Cenozoic vertebrates from Socorro County, central New Mexico

Gary S. Morgan, Spencer G. Lucas, and David W. Love
2009, pp. 321-336. https://doi.org/10.56577/FFC-60.321

in:

Geology of the Chupadera Mesa, Lueth, Virgil; Lucas, Spencer G.; Chamberlin, Richard M.; [eds.], New Mexico Geological Society 60th Annual Fall Field Conference Guidebook, 438 p. https://doi.org/10.56577/FFC-60

This page is intentionally left blank to maintain order of facing pages.

CENOZOIC VERTEBRATES FROM SOCORRO COUNTY, CENTRAL NEW MEXICO

GARY S. MORGAN[1], SPENCER G. LUCAS[1], AND DAVID W. LOVE[2]
[1]New Mexico Museum of Natural History, 1801 Mountain Road, NW, Albuquerque, NM 87104
[2]New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, NM 87801

ABSTRACT—The Cenozoic vertebrate record from Socorro County in central New Mexico consists of 20 faunas ranging in age from Eocene through Pleistocene. The Carthage Local Fauna (LF) of middle Eocene age (Bridgerian North American land-mammal "age"—NALMA) is the oldest of these faunas. The presence of the brontothere *Telmatherium* restricts the age of the Carthage LF to late Bridgerian (Twinbuttean, 46-46.5 Ma). The two other Paleogene vertebrate sites in Socorro County are both ichnofaunas, including three trackways of Eocene artiodactyls from the Baca Formation in the Gallinas Mountains and two artiodactyl tracks from Oligocene volcaniclastic sediments in the San Mateo Mountains. Despite the widespread occurrence of Miocene rocks of the Popotosa Formation in Socorro County, the only fossil so far reported from this unit is a complete skull, lower jaws, and partial skeleton of the oreodont *Merychyus major* from a late Miocene (late Clarendonian NALMA) site on the Bosque del Apache National Wildlife Refuge near San Antonio. Pliocene (Blancan NALMA) sites from the Ceja and Palomas formations in the Rio Grande valley include Abeytas, Arroyo de la Parida, Sevilleta, Silver Canyon, and Veguita. The best known of these is the Arroyo de la Parida LF with 14 species of vertebrates, including the gomphothere *Rhynchotherium tlascalae*, indicating an late early Blancan age (~3 Ma). Pleistocene sites are distributed throughout the county, including: Lake San Agustín, VLA, and White Lake from the Plains of San Agustín in northwestern Socorro County; Lemitar, San Antonio, and Socorro from the Rio Grande valley; and Chupadera Arroyo and Mockingbird Gap from the eastern portion of the county.

INTRODUCTION

Although not as well known for Cenozoic vertebrate fossils as other regions of New Mexico, Socorro County in the south-central part of the state has produced several important faunas (Fig. 1). The best known of these are the middle Eocene (Bridgerian) Carthage Local Fauna (LF) (Lucas et al., 1982; Lucas and Williamson, 1993; Lucas, 1997) and the early Pliocene (Blancan) Arroyo de la Parida LF (Tedford, 1981; Lucas and Morgan, 1996; Morgan et al., 2008a). In all, there are 20 named Cenozoic vertebrate faunas from Socorro County (Fig. 1), with at least one fauna representing every epoch from the Eocene through the Pleistocene, including: Eocene (2 faunas), Oligocene (1 fauna), Miocene (1 fauna); Pliocene (7 faunas), and Pleistocene (9 faunas). The total number of Cenozoic vertebrate localities in Socorro County is actually well over 50, as several of the faunas consist of multiple sites (e.g., the Carthage LF includes 5 sites: Lucas, 1997; the Arroyo de la Parida LF is derived from more than 30 sites: Morgan el al., 2008a). Cenozoic geologic formations in the county that have produced vertebrate fossils include the Eocene Baca and Hart Mine formations, the Miocene Popotosa Formation, and the Pliocene Ceja and Palomas formations, together with widespread unnamed deposits of late Pleistocene age. In addition, a mammal trackway is known from Oligocene volcanic rocks in the San Mateo Mountains. Fig. 2 is a stratigraphic column showing the geologic formations and chronologic distribution of Cenozoic vertebrate sites in Socorro County.

Socorro County is located near the geographic center of New Mexico and is bissected from north to south by the Rio Grande. Most of Socorro County is included within the Basin and Range physiographic province, including the Rio Grande rift (Hawley, 2005). The region is geologically complex with several prominent mountain ranges, including the Magdalena Mountains and San Mateo Mountains in the western part of the county, Chupadera Mesa in eastern Socorro County, and the Oscura and San Andres Mountains in the southeastern corner. Several structural basins associated with the Rio Grande rift are found in Socorro County, all of which have produced vertebrate fossils of Neogene age (Connell, et al., 2005). The southern Albuquerque basin in the northernmost portion of the county includes the Veguita,

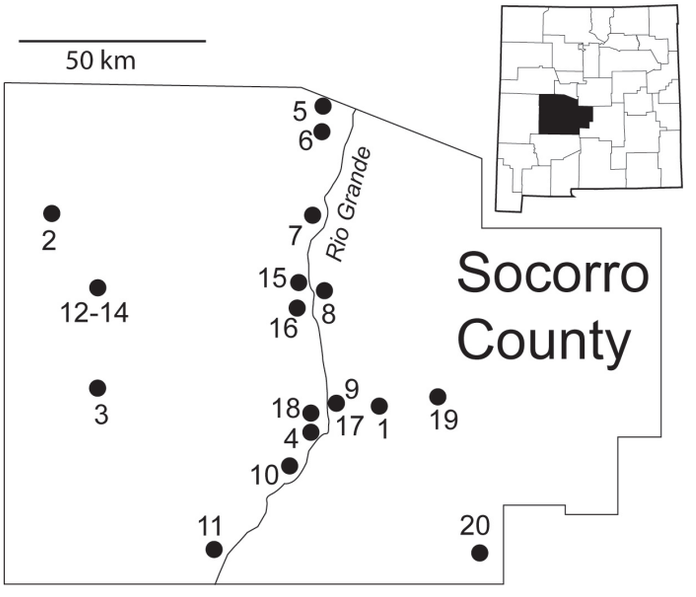

FIGURE 1. Map of Socorro County, New Mexico showing location of Cenozoic vertebrate localities. Numbers correspond to the following sites, Eocene: 1. Carthage; 2. Gallinas Mountains track site. Oligocene: 3. San Mateo Mountains track site. Miocene: 4. Bosque Del Apache. Pliocene: 5. Veguita; 6. Abeytas; 7. Sevilleta; 8. Arroyo de la Parida; 9. Fite Ranch; 10. Tiffany Canyon; 11. Silver Canyon. Pleistocene: 12. VLA; 13. White Lake; 14. Lake San Augustin; 15. Lemitar; 16. Socorro; 17. San Antonio; 18. Indian Well Wilderness; 19. Chupadera Arroyo; 20. Mockingbird Gap.

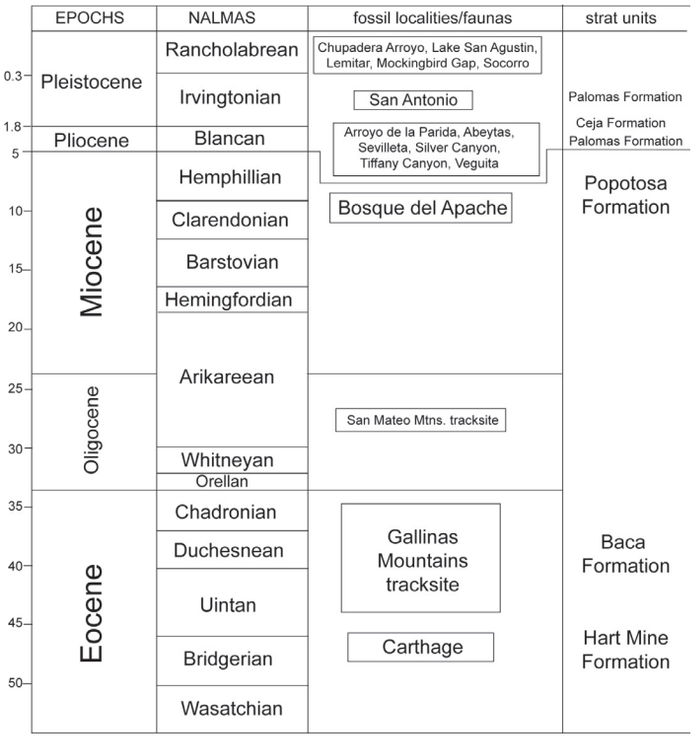

FIGURE 2. Stratigraphic column showing the geologic formations and chronologic distribution of Cenozoic vertebrate sites in Socorro County.

Abeytas and Sevilleta sites, derived from Pliocene sediments of the Ceja Formation, upper Santa Fe Group. Vertebrate sites from the Socorro basin include fossils from the Miocene Popotosa Formation, lower Santa Fe Group, on the Bosque del Apache National Wildlife Refuge (NWR) and the Pliocene Palomas Formation, upper Santa Fe Group, from Arroyo de la Parida. The Silver Canyon fauna occurs in the Palomas Formation in the San Marcial basin in southern Socorro County.

Most of the vertebrate fossils discussed here are deposited in the paleontology collection of the New Mexico Museum of Natural History (NMMNH). There are also several samples of fossils in the American Museum of Natural History (AMNH) in New York. Other abbreviations used in the text are: Local Fauna (LF); National Wildlife Refuge (NWR); New Mexico Bureau of Geology and Mineral Resources (NMBGMR); North American land-mammal "age" (NALMA); U. S. Bureau of Land management (BLM); and U. S. Fish and Wildlife Service (FWS). Tooth types and positions are indicated by upper case I, C, P, or M for upper incisors, canines, premolars, and molars, respectively, followed by a number (e.g., left P2 is a left upper second premolar), and lower case i, c, p, or m for lower teeth (e.g., right m3 is a right lower third molar). All measurements are in mm. The dental terminology for horse teeth follows MacFadden (1984). We use the traditional definition of the Pliocene-Pleistocene boundary at 1.8 Ma (e.g., Berggren et al., 1995), although others have recently moved this boundary back into the late Pliocene at 2.6 Ma, marking the onset of Northern Hemisphere glaciation (e.g. Walker and Geissman, 2009).

VERTEBRATE FOSSIL LOCALITIES FROM SOCORRO COUNTY

Eocene

Carthage

Near Carthage in Socorro County (Fig. 1, site 1), siliciclastic red beds overlie the coal-bearing Cretaceous strata mined there, so their Late Cretaceous or Cenozoic age was long certain, but fossils were needed to provide a more precise age determination. Gardner (1910, p. 454) reported the first direct evidence of their age—a fossil mammal tooth, "possibly *Palaeosyops*," a kind of middle Eocene brontothere (rhinoceros-like perissodactyl). Lucas et al. (1982) followed up on Gardner's discovery, documenting teeth of a middle Eocene (Bridgerian NALMA) brontothere they identified as cf. *Manteoceras*. Subsequent collecting near Carthage yielded unidentified turtle shell fragments, armor plates of a glyptosaurine lizard (cf. *Glyptosaurus*) and teeth and jaw fragments of various mammals: two kinds of rodent (*Reithroparamys huerfanensis* and *Leptotomus parvus*), many teeth of the brontothere *Telmatherium* (= *Manteoceras*; Mader, 1989, 2008), the horse *Orohippus pumilus* and a primate, *Notharctus tenebrosus* (Lucas, 1983, 1985, 1997; Lucas and Williamson, 1993; Lucas et al., 1982, 1983). These fossils come from a relatively thin stratigraphic interval about 15 m thick in strata long termed the Baca Formation. However, Lucas and Williamson (1993) named these strata the Hart Mine Formation, arguing that their relatively coarse-grained facies and deposition in a separate basin distinguishes them from the Baca Formation to the west. At Carthage, the Bridgerian vertebrate-fossil-bearing interval is about 130 meters above the base of the Hart Mine Formation (Lucas and Williamson, 1993; Lucas, 1997).

