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Plio–Pleistocene stratigraphy, paleoecology, and mammalian biochronology, Tijeras Arroyo, Albuquerque area, New Mexico

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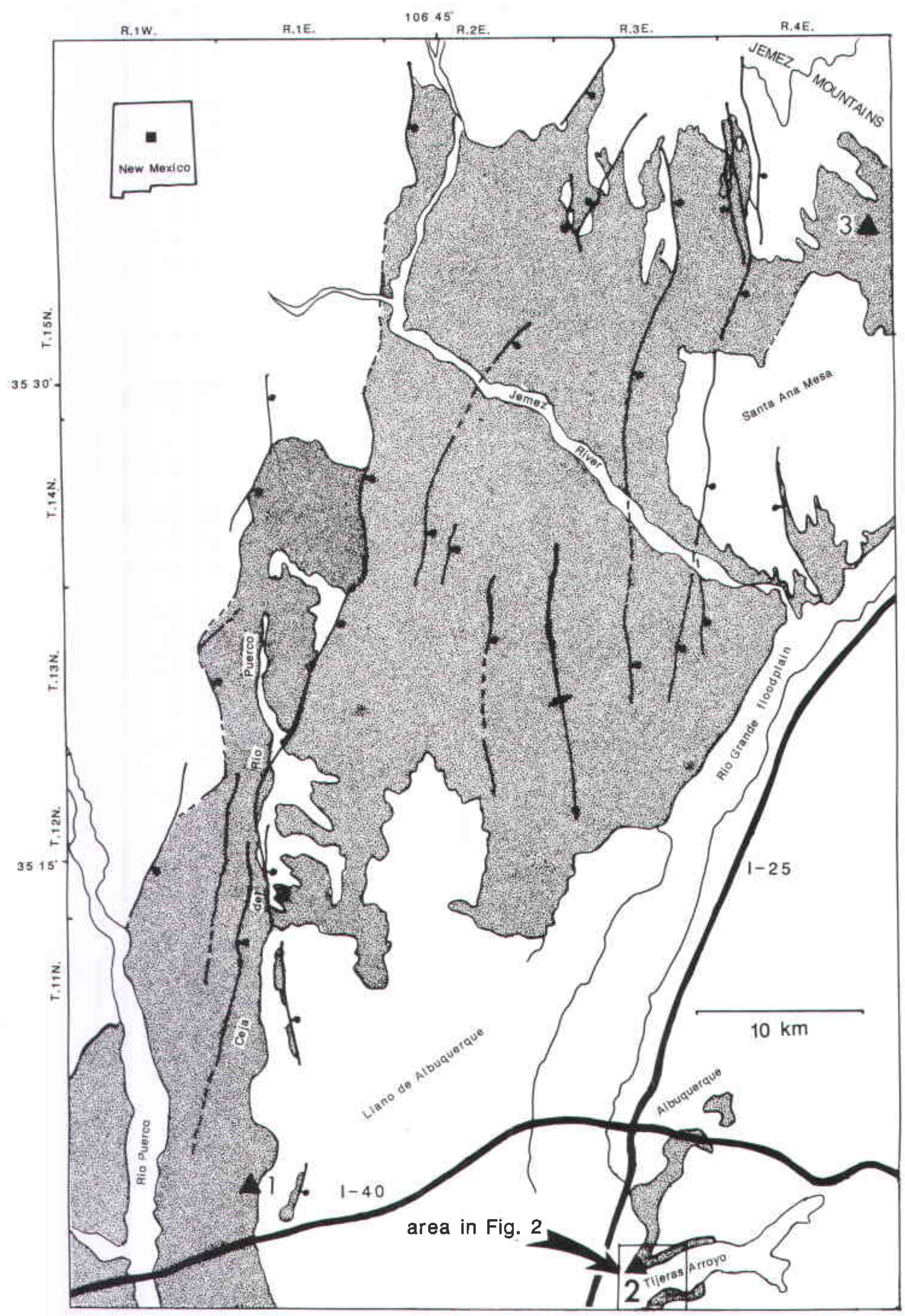

Abstract

Strata assigned to the Sierra Ladrones Formation of the Santa Fe Group in Tijeras Arroyo near the Albuquerque International Airport are more than 75 m thick and consist of sandstones, pumiceous sandstones, gravels, and minor claystones. These are deposits of a mainstem (axial) Rio Grande that intertongue eastward with alluvial-fan facies derived from the Sandia and Manzanita uplifts. Fossil mammals from the Sierra Ladrones Formation in Tijeras Arroyo indicate it is of Plio–Pleistocene (Blancan–Irvingtonian) age. Blancan mammals are *Hypolagus* cf. *H. gidleyi* and *Equus cumminsii;* Irvingtonian mammals are *Glyptotherium* cf. *G. arizonae, Equus* cf. *E. scotti,* cf. *Camelops* sp., *Mammuthus meridionalis,* and *M. imperator.* Fossils of these taxa, their taphonomy, and the enclosing sediments suggest that during the early Pleistocene the Tijeras Arroyo area was a semiarid piedmont plain with a nearby flora dominated by open grassland or short-grass prairie.

FIGURE 1—Albuquerque Basin with distribution (after Tedford, 1982) of Santa Fe Group strata (shaded) and key sections mentioned in the text: **1**, type Ceja Formation; **2**, section in Tijeras Arroyo (Figs. 2, 3); **3**, type Cochiti Formation.

Also in this issue

Introduction

Although Pleistocene mammals were first reported from the Albuquerque area (Fig. 1) by Herrick and Johnson (1900, p. 224), no serious effort has been undertaken to document these fossils until recently. This documentation (O'Neill and Rigby, 1982; Lucas and Logan, 1984; Lucas, 1987; Lucas et al., 1988) has focused on the late Pleistocene (Rancholabrean) mammals collected from gravel pits developed in relatively young terrace deposits inset into the Rio Grande valley, the Edith Formation of Lambert (1968). Fossil mammals from the Edith Formation within the Albuquerque city limits are *Glossotherium harlani, Equus* cf. *E. occidentalis, Bison* sp., *Camelops hesternus* and *Mammuthus columbi*, a typical assemblage of large Rancholabrean (Wisconsin-age) mammals.

Older Quaternary and latest Pliocene mammals, however, are also known from within the Albuquerque city limits. These low-diversity faunas, of Blancan and Irvingtonian age, were first discovered by Lambert (1968) and subsequently developed by T. R. Logan (1984; Logan et al., 1984) and us during the mid-1980's. Here, we describe these fossils that span the Plio–Pleistocene boundary and interpret their biochronological significance. In this article, NMMNH refers to the New Mexico Museum of Natural History, Albuquerque and UNM to the University of New Mexico, Albuquerque.

Stratigraphy

Upper Cenozoic deposits of the Rio Grande rift, from Colorado to Texas, have generally been referred to as the Santa Fe Group (Hawley, 1978; Lucas and Ingersoll, 1981). However, in the Albuquerque Basin, the term Santa Fe Formation, introduced here by Bryan and McCann (1937, 1938), has long been used. Bryan and McCann (1937, 1938) divided the Santa Fe Formation in the Albuquerque Basin into three informal members: lower gray, middle red, and upper buff. The lower gray and middle red members are now subsumed in the Zia Formation of Miocene (late Arikareean–Clarendonian) age (Galusha, 1966; Gawne, 1981; Tedford, 1981, 1982).

The overlying "upper buff member" of the Santa Fe Formation was originally conceived by Bryan and McCann (1937, pp. 815–816) for buff-colored, generally coarse-grained ("fan deposits") strata that are at the top of the Santa Fe Formation along the Ceja del Rio Puerco west of Albuquerque (Fig. 1). Lambert (1968) used the term "upper buff formation" to refer to Bryan and McCann's unit and also extended to it into the (current) Albuquerque city limits by identifying it east of the Rio Grande in the walls of Tijeras Arroyo (secs. 1 and 12 T9N R3E) and in the scarp southwest of the Albuquerque International Airport (Fig. 1; see also Lambert, 1978). Subsequent mapping by Kelley (1977) reflected Lambert's extension of the upper buff member to east of the Rio Grande. However, Kelley (1977) coined and applied the name Ceja Member of the Santa Fe Formation to these rocks, intending it to replace Bryan and McCann's (1937) informal term "upper buff."

