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History of Nomenclature and Stratigraphy of Rocks Adjacent to the Cretaceous-Tertiary Boundary Western San Juan Basin, New Mexico

GEOLOGICAL SURVEY PROFESSIONAL PAPER 524-D

History of Nomenclature and Stratigraphy of Rocks Adjacent to the Cretaceous-Tertiary Boundary Western San Juan Basin, New Mexico

By ELMER H. BALTZ, SIDNEY R. ASH, *and* ROGER Y. ANDERSON

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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HISTORY OF NOMENCLATURE AND STRATIGRAPHY OF ROCKS ADJACENT TO THE CRETACEOUS-TERTIARY BOUNDARY, WESTERN SAN JUAN BASIN, NEW MEXICO

By Elmer H. Baltz, Sidney R. Ash, and Roger Y. Anderson

ABSTRACT

Dinosaur-bearing shale and sandstone exposed along Ojo Alamo Arroyo in the western part of the San Juan Basin were first called the Ojo Alamo Beds of Cretaceous age in 1910 by Barnum Brown, who wrote that these beds were overlain unconformably by the Puerco Formation of Tertiary age. W. J. Sinclair and Walter Granger differentiated four lithologic units in the rocks that had been described as the Ojo Alamo Beds and lower part of the Puerco Formation by Brown. Their units are, in ascending order: (1) "shales with dinosaurs, lower horizon" (Brown's Ojo Alamo Beds); (2) lower conglomerate; (3) "shales with dinosaurs, upper horizon"; (4) conglomeratic sandstone with fossil logs (lower part of Brown's Puerco Formation). Units 1–4 were called the Ojo Alamo Beds by Sinclair and Granger, who reported that unit 4 was overlain unconformably by shale of the Puerco Formation, with the reported unconformity probably marking the boundary between Cretaceous and Tertiary rocks.

C. M. Bauer assigned the "shales with dinosaurs, lower horizon" to the upper part of the Kirtland Shale of Cretaceous age and defined the Ojo Alamo Sandstone to include the lower conglomerate, the "shales with dinosaurs, upper horizon" and the conglomeratic sandstone with fossil logs. Bauer reported that the upper dinosaur-bearing shale is a local lens enclosed between the two conglomerates of his Ojo Alamo Sandstone, and he placed the Cretaceous-Tertiary boundary at Sinclair and Granger's reported unconformity between his Ojo Alamo and the Puerco Formation. The dinosaur faunas of the Kirtland Shale and of Bauer's Ojo Alamo Sandstone were considered to be of Montana (Late, but not latest Cretaceous) age by Barnum Brown and C. W. Gilmore.

J. B. Reeside, Jr., correlated the uppermost part of Bauer's Kirtland Shale with the McDermott Formation of Cretaceous age and stated that Bauer's Ojo Alamo Sandstone was unconformable with both the underlying McDermott and the overlying Puerco. Reeside assigned the Ojo Alamo Sandstone to the Tertiary(?), although it contained dinosaurs of Late (but not latest) Cretaceous age. Later, Reeside reassigned the Ojo Alamo Sandstone to the Cretaceous.

The Puerco and Torrejon Formations in the vicinity of Ojo Alamo were distinguished from each other by Sinclair and Granger only on the basis of their early and middle Paleocene mammal faunas. G. G. Simpson pointed out that no one has found a lithologic basis for mapping the rocks containing the two faunas as two separate formations. He proposed that the rocks containing the Puerco and Torrejon faunas be called, collectively, the Nacimiento Formation, as used by C. H. Dane.

The present writers found that the upper conglomeratic sandstone of Bauer's Ojo Alamo Sandstone rests on a widespread deeply channeled erosion surface cut in his medial dinosaur-bearing shale which is a persistent unit, rather than being a lens as reported by Bauer. The present writers found also that the upper conglomeratic sandstone intertongues with the overlying Nacimiento Formation of Tertiary (Paleocene) age.

The dinosaur-bearing medial shale and the lower conglomerate of Bauer's Ojo Alamo Sandstone are here named the Naashoibito Member of the Kirtland Shale of Montana age, because of lithologic and faunal similarity to the Kirtland. The name Ojo Alamo Sandstone is here restricted to the upper conglomerate of Bauer's Ojo Alamo. The restricted Ojo Alamo Sandstone is classified as Paleocene because it intertongues with the overlying Nacimiento Formation. Pollen and spore florules from the restricted Ojo Alamo Sandstone and the basal part of the Nacimiento Formation near Barrel Spring are similar, and both florules also are similar to the Ojo Alamo and Nacimiento pollen and spore florules of Roger Y. Anderson from the eastern side of the San Juan Basin.

The restricted Ojo Alamo Sandstone of the type locality is the Ojo Alamo Sandstone of most other workers in the western, southern, and eastern parts of the Central basin of the San Juan Basin. Throughout this region the Ojo Alamo rests with erosional and regional angular unconformity on rocks of Montana age. This unconformity represents a hiatus during which rocks of latest Cretaceous age either were not deposited or were eroded from these parts of the San Juan Basin. The exact position and nature of the Cretaceous-Tertiary boundary in the northern and northeastern parts of the basin have not been established.

INTRODUCTION

During recent work on the ground-water resources of part of the San Juan Basin in northwestern New Mexico, a detailed restudy was made of the type region of the Ojo Alamo Sandstone in the southwestern part of the Central basin of the San Juan Basin (fig. 1). This investigation was necessary to determine the stratigraphic limits of the Ojo Alamo, which is the deepest aquifer from which potable water can be obtained in parts of the Central basin.

During the restudy of the stratigraphy of the rocks that have been called the Puerco Formation, the Ojo Alamo Beds, the Ojo Alamo Sandstone, the McDermott Formation, and the upper member of the Kirtland Shale, the writers found new physical evidence concerning the Cretaceous-Tertiary boundary in the San Juan Basin. New data also were found concerning the palynology of the rocks containing the Puerco mammalian fauna, which is the reference fauna for the earliest (terrestrial) provincial age of the Paleocene of North America (Wood and others, 1941, pl. 1 and p. 8).

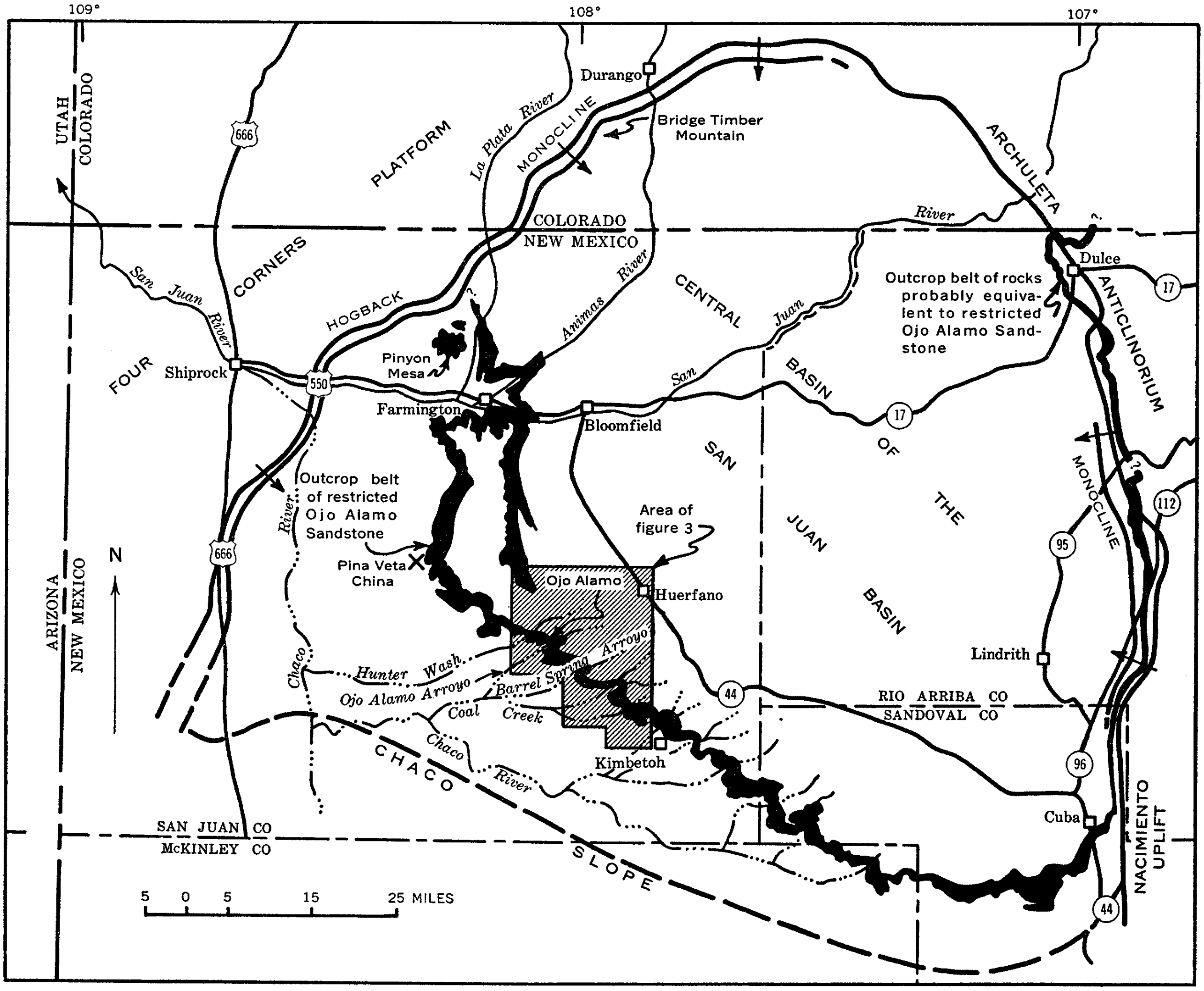

Figure 1.—Index map showing the restricted Ojo Alamo Sandstone and structural features in parts of northwestern New Mexico and southwestern Colorado.

