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New Mexico Geology, v. 30, n. 2 pp. 39-49, Print ISSN: 0196-948X, Online ISSN: 2837-6420.

<https://doi.org/10.58799/NMG-v30n2.39>

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Abstract

Upper Pleistocene and Holocene eolian sand mantles the topography in the northwestern Albuquerque Basin. A series of 12 OSL ages from surficial deposits along the Paseo del Volcan corridor, Rio Rancho, Sandoval County, indicates that the main body of eolian sand was deposited with a thickness of 0.5–1.4 m during the period from 16 to 10 ka. A red calcic paleosol with stage I carbonate morphology formed in the sand during the Holocene. The OSL-dated sand has a net sedimentation rate of 0.026 cm per year. Eight archaeological sites with features that intrude into the upper Pleistocene eolian sand are radiocarbon dated 4,600–580 ¹⁴C yrs B.P. The surface of the sand and its paleosol are truncated by sheet erosion. The top portions of features at the archaeological sites as well as most artifacts have been removed by erosion. Underlying the upper Pleistocene sand is an eroded eolian silty sand with a pink calcic paleosol with stage II carbonate morphology and an OSL estimated age ~130 ka. The eolian sand covers an alluvial/colluvial gravelly sand containing a paleosol with stage III carbonate morphology that may be Miocene. The OSL-dated eolian cover sand along the Paseo del Volcan corridor has few equivalents in the region.

Introduction

Construction of a new roadway, Paseo del Volcan, in Rio Rancho, Sandoval County, called for the assessment of eight archaeological sites along the right of way for a distance of 3.4 mi (5.4 km) paralleling the unpaved 28th Avenue NE east of Unser Boulevard. The excavations and associated archaeological geologic work were completed in 2005, and Paseo del Volcan was constructed in 2006. The study area in the northwestern Albuquerque Basin is characterized by treeless sagebrush grassland with a thin cover of historic eolian sand that masks surficial as well as older geologic deposits, making it difficult to conduct thorough archaeological surveys or to determine the nature of the surficial geology (Fig. 1). Accordingly, the local archaeological sites and surficial deposits were exposed and studied in a series of 28 backhoe trenches along the Paseo del Volcan right-of-way corridor. The geochronology of the eolian deposits and associated paleosols observed in the exposures was determined by 12 optically stimulated luminescence (OSL) dates. The study area is covered by three recently available geo-

logic maps (Personius et al. 2000; Connell 2006; Williams and Cole 2007).

At this time, only a handful of upper Quaternary deposits in New Mexico have been dated by luminescence. Investigations in the Albuquerque Basin include the OSL dating of sediments associated with Paleoindian archaeology (Holliday et al. 2006) and of terrace alluvium along the Rio Grande (Cole et al. 2007). Sediments associated with fault zones and Quaternary earthquake activity have been dated by thermoluminescence (TL) and infrared-stimulated luminescence (IRSL) (Personius and Mahan 2000, 2003; McCalpin et al. 2006). In the Jemez Mountains, OSL dating has been applied to lacustrine and volcanic deposits (Lepper et al. 2007; Lepper and Goff 2007). On the southern High Plains, pilot OSL studies of sediment from known archaeological sites have proved useful (Rich and Stokes 2001; Rich et al. 1999; Feathers 2003; Feathers et al. 2006). In south-central and southeastern New Mexico, OSL dating has provided new ages of eolian sand sheets and dune fields (Hall 2002; Hall and Goble 2006; Hall 2007; Kocurek et al. 2007). OSL is a comparatively new technique developed in the mid-1980s and is providing reliable ages of Quaternary sedimentary deposits that cannot be dated by radiocarbon or other methods.

Optically stimulated luminescence (OSL) geochronology

Overview of OSL dating

Optical dating is a method for determining the time of last exposure of a sediment to light (Aitken 1998). It is most generally used to determine the burial age of sediments but can also be used to determine the firing age of artifacts. The method provides a measurement of the number of charge carriers trapped at defects within a crystal structure. These charge carriers are produced by ionizing radiation from the decay of radioactive isotopes (U, Th, K, Rb) in rocks and sediments, as well as cosmic rays. The number of charge carriers is a function of the concentration of radioactive isotopes, flux of cosmic rays, and time. The time-dependent absorbed radiation dose due to the first two factors (dose rate) can be calculated. The charge carriers can be released by energy input in the form of light, heat, or pressure. Some recombine within the crystal lattice to produce light of a different wavelength (luminescence). Release triggered by light is referred to as optically stimulated luminescence (OSL), by heat as thermoluminescence (TL), and by pressure as triboluminescence.

In nature the natural OSL signal is zeroed by a few seconds exposure to light. In the



FIGURE 1—Sagebrush grassland and loose historic eolian sand cover, Paseo del Volcan right of way along unpaved 28th Avenue NE east of Unser Boulevard, Rio Rancho, Sandoval County; Sandia Mountains in background, photo September 2005; inset, Paseo del Volcan, photo September 2007.

TABLE 1—OSL analyses and ages of eolian sand deposits along Paseo del Volcan, Rio Rancho, Sandoval County, New Mexico.

UNL sample number	Field number	Burial depth (m)	H ₂ O (%)*	K ₂ O (%)	U (ppm)	Th (ppm)	Cosmic (Gy)
Locality 100, units 2 and 3							
UNL-1289	Volcan-5	0.27	1.84	2.19	1.1	4.8	0.28
UNL-1288	Volcan-4	0.47	0.81	2.07	1.0	4.4	0.27
UNL-1287	Volcan-3	0.67	0.91	2.31	1.1	4.9	0.27
UNL-1286	Volcan-2	0.92	1.07	2.26	1.2	5.3	0.26
UNL-1292	Volcan-8	1.25	7.18	2.36	1.6	7.8	0.24
UNL-1285	Volcan-1	2.34	5.25	2.45	1.4	5.7	0.21
Locality 200, unit 3							
UNL-1293	Volcan-9	0.29	1.62	2.19	1.2	5.8	0.28
UNL-1291	Volcan-7	0.73	1.11	2.19	1.2	4.8	0.26
UNL-1290	Volcan-6	1.13	1.55	2.20	1.2	5.0	0.25
Locality 300, soil pipe fill							
UNL-1294	Volcan-10	1.54	3.07	2.26	1.5	6.4	0.24
Locality 400, units 3 and 4 at archaeological site							
UNL-1296	Volcan-12	0.16	1.44	2.23	1.2	6.2	0.28
UNL-1295	Volcan-11	0.67	1.44	2.24	1.2	5.2	0.27

UNL number (cont.)	Dose rate (Gy/ka)	D _e (Gy)†	Recuperation (%)	Number of aliquots	Age (ka)§
Locality 100, units 2 and 3					
UNL-1289	2.64 ± 0.10	30.87 ± 1.00	1.4	21	11.7 ± 0.7
UNL-1288	2.52 ± 0.09	31.85 ± 1.20	1.6	22	12.7 ± 0.7
UNL-1287	2.76 ± 0.10	36.07 ± 1.03	1.2	22	13.1 ± 0.8
UNL-1286	2.76 ± 0.10	35.19 ± 0.96	1.5	21	12.7 ± 0.7
UNL-1292	3.06 ± 0.12	44.94 ± 1.48	1.0	26	14.7 ± 0.8
UNL-1285	2.83 ± 0.11	~363 ± 80	~1	2	~130 ± 30
Locality 200, unit 3					
UNL-1293	2.74 ± 0.10	30.75 ± 1.52	1.2	20	11.2 ± 0.8
UNL-1291	2.67 ± 0.10	37.09 ± 1.08	1.4	21	13.9 ± 0.8
UNL-1290	2.67 ± 0.10	34.97 ± 0.84	1.0	20	13.1 ± 0.7
Locality 300, soil pipe fill					
UNL-1294	2.82 ± 0.11	55.74 ± 3.66	1.8	21	19.8 ± 1.6
Locality 400, units 3 and 4 at archaeological site					
UNL-1296	2.81 ± 0.11	3.78 ± 0.30	3.3	21	1.34 ± 0.12
UNL-1295	2.73 ± 0.10	41.95 ± 1.94	0.9	21	15.4 ± 1.0

Samples collected by S. A. Hall in August–September 2005; OSL analysis completed in 2006 by R. J. Goble

* In situ moisture content

† Error on D_e is 1 standard error; Gray (Gy), equivalent dose (D_e)

§ One-sigma error on age includes random and systematic errors calculated in quadrature; ages to three significant figures

laboratory, it is stimulated by exposure to light generated by blue, green, or infrared diodes, or other comparable light source. The stimulating light wavelengths are filtered out, and the intensity of the shorter wavelength stimulated signal measured. Signals with intensities bracketing the nat-

ural signal are then reproduced using a calibrated radioactive source, a growth curve having the form of a saturating exponential constructed, and the intensity converted into a radioactive dose equivalent to that received in nature, the equivalent dose (D_e). Dividing the equivalent dose by the natural

dose rate yields the time since the sample was last exposed to light, the burial age. In most modern OSL dating the single aliquot regenerative dose (SAR) method (Murray and Wintle 2000) is used to produce an age from individual small aliquots of a sample. Multiple measurements are statistically combined to produce the final age.