Kelley's (1977) type section of the Ceja Member of the Santa Fe "Formation" (Fig. 1) is along the Ceja del Rio Puerco (sec. 19 T10N R1E) and represents the upper part of the section that Bryan and McCann (1937) originally designated "upper buff". Lambert (1968) had already described a reference section of his "Upper Buff" formation at the same site, but he included "middle" Santa Fe beds underlying Kelley's Ceja Member in this formation, as had been previously done by Wright (1946; see also Lambert, 1978, p. 151). Unfortunately, no detailed mapping, or tracing of key beds, has ever been done between the type Ceja locality and the Jemez Valley (Rincones de Zia, 35 km to the north) where Bryan and McCann originally defined their lower gray–middle red–upper buff stratigraphic sequence as the reference section for their Santa Fe Formation in the northern Albuquerque Basin.

Manley (1978) and Tedford (1982) have suggested that the Ceja Member and the more broadly defined "upper buff" member (formation) interfinger to the north with volcaniclastic sandstone and conglomerate that Bailey et al. (1969) and Smith et al. (1970) termed the Cochiti Formation of their Keres Group (see also discussion by Hawley and Galusha, 1978). However, the latter unit has never been well defined in its Jemez Mountains type area, and recent dating of associated Keres Group volcanics by Gardner et al. (1986) brackets the age of the type Cochiti between 13.5 and 6.5 million years (mid- to late Miocene).

Ceja Member (upper "upper buff") strata along the Ceja del Rio Puerco correlate with at least the middle part of the Sierra Ladrones Formation (Machette 1978a,b; Hawley, 1978, chart 1), which has a type area at the southern end of the Albuquerque Basin near San Acacia. A Sierra Ladrones Formation reference section has recently been described in the lower Rio Puerco valley (Gabaldon badland area) by Lozinsky and Tedford (1991). At that locality the formation is underlain by "middle" Santa Fe Group beds of Hemphillian (late Miocene) age correlated with the upper Popotosa Formation of Denny (1940) and Machette (1978a). Machette's type Sierra Ladrones comprises ancestral Rio Grande and intertonguing piedmont alluvial deposits. It overlies the Popotosa west of San Acacia and south of the Ladron Mountains. Basalt flows interbedded with the lower Sierra Ladrones Formation in the San Acacia and Socorro area have K-Ar ages of 4 to 4.5 million years, and a sparse Blancan vertebrate fauna has been described in the formation (as mapped by Machette, 1978b) in the Ceja del Rio Puerco escarpment about 10 km south of the type Ceja Member section (Tedford, 1981). The Sierra Ladrones depositional environment in the Albuquerque Basin has recently been described by Lozinsky et al. (1991).

TABLE 1—Stratigraphic section of the Sierra Ladrones Formations exposed in Tijeras Arroyo, NE1/4 sec. 17 and NW1/4 sec. 16 T9N R3E, Bernalillo County, New Mexico.

Unit	Lithology	Thickness (m)
Sierra Ladrones Formation:		
10.	Sandstone, noncalcareous, very light gray (N8) and light bluish-gray (5B 7/1); medium-to very coarse grained in two populations: medium- to coarse-grained (2.0–0.0 ϕ) subrounded to angular quartz grains and coarse- to very coarse grained ($\geqslant$ 1 ϕ); rounded pumice grains; trough crossbedded; top of unit is airport surface.	12.0+

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Unit	Lithology	Thickness (m)
9.	Sandstone, noncalcareous, grayish-orange (10YR 7/4), fine- to coarse-grained (0.50–3.0 ϕ); subangular quartz and chert; trough crossbedded.	6.1
8.	Sandstone, slightly calcareous, grayish-orange (10YR 7/4), fine- to coarse-grained (3.00–0.0 ϕ); subangular quartz and chert; bed has prominent reddish-brown color at a distance, with gravels in the upper 25%; trough crossbedded.	10.1
7.	Sandstone, noncalcareous, pale yellow-brown (10YR 6/2); in two populations: very fine to medium-grained (1.50–3.5 ϕ) quartz and quartzite, and quartz gravel up to 5 cm diameter; poorly sorted and very conglomeratic, with pumice in upper bed; trough crossbedded.	12.2
6.	Sandy clay and sand, calcareous, grayish orange-pink (5YR 7/2) and pinkish-gray (5YR 8/1); in three populations: fine- to coarse-grained (2.50–0.0 ϕ), subangular quartz grains, clayballs in sandstone, and pumice balls (up to 1.5 cm diameter).	3.4
5.	Sandstone, slightly calcareous, yellowish-gray (5Y 8/1), fine- to medium-grained (2.00–0.0 ϕ); poorly sorted subrounded quartz; trough crossbedded.	6.1
4.	Claystone, noncalcareous, grayish-green (10 GY 5/2).	1.2
3.	Sandstone and gravel, noncalcareous, pale yellowish-brown (10YR 6/2); in three populations: very fine- to medium-grained (1.50–3.5 ϕ) poorly sorted quartz and quartzite grains with pumice, quartz gravel (up to 5 cm diameter), and conglomerates (up to 15 cm diameter); trough crossbedded.	13.7
2.	Sandstone, noncalcareous, yellowish-gray (5Y 8/1); medium-grained (2.5–1.5 ϕ) quartz and chert; moderately sorted, frosted, subangular to subrounded grains; high-angle crossbeds and convolute bedding.	3.4
1.	Sand, noncalcareous, yellowish-gray (5Y 8/1), fine- to medium-grained (2.5–1.5 ϕ); quartz, poorly sorted subrounded grains; sandstone interbedded with laminar to massive green clay partings, one clay band 20 cm thick; fragmentary bone present; much slope debris.	8.1
0.	Covered.	
	total	76.3

