

Mammalian biochronology of the late Cenozoic basins of New Mexico

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ABSTRACT

Late Cenozoic mammalian remains have been collected from New Mexico for more than a century. The most important nineteenth-century collections came from the Española Basin. Work in this century has continued to focus mainly on the Miocene faunas in that basin and the northern part of the adjoining Albuquerque basin. The lithostratigraphy of these basins has recently been reviewed and revised, but the description of the large collections of fossil remains from the basal deposits is largely incomplete. Pliocene and early Pleistocene faunas have been found in deposits that mark the development of external drainage of the major rivers of the state. Study of these assemblages has been cursory, although the lithostratigraphy of these deposits has received considerable attention in recent years.

The Miocene basinal deposits accumulated under conditions of internal drainage in local structural environments that led to the development of partly synchronous depositional records. Biostratigraphies worked out in each basin overlap sufficiently so that the composite succession forms an important biochronological standard for southwestern North America.

The Española and Albuquerque-Belen basins contain the only Miocene faunas of importance presently known in New Mexico. Their fossil records complement one another in that the northern Albuquerque basin has the only adequate representation of the early Miocene and the Española basin a more complete record of the medial and late Miocene. Synchronous faunas in these basins show a high degree of taxo-

nomic resemblance extending to elements that represent endemic taxa or forms rare elsewhere. Compared with coeval assemblages in the Great Plains, there is considerable generic and specific similarity. This allows easy reference of the New Mexican faunal succession to the sequence of North American mammal ages that are essentially typified by the Great Plains biochronology. In addition to these taxonomic relationships, the New Mexican faunas retain throughout the Miocene characters that may typify a southwestern faunal province. The general features of the latter would include diverse and abundant artiodactyls, especially Camelidae, including a late occurrence of endemic stenomyline genera, and less diverse and abundant perissodactyls, especially horses, when compared with the Great Plains.

The fossil vertebrate record of Pliocene and early Pleistocene time in New Mexico is largely confined to the basins of the Rio Grande and the Gila River and is derived from deposits of the axial rivers that were the precursors of the modern streams and from the piedmont slope facies of the basin margins. Sites scattered along the length of the Rio Grande rift from the Santo Domingo basin near Santa Fe south to the international border have yielded Blancan and early Irvington faunas. These assemblages can be arranged in temporal order from their position in local stratigraphic columns, from their biological affinities, and with respect to dated basalts and ashes interbedded in the sediments containing the fossil remains. Important reference sequences are available in adjacent Arizona and Texas, where mammalian faunas and calibrated biochronologies compare closely

with those in New Mexico. The New Mexican record supports the southwestern biochronology for Pliocene and early Pleistocene time, including the following events and their calibration: the last appearance of hipparionine horses (*Nannippus*) and the first appearance of the South American immigrants, the glyptodont *Glyptotherium* and probably the mylodontid sloth genus *Glossotherium*, were nearly synchronous events close to the Gauss-Matuyama boundary (2.5 m.y. B.P.); at least three species *Equus* were present in the Southwest by the time of the *Nannippus* extinction; the first appearance of the Asiatic immigrant *Mammuthus* in the southwest between 1.2 and 1.4 m.y., postdating the Olduvai Event and, by definition, indicating that the Blancan-Irvingtonian boundary, at least as determined for the Southwest, lies close to the beginning of medial Pleistocene time.

INTRODUCTION

Late Cenozoic fossil mammal remains have been known from New Mexico for more than one hundred years. The most important nineteenth-century collections came from the Española basin (Fig. 1) in north-central New Mexico. Until the last decade, E. D. Cope's reports on these materials (1874, 1875, and 1877, among others; see Galusha and Blick, 1971, for complete citation) served as the only comprehensive works on this important fauna. Intensive collecting in the Neogene basins of New Mexico by personnel of the Frick Laboratory of the American Museum of Natural History began in 1924 and continued on a nearly year-to-year basis until Dr. Frick's death in 1965. Only parts of the enormous

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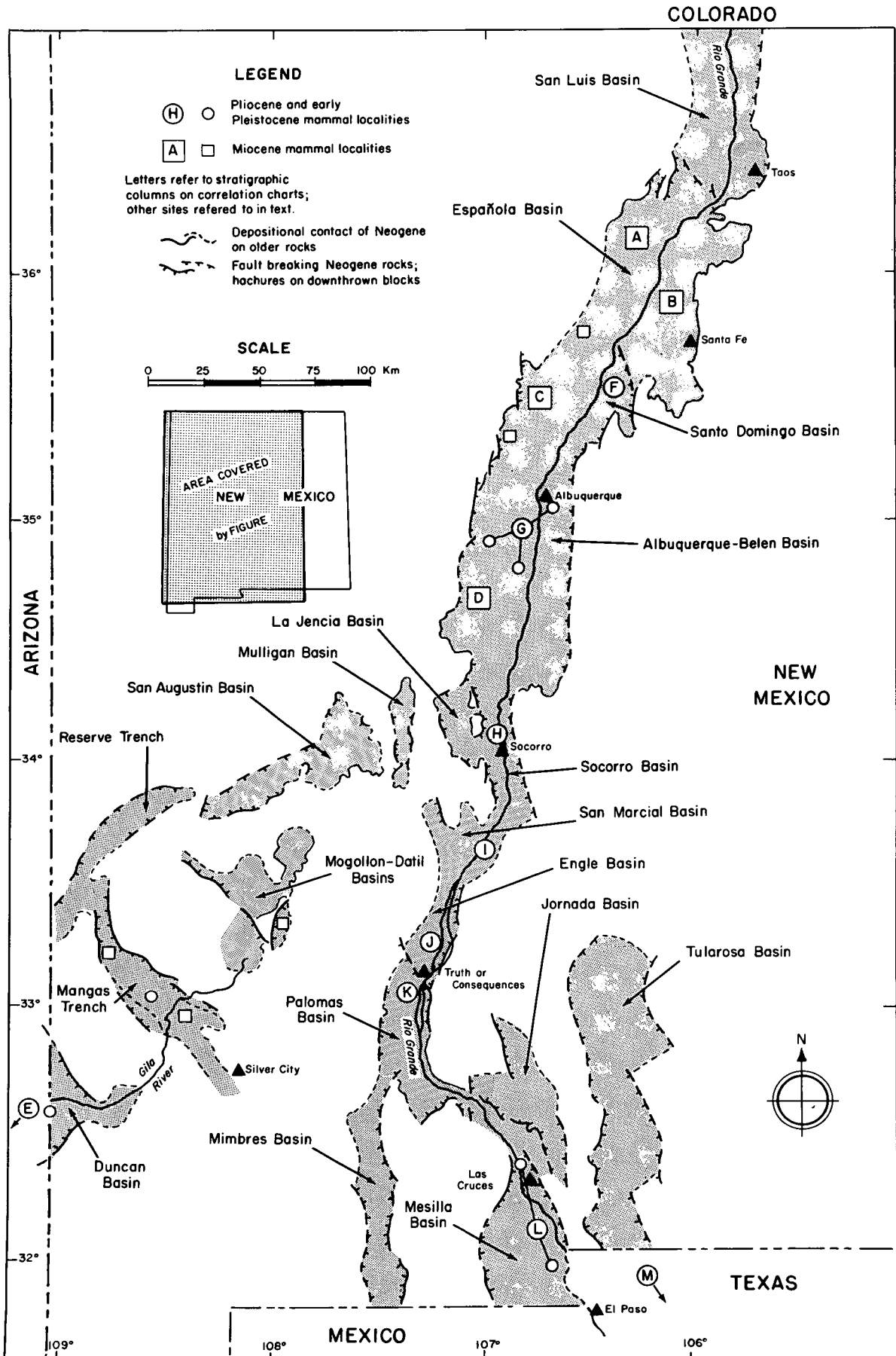


Figure 1. Map of the late Cenozoic basins (stippled) of central and southwestern New Mexico (adapted from Elston and others, 1976; Woodward and others, 1978). Letters refer to the stratigraphic columns in Figures 1-5. All sites indicated are discussed in the text.

collections that accumulated from this work were published, notably on the carnivore *Hemicyon*, the mastodons, the horned ruminants, and oreodonts (see Galusha and Blick, 1971, for a complete review of the literature). Galusha (1966) and Galusha and Blick (1971) published important geological studies of the fossiliferous Neogene deposits of northern New Mexico that provided the stratigraphic context for more recent systematic and biostratigraphic studies such as those of Frick and Taylor (1968), Gawne (1975, 1976), MacFadden (1977), and Barghoorn (1981).

This paper attempts to partially redress the lack of a comprehensive survey of the late Cenozoic faunas of New Mexico by presenting, in a tentative and preliminary way, a summary of some of the more important facts concerning the mammalian fossils of New Mexico and their stratigraphic context as revealed principally by the Frick Collection and related documentation at the American Museum of Natural History. Comparisons are also made with localities in other southwestern states and with the important sequence of faunas from the Great Plains. These data are presented in the form of correlation charts (Figs. 2-5) detailing the stratigraphic succession of the fossil samples and relevant lithostratigraphy. The text discusses the stratigraphic succession of the faunas, their composition, correlation, and age significance. Pertinent problems, both paleontological and geological, are discussed, with emphasis on the chronological significance of the record. This work relies heavily on concepts in North American mammalian biochronology discussed in general by Tedford (1970) and specifically for the late Oligocene through early Pliocene by Tedford and others (in press) in a lengthy summary. The latter work proposes boundary definitions for the Mammal Ages of this interval and these are followed in the present paper. Calibration of the North American Mammal Ages also follows the compilation of continent-wide data brought together by Tedford and others (in press).