ACKNOWLEDGMENTS

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HISTORY OF NOMENCLATURE AND AGE ASSIGNMENTS

Much of the early fieldwork and fossil collecting that provided important paleontologic data on uppermost Cretaceous and lower Tertiary rocks of the San Juan Basin was concentrated in the southwestern part of the Central basin between Hunter Wash and the eastern tributaries of Coal Creek (fig. 1). An important landmark in this sparsely populated region was Ojo Alamo (Spanish for Cottonwood Spring) where a small store for trading with the Navajo Indians was located in Ojo Alamo Arroyo. This store, which was shown in photographs in two of the early publications (Sinclair and Granger, 1914, pl. 2; Bauer, 1916, pl. 68*B*), was abandoned in 1918. However, its stone foundations can still be recognized on the north side of Ojo Alamo Arroyo at the foot of low cliffs of sandstone that contain large petrified logs. The large cottonwood tree beside the wooden-boxed spring still looks much as it does in early photographs; it is still (1964) an important landmark because, although small cottonwoods occur at other springs in this region, this cottonwood is the largest deciduous tree in this barren but spectacularly beautiful part of the San Juan Basin. Several Navajo hogans were still occupied near Ojo Alamo in 1963–64 when the fieldwork for this report was done. The location of Ojo Alamo is shown on figure 3.

The rocks studied for this report are well exposed on Ojo Alamo Arroyo from about 1 mile west of Ojo Alamo to about 2 miles east. The sequence from the top is as follows:

Unit

5. Gray to greenish-gray, pink- and red-banded clay shale, siltstone, and soft sandstone. Weathers to badlands topography.
4. Buff conglomeratic sandstone containing petrified logs; generally forms a resistant bench or cuesta. Several springs (including Ojo Alamo and Barrel Spring) issue from the lower part of this unit.
3. Gray and variegated shale and soft standstone; dinosaur-bearing. Forms irregular slopes.
2. Buff conglomeratic sandstone; soft and generally inconspicuous, although it locally forms a resistant bench.
1. Gray, greenish-gray, and variegated shale and soft sandstone, dinosaur-bearing. Forms slopes and badlands.

The nomenclature and age assignments of these rock units are shown diagrammatically on figure 2.

OJO ALAMO BEDS OF BROWN

In 1902, G. H. Pepper, of the American Museum of Natural History, found numerous dinosaur bones near Ojo Alamo. The discovery of these bones led to a reconnaissance investigation of the area in 1904 by Barnum Brown of the American Museum. Brown examined the beds of clay shale, siltstone, and sandstone along Coal Creek from which Cope's Puerco mammal fauna (then considered to be early Eocene in age, but now classified as Paleocene) was obtained.[1] These rocks (unit 5, fig. 2), then called the Puerco Formation, were traced west by Brown (1910, p. 267–268) into the badlands in the erosional amphitheater at the head of Ojo Alamo Arroyo. Brown searched for, but did not find, vertebrate or invertebrate fossils in the shale in the badlands. He described the lower part of the Puerco as being composed predominantly of sandstones that contain large petrified logs (unit 4 and probably unit 3 which is mostly soft sandstone in Ojo Alamo Arroyo west of the now-abandoned store).

Brown (1910, p. 268) reported that, less than a mile south (actually, west) of the store at Ojo Alamo, the rocks that he assigned to the Puerco rest unconformably on a conglomerate composed of red, gray, yellow, and white pebbles (unit 2, fig. 2). He considered the contact to be the division between the "uppermost Mesozoic" (Cretaceous) and the Tertiary rocks. Brown (p. 268) wrote:

> Below the conglomerate there is a series of shales and sandstones evenly stratified and usually horizontal, in which there is much less cross-bedding than commonly occurs in the Laramie formation of the northern United States.

[1] The classical Puerco fauna (the first-discovered early to middle Paleocene mammals in the world) was described in the 1880's by Cope in numerous papers. For a list of the fossils and Cope's papers, see Simpson (1936).

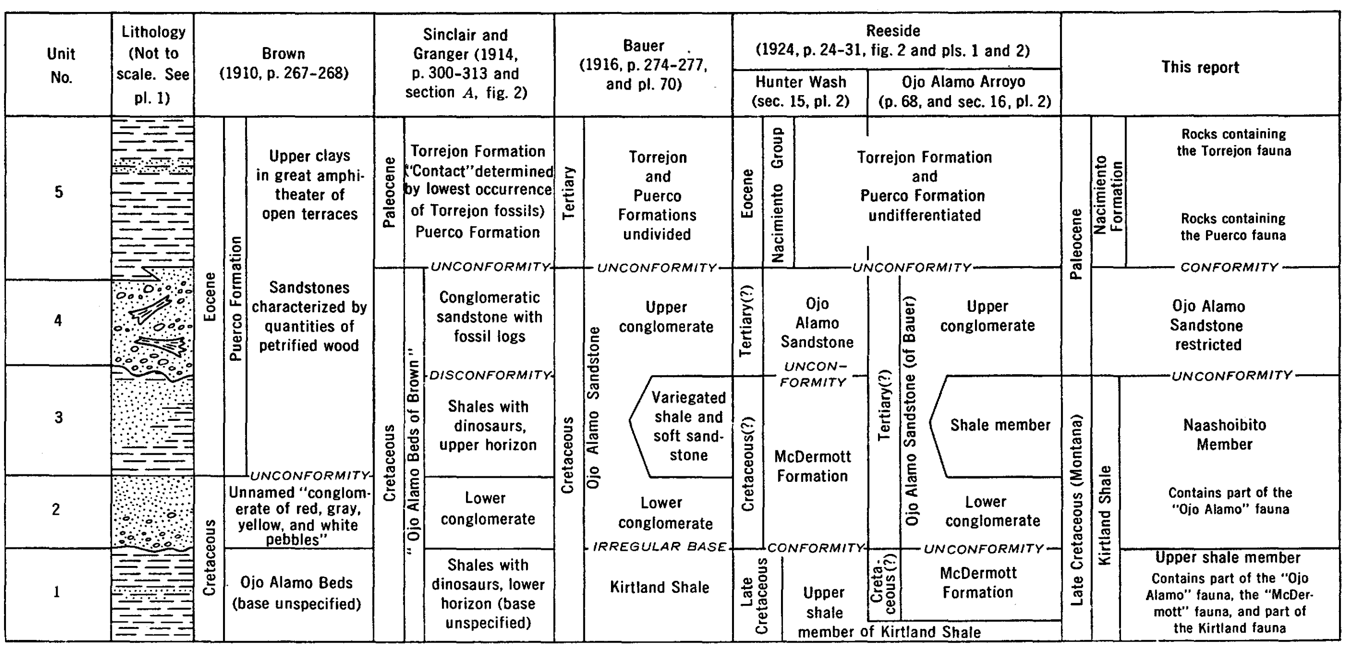

FIGURE 2.—Nomenclature and age assignments of the Ojo Alamo Sandstone and the overlying and underlying rocks near Ojo Alamo Arroyo.

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 formation.

Brown's Ojo Alamo Beds (unit 1, fig. 2) included at least the upper part of the rocks that J. H. Gardner (1909, 1910), of the U.S. Geological Survey, had mapped as the Laramie Formation in areas to the east.

Brown (1910, p. 268) found vertebrate remains in his Ojo Alamo Beds at several places from 30–100 feet below the conglomerate. The fossils consisted of fragments of carnivorous, trachodont, and ceratopsian dinosaurs and turtles. The fragments of the carnivorous dinosaurs were indeterminate; but the ceratopsian bones, especially a fragment of a supraorbital horn, were said by Brown to be from animals smaller than *Triceratops* and most closely related to *Monoclonius*. A fairly well preserved skull, lower jaw, and atlas of a trachodont dinosaur were described as a new genus and species, *Kritosaurus navajovius* Brown. According to Brown (1910, p. 267–268):

This collection is of especial interest, as it represents a fauna that is distinctly older than that of the "Lance Creek Beds or Ceratops Zone" and "Hell Creek beds" of the Laramie Cretaceous * * *.

OJO ALAMO BEDS OF SINCLAIR AND GRANGER

In 1912 and 1913, W. J. Sinclair, of Princeton University, and Walter Granger, of the American Museum of Natural History, visited the outcrops of the Upper Cretaceous and lower Tertiary rocks of the southern part of the San Juan Basin, made important observations on the stratigraphy of Brown's Ojo Alamo Beds and overlying rocks, and made significant collections of dinosaurs and fossil mammals from rocks in the vicinity of Ojo Alamo and Barrel Spring Arroyos. They found Puerco fossils (in unit 5, fig. 2) in the badlands of the amphitheater on Barrel Spring Arroyo and also in the amphitheater at the head of Ojo Alamo Arroyo.

Sinclair and Granger (1914, p. 300–304) found that the Ojo Alamo Beds and the lower part of the rocks assigned to the Puerco Formation by Brown consist of several distinct lithologic units that had not been differentiated completely by Brown (1910). In ascending order, the units named by Sinclair and Granger are (1) "shales with dinosaurs, lower horizon" (base unspecified); (2) lower conglomerate; (3) "shales with dinosaurs, upper horizon"; (4) conglomeratic sandstone with fossil logs. These units correspond to units 1–4, figure 2, of the present report. Sinclair and Granger (1914, p. 301 and stratigraphic section *A* of their fig. 2) called all these rocks the "Ojo Alamo beds of Brown." However, it is clear that units 4 and 3 were included in the Puerco Formation by Brown, because he specified (1910, p. 268) that the Puerco included, near its base, sandstones that are characterized by large quantities of petrified wood. Brown specified also that the base of the Puerco was south (west) of Ojo Alamo store, that is, below the stratigraphic position of unit 4. The unnamed conglomerate that Brown stated was unconformably overlain by the Puerco Formation and underlain by his fossiliferous Ojo Alamo Beds seems to be the lower conglomerate (unit 2) of Sinclair and Granger.