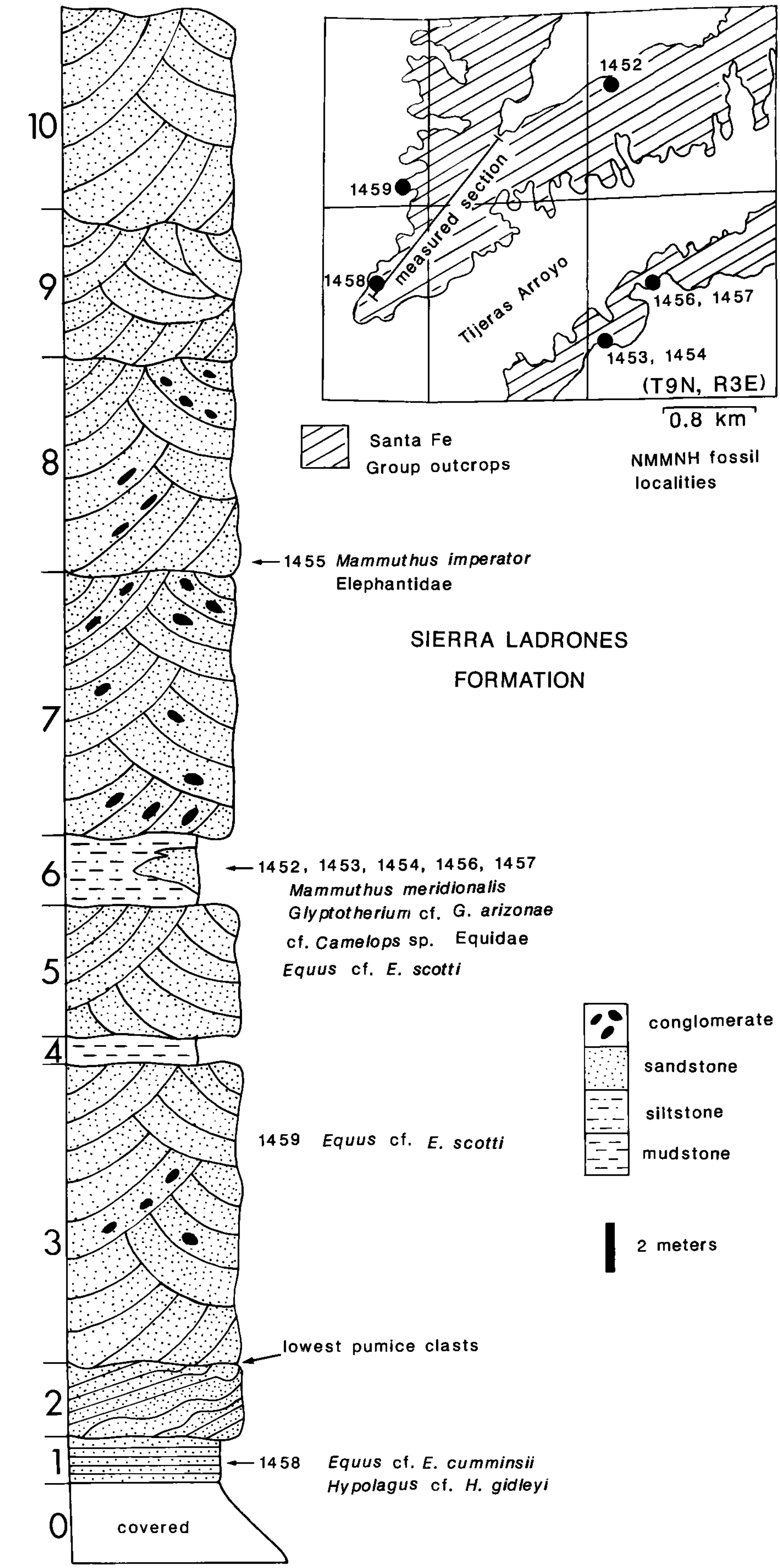

FIGURE 2—Measured stratigraphic section in Tijeras Arroyo with inset map showing fossil localities mentioned in text. See Table 1 for description of lithologic units in measured section.

The type Ceja Member, as defined by Kelley (1977) and described by Lambert (1978), is a fluvial unit dominated by channel sands and gravels. It was deposited by major tributaries to the ancestral Rio Grande that headed in the southeastern Colorado Plateau and San Pedro–Nacimiento Mountain region northwest of the Albuquerque Basin. In contrast, the upper Santa Fe beds exposed in the lower Tijeras Arroyo area east of the Rio Grande (discussed in this paper) are deposits of a main-stem (axial) Rio Grande that intertongue eastward with alluvial-fan facies derived from the Sandia and Manzanita uplifts. This ancestral fluvial system followed a course west of the base of the Sandia–Manzanita piedmont slope that was very close to the modern incised river valley in the Albuquerque metropolitan area. Upper Santa Fe beds east of the Rio Grande were also assigned to the Ceja Member by Kelley (1977) and tentatively correlated with the upper buff by Lambert (1968). However, at least the upper part of these deposits are of late Pliocene to early Pleistocene age because they contain pumice clasts derived from the 1.6 to 1.1 Ma eruptions of the Toledo Valle Grande caldera complex (Bandelier Tuff). As demonstrated here, uppermost Santa Fe Group strata in the lower Tijeras Arroyo area also contain a mammalian fauna of late Blancan and Irvingtonian age (see also Logan, 1984). We, therefore, propose that the term Ceja Member be restricted, at least at present, to upper Santa Fe Group beds (Sierra Ladrones Formation) exposed in the Puerco Valley area of the western Albuquerque Basin. Uppermost Santa Fe Group deposits in the lower Tijeras Arroyo area here are designated as part of an unnamed upper member of the Sierra Ladrones Formation that is dominated by channel deposits of the ancestral Rio Grande.

This unit is 64.8 m thick in Tijeras Arroyo and is dominated by sandstone (76% of the measured section) and lesser amounts of gravel (18%) and claystone/siltstone (6%). Particularly distinctive is the dominance of pumice, in sizes from sand grains to cobbles. The pumiceous strata at Tijeras Arroyo present a striking contrast to underlying strata that lack pumice (Table 1; Figs. 2, 3). However, we nonetheless also assign these underlying strata to the Sierra Ladrones Formation based on their lithology and stratigraphic position. Although we assign the pumice-bearing Irvingtonian strata at Tijeras Arroyo to the Sierra Ladrones Formation, we note that not only are they younger than the Sierra Ladrones, which near Socorro is about 5–1.6 Ma (S. M. Cather, written comm. 1992), but they may be a unit inset along the eastern side of the Rio Grande valley. This possibility of inset, brought to our attention by S. Cather, needs further study. The apparent unconformity at the base of the Irvingtonian sequence at Tijeras Arroyo as well as the relatively limited outcrop distribution of the pumice-bearing Irvingtonian strata supports the idea that these strata are inset into older, Ceja Formation strata. Furthermore, as Cather (written comm. 1992) notes, this inset explains both the lower elevation of the Llano de Manzano surface relative to the Llano de Albuquerque (cf. Kelley, 1977; Machette, 1978c) as well as the apparent lack of Irvingtonian strata west of the Rio Grande.

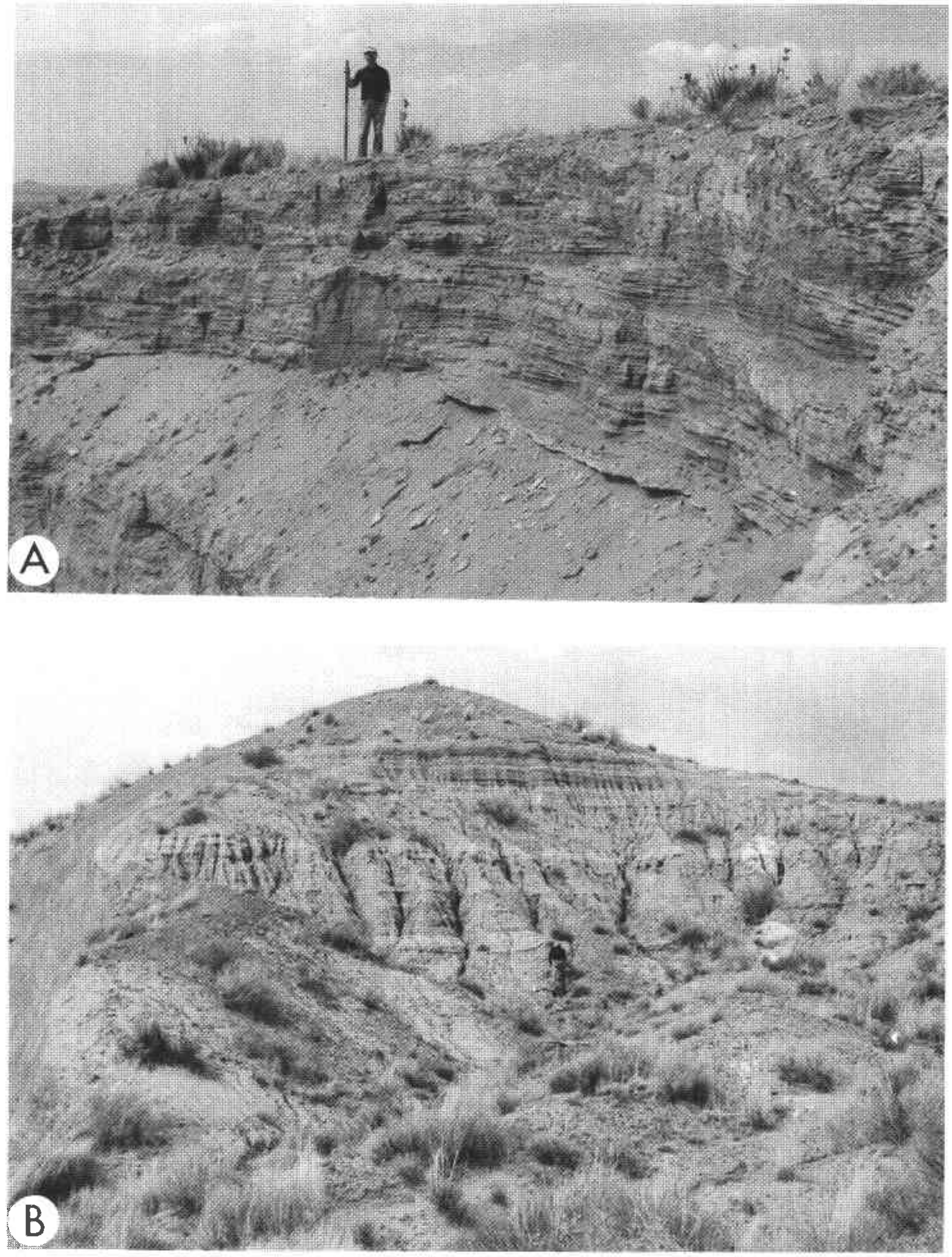

FIGURE 3—Some outcrops in Tijeras Arroyo: **A**, Sierra Ladrones Formation crossbedded sandstone (Fig. 2, unit 2); **B**, gravelly sandstones, siltstones, and sandstones of Sierra Ladrones Formation (Fig. 2, units 5–7).

