CONTRIBUTIONS TO THE GEOLOGY AND PALEONTOLOGY OF SAN JUAN COUNTY, NEW MEXICO.

1. STRATIGRAPHY OF A PART OF THE CHACO RIVER VALLEY.

By Clyde Max Bauer.

INTRODUCTION.

This preliminary paper is an attempt to set forth the principal features of the stratigraphy in a part of the San Juan Basin—to describe the succession of strata irrespective of possible correlations and thereby to establish a type section for the formations exposed and to bring out their relations to the strata immediately above and below. The paper presents only a part of the data collected by a field party of the United States Geological Survey in the season of 1915, in charge of the writer, and does not describe the economic resources of the area, such as coal, nor the general geologic problems.

In mapping formation boundaries, streams, roads, and other surface features, the plane table and alidade were used. Where the slopes are steep and the strata nearly horizontal, sections were measured directly with a hand level. Elsewhere the alidade was employed for obtaining distances and differences in elevation, and the thickness of the intervening strata was calculated from these data. Fossils were collected at localities whose positions were accurately determined, both stratigraphically and geographically.

The accompanying papers on the paleontology of the area, by C. W. Gilmore, T. W. Stanton, and F. H. Knowlton,[1] discuss the fossil collections made by the field party. For these collections and a considerable part of the other data, including mapping, much credit is due to John B. Reeside, jr., who assisted the writer both in the field and in the office, and to H. R. Bennett, who assisted in the field. Acknowledgments are also due to M. R. Campbell, who exercised general supervision over the work and made many helpful suggestions and criticisms.

[1] U. S. Geol. Survey Prof. Paper 98, pp. 279-353, 1916 (Prof. Papers 98-Q, 98-R, 98-S).

GEOGRAPHY.

The area studied and mapped comprises about 1,500 square miles in northwestern New Mexico extending along Chaco River for about 50 miles from the Great Hogback, on San Juan River, to Meyers Creek, 6 miles north of Pueblo Bonito. (See Pl. LXIV.) The area may be reached by the Denver & Rio Grande Railroad, a branch of which terminates at Farmington, on the northern edge, or by the Santa Fe Railway to Thoreau, which lies about 60 miles south of Meyers Creek. From Thoreau wagon roads lead northward and cross the Continental Divide at San Antonio and Sheep passes. The population of the area, which lies partly in the Navajo Indian Reservation, is composed largely of Navajo Indians, who raise sheep, goats, and ponies and are nomadic in their habits. Sagebrush, rubber weed, chico, and pear cactus are the most common plants of the desert plain. A few white traders have located stores (see Pl. LXVIII, *B*) in the area.

The region is arid and stands from 5,200 to about 6,500 feet above sea level. The drainage goes mainly westward through arroyos cut sharply into the westward-sloping plain (see Pls. LXVI, *C*, and LXXI, *B*) to Chaco River. Between the arroyos are broad, gently rolling interstream plains, most of them surmounted by numerous long dunes of windblown sand and offering few exposures of the stratified rocks. The arroyos, on the other hand, present excellent exposures of the strata, especially near their heads, where there are many areas of badlands (see Pls. LXVIII, *A*, and LXXI, *B*), in which vegetation and soil are lacking and the rocks can be studied in great detail. These badland areas are cut below the general level and most of them are therefore invisible from the upland, except near their edges.

San Juan River is the only permanent stream in the area. It is maintained to a large extent by the melting snows on the mountains at its source, and, although the water is muddy, it contains far less alkali than the water of the other streams of the region. Chaco River has a bed as wide as that of San Juan River, but, although it is over 150 miles long, water flows in the channel only at intervals and only for a few days at a time. Its bed during the remainder of the year is a barren sandy flat. The water supply for the area is therefore obtained almost entirely from wells and artificial lakes. The rain water, caught in artificial lakes or pools, is carefully conserved through the long, dry periods. The water from the wells is strongly alkaline and commonly salty, and in many places it is not fit for domestic use. However, through long experience, the Navajo Indians have sought out the best watering places and have sunk crude wells and constructed reservoirs for storing flood waters.

STRATIGRAPHY.

GENERAL FEATURES.

The name San Juan Basin has been used by several writers to refer to the area inclosed by the outcrop of the Cretaceous coal-bearing formations of northwestern New Mexico. This area is properly a structural basin, and the writer would therefore limit the term to the region in which the strata dip toward a common center and exclude the Zuni Basin on the south, which is separated from the main basin by a structural divide.[1] The stratigraphy of the west-central part of the San Juan Basin is described in this paper. The area includes the outcrop of strata overlying the Mesaverde formation, which have in the past been referred to the Lewis, Laramie, Puerco, Torrejon, and Wasatch formations.

The stratified rocks of this area consist of a succession of marine, brackish-water, and fresh-water sediments, which now occur as sandstone, shale, coal, and conglomerate, in almost every gradation and combination possible. The dip of the strata throughout the greater part of the area is from 1° to 3° toward the center of the basin. In the Great Hogback, however, the beds lie in a sharp monocline dipping as much as 47° in an easterly direction. This steep dip persists only a short distance, however, and beyond it the beds flatten to dips of 3° or less.

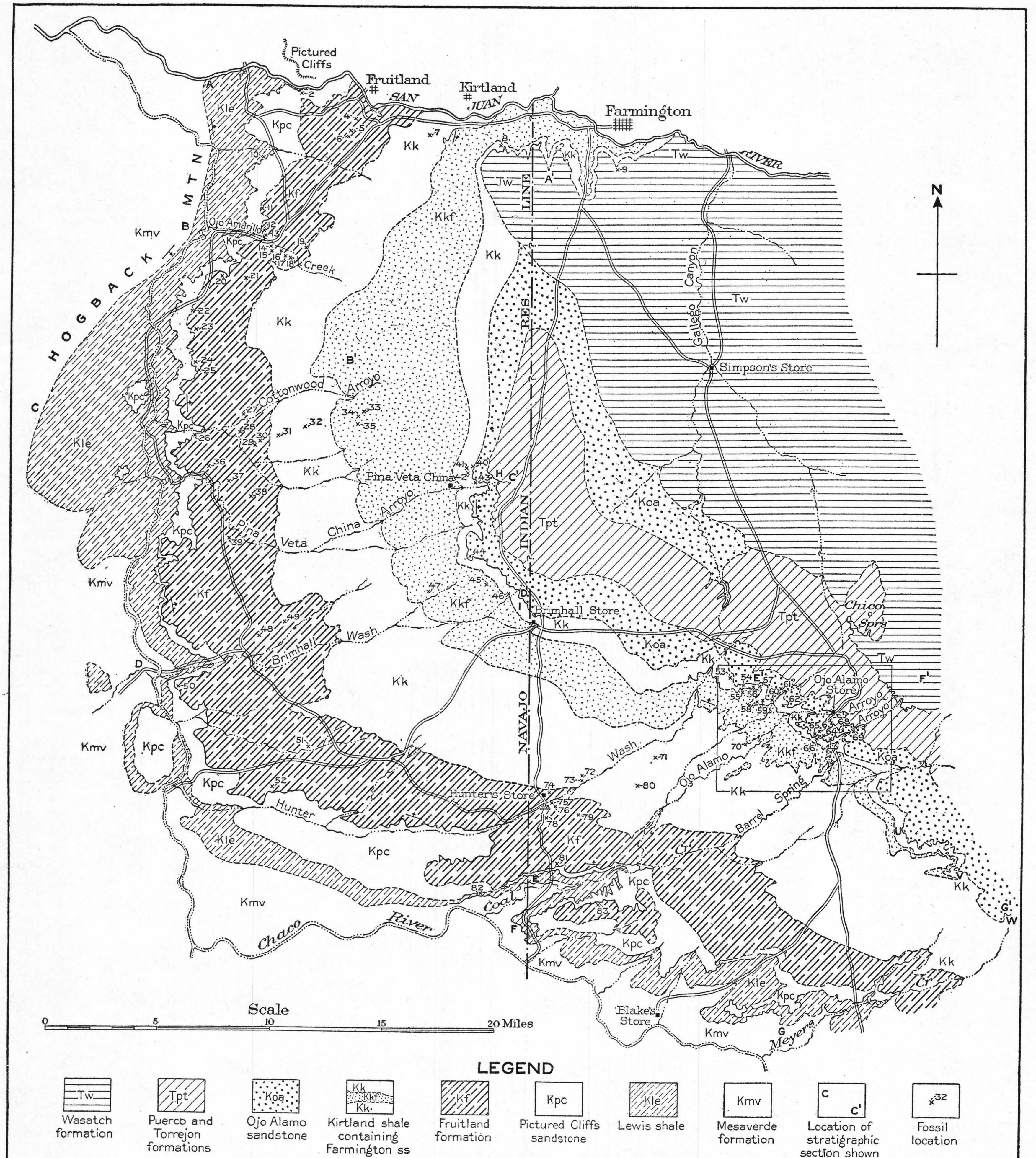
The sections given in Plate LXV show the thickness and character of the units measured along several arroyos, as shown on the map (Pl. LXIV). The area was entered from the north, and the first section was measured along San Juan River. (See A–A′, Pl. LXIV.) A generalized profile of this section is also shown in figure 27 (p. 275). Here the exposures are good, permitting a division into mappable units on a basis of lithologic differences. The Mesaverde and Lewis formations and the Pictured Cliffs sandstone were accepted as described by previous workers in the San Juan Basin,[2] as the two former have been traced directly from their type localities and the San Juan River valley is the type locality for the Pictured Cliffs sandstone.[3] The beds above this sandstone were divided into mappable lithologic units. As the present work progressed southward the distinctness of these units became more and more evident, and the sections measured were easily correlated with that along the river.