MIOCENE BASINS

Introduction

The younger Cenozoic basins in New Mexico began to form under a regime of tensional faulting that was initiated near the Oligocene-Miocene boundary (see Figs. 2-5 for calibration of epoch boundaries adopted

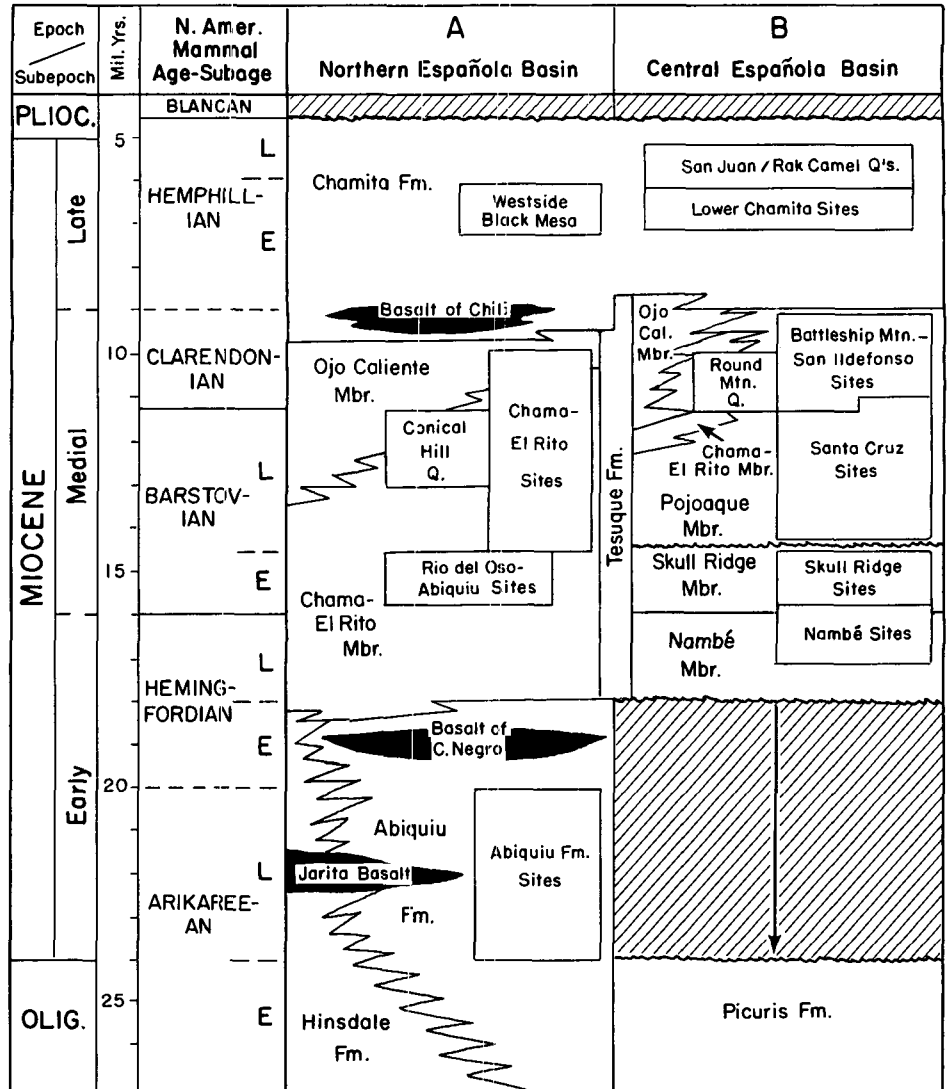


Figure 2. Lithostratigraphy and sequence of Miocene fossil mammal samples [sites and quarries (Q)] from the Española basin, Santa Fe, and Rio Arriba Counties, New Mexico. See text for discussion of data represented. The chronological limits of the mammal assemblages are indicated by the depths of the boxes enclosing the faunal or site names. Formational boundaries and interfingering relationships constrained by the faunal data, basalt, or ash ages or estimated from regional correlations. Direct superposition of stratigraphic units indicated by vertical arrows. Basalts are indicated in black and by the names of units. Only those dated are shown (see text for data and references). Calibration of the North American Mammal Ages developed from data discussed in Tedford and others (in press).

here) and persists to the present (see chapters in Riecker, 1979, for comprehensive recent summary). Strikingly aligned and interconnected troughs were outlined by a broad zone of normal faulting from southern New Mexico northward into central Colorado (Fig. 1). These rift basins were accumulating sediments in Miocene time, under conditions of internal drainage. In many places, volcanic rocks and ash inter-tongue with the basin sediments. Alluvial-

fan, fluvialite, playa, and eolian facies can be distinguished in the sedimentary deposits of these Miocene basins. Prevailing red colors attest to oxidizing depositional environments mostly above the water table. Floral evidence (Axelrod and Bailey, 1976) from medial Miocene rocks in northern New Mexico suggests a relatively mild winter climate at that time.

Fossil mammal remains are preserved in fluvialite deposits in many of the Miocene

basins but the most thoroughly explored terrane and, thus, the best developed fossil records are contained within the Española and Albuquerque-Belen basins (Fig. 1) in the northern part of the state. The thick accumulations in the southern rift basins and the Mogollon-Datil region to the southwest have been little prospected so far.

Miocene rocks of the Española basin were the earliest Neogene deposits in New Mexico to be explored paleontologically. These rocks were originally referred to as the "Santa Fe marls," later as the "Santa Fe Formation," and finally were generalized to the "Santa Fe Group" as the interrelated histories of the Neogene basins in the rift were recognized (see Galusha and Blick, 1971, for historical review). As used here, the Santa Fe Group includes all the rock units shown on the New Mexico and Texas columns in the correlation charts (Figs. 2-5) in accordance with broad usage of this term in recent years. In the Española basin, the Santa Fe Group dips westward off the flanks of the Sangre de Cristo Mountains and is broken by many intrabasinal normal faults that serve to repeat the fossiliferous units in a manner favorable to fossil collecting. The western flank of the basin is overlapped by the Miocene to Quaternary Jemez Mountains volcanic field, but to the northwest the Santa Fe Group can be seen dipping eastward from the edge of the Nacimiento and Brazos uplifts. Differing source areas and histories between the northern and central parts of the basin provided the basis for the stratigraphic units proposed by Galusha and Blick (1971). Recent revisions and additions to the stratigraphic nomenclature of Galusha and Blick (1971) have included changes in rank of most units (Kelley, 1978) and the recognition of new units in the northeastern part of the basin (Manley, 1979). These revisions do not affect the biostratigraphy discussed by Galusha and Blick (1971) nor that reviewed in the present paper, and for those reasons, the original nomenclature employed by Galusha and Blick is retained for convenience of reference. It should be noted that Kelley's (1978) important map of the Española basin postulates somewhat different stratigraphic relationships within the basin fill than concluded by Galusha and Blick (1971) or Manley (1979).

Northern Española Basin (Fig. 2, column A)

The oldest exposed unit in the northwestern part of the basin is the Abiquiu Forma-

tion. The upper part of this formation has produced a few fossil mammal remains, notably fragments of the small oreodont *Merychys* cf. *M. crabilli* and of the horse *Parahippus* from the vicinity of the type section, near the town of Abiquiu. Remains of the camel *Oxydactylus* and a mustelid, cf. *Promartes*, were obtained from rocks equated with the upper part of the formation near El Rito (T. Galusha, 1968, personal commun.). These taxa indicate a latest Arikareean (early Miocene) age for the upper part of the Abiquiu. Palynological evidence (Duchene and others, 1981) from the Abiquiu Formation and K-Ar ages (Baldrige and others, 1980) for basalts within the Abiquiu or interfingering Hinsdale Formation (Manley, 1981) agrees with the assignment of the upper part of the formation to the lower Miocene.

Volcaniclastic sandstones and conglomerates of the basal, or Chama-El Rito Member, of the Tesuque Formation disconformably overlies or possibly interfinger with the Abiquiu Formation (May, 1979). The oldest faunas in the Chama-El Rito member are found along the flanks of the Jemez Mountains between Rio del Oso and the town of Abiquiu. These assemblages lie within the biochron of the oreodont *Brachycrus*, a genus confined to late Hemingfordian and early Barstovian faunas elsewhere in North America. Such correlations indicate that the basal Tesuque Formation in the northern Española basin is older than suggested by Galusha and Blick (1971, p. 110), and that it could be as old as suggested by Manley (1979, p. 77, Fig. 4).

Higher in the Chama-El Rito Member, Proboscidea occur along with the oreodont *Ustatochoerus medius*, the moschid "deer" *Longirostromeryx*, the asymmetrically horned merycodont antilocaprid *Ramoceiros ramosus*, and early forms of the dog *Aelurodon*. The occurrence of these taxa denotes a fauna of late Barstovian age. These taxa are similar to those obtained from the type locality of the Chama-El Rito Member and at the Conical Hill Quarry at the top of the Chama-El Rito in the northern part of the basin. The Conical Hill Quarry, located in the zone of the interfingering of the Chama-El Rito and Ojo Caliente members, has also yielded the dromomerycid "deer" *Cranioceras*, the dog *Carpocyon*, and species of the horse genera *Cormohipparion* (Skinner and MacFadden, 1977, p. 918), *Neohipparion*, and *Pliohippus*, all of which characterize late Barstovian assemblages of the Great Plains.

Younger faunas from the Chama-El Rito member include the large oreodont *Ustatochoerus skinneri*, which is confined to Clarendonian assemblages of the Great Plains.

Overlying and interfingering with the Chama-El Rito Member are the unfossiliferous eolian sands of the Ojo Caliente Member. Thus, the age of the closing phases of the deposition of the Tesuque Formation in the northern Española basin cannot be estimated paleontologically. However, basalts interbedded with the basal part of the overlying Chamita Formation give K-Ar ages of about 10 m.y. (Baldrige and others, 1980) and establish a minimum age for the Tesuque deposits.

Along the western slope of Black Mesa, the Chamita Formation disconformably overlies the Tesuque. A few fossil mammals have been collected from the Chamita Formation in this area, including remains of the sloth *Pliometanastes* and the dog *Epicyon*. The joint occurrence of these taxa typifies an interval late in early Hemphillian time. Similar assemblages occur in the lower half of the Chamita in its type section (MacFadden, 1977).

Central Española Basin (Fig. 2, column B)

Badlands exposures scattered around Española and the adjacent pueblo lands provided the initial collections from the "Santa Fe marls" (Cope, 1877) and were later extensively prospected by parties from the Frick Laboratory (Galusha and Blick, 1971). The rich collections, housed now at the American Museum of Natural History, constitute one of the more important biostratigraphic sequences of Miocene age in North America.