However, J. Hawley (oral comm. 1992) reports that recently drilled and unpublished water-well data in the Albuquerque area indicate that pumice is present in upper Santa Fe Group strata stratigraphically well below the level where pumice first appears on outcrop. He thus suggests that all strata exposed at Tijeras Arroyo are part of a single stratigraphic unit. We provisionally endorse this conclusion by terming all these strata Sierra Ladrones Formation, in part because this decision is a conservative one that introduces no new nomenclature. New stratigraphic nomenclature may, however, be necessary if further study demonstrates that the pumice-bearing Irvingtonian strata exposed at Tijeras Arroyo are a distinct unit inset into older strata.

Vertebrate paleontology

Fossil mammals occur in two intervals in Tijeras Arroyo (Fig. 2) and are described below.

Glyptotherium cf. *G. arizonae*

NMMNH P-12876 from locality 1454 (Fig. 4H–I) is a caudal scute resembling the

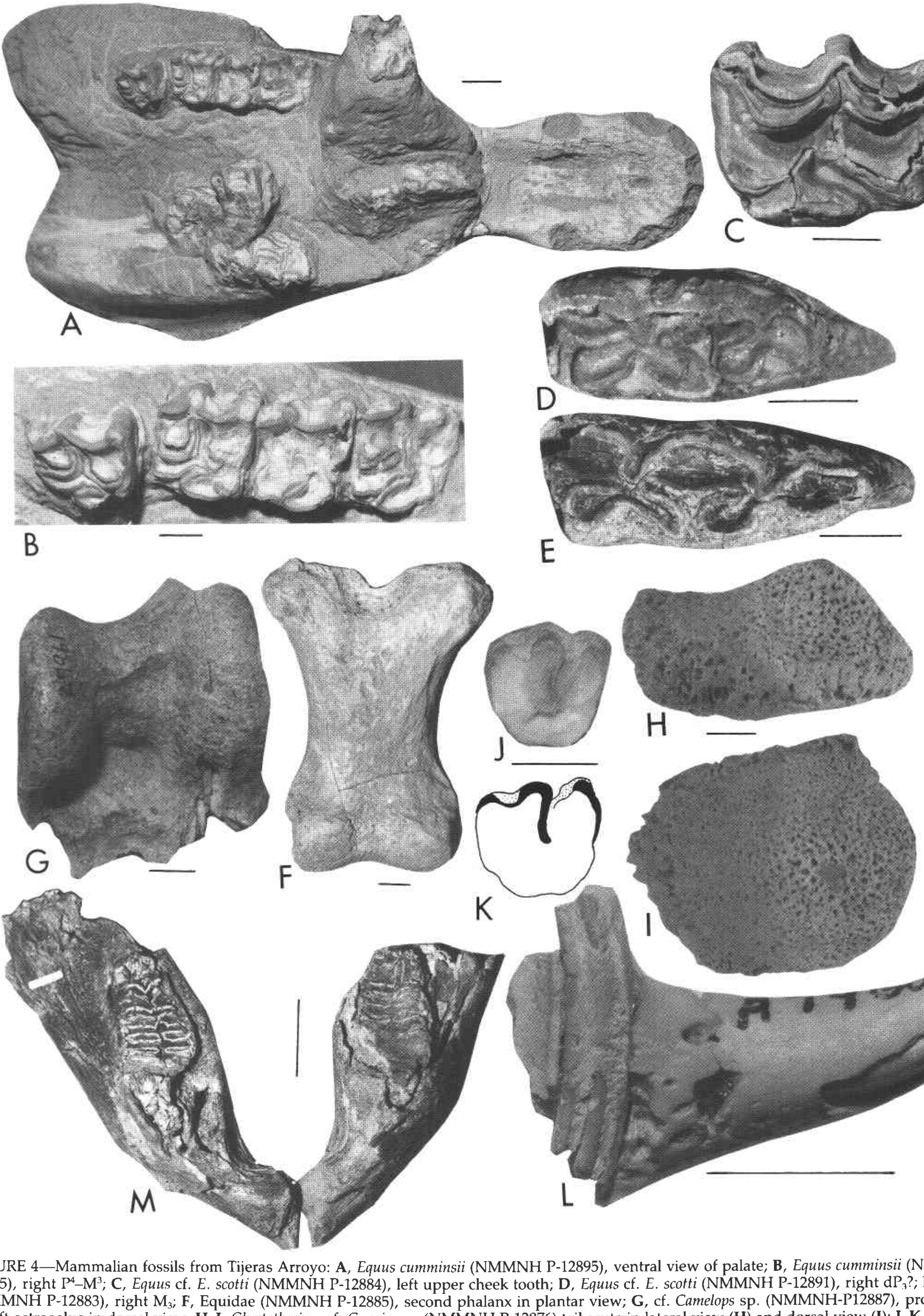

FIGURE 4—Mammalian fossils from Tijeras Arroyo: **A**, *Equus cumminsii* (NMMNH P-12895), ventral view of palate; **B**, *Equus cumminsii* (NMMNH P-12895), right P^4–M^3; **C**, *Equus* cf. *E. scotti* (NMMNH P-12884), left upper cheek tooth; **D**, *Equus* cf. *E. scotti* (NMMNH P-12891), right dP_3?; **E**, Equidae (NMMNH P-12883), right M_3; **F**, Equidae (NMMNH P-12885), second phalanx in plantar view; **G**, cf. *Camelops* sp. (NMMNH-P12887), proximal end of left astragalus in dorsal view; **H–I**, *Glyptotherium* cf. *G. arizonae* (NMMNH P-12876) tail scute in lateral view (**H**) and dorsal view (**I**); **J–K**, *Hypolagus* cf. *H. gidleyi* (NMMNH P-12938), P_3 (right is mesial, top is labial); **L**, *Hypolagus* cf. *H. gidley* (NMMNH P–12938), left dentary fragment with P_2 in lingual view; **M**, *Mammuthus meridionalis* (UNM 11028), mandible with right and left M_3. Bar scales are 1 cm except for A (2 cm), K–L (2.5 mm) and M (10 cm).

raised, convex distal scutes illustrated by Gillette and Ray (1981, fig. 93), which Logan (1984) attributed to *Glyptotherium* cf. *G. arizonae*. This is the first report of *Glyptotherium* in New Mexico. "A glyptodont" was previously reported from the Camp Rice Formation (a unit correlative, at least in part, to the Sierra Ladrones Formation) in the Mesilla Basin of southern New Mexico (Tedford, 1981, p. 1019). At 35°N latitude, the Tijeras Arroyo *Glyptotherium* is almost the northernmost occurrence of the genus (cf. Gillette and Ray, 1981, figs. 2–4). A slightly more northerly occurrence is represented by five scutes of *Glyptotherium* (NMMNH P-19244) collected by Wesley Peters at NMMNH locality 1546 in a gravel pit in the NE¼NE¼SW¼ sec. 27 T13N R4E, north of Albuquerque near Algodones (Fig. 1). This locality also is in the Sierra Ladrones Formation.

Hypolagus cf. *H. gidleyi*

NMMNH P-12938 (Fig. 4J–L) from locality 1458 consists of a right dentary fragment with the root of I_1 and a very worn P_3, a left distal tibia, a metacarpal, and two phalanges. Tedford (1981) identified this specimen as *Hypolagus* sp. White (1987, p. 438) described this specimen as *Hypolagus* cf. *H. ringoldensis*. He also stated it was "possibly from the Chamita formation," a unit of Mio–Pliocene (Clarendonian–Hemphillian) age restricted to the Española Basin of north-central New Mexico (MacFadden, 1977). This cannot be correct because this unit is not present in the Albuquerque Basin (Tedford, 1981).