Sinclair and Granger found bones of the trachodont dinosaur *Kritosaurus navajovius* Brown in unit 3 ("shales with dinosaurs, upper horizon"), and they included units 2 and 3 with Brown's Ojo Alamo Beds in which this dinosaur was first found. (Also, see Gilmore, 1916, p. 283; Colbert, 1950, p. 70–71.) Brown (in Sinclair and Granger, 1914, p. 302–303) reported that a trachodont which had been found in the Belly River beds of Canada had been named *Gryposaurus notabilis* by L. M. Lambe. According to Brown, *Gryposaurus* is the same as *Kritosaurus*, evidence that supported his earlier contention that the Ojo Alamo Beds are older than the Lance Formation of latest Cretaceous age.

Sinclair and Granger (1914, p. 301) reported that the conglomeratic sandstone with fossil logs (unit 4) rests disconformably on the "shales with dinosaurs, upper horizon" (unit 3), but they did not attribute a special significance to the disconformity. Jack Martin, a member of the expedition, found a badly worn centrum of a dinosaurian caudal vertebra lying loose on the surface of the conglomeratic sandstone with fossil logs near Barrel Spring. Sinclair and Granger admitted (p. 301) that its value as an index fossil was questionable, but they concluded that it probably had weathered from the conglomeratic sandstone. Sinclair and Granger reported (p. 304) that the conglomeratic sandstone with fossil logs was overlain unconformably by the Puerco Formation (unit 5). They indicated that an abrupt change from dinosaurian faunas to mammalian faunas occurred at the contact and specified that the dividing line between the Cretaceous and the Tertiary probably is at the reported unconformity.

Thus, Sinclair and Granger included in their Ojo Alamo Beds about 100 feet of rocks that Brown had called the lower part of the Puerco Formation, redefined the base of the Puerco as the top of the conglomeratic sandstone with fossil logs (unit 4), and raised the Cretaceous-Tertiary boundary to the top of that sandstone.

KIRTLAND SHALE AND OJO ALAMO SANDSTONE OF BAUER

In 1915 a field party directed by C. M. Bauer, of the U.S. Geological Survey, mapped a large area in the west-central part of the San Juan Basin, including the vicinity of Ojo Alamo and Barrel Spring (Bauer, 1916, pls. 64, 69). Bauer (1916, p. 274–275) subdivided the rocks that had been called the Laramie Formation by the Geological Survey in this region into a lower formation consisting of sandstone, shale, and coal which he named the Fruitland Formation of Cretaceous age, and an upper formation consisting of shale and subordinate amounts of sandstone which he named the Kirtland Shale, also of Cretaceous age. He differentiated and mapped a sequence of lenticular sandstones and interbedded shale in the medial part of the Kirtland as the Farmington Sandstone Member. (Reeside, 1924, p. 21–22, later applied the terms lower shale member and upper shale member to the parts of the Kirtland below and above the Farmington Sandstone Member.)

Bauer (1916, p. 275–276) found that his Kirtland Shale was overlain by part of the rocks that had been called the Ojo Alamo Beds by Sinclair and Granger (1914). He briefly reviewed their descriptions and concluded that the Ojo Alamo Beds should be defined more accurately because neither Brown nor Sinclair and Granger had assigned a lower stratigraphic or paleontologic limit to their Ojo Alamo Beds.

Bauer examined the Ojo Alamo Beds in Ojo Alamo and Barrel Spring Arroyos and (1916, p. 276) reported that the "shales with dinosaurs, lower horizon" (unit 1) of Brown's and Sinclair and Granger's Ojo Alamo Beds are "clearly a part of the Kirtland shale". Bauer reported that he had traced the lower conglomerate (unit 2) to places where the upper shale (unit 3) between it and the upper conglomerate (unit 4) is absent, and only a single lithologic unit is present. He (p. 276) defined the Ojo Alamo Sandstone "as consisting on Ojo Alamo Arroyo of two conglomerate beds and the shale lenses which they include * * *," and stated that the Ojo Alamo is "essentially a sandstone including lenses of shale and conglomerate * * *." Bauer did not comment on the disconformity and channel fillings at the base of the conglomeratic sandstone with fossil logs (unit 4) that Sinclair and Granger (1914, p. 301) had reported, although he remarked that the medial shale (unit 3) of his Ojo Alamo was cut by lenses of sandstone.

Gilmore (1916, 1919) examined the vertebrate fossils collected from the Fruitland Formation, Kirtland Shale, and Ojo Alamo Sandstone by Bauer's party and evaluated the evidence presented by these fossils and the fossils collected by Brown and by Sinclair and Granger. According to Gilmore (1916, p. 280–281), the trachodont dinosaur *Kritosaurus*, the trachodont teeth with papillate borders, and the maxillae with 42 rows of teeth all indicate that the faunas are older than those of the Lance Formation. Gilmore agreed with Brown in concluding that the faunas of the Fruitland, Kirtland, and (Bauer's) Ojo Alamo were distinctly older than those of the Lance.

Bauer (1916, p. 276) reported that "The Puerco formation * * * 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." Bauer combined the Puerco Formation and the overlying Torrejon Formation on his maps (pls. 64, 69) and did not comment on their ages, although he assigned them to the Tertiary as shown by his map symbols. Thus, he placed the Cretaceous-Tertiary boundary at the top of the upper conglomerate (unit 4), as had Sinclair and Granger.

McDERMOTT FORMATION AND OJO ALAMO SANDSTONE OF REESIDE

In 1924, J. B. Reeside, of the U.S. Geological Survey, published a report on the stratigraphy of the Upper Cretaceous and Tertiary rocks of much of the western half of the San Juan Basin in both New Mexico and Colorado. Reeside's report not only synthesized, summarized, and corrected the work of earlier Geological Survey field parties, but it also contained new field data and was an important contribution to the knowledge of the geology of this region.

Reeside (1924, p. 24–28) found that, along the Hogback monocline from east of Durango, Colo., to the Colorado-New Mexico State line (fig. 1), the upper shale member of the Kirtland Shale is overlain by a sequence of lenticular sandstones, conglomerate, purplish volcanic breccia and conglomerate, and tuffaceous shale. He named these rocks the McDermott Formation of Cretaceous(?) age for exposures in McDermott Arroyo just north of the State line. This unit was later redefined with slightly different upper and lower contacts and called the McDermott Member of the Animas Formation of Cretaceous and Tertiary age by Barnes, Baltz, and Hayes (1954). Along the Hogback the McDermott is overlain, in Colorado, by rocks assigned to the Animas Formation by Reeside, and, in New Mexico, by rocks assigned to the Torrejon Formation by Reeside. Reeside mapped the McDermott southward from its type locality through discontinuous exposures and found that, in the vicinity of Pinyon Mesa northwest of Farmington, N. Mex., it is overlain unconformably by rocks that he correlated with Bauer's Ojo Alamo Sandstone. Reeside reported that he had traced the McDermott, beneath the Ojo Alamo Sandstone, southward from Pinyon Mesa through the discontinuous exposures south of the San Juan River to Ojo Alamo, and thence southeastward to the northeastern part of T. 23N., R. 11 W. (Reeside, 1924, p. 24 and pl. 1), where the McDermott was said to be truncated by the Ojo Alamo Sandstone. According to Reeside (1924, p. 25),

> South of San Juan River the McDermott formation is a thin assemblage of brown sandstone and grit, gray-white sandstone, and purple and gray shale just beneath the Ojo Alamo sandstone. Except for the purple color of some of the beds, this assemblage does not look greatly like the McDermott formation in Colorado. These beds, however, contain detritus from andesites.

According to Reeside (1924, p. 25), the McDermott included the upper part of the Ojo Alamo Beds of Brown and the uppermost part of the Kirtland Shale of Bauer. Probably Reeside's McDermott in Hunter Wash is actually the lower conglomerate (unit 2) and medial shale (unit 3) of Bauer's Ojo Alamo Sandstone (fig. 2, present report), as is explained on page D9.

Reeside (1924, p. 28) accepted Bauer's (1916, p. 276) definition of the Ojo Alamo and stated that the Ojo Alamo is

> a conglomeratic sandstone containing one or more lenses of variegated shale and soft sandstone bounded below by an unconformable contact with the McDermott formation and above at the type locality by an unconformable contact with the Puerco formation. The section at the type locality shows it to be 86 feet thick.

Fragmentary plant fossils collected from rocks assigned by Reeside to the Ojo Alamo Sandstone on the western side of the Central basin were examined by F. H. Knowlton, who reported (in Reeside, 1924, p. 31–32) that some of the fossils were similar to Tertiary species, but he expressed a lack of certainty of age because many of the fossils were too badly broken for positive identification. Reeside (1924, p. 31–32) wrote that the identification and stratigraphic position of the dinosaur fauna from the vicinity of the type section of Bauer's Ojo Alamo were uncertain, and that the paleontologic data are inconclusive as to the age of the beds.

Reeside (1924, p. 31–32) classified the Ojo Alamo Sandstone as Tertiary(?) and based his age assignment, at least partly, on structural evidence, stating (p. 32) that there is a significant hiatus between the pre-Ojo Alamo deposits and the Ojo Alamo as determined by regional stratigraphic overlap of the McDermott by the Ojo Alamo. Later, Reeside (in Dane, 1932, p. 407; Reeside, 1944; Cobban and Reeside, 1952, chart 10b) accepted the evidence of the dinosaurs and classified the Ojo Alamo Sandstone as Upper Cretaceous.

PUERCO AND TORREJON FORMATIONS

The gray to greenish-gray, pink- and red-banded clay shale and siltstone and interbedded soft sandstone (unit 5) that overlie the upper conglomerate (unit 4) of Bauer's Ojo Alamo Sandstone in the Hunter Wash-Coal Creek area are generally equivalent to the rocks called the Puerco marls by Cope (1875, p. 1008–1017). These rocks (unit 5) contain two distinctly different mamalian faunas of early and middle Paleocene ages that were distinguished by Matthew (1897, p. 259–261). On the basis of the faunas, Matthew (1897) proposed that the rocks containing the older fauna be called the Puerco Formation and the rocks containing the younger fauna be called the Torrejon Formation, crediting the proposal to J. L. Wortman. They did not define the lithology of these units or map them.

