



A new discovery of a skeleton of the horse *Protohippus?*, and a summary of the Miocene (Barstovian) fossil localities near Dixon, Rio Arriba County, New Mexico

Gary S. Morgan, Aby, Scott, B., and Makaela Vogel, 2011, pp. 339-346

in:

Geology of the Tusas Mountains and Ojo Caliente, Author Koning, Daniel J.; Karlstrom, Karl E.; Kelley, Shari A.; Lueth, Virgil W.; Aby, Scott B., New Mexico Geological Society 62nd Annual Fall Field Conference Guidebook, 418 p.

This is one of many related papers that were included in the 2011 NMGS Fall Field Conference Guidebook.

Annual NMGS Fall Field Conference Guidebooks

Every fall since 1950, the New Mexico Geological Society (NMGS) has held an annual [Fall Field Conference](#) that explores some region of New Mexico (or surrounding states). Always well attended, these conferences provide a guidebook to participants. Besides detailed road logs, the guidebooks contain many well written, edited, and peer-reviewed geoscience papers. These books have set the national standard for geologic guidebooks and are an essential geologic reference for anyone working in or around New Mexico.

Free Downloads

NMGS has decided to make peer-reviewed papers from our Fall Field Conference guidebooks available for free download. Non-members will have access to guidebook papers two years after publication. Members have access to all papers. This is in keeping with our mission of promoting interest, research, and cooperation regarding geology in New Mexico. However, guidebook sales represent a significant proportion of our operating budget. Therefore, only *research papers* are available for download. *Road logs, mini-papers, maps, stratigraphic charts*, and other selected content are available only in the printed guidebooks.

Copyright Information

Publications of the New Mexico Geological Society, printed and electronic, are protected by the copyright laws of the United States. No material from the NMGS website, or printed and electronic publications, may be reprinted or redistributed without NMGS permission. Contact us for permission to reprint portions of any of our publications.

One printed copy of any materials from the NMGS website or our print and electronic publications may be made for individual use without our permission. Teachers and students may make unlimited copies for educational use. Any other use of these materials requires explicit permission.

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

A NEW DISCOVERY OF A SKELETON OF THE HORSE *PROTOHIPPIUS?*, AND A SUMMARY OF MIOCENE (BARSTOVIAN) FOSSIL LOCALITIES NEAR DIXON, RIO ARRIBA COUNTY, NEW MEXICO

GARY S. MORGAN¹, SCOTT B. ABY², AND MAKAEVA VOGEL³

¹New Mexico Museum of Natural History, 1801 Museum Road, NW, Albuquerque, NM 87104, gary.morgan1@state.nm.us

²Muddy Spring Geology, Dixon, NM 87527

³P.O. Box 425, Dixon, NM 87527

ABSTRACT—A partial skeleton of the horse *Protohippus?* was found and collected from the middle Miocene Chama-El Rito Member of the Tesuque Formation near Dixon in Rio Arriba County, New Mexico, in early 2009. This specimen consists of a nearly complete skull and articulated front and hind limbs. Neogene strata near Dixon are sparsely fossiliferous, with only five other specimens known from over 100 years of sporadic collecting, including fossils representing the borophagine canid *Aelurodon taxoides*, a second unidentified equid, the oreodont *Merychys medius*, the camel *Protolabis* sp., and a second smaller camel. Most of this fossil assemblage is derived from the Chama-El Rito Member and is indicative of the late Barstovian land-mammal “age” (~13.5-14.5 Ma); however, the occurrence of *Aelurodon taxoides* in the overlying Dixon Member(?) suggests a somewhat younger latest Barstovian age (~12.5-13.5 Ma) for that unit.

INTRODUCTION

We review the limited record of Miocene vertebrate fossils from the Chama-El Rito and Dixon members of the Tesuque Formation in the vicinity of Dixon, Rio Arriba County, northern New Mexico (Fig. 1). The best known fossil from this area is a partial skeleton of the three-toed horse *Protohippus?*, discovered by Mikaela Vogel in January 2009 and collected shortly thereafter by a field crew under our direction. The vertebrate fauna from the Dixon area also contains a few other specimens, including partial skeletons of the oreodont *Merychys* and the camel *Protolabis*, a partial skull of the bone-crushing dog *Aelurodon*, a jaw fragment of a small camel, and a horse toe. We also discuss the geologic context of the Miocene fossils in the Dixon area.

The abbreviations for tooth positions are standard for mammals, with upper case letters for upper teeth and lower case letters for lower teeth: I/i (upper/lower incisor), C/c (upper/lower canine), P/p (upper/lower premolar), and M/m (upper/lower molar). For example, P4 is an upper fourth premolar and m3 is a lower third molar. Abbreviations used in the text are: AMNH/F:AM (American Museum of Natural History, Frick Collection); BLM (U. S. Bureau of Land Management); NALMA (North American land-mammal “age”); NMMNH (New Mexico Museum of Natural History and Science), and UNM (University of New Mexico).

