55.1.78(78.9)

# Article XXII.— PALEOCENE DEPOSITS OF THE SAN JUAN BASIN, NEW MEXICO.

By W. J. Sinclair, Princeton University, and Walter Granger, American Museum of Natural History.

Plates XX–XXVII.

CONTENTS.



## Introduction.

A double interest attaches to the Paleocene formations of northwestern New Mexico because the oldest Tertiary mammal fauna so far discovered has been obtained from these beds and because it is possible to establish definitely the stratigraphic position of this fauna with reference to underlying dinosaur-bearing horizons.

The first collections from what are now known as the Puerco and Torrejon formations were made by David Baldwin for Professor Cope, from 1881 to 1888 and are now in the American Museum. They were further supplemented by the American Museum expeditions of 1892 and 1896 under Dr. Wortman, but although a considerable amount of material was thus acquired, little was known of the stratigraphic relationships of the fossiliferous beds, either to each other or to the rocks on which they rest, and but little more of the precise levels from which the collections were obtained. The most complete account of the stratigraphy hitherto published appeared in an article by Dr. J. H. Gardner in the December number of the Journal of Geology for 1910: "The Puerco and Torrejon Formations of the Nacimiento Group." Dr. Gardner's observations, however, cover only a portion of the two formations, and were made without the aid of sufficient palæontologic data.

Believing that valuable palæontologic and stratigraphic data could be acquired by a reëxamination of this field, the American Museum began in 1912, under Mr. Granger's direction, with the exploration, by a small party, of a portion of the Torrejon. Continuing in 1913, from the middle of June until early in October, with the party strengthened in numbers and equipment, a very careful examination of all of the fossiliferous area of both the Puerco and Torrejon was made. The result of the two seasons' work has been the securing of a collection which, in point of numbers and in completeness of the material, exceeds all previous collections from the Paleocene of this region.

Some time must elapse before the palæontological results are ready for publication. The geological data secured by the expedition are presented on the following pages.

## Itinerary.

The route of the expedition can readily be followed on the accompanying sketch-map, on which the localities where collections were made are indicated by numbers. Outfitting at Farmington on the San Juan River with Mr. Jack Martin of Farmington as cook and teamster and Messrs. Granger, Olsen and Sinclair as collectors, we proceeded southeasterly to Simpson's store on the Gallego, thence by way of Reidner's store, also on the Gallego, to the vicinity of Chico Springs, where a small collection of Torrejon fossils was made from two exposures about half a mile apart at the head of Chico Arroyo. Having located from here the fossiliferous horizons of the Puerco, operations were transferred to the vicinity of Barrel Spring and Ojo Alamo where a large collection was obtained from the upper-

most of the two Puerco levels, which, as will appear later, is characterized by numerous, but mostly fragmentary, remains of *Polymastodon*. Here also the relation of the Puerco to the underlying beds with dinosaurs was found to be exhibited with diagrammatic clearness. The discovery of Torrejon fossils in the section exposed in Barrel Spring Arroyo made possible a measurement of the thickness of the Puerco (see Section A, Fig. 2).

Having gathered all the fossils we could find, several camps were made some miles to the southeast on the west branch of Kimbetoh Arroyo and on Kimbetoh Arroyo at the old Dolan ranch (ruins only) about four miles above the United States Government stock-man's station at Kimbetoh. Here a surprising amount of material was collected from a lower fossil level in the Puerco, some twenty-seven or more feet above the base of this formation, and also from the Torrejon formation exposed in bluffs at the heads of the arroyos just mentioned (see Section B, Fig. 2). The fossils from the head of Kimbetoh Arroyo were afterwards found to be from a horizon one hundred feet below the level at which Torrejon fossils had hitherto been known to occur in the typical locality on Torrejon Arroyo. An exceedingly dry season, affecting water and range, made it necessary to postpone an examination of the Escavada Wash exposures and operations were transferred to the cliffs at the head of the east and west forks of Arroyo Torrejon where both fossil levels of the Torrejon formation gave most gratifying returns. From here, a brief excursion was made eastward to the Wasatch exposures in the vicinity of Ojo San Jose north of Nacimiento (Cuba) where scarcity of fossils, continuous rain and the proximity of typhoid induced us to return toward the head of Escavada Wash, collecting at intervals from the Torrejon formation along the line of cliffs which extends almost continuously from the Puerco River to the head of Escavada and beyond to the northwest. Some small Torrejon exposures in Blanco Cañon were also examined and the return trip to Farmington made by way of Chico Springs, Ojo Alamo and Pina Veta China to complete the examination of the southwestern margin of the Puerco.

## Structural Relationships; Location of Exposures.

The Paleocene formations of northwestern New Mexico occupy the center of a structural basin, about the margin of which appear the coal-bearing and other members of the Cretaceous. The dips of the Tertiary formations are, in general, toward the center of the basin. Exposures of both Puerco and Torrejon are confined to its south and southwest margin by the overlap of the basal sandstone of the Wasatch, which completely

conceals the Paleocene to the north and northeast, so far as at present known to the writers.

Although the type section of the Puerco examined by Cope is that along the Puerco River (Plate XXVII, Fig. 1) this formation may be studied to best advantage in the vicinity of Ojo Alamo, on various branches of Kimbetoh Arroyo three to four miles northeast of Kimbetoh, and on a large arroyo between Kimbetoh and Escavada Wash. Farther to the southeast, the broadening of the arroyos and the configuration of the topography prevent the occurrence of exposures of the lower part of the formation, so that on the Rio Puerco only the upper part of the Puerco is exposed, most of Cope's Puerco being referable to what is now called Torrejon (see Section D, Fig. 2). The Torrejon is well exposed in the face of the escarpment at the heads of Kimbetoh Arroyo, Escavada Wash, Alamo and Alamito Arroyos, and on both the east and west forks of Arroyo Torrejon, with small exposures in Blanco Cañon and considerable, though locally fossiliferous, areas about Chico Springs. The relation of the Puerco to the beds on which it lies may be studied to best advantage in the vicinity of Ojo Alamo.

## Pre-Puerco Formations.

In 1904, Mr. Barnum Brown collected for the American Museum some dinosaur remains in the vicinity of Ojo Alamo from shales beneath a conglomerate overlain unconformably by the Puerco. To "the shales below the conglomerate that contain numerous dinosaur and turtle remains" he gave the name Ojo Alamo beds, estimating their thickness as about 200 feet. In a note published by Dr. F. H. Knowlton,[1] Dr. J. H. Gardner claims to have found dinosaurs above the unconformity at the top of what the United States Geological Survey calls "Laramie" and "thus apparently of Puerco age" (Knowlton). It was, therefore, with considerable interest that the study of the stratigraphic relationships of the base of the Puerco was approached. Fortunately, no better sections could be desired than are found in Ojo Alamo and Barrel Spring Arroyos and on the various branches of Kimbetoh Arroyo. The contacts are clearly exposed and fossils are sufficiently abundant a few feet above and below them to afford data for age determinations. A discussion of the basal relationships of the Puerco will be limited to these sections (A and B, Fig. 2).

*Conglomeratic Sandstone with Fossil Logs:*— Along its southern and

[1] Proceedings of the Washington Academy of Sciences, Vol. XI, p. 232, footnote 47, August, 1909.

southwestern margin, the Puerco formation rests, with marked erosional unconformity, on a coarse, cross-bedded, conglomeratic, yellow-brown sandstone containing, toward its top, many large silicified logs lying prone and often invested in a capsule of indurated sand. The finer material of this sandstone is mostly angular quartz and feldspar, barely coherent. The pebbles are water-worn and chatter-marked, and comprise quartzite, jasper and various volcanics. It seems to represent material swept into the basin of accumulation by floods, perhaps during an interval of crustal uplift which stimulated the streams to carry down the gravels which had accumulated in their channels and to undermine their banks, destroying the large trees growing there. Some of these drift logs are two or three feet across and over 50 feet long. The branches and bark have been stripped off (foreground, Plate XXI). The centrum of a dinosaurian caudal vertebra was found, loose on the surface, by Mr. Jack Martin of the expedition, resting on this sandstone near the edge of Split Lip Flat, in the immediate vicinity of Barrel Spring. It was not in place, but it seems hardly probable that it had been carried to the spot where it was found by the Indians, who are afraid of fossil bones. Some may question its value as an index fossil. To us it seems probable that it had weathered out of the sandstone, as did the fragments of silicified logs lying about in its vicinity. It is badly worn and lacks the arch. This sandstone member varies in thickness from 28 to 66 feet.