The fossil mammals from the Hart Mine Formation are the only definitively Bridgerian fossil mammal assemblage from New Mexico. A single bone from the basal Baca Formation in west-central New Mexico may be of Bridgerian age (Lucas, 1990), but the other Eocene mammal assemblages from New Mexico are older (Wasatchian) or younger (Uintan-Duchesnean-Chadronian) (Lucas et al., 1981; Lucas and Williamson, 1993; Lucas et al., 1997). These Eocene fossil mammals from New Mexico provide important age determinations of the synorogenic deposits of the last phase of the Laramide orogeny (Lucas, 1984; Cather, 2004).

The Eocene mammal assemblage from near Carthage provides remarkable temporal resolution, allowing the age of the fossiliferous strata to be determined as 46-46.5 Ma. Thus, the assemblage is clearly of Bridgerian age. The strongest evidence of this is that the brontothere *Telmatherium* has its lowest occurrence during the Bridgerian, whereas the horse *Orohippus* and the primate *Notharctus* have their highest occurrences in the Bridgerian (e.g., Robinson et al., 2004). Lucas (1997) and Lucas and Williamson (1993) suggested that the Bridgerian mammals from Carthage were of middle Bridgerian (Blacksforkian) age. However, during the last decade a more precise understanding of the temporal ranges of Bridgerian mammals has developed, and this indicates that a late Bridgerian (Twinbuttean) age can be assigned to the

fossil mammal assemblage from Carthage. Particularly significant is that it is now known that *Telmatherium* is an index fossil of the Twinbuttean (Robinson et al., 2004; Mader, 2008). The Twinbuttean age of the fossil mammals from Carthage indicates a numerical age of 46-46.5 Ma for the fossiliferous strata of the Hart Mine Formation (Robinson et al., 2004; Woodburne, 2004).

Gallinas Mountains track site

Lucas and Williamson (1993) reported mammal tracks in the Eocene Baca Formation from the eastern flank of the Gallinas Mountains, northwestern Socorro County (Fig. 1, site 2). There are 18 tracks preserved within a 35 m^2 area, occurring in a 2.75-m-thick, fine-grained, arkosic sandstone. The most complete of these consist of 10 tracks on a single block of sandstone preserved in convex hyporelief. The block containing these tracks was illustrated by Lucas and Williamson (1993, fig. 6), but was too large to collect. A plaster cast of these tracks is deposited in the New Mexico Museum of Natural History (NMMNH 3009). These tracks consist of trackways of three different individuals of artiodactyls referred to the ichnogenus *Pecoripeda* (Lucas and Williamson, 1993).

Oligocene

San Mateo Mountains track site

Ferguson (1986) reported an artiodactyl trackway preserved in a volcanic tuff of Oligocene age (~27 Ma) from the central San Mateo Mountains in southwestern Socorro County (Fig. 1, site 3). The only fossil from this site consists of a slab of tuff with two artiodactyl tracks preserved in convex hyporelief (Lucas, 2001, fig. 10). These tracks are on display in the New Mexico Bureau of Geology Museum at New Mexico Tech in Socorro.

Miocene

Sediments of the Miocene Popotosa Formation are widely distributed in Socorro County, particularly on two National Wildlife Refuges (NWR) under the jurisdiction of the U. S. Fish and Wildlife Service (USFWS), the Sevilleta NWR and Bosque del Apache NWR. The Popotosa Formation is the early closed-basin fill of the Rio Grande rift and as such spans different facies from coarse mountain-front fans to medial alluvial and eolian plains to basin-center playas. The Popotosa Formation spans a considerable period of time, from the early rift development in the early Oligocene (~ 30 Ma) to the development of the Rio Grande as a through-going stream in the early Pliocene (~ 4.5-5 Ma).

The Sevilleta NWR in northern Socorro County has produced a few vertebrate fossils from the Pliocene Ceja Formation (see below), but no fossils yet from the Popotosa Formation. However, based on the presence of late Miocene (Hemphillian NALMA) fossils from the Popotosa Formation in the Gabaldon Badlands in Valencia County just north of the study area, mostly derived from distal fan and playa deposits (Lozinsky and Tedford, 1991), and late Miocene fossils from this same unit on the Bosque del Apache NWR south of Sevilleta (see next paragraph), it is only a matter of time before Miocene vertebrates are found on the Sevilleta NWR. Gary Morgan and Dave Love are currently working under a permit from the USFWS to survey the Sevilleta NWR for vertebrate fossils.

Bosque del Apache

In February 2008, Dave Love and Richard Chamberlin from the NMBGMR and Colin Cikoski from New Mexico Tech discovered the associated upper and lower jaws of a late Miocene oreodont (Mammalia: Artiodactyla: Oreodontidae) in the wall of a small arroyo on the Bosque del Apache NWR, about 1 km south of the Bosque Visitor Center (Fig. 1, site 4; NMMNH site L-7475). The Popotosa Formation on the Bosque del Apache NWR mostly consists of coarse alluvial sediments transported some distance (at least 20 km) and large sand dunes with up to 15-m slip faces preserved. The oreodont was derived from a semi-indurated brown, fine sand in a thin alluvial channel below a more extensive conglomeratic channel. A thick eolian deposit occurs below the alluvium containing the oreodont.

A large field crew from the NMMNH, NMBGMR, and FWS collected the oreodont in March 2008. The fossil consists of a nearly complete skull and still-attached lower jaws and a partial postcranial skeleton, including the cervical, thoracic, lumbar, and sacral vertebrae, numerous ribs, parts of both front limbs, and a partial left hind limb (NMMNH 57623). This specimen has been tentatively identified as the late Miocene (late Clarendonian NALMA) species *Merychyus* (=*Ustatochoerus*) *major* (Bruce Lander, pers. comm.; Morgan et al., 2009), and represents one of the youngest oreodont records from New Mexico. The geologic age control on the Popotosa Formation on the Bosque del Apache NWR consists of a radioisotopic age of 8.57±0.26 million years on a basaltic lava flow that lies within the formation northwest of the Visitor Center and an age of about 16 Ma from a pumice in the base of section derived from an eruption of a rhyolitic dome west of Magdalena (C. Cikoski, pers. comm.). Although the stratigraphic relationships between the 8.6 Ma basalt flow and the oreodont site are still unclear, the biostratigraphy of *Merychyus major* suggests that a late Miocene age (~8-10 Ma) is most likely (Lander, pers. comm.). The oreodont is only briefly mentioned here, as this important find is being described elsewhere (Morgan et al., 2009).

Pliocene

Pliocene (Blancan NALMA) vertebrate sites in Socorro County are from strata of the upper Santa Fe Group in the Rio Grande and Rio Puerco valleys. They are known from the Ceja Formation in the southern Albuquerque basin, including the Veguita, Abeytas, and Sevilleta sites, and from the Palomas Formation in the Socorro and San Marcial basins in the central and southern portions of the county, including the Arroyo de la Parida, Fite Ranch, Tiffany Canyon, and Silver Canyon sites. In the Socorro County area of the southern Albuquerque Basin, the Ceja Formation includes two major lithofacies assemblages: a basin-floor

fluvial facies dominated by ancestral Rio Puerco deposits and a piedmont-alluvial facies derived from bordering highlands to the west and north. Ancestral Puerco deposits intertongue eastward with axial-river facies of the ancestral Rio Grande that form the bulk of the Sierra Ladrones Formation east of the inner Rio Grande (Belen) Valley. Correlative upper Santa Fe, axial-river and piedmont-alluvial deposits in Rio Grande rift basins to the south (Socorro-San Marcial-Palomas basins) comprise the Palomas Formation (Lozinsky and Hawley, 1986; Mack et al., 1998; Morgan et al. 2008a). Recent refinements in Santa Fe Group nomenclature in the Albuquerque Basin are discussed by Connell (2008); and Connell and others (2005) review Late Cenozoic drainage-system evolution throughout the rift region.

Veguita

The Veguita site (Fig. 1, site 5) occurs in the Ceja Formation about 1 km east of the Rio Puerco and 10 km northwest of Veguita in northernmost Socorro County (NMMNH site L-2941) in the southern Albuquerque basin. The only fossil from Veguita is a skull fragment of a horse derived from a sandy unit, with gravelly units above and below that contained pebbles of obsidian. The fossil consists of maxillary fragment with left P2-M3 of a large horse, tentatively referred to *Equus scotti* (NMMNH P-25563; Figs. 3C, D). The bone of the maxilla is in very poor condition, so the following description is based entirely on the dentition. The teeth are characterized by their large size and complicated enamel pattern of the fossettes (measurements in Table 1). The occlusal length of P2-M3 is 201 mm. The upper premolars (P2-P4) are generally similar to one another, with only a few minor differences. The P2 has an elongated anterostyle that is absent on the two posterior premolars. All three premolars have a small pli caballin and hypoconal groove. The protocone is short and broad on P2 and somewhat more elongated and rather broad on P3-P4. The lingual margin of the protocone is preserved only on the P4, which shows a slight indentation. On the P2, the prefossette has two enamel crenulations or loops on both the anterior and posterior margins; the postfossette has one crenulation on the anterior and posterior margins. On the P3 and P4, the prefossette has one enamel crenulation on the anterior margin and four on the posterior margin; the postfossette has three crenulations on the anterior margin and two posteriorly. The M1 and M2 both have a very small pli caballin and hypoconal groove. The protocone is rather elongated and broad with a weak lingual indentation. The fossettes on M1 and M2 are complicated, especially the posterior margin of the prefossette (6-7 enamel crenulations) and anterior margin of the postfossette (5 enamel crenulations). The occlusal surface of the M3 is damaged, but this tooth looks similar to the M1 and M2. All of the upper cheek teeth also have a very complicated enamel pattern on the labial margins of the prefossette and postfossette consisting of tiny crenulations.

The P2 from Veguita is similar in size and dental morphology to the same tooth of a large *Equus* from the Tiffany Canyon site (see below). *Equus scotti* is the common large horse in New Mexico faunas ranging in age from late early (= medial) Blancan through the early Irvingtonian (Morgan and Lucas, 2003). The

TABLE 1. Measurements of *Equus* teeth from Pliocene and Pleistocene sites in Socorro County, New Mexico. See text for more complete description of specimens. L and R refer to left and right. Tooth positions are indicated by upper case P or M for upper premolars and molars, respectively, and lower case i, p, or m for lower incisors, premolars and molars. All measurements are in mm. Missing measurements are indicated by "—"

Locality, Species, Catalog Number	Tooth Position	Antero-posterior Length	Transverse Width	Crown Height
Veguita	LP2	45.2	29.4	47.4
Equus cf. *E. scotti*	LP3	32.5	32.2	54.5
NMMNH 25563	LP4	31.8	33.1	62.7
	LM1	28.6	31.6	56.1
	LM2	29.4	30.1	63.2
	LM3	35.6	26.8	57.5
Sevilleta, *Equus* sp.				
NMMNH 31485	RM3	28.7	—	53.1
Lemitar				
Equus cf. *E. scotti*	Li1	10.3	19.1	—
NMMNH 57519[1]	Ri1	10.1	18.7	—
	Li2	9.7	19.9	—
	Ri2	9.6	19.5	—
	Ri3	27.5	13.6	—
	Lp2	39.5	17.0	80
	Rp2	39.8	17.4	—
	Rp3	35.4	19.3	104
	Rp4	34.8	17.4	—
	Rm1	31.7	16.7	—
	Rm2	33.7	16.3	—
	Rm3	36.2	13.5	—
Tiffany Canyon				
Equus cf. *E. scotti*				
NMMNH 55099	RP2	40.9	28.5	64.4
NMMNH 57521	RM1/M2	31.4[2] (28.7, 25.8)	—	76.4
Mockingbird Gap	LP4	25.6	28.6	63.3
Equus conversidens	LM1	—	—	64.9
NMMNH 43793	RM1	26.2	—	62.0
	LM2	25.1	26.9	73.8
	RM2	26.1	26.7	70.7
	RM3	—	22.7	74.1

[1] Crown heights could only be taken on the left p2 and right p3. All other teeth are completely contained within the dentary and their crown height could not be measured. Li3 is unerupted and could not be measured.