GEOLOGIC CONTEXT OF THE *PROTOHIPPIUS?* SITE

The new specimen of *Protohippus?* was found in Neogene exposures just east of the Rio Embudo and southeast of the intersection of State Highways 68 and 75, west of Dixon, New Mexico (Fig. 1). The Chama-El Rito Member here is composed of Proterozoic metamorphic, Neogene volcanoclastic, and Paleozoic sedimentary detritus derived from the north and east. These

exposures lie within the Embudo fault system, and Neogene strata are here juxtaposed against Proterozoic rocks (Koning and Aby, 2003; Aby and Koning, 2004). The beds containing the fossil horse dip 55° toward 275°, but bedding attitudes are variable in the area and folding of the Neogene strata is evident. The gravel assemblage of the nearest conglomerate bed (10 m to east of the site and about 1 m stratigraphically below it) is composed of 25% intermediate volcanic rocks, 9% silicic volcanic rocks, 19% Paleozoic sandstone, 2% Paleozoic siltstone, 31% quartzite, 9% vein quartz, and 4% granite. The abundance of Paleozoic clasts in these beds may indicate that they are from the uppermost part of the Chama-El Rito Member in this area, which is distinguished from the overlying Dixon Member of the Tesuque Formation by the predominance of Neogene volcanic clasts relative to Paleozoic sedimentary clasts and has a 100 m+ section of “mixed” provenance near their contact (Aby and Koning, 2004). Tedford and Barghoorn (1993) assign a late Barstovian NALMA (~12.0-14.5 Ma) age to the fossils in the Dixon area. However, an ash in the upper part of the Chama-El Rito Member here has been

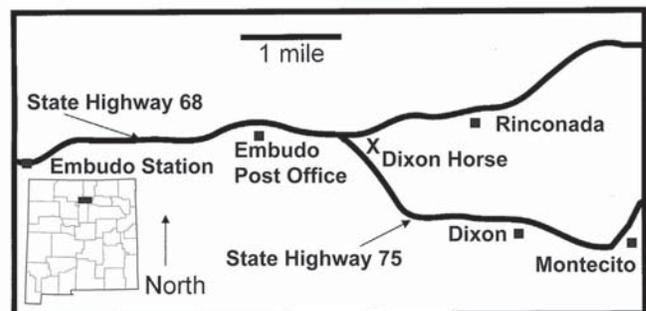


FIGURE 1. Map of the Dixon area, Rio Arriba County, northern New Mexico, showing the general locations mentioned in the text.

tentatively correlated with Skull Ridge White Ash #1 (~16 Ma) or #4 (15.3 Ma), so the precise age of these strata is uncertain (Aby and Koning, 2004).

***PROTOHIPPIUS?* SKELETON**

In January of 2009, a well preserved skull and partial postcranial skeleton of the horse *Protohippus?* (family Equidae) was found and reported to the authors by Makaela Vogel, a student at Dixon Elementary. Working in cooperation with Paul Williams from the BLM office in Taos and Patricia Hester, regional paleontologist for the BLM in New Mexico, the authors organized a field crew to excavate the *Protohippus?* skeleton on February 19, 2009. We were assisted by an enthusiastic group of students from Dixon Elementary and their parents (see list of participants in Acknowledgments).

The horse skeleton was found in sediments of the Chama-El Rito Member on the west side of Cerro Abajo (Serro Avajo on Velarde 7.5-minute quadrangle), near the confluence of the Rio Embudo and the Rio Grande, about 2 km northwest of Dixon (NMMNH locality L-7732). The skull was derived from a red silty-sandy mudstone, whereas the limb bones were preserved in a semi-indurated, reddish-brown, fine-grained sandstone lens(?) within the mudstone. Many loose bones from the postcranial skeleton were found on the surface near the skull and eroding downslope at least 10 m. The skull and associated postcranial elements were excavated, encased in a plaster jacket, removed from the field, and transported to the NMMNH paleontology laboratory and research collection for preparation and study.

The specimen of *Protohippus?* from Dixon (catalog number NMMNH 63409) includes a nearly complete skull, the associated but unattached right and left premaxillae, a partial articulated left front limb, a partial disarticulated right front limb, a partial articulated right hind limb, and numerous associated fragments of postcranial elements (Fig. 2). Considering the well-preserved condition of the skull and the presence of two articulated limbs, it is curious that the lower jaws are missing, as is virtually the entire axial skeleton, including the vertebrae, ribs, and limb girdles (scapulae and innominates). The total lack of evidence of lower teeth or pieces of vertebrae or ribs among the 100 or so fragments of the skeleton that were washed downhill from the collection site strongly suggests that the lower jaws and axial skeleton were disassociated from the skeleton soon after the death of the horse. Whether the removal of a portion of the skeleton occurred by predation, erosion, or some other biological or geological process cannot be determined at this time.

The skull of the Dixon horse is somewhat crushed laterally and slightly damaged anteriorly (Fig. 2A). Both the right and left premaxillae are preserved (with left I1-I3 and right I2), but do not retain a direct connection to the remainder of the skull. All of the cheek teeth are present (left P1-M3, right P2-M3), except the tiny P1 on the right side. The teeth are heavily worn, indicating an aged individual. Although the dental features of the cheek teeth are affected by heavy to extreme wear, the teeth have a fairly uniform morphology. The terminology for equid teeth follows MacFadden (1984).