*Shales with Dinosaurs, Upper Horizon.*— The sandstone varies in thickness because of the erosional unconformity at its top (Plate XXII) which will be discussed later. At its base it rests disconformably on a series of rusty-yellow, bluish, greenish and wine-red, banded clays with lenses of yellow channel sandstone, the Ojo Alamo beds of Brown. The disconformity between these clays and the heavy sandstone member above is no greater than usually occurs throughout the Puerco and Torrejon formations between sandstone channel-fillings and the clays in which they are cut. The clays are banded with a fair degree of regularity (Plate XX, Fig. 2) except where interrupted by the channel sandstones. A maximum thickness of some 58 feet was measured for this member (Sect. A, Fig. 2). It rests conformably on a conglomerate, the sandy matrix of which merges gradually upward with some of the sandstone lenses interstratified with the clays. A few feet above the conglomerate is a level characterized by abundant, but badly crushed, dinosaur bones, ceratopsian, trachodont and carnivorous, also turtles, crocodiles and garpikes. This seems to be the level of Brown's *Kritosaurus navajovius*. Much silicified wood strews the surface of the bone-bearing level and of the slopes above, but it seems to come from the overlying sandstone with silicified logs.

*Lower Conglomerate.*— The conglomerate below this dinosaur-bearing

horizon varies from a pebbly sandstone to a coarse conglomerate with water-worn chatter-marked quartzite, jasper, andesite and porphyrite pebbles. Sometimes it is incoherent, with a white clay-like substance feebly bonding together angular quartz and feldspar grains and the pebbles, but in other places it is cemented to form a rusty-yellow and fairly hard rock, which caps several mesas about a mile and a half below Barrel Spring. This formation has been observed only between Ojo Alamo and Barrel Spring Arroyos. It was traced southeasterly along the outcrop until it passes under ground in Barrel Spring Arroyo a few hundred yards above a point directly opposite the spring, which issues from beneath the conglomeratic sandstone with fossil logs. Its source has not been traced. Its thickness varies from 6 to 8 feet.

*Shales with Dinosaurs, Lower Horizon.*— This lower conglomerate lies, in its turn, disconformably on a series of bluish shales or, rather, clays, for they are quite incoherent. Lignite is sometimes present below the contact with the conglomerate and to the southwest of Barrel Spring, the top of this formation, for some feet below the conglomerate, is beautifully banded, wine-red strata alternating with bluish-gray. Dinosaur bones and silicified wood, both in place, occur throughout this banded zone. We did not ascertain how far below this level vertebrate fossils are found in these bluish-gray clays, but a trip down Ojo Alamo Arroyo to a point some eight miles below the store resulted in finding turtle and other reptile bones in shales apparently conformable with those just mentioned, so far as we could judge from rather hastily made observations. The only interruption to shale deposition seemed to be a prominent stratum of yellow-brown sandstone exposed some three miles below the store, in Ojo Alamo Arroyo, but this seemed to be conformable with the shales both above and below. Material is not yet available for determining whether the dinosaurs in the shales below the conglomerate differ from, or are identical with, those above it.

*Age of the Ojo Alamo Beds.*— The age of the Ojo Alamo dinosaur beds is in dispute. Mr. Brown has regarded them as certainly older than the Lance and probably correlative with the Edmonton Cretaceous. He has examined part of a trachodont maxilla collected a few feet above the conglomerate separating the two horizons at which dinosaur bones were found, also various teeth of carnivorous dinosaurs from above and below the conglomerate, obtained by the 1913 expedition and reports as follows:

"The reptilian and fish remains from the Ojo Alamo beds collected by the American Museum Expedition of 1913 are for the most part too fragmentary for specific determination. Even generic determination of isolated dinosaur teeth and bones must be considered a provisional reference. The collection is identified as follows:

| | |
|---|---|
| *Kritosaurus navajovius* Brown | maxillary and fragments of skull |
| *?Kritosaurus* sp. | dorsal centrum |
| *?Deinodon* sp. | separate teeth |
| Crocodile | tooth |
| *Lepisosteus* sp. | scales |

"The Trachodont dinosaur *Kritosaurus* is of especial interest in its bearing on the age of the beds.

"This genus was founded on an incomplete skull from Ojo Alamo collected in 1904. Bull. Am. Mus. Nat. Hist., Vol. XXVIII, Art. xxiv, pp. 267–274, 1910.

"In the type specimen the left nasal was preserved but without contact to contiguous parts. Its extraordinary form was at the time considered in part due to crushing and was not placed in the restored skull.

"Recently Mr. Lawrence M. Lambe, Ottawa Naturalist, Vol. XXVII, No. 11, Feb., 1914, described a perfect skull from the Belly River beds of Canada under the name *Gryposaurus notabilis*. In all respects, including the remarkable development of the nasals, premaxillaries and predentary and reduction of the orbital portion of the frontal, this skull agrees with the type of *Kritosaurus* and there is no doubt of its generic identity.

"The fauna of the Ojo Alamo beds is certainly older than that of the Lance and I have expressed the opinion that it was probably synchronous with the Edmonton. *Kritosaurus* is now known from the Belly River beds and has not yet appeared in extensive collections from the Edmonton, and as other reptilian remains are of primitive facies the Ojo Alamo beds may well be of Judith River Age.

"The Ojo Alamo fauna now known is as follows:

*Kritosaurus navajovius* Brown.
*?Monoclonius* sp.
*?Deinodon* sp.
*Thescelus rapiens* Hay.
Crocodile
*Lepisosteus* sp."

Mr. Gilmore has pronounced the dinosaur remains collected by Dr. Gardner from what he supposed to be the Puerco, but what is in reality Ojo Alamo, to be "a typical Ceratops-beds fauna."

Mr. Willis T. Lee favors a correlation of the dinosaur beds and associated conglomerate members with the Animas formation. If the Animas is, in turn, to be correlated with the Lance, which Dr. Knowlton regards as Tertiary, then the line between Cretaceous and Tertiary in the Ojo Alamo

region would have to be drawn by those who favor Dr. Knowlton's contentions, not at the unconformity below the Puerco where the vertebrate palæontologist would be inclined to put it, but at some level not yet discovered.

Our instructions and the object for which the expedition of 1913 was organized prevented us from devoting the necessary time to a study of the stratigraphy and palæontology of the Ojo Alamo beds, but parts of several days were spent on it by various members of the party. Not one fragment of dinosaur bone did we find above the level of the unconformity at the top of the conglomeratic sandstone with fossil logs. Whatever may be the final conclusion regarding the age of the Ojo Alamo beds, we feel reasonably certain that dinosaurs will not be found to occur in the Puerco.

## The Puerco Formation.

*Basal Unconformity.*— The Puerco clays rest unconformably on the eroded surface of the conglomeratic sandstone with fossil logs (Plate XXII). Low hills of the sandstone rise like islands through the horizontally-banded clays of the lower Puerco levels. Shallow valleys between the hills are filled with rusty-weathering blue clays, sometimes with lignite pockets in the bottoms of the depressions (Section B, Fig. 2). The unconformity is not a mere local feature. It has been traced from Pina Veta China (see map, Fig. 1) almost to Escavada Wash and would have been followed farther if the fossiliferous levels of the Puerco had been exposed beyond this point. It marks the beginning of a new deposition cycle, a *sudden* change from coarse sandstone and conglomerate to fine clays which first fill depressions in the sandstone, then completely blot out the old erosion surface under sheet upon sheet of clay with, occasionally, a stray bit of drift timber or a lens of sand, but not a single pebble. An abrupt faunal change occurs at the unconformity, from conditions favoring dinosaurs [1] to those responsible for a great radiation of Paleocene mammals, present in abundance throughout a horizon of limited thickness in the Puerco approximately 30 feet above the unconformity. For these reasons it seems to us to be the dividing line between Cretaceous and Tertiary in this region.

*The Puerco Sediments.*— Facial changes in the strata composing the Puerco formation occur so rapidly that any detailed discussion of particular sections would be quite unprofitable (compare sections A and B, Fig. 2). In general, the Puerco consists of unconsolidated clays, often brilliantly color-banded, and channel sandstones, also unconsolidated or but slightly

[1] One dinosaur vertebra found in the sandstone. See p. 301.

coherent, which cut across the clays (Plate XXV, Fig. 1). Beds of lignite or lignitic clay (Plate XXIII, Fig. 2) and deposits of oxide of manganese in irregular sheets and concretionary masses (Plate XXIV) further diversify the formation. When viewed from a distance, the Puerco exposures seem to be regularly banded (Plates XXI, XXVI), but when examined in detail great local irregularity in bedding is found to occur, with a marked tendency toward cross-bedding, and with rapid facial changes laterally not only from sandstone to clay, but from clay of reddish to that of bluish or yellowish tinge or the reverse. Much fossil wood occurs locally, silicified drift logs and pieces of lignitized wood looking like charcoal are scattered irregularly through the clays. Nodules, sheets and veins of barite are also common features.

Certain members of the lower part of the Puerco in the Ojo Alamo and Kimbetoh Arroyo sections deserve more detailed consideration because of their conspicuous colors, peculiar lithology, or their relation to the two levels at which fossil mammals occur.

