where not disturbed by bioturbation, the coppice dunes exhibit bedding that follows the curvature of the mounded sand around the mesquite. Thin crusts of silt and fine sand are part of the bedding structure; the thin crusts are likely formed during rainfall events when silt particles that have accumulated on leaves and stems of the mesquite are washed off and deposited as a drape of fine particles on the dune surface. The soft sand of the recent coppice dunes attracts burrowing animals, thus the primary bedding and internal stratigraphy of most of the coppice dunes inspected in the study area have been lost due to bioturbation. Occasionally, animals have burrowed through the coppice dunes into the underlying Loco Hills soil and unit 2 eolian sand. In some cases, sediment from the paleosol and unit 2 sand has been transported by animals upward into the coppice dunes, and in other cases sand from the dunes has been transported down into the paleosol and unit 2 sand.

Coppice Dunes, Early Land Surveys, and Torrey Mesquite

The appearance of coppice dunes is related to the expansion of Torrey mesquite. While honey mesquite has been part of the regional flora for at least 10,000 years (Van Devender, 1986), the range expansion and increase in abundance of Torrey mesquite becoming a dominant component of the desert vegetation may be a fairly recent event. In one study, the oldest Torrey mesquite in a coppice dune germinated ca. 1877, and 62% of the mesquite in coppice dunes germinated in the period ca. 1931 to 1941 (Gadzia and Ludwig, 1983). A number of investigators relying on notes from 19th century surveyors have concluded that the coppice dunes of southern New Mexico are historic in origin, resulting from overgrazing by livestock, decrease in grasses, and increased abundance of mesquite (Gile, 1975). Repeated baseline vegetation plots show a decrease in black grama grassland and an increase in mesquite and have been cited in support of the historic origin of coppice dunes (Buffington and Herbel, 1965; York and Dick-Peddie, 1969). Pollen analysis of a coppice dune also shows a decrease in grass pollen percentages, bottom to top (Hall, 1990a). However, comparisons of survey notes from the same places in the Tularosa basin of southern New Mexico disclose major discrepancies that can only be accounted for by fraudulent entries by one or more surveyors (Eidenbach and Wimberly, 1980, p. 15-16). The possibility that an unknown number of 19th century surveys may be partially or wholly spurious opens a question concerning the historical evidence for the precise age and origin of the coppice dunes.

Radioactive Isotopes From Coppice Dune

A coppice dune (loc. 13, Pl. III-G) with intact stratigraphy was sampled for ^{210}Pb and ^{137}Cs radioactive isotope analysis as a pilot study to test the historic age of the coppice dunes. The ^{210}Pb isotope is a product of radioactive decay of radon gas (^{222}Rn) in the atmosphere and is deposited over the landscape and incorporated in sediments. The ^{137}Cs isotope is produced by nuclear reactions in power plants and atomic detonations. The presence of ^{137}Cs in the environment is a consequence of aboveground testing of nuclear weapons, first producing detectable amounts of ^{137}Cs in 1954 followed by peak amounts in 1963 in sediments worldwide (Jeter, 2000).

The fine particles of ^{210}Pb and ^{137}Cs are best preserved in the muddy sediments of quiet ponds and slow-moving streams. Their presence in sand dunes is unlikely. However, coppice dunes are different from other dunes. Sand accumulates around a bush, such as mesquite. Silt and other fine particles that dust the leaves and stems of the bush are washed out by rainfall and accumulate on the dune surface. The dune's stratigraphy consists of numerous, slightly indurated silt-clay drapes piled one upon another, with a layer of fine sand in between. It is speculated that the fine radioactive particles of ^{210}Pb and ^{137}Cs are incorporated in the dune's thin mud drapes.

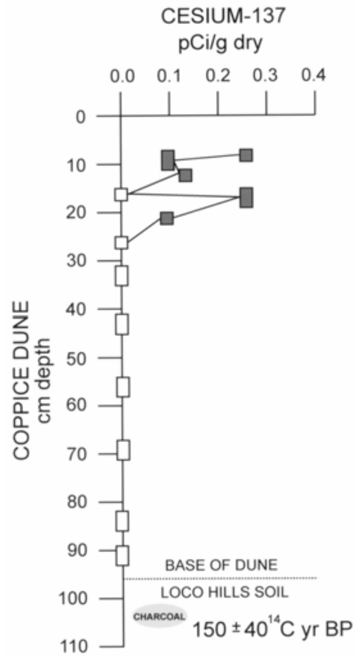

Fig. 4. Cesium-137 content vs. depth of coppice dune, loc. 13 (Fig. 11); presence of cesium-137 in upper 22 cm indicates eolian deposition accompanying atmospheric testing of atomic weapons since 1954 (Table 2).

Small amounts of ^{137}Cs in five of the upper six samples indicate that the upper 22 cm of the dune is late historic in age, deposited since 1954 (Fig. 4, Table 2). The entire coppice dune sequence appears to have accumulated continuously without significant erosional unconformity. The lower 74 cm of the dune may be historic as well. A simple net sedimentation rate of 0.47cm/year indicates that the 96-cm high dune could have accumulated in 200 years. However, because of the possibility that the coppice dune rate of accumulation may have slowed with increasing age and height, the sedimentation rate calculated from the upper 22 cm may be misleadingly slow, giving an apparent age that is too old for the entire dune. Thus, a 200-year age for the accumulation of the dune is thought to be a maximum age that may indeed be too great. A radiocarbon age on charcoal from the Loco Hills soil on which the coppice dune has formed is 150 $\pm$ 40 ^{14}C yrs BP. The coppice dune yielded too little ^{210}Pb for use in verifying the young age that is indicated by the ^{137}Cs content.

Table 2. Radioactive isotope, cesium-137, from coppice dune, loc. 13 (Pl. III-G)*

sample	*depth above base (cm)***	*^{137}Cs activity pCi/g dry*
E(uppermost)	87-89	0.260 $\pm$ 0.069
8	85-89	0.095 $\pm$ 0.028
D	83-85	0.130 $\pm$ 0.055
C	79-81	<0.027
7	77-81	0.259 $\pm$ 0.050
B	74-76	0.092 $\pm$ 0.049
A	69-71	<0.038
6	61-65	<0.044
5	51-55	<0.033
4	38-42	<0.025
3	25-29	<0.017
2	10-14	<0.055
1 (lowermost)	3-7	<0.020

*Data provided by Dr. H. W. Jeter, Mass Spec Services, P. O. Box 163, Orangeburg, NY 10962
**Exposed face of coppice dune where measured and sampled has a thickness of 96 cm

GEOCHRONOLOGY

In the Earth sciences, chronology is everything. Many of the controversies concerning the reconstruction of prehistoric environments come down to inadequate chronology of sediments and their contained fossil record. Eolian deposits in general are difficult to date, and the Mescalero sand sheet is no different. A composite chart of the stratigraphy and geochronology of the sand sheet is shown in Fig. 5.

Radiocarbon Dating

Radiocarbon dating is the most mature geochronologic method applied to late Quaternary sediments younger than 40,000 years in age (Bowman, 1990). Unfortunately, the only material discovered in the sand sheet suitable for radiocarbon analysis is fine organic matter in the weak A horizon of the Loco Hills soil that mantles and post-dates unit 2 sand and that formed on late Holocene floodplain surfaces along small drainages. Snail shells from a Pleistocene cienega deposit were also analyzed for radiocarbon age. The radiocarbon age was obtained on shell material, land and aquatic snails alike, which had been crushed to eliminate the sediment that fills fossil shells. Shell fragments that exhibited nacreous (pearly) luster, indicting original aragonite composition, and that were devoid of secondary encrusted carbonates were selected for radiocarbon assay. Almost all of the snail shells are nacreous; chalky non-nacreous shell fragments were bypassed during selection of the radiocarbon sample. The radiocarbon age is probably accurate; even if 10% of the dated material had been radioactively dead, it would have increased the age of the shells by no more than 850 years (Bowman, 1990). All of the radiocarbon ages from the Mescalero Sands in this study are accelerator mass spectrometry (AMS) methodology (Table 3).

Table 3. Radiocarbon ages from the Mescalero Sands, Eddy Co., New Mexico.

LAB NO.	MATERIAL DATED	MEASURED RADIOCARBON AGE*	$\delta^{13}C$ ‰	CORRECTED RADIOCARBON AGE	2-SIGMA CALIBRATED AGE‡
Beta-156689	organic detritus[1]	102.5 ± 0.5 pMC	-18.6	101.2 ± 0.5	modern
Beta-160894	organic detritus[1]	240 ± 40	-17.0	370 ± 40	AD 1440-1640
Beta-156688	organic detritus[2]	103.5 ± 0.5 pMC	-23.6	103.2 ± 0.5	modern
Beta-159213	organic detritus[3]	90 ± 40	-21.6	150 ± 40	AD 1660-1950
Beta-156687	organic detritus[4]	300 ± 40	-23.2	330 ± 40	AD 1460-1650
Beta-156514	snail shells	18620 ± 100	-7.7	18900 ± 100	21080-19910 BC

*AMS, Libby half-life; pMC = percent modern carbon
‡Stuiver and Reimer, 1993; Stuiver et al., 1998
[1]Loco Hills A horizon soil, locality 3 in mesquite coppice dunes (Pl. II-E); replicate samples
[2]Loco Hills A horizon soil, locality 8 in shinnery parabolic dunes (Pl. II-D)
[3]Loco Hills A horizon soil, locality 13, beneath coppice dune (Pl. III-G)
[4]A horizon soil in alluvium, locality 12 (Pl. III-I)

Optically Stimulated Luminescence (OSL) Dating

In the absence of organic matter for radiocarbon assay, sand was collected for OSL dating, two samples each from the two eolian sand units. OSL has three advantages over radiocarbon: (a) it can provide ages for sandy sediments that lack organic matter, (b) the range of OSL age potential goes much farther back in time than possible for radiocarbon, and (c) OSL can provide accurate ages on sandy sediments less than 200 years old which is more difficult for radiocarbon because of recent fluctuations in the ^{14}C content of the atmosphere. OSL ages are in calendar years. Aitken (1994, 1998) and Huntley et al. (1985) present technical accounts of OSL methodology.

The sediment samples for OSL analysis were selected from near the base and middle or top of the sand units. Each sample of sand was collected by driving a 2-inch diameter, 8-inch long cylinder into a vertical face of eolian sand that had been prepared by removing the outer 1 to 2 feet of material. Upon extraction, the ends of the sand-filled cylinder were sealed with tape to eliminate light infiltration and stored in a dark bag. An additional sample of sand was collected from around the hole from which the cylinder was taken for sediment chemistry, and a second sand sample was placed in a sealed container for determining moisture content (water attenuates radiation). In the laboratory, the sand sample for OSL analysis was taken from the center of the cylinder fill.

The method in this study is called single-aliquot regenerative optically stimulated luminescence (SAR OSL) that refers to light that is emitted as a result of exposure to the visible light from green and blue diodes. The amount of light emitted is directly related to the length of time the sample is buried and to the chemical composition of the sample. The older the sample, the more light emitted. The light originates from the release of free electrons that have been trapped at defects in the crystal lattice of the mineral grain. The trapped electrons are produced by the decay of radioisotopes in the sediment surrounding the sample. This is the first time SAR OSL has been used in New Mexico archaeology. The analyses were conducted by Dr. Ronald Goble at the University of Nebraska-Lincoln.

The OSL ages from the Mescalero Sands are internally consistent (Table 4) and provide an age for the older sand unit that is beyond the capability of radiocarbon. The OSL age of the unit 1 sand is 87,400 ± 4500 years at the base and 81,700 ± 3600 years BP in the middle of the unit; the upper sample was taken from the middle of the unit to avoid any problems associated with the argillic Bt paleosol at the top of the unit. The age of the unit 2 sand is 8900 ± 300 years at the base and 6300 ± 200 years BP in the upper portion of the unit. Both sets of ages are internally consistent even though 2-sigma standard deviation of unit 1 ages overlap.

Table 4. Optically stimulated luminescence (OSL) ages from the Mescalero Sands, Eddy Co., New Mexico; provided by Dr. Ronald Goble, Dept. of Geosciences, Univ. of Nebraska-Lincoln.

SAMPLE	Field Moisture (%)	Saturated Moisture (%)	K_2O (%)	Th (ppm)	U (ppm)
1	2.7	26.9	0.76	2.0	0.5
2	2.5	28.4	0.71	2.2	0.6
3	2.9	26.5	0.73	1.8	0.6
4	2.7	27.4	0.59	1.0	0.4

SAMPLE	D_{cosmic} ($Gy \cdot a^{-1} \cdot 10^3$)	D_{total} ($Gy \cdot a^{-1} \cdot 10^3$)	Paleodose (Gy ± $1\sigma_s$)	Aliguots (n)	Age (ka ± 1σ)
1	0.14	0.99 ± 0.02	86.16 ± 3.42	21	87.4 ± 4.5
2	0.14	0.99 ± 0.02	80.63 ± 2.49	21	81.7 ± 3.6
3	0.14	0.99 ± 0.02	8.79 ± 0.19	25	8.9 ± 0.3
4	0.14	0.76 ± 0.02	4.83 ± 0.11	23	6.3 ± 0.2

Sample 1 & 2: Unit 1 sand, loc. 1 (Pl. I-C), 280 cm & 160 cm depth, respectively
Sample 3 & 4: Unit 2 sand, loc. 8 (Pl. II-D), 455 cm & 135 cm depth, respectively

ACTIVE DUNES

Several small areas of continuous active sand dunes with little or no vegetation, each less than 400 acres, occur in the central part of the Mescalero sand sheet (Fig. 1; Pl. V-M). The active dune are all areas where eolian sand as much as five meters thick was originally present and where the thick sand has been deflated and redeposited in the immediate vicinity; none of the dune fields appear to have resulted from migration of sand and dunes into new areas. The recent dunes are as much as two meters in thickness above the initial pre-deflation sand sheet surface, generally marked by the presence of the Loco Hills soil. The active dunes appear to be recent in origin, perhaps 20^{th} century. The cause of recent dune activity is not apparent, although likely due to disturbance in the oil and gas field. Shinnery parabolic dunes surround the active dune fields. At one locality, a tree-like shin oak with a stem diameter of 3.5 inches was cored and contained about 40 growth rings. The eroded five meters of sand is mostly unit 2 sand, the same sand layer that elsewhere contains numerous archaeological sites in its upper-most levels. Sites are present but appear to be less numerous in the active dune fields, perhaps due to lower visibility.

At the margins of the dune fields are pillars of sand that are protected by shin oak (Pl. V-M, -N). The sand pillars have a superficial appearance of coppice dunes but have formed by erosion. Some of the sand pillars may be eroded remnants of vegetated parabolic dunes underlain by a thick sequence of unit 2 sand. Increasing deflation deeper into the sand sheet is halted at depth by the presence of the indurated red sand (Bt paleosol on unit 1 sand), or spring-groundwater carbonates, or caliche.

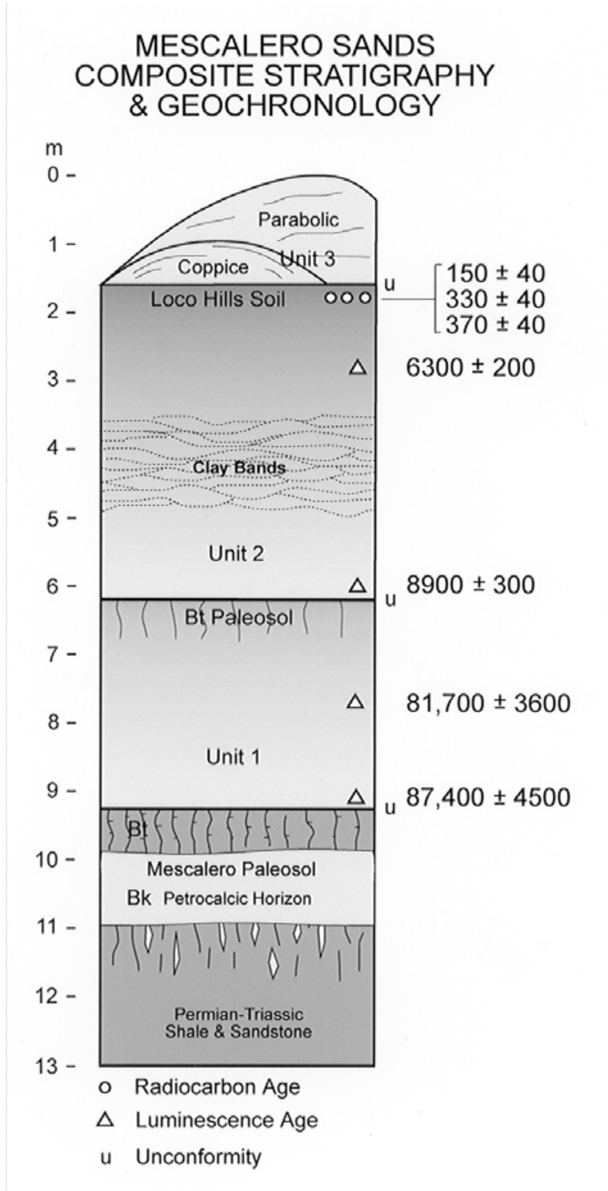

Fig. 5. Composite stratigraphy of the Mescalero Sands; maximum thickness of eolian units; no single location exhibits the entire stratigraphic sequence; radiocarbon ages are in radiocarbon years BP (Table 3); OSL ages in calendar years BP (Table 4).

ORIGIN OF THE MESCALERO SANDS

The presence of the Mescalero Sands may be related to the high relief of the Caprock escarpment that traps eolian sand carried by west winds (Fig. 6). If the relief of the western edge of the escarpment had been lower, the sand would have been carried onto the High Plains surface. Indeed, other sand sheets on the western edge of the High Plains, such as the Muleshoe dunes to the north and the Monahans dunes to the south, may have originated in this manner.

Prior to the deposition of unit 1 sand 70,000 to 90,000 years ago, eolian sand was not present in the study area. The sand that makes up unit 1 sand sheet may have originated from the deflation of sandy alluvium that was derived from the erosion and retreat of the Ogallala caprock escarpment. Comparison of the percentages of fine sand and total sand from unit 1 and the Ogallala Formation shows strong similarities

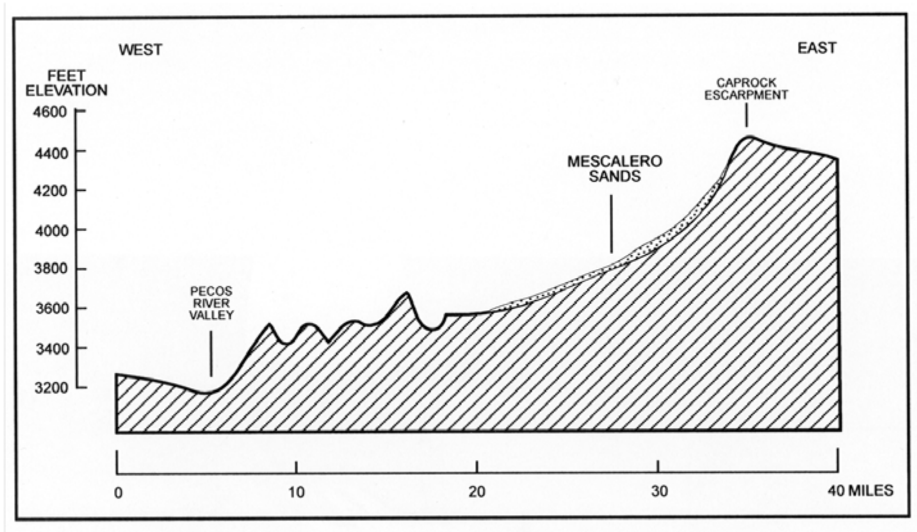

Fig. 6. Topographic profile showing position of the Mescalero Sands in the landscape; location of profile shown in Fig. 2.

(Fig. 7). Bachman (1976, p. 145) was the first to propose an Ogallala origin of the Mescalero sand: "Sand deposits are discontinuous along the banks of the Pecos River and there is very little evidence that much sand has been derived from there. I believe that most of the windblown sand in areas such as Los Medanos was derived from the Ogallala Formation." In a recent study, it was found that the chemistry of the Mescalero eolian sand differs from that of the Pecos alluvium, indicating further that Pecos River alluvium might not be the source of the sand sheet (Muhs and Holliday, 2001). Similar geochemical analyses of fine sand from the Ogallala Formation could test the Ogallala origin of the Mescalero Sands. It may be difficult to evaluate in the field an Ogallala origin of unit 1 sand, however, because the eolian sand was deposited 70,000 to 90,000 years ago and the geomorphic and stratigraphic record from that time period is missing or obscured by recent local geomorphic events.

If the older (unit 1) sand is derived from the deflation of alluvial sediments washed off of the weathered Ogallala escarpment, does the younger sand body (unit 2) have the same origin? Or is the younger sand reworked from the older sand? Field evidence indicates that the older sand sheet, unit 1, may not have been a sand source because of the development of the clay-rich argillic soil. The argillic paleosol indurates the top of the older sand, essentially sealing the sand unit and eliminating it as a major source of sand for reworking into younger deposits. Also, while the low silt content of the younger sand differs from that of the Ogallala, the low amount of silt may be a result of the fines being transported away during eolian activity. During the Wisconsinan, greater amounts of surface water in the area, discussed below, resulted in large amounts of sediment deposited in drainages leading away from the escarpment. These sediments are now largely eroded and buried but might have been the source of fine sand for the accumulation of the young eolian unit between 9000 and 5000 years ago.