[2] NMMNH 57521 is an unworn (probably unerupted) M1 or M2. Unworn teeth are longer in the anteroposterior dimension than more heavily worn teeth in which the anterior and posterior margins are essentially parallel. The first measurement (31.4 mm) was taken at the occlusal surface of the tooth; the second measurement (28.7) was taken ~25 mm below the crown; the third measurement (25.8) was taken ~50 mm below the crown.

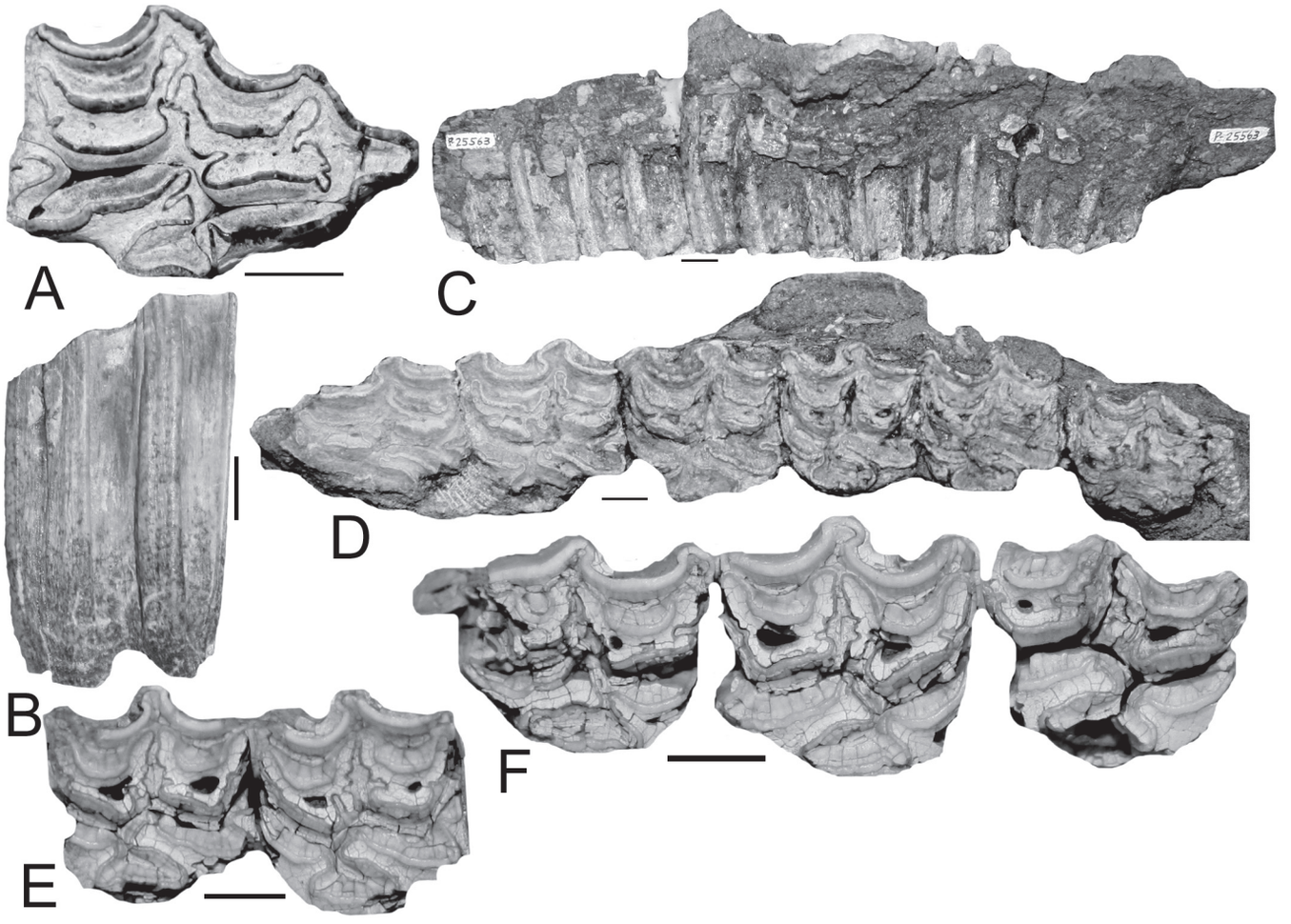

FIGURE 3. Photographs of upper teeth of *Equus* from Pliocene and Pleistocene sites in Socorro County, New Mexico. A. occlusal view and B. lateral view of NMMNH 55099, right P2 of *Equus* cf. *E. scotti* from Tiffany Canyon (site L-6951). C. lateral view and D. occlusal view of NMMNH 25563, left P2-M3 of *Equus* cf. *E. scotti* from Veguita (site L-2941). E. occlusal view of of left M1-M2 and F. occlusal view of right M1-M3, NMMNH 43793, *Equus conversidens* from Mockingbird Gap (site L-4988). All scale bars represent 1 cm.

only feature that distinguishes the Veguita upper dentition from typical teeth of *E. scotti* is the rather broad protocones with a weak lingual indentation. This same difference has been observed in other Blancan specimens from New Mexico identified as *E. scotti* (e.g., Morgan et al., 2008b), thus the tentative referral to *E.* cf. *E. scotii*. The Veguita fossil was found in the obsidian-bearing interval of the Ceja Formation, indicating an age younger than 3 Ma based on a K-Ar date on the Grants obsidian of 3.2 ± 0.3 Ma (Lipman and Mehnert, 1980). A Blancan age for this horse is likely considering that most sites from the Ceja Formation in the southern Albuquerque basin produce Blancan mammals (Morgan and Lucas, 2000, 2003).

Abeytas

In April 2006, Dave Love collected a partial metatarsal of a large *Equus* from a site in the Ceja Formation in the Rio Puerco Valley about 5 km northwest of Abeytas in the southern Albuquerque basin, northern Socorro County (NMMNH site L-6950; Fig. 1, site 6). The specimen consists of the proximal two-thirds of a metatarsal of a large species of *Equus* (NMMNH 55098; Figs. 4G, H). Measurements of this specimen (in mm) are: proximal width, 55.3; proximal depth, 44.7; minimum shaft width, 37.2. The length of the metatarsal as preserved is 235 mm, and there is no evidence of widening toward the distal end, suggesting that it may represent a stilt-legged horse (*E. francisci* group of Winans, 1989). Although this fossil is incomplete and the total length is unknown, the large size and apparent elongated shaft are suggestive of the large, stilt-legged species *E. calobatus*, which has been reported from several New Mexico Blancan sites (Morgan and Lucas, 2000, 2003; Morgan et al., 2008b). However, even a tentative referral to *E. calobatus* is unjustified based on the incomplete nature of the Abeytas specimen. Like the horse skull fragment from Veguita, the Abeytas horse metatarsal was found within the obsidian-bearing interval of the Ceja Formation, indicating an age less than 3 Ma.

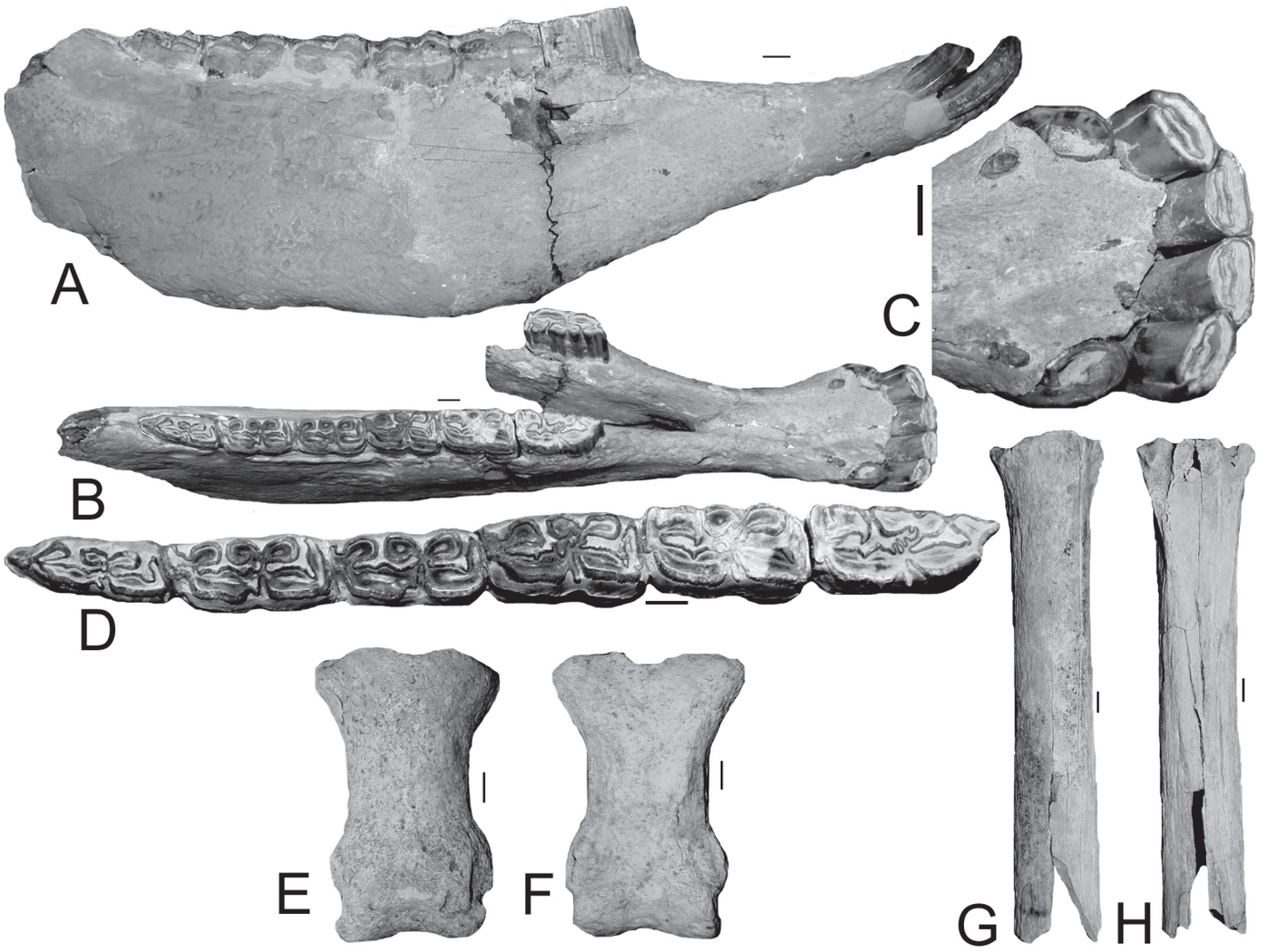

FIGURE 4. Photographs of a lower jaw and postcranial elements of *Equus* from Pliocene and Pleistocene sites in Socorro County, New Mexico. A-D, NMMNH 57519, partial right and left dentaries of *Equus* cf. *E. scotti* from Lemitar (site L-3356). A. lateral view of right dentary; B. occlusal view of dentaries with right i1-i3 and p2-m3 and left i1-i3 and p2; C. occlusal view of mandibular symphysis with right and left i1-i3; D. occlusal view of right p2-m3. E. anterior view and F. posterior view of NMMNH 30494, proximal phalanx of large *Equus* from Sevilleta (site L-4257). G. anterior view and H. posterior view of NMMNH 55098, proximal two thirds of metatarsal of large *Equus* from Abeytas (site L-6950). All scale bars represent 1 cm.

Sevilleta

Denny (1940) reported Plio-Pleistocene fossils from sands and gravels, probably derived from the Ceja Formation, from bluffs west of the Rio Grande and north of the Rio Salado in the southernmost portion of the Albuquerque basin near San Acacia in northern Socorro County (Fig. 1, site 7). This site is located on land now included within the Sevilleta NWR. The fauna reported by Denny (1940) consists of the gomphothere *Stegomastodon* and an undetermined species of *Equus*. We have not been able to relocate Denny's fossils, so the identifications are taken from his paper and are considered tentative.