The volcaniclastic Picuris Formation lies at the base of the Santa Fe Group in the eastern part of the Española basin. Its type area is in the northeastern part of the basin. The formation also crops out sporadically toward the south along the basement contact on the eastern side of the basin and extends to the vicinity of Santa Fe, where it may be represented by Spiegel and Baldwin's (1963) Bishop's Lodge Member of the Tesuque Formation (see Manley, 1979, p. 76, and Kelley, 1978, for discussion). Volcanics within the Picuris Formation have yielded K-Ar ages indicating that it is partly late Oligocene in age (Bachman and Mehner, 1978; Baldrige and others, 1980). Fragmentary fossil mammal remains have been found near the Picuris type section (T. Galusha, 1963, personal commun.), but no

diagnostic material is available for analysis.

The lithology of the Tesuque Formation in the central part of the basin clearly indicates that the crystalline rocks of the Sangre de Cristo Mountains are the major source of the three members that compose the unit. Beds of airfall tuff occur sporadically in the formation and are particularly important in the Skull Ridge Member. Toward the top of the Tesuque exposures west of the Rio Grande, volcanoclastic and eolian sand tongues are present that apparently represent a zone of interfingering with the Chama-El Rito and Ojo Caliente Sandstone members from the northern part of the basin.

The lowest unit of the Tesuque Formation in the east-central part of the basin is the Nambé Member, which is arbitrarily divided from the overlying Skull Ridge Member by a white tuff ("No. 1 white ash" of Galusha and Blick, 1971). Fossils are not abundant in the Nambé Member; most are confined to the upper part. A few specimens representing elements of the fauna of the Nambé occur in the Skull Ridge Member just above the basal tuff (Galusha and Blick 1971, p. 48). The presence of the cat *Pseudaelurus*, the dog *Tomarctus optatus*, the rhinoceros *Aphelops*, the horses *Archaeohippus* and early forms of "*Merychippus*" *isonesus* and *Protohippus* indicates a late Hemingfordian age for the Nambé. The fauna of the Nambé Member has a strong similarity with assemblages from the northern Great Plains that typify late Hemingfordian (latest early Miocene) time.

An early Barstovian (early medial Miocene) age for the Skull Ridge Member is implied by the lack of mastodont remains and the occurrence of the primitive bear *Hemicyon*, the oreodonts *Brachycrus* and *Merychys*, the joint occurrence of the giant carnivores *Amphicyon sinapius* and *A. ingens*, and horses that are large species close to "*Merychippus*" *isonesus* and "*Merychippus*" cf. "*M.*" *intermontanus*. The fauna of the Skull Ridge Member is comparable in composition with assemblages of early Barstovian age in the Great Basin and Great Plains (Tedford and others, in press). A late survival of the stenomyline camels (*Rakomylus*) and an unusual abundance of the large browsing horse *Anchitherium* are unique aspects of the fauna of the Skull Ridge Member that suggest ecological differences in comparison with contemporary assemblages from adjacent regions.

Two fission-track ages for airfall tuffs within the Skull Ridge Member have recently been reported (Izett and Naeser, 1981). The determinations, based on zircon phenocrysts, yielded ages (14.6 ± 1.2 m.y. for "No. 2 white ash"; 14.1 ± 1.1 m.y. for the "No. 4 white ash" of Galusha and Blick (1971) that seem compatible with calibration of early Barstovian time (Tedford and others, in press), particularly in view of the large standard deviation of the determinations. Greater precision can be achieved by combining all geochronological data with magnetostratigraphy as proposed by Barghoorn (1981) for the Tesuque Formation in the central Española basin.

The outcrop belt of the overlying Pojoaque Member is wider than that of the other members of the Tesuque Formation. It extends along the central part of the Española Valley and is overlapped to the west by the axial river gravels of the Pliocene Puye Conglomerate and the Miocene to Pleistocene volcanics of the Jemez Mountains. Cope's (1877) collection came nearly exclusively from the Pojoaque Member and important later collections were made by the Frick Laboratory in the vicinity of the member type section (Pojoaque Bluffs) and in the badlands bluffs northeast of Santa Cruz (see maps in Galusha and Blick, 1971). The term "Santa Cruz sites" (Fig. 2) is used here to signify the collections from the lower part of the Pojoaque Member. The most striking aspect of the fauna of the Santa Cruz sites is the abrupt appearance of gomphotheriid mastodonts, an immigrant group whose appearance defines the beginning of late Barstovian time in North America (Tedford and others, in press). These animals appear in the fossil record apparently simultaneously across North America at about 14.5 m.y. B.P. In 1874, Cope described the first mastodont, "*Mastodon*" *productus* (later referred to as *Gomphotherium*), from the Pojoaque Member, and later Frick (1926b, 1933) described a number of gomphotheriid taxa from these deposits. These proboscidean taxa have been revised by Tobien (1972, 1973) with the recognition of only *G. productum*.

Taxa from the Santa Cruz sites in the Pojoaque Member that are important for correlation with faunas in adjacent regions include: abundant beavers, *Eucastor* or *Monosaulax* (Stout, 1967); borophagine dogs, *Carpocyon*, *Aelurodon* (*A. wheeleri* Cope, 1877), and *Strobodon*; the primitive bear *Hemicyon ursinus* (Cope, 1875;

Frick, 1926a); a diversity of horses including primitive species of *Neohipparion* ("*Hipparion*" *sanfondensis* Frick, 1933) *Protohippus*, and *Pliohippus*, associated with late forms of primitive equid lineages such as "*Merychippus*" *calamarius* Cope, 1875, *Hypohippus*, and *Megahippus*. Distinctive Santa Cruz artiodactyls include diverse merycodont pronghorns, *Meryceros*, *Cosoryx*, and especially the peculiar *Ramoceros ramosus* (Cope, 1874); the moschid *Longirostromeryx*; the leptomerycid *Pseudoparablastomeryx* (Taylor and Webb, 1976); the dromomerycid *Cranioceras* [*C. teres* (Cope), 1874]; the lowest stratigraphic occurrence in the Española basin of the oreodont *Ustatochoerus* and camel *Procamelus*; and the last appearance of the camelids *Michenia* and *Miolabis*. These late Barstovian taxa also occur in the upper part of the Chama-El Rito Member, providing strong evidence for time equivalence of part of these Tesuque members across the Española basin, contrary to the correlation proposed by Manley (1979, p. 77, Fig. 4). On the other hand, the fauna of the Pojoaque Member differs appreciably from that of the underlying Skull Ridge Member, suggesting a significant hiatus between these units. All the taxa cited for the Santa Cruz sites occur together in the Valentine Formation of Nebraska; similarities at the species level are mostly with forms from the older members of the Valentine Formation (Crookston Bridge and Devils Gulch Members) (Skinner and others, 1968). The degree of faunal resemblances suggests the lack of physical barriers between the Great Plains and the southeastern Great Basin in medial Miocene time.

Recently available (Izett and Naeser, 1981) zircon fission-track ages for the lower part of the Pojoaque Member in its type section yield ages from 9.4 ± 0.9 m.y. ("blue-gray ash" of Galusha and Blick, 1971, Fig. 21) to 11.4 ± 1.1 m.y. (unnamed ash but probably "light blue or white ash" of Galusha and Blick, 1971, Fig. 21, near the base of the type section). These ages are too young to be compatible with the calibration of the late Barstovian from data assembled by Tedford and others (in press), as indicated in Figure 2 of this report. The synthesis of geochronological data and magnetostratigraphy by Barghoorn (1981) also suggests that the lower part of the Pojoaque type section includes older rocks than indicated by these fission-track dates.

The Chamita Formation represents the

youngest Miocene sediments in the central Española basin. Its type section (Galusha and Blick, 1971) is on the southwestern tip of Black Mesa at the junction of the Chama River and the Rio Grande. In this area, the Chamita, like the Tesuque in the central part of the basin, was derived from granitic and metamorphic terrane. The type section contains two zones of airfall tuff (Galusha and Blick, 1971, p. 71, Fig. 29), including distinctive lapilli tuffs in the lower zone. Tuffs similar to these have been traced along the southeastern side of Black Mesa, but they have not been identified at other purported Chamita Formation outcrops.

Galusha and Blick (1971) indicate in figures (Figs. 5, 10) that the base of the Chamita Formation intertongues with the Ojo Caliente sandstone, but they warn in the text (p. 74) that the evidence may be subject to other interpretations. May (1979) agreed with Galusha and Blick (1971, p. 74, Fig. 38) that the Chamita could be mapped along the northwestern rim of Black Mesa, where it is represented by fluvial beds overlying the eolian Ojo Caliente Sandstone. I have noted above that in this area fossil mammal remains from the Chamita Formation indicate correlation with the lower part of the type section. Kelley (1978) discusses the problem of distinguishing the Chamita and Tesuque and proposes that the Chamita be considered the highest unit of the Tesuque Formation or, alternatively, that these strata should be indicated within the Pojoaque "beds" in his terminology.

Of particular geochronological interest is Galusha and Blick's (1971) extension of the Chamita Formation west and south of the type area along the eastern foot of the Jemez Mountains. Five kilometres west of the southern tip of Black Mesa, a basalt flow that crops out on a mesa near Chili was regarded as being within the lower part of the Chamita Formation (Galusha and Blick, 1971, p. 89). Samples from this flow yielded a K-Ar age of 9.6 ± 0.2 m.y. A similar age was obtained (Baldrige and others, 1980) from a member of the nearby swarm of basalt dikes that intrude the Ojo Caliente Sandstone.

Along the Puye Cliffs escarpment at the eastern foot of the Jemez Mountains, Galusha and Blick (1971, p. 74) recognized a thin wedge of Ojo Caliente Sandstone and, beneath it, Chama-El Rito volcanoclastic sandstone (p. 66) resting on the Pojoaque Member. Stratigraphically above the Ojo Caliente and beneath the Pliocene Puye

Formation were rocks referred to the Chamita Formation. These rocks have the appropriate stratigraphic position, but there are no definitive lithological features supporting this correlation beyond the occurrence of airfall ash in the referred Chamita. In fact, the Chamita Formation in this area is a volcanoclastic conglomeratic sandstone resembling the Chama-El Rito Member of the Tesuque Formation. Kelley (1978) also recognized the occurrence of the Chama-El Rito "Formation" stratigraphically between the Puye and Tesuque Formations (his restricted sense) along the foot of the Jemez Mountains.

