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THE BACA FORMATION AND THE EOCENE-OLIGOCENE BOUNDARY IN NEW MEXICO

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INTRODUCTION

The Eocene-Oligocene transition in New Mexico was a time of significant change in magmatism and sedimentation throughout the state. During the Paleocene and Eocene, continental sediments were shed from complex uplifts and deposited in adjoining basins as the result of amagmatic basement deformation (Laramide orogeny). However, during the Oligocene much of New Mexico was characterized by massive outpourings of intermediate to silicic volcanic rocks and associated intrusions. The precise timing of this magmatic-sedimentologic change-over varies throughout the state, but in general the beginning of the Oligocene corresponds to this fundamental transition (Lucas and Ingersoll, 1981).

The sequence of rocks that span the Eocene-Oligocene boundary in west-central New Mexico is exemplary of this transition. In this area, conglomerate, sandstone, mudstone, and claystone of the Eocene Baca Formation are fluvial and lacustrine deposits that were shed from the Defiance, Zuni, Lucero, Sierra, Morenci, and Mogollon uplifts and deposited in the Baca basin (Chapin and Cather, 1981; Cather, 1983a, this guidebook, fig. 1). Volcaniclastic rocks (containing mainly clasts of quartz-latitude to andesite composition) of the Spears Formation (Oligocene) overlie the Baca Formation in west-central New Mexico and probably represent the eruptive products of stratovolcanoes in the northern part of the Mogollon-Datil magmatic province (Elston and others, 1976). The Eocene age assigned here to the Baca Formation is based both on its fossil mammals and on radiometric dates from the Spears Formation. The purpose of this paper is to review the fossil evidence used to assign an Eocene age to the Baca Formation and to compare the fossil mammals from the Baca with temporally equivalent fossil mammals from elsewhere in New Mexico and western North America. In this paper, LSUMG refers to the Louisiana State University Museum of Geoscience (Baton Rouge) and UNM-MSB refers to the Museum of Southwestern Biology, University of New Mexico (Albuquerque).

THE EOCENE-OLIGOCENE BOUNDARY IN WESTERN NORTH AMERICA

Before reviewing the fossil mammals from the Baca Formation, it is necessary to discuss the placement of the Eocene-Oligocene boundary used in this paper and its relationship to the North American land-mammal "ages" that bracket this boundary. Recent magnetostratigraphic studies by Prothero and others (1982) support placement of the Eocene-Oligocene boundary at 37 my. (see also Hardenbol and Berggren, 1978). These studies also support an earlier correlation by Berggren and others (1978) which recognized that the early part of the Chadronian land-mammal "age" is latest Eocene (fig. 1). Therefore, early Chadronian land-mammal faunas like the fauna from the Ahearn Member of the Chadron Formation in South Dakota (Clark and others, 1967), the Rancho Gaitan local fauna from northeastern Chihuahua (Ferrusquia-Villafranca, 1969) and the Little Egypt local fauna from the Chambers Formation in Trans-Pecos Texas (Wilson, 1978) are of latest Eocene age.

The definition and characterization of the Duchesnean land-mammal age has been a subject of recent debate (Emry, 1981; Golz, 1976; Lucas

and others, 1981; Tedford, 1970; Wilson, 1978). As in previous papers (Lucas and Kues, 1979; Lucas and others, 1981; Lucas, 1982), I continue to recognize the Duchesnean because its boundaries can be defined by mammal-immigration events and it has a characteristic mammalian fauna which includes *Hyaenodon*, *Hemipsalodon*, *Duchesneodus*, *Subhyracodon*, *Amynodontopsis*, *Brachyhyops*, *Protoreodon*, *Poabromylus*, *Simimeryx*, *Presbymys* and *Protadajidamo*. Magnetostratigraphic, radiometric, and biostratigraphic data (Berggren and others, 1978; McDowell and others, 1973; Prothero and others, 1982) suggest the Duchesnean may have a duration of three to four million years (fig. 1). The Twelvemile Wash local fauna from the Lapoint Member of the Duchesne River Formation in northeastern Utah (Andersen and Picard, 1972) is the type fauna of the Duchesnean land-mammal "age." Other major Duchesnean land-mammal faunas are the fauna from the Slim Buttes Formation in northwestern South Dakota (Bjork, 1967), Badwater locality 20 in central Wyoming (Black, 1978), the Tongue local fauna from the upper part of the Galisteo Formation in north-central New Mexico (Lucas, 1982), the Pearson Ranch local fauna from the upper part of the Sespe Formation in southern California (Golz and Lillegraven, 1977) and the Porvenir local fauna from the Chambers Formation in Trans-Pecos Texas (Wilson, 1978).