OSL dating can potentially be applied to sediments from a few years to several hundred thousand years in age, but the exact limits are a function of the responsiveness of the sample, the saturation level of the defects at which the charge carriers are trapped, the natural radiation flux, and the degree to which the sample was fully exposed to light. Samples for which the natural intensity lies near saturation on the growth curve (Wintle and Murray 2006) are not datable, and samples for which the signal has not been fully zeroed by light (partial bleaching) must be evaluated using specialized statistical techniques to determine a minimum age for light exposure.

Sampling method

OSL samples were collected with round metal containers 11 cm long and 8.5 cm diameter that were driven horizontally into fresh exposures. The metal containers were closed at one end; upon sample collection the open end of the sediment container was sealed with duct tape. Samples for moisture-content analysis were collected in sealable plastic jars, the lid seals reinforced with plumbers tape, and samples for chemical analysis were collected in pre-sealed plastic bags. The depth of each sample is measured to the center point of the sample in the metal container. If a root or large pebble or burrow fill was encountered during sampling, the material was discarded and a new sample was taken at another spot.

Sample preparation/dose-rate determination

Sample preparations were carried out under amber-light conditions. Samples were wet sieved to extract the 90–150 μm fraction and then treated with 1 N hydrochloric (HCl) acid solution to remove carbonates. Quartz and feldspar grains were extracted by flotation using a 2.7 gm cm⁻³ sodium polytungstate solution, then treated for 75 min in 48% hydrofluoric (HF) acid, followed by 30 min in 47% HCl. The sample was then re-sieved, and the <90 μm fraction discarded to remove residual feldspar grains. The etched quartz grains were mounted on the innermost 2 mm of 1 cm aluminum disks using Silkospray.

Chemical analyses were carried out by Chemex Labs, Inc., Sparks, Nevada, using a combination of ICP-MS and ICP-AES. Dose rates were calculated using the method of Aitken (1998) and Adamiec and Aitken (1998). The cosmic contribution to the dose rate was determined using the techniques of Prescott and Hutton (1994).

Optical measurements

Optically stimulated luminescence measurements were carried out on a Riso Automated OSL Dating System Model TL/OSL-DA-15B/C, equipped with blue and infrared diodes, using the single aliquot regenerative dose (SAR) technique (Murray and Wintle 2000). Samples were subjected to a preheat treatment of 220°C for 10 sec, with a cutheat of 160°C, based upon a preheat plateau test between 180° and 280°C on UNL-1292. A dose-recovery test (Murray and Wintle 2003) on UNL-1292 recovered 40.45 ± 0.59 Gy from an applied dose of 39.52 Gy. Thermal transfer for the same sample was 0.14 ± 0.01 Gy. Examination of the growth curves and D/Do values (Wintle and Murray 2006) for the samples showed most of the samples to be well below saturation. Optical ages are based upon a minimum of 20 aliquots. Individual aliquots were monitored for insufficient count rate, poor quality fits (i.e., large error in the equivalent dose, D_e), poor recycling ratio, strong medium versus fast component, and detectable feldspar. Aliquots deemed unacceptable based upon these criteria were discarded from the data set before averaging.

Results

Optical ages range from 19.8 ± 1.6 to 1.34 ± 0.12 ka with 1-sigma errors (Table 1). The samples appear well suited for optical dating, with dose recovery within 2-sigma error and low thermal transfer (<0.2 Gy) and recuperation. There is no indication of partial bleaching. An exception is UNL-1285, which is close to saturation on the growth curve ($D/Do = 3.3$, Wintle and Murray 2006) and unsuitable for optical dating for that reason. The age quoted for this sample ($\sim 130 \pm 30$ ka) should be regarded as an estimate only.

Stratigraphy

The eolian sand deposits exposed in the 28 trenches along Paseo del Volcan corridor are differentiated on the basis of bounding discontinuities into four informal units, following the guidelines in the North American Stratigraphic Code (North

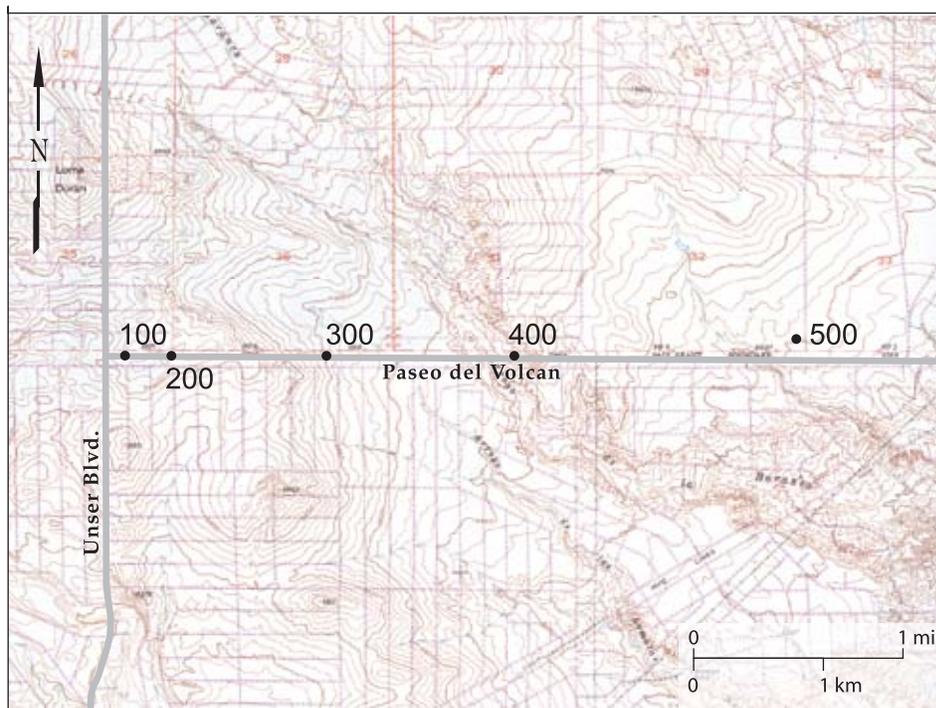


FIGURE 2—Topographic map showing OSL-dated localities along Paseo del Volcan right of way; study localities, except 500, are presently beneath the paved roadway; from Loma Machete 7.5-min quadrangle, Sandoval County, New Mexico.

American Commission on Stratigraphic Nomenclature 2005). Sedimentary properties and structures are described from Folk (1968), and sediment and paleosol colors are determined from Munsell soil color charts (Munsell 1975). The general description, horizon designations, and stage of carbonate morphology of the paleosols follow Keys to Soil Taxonomy (Soil Survey Staff 1994) and Birkeland (1999). The location of the trenches and OSL-dated sites are shown in Figures 2 and 3. The four units and their geochronology and contained paleosols are described below, from stratigraphically oldest to youngest.

