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Stratigraphy and mammalian biostratigraphy of the Paleocene Nacimiento Formation, southern San Juan Basin

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STRATIGRAPHY AND MAMMALIAN BIOSTRATIGRAPHY OF THE PALEOCENE NACIMIENTO FORMATION, SOUTHERN SAN JUAN BASIN, NEW MEXICO

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Abstract—The Paleocene Nacimiento Formation of the San Juan Basin is as much as 525 m thick and consists of nonmarine fluvial and lacustrine strata deposited in the Laramide San Juan Basin. South of Kutz Canyon, in the southern San Juan Basin, we divide the Nacimiento Formation into (in ascending order) the Arroyo Chijuillita, Ojo Encino and Escavada Members. The Arroyo Chijuillita Member is as much as 134 m thick and consists mostly of drab gray, olive and yellow bentonitic mudstones, white trough-crossbedded sandstone and minor beds of lignite. It conformably overlies, grades into and interfingers with the underlying Paleocene Ojo Alamo Sandstone. The base of the Ojo Encino Member is a resistant, trough-crossbedded sandstone complex here named the Penistaja Bed. The Penistaja Bed is as much as 60 m thick and is overlain by as much as 122 m of Ojo Encino Member strata—mostly variegated red, green and black bentonitic mudstones and trough-crossbedded sandstones. Thin (up to 50 cm) beds of silcrete and thicker beds of trough-crossbedded sandstone characterize the overlying Escavada Member, which is as much as 88 m thick. The Cuba Mesa Member of the San Jose Formation unconformably overlies the Escavada Member of the Nacimiento Formation. Locally, this unconformity is a disconformity, but across the southern San Juan Basin it is slightly angular. The three members of the Nacimiento Formation can be correlated on a lithologic basis across the southern San Juan Basin in surface measured sections and in the subsurface by geophysical well logs. These correlations also demonstrate that the two fossil mammal zones that yield Puercan faunas, the *Ectoconus* and *Taeniolabis* zones, are discrete, superposed assemblage zones. Fossiliferous zones that yield Puercan and Torrejonian faunas are separated by a 45 m "barren" interval. The *Deltatherium* and *Pantolambda* zones of the Torrejonian are largely successive but overlap to some extent. Recently defined biochronologic zonation of the Puercan and Torrejonian land mammal "ages" (Pu0–Pu3, To1–To3) are based on the first appearance of key taxa and are only loosely based on biostratigraphic zonation. Biostratigraphy of the Nacimiento Formation and correlation of Torrejonian faunas of western North America suggest that *Tetraclaenodon* should not be used to define the base of To2. Fossil mammals and magnetostratigraphy document that most of the Nacimiento Formation is of early Paleocene age (chrons 29–27, Danian), although its uppermost strata may be of early late Paleocene age (chron 26, early Thanetian). The Paleocene mammals of the Nacimiento Formation document a significant diversification of paleoplacentals during the early Paleocene and continue to provide a standard by which the early Cenozoic diversification of the Eutheria is calibrated and interpreted.

INTRODUCTION

The Paleocene Nacimiento Formation (Fig. 1) was deposited in the San Juan Basin, one of several broken-foreland basins that formed in western North America during the Laramide orogeny (Chapin and Cather, 1981; Smith, 1988). The Nacimiento Formation is famous for its early Paleocene vertebrate fossils. However, although much work has been devoted to collecting and describing these fossils, the detailed stratigraphy of the Nacimiento Formation, has received little attention. Knowledge of the stratigraphy of the Nacimiento Formation is important not only for determining the distribution, and consequently, the relative and absolute ages of the vertebrate fossils in these early Paleocene strata, but also in determining the character of various lithofacies and their distribution and age relationships. Here, we define three members of the Nacimiento Formation and document their stratigraphic correlation in the southern San Juan Basin. We also review the mammalian biostratigraphy of the Nacimiento Formation in light of this correlation. In this article, AMNH = American Museum of Natural History and NMMNH = New Mexico Museum of Natural History.

PREVIOUS STUDIES

Cope (1875, p. 1008–1017) named the "Puerco Marls" (Fig. 2) for the lower Tertiary rocks exposed along the southern and eastern edges of Mesa de Cuba, southwest of the village of Nacimiento (now the town of Cuba). Cope's Puerco Marls, named for the Rio Puerco, which runs near the type area, were defined as the "variegated marls" which overlay the "Laramie" (Fruitland and Kirtland Formations) and were overlain with supposed conformity by the "Wahsatch" (San Jose Formation).

Cope never collected vertebrate fossils from the Puerco Marls. However, David Baldwin, a professional fossil collector, later found many fossils in the Puerco Marls in exposures to the west and northwest of Cope's type area (Simpson, 1981). Baldwin sent most of these fossils to Cope, who soon realized that the fossil mammals from the Puerco are older than previously known Eocene mammals. Furthermore, Cope later suspected, probably based on information supplied by Baldwin, that two distinct faunas were present in his collections (Cope, 1888), although he continued to refer to a single fauna of the "Puerco Eocene" throughout his life (see Simpson, 1981).

Puerco and Torrejon Formations

Much of the confusion of early workers concerning the original definition of the Puerco Marls and their relation to the Puerco and Torrejon Formations of Matthew (1897) stemmed from the discovery of discrete fossil zones in the Nacimiento Formation. The AMNH sent two expeditions to the San Juan Basin under the direction of Jacob Wortman to collect fossils from earliest Tertiary strata. The first expedition of 1892 revisited many of the principal collecting localities of Baldwin, guided by Baldwin's partner, Thomas Rafferty of Farmington (Sinclair and Granger, 1914). The second expedition of 1896 found more collecting areas, especially to the east near the head of Torreon Wash. Wortman was able to determine that there were indeed two main fossiliferous zones in the Puerco Marls, each producing a very distinct fauna. As quoted by Earle and Osborn (1895, p. 1):

> the thickness of the beds is roughly estimated at 800 to 1000 feet, and as far as can be observed they lie conformably upon the Laramie. At no place examined by us can fossils be said to be abundant, but on the contrary most of the exposures are entirely barren. For convenience they are divided into Upper and Lower Beds, but this scarcely gives an adequate idea of the occurrence of the fossils, for the reason that it is only the extreme upper and lower strata that are productive; the great intermediate part we found to be singularly barren.

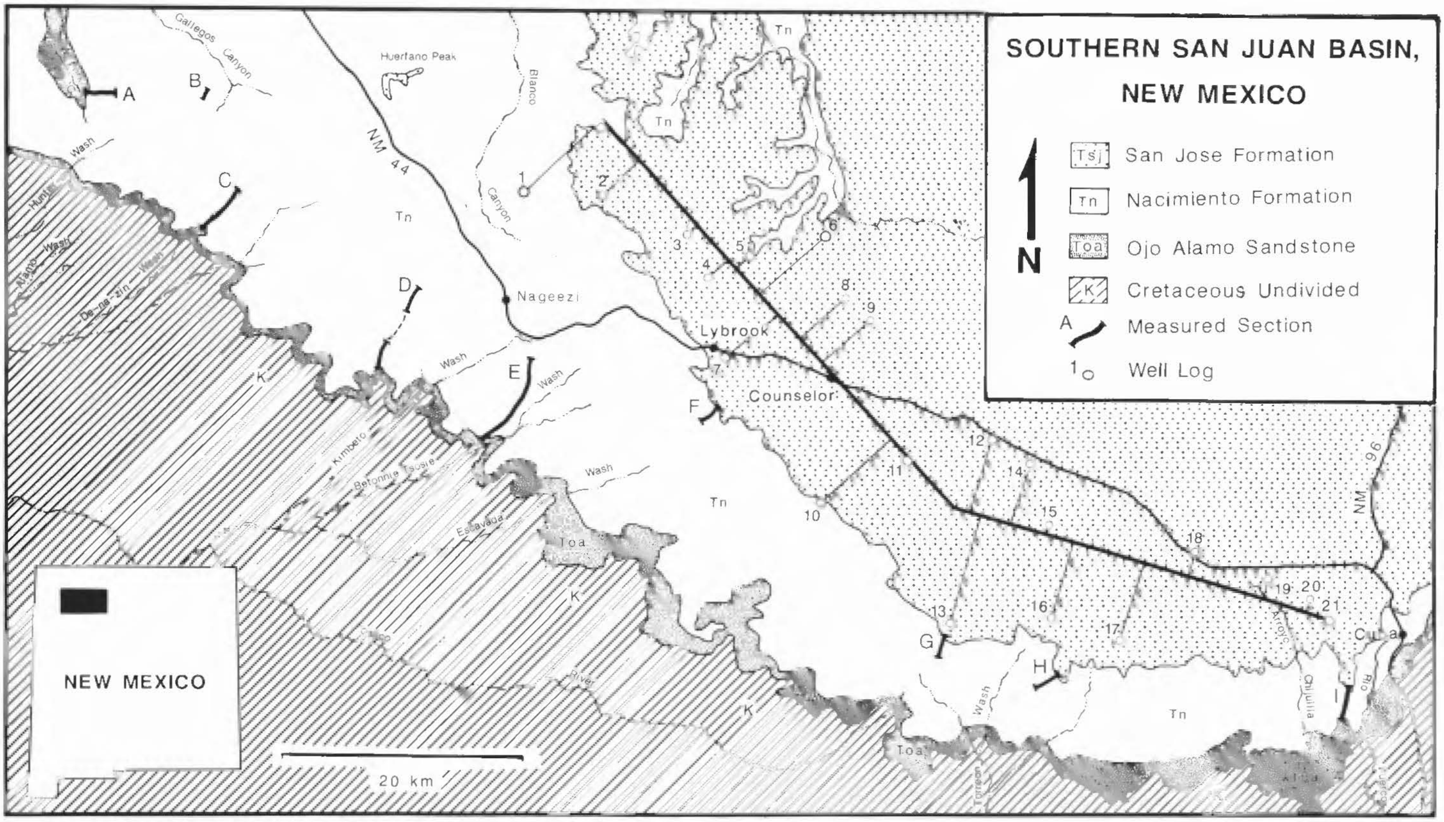
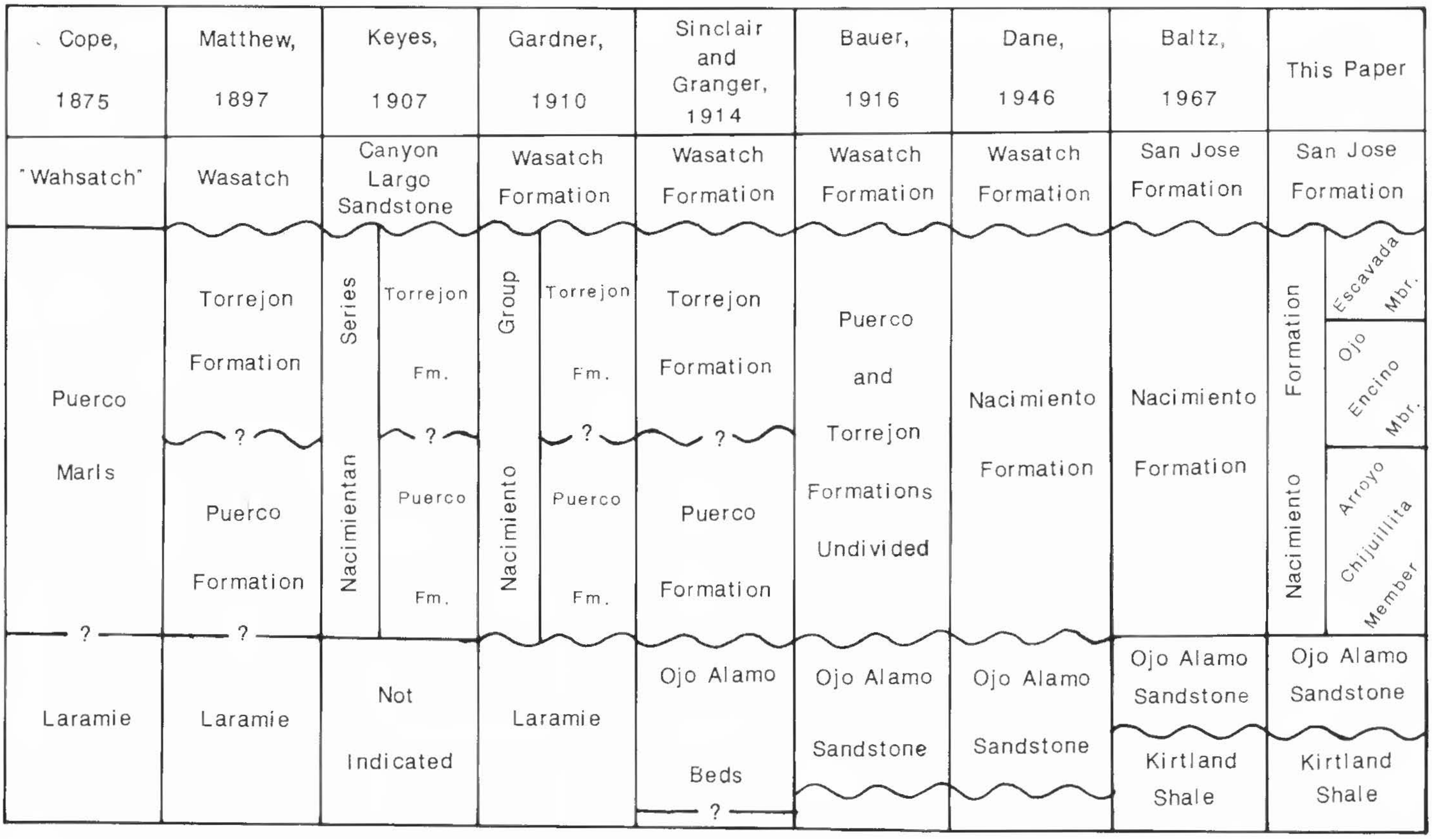


FIGURE 1. Geologic map of the southern San Juan Basin, showing localities of measured sections, cross section and well logs. Geologic map is modified from Fassett and Hinds (1971) and Smith and Lucas (1991).



Cope, 1875	Matthew, 1897	Keyes, 1907	Gardner, 1910	Sinclair and Granger, 1914	Bauer, 1916	Dane, 1946	Baltz, 1967	This Paper
"Wahsatch"	Wasatch	Canyon Largo Sandstone	Wasatch Formation	Wasatch Formation	Wasatch Formation	Wasatch Formation	San Jose Formation	San Jose Formation
Puerco Marls	Torrejon Formation	Nacimientan Series: Torrejon Fm.	Nacimiento Group: Torrejon Fm.	Torrejon Formation	Puerco and Torrejon Formations Undivided	Nacimiento Formation	Nacimiento Formation	Nacimiento Formation: Escavada Mbr. Ojo Encino Mbr.
?	? Puerco Formation	? Puerco Fm.	? Puerco Fm.	? Puerco Formation				Arroyo Chijuillita Member
? Laramie	? Laramie	Not Indicated	Laramie	Ojo Alamo Beds ?	Ojo Alamo Sandstone	Ojo Alamo Sandstone	Ojo Alamo Sandstone	Ojo Alamo Sandstone
							Kirtland Shale	Kirtland Shale

FIGURE 2. History of nomenclature of Nacimiento Formation and adjacent units.

Matthew (1897) revised the "Puerco Fauna" and restricted the term Puerco Formation to those beds which contained the lower fossiliferous strata. He created a new name, the Torrejon Formation, to encompass the upper fossiliferous strata. Matthew never visited the San Juan Basin, but relied on field observations made by Wortman and other workers. Matthew did not designate a type section for the Torrejon Formation, nor did he define precisely the contact between the Puerco and Torrejon Formations. He justified the naming of a new formation and changing the definition of the Puerco Formation as follows (Matthew, 1897, p. 260):

> . . . it was possible to demonstrate that the upper and lower beds contained two absolutely distinct faunas. They have not a species in common, and in no case does a genus pass through without serious modifications of at least subgeneric value . . . The two faunas are as different as in any two successive Eocene formations. It becomes necessary to adopt a new name to designate one of these two . . .

Matthew's definition of the Puerco and Torrejon Formations implied the existence of a hiatus or unconformity between the two units because of the great difference in the Puercan and Torrejonian mammal faunas. Many later workers, including Gardner (1910), Sinclair and Granger (1914), Bauer (1916), Reeside (1924) and others, searched in vain for such an unconformity. In fact, a hiatus in deposition is not required to explain the abrupt differences between the mammal faunas contained in the two fossiliferous intervals because, as observed by Wortman (quoted above), the fossiliferous zones that yield the Puercan and Torrejonian mammal faunas are separated by a thick interval of "barren" strata.

Keyes (1906, 1907) introduced the term Nacimientan Series to include the "Torrejon sands" and the "Puerco marls." From Keyes' statement (1907, p. 224), "in a general way the Nacimientan series covers the better known subdivision of the Puerco beds of Cope, but it includes a considerably greater section," it is not clear what strata he intended to include in his Nacimientan Series.

Gardner (1910), after studying the geology of the southeastern San Juan Basin, introduced the term Nacimiento Group to include the Puerco and Torrejon Formations, but he made no reference to Keyes (1906, 1907). Gardner commented on the difficulty in mapping the Puerco and Torrejon Formations and used the term Nacimiento Group to facilitate the mapping of these two units, as they could not be separated on lithologic criteria.

Sinclair and Granger (1914) undertook the most comprehensive study of the stratigraphy of the Nacimiento Formation to date. Their goal was to establish the precise stratigraphic relationships of the fossiliferous beds of the "Puerco and Torrejon formations." They published two relatively detailed stratigraphic sections in Barrel Spring Arroyo (now De-Na-Zin Wash) and Kimbeto Wash and relied on previously measured sections published by Gardner (1910) for Torreon Wash and Mesa de Cuba. Though Sinclair and Granger (1914, p. 304) stated that "facial changes in the strata composing the Puerco Formation occur so rapidly that any detailed discussion of particular sections would be quite unprofitable," they nevertheless indicated several correlations between important collecting areas based solely on lithologic criteria (Fig. 3).

Sinclair and Granger (1914) retained the use of the Puerco and Torrejon Formations, though they noted (p. 311) "there is so little difference between these formations that in the absence of fossils it is, at present, impossible to tell them apart." They placed the base of the Torrejon Formation at the lowest occurrence of a relatively common, diagnostic Torrejonian mammal, *Periptychus rhabdodon* (= *P. carinidens*).

Sinclair and Granger were not able to correlate between all of their fossil localities. They suggested that the thick sandstones capping the exposures at Barrel Spring Arroyo (De-Na-Zin Wash: Figs. 3 and 5) were "Wasatch" and this "heavy yellow sandstone" had perhaps scoured out the upper fossil horizons exposed to the east. They also argued strongly for an erosional unconformity separating the Puerco Formation from the underlying top of the Ojo Alamo Sandstone, which they considered to be of Late Cretaceous age based on a hadrosaur centrum found loose on an Ojo Alamo Sandstone outcrop at Barrel Spring (Fassett et al., 1987).

Many later workers, including Bauer (1916) and Reeside (1924), mapped the geology of much of the San Juan Basin. They, however, were not able to map the Puerco and Torrejon Formations as separate units and usually mapped them together as "Puerco and Torrejon Formations undivided." Dane (1946) first abandoned the use of the Puerco and Torrejon Formations, replacing them with Nacimiento Formation. Simpson (1948, 1950, 1959) supported this and argued that the names Puerco and Torrejon should be restricted to their respective faunas.

Many subsequent workers studied the stratigraphy of the Nacimiento Formation and its relationship to under- and overlying units in order to determine the Cretaceous-Tertiary boundary in the sediments deposited in the San Juan Basin, and also to determine the regional tectonic history of the basin and surrounding areas. Baltz et al. (1966) studied the stratigraphic relationships between the Ojo Alamo Sandstone and overlying Nacimiento Formation. Their study indicated that a substantial unconformity separates the upper conglomerate of Bauer's Ojo Alamo Sandstone from underlying Upper Cretaceous units, and convincingly showed that there is an interfingering relationship between the top of the Ojo Alamo Sandstone and the basal Nacimiento Formation in Barrel Spring Arroyo (De-Na-Zin Wash). This and palynological data strongly suggested that the Ojo Alamo Sandstone (sensu Baltz et al., 1966) is Paleocene in age.

Additional work by Baltz (1967), Fassett and Hinds (1971), Stone et al. (1983), Smith (1988) and Smith and Lucas (1991) made extensive use of well-log data to decipher the stratigraphy of Upper Cretaceous and Tertiary rocks of the San Juan Basin. These and other studies indicated that the Nacimiento Formation interfingers with the Animas Formation to the north, and is separated from the San Jose Formation by an angular unconformity along the southeastern edge of the San Juan Basin. This suggests that the eastern edge of the San Juan Basin had formed by late Paleocene time.

Magnetostratigraphy

Taylor (1977, 1981, 1984), Tomida (1981), Butler et al. (1977), Lindsay et al. (1981) and Butler and Lindsay (1985) established a magnetic-polarity zonation for the Nacimiento Formation and underlying units. They showed that correlation between exposures of the Nacimiento Formation using their magnetic-polarity zonation was possible. Their original correlation of this magnetic-polarity zonation with the magnetic-polarity time scale was later shown to be incorrect (Lucas and Schoch, 1982; Butler, 1985, see discussion below). However, the revised magnetic-polarity zonation for the Nacimiento Formation is useful for correlation between localities and for determining absolute ages for Nacimiento Formation strata.

Mammalian biostratigraphy

Most studies of the Nacimiento Formation focused on its fossil mammal faunas and refined zonation of the unit based on stratigraphic ranges of various taxa. Sinclair and Granger (1914) named two narrow zones of the "Puerco Formation" based on the lower fossiliferous (Puercan) interval in De-Na-Zin Wash (Fig. 3). These two zones were first noted by Wortman (quoted in Osborn and Earle, 1895, p. 2):

> The lower fossil-bearing strata occur in two layers, the lowermost of which lies within 10 or 15 feet of the base of the formation. This is succeeded after an interval of about 30 feet by a second stratum in which fossils are found, and this appeared to be by far the richer of the two. Both of the strata are of red clay, and at no place did we find them more than a few feet in thickness.

Sinclair and Granger (1914) named the lower zone the *Ectoconus* zone, and the upper fossiliferous strata the *Polymastodon* zone (*Polymastodon* is the junior synonym of *Taeniolabis*). The two zones were distinguished primarily by the presence of *Taeniolabis* in the upper fossiliferous zone, although *Ectoconus* was known to occur at both levels.

