Lucas, Spielmann and Lockley, eds., 2007, Cenozoic Vertebrate Tracks and Traces. New Mexico Museum of Natural History and Science Bulletin 42.

MAMMOTH FOOTPRINTS FROM THE UPPER PLEISTOCENE OF THE TULAROSA BASIN, DOÑA ANA COUNTY, NEW MEXICO

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Abstract—Fossil footprints from upper Pleistocene strata on White Sands Missile Range were made by proboscidean (mammoth) and camelid trackmakers. These mammals made footprints on the floor of the Tularosa Basin in sediments deposited along the margin of a shallow saline lake (Lake Otero). Radiocarbon ages from the track-bearing beds suggest that the fossil tracks were made before 30,000 ^{14}C yrs B.P. The track-bearing sequence of sediments is overlain by deposits containing evidence of episodes of increased surface runoff and relative freshening of the lake. Radiocarbon ages from these overlying deposits suggest that the inferred shift to a comparatively wetter climate was underway by about 23,000 ^{14}C yrs B.P., consistent with other paleoclimatic reconstructions in the region. Thus, contrary to speculations that the footprints may be associated with human artifacts, it is reasonably clear that the fossil tracks on the floor of Tularosa Basin are considerably older than the arrival of Clovis or Folsom peoples to the region. Mammoth tracks from the Tularosa Basin are assigned to the ichnotaxon *Proboscipeda panfamilia* and represent mammoths whose estimated shoulder heights ranged from 1.8 m (juvenile) to 3 m, and had estimated walking speeds of 6-7 km/hr. The tracks mostly head east-west and suggest that mammoths traveled to and along the shorelines of late Pleistocene Lake Otero.

INTRODUCTION

Lucas et al. (2002) documented late Pleistocene footprints of camels and proboscideans (mammoths) from a locality on the floor of the Tularosa Basin on the White Sands Missile Range (WSMR) in southern New Mexico (Fig. 1). Subsequent work has revealed additional footprints at other localities near the original track site, and radiocarbon dating has provided age estimates for the deposits associated with the footprint localities (Allen et al., 2006). Here, we present preliminary radiocarbon-dating results and document newly discovered and extensive proboscidean (mammoth) trackways from the Tularosa Basin. In this paper, NMMNH = New Mexico Museum of Natural History and Science.

HISTORY OF STUDY

Ellis Wright discovered the footprints on the Alkali Flat in Doña Ana County in 1932 (Gross, 1981, 1982). Wright believed them to be those of a giant human; and Gross (1981, p. 11) quotes a 1938 pamphlet titled "Story of the Great White Sands:"

> GIANT'S TRACKS—In the fall of 1932 Ellis Wright, a government trapper, reported that he had found human tracks of unbelievable size, imprinted in the gypsum rock on the west side of White Sands. At his suggestion a party was made up to investigate. Mr. Wright served as a guide. O. Fred Arthur, Supervisor of the Lincoln National Forest, Edgar Cadwallader and one of his sons from Mountain Park and the writer made up the party. As Mr. Wright had reported, there were 13 human tracks crossing a narrow swag, pretty well out between the mountains and the sands. Each track was approximately 22 inches long and from 8 to 10 inches wide. It was the consensus of opinion that the tracks were made by a human being for the print was perfect and even the instep plainly marked. However there was not one in the group who cared to venture a guess as to when the tracks were made or how they became of their tremendous size. It is one of the unsolved mysteries of the Great White Sands.