All of the teeth from P2-M2 have the protocone broadly connected to the protoloph (Fig. 2B). The protocone on M3 is also connected to the protoloph, but the connection is very constricted. The protocone is rounded on P2-M2, and somewhat more elongated or oval on M3. The fossettes have a very simple enamel pattern, with at most one small enamel plication on the posterior border of the prefossette and anterior border of the postfossette. A hypoconal groove is very well developed on M3, but absent on the more anterior cheek teeth. The enamel pattern on the upper cheek teeth has been strongly influenced by heavy wear, especially the connection of the protocone to the protoloph and the simple fossettes (see discussion below). The three upper incisors have well-developed elliptical enamel fossettes or infundibula. The skull has a rather prominent concave fossa anterior and dorsal to the orbits called the dorsal preorbital fossa (Fig. 2A). The shape of this fossa has been strongly affected by the lateral crushing of the skull, but it appears to be fairly deep and elongated in the anterior-posterior dimension, extending from above the posterior edge of M3 anteriorly to above the P4.

The postcranial skeleton of the *Protohippus?* specimen (NMMNH 63409) is incomplete, with only three partial limbs present. The partial left front limb is preserved and articulated in life position, including the distal end of the humerus, complete radius-ulna, nearly complete complement of carpals, metacarpal 3 and proximal phalanx, and lateral metacarpal 2 with proximal and medial lateral phalanges (Fig. 2C). The only elements from the right front limb are the distal humerus, radius-ulna, and most of the metacarpal 3 that had broken into fragments and washed downhill from the rest of the limb. The partially articulated right hind limb includes the distal end of the femur, complete tibia, complete set of tarsals (calcaneum, astragalus, cuboid, navicular, ectocuneiform), and proximal ends of metatarsals 2-4. Isolated bones separated from the rest of the skeleton and eroded downslope include: one proximal and two medial phalanges from digit 3, a partial distal phalanx (hoof) from digit 3, numerous fragments of the lateral metapodials, a lateral medial phalanx, and several isolated carpals and sesamoids.

The limbs appear to be rather slender and elongated, especially the radius-ulna and metacarpal 3 (Fig. 2C). The ratio of the total length to the proximal breadth of the metapodials is often used to determine the relative robustness of this limb element. Using the measurements below, the metacarpal 3 of the Dixon horse has a metapodial ratio of 8.8. This ratio means that the metacarpal 3 is almost nine times longer than it is wide, which is indicative of a very slender-limbed species. Selected postcranial measurements (in mm) of NMMNH 63409 are: length of radius-ulna (minus olecranon process), 231; distal width of radius-ulna, 38; length of metacarpal 3, 203; proximal width of metacarpal 3, 23; length of metacarpal 2, 199; length of proximal phalanx of digit 3, manus, 47.

The identification of the equid skull and partial skeleton from Dixon is difficult because the skull is laterally compressed and the cheek teeth are highly worn. All of the upper cheek teeth in this specimen have the protocone connected to the protoloph, a feature generally associated with the equid tribe Equini, including the genera *Plihippus* and *Protohippus* from Barstovian