Sinclair and Granger (1914) also distinguished the *Deltatherium* and *Pantolambda* zones (Figs. 3 and 5) based on the stratigraphic ranges of these two Torrejonian taxa in strata exposed at the head of Torreon Wash (see Tsentas, 1981). They noted that these two fossiliferous zones

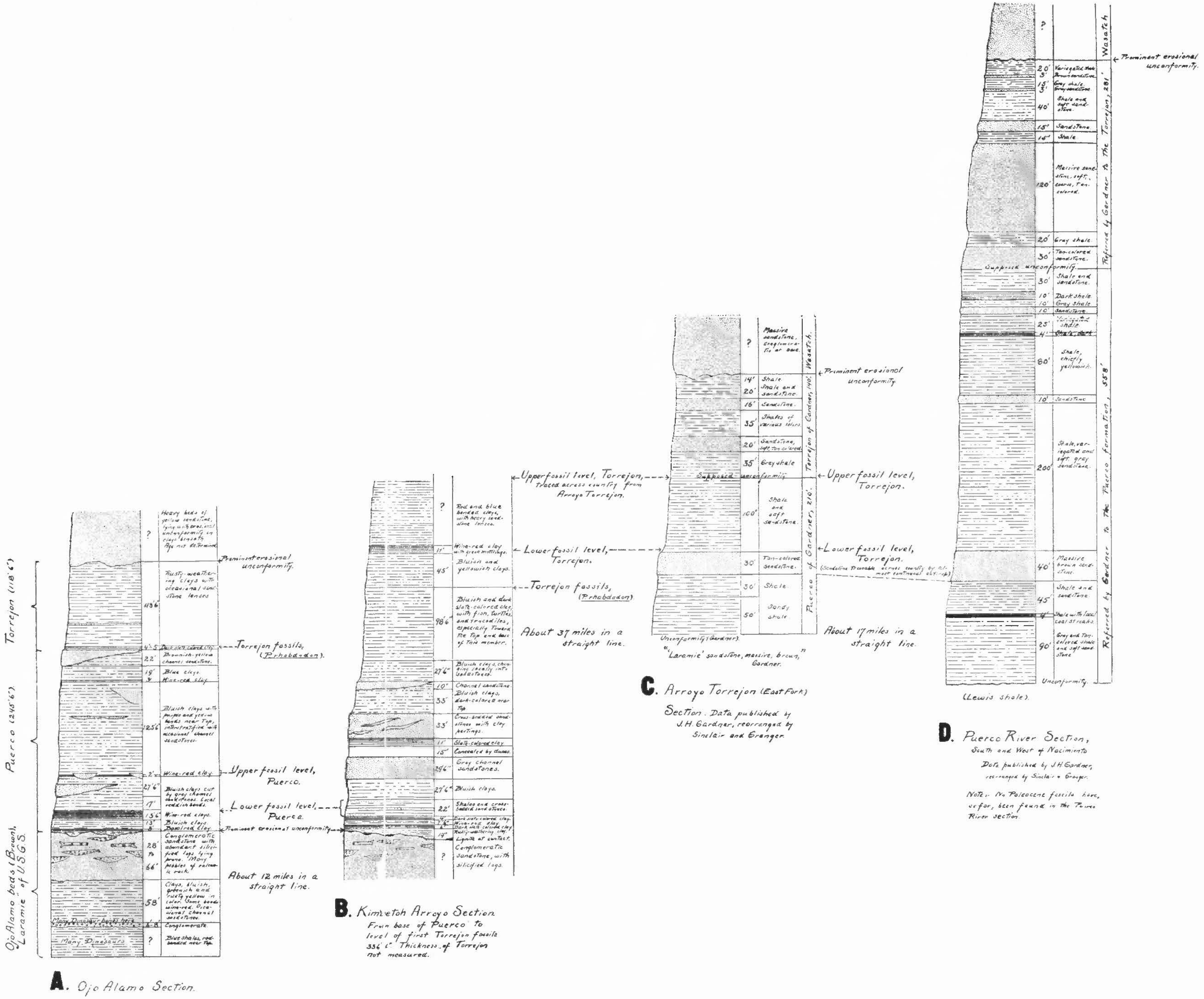


FIGURE 3. Measured sections of the Nacimiento Formation from Sinclair and Granger (1914).

were separated by 30 m of unproductive strata. They then correlated these zones with rocks exposed at the head of Kimbeto Wash, having traced both fossil zones along the almost continuous outcrop between the two localities.

Osborn (1929) later proposed the *Deltatherium* and *Pantolambda* zones, following the "life zone" concept pioneered by Osborn and Matthew (1909; see Tedford, 1970). Osborn regarded these subdivisions of the Torrejon Formation as reflecting temporal differences between the two faunal zones described by Sinclair and Granger (1914). Osborn characterized the *Deltatherium* zone by the presence of *Deltatherium fundaminis, Mioclaenus turgidus* and *Haploconus angustus,* and characterized the *Pantolambda* zone by the presence of *Pantolambda cavirictum* and *Arctocyon ferox* (=*Claenodon ferox*). Wilson (1956), however, showed that *Mioclaenus turgidus* is present in both the *Deltatherium* and *Pantolambda* zones. He argued that only *Deltatherium, Triisodon* and *Haploconus* are restricted to the lower zone and *Pantolambda* and *Arctocyon* are restricted to the upper zone. According to Wilson, other differences observed between the two zones are related to the relative abundance of certain taxa such as *Promioclaenus lemuroides,* which is common in the *Pantolambda* zone but rare in the *Deltatherium* zone.

Several workers, including Granger (1917), Matthew (1937), Wilson (1956) and Russell (1967), argued that the differences between the two zones reflect different facies or collecting bias rather than substantial age differences (see Tsentas, 1981). Wilson (1956), for example, suggested that the "*Deltatherium* zone" fauna represented a forest border environment and the "*Pantolambda* zone" fauna represented a more riparian setting.

Similar arguments have been raised regarding the significance of the Puercan *Ectoconus* and *Taeniolabis* zones. The two zones are present in superpositional relationships in only one area, De-Na-Zin Wash. In the three other areas that yield Puercan mammals, only one fossil zone is present. In Gallegos Canyon, the single zone yields *Taeniolabis* (Fig. 5; Lucas, 1984a), whereas in Kimbeto and Betonnie Tsosie Washes, Puercan faunas lack *Taeniolabis*. Van Valen (1978), Lindsay et al. (1981), Lucas (1984a, b) and Archibald et al. (1987) argued that the slight faunal differences between the two zones may be due to slight facies and corresponding environmental and ecological differences between the various "zones" as well as to collecting bias.

As discussed by Tsentas (1981), further collecting of fossil specimens, discovery of additional fossil localities, and studies of facies associations and stratigraphic ranges of various taxa may allow one to determine whether the range restrictions of the taxa within the Nacimiento Formation are due to temporal or environmental controls. In addition, correlation of various strata of the Nacimiento Formation that contain fossil mammals must be made on lithologic criteria as well as faunal content.

Despite arguments questioning the temporal significance of the fossil mammal zones of the Nacimiento Formation, further subdivision of the fossiliferous strata yielding the Torrejonian fossil mammals was proposed by Tomida (1981), followed by Taylor (1984), based on range zones determined for certain taxa in Kutz Canyon, and also relying on correlations between widely spaced early Paleocene localities in the San Juan Basin using magnetostratigraphy. Tomida (1981) proposed a three-part subdivision of the Torrejonian strata of the Nacimiento Formation, retaining the *Deltatherium* and *Pantolambda* zones of Osborn (1929), and creating a third, older division, the *Periptychus-Loxolophus* zone, correlated with the sediments yielding the Dragon local fauna, on the Wasatch Plateau of central Utah (Gazin, 1941; Tomida and Butler, 1980; Robison, 1984). This correlation was based primarily on magnetostratigraphy (Tomida and Butler, 1980; Tomida, 1981). The Dragon local fauna formed the basis for the Dragonian land mammal "age" defined by Wood et al. (1941). The Dragonian land mammal "age" is now considered to be early Torrejonian by most workers (Schoch and Lucas, 1981a, b; Tomida, 1981; Archibald et al., 1987; Sloan, 1987).

Taylor's (1984) zonation of the Torrejonian closely followed that of Tomida. However, discoveries of *Pantolambda cavirictum* in Kutz Canyon (Lucas and O'Neill, 1981) and *P. cavirictum* and *Arctocyon ferox* at localities at and near the head of Kimbeto Wash (Taylor, 1984; Archibald et al., 1987), which also yielded specimens of *Deltatherium*, forced Taylor (1984) to revise the *Deltatherium* and *Pantolambda* zones as defined by Osborn (1929). Taylor (1984) renamed the *Deltatherium* zone (sensu Osborn, 1929) the *Deltatherium-Tetraclaenodon* chronozone. The "D-T chronozone" includes the stratigraphic range of *Deltatherium* and the lower part of the entire stratigraphic range of *Tetraclaenodon*. Taylor renamed the *Pantolambda* zone (sensu Osborn, 1929) the *Pantolambda bathmodon–Mixodectes pungens* chronozone, which included the range zones of both taxa. The "D-T" and "P-M" chronozones thus retained the same temporal dimensions as the *Deltatherium* and *Pantolambda* zones originally outlined by Osborn (1929).

Sloan (1987) also divided the Torrejonian land mammal "age" into (from oldest to youngest) the *Anisonchus dracus, Deltatherium-Deuterogonodon,* and *Pantolambda* zones. Sloan's *Anisonchus dracus* zone corresponds to the *Periptychus-Loxolophus* zone proposed by Tomida (1981). The upper two of Sloan's (1987) subdivisions of the Torrejonian are based on the ranges of *Deltatherium* and *Pantolambda,* respectively. Sloan (1987) showed these zones as non-overlapping, sequential time intervals. But, as noted above and demonstrated by Lucas and O'Neill (1981), Taylor (1984) and Archibald et al. (1987), the range zones of these taxa overlap.

Archibald et al. (1987) also proposed a zonation of the Puercan and Torrejonian land mammal "ages." However their subdivisions of the Torrejonian are biochrons and are only loosely based on biostratigraphic zonation. The Puercan and Torrejonian land mammal "ages" as defined by Archibald et al. (1987) are discussed further below with regard to the correlation of continental Paleocene strata.

Lithologic correlation

Work by Taylor (1977), Tsentas (1981), Tsentas et al. (1981) and Lucas et al. (1981) revealed the feasibility of lithologic correlation between exposures of the Nacimiento Formation, at least over relatively short distances. These studies showed that particular lithologies of the Nacimiento Formation could be precisely correlated over the approximately 5 km distance separating the west flank from the east flank of Torreon Wash. Taylor (1977) demonstrated that this lithologic correlation agreed with a correlation made by magnetic-polarity zonation. Work by Rains (1981) on silcretes, a very distinctive lithology found within the Nacimiento Formation, also showed the feasibility of lithologic correlation between widely separated outcrops. Rains found that many relatively thin silcrete beds are of wide lateral extent. For example, he was able to correlate an individual silcrete bed between De-Na-Zin Wash and Kimbeto Wash, a distance of about 14 km. The ability to correlate on distinctive marker beds over considerable distances in the Nacimiento Formation suggests that, at least in some instances, the degree of lateral variation in nonmarine, fluvial deposits (e.g., Fastovsky, 1990) has been overstated.

Considerable controversy surrounds lithologic correlations between the type section of the Nacimiento Formation of Mesa de Cuba and exposures of the Nacimiento Formation of Torreon Wash, largely because of the questions surrounding the relationship of the Puerco Marls of Cope (1875) and the Puerco and Torrejon Formations of Matthew (1937; see Simpson, 1959). Gardner (1910) correlated a 40-ft-thick sandstone (fourth unit above the base of the Puerco Formation) with a sandstone (third unit above the base of the Puerco Formation) of his Arroyo Torrejon section. He remarked that this sandstone (p. 724) "is a very persistent horizon marker" and noted (p. 724) "this member was traced continuously from the Nacimiento Mountains to beyond Arroyo Torrejon."

Sinclair and Granger (1914) published measured sections from Torreon Wash and Cuba Mesa (Fig. 3) based on the measurements of Gardner (1910). They relied on the correlation of Gardner noted above to argue that Gardner misplaced the contact between the Puerco and Torrejon Formations. Sinclair and Granger (1914) also demonstrated that much of Cope's type Puerco is, in fact, correlated with the strata that produce Torrejonian age mammals in Torreon Wash (Fig. 3).

Renick (1931), Dane (1932) and Simpson (1959) argued that the "persistent horizon marker" of Gardner in his section from Mesa de Cuba is actually the Ojo Alamo Sandstone (Fig. 4; see Baltz, 1967).

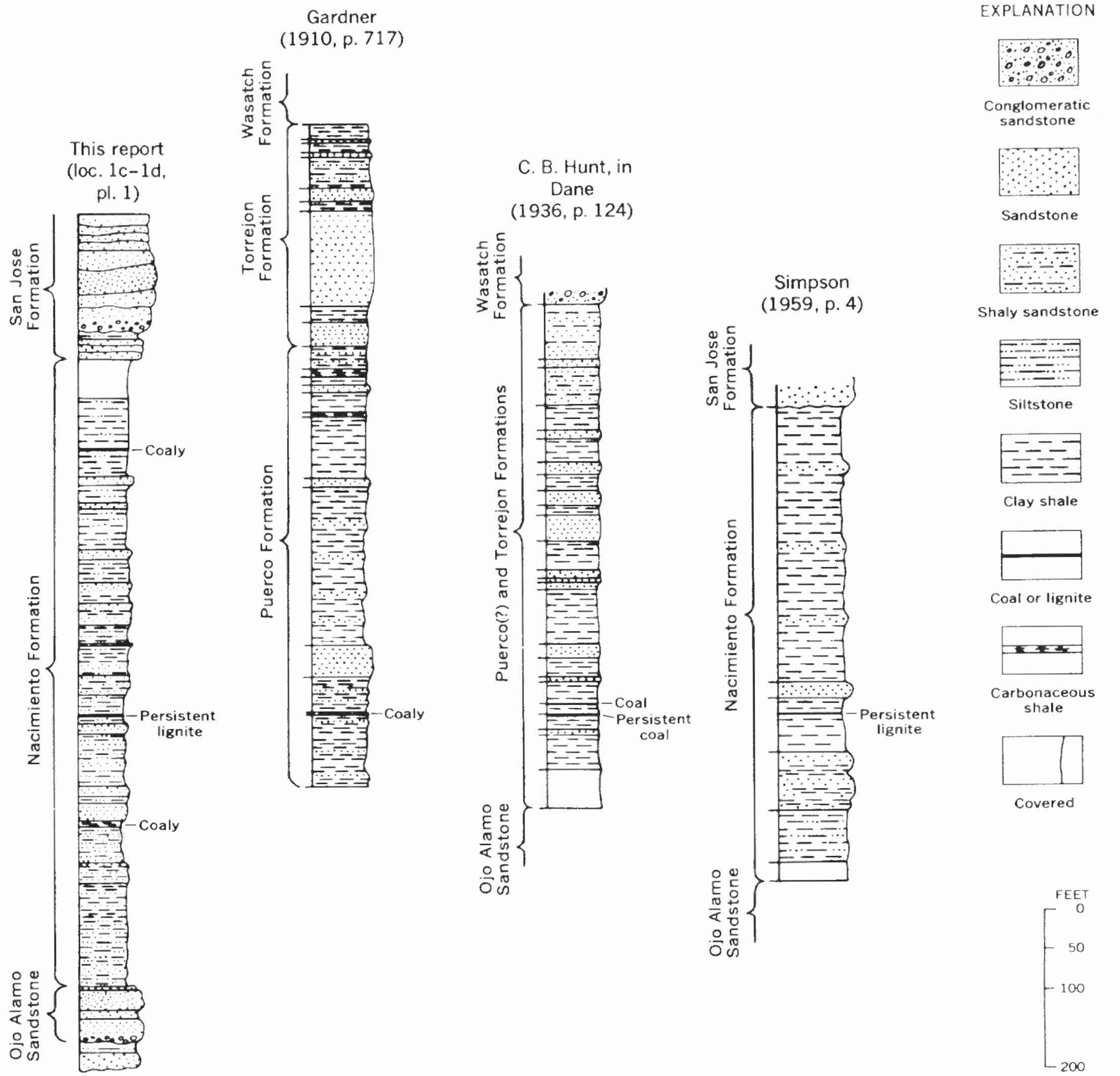


FIGURE 4. Type section of the Nacimiento Formation as measured by Gardner (1910), Hunt in Dane (1936), Simpson (1959) and Baltz (1967) from Baltz (1967).

Simpson asserted that the correlation of this bed between Torreon Wash and Mesa de Cuba was in error. However, Baltz (1967) convincingly argued that Gardner had not included the Ojo Alamo Sandstone in his measured section, which did not include the base of the Nacimiento Formation, and that his Torrejon Formation actually consisted of the basal San Jose Formation (Fig. 4).

We agree with Baltz's interpretation of Gardner's Puerco River (Mesa de Cuba) section (Fig. 4). This interpretation indicates that Gardner's "persistent horizon marker" is our Penistaja Bed (defined below), which does indeed correlate with a sandstone in our west flank of Torreon Wash section (Fig. 5). In addition, the Penistaja Bed correlates with a sandstone (the "intermittent but frequent sandstone lenses to 20′," located 200′ above the base of the Nacimiento Formation) in Simpson's (1959) measured section of the type Nacimiento Formation.

STRATIGRAPHY

Here, we divide the Nacimiento Formation in the southern San Juan Basin into three formal members and a bed. These are, in ascending order, Arroyo Chijuillita Member, Ojo Encino Member (including the Penistaja Bed) and Escavada Member. These members can be identified by their distinctive lithologies in surface sections (Figs. 5–8), on subsurface well logs and are mappable lithologic units in the southern San Juan Basin as far north as Kutz Canyon (T27N, R10W). At Kutz Canyon and north, further work is needed to delineate the internal stratigraphy of the Nacimiento Formation.

Arroyo Chijuillita Member

We coin the name Arroyo Chijuillita Member for the lowest member of the Nacimiento Formation. The name is for Arroyo Chijuillita, an intermittent tributary of the Rio Puerco just west of Mesa de Cuba in T21N, R2W, Sandoval County. The type section of the Arroyo Chijuillita Member is part of the type section (units 2–26) of the Nacimiento Formation at Mesa de Cuba, just east of Arroyo Chijuillita (Fig. 5; Appendix 1).

At its type section, the Arroyo Chijuillita Member is 81.2 m thick, conformably overlies the Ojo Alamo Sandstone and is conformably overlain by the Ojo Encino Member of the Nacimiento Formation. Of the 81.2 m present at the type section, 29.5 m (36%) are sandstone, 21.7 m (27%) are sandy or silty mudstone/muddy sandstone, 28.5 m (35%) are mudstone and 1.5 m (2%) are coal/lignite. The dominance of drab (gray, olive, buff) mudstone and sandy mudstone/muddy sandstone distinguishes the Arroyo Chijuillita Member from the overlying Ojo Encino and Escavada Members of the Nacimiento Formation. Brightly colored (red, green) mudstones do occur in the Arroyo Chijuillita Member, but they are minor.

The Arroyo Chijuillita Member in the southern San Juan Basin (Fig. 7) is 81.2 to 134 m thick. The Ojo Alamo–Arroyo Chijuillita contact is locally gradational or interfingering (Baltz et al., 1966; O'Sullivan et al., 1972). However, the base of the Arroyo Chijuillita Member (and thus, of the Nacimiento Formation) is readily recognized as the base of the first mudstone or sandy mudstone bed above the sandstone of the Ojo Alamo Sandstone. There generally is a good topographic expression of this contact with the ledge- and cuesta-forming Ojo Alamo Sandstone overlain by the less resistant slope-forming Arroyo Chijuillita Member. The top of the Arroyo Chijuillita Member is the disconformable contact of mudstone with sandstone of the overlying Penistaja Bed of the Ojo Encino Member.

The Puercan fauna of the Nacimiento Formation is from the lower part of the Arroyo Chijuillita Member in the west-central San Juan Basin. The oldest Torrejonian mammals in the San Juan Basin also are found in the Arroyo Chijuillita Member. These fossils and magnetic-polarity stratigraphy indicate the Arroyo Chijuillita Member is of early Paleocene (early Danian) age.

Ojo Encino Member

The medial Ojo Encino Member takes its name from Ojo Encino (Spanish for Oak Spring), a spring, and more recently, a Navajo Nation Chapter and boarding school, just west of Torreon Wash (sec. 22, T20N, R5W). The type section of the Ojo Encino Member, and extensive fossiliferous exposures of the unit, are nearby along the west and east flanks of Torreon Wash (Fig. 8).

At its type section (Fig. 5; Appendix 1), the Ojo Encino Member is 106.1 m thick. Mudstone (33.5 m, or 31%, of the section) and fine-grained sandstone/siltstone (38.2 m, or 36%, of the section) are the dominant lithologic types. Sandstone (22.9 m, 22%) and sandy mudstone (11.5 m, 11%) are less common lithologies. Many Ojo Encino Member mudstones are brightly variegated red and green, and are interbedded with white, trough-crossbedded, fine-grained sandstones. These colorful strata typically overlie and underlie black, highly bentonitic mudstones, thus giving the Ojo Encino Member its characteristic black-red-green-white-black color banding.

The Penistaja Bed is a brown, resistant, trough-crossbedded sandstone interval. This sandstone is a prominent ledge- and cuesta-former throughout the southern San Juan Basin. We name this sandstone interval the Penistaja Bed of the Ojo Encino Member. Penistaja is a spring in sec. 14, T20N, R4W near the type section and excellent exposures of the Penistaja Bed. At its type section (Fig. 5), the Penistaja Bed is 6.5 m thick and consists of grayish orange, fine-grained, planar to trough-crossbedded sandstone with silicified wood and cannonball concretions (Figs. 5, 7). The base of the Penistaja Bed is a sharp, scoured contact into underlying mudstone of the Arroyo Chijuillita Member. This contact probably is a disconformity that represents a within-basin change in baselevel, possibly a decrease in the rate of subsidence (cf. Blakey and Gubitosa, 1984) at the onset of Penistaja Bed deposition.

The Ojo Encino Member in the southern San Juan Basin varies in thickness from 90 to 122 m. Its apparently conformably contact with the overlying Escavada Member is at the transition from brightly colored mudrock-dominated strata of the Ojo Encino Member to the drab, sandstone-dominated, silcrete-bearing strata of the Escavada Member. The classic Torrejonian mammal faunas, the *Deltatherium* and *Pantolambda* zones of Sinclair and Granger (1914), are from the Ojo Encino Member. These fossils and magnetostratigraphy (see below) indicate the Ojo Encino Member is of early Paleocene (late Danian age).

Escavada Member

The uppermost member of the Nacimiento Formation is here named the Escavada Member, for Escavada Wash, where the type section and extensive exposures of this member are located. At its type section (Fig. 5; Appendix 1), the Escavada Member is 79.7 m thick. Sandstone is the dominant lithology (46.6 m, or 58% of the section) and much of the rest of the section is mudstone (24.8 m, or 31%, of the section). Siltstone (3.0 m, 4%) and silcrete (5.3 m, 7%) are minor lithologies of the Escavada Member. The silcretes form thin (up to 0.5 m), indurated ledges that are largely responsible for the steep slopes and resistant benches characteristic of weathered slopes in the Escavada Member. Sandstones of the Escavada Member are typically gray and trough crossbedded, and mudstones typically are dark gray and brown, bentonitic, and, in some beds, very carbonaceous. Silcretes are gray or white but weather brown and blocky.

The contact of the Escavada Member above the Ojo Encino Member (Fig. 8) is always placed at the base of the first persistent sandstone or silcrete bed above typically variegated mudstone of the upper part of the Ojo Encino Member. Thick sandstone, conglomerate and coarse-grained beds of brownish conglomeratic sandstone mark the unconformable base of the overlying Cuba Mesa Member of the San Jose Formation above the Escavada Member.

Across the southern San Juan Basin, the Escavada Member ranges in thickness from 19.2 to 88 m, its thickness being controlled largely by the overlying unconformity at the base of the San Jose Formation. No age-diagnostic fossils are known from the Escavada Member, but magnetic-polarity stratigraphy suggests it is of early late Paleocene age (see below).

WELL-LOG CORRELATION

Correlation of well logs with a composite section of the Nacimiento Formation (Fig. 9), and correlation between closely spaced well logs in the southern San Juan Basin (Fig. 10) reveals typical electric-log signatures for the Nacimiento Formation and also demonstrates the efficacy of long-range correlation of certain lithologic units via electric logs.

A prominent medial sandstone within the Nacimiento Formation correlates with the Penistaja Bed, marking the base of the Ojo Encino Member. This bed is particularly evident in logs 13–21 (Fig. 10), although in logs west of this, the contact between the Ojo Encino and Arroyo Chijuillita Members becomes less certain in the subsurface. However, our composite section correlates well with a nearby electric log (Fig. 10, well log no. 7, Appendix 2) and allows the position of the Ojo Encino and Arroyo Chijuillita Members to be placed with considerable confidence in the subsurface. The Escavada Member, although containing a relatively high percentage of sandstone (58% in our Escavada Wash measured section, Appendix 1), shows a nearly flat electric log signature (spontaneous potential and resistivity) in most well logs studied (Fig. 10).

The base of the overlying San Jose Formation is difficult to pick in many of the well logs used in this study, particularly in logs 2–4 and 6–9 (Fig. 10). In the central and eastern San Juan Basin, the basal Cuba Mesa Member of the San Jose Formation produces a well-defined and easily identified sandstone marker, although this basal member pinches out to the north (Smith, 1988; Smith and Lucas, 1991). However, in areas of surface exposure in the southwestern San Juan Basin (T23N, R7W), a basal tongue of the Cuba Mesa Member locally nearly pinches out, resulting in a mudstone-on-mudstone contact between the Nacimiento Formation and the San Jose Formation. This mudstone-on-mudstone contact is reflected in the subsurface electric-log signatures of several nearby well logs (Fig. 10).