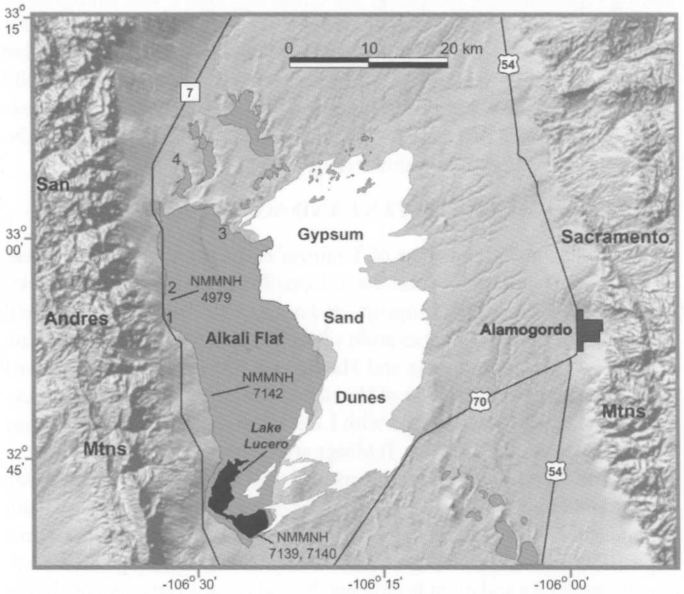

FIGURE 1. Location map of Pleistocene mammal tracksites on White Sands Missile Range and White Sands National Monument, southern New Mexico. Alkali Flat and smaller wind-deflation basins are indicated by gray shading. Radiocarbon dates (Table 1) were obtained from deposits associated with late Pleistocene Lake Otero at localities 1, 2, 3 and 4.

No study or other documentation of the footprints took place until 1981. At that time, a group from the New Mexico Bureau of Mines and Mineral Resources including David Love, John Hawley and Donald Wolberg, examined the footprints at the request of archaeologist Peter Eidenbach (Hawley, 1983, p. 28). Wolberg (in Gross, 1981, 1982) identified the tracks as those of an elephant (mammoth), artiodactyl (camel) and an undetermined mammal. Lucas et al. (2002, fig. 2) reproduced some photographs taken of the footprints at that time.

On a 9 June 1984 tour of the area by the New Mexico Archaeological Council, a large mammoth-molar fragment was observed by

TABLE 1. Radiocarbon ages associated with the mammoth tracksites on the WSMR.

Radiocarbon Age[1]	Lab Number	Material[2]	^{13}C ‰[3]	Stratigraphic Unit[4]	Locality[5]
Lake-margin deposits (Lake Otero)					
31640 (350)	Beta 204417	macrophytes	-22.6	lower	2
31500 (250)	Beta 210311	"	-22.4	"	2
31020 (320)	Beta 204418	"	-14.0	"	3
22800 (130)	Beta 206641	charcoal	-23.9	upper	4
21720 (80)	Beta 206642	ostracodes	0.1	"	1
20700 (70)	Beta 206643	"	-5.5	"	3
19430 (70)	Beta 202927	macrophytes	-23.0	"	1

[1] Radiocarbon ages determined by accelerator mass spectrometry; 1-sigma error reported by the lab in parenthesis.
[2] Plant materials were subjected to standard acid-base-acid pretreatment.
[3] Carbon isotopic ratios in delta notation (relative to the PDB standard); used to correct for isotopic fractionation.
[4] "lower" corresponds to the track-bearing beds, "upper" to overlying deposits.
[5] Locality numbers indicated on index map.

Hawley, Love and others in a small gully within 250 m of the tracksite. Unfortunately, there is no record that this fossil was ever recovered.

In 2001, Lucas, Morgan and Myers re-examined the tracksite, tracing representative footprints and collecting metric and stratigraphic data. Lucas et al. (2002) documented the tracksite noting that, in 2001, footprints were exposed over an area of about 75,000 m^2, and included 25 footprints of proboscideans and 64 camel footprints. Since the 2002 publication, we have discovered additional footprint sites, including extensive mammoth trackways on the southern shore of Lake Lucero in the White Sands National Monument (Fig. 1).

GEOLOGICAL CONTEXT AND AGE OF THE TRACKS

Footprints on the floor of Tularosa Basin are found in the lower few meters of outcrops of sediment deposited in and around late Pleistocene Lake Otero. The footprints and associated deposits are exposed as a result of extensive excavation of the basin floor by wind deflation during the Holocene. Lucas and Hawley (2002) assigned the exposed strata to the Otero Formation of Herrick (1904). A more detailed discussion of the deposits associated with Lake Otero is in preparation as part of ongoing work; preliminary findings are briefly summarized below.