AGE OF THE BACA FORMATION

Stratigraphy and Fossil-Mammal Localities

The Baca Formation of VVilpolt and others (1946) is exposed in west-central New Mexico along a discontinuous arc that extends from the

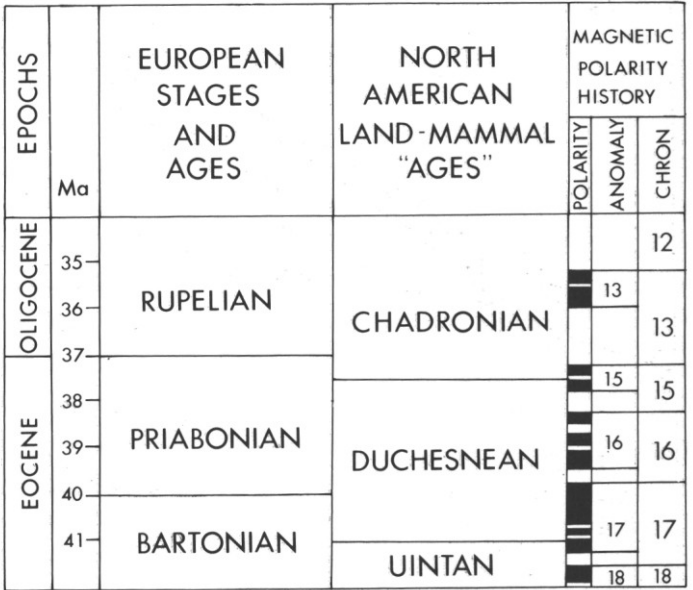


Figure 1. Interval of Cenozoic time scale across the Eocene-Oligocene boundary. Placement of boundaries based primarily on Berggren and others (1978) and Prothero and others (1982).

Bear Mountains north of Magdalena westward to the New Mexico—Arizona border (fig. 2). In this area the Baca Formation disconformably overlies the Upper Cretaceous Mesaverde Group (mostly Crevasse Canyon Formation of Coniacian-Santonian age; Tschudy, 1976). The Spears Formation overlies the Baca Formation in west-central New Mexico, and the contact between these two units is generally conformable and gradational (for example, Cather, 1982).

Typically, the Baca Formation is a redbed sequence of mudstone, sandstone, and lesser amounts of claystone and conglomerate that averages about 180 m in thickness and attains a maximum thickness of 370 m (Cather, 1980, 1982; Johnson, 1978; Schrodtt, 1980; Snyder, 1971). Depositional systems represented by the Baca Formation in west-central New Mexico consist of a braided-alluvial-plain system and a lacustrine system, the latter system located in the area presently occupied by the Bear and Gallinas Mountains, north and northwest of Magdalena (Cather, 1983b, this guidebook, fig. 2).

Sedimentary rocks east of the Rio Grande in the Carthage—Joyita Hills area, that are lithologically similar to and occupy the same stratigraphic position as the Baca Formation in west-central New Mexico, also have been assigned to the Baca Formation (Spradlin, 1976; Wilpolt and others, 1946; Wilpolt and Wanek, 1951). These rocks were deposited in a basin (Carthage—La Joya basin) distinct from the basin (Baca basin) in which the Baca Formation in west-central New Mexico was deposited (Chapin and Cather, 1981; Lucas and Ingersoll, 1981). The only fossil mammals recovered from the Baca Formation east of the Rio Grande appear to be of middle Eocene (Bridgerian) age (Gardner, 1910; Lucas and others, 1982). Since these fossil mammals are of limited use in placement of the Eocene-Oligocene boundary, they are not further considered in this paper.