The following table gives the names and thicknesses of the several formations described in these pages, as well as the names previously used for them:

[1] Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 376–426, 1907.

[2] Schrader, F. C., The Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 285, pp. 241–258, 1906. Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, pp. 376–426, 1907.

[3] Holmes, W. H., Geology of the San Juan district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., for 1875, p. 248, 1877.



GEOLOGIC MAP OF WEST-CENTRAL PART OF THE SAN JUAN BASIN, N. MEX., FROM THE GREAT HOGBACK TO MEYERS CREEK.

The rectangle indicates the area shown on Plate LXIX.

Geologic formations in the west-central part of the San Juan Basin, N. Mex.

Holmes, 1877.[a]	Shaler, 1907.[b]	Gardner, 1909.[c]	Sinclair and Granger, 1914.[d]	This paper.	
				Formation.	Thickness (feet).
Wasatch.	(Undifferentiated Tertiary.)	Wasatch.	Wasatch.	Wasatch formation.	500+
[Absent in area described.]		Torrejon.	Torrejon.	Torrejon and Puerco formations.	390
		Puerco.	Puerco.		
Laramie.	Laramie.	......(?)......	Ojo Alamo.	Ojo Alamo sandstone.	63–110
		Laramie.	........(?)........	Kirtland shale, including Farmington sandstone member.	836–1,180 0–455
				Fruitland formation.	194–292
Pictured Cliffs.			[Not described.]	Pictured Cliffs sandstone.	49–275
Sand shale group.	Lewis.	Lewis.		Lewis shale.	76–475
Mesa Verde.	Mesaverde.	Mesaverde.		Mesaverde formation.	1,980

[a] Holmes, W. H., Geology of the San Juan district: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., for 1875, p. 244, 1877.
[b] Shaler, M. K., A reconnaissance survey of the western part of the Durango-Gallup coal field of Colorado and New Mexico: U. S. Geol. Survey Bull. 316, p. 376, 1907.
[c] Gardner, J. H., The coal field between Gallina and Raton Spring, N. Mex., in the San Juan coal region: U. S. Geol. Survey Bull. 341, p. 338, 1909.
[d] Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin, N. Mex.: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 297–316, 1914.

MESAVERDE FORMATION.

The Mesaverde, which is the lowest formation examined in this area, exhibits the same characteristics here as in the type locality, the Mesa Verde National Park, except that it is somewhat thicker. Where the Great Hogback is cut by Chaco River the thickness of the Mesaverde is 1,980 feet. At this place it presents a striking monocline with an eastward dip of 35°–47°. The formation is composed here of a lower sandstone member, which contains coal in its upper part; a middle shaly member, which comprises thin-bedded sandstone, shale, and coal; and an upper massive sandstone member. This formation was not studied in detail and only its upper limit was mapped.

LEWIS SHALE.

The Lewis shale (see Pl. LXVI, *B*) is marine in origin and very similar to the shale at Fort Lewis, Colo., the type locality.[1] It is thinner here, however, than at Fort Lewis, being about 475 feet thick on San Juan River, decreasing gradually southward as far as Coal Creek, where it is 76 feet thick, and increasing again to 103 feet on Meyers Creek. (See Pl. LXV.) The Lewis shale exhibits the same lithologic characteristics throughout the field. It is a greenish-gray sandy shale with local streaks of yellowish calcareous shale. On San Juan River it has also a prominent layer of buff lime concretions about 100 feet above its base. Three collections of fossils were obtained from it and have been identified by T. W. Stanton. They are listed below. (See also Pl. LXV.)

Collection 1 (9277):
- Anomia sp.
- Inoceramus? sp.
- Lucina sp.
- Lunatia sp.
- Baculites sp.
  - Marine Montana fauna.

Collection 10 (9273):
- Inoceramus barabini Morton.
- Placenticeras intercalare Meek and Hayden.
- Undetermined burrows.

[1] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, La Plata folio (No. 60), 1899.

Collection 82 (9296):
- Ostrea inornata Meek and Hayden.
- Syncyclonema sp.
- Leda sp.
- Cardium speciosum Meek and Hayden.
- Liopistha undata Meek and Hayden.
- Lunatia sp.
- Placenticeras sp.

Marine Montana fauna.

PICTURED CLIFFS SANDSTONE.

Overlying the Lewis shale conformably is the Pictured Cliffs sandstone (see Pl. LXVII, *A*) of near-shore marine origin. Its contact with the Lewis is gradational, but in the aggregate its lithology is distinct from that of the beds beneath. As the name indicates, it is a sandstone that forms cliffs, particularly on San Juan River immediately west of Fruitland, where there are prominent cliffs of copper-colored sandstone 20 to 40 feet high. Farther south it is a yellowish to light-gray or brown sandstone and not so massive. It diminishes in thickness from 245 feet on San Juan River to 49 feet on Brimhall Wash, and from that place increases to 91 feet on Meyers Creek. (See Pl. LXV.) *Halymenites major* is abundant in this formation, and the following fossils, identified by T. W. Stanton, were also collected from it:

Collection 2 (9278):
- Serpula sp.
- Inoceramus barabini Morton.
- Cardium speciosum Meek and Hayden.
- Tellina scitula Meek and Hayden?.
- Leptosolen? sp.
- Mactra gracilis Meek and Hayden?.
- Corbula sp.
- Turris? sp.
- Odontobasis? sp.
- Haminea sp.
- Actæon sp.