1. *Ojo Alamo Section.*— In the vicinity of Barrel Spring and Ojo Alamo, a three-foot stratum of clay, mottled red and green, rests unconformably on the top of the conglomeratic sandstone with petrified logs (Plate XXII) which sometimes rises through it as small hills, and sometimes is separated from it by shallow valleys filled with bluish and rusty-colored clays. After an interval of 13 feet, or more, of bluish clays a second prominent zone of greenish-mottled red clays occurs (Plate XXIII, Fig. 2), 13½ to 15½ feet thick. Towards the top of this zone, some jaw fragments and a much distorted skull of the genus *Ectoconus* were collected and locally numerous turtle and crocodile fragments were noted. Wortman's field letter to the American Museum, written under date of March 28th, 1892, from the head of Coal Creek, places his lower horizon affording Puerco fossils at 20 feet above the Laramie (10 or 15 feet according to the notes he published later). We, therefore, regard the upper levels of the second red zone as the lower fossil level of Wortman. Except for the specimens noted and some fragments of turtle carapace, nothing was collected from it in the vicinity of Ojo Alamo, but farther to the southeast a large collection was assembled from the same horizon, as will be discussed in the following section. Above this red clay zone are various clays of bluish or yellowish color intersected by gray sandstone channel-fillings, above which are one or more narrow bands of wine-red, greenish-mottled clay. In Barrel Spring Arroyo, the top of this third reddish zone is 46 feet, 6 inches above the top of the second red zone. Along the contact of the red clay with an overlying greenish clay abundant, but fragmentary, mammal bones occur, an assemblage characterized by the presence of *Polymastodon* which was not found at any other level. This is

Wortman's second horizon which he estimates, both in his field letter and published notes, to be 30 feet above his lower fossiliferous horizon. In Ojo Alamo Arroyo, the *Polymastodon* fauna occurs in two (or more) wine-colored clay bands separated by bluish clays, totaling $8\frac{1}{2}$ feet in thickness and separated from the second reddish zone by bluish clays and channel sandstones aggregating 33 feet. These differences are due in part to local variations in the thickness of the beds. Altogether there is a difference of only 5 feet between the highest levels at which *Polymastodon* was found.

A peculiar feature of the gray channel sandstones below the upper fossil level of the Puerco is the presence of cylinders, spherical aggregates and irregular sheets of oxide of manganese (Plate XXIV). The contrast of the black beds and concretionary masses of manganese against the gray of the sandstone channels is most conspicuous. Leaf impressions were found in some of the sheet deposits, in a matrix of sand, manganese oxide and perhaps a little lignite, and at one locality on the south side of Barrel Spring Arroyo a small collection of rather poorly preserved impressions was made from several sheets of manganese oxide in channel sandstone, a little below the level of the upper fossil horizon of the Puerco (Plate XXIV). These were submitted to Dr. F. H. Knowlton who reports as follows: —

"With a fair degree of probability I am able to identify the following species:

*Ficus occidentalis* Lesq.
*Artocarpus* sp. ined.
*Paliurus zizyphoides?* Lesq.
*Viburnum lakesii?* Lesq.
*Platanus* sp. cf. *P. haydenii* Newb.
*Populus* cf. *P. cuneata* Newb.
*Viburnum* sp.?
Fragments.

"The *Ficus, Paliurus* and *Viburnum lakesii* are species of the Denver and Raton formations. The *Artocarpus* is the same, apparently, as an undescribed species from the Raton formation, while the others, if correctly identified, should indicate Fort Union.

"While I cannot be very positive about it, so far as I can determine from the imperfect material available, the age indicated is that of the Denver or perhaps as late as Fort Union. This is apparently of the same age as material obtained last year by Dr. W. T. Lee near Pagosa Junction, Colorado."

This is the first collection of fossil plants to be made from the Puerco, and is in no way opposed to a reference of the formation to the Paleocene,

but we do not feel that it is sufficient to justify any correlation of the Puerco with formations elsewhere in which the Puerco types of mammals have not been found. Least of all do we think that it should be used as proof of contemporaneity with certain formations containing dinosaurs (Lance, Denver) from which the Fort Union flora is reported, but this is not the place to discuss controversial matters.

With the exception of a fourth wine-red clay band 125½ feet above the upper fossil level, the remaining beds in the Ojo Alamo section, for the present referred to the Puerco, are a monotonous succession of clays with occasional channel sandstones. Two of these channels, intersected by Barrel Spring Arroyo, are quite thick, but rapidly thin out laterally and are replaced by clays. Above the uppermost of these two sandstone channels, three specimens of *Periptychus rhabdodon*, a characteristic Torrejon species, were collected (Sect. A, Fig. 2) and from this level upward the beds are regarded as Torrejon, but there is no visible stratigraphic break between them and the underlying Puerco unless the disconformity at the base of the channel sandstone on which the clays with *Periptychus rhabdodon* rest may be so regarded, and this disconformity cannot be followed beyond the edge of the sandstone channel.

2. *Kimbetoh Arroyo Section.*— Some 12 miles to the southeast, in a straight line, extensive exposures of the Puerco are found on Kimbetoh Arroyo and its branches and on a nameless arroyo between Kimbetoh and Escavada Wash. Here considerable facial change in the character of the lower Puerco sediments is noticeable (compare Sections A and B, Fig. 2). The first red clay has disappeared. The second is largely replaced by slate-colored and bluish clays, but the level of the first fossil horizon is quite constant, and along the contact of a dark slate-colored clay with bluish clays and cross-bedded sandstones above, a surprising amount of material was obtained, including an almost complete skeleton of *Ectoconus* and several creodont and other skulls. Fossils range through a greater thickness of beds here than farther to the northwest, the highest specimen occurring 22 feet above the zone of greatest abundance. In all this assemblage of scores of specimens, there is not a single fragment referable to *Polymastodon*. The remaining beds, to the level of the first Torrejon fossils, are monotonous in character, sands and clays much more irregular in stratification than would appear from the somewhat diagrammatic sections here given. The presence of abundant concretion-covered crocodile, turtle and fish remains near the top and base of a thick clay member below the level of the first Torrejon fossils is a feature peculiar to the Kimbetoh area. Whether they should be referred to the Puerco or the Torrejon does not appear, for the remains are either too fragmentary or not sufficiently

characteristic. For the present, the boundary has been drawn here, as in the Ojo Alamo section, at the level of the first occurrence of *Periptychus rhabdodon.*

*Thickness of the Puerco.*— The Puerco is not separated from the overlying Torrejon by any lithologic or stratigraphic break which we could detect. We have referred to the Puerco that portion of the series of Paleocene sands and clays between the basal unconformity and the lowest level at which Torrejon fossils have been found. In Barrel Spring Arroyo, one specimen of the Torrejon species *Periptychus rhabdodon* was found at the top of a dark slate-colored clay abounding in turtles, crocodiles and gar-pikes, and two in clays immediately above this stratum some 245 feet 6 inches above the unconformity at the base of the Puerco. In the Kimbetoh Arroyo section a thickness of beds 336 feet 6 inches (more or less) occurs between the basal unconformity and the level of a specimen of *P. rhabdodon,* also associated with turtles, crocodiles and fish and lying 45 feet below the lower fossil level of the Torrejon, to be described later. Further collecting may carry the level of Torrejon fossils still lower, so that it is unsafe to infer unconformable relationships from the differences in thickness of the Puerco in the two sections measured by us.

In the Arroyo Torrejon section of Dr. Gardner (Section C, Fig. 2), the full thickness of the Puerco is certainly not exposed. Of the 210 feet referred by him to that formation, 100 feet is now known to belong to the Torrejon because Torrejon fossils in abundance are found at the point indicated in the section (Sect. C, Fig. 2) 100 feet below his Puerco-Torrejon contact. The remaining 110 feet is exposed in the lower line of cliffs along the east and west forks of Torrejon while the greater portion of the formation is concealed beneath dune sand and fine wind-blown silts in the broad desert valley between the cliffs and Encino Spring.

In the Puerco River section (D, Fig. 2) Gardner's 558 feet of Puerco is reduced to 179 feet by the discovery of Torrejon fossils immediately above the 30 foot bed of sandstone (third member above the base in his Arroyo Torrejon section) which Dr. Gardner correlates with a 40 foot stratum of sandstone (fourth member above base) in his Puerco River section. The fossil level has not, however, been traced that far east, but the sandstone below it can be readily followed. We have not examined the contact of the Puerco with the Lewis shale indicated in Gardner's section. If the relationship is as indicated it is possible that the lower levels of the Puerco have been concealed by overlap of higher horizons.

*Fossil Levels; Origin of the Puerco Sediments.*— The position of the two levels in the Puerco affording fossil mammals has already been indicated. The lower is characterized by many individuals referable to several genera

and species of the family Periptychidae; the upper has afforded all the specimens of *Polymastodon* collected by us. So far, no mammals have been obtained from any other horizon in this formation. Why this is so is by no means apparent.