Unit 1, Miocene basin fill

Older, pre-Quaternary sediments are exposed in trenches at localities 300 and 500 and are referred to as unit 1 in this investigation (Fig. 4). The sediment is coarse to fine quartz sand with many small unsorted rounded pebbles. Unit 1 is dominated by

an 80–100-cm-thick, well-developed calcic paleosol with stage III carbonate morphology. Small pebbles are common throughout the calcic horizon and indicate that the sediment in which the paleosol developed may be colluvium. The colluvium likely represents weathered sedimentary units of the underlying basin fill of the Santa Fe Group.

The upper part of the paleosol is missing due to erosion, and only a rare remnant of a Bt horizon is present. The upper 25 cm of the calcic horizon is characterized by weak laminar structure. Nodule-like structures are carbonate-lined casts of cicada insect burrows. The degree of cementation is weak to strong. Carbonate filaments are generally absent, although the occasional one is present along the horizontal planes of the laminar structures when cracked open. The base of the thick calcic horizon is not well exposed in the trenches, leaving uncertain the nature of the sediments in which the soil formed in this area. The

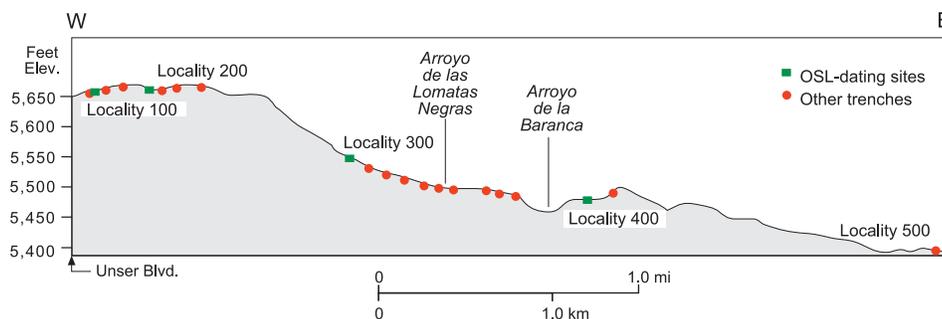


FIGURE 3—Topographic profile with study localities along 3.4 mi on the right-of-way centerline of Paseo del Volcan, Rio Rancho, Sandoval County; from Loma Machete 7.5-min quadrangle.

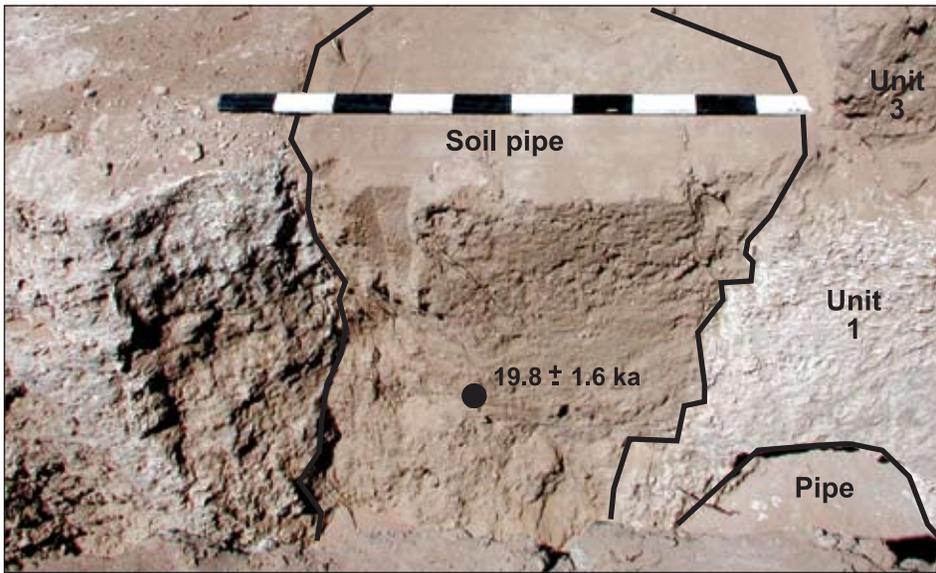
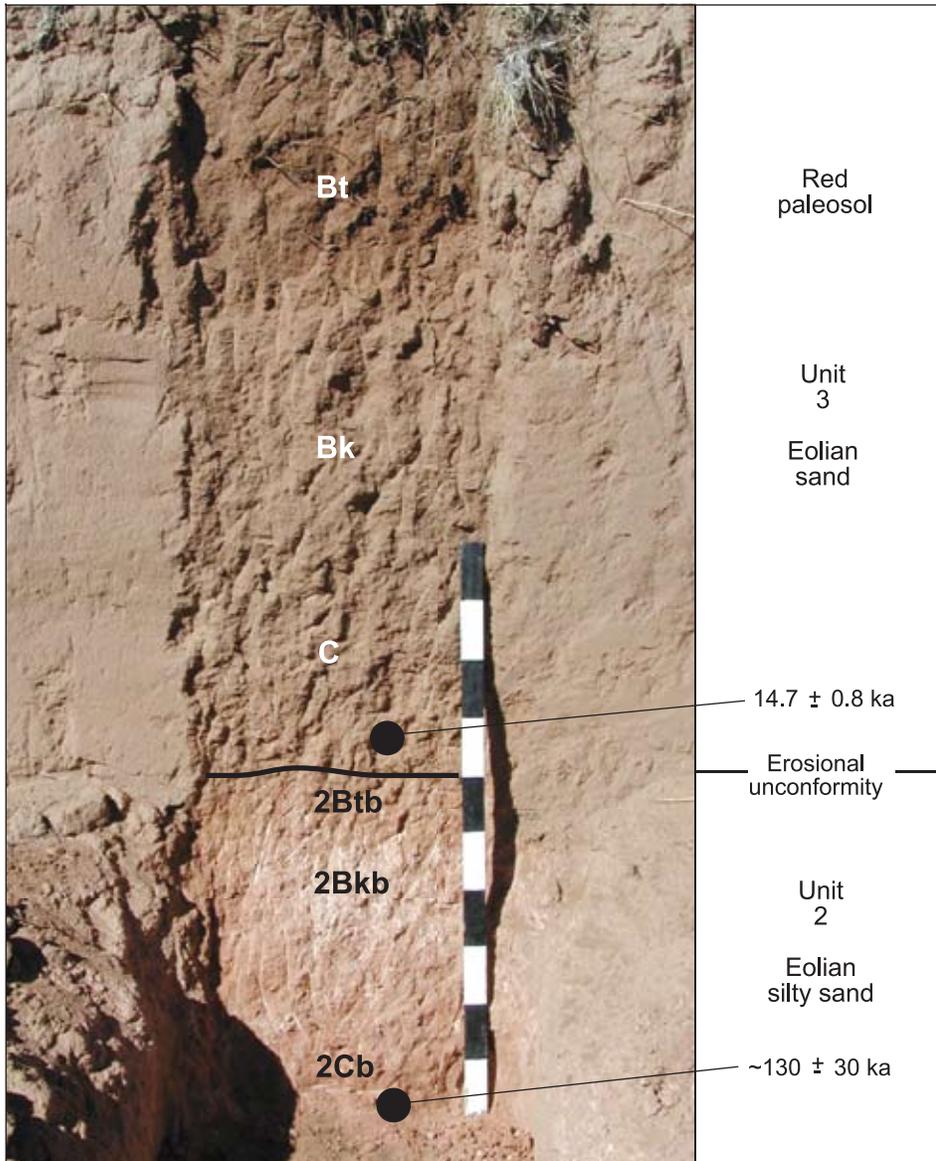


FIGURE 4—Solution soil pipes in unit 1 Miocene basin-fill deposits with calcic paleosol with stage III carbonate morphology, locality 300. Unit 3 eolian sand overlies unit 1 and has been partly removed, exposing the circular pipe at the top of the calcic horizon. OSL date (UNL-1294) indicates glacial-age filling of this soil pipe.



calcic paleosol, especially at locality 300 (S. D. Connell, pers. comm. 2005), matches the soil morphology and topographic position of the Rincones surface in the northwestern Albuquerque Basin placing it stratigraphically below and older than the Llano de Albuquerque surface (ca. 2.0–2.5 Ma); the Rincones surface is Miocene and is buried by Pliocene deposits of the Ceja Formation (Connell and Smith 2005; Connell 2006).