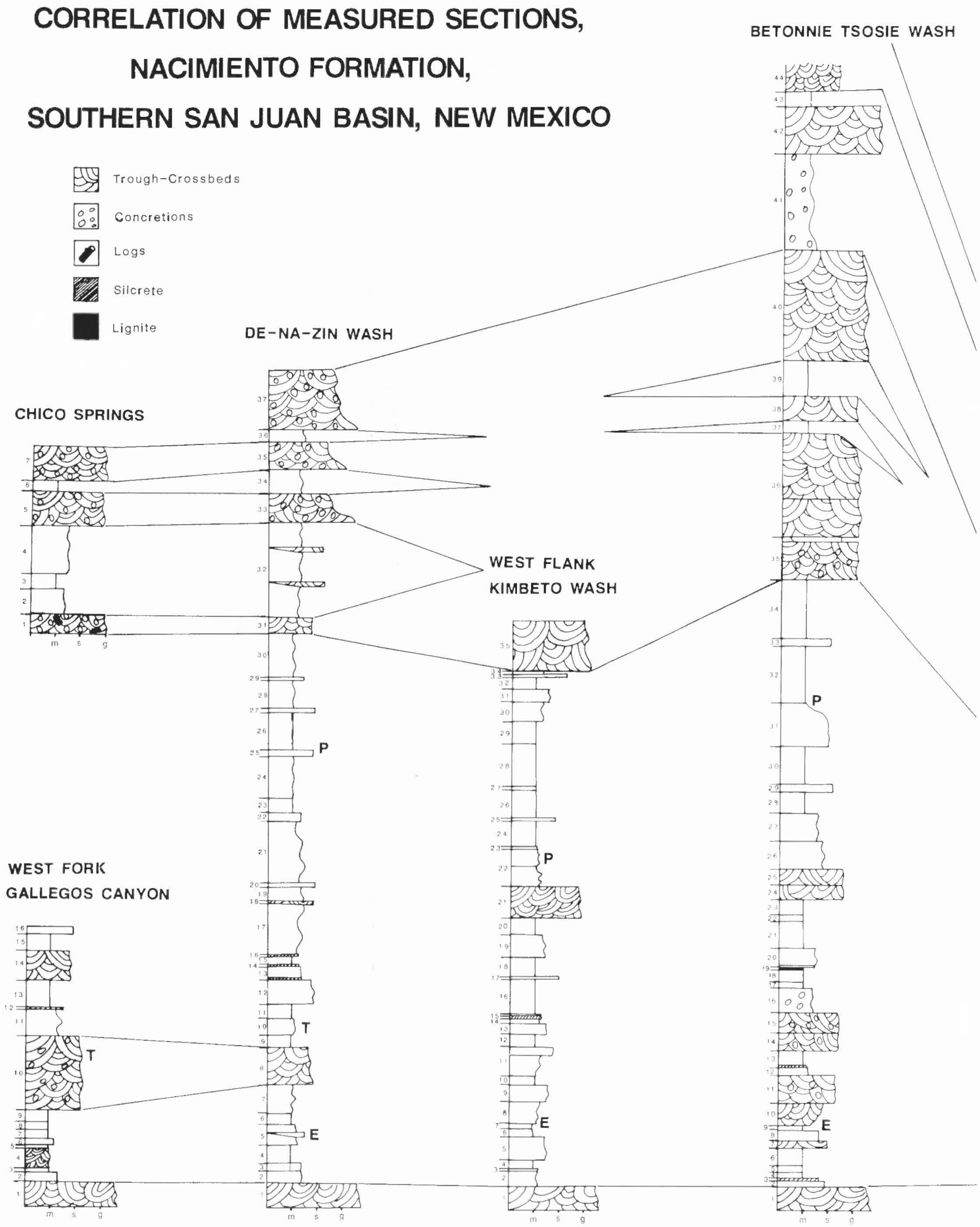
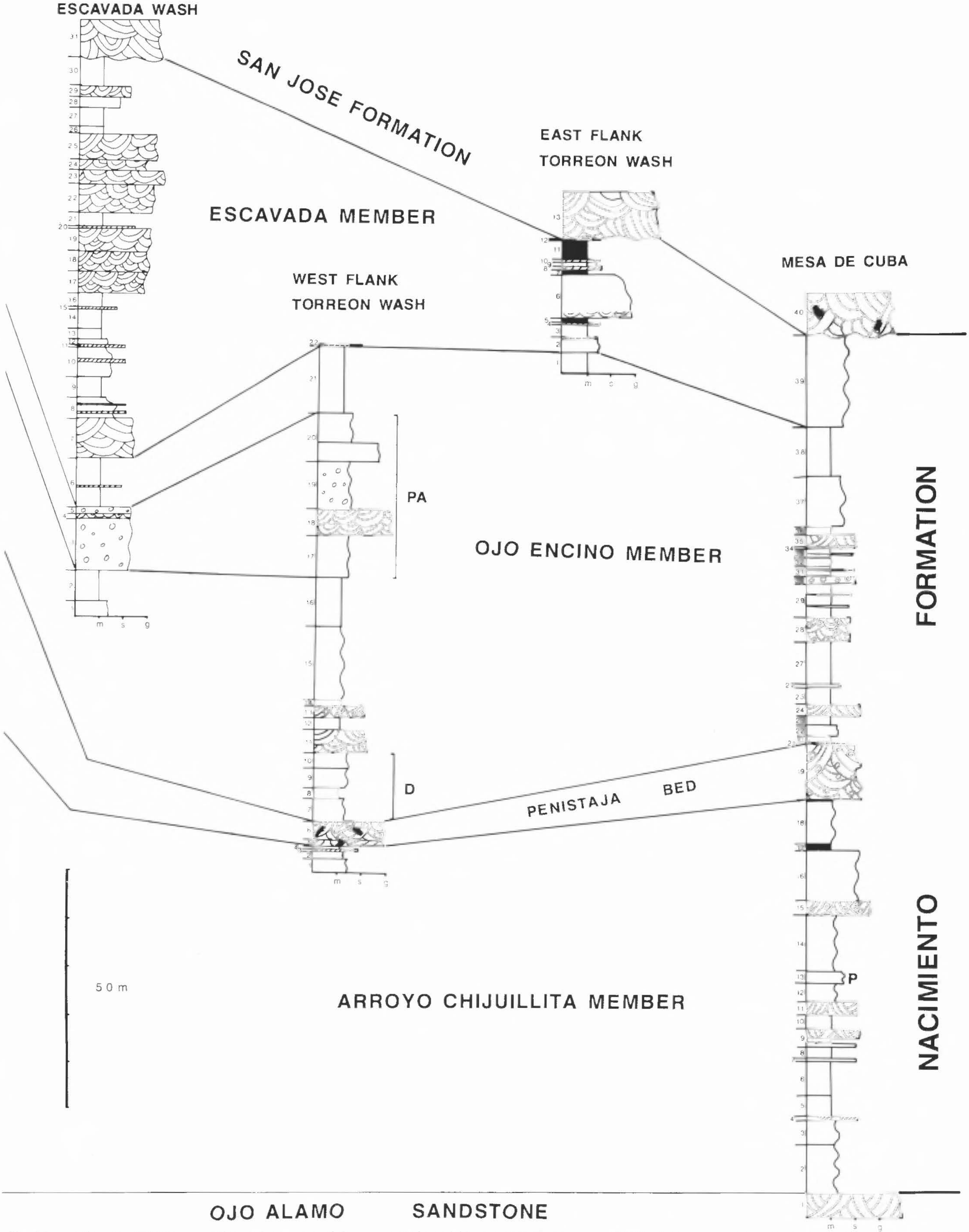


FIGURE 5. Correlation of measured sections of the Nacimiento Formation, San Juan Basin, New Mexico. Abbreviations: E = "*Ectoconus* zone," T = "*Taeniolabis* zone," D = "*Deltatherium* zone," Pa = "*Pantolambda* zone," P = lowest occurrence of *Periptychus carinidens* (all sensu Sinclair and Granger, 1914) based on



Sinclair and Granger (1914), unpublished field notes of Granger (1913) and Sinclair (1913), Simpson (1959), field notes and locality information stored at the New Mexico Museum of Natural History and authors' field observations.

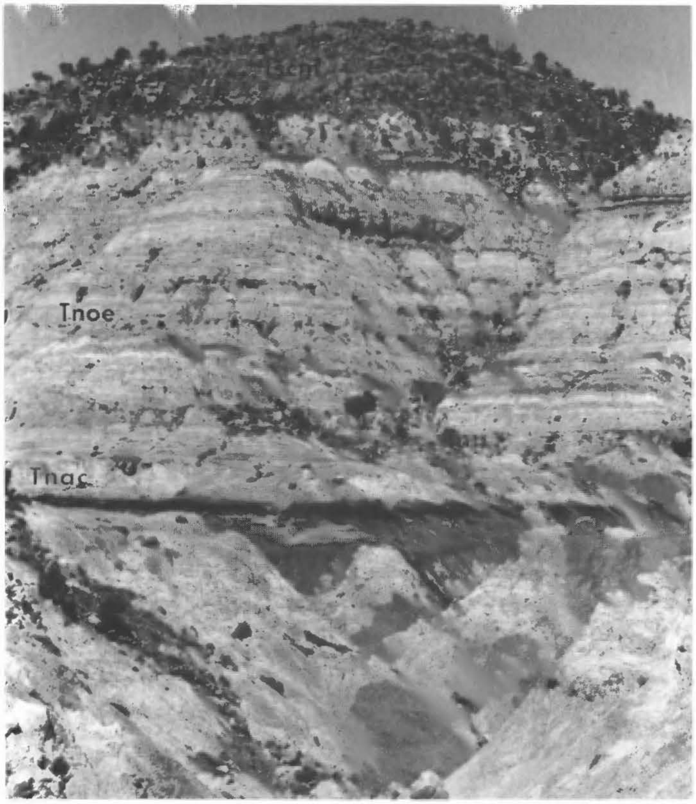


FIGURE 6. Mesa de Cuba and type section of the Nacimiento Formation. Top of Arroyo Chijuillita Member (Tnac, note prominent lignite layer), Penistaja Bed (Tnp), Ojo Encino Member (Tnoe), Escavada Member (Tne) and San Jose Formation, Cuba Mesa Member (Tscm) are labeled.

Correlation between our composite Nacimiento Formation section and log no. 7 (Fig. 9) facilitates subsurface correlation of the San Jose–Nacimiento contact in the southwestern San Juan Basin (Fig. 10). A prominent sandstone in log no. 3 (Fig. 10), above our pick of the San Jose–Nacimiento contact, is probably a tongue of the Cuba Mesa Member that occurs above an interfingering tongue of the mudstone-dominated Regina Member of the San Jose Formation.

Subsurface correlation of the Nacimiento Formation and its three members demonstrates the gradual southeastward thinning of the Nacimiento Formation. Much of this thinning is apparently intraformational, but the Escavada Member is reduced in thickness more than underlying members. This supports our conclusion that at least some of the thinning of this upper member is due to removal by the erosional unconformity at the base of the overlying San Jose Formation.

PALEONTOLOGY

History

Paleocene vertebrate fossils were first discovered in the San Juan Basin by David Baldwin, a professional fossil collector, in 1879 (see Simons, 1963). During 1876–1879, Baldwin had previously collected fossils from the lower Eocene strata of the San Jose Formation. He sent several teeth obtained from the underlying Paleocene beds to O. C. Marsh at Yale University, but these specimens were probably not examined by Marsh until 1894 (Simpson, 1981). Baldwin, disgruntled as a result of his treatment by Marsh, began, in 1879, to send fossils to E. D. Cope, Marsh's bitter rival. The significance of these fossils, the first early Paleocene mammalian fossils ever found, was soon recognized by Cope. Between the years 1881 and 1888, Cope published 41 papers bearing on the "Puerco Eocene" fossils he received from Baldwin (Simpson, 1981; Lucas, 1982).

In following years, expeditions from several institutions made collections from the early Paleocene deposits of the San Juan Basin. A thorough history of early collecting in the San Juan Basin was provided by Simpson (1981). Important collections of early Paleocene fossils from the San Juan Basin are now in the American Museum of Natural History, New York; Museum of Paleontology, University of California, Berkeley; University of Kansas, Lawrence; University of Arizona, Tucson and New Mexico Museum of Natural History, Albuquerque.

Biochronological significance

The absence of dinosaurs readily distinguishes early Paleocene terrestrial faunas from preceding Cretaceous faunas. For the first time, mammals became the most numerous and diverse land vertebrates. The early Paleocene mammal faunas from the Nacimiento Formation (Figs. 11–15) are especially significant because they are the most diverse early Paleocene mammal faunas known, and they are derived from a sequence of rocks that accumulated during approximately 4 million years of the early Paleocene.

The two early Paleocene mammal faunas from the Nacimiento Formation are very different in composition (see Tables 1, 2). These dif-

TABLE 1. Faunal list showing Puercan mammalian taxa from the Nacimiento Formation. List is compiled from a variety of sources including Matthew (1937), Van Valen (1978) and Standhardt (1981).

- Order MULTITUBERCULATA
  - Family EUCOSMODONTIDAE
    - *Eucosmodon americanus* (Cope, 1885c)
  - Family NEOPLAGIAULACIDAE
    - *Mesodma formosa* Marsh, 1989
    - *Mesodma thompsoni* Clemens, 1963
    - *Neoplagiaulax macintyrei* Sloan, 1981
    - *Parectypodus vanvaleni* Sloan, 1981
  - Family PTILODONTIDAE
    - *Kimbetohia campi* (Granger, Gregory, and Colbert in Matthew, 1937)
    - *Ptilodus tsosiensis* Sloan, 1981
  - Family TAENIOLABIDIDAE
    - *Catopsalis foliatus* (Cope 1882a)
    - *Taeniolabis taoensis* (Cope, 1882b)
- Order MARSUPIALIA
  - Family DIDELPHIDAE
    - *Peradectes pusillus* Matthew and Granger, 1921
    - *Peradectes* n. sp. Standhardt, 1980
- Order "PROTEUTHERIA"
  - Family PALAEORYCTIDAE
    - *Cimolestes simpsoni* (Reynolds, 1936)
  - Family LEPTICTIDAE
    - cf. *Leptictis* sp.
    - *Prodiacodon* n. sp. Standhardt, 1980
- Order LIPOTYPHLA
  - Family ADAPISORIIDAE
    - *Mckennatherium* n. sp. Standhardt, 1980
- Order CARNIVORA
  - Family MIACIDAE
    - cf. *Ictidopappus* Simpson, 1935
- Order TAENIODONTA
  - Family CONORYCTIDAE
    - *Onychodectes tisonensis* Osborn and Earle, 1895
  - Family STYLINODONTIDAE
    - *Wortmania otariidens* (Cope, 1885b)
    - n. gen. et sp. Lucas and Williamson, 1992
- Order "CONDYLARTHRA"
  - Family ARCTOCYONIDAE
    - *Oxyclaenus cuspidatus* (Cope, 1884)
    - *Oxyclaenus simplex* (Cope, 1884)
    - *Loxolophus hyattianus* (Cope, 1885a)
    - *Loxolophus kimbetovius* (Matthew, 1937)
    - *Loxolophus pentacus* (Cope, 1888)
    - *Loxolophus priscus* (Cope, 1888)
    - *Desmatoclaenus protogonioides* (Cope, 1882e)
    - *Desmatoclaenus diannae* Van Valen, 1978
    - *Mimotricentes mirielae* Van Valen, 1978
    - *Platymastus palantir* Van Valen, 1978
    - *Eoconodon gaudrianus* (Cope, 1888)
    - *Eoconodon coryphaeus* (Cope, 1882c)
  - Family PERIPTYCHIDAE
    - *Ectoconus ditrigonus* Cope, 1882
    - *Hemithlaeus kowalevskianus* Cope,1882b
    - *Gillisonchus gillianus* (Cope, 1882a)
    - *Conacodon entoconus* (Cope, 1882d)
    - *Conacodon kohlbergeri* Archibald, Schoch and Rigby, 1983
    - *Periptychus coarctatus* (Cope, 1883)
    - *Escatepos campi* Reynolds, 1936
    - *Oxyacodon agapetillus* (Cope, 1884)
    - *Oxyacodon apiculatus* Osborn and Earle, 1895
    - *Oxyacodon priscilla* Matthew, 1937
    - *Oxyacodon? cophater* (Cope, 1884)
  - Family MIOCLAENIDAE
    - *Bomburia prisca* (Matthew, 1937)
    - *Ellipsodon witkoi* Van Valen, 1978
    - *Protoselene bombadili* Van Valen, 1978
    - *Choeroclaenus turgidunculus* Simpson, 1937
    - *Promioclaenus priscus* Cope, 1888)
    - *Promioclaenus vanderhoofi* (Simpson, 1936)
    - *Promioclaenus wilsoni* Van Valen, 1978

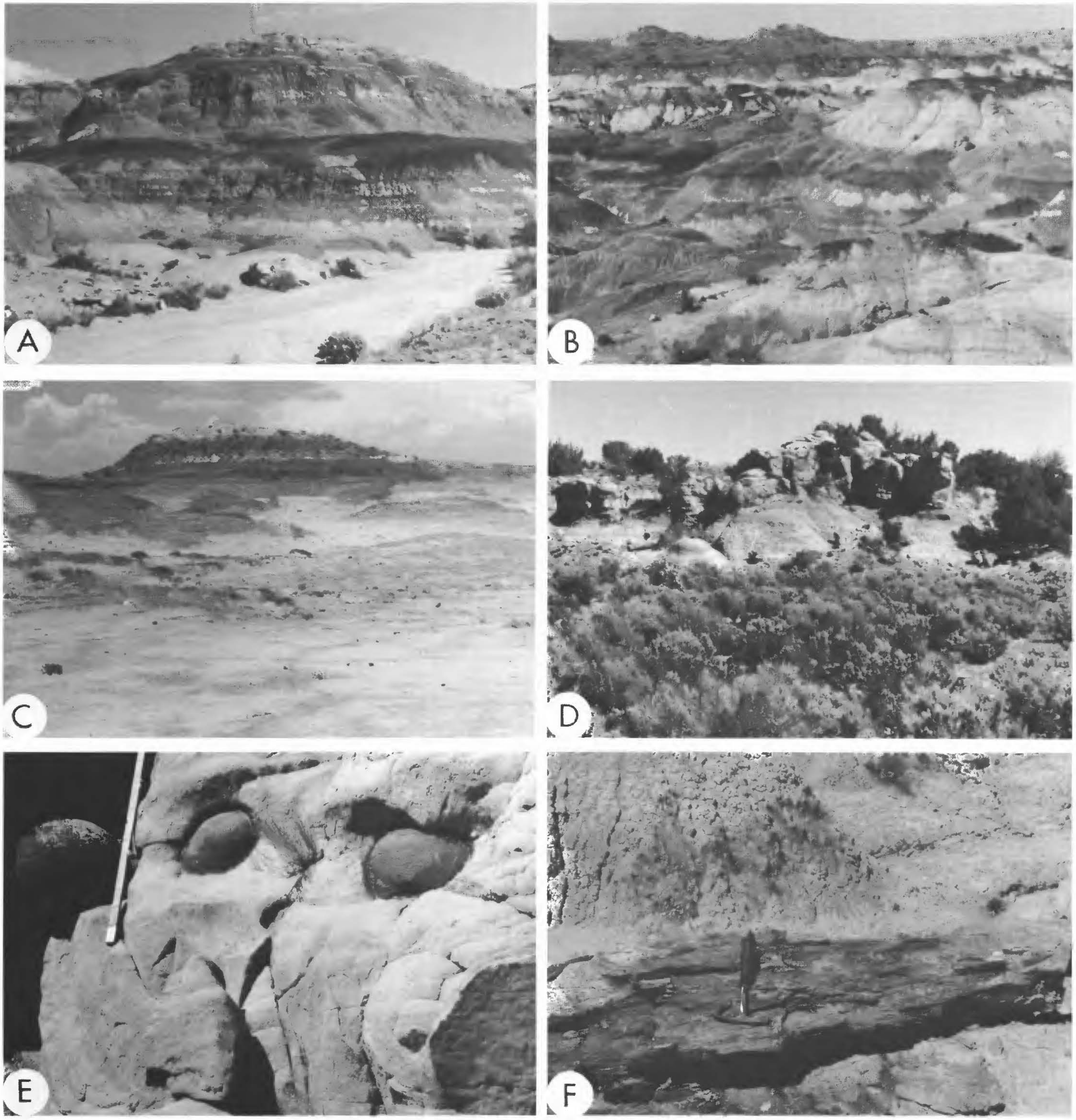


FIGURE 7. Views of Nacimiento Formation in the southern San Juan Basin. A, Basal Arroyo Chijujillita Member exposed in De-Na-Zin Wash, showing *Taeniolabis* zone (sensu Sinclair and Granger, 1914). B, Arroyo Chijuillita Member exposed in Gallegos Canyon. C, Base of Arroyo Chijuillita Member exposed in Tsosie Wash, showing *Ectoconus* zone (sensu Sinclair and Granger, 1914). D, Type section of Penistaja Bed, west flank of Torreon Wash. E, Cannonball concretions in type section of Penistaja Bed (note 1.5 m jacob staff for scale). F, Penistaja Bed and overlying mudstones of the Ojo Encino Member at Ojo Encino Member type section, west flank of Torreon Wash.

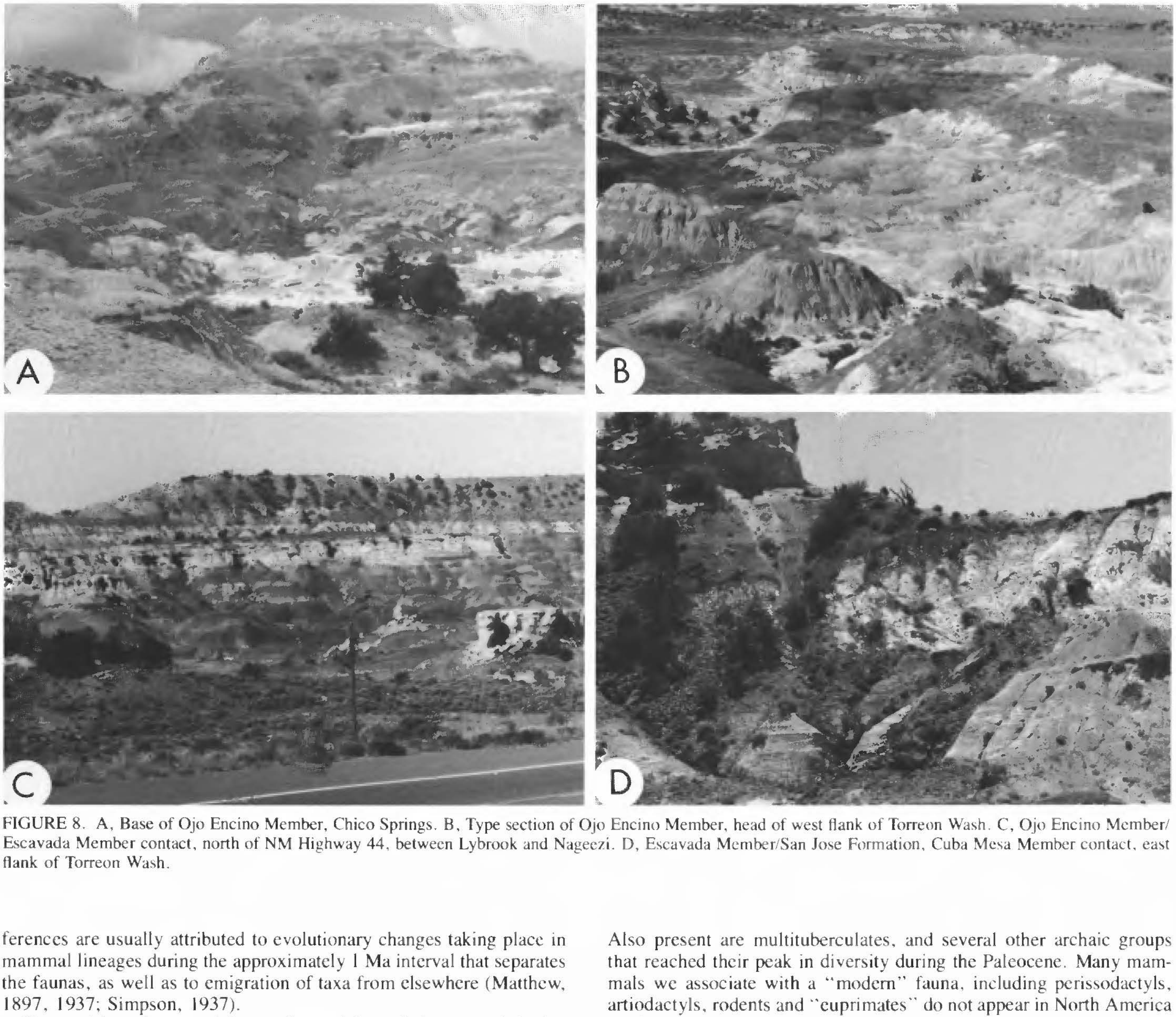


FIGURE 8. A, Base of Ojo Encino Member, Chico Springs. B, Type section of Ojo Encino Member, head of west flank of Torreon Wash. C, Ojo Encino Member/Escavada Member contact, north of NM Highway 44, between Lybrook and Nageezi. D, Escavada Member/San Jose Formation, Cuba Mesa Member contact, east flank of Torreon Wash.

ferences are usually attributed to evolutionary changes taking place in mammal lineages during the approximately 1 Ma interval that separates the faunas, as well as to emigration of taxa from elsewhere (Matthew, 1897, 1937; Simpson, 1937).