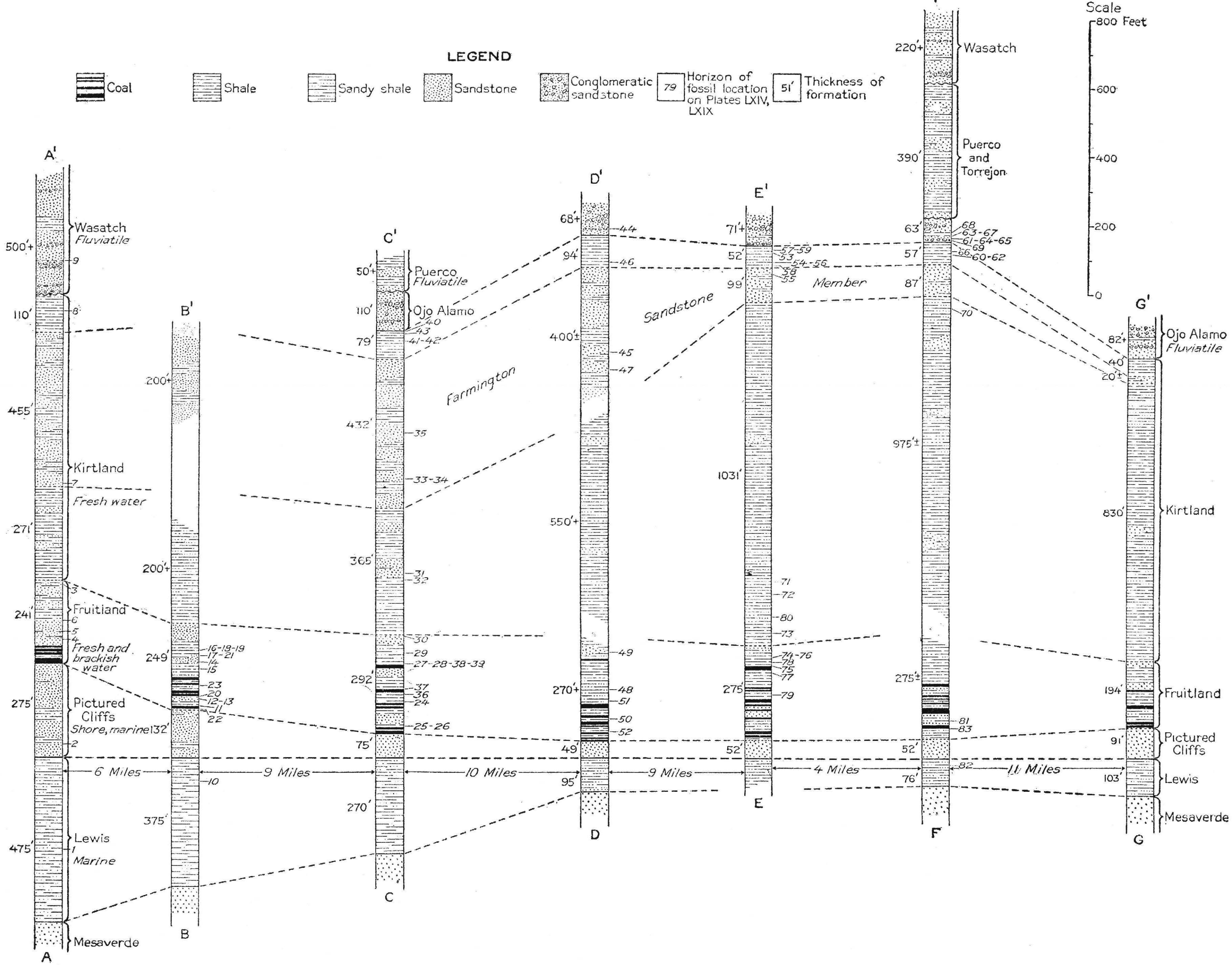
Marine Montana fauna.

FRUITLAND FORMATION.

Conformably above the Pictured Cliffs sandstone lie the brackish and fresh water beds of the coal-bearing Fruitland formation, and the contact presents the usual characteristics of interfingering beds. The name Fruitland is derived from that of a settlement on San Juan River which lies on the outcrop of this formation. The formation consists of sandstone, shale, and coal. (See Pl. LXVII, *B*.) It is very irregularly bedded, and the several beds range from sandy shale and shaly or clayey sandstone in all conceivable proportions to rocks that can be definitely called sandstone or shale. The variation in some places is so rapid both laterally and vertically that weathering of the unequally indurated rocks produces pillars, knobs, capped prisms, pyramids, and fantastic shapes of all sorts. This irregularity is most marked in the gray-white sandstone and gray sandy shale, but to some degree it affects also the coal beds. Nevertheless the coal beds, although they are lenticular, are more persistent than the sandstone and shale with which they are interbedded. Large concretions of iron carbonate which weather dark brown or black occur at several horizons. These concretions commonly contain barite, which has been introduced into them subsequent to the deposition of the strata, and many of them have in this manner been converted by veins of crystallized barite into large septaria. The Fruitland formation is more sandy than the overlying Kirtland shale, into which it merges by a gradational zone containing in many places sandstone lenses that are apparently of fluviatile origin. The thickness of the Fruitland formation is fairly constant in this field, ranging from 194 to 292 feet. (See Pl. LXV.) The fossils of this and the succeeding formations up to the Puerco are listed and discussed in the papers by Messrs Gilmore, Stanton, and Knowlton already mentioned.

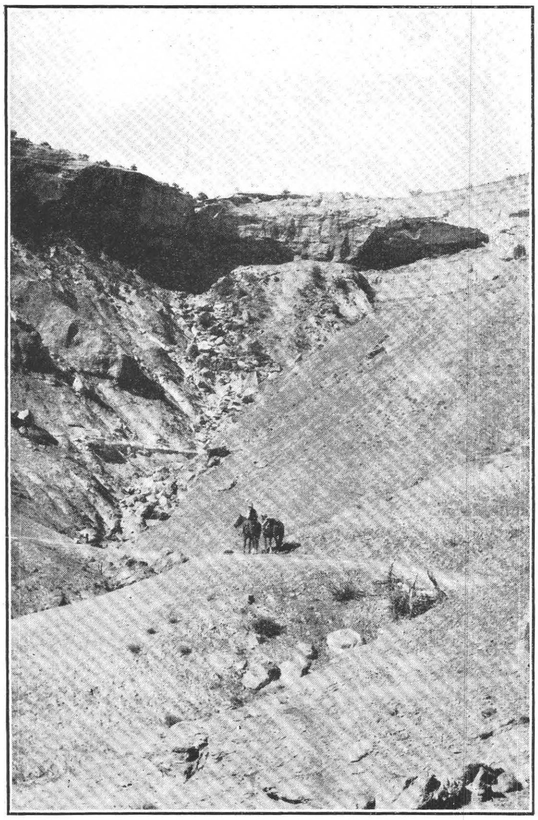
KIRTLAND SHALE.

The Kirtland shale lies conformably upon the Fruitland and is predominantly clayey. The name is taken from that of a post office on San Juan River. The strata are composed mostly of gray shale, with some brown, bluish, greenish, and yellowish shales, easily weathering gray-white sandstone, and the brown resistant sandstone of the Farmington member described below. Barite occurs in concretions and veins in these strata. The eroded surface of the Kirtland shale presents a billowy appearance, with well-rounded surfaces. It is readily affected by erosion, giving rise to extensive badlands. The shale, so far as known, is of fresh-water origin, although possibly it was formed in deltas and lagoons. It is divided, as shown in the San Juan River section (A–A′, Pl. LXV), into three parts—a lower shale 271 feet thick, a sandy part, here named the Farmington sandstone member (see Pl. LXVIII, *A*), and an upper shale 110 feet thick (see Pls. LXXI, *A*, and LXVI, *C*).

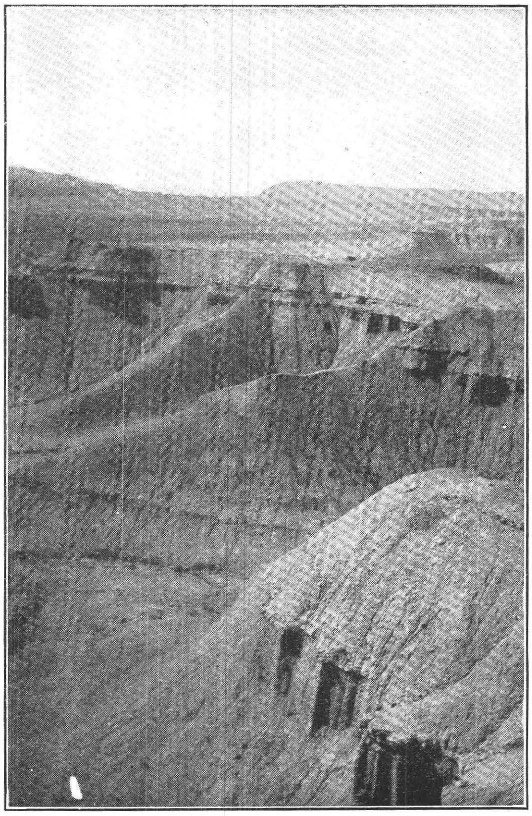


STRATIGRAPHIC SECTIONS ALONG CHACO VALLEY, N. MEX., FROM SAN JUAN RIVER TO MEYERS CREEK.

For locations see Plate LXIV.