The origin of the recent parabolic and coppice dunes is more obvious: both dune forms are accumulating sand that is deflated from unit 2 sand. Locally, some coppice dunes incorporate small amounts of red sand deflated from the Bt paleosol that caps unit 1 sand when the younger unit 2 sand source is depleted, although the indurated stage of the unit 1 Bt paleosol makes it less susceptible to erosion.

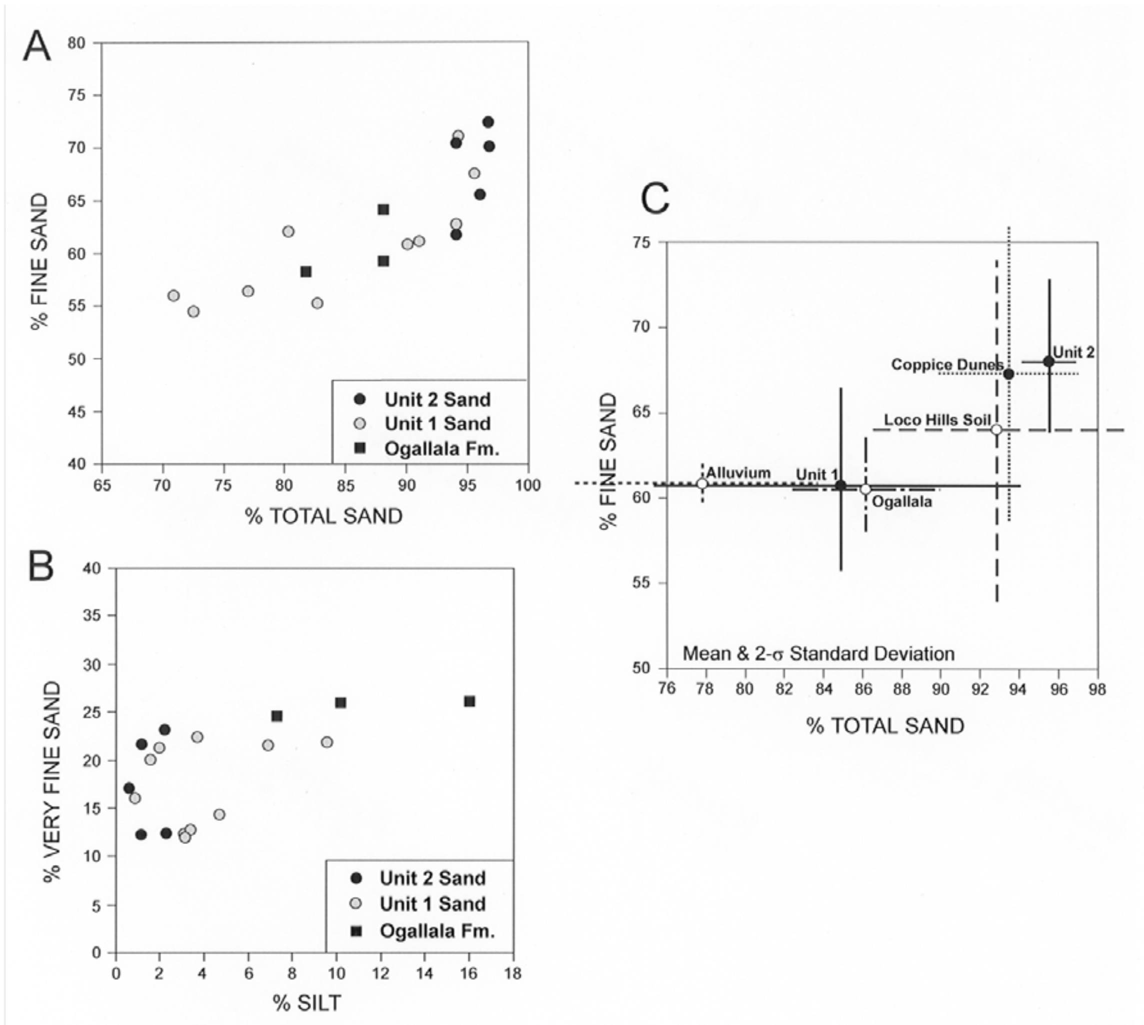

Fig. 7. Sedimentologic data; A = % fine sand vs. % total sand; B = % fine sand vs. % total sand for all stratigraphic units; C = % very fine sand vs. % silt; Ogallala Fm., Mescalero sand sheet, local alluvium; NE Eddy Co., New Mexico; data in Appendices A and B

LATE PLEISTOCENE SPRING AND CIENEGA DEPOSITS

Several exposures of light olive gray calcareous sands occur in drainages along the eastern margin of the sand sheet (Pl. IV-J, -K, -L). These deposits represent former springs and cienegas at a time during the late Pleistocene when the water table was high. A spring is defined by the intersection of the water table with the ground surface, and a cienega is defined as a stream that flows from a spring, generally in arid lands. A higher water table meets both conditions. At locality 11, spring deposits occur in a 5-meter vertical sequence, the eroded remnant of a one-half mile wide cienega (Pl. IV-K, -L).

Alluvium and eolian sand overlie mollusk-bearing spring deposits at locality 14 along Square Lake Rd. (Pl. IV-J). Snail shells from the deposit have a radiocarbon age of 18,900 ± 100 ^{14}C yrs BP indicating a full-glacial age for the high water table and spring flow and accompanying accumulation of sediments and fossils.

Water was flowing in the prehistoric springs and cienegas before the unit 2 eolian sand accumulated on the sand sheet. The banks of the old springs and cienega drainages may be potential campsites for Paleoindian hunters and may be buried by unit 2 eolian sand. Other late Pleistocene spring deposits can be seen in aerial photographs along the foot of the Caprock escarpment (Fig. 8) and may occur as well along paleo-drainages buried beneath the sand sheet.

Late Pleistocene Mollusks

Small collections of spring and cienega matrix from localities 11 and 14 were wet screened for fossils, resulting in the recovery of aquatic snails, land snails, small fragments of mammal bone, and ostracodes. Pollen analysis of the sediments was unsuccessful. A preliminary list of molluscan species is in Table 5. One of the more abundant species at both localities is *Pupilla muscorum*, a land snail that occurs at higher elevation in the mountains of southern and northern New Mexico. In a study of modern land snail distribution in mountainous regions of New Mexico, *P. muscorum* was found at 8000 to 10,800 feet elevation on Sierra Blanca (Dillon and Metcalf, 1997), 4000 feet higher in elevation than the late Pleistocene Mescalero Sands fauna. Other late Pleistocene spring deposits at Nash Draw, south of the study area, also contain numerous fossil mollusks reported by Ashbaugh and Metcalf (1986). They conclude that (a) late Pleistocene molluscan faunas are more diverse than modern faunas and that (b) the species assemblages indicate that the local climate was cooler and wetter than today. The Mescalero Sands fossil mollusks indicate the same paleoecology.

Table 5. Late Pleistocene mollusks from Mescalero Sands, preliminary list.

	Locality 11 [4160 ft. elev.]	Locality 14* [3950 ft. elev.]
AQUATIC		
Bakerilymnaea dalli		X
Fossaria modicella	X	X
Gyraulus circumstriatus		X
Lymnaea sp.		X
TERRESTRIAL		
Carychium exiguum	X	
Deroceras laeve	X	X
Gastrocopta sp.	X	X
Hawaiia miniscula	X	X
Pupilla blandi		X
Pupilla muscorum	X	X
Succinea sp.	X	X
Vallonia gracilicosta	X	X
Vertigo milium	X	X
Vertigo sp.	X	X

*Aragonitic shells from loc. 14 have a radiocarbon age of 18,900 ± 100 ^{14}C yrs BP

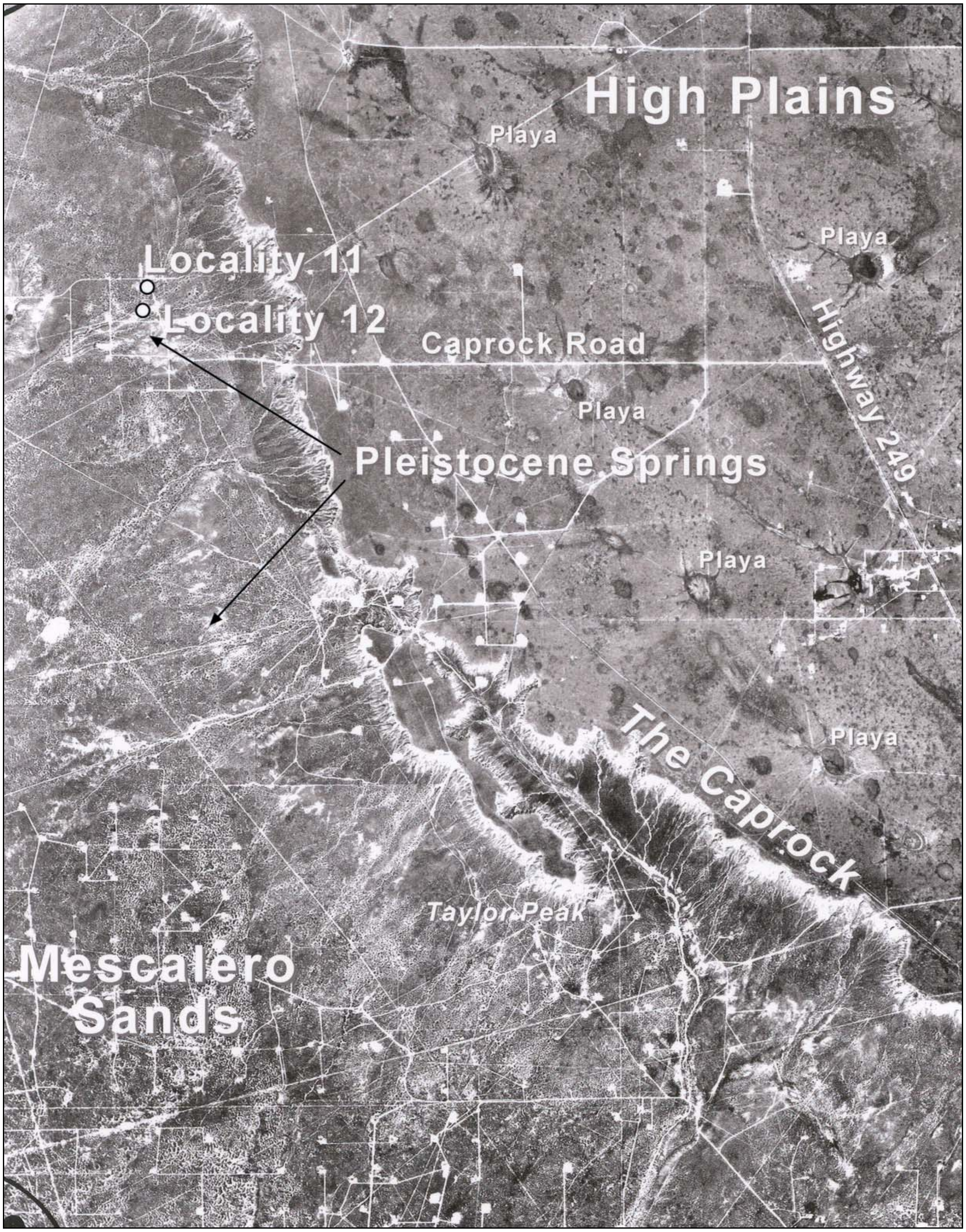

Fig. 8. Color infrared aerial photograph, converted to grayscale, of the western Caprock escarpment north of US Highway 82 (off of image), Eddy-Lea county, New Mexico; late Pleistocene spring and cienega deposits are visible as a white band; numerous playas on the High Plains surface are visible as round features darker in color than the surrounding area due to fine-textured soils, greater soil moisture, and denser vegetation in the playa basins; some of the basins have small drainages leading to them; west of the Caprock, several streams drain westward into the present-day Mescalero sand sheet; 4.8 mi. across; image taken 9-18-83.

PALEOECOLOGY, PALEOCLIMATES, AND PALEOLANDSCAPES

The following is a summary of the geomorphic history of the Mescalero Sands and associated ancestral landscapes during the late Pleistocene.

100,000--130,000 (to <400,000?) years ago

During the Sangamon Interglaciation, the regional climate was arid, perhaps drier than the Holocene. During this period of dry climate, the calcic Mescalero paleosol may have developed on the weathered surface of Permian and Triassic shale and sandstones. The Mescalero paleosol may also have formed during pre-Sangamonian periods of arid climate. The Mescalero paleosol underlies the Mescalero Sands and occurs throughout the region beyond the sand sheet.

90,000--100,000 years ago

Subsequent to the formation of the Mescalero paleosol and prior to its burial by the unit 1 sand of the Mescalero sand sheet, an episode of erosion removed the upper soil horizons leaving behind the resistant petrocalcic horizon or caliche.

70,000--90,000 years ago

During the warm late Eowisconsin (oxygen isotope stage 5A) and the early part of the Early Wisconsinan (stage 4), the unit 1 eolian sand was deposited on top of the eroded Mescalero paleosol. The source of the eolian sand is probably alluvium derived from eastward retreat of the Caprock escarpment of the Ogallala Formation. Unit 1 is the first eolian sand body of the Mescalero Sands; prior to this time, the sand sheet did not exist.

15,000--70,000 years ago

After deposition of unit 1 sand, the sand sheet was stable during the remainder of the Wisconsinan, and a non-calcic red argillic soil formed on the eolian sand. The Bt soil developed during the moist climate of the Wisconsinan. Because of the absence of a calcic horizon in the paleosol, the annual precipitation may have exceeded 20 inches, 50% more than modern rainfall. The vegetation may have been a sagebrush grassland (Hall, 2001).

15,000--25,000+ years ago

During the late Pleistocene, environmental conditions were cooler and wetter than today. More surface water was present west of the Caprock escarpment, as indicated by the presence of mollusk-bearing spring and cienega deposits. A higher water table in the Ogallala filled countless playa lakes on the adjacent high plains and fed numerous springs at the foot of the Caprock escarpment.

9000--15,000 years ago

The dramatic shift to warmer and drier conditions at the end of the last glacial maximum resulted in major geomorphic, hydrologic, and biotic changes. The water table dropped, playa lakes dried, springs quit flowing, and sagebrush vanished from the grasslands. General erosion of the landscape resulted in the removal of the upper part of the Wisconsinan argillic soil, exposing the red Bt horizon at the denuded surface. During this time interval, Paleoindians may have camped at remnant springs and cienegas.

5000--9000 years ago

During the early half of the Holocene after the shift from moist to drier climate, winds picked up fine sand from dried cienegas and streams and deposited the sand as eolian unit 2. The eolian sand unit formed a mantle over the Wisconsinan red Bt paleosol and the older unit 1 sand. The vegetation may have been desert shrub grassland. Early Archaic people may have either avoided the Mescalero Sands during the accumulation of unit 2 eolian sand or their sites are obliterated by eolian processes; very few sites from this time interval have been discovered.

500--5000 years ago

After the deposition of unit 2 eolian sand, the Mescalero Sands were quasi-stable, the surface vegetated but with low-relief parabolic dunes and some sand movement, perhaps resembling modern conditions shown in Plate VI-T. A soil did not form during this time interval, except for organic-rich anthrosols associated with prehistoric occupations. Most of the archaeological sites on the sand sheet correlate with this period of quasi-stability. The vegetation on the sand sheet was a desert grassland or desert shrub grassland, perhaps with shin oak.

100--500 years ago
During this recent time interval, the Loco Hills soil formed on the sand sheet and on floodplains of small streams that drain through the area and on colluvial slopes. The Loco Hills is an A horizon soil that formed on stable surfaces by the accumulation of organic matter from desert grassland vegetation. The Loco Hills soil may merge with organic-rich anthrosols at archaeological sites.

0--100 years ago
The greatest, most rapid geologic change that has occurred in the Mescalero Sands since it formed is the recent deflation of the sand sheet and accumulation of coppice and parabolic dunes. The recent erosion of the previously stable sand sheet and Loco Hills soil is probably related to historic land use changes, especially the introduction of large numbers of grazing animals that would have affected plant cover on the sand sheet. In the past century, vast areas of the sand sheet have been deflated and the resulting sand accumulating as coppice dunes around Torrey mesquite and parabolic dunes where shin oaks are present.

Commentary On Late Prehistoric Climatic History
The archaeological record of the past 5000 years converges on the stable surface of unit 2 eolian sand. Sedimentary deposits that could contain information on past environments are not present on the sand sheet. Thus, direct evidence for prehistoric paleoclimatic history of the Mescalero Sands is elusive.

The regional paleoenvironmental history of southeastern New Mexico is incomplete, although a general picture can be summarized. The hot and dry climate of the mid-Holocene, Antevs' altithermal, dominated the regional landscape. The last phase of accumulation of unit 2 eolian sand coincides with this period of aridity. After the altithermal, the climate gradually became less arid. A period of slightly cooler, moister climate was evident by about 2500 years ago and lasted to about 1000 years ago. While slightly moister conditions during this time interval are recorded in alluvial sequences (Hall, 1990b), the Mescalero sand sheet did not respond to the moister climate, unless the response was increased vegetative cover and greater stability of the sand sheet. Similarly, the end of the interval of moist climate and change to drier conditions about 1000 years ago had no discernible effect on the sand sheet. The peak of the recent dry conditions about 500 years ago again does not seem to be visible in the sand sheet record, although it is at this time that the Loco Hills soil began to form on the sand sheet and elsewhere. While sand sheet stability and the formation of the Loco Hills soil coincide with the last half of the Little Ice Age and its cooling effects at high latitudes and high elevation sites, the geomorphic response at low elevations is unremarkable. Regardless, the presence of the Loco Hills soil testifies to landscape stability, perhaps in response to slight increased moister and denser ground cover during the past few centuries up until the dramatic changes related to historic landuse.

GEOARCHAEOLOGY OF THE MESCALERO SANDS

Geoarchaeology is the study of Earth-surface processes as related to the prehistoric cultural record. It is generally applied on three levels of analysis: (a) evaluation of micro-stratigraphy, sedimentology, and soils in order to assess site integrity and preservation, (b) assessment of the location, stratigraphy, and chronology of sites as related to local geomorphic history, and (c) critique of the geomorphic-archaeological record as it is related to regional paleoclimatic and paleoenvironmental history.

Concentration Of Archaeological Sites On The Stable Sand Sheet

The most significant result of the present investigation is the determination of the relationship between the occurrences of archeological sites to the geomorphology of the sand sheet. Nearly all of the archaeology in the Mescalero Sands occurs in association with unit 2 eolian sand. The sand unit was deposited between about 9000 and 5000 calendar years ago (ca. 8450-4450 radiocarbon years BP). After 5000 years ago, the sand sheet stabilized. Most of the prehistoric occupation of the sand sheet appears to have occurred in the past 5000 years during the period of stability. This accounts for two observations made by archaeologists: (a) most sites are shallow and occur at or close to the top of the sand, and (b) adjacent features from some sites yield a wide range of radiocarbon ages. Essentially, the last 5000 years of archaeology in the Mescalero Sands occur on the same geomorphic surface.

The above interpretations may have further implications to prehistoric occupation of sand sheets, especially the question whether or not occupation of a sand sheet is more likely to occur while the sand is accumulating or will more likely occur after sand accumulation ceases and the sand sheet stabilizes. The evidence from the Mescalero Sands indicates the latter, that sites post-date the deposition of the sand sheet (Fig. 9).

A critique of the GBFEL-TIE project in the Tularosa basin, discussed below, indicates the same relationship, that archaeological sites post-date an early Holocene period of eolian sand deposition. If sites of various ages occur at or near a surface because it is an old stable surface, then the inventory of sites during archaeological surveys of sand sheets may be fairly complete. The occurrence of older, buried sites, however, is always a possibility. Indeed, because of the rarity and significance of deeply buried older sites, the field investigator may want to be alert to their potential presence.

A question about site preservation in a sand sheet should be raised because it concerns a possible bias in the local archaeological record. What are the chances that a site will be preserved in a sand sheet during the time period that the sand is actively accumulating? The answer is not known, but it can be speculated that the probability of preservation of a site from the period of eolian sand activity on a sand sheet is lower than the probability of preservation of a site from the stable sand sheet surface. If the speculation is true, then the presence of an eolian sand sheet on the landscape may introduce a bias in the archaeological record: most of the visible sites will post-date the period of eolian sand deposition, and archaeological sites dating from the period of sand deposition may be strongly under-represented.

Where many archaeological sites of different ages occur at the same geomorphic surface that also is the modern surface, there will be a tendency for those sites to exhibit a stronger degree of bioturbation than will sites that are buried. When artifacts and features do not occur at the same surface, a challenge is raised to determine if it is a case where site-formation processes have resulted in features that extend far below the surface, or whether artifacts are bioturbated into older sand. In some cases where bioturbation is severe, it may not be possible to make the determination.