We assign NMMNH P-12938 to *Hypolagus* cf. *H. gidleyi* for the following reasons: 1) I–P_3 diastema length (16.5 mm) and P_3 anteroposterior length (3.5 mm) fall within the range of variation for *H. gidleyi* (but outside that of *H. ringoldensis*: White, 1987, fig. 9); 2) the P_3 lacks an anterior reentrant (Fig. 4J–K), which is part of the diagnosis of *H. gidleyi* (White, 1987, p. 434); and 3) the posteroexternal reentrant on P_3 is deflected posteriorly, a characteristic not typical of *H. ringoldensis* but within the range of variation of *H. gidleyi* (White, 1987, fig. 7).

Equus cf. *E. cuminsii*

NMMNH P-12895 from locality 1458 (Fig. 4A–B) includes a damaged palate containing left P^2–M^3 and right P^3–M^3, the maxillary symphysis, atlas, axis and two cervical vertebrae, incomplete right humerus, distal tibia, and cranial fragments. This specimen is referred to *Equus* cf. *E. cumminsii* on the basis of occlusal morphology (note the absence of enamel crenulations and absence of a hypoconal groove: Osborn, 1918, p. 270, pl. 24; Gidley, 1901, p. 127, fig. 17). This assignment remains tentative, however, because the type specimen of *E. cumminsii* Cope consists of two isolated upper molariform teeth and the species may, strictly speaking, be a *nomen dubium*. Tedford (1981) identified this specimen as *Equus simplicidens*, but it is too small to pertain to that species. *E. cumminsii* is a Blancan horse (Kurten and Anderson, 1980).

TABLE 2—Dimensions of *Equus* teeth (in mm) from the Sierra Ladrones Formation at Tijeras Arroyo.[1], length measured labially;[2], maximum width from protocone to mesostyle.

	mesiodistal length[1]	lingual-labial width[2]
NMMNH P-12895		
left P^2	40.5	24.0
left P^3	26.7	34.2
left P^4	24.3	27.9
left M^1	29.3	27.0
left M^2	28.0	28.6
left M^3	30.6	19.6
NMMNH P-12891		
right dP_3?	34.4	17.7
right dP_4?	35.2	13.6
NMMNH P-12940		
left upper molariform	31.8	32.2
NMMNH P-12941		
left upper molariform	35.0	33.6
NMMNH P-12884		
left upper molariform	33.1	28.2
NMMNH P-12883		
right M_3	42.0	16.6
NMMNH P-12936		
right lower molariform	(36.0)	11.4

Equus cf. *E. scotti*

NMMNH P-12891 from locality 1459 is a damaged right dentary with dP_3 (Fig. 4D) and dP_4, and the unerupted fragments of P_2 and M_1. These teeth are in the size range of *E. scotti* and *E. giganteus*. NMMNH P-12940, P-12941, and P-12884 are left upper molariform teeth from locality 1454, P-12940 and P-12884 being relatively unworn (Fig. 4C). NMMNH P-12937 from locality 1457 is a fragmented lower molariform (P_3?) tooth, and NMMNH 12936 is a lower deciduous molariform tooth from locality 1457. These teeth are assigned to *Equus* cf. *E. scotti* on the basis of size (Table 2).

Equidae

NMMNH P-12883 from locality 1454 is a right M_3 (Fig. 4E) referred to *Equus* on the basis of occlusal morphology. NMMNH P-12878 from locality 1454 is a distal tibia, a proximal humerus and additional bone fragments. The transverse length and maximum oblique articular length of the distal tibia fall in the size range of *E. niobrarensis* and are intermediate between *E. conversidens and E. niobrarensis*, respectively (Harris and Porter, 1980). NMMNH P-12881 from locality 1454 is a partial maxillary symphysis containing the alveoli of I^1–I^3 and fragmentary roots of the canines (length = 16.7 mm, width = 13.7 mm). NMMNH P-12885 from locality 1454 is a large first phalanx; the overall dimensions of length, width of proximal surface, depth of proximal surface, and width of distal surface fall into the upper size range of *E. scotti* (Akersten, 1972, table 14; Harris and Porter, 1980, table 1). NMMNH P-12890 from locality 1454 is a left navicular (anteroposterior length = 47.6 mm, width = 60.7 mm). NMMNH P-12892 from locality 1445 is a right innominate with ischium, pubis, and partial ilium (maximum preserved length = 410 mm, maximum acetabular length = 68.9 mm). NMMNH P-12939 is a metacarpal from locality 1454. Overall size and comparison with Harris and Porter's (1980, p. 59, fig. 7) scatter plot of proximal and midshaft widths suggest a small specimen of *E. conversidens* or a horse of similar size.

cf. *Camelops* sp.

NMMNH P-12887 from locality 1456 (Fig. 4G) is a right proximal astragalus. Morphology (note the wide valley and convexity of the proximal trochlea and also the high narrow lateral condyle) excludes the Llamini but typifies the Camelini (Webb, 1965, p. 29). This specimen is referred tentatively to *Camelops* on the basis of its resemblance to the astragalus of *C. hesternus* illustrated by Webb (1965, pp. 29, 31, fig. 17).

Mammuthus meridionalis

NMMNH P-12894 from locality 1452 is an incomplete mandible (Fig. 4M) with left and right M_3 (Fig. 5A). Although the mandibular symphysis is incomplete anteriorly, the spout was relatively short and not significantly flexed ventrally. The horizontal rami are relatively long, low, and narrow. What is present of the ascending rami suggests they were relatively low and inclined posteriorly.

The right M_3 is better preserved and more complete. Both M_3s are heavily worn and relatively long (282^+ mm). On the right M_3, six plates are preserved, but the position of the anterior alveoli and length of the anterior worn dentine suggest at least two additional plates were present. Plate enamel is extremely thick (average enamel thickness = 38 mm), and the plate ratio (4.0) is very low. Because of extreme wear, it is impossible to estimate accurately crown height, but it appears to have been low. These features indicate that NMMNH P-12894 is a very primitive *Mammuthus* assignable to *M. meridionalis* (Lucas and Effinger, 1991).

Mammuthus imperator

NMMNH P-12888 (Fig. 5B–C) from locality 1455 is a left M^3 in a maxillary fragment. This tooth has 20+ plates, enamel of moderate thickness (3.0 mm), and a plate ratio of 6. It is 330+ mm long, 190 mm high, and 103 mm wide. All metrics