Fossil mammal remains from the referred Chamita Formation west of the Rio Grande along the Puye escarpment are of Clarendonian (medial Miocene) age. Scattered sites from west of San Ildefonso to Battleship Mountain attributed to either the Tesuque or Chamita Formations produced Clarendonian taxa such as the oreodonts *Ustatochoerus skinneri* and *U. californicus*, the antilocaprine pronghorn *Plioceros*, the camel *Megatylopus*, the horses *Griphippus*, *Cormohipparion* cf. *C. occidentale*, and *Dinohippus*, all of which are shared with Clarendonian assemblages in the Great Plains (Tedford and others, in press; Webb, 1969). The fauna of the Round Mountain Quarry in the referred Chamita Formation north of Battleship Mountain (Galusha and Blick, 1971, p. 74, Figs. 8, 38) includes merycodont pronghorns (*Ramoceros*, *Cosoryx*) associated with the small horse *Griphippus* cf. *G. gratus*; two forms of *Pliohippus* (one close to *P. pernix*); the llama *Hemiauchenia*; and the joint occurrence of the borophagine dogs *Aelurodon* and *Epicyon*. All these taxa indicate that the fauna of Round Mountain Quarry is of early Clarendonian age. As mentioned above, the youngest faunas from the Chama-El Rito Member of the Tesuque Formation in the northern Española basin are also of Clarendonian age.

Until more detailed studies are conducted, the evidence reviewed in the preceding paragraphs indicates overlap of the basal Chamita and uppermost Tesuque Formations as these units were recognized by Galusha and Blick (1971). It seems likely that there is intertonguing of sedimentary rocks of plutonic and volcanic provenance beneath the eastern side of the Jemez Mountain volcanic field, as suggested by Galusha and Blick (1971) and Kelley (1978). Continuity of deposition and lack of de-

monstrable hiatuses between the Tesuque and Chamita Formations seems indicated, as Kelley (1978) has pointed out.

A magnetostratigraphic and biostratigraphic study of the type section of the Chamita Formation by MacFadden (1977) confirms its Hemphillian (late Miocene) age and indicates that the fauna of the San Juan and Rak Camel Quarries in the upper tuffaceous zone of the formation are of late Hemphillian (latest Miocene) age. The occurrence of an Asiatic immigrant, the wolverine *Plesiogulo*, is definitive in this age determination. The associated fauna includes a typical southern Great Plains horse (*Dinohippus* and *Astrohippus*) and camel (*Megatylopus* and *Hemiauchenia*) fauna associated with the unique antilocaprine pronghorn *Osbornoceros*. Other pronghorns (*Ilingoceros* and cf. *Plioceros*) and a beaver (*Dipoides williamsi*) are of Great Basin biogeographic affinity. MacFadden and Manley (1976) report a zircon fission-track age of 5.6 ± 0.9 m.y. for an ash 5 m below the top of the upper tuffaceous zone and about 35 m above the San Juan and Rak Camel Quarries horizon. In the lower part of the Chamita Formation stratotype (and on the western slope of Black Mesa; see above), the occurrence of the megalonychid sloth *Pliometanastes* and the borophagine dog *Epicyon* cf. *E. haydeni* indicates correlation with faunas of later early (or medial) Hemphillian age elsewhere in North America.

MacFadden (1977) concluded that the entire Chamita stratotype was late Hemphillian in age and he chose to explain the occurrences of some taxa as range extensions into late Hemphillian time. He based his correlation of the Chamita magnetostratigraphy on zircon fission-track ages obtained from two airfall tuffs in the Chamita Formation and paleontological correlation of the upper tuffaceous zone with the Coffee Ranch Local Fauna (the typical fauna of the Hemphillian Mammal Age) from the upper part of the Hemphill beds in the Panhandle of Texas. Actually, three fission-track dates have been obtained on the airfall tuff at the Coffee Ranch Quarry site. Two glass (Boellstorff, 1976; Izett, 1975) dates and one zircon (Izett, 1975) date have been published. The zircon age is 6.6 ± 0.8 m.y., which may not be significantly different from that obtained by MacFadden and Manley (1976) from the paleontologically correlative upper tuffaceous zone of the Chamita Formation. If this calibration is

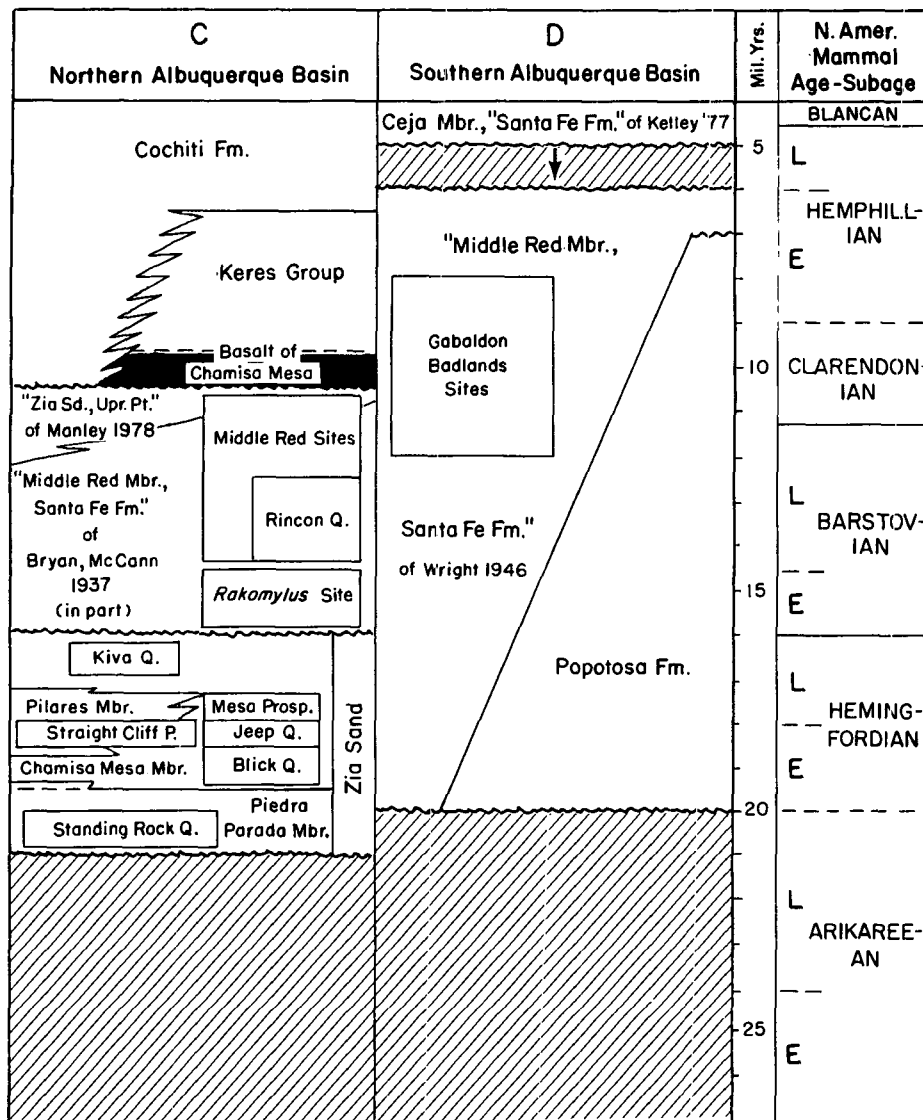


Figure 3. Lithostratigraphy and sequence of Miocene fossil mammal samples [sites, prospects (P) and quarries (Q)] from the Albuquerque-Belen basin from Sandoval to Valencia Counties, New Mexico. See text for discussion of data represented. Graphic conventions explained in the legend for Figure 2.

it necessary to propose modifications that would more precisely express the stratigraphic relationships observed in specific areas. As a result, various problems in the recognition of lithostratigraphic units and their nomenclature have arisen, as discussed by Galusha (1966), Kelley (1977), Manley (1978), Hawley (1978, p. 178-182), and Hawley and Galusha (1978, p. 177-178). In the following synopsis of the biostratigraphy of these deposits, the stratigraphic nomenclature of Galusha (1966) will be used as far as possible, because it served as the basis for the documentation of these fossil collections.

The Zia Sand of Galusha (1966) lies at the base of the Neogene section in the Rincones de Zia and upper reaches of the Jemez River on the southern flank of the Nacimiento and Jemez Mountains (see Galusha, 1966, for maps). Galusha (1966) divided the Zia Sand into two members: a lower, eolian unit, the Piedra Parada Member; and an upper, largely fluvial unit, the Chamisa Mesa Member. Recently, Gawne has recognized a third and uppermost member of red mudstone and interbedded sandstone, the Pilares Member, from outcrops south of the Jemez River along the northern escarpment of the Ceja del Rio Puerco (unnumbered square, southwest of section C, Fig. 1 of this paper). Deposits of the Piedra Parada Member constituted the original typification of the "lower gray member of the Santa Fe Formation" by Bryan and McCann (1937). Rocks that represent the Chamisa Mesa and Pilares members were included in the "middle red member of the Santa Fe Formation" by Bryan and McCann (1937); the red mudstones of the Pilares Member were undoubtedly important in this concept, as they crop out prominently along the northern Ceja del Rio Puerco in the area most intensively studied by these pioneer workers. Recently, an enlarged concept of the Zia Sand has been advocated by Kelley (1977) and Manley (1978), who regard this unit as a facies of most of the Santa Fe Group in the northern Albuquerque basin.

Important fossiliferous sections include those of the stratotype of the Piedra Parada Member in the Cañada of the same name, the western Rincones de Zia, and the Chamisa Mesa Member type section in the upper reaches of Arroyo del Pueblo which drains the southern flank of Chamisa Mesa southeast of Jemez Pueblo (Galusha, 1966, Figs. 3 and 5). The faunal succession reconstructed from these outcrops by Galusha (1966) is symbolized here in Figure 3 by four sites (Standing Rock Quarry through

correct, an alternative correlation of the upper tuffaceous zone of the Chamita Formation seems possible. Accepting an age of about 6 m.y. for the upper tuffaceous zone and the magnetostratigraphy of MacFadden (1977), this zone would lie within the lower reversed event in chron 6 (MacFadden's magnetically indeterminate zone would thus be the normal event at the top of chron 7), and the lower tuffaceous zone in the upper part of chron 7. These correlations would agree with the calibration of the biochronology of the Hemphillian developed from data elsewhere in the United States (Tedford and others, in press).