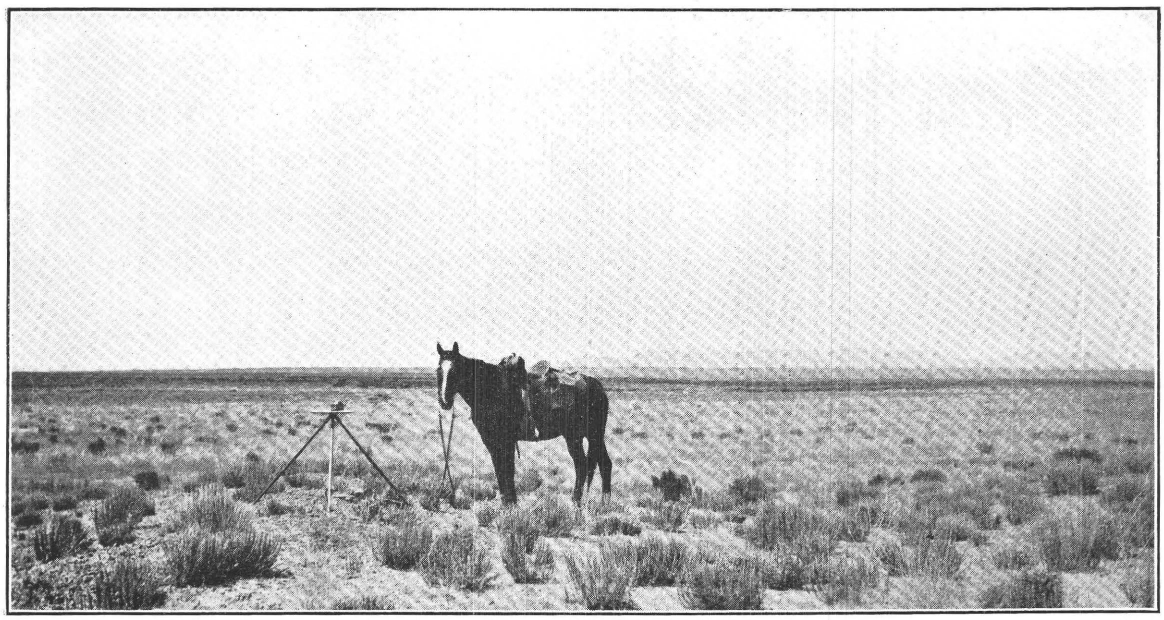


A. KIRTLAND SHALE OVERLAIN BY WASATCH FORMATION ON SOUTH SIDE OF SAN JUAN RIVER OPPOSITE FARMINGTON, N. MEX.



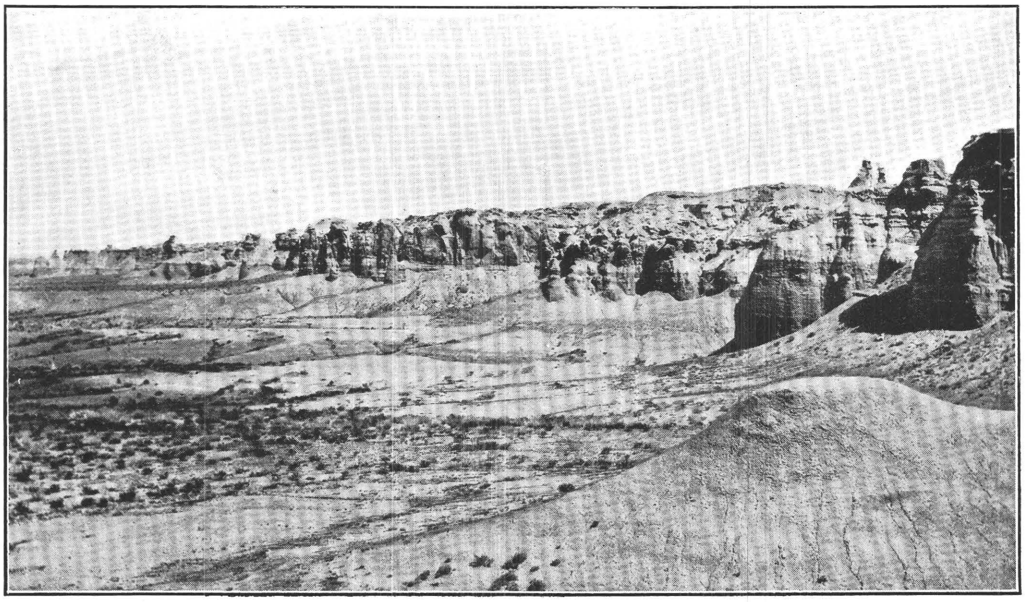
B. OUTCROP OF LEWIS SHALE ALONG CHACO RIVER, N. MEX., 1 MILE EAST OF POINT WHERE IT CUTS THROUGH THE GREAT HOGBACK.

The Great Hogback is composed of rocks of the Mesaverde formation and appears in the distance. Exposure shows sandy beds in the Lewis shale. View looking northwestward.



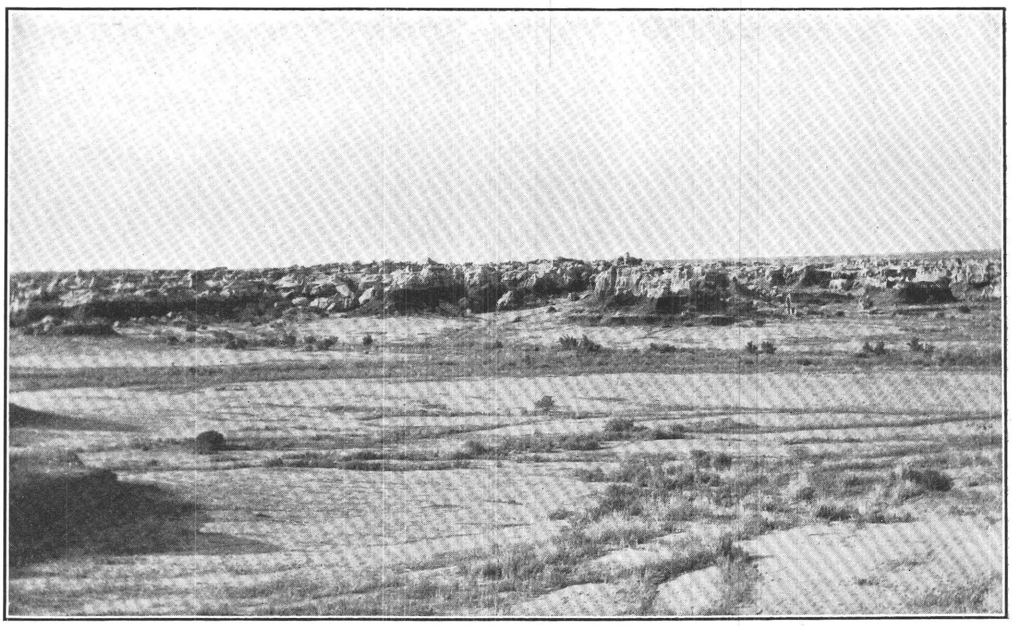
C. THE DESERT PLAIN VIEWED NORTHWESTWARD ACROSS THE VALLEY OF CHACO RIVER, N. MEX., SOUTH OF HUNTER WASH.

Chaco River and other arroyos are intrenched from 75 to 200 feet in this plain, which slopes westward 25 feet to the mile. The Great Hogback is seen in the distance. Elevation above sea level at plane table, 5,680 feet.