Anthrosols And Archaeological Sites

An anthrosol is an organic-rich soil A horizon that has formed by the accumulation of organic matter due to human occupation and activity at an archaeological site. The degree of anthrosol development is determined by the duration, intensity, and type of human activity. Anthrosols are not regional soils; their distribution is limited to the area of the archaeological site. They are site-specific and form during the time period of human activity. Thus, the age of an anthrosol will not be the same but will vary from one site to another, the age coinciding with the period of site occupation. At an archaeological site on the Mescalero sand sheet, an anthrosol and the younger Loco Hills soil will merge where the younger Loco Hills soil drapes over an anthrosol. Bioturbation can merge the two A horizons and in the field they will appear to be one soil.

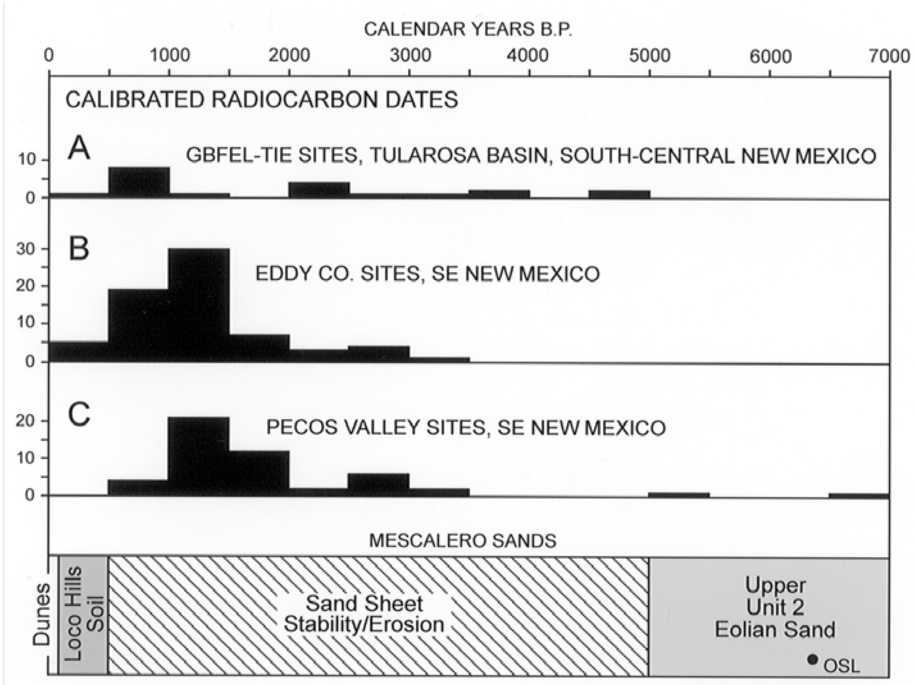

Fig. 9. Frequency of radiocarbon ages from archaeological sites in the (A) GBFEL-TIE project, Tularosa basin (Swift, 1991a), (B) from sites in Eddy Co., New Mexico (calibrated ages in Katz and Katz, 2000, excluding sites listed by Sebastian, 1989), and (C) from sites in the Pecos Valley region of the Roswell district (Sebastian, 1989); radiocarbon ages are converted to calendar years (Calib 4.1 program, Stuiver and Reimer, 1993, Stuiver et al., 1998).

Site Preservation And Visibility

The two most important geomorphic processes that affect the visibility and preservation of archaeological sites on the Mescalero Sands are deflation-deposition and bioturbation. While site erosion may be clear in the field, bioturbation can be more difficult to recognize.

Erosion of sites. Because the Mescalero sand sheet originated about 90,000 years ago and the upper eolian sand unit 2 formed only 5000 to 9000 years ago, sites may potentially occur anywhere on the surface of the sand sheet. Sites are commonly visible because of erosion that has exposed artifacts on the surface. Unfortunately, the same erosion that exposes prehistoric cultural materials also leads to site destruction through removal of the sediments that are the matrix of the site, leaving behind artifacts, fire-cracked rock, and other materials on the eroded surface (Pl. VI-Q, -R). When this is the case, the original context of the artifacts and associated features is lost. Thus, when artifacts are observed in the field, that portion of the site is already largely gone.

Coppice dunes. Coppice dunes are products of erosion and deposition (Pl. II-F). Their presence signals active deflation of the underlying sand that, in the Mescalero sand sheet, is the archaeology-bearing surface of unit 2 eolian sand. Deflation between and around the coppice dunes removes the sand matrix of archaeological sites, leaving behind coarser particles that cannot be carried easily by the wind. The site's artifacts, burned caliche, and other pebble-sized materials are concentrated on the deflated surface forming an archaeological pavement. In this manner as well, artifacts from sites of different prehistoric occupations spanning hundreds and thousands of years may end up on the same erosional surface. At the same time, mesquite coppice dunes form a protective cap on the underlying surface. If an archaeological site is present, it may be protected beneath the dune. Unfortunately, mesquite roots disturb site stratigraphy. Burrowing animals also focus on the soft dune sand, further disrupting site integrity. A summary of sand sheet stratigraphy with the occurrence of archaeological sites in coppice-dune fields is shown in Figure 10.

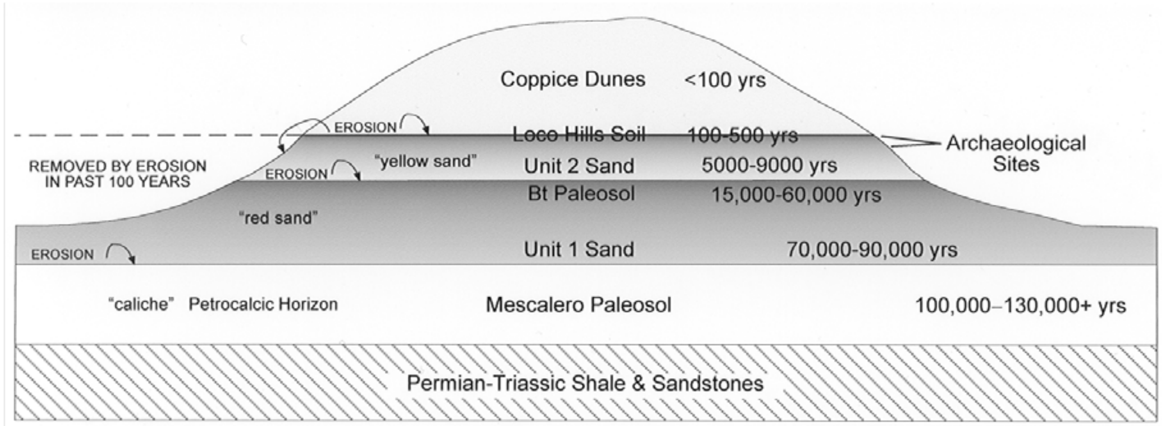

Fig. 10. A geomorphic-geoarchaeological summary of eroded areas of coppice dunes in the Mescalero Sands, indicating the stratigraphic position at the top of unit 2 sand where most archaeological sites will occur; artifacts from the top of unit 2 sand are commonly deflated from sites and are resting atop the eroded red sand.

Erosion—deposition—stone lines. One of the more confusing geoarchaeological cases that occurs on sand sheets is where an *in situ* site has been deflated, the artifacts and pebbles concentrated as a lag on the erosion surface, and the artifact and pebble lag buried by fresh sediment (Fig. 11). When viewed in stratigraphic profile, the artifacts and pebbles form a stone line. The stone line is one-pebble thick and can occur as a continuous line of stones or as an occasional stone at the same horizon (Johnson, 1989). The stone line, especially if a truncated feature is associated with it such as shown in Figure 11, may be easily confused with an *in situ* living floor (Pl. VI-S).

Deposition and shinnery parabolic dunes. Visibility of archaeological sites in shinnery parabolic dunes is vastly different from that of mesquite coppice dunes. In coppice dunes, artifacts from deflated sites are strewn across the eroded surface, visible to all. In parabolic dunes, however, the area of deflation is a small bowl-shaped depression in the center of the dune. While sand is removed from the depression and accumulates on the crest of the small dune, other sand from upwind dunes enters the depression and is deposited as a thin mantle of sand. In the Mescalero parabolic dunes, the crest and sides are covered by shin oak (Pl. V-O). The deflated depression of the dune also contains some plants, although not as dense as the dune crest and margins. Thus, the deflation of sand in the shinnery parabolic dunes is not as thorough and complete as that that takes place in the areas of coppice dunes. The archaeological significance is that there may be just as many sites in the parabolic dune field as there are in the coppice dunes, but the sites are still buried or otherwise hidden from view where parabolic dunes are present.

Turbation Of Eolian Sand

Turbation is the disturbance of the original bedding and primary depositional features of a sedimentary deposit, including archaeological sites. Bioturbation is disturbance caused by plants and animals. Bioturbation of archaeological sites not only disrupts sediment layers and obliterates features, but it also displaces and moves artifacts and other site-related materials, both vertically and laterally in the sediment column. In the Mescalero sand sheet, bioturbation occurs through burrowing activity of small mammals, lizards, insects, and ants and the presence of roots of mesquite, shin oak, and other woody plants and grasses. While it is fairly clear that erosion and deposition can destroy and obscure sites, bioturbation can be subtle, and the evidence for it can become lost when bioturbation is extreme and all sediments are mixed again and again.

Turbation is generally observed because of differences in the color of the sediment that fills burrows and the color of the sediment that surrounds the burrow fill. Also, sedimentologic differences can signal turbation; burrow fills may contain mixed sediment while the surrounding sediment is finely bedded, or burrow fills may be coarser or finer textured than the surrounding sediment. In this investigation, it was found that eolian sand that has a uniform color and uniform sedimentology may also be turbated. Insect burrows were found to weather out in micro-relief due to differential cementation and consistency of sand in burrows versus surrounding sand (Pl. V-P). Thus, even when there is no visible evidence of turbation, the sediments may be severely disturbed, a discouraging prospect.

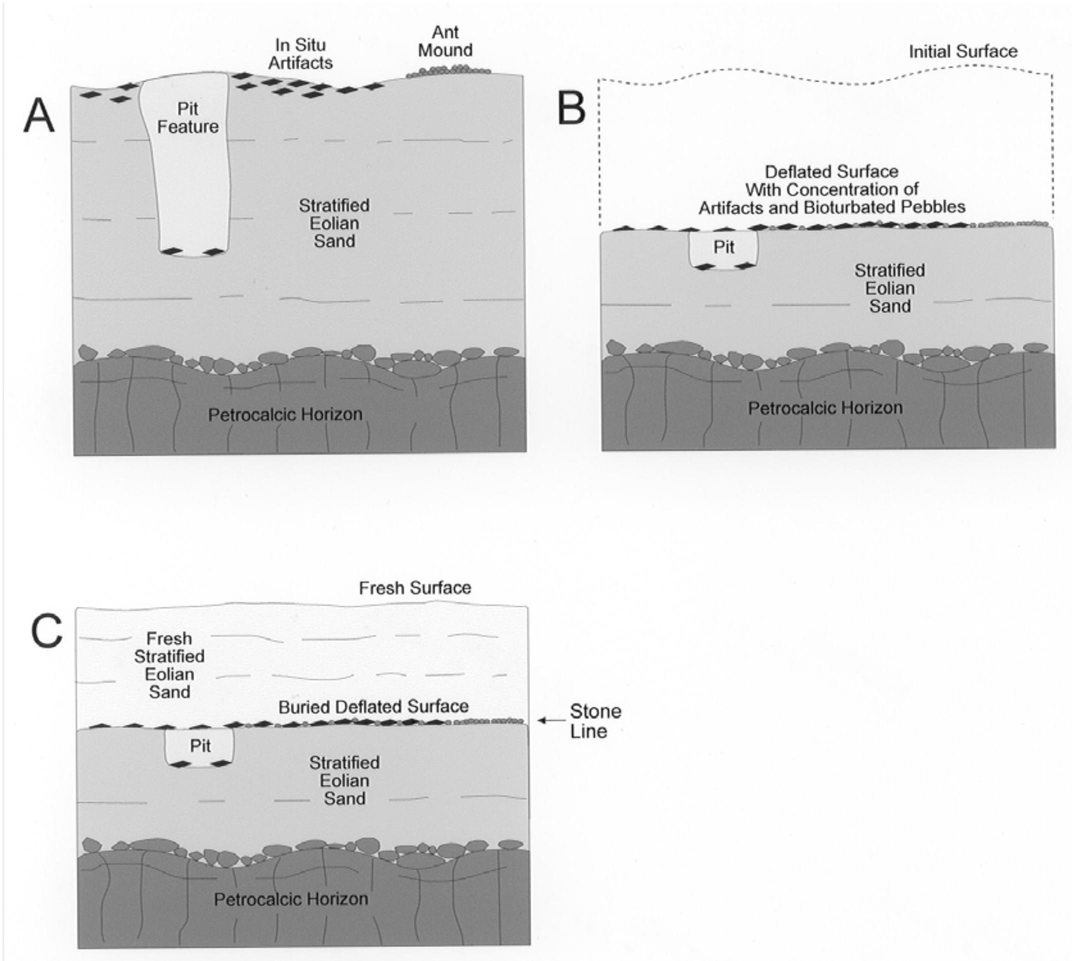

Fig. 11. (A) An *in situ* site of the stable surface of the sand sheet, (B) erosion and concentration of artifacts on an erosional surface, and (C) subsequent burial of artifact-strewn surface can result in (1) the appearance of an *in situ* cultural living floor and (2) that the age of the stratified eolian sand is incorrectly equated with the age of the artifacts.

Degrees of turbation are apparent in the field. Turbation by insects, for example, may involve movement or churning of sediment within a narrow zone, perhaps less than 10 cm. At the other extreme, large burrowing mammals may move large volumes of sediment through a vertical column of more than a meter, completely destroying site features. Johnson (1997, p. 21-22) notes numerous examples of disturbed soils in the Tularosa basin, especially by cicadas and rodents, and that the burrowing activity of badgers can completely destroy petrocalcic horizons of Pleistocene soils.

Burrowing animals can bring vast amounts of sediment to the surface, including fragments of caliche from a buried paleosol. In the Mescalero Sands where eolian sand is thin, individual ant colonies bring hundreds of small caliche pebbles to the surface. A study of ant activity on the sand sheet has shown that as much as 84 grams of material per m^2 of area is brought to the surface in one year; if uniform, this is equivalent to 749 pounds per acre per year, or 37 tons per acre per century (Whitford et al., 1986).

Biomantle—stone zone. During turbation, small caliche pebbles, as well as larger pebbles brought to the surface by larger animals, become thoroughly mixed in a zone called the biomantle. If artifacts from an archaeological site are present, they too are mixed into the amalgam of the biomantle. The biomantle can be a meter or more in thickness. Larger pebbles and artifacts may accumulate in a stone zone at the base of the biomantle (Johnson, 1989). The concentration of large pebbles and artifacts in a stone zone at depth may artificially resemble a buried site (Fig. 12), similar to the case with stone lines (Fig. 11).

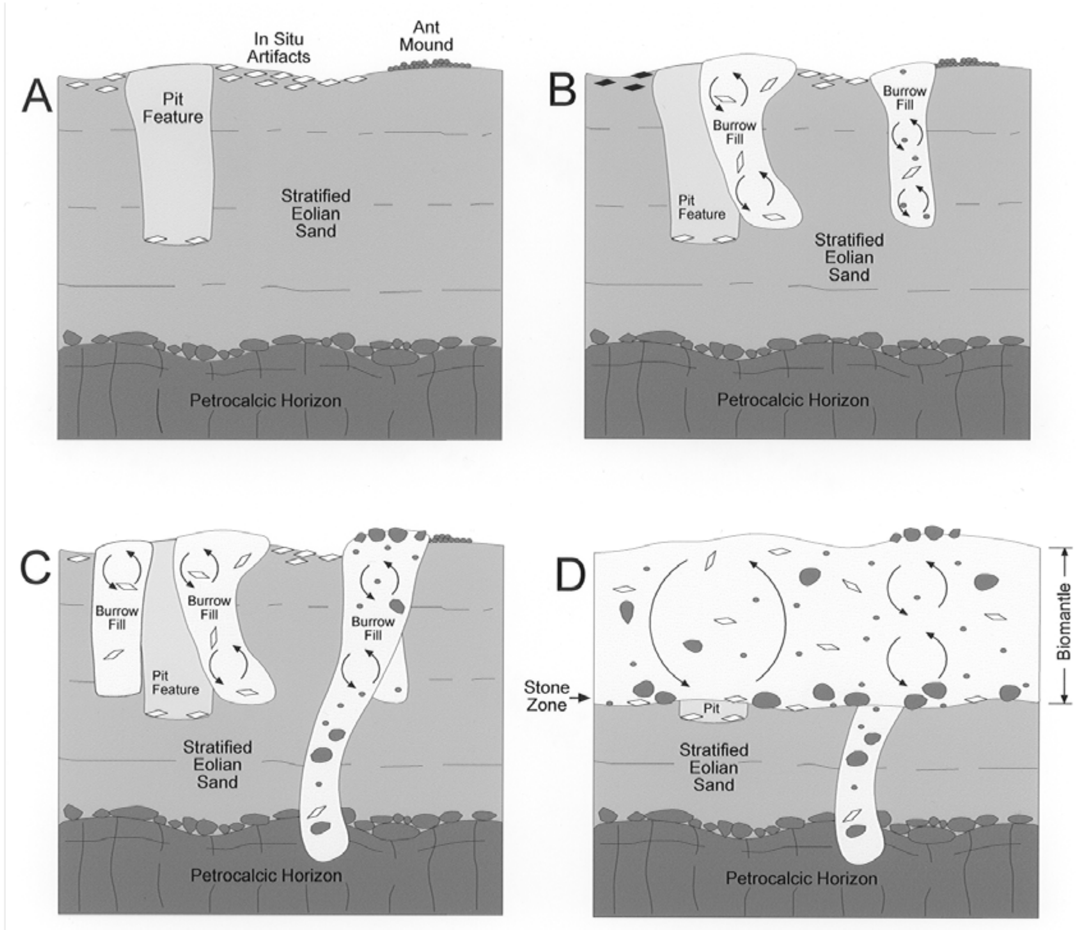

Fig. 12. The bioturbation of an archaeological site at the surface of stratified eolian sand, with time resulting in a thoroughly mixed zone (biomantle) and the development of a stone zone at its base; the prehistoric cultural levels may appear to extend to some depth; the presence of caliche pebbles scattered throughout the biomantle is evidence of bioturbation; this degree of bioturbation and biomantle development has been documented in alluvial fan deposits in the Tularosa basin (Johnson, 1997).

Evidence for large-scale bioturbation can be seen in the field by the presence of numerous small fragments of unburned caliche. Natural-occurring pebbles in eolian sand are virtually nonexistent. Scattered pebbles on the surface of an eolian sand unit indicate that a burrowing animal has brought the pebbles to the surface. The pebbles may be moved from the surface down into the sand body by continued bioturbation. When bioturbation occurs, it is seldom an isolated one-time event. Instead, it usually involves multiple turbation events again and again at the same location. Thus, in time, pebbles become mixed throughout the sand body resulting in a biomantle.

Coppice Dune Erosion And Long-Term Loss Of Archaeological Sites

Sites are partly protected as long as the coppice dunes survive. The present coppice dunes have been developing for about 100 years. The dunes accumulate sand that originates from deflation of the area around the dune. As deflation continues, the dunes grow higher. Eventually a threshold is reached where the deflated inter-dune areas are lowered to a level where saltating sand can no longer reach the upper surface of the coppice dunes (Pl. II-F). When that happens, the dune margins are eroded by continued deflation; the sides of the dunes become steepened and collapse; as the dune erodes, the mesquite shrub dies in exposed increments; raindrop splash furthers the process of dune destruction. When the dune is gone, the archaeological remains that were initially protected by the dune may be lost to erosion as well. While the above is in part speculative, the initial stages of coppice dune destruction have been observed along Bear Grass Draw. It may take another 100 years for the process of erosion to completely destroy the coppice dune field (Fig. 13).