Northern Albuquerque Basin (Fig. 3, column C)

Outcrops in the northern and northwestern Albuquerque basin (Kelley, 1977) expose about 700 m of clastic sedimentary rocks that represent the Santa Fe Group. The stratigraphy of these deposits was first studied in the northwestern part of the basin by Bryan and McCann (1937) and an informal subdivision into three members of the "Santa Fe Formation" was proposed. Subsequent authors have tried to employ this stratigraphy elsewhere in the basin (Denny, 1940; Wright 1946) or have found

Mesa Prospect) that have yielded the most important collections. Gawne (1975, 1976) gives faunal lists for these sites and estimates of their ages. Recent revision of the definition and characterization of the Arikareean and Hemingfordian Mammal Ages and informal subages (Tedford and others, in press) indicates a latest Arikareean age for Standing Rock Quarry at the base of the Piedra Parada Member based on the joint occurrence of the bearlike carnivorans *Daphoenodon* and *Cephalogale*, the camel *Stenomylus* cf. *S. gracilis*, and the mustelid *Promartes* cf. *P. lepidus*. The Blick Quarry (and stratigraphically equivalent *Cynarcoides* Quarry) fauna in the lower part of the Chamisa Mesa stratotype is early Hemingfordian in age and contains the pica *Oreolagus* and the dog *Tomarctus*, besides the endemic camel *Blickomylus* (Frick and Taylor, 1968). The Jeep Quarry assemblage includes the rodent *Mesogaulus*, the carnivoran *Amphicyon*, and the camel *Protolabis*, all of which appear in the Runningwater Formation of Nebraska that contains the definitive faunal succession for the early Hemingfordian. *Merycodus* is also reported at Jeep Quarry (and at the younger Mesa Prospect). This genus is not so far known in the Runningwater Formation, but occurs in late Hemingfordian deposits in Nebraska. The Jeep Quarry fauna is otherwise typical of the early Hemingfordian, including the occurrence of *Promartes*, which is not known in younger assemblages. Five metres higher than Jeep Quarry, Mesa Prospect provides the first record of horses in the Zia Sand faunal succession. The taxa present represent a unique joint occurrence of *Parahippus* cf. *P. tyleri*, an early Hemingfordian form, with "cf. *Merychippus*," identified by hypsodont, cement-bearing equid cheek teeth. This is the only locality in North America where such a joint association has been discovered. The presence of an important hiatus within the biostratigraphic record of the Hemingfordian Age in Nebraska limits knowledge of the earliest appearance of the definitive taxa there. It is possible that the New Mexico succession fits into this temporal gap as mentioned by Gawne (1975, 1976).

Galusha (1966, Fig. 5) arbitrarily chose a limestone above the Mesa Prospect as a key horizon on which to map the top of the Zia Sand at Chamisa Mesa. The rocks above this limestone were referred to the "Santa Fe Formation" by Galusha (1966). However, the fauna of the Arroyo Chamiso Prospect five metres above the base of the "Santa Fe Formation" as defined by Galu-

sha (1966, Fig. 5) contains the endemic advanced stenomyline camel *Blickomylus galushi*, whose local range zone extends downward to the Blick Quarry level (Frick and Taylor, 1968). The fauna of the Arroyo Chamiso Prospect seems to be in faunal continuity with the assemblages beneath it. Galusha (1966, Fig. 5) indicates the occurrence of *Rakomylus* ten metres higher in the section; this sister taxon of *Stenomylus* is known elsewhere only from the early Barstovian (Skull Ridge Member) of the Española basin. This biostratigraphy suggests that if a hiatus exists in the Chamisa Mesa section, its location would be between these critical fossil occurrences. Furthermore, the *Rakomylus* site tuffaceous deposits are more easily equated with the ash-bearing lower part of the "Middle Red Member of the Santa Fe Formation" above the Zia Sand as mapped by Galusha (1966, Fig. 2) in the Rincones de Zia south of Chamisa Mesa.

A late Hemingfordian fauna occurs in rocks mapped (Galusha, 1966, Fig. 2) as the Zia Sand at Kiva Quarry east of the Jemez fault and close to the Jemez River on the edge of the Zia Pueblo Grant. This important site contains the borophagine dog *Tomarctus* cf. *T. optatus* and horses that are primitive members of the *Protohippus* group. These taxa also occur in the upper part of the Nambé Member of the Tesuque Formation in the Española basin.

Southward along the Ceja del Rio Puerco, the badlands escarpment that forms the western edge of the Llano de Albuquerque, outcrops of the Zia Sand overlie Cretaceous rocks (and possibly wedges of Galisteo Formation; Gawne, 1981). In this area, Gawne recognized the Piedra Parada and Chamisa Mesa Members of the Zia Sand and defined a third and uppermost unit of the Zia Sand, the Pilares Member, from outcrops there. Faunas are known from each of these members. Especially useful collections have been made in Cañada Pilares that indicate that the sequence includes deposits of late Arikareean to early Hemingfordian age correlative with assemblages from the Jemez River region to the north. The occurrence of the early Hemingfordian rhinoceros *Menoceras* cf. *M. marslandense* at Straight Cliff Prospect at the top of the Pilares Member in Cañada Pilares indicates that an important disconformity occurs between this horizon and the levels a few tens of metres higher that produced late Barstovian assemblages.

The faunal succession within the Zia Sand of Galusha (1966) and Gawne (1981)

represents an important biostratigraphic sequence. In comparison with the Española basin, it overlaps the faunas within the Nambé Member of the Tesuque Formation and extends downward to include assemblages comparable in age with those from the Abiquiu Formation. Despite some unique attributes (for example, the stenomyline camels), collections from the Zia Sand can be readily correlated with the Nebraska late Arikareean through late Hemingfordian faunal succession.

Outcrops in the northern Albuquerque basin indicate that an important disconformity separates the Zia Sand of Galusha (1966) from the overlying deposits of the Santa Fe Group. This disconformity lies within the "middle red member of the Santa Fe Formation" of Bryan and McCann (1937) and the "main body of the Santa Fe Formation" of Kelley (1977). Fossil mammal remains from the "middle red member" above the Zia Sand in the Rincones de Zia and Ceja del Rio Puerco outcrops suggest that the hiatus may be as long as the duration of the early part of Barstovian time. The *Rakomylus* site at Chamisa Mesa, if above the disconformity (see discussion above), may indicate a lesser gap in time in that area.

Most of the fossil material from the post-Zia Sand rocks was obtained from scattered sites, but a few concentrations of fossils were found in the western Rincones de Zia. One of these is the Rincon Quarry from the lower part of the "Santa Fe Formation equivalent" as mapped by Galusha (1966, Fig. 2), just west of the Rincon fault. The Rincon Quarry assemblage includes primitive species of the horses *Pliohippus* and *Neohipparion*, and the borophagine dogs "*Tomarctus*" *temerarius* and *Aelurodon ferox*. It closely resembles the fauna of the Santa Cruz sites in the lower part of the Pojoaque Member in the Española basin. Faunas of this character are also found in the post-Zia "middle red member" along the northern Ceja del Rio Puerco from Cañada Navajo south to Cañadas Pilares and Moquino.

Younger faunas occur in the higher part of the "middle red member" in the block bounded by the Jemez and Rincon faults (as mapped by Galusha, 1966, Fig. 2), where derived species of the horses *Neohipparion*, *Pliohippus* cf. *P. pernix*, and *Cormohipparion* cf. *C. occidentale* indicate a Clarendonian age. Eastward across the Rincon fault (Zia fault of Kelley, 1977), rocks assigned by Galusha (1966, Fig. 2) to the "upper buff member of the Santa Fe Formation" of

Bryan and McCann (1937) have also produced Clarendonian faunas. Similar middle Miocene faunas occur in the Arroyo Arenoso drainage north of the Jemez River where the rocks were mapped as Zia Sand by Smith and others (1970). These Clarendonian deposits also have been mapped as "Zia Member" by Kelley (1977), and "Zia Sand-upper part" or "Cochiti Formation" by Manley (1978).

The basalt of Chamisa Mesa, lowest unit in the Keres Group of Bailey and others (1969), caps the Santa Fe Group at Chamisa Mesa (Smith and others, 1970). This unit has a K-Ar age of 10.4 m.y. (Bailey and Smith, 1978) and thus provides a maximum age for the top of the "middle red member" and "Zia Sand-upper part" in agreement with the Clarendonian age of the youngest faunas from these units.

Southern Albuquerque Basin (Fig. 3, column D)

The thickest exposed section of the Santa Fe Group occurs in the Gabaldon Badlands west of the Puerco River and south of Highway 6 (Kelley, 1977; Wright, 1946). Over 1,000 m of playa mudstones and overlying sandstones and conglomerates make up this faulted, westward-dipping section. Scattered mammalian fossils occur in the upper third of the section. Wright (1946) noted merycodont antilocaprid remains; collections made by Galusha include the dog *Epicyon* cf. *E. haydeni*; the camels *Michenia*, *Alforjas*, *Megatylopus*, and *Aepycamelus*; and the antilocaprine pronghorns *Plioceros* or *Texoceros*. These taxa indicate the presence of a late Clarendonian fauna, although the higher fossiliferous horizons possibly extend into the early Hemphillian. This is one of the youngest Miocene faunas obtained from the Santa Fe Group in the Albuquerque-Belen basin.

Southward around the eastern and western flanks of Sierra Ladron, the Santa Fe seems to overlie the Popotosa Formation (see discussion in Kelley, 1977), but the K-Ar ages available for the Popotosa (Bachman and Mehnert, 1978; Chapin and others, 1978) indicate that, like the Santa Fe, it spans much of Miocene time. However, unlike the Santa Fe Group in the Albuquerque-Belen basin, the Popotosa Formation includes volcanics and volcanoclastic sediments and is confined to the southern part of the basin and the adjacent Socorro and La Jencia basins.

