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

by Spencer G. Lucas, Thomas E. Williamson, New Mexico Museum of Natural History, 1801 Mountain Road N.W., Albuquerque, New Mexico, 87104; and Jay Sobus, College of Human Ecology, 2100 Marie Mount Hall, University of Maryland, College Park, Maryland 20742–7531

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 Hymotherium cf. H. gidleyi and Equus cammenisii; Irvingtonian mammals are Glyptotherium cf. G. arizoneae, 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

Laramide stratigraphy of the Little Hatchet Mountains p. 9
Gallery of Geology—Killion Canyon p. 16
Geographic names p. 17
1992 Mineral Symposium abstracts p. 18
1993 NMGS Fall Field Conference p. 20
Service/News p. 21
Upcoming meetings p. 22
1994 NMGS Fall Field Conference p. 23
Staff notes p. 23
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'Neil 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 harlanii, Equus cf. E. occidentalis, Bison sp., Camelops hesternus and Mammutthus columbi, a typical assemblage of large Rancholabrean (Wisconsin-age) mammals.

Older Quaternary and latest Pleistocene 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 biogeochronological significance. In this article, NMNMNH 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 faunas: 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 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 stratigraphers, 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 underlining 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) intertongue with the lower volcaniclastic deposits 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 that recently has 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 aluvial 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 Blanccan 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, NE 1/4 sec. 1 and NW 1/4 sec. 16 T9N R3E, Bernallillo County, New Mexico

<table>
<thead>
<tr>
<th>Unit</th>
<th>Lithology</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sierra Ladrones Formation:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>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 d) subrounded to angular quartz grains and coarse- to very coarse grained (≥ 1 d); rounded pumice grains; trough crossbedded; top of unit is airport surface.</td>
<td>12.0+</td>
</tr>
<tr>
<td>Unit</td>
<td>Lithology</td>
<td>Thickness (m)</td>
</tr>
<tr>
<td>------</td>
<td>-----------</td>
<td>---------------</td>
</tr>
<tr>
<td>9.</td>
<td>Sandstone, noncalcareous, grayish-orange (10YR 7/4), fine- to coarse-grained (0.50-3.0 φ); subangular quartz and chert; trough crossbedded.</td>
<td>6.1</td>
</tr>
<tr>
<td>8.</td>
<td>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.</td>
<td>10.1</td>
</tr>
<tr>
<td>7.</td>
<td>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.</td>
<td>12.2</td>
</tr>
<tr>
<td>6.</td>
<td>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).</td>
<td>3.4</td>
</tr>
<tr>
<td>5.</td>
<td>Sandstone, slightly calcareous, yellowish-gray (5Y 8/1), fine- to medium-grained (2.00-0.0 φ); poorly sorted subrounded quartz; trough crossbedded.</td>
<td>6.1</td>
</tr>
<tr>
<td>4.</td>
<td>Claystone, noncalcareous, grayish-green (10 GY 5/2).</td>
<td>1.2</td>
</tr>
<tr>
<td>3.</td>
<td>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.</td>
<td>13.7</td>
</tr>
<tr>
<td>2.</td>
<td>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 convoluted bedding.</td>
<td>3.4</td>
</tr>
<tr>
<td>1.</td>
<td>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 parts, one clay band 20 cm thick; fragmentary bone present; much slope debris.</td>
<td>8.1</td>
</tr>
<tr>
<td>0.</td>
<td>Covered.</td>
<td>76.3</td>
</tr>
</tbody>
</table>

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 provide 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.

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 154 (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 P₄-M₃; C, Equus cf. E. scotti (NMMNH P-12884), left upper cheek tooth; D, Equus cf. E. scotti (NMMNH P-12881), right dP₃; E, Equidae (NMMNH P-12883), right M₂; 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), P₃ (right is mesial, top is labial); L, Hypolagus cf. H. gidley (NMMNH P-12938), left dentary fragment with P₃ in lingual view; M, Mammuthus meridionalis (UNM 11028), mandible with right and left M₂. 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 NE1/4NE1/4SW1/4 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. 4–L) from locality 1458 consists of a right dentary fragment with the root of I, and a very worn P3, 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 Esponal 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–P5, diastema length (16.5 mm) and P1, 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 P1 lacks an anterior reentrant (Fig. 4–K), which is part of the diagnosis of H. gidleyi (White, 1987, p. 434); and 3) the posteroexternal reentrant on P1 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. scotti

NMMNH P-12889 from locality 1459 is a damaged right dentary with dP3 (Fig. 4D) and dP4, and the unerupted fragments of P2 and M1. 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 (P7?) tooth, and NMMNH P-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

Equus cf. E. scotti

NMMNH P-12889 from locality 1459 is a right M3, (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. nobrarensis and are intermediate between E. convorsidersis and E. nobrarensis, respectively (Harris and Porter, 1980). NMMNH P-12881 from locality 1454 is a partial maxillary symphysis containing the alveoli of P1–P 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. convorsidersis or a horse of similar size.

Mammuthus meridionalis

NMMNH P-12894 from locality 1452 is an incomplete mandible (Fig. 4M) with left and right M3 (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 M3 is better preserved and more complete. Both Ms are heavily worn and relatively long (282 mm). On the right M3, 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 Eiffinger, 1991).