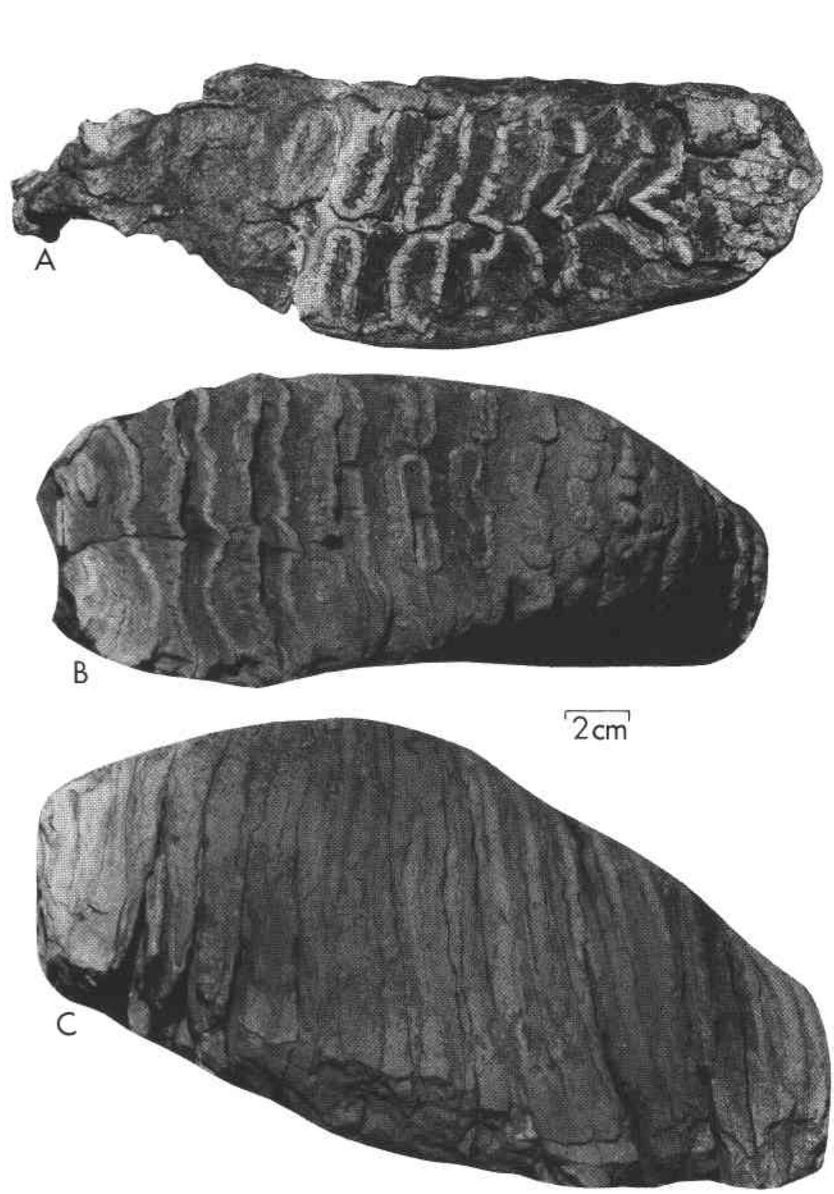

FIGURE 5—Mammoth molars from Tijeras Arroyo: **A**, *Mammuthus meridionalis* (UNM 11028), occlusal view of right M_3; **B–C**, *Mammuthus imperator* (NMMNH P-12888), occlusal view (**B**) and lateral view (**C**).

thus place it comfortably within the range of *Mammuthus imperator* (Madden, 1981; Lucas and Effinger, 1991).

Mammuthus sp.

NMMNH P-12893 from locality 1453 consists of right and left ilia, incomplete pubic bones, and the right acetabulum. The ilia are very wide and flaring, and the innominate is otherwise typical of the Elephantidae. Given the relatively large size of the acetabulum (see Olsen, 1979), this pelvis is assigned to *Mammuthus* sp.

Taphonomy and paleoecology

We present here a few taphonomic and paleoecological inferences for the Sierra Ladrones Formation in Tijeras Arroyo based principally on localities 1452, 1453, and 1454. The immediate context of the *Mammuthus* pelvis (locality 1453) was excavated in a controlled manner, so reconstruction of the local sedimentary context was possible. In general, the section is underlain by a clast-supported bed of gravel- to cobble-sized rocks of undetermined lateral extent. Above this level lie alternating gravel lenses and sand units of varying coarseness, with fine-grained sands typically interbedded with gravel lenses (Fig. 6A). Clay bodies (0.5–1.5 m diameter) are present, and medium- to coarse-grained sands often contain tuffaceous pebbles. Gravel lenses in medium- to fine-grained sand units have the appearance of inverted channels (convex on their upper surfaces), although these do not form continuous structures. Some indication of normal grading is evident, but there is no evidence of consistent clast orientation or imbrication.

The pubic symphysis of the mammoth pelvis was intact during deposition because both innominates were in anatomical position. The pelvis was oriented N45°W (bearing through the pubic symphysis and the articular surfaces of the ilia) with a dip of 20° along magnetic N25°E. This orientation is consistent with a southward-flowing current, with the long axis of the pelvis parallel to flow.

The sedimentary context of the *Mammuthus* mandible (locality 1452) consists of a upward-fining sequence of clast-supported gravels overlain by poorly sorted quartz sands and 15 cm of eolian soil. Clay bodies formed a nearly continuous surface on which the mandible lay; such a

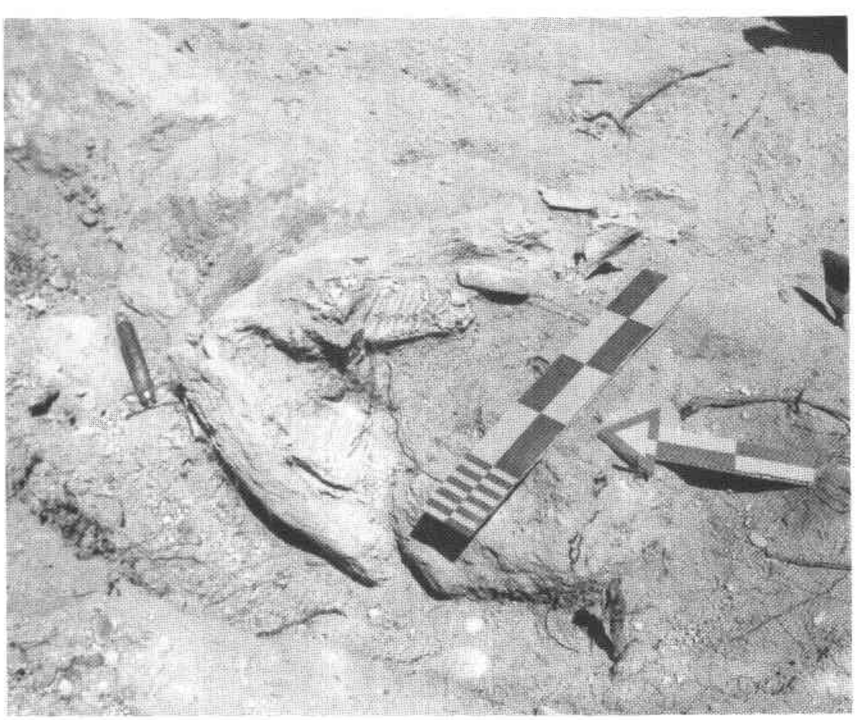

FIGURE 6—*Mammuthus* mandible in situ at locality 1452 (note cobble embedded in right ramus and the scoured and weathered condition of the bone).

surface may represent cut-bank failure or accretion on a longitudinal channel bar. The sequence is capped by about 2 cm of fine-grained sands and pebbly lag deposits. The mandible lay at an angle of about 20° at the foot of a clay bar running southeast–northwest, bearing N50°E. A subspherical clay body apparently fixed the left ramus to the clay surface, and the eroded surface of the bone indicates a period of in-place scouring prior to burial (Fig. 6B).

Localities 1452 and 1453 resemble the characteristic lithofacies of low-sinuosity fluvial systems (see, for example, Williams and Rust, 1977). Bar migration and channel shifts produce an alternating sedimentary morphology that is clearly present at both *Mammuthus* sites. Inverted gravel lenses (transverse sections of longitudinal point bars), rolled subspherical clay bodies, and other large transported clasts, together with larger clay masses of accretionary origin, all point to a low-sinuosity, high-energy (braided) fluvial environment with frequent channel shifts and intermittent subaerial exposure. This is characteristic of the present-day Rio Grande system.

The preservation and condition of the fossils support such an interpretation. These sites appear to have been winnowed of all but large, traction-transported elements corresponding to transport groups two and three (Voorhies, 1969). Both *Mammuthus* specimens indicate some degree of predepositional attrition and transport. The mandible displays extensive stress-line weathering along the lateral aspects of the right and left horizontal rami and exfoliation of superficial laminae on the lateral surface of the right ramus comparable to stages 3 and 4 of Behrensmeyer's (1978) weathering scale. This indicates perhaps as long as a year of subaerial exposure before burial, depending on local climatic conditions. The accumulation of cobbles around the jaw (including a 10-cm cobble lodged between the molar and ramus), as well as extensive superficial pitting and scouring, suggest in situ abrasion by transported particles. Finally, the articulated condition of both pubic and mandibular symphyses suggests that burial was rapid. The transport-resistant nature of both *Mammuthus* specimens, their weathered condition, and the absence of associated skeletal elements despite evidence of rapid burial all imply high-energy deposition.

This contrasts with the lithology of the fossil-bearing mud unit (locality 1454) that yielded *Glyptotherium* and *Equus*. The massive clay unit suggests the presence of an abandoned channel, and perhaps local sediment stabilization by vegetation. The fragmentary nature of teeth and bones appears to be due to recent weathering rather than to the original depositional environment.