Other Miocene Sites

Basins within the depressions created by warping and tensional faulting of the Oligocene Mogollon-Datil volcanic plateau began to receive sediments in early Miocene time, as demonstrated by K-Ar dates on interbedded basaltic andesites in the basal part of the sedimentary sequence (Elston and others, 1976). These rocks are part of Gilbert's (1875) Gila Conglomerate, now often referred to as the Gila Group, an undifferentiated sequence of rock units that span most of late Cenozoic time. Little exploration for vertebrate fossils has been done in these relatively coarse-grained deposits. One recently discovered site, low in the exposed Gila section on the western slope of the Black Range at the head of the Taylor Creek drainage, western Sierra County, has produced oreodont remains from volcanoclastic sandstone. The fragmentary material indicates a medium-sized oreodont that seems to have affinities with *Promerycochoerus carrikeri* and thus suggests a late Arikareean (early Miocene) age for the enclosing sediments.

Late Miocene (Hemphillian) fossils are known from the Mangas Trench, a graben-like depression that encircles the southwestern perimeter of the Mogollon-Datil Plateau (Fig. 1). Cope (1884) first reported a rhinoceros skull, "*Aphelops*" *fossiger* (now *Teleoceras fossiger*), from a conglomerate on Dry Creek near its junction with the San Francisco River in the northern part of the Mangas Trench in southwestern Catron County. Recently, residents in the area have recovered remains of late Hemphillian horses (*Dinohippus* sp. and *Astrohippus stocki*) from the southern end of the Mangas Trench in central Grant County (W. Leopoldt, 1980, personal commun.)

PLIOCENE AND EARLY PLEISTOCENE BASINS

The vertebrate fossil record of Pliocene and early Pleistocene time in New Mexico is largely confined to the basins of the Rio Grande and the Gila River. These fossil localities are mostly in the axial river sands and gravels of the precursors of the modern streams or in the interfingering distal alluvial-fan or piedmont facies. Interbedded basalts and airfall tuffs provide important radiometric or fission-track age controls for the Pliocene and Pleistocene basin fills and their contained vertebrate fossils. Especially

important reference points are provided by recognition of the Yellowstone or Pearlette ashes (Type B, 2.1 m.y., and Type 0, 0.6 m.y., have been identified in New Mexico), the Bishop Tuff (0.7 m.y.), and the nearby Bandelier Tuff from the Valles and Cerro Toledo calderas in northern New Mexico (dates spanning the interval 1.5–1.2 m.y.) (Izett and others, 1981). Pliocene and early Pleistocene fossil vertebrates from nearby Arizona and Texas have been calibrated radiometrically or with reference to magnetostratigraphy. The calibrated biostratigraphic sequences are discussed here with respect to the New Mexico evidence. A high degree of taxonomic resemblance between the New Mexican Pliocene and Pleistocene faunas and those of the adjacent southwest encourages reliance on the faunal sequence for correlation purposes.

San Pedro Valley, Arizona (Fig. 4, column E)

The faunal succession in the San Pedro Valley of southeastern Arizona has been well established and calibrated (Johnson and others, 1975) and covers most of the interval represented by the New Mexico record. Important biochronological markers in this sequence are the appearance of the South American immigrant *Glyptotherium* and extinction of the small three-toed horse *Nannippus*. The last appearance of *Nannippus* occurs stratigraphically between strata containing the Wolf Ranch and California Wash local faunas in the St. David Formation. This occurrence lies near the boundary between the Gauss and Matuyama chrons (approximately 2.5 m.y. B.P.). *Glyptotherium* first appeared just prior to the Olduvai Event (older than 1.9 m.y. B.P.) in the San Pedro Valley, but in the adjacent Safford Valley, at 111 Ranch, recent work (Galusha and others, unpub. data) shows that *Glyptotherium* occurs with *Nannippus* near the Gauss-Matuyama boundary.

Hueco Bolson, Texas (Fig. 5, column M)

Additional support for the calibration of the faunal events detailed for Arizona is provided by the biostratigraphic sequence in the Hueco Bolson southeast of El Paso (Strain, 1966). Strain has generalized the faunal sequence that crosses the local Fort Hancock-Camp Rice formational boundary as his Hudspeth Fauna. *Nannippus* and *Glyptotherium* occur in the lower part

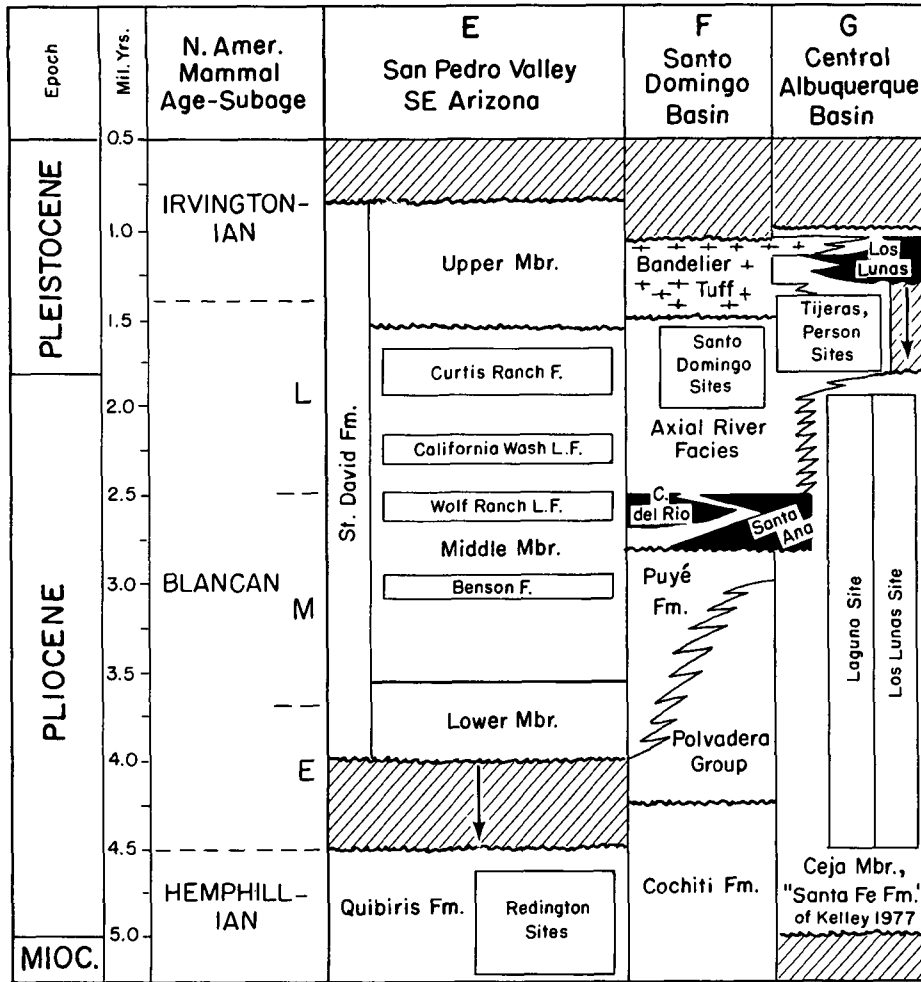


Figure 4. Lithostratigraphy and sequence of Pliocene through early Pleistocene fossil mammal faunas (F.), local faunas (LF), and sites, including a relevant biochronological sequence in adjacent Arizona and equivalents in the Albuquerque-Belen basin, Sandoval to Valencia Counties, New Mexico. See text for discussion of the data represented. Graphic conventions explained in the legend for Figure 2.

of the Camp Rice Formation in that area. The fossiliferous interval producing the Hudspeth Fauna is bounded above by the Borchers Ash (Pearlette Type B), dated elsewhere at about 2.1 m.y. B.P. The concordance of calibration of these biostratigraphic sequences from Arizona to Texas gives some confidence in the use of the Pliocene faunal sequence in the southwest in local correlation.

The Hudspeth fauna has a close taxonomic ally in the Red Light Local Fauna described by Akersten (1972) from the Red Light Bolson. This locality is also in Hudspeth County, southeast of the Hueco Bolson. Akersten's (1972) study of the Red Light Local Fauna clarifies the taxonomy of some of the better-represented elements

in the two faunas, especially the horses, which are also the most abundant remains in the Pliocene collections from New Mexico. The work in Texas clearly indicates the coexistence, near the close of the biochron of *Nannippus*, of three species of *Equus*: *E. simplicidens*, *E. scotti*, and *E. cumminsii*. These are, respectively, large *E. grevyi*-like form, a large *Asinus*-like form, and a smaller stilt-legged *Hemionus*-like form. Work in progress (T. Galusha and others, unpub. data) at 111 Ranch, in the Safford Valley Arizona, indicates a similar coexistence at the close of Gauss time.

Important data fixing the minimum age for the Blanca-Irvingtonian boundary have been briefly reviewed by Izett (1977) in his discussion of the biostratigraphy of the Tule

Formation in the Texas Panhandle and the dating of its contained volcanic ashes. At the base of the Tule Formation, the mammoth *Mammuthus*, an Asian immigrant, and the mastodont *Stegomastodon* are associated with *Equus simplicidens* and a hemione, *E. semiplicatus*. An ash of Cerro Toledo affinity occurs with these fossils, indicating an age of 1.2 to 1.5 m.y. (K-Ar and fission-track dating of source rocks) (Izett and others, 1981) for this association and thus provides radiometric calibration of the earliest Irvingtonian faunas of the southern Great Plains adjacent to New Mexico. Using the biochronological framework provided by the Arizona and Texas data, and the constraining association of the New Mexican faunas with dated basalts and tuffs, preliminary assessments of the ages of the assemblages and the fossiliferous rocks can be made, as indicated in Figures 4 and 5.

Santo Domingo Basin (Fig. 4, column F)

In 1926–1928, Joseph Rak of the Frick Laboratory collected fossil mammal remains from the axial gravels (map symbol: QT g, Smith and others, 1970; Ts, undivided Santa Fe Formation; Kelley, 1977) on the eastern side of the Rio Grande in the vicinity of the Santo Domingo Pueblo in Sandoval County. These deposits are interbedded with the basalt of Santa Ana Mesa and possibly with the coeval Cerros del Rio flows (2.5–2.6 m.y.) (Bachman and Mehner, 1978) and are overlain by the Otowi Member of the Bandelier Tuff (1.4–1.5 m.y.) (Izett and others, 1981, Table 11). The mammalian fauna includes the horse *E. scotti* and a hemione resembling *E. calobatus*. *Nannippus* has not been recorded at this site; this absence plus the resemblance of the *Equus* species to those from the Tule Formation of Texas suggest that the fauna may be very late Blancan in age.