Fossil mammals from the Baca Formation in west-central New Mexico have mostly been collected from rocks of the braided-alluvial-plain system, although a few fossils have been discovered in rocks of the delta facies of the lacustrine system (Cather, 1980; Schiebout and Schrodtt, 1981b; Schrodtt, 1980). Isolated bones and bone fragments are present at a number of localities in the Baca Formation, but identifiable spec-

imens have only been collected at a few localities. These few localities are: (1) the west side of Mariano Mesa, northeast of Quemado (secs. 15, 16, and 21, T3N, R16W); (2) the vicinity of Veteado Mountain, north of Omega (sec. 33, T4N, R14W); (3) White Mesa, north of Datil (sec. 1, T1N, R10W and sec. 31, T2N, R9W); and (4) north of the Gallinas Mountains, northwest of Magdalena (sec. 31, T2N, R6W). More detailed locality information is available from Cather (1980), Schrodtt (1980), and Snyder (1970). The stratigraphically highest fossil mammal from these localities is about 30 m below the Baca-Spears contact (at the west side of Mariano Mesa: Schrodtt, 1980), and the stratigraphically lowest fossil mammal is 37.5 m above the Baca-Mesaverde contact (at White Mesa: Snyder, 1970). However, rock-stratigraphic correlation of the fossil mammal localities in the Baca Formation still remains to be undertaken.

Fossil Mammals from the Baca Formation

Schiebout and Schrodtt (1981a, b) and Schrodtt (1980) have described the fossil mammals known from the Baca Formation in west-central New Mexico. Here, I reevaluate the identifications and temporal significance attributed to the Baca mammals by these authors.

Hyaenodon (Protohyaenodon) sp.

Schrodtt (1980, p. 102) assigned a right M3 trigonid (LSUMG 2312-14) from near Veteado Mountain to "*Hyaenodon* sp. 1 am confident that this specimen pertains to *Hyaenodon* and note that its small size (width M3=5.2 mm) justifies assignment to the subgenus *Protohyaenodon* as defined by Mellett (1977). LSUMG 2312-14 falls within the size range of two species of *Hyaenodon* (*Protohyaenodon*), the Duchesnean *H. (P.) venturae* and the early Chadronian—middle Orellan *H. (P.) erucians*. Clearly, a species-level identification of the Baca specimen is impossible.

Hyaenodon first appeared in North America during the Duchesnean, evidently as an immigrant from the Old World (Mellett, 1977). It became extinct during the Arikarean (late Oligocene). The occurrence of *Hyaenodon* in the Baca Formation is consistent with, though not necessarily demonstrative of, a Duchesnean age assignment.

Brontotheriidae, genus indeterminate

The most common fossil mammals from the Baca Formation are brontotheres. However, most of the specimens are isolated postcrania and