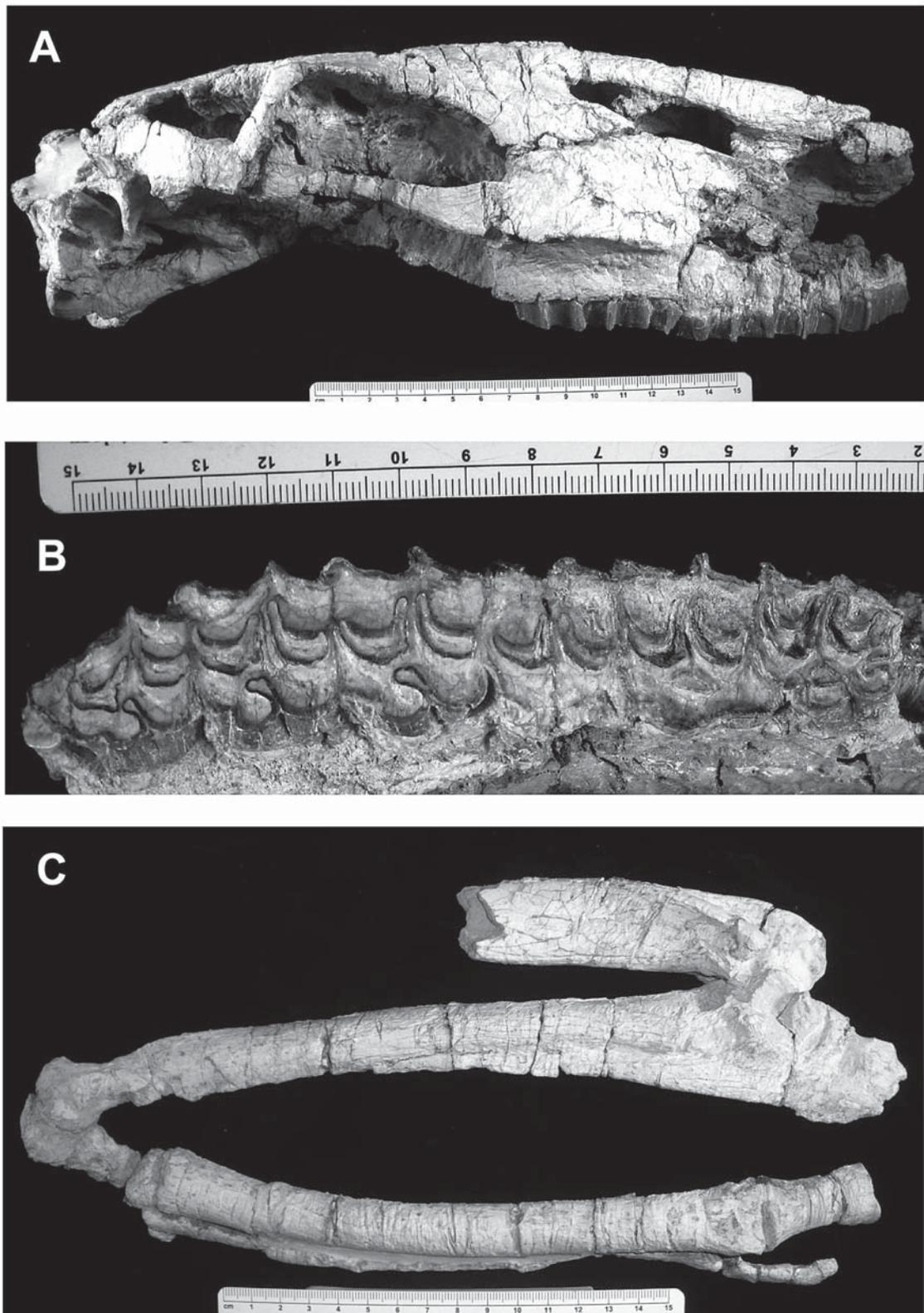


FIGURE 2. Skull and front limb of the horse *Protohippus?* (NMMNH 63409) from the Chama-El Rio Member of the Tesuque Formation, middle Miocene (late Barstovian), near Dixon, Rio Arriba County, New Mexico. A. Right lateral view of the skull. B. Occlusal view of the left upper cheek teeth (P1-M3). C. Articulated left front limb. Scale is in mm.

faunas in the Española Basin (MacFadden, 1998). An isolated protocone that is not connected to the protoloph is typical of the equid tribe Hipparionini, including the genera *Cormohipparion* and *Neohipparion* from Barstovian faunas in the Española Basin (MacFadden, 1998). However, in highly worn teeth of hipparionine horses, including primitive species of *Cormohipparion* and *Neohipparion*, the protocone may become connected to the protoloph. MacFadden (1984, fig. 54) illustrated an upper dentition of a Barstovian specimen of *Neohipparion coloradense* in which the protocone is connected to the protoloph on all upper teeth except the M3.

We compared the upper dentition of the Dixon horse with a complete set of upper cheek teeth (P2-M3) identified as *Neohipparion coloradense* (NMMNH 63417), part of the late Barstovian Santa Cruz Fauna from the Pojoaque Member of the Tesuque Formation in southern Rio Arriba County, about 20 km south of Dixon. The dentition of the Santa Cruz specimen of *N. coloradense* is in medium wear (mesostyle crown height of M3 is 31 mm, compared to 21 mm in the M3 of the Dixon horse). The Santa Cruz equid is distinctly smaller than the Dixon horse (measurements in mm of Santa Cruz specimen first, NMMNH 63417, followed by the Dixon specimen, NMMNH 63409): length of upper tooththrow (P2-M3), 125, 133; length of P2, 26, 30; length of M3, 19, 23. The Santa Cruz teeth have an oval protocone (somewhat more elongated on M3) that is isolated on P3-P4 and M2-M3, but connected to the protoloph on the more heavily worn P2 and M1. Compared to the Dixon horse, the teeth referred to *N. coloradense* have an oval-shaped protocone that is isolated from the protoloph on P3-P4 and M2-M3, more complicated fossettes, a small pli caballin, and a well developed hypoconal groove, as well as a shorter and more triangular anterostyle on P2. However, several of these differences could be a result of the extreme wear on the teeth of Dixon horse. Among the four genera of horses known from late Barstovian faunas in the Española Basin (*Cormohipparion*, *Neohipparion*, *Pliohippus*, and *Protohippus*) the enamel pattern of the upper teeth in the Dixon equid, in particular the least worn tooth, the M3, is more similar to *Protohippus* than to the other three genera (Hulbert, 1988; R. Hulbert, pers. commun.).