According to Sinclair and Granger (1914, p. 305–306 and section *A* of their fig. 2), the rocks containing the Puerco fauna at Ojo Alamo and Barrel Spring Arroyo are about 76 feet thick and are overlain by unfossiliferous beds, 169.5 feet thick, which they assigned also to the Puerco Formation. In the Hunter Wash-Coal Creek area, the Puerco Formation of Sinclair and Granger is overlain by rocks that contain the Torrejon fauna and were assigned by Sinclair and Granger (p. 310) to the Torrejon Formation. Although the Puerco and Torrejon Formations were thought (Matthew, 1921, p. 216, 218, 220; Reeside, 1924, p. 35) to be separated by a hiatus because of the evolutionary differences in their faunas, Sinclair and Granger (1914, p. 307–308) reported that they could not detect any traceable lithologic or stratigraphic break that separates the Puerco and Torrejon and they based their (unmapped) separation strictly on the stratigraphic positions of the lowest Torrejon fossils that they found at several places.

Gardner (1910, p. 713) had proposed that the Puerco and Torrejon Formations be included in a lithologically mappable unit which he called the Nacimiento Group. Sinclair and Granger (1914), Dane (1932, 1936), and Simpson (1948, 1959) found that Gardner had defined the Puerco and Torrejon Formations incorrectly at his type locality (near Cuba, N. Mex.) of the Nacimiento Group. The interesting history of the nomenclature of the Puerco and Torrejon Formations of the Nacimiento Group has been discussed in detail by Simpson (1948, p. 263–273; 1950, p. 74–78; 1959, p. 1–3, 16–21). Simpson (1948) concluded that the rocks containing the Puerco and Torrejon faunas should be called, collectively, the Nacimiento Formation (as used by Dane, 1946), and that the terms "Puerco" and "Torrejon" should be used only as suggested by Wood and others (1941, pl. 1, p. 8–9) and Simpson (1947), for the Puercan and Torrejonian provincial ages that represent, respectively, early Paleocene time and part of middle Paleocene time. This practical solution is necessary because no one has yet found a lithologic basis for mapping a contact between the rocks containing the Puerco fauna and the rocks containing the Torrejon fauna.

Therefore, the rocks (unit 5, fig. 2) that Sinclair and Granger, Bauer, and Reeside called the Puerco and Torrejon Formations in the Hunter Wash-Coal Creek area are assigned to the Nacimiento Formation by the present writers. These rocks in this region have already been shown as the Nacimiento Formation on maps by Dane and Bachman (1957) and O'Sullivan and Beikman (1963).

STRATIGRAPHY

PRESENT WORK

The present writers found that in the typical region (fig. 3), the Ojo Alamo Sandstone of Bauer and the underlying rocks are almost continuously exposed be-

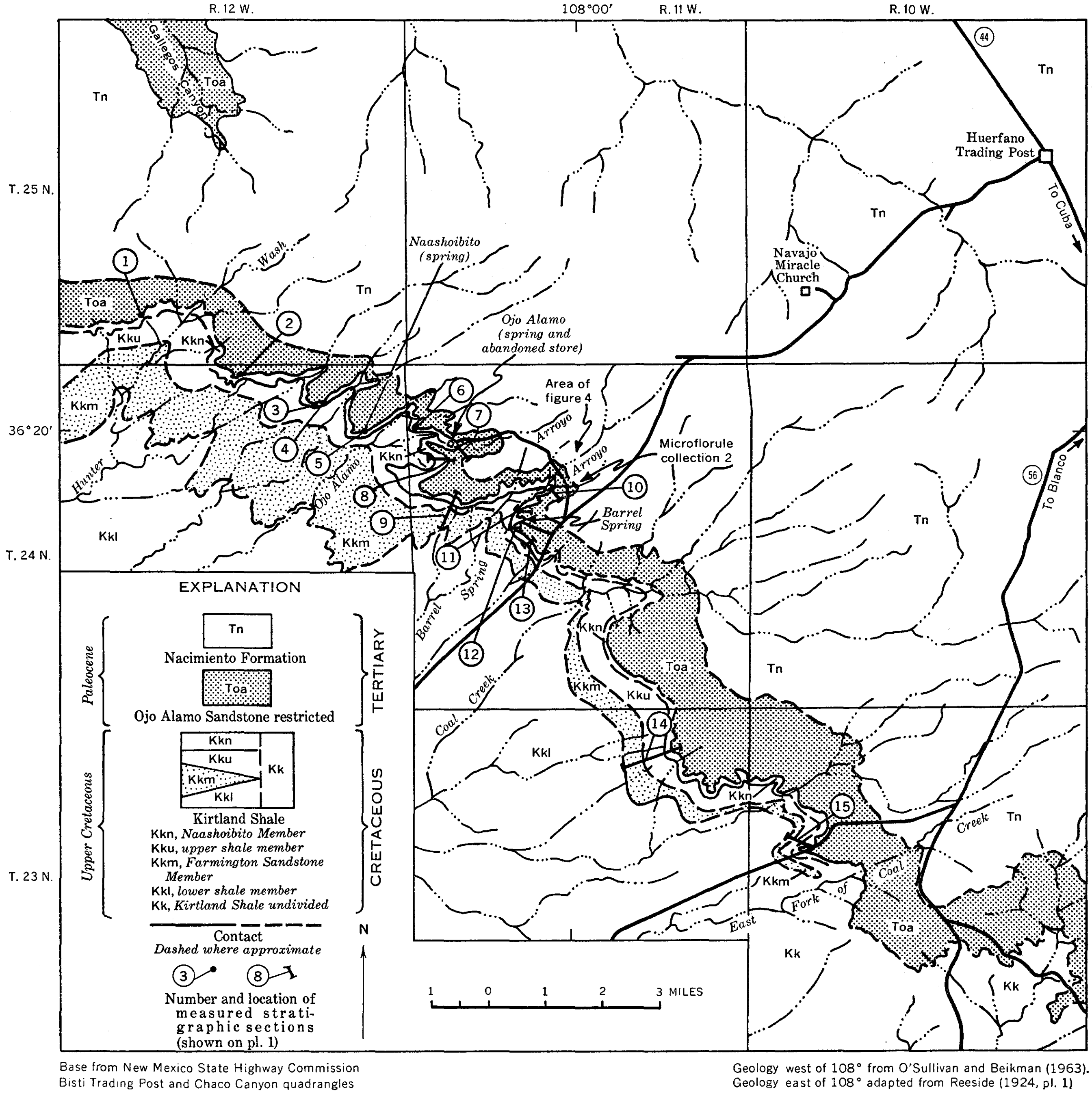

FIGURE 3.—Geologic map of the type region of the restricted Ojo Alamo Sandstone, southern San Juan County, N. Mex.

tween Hunter Wash and Barrel Spring Arroyo, and that they are well exposed at many places east of Barrel Spring. However, the contact of the Ojo Alamo and the overlying Nacimiento Formation is concealed at most places, except in the upper reaches of Ojo Alamo and Barrel Spring Arroyos and their tributaries. The localities of the stratigraphic sections of Sinclair and Granger (1914), Bauer (1916), and Reeside (1924) were examined, and their stratigraphic units were traced southeastward and northwestward from Ojo Alamo Arroyo. Fifteen stratigraphic sections were measured and are shown on plate 1.

The lithologic units of the Ojo Alamo Beds, as described by Sinclair and Granger (1914), can be traced with confidence throughout the typical region. However, unit 4—the conglomeratic sandstone with fossil logs (the upper conglomerate of Bauer's Ojo Alamo Sandstone)—rests on a deeply channeled erosion surface cut in the underlying dinosaur-bearing rocks, and it intertongues with the overlying Nacimiento Formation. Furthermore, unit 3—the "shales with dinosaurs, upper horizon" (the medial shale of Bauer's Ojo Alamo)—is a persistent unit throughout the Hunter Wash-Coal Creek area and is not a lens enclosed between the upper and lower conglomerates, as was reported by Bauer (1916) and Reeside (1924). These stratigraphic relations indicate that the nomenclature and stratigraphic assignments of Bauer's and of Reeside's Ojo Alamo Sandstone and the underlying rocks should be revised. The revised stratigraphic assignments are shown on figure 2 and plate 1 and are discussed more fully in the following sections of this paper.

KIRTLAND SHALE

UPPER SHALE MEMBER

Definition

The upper shale member of the Kirtland Shale of the present report (fig. 3 and pl. 1) is the part of the Kirtland above the Farmington Sandstone Member as mapped by Bauer (1916, pls. 64, 69) in the Hunter Wash-Barrel Spring area. This is also the upper shale member of the Kirtland as mapped in this area by Reeside (1924, pl. 1), except that the rocks assigned by Reeside to the McDermott Formation in the Hunter Wash-Coal Creek area are included, at places, in the upper shale member by the present writers. The McDermott is not recognized in the Hunter Wash-Coal Creek area by the present writers.

On the basis of Brown's (1910) first usage, the name Ojo Alamo should have been applied to at least part of the rocks that Bauer (1916) named the Kirtland Shale. Sinclair and Granger (1914, p. 302) wrote that the lower part of their Ojo Alamo Beds (the "shales with dinosaurs, lower horizon") extends at least 8 miles down Ojo Alamo Arroyo southwest of the store, and thus it includes nearly all the rocks that Bauer (1916) included in the Kirtland. However, Brown (1910, p. 268) and Sinclair and Granger (1914, p. 304) used the name Ojo Alamo Beds in a biostratigraphic sense for what they considered to be the highest dinosaur-bearing unit in the San Juan Basin, and Sinclair and Granger used a stratigraphically higher top for their Ojo Alamo Beds than the top that Brown had specified. Neither Brown nor Sinclair and Granger specified a paleontologic or lithologic base for the unit, as Bauer (1916, p. 276) pointed out.