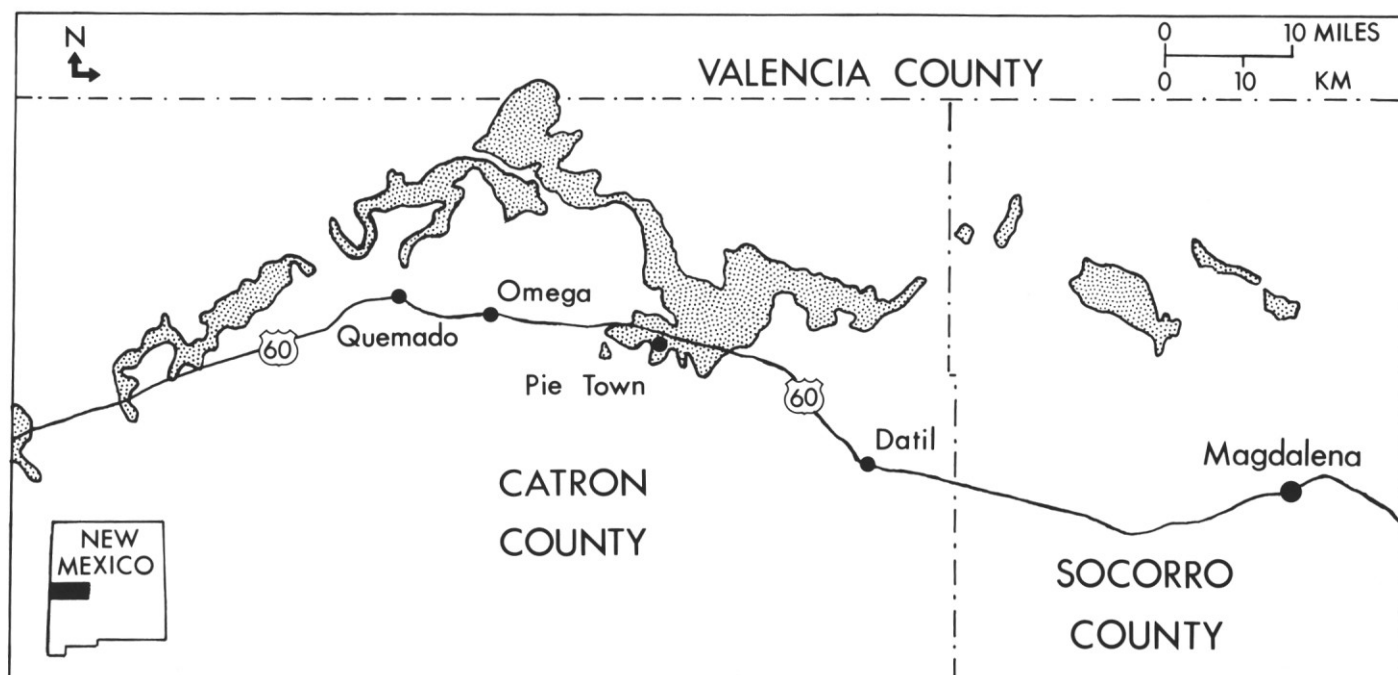


Figure 2. Distribution of outcrops of the Baca Formation (stippled) in west-central New Mexico. Outcrop pattern from New Mexico Highway Geologic Map.

bone and tooth fragments that defy precise identification. Even the few cranial and complete dental specimens of brontotheres from the Baca are impossible to identify at the genus level because of the confused state of brontothere taxonomy that is the legacy of Osborn's (1929) work.

LSUMG 2300-1, a partial skull (Schiebout and Schrodt, 1981b, fig. 2) and LSUMG 2300-22, a left I_{43} (Schrodt, 1980, p. 170), both from 2) and LSUMG 2300-22, a left I_{43} (Schrodt, 1980, p. 170), both from the west side of Mariano Mesa, represent a relatively large and advanced brontothere. LSUMG 2312-12, an incisor (Schrodt, 1980, p. 168) and LSUMG 2312-8, a horn tip (Schrodt, 1980, p. 171), both from the vicinity of Veteado Mountain, may represent the same taxon. Other brontothere postcrania and tooth and bone fragments reported by Schrodt (1980), shown to me in the field by S. M. Cather (northern Gallinas Mountains) and in the New Mexico Bureau of Mines and Mineral Resources collection (from near Veteado) also pertain to a large and relatively advanced brontothere.

Schiebout and Schrodt (1981a, b) and Schrodt (1980) tentatively assigned LSUMG 2300-1 to *Menodus*, a Chadronian brontothere genus. However, there are four reasons why tentative assignment of this skull to *Menodus* and the consequent claim that it supports a Chadronian age assignment for the Baca Formation are misleading. First, Schiebout and Schrodt (1981a, b) and Schrodt (1980) used the name *Menodus* because they accepted the unsubstantiated claim of Clark and others (1967, p. 50-51) and Scott (1940, p. 907) that all Chadronian brontotheres pertain to either *Menodus* or "*Teleodus*." "*Teleodus*" is only represented by a single Chadronian specimen (Lucas and Schoch, 1982), and there is no reason to believe that the great morphological diversity represented by the remaining Chadronian specimens of brontotheres should be subsumed in a single genus, although admittedly the six genera recognized by Osborn (1929) seems excessive. Second, the size of the skull and shape of the horns of LSUMG 2300-1 indicate that even tentative assignment to *Menodus* (*sensu* Osborn, 1929) is incorrect. The skull length (tip of nasals to occiput vertex) of LSUMG 2300-1 is about 55 cm (a maximum) whereas comparable measurements of skulls of *Menodus* (Osborn, 1929, p. 523) range from 62 to 77 cm, significantly longer than the Baca skull. In addition, the horns on skulls of *Menodus* (Osborn, 1929, figs. 436, 439, 440, 442) are short, thick and widely separated, unlike the much longer, thinner, and closely spaced horns of LSUMG 2300-1. Third, the Baca skull is nearly the same size as the holotype skull of *Diplacodon progressum* (length 54 cm), a Uintan brontothere from northeastern Utah (Peterson, 1934). The only difference between LSUMG 2300-1 and *D. progressum* is in horn size and shape. Fourth, relatively large and homed brontotheres are known from Duchesnean deposits (Lucas, 1982; Wilson, 1977). LSUMG 2300-1, therefore, does not necessarily indicate a Chadronian age for the Baca Formation.