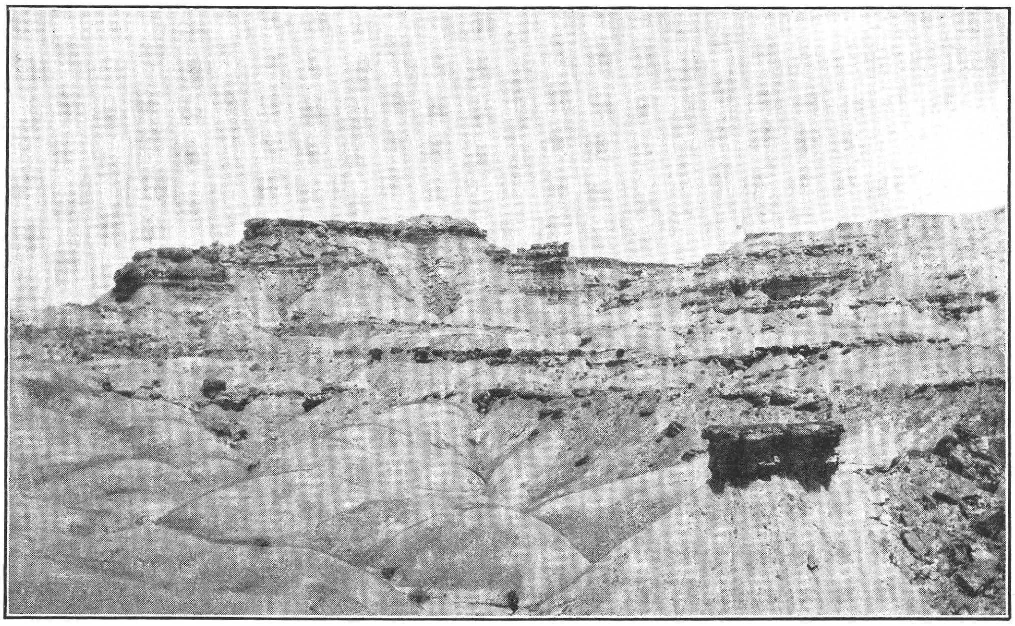
A. PICTURED CLIFFS SANDSTONE OVERLYING LEWIS SHALE ON NORTH SIDE OF COAL CREEK, N. MEX., 2 MILES FROM ITS MOUTH.

View looking westward.



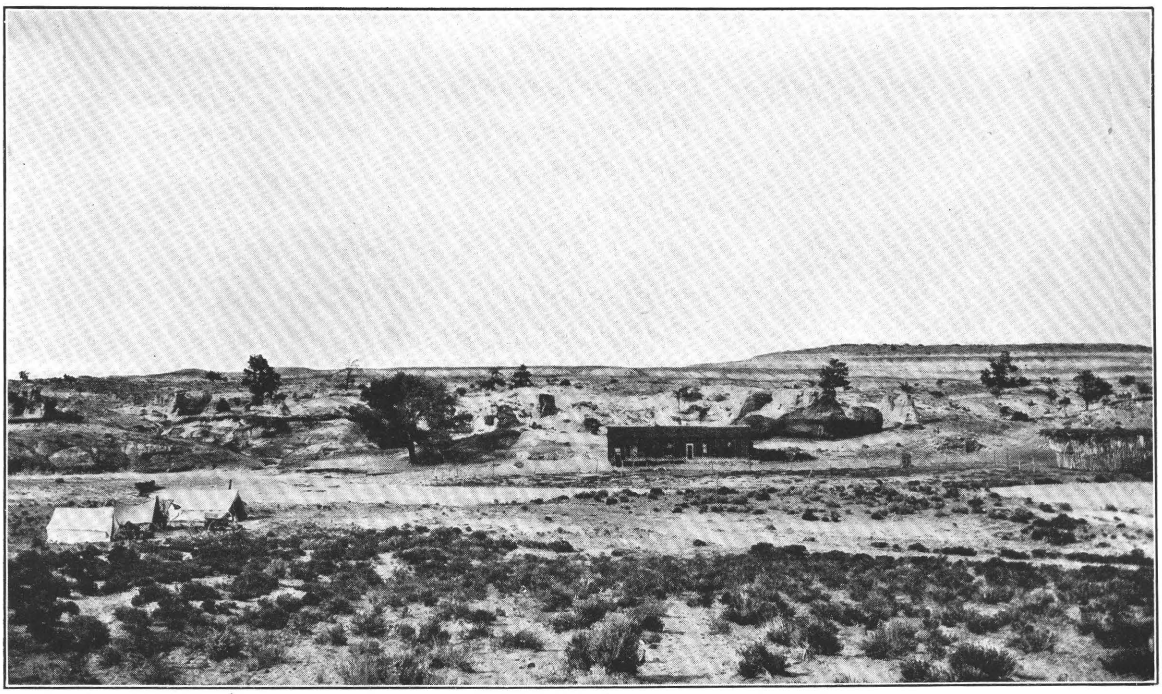
B. OUTCROP OF LOWER PART OF FRUITLAND FORMATION 1 MILE SOUTHWEST OF HUNTER'S STORE, N. MEX.

Coal bed is overlain by peculiarly weathered gray-white sandstone. Flat in foreground underlain by shale. View looking southeastward.



A. FARMINGTON SANDSTONE MEMBER OF KIRTLAND SHALE NEAR THE HEAD OF COTTONWOOD ARROYO, N. MEX.

Part of sandstone shown is 300 feet thick; upper part of Farmington sandstone, about 130 feet, is eroded at this place.



B. OJO ALAMO SANDSTONE AT OJO ALAMO STORE, N. MEX.

Puerco formation overlying Ojo Alamo sandstone is shown in the distance. View looking northward.

The sandstone member forms a prominent bluff on San Juan River, where it is 455 feet thick, but toward the south it is gradually replaced by lenses of shale. On the head of Coal Creek the member disappears as a mappable unit, and farther south it is represented only by isolated sandstone lenses in the Kirtland shale. A study of the sandstone lenses making up the Farmington shows that they are irregular in thickness, cross-bedded, and composed almost invariably of two parts—at the base an easily eroded yellowish sandstone carrying clay pellets of various sizes and in some lenses sandstone pebbles similar to the matrix, as large as 4 inches in diameter, and at the top a markedly resistant brownish sandstone whose upper portion is commonly of a dark chocolate-brown color on the exposed surface and dark gray on the fresh surface. All the lenses in the Farmington sandstone member lie on more or less irregular surfaces of interbedded shale and exhibit the characteristics of channel and flood-plain deposits. An individual lens will usually have a maximum thickness of 20 feet, a lateral extent of 15 or 20 yards, and a length of several hundred yards.

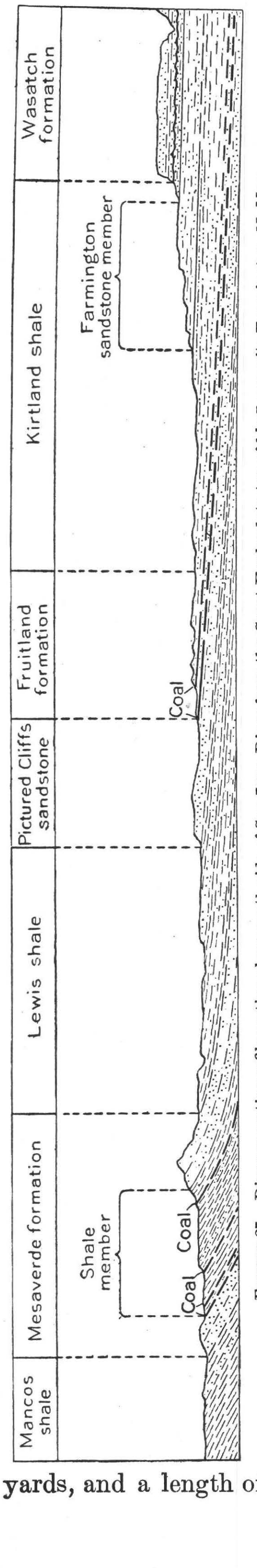


FIGURE 27.—Diagrammatic profile section along south side of San Juan River from the Great Hogback to top of bluff opposite Farmington, N. Mex.

The upper part of the Kirtland shale (see Pls. LXVII, *A*, and LXXI, *A*) is remarkably uniform in thickness from San Juan River to the southern limit of the area, ranging from 40 to 110 feet. It is composed of shale and lenses of easily weathered gray-white sandstone, and is thus very similar to the lower part. It is banded in many places with various colors, such as appear in the lower part of the Kirtland, but yellow, blue-gray, and purplish beds are more common.

OJO ALAMO SANDSTONE.

Overlying the Kirtland shale (see Pl. LXXI, *A*) with apparent conformity is a thin formation of conglomeratic sandstone and shale. These beds were first described by Barnum Brown,[1] of the American Museum of Natural History, New York, who named them Ojo Alamo, from the locality in which they were examined, but assigned no base and indicated no relation between them and the underlying beds. On Ojo Alamo Arroyo Brown found dinosaur-bearing shale below a conglomerate, which is overlain unconformably by the Puerco formation. The following statement is taken from his description:

> Less than a mile south of the store at Ojo Alamo the Puerco formation rests unconformably on a conglomerate that is composed of red, gray, yellow, and white pebbles. * * * Below the conglomerate there is a series of shales and sandstones, evenly stratified and usually horizontal. * * *
>
> The shales below the conglomerate that contain numerous dinosaur and turtle remains I shall designate as the Ojo Alamo beds. They were estimated to be about 200 feet thick, but owing to lack of time I was unable to determine their relation to the underlying formations.