Composition of mammal faunas changed through time so rapidly that mammalian vertebrate paleontologists developed a series of "provincial land mammal ages" to correlate fossil-bearing, continental deposits of North America (Wood et al., 1941). The Puerco and Torrejon faunas of the San Juan Basin were designated the reference faunas for the Puercan and Torrejonian "ages." Recently, the Puercan and Torrejonian have been redefined to refer strictly to intervals of time based on the first occurrences of key taxa (Archibald et al., 1987). Under this definition, the "Puercan" and "Torrejonian" faunas of the San Juan Basin each occur in rocks deposited in only portions of the time interval bearing their name.

Structure of the Paleocene faunas

The increase in taxonomic diversity and morphology that occurred among eutherian mammals during the Paleocene is often cited as the "mammalian radiation," which signaled the rise of mammalian dominance following the demise of the dinosaurs. Late Cretaceous mammalian faunas of North America are dominated by the long-lived order Multituberculata, the Marsupialia, and less common, very small placental mammals (Sloan, 1970). The Puercan and Torrejonian faunas of the Nacimiento Formation, on the other hand, are dominated by primitive, archaic "ungulates" that are included in the "Condylarthra." Also present are multituberculates, and several other archaic groups that reached their peak in diversity during the Paleocene. Many mammals we associate with a "modern" fauna, including perissodactyls, artiodactyls, rodents and "euprimates" do not appear in North America until the late Paleocene or early Eocene. Most or all of these groups immigrated to North America at this time (Kraus and Maas, 1987). The Paleocene mammalian faunas of North America, therefore, are generally no longer viewed as a transitional fauna but, rather, are considered to be composed almost entirely of endemic, archaic taxa that were later superseded by members of modern groups.

Paleoplacentals and neoplacentals

Osborn (1894) distinguished two groups of placental mammals, the Mesoplacentalia and the Cenoplacentalia. Osborn and Earle (1895, p. 3–4) further noted that "the difference between these two groups consists mainly in the lower state of evolution and apparent incapacity for higher development exhibited by the mesoplacentals in contrast with the capacity for rapid development shown by the cenoplacentals." They identified "amblypods" (pantodonts + uintatheres), "condylarths," creodonts, tillodonts, insectivores and "lemuroid" primates as mesoplacentals, and proboscideans, artiodactyls, perissodactyls, carnivores, rodents and "anthropoid" primates as cenoplacentals. Because the taxa Mesoplacentalia and Cenoplacentalia do not refer to monophyletic groups, they have never been used by paleomammalogists since Osborn. However, these concepts may have some utility when stripped of their formal taxonomic meaning. We propose to recast them as the terms paleopla-

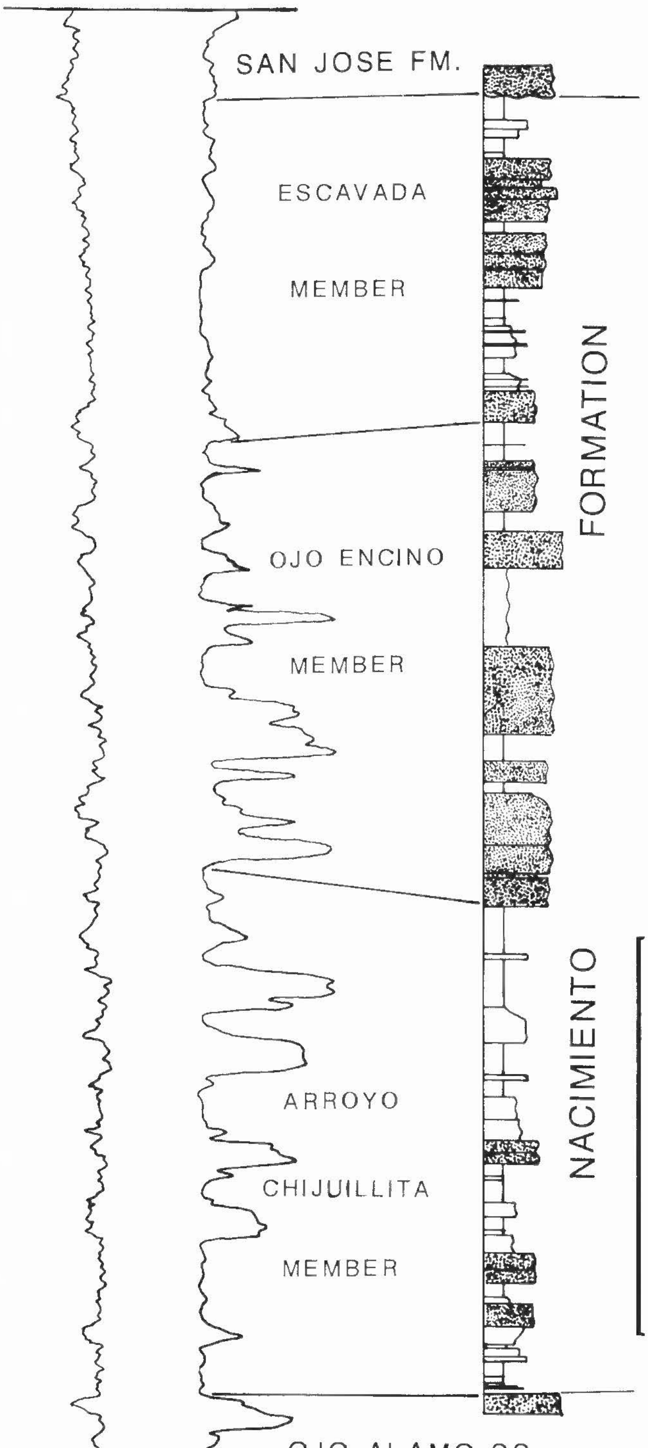


FIGURE 9. Nacimiento Formation composite section produced from sections E (Betonnie Tsosie Wash) and F (Escavada Wash) (Fig. 5) correlated with well log no. 7 (Fig. 10; see Appendix 2). Measured section and well log are drawn to the same vertical scale.

centals and neoplacentals, to refer to two distinct adaptive radiations of eutherians.

Thus, Paleocene-Eocene eutherians present us with a broad dichotomy into which most eutherian orders are readily placed (Tables 1, 2). Paleoplacentals (Table 3) originated during the Late Cretaceous or early Paleocene and were mostly evolutionary dead ends. Paleoplacentals had lower encephalization quotients and more primative brains than neoplacentals, more generalized limb structures and, although they converged on many dental structures of neoplacentals, they evolved these dentitions from different, mostly zalambdodont, starting points.

Neoplacentals originated primarily during the late Paleocene-Eocene and encompass most of the extant mammalian orders (Table 3). Their relatively higher encephalization quotients and more sophisticated brains, specialized limb structures and more "advanced" dentitions have usually been thought to have given them a competitive edge over contemporaneous paleoplacentals. This is supposedly why paleoplacentals became extinct and neoplacentals did not. Yet paleoplacentals and neoplacentals coexisted throughout the Eocene for some 20 million years or more.

Dissecting the evolution of eutherians during the Paleocene-Eocene into paleoplacental and neoplacental adaptive radiations has some heuristic value. It not only highlights the question of paleoplacental extinction (a complex phenomenon that took place on at least four continents over millions of years, and for which competitive inferiority seems a facile but untestable explanation). Thus, why did the paleoplacental adaptive radiation produce so many adaptive types convergent on neoplacentals yet fail to survive to the present? We don't know the answer to this question, but we believe it underscores a point made recently by Gould (1989) in his analysis of the Middle Cambrian fauna of the Burgess Shale.

Gould argued that this fauna represented a vast experiment in multicellular life that suffered extinction (with no descendants) for uncertain, perhaps chance, reasons. The high diversity of the Burgess Shale fauna lends the early diversification of multicellular life an asymmetrical, "bottom-heavy" pattern in which the highest diversity occurs early during the diversification process and is followed by decimation (Gould et al., 1987). The paleoplacental diversification of the Paleocene-Eocene creates, at the ordinal level, a similar asymmetry in the early evolution of the eutherians that reflects early experimentation by a variety of phylogenetic lineages.

Paleocene mammal faunas of the Nacimiento Formation

Paleocene eutherians from the Nacimiento Formation, with few exceptions (e.g., the miacid carnivores), represent one of the most significant records of paleoplacental diversification. The "Condylarthra" is now considered to be a group of primitive "ungulates," which may or may not have given rise to many of the neoplacental orders such as the Perissodactyla and Artiodactyla. The Puercan and Torrejonian "condylarths" are usually divided into five or six families, reflecting their morphologic diversity during this time.

The Arctocyonidae are a group of relatively unspecialized, possibly omnivorous animals with large canines. *Mimotricentes* (Fig. 14A–C) is one of the most common arctocyonids found in Torrejonian strata of the Nacimiento Formation. The Mioclaenidae are generally small, primitive "condylarths" that include *Promioclaenus* (Fig. 14I, K–L) and the more specialized *Mioclaenus* (Fig. 14D–F), both of Torrejonian age. The Torrejonian *Tetraclaenodon* (Fig. 14G–H, J) was once thought to be closely related to the first horses but is now generally believed to be close to the ancestry of an archaic group of herbivorous and omnivorous animals, the Phenacodontidae.

The Periptychidae are perhaps the most unusual of the early Paleocene "ungulates"; they have strange, enlarged premolars, perhaps reflecting a mostly herbivorous diet. They encompass some of the largest of the early herbivores, including *Ectoconus* (Fig. 12D–E) and *Periptychus coarctatus* (Fig. 12A–C) of Puercan age, and *Periptychus carinidens* (Fig. 13I–K) of Torrejonian age. Other smaller periptychids include *Conacodon* (Fig. 12F–H), *Hemithlaeus* (Fig. 12I, L–M) and *Gillisonchus* (Fig. 12J–K) from the Puercan, and *Anisonchus* (Fig. 13F–H) and *Haploconus* (Fig. 13L, P–Q) from the Torrejonian.

The Mesonychidae, sometimes considered a separate order, the Mesonychia, are a group of early ungulates that show specializations for a carnivorous diet. *Dissacus* (Fig. 15D) is known from the Torrejonian, and *Eoconodon* (Fig. 12F–H), of Puercan age, though usually not classified as a mesonychid, may be closely related. Many workers have

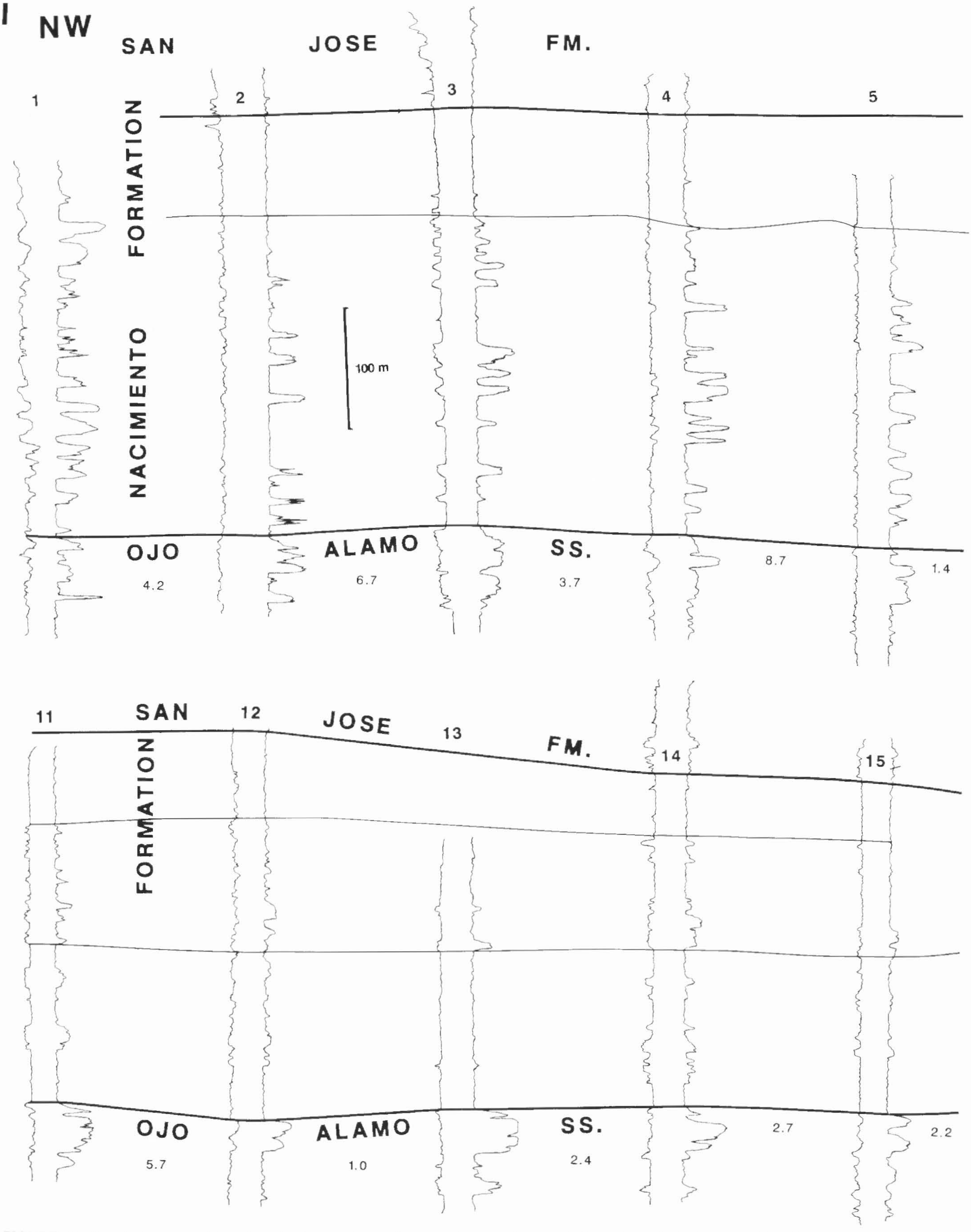
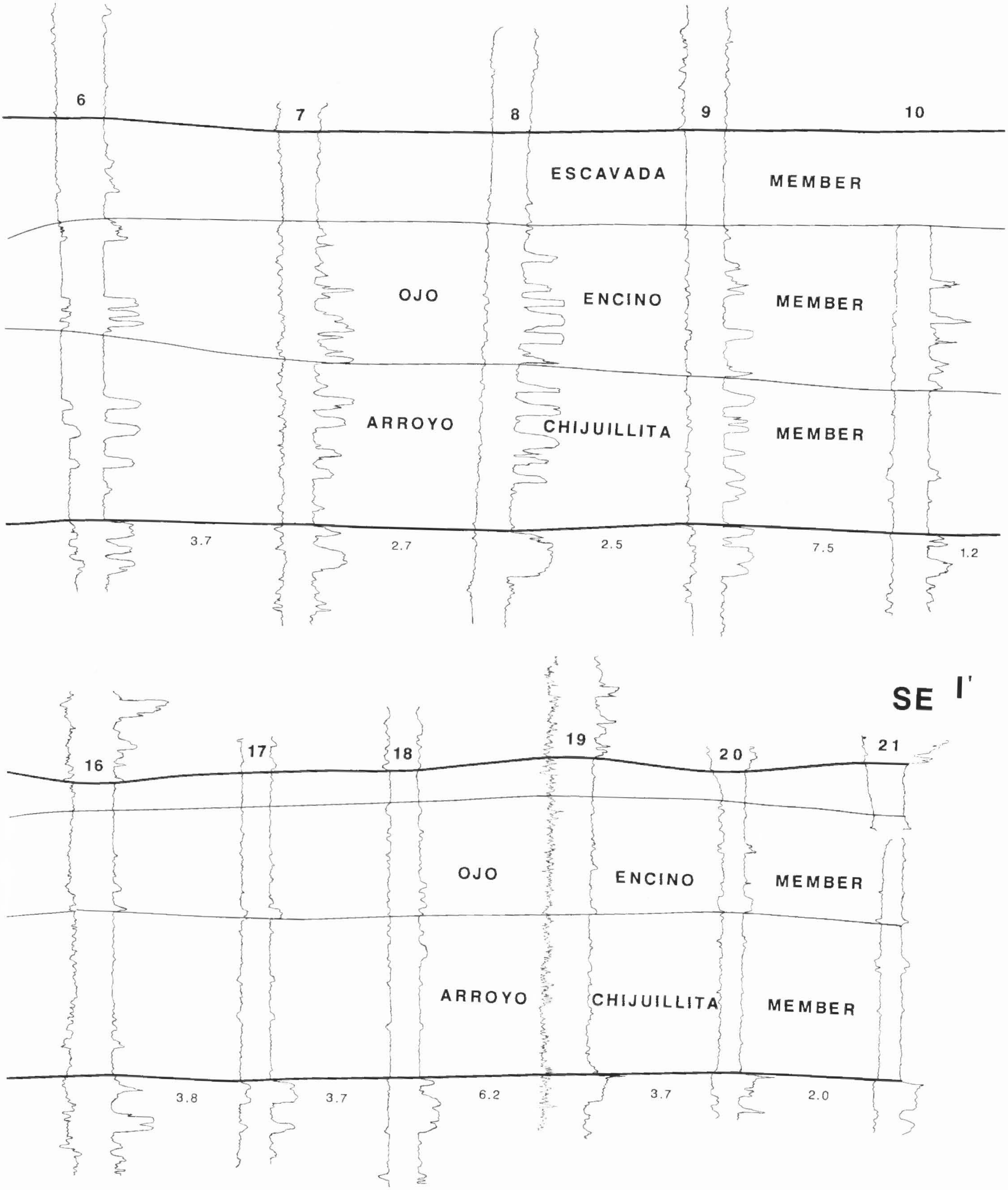


FIGURE 10. Correlation of well logs from Nacimiento Formation (see Appendix 2 for well log information). Well logs identified on geologic map are labeled above each log. Distance (in km) between logs as projected on cross section A–A′ are noted between bases of adjacent logs.


6
7
8
9
10
ESCAVADA MEMBER
OJO ENCINO MEMBER
ARROYO CHIJUILLITA MEMBER
3.7
2.7
2.5
7.5
1.2
SE I'
16
17
18
19
20
21
OJO ENCINO MEMBER
ARROYO CHIJUILLITA MEMBER
3.8
3.7
6.2
3.7
2.0

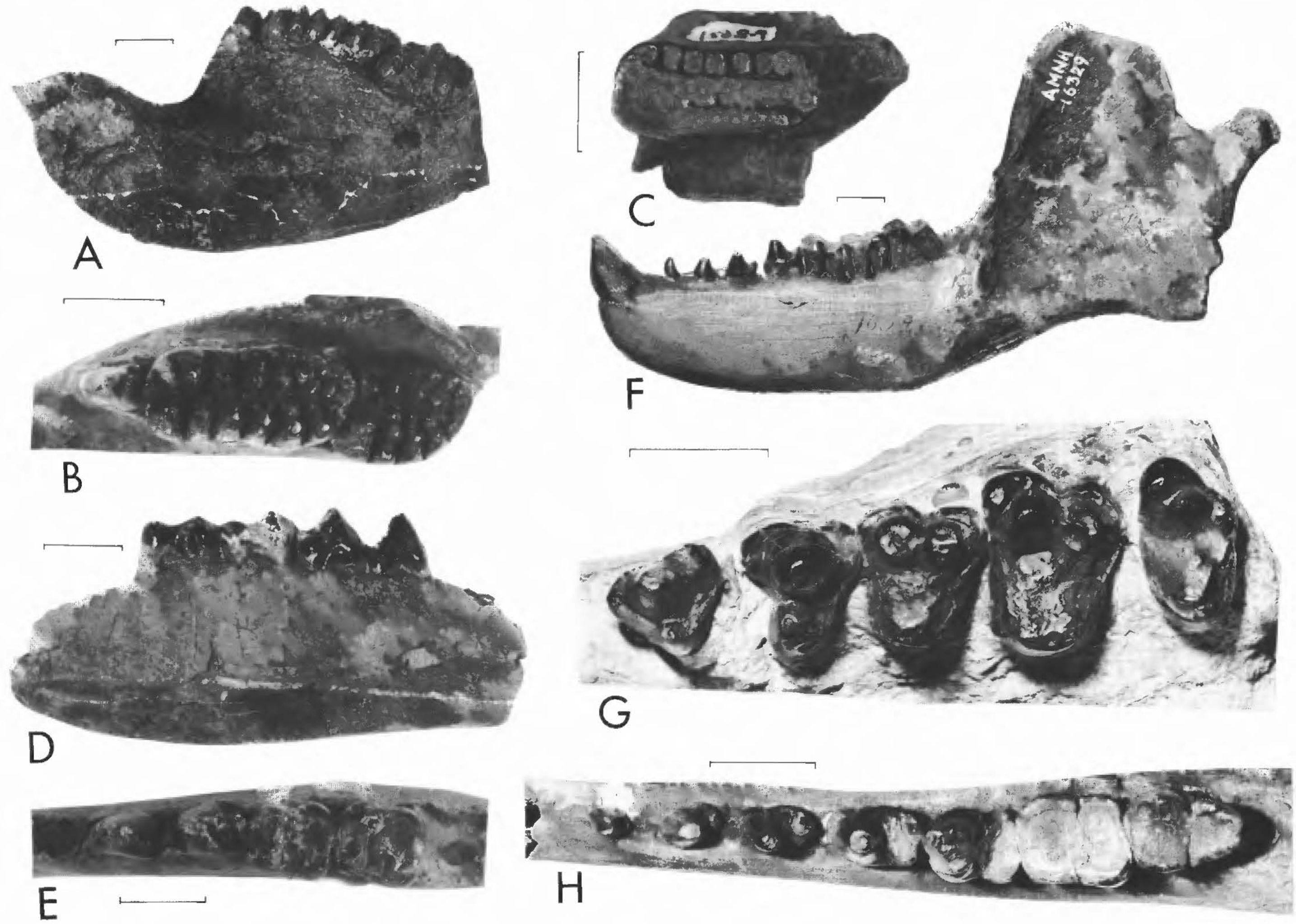


FIGURE 11. Typical taxa from Puercan age strata of the Nacimiento Formation, San Juan Basin. A–B, *Taeniolabis taoensis*, NMMNH P-8631, right dentary fragment with P_4–M_2 in lingual (A) and occlusal (B) views. C, *T. taoensis*, NMMNH P-8621, left M^1 (reversed) in occlusal view. D–E, *Loxolophus kimbetovius*, NMMNH P-8792, right dentary fragment with P_3–M_2 in lateral (D) and occlusal (E) views. F, *Eoconodon coriphaeus*, AMNH 16329, left dentary with C_1–M_3 in lateral view. G, *E. coriphaeus* (holotype), AMNH 3181, left P^3–M^3 in occlusal view. H, *E. coriphaeus*, AMNH 16329, left P_1–M_3 in occlusal view. All scale bars equal 1 cm.

hypothesized that mesonychids gave rise to whales (e.g., Gingerich et al., 1983b).

Other paleoplacental mammals are the Taeniodonta, including *Conoryctes* and *Psittacotherium* (Fig. 13M–O) of Torrejonian age, which show specializations believed to indicate a predisposition for digging (Schoch, 1986). The Pantodonta, represented by Torrejonian *Pantolambda* (Fig. 15E–G), are the largest clearly herbivorous early Paleocene mammal. *Deltatherium* (Fig. 15K–M) from the Torrejonian may be an early representative of another archaic group, the Tillodontia.

Although nearly all the early Paleocene mammals of the Nacimiento Formation are paleoplacentals, one "modern" order, the Carnivora, has its origins in the early Paleocene of North America. In the Nacimiento Formation, representatives of the Carnivora include the miacid *Protictis* (Fig. 15A–C) from the Torrejonian.

The Puercan and Torrejonian faunas also contain numerous small mammals, including marsupials and small, primitive, paleoplacental mammals. Most of these small insectivore-like paleoplacentals are placed into archaic orders. Some of the smaller mammals, such as Torrejonian *Mixodectes* (Fig. 15H–J), are believed to be closely related to Primates.