We have collected several Pliocene fossils from outcrops in this same general area, north of the Rio Salado and southeast of the Sevilleta NWR headquarters (NMMNH sites L-4257, L-4440, L-4441). These deposits are derived from the ancestral Rio Puerco and correlate with the Ceja Formation. We found teeth and postcranial elements representing two species of *Equus*, one small and the other much larger. Neither horse is represented by complete enough material for a species-level identification. The smaller species of *Equus* is represented by an M3 and a metatarsal shaft. The right M3 (NMMNH 31485; Table 1) has a narrow, elongated protocone lacking a lingual indentation. A small pli caballin is present. The fossettes are simple, with a single enamel fold on both the anterior and posterior margins of the prefossette and postfossette. The Sevilleta tooth is considerably smaller and has a simpler enamel pattern than an M3 tentatively referred to *E. scotti* from Veguita (see above and Table 1). The simple enamel of the fossettes and the elongated protocone are similar to M3s referred to the small species *E. cumminsii* from the early Blancan Arroyo de la Parida LF (Morgan et al., 2008a) and the late Blancan Blanco LF in Texas (Dalquest, 1975). However, the Parida

and Blanco M3s (anteroposterior lengths of 25.7, 24.0, respectively) are even smaller than the Sevilleta tooth (anteroposterior length, 28.7). A partial metatarsal (NMMNH 31486) lacks both the proximal and distal ends, but the shape of the shaft clearly identifies this specimen as an equid. It is much too robust for *Nannippus* and thus appears to represent a small *Equus*. The minimum shaft width is 31.1 mm, which is considerably smaller than the metatarsal of a large *Equus* from Abeytas (see above) with a minimum shaft width of 37.2.

A large *Equus* is represented in the Sevilleta LF by a large, robust proximal phalanx (NMMNH 30494; Figs. 4E, F). Measurements of this phalanx (in mm) are: total length, 91.5; proximal width, 62.3; proximal depth, 39.8; minimum shaft width, 38.3; distal width, 48.5; distal depth, 32.7. This toe is slightly larger than the largest of five proximal phalanges of *Equus* from Arroyo de la Parida (Morgan et al., 2008a). There are two large species of *Equus* from Arroyo de la Parida, one referred to *E. scotti* and the other similar to the stilt-legged species *E. calobatus* (Morgan et al., 2008a). The Sevilleta vertebrate assemblage, consisting of two unidentified species of *Equus* and the proboscidean *Stegomastodon*, indicates an age somewhere between early Blancan and early Irvingtonian (~1-5 Ma). However, all other well-dated vertebrate faunas from the Ceja Formation are Blancan in age (Morgan and Lucas, 2003).

Arroyo de la Parida

The Arroyo de la Parida LF consists of Pliocene (Blancan) vertebrate fossils derived from more than 30 localities in the Palomas Formation, located 1-2 km east of the Rio Grande and about 8-12 km northeast of Socorro, Socorro County (Fig. 1, site 8). The fossils occur in a 70 m thick sequence of sands and gravels that constitute the axial river (ancestral Rio Grande) facies of the Palomas Formation. The strata in the vicinity of Arroyo de la Parida are located at the northern end of the Socorro basin, representing one of the northernmost occurrences of the Palomas Formation. Fossils were collected from a narrow north-south-trending outcrop belt of the Palomas Formation about 1 km in breadth, extending from Arroyo de la Parida north almost 5 km to Arroyo del Veranito, on land administered by the U. S. Bureau of Land Management (BLM).

Vertebrate fossils were first found in Arroyo de la Parida by Needham (1936), who reported a complete pair of lower jaws of the gomphotheriid proboscidean *Rhynchotherium* and a lower molar of the horse *Plesippus* (= *Dolichohippus*, now considered a subgenus of *Equus*). Tedford (1981) briefly reviewed a sample of fossils collected from the Arroyo de la Parida area in 1953 by Curt Teichert, including three species of horses, *Equus simplicidens*, *E.* cf. *E. cumminsii*, and *E.* cf. *E. scotti*, the small antilocaprid *Capromeryx*, and the gomphothere *Stegomastodon*. Lucas and Morgan (1996, 2005) described and illustrated the mandibles of *Rhynchotherium*, referring them to the late Blancan species *R. falconeri*. Lucas and Morgan (2008) referred the *Rhynchotherium* from Arroyo de la Parida to the species *R. tlascalae*. Morgan et al. (2008a) reviewed the late early Blancan vertebrate fauna from Arroyo de la Parida, including fossils collected by Needham, Teichert, the NMBGMR, and the NMMNH. The Arroyo de la Parida LF consists of 14 species, including (Morgan et al., 2008a; Lucas and Morgan, 2008) the land tortoise *Hesperotestudo* and 13 mammals: the ground sloth *Megalonyx* cf. *M. leptostomus*; an indeterminate species of medium-sized sabertooth cat; an indeterminate species of rabbit; four species of horses, *Equus* cf. *E. cumminsii*, *E. scotti*, *E. simplicidens*, and an unidentified species of *Equus*; the large camelid *Camelops* cf. *C. traviswhitei*; the small llama *Hemiauchenia* sp.; the small pronghorn antilocaprid *Capromeryx* sp.; and two gomphotheriid proboscideans, *Rhynchotherium tlascalae* and *Stegomastodon* sp.

The Arroyo de la Parida LF consists of a fairly typical faunal assemblage found in New Mexico Blancan sites (Morgan and Lucas, 2003), mostly consisting of large grazing ungulates and dominated by horses of the genus *Equus*. Five species of mammals from the Arroyo de la Parida LF are restricted to the Blancan: *Megalonyx leptostomus*, *Equus simplicidens*, *E. cumminsii*, *Camelops traviswhitei*, and *Rhynchotherium tlascalae*. The Arroyo de la Parida LF is interpreted to be late early Blancan in age (3.0-3.6 Ma). A very early Blancan age is ruled out by the presence of *Camelops*, *Equus scotti*, and *E. simplicidens*, whereas a late Blancan age is excluded by the absence of Interchange mammals. Based on the presence of *Rhynchotherium*, which became extinct in the latest Blancan, Arroyo de la Parida is older than 2.2 Ma (Lindsay et al., 1984; Lucas and Morgan, 2008). The diversity of *Equus*, including four and possibly five species distributed among three subgenera, suggests that the Arroyo de la Parida LF more likely belongs in the younger half of the time range cited above (i.e., younger than ~3.2 Ma). This fauna is similar in age to a number of other late early Blancan faunas (= medial Blancan of Tedford, 1981 and Morgan and Lucas, 2003) from deposits of the Santa Fe Group in the Rio Grande Valley in the central and southern part of New Mexico, including: Pajarito, Belen, and Los Lunas from the Ceja Formation in the southern Albuquerque basin in Bernalillo and Valencia counties; Elephant Butte Lake and Cuchillo Negro Creek from the Palomas Formation near Truth or Consequences in Sierra County; and Tonuco Mountain from the Camp Rice Formation north of Las Cruces in Doña Ana County (Morgan et al., 1998; Morgan and Lucas, 2000, 2003).

Fite Ranch

Tedford (1981) reported postcranial bones of *Equus* and *Camelops* collected by George Pearce in 1953 from the Dean Fite Ranch near San Antonio, central Socorro County (Fig. 1, site 9). We have examined these specimens in the AMNH collection, consisting of an astragalus of *Equus* and the proximal two-thirds of a metatarsal of *Camelops*. Neither of these specimens is age diagnostic beyond indicating either a Pliocene or Pleistocene age; however, a Blancan age is indicated by their occurrence in the Palomas Formation.

Tiffany Canyon

Tiffany Canyon is located on the Armendaris Ranch just south of Bosque Del Apache NWR, about 0.5 to 1 km east of NM Route

1, south-central Socorro County (NMMNH sites L-6951, L-7668, L-7669; Fig. 1, site 10). Ancestral Rio Grande deposits referable to the Palomas Formation crop out for a distance of about 500 m in the south bank of Tiffany Canyon. The stratigraphic section of these deposits, consisting of brown, cross-bedded, fine- to medium-grained sand and gravel, ranges from less than 5 m in thickness to almost 10 m. Ancestral Rio Grande deposits are older than 850 ka, the youngest date for the top of these river deposits, suggesting a lower Pleistocene or more likely Pliocene age for the strata exposed in Tiffany Canyon.

Steve Cather first found a fossil in Tiffany Canyon in the early 1990s, and in 2005 he collected an upper premolar of a large *Equus*. In October 2008, Colin Cikoski, Dave Love, and Gary Morgan visited Tiffany Canyon and collected additional fossils, including an upper molar and several postcranial elements of *Equus*. The most diagnostic fossil from Tiffany Canyon is a well-preserved right P2 of *Equus* (NMMNH 55099; Figs. 3A, B; Table 1). This tooth has a rather narrow, elongated anterostyle. The protocone is short and broad, with a weak lingual indentation. A well-developed pli caballin is present, as is a strong hypoconal groove that extends nearly to the base of the crown. The fossettes are not particularly complicated. The prefossette has two enamel folds on both the anterior and posterior margins, whereas the postfossette has a single enamel crenulation on the anterior and posterior margins. This P2 is somewhat smaller than the P2 described above from Veguita (anteroposterior length 40.9, 45.2, respectively). Otherwise, the characters of the protocone, pli caballin, hypoconal groove, and complication of the fossettes are very similar in the two teeth. A right M1 or M2 of *Equus* from Tiffany Canyon is unerupted and unworn, so most enamel features of the crown are not visible (NMMNH 57521; Table 1). There is a strong hypoconal groove that extends nearly to the base of the tooth. The protocone is rather narrow and elongated, but lacks a lingual indentation. Both of the upper teeth from Tiffany Canyon are from large horses tentatively referred to *E. scotti*. This is the common large horse in New Mexico faunas from the late early Blancan through the early Irvingtonian. A Blancan age is suggested for the Tiffany Canyon LF by the occurrence of the fossils in the Palomas Formation.

Silver Canyon

Gary Morgan, Mike O'Neill, and Brenda Wilkinson collected a small sample of fossils in 1998 from the Palomas Formation near Silver Canyon in the San Marcial basin just west of the northern end of Elephant Butte Lake in southernmost Socorro County (NMMNH site L-3682; Fig. 1, site 11). The Silver Canyon LF consists of three taxa of mammals, including the horse *Equus*, the rodent *Neotoma*, and an unidentified gomphotheriid proboscidean (Morgan and Lucas, 2003). A large *Equus* is represented in the fauna only by postcranial remains. A mandible of a fairly large rodent appears to referable to the woodrat *Neotoma*, although the teeth are too worn for a species-level identification. The proboscidean fossils consist of postcranial bones, as well as a number of tooth fragments identifiable only as Gomphotheriidae. The age of this fauna cannot be determined on the basis of the fossil material currently known, although a Blancan age is most likely considering that all other vertebrate faunas so far known from the Palomas Formation are Blancan. The Silver Canyon fauna is certainly early Pleistocene (early Irvingtonian NALMA) or older, as gomphotheriid proboscideans are unknown in the southwestern United States from younger faunas (Morgan and Lucas, 2003).

PLEISTOCENE

Pleistocene sites are widely distributed throughout Socorro County (Fig. 1), including the Rio Grande Valley (Lemitar, Socorro, San Antonio), the Plains of San Agustín in the northwestern part of the county (VLA, White Lake, Lake San Agustín), and several sites in the eastern and southeastern part of the county (Chupadera Arroyo, Mockingbird Gap). Only the San Antonio site occurs in a named geologic formation, the Palomas Formation of lower Pleistocene age. The rest of the sites are from unnamed or undifferentiated sediments (Quaternary alluvium, QAL on most geologic maps).