Central Albuquerque Basin (Fig. 4, column G)

Outcrops on the eastern side of the Rio Grande within the southern metropolitan area of the city of Albuquerque (especially the gravel pits east of the Person Power Plant) and south to Tijeras Arroyo have yielded fossil mammal remains from the pumice-bearing, axial river deposits assigned by Lambert (1968, 1978) to the "Ceja Member of the Santa Fe Formation" of

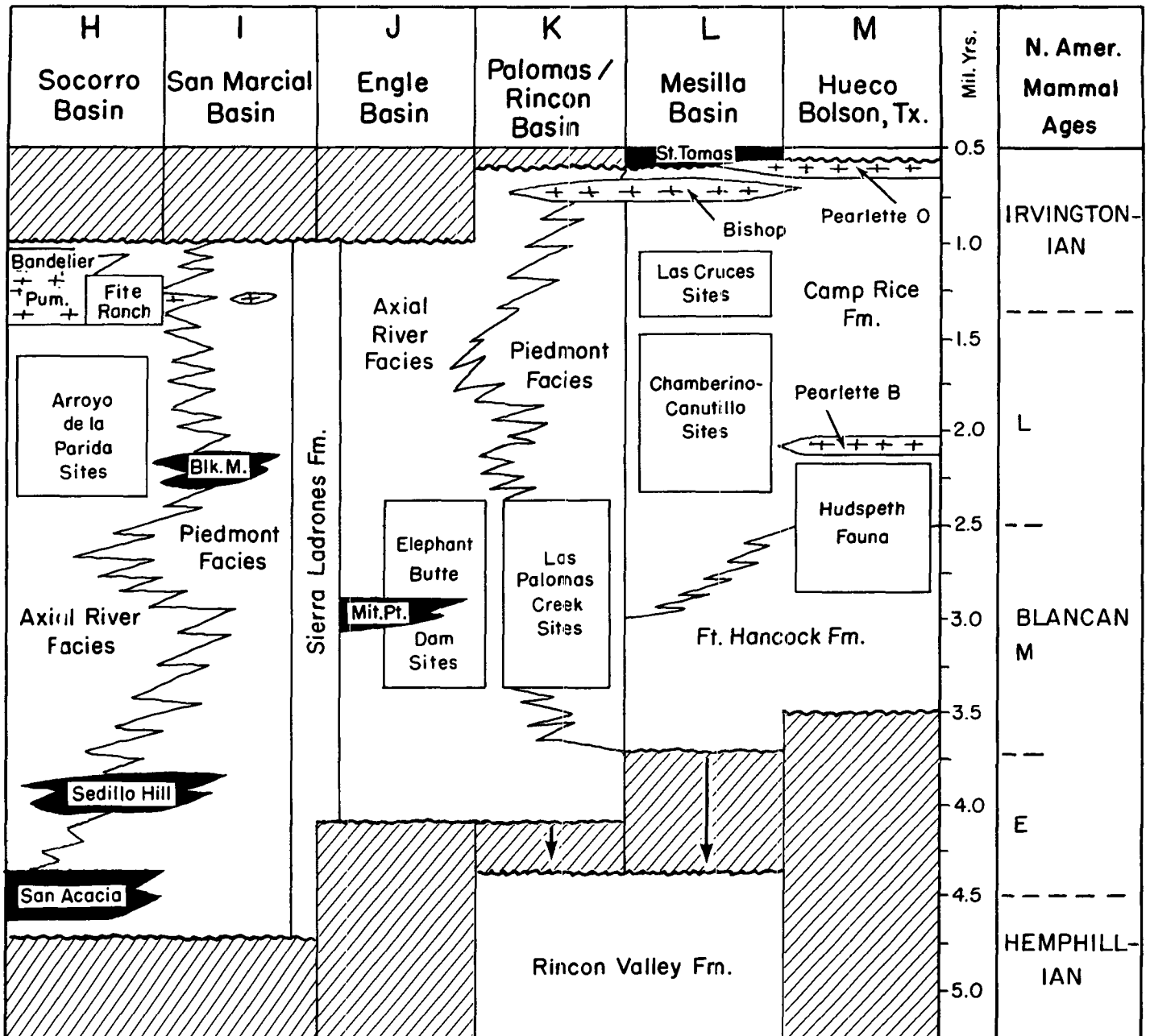


Figure 5. Lithostratigraphy and sequence of Pliocene through early Pleistocene fossil mammal faunas and sites from Socorro to Doña Ana Counties, New Mexico, compared with an adjacent sequence in nearby Hudspeth County, Texas. See text for discussion of the data represented. Graphic conventions explained in the legend for Figure 2. Dated basalts abbreviated: "Blk. M.," Black Mountain; "Mit. Pt.," Mitchell Point.

Kelley (1977). Review of the collections (contained in the University of New Mexico, Department of Zoology) shows that *Equus simplicidens* is present in association with the rabbit *Hypolagus*. The pumice represents the Guaje pumice (Izett and others, 1981, Table 10) of the Otowi Member of the Bandelier Tuff. A date close to 1.4 m.y. B.P. (Izett and others, 1981, Table 11) for this pumice provides calibration for the latest Blancan fauna from these sites.

Southwest of Albuquerque, fossil mammal remains have been found at two sites attributed here to the Ceja Member. One of these sites occurs in the deformed strata that lie beneath the andesites of the Cerro de Los Lunas volcano. These sediments were mapped by Kelley (1977) as undivided Santa Fe Formation and Ceja Member (the gravel facies, Kelley, 1977, p. 18). A jaw fragment of the giant marmot *Paenemarmota* was collected from the "Santa Fe" near where

State Highway 6 ascends the Cejita. This taxon is confined to Blancan faunas of the southwest and southern Great Plains (Repenning, 1962). It is not possible to be sure of the position within the Blancan of this occurrence, except that the site can be no younger than the andesite of the Los Lunas volcano (1.1–1.3 m.y.) (Bachman and Mehnert, 1978), which overlies the "Santa Fe" with angular unconformity.

Northwest across the Llano de Albu-

querque from Los Lunas, where the northern boundary of the Isleta Pueblo Grant crosses the Ceja del Rio Puerco (Wright, 1946, Site 14), the Ceja Member contains small mammal, bird and, turtle remains in pinkish sandstone with concretions (probably the unit toward the base of Wright's section 14, 1946, Fig. 7). The most abundant taxon in this assemblage is a gopher *Geomys (Nerterogeomys)* close to Strain's *G. (N.) paenebursarius*, a late Blancan form. The subgenus ranges through Blancan time and, therefore, these fossils do not allow more precise age determination.

Socorro through Palomas Basins (Fig. 5, columns H-K)

Pliocene and lower Pleistocene sediments that crop out in the Socorro constriction of the Rio Grande Valley, referred to the Santa Fe Formation by Denny (1940) and Kelley (1977), have recently been described as the Sierra Ladrones Formation by Machette (1978). The Sierra Ladrones Formation contains locally derived piedmont facies and interfingering axial river facies of an ancestral Rio Grande. A basalt at Sedillo Hill southwest of Socorro, interbedded at the facies boundary, has provided a 4.0 m.y. minimum age for axial river deposition in the Socorro basin (Bachman and Mehnert, 1978). At San Acacia, a deformed basalt dated at 4.5 m.y. B.P. (Bachman and Mehnert, 1978) is interbedded with piedmont slope and alluvial-flat sediments referred to the Sierra Ladrones Formation (Machette, 1978). Further downstream in the San Marcial basin, the basalt at Black Mesa overlies cross-bedded sands of the younger basin fill and is dated at 2.2 m.y. B.P. (Bachman and Mehnert, 1978).

Fossil vertebrate remains occur in the axial facies of the Sierra Ladrones Formation at several localities. In particular, the outcrops in the Arroyo de La Parida northeast of Socorro (Needham, 1936) yielded remains of the mastodonts *Stegomastodon* and *Rhynchotherium* (Gazin in Needham, 1936), the horse *E. simplicidens*, the hemione *E. cf. E. cumminsii*, the large ass *E. cf. E. scotti*, and the small pronghorn cf. *Capromeryx*. Except for the occurrence of *Rhynchotherium*, this association is typical of the late Blancan southwestern faunas and therefore the assemblage is assigned to that age. Denny (1940, p. 93) reported a similar fauna from outcrops now assigned to the Sierra Ladrones Formation just north of

the Rio Salado on the western side of the Rio Grande.

At San Antonio, outcrops of pumice-bearing sands on the Fite Ranch, attributed to the Bandelier eruptions (Cerro Toledo; Izett and others, 1981, Table 10), contain waterworn bones of *Equus* and *Camelops* and, apparently, produced remains of a turkey (Needham, 1936). The fossil vertebrate material is not diagnostic of age beyond a Pliocene or Pleistocene assignment but the associated pumice indicates a date of 1.2–1.4 m.y. (Izett and other, 1981).

Southward, the axial river gravels of the ancestral Rio Grande and interfingering piedmont facies seem continuous into the Palomas basin. For this reason, the term Sierra Ladrones Formation is tentatively extended to that region. The Rincon sub-basin connects the Palomas basin eastward into the Jornada basin, but late Cenozoic faulting has restricted continuity southward into the Mesilla basin. Fossil mammal remains have been collected from the axial river facies in the Engle basin on the western side of Elephant Butte Reservoir and in the Palomas basin in the vicinity of Truth or Consequences south to Las Palomas Creek. The assemblages, as far as they can be judged, are all of similar character. Mastodont remains were reported to be fairly common on the shores of Elephant Butte Reservoir, but the material is not available for identification; the horse *E. simplicidens*, the large camel *Gigantocamelus*, and the tapir *Tapirus* also are present. The sites are assigned to the medial Blancan on the basis of the close stratigraphic association with basalt dated at 2.9 m.y. B.P. (Bachman and Mehnert, 1978) at Mitchell Point on the western side of the reservoir.