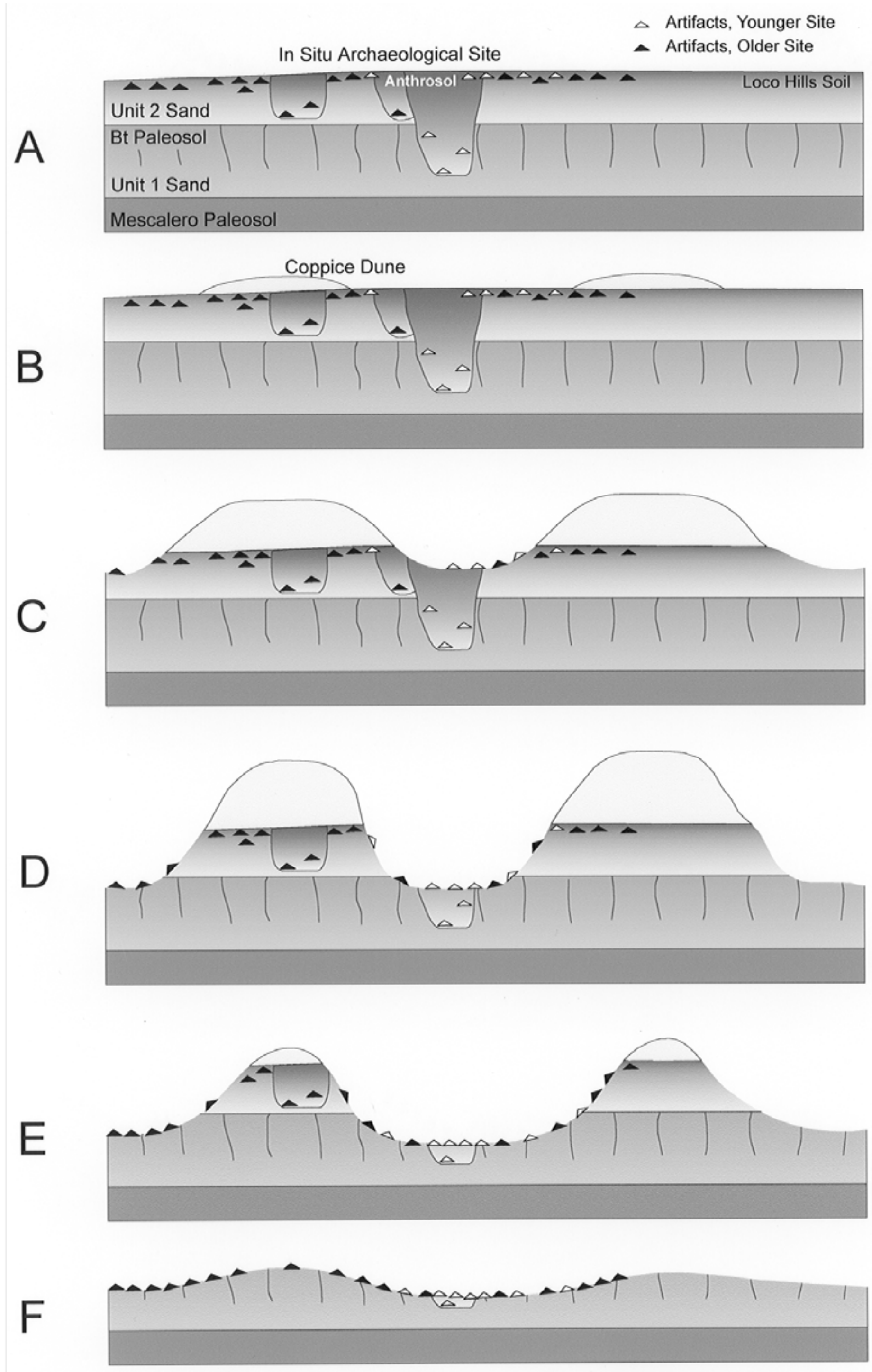

Fig. 13. Origin, development, and erosion of coppice dunes and the effects on archaeological sites, Mescalero Sands, southeastern New Mexico; explanation of each panel follows below.

A = Stable desert grassland landscape, development of Loco Hills soil about 100 to 500 years ago; archaeological sites are intact and little disturbed by erosion; Loco Hills soil mantles and blends with older A horizon anthrosols (formed by human occupation) at archaeological sites; black triangles are artifacts from an older occupation and white triangles are artifacts from a younger occupation at the same locality.

B = Destabilization of local desert grassland landscape; expansion of Torrey mesquite (*Prosopis glandulosa torreyana*) into grasslands; decrease in ground cover results in soil drying and deflation of sand that is transported by wind and accumulates around the base of shrubs, especially Torrey mesquite; the destabilization of the desert grassland probably occurred in the late 19th century due to changes in local land-use, land use changes that may be part of a regional pattern

C = Accelerated deflation in the 20th century results in loss of Loco Hills soil and underlying sand and marks the beginning of erosion of archaeological sites at the top of sand unit 2 and the lowering and mixing of artifacts onto an erosional surface; coppice dunes become wider and higher as sand is eroded from interdunal areas and accumulates around shrubs; many areas of coppice dunes in the Mescalero Sands are at this stage

D = Continued deflation in the late 20th century results in deflation of archaeological sites and lowering of artifacts onto the older, more indurated red sand (unit 1); coppice dunes become higher as additional sand accumulates around shrubs; however, at a later stage of development as more sand is removed from interdunal areas, the margins of the coppice dunes are eroded, becoming steep and collapsing, thereby reducing dune width; the rate of dune growth may decline because of less saltating sand reaching the accumulation surface; erosion rates in the interdunal areas may slow because of the greater resistance of the indurated argillic Bt paleosol at the top of the unit 2 red sand; artifacts from old and young archaeological sites are mixed; intact portions of sites are preserved beneath coppice dunes, although mesquite roots can damage site stratigraphy; also, burrowing animals are attracted to the mounds of loose sand that makeup the coppice dunes, further mixing site stratigraphy and artifact distribution beneath the dunes; some areas of coppice dunes in the Mescalero Sands are at this stage of development

E = Further erosion and loss of the coppice dune sand; the dune landform is predominantly erosional at this stage instead of depositional, and as a consequence, in situ archaeology occurs "high" in the "dune;" note that in situ younger artifacts occur lower in elevation than do in situ older artifacts; young and old artifacts become mixed during erosion; artifact concentration is greater on an erosional surface plane than in their original stratigraphic position where they may be dispersed over several decimeters of sand; this stage of advanced erosion is infrequent in the Mescalero Sands, occurring at present where sand loss is accentuated by overland flow and sheet erosion

F = Terminal stage of coppice dune erosion where all the dune landforms have been removed by erosion down to the resistant argillic Bt soil in unit 1 sand; this stage has not been reached yet in the Mescalero Sands area, but it is estimated that, at the present rate of development, the coppice dunes will be largely destroyed by erosion within the next 100 years; most of the in situ archaeology will be lost as well except for cultural features that are intrusive into older deposits

TESTING FOR TURBATION

The disturbance of surface sediments and soils by burrowing animals can be especially severe in the soft sandy substrate of a sand sheet. The absence of stratification can indeed be evidence for bioturbation. It may be justified to assume that bioturbation has occurred and to look for evidence against it, instead of the other way around.

In the Mescalero Sands, mesquite coppice dunes occur where both unit 1 and unit 2 sands are thin. The soft thin unit 2 sand and the thin Loco Hills A horizon soil that mantles unit 2 sand are readily eroded, exposing the underlying unit 1 red sand. The late Pleistocene red sand is harder than the yellow sand due to secondary precipitation of iron oxides and clays originating through late Pleistocene pedogenesis. Consequently, burrowing animals focus on the softer dune sand and can completely destroy a dune's internal stratigraphy. Burrowing activity commonly extends down into the underlying Loco Hills soil and unit 2 sand, thereby disturbing archaeological sites that may be present. So, even though remnant patches of sites may be preserved beneath coppice dunes in eroded areas, they may be severely disturbed by bioturbation.

The only way to know the extent of bioturbation is by careful excavation. Nevertheless, some field observations can be made prior to excavation that will provide preliminary insights on site integrity. If the following observations are negative, the potential for bioturbation and serious disturbance of sites is diminished.

LOOK FOR THESE
1. Rodent burrows at margins of coppice dune
2. Caliche pebbles (non-cultural) on sand
3. Scattered caliche pebbles within the sand column
4. Zones of caliche pebbles in the a sand column

DO THIS
3. Brush near-vertical face for faint outlines of burrow fills, fecal pellets
4. Trowel a clean face for outline of large burrow fills, caliche pebbles
5. Brush a freshly troweled face for faint outlines of smaller burrows
6. Leave a fresh face exposed to wind for a week or more; sandblasting can reveal burrows and other subtle turbation features

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FIELD TESTS TO IDENTIFY SAND UNITS

One of the goals of the *Field Guide* is to identify means by which Mescalero sand units and paleosols can be recognized in the field. It is anticipated that this information can be used for determining the potential occurrence of archaeological sites. The following criteria cover commonly-encountered field situations although exceptions are to be expected.

Table 6. Field observations that can aid the identification of sand units and the likelihood of the occurrence of archaeological sites.

<u>1. COLOR</u>

The sands are color coded, old sands generally redder that young sands; white color generally means carbonates; tested with Munsell Soil Color Charts

Reddish yellow (5YR 6/6) .... ♦ Unit 2
Yellowish red to red (5YR 5/5-8 to 2.5YR 4-5/8) .... ⊗ Unit 1
White or pink (5YR 7-8/1-4) .... ⊗ caliche, or spring deposit

<u>2. DUNES</u>

Index to thickness of eolian sands

Coppice dunes .... ⊗ thin sands
Parabolic dunes .... ⊗ thin or thick sands

<u>3. CARBONATES</u>

Index to calcic soils or spring deposits; tested with 10% HCl

No reaction to HCl .... ♦ either Unit 1 or Unit 2
Positive reaction to HCl .... ⊗ caliche, or spring deposit

<u>4. STRATIGRAPHY</u>

Sequence of sand layers; sites are associated with Loco Hills soil and upper Unit 2 sand

TOP of stratigraphic sequence
Dune .... ⊗ coppice or parabolic
Dark yellow sand (or darker than other sand), thin .... ♦ Loco Hills soil
Yellow sand .... ♦ Unit 2
    No bands .... ♦ thin Unit 2 sand
    Bands .... ⊗ thick Unit 2 sand
Red sand .... ⊗ Unit 1, with Bt paleosol*
White sand .... ⊗ caliche, or spring deposit
BOTTOM of stratigraphic sequence

* Erosion commonly exposes red sand at surface, and artifacts that have been eroded out of younger yellow sands may occur on the eroded surface of the red sand

<u>5. CLAY BANDS</u>

Observed in the middle of thick unit 2 sand; sites may occur *above* clay bands

Above clay bands .... ♦ upper Unit 2
In clay bands .... ⊗ middle Unit 2
Below clay bands .... ⊗ lower Unit 2

♦ High potential for the presence of archaeological sites
⊗ Low potential for the presence of sites, or No potential for sites

GEOMORPHOLOGY and GEOARCHAEOLOGY of the MESCALERO SANDS and WHITE SANDS: A COMPARISON

The geomorphic and geoarchaeologic record from the Mescalero Sands (this study, Fig. 14) is compared with that from the southern Tularosa basin, especially the GBFEL-TIE project (Blair et al., 1990a; 1990b). The GBFEL-TIE project evaluated about 100 square km and the Mescalero project evaluated about 1000 square km. At first inspection, there is a one-to-one relationship in the sequence of eolian deposition, erosion, and soil development. The geochronology of eolian activity in the two regions, however, does not correspond, providing a different perspective as well on the archaeological record of the two regions. A critical review of the differences in the geochronology of the two sand sheets suggests that the age assignments to the eolian deposits in the southern Tularosa basin may be too young.

Mescalero Paleosol And Q1 Paleosol

Both the Mescalero Sands and the sand sheet in the Tularosa basin are underlain by a well-developed calcic paleosol. The stage III-weak IV Mescalero paleosol pre-dates the 90,000-year age of the overlying eolian sand and, although no evidence is in hand that would identify a specific period of soil formation, the last stage of formation may have occurred during the Sangamonian. While the calcic paleosol in the Tularosa basin is similarly undated, Blair et al. (1990a, b) concluded that the stage III-IV Q1 paleosol might have developed between 50,000 to 250,000 years ago. A well-constrained age for each of the paleosols is yet to be determined.

Unit 1 Eolian Sand And Q2 Eolian Sand

Both studies conclude that a major erosional unconformity exists between the calcic paleosols and overlying layer of eolian sand (unit 1 and Q2). The Mescalero unit 1 sand is 3 to 4 meters thick although in many exposures it is less than one-half meter thick; it is always present. In contrast, the Q2 eolian sand is seldom more than 1.5 meters thick and is absent in about one-third of the reported trenches. Both eolian units are capped by a strong Bt paleosol; the fossil soil in the Tularosa basin includes a stage II carbonate horizon, while the one in the Mescalero Sands does not include carbonates. Differences in precipitation, drier in Tularosa and moister in Mescalero, can account for the variability in carbonate content.

The Mescalero unit 1 is directly dated by OSL as between about 70,000 and 90,000 years old. The Tularosa Q2 eolian sediments were not dated; the age assignment of 9400 to 15,000 years old is based on correlation with nearby alluvium, with one radiocarbon age, and a range of uranium ages on secondary carbonates. Neither the Mescalero unit 1 nor the Tularosa Q2 sands contain archaeology although the Tularosa Q2 sand could incorporate Paleoindian sites if the assigned age of the sand is correct.

A critical assessment of the geochronology of the Q2 eolian sand and its Btk/Bk stage II paleosol suggests that there isn't enough time for both the eolian sand to accumulate and the associated soil to form. The Q2-paleosol unit is assigned a combined chronology of 5600 years by Blair et al. (1990a, b). If Q2 eolian sand accumulated in 2000 years, a minimum amount of time, only 3600 years remain for soil development and for pedogenic clays and stage II carbonates to accumulate. Gile et al. (1981, p. 68) estimate that a minimum of 8000 years is necessary for stage II carbonates to accumulate in non-gravelly sediment. Thus, more time is required to allow for the origin and development of Q2 sand and paleosol. Largely because of the geologic time required for argillic stage II soil development, the Q2 sand unit may be older than initially reported.

Unit 2 Eolian Sand And Q3 Eolian Sand

In the Mescalero area, unit 2 sand is at least 5 meters thick in the central part of the sand sheet and in the margins of the sand sheet less than one-half meter thick. In the Tularosa basin, Q3 sand is generally less than 1 meter thick and is missing from several reported sections. The Mescalero unit 2 eolian sand is directly dated by OSL as between about 5000 and 9000 years old. The Tularosa Q3 eolian sand was not directly dated, rather the age assignment of 400 to 7300 years for the Q3 sand is based on 20 radiocarbon ages (440 $\pm$ 70 to 4075 $\pm$ 120 ^{14}C yr BP) on charcoal from archaeological hearths near the study area, the hearths assumed to be *in situ* and not intrusive in the Q3 sand. The pre-4075-year age of Q3 sand is based on correlation with radiocarbon-dated alluvium elsewhere in the region.

All of the prehistoric archaeology in the two study areas occurs in association with this eolian sand. However, in the Mescalero Sands, the archaeology largely post-dates the deposition of unit 2 sand (Fig. 9). The prehistoric occupation of the Mescalero Sands occurred during a period of sand sheet quasi-stability during the past 5000 years after the deposition of unit 2 sand. In the Tularosa basin, the use of archaeology to provide the age of the Q3 eolian sand may be in error if site features are intrusive into Q3 sand or if

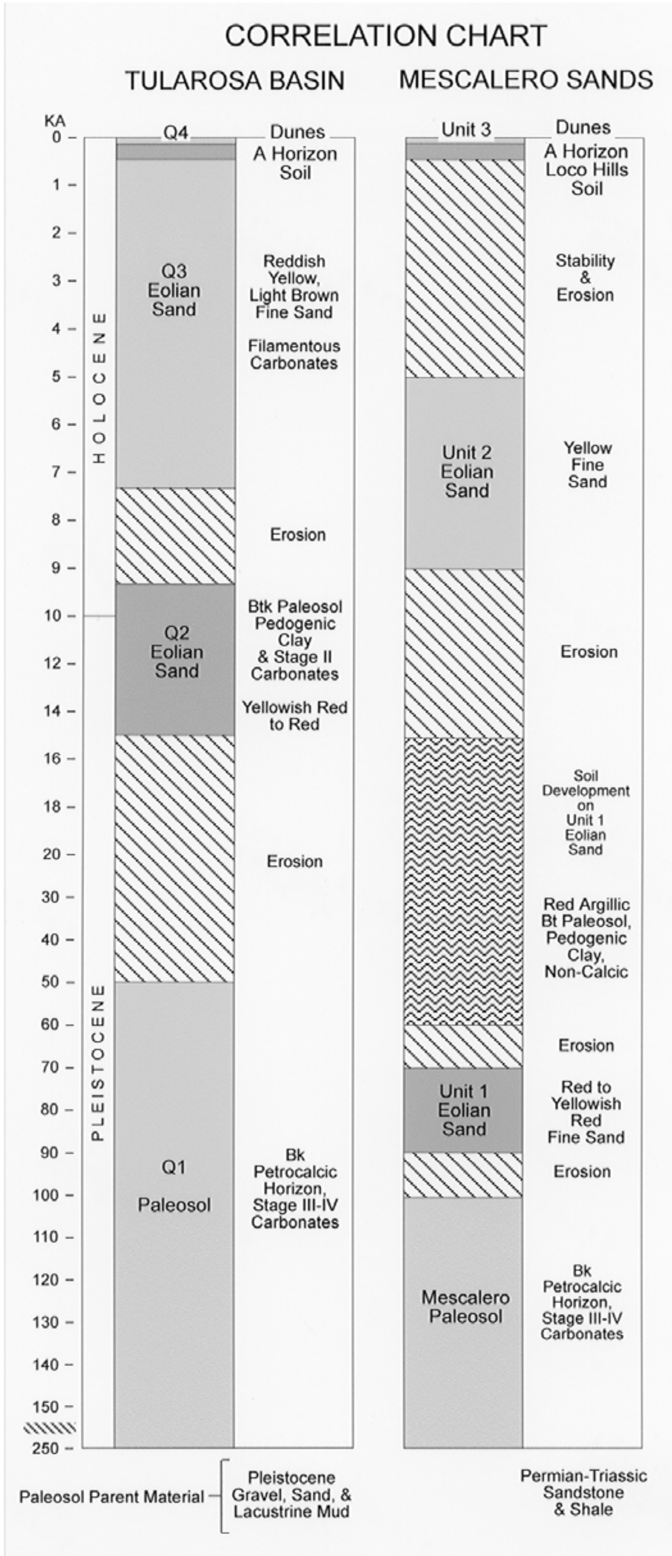

Fig. 14. Correlation chart of Mescalero Sands (this study) and southern Tularosa Basin (GBFEL-TIE) (Blair et al., 1990a, 1990b), southeastern and south-central New Mexico; change in scale at 10, 20, and 150 ka.

features occur at the surface and post-date the sand sheet. It is a challenge to archaeology and geoarchaeology to determine whether or not a site and its features are contemporaneous with or post-date the deposits with which the site is associated. Commonly, the presence of an archaeological site may be accepted as *de facto* evidence for the age of the deposit with which it is associated. By using archaeology to provide ages of geologic deposits, the deposits will be assigned an age that instead represents the time span of the local archeological record. In all cases, an archaeology-based age will be too young for the age of the deposits. A way to resolve this issue is to determine in the field the micro-stratigraphy of the sites and the relationship of the site and its artifacts and features to the geologic deposits in which the site occurs. Unfortunately, in the soft substrate of a sand sheet, bioturbation may obscure the stratigraphic evidence and make a determination of site/deposit relationship impossible to achieve. The problem may be solved by determining the age of the deposits independent of the associated archaeology, a research strategy that was successful at the Mescalero Sands.

Loco Hills Soil And Tularosa Basin Q3A Soil

A significant similarity in the geomorphology of both areas is the presence of an A horizon soil, named the Loco Hills soil in the Mescalero Sands and regarded as the uppermost member (Q3A) of the Q3 eolian sand in the Tularosa basin. In the Mescalero sand sheet, the Loco Hills A horizon soil formed independent of substrate and mantles unit 1 and unit 2 eolian sands and recent alluvium and slope-wash sediments. Its radiocarbon age is about 100 to 500 years BP. Humates from the A horizon soil in the Tularosa basin have a radiocarbon age of 160 $\pm$ 90 ^{14}C yr BP (Swift, 1991b), matching the radiocarbon age of the Loco Hills soil in the Mescalero Sands. The young, recent A horizon soil represents sand sheet stability and the development of a desert grassland vegetation throughout the broad region in the past 500 years.

Unit 3 Dunes And Q4 Dunes

Mescalero unit 3 and Tularosa Q4 are both recent mesquite coppice dunes that post-date the archaeological record and are historic in age. Parabolic dunes also occur in the Mescalero Sands but not in the Tularosa basin. One coppice dune in the Mescalero Sands is directly dated: the age of the soil below the dune on which the coppice dune has formed is 150 $\pm$ 40 ^{14}C yrs BP, and ^{137}Cs content of the dune sand indicates that the upper 22 cm of the coppice dune accumulated since AD1954. One of the dramatic effects of land-use changes and erosion in the past century has been the destruction of the desert grassland, the loss of the Loco Hills soil, the erosion of the upper part of the unit 2 eolian sand body, and the destruction of archaeological sites that occur on the surface of unit 2 eolian sand or in association with the Loco Hills soil.