Soil pipes in stage III calcic horizon

Soil pipes are present in the stage III calcic paleosol at localities 300 and 500 (Fig. 4). Pipes are only in the stage III paleosol, not in the younger stage II paleosol, probably due to the greater degree of cementation and hardness of the stage III carbonates compared with the stage II paleosol. The pipes observed in this study are clearly solution features that are secondary to calcic paleosol development. The material that fills the pipes is loose, brown, pebbly, unsorted sand. The pebbles are rounded, carbonate-coated quartz and feldspar; small pebbles of caliche from the paleosol also are present in the fill. The pipes are common in the stage III paleosols but could be of different ages, representing multiple discrete periods of development. A single OSL age from the fill of a larger pipe at locality 300 is 19.8 ± 1.6 ka (UNL-1294), indicating solution and filling during the last glacial maximum of the Late Wisconsinan (Fig. 4). The pipe fill is ~4 k.y. older than the earliest OSL age of the overlying unit 3 eolian sand. The origin of the pipe fill sand and the overlying unit 3 eolian sand do not appear to be directly related.

Unit 2, middle(?) Pleistocene silty sand

Erosional remnants of the unit 2 eolian silty sand are exposed at the base of some trenches at most localities, although natural outcrops of the unit are not present and have not been identified in the area. Where exposed in trenches, the sediment is well-sorted, very fine quartz sand with a silt content ranging from 7 to 40% and averaging 25% (Table 2). Pebbles are absent in the eolian sand. The OSL age of the silty sand at one locality is ca. 130 ± 30 ka (UNL-1285), although the sample was close to saturation, and the age should be regarded as a minimum estimate only (Fig. 5).

Associated with the silty sand is a calcic paleosol with stage II carbonate morphology. The calcic horizon is approximately 60–80 cm thick with 5–23% carbonate. Car-

FIGURE 5—Locality 100 (north) with unit 2 eolian silty sand overlain by unit 3 eolian sand; two OSL-dated horizons. This locality is in a small depression, and the calcic horizon of the red paleosol is less well developed although the darker colored Bt horizon is present and can be traced directly to the south end of the trench where four OSL dates were obtained (Fig. 6). The “b” designation represents buried soil horizons.

TABLE 2—Sediment data from eolian deposits and paleosols at Paseo del Volcan, Rio Rancho, Sandoval County, New Mexico. Samples are in centimeters depth; numbers are percentages; textural terminology by Wentworth scale; “—” = not measured; OC = % organic carbon determined by Walkley-Black method; % carbonate content determined by chittick method. Analysis by Milwaukee Soil Laboratory, 6917 W. Oklahoma Ave., Milwaukee, Wisconsin 53219.

Sample	Sand (mm)					Recalculated					
	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 <3.9 µm	OC (%)	CaCO ₃ (%)	Fe-oxalate (%)
Locality 100, south end of trench, UNL-1286, 1287, 1288, and 1289 (Fig. 6)											
Unit 3, Bt											
0–10 cm	0.8	8.7	33.2	40.4	16.9	77	10	13	0.29	1.9	0.02
10–20	0.8	9.3	32.4	40.5	17.0	81	8	11	0.20	1.4	0.02
20–30	1.1	9.9	32.9	40.3	15.8	84	7	9	0.17	1.2	0.02
Unit 3, Btk											
30–40	1.0	10.3	33.0	39.9	15.8	86	6	8	0.11	2.0	0.01
40–50	1.1	9.0	32.7	41.1	16.1	88	5	7	0.07	2.0	—
50–60	1.0	6.8	29.4	43.0	19.8	89	4	7	0.04	1.6	—
Unit 3, C											
60–70	0.6	5.8	28.5	44.5	20.6	92	5	3	0.02	1.3	—
70–80	0.2	5.2	28.6	44.5	21.5	92	5	3	0.02	1.0	—
80–90	0.3	5.2	28.1	41.9	24.5	89	7	4	0.03	1.6	—
Unit 2, 2Bkb											
90–100	0.8	8.1	21.3	29.5	40.3	61	29	10	0.08	5.5	—
100–110	0.3	7.1	21.2	30.3	41.1	59	30	11	0.09	5.6	—
Locality 100, deep cut at north end of trench, UNL-1285 and 1292 (Fig. 5)											
Unit 2, 2Btb											
130–140 cm	1.8	7.8	20.9	36.8	32.7	73	12	15	0.11	2.4	0.02
Unit 2, 2Bkb											
170–180	1.3	6.2	16.1	33.8	42.6	47	31	22	0.10	23.2	—
Unit 2, 2Cb											
230–240	1.2	11.9	17.2	36.1	33.6	89	7	4	0.01	3.0	—
Locality 200, UNL-1290, 1291, and 1293 (Figs. 7, 11)											
Unit 3, Bt											
0–10 cm	1.6	12.3	28.7	36.6	20.8	74	12	14	0.32	2.5	0.02
10–20	2.1	13.4	27.5	36.5	20.5	78	9	13	0.23	1.8	0.02
20–30	1.7	13.2	26.7	36.0	22.4	81	8	11	0.21	2.0	0.02
Unit 3, Btk											
30–40	1.6	13.3	24.8	34.3	26.0	80	11	9	0.14	4.4	0.01
40–50	3.2	18.8	24.7	28.6	24.7	80	10	10	0.10	6.7	0.01
50–60	8.4	32.5	24.8	18.9	15.4	83	8	9	0.06	5.4	—
Unit 3, C											
60–70	11.6	40.0	25.0	14.9	8.5	90	5	5	0.03	2.8	—
70–80	4.6	30.2	27.2	25.1	12.9	91	5	4	0.02	2.3	—
80–90	2.5	25.2	31.4	27.1	13.8	91	6	3	0.01	2.2	—
90–100	2.3	21.3	32.9	29.5	14.0	91	5	4	0.01	1.9	—
100–110	1.5	19.0	32.4	31.2	15.9	89	8	3	0.02	2.3	—
110–120	1.0	11.9	28.7	36.7	21.7	85	12	3	0.03	2.6	—
Locality 400, UNL-1295 and 1296 (Fig. 9)											
Unit 4, Bw											
15–25 cm	0.1	3.1	25.0	42.8	29.0	85	9	6	0.14	2.6	—
Unit 3, Bk											
40–50	0.1	2.0	25.4	45.6	26.9	77	17	6	0.15	4.6	—
Unit 3, C											
60–70	0.1	2.9	31.6	47.9	17.5	88	8	4	0.06	3.4	—
Unit 2, 2Bkb											
100–110	0.3	0.7	4.7	26.0	68.3	56	40	4	0.09	5.2	—