Mammuthus imperator

NMMNH P-12888 (Fig. 5B–C) from locality 1455 is a left M3 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

<table>
<thead>
<tr>
<th>TABLE 2—Dimensions of Equus teeth (in mm) from the Sierra Ladrone Formation at Tijeras Arroyo</th>
<th>width</th>
</tr>
</thead>
</table>
| NMMNH P-12895    |\begin{tabular}{l|l}
left P1 & 40.5 \\
left P2 & 28.7 \\
left P3 & 24.3 \\
left M1 & 29.3 \\
left M2 & 28.0 \\
left M3 & 30.6 \\
right dP3? & 34.4 \\
right dP4? & 35.2 \\
right M1 & 31.8 \\
right M2 & 35.0 \\
right M3 & 33.1 \\
right M4 & 40.5 \\
right M5 & 42.0 \\
right M6 & (36.0) \\
right M7 & 11.4 \\
\end{tabular} | width |
| NMMNH P-12884    |\begin{tabular}{l|l}
left upper molariform & 28.2 \\
right upper molariform & 33.1 \\
right lower molariform & 16.6 \\
\end{tabular} | width |
| NMMNH P-12883    |\begin{tabular}{l|l}
right M1 & 27.0 \\
right M2 & 27.9 \\
right M3 & 28.6 \\
right M4 & 19.6 \\
right M5 & 17.7 \\
right M6 & 13.6 \\
\end{tabular} | width |
| NMMNH P-12940    |\begin{tabular}{l|l}
right upper molariform & 32.2 \\
left upper molariform & 33.6 \\
\end{tabular} | width |
| NMMNH P-12941    |\begin{tabular}{l|l}
left upper molariform & 31.8 \\
right upper molariform & 35.0 \\
\end{tabular} | width |
| NMMNH P-12936    |\begin{tabular}{l|l}
right lower molariform & 11.4 \\
\end{tabular} | width |
| NMMNH P-12894    |\begin{tabular}{l|l}
left upper molariform & 28.2 \\
\end{tabular} | width |
| NMMNH P-12940    |\begin{tabular}{l|l}
right upper molariform & 33.1 \\
left upper molariform & 35.0 \\
\end{tabular} | width |
| NMMNH P-12883    |\begin{tabular}{l|l}
right M1 & 27.0 \\
right M2 & 27.9 \\
right M3 & 28.6 \\
right M4 & 19.6 \\
right M5 & 17.7 \\
right M6 & 13.6 \\
\end{tabular} | width |
| NMMNH P-12936    |\begin{tabular}{l|l}
right lower molariform & 11.4 \\
\end{tabular} | width |
| NMMNH P-12884    |\begin{tabular}{l|l}
left upper molariform & 33.1 \\
right upper molariform & 35.0 \\
\end{tabular} | width |
| NMMNH P-12936    |\begin{tabular}{l|l}
right lower molariform & 11.4 \\
\end{tabular} | width |
| NMMNH P-12891    |\begin{tabular}{l|l}
right upper molariform & 33.1 \\
left upper molariform & 35.0 \\
\end{tabular} | width |
| NMMNH P-12936    |\begin{tabular}{l|l}
right lower molariform & 11.4 \\
\end{tabular} | width |
| NMMNH P-12894    |\begin{tabular}{l|l}
left upper molariform & 33.1 \\
right upper molariform & 35.0 \\
\end{tabular} | width |
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 context...
surface may represent cut-bank failure or accretion on a longitudinal channel bar. The sequence is capped by about 2 cm of fine-grained sand and pebbly lag deposits. The mandible lay at an angle of about 20° at the foot of a clay bar running south-east-northwest, bearing N50°E. A sub-spherical 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 Mammutthus sites. Inverted gravel lenses (transverse sections of longitudinal point bars), rolled sub-spherical 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 intermitted 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-transferred elements corresponding to transport groups two and three (Voorhies, 1969). Both Mammutthus 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 Mammutthus 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 La-
Lucas et al.  
(Continued from p. 8)

Kurten, B., and Anderson, E., 1980, Pleistocene mam- 
mals of North America: Columbia University Press, 

Lambert, P. W., 1978, Upper Santa Fe stratigraphy and 
geomorphic features of the Llano de Albu- 
querque, New Mexico: New Mexico Bureau of Mines and 

Logan, T. R., 1984, Early Irvingtonian (early Plis- 
tocene) 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.

Blancan-Irvingtonian boundary in the Cen- 
tral New Mexico: New Mexico Geological So- 
lociety, Guidebook to 33rd Field Conference, pp. 
1-330.

Geologic map of the Jemez Mountains, New Mex- 
ico: U.S. Geological Survey, Miscellaneous Geo- 
logic Investigations Map I-571.

Tedford, R. H., 1981, Mammalian biochronology of 
the late Cenozoic mammals of New Mexico: New 
Mexico Bureau of Mines and Mineral Resources, 
Guidebook to 33rd Field Conference, pp. 82-84.

Osborn, H. F., 1918, Equidae of the Oligocene, Mi-
ocene, and Pliocene of North America, icono-
tographic type revision: Memoir of the American 
1-330.

Geologic map of the Jemez Mountains, New Mex- 
ico: U.S. Geological Survey, Miscellaneous Geo-
logic Investigations Map I-571.

Tedford, R. H., 1981, Mammalian biochronology of 
the late Cenozoic mammals of New Mexico: New 
Mexico Bureau of Mines and Mineral Resources, 
Guidebook to 33rd Field Conference, pp. 82-84.

Osborn, H. F., 1918, Equidae of the Oligocene, Mi-
ocene, and Pliocene of North America, icono-
tographic type revision: Memoir of the American 
1-330.

Geologic map of the Jemez Mountains, New Mex- 
ico: U.S. Geological Survey, Miscellaneous Geo-
logic Investigations Map I-571.