The other brontothere specimens from the Baca Formation may pertain to the same taxon as LSUMG 2300-1, but there is no way to be certain of this. Indeed, the most that can be said about the brontotheres from the Baca Formation is that they are relatively advanced brontotheres that could be of late Uintan, Duchesnean or, perhaps, early Chadronian age. Both the incompleteness of available specimens and the current state of brontothere taxonomy obviate genus-level identification of the Baca brontotheres at this time.

Brachyhyops wyomingensis

I fully concur with Schrodt's (1980, p. 83) assignment of LSUMG 2313-2, a left I_{34-M} , from near Veteado Mountain, to *Brachyhyops wyomingensis*. A trackway discovered by Cather (1980) in the lower part of the Baca Formation north of the Gallinas Mountains (fig. 3) may represent the tracks of a group of *Brachyhyops*. These tracks resemble those of extant suids and tayassuids (Murie, 1974), and a small entelodont like *Brachyhyops* thus seems a likely perpetrator.

Brachyhyops is the first North American entelodont and is known from Duchesnean and early Chadronian deposits (Emry, 1975). Its presence is consistent with a Duchesnean age assignment for the Baca Formation in west-central New Mexico.

Protoreodon pumilus

Snyder (1970, fig. 3) described a maxillary fragment bearing right P4-M3 (American Museum of Natural History 99097) from White Mesa that pertains to *Protoreodon pumilus* (Schrodt, 1980, p. 88). *Protoreodon pumilus* is known from Uintan, Duchesnean and early Chadronian localities (Wilson, 1971). Its occurrence in the Baca Formation is consistent with a Duchesnean age assignment, although some authors (Savage and Russell, 1983, p. 118; Snyder, 1970) have considered the White Mesa locality to be of Uintan age.



Figure 3. Entelodont (*Brachyhyops*?) trackway in lower part of Baca Formation in section 31, T2N, R6W. Fully extended Brunton compass is 21 cm long. Photography courtesy of Adrian Hunt.

Agriochoeridae, genus indeterminate

Schrodt (1980, p. 88) identified two M, fragments, LSUMG 2313-4 from the vicinity of Veteado Mountain and LSUMG 2314-6 from the west side of Mariano Mesa, as *Protoreodon pumilus*. Although these specimens may pertain to *P. pumilus*, they are so incomplete that assignment to the Agriochoeridae, genus indeterminate seems the only justifiable identification. Agriochoerids are known from Uintan, Duchesnean, and Chadronian faunas (Wilson, 1971).

Protoceratidae, genus indeterminate

Schrodt (1980, p. 93) referred an isolated left M, or M, from White Mesa to *Leptomeryx* (LSUMG 2304-1). Although I agree with Schrodt (1980) that this tooth does not pertain to *Hendryomeryx* (the entelodont is not connected to the metaconid by a crest), I see no way to distinguish it from isolated lower molars of other protoceratids, including *Poebro-mylus* and *Leptoreodon*. Therefore, LSUMG 2304-1 can only be certainly identified as Protoceratidae, genus indeterminate. Protoceratids (*sensu* Wilson, 1974) are known from Uintan, Duchesnean, and Chadronian faunas.

Camelidae, genus indeterminate

Schrodt's (1980, p. 95) firm assignment of LSUMG 2390-3, an isolated premolar from the west side of Mariano Mesa, to *Eotylpus* seems impossible to justify. This relatively large (length 11.7 mm; width 5.7 mm) and blade-like tooth has a median rib on its lingual aspect. It appears to belong to a primitive camelid, and *Eotylpus* is a possibility but not a certainty. Camelids first appeared in North America during the Duchesnean (Wilson, 1974).