The presence of fish, crocodiles and turtles (*Trionyx* and other genera) in the same stratum and at the same level with mammal bones shows conclusively that these deposits have been formed by water. Lignitized plant rags and pieces of silicified drift wood with the bark worn off, found stranded in the fine clay of the fossil horizons, tell the same story. The presence of cross-bedding inclined at low angles, (except in the sandstone channels) and the frequent occurrence of the latter cutting clays speak eloquently for accumulation on river flood plains or on the surfaces of broad, low-grade, coalesced alluvial fans. That the streams were low-grade is shown by the complete absence of pebbles in the Puerco, and by the horizontal extent of some of the clay bands. Bogs, apparently occurring in backwaters in the channels or in depressions between the fans became filled with accumulations of oxide of manganese, preserving impressions of the leaves of figs (*Ficus*), plane trees (*Platanus*), poplars (*Populus*), relatives of the breadfruit (*Artocarpus*), and various shrubs, (*Paliurus, Viburnum*) which, together with the frequent large drift logs in the clays (Plate), may be taken as indicative of a heavy growth of vegetation along the streams and, presumably, in the interstream areas also. Whatever deposits of mud or sand were accumulated by the streams would form in the permanently or temporarily submerged portions of the basin of accumulation traversed by the streams. Such continuous strata as the dark slate-colored clay below the fossil zone in the Kimbetoh area may represent an old vegetable soil on the surface of a broad fan or an accumulation in a fan-delta lake basin which was filled by the deposits of a shifting stream (the cross-bedded sands and clays in which the mammal bones are found). We have not observed any indications of aridity.

The mode of occurrence of the fossils may throw some light on the origin of the deposits in which they occur. Lack of association of parts is the rule. Maxillæ, jaws, and teeth, the most resistant parts of the skeleton, greatly predominate in the collections. Rarely is the skull found with other skeletal parts and only once has an almost complete skeleton been discovered. Occasionally a well preserved skull or other strong bone may be found in one of the channel sandstones interrupting a fossil level. In damp woods, the bones of animals would eventually decay and only in water-laid sediments would there, probably, be an accumulation of the more resistant parts representing an epitome of the fauna of the region. Some of these bones might have been washed into the streams during heavy rains; many, no doubt, are the remains of creatures mired and drowned at drinking

places; others may be from animals dragged into the water by crocodiles, while the activities of these animals and of carnivorous turtles and fish perhaps help to explain the wide scattering to which the remains of Puerco mammals have been subjected. A quarter, at least, of the Puerco specimens, collected by the 1913 expedition, show traces of gnawing, probably by small plagiaulacids. This undoubtedly proves that many of the bones lay for some time on the surface of the ground before they found their way into the streams or were covered in flood time by water-borne sediments.

The origin of the red color of some of the clays has not been looked into chemically, but from the occurrence of fish, turtles and crocodiles in the red bands of both the Puerco and Torrejon it would seem that they are water-deposited and, perhaps, owe their red color to subsequent dehydration on drying.

## The Torrejon Formation.

The larger part of Cope's Puerco River section (D, Fig. 2 and Plate XXVII, Fig. 1) is now referred to what Dr. Wortman called the Torrejon formation. No fossils were found by Cope in this section nor did any of Baldwin's collections come from here.[1] When Wortman discovered the presence of two Puerco levels in the Ojo Alamo exposures and a higher level (upper fossil level of the Torrejon) in the cliffs at the head of the branches of Arroyo Torrejon, he did not wish to announce that he had discovered something older than what had up to that time been called the oldest Tertiary, so retained the name Puerco for the oldest beds in which he found fossils and gave a new name, Torrejon, to the higher levels which are now known to make up the largest part of Cope's original Puerco.

*The Torrejon Sediments.*— The Torrejon closely resembles the Puerco in the character of its materials except for the appearance of gravels (quartzite, jasper, red shale, &c) in some of the channel sandstones. At the type locality on the east and west forks of Arroyo Torrejon, where it is exposed in the face of a cliff capped by the basal sandstone of the Wasatch, it differs from the Puerco in having two zones, 100 feet apart, characterized by an abundance of small, rusty, calcareous concretions (Plate XXVII, Fig. 2). It is in these concretionary zones that the fossils occur. The color of the concretion-bearing clays varies from red mottled with green to gray. In the exposures along the Torrejon, a heavy persistent sandstone lies below

[1] So far as we could ascertain from Baldwin's partner, Thomas Rafferty of Farmington, New Mexico, who acted as guide and teamster for Wortman's first expedition, Cope's collections as well as those of the 1892 expedition were secured largely in the vicinity of Chico Springs (Torrejon), head of Coal Creek (*i. e.* Ojo Alamo and Barrel Spring vicinity, Puerco), and on Kimbetoh Arroyo (Puerco and Torrejon).

the lower fossil horizon (see next paragraph), but whether it is referable to the Puerco or the Torrejon is, for the present, doubtful. In other respects, there is so little difference between these formations that in the absence of fossils it is, at present, impossible to tell them apart.

*Torrejon Fossil Levels.*— From the important part which fossils must play in locating the lower boundary of the Torrejon formation it seems advisable to consider, in this place, the fossil levels. Previous to 1913, Torrejon mammals were known to occur in but a single horizon, which in the type locality is a zone of gray (sometimes reddish) clay abounding in rusty concretions (upper fossil level of Sections B and C, Fig. 2 and Plate XXVII, Fig. 2) and affording remains of *Euprotogonia, Periptychus rhabdodon, Pantolambda* and other characteristic Torrejon forms. At the base of this zone, Dr. Gardner placed his boundary between the Puerco and the Torrejon (see Sect. C, Fig. 2). We have found that a second fossil horizon occurs in the type section, with *Euprotogonia* etc., exactly 100 feet below the former. From both, extensive collections of splendidly preserved material were made and both were traced by almost continuous outcrops from the East Fork of Arroyo Torrejon to the west branch of Kimbetoh Arroyo (see map, Fig. 1). Some small exposures of the upper horizon in Blanco Cañon were also examined. Neither level has been found in the Rio Puerco section, apparently dying out laterally, while to the northwest, in the Ojo Alamo section, a heavy yellow sand-stone (? basal Wasatch?) rests unconformably on the Torrejon clays, cutting out the levels at which the two fossil layers might be expected to occur. These relations are clearly shown in the sections presented herewith. We have not been able to definitely correlate the Chico Springs exposures with either of these levels, owing to facial changes in the character of the beds and the concealment of outcrops between the head of Chico Arroyo and the head of the west branch of Kimbetoh Arroyo where the lower horizon is well exposed, but the fauna indicates, with a fair degree of certainty, that this horizon is the lower level.

It may be of interest to note that the upper horizon is rich in fossils to the eastward and almost barren in its western extent, while the lower horizon is highly fossiliferous in its westerly outcrops and only sparingly so to the eastward. It seems probable that the larger part of Baldwin's Torrejon collection and nearly all of the Torrejon fossils obtained by the American Museum Expedition of 1892 came from the lower horizon, and to the westward of Escavada, while the collections of the expeditions of 1896 and 1912 were from the upper horizon of Escavada, Torrejon and intervening arroyos. Thus, while the whole Torrejon collection was about evenly divided between the upper and lower levels the existence of more than one level was not known, partly because fossils had not been obtained from both

levels in the same exposure and partly because the levels had not been carefully traced out from one exposure to another. The most important point of difference between the faunæ of the two levels, noted in a preliminary examination, is that the genus *Deltatherium* is confined to the lower horizon.

*Thickness of the Torrejon.*— This varies greatly from place to place, partly due to the fact that fossils have had to be used, so far, in locating the base of the Torrejon, and partly to an erosional unconformity at the top, beneath the basal Wasatch sandstone (Plate XXVII, Fig. 2). Still another difficulty arises from the lack of detailed contour maps which makes it impossible to correlate the various sandstones which overly unconformably the Torrejon clays. Some of these are Wasatch and some seem to be considerably younger. In the Ojo Alamo section, 113 feet 6 inches of beds between the level of three specimens of *Periptychus rhabdodon* and a heavy sandstone, resting unconformably on the clays, are referable to the Torrejon. The sandstone is not definitely determinable as Wasatch. Manifestly, the discovery of Torrejon fossils lower down than the *Periptychus* would change the position of the Puerco-Torrejon boundary as now drawn. In the Kimbetoh Arroyo section, a much greater thickness of the Torrejon is exposed. Here *Periptychus rhabdodon* was found 45 feet below the lower fossil level. Both of the reddish fossiliferous zones are represented. In addition to these, there is a considerable thickness of dove-colored, yellowish, dark slate-colored and other clays, with channel sandstones, between the upper fossil level and the Wasatch sandstone, which may be Torrejon or younger. They are well exposed at the head of Kimbetoh Arroyo and in adjacent portions of Blanco Cañon. To the southeast they are overlapped by the Wasatch sandstone. To the northwest, the slight easterly dip of the Paleocene formations and the overlapping of younger sandstones prevents their occurrence. Unfortunately, no fossils were found in them. Owing to a lack of the necessary facilities, the thickness of the Torrejon was not measured in this section. On the Arroyo Torrejon, Gardner's estimate of 140 feet is increased to 240 feet by the discovery of the lower fossil stratum referred to above, which also increases the Torrejon part of the Rio Puerco section from 281 to 660 feet. The unconformities which Dr. Gardner thought he could recognize do not exist, as they were founded on assumptions which the discovery of the lower fossil level of the Torrejon has shown to be untenable. The varying thickness of the Torrejon formation shown in the sections (Fig. 2) may be due to unconformable relationships with the Puerco, but this can neither be proved nor disproved by present evidence. It seems probable from the variation in position of the lower limit of the Torrejon, but as this has been determined by fossils, whose presence depends on the chance of preservation, exposure

and subsequent collection, the boundary cannot be regarded as fixed. It will probably be shifted by subsequent work.