Summary Of Comparisons

The two geoarchaeology-of-sand-sheets projects, Mescalero and the GBFEL-TIE, have produced similar results even though there are differences in the interpretation of the ages of the two sand sheets. Specifically, the Mescalero sand sheet is thicker and contains a more complete stratigraphic record than found in the Tularosa basin. The Tularosa basin experienced a greater degree of deflation than did the Mescalero sand sheet. Some of these differences in erosion and sand sheet preservation, including variation in soil carbonates, may be attributed to the slightly drier climate in the Tularosa basin and the moister climate in the Mescalero Sands. Also, the Tularosa basin does not have the advantage of shin oak ground cover that may have plays an important role in sand capture, sand retention, and stability of the Mescalero sand sheet. The presence of a recent A horizon soil in both the Tularosa basin and the Mescalero Sands may represent regional sand sheet stability and the widespread development of desert grassland vegetation. The demise of the grassland vegetation, deflation of the A horizon soil, and the development of mesquite coppice dunes are also shared histories throughout the broad region.

While the geomorphology and stratigraphy of the Mescalero and Tularosa sand sheets are virtually identical, the geochronology is strongly divergent. The source of the divergence may be related to the situation that the eolian sand units of the Mescalero Sands are directly dated by optically stimulated luminescence, resulting in age assignments that are independent of archaeology and independent of assumed correlations with other geomorphic events. In contrast, the eolian sands in the Tularosa basin are not directly dated. Instead, the age assignments of eolian sands in the Tularosa basin are based on ages of nearby archaeological sites and the assumption that the eolian deposits are time-equivalent to regional alluvial deposits. The presence of numerous archaeological sites associated with Holocene eolian sand in both areas is noteworthy. In the Mescalero Sands, where the sand bodies are dated by OSL, most of the archaeology post-dates the youngest eolian sand, indicating prehistoric occupation in the past 5000 years during sand-sheet quasi-stability. In contrast in the Tularosa basin, the age of the undated Q3 sand body is assumed to be the same as that of nearby archaeological sites and alluvium, thus suggesting that prehistoric occupation of the Tularosa basin occurred during a period of sand deposition and sand-sheet instability.

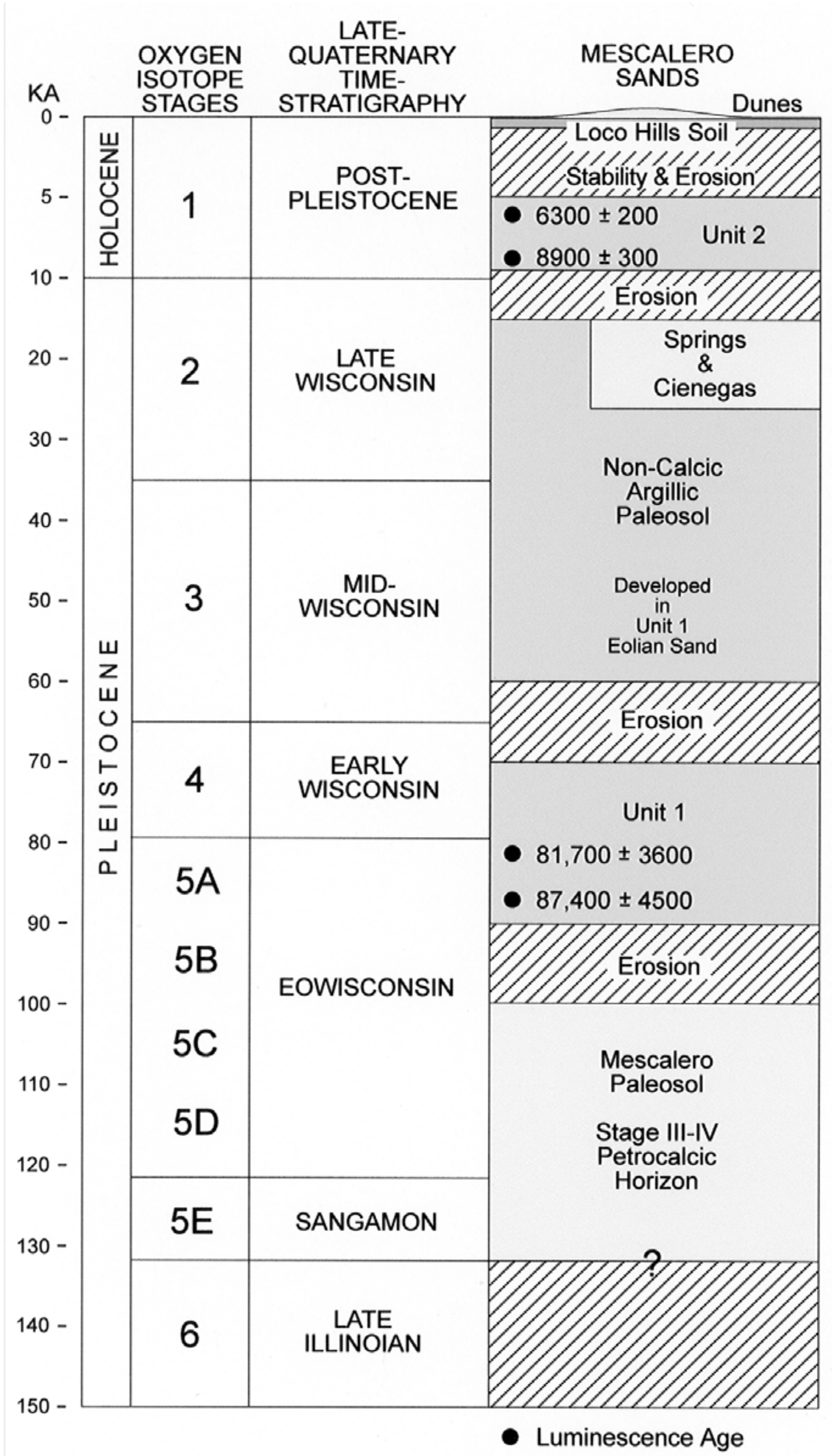

Fig. 15. Late-Quaternary time-stratigraphy of the Mescalero Sands, with OSL ages (Table 4); Late-Quaternary time-stratigraphy and oxygen isotope stages from Richmond and Fullerton (1986); change in scale at 10 ka; the age of the Mescalero paleosol is uncertain and might include Sangamon and/or pre-Sangamonian periods of formation.

CONCLUSIONS

The Mescalero sand sheet accumulated in two episodes of eolian sand deposition, the first 70,000 to 90,000 years ago (unit 1) and the last 5000 to 9000 years ago (unit 2) (Fig. 15). The prehistoric occupation of the Mescalero Sands occurred mainly after the sand sheet stabilized 5000 years ago. Thus, archaeological sites are concentrated on the mid-Holocene surface of the sand sheet, although site-formation processes result in features that intrude into both sand units where they are thin. Late in the history of the sand sheet about 100 to 500 years ago, the Loco Hills soil formed, mantling the sand sheet and floodplains along small drainages as well as archaeological sites. It is an A horizon soil that probably developed in company with a regional desert grassland vegetation. The geologic history of the sand sheet is summarized in Table 7.

In the past 100 years, the archaeological record has been altered dramatically by deflation of the sand sheet and Loco Hills soil and the expansion of Torrey mesquite, resulting in the formation of a coppice dune field where the sand sheet is thin. Where the sand sheet is thick and covered by shin oaks, a parabolic dune field formed. The accompanying erosion has resulted in the loss of large areas of many archaeological sites. Although sites may be intact beneath coppice dunes, burrowing animals focus on the dunes and may further disrupt site stratigraphy and features. Both coppice dunes and parabolic dunes bury sites; large parabolic dunes especially reduce site visibility in the field. Erosion, burial, and bioturbation are major causes of the loss of archaeological information on the sand sheet.

The geomorphic and geoarchaeologic record from the Mescalero Sands is nearly identical to the record from the Tularosa basin sand sheet (setting aside the published chronology of the Tularosa record), suggesting a regional pattern that may be justified to extrapolate to other areas of eolian sand in southeastern New Mexico and adjacent Texas.

Table 7. Summary of the geomorphology, geoarchaeology, and paleoenvironments of the Mescalero Sands, NE Eddy Co., southeastern New Mexico (this study)

YEARS AGO	STRATIGRAPHY	PROCESSES	ENVIRONMENTS	GEOARCHAEOLOGY
0-100	Unit 3 coppice & parabolic dunes; unconformity with Loco Hills soil & Unit 2 sand	Deposition of coppice & parabolic dunes; severe deflation of Unit 1 & 2 sands & red Bt paleosol	Land use changes, disturbance of desert grasslands, decrease in grass cover, expansion of Torrey mesquite & shin oak	Active erosion of sites by wind & slope processes; burial of sites by coppice & parabolic dunes
100-500	Loco Hills soil, A horizon	Soil A horizon development on stable landscape, mantles Unit 1 & 2 sand & late Holocene alluvium	Desert grassland & shin oak vegetation	Site surfaces are stabilized by Loco Hills soil; sites subject to disturbance by bioturbation
500-5000	Unconformity	Sand sheet quasi-stability of Unit 2 sand	Desert grassland, shrub grassland, with shin oaks	Archaeological sites date to this period, indicating prehistoric occupation coinciding with sand sheet quasi-stability
5000-9000	Unit 2 eolian sand	Deposition of eolian sand Unit 2	Early Holocene, strong winds; desert grassland	Early Archaic sites are absent from sand sheet

9000-15,000	Unconformity	Erosion of red Bt paleosol at top of Unit 1 sand; erosion of cienega alluvial and spring deposits	Drying climate, lowering of water table, cienegas and springs begin to dry up	Margins of remnant cienegas and springs may have been Paleoindian campsites
15,000-25,000+	Cienega and spring deposits	Deposition of alluvium and spring-related deposits with land and freshwater snails	High water table, dewatering of Ogallala aquifer; last glacial maximum vegetation is a sagebrush grassland	
15,000-60,000	Noncalcic red Bt paleosol	Weathering of Unit 1 eolian sand, development of noncalcic argillic paleosol	Wisconsinan glacial-age climate, wetter than today; shrub grassland vegetation	
70,000-90,000	Unit 1 eolian sand	Deposition of eolian sand Unit 1	Late Eowisconsin-Early Wisconsin, oxygen isotope stage 5A-4	
90,000-100,000	Unconformity	Erosion of calcic Mescalero paleosol	Cooler oxygen isotope stage 5B	
100,000-130,000 or earlier (<400,000)	Mescalero paleosol, stage III-weak stage IV petrocalcic horizon	Calcic soil development on Permian-Triassic shale and sandstones	Dry climate, oxygen isotope stage 5E-5C, warm Sangamon Interglaciation and late Eowisconsin	

REFERENCES CITED

Aitken, M. J.
1994 Optical dating: A non-specialist review. *Quaternary Science Reviews* 13:503-508.

1998 *An Introduction to Optical Dating*. Oxford University Press, New York.

Ashbaugh, K. M., and A. L Metcalf
1986 Fossil molluscan faunas from four spring-related deposits in the northern Chihuahuan Desert, southern New Mexico and westernmost Texas. Circular 200, New Mexico Bureau of Mines & Mineral Resources, Socorro.

Bachman, G. O.
1976 Cenozoic deposits of southeastern New Mexico and an outline of the history of evaporite dissolution. *Journal of Research of the U. S. Geological Survey*, v. 4, p. 135-149.

1980 Regional geology and Cenozoic history of the Pecos region, southeastern New Mexico. *U. S. Geological Survey, Open-file Report* 80-1099, 116 p.

Blair, T. C., J. S. Clark, and S. G. Wells
1990a Quaternary stratigraphy and landscape evolution and its application to archeological studies, *in* Anschuetz, K. F., W. H. Dolman, and R. C. Chapman, eds., *Landscape Archeology in the Southern Tularosa Basin, Volume 1: Small Site Distributions and Geomorphology*. Univ. of New Mexico, Office of Contract Archeology, Albuquerque, p.167-206.

1990b Quaternary continental stratigraphy, landscape evolution, and application to archeology: Jarilla piedmont and Tularosa graben floor, White Sands Missile Range, New Mexico. *Geological Society of America Bulletin* 102:749-759.

Bowman, S.
1990 *Radiocarbon Dating*. Univ. California Press, Berkeley.

Buffington, L. C., and C. H. Herbel
1965 Vegetational changes on a semiarid grassland range from 1858 to 1963. *Ecological Monographs* 35:139-164.

Darton, N. H.
1928 "Red Beds" and associated formations in New Mexico. *U. S. Geological Survey Bulletin* 794.

Dick-Peddie, W. A.
1993 *New Mexico Vegetation: Past, Present, and Future*. University of New Mexico Press, Albuquerque, 244 p.

Dillon T. J., and A. L. Metcalf
1997 Altitudinal distribution of land snails in some montane canyons in New Mexico, *in* Metcalf, A. L., and Smartt, R. A. eds., Land Snails of New Mexico. New Mexico Museum of Natural History and Science Bulletin No. 10, p. 109-127.

Eidenbach, P. L., and M. L. Wimberly
1980 Condition of the environment during historic times: An anecdote from the notorious Atkinson land surveys, *in Archaeological Reconnaissance in White Sands National Monument, New Mexico, 1978*. Human Systems Research, Inc., Tularosa, New Mexico.

Gadzia, J. S. G., and J. A. Ludwig
1983 Mesquite age and size in relation to dunes and artifacts. *Southwestern Naturalist* 28:89-94.

Gile, L. H.
1975 Holocene soils and soil-geomorphic relations in an arid region of southern New Mexico. *Quaternary Research* 5:321-360.

1985 *The Sandhills Project Soil Monograph, A Study of Soils and Landscapes on the Southern High Plains*. Rio Grande Historical Collections, New Mexico State University Library, Las Cruces, New Mexico, 331 p. (reissued 1988)

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*. Memoir 39, New Mexico Bureau of Mines & Mineral Resources, Socorro.

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

Hall, S. A.
1990a Pollen evidence for historic vegetational change, Hueco Bolson, Texas. *Texas Journal of Science* 42:399-403.

1990b Channel trenching and climate change in the southern U. S. Great Plains. *Geology* 18:342-345.

2001 Geochronology and paleoenvironments of the glacial-age Tahoka Formation, Texas and New Mexico High Plains. *New Mexico Geology* 23:71-77.

Hawley, J. W.
1993 The Ogallala and Gatuna formations in the southeastern New Mexico region, a progress report. *New Mexico Geological Society, Guidebook* 44, p. 261-269.

Holliday, V. T.
2001 Stratigraphy and geochronology of upper Quaternary eolian sand on the Southern High Plains of Texas and New Mexico, United States. *Geological Society of America Bulletin* 113:88-108.

Huntley, D. J., D. I. Godfrey-Smith, and M. L. W. Thewalt
1985 Optical dating of sediments. *Nature* 313:105-107.

Jeter, H. W.
2000 Determining the ages of recent sediments using measurements of trace radioactivity. *Terra et Aqua* 78:1-11.

Johnson, D. L.
1989 Subsurface stone lines, stone zones, artifact-manuport layers, and biomantles produced by bioturbation via pocket gophers (*Thomomys bottae*). *American Antiquity* 54:370-389.

1997 *Geomorphological, geoecological, geoarchaeological and surficial mapping study of McGregor Guided Missile Range, Fort Bliss, New Mexico*. Vol. I-A. Geo-Marine, Inc., Plano, Texas.

Julyan, R.
1996 *The Place Names of New Mexico*. Univ. New Mexico Press, Albuquerque.

Katz, S., and P. Katz
2000 *Prehistory of the Pecos Country, Southeastern New Mexico*, *in* Katz, S. and P. Katz, eds., *The Archaeological Record of Southern New Mexico: Sites and Sequences of Prehistory, Part III*. Final text draft submitted to the New Mexico Historic Preservation Division, Office of Cultural Affairs, Santa Fe, in fulfillment of Historic Preservation Division Project No. 35-99-14264.19.

Kelley, V. C.
1971 *Geology of the Pecos Country, Southeastern New Mexico*. Memoir 24, New Mexico Bureau of Mines & Mineral Resources, Socorro.

Martin, W. C., and C. R. Hutchins
1980 *A Flora of New Mexico*. 2 Vols., J. Cramer, Vaduz.

Muhs, D. R. and V. T. Holliday
2001 Origin of late Quaternary dune fields on the southern High Plains of Texas and New Mexico. *Geological Society of America Bulletin* 113: 75- 87.

Peterson, R. S. and C. S. Boyd
1998 Ecology and management of sand shinnery communities: A literature review. USDA, Forest Service, General Technical Report RMRS-GTR-16.

Powers, D. W., and R. M. Holt
1993 The Upper Cenozoic Gatuna Formation of southeastern New Mexico. *New Mexico Geological Society, Guidebook* 44, p. 271-282.

Richmond, G. M., and D. S. Fullerton
1986 Introduction to Quaternary glaciations in the United States of America. *Quaternary Science Reviews* 5:3-10.

Sebastian, L.
1989 The Archaic period, *in* Sebastian, L., and S. Larralde, eds., *Living on the Land: 11,000 Years of Human Adaptation in Southeastern New Mexico.* New Mexico Bureau of Land Management, Cultural Resources Series No. 6, p. 41-57.

Stuiver, M., and P. J. Reimer
1993 Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. Radiocarbon 35:215-230.

Stuiver, M, P. J. Reimer, E. Bard, J. W. Beck, G. S. Burr, K. A. Hughen, B. Kromer, G. McCormac, J. van der Plicht, and M. Spurk
1998 INTCAL98 radiocarbon age calibration, 24,000—0 cal BP. *Radiocarbon* 40:1041-1083.

Swift, M. K.
1991a Radiocarbon analysis, *in* Dolman, W. H., R. C. Chapman, J. A. Schutt, M. K. Swift, and K. D. Morrison, eds., *Landscape Archeology in the Southern Tularosa Basin, Vol. 2, Testing, Excavation, and Analysis*. Office of Contract Archeology, University of New Mexico, Albuquerque, p. 411-414.

1991b Dating the Q3A horizon, *in* Dolman, W. H., R. C. Chapman, J. A. Schutt, M. K. Swift, and K. D. Morrison, eds., *Landscape Archeology in the Southern Tularosa Basin, Vol. 2, Testing, Excavation, and Analysis*. Office of Contract Archeology, University of New Mexico, Albuquerque, p. 414-415.

Van Devender, T. R.
1986 Pleistocene climates and endemism in the Chihuahuan Desert flora, *in* Barlow, J. C., A. M. Powell, and B. N. Timmermann, eds., *Transactions of the Second Symposium on the Resources of the Chihuahuan Desert*. Chihuahuan Desert Research Institute, Alpine, Texas, p. 1-19.

Whitford, W. G., D. Schaefer, and W. Wisdom
1986 Soil movement by desert ants. *Southwestern Naturalist* 31:273-274.

York, J. C., and W. A. Dick-Peddie
1969 Vegetational changes in southern New Mexico during the past hundred years, *in* McGuinnes, W. G., and B. J. Goldman, eds., *Arid Lands in Perspective*. Univ. of Arizona Press, Tucson.

Appendix A

Sediment data from Mescalero Sands; samples are in centimeters depth; numbers are percentages; Wentworth scale; Munsell Soil Color Chart.