The shape and structure of the dorsal preorbital fossa is another character that is useful for separating skulls of Barstovian horse genera. *Pliohippus* has a prominent preorbital fossa and also has a complicated malar fossa on the lateral surface of the maxilla immediately anterior to the orbit (MacFadden, 1992, fig. 5.20A). The Dixon equid has a shallow, well-defined preorbital fossa but the maxilla anterior to the orbit shows no evidence of a malar fossa (Fig. 2A). The posterior edge of the preorbital fossa in the Dixon specimen is not particularly deep or pocketed as in *Cormohipparion* (MacFadden, 1984) and seems to be most similar to *Neohipparion* and *Protohippus*, not particularly deep but with distinct dorsal and posterior rims. The Dixon equid skull can be distinguished from *Pliohippus* and *Cormohipparion* by differences in the dorsal preorbital fossa and from *Neohipparion* by features of the upper dentition. Based on the similarity in size, dental morphology of the teeth (especially the M3), and the structure of the dorsal preorbital fossa, the Dixon equid is

tentatively referred to *Protohippus*. We designate this tentative referral throughout the paper by placing a “?” after the genus *Protohippus*? This tentative generic referral can also be indicated by the taxonomic convention “cf. *Protohippus* sp.” *Protohippus* is known from late Barstovian faunas in the Española Basin, Great Plains, and the Gulf Coastal Plain of Florida and Texas (MacFadden, 1984; Hulbert, 1988.)

PREVIOUSLY REPORTED FOSSILS FROM THE DIXON AREA

The area near Dixon, New Mexico, is only sparsely fossiliferous. The first fossil from this region was collected by E. D. Cope in 1874 (Cope, 1877, p. 21) from “...the valley of Embuda Creek [Embudo Creek or Rio Embudo], and the cañadas which extend from it to the southward and eastward. After careful examination of this region, I [Cope] could only find a single fossil, namely, a penultimate phalange of a lateral digit of probably a three-toed horse.” We have not seen this specimen, and thus do not know if it represents the same species as the skeleton of *Protohippus*? described above, which includes a “penultimate phalange” (=medial phalanx) of a lateral digit, or another species of three-toed horse. Previous samples from the Dixon area also include a partial skeleton of the camel *Protolabis*, a skull of the canid *Aelurodon* from the Frick Collection at the AMNH, and a partial skeleton of the oreodont *Ustatochoerus* (= *Merychys*) from the UNM collection (Tedford and Barghoorn, 1993; R. Tedford, personal commun. 2004). Local residents have also reported rare, isolated bones to S. Aby. A partial edentulous jaw of an indeterminate species of small camel (NMMNH 63411) was found in the Dixon Member near Montecito (east of Dixon; NMMNH locality L-7607) during geologic mapping of the Trampas 7.5-minute quadrangle by S. Aby in February of 2004. The most complete mammal fossils in this area, including the *Protohippus*? skeleton and partial skeletons of *Merychys* and *Protolabis*, are found in the Chama-El Rito Member of the Tesuque Formation (Steinpress, 1981; Koning and Aby, 2003), which has been correlated with the upper member of the Picuris Formation (Aby et al., 2004). Cope’s description of the locality where the horse toe was collected is generalized, but his fossil may have come from the overlying Dixon Member of the Tesuque Formation (Steinpress, 1980, 1981). Tedford and Barghoorn (1993) and Wang et al. (1999) attributed the *Aelurodon* skull to the Dixon Member, and the indeterminate camel jaw (NMMNH 63411) is also from the Dixon Member.

Tedford and Barghoorn (1993) reported a partial skeleton of the oreodont *Ustatochoerus* (= *Merychys*, after Lander, 1998) *medius* from the lower part of the Chama-El Rito Member near Rinconada (Fig. 3). This specimen was previously housed in the paleontology collection in the Department of Earth and Planetary Sciences at UNM, but has since been transferred to the NMMNH. According to labels in the UNM collection, this specimen was collected by Art Montgomery in March 1976 “2 miles north of Embudo, on the east side of Highway 64, ~½ mile east of highway.” For several reasons, it is difficult to determine the precise locality from this description. U. S. Highway 64 runs east-west