The name Kirtland Shale has been established firmly in the geologic literature of the San Juan Basin since the work of Bauer (1916) and Reeside (1924) who treated these rocks strictly as a rock-stratigraphic unit. Furthermore, the reptilian fauna of these rocks was established firmly in the paleontologic literature as being the fauna of Bauer's Kirtland Shale by Gilmore's (1916, 1919, 1935) work on the fossils. Other paleontologic reports also use the terms Kirtland Shale and Kirtland fauna in the same way as used by Gilmore. Therefore, we believe that it is inadvisable to replace the name Kirtland by Ojo Alamo, despite Brown's priority of usage.

Lithology and Thickness

The upper shale member of the Kirkland Shale is well exposed in extensive badlands at many places. The member is composed of claystone, siltstone, and varied but subordinate amounts of interbedded lenticular soft sandstone and shaly sandstone. The colors range from light gray, olive gray, and olive green to maroon and purple. Relatively abrupt lateral gradations from brightly colored banded variegated beds to drab-gray olive-green beds are characteristic. Fragments of dinosaur bone and petrified wood occur at several stratigraphic positions in the member. In the vicinity of Ojo Alamo and Barrel Spring Arroyos, beds of lignite, dark-gray carbonaceous shale, purple tuffaceous(?) shale, and highly lenticular stream-channel sandstone occur in the upper part of the member (pl. 1). The upper shale member is 60–100 feet thick between Hunter Wash and Barrel Spring Arroyo where it rests conformably on the Farmington Sandstone Member of the Kirtland Shale.

East of Coal Creek (section 14), the drab-gray and olive-gray rocks mapped by Reeside (1924, pl. 1) as the upper shale member of the Kirtland are 16–25 feet thick. Here, the stratigraphic position of the underlying Farmington Sandstone Member may be slightly higher than its position near Ojo Alamo and Barrel Spring Arroyos, possibly accounting partly for the diminished thickness of the upper shale member. East of locality 15, in the northwestern part of T. 23 N., R. 10 W., the Farmington Sandstone Member wedges out (Reeside, 1924, pl. 1). The Kirtland is shown in figure 3 of the present report as an undivided unit east of this wedge out.

According to Reeside (1924, p. 25), the McDermott Formation (the McDermott Member of the Animas Formation of Barnes, Baltz, and Hayes, 1954) included the uppermost part of Bauer's Kirtland Shale. Reeside (1924, p. 25) wrote that the McDermott Formation south of the San Juan River is distinguished mainly by the purple color and "andesitic detritus" of some of its beds. However, the upper part of the upper shale member of the Kirtland and the medial shale of Bauer's Ojo Alamo Sandstone both contain purplish-weathering beds that grade laterally into drab shale and sandstone, and the colors are not, in themselves, a good criterion for distinguishing stratigraphic units.

Reeside (1924, fig. 2, p. 29; section 16, pl. 2; and p. 67–68) indicated that three units of conglomerate are present at the type locality of the Ojo Alamo. The lowest conglomerate is specified as being the basal unit of the McDermott Formation. The present writers found that, although variegated shale occurs in the upper shale member of the Kirtland, there is no conglomerate below the lower conglomerate of Bauer's and Reeside's Ojo Alamo Sandstone at the type locality. In Ojo Alamo Arroyo about three-fourths mile west of the abandoned store (west of loc. 6), the lower conglomerate of Bauer's Ojo Alamo Sandstone rests on variegated and purple-weathering (tuffaceous?) shale, 30–40 feet thick, which seems to be Reeside's McDermott Formation. The shale lies on a locally exposed lenticular light-gray coarse-grained sandstone, about 10 feet thick, which is probably the basal unit of Reeside's McDermott at this place. The writers did not find any pebbles in this sandstone, although it is overlain by a scree of recent lag gravel derived from the stratigraphically higher conglomerates.

In the first tributary northwest of Ojo Alamo Arroyo, Reeside's (1924, pl. 1) map indicates that the McDermott is present between the upper shale member of the Kirtland and the Ojo Alamo Sandstone. However, Reeside's (p. 68–69) stratigraphic section measured in this tributary wash (sec. 6, T. 24 N., R. 11 W.) indicates that the McDermott is not present and specifies that the lower conglomeratic sandstone of his Ojo Alamo Sandstone rests unconformably on drab shale which he assigned to the Kirtland Shale in his section. The variegated rocks that Reeside assigned to the McDermott in Ojo Alamo Arroyo either are not present, or they grade laterally into the drab beds that he assigned to the Kirtland in his stratigraphic section of the tributary wash. In this area, there seem to be no clearly defined criteria for distinguishing and separating Reeside's McDermott from the rocks that he assigned to the upper shale member of the Kirtland.

Reeside (1924, section 15, pl. 2) indicated that the McDermott Formation in Hunter Wash consists of a basal conglomerate overlain by shale which is overlain, in turn, by conglomerate of his Ojo Alamo Sandstone. In this area also, the writers were unable to find a conglomerate below the stratigraphic position of the lower conglomerate of Bauer's Ojo Alamo which they traced from the type locality. At the excellent exposures in the main eastern tributary of Hunter Wash (just east of loc. 2, fig. 3 of the present report) the upper shale member of Bauer's Kirtland contains variegated shale which might be the rocks assigned to the McDermott by Reeside. However, locally in these outcrops, the rocks equivalent to the medial unit of Bauer's Ojo Alamo also consist largely of variegated shale, including purplish-weathering beds. Reeside apparently subscribed to Bauer's report that the Ojo Alamo was entirely sandstone in this area (section *J*, Bauer's pl. 70); therefore, it is probable that the basal conglomerate and the shale of Reeside's McDermott in Hunter Wash are actually the rocks that are equivalent to the thin lower conglomerate and the medial shale and sandstone unit of Bauer's type Ojo Alamo (fig. 2).

The possible stratigraphic equivalence of rocks in the Hunter Wash-Coal Creek area to the type McDermott cannot be demonstrated by tracing, because the exposures northwest of Hunter Wash are widely separated. Also, R. B. O'Sullivan and E. H. Baltz found, by detailed mapping, that the McDermott Member of the Animas Formation thins southward from its type locality in Colorado and is cut out by the unconformity at the base of the rocks assigned by Reeside to the Ojo Alamo Sandstone east of La Plata River northwest of Farmington near the center of T. 30 N., R. 13 W. The McDermott is not present between this area and the southernmost good exposures several miles south of the San Juan River, although purplish beds occur in the upper part of the Kirtland near the road to Bisti south of the river. (See O'Sullivan and Beikman, 1963, sheet 1. Beds equivalent to the McDermott Member are shown as the lower part of the Animas Formation on this map.)

For the reasons discussed above, the present writers do not use the name McDermott for any of the rocks in the Hunter Wash-Coal Creek area. The variegated rocks present in many places below the lower conglomerate of Bauer's Ojo Alamo Sandstone are included in the upper shale member of the Kirtland.

NAASHOIBITO MEMBER

Definition

The Naashoibito (pronounced Nah-ah-shói-bi-tóh) Member of the Kirtland Shale is here named and defined to include the lower conglomerate and the (medial) shale and soft sandstone unit of Bauer's (1916, p. 276) type Ojo Alamo Sandstone. The Naashoibito Member is the lower conglomerate and "shales with dinosaurs, upper horizon" of Sinclair and Granger's (1914, p. 300–304 and stratigraphic section *A* of their fig. 2) Ojo Alamo Beds. The Naashoibito Member is the upper part of the rocks mapped (in the Hunter Wash-Barrel Spring area) as the upper shale member of the Kirtland Shale by O'Sullivan and Beikman (1963, sheet 1).

The shale and soft sandstone unit (unit 3, fig. 2) of the Naashoibito is persistent, rather than being a local lens enclosed between the lower conglomerate of the member and the overlying conglomeratic sandstone as was reported by Bauer (1916) and Reeside (1924). A deeply channeled erosion surface at the top of the shale and soft sandstone unit of the Naashoibito sharply separates it from the overlying upper conglomeratic sandstone of Bauer's Ojo Alamo. This unconformity is a widespread mappable stratigraphic surface separating lithologically distinct rock units that should not be considered as parts of the same rock-stratigraphic unit (formation).

The type locality of the Naashoibito Member of the Kirtland Shale is here specified as Naashoibito (Navajo for "Lizard Spring"), a small spring with a nearby small cottonwood tree at locality 5 (fig. 3) in sec. 1, T. 24 N., R. 12 W. At this locality the basal conglomeratic sandstone is 2–4 feet thick, and the overlying shale and soft sandstone unit is (locally only) 22 feet thick. A descriptive section of the rocks at locality 5 is given at the end of this report. Because of lateral changes of facies and thickness of the Naashoibito Member, a reference section of the member near Barrell Spring (loc. 11) also is given at the end of this report.

The Naashoibito Member is lithologically similar (except for the lenses of siliceous pebbles in the basal sandstone and a locally greater proportion of sandstone in the shale and soft sandstone unit) to the underlying parts of the Kirtland Shale. East of Coal Creek (locs. 14, 15) the basal sandstone contains only a few clay pebbles, and it and the overlying shale and soft sandstone unit are distinguishable from the upper shale member of the Kirtland mainly on the basis of stratigraphic position. Similarly, west of Hunter Wash (loc. 1) siliceous pebbles are scarce in the basal sandstone, and the rocks above and below it are very similar. At many places the basal conglomeratic sandstone of the Naashoibito Member is disconformable with the underlying rocks, but at other places the contact seems to be gradational. Because of the lithologic similarity of the Naashoibito Member to the underlying parts of the Kirtland, the present writers assign the Naashoibito to the Kirtland Shale.

The Naashoibito Member was traced only a short distance east of locality 15, and the Kirtland Shale east of this point is shown on figure 3 as an undivided unit.

Lithology and Thickness

The Naashoibito Member is persistent throughout the Hunter Wash-Coal Creek area (fig. 3 and pl. 1) at least as far east as locality 15. The thickness of the member ranges from about 10 feet at locality 4 to about 88 feet at locality 13. At the type locality (loc. 5) the Naashoibito Member is only 22 feet thick because most of the member is cut out, locally, by the channeled unconformity at the base of the overlying conglomerate of the restricted Ojo Alamo Sandstone.