VLA

This site occurs on the grounds of the Very Large Array (VLA), a series of radiotelescopes operated by the National Radio Astronomy Observatory (NRAO) on the Plains of San Agustín, about 35 km west of Magdalena in western Socorro County (NMMNH site L 3901; Fig. 1, site 12). Dave Love discovered this site and alerted Robert Hjellming of the NRAO who in turn contacted the NMMNH. In the mid 1990s, a NMMNH field crew collected late Pleistocene fossils from the VLA site, about 100 m north of the visitor's center. The fossils are derived from an exposure of grayish, fine-grained sands and silty sands that is about 10 m wide from north to south, but extends several hundred meters east to west. These sediments represent lacustrine deposits formed near the shoreline of a large lake complex, Lake San Agustín, that occupied much of the current Plains of San Agustín during middle and late Pleistocene time (Allen, 2005). The VLA site is located on the southwestern shore of the White Lake basin, the northeasternmost of the three major lake basins that comprised the larger Pleistocene Lake San Agustín (Weber, 1994). The majority of fossils from the VLA site are bones and teeth of small vertebrates, but there are also mammoth tooth fragments, as well as a sample of freshwater and terrestrial mollusks. The vertebrate fauna from the VLA site consists of nine species: two large mammals, the mammoth *Mammuthus columbi* and an unidentified camelid, and seven species of small vertebrates, a small bony fish, the frog *Rana*, the salamander *Ambystoma*, the mud turtle *Kinosternon*, a duck (Anatidae), the vole *Microtus*, and the muskrat *Ondatra*. The majority of these are aquatic species often associated with Pleistocene deposits of freshwater origin (Harris, 1993; Morgan and Lucas, 2005). A late Pleistocene (late Rancholabrean NALMA) age for the VLA fauna is indicated by several published radiocarbon dates, ranging from 11,455-23,070 years Before Present, on sediments from the upper 5 m of lacustrine strata of Lake San Agustín, derived from cores in the Horse Springs basin about 50 km southwest of the VLA site

(Markgraf et al., 1983). Morgan and Lucas (2005) combined the VLA, White Lake, and Lake San Agustín sites as the Lake San Agustín Fauna (see below).

White Lake

The White Lake site is derived from strata along the northeastern shore of the White Lake basin, about 5 km northeast of the VLA site, including roadcuts both north and south of US Route 60 and from another site 0.5 km north of US 60 (NMMNH site L-6735; Fig. 1, site 13). The White Lake site was originally discovered by Robert Weber of the NMBGMR, who contacted Art Harris at the University of Texas El Paso where the fossils from this site are now housed (Harris, 1993). Weber observed a mammoth tusk that came from the lake beds near the turnoff to the VLA, in the same general vicinity as L-6735 (pers. comm. to Dave Love). The whereabouts of this tusk are unknown, although it probably was never collected. The original White Lake site just north of US 60 was collected by Robert Weber and Art Harris, whereas fossils from exposures along US 60 were collected by Gary Morgan and Richard White in 2004 and 2005. The sediments from these sites are very similar to those from the VLA site, consisting of grayish, lacustrine, fine-grained sands and silts. With the exception of mammoth, the White Lake LF consists of extant vertebrates, mostly small taxa, including 11 species (from Harris, 1993; Morgan and Lucas, 2005; this paper): four amphibians (the toad *Bufo*, the spadefoot toad *Scaphiopus*, *Rana*, and *Ambystoma*), three water birds (a grebe, the duck *Anas*, and goose *Branta*), three rodents (*Peromyscus* sp., *Microtus pennsylvanicus*, and *Ondatra zibethicus*), and the rabbit *Sylvilagus*. The site also contains abundant gastropods, including both freshwater and terrestrial species. The vertebrate faunas from White Lake and VLA are very similar, and both sites are late Pleistocene in age based on the radiocarbon dates cited above.

Lake San Agustín

The Lake San Agustín Fauna (Fig. 1, site 14) was collected from sites that are widely distributed throughout the White Lake basin, Horse Springs basin, and C-N basin, the three basins that comprised Pleistocene Lake San Agustín (Weber, 1994; Robert Weber, in litt, 17 March 2002). Weber (1994) did not provide specific locality data for his Lake San Agustín Fauna, which included multiple sites. Therefore, his list of the Lake San Agustín Fauna may include fossils discussed above under the White Lake LF, but not the VLA LF, which was not discovered until the late 1990s. The late Pleistocene (Rancholabrean) fauna from Lake San Agustín, includes (Weber, 1994): horse (*Equus*), camel (*Camelops*?), bison (*Bison*), mammoth (*Mammuthus*), short-faced bear (*Arctodus*), rabbit, ground squirrel, muskrat (*Ondatra*), and vole (*Microtus*), as well as fish, frog, salamander, water birds, and owl. The small vertebrates from Lake San Agustín are very similar to those from VLA and White Lake described above, with all three faunas containing frog, salamander, water birds, muskrat, and vole. Three of the large mammals Weber (1994) identified from the Lake San Agustín fauna, *Arctodus*, *Equus*, and *Bison*, as well as a ground squirrel and an owl, are not present in the VLA or White Lake sites. On the basis of their close proximity and similarity in depositional history and age, Morgan and Lucas (2005) combined the vertebrate assemblages from the Lake San Agustín, VLA, and White Lake sites as the Lake San Agustín Fauna.

Lemitar

The Lemitar site (NMMNH L-3356; Fig. 1, site 15) is located in a gravel pit just east of Interstate Highway 25, 2 km northwest of Lemitar and 3 km west of the Rio Grande in central Socorro County. The only fossil unequivocally collected from the Lemitar gravel pit is a left dentary with m2-m3 (NMMNH 25098) of the American mastodon *Mammut americanum*, previously described and illustrated by Lucas and Morgan (1997, 2005). The jaw was found by Mrs. P. V. Haddock of Socorro, who donated it to the New Mexico Bureau of Mines in 1974. The Bureau of Mines paleontology collection, including the Lemitar mastodon jaw, was transferred to the NMMNH in 1994. The mandible was found embedded in a coarse gravel with rounded quartz pebbles characteristic of axial river gravels of the ancestral Rio Grande. The outer surface of the mandible and teeth were firmly encrusted with a shell of limonite cement, which was removed during preparation (notes of R. H. Weber). Weber also collected a partial *Equus* tooth in this same pit, from sands and gravels of a late Pleistocene river channel deposit. The whereabouts of this tooth are unknown. Both axial river gravels of the ancestral Rio Grande of presumed Pliocene or lower Pleistocene age and upper Pleistocene channel deposits are present in the Lemitar pit. It is unclear from which of these two units the mastodon jaw was collected. All other records of *Mammut americanum* from New Mexico are from late Pleistocene (Rancholabrean) faunas (Lucas and Morgan, 1997, 2005; Morgan and Lucas, 2005).

A third fossil attributed to the Lemitar gravel pit consists of associated right and left dentaries of a large horse (*Equus*). This fossil has an unusual provenance. The jaws were found by an electrician who collected them in pieces over several days from construction gravels at an apartment building in downtown Socorro (Wolberg et al., 1984). An investigation by Donald Wolberg, a paleontologist formerly with the NMBGMR, determined that the load of gravel containing the horse jaws probably came from a gravel pit in the Lemitar area, located just a few miles north of Socorro. The horse jaw is broken in several places revealing a layer of goldish-colored limonite cement around the roots of the teeth. This unusual limonite cement also occurs on the mastodon jaw discussed in the previous paragraph, further indicating the derivation of the horse jaw from the Lemitar gravel pit (NMMNH site L-3356). However, because the horse jaw was not recovered from the gravel pit, its locality must be considered uncertain.

The Lemitar horse consists of right and left dentaries with right i1-i3 and p2-m3 and left i1-3 and p2 from a large species tentatively referred to *Equus* cf. *E. scotti* (NMMNH 57519; Figs. 4A-D). Dental measurements are provided in Table 1. Other measurements (in mm) are: occlusal length of p2-m3; 208; length of diastema (i3-p2), 119.2; maximum breadth across lower incisors at i3, 63.2; depth of dentary at anterior edge of p2, 70.5. The p2

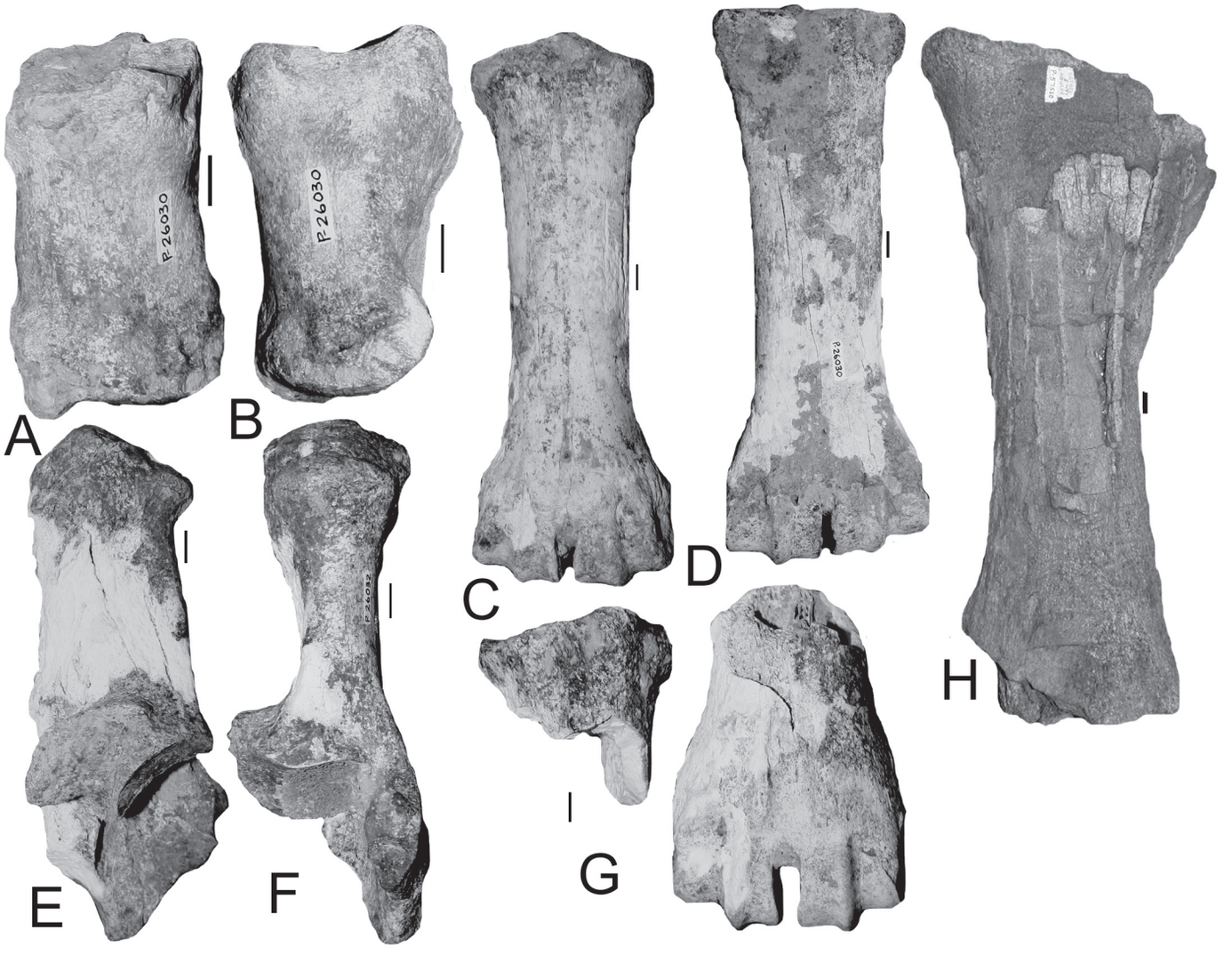

FIGURE 5. Photographs of *Bison* and proboscidean postcranial elements from Pleistocene sites in Socorro County, New Mexico. A. anterior view and B. posterior view of NMMNH 26030, a proximal phalanx of *Bison* from Socorro (L-3113). C. anterior view and D. posterior view of NMMNH 26030, a metacarpal of *Bison* from Socorro (L-3113). E. medial view and F. dorsal view of NMMNH 26032, a left calcaneum of *Bison* from Socorro (L-3113). G. anterior view of NMMNH 26031, a partial metatarsal (midshaft missing) of *Bison* from Socorro (L-3113). H. anterior view of NMMNH 57520, a juvenile left femur of a proboscidean from Indian Well Wilderness (site L-7714). All scale bars represent 1 cm.

has a large pli caballinid, a very small linguaflexid separating the metaconid and metastylid, and an entoflexid with a highly crenulated labial margin with six enamel folds. The p3 and p4 have a large paralophid that extends across the entire anterior margin of the tooth, a large pli caballinid, and a sharply V-shaped linguaflexid that is better developed than on p2. The labial margin of the entoflexid on p3 and p4 has four enamel folds. All three lower premolars have a short, narrow entoflexid that does not enter the isthmus. The m1 and m2 share many characters with the p3 and p4, including a strong paralophid extending across the anterior margin, a short narrow entoflexid that does not enter the isthmus, and a deep V-shaped linguaflexid. The pli caballinid is small on m1 and m2, larger on m3. The labial margin of the entoflexid is simple on the lower molars, with one or two small enamel crenulations.