The long-lived order Multituberculata, which has its origins in the Late Triassic or Early Jurassic, reaches its peak in diversity during the early Paleocene. The largest multituberculate was *Taeniolabis* (Fig. 12A–C) from the Puercan. A smaller, closely related genus is the Torrejonian *Catopsalis* (Fig. 13A–C), which is relatively rare in the Nacimiento Formation.

The Torrejonian fauna of the San Juan Basin is much more diverse than the Puercan fauna (Tables 1, 2). This is partly a function of outcrop area. Fossiliferous Puercan strata occur over a very limited outcrop area in the San Juan Basin, whereas Torrejonian age strata occur over a much wider stratigraphic interval and are fossiliferous through much of the Nacimiento Formation outcrop belt. However, most workers agree that most of the difference in diversity between the two faunas is due to a rapid increase in taxonomic and morphologic diversity in eutherian mammals that took place throughout the early Paleocene (Van Valen, 1978; Archibald, 1983).

CORRELATION

Much of the previous correlation of strata of the Nacimiento Formation relied on particular taxa of fossil mammals that were believed to have restricted stratigraphic ranges. For example, Taylor (1984), as part of his review of Torrejonian mammals of the Nacimiento Formation, briefly discussed correlation of fossil localities of the Nacimiento Formation in order to determine the stratigraphic ranges of various mammal taxa. He correlated University of Kansas locality 15 from the head of Alamita Arroyo with the "*Pantolambda* zone" (sensu Sinclair and Granger, 1914) based largely on the presence of *Pantolambda*

TABLE 2. Faunal list showing Torrejonian mammalian taxa from the Nacimiento Formation. List is compiled from a variety of sources including Matthew (1937), Van Valen (1978), Taylor (1981, 1984) and Tsentas (1981).

- Order MULTITUBERCULATA
  - Family EUCOSMODONTIDAE
    - *Stygimys teilhardi* (Granger and Simpson, 1929)
    - *Eucosmodon molestus* (Cope, 1886)
    - *Eucosmodon?* sp. (Wilson, 1956c)
  - Family CIMOLODONTIDAE
    - *Anconodon gidleyi* Sloan, 1981
  - Family NEOPLAGIAULACIDAE
    - *Parectypodus travessartianus* (Cope, 1882)
    - *Parectypodus clemensi* Sloan, 1981
    - *Neoplagiaulax macrotomeus* (Wilson, 1956)
    - *Ectypodus szalayi* Sloan, 1981
    - *Mimetodon krausei* Sloan, 1981
  - Family PTILODONTIDAE
    - *Ptilodus mediaevus* Cope, 1881
  - Family TAENIOLABIDIDAE
    - *Catopsalis fissidens* Cope, 1884
- Order MARSUPIALIA
  - Family DIDELPHIDAE
    - *Peradectes* n. sp. a Taylor, 1984
    - *Peradectes* n. sp. b Taylor, 1984
- Order "PROTEUTHERIA"
  - Family LEPTICTIDAE
    - *Prodiacodon puercensis* Matthew, 1913
    - *Prodiacodon* n. sp. ? (Wilson, 1956a)
  - Family MIXODECTIDAE
    - *Mixodectes pungens* Cope, 1883
    - *Mixodectes malaris* (Cope, 1883)
  - Family PALAEORYCTIDAE
    - *Acmeodon secans* Matthew and Granger, 1921
    - *Palaeoryctes puercensis* Matthew, 1913
    - cf. *Gelastops* sp. Simpson, 1935
  - Family PENTACODONTIDAE
    - *Pentacodon inversus* (Cope, 1888)
    - *Pentacodon occultus* Matthew, 1937
    - *Pentacodon* n. sp. (Wilson, 1956a)
    - *Coriphagus encinensis* (Matthew and Granger, 1921)
    - n. gen. et sp. Taylor, 1984
- PLESIADAPIFORMES (Order indet.)
  - Family MICROSYOPIDAE
    - *Palaechton nacimienti* Wilson and Szalay, 1972
    - *Palaechthon woodi* Gazin, 1971
    - *Palaechthon problematicus* (Jepsen, 1930)
    - *Palaechthon* sp.
    - *Plesiolestes torrejonius* Kay and Cartmill, 1977
  - Family PAROMOMYIDAE
    - cf. *Paromomys* sp. (Tomida, 1981)
- Order CARNIVORA
  - Family VIVERRAVIDAE
    - *Bryanictis vanvaleni* (MacIntyre, 1966)
    - *Protictis haydenianus* (Cope, 1882)
    - *Protictis* n. sp. (Taylor, 1981; 1984)
- Order TAENIODONTA
  - Family CONORYCTIDAE
    - *Conoryctella pattersoni* Schoch and Lucas, 1981c
    - *?Conoryctella* cf. *C. dragonensis* Schoch and Lucas, 1981c
    - *Conoryctes comma* Cope, 1881
    - *Huerfanodon torrejonius* Schoch and Lucas, 1981b
  - Family STYLINODONTIDAE
    - *Psittacotherium multifragum* Cope, 1882
- Order MESONYCHIA
  - Family MESHONYCHIDAE
    - *Dissacus navajovius* (Cope, 1881)
    - *Ankalagon saurognathus* (Wortman, in Matthew, 1897)
    - *Microclaenodon assurgens* (Cope, 1884)
- Order "CONDYLARTHRA"
  - Family ARCTOCYONIDAE
    - *Chriacus baldwini* (Cope, 1882)
    - *Chriacus pelvidens* (Cope, 1881)
    - cf. *Loxolophus kimbetovius* Tomida (1981)
    - *Mimotricentes subtrigonus* (Cope, 1881)
    - *Arctocyon ferox* (Cope, 1883)
    - "*Neoclaenodon*" *procyonoides* Matthew, 1937
    - *Goniacodon levisanus* (Cope, 1883)
    - *Triisodon quivirensis* Cope, 1881
    - *Triisodon antiquus* (Cope, 1882)
    - *Triisodon crassicuspis* (Cope, 1882)
    - *Prothryptacodon ambiguus* (Van Valen, 1967)
    - *Deuterogonodon noletil* Van Valen, 1978
  - Family MIOCLAENIDAE
    - *Mioclaenus turgidus* Cope, 1881
    - *Ellipsodon inaequidens* (Cope, 1884)
    - *Ellipsodon grangeri* Wilson, 1956b
    - *Ellipsodon yotankae* Van Valen, 1978
    - *Promioclaenus acolytus* (Cope, 1882)
    - *Promioclaenus aequidens* (Matthew, 1937)
    - *Promioclaenus lemuroides* (Matthew, 1897)
    - *Protoselene opisthacus* (Cope, 1882)
    - n. gen. et sp. (Taylor, 1981; 1984)
  - Family HYOPSODONTIDAE
    - *Litomylus osceolae* Van Valen, 1978
  - Family PHENACODONTIDAE
    - *Tetraclaenodon puercensis* (Cope, 1881)
    - n. gen. et sp. (Wilson, 1956a)
  - Family PERIPTYCHIDAE
    - *Anisonchus sectorius* (Cope, 1881)
    - *Haploconus angustus* (Cope, 1881)
    - *Haploconus corniculatus* (Cope, 1888)
    - *Periptychus carinidens* Cope, 1881
    - *Oxyacodon tecumsae* Van Valen, 1978
- Order TILLODONTA
  - Family Incertae Sedis
    - *Deltatherium fundaminus* Cope, 1881
- Order PANTODONTA
  - Family PANTOLAMBDIDAE
    - *Pantolambda bathmodon* Cope, 1882
    - *Pantolambda cavirictum* Cope, 1883

bathmodon. The logic behind much of the resulting correlation is circular, as discussed by Tsentas (1981), because it relies on a preconceived notion that the ranges are restricted without demonstration of this by independent lithologic criteria.

The use of magnetic-polarity stratigraphy to correlate strata of the Nacimiento Formation offers a method of correlation independent of fossil mammals. Butler et al. (1977), Tomida (1981), Tomida and Butler (1980), Taylor (1977, 1981, 1984), Lindsay et al. (1981) and Butler and Lindsay (1985) determined a magnetic-polarity zonation for parts of the Nacimiento Formation at several sites in the San Juan Basin, including Kutz Canyon, De-Na-Zin Wash, Kimbeto Wash, Betonnie Tsosie Wash and Torreon Wash. They originally correlated the lowest of four normal polarity zones with magnetic polarity chron 28 and the highest with chron 25 of the Ness et al. (1980) magnetic polarity time scale. Later, this correlation was demonstrated to be in error (Lucas and Rigby, 1979; Lucas and Schoch, 1982). After correction for post-depositional remagnetization in some of their samples, they correlated the three lower normal polarity zones with chrons 29–27 (Butler and Lindsay, 1985).

However, in this revised correlation, Butler and Lindsay (1985) did not correlate the uppermost normal polarity zone with chron 26. They showed the magnetic polarity zonation of the San Juan Basin relative to a vertical scale (Butler and Lindsay, 1985, p. 551, fig. 13). The uppermost normal polarity zone changes in thickness from approximately 30 m (Lindsay et al., 1978, 1981; Taylor, 1981; Tomida, 1981; Butler and Lindsay, 1985) to only 8 m in their revised correlation. No explanation of this change was offered. Butler and Lindsay (1985) stated, however, that the correlation of this uppermost normal polarity zone in their San Juan Basin magnetic polarity zonation was uncertain but "of little consequence." It thus would appear that this upper normal polarity zone is drawn to a smaller size in the revised correlation to

TABLE 3. Orders included in paleoplacental and neoplacental mammals proposed herein.

PALEOPLACENTALS	NEOPLACENTALS
Anagalida	Proboscidea
Creodonta	Carnivora
Tillodontia	Rodentia
Taeniodonta	Meridiungulata
Pantodonta	Perissodactyla
Dinocerata	Artiodactyla
Edentata	Cetacea
"Condylarthra"	Chiroptera
Plesiadapiform Primates	"Euprimates"
	Lagomorpha

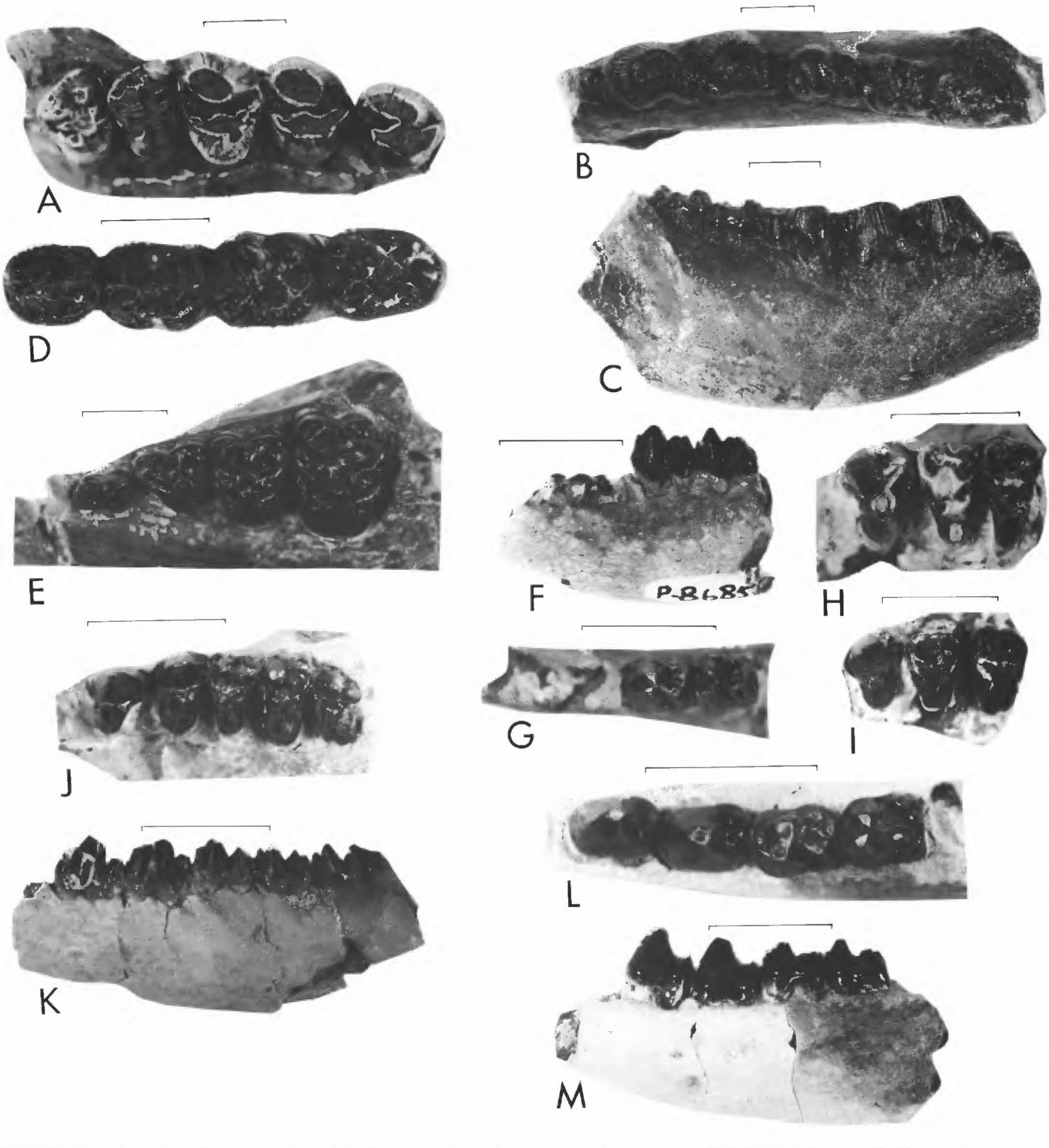


FIGURE 12. Typical taxa from Puercan age strata of the Nacimiento Formation. A, *Periptychus coarctatus*, NMMNH P-8620, right P^2–M^2, in occlusal view. B–C, *P. coarctatus*, NMMNH P-19223, right dentary fragment with P_3–M_3 in occlusal (B) and lateral (C) views. D, *Ectoconus ditrigonus*, NMMNH P-15173, left P_4–M_3 in occlusal view. E, *E. ditrigonus*, NMMNH P-1, left DP^2–M^1 in occlusal view. F–G, *Conacodon entoconus*, NMMNH P-8685, left dentary fragment with M_{1-2}, in lateral (F) and occlusal (G) views. H, *C. entoconus*, NMMNH P-15109, left P^4–M^2, in occlusal view. I, *Hemithlaeus kowalevskianus*, NMMNH P-8680, right P^4–M^2 in occlusal view. J, *Gillisonchus gillianus*, NMMNH 15111, left P^3–M^3 (reversed) in occlusal view. K, *G. gillianus*, NMMNH P-20881, left dentary fragment with P_3–M_3 in lateral view. L–M, *H. kowalevskianus*, NMMNH P-15045, left dentary fragment with P_3–M_2 in occlusal (L) and lateral (M) views. All scale bars equal 1 cm.

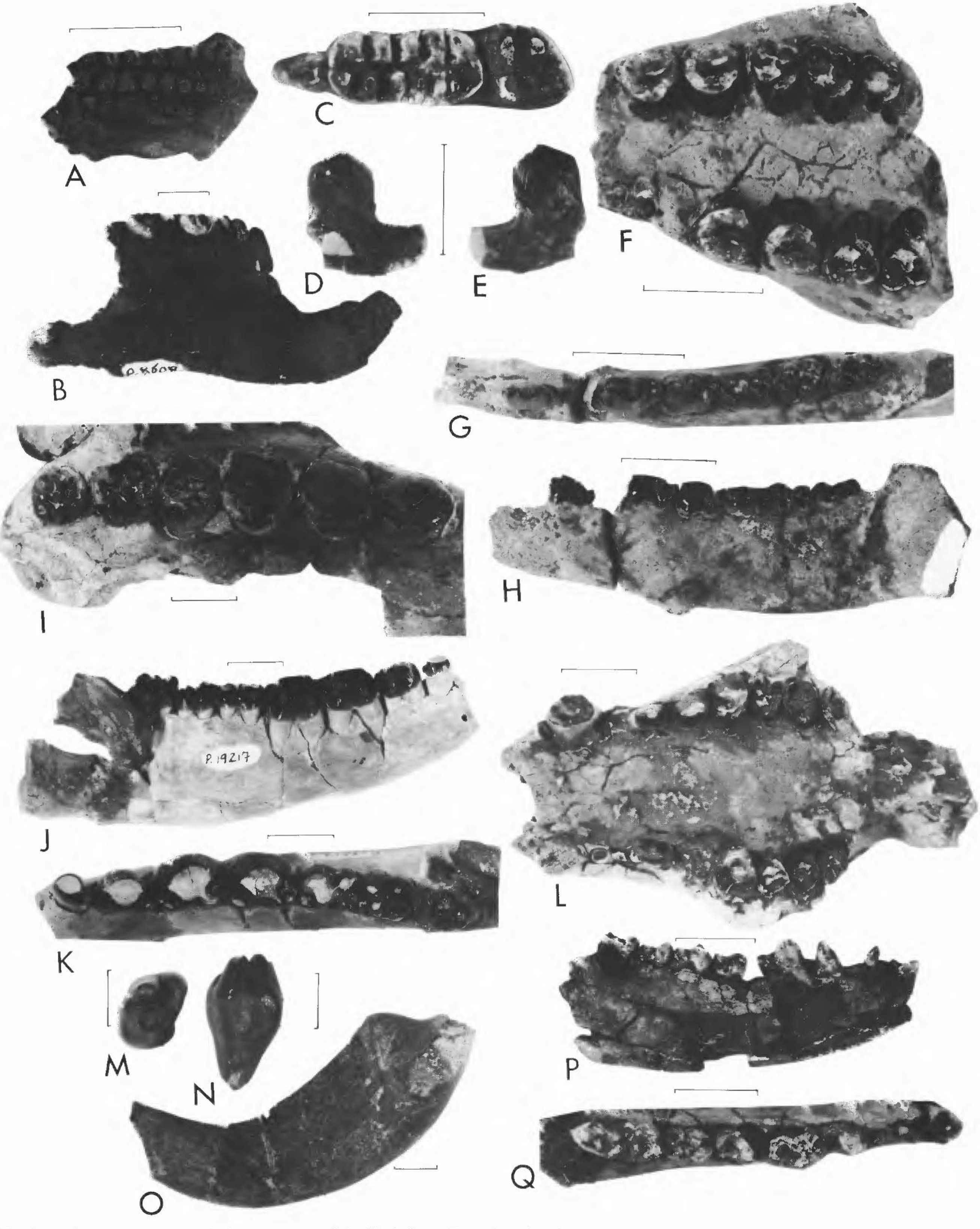


FIGURE 13. Typical taxa from Torrejonian age strata of the Nacimiento Formation, San Juan Basin. A–C, *Catopsalis fissidens*, NMMNH P-8608, right M^1 in occlusal view (A), left dentary fragment with P_4–M_2 in lateral (B) and occlusal (C) views. D–E, *Ptilodus mediaevus*, NMMNH P-18580, left dentary fragment with P_{3-4} in lingual (D) and lateral (E) views. F, *Anisonchus sectorius*, NMMNH P-20882, palate with left P^3–M^3 and right P^3–M^2 in occlusal view. G–H, *A. sectorius*, NMMNH P-20747, left dentary fragment with P_2–M_3 in occlusal (G) and lateral (H) views. I, *Periptychus carinidens*, NMMNH P-19482, right P^2–M^3 in occlusal view. J–K, *P. carinidens*, NMMNH P-19217, right dentary fragment with P_1–M_3, in lateral (J) and occlusal (K) views. L, *Haploconus angustus*, AMNH 16680, palate with left P^2–M^2 and right P^2, P^4–M^3 in occlusal view. M–N, *Psittacotherium multifragum*, NMMNH P-19838, right P_4 in occlusal (M) and mesial (N) views. O, *P. multifragum*, NMMNH P-16184, right C_1, in lateral view. P–Q, *H. angustus*, AMNH 16688, right dentary fragment with P_1–M_3 in lateral (P) and occlusal (Q) views. All scale bars equal 1 cm.

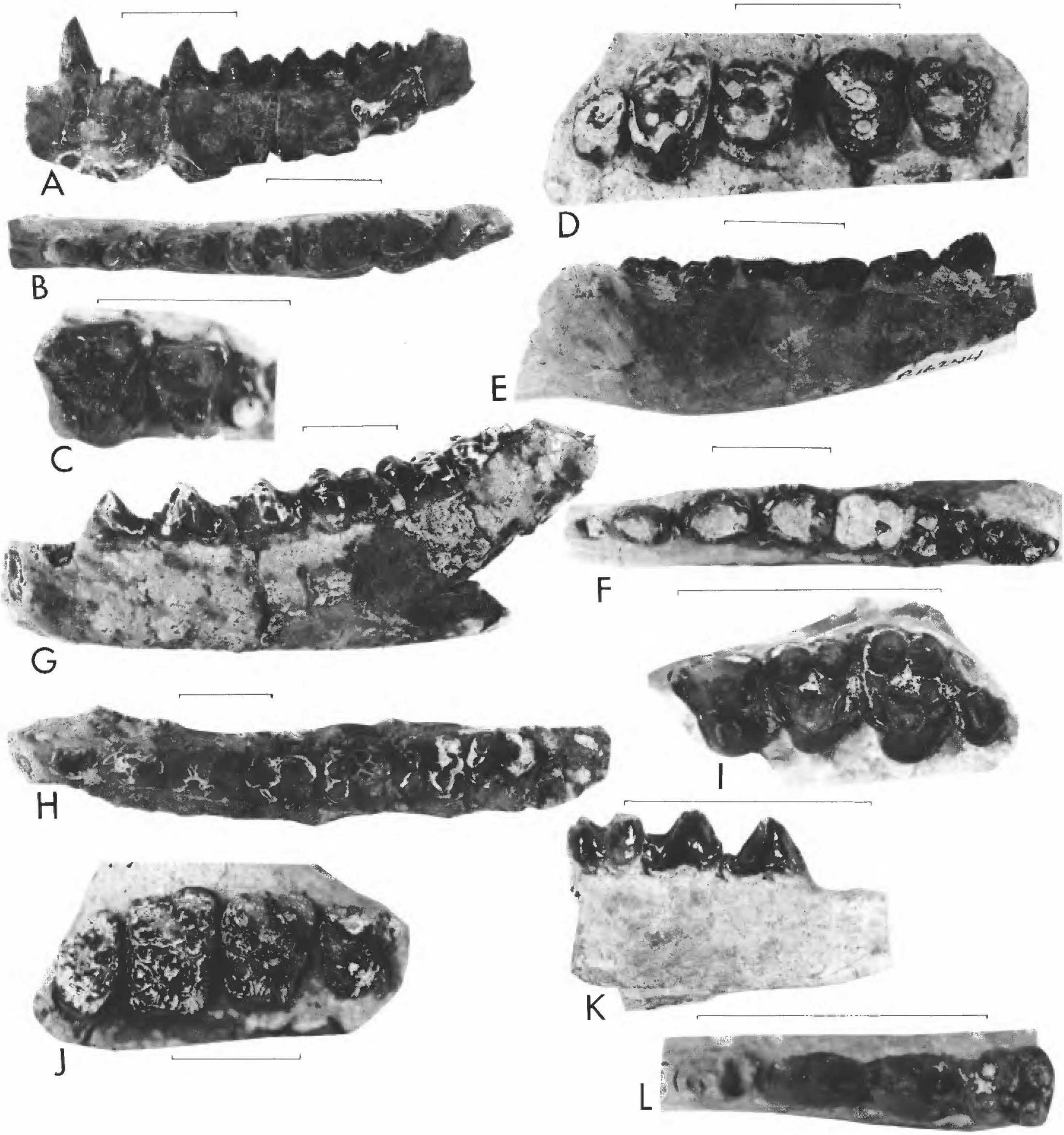


FIGURE 14. Typical taxa from Torrejonian age strata of the Nacimiento Formation, San Juan Basin. A–C, *Mimotricentes subtrigonus*, NMMNH P-15779, left dentary fragment with P_2, P_4–M_3 in lateral (A) and occlusal (B) views and right P^4–M^1 in occlusal view (C). D, *Mioclaenus turgidus*, NMMNH P-20885, right P^3–M^3 in occlusal view. E–F, *M. turgidus*, NMMNH P-16244, right dentary fragment with P_2–M_3 in lateral (E) and occlusal (F) views. G–H, *Tetraclaenodon puercensis*, NMMNH P-19480, left P_2–M_3, in lateral (G) and occlusal (H) views. I, *Promioclaenus acolytus*, NMMNH P-15747, left P^4–M^3 in occlusal view. J, *T. puercensis*, NMMNH P-19270, right P^4–M^3, in occlusal view. K–L, *P. acolytus*, NMMNH P-19390, left dentary fragment with P_3–M_1 in lateral (K) and occlusal (L) views. All scale bars equal 1 cm.