Duchesnean Age of the Baca Formation

As the preceding review of the fossil mammals from the Baca Formation in west-central New Mexico indicates, a larger fossil mammal fauna is needed from the Baca Formation before an unequivocal age

assignment can be determined. Nevertheless, all fossil mammals from the Baca Formation are consistent with a Duchesnean age assignment (Lucas and others, 1981; Lucas, 1982). Schiebout and Schrodt (1981a, b) and Schrodt (1980) considered the fossil mammals from the Baca Formation to be temporally equivalent to the Porvenir local fauna from the Chambers Formation in Trans-Pecos Texas. I am in agreement with this correlation, but unlike Schiebout and Schrodt (1981a, b) and Schrodt (1980) I consider the Porvenir local fauna to be Duchesnean and late Eocene, not Chadronian and early Oligocene. Therefore, there is no vertebrate fossil evidence that supports assignment of an Oligocene age to any part of the Baca Formation. Assignment of a Uintan age to the White Mesa locality and to unfossiliferous strata of the lower part of the Baca Formation is possible, but more data are needed to confirm such an assignment. It should also be noted that latest Eocene and Oligocene radiometric dates from the Spears Formation (Osburn and Chapin, 1983) are consistent with a Duchesnean age assignment based on fossil mammals for the underlying Baca Formation.

OTHER DUCHESNEAN MAMMALS FROM NEW MEXICO

Besides the Baca Formation in west-central New Mexico, two other areas in the state have produced fossil mammals of Duchesnean age. Correlation of these fossil mammals with those from the Baca Formation is briefly reviewed here.

Galisteo Formation

Lucas (1982) included the following fossil mammals from the upper part of the Galisteo Formation in north-central New Mexico in the Tongue local fauna: *Hemipsalodon grandis* (= *Pterodon* sp. of Lucas and Kues, 1979, and Lucas and others, 1981), *Duchesneodus* (= *Teleodus*: Lucas and Schoch, 1982) cf. *D. uintensis*, Brontotheriidae, *Forstercooperia minuta*, *Amynodon* sp., *Protoreodon* sp., *Poabromylus* cf. *P. minor* and Protoceratidae. Lucas and Kues (1979), Lucas and others (1981), and Lucas (1982) presented arguments that support assignment of a Duchesnean age to the Tongue local fauna. Oligocene radiometric dates from the Espinazo Formation (Kautz and others, 1981), which overlies the Galisteo Formation in the Hagan basin—Cerrillos area, are consistent with this age assignment. Therefore, the Tongue local fauna and the fossil mammals from the Baca Formation in west-central New Mexico are temporally equivalent within the resolution of one land-mammal "age." However, a more extensive mammalian fauna from the upper part of the Galisteo Formation and from the Baca Formation is needed before it can be determined whether the Tongue local fauna and Baca fauna are precise correlatives or whether one of these faunas is slightly older than the other.

Rubio Peak Formation

I report here for the first time the occurrence of a brontothere in the Rubio Peak Formation in the northern Black Range, southwestern New Mexico. This specimen was collected by Mr. Charles Hutchins along Turkey Creek northwest of Winston in the fall of 1961. Mr. Hutchins, now deceased, allowed a cast of the specimen to be retained in the collections of the Museum of Southwestern Biology, University of New Mexico, but the whereabouts of the original specimen are unknown. Precise topographic and stratigraphic provenience also are not available, but information provided by Hutchins indicates that the specimen was collected in an area encompassed by secs. 30, 31, 32, T 10S, R8W, secs. 23, 24, 25, T10S, R8W, and sec. 5, T 11S, R8W. It almost certainly was derived from rocks mapped in the Black Range as Rubio Peak Formation by Hedlund (1977) and Woodard (1982). The same rocks previously were mapped as "early andesite volcanic sequence"

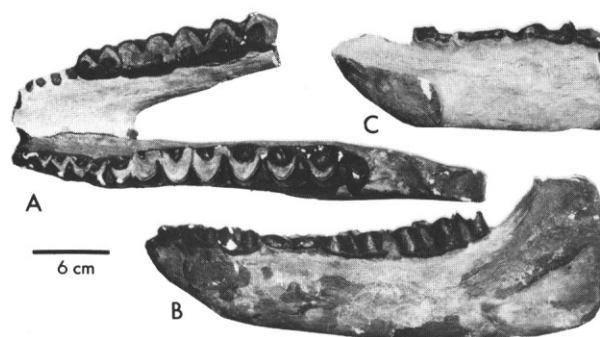


Figure 4. UNM-MSB-A3369, cast of lower jaw of *Duchesneodus* sp. from the Rubio Peak Formation near Winston, New Mexico. (A) Occlusal view. (B) Left lateral view. (C) Lingual view of right ramus.

by Ericksen and others (1970), "Spears (?) Formation" by Coney (1976), and "andesite" by Fodor (1976) and Maxwell and Heyl (1976).