The lower, track-bearing part of the lacustrine sequence consists of interbedded gypsiferous clay and stuctureless-to-laminated gypsum silt and sand. Thin beds of carbonate mud are also present. Subaqueous depositional environments are indicated by beds containing ostracodes, aquatic mollusks and plant fragments. Periodic subaerial exposure of the lake margin is suggested by sedimentary structures, including mud cracks and lamination textures similar to those formed by algal mats on modern mud flats.

The upper lacustrine sequence is comparatively enriched in siliciclastic clay, silt and sand. Beds in the upper part of the lacustrine sequence contain diverse assemblages of ostracodes and other aquatic organisms. The lithologies and distribution of aquatic organisms in the upper part of the lacustrine sequence suggest episodes of increased discharge of sediment-laden surface water and relative freshening of the lake. The upper part of the lacustrine sequence grades northward into fluvial-distributary deposits containing large meandering channels with coarse-grained clastic fills, also suggesting episodes of comparatively wetter climate and enhanced fluvial activity in the basin.

Three samples of plant fragments from the lower, track-bearing sequence have yielded radiocarbon ages slightly greater than 31,000 ^{14}C yrs B.P (Table 1). Accuracy of these ages is uncertain because contamination of samples of this antiquity with small amounts of modern carbon would cause the apparent ages to be significantly too young. Conversely, an unknown hardwater effect in aquatically-derived materials would cause the apparent ages to be too old.

Samples consisting of ostracode valves, plant fragments, and charcoal from overlying deposits have yielded four radiocarbon dates ranging from 22,800 to 19,430 ^{14}C yrs B.P (Table 1). These dates are comparable with independent chronologies for the onset of significantly wetter climatic conditions in adjacent lake basins during the last glacial maximum (e.g., Wilkins and Currey, 1997; Allen and Anderson, 2000). The stratigraphic relations and radiocarbon dates suggest that the footprints and trackways on the floor of Tularosa Basin were made before this major late Wisconsinan pluvial episode. This also means that the mammoth and camel tracks in the Tularosa Basin predate the arrival of humans in New Mexico, as documented by the Clovis and Folsom sites at ~ 12,000 14C yrs B. P.

TRACKSITES

The tracksite documented by Lucas et al. (2002) is NMMNH locality 4979, located at and around UTM zone 13S, 358368E, 3644477N, NAD 27. Most tracks are preserved in convex relief, and all appear to be undertracks. In general, the tracks are poorly preserved; their soft gypsite matrix has been deeply eroded. At NMMNH locality 4979, two kinds of tracks are preserved, those of a large proboscidean, almost certainly a mammoth, and those of a smaller, quadrupedal mammal, a camel (Lucas et al., 2002; Allen et al., 2006). Similar tracks were reported by Allen et al. 92006) north of locality 4979 (near locality 3 in Figure 1).

Bustos recently discovered two tracksites on the Alkali Flats. At one of the sites, NMMNH locality 7142 (UTM zone 13S, 364270E, 3632752N, NAD 27), tracks are shallow depressions or haloes on the sediment surface (Fig. 2B). The other site is NMMNH locality 7144 at and around UTM zone 13S, 363802E, 3633148N, NAD 27, where there are multiple trackways. Footprints in these trackways vary in diameter from 38 to 89 cm, and further study should be undertaken here.

The most recently discovered extensive mammoth trackways (Figs. 2-4) are on the southern shore of Lake Lucero in the White Sands National Monument (Fig. 1). These trackways are at NMMNH locality 7139 (UTM zone 13S, 369771E, 3615097N, NAD 27) and locality 7140 (369978E, 3615228N). Hundreds of proboscidean tracks are present at these sites (Figs. 2-4), and all trackways bear nearly east-west. We mapped two trackways at these sites (Fig. 5) as characteristic examples.

MAMMOTH TRACKS

In 2001, at NMMNH locality 4979, there were 25 round to ovoid, large (maximum diameter ranges from 43 to 62 cm) tracks (Lucas et al., 2002, figs. 2A, C-E; 3A-B). No separate toe impressions were preserved, and two trackways were identified, one of four tracks, the other of six tracks. Manus and pes imprints overlap, as is typical in proboscidean tracks, and stride length is 2-3 m. Allen et al. (2006) illustrated five proboscidean tracks north of NMMNH locality 4979, which disturbed an extensive fossil algal mat.