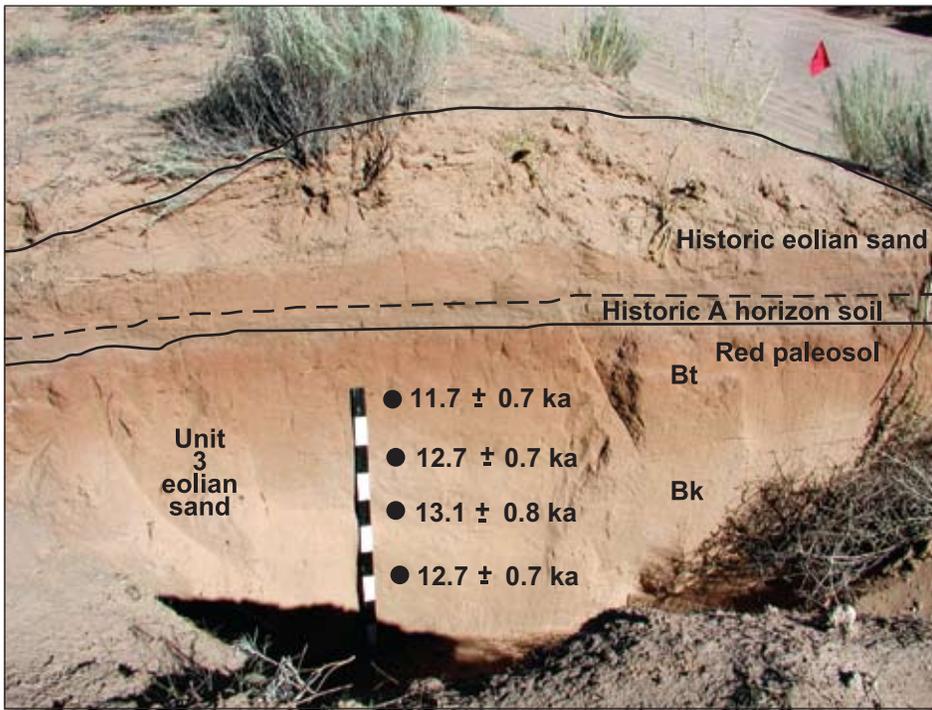
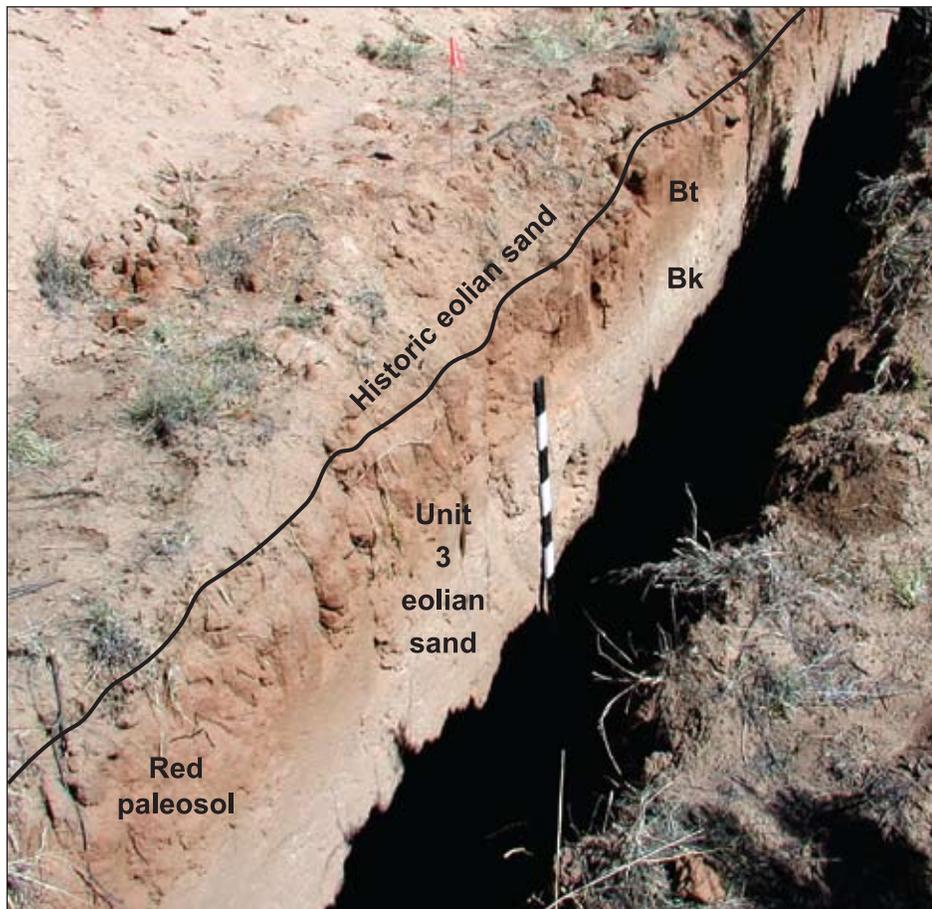


FIGURE 6—Locality 100 (south) with unit 3 eolian sand and red paleosol and four OSL-dated horizons (Table 1); the berm of sand above unit 3 preserves the historic A horizon soil. The berm is formed by sand that has accumulated since the 1970s along the edge of the bladed 28th Avenue NE visible in the upper right. The lower part of the berm is composed of sand deflated from the red paleosol Bt horizon; overlying that is sand deflated from the paleosol Bk horizon. The berm extends only a few meters from the roadway. Beyond the berm, the historic A horizon soil is missing due to erosion.



bonates are commonly pod-like casts of cicada insect burrow fills approximately 10–15 mm diameter in which carbonates line burrow fills and break out as elongated masses, similar to the carbonate-cemented cicada burrow casts in the well-developed calcic paleosol in unit 1. The degree of cementation is weak, and carbonate nodules are absent. The upper 10–15 cm of the calcic horizon is weathered and has less carbonate and rare weak carbonate filaments. The sediment matrix is pink (7.5YR 7/4) fine silty sand. The A horizon and red B horizons (Bw or Bt) are largely absent due to erosion before 16 ka, the earliest age of the overlying unit 3 eolian sand.

The sediment above the calcic horizon is very fine, silty, yellowish-red sand (5YR 5/6) that may represent the lower part of the paleosol Bt horizon. It is massive without bedding and is noncalcareous except for rare carbonate filaments. The sediment below the stage II calcic horizon is strong brown, fine to very fine quartz sand (7.5YR 5/6). It is massive without bedding and is largely noncalcareous.

Unit 3, upper Pleistocene sand

The surficial geology of the area is dominated by the unit 3 eolian sand that accumulated during the period ca. 16 to 10 ka as determined by OSL dating (Figs. 6 and 7). The sand is light brown (7.5YR 6/4) and composed of fine to medium, subrounded to rounded quartz grains. The thickness of unit 3 ranges from 52 to 139 cm and averages 96 cm based on 22 measured sections exposed in trenches. The sand is massive, lacking any bedding, but has been bioturbated by cicada insects that produced burrow fills approximately 12 mm in diameter; the influence of cicada bioturbation on OSL ages is discussed below. The unit 3 eolian sand rests directly on the eroded surface of the middle(?) Pleistocene unit 2 eolian sand at most localities. Unit 3 sand also directly overlies unit 1 deposits and calcic paleosols with stage III carbonate morphology at localities 300 and 500. The undulation of the present-day topography in the study area follows the trench exposures of the unit 3 sand.

The most notable aspect of the unit 3 eolian sand is a red calcic paleosol at the top of the unit and at the present-day surface except where covered by loose sand. The paleosol has a yellowish-red (5YR 4/6) Bt horizon, 9–14% clay, with a whitened Btk/Bk calcic horizon, 2–7% carbonate, that exhibits stage I carbonate morphology (Birkeland 1999). The red color is clay and iron coats on quartz sand grains. The whitened color is due to

FIGURE 7—Locality 200, unit 3 eolian sand with red paleosol and whitened calcic horizon with stage I carbonate morphology. Sediment samples and three OSL samples were collected to the right of the 1-m scale (Fig. 11). The historic A horizon soil is missing due to erosion. The historic loose eolian sand at this locality is 6 cm thick.

carbonate coats on sand grains; carbonate filaments are rare or absent. The paleosol appears structureless in trench exposures. However, in areas where the loose historic eolian sand had been removed by a grader, exposing the top of the paleosol, wind-sand abrasion of the paleosol surface shows the presence of weak ped structures 10–14 cm across (Fig. 8).

The red paleosol probably formed throughout most of the Holocene. The paleosol was sampled at 10-cm intervals at locality 200 where three OSL ages were obtained (Table 1). The paleosol exhibits a clay bulge in the upper 60 cm depth that is truncated at the top surface by erosion. The paleosol also has a carbonate bulge from 30 to 60 cm depth where the amount of carbonate is twice that of the sediment above and below. Percentages of organic carbon and Fe-oxalates increase upward in the soil profile, a result of horizonization (Table 2).