The basal conglomeratic sandstone of the Naashoibito Member is persistent throughout the region (fig. 3) and was used as a datum for the correlated stratigraphic sections shown on plate 1. The sandstone is fine grained to very coarse grained, irregularly bedded, buff, light tan, or white, and it contains, at many places, scattered pebbles and lenses of pebbles. Generally, the thin conglomeratic sandstone is consolidated well enough to form a small ledge or bench, although it is not a conspicuous unit. Where the unit is mostly gravel, as locally near Ojo Alamo and Barrel Spring Arroyos, it is poorly consolidated and forms a slope or an inconspicuous rounded bench. The pebbles are well rounded, and they range in size from less than an inch to 3 inches. Most of the pebbles are pinkish to gray quartz and quartzite, but other rock types, such as granite, rhyolite, porphyritic intermediate volcanic rocks, and gray, yellow, red, and green chalcedony are common. Pebbles of fossiliferous, silica-replaced Paleozoic limestone are present also. In the vicinity of Ojo Alamo and Barrel Spring Arroyos, pebbles are largest and most abundant. To the east the abundance and size of pebbles decreases, and in the northeastern part of T. 23 N., R. 11 W. (stratigraphic section 14) the basal sandstone contains only small clay pebbles. Farther east (stratigraphic section 15) pebbles were not found. A locally conglomeratic thin sandstone reported by Reeside (1924, p. 70) to be in the lower part of the Ojo Alamo Sandstone in sec. 26, T. 23 N., R. 10 W., and in sec. 3, T. 22 N., R. 9 W., probably is equivalent to the basal conglomeratic sandstone of the Naashoibito Member.

The thickness of the conglomeratic sandstone is irregular and ranges from about 2 feet on Ojo Alamo Arroyo to about 15 feet on Hunter Wash (sections 5 and 1, respectively). At locality 15, where the sandstone does not contain pebbles, it is 22 feet thick. Part of the variation in thickness of this unit is the result of scouring and channeling at its base. Locally, the relief on this erosion surface is as much as 5 feet; at some places, however, the conglomeratic sandstone seems to grade into the underlying rocks. The conglomeratic sandstone is conformable with the overlying rocks of the Naashoibito Member.

The upper part of the Naashoibito Member consists of varied proportions of claystone, siltstone, sandy shale, shaly sandstone, and soft sandstone. Most of the shale is somber gray or olive gray; but purple to maroon bands are present at many places, and in the vicinity of Ojo Alamo and Barrel Spring Arroyos and the eastern branch of Hunter Wash, much of the shale weathers purple or maroon. The sandstones range from very fine grained to coarse grained and generally are relatively soft, so that they form steep slopes or rounded poorly defined small ledges. At many places, parts of the sandstones weather to ferruginous concretionary "cannonballs" that are as much as 3 feet in diameter. The sandstones are light olive gray, buff, light tan, and commonly weather almost white. The relative proportions of sandstone and shale are varied because of the local lateral gradations of sandstone into shale. These lateral gradations are displayed particularly well in the vicinity of Ojo Alamo and Barrel Spring Arroyos where the striking purplish and maroon shale beds are locally replaced almost completely in short distances by lateral gradation into soft sandstone and olive-gray shale (sections 6–13, pl. 1). Bones of dinosaurs and turtles are common and were found throughout the entire unit. Although the general aspect of this unit is similar to that of the upper shale member of the Kirtland, the Naashoibito Member contains a larger proportion of sandstone than does the upper shale member.

The thickness of the shale and soft sandstone unit of the Naashoibito Member varies markedly in very short distances because of the deeply channeled erosion surface at its top. Relatively narrow steep-walled channels are cut in the shale and sandstone and are filled with coarse-grained pebbly sandstone of the overlying (restricted) Ojo Alamo Sandstone. The minimum observed thickness of the shale and soft sandstone unit of the Naashoibito Member is about 5 feet at locality 4 where a well-exposed local channel cuts out most of the unit. The unit is thickest in the vicinity of Barrel Spring Arroyo at localities 11 and 13 where it is about 75 and 83 feet thick, respectively. However, between these localities, most of the unit is cut out, and it is only about 15 feet thick at locality 12. Excellent exposures of steep-walled channels cut in the unit and filled with conglomeratic sandstone of the (restricted) Ojo Alamo occur in the side canyon in which Barrel Spring is located between localities 11 and 12.

Correlation

The Naashoibito Member has been mapped only in the Hunter Wash-Coal Creek area (fig. 3); therefore, its extent and correlation in other parts of the San Juan Basin are not known.

The Naashoibito Member is similar in lithology and stratigraphic position to rocks in the northwestern part of the basin. The presence of pebbles in the basal sandstone suggests correlation of the Naashoibito with the McDermott Member of the Animas Formation which lies under the (restricted) Ojo Alamo Sandstone northwest of Farmington. However, O'Sullivan and Baltz found that, northwest of Farmington near Pinyon Mesa (northeastern part of T. 30 N., R. 14 W.) where the Kirtland Shale is overlain by the McDermott, the upper part of the upper shale member of the Kirtland also contains variegated shale (including reddish and purplish beds) and soft sandstone similar to the rocks of the Naashoibito Member. Siliceous pebbles occur in some of the sandstones of the upper shale member at Pinyon Mesa, although these pebbles are smaller and less numerous than in the basal conglomeratic sandstone of the Naashoibito Member in the Hunter Wash-Coal Creek area. Variegated shale and soft pebble-bearing sandstone occur in the upper shale member of the Kirtland near the type locality of the McDermott Member in Colorado (Barnes and others, 1954), and pebble-bearing sandstone and variegated shale occur at a few places in the upper part of the undivided Fruitland Formation and Kirtland Shale of Baltz (1962, p. 67–68) in the southeastern part of the Central basin near Cuba, N. Mex.

The possible correlation of the Naashoibito Member with rocks in the upper part of the Kirtland elsewhere in the basin cannot be established without careful mapping.

Age

The Naashoibito Member of the Kirtland contains some of the dinosaur fossils that have been assigned to Bauer's "Ojo Alamo Sandstone" in the paleontologic literature. A careful survey of the literature that describes the collecting localities (nearly all in the area of fig. 3) indicates that the following dinosaur forms occur in the rocks now assigned to the Naashoibito

Member (the medial part of Bauer's and Reeside's Ojo Alamo):

Form	*Source*
Saurischia:	
Megalosauridae:	
Teeth of carnivorous dinosaurs.	Gilmore (1916, p. 288; 1919, p. 67).
Deinodon? (stratigraphic position not clearly specified).	Brown in Sinclair and Granger (1914, p. 302–303).
Fragmentary vertebrae of a large carnivorous dinosaur of the proportions of *Tyrannosaurus*.	Gilmore (1919, p. 67); Reeside (1924, p. 31).
Cetiosauridae:	
Alamosaurus sanjuanensis Gilmore.	Gilmore (1922, p. 2 and stratigraphic section, p. 6).
Ornithischia:	
Hadrosauridae (Trachodontidae):	
Kritosaurus navajovius Brown, and other undetermined fragments, including teeth.	Brown (1910, p. 268–269); Sinclair and Granger (1914, p. 301–302); Gilmore (1916, p. 285).
Scelidosauridae:	
Scapula and dermal plates of unidentified genus of armored dinosaur.	Gilmore (1919, p. 65–66).
Ceratopsidae:	
Fragments referable to the ceratopsians, but not sufficient for generic determination.	Gilmore (1916, p. 286–287; 1919, p. 65).
Fragmentary skull distinct from *Triceratops*, *Ceratops*, or *Monoclonius*; probably an undescribed form.	Gilmore (1919, p. 65).

The above summary indicates that lists of the Ojo Alamo dinosaur fauna presented by Gilmore (1919, p. 9), Reeside (1924, p. 31), and Colbert (1950, p. 71) are not entirely correct. The dinosaur fauna from Bauer's Ojo Alamo Sandstone (the Naashoibito Member of the Kirtland) consists of only two identified species, *Kritosaurus navajovius* and *Alamosaurus sanjuanensis*, whose stratigraphic positions are undoubted. The specimen of *Monoclonius?* which Gilmore (1916, p. 285; 1919, p. 9) lists as being in the Ojo Alamo actually was found by Brown (1910, p. 268) in his Ojo Alamo Beds below Bauer's Ojo Alamo Sandstone. Gilmore (1916, p. 281) wrote that a ceratopsian ischium identified as pertaining to *Monoclonius* was in the Bauer collection from the Ojo Alamo Sandstone. However, the only ischium listed in the descriptions of collecting localities (Gilmore, 1916, p. 286–287 and footnote 1, p. 287) was reported as being from the upper part of the Kirtland near Farmington. The other specimen referred to *Monoclonius* was found in the Fruitland Formation (Gilmore, 1916, p. 285–286). The stratigraphic position of the teeth assigned to *Deinodon?* by Brown (in Sinclair and Granger, 1914, p. 302–303) was not specified. Referring to the large carnivorous dinosaur teeth from the Bauer collection, Gilmore (1916, p. 288) wrote "Specimens like these have no value for correlation, as similar teeth are found in the Judith River, Belly River, Two Medicine, and Lance formations."

Alamosaurus is known only from the San Juan Basin and from the lower part of the North Horn Formation of Utah. Gilmore (1946, p. 48–50) concluded that the reptilian faunas of the North Horn and (Bauer's) Ojo Alamo are equivalent in age, mainly because *Alamosaurus sanjuanensis* occurs in both. Outside the San Juan Basin the genus *Kritosaurus* occurs only in the Judith River and Two Medicine Formations of Montana and the Belly River and Edmonton Formations of Canada. These rocks are of Montana age and older than the Lance Formation of latest Cretaceous age. Thus, on the basis of *Kritosaurus*, the Naashoibito Member is Montana age. This conclusion is supported (but not necessarily substantiated) by Gilmore's (1919, p. 8–9) opinion that the affinities of the armored dinosaur remains are unquestionably with armored dinosaurs older than *Ankylosaurus* of the Lance Formation. The turtles from Bauer's Ojo Alamo were considered to be not as useful for correlation as the dinosaurs (Gilmore, 1916, p. 280).