*Torrejon-Wasatch Relationships.*— The Torrejon clays are overlain unconformably by heavy beds of gray conglomeratic sandstone which forms the rim-rock of the Torrejon and Escavada cliffs (Plate XXVII, Fig. 2) and probably represents a confluent alluvial fan deposit formed during a new depositional cycle in which coarse sediments succeeded clays and finer-grained sandstones. The erosion of the Torrejon clays previous to the deposition of this sandstone and its overlap beyond the edge of the Paleocene to the east and north accounts for the variation in level of the top of the Torrejon in the various sections and for its absence about the north and east margins of the San Juan Basin.

*Origin of the Torrejon Sediments.*— So far as the fossil layers are concerned, there does not seem to be any doubt of the aqueous origin of the deposit. All proofs cited in discussing the Puerco apply more or less to the Torrejon. There is less petrified wood present, but this is more than offset by the *Unio* beds which occur repeatedly in the type section, in gray clays of the upper fossil layer, often preserved as lenses of rotten shells seen on cross-section in the clay bluffs; at other times impressions of the *Unios* are found in masses of rusty calcareous concretion. Shells of land molluscs (*Pupa*, members of the *Helicidæ*) also occur in the clays affording mammal bones. On west Torrejon, small clay pellets, both round and angular, occur in a fine-grained clayey sandstone of the upper fossil layer forming the matrix of a partial skeleton, probably of *Pantolambda*. The abundant limy concretions may indicate aqueous deposition or they may be due to ground water circulating through the clay after deposition had taken place.

## Age of the Puerco and Torrejon.

Both formations have for a long time been referred to as of Basal Eocene age. More recently, Paleocene seems to be growing in favor. Hitherto, we have not had data for working out satisfactorily evolutionary changes within the limits of each formation, owing to a lack of accurate information regarding levels. This is now available and will, doubtless, be of assistance in establishing more accurate correlations, but probably will not change materially our ideas of geologic age.

## "Nacimiento" as a Group Name.

If no attention is to be paid to fossils, the "Nacimiento Group" proposed by Dr. Gardner to include the Puerco and Torrejon may be a convenient

term for map-making purposes. Its use might be further justified if there was no basis for the separation of the formations to which it applied, but this is very far from being the case. Although there is no marked difference in lithology between them and the presence of an unconformity has not been established, the difference in faunas is considerable, involving changes of not less than subgeneric value in the case of so-called genera common to the Puerco and Torrejon, with the introduction in the latter of many forms not known from either Puerco level. The rules of the United States Geological Survey for the discrimination of formations specify that "When two formations of closely similar lithologic character are in contact it will sometimes be necessary to depend almost entirely on the contained fossils in separating them." [1] This fully covers the case in point. The fixing of the boundary between the Puerco and the Torrejon is merely a matter of careful collecting and adequate mapping on a sufficiently large scale and with the proper detail. We fail to see the necessity for a group name.

## Summary.

The more important stratigraphic results may be summarized as follows:—

1. Separation of the pre-Puerco beds into several members which are, in descending order, a heavy conglomeratic sandstone with much fossil wood, a series of clays with channel sandstones, a conglomerate and a series of dove-colored clays, red-banded near the top. The two conglomeratic members have disconformities at their bases. Dinosaurs occur, especially at two levels separated by the lower conglomerate. More or less of this series of beds may be correlateable with the Animas formation.

2. Complete confirmation of Barnum Brown's observation regarding the unconformable relationship of the Puerco with respect to the conglomeratic sandstone with fossil logs on which it rests. A topography in low relief was developed on the surface of this sandstone previous to the deposition of the Puerco clays, which cover up these hills and valleys.

3. Accurate location of the two Puerco fossil levels and demonstration of the fact that *Polymastodon* is confined to the uppermost of the two levels. For their position see sections A and B, Fig. 2.

4. Measurement of the thickness of the Puerco on continuous exposures from the unconformity at its base to the level of the first occurrence of Torrejon fossils.

5. Discovery of fossil plants in the Puerco.

---

[1] U. S. G. S., 24th annual report, p. 23, part of rule 3.

6. Accumulation of data which seem to prove the fluviatile origin of the Puerco sediments.

7. Discovery of a new fossil horizon in the Torrejon, 100 feet below the horizon from which fossils had hitherto been obtained.

8. Finding of Torrejon fossils at still lower levels (see sections).

9. Location of the Torrejon levels with reference to those of the Puerco (see sections A and B, Fig. 2).

10. Correlation of the Rio Puerco and Arroyo Torrejon sections published by Dr. Gardner of the U. S. Geological Survey with the sections measured by the American Museum party.

11. Accumulation of data which seem to prove the fluviatile origin of the Torrejon sediments.

## Collecting Localities.

For the convenience of subsequent workers, the principal collecting localities of the 1913 expedition are here listed. These are indicated on the map (Fig. 1) by numbers.

1. Two miles above Chico Springs. Torrejon, probably lower horizon. Two small exposures well up toward the head of Chico Arroyo. The larger exposures surrounding the store on Chico Arroyo proved barren. Small collection. Much concretion adhering to bones.

2. Two miles above Ojo Alamo. Lower and upper fossil horizons of the Puerco in great rincon of badlands on Ojo Alamo and Barrel Spring Arroyos and their branches. Principal exposures of *Polymastodon* horizon (upper fossil level of Puerco) found. Large collection from upper level. Skull of *Polymastodon*.

3. Three miles east of Ojo Alamo. Torrejon exposures at the head of Barrel Spring Arroyo. Three specimens of *Periptychus rhabdodon* found.

4. Five miles northwest of Ojo Alamo. Puerco exposures at the head of the west branch of Canon Gallego. *Polymastodon* horizon. Only two specimens found (both *Polymastodon* teeth).

5. First draw west of Kimbetoh Arroyo. Exposures on the west side of the draw. A short stretch of the lower Puerco fossil level at the base of the bluff. Small collection.

6. Old Dolan ranch, Kimbetoh Arroyo, four miles above Kimbetoh. Puerco exposures on both sides of the arroyo, but lower fossil level seen to advantage on east side. Skeleton of *Ectoconus* from beds in bluffs southeast of ruins of old ranch house.

7. Three miles east of Kimbetoh. Exposures of lower fossil level, Puerco, in branches of Kimbetoh Arroyo and in extensive badlands on nameless arroyo between Kimbetoh Arroyo and Escavada Wash, above where road to Cuba crosses. Very rich. Several good skulls.

8. Head of Kimbetoh Arroyo. Lower fossil level, Torrejon, exposed on both sides of the arroyo, well up toward the Blanco divide. Material all fragmentary, much of it concretion-covered, but in places abundant. Upper Torrejon horizon exposed, but barren.

9. Head of the west branch of Kimbetoh Arroyo. Lower fossil layer of Torrejon seen on the southwest face of the bluffs forming the Blanco divide. Abundant material; some partially complete skulls.

10. West branch Arroyo Torrejon. Both Torrejon horizons in face of cliff below Wasatch rim-rock. Good material from both horizons.

11. East branch Arroyo Torrejon. Same horizons as on west branch. Good material from both horizons.

12. Cliffs at head of Alamo Arroyo. Very limited exposures of upper Torrejon horizon.

13. Cliffs at head of Alamito Arroyo. Fairly rich exposures of upper Torrejon level. A small area of the lower level yielded one specimen.

14. Cliffs at the head of Escavada Wash. Both horizons of the Torrejon. Exposures extensive, but not very fossiliferous.

15. East and west branches of unnamed arroyo between Kimbetoh and Escavada. Upper Torrejon horizon extensively exposed but barren. Lower horizon of limited exposure and only very sparingly fossiliferous.