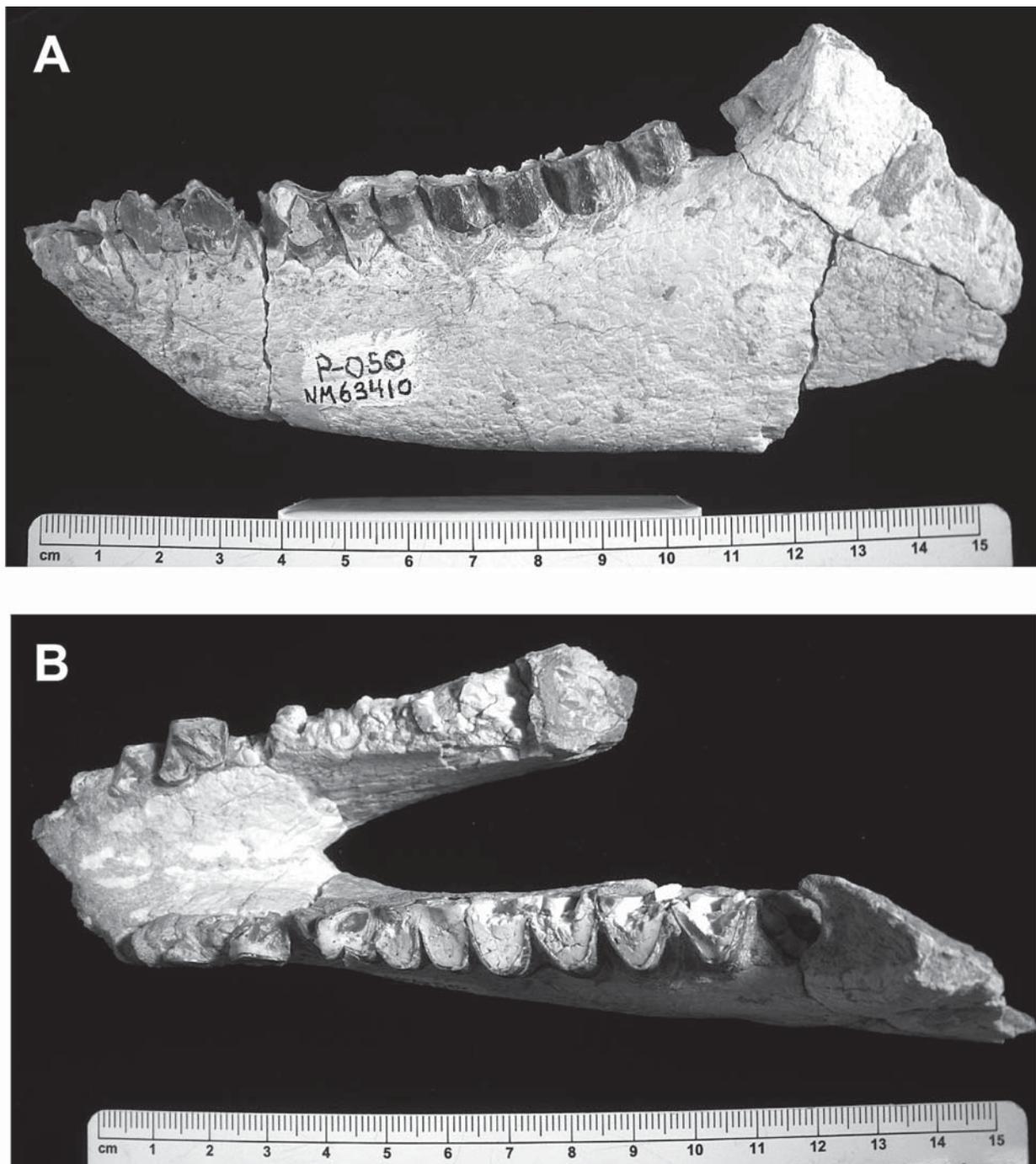


FIGURE 3. Partial right and left dentaries of the oreodont *Merychys medius* (NMMNH 63410) from the Chama-El Rio Member of the Tesuque Formation, middle Miocene (late Barstovian), near Dixon, Rio Arriba County, New Mexico. A. Lateral view of the left dentary. B. Occlusal view of the right and left dentaries. Scale is in mm.

between Embudo and Rinconada, not north-south. Thus, the oreodont site is probably about 2 miles *east* of Embudo on the *south* side of US 64. Also, the location of the village of Embudo on the Velarde 7.5-minute quadrangle is about 2 miles west of the Embudo post office. We do not know which of the two Embudo

locations the collector used to pinpoint the oreodont site. There are outcrops of the Chama-El Rito Member throughout this area, including the *Protohippus?* site on the west side of Cerro Abajo, which is about 3 miles east of the village of Embudo and 1 mi east of the Embudo post office, south of US 64.

The Embudo oreodont specimen (NMMNH 63410; NMMNH locality L-8287; Fig. 3) consists of partial right and left lower jaws, with the right dentary containing p1 and p2 and roots of the remaining teeth and the left dentary containing p1-p4 and m1-m3 (p1, p4, and m3 have the tooth crowns somewhat damaged). The specimen also has several associated postcranial elements, including a partial axis vertebra, distal humerus, and three partial metapodials. The morphology and size of the oreodont lower jaws from near Dixon compare well with specimens of *Merychys medius novomexicanus*, originally described from the Pojoaque Member of the Tesuque Formation from the Santa Cruz area in Rio Arriba County (Frick, 1929; Schultz and Falkenbach, 1941; Lander, 1998). The Chama-El Rito and Pojoaque members of the Tesuque Formation contain similar late Barstovian mammal faunas (Tedford and Barghoorn, 1993; Tedford et al., 2004). Selected measurements (in mm) of the left mandible of *M. medius* from Dixon (NMMNH 63410) are: length of p1-m3 (alveoli), 109; length of p1-p4 (teeth), 45. The length of p1-m3 is somewhat less than the minimum (114 mm) of 15 individuals of *M. medius novomexicanus* from the Española Basin measured by Schultz and Falkenbach (1941, table 9). However, their measurements were on teeth, whereas our measurement was from the anterior alveolus of p1 to the posterior alveolus of m3, since crowns of both p1 and m3 are damaged. The tooth crowns usually extend beyond the alveoli, which would explain the slightly smaller p1-m3 measurement in the Embudo specimen. The tooth measurement of p1-p4 in NMMNH 63410 of 45 mm is within the observed range of this measurement (44-54 mm) for the Española Basin sample of *M. medius novomexicanus* in Schultz and Falkenbach (1941).