Dinosaur remains are so common in the Naashoibito Member that it seems likely that some of the other dinosaurs assigned by previous writers to the uppermost Kirtland and to the McDermott actually came from the Naashoibito. However, the descriptions of the stratigraphy and the collecting localities are sufficiently vague and conflicting that the present writers are unable to resolve this problem completely. If some of the Kirtland and "McDermott" forms did come from the Naashoibito, their occurrence would support the Montana age assignment of the Naashoibito, because all published opinions on the age of the dinosaur fossils of the Fruitland, Kirtland, and Ojo Alamo of Bauer indicate agreement on the Montana age of the dinosaur faunas. (See Brown (1910) p. 267, and Brown in Sinclair and Granger (1914) p. 303; Gilmore (1916) p. 281, (1919) p. 8, (1922) p. 67, (1935), p. 186–187; Lull (1933) p. 6–8; Lull and Wright (1942) p. 12–13; Colbert (1950) p. 70.)

Despite this agreement, the Ojo Alamo Sandstone of Bauer has somehow been assigned to the latest Cretaceous as an equivalent of the Lance in many reports. (See Lull, 1933, fig. 1, p. 7; Lull and Wright, 1942, pl. 1; Cobban and Reeside, 1952, chart 10b; Colbert, 1961, p. 247.) Lull and Wright (1942, p. 12) stated that the invertebrates possibly indicate a slightly younger Cretaceous age than do the dinosaurs, citing a statement by Russell (1930). However, Russell (p. 155–158) merely mentions this possibility and specifies that the Fruitland, Kirtland and Bauer's Ojo Alamo are older than the Lance and Hell Creek Formations. According to Stanton (1916, p. 310), the invertebrates of the Fruitland Formation are older than the Lance Formation. Stanton suggested that the Fruitland, Kirtland, and Bauer's Ojo Alamo might include equivalents of everything from the Fox Hills through the Lance, but he had practically no invertebrate fossils from anything but the Fruitland on which to base this suggestion. *Triceratops* (the "zone of *Triceratops*") which characterizes the Hell Creek and Lance Formations (latest Cretaceous) of the northern Great Plains has not been found in the San Juan Basin, nor has the primitive mammalian fauna which occurs in the Lance (Wood and others, 1941, p. 8).

In summary, *Kritosaurus navajovius* is the only positively identified diagnostic dinosaur fossil whose stratigraphic position is established firmly as being in the Naashoibito Member. *Kritosaurus navajovius* occurs also in the underlying parts of the Kirtland Shale associated with other Montana dinosaurs, and the total fauna of all members of the Kirtland in the Hunter Wash-Coal Creek area is considered to be Montana in age.

VERTEBRATE FAUNA OF THE KIRTLAND SHALE

Because the Kirtland Shale is redefined (in this report) to include the rocks which previous writers have indicated contain the Kirtland, McDermott, and Ojo Alamo vertebrate faunas, it is appropriate to list the vertebrate fauna of the Kirtland Shale of this report. The following list is compiled from the reports of Brown (1910), Sinclair and Granger (1914), Bauer (1916), Gilmore (1916, 1919, 1922, 1935), Lull (1933), Lull and Wright (1942), and Colbert (1950). The writers have consulted the original reports to determine the collecting localities, and thus confirm the stratigraphic positions, of the fossils assigned to the Kirtland.

Fish:
- *Lepisosteus* sp. (scales)
- *Myledaphus* sp. (teeth)
- *Squatinidae* (single tooth)

Turtles:
- *Neurankylus baueri* Gilmore
- *Baena ornata* Gilmore
  - *nodosa* Gilmore
- *Boremys grandis* Gilmore
- *Thescelus hemispherica* Gilmore
  - *rapiens* Hay

Turtles—Continued
- *Basilemys nobilis* Hay
- *Adocus bossi* Gilmore
  - *kirtlandius* Gilmore
- *Asperidites ovatus* Gilmore
  - *vorax* Hay
- *Plastomenus robustus* Gilmore
- *Compsemys* sp.

Dinosaurs:
- Saurischia:
  - Large carnivorous dinosaurs:
    - Vertebrae
    - *Deinodon*? sp.
    - *Gorgosaurus libratus* Lambe
  - Large sauropod:
    - *Alamosaurus sanjuanensis* Gilmore
- Ornithischia:
  - Duck-billed dinosaurs (trachodonts):
    - *Kritosaurus navajovius* Brown
    - *Parasaurolophus tubicen* Wiman
  - Horned dinosaurs (ceratopsians):
    - *Monoclonius* sp.
    - *Pentaceratops sternbergii* Osborn
      - *fenestratus* Wiman
    - *Chasmosaurus* sp.
    - *Ceratops*? sp.
  - Armored dinosaur, scapula and dermal plates of unidentified form

Crocodiles and alligators:
- *Crocodylus* sp., crocodile teeth
- *Brachychampsa*? sp., alligator teeth

OJO ALAMO SANDSTONE RESTRICTED

Definition

We propose here that the name Ojo Alamo Sandstone be restricted to apply only to the upper conglomerate of Bauer's (1916, p. 276) type Ojo Alamo Sandstone on Ojo Alamo Arroyo. The restricted Ojo Alamo Sandstone of the present report is the conglomerate sandstone with fossil logs of the Ojo Alamo Beds of Sinclair and Granger (1914). A stratigraphic section measured at locality 7 on Ojo Alamo Arroyo (fig. 3 and pl. 1) is designated as the typical section of the restricted Ojo Alamo Sandstone and is given at the end of this report. Another section measured at locality 10 on Barrel Spring Arroyo is designated as a reference section and also is given at the end of the report.

The restricted Ojo Alamo Sandstone, as here defined, is the cuesta-forming coarse-grained conglomeratic arkosic sandstone that contains numerous silicified fossil logs and thin local lenses of shale, that is separated by an erosional unconformity from the underlying dinosaur-bearing Kirtland Shale, and that intertongues with the overlying Nacimiento Formation. In the Ojo Alamo-Barrel Spring area the Ojo Alamo Sandstone, as here restricted, is 35–62 feet thick. The general surface extent of the restricted Ojo Alamo Sandstone, as now known, is shown on figure 1. The greatest measured thickness of the Ojo Alamo is about 200 feet along the bluffs of the San Juan River south of Farmington.

The term Ojo Alamo Sandstone has been used in the rock-stratigraphic sense in reports by many surface and subsurface geologists, and, except in the type area mapped by Bauer (1916) and Reeside (1924), it has been applied only to the rocks that the present writers have found to be generally equivalent to the Ojo Alamo Sandstone as restricted in this report. (See Dane, 1936, pl. 1; Dane and Bachman, 1957; Anderson, 1960; Baltz, 1962; O'Sullivan and Beikman, 1963; also Reeside's Ojo Alamo on the western side of the basin and east of Barrel Spring Arroyo as shown on his pl. 1.) Therefore, because of this widespread and nearly uniform geologic usage of the term in almost the exact sense of the restricted Ojo Alamo of this report, it seems advisable to retain the name Ojo Alamo Sandstone for this unit. It is unfortunate that usages of the term Ojo Alamo Sandstone over the past few decades have resulted in the exclusion of the original Ojo Alamo Beds of Brown.

Lithology and Thickness

The restricted Ojo Alamo Sandstone consists of soft to well-consolidated coarse-grained arkosic sandstone that caps prominent cuestas in the Hunter Wash-Coal Creek area. The sandstone is highly crossbedded and is mostly a series of coalescing stream deposits and, possibly, some dune sand. Pebbles ranging in largest dimension from less than 1–4 inches form distinct pods and lenses and also are scattered throughout much of the Ojo Alamo Sandstone. At places the lower beds of the Ojo Alamo that fill channels cut into the underlying Naashoibito Member of the Kirtland Shale contain much sand and shale reworked from the Naashoibito. The channel fill also contains large blocks of shale that caved from the walls (section 13) and were engulfed in the conglomeratic sand of the Ojo Alamo. Most of the Ojo Alamo consists of medium-grained to very coarse grained angular arkosic sand that is distinct from the sediments of underlying rocks. The pebbles, however, are similar to those of the basal sandstone of the Naashoibito Member of the Kirtland, and the same variety of rock types was noted in the pebbles of both units. At places the outcrops of the Ojo Alamo are highly irregular, and numerous pinacles are capped by ledges of hard brown ferruginous sandstone or by silicified fossil logs. Prone silicified logs ranging from several inches in diameter and several feet in length to 5 feet in diameter and 40 feet in length are numerous in the conglomeratic sandstone at all localities. Near Ajo Alamo and Barrel Spring Arroyo the Ojo Alamo Sandstone contains local thin lenses of olive-green to gray shale and sandy shale.

The upper part of the Ojo Alamo Sandstone is concealed or is poorly exposed, except in the vicinity of Ojo Alamo and Barrel Spring Arroyos and the badlands between these arroyos (sections 7, 10). The upper part is not so coarse as the lower part, and the pebbles in the upper part are smaller and less abundant than in the lower part. Silicified logs occur in the upper part at places between Ojo Alamo and Barrel Spring Arroyos. The upper part of the Ojo Alamo Sandstone is characterized by sweeping tangential crossbeds. It is overlain conformably by, and grades upward into, olive-green reddish-weathering shale of the Nacimiento Formation. In the badlands on Barrel Spring Arroyo, and near the drainage divide between Barrel Spring and Ojo Alamo Arroyos, the upper part of the Ojo Alamo thins, becomes more argillaceous, and wedges out northward into shale of the lower part of the Nacimiento Formation. This intertonguing relationship is discussed more fully below.