Socorro

In 1995, a NMMNH crew collected several Pleistocene fossils from the Hefner gravel pit about 2 km north of Socorro (NMMNH site L-3113; Fig. 1, site 16), Socorro County. The fossils were collected from a brown, silty sand about 1 m above an undated volcanic ash in the west wall of the gravel pit. Attempts to date this ash, including both traditional Ar/Ar dating and chemical fingerprinting, were unsuccessful. The fauna consists of a partial tooth of *Equus* and a horn core fragment and several postcranial bones of *Bison* (Morgan and Lucas, 2005). The horse tooth is a heavily worn, partial left P2, lacking the posterior portion of the metacone (NMMNH 26035). The P2 is from a large species of *Equus* based on an anteroposterior length of 41.8 mm for the

partial tooth. Although the Socorro tooth is too incomplete for a species-level identification, *E. niobrarensis* is the typical large horse found in New Mexico Rancholabrean faunas (Morgan and Lucas, 2005).

The Socorro LF contains several complete and well-preserved postcranial elements of *Bison*, as well as a small fragment of a bison horn core. The bison bones are all heavily mineralized and some are partially coated with a thin layer of cemented, brown silty sand. Although most of the *Bison* bones from site L-3113 are cataloged with separate numbers, they were found in a small area and there is no duplication of elements, suggesting the fossils may represent a single individual. *Bison* specimens present in the sample include: horn core fragment (NMMNH 26029); complete left metacarpal, associated proximal phalanx, and possibly associated distal end of right radius-ulna (NMMNH 26030; Figs. 5A-D); associated proximal and distal ends of left metatarsal with shaft missing (NMMNH 26031; Fig. 5G); left calcaneum (NMMNH 26032; Figs. 5E, F); partial left cubonavicular (NMMNH 26033). Measurements of the most complete postcranial elements are presented in Table 2.

The radius-ulna, metacarpal, calcaneum, and proximal phalanx from Socorro are very similar in size and morphological characters to the same elements of *Bison* from the Jal LF in Lea County, southeastern New Mexico (Morgan and Lucas, 2006). The length of the metacarpal from Socorro (221 mm) is very near the mean of a series of 28 metacarpals (mean, 222 mm; observed range, 211-238 mm) of the extinct species *Bison antiquus* (McDonald, 1981, table 22), and is smaller than a series of 16 metacarpals (observed range, 234-264 mm) of the extinct species *B. latifrons* (McDonald, 1981, table 18). However, the Socorro *Bison* sample lacks an identifiable horn core, and thus can only be referred to *Bison* sp. *Bison* is the diagnostic genus for North American Rancholabrean faunas, thus establishing a late Pleistocene age for the Socorro LF (Bell et al., 2004).

San Antonio

Needham (1936) reported several postcranial bones of the wild turkey *Meleagris gallopavo* from a bluff about 4.5 km northeast of San Antonio, 3 km east of the Rio Grande, and 2 km north of US Route 380 in central Socorro County (Fig. 1, site 17). Needham (1936, p. 537) described the stratigraphy where the turkey fossils were found as… "a bed of pumicite…underlain by some thirty feet of light-colored gravel and sand and buff silt, typical of the Santa Fe Formation as developed east of the Rio Grande near Socorro" (e.g., Arroyo de la Parida). Gary Morgan and David Love visited the San Antonio site in 2008, which has been mined in recent years to remove the volcanic ash for stonewashing blue jeans. According to John Hawley (pers. comm. to Love), the turkey fossils were not actually derived from the volcanic ash or pumicite, but were recovered from a buff-colored, fine sand and silt that directly underlies the ash. This is probably the uppermost unit of an approximately 10 m thick section of ancestral Rio Grande deposits referable to the Palomas Formation that underlies the ash. The volcanic ash unit at the San Antonio site has been correlated with the lower Bandelier tuff dated at about 1.6 Ma (Tedford, 1981; Dunbar et al., 1996). Thus, the San Antonio site is older than 1.6 Ma, placing it in the early Pleistocene (early Irvingtonian NALMA) or possibly in the Pliocene.

The avian paleontologist Alexander Wetmore identified the turkey bones from the San Antonio site for Needham (1936) as parts of the humerus, ulna, and radius of the living species of wild turkey *Meleagris gallopavo*. In a review of fossil turkeys from southwestern Pleistocene sites, Rea (1980) listed the fossils from San Antonio as the distal humerus, nearly complete ulna, and radius lacking the distal end, of the extinct bigfoot turkey *M. crassipes*. San Antonio is the oldest known record of *M. crassipes*; most other fossils of this species are from southwestern late Pleistocene cave deposits (Rea, 1980).

Indian Well Wilderness

The Indian Well Wilderness site is located in a small arroyo on the Bosque Del Apache NWR, about 1 km north of the Bosque Visitor Center, central Socorro County (NMMNH site L-7667; Fig. 1, site 18). In February 1987, Steve Cather and John Hawley collected a partial femur of a proboscidean from this site. The fossil was found in the arroyo bottom, in the vicinity of a 5-10 m

TABLE 2. Postcranial measurements (in mm) of *Bison* sp. from the Socorro LF, Socorro County, New Mexico.

Element and Catalog Number	Total Length	Proximal Width	Proximal Depth	Minimum Shaft Width	Distal Width	Distal Depth
radius-ulna (distal end) NMMNH 26030	—	—	—	—	99.4	57.5
metacarpal 3 NMMNH 26030	221	78.9	45.3	50.1	81.3	45.2
metatarsal 3[1] NMMNH 26031	—	61.2	59.5	—	78.9	43.5
calcaneum[2] NMMNH 23032	161	53.4	60.6	—	45.4	51.1
proximal phalanx NMMNH 26030	78.4	39.4	42.3	37.4	45.2	32.6

[1] The shaft of the metatarsal is missing; the proximal and distal ends are intact.

[2]The orientation of the calcaneum is different from that of the other postcranial elements in this table. The proximal width and depth are the maximum width and depth at the articular facet with the astragalus; the distal width and depth are the maximum width and depth of the tuberosity.

thick outcrop of consisting of brownish, unconsolidated, medium to coarse sands. These Rio Grande deposits appear to be a terrace that is Pleistocene in age, probably between 150 and 130 ka. However, it is possible that the terrace is only the upper part of this section and that it is superimposed on older Rio Grande deposits, but there is no obvious unconformity beneath the terrace.

The fossil from the Indian Well Wilderness site consists of a heavily mineralized but poorly preserved partial left femur of a juvenile proboscidean (NMMNH 57520; Fig. 5H). The femur lacks both the proximal and distal ends and much of the external surface of the bone, especially on the posterior surface. The epiphysis containing the femoral head is missing and was not fused to the femoral shaft, suggesting that the specimen represents a juvenile individual. The femur is from a proboscidean with short, robust limbs, most likely a gomphothere (Gomphotheriidae) or mastodon (Mammutidae). Mammoths (*Mammuthus*) can be ruled out based on their longer and more slender femora. Measurements (in mm) of the partial femur (NMMNH 57520), as preserved (all measurements are minimum values owing to the absence of the proximal and distal ends): total length, ~430; proximal breadth, ~190; distal breadth, ~140; minimum shaft width, ~95. The presence of a gomphothere would be at odds with the proposed upper Pleistocene age of the terrace comprising the Indian Well Wilderness site, as this group of proboscideans is absent from the southwestern U. S. after the early Pleistocene. However, as noted above, the femur could also belong to the mastodon *Mammut*, which has been found in several New Mexico late Pleistocene sites (Lucas and Morgan, 2005).

Chupadera Arroyo

The late Robert Weber of the NMBGMR discovered several late Pleistocene sites containing vertebrate fossils in the vicinity of Chupadera Arroyo about 12-15 km west of Bingham in the northern Jornada del Muerto basin, eastern Socorro County (NMMNH sites L-5010, 5026-5029; Fig. 1, site 19). These sites are located just north of Pleistocene Lake Trinity, a lake that developed in the northern Jornada del Muerto basin at about the same time as Lake Otero formed in the Tularosa basin farther south (Neal et al., 1983; Kirkpatrick and Weber, 1996: Weber, 1997). The fossils consist of isolated mammoth (*Mammuthus*) tooth and tusk fragments found as highly eroded surface scatters resulting from weathering decomposition (Weber, pers. comm.). Based on the fossils discovered by Weber, many previous authors have mentioned the presence of mammoths in the Mockingbird Gap Paleoindian site, a Clovis occupation site located near Chupadera Arroyo (e.g., Haynes, 1970; Kurtén and Anderson, 1980; Harris, 1985; 1993; Lucas and Effinger, 1991). However, Weber was not convinced that the mammoth fossils actually were associated with Clovis artifacts in the Mockingbird Gap site. In a letter dated 17 March 2002, Weber stated "There is no definitive evidence that this was a mammoth kill by the Clovis occupants of the site, as the tooth enamel fragments are from a surface scatter in a fringe area of the site that contained no associated Clovis artifacts." To eliminate any confusion with the Mockingbird Gap Clovis site, Morgan and Lucas (2002) named the Chupadera Arroyo site for the fragmentary mammoth fossils from NMMNH sites L-5010, 5026-5029. To further complicate matters, there is a paleontological site named for Mockingbird Gap (see below), located 40 km south of Chupadera Arroyo in the immediate vicinity of Mockingbird Gap (In contrast, the Mockingbird Gap archaeological site is nowhere near the geographic feature called Mockingbird Gap).

The mammoth fossils from Chupadera Arroyo include four enamel fragments (NMMNH 35636) from NMMNH site L-5010; seven enamel fragments (NMMNH 36076) from site L-5027; and three enamel fragments (NMMNH 36077) from site L-5029. Kurtén and Anderson (1980) listed the Mockingbird Gap (= Chupadera Arroyo) mammoth record as *Mammuthus jeffersonii* (now synonymized with *M. columbi*). Morgan and Lucas (2002) referred the tooth fragments from this site to *M. columbi* on the basis of their thin, complicated enamel. The age of the Chupadera Arroyo sites is probably late Pleistocene (late Rancholabrean), although there are no associated radiocarbon dates.

Mockingbird Gap

In September 1930, Tom Charles of Alamogordo, New Mexico collected two camel teeth (*Camelops*) and an associated upper dentition of a horse (*Equus*) from a late Pleistocene site near Mockingbird Gap in southeastern Socorro County (NMMNH site L-4988; Fig. 1, site 20). Mockingbird Gap is located in the southeastern corner of Socorro County on the White Sands Missile Range between the Oscura Mountains on the north and the San Andres Mountains on the south. Morgan and Lucas (2002) first discussed this fossil site, which is not the same site as the Mockingbird Gap Paleoindian site mentioned by previous authors, located about 40 km farther north in the vicinity of Chupadera Arroyo (see discussion above). Mr. Charles found the teeth about 2-3 m below the surface while digging a well. One of the camel teeth still retains adhering gypsiferous sand.

A camel tooth and the horse teeth from the Mockingbird Gap site were donated by Charles to the University of New Mexico vertebrate paleontology collection, which was later transferred to the NMMNH,, He donated a second camel tooth to the American Museum of Natural History. Measurements (in mm) of a right M3 of *Camelops* in the AMNH are: anteroposterior length, 41.4; anterior width, 21.9; posterior width, 18.4; maximum crown height, 55.5. Only two measurements can be taken on the posterior half of a left M1 or M2 of *Camelops* (NMMNH 35629): posterior width, 17.2; maximum crown height, 55.9. The two camel teeth from Mockingbird Gap compare closely in size and morphology with the late Pleistocene species *Camelops hesternus* (Webb, 1965).