Later Sinclair and Granger,[2] of the same institution, while making a thorough investigation of the Puerco formation, examined the Ojo Alamo locality, and found that the dinosaur-bearing shale on Ojo Alamo and Barrel Spring arroyos is split by a thin conglomerate, referred to by them as the "lower conglomerate."

According to their interpretation

> The Puerco formation rests with marked erosional unconformity on a coarse cross-bedded conglomeratic yellow-brown sandstone * * * which varies in thickness

[1] Brown, Barnum, The Cretaceous Ojo Alamo beds of New Mexico, with description of the new dinosaur genus Kritosaurus: Am. Mus. Nat. Hist. Bull., vol. 28, pp. 267-274, 1910.

[2] Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin, N. Mex.: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 297-316, 1914.

from 28 to 66 feet. [This sandstone] rests disconformably on * * * rusty-yellow, bluish, greenish, and wine-red banded clays with lenses of yellow channel sandstone. * * * A maximum thickness of some 58 feet was measured for this member. * * * [It contains] abundant but badly crushed dinosaur bones, ceratopsian, trachodont, and carnivorous, also turtles, crocodiles, and garpikes. [The sandstone lies on a "lower conglomerate," which] varies from a pebbly sandstone to a coarse conglomerate with waterworn, chatter-marked quartzite, jasper, andesite, and porphyrite pebbles. * * * Its source has not been traced. Its thickness varies from 6 to 8 feet. * * * This lower conglomerate lies in its turn disconformably on a series of bluish shales, or rather clay, for they are quite incoherent. * * * [This shale contains dinosaur bones.] A trip down Ojo Alamo Arroyo to a point some 8 miles below the store resulted in finding turtle and other reptile bones in shales apparently conformable with those just mentioned.

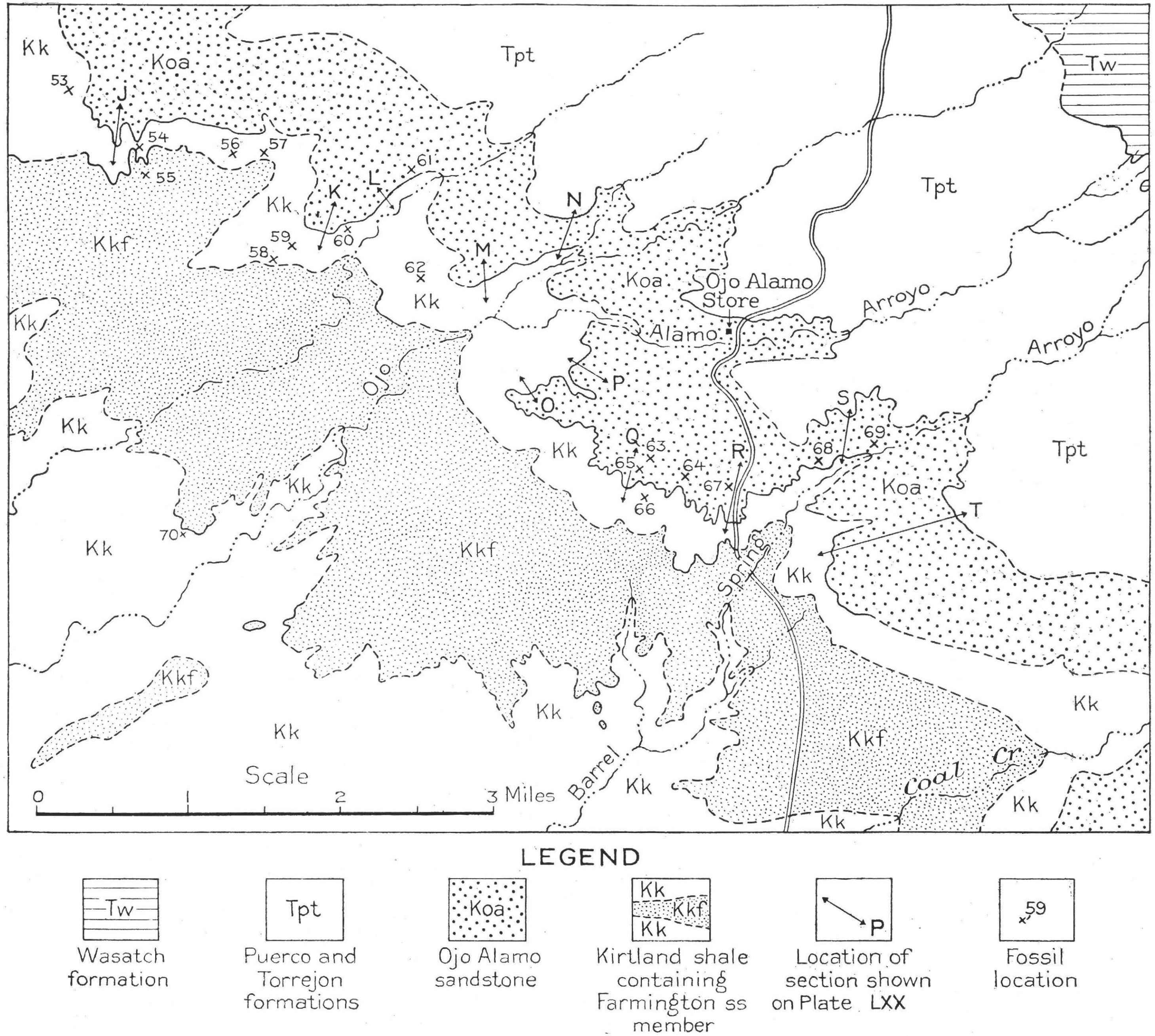
The discrepancies in these descriptions and the failure of these investigators to assign a stratigraphic or paleontologic lower limit to the Ojo Alamo beds call for a more accurate definition of them. The present writer, therefore, made a careful study of these beds in the type locality. Sections (lettered H to W on Pl. LXX; locations of H, I, U, V, and W shown on Pl. LXIV, and of J to T on Pl. LXIX) were measured and compared. On Ojo Alamo and Barrel Spring arroyos (see Pl. LXXI, *A*, and sections O to S, Pl. LXX) the succession of shale and conglomerate as described by Sinclair and Granger was noted. Section P, measured on Ojo Alamo Arroyo, shows 25 feet of the "upper conglomerate" (see Pl. LXVIII, *B*) lying on the 34 feet of wine-red and bluish-gray banded shales interbedded with lenses of gray-white, easily eroded sandstone. This in turn lies on 9 feet of poorly consolidated conglomerate, which has an irregular base, the irregularities amounting to 2 or 3 feet in a horizontal distance of 50 feet. Below the lower conglomerate is a bluish-gray to greenish-gray shale, banded here and there with purplish beds and gray-white sandstone lenses. This lower shale is lithologically similar to and conformable with the beds below. Both of the shales just mentioned contain dinosaur and turtle remains, as shown in section Q, measured on Barrel Spring Arroyo. However, the lower conglomerate has been traced laterally to points where the shale between it and the upper conglomerate is absent, and only a single lithologic unit is present. (See sections, Pl. LXX.) Moreover, the lower shale of Sinclair and Granger is lithologically like the shale below the lower conglomerate on Ojo Alamo Arroyo and is clearly a part of the Kirtland shale. Furthermore, the shale that lies between the conglomerate beds on Ojo Alamo and Barrel Spring arroyos is cut in many places by irregular lenses of gray-white, easily eroded sandstone, which give it so irregular and indefinite an outline that it is not mappable. At localities H, I, J, L, M, T, U, V, and W this shale is not a definite unit.

As Brown, Granger, and Sinclair do not agree on the upper limit of the formation, Brown placing it at the base of the "upper conglomerate" and Sinclair and Granger at the top, and as neither of them assigned a lower limit, it is necessary to redefine the lithologic Ojo Alamo as determined by the writer. As he found the formation to be essentially a sandstone including lenses of shale and conglomerate, it seems desirable to call it Ojo Alamo sandstone and to define it as consisting on Ojo Alamo Arroyo of two conglomeratic beds and the shale lenses which they include. Its thickness where it is overlain by the Puerco formation (see sections H, N, S, and T) ranges from 63 to 110 feet.