Unit 4, upper Holocene sand

Unit 4 is a thin layer of eolian sand at locality 400 that overlies the older unit 3 on a bench above Arroyo de la Baranca, a small ephemeral wash. The sand is yellowish-brown (10YR 5/6), fine to very fine, massive quartz. Isolated pebbles are rare, and there are no visible carbonates. Cicada insect burrow fills 11–12 mm in diameter are numerous. Rodent burrow fills 4 cm in diameter are also present. Where exposed in trenches, the sand is less than 40 cm thick. The upper half of the sand is slightly darker in color and may represent a weak Bw soil horizon. The middle of the unit 4 sand is OSL-dated 1.34 ± 0.12 ka (UNL-1296); it is the only case of upper Holocene eolian sand encountered in the Paseo del Volcan investigation. The Holocene sand buries an archaeological site on the eroded surface of the unit 3 sand and is radiocarbon dated $2,580 \pm 40$ ^{14}C yrs B.P. (Fig. 9). It is estimated that the unit 4 sand was deposited during the period that post-dates the prehistoric occupation of the site to a time after the OSL age from the middle of the unit, approximately from 2.5 to 1.0 ka.

Historic eolian sand

The topography in the study area is characterized by a thin mantle of loose eolian sand generally 4–18 cm thick that, where present, obscures the underlying surficial geology as well as artifacts and features of archaeological sites (Fig. 7). It is strong brown in color (7.5YR 5/6) and is composed of quartz with minor amounts of feldspar, muscovite, and grains of calcium carbonate, probably caliche. The texture is very coarse to very fine and poorly sorted. The loose sand is likely derived by historic deflation of nearby washes where sand supply is abundant. Low berms of eolian sand are found along the edges of bladed roads in Rio Rancho, such as along 28th Avenue NE in the project area. The road system was



FIGURE 8—Weak ped structure of the red paleosol in unit 3 eolian sand; peds approximately 10–14 cm across; scrapped area between locality 100 and 200; 1-m scale.

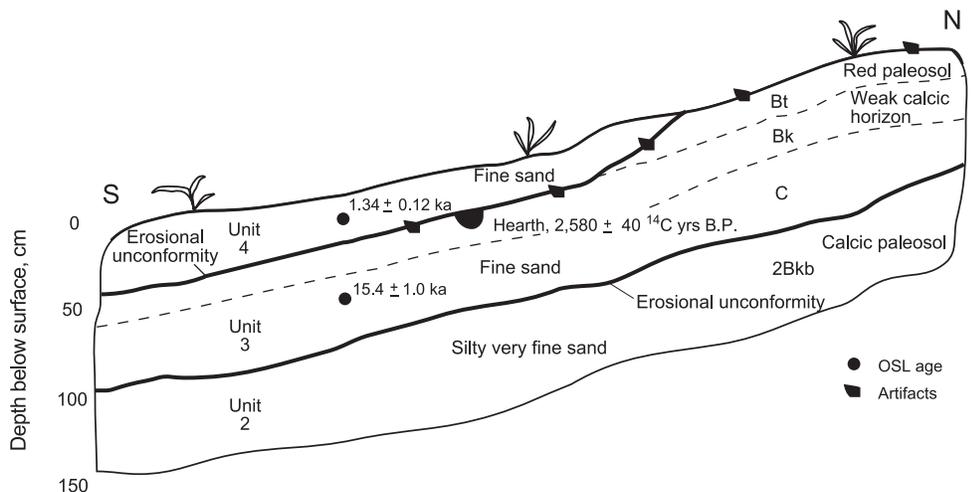


FIGURE 9—Locality 400 where unit 2 eolian sand was deposited and eroded, and unit 3 eolian sand was deposited on the eroded surface of unit 2. Unit 3 was subsequently eroded by gullying, and unit 4 eolian sand was deposited on the eroded surface of unit 3. Before deposition of unit 4, prehistoric site LA 55509 was occupied; this is the only case in the Paseo del Volcan corridor of Holocene eolian sand. The unit 4 sand is probably derived from nearby Arroyo de la Baranca; the 15.4 ± 1.0 ka age (UNL-1295) is the earliest OSL date from unit 3 eolian sand.

bladed in the 1970s, and the eolian berms date from then. The berms are formed by loose sand that has been deflated from the graded roads and deposited at the road side. The berms, where present, have protected the underlying historic A horizon soil from erosion (Fig. 6).

Historic A horizon soil

A weak A horizon soil is present beneath the loose eolian sand (Fig. 6). The A horizon is 10–12 cm thick and is immediately on top of the eroded surface of the upper Pleistocene unit 3 sand and its red paleosol described above. The A horizon soil is not related to the red paleosol. The A horizon is brown to dark brown (7.5YR 4/4) and is developed in very coarse to very fine, poorly sorted, quartz sand. The weak A horizon may have formed within the past 100 yrs, although not directly dated, but is largely missing now due to modern erosion. Owing to their thinness and ephemeral nature, neither the historic sand nor the historic A horizon soil

are assigned informal unit status in this investigation.

Discussion

Sedimentation rate of unit 3

Linear regression analysis of depth versus OSL age (mid-point values) of unit 3 eolian sand from localities 100 and 200 yields a net sedimentation rate of 0.026 cm per year (Fig. 10). However, inspection of Figure 10 shows an apparent clustering of OSL ages between 47 and 113 cm depth. Part of this pattern is the stratigraphic reversal of the ages of samples UNL-1286 and UNL-1290 that are too young compared with other samples in their column. Two possible explanations for the stratigraphic reversal of the two ages are (a) disturbance or (b) rapid sedimentation within that interval of eolian sand.

Disturbance by cicada insects—In the field, we were careful to avoid obvious animal burrow fills and other disturbances

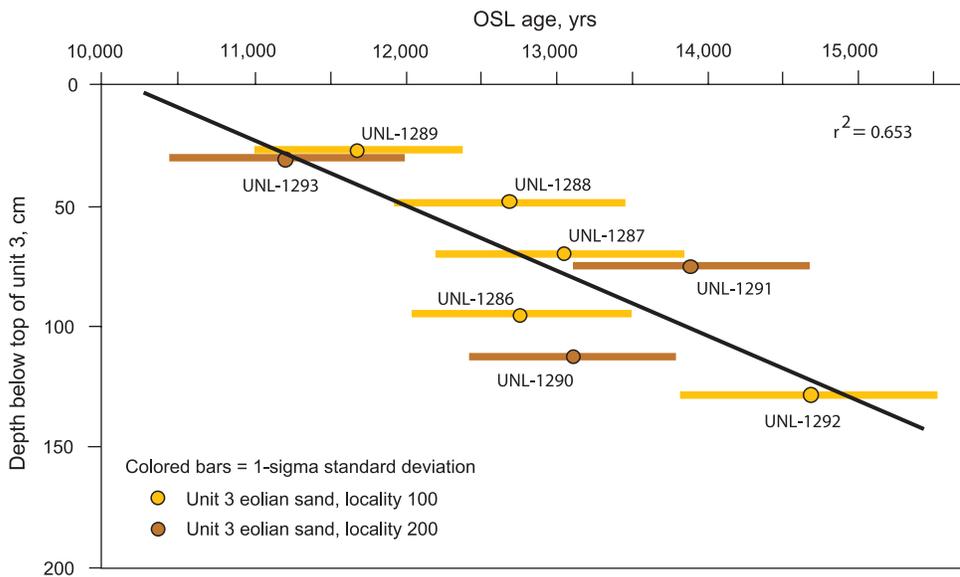


FIGURE 10—Depth versus OSL age of unit 3 eolian sand, localities 100 and 200 (data from Table 1). The age of the top of the eolian sand unit (zero depth) is extrapolated to 10,200 yrs; net sedimentation rate is 0.026 cm per year.