Tedford and Barghoorn (1993) also reported a partial skeleton of the protolabine camelid *Protolabis* from the lower part of the Chama-El Rito Member near Rinconada in Rio Arriba County. Based on records of the Frick Laboratory at the AMNH, this specimen was collected by Ted Galusha and John Blick in June 1950 from a section of heavy fan gravels along the base of the hills [Cerro de Arriba] south of U. S. Highway 64, which is about 3 km east of the *Protohippus?* site. We were not able to examine this specimen, but it is housed in the AMNH (F:AM 50903; Field # Esp-498-3346) and consists of a partial skull, partial mandible, front limb with scapula, humerus, radius-ulna, metacarpal, and articulated phalanges, and metatarsal and foot bones from the hind limb (B. Berger, personal commun., 2004; Frick Laboratory catalog).

Tedford and Barghoorn (1993) identified a skull of the large borophagine canid *Aelurodon ferox* from the Dixon Member near Dixon and considered this site to be latest Barstovian in age, equivalent to the younger assemblages from the Chama-El Rito Member in the Chama basin. Wang et al. (1999, p. 196, fig. 82A) described and illustrated this same specimen, a crushed skull with I1-M2 (F:AM 67047) that they referred to *A. taxoides*, from "... 1 mi west of Dixon, 200 ft below Ojo Caliente Sandstone." Except for the skull from Dixon, all other records of *A. taxoides* are from the Clarendonian NALMA, further supporting a latest Barstovian age for the New Mexico specimen.

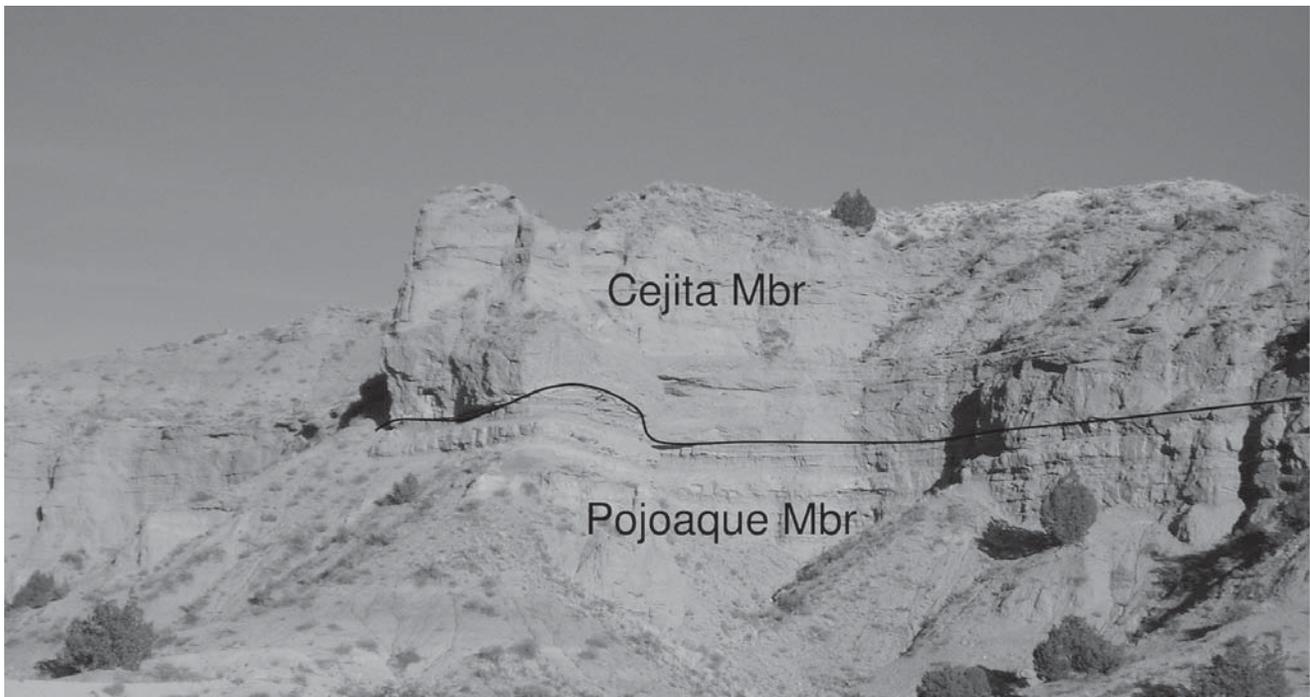
ACKNOWLEDGMENTS

We are grateful to Makaela Vogel, who found the *Protohippus?* fossil, and to her parents Jim and Kristen Vogel for alerting us to the presence of the specimen. For help in the field we thank the Vogel Family, Lluvia, Lorali, Salome, and Hannah Aby, Molly and Maggi Malone, and Siri Hollander. Paul Williams and Patricia Hester of the U. S. Bureau of Land Management gave us permission to excavate the specimen. J. B. Norton skillfully prepared the *Protohippus?* skeleton in the NMMNH preparation lab. We thank Benjamin Burger and Richard Tedford of the American Museum of Natural History for additional information on specific specimens. Richard Hulbert provided information on the identification of the *Protohippus?* skeleton. Spencer Lucas and Richard White made helpful comments on the manuscript.