The tracks at NMMNH localities 7139 and 7140 are similar in preservation to those at locality 4979. Thus, they are ovoid to round gypsite casts (Figs. 2-4) that contrast with the surrounding sediment in being darker-colored and more coarsely crystalline. This is probably because the tracks, upon being impressed in the moist gypsum silt and sand, compacted the underlying gypsum and provided a micro-environment for the growth of coarse gypsum crystals, so that they became more resistant to erosion than the surrounding sediments. Extant oryx are now leaving similar, pedestalled tracks on the Alkali Flat near the Pleistocene tracksites.

At the Lake Lucero tracksites, only a few tracks show unambiguous digit imprints (Fig. 3F), and there is a wide range of variation in size and shape that we attribute to: (1) undertracks, which are usually smaller tracks (Fig. 3E); (2) incomplete overstepping, where two tracks are

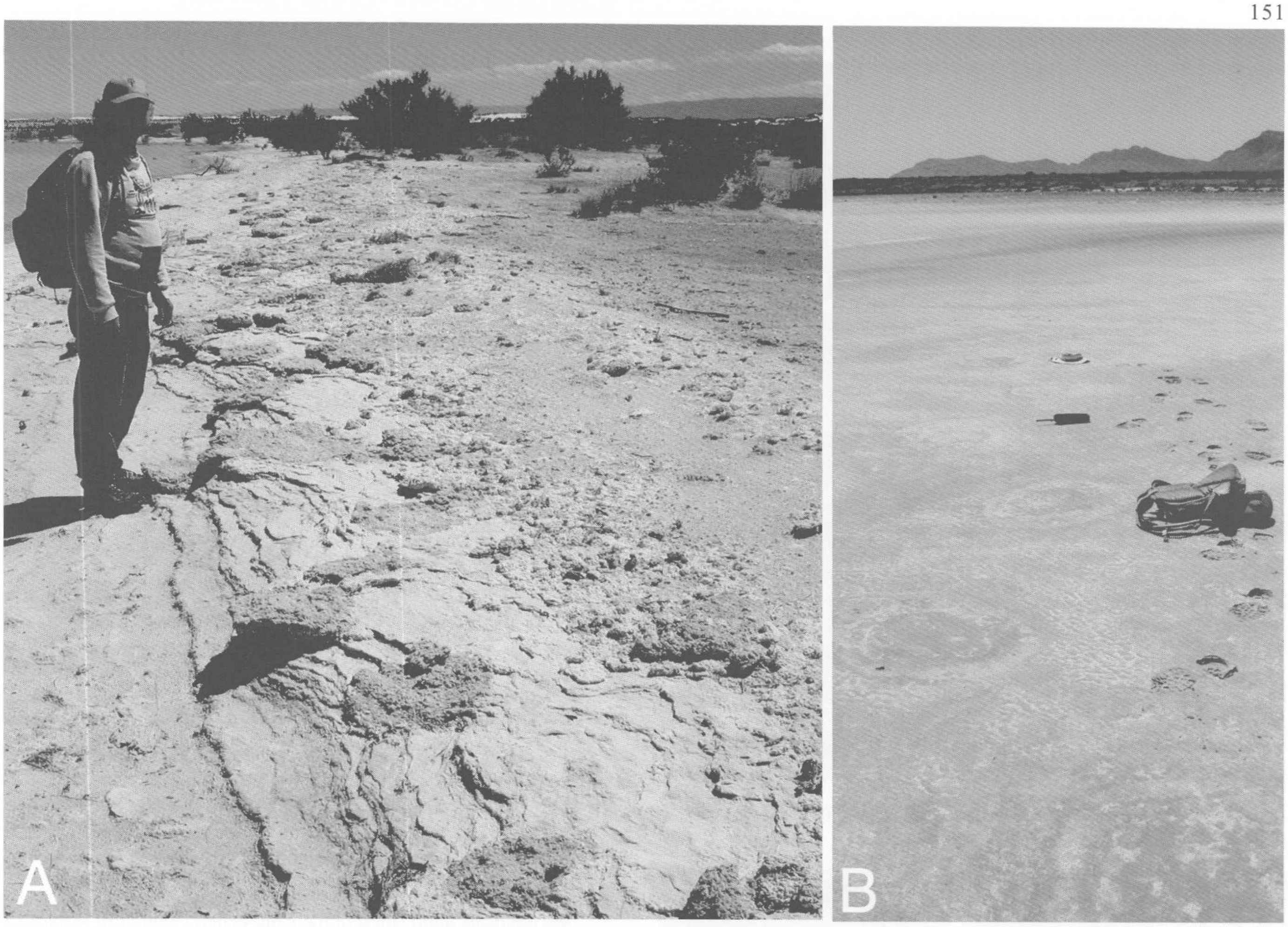

FIGURE 2. **A**, Overview of mammoth trackways at NMMNH locality 7140 on southern shore of Lake Lucero. **B**, Overview of mammoth trackway at NMMNH locality 7142 on Alkali Flat.

nearly superimposed or adjacent, producing a single, relatively long and ovoid shape (Figs. 3D, 4D); (3) differential erosion of the pedestalled tracks, which has altered shape and/or size (e.g., Fig. 3E); and (4) differential cementation and recystallization of the tracks, resulting in a range of morphologies that are usually "spread out" (Figs. 3B, 4A, C).

At NMMNH localities 7139 and 7140, we measured the sizes of tracks in two trackways (Fig. 5). At locality 7139, 10 measured tracks in a trackway range from 15 to 50 cm long and from 25 to 43 cm wide. Mean length is 32 cm, whereas mean width is 34 cm. This is the trackway of a relatively small (juvenile) mammoth. At locality 7140, 10 measured tracks in a trackway range from 38 to 70 cm long and from 33 to 65 cm wide. Mean length is 53 cm, whereas mean width is 45 cm. Stride lengths range from 105 to 230 cm, with a mean value of 158 cm (locality 7139) and 173 cm (locality 7140), much less than those of a