	SAND (mm)					RECALCULATED					
SAMPLE	2.0-1.0 v. coarse	1.0-0.5 coarse	0.5-0.25 medium	0.25-0.125 fine	0.125-0.0625 very fine	SAND	SILT	CLAY <3.9μm	OM	CAR-BONATES	COLOR
Ogallala Fm., caprock caliche											
85	11.2	18.7	18.9	25.6	25.6	64.3	21.5	14.2	-	89.5	-
200	0.6	1.9	7.6	59.5	30.0	87.3	9.3	3.3	-	86.9	-
270	0.9	14.8	10.7	17.4	56.3	44.2	40.8	15.0	-	80.6	-
Ogallala Fm., below caprock caliche											
350	2.6	1.9	11.2	58.2	26.1	81.8	16.0	2.2	0.3	14.6	5YR7/3
550	0.8	0.6	13.4	59.2	26.0	88.2	10.2	1.6	0.3	5.3	5YR7/3
800	0.1	0.1	11.2	64.1	24.5	88.2	7.3	2.1	0.3	3.3	5YR7/3
Locality 1, Valley Gas Rd. sand pit											
80	0	0.9	31.1	55.2	12.7	82.8	3.4	13.8	-	0.3	2.5YR4/8
200	0	0.6	26.5	61.1	11.8	91.1	3.2	5.7	-	1.3	2.5YR5/8
320	0	0.7	15.5	62.7	21.2	94.2	2.0	3.8	-	0.5	5YR5/8
370, cal.	0.5	0.8	11.4	53.2	34.2	35.5	20.6	43.9	-	17.9	-
Locality 2, Valley Gas Rd. soil pt											
coppice d.	0	0.3	20.7	61.5	17.5	90.9	3.0	6.1	-	0.9	-
10, A hor.	0	1.5	28.2	52.9	17.4	92.7	4.2	3.1	0.30	0.3	5YR5/6
60	0	0.8	26.2	60.8	12.2	90.2	3.1	6.7	-	0	2.5YR5/8
130	0	1.2	28.1	56.4	14.3	77.1	4.7	18.2	-	0.3	2.5YR4/8
Locality 3, Old Loco Rd. soil pit											
coppice d.	0	0.8	19.1	60.2	19.9	90.4	3.2	6.4	-	0.1	5YR5/5
10, A hor.	0.1	1.2	19.2	56.3	23.2	82.0	7.8	10.3	0.75	0.4	5YR4/4
40	0	2.2	22.0	54.4	21.5	72.6	6.9	20.5	-	0.1	2.5YR4/8
80	0	1.8	20.5	55.9	21.8	70.9	9.6	19.5	-	0.8	2.5YR4/8
110, cal.	29.6	18.9	19.4	21.3	10.8	81.9	10.2	7.9	-	63.8	-
Locality 4, F Lane soil pit											
50	0	0.2	14.9	61.7	23.1	94.2	2.2	3.6	-	0	5YR5/6
180	0	0.4	15.3	62.0	22.3	80.4	3.7	15.9	-	0.5	2.5YR4/8
240, cal.	33.2	18.7	15.0	21.1	12.0	79.0	10.6	10.3	-	63.5	-
Locality 5, Hagerman Cutoff caliche pit											
caliche	9.0	12.5	15.5	37.9	25.1	48.4	27.0	24.7	-	51.6	-
Locality 8, Booger Langston Rd. sand dunes and spring deposits											
100, para. d.	0	0	14.9	78.9	6.2	98.2	0.2	1.6	-	0.1	5YR6/6
170, A hor.	0	0	13.6	77.8	8.6	98.1	0.4	1.5	0.15	0.3	5YR6/6
250	0	0	15.6	72.3	12.1	96.8	1.2	2.0	-	0.3	5YR6/6
400, bands	0	0	14.8	74.8	10.4	92.9	0.5	6.6	-	0.7	5YR5/8
400, excl. b.	0	0	13.0	70.0	17.0	96.9	0.6	2.5	-	0.1	5YR6/6
500	0	0	12.9	65.5	21.6	96.1	1.2	2.7	-	0.2	5YR6/6
640, spring	2.0	5.3	16.0	53.9	22.8	63.2	25.3	11.5	-	36.3	-
Locality 9, Square Lake Rd. caliche pit											
caliche	8.1	12.8	17.9	36.0	25.2	23.2	54.5	22.3	-	55.3	-
Locality 10, Square Lake Rd. soil pit											
30, A hor.	0	0.5	20.9	68.8	9.8	96.2	1.8	2.0	0.29	0.2	5YR5/6
50	0	0.4	17.1	70.3	12.3	94.2	2.3	3.5	-	0.3	5YR5/8
110	0	0.1	10.9	59.4	29.6	27.6	22.8	49.6	-	0	2.5YR4/6
Locality 11, Caprock Rd. spring deposits											
spring	0.1	0.1	8.0	65.0	26.8	85.1	9.8	5.0	-	0.3	-
Locality 12, Caprock Rd. alluvial section											
30, coppice	0	0.1	16.0	68.3	15.6	94.4	2.7	2.9	-	1.0	10YR6/4
70	0	10.2	16.2	66.0	17.5	94.4	3.1	2.5	-	2.1	10YR6/4
90, A hor.	0	0.1	9.4	59.9	30.6	82.2	11.3	6.5	0.93	1.7	10YR4/3
150	0.4	0.5	9.8	61.8	27.5	73.3	13.7	13.0	-	9.9	7.5YR5/4

Appendix A (continued)

SAMPLE	SAND (mm) 2.0-1.0 v. coarse	1.0-0.5 coarse	0.5-0.25 medium	0.25-0.125 fine	0.125-0.0625 very fine	RECALCULATED SAND	SILT	CLAY <3.9μm	OM	CAR-BONATES	COLOR
Locality 14, Square Lake Rd. spring-cienega deposit											
40	0	0	4.5	64.1	31.3	94.4	1.1	4.5	-	0.6	2.5YR5/8
120	0	0.1	12.2	64.2	23.4	80.7	7.7	11.6	-	1.5	2.5YR5/6
185, spring	0.3	0.5	10.5	66.0	22.7	84.6	5.7	9.7	-	7.9	-
Locality 15, Shugart Rd. sand pit											
40, A hor.	0	0.1	13.7	64.2	22.0	95.6	2.0	2.5	0.30	0	5YR5/6
125	0	0	12.9	71.0	16.0	94.3	0.9	4.7	-	0.8	2.5YR4/8
350	0	0.1	12.4	67.5	20.0	95.7	1.6	2.8	-	1.3	5YR6/6
Mescalero paleosol east of Ishee Lake, Eddy-Chaves Co. line (Fig. 3)											
caliche	8.2	9.9	18.0	46.9	17.0	93.5	1.4	5.1	-	69.4	-

“0” = measured but zero percent; “-“ = not measured

Appendix B

Sedimentology data from deposits in the Mescalero Sands area, northeastern Eddy Co., New Mexico; mean values with 1 sigma standard deviation; number of samples in parentheses; data from Appendix A (Wentworth scale); mean values plotted in Fig. 7.

sample	medium sand %	fine sand %	very fine sand %	total sand %	silt %
Ogallala Fm. (3)	11.9 ± 1.3	60.5 ± 3.2	25.5 ± 0.9	86.1 ± 3.7	11.2 ± 4.4
Unit 1 sand (10)	21.0 ± 6.8	60.7 ± 5.5	17.4 ± 4.4	84.9 ± 9.4	3.9 ± 2.6
Unit 2 sand (5)	14.7 ± 1.8	68.0 ± 4.3	17.2 ± 5.1	95.6 ± 1.4	1.5 ± 0.7
Loco Hills soil (5)	19.1 ± 6.0	64.0 ± 10.0	16.2 ± 6.8	92.9 ± 6.4	3.2 ± 2.9
Coppice dunes (4)	17.7 ± 2.7	67.2 ± 8.6	14.8 ± 6.0	93.5 ± 3.6	2.3 ± 1.4
Alluvium (2)	9.6 ± 0.3	60.8 ± 1.3	29.0 ± 2.2	77.8 ± 6.3	12.5 ± 1.7

Appendix C

Sediment data from Coppice Dune, loc. 13, Mescalero Sands; numbers are percentages; Wentworth scale.

SAMPLE	SAND (mm) 2.0-1.0 v. coarse	1.0-0.5 coarse	0.5-0.25 medium	0.25-0.125 fine	0.125-0.0625 very fine	RECALCULATED SAND	SILT	CLAY <3.9μm	OM	CAR-BONATES
8, upper	0	0.1	3.9	61.1	34.9	90	6	4	0.5	2.5
7	0	0	3.7	56.9	39.4	86	8	6	0.9	3.4
6	0	0.1	6.4	55.6	37.9	83	10	7	1.1	3.7
5	0	0	5.5	60.2	34.3	88	6	6	0.6	2.1
4	0	0.1	7.4	52.9	39.6	86	8	6	0.7	2.7
3	0	0	10.6	68.4	21.0	91	5	4	0.5	1.7
2	0	0.1	12.1	65.0	22.8	90	6	4	0.6	1.8
1, lower	0	0.1	9.8	65.0	25.1	91	6	3	0.5	1.6
LH soil	0.1	0.5	13.0	63.7	22.7	86	7	7	0.7	3.4

Appendix D

FIELD LOCALITIES

The following 15 field localities in the Mescalero Sands, northeastern Eddy Co., New Mexico, represent the stratigraphic and geomorphic record of the sand sheet. Localities 1-4 are on Map 1 (Fig. 16); localities 5-10, 14 are on Map 2 (Fig. 17); localities 11,12 are on Fig. 8; Bureau of Land Management jurisdiction except where noted; sediment data presented in Appendix A; stratigraphic measurements in centimeters, colors from Munsell Soil Color Charts.

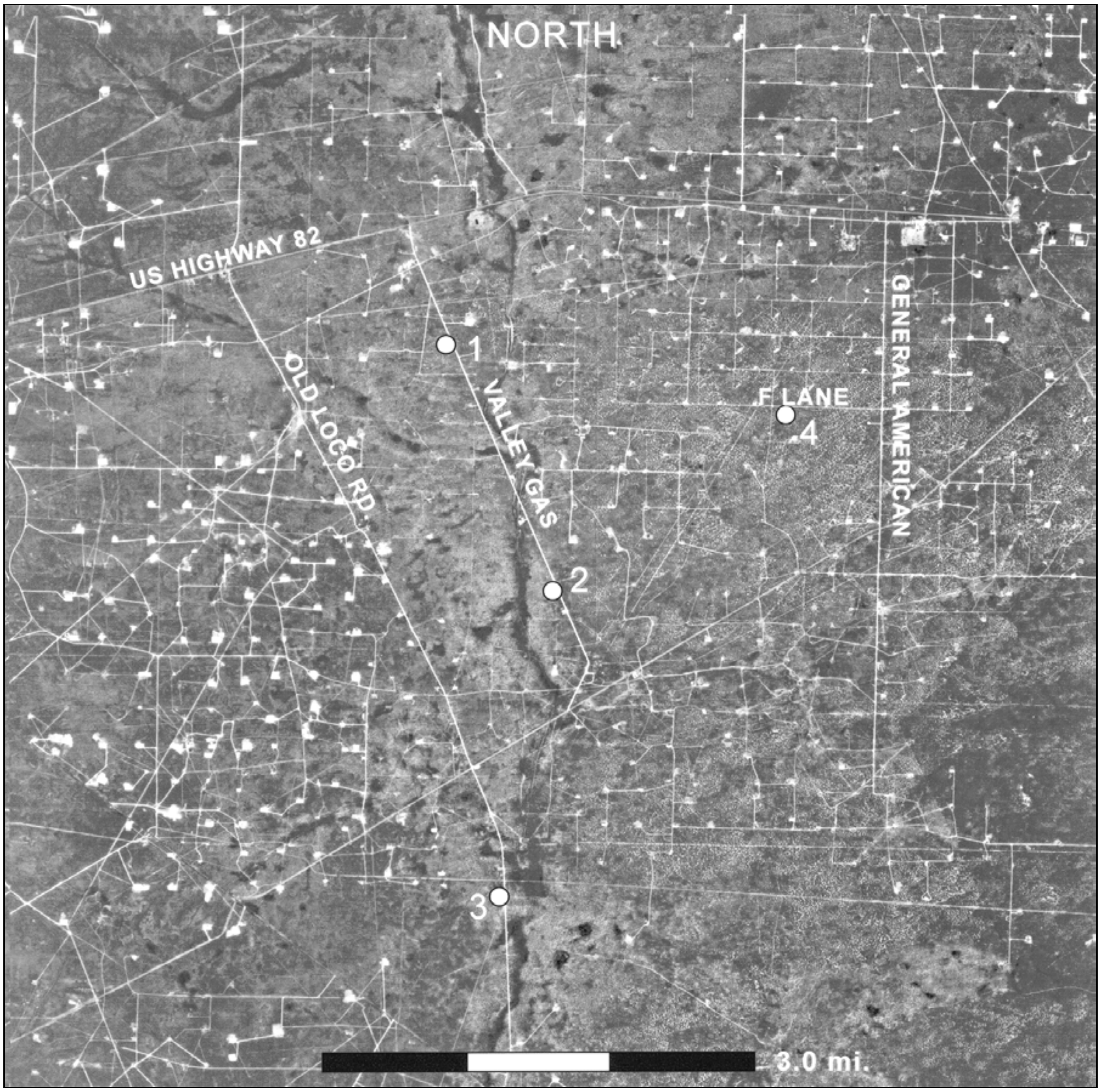

Fig. 16. Map 1. Color infrared aerial photograph, altered to grayscale; centered over Bear Grass Draw west of Loco Hills community (just off the eastern edge of the image along US Highway 82); the numbered localities are documented stratigraphic and geomorphic study sites and soil pits; dark areas along drainages are moist ground and dense grasses; the apparently featureless plain on the western half of the image is thin eolian sand cover with low mesquite coppice dunes underlain by late Pleistocene caliche; the rough-appearing surface east of Bear Grass Draw is composed of small parabolic dunes and shin oak vegetation; small white squares are oil-well pad sites connected by caliche-paved roads; image taken 6-30-83.

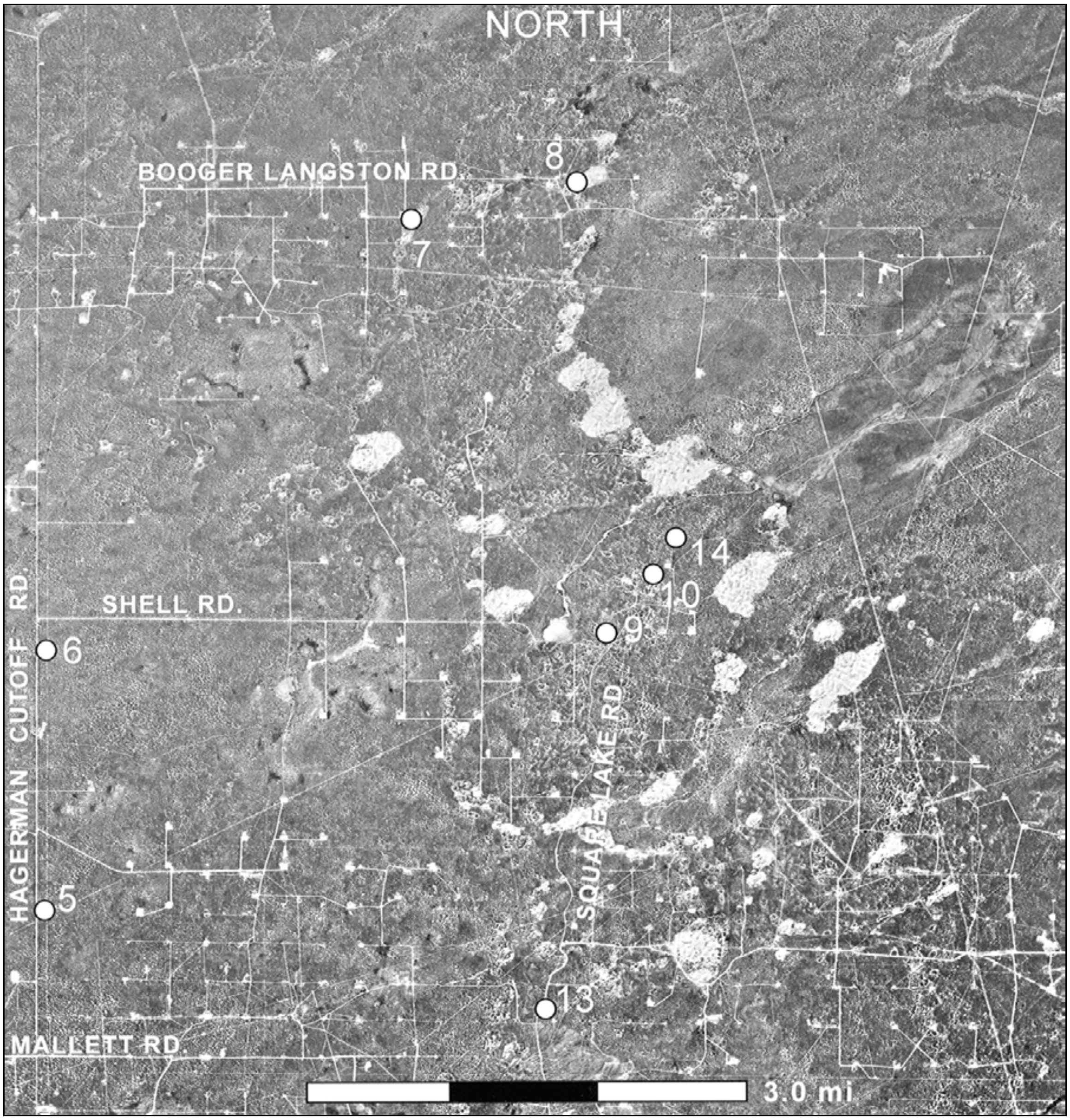

Fig. 17. Map 2. Color infrared aerial photograph, converted to gray scale, of Mescalero Sands northeast of Loco Hills community; broad dark areas are shin oak-covered parabolic dunes; gray areas are thin eolian sand cover with scattered mesquite coppice dunes; white patches are active dune fields; small dark patches are depressions with dense plant cover; image taken 9-25-83.

Locality 1. Valley Gas Rd. sand pit, state land; 0.8 mi. south of US Hwy. 82 on Valley Gas Rd. (Eddy Co. 212), west side of road at junction with side road; OSL samples from unit 1 sand collected here (Pl. I-C) [State of New Mexico land].

0-40	Unit 2, yellowish red fine sand, darker-colored Loco Hills soil A horizon at top; mesquite coppice dunes resting directly on Loco Hills soil
40-110	Unit 1, red Bt paleosol in fine sand
110-350	Unit 1, red to yellowish red fine sand, massive, carbonate filaments; OSL samples taken at 200 cm (81,700 ± 3600 yrs) and 320 cm depth (87,400 ± 4500 yrs)
350-370+	Btk Mescalero paleosol, carbonate nodules in dark red clay; Bt horizon present here although it is eroded and missing elsewhere

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Locality 2. Valley Gas Rd. soil pit; 2.8 mi. south of US Hwy. 82 on Valley Gas Rd. (Eddy Co. 212), west side of road.

0-25	Unit 2, yellowish red fine sand, darker-colored Loco Hills soil A horizon at top, soil bioturbated, basal contact irregular and bioturbated; mesquite coppice dunes rest directly on Loco Hills soil
25-120	Unit 1, red fine sand, weakly calcareous below 85 cm, burrow fill of Loco Hills A horizon sediment at 75-80 cm depth
120-135+	Bk Mescalero paleosol, red sand, carbonates

Locality 3. Old Loco Rd. soil pit; 0.9 mi. south of Hagerman Cutoff (Eddy Co. 217) on Old Loco Rd. (Eddy Co. 210), west side of road; radiocarbon age of Loco Hills soil obtained here (Pl. II-F).

0-15	Loco Hills soil A horizon, reddish brown fine sand, bioturbated; mesquite coppice dunes rest directly on soil; radiocarbon ages from A horizon are 370 $\pm$ 40 and modern (Table 3)
15-102	Unit 1, red sand, calcareous throughout, indurated, massive, lower 40 cm slightly redder with more carbonate films; sharp basal contact
102-115+	Bk Mescalero paleosol, moderately hard massive carbonates cementing sand grains

Locality 4. F Lane soil pit; 0.7 mi. west of General American Rd. (Eddy Co. 216) on F Lane, south side of lane, 0.8 mi. north of Hagerman Cutoff on General American Rd. to F Lane, or 1.3 mi. south of US Hwy. 82 on General American Rd. to F Lane; shinnery parabolic dunes (Fig. 3; Pl. V-O).

0-113	Unit 2, yellowish red fine sand, massive, soft, turbated; A horizon soil not clear; gradual transition to underlying unit due to turbation
113-234	Unit 1, red fine sand, non calcareous, massive, more indurated towards base
234-235	Light gray sand, subangular, grains partly coated by carbonate; layer of sand occurs at sharp boundary between caliche and overlying red sand
235-250+	Bk Mescalero paleosol, hard, dense carbonate-cemented sand; sharp upper boundary, slightly undulating; evidence for severe erosion of late Pleistocene Mescalero paleosol

Locality 5. Hagerman Cutoff caliche pit; 4.4 mi. north of US Hwy. 82 at Loco Hills on Hagerman Cutoff (Eddy Co. 217), east side of paved road; numerous mesquite coppice dunes.

0-65	Unit 2 reddish yellow sand with Loco Hills soil mantling unit 2 sand
65-125	Unit 1 red sand, strongly turbated with numerous small burrow fills; red sand fills burrows and pipes in underlying caliche
125-275+	Bk Mescalero paleosol, dense but not strongly indurated carbonate-cemented sand, absence of laminar structures; voids in upper 40 cm filled with yellowish red sand, voids 40-60 cm below top of caliche filled with red sand; upper surface of caliche pitted by solution; solution pipes extend through caliche and are filled with red sand; inside surface of pipes coated with secondary carbonates

Locality 6. Hagerman Cutoff coppice dune; 6.0 mi. north of US Hwy. 82 at Loco Hills on Hagerman Cutoff (Eddy Co. 217), east side of paved road, 0.2 mi. south of junction with Shell Road; numerous mesquite coppice dunes; soft sand on shoulder.

0-195	Unit 3, coppice dune, massive bedding due to severe bioturbation
195-226	Unit 2, reddish yellow fine sand, Loco Hills soil A horizon indistinct due to bioturbation, thickness of unit uncertain
226-239	Unit 1, yellowish red sand, gradational upper boundary with unit 2
239-240	Light gray sand marks sharp contact between red sand above and caliche below
240-248+	Bk Mescalero paleosol, dense carbonate, sharp upper boundary indicating post- paleosol erosion at this locality

Locality 7. Booger Langston Rd. sand dunes; 3.0 mi. east of Hagerman Cutoff on Booger Langston Rd. (Eddy Co. 256), at right-angle turn from east to north, walk eastward towards high dunes; small area of active dunes in shinnery parabolic dune area (Pl. V-M). Stratigraphy not measured. Good exposure of unit

2 sand with clay bands and Loco Hills soil A horizon covered by recent dune sand. A small archaeological site is eroding out of the upper part of unit 2.

Locality 8. Booger Langston Rd. sand dunes and spring deposits; 4.4 mi. east of Hagerman Cutoff on Booger Langston Rd. (Eddy Co. 256), just around corner SE of oil tanks on west side of road, walk east from road past abandoned well and oil spill towards the eastern edge of the active dunes which is the eastern margin of the study locality; shinnery parabolic dunes; site of 2 OSL ages from unit 2 sand and radiocarbon age from Loco Hills A horizon soil (Pl. II-D).