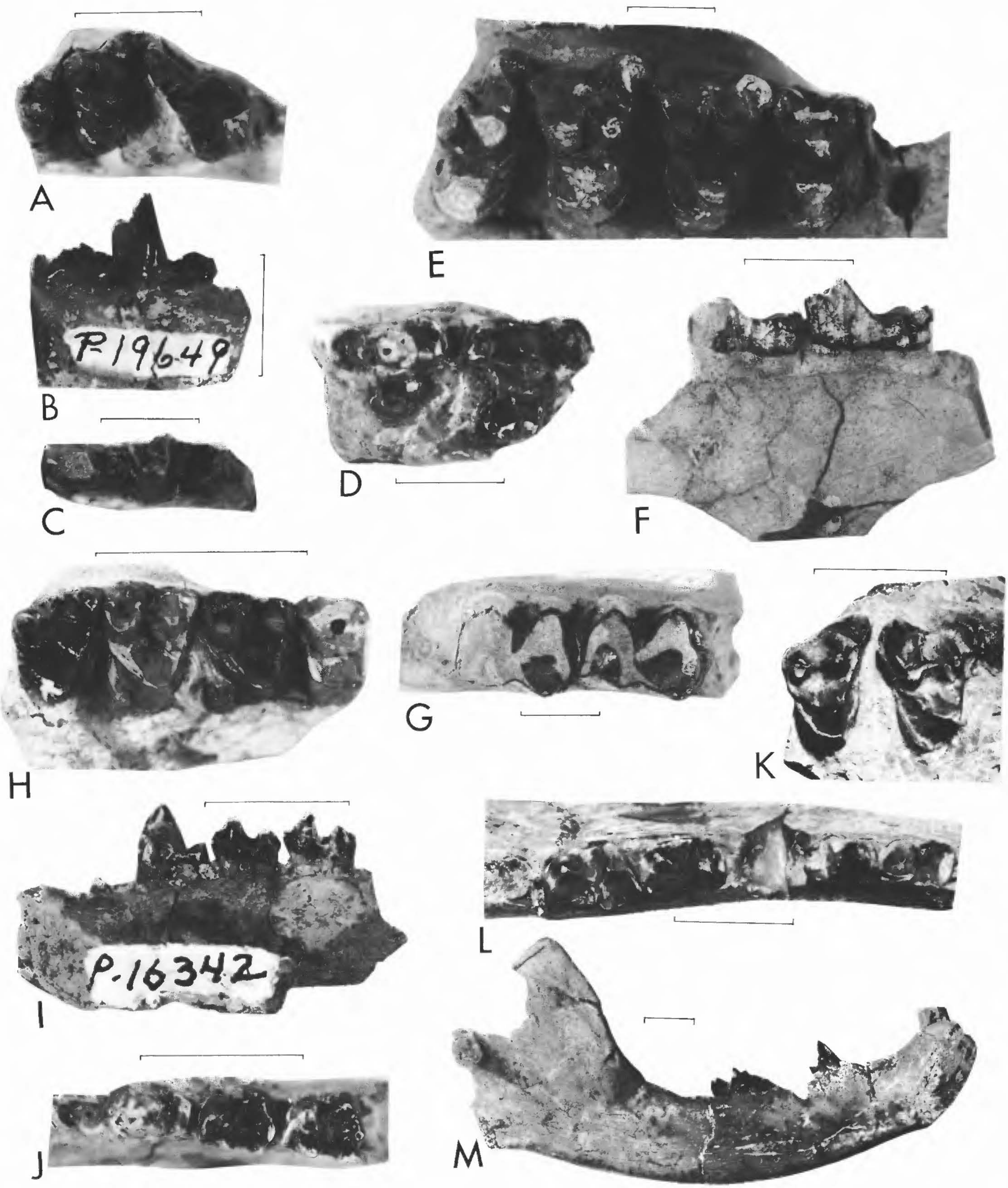


FIGURE 15. Typical taxa from Torrejonian age strata of the Nacimiento Formation, San Juan Basin. A, *Protictis haydenianus*, NMMNH P-15751, right P^4–M^2 in occlusal view. B–C, *P. haydenianus*, NMMNH P-19649, left dentary fragment with P_4–M_1 in lateral (B) and occlusal (C) views. D, *Dissacus navajovius*, NMMNH P-15686, left P^4–M^1 in occlusal view. E, *Pantolambda cavirictum*, NMMNH P-20884, right P^4–M^3 in occlusal view. F–G, *Pantolambda* cf. *P. cavirictum*, NMMNH P-19774, right dentary fragment with M^{1-2} in lingual (F) and occlusal (G) views. H, *Mixodectes pungens*, NMMNH P-20883, right P^4–M^3 in occlusal view. I–J, *M. pungens*, NMMNH P-16342, right dentary fragment with P_4–M_2 in lingual (I) and occlusal (J) views. K, *Deltatherium fundaminis* (holotype), AMNH 3315, right M^{2-3} in occlusal view. L–M, *D. fundaminis* (holotype of *Lipodectes penetrans*), AMNH 3335, left dentary with P_3, partial M_1–M_2 in occlusal (L) and lingual (M) views. All scale bars equal 1 cm.

de-emphasize its importance. This revised magnetic-polarity zonation with the shortened uppermost normal polarity chron was followed by Archibald et al. (1987, fig. 3.2) in their correlation of the Nacimiento Formation with the time scale of Berggren et al. (1985).

Contrary to Butler and Lindsay (1985), we believe that correlation of the uppermost polarity chron of the Nacimiento Formation is of critical importance to determining the age of the top of the Nacimiento Formation. Such age determination constrains the magnitude of the unconformity separating the Nacimiento Formation from the overlying San Jose Formation in the southern San Juan Basin, and allows determination of the rates of sediment accumulation of upper strata of the Nacimiento Formation. The age of the uppermost strata of the Nacimiento Formation may also bear on the relationship of the Nacimiento Formation to the Animas Formation of the northern San Juan Basin which is, at least partly, laterally equivalent (Smith and Lucas, 1991).

We correlate the uppermost normal polarity zone of Lindsay et al. (1981) with magnetic polarity chron 26 (Fig. 16) (cf. Lucas and Schoch, 1982). Correlated to the time scale of Harland et al. (1990), this gives the upper limit of the Nacimiento Formation as early Thanetian, or late Paleocene in age. This normal polarity zone, however, is only present in the Kutz Canyon section of Lindsay et al. (1981). The only other upper Nacimiento sections in which Lindsay et al. (1981) determined the magnetic polarity zonation were at the east and west flanks of Torreon Wash (Fig. 5). There, the uppermost normal polarity zone is absent. However, the entire Nacimiento Formation is thinner in this area and in the southeastern limit of the Nacimiento Formation. (Figs. 5, 10).

The Escavada Member, which contains the normal polarity zone we correlate with chron 26, is approximately 130 m thick in Kutz Canyon (based on Taylor, 1977, 1981; Lindsay et al., 1981). The Escavada Member is only 23.3 m thick at the east flank of Torreon Wash (Figs. 5, 10). This thinning may be due, at least in part, to removal of the top of the Nacimiento Formation at the unconformity at the base of the overlying San Jose Formation (Baltz, 1967). Tsentas (1981) and Lucas et al. (1981) documented relief at the base of the San Jose Formation of approximately 10 m at the head of Torreon Wash. However, much of the thinning of the Nacimiento Formation is also due to intraformational thinning (Butler and Lindsay, 1985). For example, the strata between the bases of magnetic-polarity zones correlated with chrons 28 and 27, respectively, are approximately 150 m thick in Kutz Canyon but only 75 m thick at Torreon Wash (Taylor, 1977, 1981). Intraformational thinning of the Nacimiento Formation may have facilitated removal of the upper normal magnetic polarity chron from the upper Nacimiento Formation by erosion of the rocks that record the upper magnetic normal polarity zone.

Our correlation of the Nacimiento Formation relative to the magnetic-polarity zonation of Lindsay et al. (1981) and the time scale of Harland et al. (1990) (Fig. 16) indicates that the basal Arroyo Chijuillita Member spans the interval between the base of normal polarity chron 29 to a position near the base of chron 27. The middle Ojo Encino Member spans the interval between a position near the base of chron 27 and the top of chron 27. The Escavada Member spans the interval between the base of chron 26 and extends to at least the lower part of chron 25, at least in Kutz Canyon. In Torreon Wash, the Escavada Wash Member may extend only as far as the reversed part of chron 26.

Our correlation of fossiliferous zones within the Nacimiento Formation with this time scale agrees with Butler and Lindsay (1985) insofar as the Puercan *Ectoconus* and *Taeniolabis* zones (sensu Sinclair and Granger, 1914), both fall within chron 29 normal contained within the base of the Arroyo Chijuillita Member. Moreover, the two zones can be correlated between their various fossil localities on strictly lithologic criteria (Fig. 5).

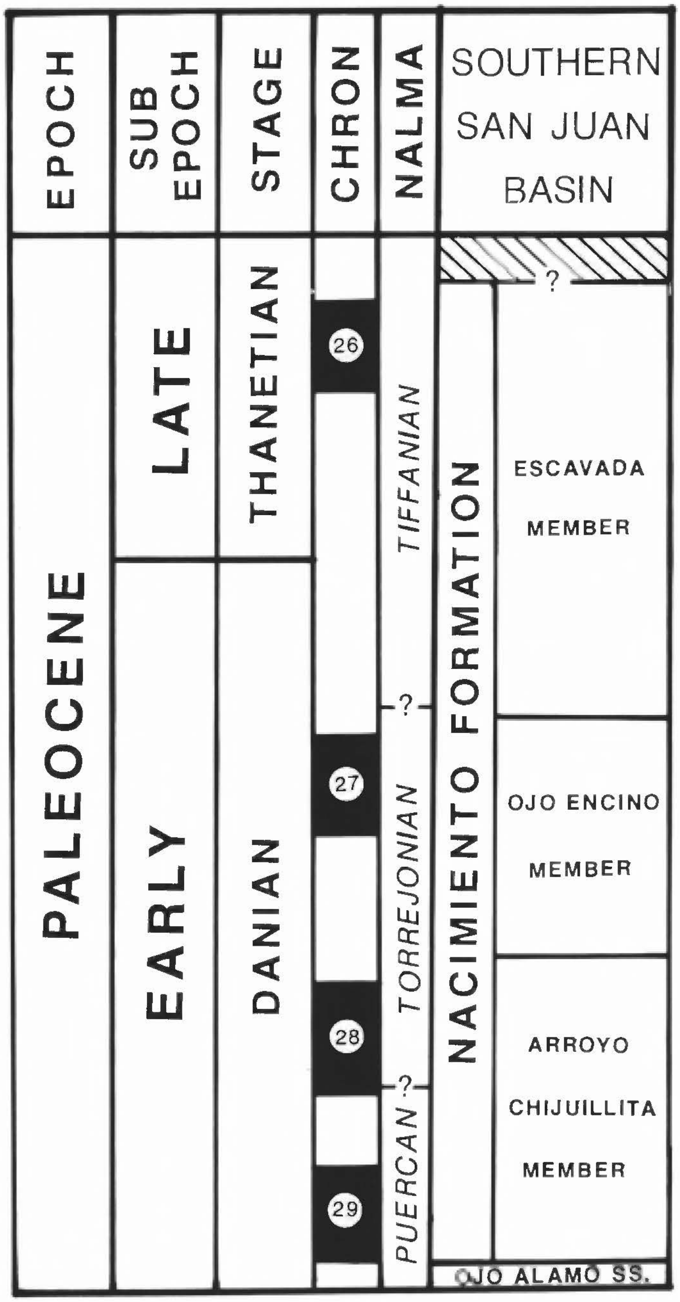


FIGURE 16. Correlation chart of the Nacimiento Formation with the time scale of Harland et al. (1990). Magnetic polarity zonation of the Nacimiento Formation is based on Lindsay et al. (1978, 1981), Taylor (1977, 1981, 1984) and Tomida (1981).

Correlations by Rigby and Lucas (1977) and Rigby (1981), which show fossil localities in a tongue of the Ojo Alamo Sandstone, below the *Ectoconus* zone exposed at Mammalon Hill in Tsosie Wash, are in error. Only one Puercan vertebrate fossil horizon is exposed in Tsosie Wash, and this is the fossil zone identified by Sinclair and Granger (1914, pl. 26). Rigby and Lucas (1977) and Rigby (1981) collected fossil mammals from the *Ectoconus* zone (sensu Sinclair and Granger, 1914) at Mammalon Hill, a prominent and very fossiliferous locale. They also collected fossil specimens, including a partial skeleton of *Gillisonchus gillianus* (see Rigby, 1981) from an adjacent pan to the north of Mammalon Hill. We find that the pan and Mammalon Hill expose a single, relatively thin, fossiliferous horizon that corresponds to the *Ectoconus* zone described by Sinclair and Granger (1914). Rigby and Lucas (1977) and Rigby (1981), however, mistakenly correlated the fossiliferous horizon exposed on the pan with a sandstone (Fig. 5, units 9–10, Betonnie Tsosie Wash Section) stratigraphically below the fossiliferous horizon exposed on Mammalon Hill. Moreover, Rigby and Lucas (1977) and Rigby (1981) considered this lower sandstone to be a tongue of the Ojo Alamo Sandstone. Though the lower sandstone may be a tongue of the Ojo Alamo Sandstone, we were unable to substantiate the correlations shown by Rigby and Lucas (1977) and Rigby (1981) and therefore consider this sandstone to be part of the Nacimiento Formation.

Archibald et al. (1987) redefined the Paleocene land mammal "ages," and defined the base of the Torrejonian as the evolutionary first occurrence of *Periptychus carinidens*. The stratigraphically lowest occurrence of *Periptychus carinidens* occurs in our west flank of Kimbeto Wash section (Fig. 5). Tomida (1981) indicated that the stratigraphically lowest occurrences of *Periptychus carinidens* in Kutz Canyon, De-Na-Zin Wash, Kimbeto Arroyo and Betonnie Tsosie Wash are within the magnetic polarity chron now correlated with chron 28 normal. The lowest occurrence of *Periptychus carinidens* usually corresponds to the lowest fossiliferous zone above the "barren interval," which separates the fossiliferous zones that produce Puercan and Torrejonian mammal taxa. In Betonnie Tsosie Wash, poorly preserved vertebrate fossils were found approximately 15 m below the lowest stratigraphic level that produced *P. carinidens*.

The evolutionary event that led to the first *Periptychus carinidens* probably occurred during the time interval represented by sediment in the "barren interval." Therefore, the Puercan and Torrejonian boundary cannot be precisely placed in the Nacimiento Formation (Fig. 16). However, the lowest fossiliferous zone above the "barren interval" is located at approximately the same stratigraphic level in a number of widely separated areas throughout the basin and therefore appears to form a useful datum that is above the Puercan-Torrejonian boundary. This datum occurs near the top of our Arroyo Chijuillita Member in the southern San Juan Basin. The stratigraphic position of the lowest occurrence of *Periptychus carinidens* in De-Na-Zin Wash, Kimbeto Wash and Betonnie Tsosie Wash may correlate with the lowest occurrence of *P. carinidens* at Mesa de Cuba (Fig. 5), based on independent lithologic correlation. Magnetic-polarity zonation of the Nacimiento Formation has not been determined at this locality.

Correlation of the Nacimiento Formation with other early Paleocene deposits of the Rocky Mountain region depends primarily on correlation of magnetic-polarity zones and on fossil mammals. Magnetostratigraphy has proven to be very useful for correlation of early Paleocene continental deposits of North America. Where magnetostratigraphy has been applied to early Paleocene deposits, the resulting correlations are in general agreement with those based on biostratigraphy using fossil mammals (see Archibald, 1987). However, because not all deposits allow the use of magnetostratigraphy and because relatively large magnetochrons prevent relatively high precision correlation, mammalian biochronology remains the most precise way to correlate fossiliferous Paleocene continental deposits. However, magnetostratigraphy is extremely useful, not only by supplying an independent method for correlating between widely separated areas, but also in providing absolute age control to strata and their contained fossil faunas.

Correlations using fossil mammals are potentially very useful but are hampered both by the need for up-to-date taxonomic revision of many mammal taxa and considerable provinciality between northern and southern early Paleocene mammal faunas. For example, northern late Torrejonian (To3: Archibald et al., 1987) faunas of Wyoming and Montana are generally dominated by plesiadapiform Primates such as *Palaechthon* or *Paromomys*, whereas southern faunas are dominated by "condylarths" such as *Tetraclaenodon* and the periptychid *Periptychus*, and *Mixodectes*. Anthony and Maas (1990) reported that tests of Paleocene faunas using Simpson's faunal resemblance indices indicates that the late Puercan (Pu2/3: Archibald et al., 1987) showed evidence of a sharp north-south biogeographic provincial boundary in southern Wyoming. Late Torrejonian (To3) faunas show evidence of an indistinct north-south provincial boundary. Sloan (1987) suggested that the north-south provincial boundary separating late Torrejonian faunas coincided with the early Paleocene continental divide. McKinney and Schoch (1984) attributed these faunal differences to either a north-south variation in land-mammal communities or to different environmental/faunal facies being represented at collecting localities. These two factors are not necessarily mutually exclusive.

Archibald et al. (1987) recently revised the concept of Paleocene North American land mammal "ages" (NALMAs). Faunal comparisons are used as the primary method of determining relative ages of widely separated faunas (Archibald et al., 1987). This is a conceptual break from the definition of NALMAs of Wood et al. (1941), who identified a type locality (and fauna) as the basis for each NALMA. Archibald et al. (1987) stated that in many instances, their redefined NALMAs cannot be defined with precision in type sections, though they indicate that the eventual definition of biostratigraphic-based stages and corresponding ages is a goal for the future.

Archibald et al. (1987) divided the Puercan and Torrejonian into interval zones that are limited and defined by the successive appearance of unrelated taxa. The Puercan of Archibald et al. (1987) is the time interval between the first appearance of the didelphid marsupial *Peradectes* and the first appearance of the archaid "ungulate" *Periptychus carinidens*, and is subdivided into three zones, numbered Pu1–Pu3. Archibald and Lofgren (1990) recognized a fourth, older subdivision of the Puercan (Pu0).

In this redefinition of the Puercan, only the last two subdivisions, Pu2 and Pu3, are recognized in the original type locality of the Puercan defined by Wood et al. (1941). Pu2 is temporally equivalent to the *Ectoconus* zone of Sinclair and Granger (1914) and is equal to the *Hemithlaeus* facies of Van Valen (1978). Pu3 is temporally equivalent to the *Taeniolabis* zone of Sinclair and Granger (1914). Archibald et al. (1987) stated that one of the difficult problems with subdividing the Puercan is the inability to identify clearly zones within the type Puercan of the San Juan Basin (but see above). They therefore recommended that the Pu2 and Pu3 subzones be used provisionally outside of De-Na-Zin Wash, San Juan Basin.

Our correlations (Fig. 5) indicate that the two fossil zones that produce Puercan fossils in the San Juan Basin can be correlated lithologically or by their stratigraphic position. These studies show that the zone yielding fossils of Pu3 (as exposed in Gallegos, Alamo and De-Na-Zin Washes) is in all places stratigraphically higher than the zone producing fossils of Pu2 (Alamo, De-Na-Zin, Kimbeto and Betonnie Tsosie Washes). This suggests that the differences in the two faunas, though slight, can be attributed to temporal changes between the faunas rather than just facies differences between the fossil zones and facies control of particular taxa. However, sampling bias is probably responsible for some apparent presences or absences of rare taxa in these two zones (Lucas, 1984b).

Archibald et al. (1987) redefined the Torrejonian as the time interval between the first appearance of the archaic ungulate *Periptychus* (distinct from Puercan *Periptychus*, which they assigned to *Carsioptychus*) and the first appearance of *Plesiadapis praecursor*. They divided the Torrejonian into three zones, To1–To3. Gingerich (1975a, 1976) and Gingerich et al. (1983a) proposed a fourth division for the Torrejonian (To4), but this was not accepted by Archibald et al. (1987).

All three of the subzones proposed by Archibald et al. (To1–To3) are represented by faunas of the Nacimiento Formation in the San Juan Basin. However, To1 is based primarily on the Dragon local fauna of Utah. To2 and To3 are both based primarily on faunas from the San Juan Basin. To2 and To3 are approximately temporally equivalent to the *Deltatherium* and *Pantolambda* zones, respectively, of Sinclair and Granger (1914), where originally defined. The base of To2 is defined as the first occurrence of *Tetraclaenodon*, and the base of To3 is defined as the first occurrence of *Pantolambda*.

Tomida (1981) and Tomida and Butler (1980) used magnetostratigraphy to show that some fossil localities and their corresponding faunas of the Nacimiento Formation are temporally equialent to the Dragon local fauna, Utah. Torrejonian localities in the San Juan Basin are found in the magnetic zones correlated with magnetic polarity chrons 28, 27r and 27. To3 is found in the upper part of chron 27r through chron 27, To2 is contained completely within chron 27r and To1 is found in 28 and the base of 27r. Tomida and Butler (1980) determined that the Dragon local fauna is found in the upper part of chron 28 and the base of chron 27r. Using magnetostratigraphy, Tomida and Butler (1980) and Tomida (1981) demonstrated that there are fossil localities in the

Nacimiento Formation that also occur in chron 28 and the lower parts of 27r, and therefore correlate with those of the Dragon local fauna. However, the localities that produce fossils of To1 in the San Juan Basin are few in number and generally produce few fossils. Tomida (1981) listed a total of only 11 specimens assigned to seven taxa from the University of Arizona collections from To1.

Comparison of certain fossil taxa from the Nacimiento Formation with those from the Dragon local fauna suggest that part of the latter may actually correlate with localities considered to be To2 in the Nacimiento Formation. Correlations using the multituberculate *Catopsalis fissidens* (=*C. utahensis:* Middleton, 1982, 1983; Williamson et al., 1991; Lucas et al., in press) and the taeniodont *Conoryctella pattersoni* (see Schoch and Lucas, 1981a, b; Schoch, 1986) indicate that localities in Kutz Canyon and at Chico Springs (Fig. 5) are temporally equivalent to those at Dragon Canyon, Utah. However, the presence of *Tetraclaenodon* at the Nacimiento localities would place them within To2 (sensu Archibald et al., 1987), suggesting that part of the Dragon local fauna falls within To2. Alternatively, the absence of *Tetraclaenodon* from the Dragon local fauna may be due to facies differences. Absence of *Tetraclaenodon* from the lowest Torrejonian levels of the Nacimiento Formation may also be due to sampling bias, as very few specimens have been recovered from these lower levels. This would imply that the first appearance of *Tetraclaenodon* is a poor indicator of the base of To2.

Archibald et al. (1987) gave the most comprehensive list of correlative Puercan and Torrejonian fossil localities of North America. Middle to late Puercan (Pu2/3) faunas include those from the Denver Formation, Colorado; the Wagonroad local fauna and Gas Tank Hill local fauna from the North Horn Formation, Utah; the Purgatory Hill local fauna and Garbani local faunas from the Tullock Formation of northeastern Montana and the RAV W-1 fauna from southwestern Saskatchewan. Very few early and middle Torrejonian faunas are known outside the San Juan Basin. Only the Dragon local fauna, Utah, correlates with the early Torrejonian (To1) of the San Juan Basin. The middle Torrejonian (To2) has no obvious correlatives outside the San Juan Basin although Archibald et al. (1987) tentatively correlated the Laudate local fauna from the poorly fossiliferous Goler Formation in southern California, based largely on the presence of *Tetraclaenodon* and the absence of *Pantolambda*. The late Torrejonian (To3), in contrast, is represented by many faunas outside the San Juan Basin, including faunas from Gidley quarry and Siberling quarry in the Lebo Formation, Crazy Mountain basin, Montana; Rock Bench quarry in the Fort Union Formation, Bighorn Basin, Wyoming, and Swain quarry in the Fort Union Formation, Washakie Basin, Wyoming.