modern Asian elephant listed by Higgs et al. (2003a, b). The width (gauge) of the trackways is narrow, but not as narrow as some reported in the literature (e.g., McNeil et al., 2007). It seems likely that at the Lake Lucero sites the proboscidean trackmakers were walking on a soft, gypsiferous ground surface, and this affected their gait.

TRACKMAKER AND ICHNOTAXONOMY

Given the large size of these tracks, their late Pleistocene age and the presence of mammoth body fossils in the Otero Formation (Morgan and Lucas, 2002), the tracks from the southern shore of Lake Lucero are certainly those of mammoths. These tracks closely resemble the tracks of living elephants (Fig. 6) and previously published fossil tracks identified as proboscidean in being large, round to ovoid impressions (e.g., Johnston, 1937; Brady and Seff, 1959; Panin and Avram, 1962; Scrivner and Bottjer, 1986; Reynolds, 1999; Chandler, 2000; McNeil et al., 2005, 2007).

Panin and Avram (1962, p. 460) proposed the new ichnotaxon *Proboscipeda enigmatica* for proboscidean tracks from the Miocene of Romania. This is the oldest ichnotaxonomic name for proboscidean tracks. They described these tracks from a trampled surface with an area of ~ 100 m^2 covered with 100 tracks (Panin and Avram, 1962, pl. 1, fig. 13). Panin and Avram (1962) made it clear they were naming a new ichnogenus and ichnospecies; the caption to their figure 14 is essentially a holotype designation, and their text (p. 459-460) describes and compares the tracks to those of living elephants and hippopotami, which provides a diagnosis. We designate the one footprint they illustrated separately (Panin and Avram, 1962, pl. 1, fig. 14) the lectotype of *P. enigmatica*. Panin and Avram (1962) described the tracks of *P. enigmatica* as having an oval shape (longer than wide), pockmarked texture and dimensions of 40 x 30 cm (length x width) to 25 x 19 cm, most without toe imprints but some with three anteriorly-directed digit imprints and two laterally-directed digit imprints. They were attributed to a deinothere, a common kind of Old World Miocene proboscidean.