REFERENCES

- Aby, S. B. and Koning, D., 2004, Sedimentology of the Tesuque Formation and tectonics of the Embudo fault system: New Mexico: New Mexico Geological Society, 55th Field Conference Guidebook, p. 351-358.
- Aby, S. B., Bauer, P. W., and Kelson, K. L., 2004, The Picuris Formation: A late Eocene to Miocene sedimentary sequence in northern New Mexico: New Mexico Geological Society, 55th Field Conference Guidebook, p. 335-350.
- Cope, E. D., 1877, Report upon the extinct Vertebrata obtained in New Mexico by parties of the expedition of 1874. Part II; in, Wheeler, G.M., 1887, Report upon United States geographical surveys west of the one hundredth meridian, vol. 4, Paleontology: Washington, D.C., Government Printing Office, p. 1-370.
- Frick, C., 1929, Childs Frick Tertiary-Quaternary explorations, 1928: Natural History, v. 29, p. 106-108.
- Hulbert, R. C., Jr., 1988, *Calippus* and *Protohippus* (Mammalia, Perissodactyla, Equidae) from the Miocene (Barstovian-early Hemphillian) of the Gulf Coastal Plain: Bulletin of the Florida State Museum, Biological Sciences, v. 32, no. 3, p. 221-340.
- Koning, D. J., and Aby, S. B., 2003, Geologic map of the Velarde Quadrangle, Rio Arriba County, New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Geologic Map 79, scale 1:24,000.
- Lander, B., 1998, Chapter 27. Oreodontoidea; in, Janis, C. M., Scott, K. M., and Jacobs, L. L., eds., Evolution of Tertiary mammals of North America, Volume 1: terrestrial carnivores, ungulates, and ungulate-like mammals: Cambridge, Cambridge University Press, p. 402-425.
- 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. 171, p. 1-195.
- MacFadden, B. J., 1992, Fossil horses: systematics, paleobiology, and evolution of the family Equidae: Cambridge, Cambridge University Press, 369 p.
- MacFadden, B. J., 1998, Chapter 37, Equidae, in Janis, C. M., Scott, K. M., and Jacobs, L. L., eds., Evolution of Tertiary mammals of North America, Volume 1: terrestrial carnivores, ungulates, and ungulate-like mammals: Cambridge, Cambridge University Press, p. 537-559.
- Schultz, C. B. and Falkenbach, C. H., 1941, Ticholeptinae, a new subfamily of oreodonts: Bulletin of the American Museum of Natural History, v. 79, p. 1-105.
- Steinpress, M. G., 1980, Neogene stratigraphy and structure of the Dixon area, Española Basin, north-central New Mexico [M.S. thesis]: Albuquerque, University of New Mexico, 127 p. plus 2 plates.
- Steinpress, M. G., 1981, Neogene stratigraphy and structure of the Dixon area, Española basin, north-central New Mexico: Summary: Geological Society of America Bulletin, Part 1, v. 92, p.1023-1026.
- Tedford, R. H. and Barghoorn, S., 1993, Neogene stratigraphy and mammalian biochronology of the Española Basin, northern New Mexico: New Mexico Museum of Natural History and Science, Bulletin 2, p. 158-168.

- Tedford, R. H., Albright, L. B., III, Barnosky, A. D., Ferrusquia-Villafranca, I., Hunt, R. M., Jr., Storer, J. E., Swisher, C. C., III, Voorhies, M. R., Webb, S. D., and Whistler, D. P., 2004, Mammalian biochronology of the Arikareean through Hemphillian interval (late Oligocene through early Pliocene epochs), in Woodburne, M. O., ed., Late Cretaceous and Cenozoic mammals of North America: biostratigraphy and geochronology: New York, Columbia University Press, p. 169-231.
- Wang, X., Tedford, R. H., and Taylor, B. E., 1999, Phylogenetic systematics of the Borophaginae (Carnivora: Canidae): Bulletin of the American Museum of Natural History, no. 243, 391 p.



Photograph showing the Cejita Member of the Tesuque Formation overlying the Pojoaque Member, looking northeast at the bluffs just east of the southeast corner of Ohkay Owingeh Pueblo. The Cejita Member is coarser-grained than the Pojoaque Member, but the sediment in both units is largely derived from the Peñasco embayment. Late Barstovian (middle Miocene) fossils were found a short distance above this contact that include the small fox-like canid *Leptocyon vafer*, the larger borophagine canid *Aelurodon sp.*, a beaver *Monosaulax pansus*, the antilocaprids (pronghorns) *Meryceros crucensis* and *Ramoceros ramosus*, and the gomphotheriid proboscidean (mastodon) *Gomphotherium productum* (Love sites of Koning et al., 2005). Several of these same late Barstovian mammals were also found below the contact in fine-grained sediments of the Pojoaque Member, including *Aelurodon*, *Meryceros* and *Gomphotherium*, as well as the land tortoise *Hesperotestudo*, a rhinoceros, a three-toed horse, and at least three species of camels. Information about the geology and fossils collected east of here can be found in the Aby, Morgan, and Koning paper on the next page.