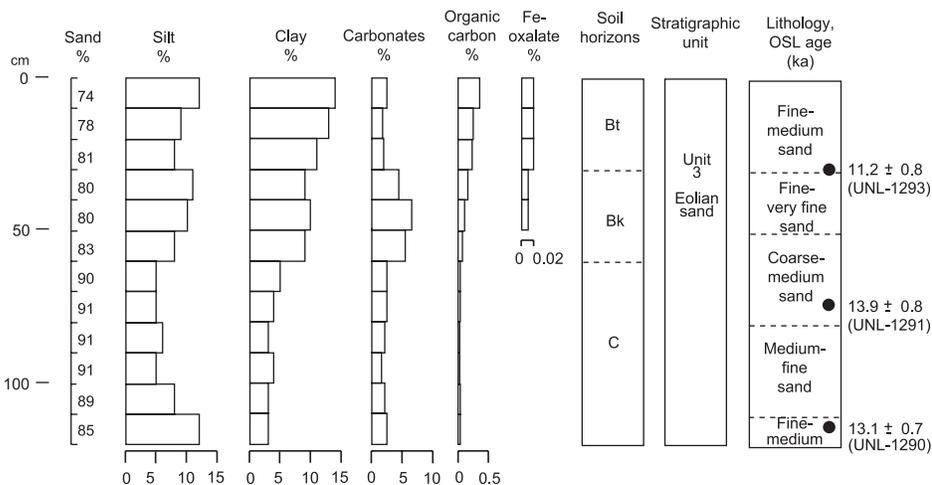


FIGURE 11—Texture, soil horizons, and OSL ages, unit 3 eolian sand, locality 200 (Table 2); outcrop shown in Figure 7. The top of the red paleosol Bt horizon is truncated by erosion. The upward increasing percentages of organic carbon and Fe-oxalates likely represent Holocene pedogenesis.

in the sediment when collecting the OSL samples. Also, the laboratory data for these samples show tight clusters in their D_e distributions with no indication of quartz-grain or sediment mixing. However, cicada (Homoptera: Cicadidae) insect burrow fills are visible in the upper part of unit 3 and throughout units 1, 2, and 4. Cicada burrow fills are also present in the late Holocene features and hearths of the archaeological sites at the surface of the unit 3 sand. Cicada insect nymphs spend many years underground, tunneling and living on plant rootlets, generally within the upper 50 cm of the soil column (O'Geen and Busacca 2001; O'Geen et al. 2002). During burrowing activity, cicadas backfill their burrows with the sediment that they are digging through, resulting in sediment displacement of 10–20 cm, based on observations of burrows at outcrops. The burrow fills are 10–20 mm in diameter and are characterized by cres-

cent structures. They are generally visible only when the cicada nymphs have tunneled through sediment of different color or texture, producing burrow fills that contrast in appearance from the surrounding sediment matrix. In this study, burrow fills observed in the calcic paleosols of units 1 and 2 are lined with carbonates, probably due to differences in the permeability of the burrow fills compared with the surrounding matrix. However, cicada burrows in a thick deposit of homogeneous sediment may not be visible to the field observer. It has been shown that cicada insect bioturbation may be ubiquitous in some eolian sand and sandy alluvium (Hall and Goble 2006; Hall and Periman 2007) and that bioturbation is an important component of pedogenesis that affects the microstratigraphy of many soils (Courty et al. 1989; Holliday 2004). The effect of cicada burrowing on OSL dates has been discussed in a study of

the Mescalero Sands in southeastern New Mexico (Hall and Goble 2006). It was concluded that the degree of potential sediment displacement and accompanying age differences fall within the one-sigma error of the OSL dates. The same relationship applies as well to the OSL ages from the unit 3 sand in this study.

Rapid sedimentation—From the apparent clustering of OSL ages, one could infer that unit 3 eolian sand from the 47–113 cm interval, representing the period 12.5–14 ka, may have accumulated rapidly. The sedimentation rate for that interval is 0.044 cm per year, nearly twice that of the whole column of dated sand (0.026 cm per year). The sedimentology of the 47–113 cm zone at locality 200 is characterized by slightly higher percentages of coarse sand and lower amounts of silt (Fig. 11), perhaps in accord with an episode of more rapid eolian sand accumulation, assuming a constant background influx of atmospheric silt. If correct, the accumulation rate of the remainder of the dated sand column below and above the 47–113 cm interval would be 0.014 cm per year. Regardless, a two-sigma standard deviation of the OSL ages is large, and many of the ages overlap at that level. Accordingly, the OSL ages may not have a sufficiently high resolution to determine differences in sedimentation rate with confidence.

Although the rate of sedimentation of unit 3 could be variable, multiple paleosols or discontinuities or sedimentologic breaks within the sand body that could indicate an interruption in its deposition are absent. Overall, the record supports the interpretation of a process of slow uninterrupted eolian sedimentation of the unit 3 cover sand in this area during 16–10 ka.

Erosion of unit 3 eolian sand and archaeological sites

Unit 3—Field and laboratory data along Paseo del Volcan indicate that the top of unit 3 sand and the top of the red paleosol are eroded. The paleosol A horizon is missing, and the clay-enriched Bt horizon is truncated (Fig. 11). The amount of soil profile that is missing may be as much as 30 cm. Extrapolation of the sedimentation rate to zero depth at the uppermost horizon of the unit 3 sand yields an age of 10.2 ka. If it is assumed that the top 30 cm of the eolian sand is missing and the rate of sedimentation (0.026 cm per year) is extrapolated an additional 30 cm, the period of deposition of the unit 3 eolian sand would be extended to 9.0 ka. Although uncertainties apply, the eolian sand may have accumulated as late as 9 ka before red paleosol development and its erosion.

Archaeological sites—All of the archaeological sites along the Paseo del Volcan corridor are at the surface of the upper Pleistocene unit 3 eolian sand at localities 100, 200, 300, and 500. Site features, such as hearths and pits, intrude into the red paleosol at the top

of the unit 3 sand. Charcoal from 12 features at eight archaeological sites along the corridor yielded radiocarbon dates that range from $4,600 \pm 50$ to 580 ± 40 ^{14}C yrs B.P. (Raymond et al. 2008). Most of the hearth and pit features exhibit erosion, the top portion having been removed by the same erosion that truncated the upper part of the Bt horizon of the red paleosol in the unit 3 sand. It is estimated from the degree of truncation of the Bt soil horizon at localities 100 and 200 that perhaps as much as 30 cm of the upper part of unit 3 eolian sand may have been removed by erosion. Not only are the tops of pit features removed by erosion, but most of the artifacts that are expected to be adjacent to these features, based on other archaeological excavations, are absent. The occupation surfaces of the sites are missing as well. We conclude that the artifacts are missing because they have been removed by erosion. Unfortunately, the archaeological sites with their different ages and states of preservation do not provide useful information on the timing of the erosion of the unit 3 eolian sand, although the erosion occurred during the late Holocene after the red paleosol formed and after the archaeological sites were occupied. An exception is the archaeological site at locality 400 where a hearth is radiocarbon dated $2,580 \pm 40$ ^{14}C yrs B.P.; the site is partly buried by unit 4 eolian sand with an OSL age of 1.34 ± 0.12 ka (Fig. 9). At locality 400, gully erosion had begun sometime before 2.6 ka but had ended before 1.3 ka.

Sheet erosion—The erosion of the top portion of the eolian cover sand is a result of either sheet erosion or deflation. However, because of the general absence of artifacts around the archaeological hearth and pit features, it is likely that the erosion was caused by sheet erosion. If deflation had been the primary cause of the erosion, artifacts that are too large to be entrained by wind would be preserved around the site features, but they are not. Based on many trenches exposing surficial deposits in the Paseo del Volcan corridor, gully erosion does not seem to have played a role in the erosion, except at locality 400.

Correlation of eolian sand

Boca Negra Wash

South of Rio Rancho in the Boca Negra Wash area on the West Mesa across the Rio Grande from Albuquerque, a sequence of eolian sand, thin playa muds, paleosols, and Folsom archaeology has been dated by radiocarbon and OSL (Holliday et al. 2006). During the period of eolian sand deposition along Paseo del Volcan, lacustrine muds were accumulating in small shallow playas on the West Mesa from 17 to 3 ka. Eolian sand was also being deposited in the Boca Negra Wash area from 25 to 20 ka, and, at an isolated outcrop, 6 ka. Based on current information, the Paseo del Volcan and Boca Negra Wash eolian records appear to be out of phase with each other.