The brontothere specimen, UNM-MSB-A3369, is a lower jaw bearing left P2-M₂, right P4-142, incomplete left C and right M2, and the roots of the right C, P, and P3 (fig. 4). Salient features that justify identification of this specimen as *Duchesneodus* sp. are: (1) its size (Table 1) is close to that of specimens of *D. uintensis* (Lucas, 1982, Table 2); (2) presence of relatively small canines with round cross-sections; (3) lack of postcanine diastemata; (4) lack of PI; (5) relatively molariform (entoconids distinct) ^{132,4}; (6) lower cheek teeth with nearly vertical labial aspects; (7) cingula on labial aspects of lower cheek teeth relatively weak; and (8) mandibular symphysis extends to under the P4-M1 juncture.

The occurrence of *Duchesneodus* suggests that a horizon of Duchesnean age is present in the Rubio Peak Formation in the northern Black Range. If this preliminary conclusion is correct, then part of the Rubio Peak Formation is, within the resolution of one land-mammal "age," temporally equivalent to the Baca Formation in west-central New Mexico and the upper part of the Galisteo Formation in north-central New Mexico. Identification of a Duchesnean-age mammal from the Rubio Peak Formation also is consistent with radiometric dates reported from the Rubio Peak Formation (Loring and Loring, 1980; Marvin and Cole, 1978) that suggest it transgresses the Eocene-Oligocene boundary.

Table 1. Measurements (in cm) of the dentition of UNM-MSB-A3369, cast of a lower jaw of *Duchesneodus* sp. from the Rubio Peak Formation near Winston, New Mexico. L = maximum antero-posterior length, AW = maximum width of trigonid, PW = maximum width of talonid.

	L	AW	PW
P ₂	2.23	1.63	1.72
P ₃	3.10	2.06	2.23
P ₄	3.39	2.42	2.59
M ₁	4.62	2.80	2.92
M ₂	5.61	3.08	3.35
M ₃	7.86	3.28	3.30

EPOCHS	Ma	N. AM. LAND- MAMMAL "AGES"	1	2	3
			SOUTH- WESTERN NEW MEXICO	WEST- CENTRAL NEW MEXICO	NORTH- CENTRAL NEW MEXICO
OLIGOCENE	35	CHADRONIAN		Spears	Espinaso
	36			Formation	Formation
	37				
EOCENE	38	DUCHESNEAN	"Rubio		
	39		Peak "	Baca	Galisteo
	40		Formation	Formation	Formation
	41				
		UINTAN			

Figure 5. Preliminary correlation of mammal-bearing late Eocene deposits of New Mexico. Column 1 represents the northern Black Range, column 2 represents the Quemado-Magdalena area and column 3 represents the Hagan basin-Cerrillos area.

CONCLUSIONS

Based on the preceding information, it is possible to present a preliminary correlation of mammal-bearing late Eocene deposits in New Mexico (fig. 5) and put forth the following conclusions. First, fossil mammals from the Baca Formation in west-central New Mexico indicate a Duchesnean (late Eocene) age. Some strata of the Baca Formation may be as old as Uintan, but there is no reason to assign an Oligocene age to any part of the Baca. The Eocene-Oligocene boundary in west-central New Mexico is at or near the contact between the Baca and Spears Formations. Second, fossil mammals from the upper part of the Galisteo Formation in north-central New Mexico are Duchesnean, and within the resolution of one land-mammal "age" are temporally equivalent to the fossil mammals from the Baca Formation. The Eocene-Oligocene boundary in north-central New Mexico is at or near the contact between the Galisteo and Espinaso Formations. Third, a fossil mammal from the Rubio Peak Formation in southwestern New Mexico suggests a Duchesnean age for part of the Rubio Peak Formation that is consistent with radiometric dates that suggest the Rubio Peak transgresses the Eocene-Oligocene boundary.

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