0-160	Unit 3, reddish yellow fine sand, subangular-subrounded, weak thin laminations, recent sand, eroded edge of parabolic dune covered by shin oak
160-175	Loco Hills soil A horizon, reddish yellow fine sand, slightly darker color in the field than overlying and underlying sand even though Munsell color is the same; soil appears to extend horizontally through the area of active dunes, indicating that the deflation and unit 3 dune deposition is recent eolian activity; radiocarbon age is modern (Table 3)
175-335	Unit 2, reddish yellow fine sand, massive, noncalcareous; OSL sample taken from 295 cm depth (6300 $\pm$ 200 yrs)
335-455	Unit 2, banded sand, bands are yellowish red fine sand, fine sand between bands is reddish yellow, bands and sand are noncalcareous, bands may be formed by iron-oxide accumulation which makes the bands redder and resistant to erosion, resulting in them standing out in relief upon deflation
455-620	Unit 2, reddish yellow fine sand, subrounded-rounded, massive, noncalcareous, strongly turbated as indicated by indurated burrow fills that stand out in relief upon abrasion of vertical sand face by wind (see Pl. V-P); OSL sample taken from base of this zone at 615 cm depth (8900 $\pm$ 300 yrs); locally, a 25-cm thick zone of less red sand occurs at the base of unit 2 although this sand was not present at the section from which the lower OSL sample was collected; Unit 1 red sand is not present here although it occurs in a blowout just west of the study locality
620-650+	Spring deposits, calcareous sand, has the appearance of caliche; contains small shells of land and freshwater snails especially at the blowout at the oil spill closer to the road where the spring deposits are overlain by red sand; evidence for higher water table prior to formation of sand sheet

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Locality 9. Square Lake Rd. caliche pit; 0.1 mi. north on Square Lake Rd. (Eddy Co. 220) from jct. with Shell Rd. (Eddy Co. 253), east side.

0-25	Loco Hills soil A horizon; rests directly on red sand or with very thin unit 2 eolian sand; covered by shinnery parabolic dune sand (unit 3)
25-55	Unit 1, red sand, turbated, slightly indurated, noncalcareous, fills pipes in caliche
55-230	Bk Mescalero paleosol, soft, slight induration, absence of lamellae, carbonates concentrated in zone upper 65 cm, lower 110 cm carbonate nodules to 10 cm dia., manganese coats; paleosol developed in red Triassic shale; small, round shale inclusions enveloped by carbonates in upper 65 cm

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Locality 10. Square Lake Rd. soil pit; 0.3 mi. north on Square Lake Rd. from jct. with Shell Rd., east side, near loc. 9 caliche pit; caliche exposed in shallow road cut near soil pit; shinnery parabolic dunes (Pl. III-H).

0-27	Unit 3, reddish yellow fine sand, massive, noncalcareous, soft; forms parabolic dune
27-38	Loco Hills soil A horizon, yellowish red fine sand, slightly darker than overlying and underlying sand, gradational contact both top and base, turbation
38-64	Unit 2, yellowish red fine sand, massive, slightly indurated, noncalcareous, turbated, burrow fills with red sand from underlying bed
64-85	Transition zone from yellowish red to red sand of Bt paleosol
85-255+	Mescalero paleosol, Bt and Btk horizons, red sand, clay coats, manganese coats on ped surfaces, peds 10 cm across, carbonates below 135 cm, soft and hard concretions 2-3 cm dia., vertically aligned pockets and lenses of carbonate; this is a rare record of the upper part of the Mescalero paleosol Btk horizon

Near Loc. 10 closer to the road is a shallow soil pit in the crest of a small parabolic dune that extends 110 cm above floor of its deflation basin:

0-38	Unit 3, reddish yellow sand, massive, gradational lower contact; forms crest of small parabolic dune
38-68	Loco Hills soil A horizon, reddish yellow fine sand, massive, turbated
68-120+	Unit 2, reddish yellow fine sand, massive, slightly indurated and redder at depth; this is the sand in which the blowout is formed

Locality 11. Caprock Rd. spring and cienega deposits; less than 0.1 mi. south of jct. of Caprock Rd. (Eddy Co. 255) with Radio Rd. (Eddy Co. 254); white-light olive spring deposits are exposed along road cut on both sides of Caprock Rd. and extend south for about ½ mile; the exposure just south of the Radio-Caprock rd. jct. is the highest preserved level of the 5+ meter thick deposits (Pl. IV-K, -L).

The spring-cienega deposits consist of white to light olive fine sand with carbonate matrix although soft and not indurated. The upper part of the deposit exposed along Caprock Rd. is eroded and weathered with numerous burrows and, especially below 40 cm, plant casts, and iron-oxide stains. Snail shells, mostly land and some aquatics, occur at the Caprock Rd. exposure (Table 5). Calcareous snail-bearing cienega deposits are also exposed in the small arroyo south of the road cuts. Cienega deposits are exposed in most of the small drainages in the adjacent area. Fragments of fossil mammalian bones occur sparsely in the cienega deposits. Although these deposits are not directly dated, they are late Pleistocene in age, likely correlating with the Square Lake Rd. spring deposit with a radiocarbon age 18,900 $\pm$ 100 ^{14}C yrs BP. The snail species that occur in these spring-cienega sediments are locally extinct, occurring today only in moister, cooler habitats in the central and northern New Mexico mountains.

Locality 12. Caprock Rd. alluvial section; 0.1 mi. south on Caprock Rd. (Eddy Co. 255) from jct. with Radio Rd. (Eddy Co. 254), west of Caprock Rd. in small unnamed arroyo about 200 feet, alluvial section on right bank of arroyo; this alluvial section was selected for analysis because of the prominent A horizon paleosol overlain by mesquite coppice dunes; the radiocarbon age of the A horizon is 330 $\pm$ 40 ^{14}C yrs BP; a single A horizon soil such as this one occurs towards the top of thin alluvial sequences in small drainages throughout the eastern half of the sand sheet and correlates with the Loco Hills soil that mantles eolian sand unit 2 (Pl. III-I).

0-56	Unit 3, light yellowish brown fine eolian sand, rounded, fine laminations; mesquite coppice dune
56-80	Light yellowish brown gravelly sand, subrounded-rounded, laminated in lower part, upper part turbated, caliche gravels, forms sharp erosional basal contact with underlying Loco Hills A horizon soil, small caliche gravels at contact; small gravel-filled scour trough 29 cm deep (109 cm depth) through underlying soil, gravels fine upwards, 5 cm dia. at base of trough; alluvium
80-105	Loco Hills soil, A horizon, dark brown, fine sand, upper contact sharp, erosional; lower contact gradational; soil developed in alluvium; AMS radiocarbon age is 330 $\pm$ 40 ^{14}C yrs BP
105-210+	Brown fine sand, subrounded, massive, occasional caliche gravel; alluvium; late Holocene alluvial fill inset into late Pleistocene spring-cienega deposits in this and other adjacent drainages

Locality 13. Square Lake Rd. coppice dune; just north on Square Lake Rd. (Eddy Co. 220) from jct. with Mallet Rd. (Eddy Co. 257), or 3.6 mi. north of US Hwy. 82 on Square Lake Rd., road cut, east side; Square Lake Rd. is 2.8 mi. east of highway crossing at Loco Hills on US Hwy. 82 (Pl. III-G).

This coppice dune was chosen because of its well-preserved internal stratigraphy for pilot ^{210}Pb and ^{137}Cs analysis to test a 20th century origin of coppice dunes. A series of eight samples was collected from the 1-meter dune. The ^{137}Cs signature indicates the upper 22 cm of the dune accumulated since 1954. The ^{210}Pb signature from the upper- and lower-most samples, however, was too weak to interpret; sediment data in Appendix C (Fig. 4; Table 2).

The coppice dune is associated with a broad colluvial-alluvial surface. The dune itself rests on a sharp contact with an underlying A horizon of the Loco Hills soil. The soil forms a low rise directly beneath the dune, suggesting that the mesquite that formed the dune also protected the underlying soil and its surface from erosion; other coppice dunes in the region also exhibit this character. The A horizon is about 20 cm thick and, immediately beneath the dune, is developed on 70-80 cm of eolian sand. The low mound of sand rests on a deposit of sand and gravel, the gravel consisting of caliche fragments. The entire deposit is exposed for some distance along Square Lake Rd. and is derived from hill slope wash. The Mescalero paleosol is exposed at a distant hilltop and is the likely source of the caliche gravel. The radiocarbon age of charcoal from the Loco Hills soil just beneath the coppice dune is 150 ± 40 ^{14}C yrs BP.

Locality 14. Square Lake Rd. spring-cienega deposit; 8.3 mi. north of US Hwy. 82 on Square Lake Rd. (Eddy Co. 220), or 1.5 mi. north on Square Lake Rd. from jct. with Shell Rd. (Eddy Co. 253), a low-water crossing of unnamed arroyo, east side of crossing; snail shells from this locality have a radiocarbon age of 18,900 ± 100 ^{14}C yrs BP; upper part of stratigraphy disturbed by road and culvert building; mesquite coppice dunes; this locality is a broad alluvial plain and, according, the eolian geomorphology may not be representative of the sand sheet; the alluvial geology was not investigated; the following is a general stratigraphic sequence above the spring-cienega deposit (Pl. IV-J); disturbed roadbed material, alluvium, and mesquite coppice dune sands overlie the sequence.

0-54	Red sand, massive, noncalcareous, probably eolian in origin, may be eolian unit 2 but if it is this is the only locality where unit 2 sand is red
54-66	Bt paleosol, thin, indurated, may be developed in alluvium
66-81	Red sandy clay, carbonate films, indurated, may be thin bed of alluvium
81-166	Red sand, massive, carbonate films, not indurated, may be eolian unit 2
166-246	Spring-cienega deposit, pink, 40 to 80 cm thick, carbonate-coated sand, soft lacking induration, sharp upper contact with overlying red sand, strongly bioturbated with numerous burrow fills containing red sand derived from overlying unit, lower half of deposit with small carbonate nodules; shells of land and freshwater snails occur throughout deposit; shells are well- preserved with nacreous (pearly) luster; shell fragments from this locality provided an AMS radiocarbon age of 18,900 ± 100 ^{14}C yrs BP (Table 3)

Locality 15. Shugart Rd. sand pit; 1.9 mi. south on Shugart Rd. (Eddy Co. 222) from US Hwy. 82, east 0.4 mi. on well-pad road, exposure just off north side of road and NW corner of well pad; shinnery parabolic dunes; locality 15 not shown on aerial photographs.

0-35	Unit 3, recent sand, parabolic dune
35-115	Unit 2, yellowish red fine sand, upper part mantled by Loco Hills soil A horizon, indistinct upper contact due to turbation, strong bioturbation throughout
115-315	Unit 1, Bt paleosol, red sand, rounded-subrounded, massive, soil not as strongly developed as elsewhere in sand sheet
315-415	Unit 1, Reddish yellow fine sand, massive, carbonate filaments
415-445+	Unit 1, Reddish yellow fine sand, massive, non-calcareous; Bk Mescalero paleosol not encountered during trenching and not exposed in vicinity

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GLOSSARY

The following terms are defined in the context of the *Field Guide to the Geoarchaeology of the Mescalero Sands, Southeastern New Mexico* and are excerpted in part from the *Glossary of Geology* (1997, 4th ed., American Geological Institute, 4220 King St., Alexandria, Virginia 22302) and the *Glossary of Soil Science Terms* (1996, Soil Science Society of America, 677 South Segoe Road, Madison, Wisconsin 53711).

A horizon. The upper horizon of a soil characterized by an accumulation of humified organic matter and mixed with the mineral fraction; the gray color of the A horizon is a result of its organic content; the *Loco Hills soil* in this study is an A horizon soil that occurs throughout the Mescalero Sands region.

Argillic horizon. A mineral soil Bt horizon that is characterized by the accumulation of silicate clays that have been moved to that zone by water fronts infiltrating from above; oriented clay may coat peds and sand grains and fill voids; a paleosol with a red argillic Bt horizon occurs at the top of unit 1 eolian sand in the Mescalero Sands.

B horizon. A mineral soil horizon formed below an A or E horizon with a concentration of secondary silicate clays and carbonates; the B horizon is time-dependent and soil chronosequences are based on paleosol B horizons; Bt = accumulation of pedogenic silicate clay, Bk = accumulation of pedogenic carbonates, commonly calcium carbonate.

Bioturbation. The disruption and disturbance of the primary layering of soils and sediments by burrowing animals and plant roots.

Caliche. A term used in the southwestern United States for secondary carbonates that are precipitated in the B horizon of a soil; designated the Bk horizon ("K horizon" is now considered to be an obsolete term for secondary soil carbonates); although applied to all soil carbonates, caliche more commonly refers to thick zones of hard dense carbonate cementation or petrocalcic horizon. In the Mescalero Sands, the soft A horizon and upper part of the B horizon of the late Pleistocene Mescalero paleosol have been removed by erosion, and the more resistant petrocalcic horizon or caliche is all that is left in most areas.

Caprock. The massive caliche that forms a cap on the Ogallala Formation; in the study area the caliche is about 11 feet thick and is the resistant layer of a prominent escarpment that is called the Mescalero Ridge; the caliche formed by soil development processes upon cessation of deposition of eolian sand on the Ogallala during the Pliocene.

Cienega. A spring-fed stream in a semi-arid or arid land.

Coppice dune. A small sand dune in the shape of a circular mound that forms around the base of a shrub where decreased wind velocity has resulted in sand deposition; numerous coppice dunes that have formed around Torrey mesquite shrubs occur at the margins of the Mescalero sand sheet; also called *nebkhas* (or *nabkhas*) in Africa.

Deflation. Wind erosion.

Eolian. Processes or sediments related to wind.

Eowisconsin. The interval of time between the Sangamon Interglaciation and Wisconsin Glaciation that is characterized by alternating cool and warm climate as indicated by oxygen isotope stage 5A-5E; some include the Eowisconsinan as part of the Sangamonian; in the Mescalero Sands, formation of the Mescalero paleosol may have included Sangamon and early Eowisconsin time, and the unit 1 eolian sand began to accumulate during the late Eowisconsin (stage 5A) warm interval (Fig. 15).

Erosion. The entrainment and removal of particles by running water, currents, wind, or ice; distinct from transportation and deposition of particles.

Geoarchaeology. The study of the relationship between archaeology and the biophysical landscape, especially the geology, geomorphology, soils, and paleoecology of archaeological sites; also concerns the analysis of site location, formation, and preservation.

Geomorphology. The science that deals with the origin of landforms and with the history of erosion, deposition, and weathering as recorded by these surface features; geomorphology includes both historical and process aspects of landform development.

Holocene. The most recent epoch of the geologic time scale, arbitrarily assigned an age of 10,000 years ago to present; the Holocene and Pleistocene epochs comprise the Quaternary Period; most of the archaeology of the Mescalero Sands occurs in Holocene-age sediments or soils or on Holocene-age surfaces; formerly called the Recent.

Horizon. [pedology] A layer of soil with a color, texture, mineralogy, chemistry, and structure that differ from that of other layers; [geology] A two-dimensional surface such as a bedding plane or a very thin distinctive bed.

Loco Hills soil. A late prehistoric A horizon soil that formed on the stabilized eroded surface of unit 2 and unit 3 eolian sands and on recent alluvium in the Mescalero sand sheet; named in this study for Loco Hills community in northeastern Eddy Co., New Mexico; radiocarbon ages from the soil range from ca. 100 to 500 radiocarbon years ago.

Mescalero paleosol. The Mescalero paleosol is a petrocalcic soil named in this study that formed on Permian and Triassic sedimentary rocks in the region; it is buried by the Mescalero sand sheet and is estimated to have formed between 130,000 and 100,000 years ago during the Sangamon and early Eowisconsinan.

Mesquite. A shrub or small tree of the genus *Prosopis* in the Fabaceae family (formerly Leguminosae); four forms occur in New Mexico: screwbean mesquite (*P. pubescens*), velvet mesquite (*P. velutina*; formerly *P. juliflora velutina*), honey mesquite (*P. glandulosa glandulosa*), and Torrey mesquite (*P. glandulosa torreyana*; formerly *P. juliflora torreyana*); in the Mescalero Sands, coppice dunes are formed around Torrey mesquite.

Ogallala Formation. A Miocene-Pliocene formation that extends 800 miles from Texas to South Dakota; the 100 to 500 foot thick formation consists of basal alluvial gravels originating from streams that flowed out of the Rocky Mountains; in the southern plains, the upper part of the Ogallala consists of thick sections of sand representing eolian sand sheets originating from deflation of the ancient Pecos River floodplain; the end of deposition of the Ogallala is marked by the development of the massive Caprock caliche of pedogenic origin; the resistance of the caliche to erosion has resulted in the preservation of the High Plains surface of west Texas and eastern New Mexico (from T. Gustavson, 1990, *Tertiary and Quaternary stratigraphy and vertebrate paleontology of parts of northwestern Texas and eastern New Mexico*. Guidebook 24, Bureau of Economic Geology, Austin, Texas); in the study area the upper 15 feet of Ogallala Formation exposed below the caliche caprock is fine sand of eolian origin.

Optically stimulated luminescence (OSL). Luminescence refers to the property of a mineral crystal to emit light when it is subjected to heat or light. Thermoluminescence (TL) is the light emitted in response to heat; optically stimulated luminescence (OSL) is the light emitted in response to visible light from a laser. The amount of light emitted is directly related to the length of time the sample is buried; the older the sample, the more light emitted. The light originates from the release of free electrons that have been trapped at defects in the crystal lattice of a mineral grain; the trapped electrons are produced by the decay of radioisotopes in the sediment surrounding the sample. OSL ages, mainly on quartz and feldspar, may range from a few decades to 200,000 or more years.

Oxygen isotope stage. Systematic changes in the oxygen isotope content of marine foraminifera tests from deep sea cores are related to glacial and interglacial cycles; the oxygen isotope variations are zoned into stages (Fig. 15); because of the confusion in the world literature of multiple names for Quaternary events, oxygen isotope stages have become an informal universal time-stratigraphy that is applied to glacial and interglacial sequences.

Paleosol. An ancient, prehistoric, fossil soil that formed in the past under environmental conditions of topography, geomorphology, vegetation, and climate that do not exist at that location today. The latest version of the North American Code of Stratigraphic Nomenclature (1983, *Amer. Assoc. Petroleum Geologists Bull*., v. 67, p. 841-875) uses the term *geosol* instead of paleosol. However, according to the Code's definition, a geosol must be buried, thus excluding exhumed and relict soils from qualifying as fossil soils. Accordingly, the term geosol is set aside in favor of paleosol.

Parabolic dune. A sand dune with a long, scooped-shaped form, convex in the downwind direction so that its horns point upwind; numerous small, recent, sub-circular parabolic dunes covered partly by shin oak occur in the central Mescalero Sands.

Petrocalcic horizon. A continuous, indurated calcic horizon (Bk) of a soil that is cemented by calcium carbonate; commonly known as caliche; the Mescalero paleosol has a petrocalcic horizon; the Ogallala caprock is a petrocalcic horizon.

Pleistocene. The earlier of two epochs of the Quaternary Period; extends from 1.65 million years to 10,000 years ago; only Paleoindian archaeology is found in sediments or soils of the Pleistocene Epoch; *late Pleistocene* includes the Sangamon Interglaciation and the Wisconsin Glaciation, 132,000 to 10,000 years ago (Richmond and Fullerton, 1986).

Quaternary. The most recent period of the geologic time scale, including the Pleistocene and Holocene epochs, extending from 1.65 million years ago to today.

Radiocarbon ages. Radiocarbon dating is the most mature method of age determination in geomorphology and archaeology. Organics and carbon-containing materials can be dated as old as about 40,000 years. However, radiocarbon years are not the same as calendar years; the amount of ^{14}C in the atmosphere has not been constant through time. By measuring the amount of ^{14}C in tree-rings and annually-deposited sediments of known calendar age, radiocarbon years can be calibrated to calendar years.

Sand sheet. A large plain of eolian sand that covers the landscape; may be composed of one or more sand units, each originating during different periods in the past; sand dunes may occur on the surface.

Sangamon Interglaciation. The period of time between the Illinoian and Wisconsin continental glaciations, an interval of warm climate, perhaps warmer than the Holocene; its age is about 132,000 to 122,000 years ago (oxygen isotope stage 5E) although some workers extend the Sangamonian to as recent as 80,000 years ago (stage 5A-E); the Mescalero paleosol is interpreted to have begun forming during Sangamon aridity.

Sediment. Sediment is a mass of gravel, sand, silt, and clay particles that have accumulated by deposition from running water, wind, or ice and that may include materials originating from chemical precipitation; generally occurring in layers on the Earth's surface in a loose, unconsolidated form.

Sedimentation. The act or process of forming or accumulating sediment; the process of sediment deposition.

Sedimentation analysis. Determination of the particle size, shape, roundness, sorting, color, mineralogy, cementation, sedimentary structures, and bedding of sediment.