Though several late Puercan sites are known from the Rocky Mountain region, the youngest occurs in the lower part of chron 28r. The oldest known Torrejonian faunas, represented by the Dragon local fauna and several small faunas from localities in the San Juan Basin, occur near the middle of chron 28. Therefore, a gap of approximately 1 million years (time scale of Harland et al., 1990) separates the youngest Puercan faunas from the oldest Torrejonian faunas. Also, the early and middle Torrejonian faunas are very poorly represented. Krause and Maas (1990) indicated that To1 and To2 are among the lowest in generic completeness estimates of all Paleocene faunal zones (67 and 71, respectively). The resulting bias, no doubt, is largely responsible for the high disappearance rates and relatively low appearance rates reported by Krause and Maas (1990) for Pu3, as well as the very low disappearance rates indicated for both To1 and To2.

CONCLUSIONS

Stratigraphy and biostratigraphy of the Nacimiento Formation are important for several reasons. First, the Nacimiento Formation contains fossils of mammals that serve as important early Paleocene reference faunas. In addition, these faunas occur throughout an interval of strata, allowing the determination of the relative and absolute ages of these faunas. Therefore, studies of the stratigraphic distribution of fossil mammals can help us correlate other fossiliferous continental strata, as well as supply the patterns necessary to generate models of mammal evolution for the early Cenozoic.

Continued refinement of our lithologic correlation of the Nacimiento Formation and extension of this correlation to Kutz Canyon and other exposures in the northwestern San Juan Basin will result in a more precise biostratigraphy of the Nacimiento Formation and will allow a more refined correlation with other early Paleocene fossil localities throughout North America.

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APPENDIX 1—MEASURED STRATIGRAPHIC SECTIONS

The numbered, lithologic units in the measured sections in Fig. 5 are described here. Colors are those of Goddard et al. (1984).

West Fork Gallegos Canyon

Top of section is located at NW¼ NE¼ SW¼ sec. 14, T25N, R12W (USGS Carson Trading Post, 7.5-minute map), San Juan County, New Mexico. Dip of strata is less than 5°.

unit	lithology	thickness (m)
	Nacimiento Formation:	
	Arroyo Chijuillita Member:	
16	Sandstone: yellowish gray (5 Y 7/2); very fine grained; well sorted; subrounded; well indurated; quartzarenitic; noncalcareous; forms platy, bioturbated ledge.	0.5
15	Mudstone: yellowish gray (5 Y 7/2); noncalcareous.	3.5
14	Sandstone: yellow gray (5 Y 7/2); very fine grained; well sorted; subrounded; well indurated in places; noncalcareous; subarkosic; trough crossbedded.	6.1
13	Mudstone: brownish gray (5 YR 4/1); slightly sandy in places.	6.0
12	Silcrete: light gray (N 7).	1.0
11	Sandstone: light olive gray (5 Y 5/2); fine grained; well sorted; subrounded-subangular; volcanic litharenite; noncalcareous; clayey in places with lignitic seams and some black plates of manganese?-cemented sandstone.	5.6
10	Sandstone: white (N 9), with manganese?-cemented zones; brown (5 YR 4/1); fine grained; moderately sorted; subrounded; subarkosic; calcareous; trough crossbedded.	15.0
	Offset from NW¼ NW¼ SW¼ sec. 14, T25N, R12W to SE¼ NE¼ sec. 15, T25N, R12W.	
9	Mudstone: light brownish gray (5 YR 6/1) with slickensides; moderate yellowish brown (10 YR 5/4); noncalcareous.	2.2
8	Mudstone: light olive gray (5 Y 6/1) with moderate red brown (10 R 4/6) slickensides.	1.5
7	Mudstone: mottled pale red (5 R 6/2) and grayish red (5 R 4/2), noncalcareous.	1.5
6	Mudstone: light brownish gray (5 YR 6/1); noncalcareous.	1.3
5	Mudstone: brownish gray (5 YR 4/1) with some goethite in streaks and blobs; moderate brown (5 R 4/4); noncalcareous.	0.8
4	Muddy siltstone: yellowish gray (5 Y 8/1); noncalcareous, and laterally equivalent sandstone: pinkish gray (5 YR 8/1); fine-medium grained; moderately sorted; subrounded; subarkosic; noncalcareous; trough crossbedded.	3.9
	Offset from SE¼ NE¼ sec. 16, T25N, R12W, to SE¼ NW¼ SW¼ sec. 10, T25N, R12W.	
3	Mudstone: grayish red purple (5 RP 4/2); slickensided; gleyed; noncalcareous; forms prominent purple band.	0.6
2	Sandy mudstone: grayish red (5 Y 6/1); noncalcareous; forms very prominent band.	1.3
	Ojo Alamo Sandstone:	
1	Sandstone: very pale orange (10 YR 8/2); fine-coarse grained; moderately sorted; subrounded-subangular; quartzarenitic; noncalcareous; exposed along arroyo cut and adjacent areas.	not measured

Chico Springs

Top of section is located in SE¼ SE¼ SE¼ sec. 28, T25N, R11W (USGS Huerfano Trading Post NW, 1966, 7.5-minute map), San Juan County, New Mexico. Dip of strata is less than 5°.

unit	lithology	thickness (m)
	Nacimiento Formation:	
	Ojo Encino Member:	
7	Sandstone: yellowish gray (5 Y 8/1); very fine to medium grained; poorly sorted; subrounded; subarkosic; multistoried; trough crossbedded; contains silica pebble conglomerate at base and cannonball concretions; forms prominent cliff.	22.5
6	Mudstone: same color and lithology as unit 3.	2.4
5	Sandstone: same lithology and color as unit 1.	6.5
4	Silty mudstone: same lithology and color as unit 2; with sandstone: light olive gray (5 Y 6/1); very fine-fine grained; poorly sorted; subangular; quartzarenitic; noncalcareous.	10.3

3	Mudstone: light brownish gray (5 YR 6/1).	3.8
2	Silty mudstone: yellowish gray (5 Y 7/2); noncalcareous; laminar (some fissility).	4.5
1	Sandstone: pale yellow brown (10 YR 6/2) weathered, yellow gray (5 Y 7/2) fresh; very fine-fine grained; poorly sorted; subangular quartzarenitic; calcareous; contains brown cannonball concretions and silicified logs; trough crossbedded.	4.3

Base of section is located in NE¹/₄ SE¹/₄ SE¹/₄ sec. 28, T25N, R11W.

De-Na-Zin Wash

Top of section is located in SE¹/₄ NW¹/₄ NW¹/₄ sec. 10, T24N, R11W (USGS Huerfano Trading Post SW, 1966, 7.5-minute map), San Juan County, New Mexico. Dip of strata is less than 5°.

unit	lithology	thickness (m)
	Nacimiento Formation:	
	Ojo Encino Member:	
37	Sandstone: same lithology and color as unit 35; caps drainage divide.	12.0
36	Mudstone: lithology and color like unit 34.	2.9
35	Sandstone: lithology and color like unit 33.	6.0
34	Mudstone: light olive gray (5 Y 6/1); deeply weathered.	5.3
33	Sandstone: yellowish gray (5 Y 8/1); very fine to medium grained; poorly sorted; subrounded; subarkosic; multistoried; trough crossbedded; contains silica pebble conglomerate at base and cannonball concretions; forms prominent cliff.	22.5
32	Sandy siltstone: same lithology and color as unit 24; some trough-crossbedded sandstone ledges, lenses; contains a few thin, discontinuous silcretes.	19.5
	Lowest Tongue of Penistaja Bed:	
31	Sandstone: yellowish gray (5 Y 8/1); weathers light brown (5 YR 6/4); fine grained; well sorted; subarkosic; noncalcareous; forms ledge, trough crossbedded, top bioturbated, laterally equivalent to silcrete.	3.0
	Arroyo Chijuillita Member:	
30	Sandy siltstone: same lithology and color as unit 28.	9.0
29	Silcrete: light brownish gray (5 YR 6/1); forms ledge.	0.3
28	Sandy siltstone: same lithology and color as unit 24; top 0.7 m has silcrete nodules.	6.5
27	Sandstone: same lithology and color as unit 25.	0.6
26	Mudstone: yellowish gray (5 Y 7/2); noncalcareous.	7.6
25	Sandstone: yellow gray (5 Y 8/1); fine-medium grained; moderately sorted; subrounded; subarkosic; noncalcareous; forms prominent marker bed.	1.0
24	Sandy siltstone: lithology and color like unit 15.	8.5
23	Mudstone: pale red brown (10 R 5/4); noncalcareous; forms prominent red band.	3.2
22	Sandy mudstone: near brownish gray (5 YR 4/1); gleyed; calcareous; forms prominent purple band.	1.2
21	Sandy siltstone: lithology and color like unit 17; with a silcrete lens: lithology and color like unit 16; and sandstone lenses: lithology and color like unit 20; trough crossbedded.	12.0
20	Sandstone: white (N 9) and pinkish gray (5 YR 8/1); very fine grained; well sorted; subrounded; quartzarenitic; trough crossbedded; top very bioturbated; laterally equivalent to persistent silcrete ledge.	0.8
19	Sandy siltstone: lithology and color like unit 15.	2.4
18	Sandstone: very pale orange (10 YR 8/2) to light brown (5 YR 6/4); fine grained; well sorted; subrounded; subarkosic; noncalcareous; trough crossbedded; forms ledge.	0.8
17	Sandy siltstone: lithology and color like unit 15; with thin white sandstone: lithology and color like unit 12.	10.5
16	Silcrete; pinkish gray (5 YR 8/1); forms ledge.	0.2
15	Sandy siltstone: light brownish gray (5 YR 6/1); noncalcareous.	1.5
14	Silcrete: light gray (N 7); vesicular texture; vesicles filled with dark yellow brown (10 YR 4/2) fine-grained matrix.	0.2
13	Silty mudstone: pale red near (10 R 6/2) and (5 R 6/2); noncalcareous; overlies thin silcrete and forms prominent band.	2.6
12	Clayey sandstone: yellowish gray (5 Y 8/1); very fine grained; well sorted; subrounded; litharenitic; calcareous.	4.8
11	Mudstone: brownish gray (5 YR 4/1) and muddy siltstone: yellowish gray (5 Y 8/1); noncalcareous.	2.7
10	Silty sandstone: lithology and color like unit 5; forms "*Taeniolabis* zone" (sensu Sinclair and Granger, 1914), 0.5–3.0 m thick with occasional channel sandstones (lithology and color like unit 8) cutting into this unit and underlying unit 9.	3.0
9	Sandy mudstone: mottled light brownish gray (5 YR 6/1), pale red (5 R 6/2) and light olive gray (5 Y 6/1); slightly calcareous.	2.8
8	Sandstone: yellowish gray (5 Y 8/1) to dark yellowish orange (10 YR 6/6); has dark brown (10 YR 4/2) bedding planes of organic material, dark gray (N 3) manganese? nodules, and silicified wood; very fine-fine grained; moderately sorted; subangular; litharenitic; noncalcareous; clayey in places; trough crossbedded.	8.3
7	Mudstone: yellowish gray (5 Y 7/2); with thin sandstone lenses: yellowish gray (5 Y 8/1); very fine grained; well sorted; subrounded; subarkosic; noncalcareous.	5.7
6	Silty mudstone: mottled light olive gray (5 Y 6/1) and grayish red purple (5 RP 4/2) and thin silcrete; pinkish gray (5 YR 8/1); with local, thin (about 10 cm), brownish black (5 YR 2/1) lignitic mud at 1.25 m; prominent red streak at 0.5 m.	2.5
5	Silty sand: grayish red (10 R 4/2); very fine-medium grained; poorly sorted; subangular; micaceous volcanic litharenitic; noncalcareous; forms red doublet of "*Ectoconus* zone" (sensu Sinclair and Granger, 1914) and contains occasional sandstone lenses.	4.9
4	Mudstone: light brownish gray (5 YR 6/1); noncalcareous.	3.9
3	Silty mudstone: mottled grayish red purple (5 RP 4/2) and grayish orange (10 YR 7/4); gleyed; calcareous; top 0.2 m has goethite blobs.	1.6
2	Sandy mudstone: very pale orange (10 YR 8/2) and grayish orange (10 YR 7/4); fine-coarse grained; poorly sorted; subrounded; quartzose.	2.5
	Ojo Alamo Sandstone:	
1	Sandstone: yellowish gray (5 Y 7/2); fine-coarse grained; poorly sorted; subrounded; quartzarenitic; noncalcareous; trough crossbedded.	not measured

Base of section is located in NE¹/₄ SE¹/₄ SE¹/₄ sec. 9, T24N, R11W.

West Flank Kimbeto Wash

Top of section is located at NE¹/₄ NE¹/₄ NE¹/₄ sec. 12, T23N, R10W (USGS Kimbeto, 1967, 7.5-minute map), San Juan County, New Mexico. Dip of strata is less than 5°.

unit	lithology	thickness (m)
	Nacimiento Formation:	
	Ojo Encino Member, Penistaja Bed:	
35	Sandstone: yellowish gray (5 Y 8/1); medium to coarse grained; moderately sorted; subangular; feldsarenitic; noncalcareous; trough crossbedded near base, planar laminated above 1 m.	10.5
	Arroyo Chijuillita Member:	
34	Mudstone: color and lithology like unit 32.	1.0
33	Sandstone: weathered, dark yellowish orange (10 YR 6/6); fine grained; well sorted; subrounded; quartzarenitic; noncalcareous.	0.5
32	Mudstone: light olive gray (5 Y 5/2); noncalcareous.	2.3
31	Sandstone: weathers grayish orange (10 YR 7/4); very fine grained; well sorted; quartzarenitic; noncalcareous.	2.5
30	Siltstone: weathers light olive gray (5 Y 5/2), slightly more yellow, fresh; noncalcareous.	4.0
29	Mudstone: olive gray (5 Y 4/1), light olive gray (5 Y 5/2) and grayish red (10 R 4/2) banded; not laterally extensive.	4.5
28	Mudstone: color and lithology like unit 26.	8.5
27	Mudstone: light olive gray (5 Y 5/2); forms extensive band.	0.8
26	Mudstone: same color and lithology as unit 16.	6.0
25	Siltstone and silcrete: siltstone is white (N 9); noncalcareous; silcrete is light gray (N 7) and composes lower 0.2 m.	1.0
24	Mudstone: same color and lithology as unit 16.	5.8
23	Lignite; moderate yellowish brown (10 YR 5/4); noncalcareous; contains turtle shells and gar scales.	0.3

22	Mudstone, muddy sandstone and intraformational conglomerate: mudstone is same color and lithology as units 16 and 13; muddy sandstones are light olive gray (5 Y 5/2); fine to medium grained; poorly sorted; subrounded; feldsarenitic; intraformational conglomerates are olive gray (5 Y 4/1); fine to coarse grained with clayballs up to about 2 cm; poorly sorted; subangular to subrounded; upper 4 m of unit composed of mudstones, sandstones and conglomerates intercalated in thin beds (<0.2 m), with carbonized plant remains and abundant gar scales, crocodilian teeth, turtle shell fragments, and rare mammal teeth.	8.0
	Offset from SW¼ SW¼ NW¼ sec. 7, T23N, R9W, to SW¼ SW¼ NE¼ sec. 14, T23N, R10W.	
21	Sandstone: dark yellowish orange (10 YR 6/6), dark yellowish brown (10 YR 5/4) to dark yellowish brown (10 YR 2/2); medium-coarse grained; poorly sorted; subangular; litharenitic; calcareous and well indurated at base where it forms a dark brown bench; multistoried and trough crossbedded; thins to northeast over several kilometers; offset to north on top of sandstone.	5.5
20	Mudstone: light olive gray (5 Y 6/1) to olive gray (5 Y 4/1); noncalcareous.	3.5
19	Siltstone and mudstone: siltstone is light olive gray (5 Y 6/1); noncalcareous; intercalated with thin (0.5 m) bands of mudstone; mudstone is same color and lithology as mudstone of unit 18.	4.6
18	Mudstone and silcrete: mudstone is olive gray (5 Y 4/1); noncalcareous; topped by thin light gray (N 7) silcrete.	3.6
17	Sandstone: olive gray (5 Y 4/1); medium grained; well sorted; subrounded; feldsarenitic; calcareous; planar beds; thinly bedded.	1.0
16	Mudstone: same color and lithology as unit 14.	7.5
15	Siltstone and silcrete: siltstone is light olive gray (5 Y 5/2); noncalcareous; silcrete is light gray (N 7); variable in thickness, thinning to west; very persistent, here silcrete composes lower 0.2 m.	0.4
14	Mudstone: color and lithology like unit 10; contains some reddish or purplish streaks; noncalcareous.	1.1
13	Muddy sandstone: olive gray (5 Y 4/1), weathers light olive gray (5 Y 6/1), with some reddish mottles on weathered surface; fine to medium grained; moderately sorted; subrounded; feldsarenitic; noncalcareous.	2.1
12	Mudstone: grayish red (10 R 4/2) and pale olive (10 Y 6/2) mottled; contains a few grayish streaks of selenite that cut across bedding; very prominent marker bed.	2.8
11	Sandstone, muddy sandstone, mudstone and silcrete: sandstone color and lithology like sandstone of unit 9; muddy sandstone is olive gray (5 Y 4/1); fine to medium grained; moderately sorted; subrounded; feldsarenitic; noncalcareous; mudstone color and lithology like unit 10; silcrete thin and not persistent.	6.0
10	Mudstone: color and lithology like unit 7.	2.0
9	Silty mudstone and sandstone: silty mudstone is grayish red (10 R 4/2) and pale olive (10 Y 6/2) mottled; sandstone is yellowish gray (5 Y 7/2); very fine grained; well sorted; quartzarenitic; ripple laminated; red and white bands form persistent marker bed.	3.5
8	Mudstone: color and lithology like unit 6; fossiliferous; equals Black Toe faunal level of Standhardt (1980) and Archibald et al. (1987); equals *Ectoconus* zone of Sinclair and Granger (1914).	4.0
7	Mudstone: color and lithology like unit 4.	0.9
	Offset from NW¼ SE¼ SE¼ sec. 14, T23N, R10W, to NW¼ NW¼ NW¼ sec. 23, T23N, R10W.	
6	Mudstone: olive gray (5 Y 4/1), weathers light olive gray (5 Y 6/1); massive; slickensided.	1.5
5	Sandstone: yellowish gray (5 Y 8/1); very fine grained; well sorted; subrounded; subarkosic; contains some silicified wood; trough crossbedded.	4.0
4	Mudstone: olive gray (5 Y 4/1), weathers brownish gray (5 YR 4/1); massive; brittle; slickensided.	1.5
3	Sandy mudstone: olive gray (5 Y 4/1); noncalcareous.	0.9
2	Muddy siltstone: pale brown (5 YR 5/2); noncalcareous; bioturbated and ripple laminated to massive.	3.5
	Ojo Alamo Sandstone:	
1	Sandstone: very pale orange (10 YR 8/2); fine-coarse grained; moderately sorted; subrounded-subangular; quartzarenitic; noncalcareous.	not measured

Base of section is located in NW¼ NE¼ NW¼ sec. 23, T23N, R10W.

Betonnie Tsosie Wash

Top of section is located in NE¼ SW¼ SW¼ sec. 16, T25N, R8W (Lybrook NW, 1966, 7.5-minute map), San Juan County, New Mexico. Dip of strata is less than 5°.

unit	lithology	thickness (m)
	Nacimiento Formation:	
	Ojo Encino Member:	
44	Muddy sandstone: equals base of *Pantolambda* zone of Sinclair and Granger (1914); highly weathered.	not measured
43	Mudstone: lithology and color like mudstone of unit 39.	5.7
	Offset from SE¼ SW¼ NW¼ sec. 16, T23N, R8W, to NE¼ SE¼ SW¼ sec. 17, T23N, R8W.	
42	Sandstone: lithology and color like unit 40.	10.5
	Offset from NE¼ SE¼ SW¼ sec. 17, T23N, R8W, to SE¼ NE¼ NE¼ sec. 19, T23N, R8W.	
41	Siltstone: pale olive (10 Y 6/2); noncalcareous, with grayish brown (5 YR 3/2), calcareous spherical concretions that weather to radiating "needles"; lower 2–3 m of unit interfingers with underlying sandstone; top grades to black mudstone (like unit 39); highly fossiliferous with abundant turtle and crocodilian bones.	19.5
40	Sandstone: yellowish gray (5 Y 8/1); medium-coarse grained; moderate sorting; subangular; micaceous feldsarenitic; noncalcareous; trough crossbedded; contains large, brown (5 YR 3/4), calcareous cannonball concretions; part of large multistory channel complex with some mud wedges seen laterally; highly weathered and vegetated at top.	22.5
39	Mudstone: lithology and color like mudstone of unit 37.	3.0
38	Sandstone: yellowish gray (5 Y 8/1); medium-coarse grained; moderately sorted; subangular; micaceous feldsarenitic; noncalcareous; with large, moderate brown (5 Y 8/1), calcareous, cannonball concretions; contains large silicified logs and mud ripups up to 3 cm across.	4.5
37	Mudstone: lithology and color like mudstone of unit 34.	3.0
	Offset from SE¼ NE¼ NE¼ sec. 19, T23N, R8W, to NE¼ NW¼ SE¼ sec. 19, T23N, R8W.	
36	Sandstone: lithology and color like unit 35; fines upward last 2.5 m to greenish muddy sandstone.	22.0
	Offset from SE¼ NW¼ SE¼ sec. 19, T23N, R8W, to NE¼ NE¼ SE¼ sec. 25, T23N, R9W.	
35	Sandstone: lithology and color like unit 24; with large, cannonball concretions about 0.5 m in diameter; 1.5 m band of greenish finer sandstone at top.	9.0
	Offset from NE¼ NE¼ SE¼ sec. 25, T23N, R9W, to NW¼ NE¼ SE¼ sec. 25, T23N, R9W.	
	Arroyo Chijuillita Member:	
34	Mudstone: lithology and color like mudstone of unit 30.	12.7
33	Muddy sandstone: light olive gray (5 Y 6/1); very fine-fine grained; very poorly sorted; micaceous feldsarenitic; noncalcareous; contains concretions like those of unit 32.	1.5
32	Mudstone: lithology and color like mudstone of unit 21; some brown and gray concretions scattered on surface, many of which contain plant and bone fragments.	12.0
31	Sandstone: lithology and color like unit 24; trough crossbedded.	8.7
30	Mudstone: lithology and color like mudstone of unit 28.	8.0
29	Mudstone and sandy mudstone: light olive gray (5 Y 6/1); laminated with much organic material; very extensive but locally pinches out or is obscured by cover of overlying black mudstone.	1.5
	Offset from NE¼ SE¼ SE¼ sec. 25, T23N, R9W, to NE¼ NE¼ NW¼ sec. 36, T23N, R9W.	
28	Mudstone: color and lithology like mudstone of unit 21.	4.5

27	Mudstone and muddy sandstone: mudstone is light olive gray (5 Y 6/1) with mottles of dark gray (N 3) and light brownish gray (5 YR 6/1); slickensided; slickensides are light olive brown (5 Y 5/6); muddy sandstone is yellowish gray (5 Y 7/2); very fine-medium grained; poorly sorted; subangular-subrounded; micaceous litharenitic; ripple laminated; sandstone forms lenses; unit forms distinctive multicolored band to south, channel that cuts into this contains gar scales and silicified wood.	5.1

Offset from NE¼ NE¼ NW¼ sec. 36, T23N, R9W, to SW¼ NE¼ NW¼ sec. 36, T23N, R9W.

26	Sandstone: grayish orange (10 YR 7/4) and yellowish gray (5 Y 8/1); very fine grained; well sorted; subrounded; subarkosic; slightly calcareous.	6.0
25	Sandstone: same color and lithology as unit 24.	3.0
24	Sandstone: yellowish gray (5 Y 7/2); medium-coarse grained; moderate sorting; subangular; feldsarenitic; noncalcareous; trough crossbedded; contains brownish gray (5 YR 4/1), calcareous cannonball concretions; sandstone is ridge former; hematized in places; becomes clayey to north.	3.0

Offset from SW¼ NE¼ NW¼ sec. 36, T23N, R9W, to SW¼ NE¼ SW¼ sec. 36, T23N, R9W.

23	Mudstone: lithology and color like mudstone of unit 21.	3.0
22	Mudstone: light olive gray (5 Y 6/1) and light brown (5 YR 5/6) and dark yellowish orange (10 YR 6/6); noncalcareous.	1.5
21	Mudstone: light olive gray (5 Y 6/1); some carbonaceous mudstone lenses; lithology and color like unit 19.	5.3
20	Sandstone and mudstone: sandstones grayish yellow (5 Y 8/4); fine grained; well sorted; quartzarenitic; mudstones same color and lithology as unit 18; noncalcareous; some lignitic shale (like unit 19).	4.1
19	Carbonaceous mudstone: brownish gray (5 YR 4/1); noncalcareous; makes distinctive marker bed.	0.5
18	Mudstone: same color and lithology as unit 9.	3.0
17	Mudstone: brownish gray (5 YR 4/1); noncalcareous.	1.5

Offset from NW¼ SE¼ SW¼ sec. 36, T23N, R9W (Lybrook NW, 1966, 7.5-minute map), to NE¼ NE¼ NE¼ sec. 2, T22N, R9W (Kimbeto, 1967, 7.5-minute map).