Scrivner and Bottjer (1986, p. 301) subsequently used the name *Proboscipeda* sp. to refer to a Miocene proboscidean trackway from California, which they described as "deep circular depressions with only slight toe outlines preserved." Reynolds (1999) redescribed these tracks, which are part of a single trackway in the Barstovian Barstow Formation, and have poor or no toe imprints, diameters of about 50 cm and a stride length of about 275 cm.

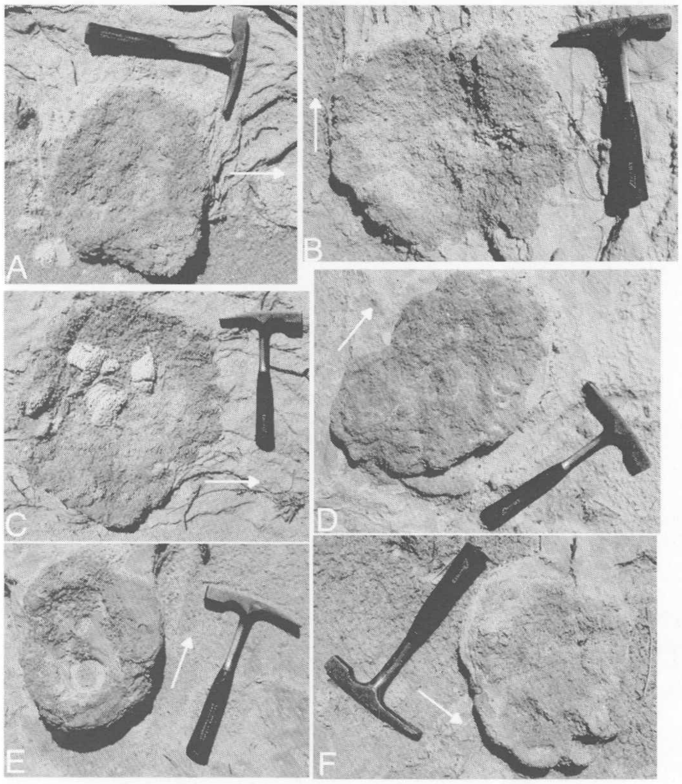

FIGURE 3. Selected mammoth tracks from the southern shore of Lake Lucero. Arrows indicate inferred direction of travel.

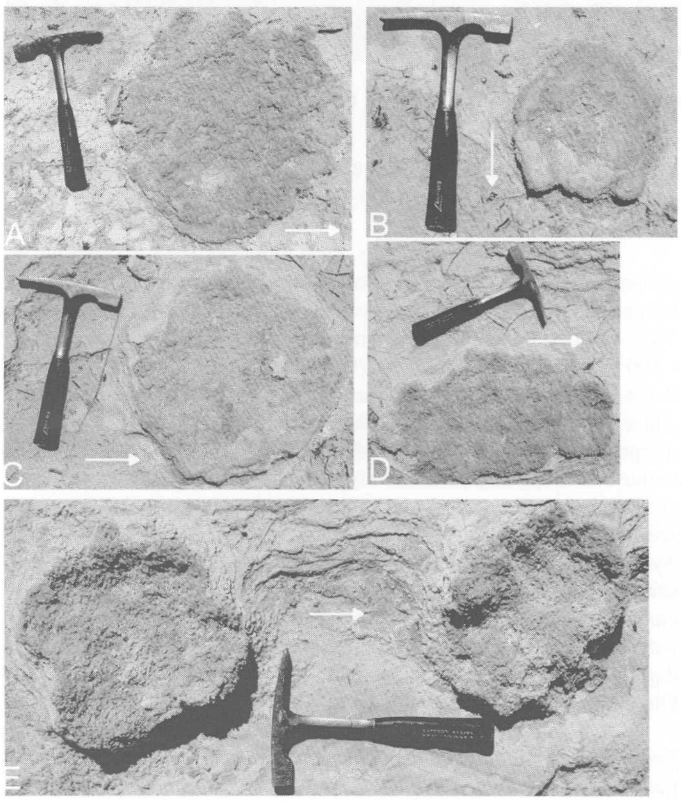

FIGURE 4. Selected mammoth tracks from the southern shore of Lake Lucero. Arrows indicate inferred direction of travel.