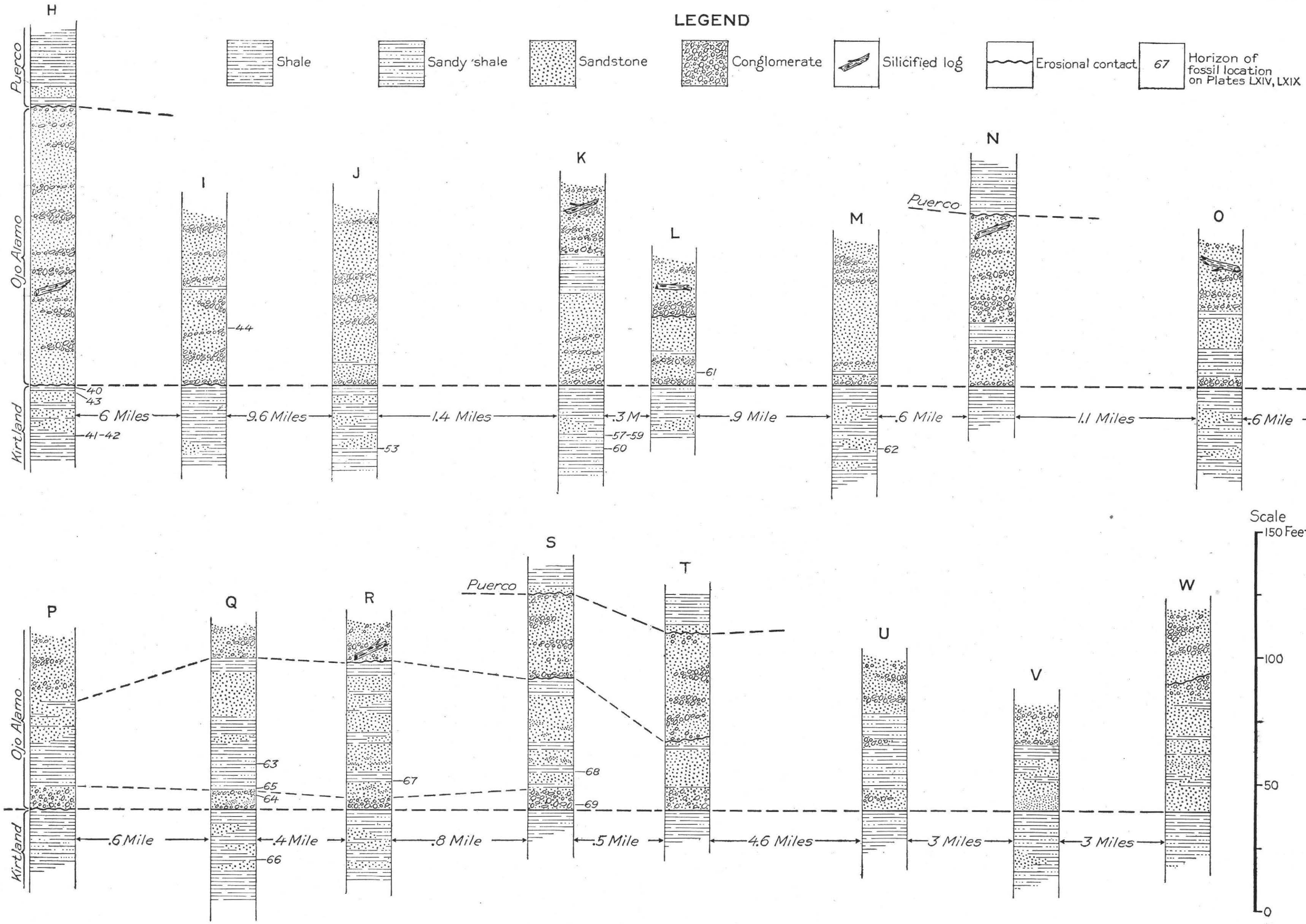
About 70 per cent of the pebbles of the Ojo Alamo are of jasper, variously colored chert, or pink or white quartzite. Of the remainder, pebbles of sandstone, andesite, felsite, porphyrite, gneiss, and schist are fairly common, and pebbles of granite and obsidian are also present. Practically all the pebbles are well rounded. They range in size from sand grains to a few that are 6 inches in diameter. The Ojo Alamo sandstone is highly cross-bedded, and the pebbles occur at different horizons or are scattered through it irregularly. In some places the lower 20 or 30 feet of it is almost lacking in pebbles. On Ojo Alamo Arroyo the lower bed of conglomerate is poorly consolidated, but on the south side of Barrel Spring Arroyo it is quartzitic and very resistant, capping several low buttes in the vicinity. Between localities U and V also the lower bed is very resistant, forming the cap rock for many small buttes.

PUERCO AND TORREJON FORMATIONS.

The Puerco formation (see Pls. LXVIII, *B*, and LXXI, *B*) overlies the Ojo Alamo sandstone with an unconformity by erosion, the irregularity in the contact where seen amounting to 15 or 20 feet, but no discordance of dips between the two formations was noted.



MAP SHOWING DETAILS OF GEOLOGY IN VICINITY OF OJO ALAMO, N. MEX.



SECTIONS OF OJO ALAMO SANDSTONE FROM PINA VETA CHINA TO THE HEAD OF MEYERS CREEK, N. MEX.

For locations see Plates LXIV and LXIX.

Considerable interest has been attached to the Puerco formation because of the primitive mammalian fauna which it contains and because it is confined, so far as known, to the San Juan Basin in New Mexico, though Torrejon mammals have been collected from the Fort Union of Montana.[1]

The Puerco was first described by Cope [2] in 1875. He believed it to overlie the "Laramie" conformably [3] on evidence presented to him by David Baldwin, a collector, who obtained most of the fossils from the Puerco for Cope. However, Cope also states in his paper on the Eocene plateau that the Eocene Wasatch overlies the Puerco "with apparent conformability."

Endlich [4] and Holmes,[5] in their early reconnaissance work in Colorado and New Mexico, apparently mistook the Kirtland shale, or, as Gardner [6] suggests, the lower members of the Wasatch, for the Puerco, inasmuch as typical Puerco mammals have not been found outside of a small area near the center of the San Juan Basin in New Mexico and have not been found in the deposits described by Endlich and Holmes.

The collecting by Baldwin under Cope's direction was actively carried on at intervals from 1880 to 1885, and numerous articles on the fauna were published. In 1892 J. L. Wortman took up the problems connected with the Puerco and headed an expedition to the San Juan Basin. His results were summarized in a paper by Osborn and Earle,[7] in which is quoted a statement from Wortman's notebook that "the Puerco beds so far as can be observed lie conformably upon the Laramie." Wortman again visited the region in 1896 and added much to the collections already obtained. W. D. Matthew [8] then began a systematic study of the Puerco fauna, and in 1897 his paper on it was published.

In 1907 J. H. Gardner,[9] in connection with the mapping of the coal beds in this area, made some observations on the Puerco. His conclusions were published in 1910.[10] His work was followed by the careful study of the Puerco and Torrejon formations, including extended collecting, in 1912–13 by Walter Granger and W. J. Sinclair, whose stratigraphic results were published in 1914.[11]

The Puerco formation was not studied in detail by the present writer, and only its general features will be set forth here. It is very lenticular and irregular in bedding and, like the underlying beds, is of fluviatile origin. It consists of clay, sandy shale, easily weathered sandstone, and resistant sandstone. The striking feature of the Puerco formation, aside from its mammalian fauna, is its color, which is predominantly bluish gray and gray-white, but banded with lemon-yellow sand and wine-red clay. It contains also lenses and concretions of resistant sandstone cemented with manganese dioxide, which are almost black and present a bold contrast to the other strata of the region. Barite is common in isolated concretions, as well as in veins and in sheets.

The Puerco is overlain by the Torrejon formation, which is very similar to it lithologically and was not separated from it by the writer in mapping. Owing to the close similarity in lithology such separation of the Puerco and Torrejon (see Pl. LXXI, *B*) as has been made in the past has depended entirely on fossil collections,[12] and although the fossils seem to indicate an unconformity between the two formations the writer has yet found no stratigraphic reason for such division.