Outcrops of the distal piedmont facies in the Palomas basin, especially in the Los Palomas Creek area, have yielded a more diverse fauna, including the gopher *Nerterogeomys*; the cotton rat *Sigmodon*; the horse *Nannippus*, *Equus simplicidens*, and *E. cf. E. cumminsii*; the holotype of the mastodon, *Mammuthus raki* (Frick, 1933); a peccary; and a camel. The presence of *Nannippus* suggest an age greater than 2.5 m.y.; the remainder of the Las Palomas Creek assemblage is compatible with a Blancan age. Hawley (1978, p. 83) reports another Blancan site near Hatch in the southern part of the Palomas basin. The mammals occur in the Sierra Ladrones Formation (Camp Rice equivalent, *vide* Hawley, 1978), which there overlies the Rincon Valley Formation red beds that were deposited in a basin of

internal drainage before development of the Rio Grande system.

Mesilla Basin (Fig. 5, column L)

Hawley (1975, 1978) reconstructed the main aspects of the Pliocene and Pleistocene history of the Mesilla basin. He concluded that the Mesilla and Hueco basins were gradually integrated in late Pliocene time as fluvial sands were brought into the Mesilla basin through the constriction north of Las Cruces. These sands interfingered southward with piedmont-slope deposits, which eventually filled the Mesilla bolson and overflowed into the Hueco bolson through Fillmore Pass. Hawley therefore extended Strain's (1966) Neogene lithostratigraphy of the Hueco basin into the Mesilla basin. The finer-grained red clastics of the closed Hueco and Mesilla basins are referred to the Fort Hancock Formation. These deposits intertongue with and are overlain by the Camp Rice Formation, which represents the deposits of the through-flowing axial drainage that reached the Mesilla basin from the north.

Important collections have been made in the southern part of the basin along the escarpment carved by later Pleistocene erosion of the western wall of the Rio Grande Valley. Outcrops of the Camp Rice Formation along the western side of the Rio Grande in Doña Ana County, New Mexico, from near Chamberino (New Mexico) south to opposite Canutillo (Texas) have yielded fossil mammal remains from red muddy sands and interbedded gravels through a thickness of nearly 70 m. The fauna of the lower part of the section includes a small mylodontid sloth, cf. *Glossotherium chapadmalense*; a glyptodont; a mastodont *Cuvieronius*; a coyote, *Canis cf. C. latrans*; a tapir; the horses *Equus cf. E. scotti* and *E. cf. E. calobatus*; a camel, *Camelops*; and the holotype of a large deer *Navahoceros las-cruceensis* (Frick, 1937). The uppermost gravel west of La Union produced a partial mammoth skull, *Mammuthus*, indicating that the faunal sequence extends into Irvingtonian time. *Nannippus* has not been found in these deposits, and this fact, together with the similarity of the Mesilla horses to those from earliest Irvingtonian deposits in the Tule Formation of Texas, suggest a very young Blancan or possibly early Irvingtonian age for the fauna. Gravel pits north of Las Cruces (Hawley and others, 1969) have yielded an earliest Irvingtonian fauna documenting the coexistence of

the mastodont *Cuvieronius*, the mammoth *Mammuthus*, and at least two species of *Equus*. Thus, the faunas of the Camp Rice Formation of the Mesilla Basin seem younger than the Hudspeth Fauna of the Hueco basin. In both basins, deposition of the Camp Rice Formation terminated just after Bishop or Pearlette 0 ash time (0.7–0.6 m.y. B.P.). Valley incision by an integrated Rio Grande was underway by the time the Santo Tomas basalt field began to erupt (0.5 m.y. B.P.) (Hawley, 1981, personal commun.).

Other Pliocene Sites

Blancan mammals are known from Gila Group deposits in the Mangas Trench, a basin adjacent to the Mogollon Plateau northwest of Silver City, Grant County, New Mexico. As noted above, late Hemphillian faunas are also known from this basin, and the occurrence of *Mammuthus* remains from outcrops along the San Francisco River in the northern part of the same basin indicates that the deposits of the Gila Group in this region accumulated at least from late Miocene through early Pleistocene time.

The principal sites for Blancan mammals in the Mangas Trench are near Buckhorn in Grant County. Outcrops in that area have yielded remains of the horses *Nannippus* and *Equus* cf. *E. simplicidens* associated with the camels *Camelops* and *Hemiauchenia* cf. *H. blancoensis*, and peccary *Platygonus*, mastodonts, carnivores, rodents, and rabbits. The joint occurrence of the two horses implies a medial Blancan age, as discussed above.

Adjacent to the Arizona–New Mexico border (see Fig. 1), the Gila River has exposed fluvial and lacustrine deposits of the Gila Group in the Duncan Basin (Morrison, 1965). Fossil mammals have been collected by the Frick Laboratory of the American Museum and the University of Arizona (Linsay and Tessman, 1974, p. 7) from the finer-grained facies in the upper 100 m of the section exposed along the Gila River from near Virden (New Mexico) north to Clifton (Arizona). These collections include the joint association of the horses *Nannippus*, *Equus* cf. *E. simplicidens*, and a smaller *Equus* sp.; the sloth *Glossotherium chapadmalense*; a glyptodont; mastodonts; canids and felids (including *Felis* cf. *F. lacustris*); camels; the peccary *Platygonus*; antilocaprids; rodents including *Geomys*; and the rabbit *Hypo-*

lagus. This association of taxa indicates a medial Blancan age for the Gila Group deposits in the Duncan basin according to the criteria advanced in this report.

CONCLUSIONS

This review of the fossil mammal remains from the deposits contained in the late Cenozoic basins of New Mexico serves to emphasize the richness and diversity of the record already available in museum collections. So little of these collections has been published in sufficient detail that the present compilation can be only a very preliminary attempt to indicate the nature of the Neocene mammal record in New Mexico and its geochronological significance. The results are nevertheless interesting, because this is the first such comprehensive survey of the available information. These data are best summarized in the columnar sections that illustrate this paper (Figs. 2–5). The columns give the lithostratigraphy and biostratigraphy for selected areas in New Mexico (see Fig. 1). The correlation of this evidence is indicated by the juxtaposition of these columns against one another and against a relative time scale of biological events (North American Mammal Ages and informal subages) (Tedford and others, in press) that, in turn, has been calibrated by radiometric age determinations from widely scattered data from the United States (summarized in Tedford and others, in press). Several biological conclusions follow from these correlations and particularly from comparison of the New Mexican faunas with adjacent regions. These topics are discussed in the paragraphs that follow.

The Santa Fe Group in the Española basin contains one of the more important Miocene faunal successions known in North America. With study, it will emerge as a standard for comparison with similar sequences elsewhere in the continent. The faunal succession has a close biological relationship with correlative Miocene faunas of the Great Plains. Nevertheless, the New Mexican faunas show some compositional differences and differences of abundance of certain groups, when compared with coeval assemblages of the Great Plains, that may characterize a southwestern faunal province. The persistence in time of the stenomyline camels, the abundance and diversity of camels in general, the lower diversity of horses until the late Barstovian, the diversity and abundance of merycodontine pronghorns, and the lower diversity of

cervids are in contrast with Great Plains faunas and more closely resemble early and middle Miocene faunas of the southern Great Basin. Latest Miocene faunas of the Española basin also resemble their southern plains equivalents, but they have a greater diversity of antilocaprine pronghorns that again is similar to the Great Basin. These similarities and differences suggest that in Miocene time the northern Rio Grande rift basins lay in a region of faunal transition between the Great Plains and Great Basin zoogeographic provinces. The strong affinity of the New Mexican faunas with their contemporaries on the Great Plains suggests ecological continuity and the lack of physical barriers between these regions.

A similarly important faunal succession is present in the northern Albuquerque–Belen basin, especially within the lower Miocene Zia Sand, where faunas older than those known from the basal Tesuque Formation occur. If correlations of the Zia faunal sequence with the Great Plains are correct, the faunas may partially fill an important hiatus in the Great Plains record of medial Hemingfordian time. Compared with contemporary assemblages of the Great Plains, the Zia faunas demonstrate an abundance of endemic stenomylines and geomyid rodents, diverse merycodonts and camels, and the lack of horses until high in the sequence. Other southwestern early Miocene faunas, ranging from the Big Bend of Texas (Stevens, 1977) to the Mojave Desert of California (Woodburne and others, 1974), similarly contain diverse artiodactyls (including stenomylines) and few horses. These assemblages suggest the presence of an early Miocene faunal province in the Southwest as discussed by Stevens (1977, p. 63) that may represent a more arid environment than existed at that time to the north on the Great Plains or in the Gulf coastal region.

The Pliocene and early Pleistocene faunas of New Mexico are very poorly known, and none has been described in the literature. The data contributed in this report organize diverse information from museum collections on the general nature of these younger assemblages and put them into stratigraphic context. Sufficient data are available to document the nature of the Plio-Pleistocene faunal succession in New Mexico and, in many cases, to calibrate the succession with radiometrically dated volcanic flows or ash contained within the fossiliferous deposits. Published geochronological studies of Pliocene and Pleistocene

faunal sequences in adjacent Texas and Arizona also help calibrate corresponding parts of the New Mexico record as indicated in Figures 4 and 5 in this paper.

Among the more important conclusions emerging from the preliminary study of New Mexican Plio-Pleistocene faunas is the confirmation that in the Southwest there was considerable taxonomic diversity with in the genus *Equus* by medial Blancan time. Deposits of Blancan age in this region contain some of the earliest appearances of certain South American immigrants in North America. The ground sloth *Glossotherium* and the glyptodont *Glyptotherium* are recorded at several sites across the Southwest in medial and late Blancan time. Evidence from New Mexico supports the suggestion of Izett (1977) that in the Southwest the earliest appearance of the Asian immigrant, the mammoth (*Mammuthus*), and, by definition (Savage 1951), the beginning of Irvingtonian time, lie close to the time of eruption of the Cerro Toledo pumice (1.4–1.2 m.y. B.P.). An earlier North American appearance of the mammoth seems possible, as mentioned by Kurten and Anderson (1980), but the event is undocumented so far. It is clear from this review that the latest Cenozoic faunal succession of New Mexico is of special interest biologically and geochronologically and that, as such, it deserves more attention than it has received.

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