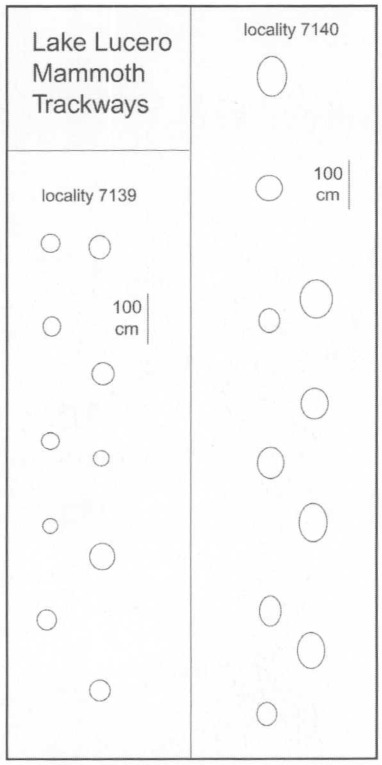

FIGURE 5. Diagrammatic map of two mammoth trackways, one at NMMNH locality 7139, the other at locality 7140. The footprints are shown as schematic ovals or circles that are to scale. Note that the relatively wide gauge and incomplete footprint alternation of trackway at locality 7139 could be due to pathology, gait and/or some incomplete preservation of footprints.

We advocate application of the ichnogeneric name *Proboscipeda* to all Neogene proboscidean footprints and diagnose the ichnogenus as very large (20-70 cm diameter), ovoid to circular depressions that may show 3 to 5 short, blunt, anteriorly-directed digit impressions and, in trackways, typically show overstepping of manus and pes imprints. We thus consider the ichnogeneric name *Stegomastodonichum*, coined by Aramayo and Bianco (1987) for Pleistocene proboscidean tracks from Argentina, to be a junior subjective synonym of *Proboscipeda*. In this volume, McNeil et al. (2007) name a second ichnospecies of *Proboscipeda*, *P. panfamilia*, for Pleistocene tracks from western Canada. The smaller, ovoid tracks of *P. enigmatica* can be distinguished from the larger, circular tracks of *P. panfamilia*, and we assign the proboscidean footprints from the Tularosa Basin to *P. panfamilia*.

Note that Remeika (2001) used the name *Stegmoastodonichnum* for Pliocene (Blancan) proboscidean tracks from the Fish Creek Canyon ichnofauna in the Anza-Borrego State Park, California. He named a new ichnospecies, *S. garbanii*, but failed to diagnose it, only stating that the ichnospecies diagnosis is "as for ichnogenus," which fails to diagnose it from Aramayo and Bianco's (1987) ichnospecies *S. australis*. We thus regard *S. garbanii* as a *nomen nudum*. There are no features of *S. garbanii* that distinguish it from *Proboscipeda*, and the oval footprint shape and well-defined digits of the holotype (Remeika, 2001, fig. 16) support assignment to *P. enigmatica*. Remeika (2006) recently introduced the ichnogeneric name *Mammuthichnum* for mammoth tracks in the Anza-Borrego State Park, California, but failed to diagnose the ichnogenus or name a type ichnospecies, so we regard *Mammuthichnum* as a *nomen nudum*.

SIZE AND GAIT

Few metric data on mammoth foot size are available, but an articulated hind foot of a Colombian mammoth from the Hot Springs site in