County Dump fault

The County Dump fault is exposed on the Llano de Albuquerque and was evaluated with a series of trenches across the fault zone just north of I-40 where the fault crosses badlands east of the Llano escarpment (McCalpin et al. 2006). Although some of the stratigraphic units exposed in trenches are related to fault movements, at least three upper Quaternary units are eolian sand and, although displaced by some degree with faulting, extend across the fault zone at the top of the sequence. The oldest unit is TL-dated ca. 41–38 ka, the intermediate unit is ~28 ka, and the youngest is 4 ka. Older alluvial and colluvial units are also present.

Hubbell Spring fault zone

South of Albuquerque and west of the Manzano Mountains, the Hubbell Spring fault extends north-south displacing alluvial-fan and eolian-colluvial deposits. Eolian sediments exposed in a trench through the fault zone were dated by TL and IRSL (Personius and Mahan 2003). The ages of the three younger eolian sand units are 60–52 ka, 34–27 ka, and 14–11 ka.

Chaco dune field, San Juan Basin

The Chaco dune field of the San Juan Basin is one of the most thoroughly documented in northern New Mexico, although the geochronology of the eolian sand is based almost entirely on radiocarbon ages from archaeological sites, indicating that Holocene eolian sand deposition occurred between about 6 and 2 ka. In the past 2,000 yrs, according to the published reports, the sand sheet was primarily stable and vegetated by desert shrub grassland, resulting in the formation of a red desert soil (Hall 1983, 1990; Schultz 1983; Wells et al. 1990).

Southern New Mexico, adjacent Texas

An OSL-dated sequence from the Mescale-ro Sands of southeastern New Mexico documents eolian sand accumulation during two separate periods, 90–75 ka and 9–5 ka (Hall 2002; Hall and Goble 2006). Another OSL-dated sequence from the Hueco Bolson near El Paso, Texas, shows that eolian sand accumulated during two periods, the older dated ca. 44 ka and the younger period dated 24–5 ka (Hall 2007). A series of OSL ages from a core through the White Sands dunes indicates that the dune field formed beginning 7 ka and continuing to today (Kocurek et al. 2007). A summary of radiocarbon-dated eolian sand deposits in the southern High Plains concludes that most of the eolian sand accumulated during the late Holocene with localized eolian sedimentation beginning no earlier than ca. 13 ka (Holliday 2001).

Although luminescence studies are providing new information on the geochronology of sand sheets, patterns of eolian sand deposition across the region have yet to emerge. Currently, the sequence of eolian sand at Paseo del Volcan, especially the prominent unit 3 sand that is OSL-dated 16–10 ka, appears to stand alone without clear equivalents. Exceptions are the younger eolian sand at the Hubbell Spring fault zone (Personius and Mahan 2003) and the younger eolian sand in the Hueco Bolson (Hall 2007), both sand units accumulating during the same time period that the unit 3 sand was deposited along Paseo del Volcan.

Summary and conclusions

The surficial geology of a small area in Rio Rancho in the northwest Albuquerque Basin is characterized by an upper Pleistocene eolian cover sand (Fig. 12). The surficial sand is 0.5–1.4 m thick and accumulated during the period 16–10 ka based on OSL dating. A red calcic paleosol with stage I carbonate morphology formed in the sand during the Holocene. During the late Holocene, several archaeological sites were occupied on the surface of the Pleistocene cover sand, and hearths and features from the sites are intruded into the sand. At sometime during the late Holocene, after the development of the red paleosol and after the local prehistoric occupation, sheet erosion removed the top of the sand, truncating the red paleosol as well as the top portion of archaeological hearths and features. A brief episode of local eolian activity occurred along a local wash ca. 2.5–1.0 ka, depositing eolian sand on the eroded surface of the Pleistocene cover sand. Mantling the surficial geology of the area is a thin deposit of historic-age loose eolian sand and an underlying historic A horizon soil.

The upper Pleistocene cover sand rests unconformably on the eroded surface of older eolian silty sand with a paleosol with stage II carbonate morphology that is middle(?) Pleistocene in age and on an alluvial-colluvial deposit (Miocene) with a thick stage III calcic paleosol that contains many soil pipes. The period of eolian sand deposition 16–10 ka along Paseo del Volcan does not appear to have an equivalent in the region, although it is anticipated that, as other sequences are directly dated optically, a pattern of eolian sedimentation will emerge.

Acknowledgments

We wish to acknowledge the U.S. Department of Transportation, Federal Highway Administration, the New Mexico Department of Transportation, the City of Rio Rancho, and Parsons Brinckerhoff for facilitating this study. We thank the reviewers Shannon Mahan, Sean Connell, and Bruce

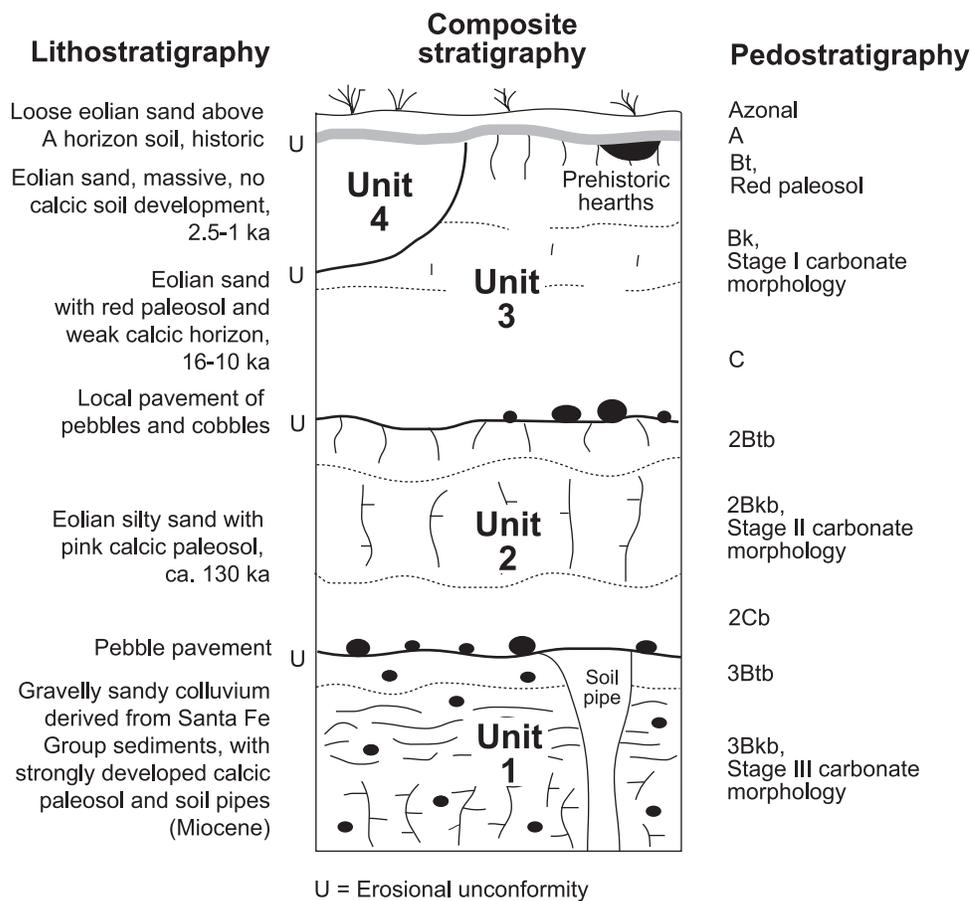


FIGURE 12—Composite stratigraphy of the surficial geology along Paseo del Volcan, Rio Rancho, Sandoval County, New Mexico; local archaeological sites are radiocarbon-dated 4,660–580 yrs B.P. and intrude unit 3 eolian sand and red paleosol; the “b” designation represents buried soil horizons.

Allen for their thoughtful suggestions to the manuscript. We especially thank Sean Connell for visiting us in the field and sharing his knowledge of the local geology.

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