Sedimentology. The study of sediments and sedimentary rocks and the processes by which they were formed.

Shin oak. A shrubby species of oak (*Quercus havardii*) occurring in sandy soils in western Oklahoma, west Texas and Texas panhandle, and southeastern New Mexico, forming one of the country's largest oak stands occupying 5 to 7 million acres; named for Valery Havard, an army physician, who described the sand hills country of the Pecos River area in the early 1880s; P. A. Rydberg (1901, *Bull. New York Botanical Garden* 2:187-233) described and named the new species for Valery Havard who collected specimens of it; also called shinnery; shin and shinnery are from Louisiana French for *chêne* and *chênière* which mean oak and oak woodland (from Peterson and Boyd, 1998).

Soil. The unconsolidated mineral or organic material on the immediate surface of the Earth that show the effects of weathering, climate, organisms, vegetation, topography, parent material, and time; serves as a natural medium for plant growth; soils are products of weathering that form on stable geomorphic surfaces.

Soil chronosequence. A group of related soils or paleosols in the same area that differ, one from the other, primarily as a result in differences in time as a soil-forming factor; the soil chronosequence from south-central New Mexico is a standard for evaluating calcic soils in the southwestern U.S. (Gile et al., 1966; Gile et al., 1986); because of various soil-forming factors, soil chronosequences provide relative ages, not absolute ages, of soils; furthermore, paleosol ages are always two different sets of numbers: (a) the duration of time it takes for a soil to form, and (b) the period of time in geologic history during which soil development occurred; in this study, for example, the Mescalero paleosol formed over a period of 30,000 years beginning about 130,000 years ago and ending 100,000 years ago.

Stone line. A sheet-like lag concentration of pebbles and gravels buried by surficial sediment; in cross-section, the stone line may appear either as a few scattered pebbles or as a discrete layer of pebbles; many stone lines represent buried erosional surfaces; a stone line containing small gravels and artifacts buried by fresh sediment may have the appearance of a prehistoric living floor.

Stone zone. A layer more than one stone thick; stone zones form in the subsurface by the selective accumulation of pebbles and gravels at the base of a zone of bioturbation (biomantle); the stone zone does not represent a lag concentration such as occurs with stone lines, rather it forms over time as stones accumulate at the base of the biomantle (Johnson, 1989, 1997, Fig. 149-150); a concentration of artifacts in a stone zone may give the false appearance of a level of prehistoric occupation.

Stratigraphy. The science of rock strata; the study of the succession, age, lithologic composition, fossil content, and all characters of rocks as strata and their interpretation in terms of environment of deposition and geologic history.

Wisconsin Glaciation. Refers to the time of the last major continental glaciation of North America and extends from about 80,000 to 15,000 years ago; subdivided into Early, Middle, and Late Wisconsin; the last glacial maximum occurred about 21,000 calendar years ago (or 18,000 ^{14}C years BP); named for glacial deposits in the state of Wisconsin.

FREQUENTLY ASKED QUESTIONS

Q Do we still have to survey for archaeological sites?

A Yes. Sites can occur anywhere on the sand sheet. Nearly all *in situ* sites, however, occur at the top of unit 2 sand and are mantled by the Loco Hills A horizon soil. The red sand (unit 2) is too old to have archaeology associated with it, although it may contain intrusive features. Early Archaic and Paleoindian sites may be associated with former springs and cienega drainages; these older sites may be buried by eolian sand.

Q In the coppice dunes, why are artifacts strewn over the red sand?

A The artifacts have been eroded from a site. The artifacts and pebbles that were too large to be carried away by wind were left behind as a lag. An *in situ* area of the site may still be preserved beneath the coppice dune, although it may be disturbed by bioturbation.

Q What is the red sand?

A The red sand is what is left of an old red paleosol that occurs on the older eolian sand (unit 1) that was deposited about 70,000 to 90,000 years ago. The red soil formed on the stable surface of unit 1 sand about 15,000 to 60,000 years ago.

Q Do sites occur in the red sand?

A No. Although artifacts may occur on the eroded surface of the red sand and features may intrude into the red sand, the red sand itself will not contain archaeology. Excavations of sites can safely stop when the unit 1 red sand is encountered, unless intrusive features are present.

Q What is the origin of all the little pieces of caliche that occur scattered around sites?

A They are either broken fragments of larger chunks of caliche used at the site or they are fragments of the underlying petrocalcic horizon of the Mescalero paleosol that have been brought to the surface by burrowing animals; sometimes both. When you see lots of little pieces of caliche on the surface, it most likely means that the sediments have been at least partly bioturbated and nearby sites must be viewed with this in mind. If you see scattered caliche pebbles in the profile of a site, it may mean the presence of a biomantle and that the sediments and artifacts have been churned up by bioturbated.

Q Why do hearths and features from young sites sometimes occur in the old red sand?

A The features are intrusive into the old red sand. At the margins of the sand sheet, especially around mesquite coppice dunes, the site-bearing unit 2 sand is fairly thin. Thus, some features that were dug into the ground by prehistoric occupants completely go through the habitation sand (unit 2) into older red sand (unit 1). When a site is partly disturbed by turbation, it may be hard to see this relationship clearly in the field.

Q Why are there more sites in areas of coppice dunes, such as Bear Grass Draw, compared with areas covered by shin oak?

A The answer may involve site visibility. Sites around coppice dunes have good visibility because of recent deflation. The areas with parabolic dunes are less eroded and sites are less well exposed.

PLATE EXPLANATIONS

Plate I

Fig. A. Late Pleistocene Bk petrocalcic horizon of the Mescalero paleosol on Triassic shale, east of Ishee Lake on the Eddy-Chaves Co. line; eolian sand is thin or absent; the calcic paleosol-supported surface is mapped by Kelley (1971) as "*Qd*, disturbed gravels" and, farther east, "*Qs*, caliche soil."

Fig. B. Unit 1 eolian sand with red Bt paleosol above eroded petrocalcic horizon of the Mescalero paleosol.

Fig. C. Unit 1 eolian sand with red Bt paleosol at top; thin deposit of Loco Hills A horizon soil occur above the red paleosol; mesquite coppice dune caps the sequence; OSL ages from this locality provides the geochronology of unit 1 eolian sand; unit 1 sand rests directly on eroded Mescalero paleosol petrocalcic horizon; Valley Gas Rd. sand quarry, loc. 1; 10-cm increment 1-meter scale.

Plate II

Fig. D. Unit 2 eolian sand with clay bands, loc. 8; the upper OSL sample was collected here; the lower OSL sample was collected at a lower position off the image; the weak, poorly visible Loco Hills soil occurs at the top of unit 2 sand; the Loco Hills A horizon soil at this section was radiocarbon dated "modern."

Fig. E. Loco Hills soil is the dark band at 10 cm below the top of the 1-meter scale; Old Loco Rd., loc. 3; organic matter from A horizon at this site is radiocarbon dated 370 $\pm$ 40 ^{14}C yr BP and modern; white material on floor of soil pit is Mescalero paleosol carbonates; above the Loco Hills soil is a low coppice dune; below paleosol is unit 1 red sand; here the Loco Hills soil formed on much older unit 1 sand.

Fig. F. Fig. 35. Erosion of coppice dunes exposing red sand (unit 1); unit 2 eolian sand and the Loco Hills soil occur above the red sand to the right of the dying mesquite; the absence of pebbles, caliche, and artifacts on the deflated surface indicate that this is not an archaeological site and that the sand units at this location are not recently turbated.

Plate III

Fig. G. Torrey mesquite coppice dune, Square Lake Rd. locality 13; red tags trace Loco Hills soil A horizon; yellow tags are position of sediment samples for radioactive-isotope analysis (Table 4); upper two samples shown here have cesium levels indicating that the upper 22 cm of the dune accumulated since 1954; 4 additional samples from the same zone also contain cesium-137; the radiocarbon age of charcoal in the Loco Hills soil just beneath the coppice dune is 150 $\pm$ 40 ^{14}C yrs B.P.; 10-cm increment 1-m scale.

Fig. H. Square Lake Rd. soil pit locality 10; unit 2 eolian sand overlying rare occurrence of Bt and Btk horizons of the late Pleistocene Mescalero paleosol.

Fig. I. Locality 12; late Holocene alluvial fill with dark brown A horizon paleosol radiocarbon age 330 $\pm$ 40 ^{14}C yrs BP; young paleosol overlain by alluvium and coppice dunes.

Plate IV

Fig. J. Square Lake Rd., locality 14; white zone at base of exposure is carbonate-encrusted sand of a spring deposit, the radiocarbon age of snail shells from the spring deposit is 18,900 $\pm$ 100 ^{14}C yrs BP (Table 3); eolian sand with a possible thin red Bt paleosol overlies the spring deposit; eolian sand overlies red paleosol; mesquite coppice dune at top of section; the sediments may have a fluvial component and may not correlate with upland sand sheet deposits.

Fig. K. Late Pleistocene cienega deposits; exposed along Caprock Rd., loc. 11; mesquite coppice dune on top of eroded cienega sands; fossil snails from this outcrop are listed in Table 7; 1-meter scale.

Fig. L. Spring deposits exposed in arroyo west of Caprock Rd. locality 11; these deposits contain land and freshwater snails, pill clams, and bone fragments of mammals; late Holocene alluvium exposed on left bank.

Plate V

Fig. M. Small area of active dunes, locality 7; deflated unit 2 sand; pillar of sand right of center shows red clay bands; in the distance is the Caprock escarpment of the Ogallala Formation.

Fig. N. Erosional pedestals in area of parabolic dunes; the margins of parabolic dunes are protected by shin oaks and, upon deflation, portions of dune margins are left behind as mounds that mimic coppice dunes.

Fig. O. Shinnery parabolic dunes and concave deflation basins or blowouts; finding *in situ* archaeological sites here would be difficult because of the dense vegetation and recent sand around the margins of the dunes; finding deflated sites would be difficult because of the constant refilling of the blowouts with recent sand.

Fig. P. Burrow fills, probably cicada insects, in lower unit 2 sand, loc. 8; burrow fills are visible in micro-relief on this vertical face due to differential hardness of the individual burrows and surrounding sand; in this example, burrows overlap and turbate other burrows; upon excavation of a clean surface, the visibility of the burrow fills is lost; penny for scale.

Plate VI

Fig. Q. Deflated archaeological site in the Mescalero Sands; artifacts are no longer *in situ*, the sediment matrix that held the site together is gone and the artifacts and associated materials have been lowered onto the erosion surface.

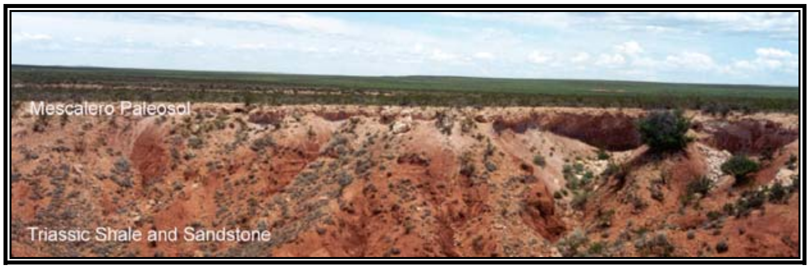
Fig. R. Deflated archaeological site; gray stones are fire-altered caliche; white material is weathered Bk horizon or caliche of the Mescalero paleosol; red sand (unit 1 Bt paleosol) occurs above the caliche; unit 2 sand that contained the archaeological site has been removed by deflation; a portion of the original site may be preserved beneath the mesquite coppice dune.

Fig. S. Caliche-lined hearth is intrusive into older red sand (unit 1); original prehistoric surface of the site has been removed by erosion, and artifacts and caliche pebbles have been lowered onto the erosion surface; loose, recent wind-deposited sand fills the depression of the prehistoric hearth; if this feature and associated artifacts and pebbles on the eroded surface were to be buried by fresh sand, the buried surface would be a stone line and have the appearance of a prehistoric living floor.

Fig. T. Area of quasi-stable sand sheet south of the study area east of Carlsbad; small, low parabolic dunes in fore- and middle-ground with higher dunes in background; shin oaks, grasses, yucca, sand sage, absence of mesquite; ca. 80% ground cover; absence of A horizon soil; except for the fences and utility lines, this may be what the Mescalero Sands looked like during the late Holocene, 5000 to 500 years ago, when the sand sheet was inhabited by prehistoric people.

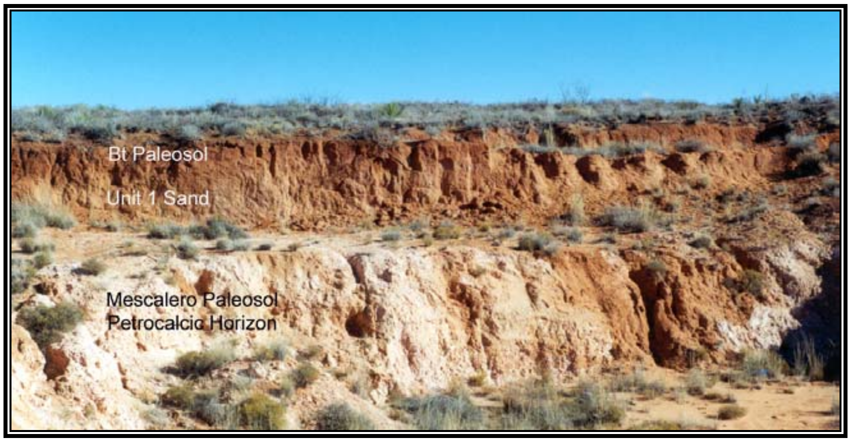
Plate I

A



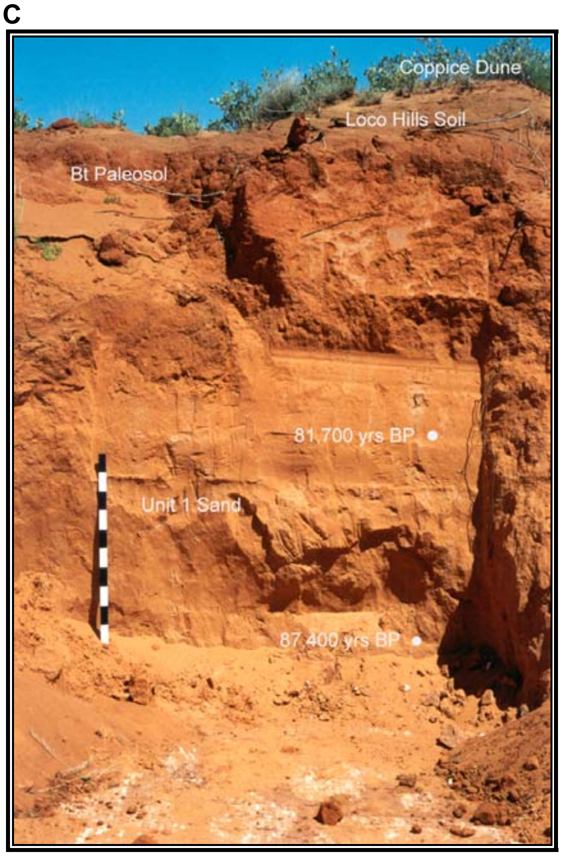
Mescalero Paleosol
Triassic Shale and Sandstone

B



Bt Paleosol
Unit 1 Sand
Mescalero Paleosol
Petrocalcic Horizon

C



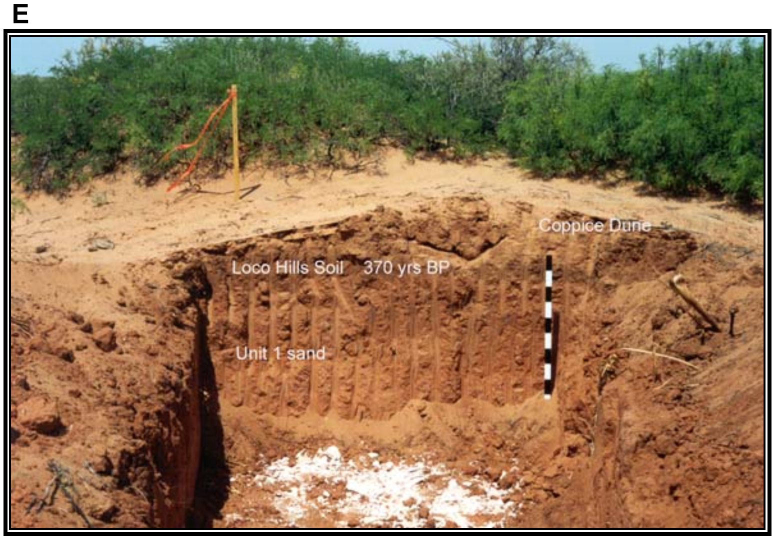
Coppice Dune
Loco Hills Soil
Bt Paleosol
81,700 yrs BP
Unit 1 Sand
87,400 yrs BP

Plate II

D


Parabolic Dune
Loco Hills Soil
6300 yrs BP
Unit 2 Sand
Clay Bands

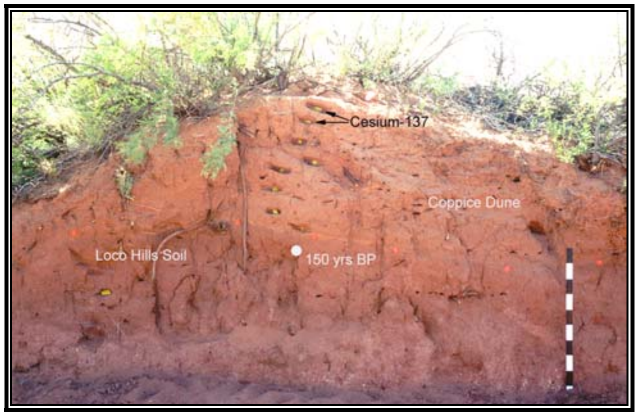
E


Coppice Dune
Loco Hills Soil
370 yrs BP
Unit 1 sand

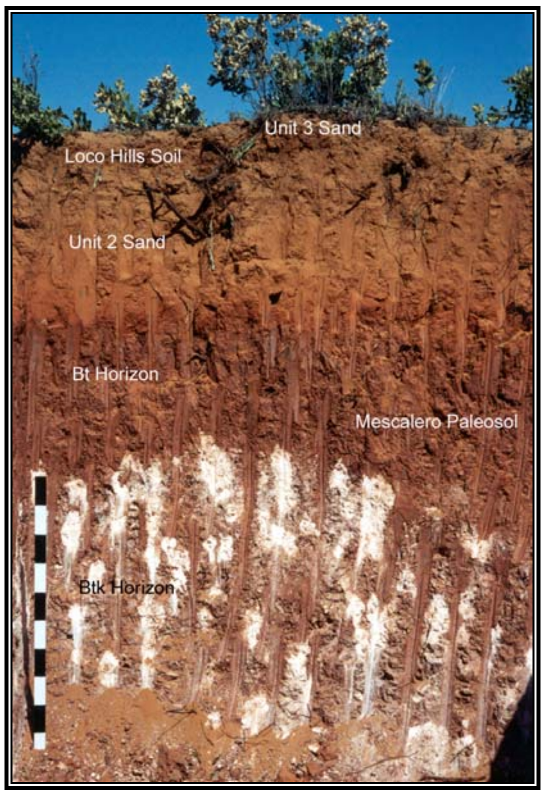
F

Plate III

G



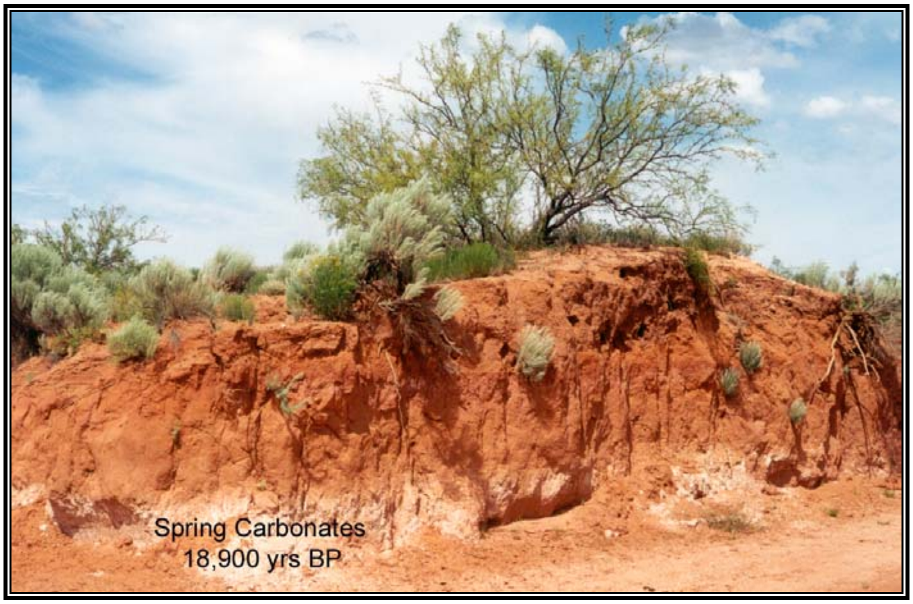
H



I

Plate IV

J



K

L

Plate V

M

N

O

P

Plate VI

Q

R

S

T