The small horse *Equus conversidens* is represented in the Mockingbird Gap site by an associated upper dentition consisting of right M1-M3, left P4-M2, and fragments of several other upper teeth (NMMNH 43793; Figs. 3E, F). The upper cheek teeth lack a pli caballin and have a small hypoconal groove that would have disappeared with wear. The protocone is short and broad with a

tiny lingual indentation at its anterior end. The fossettes are fairly simple with one enamel crenulation on the anterior margin of the prefossette and posterior margin of the postfossette and two to three enamel crenulations on the posterior margin of the prefossette and anterior margin of the postfossette. Measurements of the six complete or nearly complete teeth from Mockingbird Gap indicate that this was a small horse (Table 1). *E. conversidens* is the common small species of *Equus* found in late Pleistocene (Rancholabrean) faunas throughout New Mexico (e.g., Harris and Porter, 1980; Morgan and Lucas, 2005). Both *Camelops hesternus* and *Equus conversidens* are present in the Rancholabrean Lake Otero Fauna, derived from similar gypsiferous sediments of lacustrine origin, also located on the White Sands Missile Range but farther south in Sierra and Doña Ana counties (Morgan and Lucas, 2002). Radiocarbon dates of 19,430 to 31,640 yrBP associated with the Lake Otero Fauna (Lucas et al., 2007) suggest a late Pleistocene age for the Mockingbird Gap site.

DISCUSSION

Although Eocene sedimentary rocks have a very limited outcrop area in Socorro County (Lucas and Williamson, 1993), both the Baca and Hart Mine formations have produced vertebrate faunas. The Bridgerian Carthage LF is derived from the Hart Mine Formation near Carthage in central Socorro County, and the Gallinas Mountain track site occurs in the Baca Formation in the northwestern part of the county (Fig. 1). The only Oligocene rocks in the county are of volcanic origin, yet artiodactyl tracks are known from a volcaniclastic unit in the San Mateo Mountains (Ferguson, 1986; Lucas, 2001). Miocene sedimentary rocks of the Popotosa Formation are fairly widespread in Socorro County west of the Rio Grande; however, only a single vertebrate fossil has been reported from this unit in the county, an oreodont skeleton from the Bosque del Apache NWR south of San Antonio (Fig. 1). Extensive outcrops of the Popotosa Formation on the Sevilleta NWR in northwestern Socorro County have not yet been adequately surveyed for vertebrate fossils. The presence of a rather diverse vertebrate fauna derived from the Popotosa Formation in the Gabaldon Badlands in Valencia County west of Belen (Lozinsky and Tedford, 1991), about 30 km north of the Sevilleta NWR, suggests the Popotosa Formation farther south in Socorro County will produce additional vertebrate fossils.

Axial river and tributary piedmont alluvial deposits of the ancestral Rio Grande system of Pliocene and possibly lower Pleistocene age, referred to the Ceja and Palomas formations of the upper Santa Fe Group, crop out in Socorro County. The former unit is restricted to the Albuquerque basin where it is dominated by deposits of the ancestral Rio Puerco; the latter formation occurs in basins to the south (Socorro-San Marcial-Palomas). The Ceja and Palomas formations have rather narrow outcrop belts in the Rio Puerco and Rio Grande valleys, from Veguita in northernmost Socorro County south to Silver Canyon at the northern end of Elephant Butte Lake in the southernmost part of the county. The faunas from the Ceja Formation in the southern Albuquerque basin (Veguita, Abeytas, Sevilleta) and the Palomas Formation in the Socorro basin (Arroyo de la Parida) and San Marcial basin (Silver Canyon) all appear to be early Pliocene in age (late early Blancan, ~3.0-3.5 Ma), based on the presence of a diverse fauna of *Equus* (at least four species) and *Camelops*, together with the absence of mammals characteristic of the Great American Biotic Interchange that appeared in New Mexico after 3 Ma. There are many other early Blancan faunas from fluvial deposits in the Rio Puerco valley to the north and the Rio Grande valley both north and south of Socorro County (Morgan and Lucas, 2003), including the Ceja Formation in Valencia County (Belen and Los Lunas LFs) and Bernalillo County (Mesa del Sol and Mountainview LFs), the Palomas Formation in Sierra County (Cuchillo Negro Creek and Truth or Consequences LFs), and the Camp Rice Formation in Dona Ana County (Tonuco Mountain LF).

The wealth of early Blancan faunas in the central Rio Grande valley is probably a result of the integration of the Rio Grande from the Albuquerque basin to southern New Mexio by latest Miocene or early Pliocene time, followed by the extensive deposition and accumulation of sediments during the Pliocene (Mack et al., 1997, 1998). The Rio Grande aggraded from below its present level (by perhaps several hundred meters) to roughly 100 m above its present level by about 850 ka ago (Connell et al., 2005). Then the river entrenched through its own older deposits during the past 850 ka, exposing the strata that produce Blancan vertebrate faunas. The onset of this period of deposition may correspond with warmer, wetter climatic conditions in the early Pliocene, the so-called Pliocene warm period (3.1-4.6 Ma), the most recent period of sustained global warmth (Thompson, 1991). The abundance of giant land tortoises (*Hesperotestudo*) in New Mexico Pliocene faunas supports the idea of a warmer, frost-free climate at this time (Morgan and Lucas, 2003). Other river valleys in the Southwest show a similar trend of sediment deposition and formation of vertebrate faunas during the Pliocene, including the Buckhorn and Pearson Mesa faunas from the Gila River valley in southwestern New Mexico (Morgan et al., 1997; 2008b) and numerous Blancan faunas in southeastern Arizona, including Bear Springs and 111 Ranch from the San Simon River valley (Galusha et al., 1984; Tomida, 1987), Benson from the San Pedro River valley (Johnson et al., 1975), and several faunas from the Verde River valley (Czaplewski, 1987).

A concentration of vertebrate sites occurs on the Plains of San Agustín in the northwestern part of the county, associated with a large Pleistocene lake complex that occurred in this region, Pleistocene Lake San Agustín (Weber, 1994). The Mockingbird Gap site in the southeasternmost corner of Socorro County appears to be associated with Pleistocene Lake Trinity (Weber, 1997). Most of the remaining Pleistocene faunas in Socorro County are associated with deposition by the ancestral Rio Grande, although representing different time intervals, including both the Irvingtonian (early to middle Pleistocene) and Rancholabrean (late Pleistocene). The oldest of the Socorro County Pleistocene sites is the early Irvingtonian San Antonio LF, associated with a pumice derived from the lower Bandelier eruption at about 1.6 Ma. The Soccoro LF contains *Bison* and consequently is much younger (late Pleistocene, Rancholabrean).

ACKNOWLEDGMENTS

We are grateful to the many people over the years who have collected vertebrate fossils from Socorro County and donated them to the New Mexico Museum of Natural History and several other paleontological collections. Steve Cather and John Hawley from the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) discovered a Pliocene proboscidean femur from Bosque Del Apache and Cather also found a horse tooth in Tiffany Canyon. The late Robert Weber of the NMBGMR discovered several important fossil sites from Pleistocene Lake San Agustín. Others who have collected vertebrate fossils from Socorro County include: Richard Chamberlin, Tom Charles, Colin Cikoski, Charles Ferguson, Ed Frye, P. V. Haddock, Mike O'Keefe, Warren Slade, Richard White, and Donald Wolberg. For access and permits to collect fossils on federal land, we are grateful to the U. S Fish and Wildlife Service (Bosque Del Apache NWR), the U. S. Bureau of Land Management (Arroyo de la Parida, Silver Canyon), and the National Radio Astronomy Observatory (VLA site). Patricia Hester and Mike O'Neill (BLM), Tom Melanson (Bosque Del Apache NWR), and Robert Hjellming (NRAO) were instrumental in helping us obtain permits. We also thank several private landowners who allowed us to collect fossils on their land, including Ted Turner and Tom Waddell for permission to collect in Tiffany Canyon on the Armendaris Ranch. John Hawley and Richard White provided helpful comments on the manuscript.

REFERENCES

Allen, B. D., 2005, Ice Age lakes in New Mexico: New Mexico Museum of Natural History and Science, Bulletin 28, p. 107-114.

Bell, C. J., Lundelius, E. L., Jr., Barnosky, A. D., Graham, R. W., Lindsay, E. H., Ruez, D. R., Jr., Semken, H. A., Jr., Webb, S. D., and Zakrzewski, R. J., 2004, The Blancan, Irvingtonian, and Rancholabrean mammal ages; *in* Woodburne, M. O., ed., Late Cretaceous and Cenozoic mammals of North America: Biostratigraphy and geochronology: New York, Columbia University Press, p. 232-314.

Berggren, W. A., Hilgen, F. J., Langereis, C. G., Kent, D. V., Obradovich, J. D., Raffi, I., Raymo, M. E., and. Shackleton, N. J., 1995, Late Neogene chronology: New perspectives in high-resolution stratigraphy: Geological Society of America Bulletin, v. 107, p. 1272-1287.

Cather, S. M., 2004, Laramide orogeny in central and northern New Mexico and southern Colorado; *in* Mack, G. H. and Giles, K. A., eds., The geology of New Mexico: a geologic history: New Mexico Geological Society, Special Publication 11, p. 203-248.

Connell, S. D., 2008, Refinements in the stratigraphic nomenclature of the Santa Fe Group, northwestern Albuquerque Basin, New Mexico: New Mexico Geology, v. 30, p. 14-35.

Connell, S. D., Hawley, J. W., and Love, D. W., 2005, Late Cenozoic drainage development in the southeastern Basin and Range of New Mexico, southeasternmost Arizona and western Texas: New Mexico Museum of Natural History and Science, Bulletin 28, p. 125-150.

Czaplewski, N. J., 1987, Middle Blancan vertebrate assemblage from the Verde Formation, Arizona: Contributions to Geology, University of Wyoming, v. 25, p. 133-155.

Dalquest, W. W., 1975, Vertebrate fossils from the Blancan Local Fauna of Texas: Occasional Papers, The Museum, Texas Tech University, no. 30, 52 p.

Denny, C. S., 1940, Tertiary geology of the San Acacia area, New Mexico: Journal of Geology, v. 48, p. 73-106.

Dunbar, N. W., McIntosh, W. C., Cather, S. M., Chamberlin, R. M., Harrison, B., and Kyle, P. R., 1996, Distal tephras from the Jemez volcanic center as potential time-stratigraphic markers in ancestral Rio Grande sediments from the Socorro area: New Mexico Geological Society, 47th Fall Field Conference Guidebook, p. 69-70.

Ferguson, C. A., 1986, Oligocene eolianites and ichnofossils in the central San Mateo Mountains: New Mexico Geology, v. 8, p. 12-13.

Galusha, T., Johnson, N. M., Lindsay, E. H., Opdyke, N. D., and Tedford, R. H., 1984, Biostratigraphy and magnetostratigraphy, late Pliocene rocks, 111 Ranch, Arizona: Geological Society of America Bulletin, v. 95, p. 714-722.

Gardner, J. H., 1910, The Carthage coal field, New Mexico: U. S. Geological Survey Bulletin 381, p. 452-460.

Harris, A. H., 1985, Late Pleistocene vertebrate paleoecology of the West: Austin, University of Texas Press, 293 p.

Harris, A. H., 1993, Quaternary vertebrates of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 2, p. 179-197.

Harris, A. H. and Porter, L. S. W., 1980, Late Pleistocene horses of Dry Cave, Eddy County, New Mexico: Journal of Mammalogy, v. 61, p. 46-65.

Hawley, J. W., 2005, Five million years of landscape evolution in New Mexico: an overview based on two centuries of geomorphic conceptual-model development: New Mexico Museum of Natural History and Science, Bulletin 28, p. 9-93.

Haynes, C. V., 1970, Geochronology of man-mammoth sites and their bearing on the origin of the Llano Complex; *in* Dort, W., Jr, and Jones, J. K., Jr., Pleistocene and Recent environments of the central Great Plains: Department of Geology, University of Kansas, Special Publication 3, p. 78-92.

Johnson, N. M., Opdyke, N. P., and Lindsay, E. H., 1975, Magnetic polarity stratigraphy of Pliocene-Pleistocene terrestrial deposits and vertebrate faunas, San Pedro Valley, Arizona: Geological Society of America Bulletin, v. 86, p. 5-12.