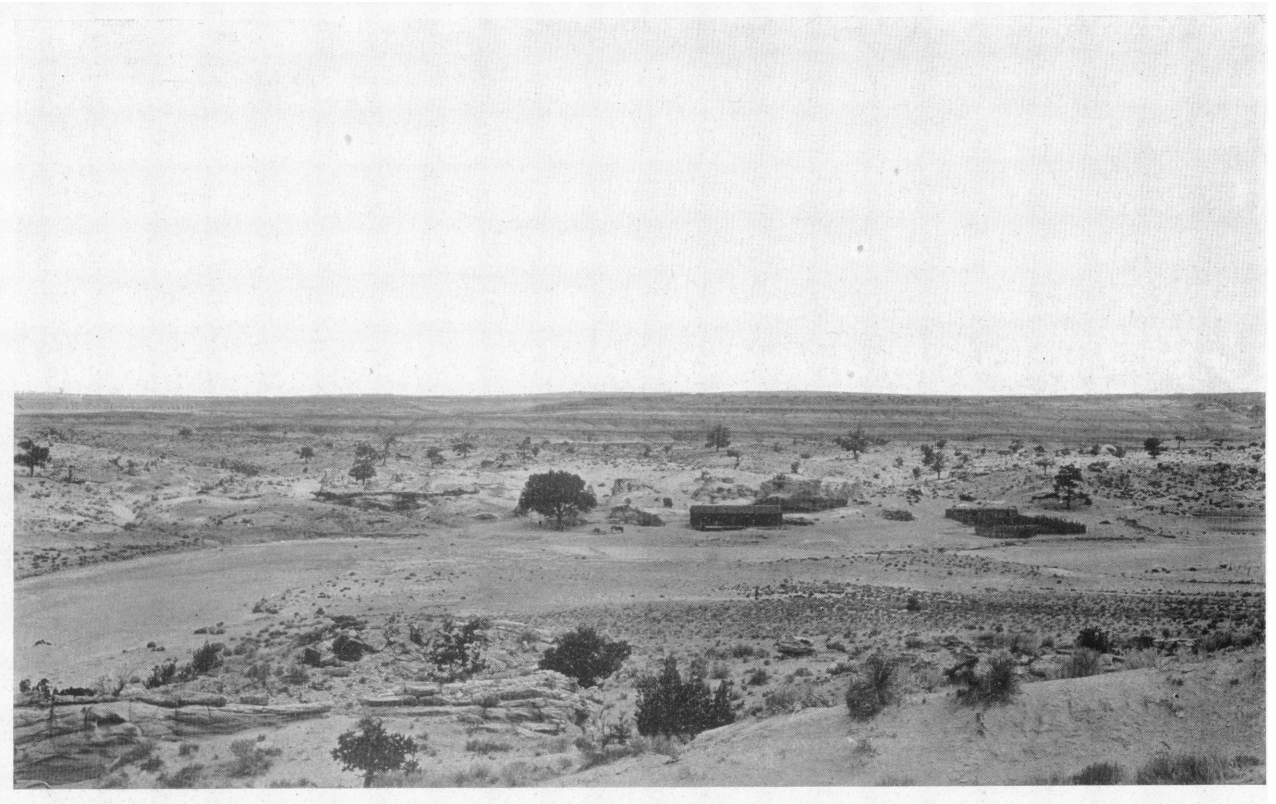
16. Cañon Blanco, a few miles above the Indian Mission. Upper Torrejon horizon exposed in several isolated areas and almost barren.

17. Head of an easterly tributary to the Torrejon Arroyo. Very limited exposures of the upper Torrejon horizon. A small collection obtained in 1912. This is the most easterly locality from which Torrejon mammals have been recorded.

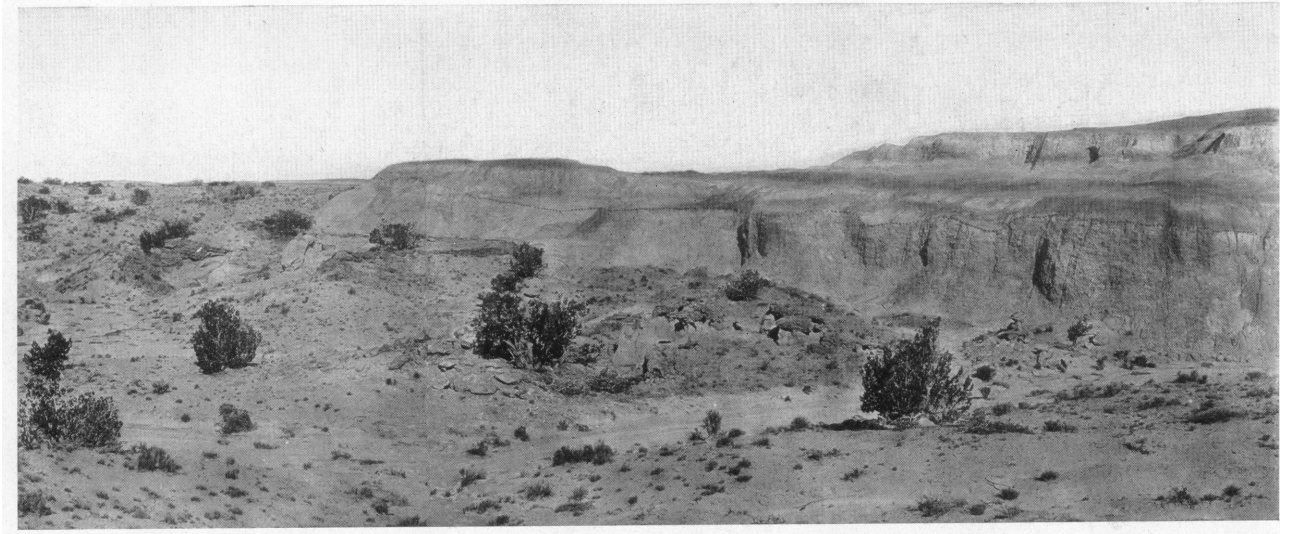
18. Pina Veta China. A few miles north of the trading store. Basal Puerco and Ojo Alamo beds. No fossils obtained.

Fig. 1. Ojo Alamo beds looking north from Barrel Spring. The conglomeratic sandstone with fossil logs forms the castellated rocks on the ridge-crest. Upper horizon of dinosaur-bearing clays beneath the sandstone.

Fig. 2. Ojo Alamo beds a short distance below Barrel Spring. Conglomeratic sandstone with logs caps ridge to left. Upper dinosaur horizon just above junction of badland face and talus. Lower conglomerate at top of talus and strewing slope in foreground. Lower dinosaur horizon underlying talus and in bottom of arroyo at lower left-hand corner of picture.



Looking north toward Ojo Alamo. Puerco beds in distance. Conglomeratic sandstone with logs back of store and in foreground. Note large silicified log in lower left-hand corner.



Unconformable contact of the Puerco clays on the conglomeratic sandstone with fossil logs. Contact line accentuated by dotting. Silicified logs near cedars in foreground. Between Barrel Spring and Ojo Alamo Arroyos, looking north.

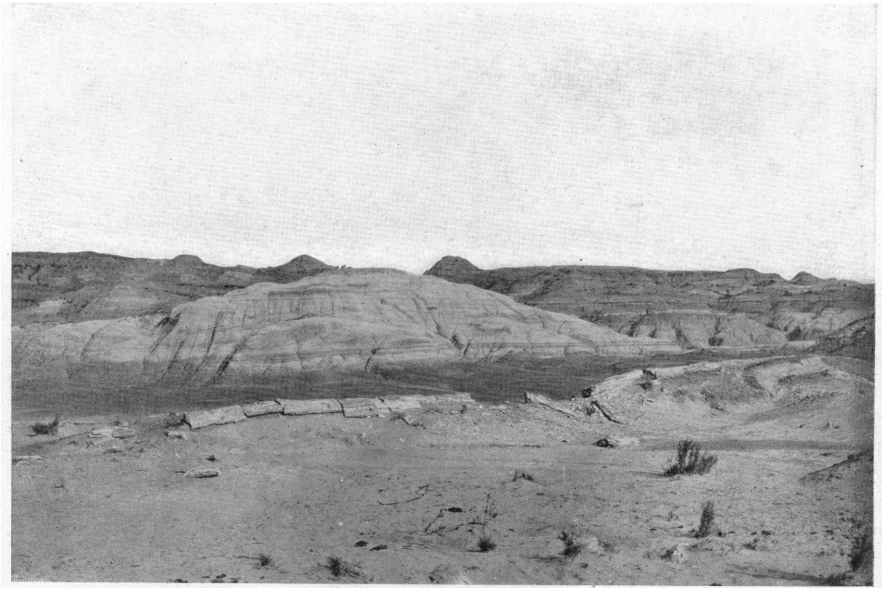


Fig. 1. Silicified log in clays below channel sandstone, Puerco beds in Barrel Spring Arroyo. The *Polymastodon* layer is about half way up the slope in the middle distance, to the right.