The sands and gravels of the Sierra Ladrones Formation at Tijeras Arroyo thus were deposited on an arid or semiarid piedmont plain via a system of shifting or ephemeral streams (Lambert, 1968). The stratigraphy of the region shows an alternating pattern of matrix-supported gravel clasts with interbedded fine-grained intervals, indicating alternating high- and low-energy systems with frequent upward-fining depositional episodes. On the whole, coarser materials become more common as one proceeds up the section, which may indicate a gradual transition from more distal to more proximal fluvial deposition over the region. On a smaller scale, localities 1452 and 1453 clearly indicate the high-energy regime and dissected topography of a low sinuosity river, both in nature of the local sedimentology and in fossil assemblages, which are deficient in small, low density elements with low cross-sectional areas. Locality 1454 appears to represent a local, lower energy variant of such a depositional environment.

We can only make the most general paleoenvironmental inferences based on the vertebrate fossils because they are so few and scattered. The occurrence of large grazing mammals such as *Equus* and *Camelops* suggests a nearby flora dominated by open grassland or short-grass prairie. *Mammuthus* was presumably both a grazing and browsing mammal and therefore indicates either kind of vegetation or a grassland–woodland mosaic.

Biochronology

The fossil mammals from Tijeras Arroyo indicate that the strata exposed there are of Blancan and Irvingtonian age. Two taxa, *Hypolagus* cf. *H. gidleyi* and *Equus cumminsii*, are found in the lowermost exposures of the Sierra Ladrones Formation. *H. gidleyi* is known primarily from Blancan faunas, although some specimens may be as old as Barstovian (White, 1987). *E. cumminsii* is a typically Blancan species but is not known from earliest Blancan localities (Kurten and Anderson, 1980). This fossiliferous level of the Sierra Ladrones Formation is thus broadly correlative with other Blancan faunas in the Santa Fe Group (e.g., Lucas and Oakes, 1986), but a more precise correlation is not possible.

The fossiliferous interval at Tijeras Arroyo in the middle-upper exposures of the Sierra Ladrones Formation contains *Mammuthus* as its most common element. The presence of mammoth is taken by us as incontrovertible evidence of its post-Blancan age. Other mammals present, *Equus* cf. *E. scotti*, cf. *Camelops* sp., and *Glyptotherium* cf. *G. arizonae*, suggest an Irvingtonian age. This age is consistent with abundant reworked Guaje Pumice present in the Sierra Ladrones Formation at Tijeras Arroyo (Lambert, 1968), which indicates these strata are no older than about 1.61 Ma (unpubl. $^{40}Ar/^{39}Ar$ date: W. McIntosh and S. Cather, pers. comm. 1992). The section at Tijeras Arroyo thus produces both Blancan (Pliocene) and Irvingtonian (Pleistocene) mammals. However, it clearly is not a continuous record of the Blancan–Irvingtonian transition. It does, nevertheless, provide one of the few documented faunas of Irvingtonian mammals from New Mexico, which includes one of the northernmost occurrences of glyptodonts as well as a very primitive *Mammuthus*.

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References

Akersten, W. A., 1972, Redlight local fauna (Blancan) of the Love Formation, southeastern Hudspeth County, Texas: Bulletin of the Texas Memorial Museum, v. 20, pp. 1–53.

Bailey, R. A., Smith, R. L., and Ross, C. S., 1969, Stratigraphic nomenclature of volcanic rocks in the Jemez Mountains, New Mexico: U. S. Geological Survey, Bulletin 1274–P, 19 pp.

Behrensmeyer, A. K., 1978, Taphonomic and ecologic information from bone weathering: Paleobiology, v. 4, pp. 150–162.

Bryan, K., and McCann, F. T., 1937, The Ceja del Rio Puerco: a border feature of the Basin and Range province in New Mexico. I. Stratigraphy and structure: Journal of Geology, v. 45, pp. 801–828.

Bryan, K., and McCann, F. T., 1938, The Ceja del Rio Puerco: a border feature of the Basin and Range province in New Mexico, II. Geomorphology: Journal of Geology, v. 46, pp. 1–16.

Denny, C. S., 1940, Tertiary geology of the San Acacia area, New Mexico: Journal of Geology, v. 48, no. 1, pp. 73–106.

Galusha, T., 1966, The Zia Sand Formation, new early to medial Miocene beds in New Mexico: American Museum Novitates, no. 2271, pp. 1–12.

Gardner, J. N., Goff, F., Garcia, S. R., and Hagan, R. C., 1986, Stratigraphic relations and lithologic variations in the Jemez volcanic field, New Mexico: Journal of Geophysical Research, v. 91, no. B2, pp. 1763–1778.

Gawne, C. E., 1981, Sedimentology and stratigraphy of the Miocene Zia Sand of New Mexico: Geological Society of America, Bulletin, v. 92, pp. 999–1007.

Gidley, J. W., 1901, Tooth characters and revision of the North American species of the genus *Equus*: Bulletin of the American Museum of Natural History, v. 14, pp. 91–142.

Gillette, D. D., and Ray, C. E., 1981, Glyptodonts of North America: Smithsonian Contributions to Paleobiology no. 40, Washington, D. C., Smithsonian Institution Press, 255 pp.

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

Hawley, J. W. (compiler), 1978, Guidebook to the Rio Grande rift in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources, Circular 163, 241 pp.

Hawley, J. W., and Galusha, T., 1978, Bernalillo to south of San Ysidro: New Mexico Bureau of Mines and Mineral Resources, Circular 163, pp. 177–183.

Herrick, C. L., and Johnson, D. W., 1900, The geology of the Albuquerque sheet: Denison University, Science Laboratories Bulletin, v. 11, pp. 175–239.

Kelley, V. C., 1977, Geology of Albuquerque Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 33, 60 pp.

(Continues on p. 15)