WASATCH FORMATION.

The Wasatch formation, which probably exceeds 2,000 feet in thickness in the San Juan Basin, overlies the Torrejon unconformably and overlaps upon the Ojo Alamo and Kirt-

1 Douglass, Earl, The discovery of Torrejon mammals in Montana: Science, new ser., vol. 15, pp. 272–273, 1902.

2 Cope, E. D., The Eocene plateau: Chief Eng. Ann. Rept. for 1875, pt. 2, Appendix G1, ch. 6, pp. 1008–1017.

3 Cope, E. D., The relations of the Puerco and Laramie deposits: Am. Naturalist, vol. 19, pp. 985–986, 1885.

4 Endlich, F. M., The San Juan region: U. S. Geol. and Geog. Survey Terr. Ninth Ann. Rept., for 1875, pp. 189–190, 1877.

5 Holmes, W. H., La Plata Valley: Idem, pp. 245–267.

6 Gardner, J. H., The Puerco and Torrejon formations of the Nacimiento group: Jour. Geology, vol. 18, No. 8, pp. 702–741, 1910.

7 Osborn, H. F., and Earle, Charles, Fossil mammals of the Puerco beds, collection of 1892: Am. Mus. Nat. Hist. Bull., vol. 7, pp. 1–2, 1895.

8 Matthew, W. D., A revision of the Puerco fauna: Am. Mus. Nat. Hist. Bull., vol. 9, pp. 259–323, 1897.

9 Gardner, J. H., The coal field between Gallina and Raton Spring, N. Mex., in the San Juan coal region: U. S. Geol. Survey Bull. 341, pp. 335–351, 1909.

10 Gardner, J. H., The Puerco and Torrejon formations of the Nacimiento group: Jour. Geology, vol. 18, No. 8, pp. 702–741, 1910.

11 Sinclair, W. J., and Granger, Walter, Paleocene deposits of the San Juan Basin, N. Mex.: Am. Mus. Nat. Hist. Bull., vol. 33, pp. 297–316, 1914.

12 Matthew, W. D., A provisional classification of the fresh-water Tertiary of the West: Am. Mus. Nat. Hist. Bull., vol. 12, pp. 19–77, 1899.

land formations. It consists of an alternation of conglomerate, conglomeratic sandstone, and shale. The basal member of the formation on San Juan River (see Pl. LXVI, *A*) has a thickness of 80 to 100 feet and consists of a well-indurated conglomeratic sandstone which contains pebbles of crystalline, volcanic, and sedimentary rocks. The pebbles range from sand grains to pebbles 8 inches in diameter and, together with the cross-bedding of the formation, suggest deposition by fairly rapid streams. This lower member of the Wasatch is separated from a similar member above it by 50 to 75 feet of greenish-gray and yellowish sandy shale and a few thin beds of carbonaceous shale. This alternation of shale and conglomeratic sandstone is repeated many times in the section exposed along San Juan River. The formation was not studied in detail and only its base was mapped. One collection of fossil leaves from the Wasatch at locality 9 (see Pl. LXIV) is discussed below by F. H. Knowlton:

This material is very fragmentary. It includes, apparently, two ferns, one Pteris-like and the other Anemia-like, but neither is sufficiently well preserved to be identified. There is also a monocotyledon that may be a palm ray or a large leaf of a sedge. The only dicotyledon present is a Sapindus not unlike a large leaflet of *S. angustifolia* Lesquereux, a Green River species.

This lot appears to be Tertiary, but it is too fragmentary to place positively.

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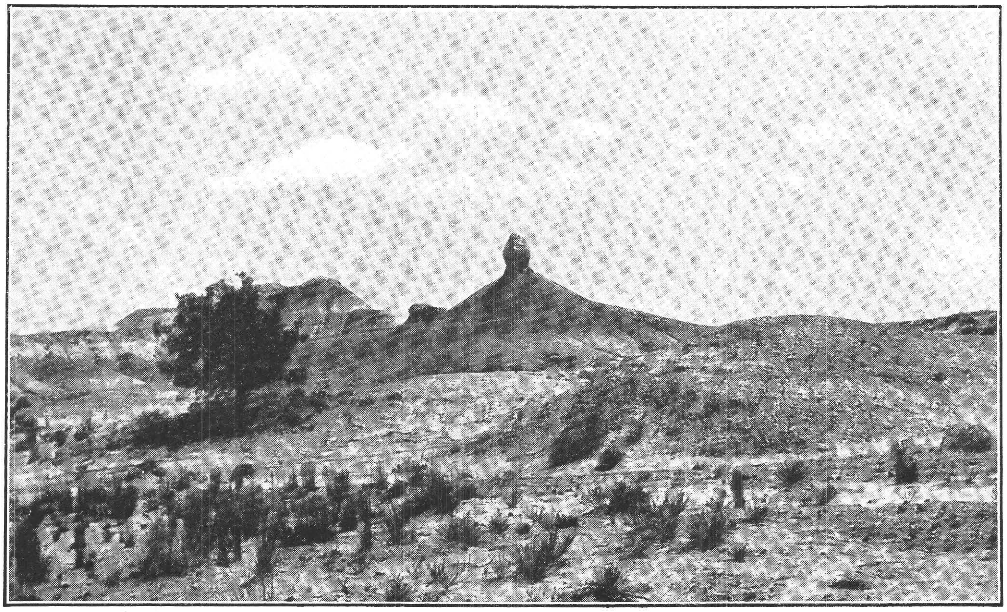
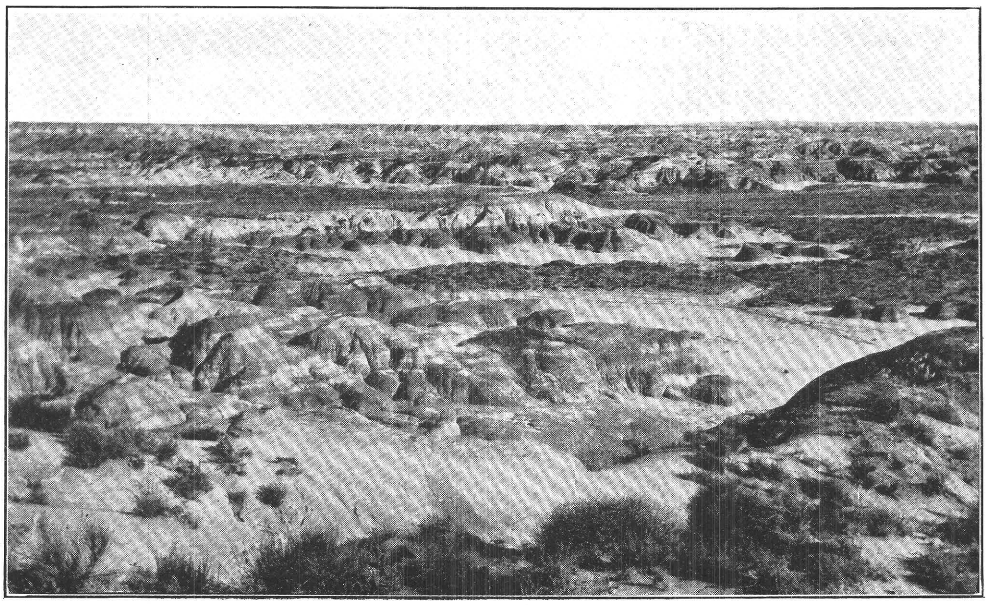


A. VIEW EASTWARD FROM DIVIDE BETWEEN OJO ALAMO AND BARREL SPRING ARROYOS, N. MEX.

Kirtland shale in foreground. Conical butte capped with lower part of Ojo Alamo sandstone. Butte at left consists of Kirtland shale at base, overlain by conglomeratic sandstone of Ojo Alamo, and that in turn by the middle or shale member of the same formation, with pebbles from the disintegrated upper conglomeratic member scattered over the top.



B. EXPOSURE OF PUERCO AND TORREJON FORMATIONS MAKING BADLANDS 1½ MILES ABOVE STORE ON OJO ALAMO ARROYO, N. MEX.

Sky line in center of view shows evenness of interstream areas, which form a westward-sloping plain along Chaco River, the same plain as that shown in figure 27. Altitude of plain, about 6,400 feet.