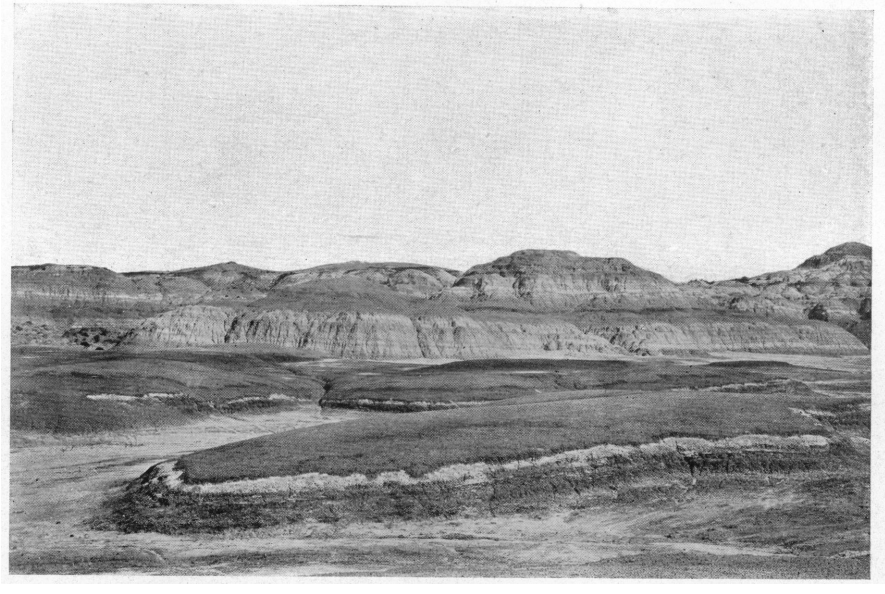
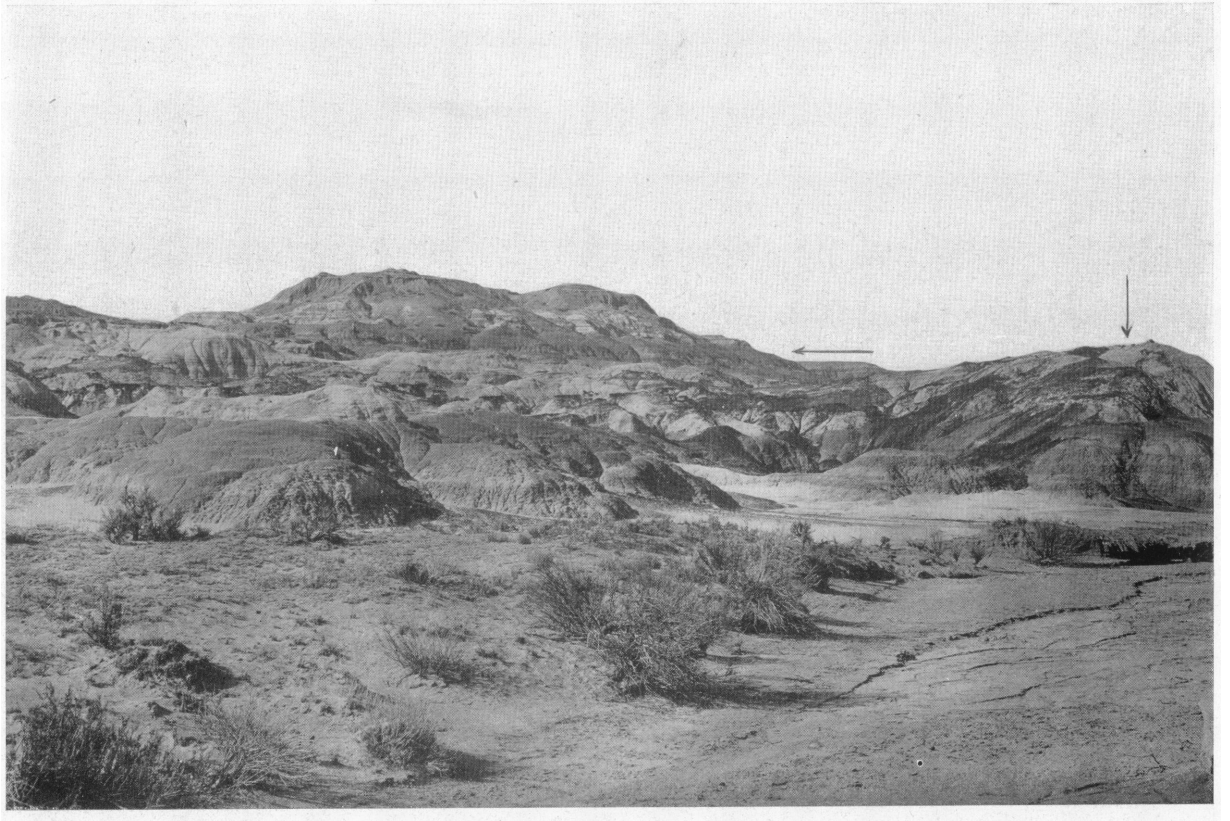


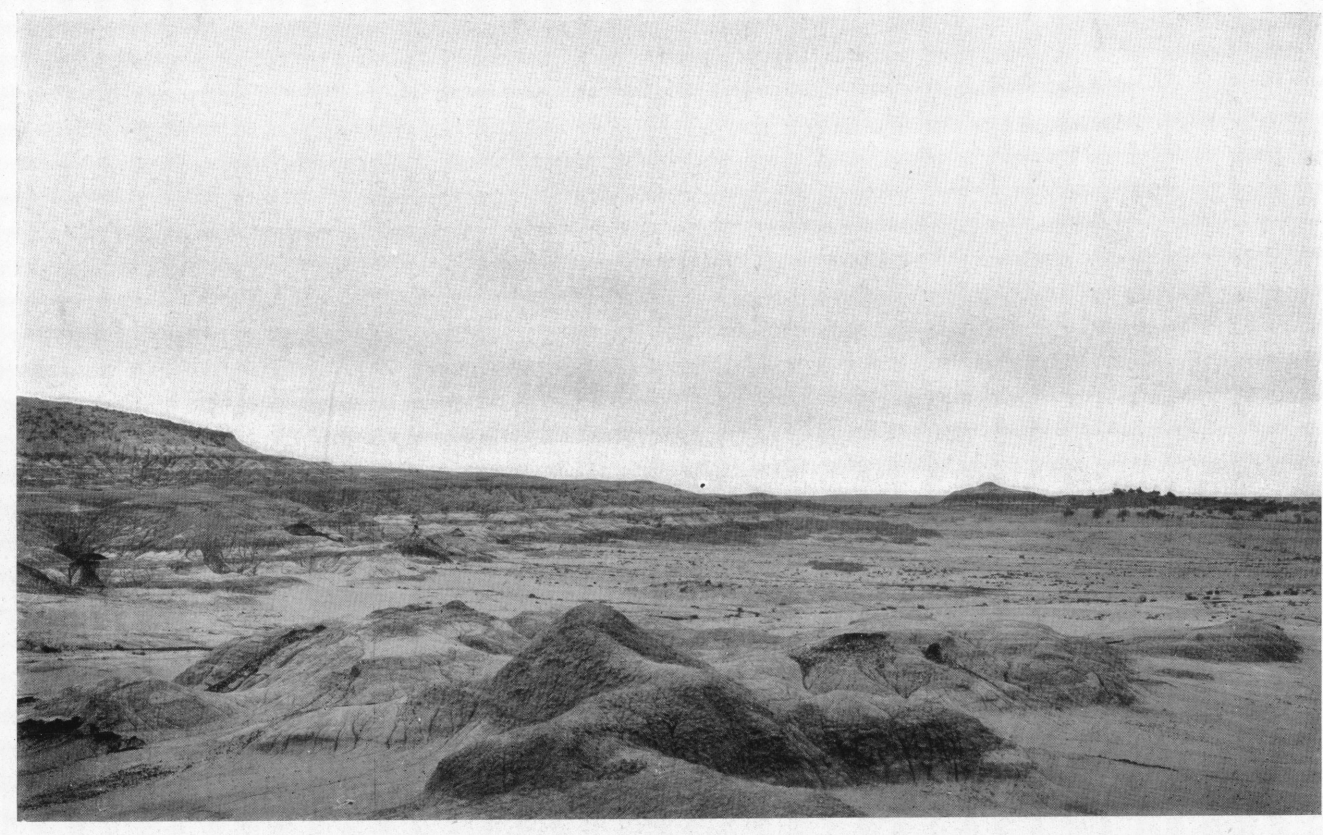
Fig. 2. Puerco exposures between Barrel Spring and Ojo Alamo Arroyos. Lignitic clays in foreground; red-banded clays of lower fossil level in middle distance. The white band below the lignitic clay is fibrous barite in small sheets and veins.