Gillette, D. D., Wolberg, D. L., and Hunt, A. P., 1986, Tyrannosaurus rex from the McRae Formation (Lancian, Upper Cretaceous), Elephant Butte Reservoir, Sierra County, New Mexico: New Mexico Geological Society, Guidebook to the 37th Field Conference, pp. 235–238.
Harland, W. B., Armstrong, R. L., Cox, A. V., Craig, L.E., Smith, A. G., and Smith, D. G., 1990, A geologic time scale 1989: Cambridge University Press, New York, 263 pp.
Hodgson, S. A., 1991, The geology and tectonics of the northern Little Hatchet Mountains, Grant and Hidalgo Counties, southwestern New Mexico: Unpublished MS thesis, New Mexico State University, Las Cruces, 117 pp.
La Rocque, A., 1960, Molluscan faunas of the Flagstaff Formation of central Utah: Geological Society of America, Memoir 78, 100 pp.
Lasky, S. G., 1947, Geology and ore deposits of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: U.S. Geological Survey, Professional Paper 208, 101 pp.
Lawton, T. F., and Clemons, R. E., 1992, Klondike Basin—late Laramide depocenter in southern New Mexico: New Mexico Geology, v. 14, no. 1, pp. 1–7.
Lawton, T. F., Mack, G. H., Basabilvazo, G. T., Wilson, D. A., Lucas, S. G., and Kietzke, K. K., 1990, Uppermost Cretaceous and Paleocene strata in the Little Hatchet Mountains, southwestern New Mexico (abs.): New Mexico Geology, v. 12, no. 1, p. 16.
Lipman, P. W., and Hagstrum, J. T., 1992, Jurassic ash-flow sheets, calderas, and related intrusions of the Cordilleran volcanic arc in southeastern Arizona: implications for regional tectonics and ore deposits: Geological Society of America, Bulletin, v. 104, pp. 32–39.
Lipman, P. W., and Sawyer, D. A., 1985: Mesozoic ash-flow caldera fragments in southeastern Arizona and their relation to porphyry copper deposits: Geology, v. 13, pp. 652–656.
Loring, A. K., and Loring, R. B., 1980, K/Ar ages of middle Tertiary igneous rocks from southern New Mexico: Isochron/West, no. 28, pp. 17–19.
Lucas, S. G., Basabilvazo, G. T., and Lawton, T. F., 1990, Late Cretaceous dinosaurs from the Ringbone Formation, southwestern New Mexico, U.S.A.: Cretaceous Research, v. 11, pp. 343–349.
Lucas, S. G., and González-León, C., 1990, Reporte preliminar sobre dinosarios del Cretácico Tardío de la cuenca de Cabullona, Sonora: Universidad de Sonora, Departemento Geología Boletin, v. 7 , no. 1, pp. 1–6.
Marvin, R. G., Naeser, C. W., and Mehnert, H.H., 1978, Tabulation and radiometric ages—including unpublished K-Ar and fission-track ages—for rocks in southeastern Arizona and southwestern New Mexico: New Mexico Geological Society, Guidebook to the 29th Field Conference, pp. 243–252.
Rosaz, T., 1989, Le passage des Cordillères nord-américains aux Sierras Madres mexicaines le long du Texas Lineament— Géologie de SW du Nouveau-Mexique (USA): Bulletin Centres de Recherces-Exploration–Production Elf Aquitaine, v. 13, pp. 247–275; New Mexico Bureau of Mines and Mineral Resources, Open-file Report 385 [in French, with English summary and captions].
Seager, W. R., 1983, Laramide wrench faults, basement-cored uplifts, and complimentary basins in southern New Mexico: New Mexico Geology, v. 5, pp. 69–76.
Seager, W. R., and Mack, G. H., 1986, Laramide paleotectonics of southern New Mexico; in Peterson, J. A., (ed.), Paleotectonics and sedimentation in the Rocky Mountain region, United States: American Association of Petroleum Geologists, Memoir 41, pp. 669–685.
Seager, W. R., Mack, G. H., Raimonde, M. S., and Ryan, R. G., 1986, Laramide basement-cored uplift and basins in south-central New Mexico: New Mexico Geological Society, Guidebook to the 37th Field Conference, pp. 123–130.
Thorman, C. H., and Drewes, H., 1980, Geologic map of the Victorio Mountains, Luna County, southwestern New Mexico: U.S. Geologic Survey, Miscellaneous Field Studies Map MF-1175, scale 1:24,000.
Wilcox, R. E., Harding, T. P., and Seely, D. R., 1973, Basic wrench tectonics: American Association of Petroleum Geologists, Bulletin, v. 57, pp. 74–96.
Wilson, D. A., 1991, Depositional environments, provenance, and age determination of the Skunk Ranch Formation, Little Hatchet Mountains, southwestern New Mexico: Unpublished MS thesis, New Mexico State University, Las Cruces, 87 pp.
Zeller, R. A., Jr., 1970, Geology of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 96, 22 pp. □

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(*Continued from p. 8*)

Kurten, B., and Anderson, E., 1980, Pleistocene mammals of North America: Columbia University Press, New York, 442 pp.
Lambert, P. W., 1968, Quaternary stratigraphy of the Albuquerque area, New Mexico: Unpublished PhD dissertation, University of New Mexico, 329 pp.
Lambert, P. W., 1978, Upper Santa Fe stratigraphy and geomorphic features of the Llano de Albuquerque: New Mexico Bureau of Mines and Mineral Resources, Circular 163, p. 151.
Logan, T. R., 1984, Early Irvingtonian (early Pleistocene) mammals from the upper part of the Santa Fe Group, Albuquerque-Belen Basin, central New Mexico: Geological Society of America, Rocky Mountain Section, Abstracts with Programs, v. 16, no. 4, p. 245.
Logan, T. R., Lucas, S. G., and Sobus, J. C., 1984, Blancan-Irvingtonian boundary in the Ceja Member of the Santa Fe Formation, Tijeras Arroyo, Albuquerque area, New Mexico: New Mexico Geology, v. 6, no. 1, p. 14.
Lozinsky, R. P., Hawley, J. W., and Love, D. W., 1991, Geologic overview and Pliocene–Quaternary history of the Albuquerque Basin, central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 137, p. 157–162.
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 pp.
Lucas, S. G., 1987, American mastodont from the Sandia Mountains, New Mexico: New Mexico Journal of Science, v. 27, pp. 29–32.
Lucas, S. G., and Effinger, J. A., 1991, *Mammuthus* from Lincoln County and a review of the mammoths from the Pleistocene of New Mexico: New Mexico Geological Society, Guidebook to 42nd Field Conference, pp. 277–282.
Lucas, S. G., and Ingersoll, R. V., 1981, Cenozoic continental deposits of New Mexico: an overview: Geological Society of America Bulletin, v. 92, pp. 917–932.
Lucas, S. G., and Logan, T. R., 1984, Pleistocene horse from the Albuquerque area, New Mexico: New Mexico Journal of Science, v. 24, pp. 29–32.
Lucas, S. G., and Oakes, W., 1986, Pliocene (Blancan) vertebrates from the Palomas Formation, south-central New Mexico: New Mexico Geological Society, Guidebook to 37th Field Conference, pp. 249–255.
Lucas, S. G., Williamson, T., and Sobus, J., 1988, Late Pleistocene (Rancholabrean) mammals from the Edith Formation, Albuquerque, New Mexico: New Mexico Journal of Science, v. 28, pp. 51–58.
MacFadden, B. J., 1977, Magnetic polarity stratigraphy of the Chamita Formation stratotype (Mio-Pliocene) of north-central New Mexico: American Journal of Science, v. 277, pp. 769–800.
Machette, M. N., 1978a, Geologic map of the San Acacia quadrangle, Socorro County, New Mexico: U. S. Geological Survey, Geologic Quadrangle Map GQ-1415.
Machette, M. N., 1978b, Preliminary geologic map of the Socorro 1° × 2° quadrangle, central New Mexico: U.S. Geological Survey, Open-file Report 78-607.
Machette, M. N., 1978c, Quaternary faults in the southwestern United States by using buried calcic paleosols: Journal of Research, U.S. Geological Survey, v. 6, pp. 369–381.
Madden, C., 1981, Mammoths of North America: Unpublished PhD dissertation, University of Colorado, 241 pp.
Manley, K., 1978, Geologic map of Bernalillo NW quadrangle, Sandoval County, New Mexico: U. S. Geological Survey, Geologic Quadrangle Map GQ-1445.
Olsen, S. J., 1979, Osteology for the archaeologist: Peabody Museum, Cambridge, 186 pp.
O'Neill, F. M., and Rigby, J. K., Jr., 1982, A rare-fossil skeleton of *Camelops* from Pleistocene deposits near Albuquerque: New Mexico Geological Society, Guidebook to 33rd Field Conference, pp. 82–84.
Osborn, H. F., 1918, Equidae of the Oligocene, Miocene, and Pliocene of North America, iconographic type revision: Memoir of the American Museum of Natural History, new series, v. 2, pp. 1–330.
Smith, R. L., Bailey, R. As., and Ross, C. S., 1970, Geologic map of the Jemez Mountains, New Mexico: U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-571.
Tedford, R. H., 1981, Mammalian biochronology of the late Cenozoic basins of New Mexico: Geological Society of America Bulletin, v. 92, pp. 1008–1022.
Tedford, R. H., 1982, Neogene stratigraphy of the northwestern Albuquerque Basin: New Mexico Geological Society, Guidebook to 33rd Field Conference, pp. 273–278.
Voorhies, M., 1969, Taphonomy and population dynamics of an early Pliocene vertebrate fauna, Knox County, Nebraska: University of Wyoming Contributions to Geology, Special Paper 2, 69 pp.
Webb, S. D., 1965, The osteology of *Camelops*: Science Bulletin of the Los Angeles County Museum, v. 1, 54 pp.
White, J. A., 1987, The Archaeolaginae (Mammalia, Lagomorpha) of North America, excluding *Archaeolagus* and *Palolax*: Journal of Vertebrate Paleontology, v. 7, pp. 425–450.
Williams, G. E., and Rust, B. R., 1977, The sedimentology of a braided river: Journal of Sedimentary Petrology, v. 39, pp. 649–679.
Wright, H. E., Jr., 1946, Tertiary and Quaternary geology of the lower Puerco area, New Mexico: Geological Society of America Bulletin, v. 57, pp. 383–456. □