Kirkpatrick, D. T. and Weber, R. H., 1996, Quaternary geology and archaeology of the Lake Trinity Basin, White Sands Missile Range, New Mexico; *in* La Jornada, Papers in honor of William F. Turney: The Archaeological Society of New Mexico, No. 22, p. 109-127.

Kurtén, B. and Anderson, E., 1980, Pleistocene mammals of North America: New York, Columbia University Press, 442 p.

Lindsay, E. H., Opdyke, N. D., and Johnson, N. M., 1984, Blancan-Hemphillian land mammal ages and late Cenozoic mammal dispersal events: Annual Review of Earth and Planetary Sciences, v. 12, p. 445-488.

Lipman, P.W., and Mehnert, H.H., 1980, Potassium-argon ages from the Mount Taylor volcanic field, New Mexico: U.S. Geological Survey Professional Paper 1124B, p. B1-B8.

Lozinsky, R. P. and Hawley, J. W., 1986, The Palomas Formation of south-central New Mexico—A formal definition: New Mexico Geology, v. 8, p. 73-82.

Lozinsky, R.P. and Tedford, R.H., 1991, Geology and paleontology of the Santa Fe Group, southwestern Albuquerque Basin, Valencia County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 132, 35 p.

Lucas, S. G., 1983, The Baca Formation and the Eocene-Oligocene boundary in New Mexico: New Mexico Geological Society, 34th Fall Field Conference Guidebook, p. 187-192.

Lucas, S. G., 1984, Correlation of Eocene rocks of the northern Rio Grande rift and adjacent areas: Implications for Laramide tectonics: New Mexico Geological Society, 35th Fall Field Conference Guidebook, p. 123-128.

Lucas, S. G., 1985, *Leptotomus* (Mammalia, Rodentia) from the Eocene "Baca" Formation, south-central New Mexico: New Mexico Journal of Science, v. 24, p. 43-46.

Lucas, S. G., 1990, Middle Eocene mammal from the base of the Baca Formation, west-central New Mexico: New Mexico Journal of Science, v. 30, p. 35-39.

Lucas, S. G., 1997, Middle Eocene (Bridgerian) mammals from the Hart Mine Formation, south-central New Mexico: New Mexico Museum of Natural History and Science, Bulletin 11, p. 65-72.

Lucas, S. G., 2001, The age of mammals and the age of volancoes in New Mexico: An outline of the Cenozoic geology and paleontology of the state: New Mexico Museum of Natural History and Science, Bulletin 18, p. 31-47.

Lucas, S. G. and Effinger, J. E., 1991, *Mammuthus* from Lincoln County and a review of the mammoths from the Pleistocene of New Mexico: New Mexico Geological Society, 42nd Fall Field Conference Guidebook, p. 277-282.

Lucas, S. G. and Morgan, G. S., 1996, The Pliocene proboscidean *Rhynchotherium* (Mammalia: Gomphotheriidae) from south-central New Mexico: Texas Journal of Science, v. 48, p. 311-318.

Lucas, S. G. and Morgan, G. S., 1997, The American mastodont (*Mammut americanum*) in New Mexico: Southwestern Naturalist, v. 42, p. 312-317.

Lucas, S. G. and Morgan, G. S., 2005, Ice Age proboscideans of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 28, p. 255-261.

Lucas, S. G. and Morgan, G. S., 2008, Taxonomy of *Rhynchotherium* (Mammalia, Proboscidea) from the Miocene-Pliocene of North America: New Mexico Museum of Natural History and Science, Bulletin 4, p.71-87.

Lucas, S. G. and Williamson, T. E., 1993, Eocene vertebrates and late Laramide stratigraphy of New Mexico: New Mexico Museum of Natural History and Science, Bulletin 2, p. 145-158.

Lucas, S. G., Estep, J. W. and Froehlich, J. W., 1997, *Mesohippus* (Mammalia, Perissodactyla, Equidae) from the Chadronian (late Eocene) of south-central New Mexico: New Mexico Museum of Natural History and Science, Bulletin 11, p. 73-75.

Lucas, S. G., Sullivan, R. M. and Logan, T. E., 1983, Glyptosaurine lizard from the Eocene Baca Formation, south-central New Mexico: New Mexico Geology, v. 5, p. 77-78.

Lucas, S. G., Schoch, R. M., Manning, E. and Tsentas, C., 1981, The Eocene biostratigraphy of New Mexico: Geological Society of America Bulletin, v. 92, p. 951-967.

Lucas, S. G., Wolberg, D. L., Hunt, A. and Schoch, R. M., 1982, A middle Eocene titanothere from the Baca Formation, south-central New Mexico: Journal of Paleontology, v. 56, p. 542-545.

Lucas, S. G., Allen, B. D., Morgan, G. S., Myers, R. G., Love, D. W., and Bustos, D., 2007. Mammoth footprints from the upper Pleistocene of the Tularosa Basin, Doña Ana County, New Mexico: New Mexico Museum of Natural History and Science, Bulletin 42, p. 149-154.

MacFadden, B. J., 1984, Systematics and phylogeny of *Hipparion*, *Neohipparion*, *Nannippus*, and *Cormohipparion* (Mammalia, Equidae) from the Miocene and Pliocene of the New World: Bulletin of the American Museum of Natural History, v. 179, p. 1-195.

Mack, G. H., Love, D. W., and Seager, W. R., 1997, Spillover models for axial rivers in regions of continental extension: the Rio Mimbres and Rio Grande in the southern Rio Grande rift, USA: Sedimentology, v. 44, p. 637-652.

Mack, G. H., Salyards, S. L., McIntosh, W. C., and Leeder, M. R., 1998, Reversal magnetostratigraphy and radioisotopic geochronology of the Plio-Pleistocene Camp Rice and Palomas formations, southern Rio Grande rift: New Mexico Geological Society, 49th Fall Field Conference Guidebook, p. 229-236.

Mader, B. J., 1989, The Brontotheriidae: A systematic revision and preliminary phylogeny of North American genera; *in* Prothero, D. R. and Schoch, R. M., eds., The evolution of perissodactyls: New York, Oxford University Press, p. 458-484.

Mader, B. J., 2008, A species level revision of Bridgerian and Uintan brontotheres (Mammalia, Perissodactyla) exclusive of *Palaeosyops*: Zootaxa, no. 1837, 85 p.

Markgraf, V., Bradbury, J. P., Forester, R. M., McCoy, W., Singh, G., and Sternberg, R., 1983, Paleoenvironmental reassessment of the 1.6-million-year-old record from San Agustin basin, New Mexico: New Mexico Geological Society, 34th Fall Field Conference Guidebook, p. 291-298.

McDonald, J. N., 1981, North American *Bison*: Their classification and evolution: Berkeley, University of California Press, 316 p.

Morgan, G. S. and Lucas, S. G., 2000, Pliocene and Pleistocene vertebrate faunas from the Albuquerque basin, New Mexico: New Mexico Museum of Natural History and Science, Bulletin 16, p. 217-240.

Morgan, G. S. and Lucas, S. G., 2002, Pleistocene vertebrates from the White Sands Missile Range, southern New Mexico: New Mexico Geological Society, 53rd Fall Field Conference Guidebook, p. 267-276.

Morgan, G. S. and Lucas, S. G., 2003, Mammalian biochronology of Blancan and Irvingtonian (Pliocene and early Pleistocene) faunas from New Mexico: Bulletin of the American Museum of Natural History, v. 278, p. 269-320.

Morgan, G. S. and Lucas, S. G., 2005. Pleistocene vertebrate faunas in New Mexico from alluvial, fluvial, and lacustrine deposits. New Mexico Museum of Natural History and Science, Bulletin 28, p. 185-248.

Morgan, G. S. and Lucas, S. G., 2006, Pleistocene vertebrates from southeastern New Mexico: New Mexico Geological Society, 7th Fall Field Conference Guidebook, p. 317-335.

Morgan, G. S., Lucas, S. G., and Estep, J. W., 1998, Pliocene (Blancan) vertebrate fossils from the Camp Rice Formation near Tonuco Mountain, Doña Ana County, southern New Mexico. New Mexico Geological Society, 49th Fall Field Conference Guidebook, p. 237-249.

Morgan, G. S., Sealey, P. S., and Lucas, S. G., 2008a, Pliocene (Blancan) vertebrates from Arroyo de la Parida, Palomas Formation, Socorro County, central New Mexico: New Mexico Museum of Natural History and Science, Bulletin 44, p. 189-206.

Morgan, G. S., Sealey, P. S., and Lucas, S. G., 2008b, Late Pliocene (late Blancan) vertebrate faunas from Pearson Mesa, Duncan basin, southwestern New Mexico and southeastern Arizona: New Mexico Museum of Natural History and Science, Bulletin 44, p. 141-188.

Morgan, G. S., Lander, B., Love, D. W., Chamberlin, R., and Cikoski, C., 2009, A skull and partial skeleton of the oreodont *Merychyus major* (Mammalia: Artiodactyla: Oreodontidae) from the Miocene Popotosa Formation, Bosque del Apache National Wildlife Refuge, Socorro County, New Mexico: New Mexico Geology, v. 31.

Morgan, G. S., Sealey, P. L., Lucas, S. G., and Heckert, A. B., 1997, Pliocene (latest Hemphillian and Blancan) vertebrate fossils from the Mangas basin, southwestern New Mexico: New Mexico Museum of Natural History and Science, Bulletin 11, p. 97-128.

Neal, J.T., Smith, R.E., and Jones, B.F., 1983, Pleistocene Lake Trinity, an evaporite basin in the northern Jornada del Muerto, New Mexico: New Mexico Geological Society, 34th Fall Field Conference Guidebook, p. 285-290.

Needham, C. E., 1936, Vertebrate remains from Cenozoic rocks: Science, v. 84, p. 537.

Rea, A. M., 1980, Late Pleistocene and Holocene turkeys in the Southwest: Contributions in Science, Natural History Museum of Los Angeles County, no. 330, p. 209-224.

Robinson, P., Gunnell, G. F., Walsh, S. L., Clyde, W. C., Storer, J. E., Stucky, R. K., Froehlich, D. J., Ferrusquia-Villafranca, I. and McKenna, M. C., 2004, Wasatchian through Duchesnean biochronology; *in* Woodburne, M. O., ed., Late Cretaceous and Cenozoic mammals of North America: Biostratigraphy and geochronology: New York, Columbia University Press, p. 106-155.

Tedford, R. H., 1981, Mammalian biochronology of the late Cenozoic basins of New Mexico: Geological Society of America Bulletin, v. 92 (pt. I), p. 1008-1022.

Thompson, R. S., 1991, Pliocene environments and climates in the western United States: Quaternary Science Reviews, v. 10, p. 115-132.

Tomida, Y., 1987, Small mammal fossils and correlation of continental deposits, Safford and Duncan basins, Arizona, USA: Tokyo, National Science Museum, 141 p.

Walker, J. D., and Geissman, J.W., compilers, 2009, Commentary—2009 Geologic Time Scale: GSA Today, v. 19, no. 4/5, p. 60-61.

Webb, S. D., 1965, The osteology of *Camelops*: Bulletin of the Los Angeles County Museum, Science, no. 1, 54 p.

Weber, R. H., 1994, Pluvial lakes of the Plains of San Agustín: New Mexico Geological Society, 45th Fall Field Conference Guidebook, p. 9-11.

Weber, R. H., 1997, Geology of the Mockingbird Gap Site in central New Mexico; *in* Layers of Time, Papers in honor of Robert H. Weber. The Archaeological Society of New Mexico, no. 23, p. 115-122.

Winans, M. C., 1989, A quantitative study of North American fossil species of the genus *Equus*; *in* Prothero, D. R. and Schoch, R. M., eds., The Evolution of the Perissodactyls: New York, Oxford University Press, p. 262-297.

Wolberg, D. L., Hunt, A. P., and Wentworth, W., 1984, Plio-Pleistocene vertebrates from Socorro-area outcrops, gravel pits, museum cases, and apartments: New Mexico Geology, v. 6, p. 14.

Woodburne, M. O., 2004, Global events and the North American mammalian biochronology; *in* Woodburne, M. O., ed., Late Cretaceous and Cenozoic mammals of North America: Biostratigraphy and geochronology: New York, Columbia University Press, p. 315-343.