Locality in Puerco beds in Barrel Spring Arroyo where fossil leaves were found in concretionary manganese oxide. Position of leaf-deposits indicated by vertical arrow, on top of spur to right. Horizontal arrow points to upper fossil level of the Puerco (*Polymastodon* horizon).

Fig. 1. Gray channel sandstone cutting out *Polymastodon* zone (upper fossil level of the Puerco) in Ojo Alamo Arroyo. Looking east. Contact accentuated.

Fig. 2. Lower fossil level of the Puerco at base of cliff. Dark shale below fossil level capping bench in foreground. Exposure in nameless arroyo about 3 miles east of Kimbetoh station. Looking west. Same pocket as that shown in Pl. XXVI.



Puerco exposures in nameless arroyo about 3 miles east of Kimbetoh station. The beds dip slightly to the northeast. The lower fossil level appears on the surface of the flat and about the buttes in the foreground. It also surrounds the conical butte in the distance on the right. Looking southeast.

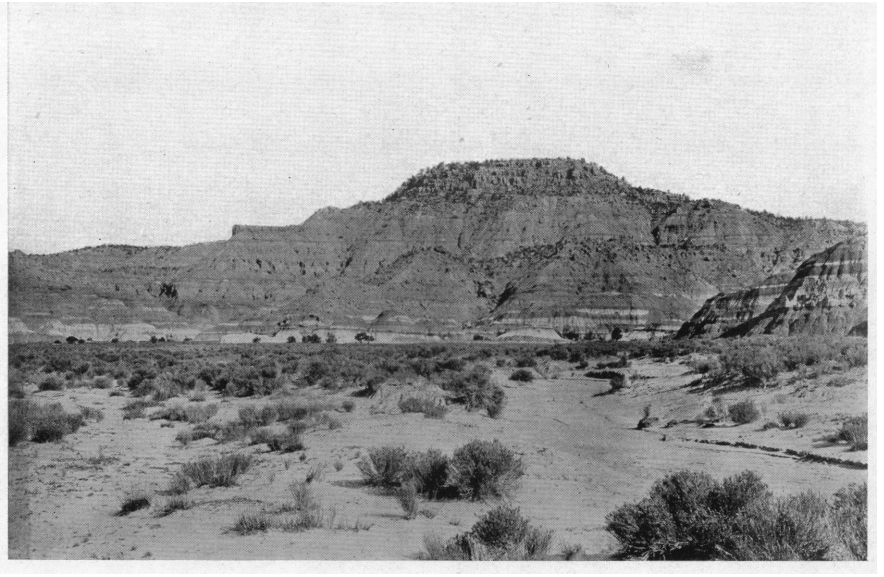


Fig. 1. Part of Cope's type section of the Puerco on the west side of Rio Puerco about four miles below Cuba. Wasatch sandstone caps cliff. A small amount of Puerco at the base; the rest Torrejon.

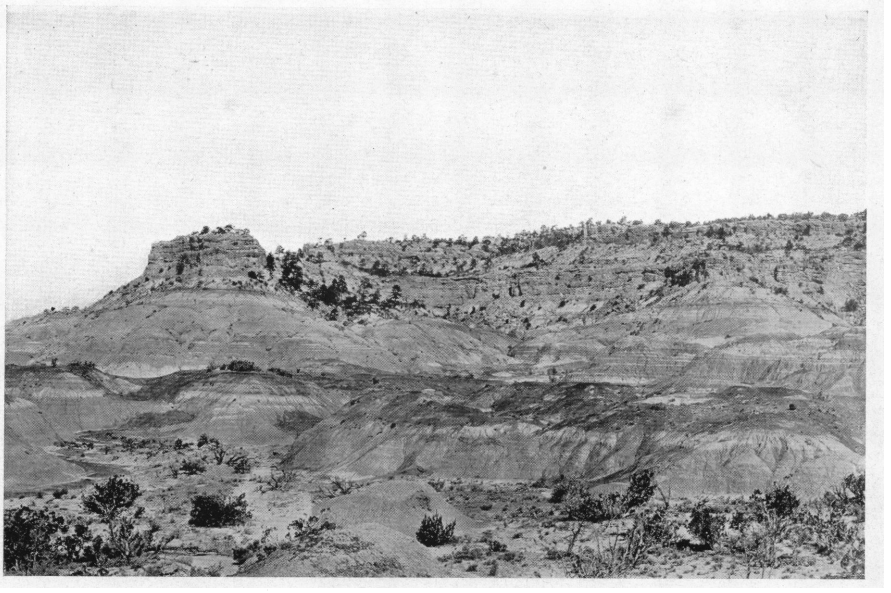


Fig. 2. Cliffs at head of west fork of Arroyo Torrejon. Cap rock is basal sandstone of the Wasatch. Concretion-covered slope in foreground marks position of upper fossil level of the Torrejon formation.

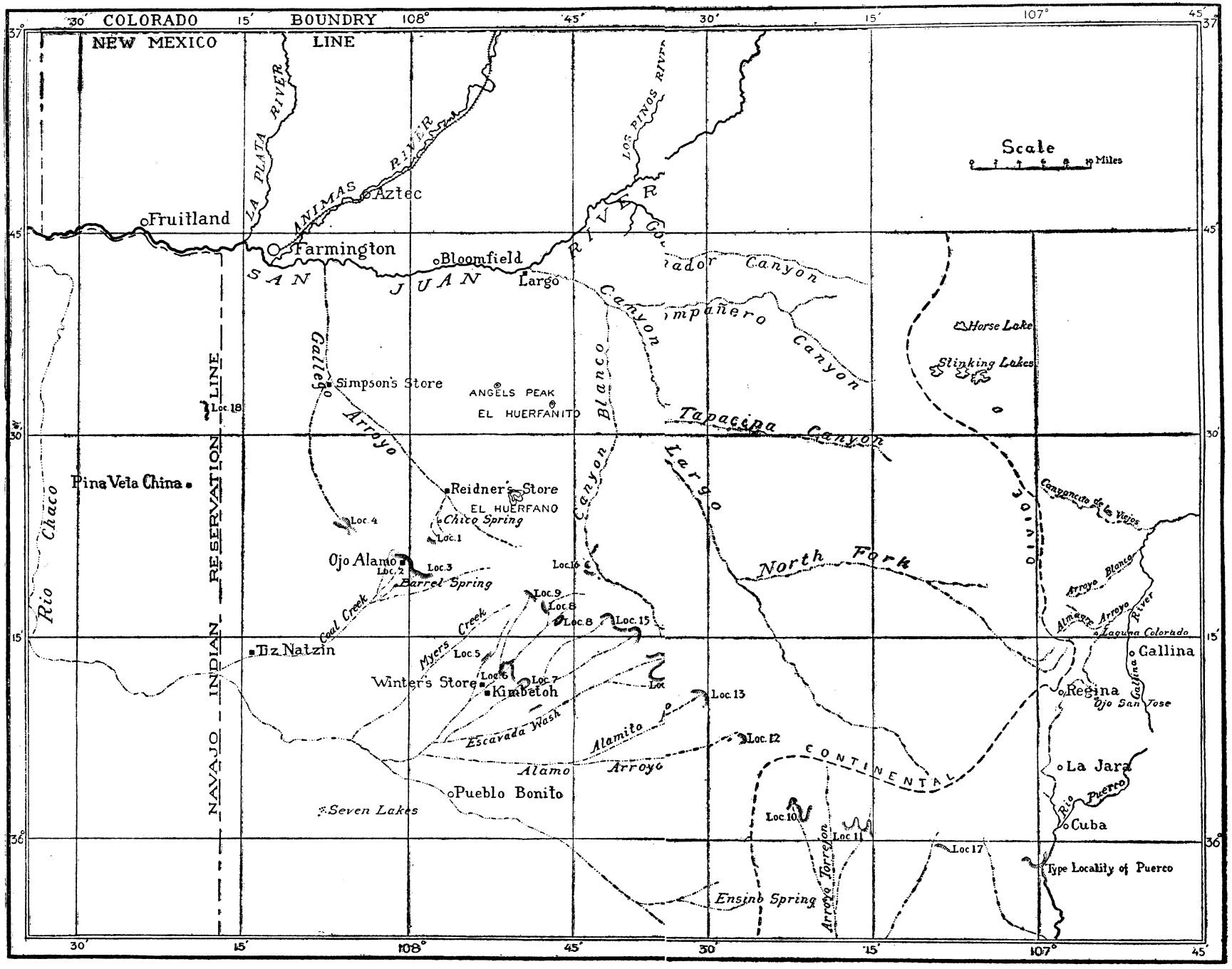



Fig. 1. Sketch Map of a portion of northwestern New Mexico, showing location of more important Paleocene exposures. The numbers refer to the list of collecting localities at the end of this paper. Adapted from topographic maps of the U Geological Survey.

Fig. 2. Semi-diagrammatic sections showing the relation of the Puerco, Torrejon and Wasatch to each other and to underlying formations. San Juan Basin, New Mexico.