16	Siltstone: same color and lithology as unit 12; contains some manganese? concretions like those in unit 11.	4.6
15	Sandstone, siltstone and mudstone: lithologies and colors like unit 14; thin (0.2 m) mudstone with silcrete at base, lithologies and colors like unit 9.	4.0
14	Sandstone and siltstone: sandstone lithology and coloration like unit 11; siltstone lithology and coloration like unit 12; sandstone is at base with some siltstone in upper part of unit.	4.5
13	Mudstone and silcrete: mudstone lithology and coloration like unit 9; silcrete lithology and coloration like unit 3; thin silcrete is at base of unit.	3.0
12	Siltstone: grayish orange (10 YR 7/4); contains small calcite crystals; forms very prominent band.	1.5
11	Sandstone: yellowish gray (5 Y 8/1); very fine; well sorted; subrounded; subarkosic; calcareous; trough crossbedded with some yellowish gray (5 Y 7/2) clay flasers; contains locally medium dark gray (N 4) manganese?-cemented sandstone.	6.0

Offset from NE¼ NE¼ NE¼ sec. 2, T22N, R9W, to SW¼ SE¼ SW¼ sec. 35, T23N, R9W (Kimbeto, 1967, 7.5-minute map).

10	Mudstone: mostly light olive (5 Y 6/1) with dark yellowish orange (10 YR 6/6) and grayish yellow (5 Y 8/4) slickensides; contains some sandstone lenses like unit 11; trough crossbedded; fossiliferous, contains upper part of *Ectoconus* zone of Sinclair and Granger (1914).	4.5
9	Mudstone: lithology and coloration like unit 5; this is base of *Ectoconus* zone of Sinclair and Granger (1914).	0.8
8	Clayey sandstone: yellowish gray (5 Y 7/2) and grayish orange (10 YR 7/4); very fine grained; well sorted; subangular; subarkosic; slightly calcareous.	2.0
7	Sandstone: yellowish gray (5 Y 8/1); very fine grained; well sorted; subrounded; subarkosic; contains some silicified wood; trough crossbedded.	1.2
6	Mudstone: mottled pale greenish yellow (10 Y 8/2) and moderate brown (5 YR 3/4); forms prominent red and green band; in some places red color dominates.	3.1
5	Mudstone: light olive gray (5 Y 5/2); slickensided.	1.7
4	Mudstone: light olive gray (5 Y 6/1); slickensided; noncalcareous.	1.3
3	Silcrete: pale olive (10 Y 6/2) to light olive gray (5 Y 6/1).	0.3
2	Siltstone: pale brown (5 YR 5/2); noncalcareous; bioturbated and ripple laminated to massive; laterally equivalent to reddish clays and some thin silcretes.	1.3

Ojo Alamo Sandstone:

1	Sandstone: yellowish gray (5 Y 7/2); medium-coarse grained; moderately sorted; subrounded; sublitharenitic; noncalcareous; trough crossbedded.	4.5

Base of section is located in NW¼ NE¼ NW¼ sec. 2, T22N, R9W (Kimbeto, 1967, 7.5-minute map), San Juan County, New Mexico.

Escavada Wash

Top of section is located at SE¼ SW¼ SW¼ sec. 27, T23N, R7W (USGS Lybrook, 1966, 7.5-minute map), Sandoval County, New Mexico. Dip of strata is less than 5°.

unit	lithology	thickness (m)
	San Jose Formation:	
	Cuba Mesa Member:	
31	Sandstone: dark yellowish orange (10 YR 6/6); medium-coarse grained; moderately sorted; subrounded; subarkosic; noncalcareous; trough crossbedded, contains silicified wood; conglomeratic at base with quartzite pebbles.	not measured
	unconformity	
	Nacimiento Formation:	
	Escavada Member (type section):	
30	Silty mudstone: brownish gray (5 YR 4/1) with moderate yellowish brown (10 YR 5/4) streaks.	6.0
29	Sandstone: yellowish gray (5 Y 8/1); fine grained; well sorted; subrounded; subarkosic; calcareous; trough crossbedded; forms cliff.	2.8
28	Sandy siltstone: yellowish gray (5 Y 8/1); slightly calcareous.	2.3
27	Mudstone: lithology and color like unit 17.	3.8
26	Mudstone: pale red (5 R 6/2); slightly calcareous.	1.0
25	Clayey sandstone: lithology and color like unit 18.	6.0
24	Sandstone: lithology and color like unit 23; trough crossbedded.	2.8
23	Sandstone: very light gray (N 8); very fine-medium grained; poorly sorted; subrounded; quartzarenitic; calcareous; trough crossbedded; with dark brown granular scallops set in white sandstone.	3.0
22	Sandstone: yellowish gray (5 Y 8/1); very fine-coarse grained; poorly sorted; subrounded; subarkosic; noncalcareous; mostly low angle trough crossbedded; pebbly intervals laminar; forms cliff.	5.1
21	Mudstone: lithology and color like unit 9.	2.3
20	Silcrete: color and lithology like unit 11.	0.2
19	Clayey sandstone: lithology and color like unit 18.	5.2
18	Sandstone: lithology and color like unit 17; trough crossbedded, contains cannonballs; calcite-cemented zones form brown chutes and ledges.	4.4
17	Clayey sandstone: pinkish gray (5 YR 8/1); fine grained; well sorted; subrounded; sublitharenitic; noncalcareous; trough crossbedded; greenish clay streaks.	4.5
16	Mudstone: lithology and color same as unit 13.	2.5
15	Silcrete: lithology and color same as unit 11; very persistent.	0.1
14	Mudstone, sandstone and silcrete: lithology and color same as unit 12.	3.0
13	Mudstone: lithology and color same as unit 9.	1.8
12	Mudstone, sandstone and silcrete: lithology and color same as unit 10.	1.3
11	Silcrete: light gray (N 7); weathers moderate orange pink (5 YR 8/4); forms prominent marker bed.	0.2
10	Mudstone, sandstone and silcrete: lithologies and colors same as unit 8.	5.0
9	Mudstone: brownish gray (5 YR 8/1); noncalcareous.	3.0
8	Mudstone, sandstone and silcrete: mudstones light gray (N 7) to light brownish gray (5 YR 6/2); sandstones light brownish gray (5 YR 6/1); very fine grained; well sorted; sub-	

	rounded; quartzarenitic; noncalcareous; silcretes are pinkish gray (5 YR 8/1).	4.5
7	Sandstone: light brownish gray (5 YR 6/1); weathers grayish orange pink (5 YR 7/2); fine grained; well sorted; subangular; quartzarenitic; silcrete-like; trough crossbedded; green/gray clay streaks in places; ripple laminated at base.	8.3
Ojo Encino Member:		
6	Mudstone: lithology and color same as unit 2; several, thin, discontinuous silcretes and sandy lenses.	11.3
5	Sandstone: lithology and color same as unit 3.	2.0
4	Sandstone: yellowish gray (5 Y 8/1); very fine grained; well sorted; subrounded; subarkosic; calcareous; trough crossbedded.	0.8
3	Sandstone: pale yellowish brown (10 YR 6/2) very fine grained; well sorted; subrounded; litharenitic; noncalcareous; many siderite concretions.	10.2
2	Mudstone: brownish gray (5 YR 4/1) to light olive gray (5 Y 6/1) with dark yellowish brown (10 YR 4/2) slickensides.	6.5
1	Silty mudstone: yellowish gray (5 Y 7/2); noncalcareous.	not measured

Base of section is located in NW¼ NW¼ NW¼ sec. 34, T23N, R7W.

West Flank Torreon Wash

Top of section is located at SE¼ SE¼ NW¼ sec. 27, T21N, R5W (USGS Deer Mesa, 1966, 7.5-minute map), Sandoval County, New Mexico. Dip of strata is less than 5°.

unit	lithology	thickness (m)
Escavada Member:		
22	Silcrete: yellowish gray (5 Y 8/1).	0.1
Ojo Encino Member (type section):		
21	Mudstones: lithology and color like unit 9.	14.1
20	Sandstone and siltstone: sandstone is pinkish gray (5 YR 8/1); very fine grained; well sorted; subrounded; subarkosic; calcareous; siltstone is pale red (10 R 6/2); noncalcareous; mostly sandstone with thinner siltstone beds, siltstone more common in upper 1.2 m of unit.	10.5
19	Siltstone: light brownish gray (5 YR 6/1); with many small pale brown (5 YR 5/2) siderite? nodules.	9.5
18	Sandstone: yellowish gray (5 Y 8/1); medium-coarse grained; moderately sorted; volcanic litharenitic; trough crossbedded; many red/green clay lenses.	9.5
17	Sandy mudstone and sandstone: sandy mudstone is pale brown (5 YR 4/1); sandstone is grayish olive green (5 GY 3/2); very fine-fine grained; moderately sorted; subrounded; volcanic litharenitic; noncalcareous; forms thin greenish stringers and green and pink banded clay.	8.9
16	Mudstone: brownish black (5 YR 2/1); slickensided; laterally very persistent marker bed.	10.5
Offset from SW¼ SE¼ NW¼ sec. 27, T21N, R5W, to NE¼ NW¼ NW¼ sec. 27, T21N, R5W.		
15	Siltstone and sandstone: siltstone is light olive gray (5 Y 6/1) and grayish red (10 R 4/2); slightly calcareous; sandstone is pinkish gray (5 YR 8/1); very fine grained; subrounded; quartzarenitic; silcrete-like; trough crossbedded; upper 4.5 m of unit is reddish.	15.0
14	Muddy sandstone: grayish yellow green (5 GY 7/2); very fine grained; poorly sorted; subangular; subarkosic.	1.2
13	Sandstone: dusky yellow (5 Y 6/4); very fine grained; well sorted; subrounded; subarkosic; noncalcareous; contains large pale brown (5 YR 5/2) calcareous cannonballs and rollbars; also contains silicified wood.	2.2
12	Sandy siltstone: light brownish gray (5 YR 6/1); slightly calcareous; a thin (5 cm) pinkish gray (5 YR 8/1) silcrete; occurs 0.7 m above base.	2.3
11	Sandstone: dusky yellow (5 Y 6/4); fine grained; well sorted; subrounded; arkosic litharenitic; noncalcareous; low angle trough crossbeds.	4.5
10	Sandy mudstone and sandstone: sandy mudstone is yellowish gray (5 Y 8/1); sandstone is grayish yellow (5 Y 8/4); very fine grained, well sorted; subarkosic; noncalcareous; grayish red (5 R 4/2), calcareous siderite? concretions up to 0.3 m across occur in sandy mudstones and sandstones.	2.6
9	Silty mudstone: yellowish gray (5 Y 7/2); contains bands of selenite.	3.4
8	Siltstone and mudstone: brownish gray (5 YR 4/1); noncalcareous.	2.0
7	Mudstone, silty mudstone and siltstone: mudstone and silty mudstone are pale brown (5 YR 5/2) and pale yellow brown (10 YR 6/2); siltstone is yellow gray (5 Y 7/2); noncalcareous.	4.5
Offset from NE¼ NW¼ NW¼ sec. 27, T21N, R5W, to SE¼ SE¼ SW¼ sec. 28, T21N, R5W.		
Penistaja Bed (type section):		
6	Sandstone: lithology and color like unit 5; trough crossbedded; 1 m above base are 0.3–0.6 m diameter dark cannonball concretions; upper 1.2 m has silicified logs and cannonball concretions; offset to north on top of sandstone.	5.5
5	Sandstone: grayish orange (10 YR 7/4); fine grained; well sorted; subrounded; subarkosic; noncalcareous; contains clay ripups and silicified logs; planar to trough crossbedded.	1.0
Arroyo Chijuillita Member:		
4	Mudstone: light olive gray (5 Y 6/1); slickensides are moderate yellowish brown (10 YR 5/4); noncalcareous.	0.5
3	Silcrete: light brownish gray (5 Y 6/1).	0.1
2	Sandy mudstone: brownish gray (5 YR 4/1); calcareous.	1.1
1	Clayey sandstone: yellowish gray (5 Y 7/2) to dusky yellow (5 Y 6/4); very fine-fine grained; moderately sorted; subangular; quartzarenitic; noncalcareous.	2.5+

Base of section is located at SE¼ SW¼ SW¼ sec. 28, T21N, R5W.

East Flank Torreon Wash

Top of section is located at NE¼ SE¼ sec. 32, T21N, R4W (USGS Deer Mesa, 1966, 7.5-minute map), Sandoval County, New Mexico. Dip of strata is less than 5°.

unit	lithology	thickness (m)
San Jose Formation:		
Cuba Mesa Member:		
13	Sandstone: yellowish gray (5 Y 8/1); fine-medium grained; moderately sorted; subarkosic; very calcareous; planar bedded at base, grades up to trough crossbeds; contains silicified logs, quartzite cobbles and organic fragments at base.	not measured
unconformity		
Nacimiento Formation:		
Escavada Member:		
12	Silcrete: light brownish gray (5 GY 6/1); weathers light brown (5 YR 6/4) and dark yellowish orange (10 YR 6/6); very persistent.	0.2
11	Sandy lignite: lithology and color like unit 7.	4.0
10	Silcrete: light brownish gray (5 YR 6/1); discontinuous.	0.1
9	Siltstone: light brownish gray (5 YR 6/1); noncalcareous.	1.2
8	Silcrete: same lithology and color as unit 4; forms ledge.	0.3
7	Sandy lignite: brownish gray (5 YR 4/1); slickensides are grayish black (N 2); noncalcareous; slope former.	0.8
6	Sandstone: light gray (N 7); medium grained; well sorted; subrounded; quartzarenitic; noncalcareous; multistoried, lower 0.6 m trough crossbedded, upper 0.4 m is clayey and massive.	10.0
5	Sandy mudstone: pale brown (5 YR 5/2); noncalcareous.	0.9
4	Silcrete: weathers pinkish gray (5 YR 8/1); light brownish gray (5 YR 6/1) fresh; forms ledge.	0.1
3	Silty mudstone: brownish gray (5 YR 4/1); calcareous.	2.4
2	Siltstone, muddy siltstone and silcrete: siltstone and muddy siltstone are pinkish gray (5 YR 8/1) and light olive gray (5 Y 6/1); contain some calcite crystals; silcrete is pinkish gray (5 YR 8/1) and is a ledge former.	2.9
1	Mudstone and silty mudstone: brownish gray (5 YR 4/1); slightly calcareous.	not measured

Base of section is located at NE¼ NE¼ sec. 32, T21N, R4W.

Mesa de Cuba

Top of section located at NW¼ NE¼ NE¼ sec. 9, T20N, R2W (USGS Mesa Portales, 1961, 7.5-minute map), Sandoval County, New Mexico. Dip of strata is less than 5°.

unit	lithology	thickness (m)
	San Jose Formation:	
	Cuba Mesa Member:	
40	Sandstone: grayish orange (10 YR 7/4); fine-very coarse grained; poorly sorted; subrounded; micaceous litharenitic; noncalcareous; forms bench, then cliff; contains silicified wood; light brown (5 YR 5/6) and pale reddish brown (10 R 5/4).	not measured
	unconformity	
	Nacimiento Formation (type section):	
	Escavada Member:	
39	Sandstone and mudstone: lithology and coloration like unit 37, but much covered by blocks of San Jose Formation and vegetation.	19.2
	Ojo Encino Member:	
38	Mudstone: lithology and coloration like unit 36 but with hint of purple at base.	10.7
37	Sandstone and mudstone: sandstone lithology and coloration like unit 32; mudstone like unit 33; unit dominated by sandstone.	11.4
36	Mudstone: lithology and color like unit 24.	1.5
35	Sandstone: moderate yellowish brown (10 YR 5/4); fine grained; well sorted; subrounded; subarkosic; slightly calcareous; forms big bench, lenticular over 200 m, some arcuate crossbeds and soft sediment deformation, massive in places; much vertical jointing; attains thickness of 6.1 m.	2.8
34	Silcrete: lithology and color like unit 19.	0.2
33	Mudstone: lithology and color like unit 31; some thin yellow sandstones as in unit 30; sandstone lithology and color like unit 28.	22.9
32	Sandy mudstone: brownish gray (5 YR 4/1); not calcareous; forms prominent "purple" band.	1.7
31	Mudstone: lithology and color like unit 29, but with brownish gray (5 YR 4/1), calcareous ironstone concretion debris; some thin (0.6 m), lenticular sandstones 1.1 m above base.	2.2
30	Sandstone: lithology and color like unit 26; contains cannonball concretions like those in unit 28.	2.4
29	Mudstone: lithology and color like unit 27; some thin sandy beds.	6.8
28	Sandstone: grayish orange (10 YR 7/4) to yellowish gray (5 Y 7/2); very fine grained; well sorted; subrounded; subarkosic; noncalcareous; contains pale brown (5 YR 5/2), calcareous cannonball concretions; sandstone contains epsilon crossbeds in places; cliff-forming in places.	5.0
27	Mudstone: light olive gray (5 Y 6/1); noncalcareous; some thin sandy beds.	8.4
26	Sandy siltstone: grayish yellow green (5 GY 7/2) to pale olive (10 Y 6/2); noncalcareous.	0.7
25	Mudstone: brownish gray (5 YR 4/1); slightly calcareous.	3.0
24	Sandstone: pale yellowish brown (10 YR 6/2); fine grained; well sorted; subrounded; subarkosic; trough crossbedded.	2.2
23	Silty mudstone: brownish gray (5 YR 4/1); calcareous.	1.4
22	Sandy mudstone: yellowish orange (5 Y 7/2); calcareous.	2.3
21	Mudstone: light olive gray (5 Y 6/1); noncalcareous; forms very persistent green band.	1.3
20	Silcrete: pinkish gray (5 YR 8/4) and light brownish gray (5 YR 6/1); forms very persistent "purple" band.	0.3
	Penistaja bed:	
19	Sandstone: grayish orange (10 YR 7/4) to yellowish gray (5 Y 7/2); very fine grained; well sorted; subrounded; subarkosic; very calcareous; with pale brown (5 YR 5/2) cannonball concretions; sandstone is multistoried with numerous channels that exhibit basal scours and contain epsilon crossbeds with clay drapes; soft sediment deformation.	11.1
	Arroyo Chijuillita Member (type section):	
18	Mudstone, sandy mudstone and lignite: yellowish gray (5 Y 7/2); noncalcareous; some thin (5–10 cm) lignitic streaks, dark yellowish brown (10 YR 4/2) and moderate brown (5 YR 3/4); sulfurous partings are grayish yellow (5 Y 8/4) and some thin yellowish sandstones (0.2 m thick).	10.0
17	Muddy lignite: black (N 1); noncalcareous; very persistent.	1.5
16	Sandstone and mudstone: sandstone is yellowish gray (5 Y 7/2); very fine grained; well sorted; subangular; micaceous litharenitic; noncalcareous; mudstone is light olive gray (5 Y 5/2); noncalcareous; sandstone and mudstone contain many dark gray (N 3) manganese? nodules above 1.5 m above base of unit.	10.1
15	Sandstone: yellowish gray (5 Y 7/2); very fine-fine grained; moderately sorted; subangular; subarkosic; contains brown cannonball concretions up to 1 m across.	2.3
14	Siltstone and sandy mudstone: siltstone is light brownish gray (5 YR 6/1) with moderate brown (5 YR 3/4) slickensides; sandy mudstone is yellowish gray (5 Y 7/2); slightly calcareous; siltstone forms distinctive "purple" band in upper 8 m of unit.	11.6
13	Mudstone and sandstone: mudstone is light olive gray (5 Y 6/1); sandstone is yellowish gray (5 Y 7/2); very fine-fine grained; moderately sorted; subrounded-subangular; subarkosic; noncalcareous; mudstone contains organic debris; sandstone exhibits trough and epsilon crossbeds.	2.5
12	Silty mudstone: light olive gray (5 Y 6/1); noncalcareous.	3.5
11	Sandstone: lithology and color like upper sandstone of unit 9.	2.8
10	Mudstone: lithology and color like mudstone of unit 9.	2.8
9	Mudstone and sandstone: mudstone is medium dark gray (N 4) to dark gray (N 3) clay (0.35); sandstone is yellowish gray (5 Y 8/1); very fine grained; well sorted; subrounded; subarkosic; noncalcareous; trough crossbedded; sandstone is upper 2 m of unit.	2.4
8	Mudstone: light olive gray (5 Y 6/1); slightly calcareous.	2.9
7	Sandstone: very pale orange (10 YR 8/2); very fine grained; well sorted; subrounded; subarkosic; slightly calcareous; makes scour base on coal; trough crossbedded.	1.3
	Offset from NE¼ NE¼ SE¼ sec. 9, T20N, R2W, to SW¼ SW¼ sec. 13, T20N, R2W.	
6	Silty mudstone: brownish gray (5 YR 4/1) with streaks of moderate yellowish brown (10 YR 5/4) and thin (10 cm), black (N 1) bituminous coal, at top.	6.6
5	Mudstone: light olive gray (5 Y 6/1); slightly calcareous.	4.0
4	Sandstone: yellowish gray (5 Y 7/2); fine grained; well sorted; subarkosic; noncalcareous; contains a thin lenticular silcrete.	1.0
3	Mudstone: lithology and color like unit 2, but well exposed.	5.2
2	Mudstone: yellowish gray (5 Y 7/2); noncalcareous, much covered by soil and granite pediment gravel.	10.7
	Ojo Alamo Sandstone:	
1	Sandstone: grayish orange (10 YR 7/14) and moderate yellowish brown (10 YR 5/4); very fine-medium coarse grained; moderately sorted; subrounded; micaceous litharenitic; noncalcareous; fines upward to trough crossbeds; exposed in base of arroyo.	not measured
	Base of section is located at NW¼ NW¼ sec. 24, T20N, R2W.	

Appendix 2 on next page

APPENDIX 2—WELL LOG INFORMATION

#	Company	Well	Coord.	Location Sec.	Location Twp.	Location Rge.	GL	Base	Top	Thick
1	Dugan Production Corp.	Chaco #2	SE	6	24N	8W	2045	1702		
2	Merrion Oil and Gas Corp.	Roadrunner #1	NW	2	24N	8W	2189	1724	2077	353
3	Compass Exploration Inc.	State #1-16	SW	16	24N	7W	2213	1640	1990	350
4	Val R. Reese and Assoc.	Escrito Gallup	NE	27	24N	7W	2114	1654	1995	341
5	Grace Petroleum Corp.	Grace Federal 24-1	NW	24	24N	7W	2025	1589		
6	El Paso Natural Gas Co.	Canyon Largo #216	NE	15	24N	6W	2042	1521	1863	341
7	Val R. Reese and Assoc.	Nancy "B" #1-14	NE	14	23N	7W	2156	1727	2059	332
8	El Paso Natural Gas Co.	Canyon Largo #263	SW	35	24N	6W	2017	1562	1889	327
9	El Paso Natural Gas Co.	Bolaca 4-E	SE	1	23N	6W	2060	1566	1892	326
10	Robert L. Bayless	Glin Thomas	SW	22	22N	6W	2158	1832		
11	Apache Corporation	Jair No. 2	SW	8	22N	5W	2142	1713		
12	Humble Oil and Refin. Co.	Jicarilla "B" 1	NE	1	22N	5W	2065	1606	1934	328
13	Shell Oil Co.	Pool Four #1	SE	22	21N	5W	2176	1875		
14	The Skelly Oil Co.	Jicarilla E #1	NE	8	22N	4W	2083	1638	1916	277
15	Exeter Drilling Co.	Jicarilla Apache #1	NW	28	22N	4W	2102	1703	1983	280
16	Dugan Production Corp.	SIS #1	NW	21	21N	4W	2177	1793	2069	276
17	Dugan Production Corp.	Husky Federal #2	NW	25	21N	4W	2160	1810	2069	259
18	Grace Oil Co.	Divide No. 1	NE	3	21N	3W	2231	1624	1886	262
19	R. E. Lauritsen	Federal 8-21-2 No. 1	SE	8	21N	2W	2182	1682	1950	268
20	Benson Mineral Group	Federal 15-21-2 No. 1	SE	15	21N	2W	2187	1788	2041	253
21	Sun Oil Company	MC Elvain Gov't	NW	23	21N	2W	2151	1786	2050	265