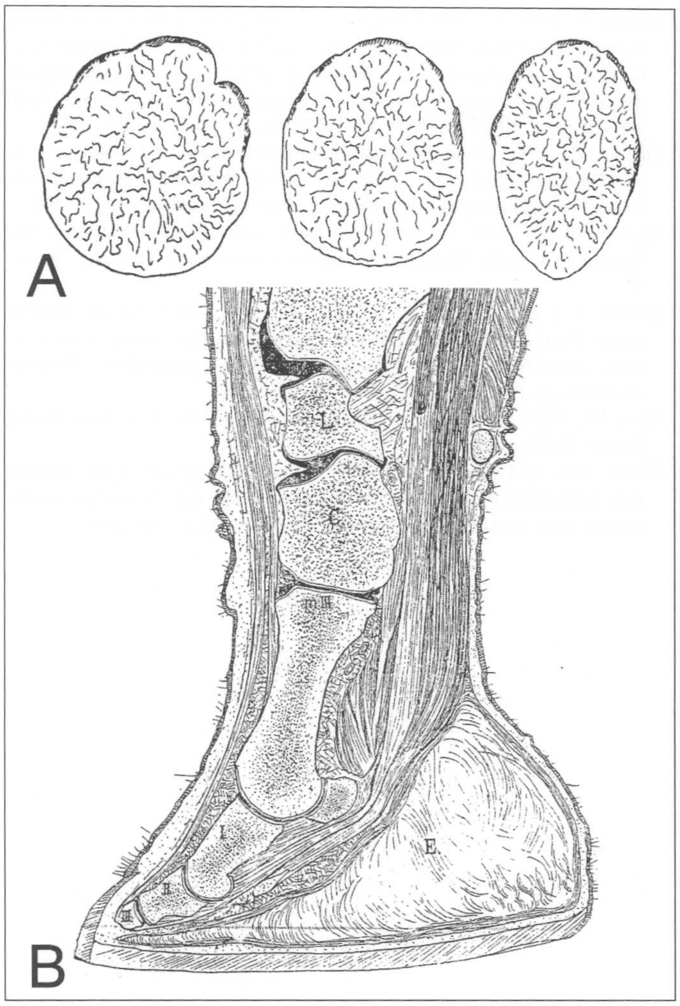

FIGURE 6. Outline drawings of footprints (**A**) of living African elephants (from Panin and Avram, 1962) and (**B**) cross section through the foot of a living elephant (from Weber, 1928). Note the elastic fleshy pad (E) that forms much of the plantar portion of the foot.

South Dakota has a maximum diameter of ~25.8 cm (Mol and Agenbroad, 1994). This is much smaller than most of the tracks described here, but all elephants have fleshy pads around the feet, so foot diameter based on bones is much smaller than actual foot diameter (Fig. 6). Indeed, Weber's (1928, fig. 279) illustration of the forefoot of a living elephant indicates that the foot diameter of the fleshy pad is slightly more than twice the foot diameter based on the skeletal elements alone (Fig. 6).

We follow the approach of McNeil et al. (2005, 2007) to estimate the walking speeds of the mammoths that made the trackways at NMMNH localities 7139 and 7140 (Fig. 5). Thus, we use Alexander's (1976) formula: $u = 0.25g^{0.5}\lambda^{1.67} h^{-1.17}$. In this formula, g = acceleration due to gravity, h = shoulder height, λ = stride length and u = speed of the animal. McNeil et al. (2005, 2007) present data that relate foot length to shoulder height in living elephants. Based on these data, shoulder height of the mammoth (almost certainly a Columbian mammoth) that made the trackway at NMMNH locality 7139 can be estimated as 1.8 m (based on an average foot length of 34 cm, a juvenile mammoth), whereas the mammoth at locality 7140 has an estimated shoulder height of 3.0 m (average foot length of 53 cm). With average stride lengths of 1.58 m (locality 7139) and 1.73 m (locality 7140), the equation indicates walking speeds of 1.68 m/sec (~ 6 km per hour) at locality 7139 and 1.95 m/sec (~ 7 km per hour) at locality 7140. These are fairly rapid walking speeds for an elephant. The tracks mostly head east-west and suggest that mammoths traveled to and along the shorelines of late Pleistocene Lake Otero.

ACKNOWLEDGMENTS

The U.S. Army granted access to the WSMR. Peter Eidenbach of Human Systems Research made arrangements through the Whites Sands Missile Range for the 1981 visit and photographs. This report has been approved for public release by White Sands Missile Range for unlimited distribution. The White Sands Missile Range Operational Security review was completed September 6, 2007. Ester Singer assisted in the measurement of footprinst and trackways. Greg McDonald provided us with a copy of Remeika (2006). We thank Paul McNeil and Martin Lockley for their careful reviews of the manuscript.

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