At the west side of the erosional amphitheater on Barrel Spring Arroyo, a thin lignite lens containing abundant fossil leaves (assigned to the Nacimiento Formation) lies on the upper part of the Ojo Alamo Sandstone. Also, a stratigraphically lower lignitic shale (also assigned to the Nacimiento) lies on the lower part of the Ojo Alamo in the middle of the amphitheater in Barrel Spring Arroyo where the upper and lower parts of the sandstone are separated by a southward-thinning tongue of shale of the Nacimiento Formation. The total thickness of the Ojo Alamo Sandstone could be determined only in the upper parts of Ojo Alamo Arroyo and Barrel Spring Arroyo where it is 35.5 and 62.5 feet thick, respectively (sections 7, 10). Abrupt local thickening and thinning of the Ojo Alamo Sandstone is the result of the channeled unconformity at the base and the intertonguing relationship of the upper part of the formation.

Contact of the Ojo Alamo Sandstone and the Nacimiento Formation

Sinclair and Granger (1914), Bauer (1916, p. 276), and Reeside (1924, p. 30) all reported an unconformity at the top of the Ojo Alamo. The only detailed description of the contact is that reported by Sinclair and Granger (1914, p. 304):

> The Puerco clays rest unconformably on the eroded surface of the conglomeratic sandstone with fossil logs * * *. 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 * * *. It has been traced from Pina Veta China * * * 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.

The statement that the contact was traced from Pina Veta China (now abandoned) almost to Escavada Wash could not be verified because the contact is mostly concealed by alluvium and stabilized dune sand. The intertonguing relationship between the Ojo Alamo Sandstone restricted and the Nacimiento Formation is well exposed in the upper part of Barrel Spring Arroyo north of the wagon road to Ojo Alamo. The upper and lower parts of the Ojo Alamo are separated by a thin unit of sandy shale and shaly sandstone at locality 11. This shaly unit was traced northward; at locality 10 it has thickened, and its upper part consists of reddish-weathering sandy clay shale. At locality 10 the upper part of the Ojo Alamo is overlain by, and grades upward into, another reddish-weathering clay shale that is a persistent and conspicuous band in the lower part of the Nacimiento in the badlands to the north in the amphitheater on Barrel Spring Arroyo. About one-fourth mile north of the wagon road to Ojo Alamo the upper part of the Ojo Alamo Sandstone thins and wedges out into shale of the Nacimiento Formation. Here the shale unit, which farther south separates the upper and lower parts of the Ojo Alamo, thickens and merges with the overlying shale of the Nacimiento, and thus is seen to be a southward-thinning tongue of the basal part of the Nacimiento Formation.

Similar stratigraphic relationships are well exposed in secs. 9 and 10, T. 24 N., R. 11 W., at the west side of the erosional amphitheater on a drainage divide between the westernmost tributaries of Barrel Spring Arroyo. These exposures are shown on figure 4. The contact of the upper part of the Ojo Alamo with the Nacimiento, as shown on figure 4, is the contact of the conglomeratic sandstone with fossil logs and the Puerco Formation shown in Sinclair and Granger's (1914, pl. 22) photograph which was taken about one-eighth mile west of the locality of figure 4. The contact is slightly undulatory, but it is not so irregular as portrayed by Sinclair and Granger, and the intertonguing relationship seems to indicate a conformable contact of the Ojo Alamo and the Nacimiento Formation.

The "hills of sandstone" of Sinclair and Granger that rise "like islands through the horizontally banded clays of the lower Puerco levels" are the southward-thickening upper part of the Ojo Alamo, and the sandstone actually lies on the lower red clay (described at loc. 10) in the badlands near the wagon road in Barrel Spring Arroyo. At places in the badlands the outcrop band of the lower red clay partly surrounds erosional remnants of the upper part of the Ojo Alamo, possibly creating an impression that the clay "laps" against "islands" of sandstone. The red clay that rests on the upper part of the Ojo Alamo Sandstone at the southernmost exposures of the base of the Nacimiento Formation (locs. 7, 10) rests on shale, and it is 30–40 feet above the lower part of the Ojo Alamo north of the wedge out of the upper part of the Ojo Alamo. This clay probably is the "second" clay in which Sinclair and Granger (1914, p. 305) found the lowest Puerco fossils in Ojo Alamo and Barrel Spring Arroyos. However, where the "second" red clay rests on the upper part of the Ojo Alamo, Sinclair and Granger (1914, pl. 22, where red shale overlies the "conglomeratic sandstone with fossil logs") seem to have mistaken it for the lower red clay. This local confusion of the stratigraphic positions of the two reddish-weathering clay shales probably accounts for the statement of Sinclair and Granger (1914, p. 305) that—

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.

The restricted Ojo Alamo Sandstone and the Nacimiento Formation intertongue in the vicinity of the San Juan River near Farmington (O'Sullivan and Beikman 1963, sheet 1), and subsurface correlations in the southeastern part of the central basin were stated by Baltz (1962, p. 93, 100) to suggest intertonguing of the restricted Ojo Alamo Sandstone and the Nacimiento Formation.

Age

The restricted Ojo Alamo Sandstone is considered to be early Paleocene in age because of its gradational and intertonguing relationship with the lower part of the overlying Nacimiento Formation, and because of its unconformable relationship with the underlying Cretaceous rocks.

All the reptilian fossils that were reported by previous workers from the Ojo Alamo Sandstone were found in the rocks assigned by the present writers to the Kirtland Shale. The badly worn centrum of the dinosaurian caudal vertebra found by Jack Martin, of Sinclair and Granger's expedition (1914, p. 301), lying loose on the restricted Ojo Alamo Sandstone near Barrel Spring cannot be considered as an index fossil; it reached the position where it was found possibly because of reworking or, more likely, because it was carried there by humans. This area had been frequented by whites as well as by Indians, and paleontologic collecting parties also had preceded Sinclair and Granger.

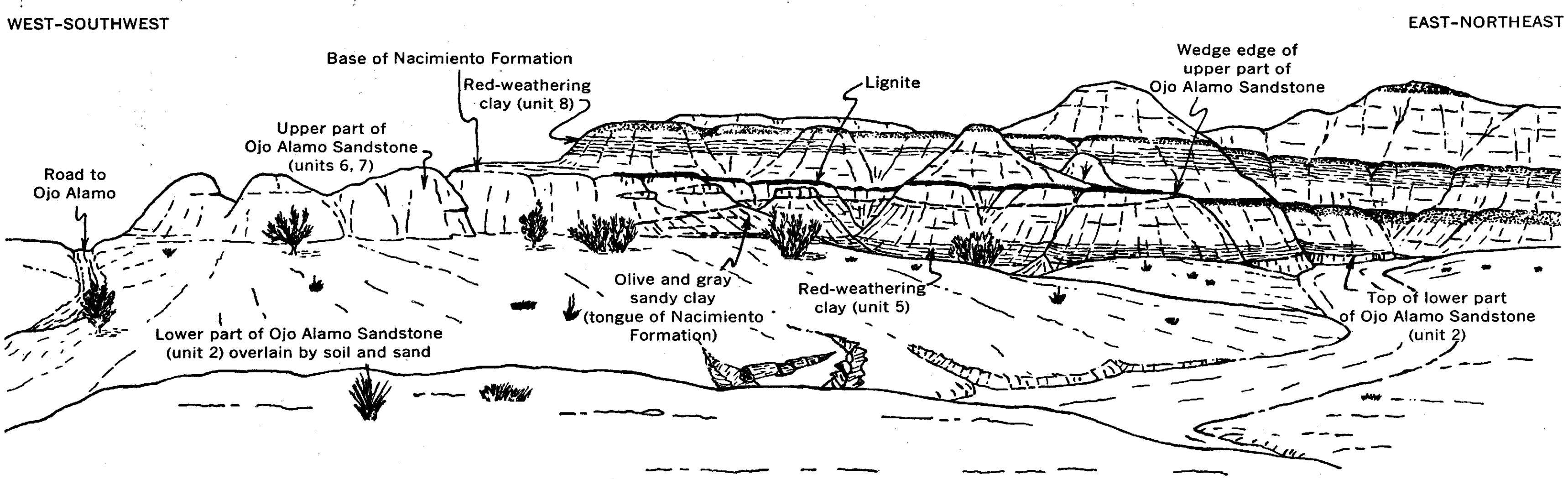

FIGURE 4.—Sketch of ridge at west side of erosional amphitheater on Barrel Spring Arroyo showing northeast-dipping Ojo Alamo Sandstone and shale of the lower part of the Nacimiento Formation. Numbered units correlate with the correspondingly numbered units of the descriptive stratigraphic section measured at locality 10, which is about 1 mile south of this ridge.

The only fossils found in the restricted Ojo Alamo Sandstone are plant fossils. The fossil logs which are common in the Ojo Alamo (and locally in the Fruitland Formation, Kirtland Shale, and Nacimiento Formation as well) have not been reported to have a determinable stratigraphic significance. The fossil leaves reported by F. H. Knowlton (in Reeside, 1924, p. 31–32) to suggest Tertiary age were collected on the western side of the Central basin from rocks which Reeside assigned to the Ojo Alamo Sandstone. Reconnaissance and detailed mapping indicate that the rocks containing the leaves are the same as the Ojo Alamo Sandstone, as here restricted.

A well-preserved and diversified pollen and spore florule (colln. 1) was obtained from a bed of lignitic shale enclosed between the upper and lower parts of the restricted Ojo Alamo Sandstone at locality 11 on the mesa about one-eighth mile north of Barrel Spring. Another well-preserved and diversified pollen and spore florule (colln. 2) was obtained from the lower part of the Nacimiento Formation. This collection was obtained from an extensive well-exposed bed of lignite that is a few feet above the base of the tongue of the Nacimiento Formation in sec. 10, T. 24 N., R. 11 W., in Barrel Spring Arroyo (fig. 3 and pl. 1). The lignite from which collection 2 was obtained is about 30 feet below the stratigraphic position (top of "wine-red clay," 13.5 ft thick) of the lowest Puerco fossils found in the Nacimiento by Sinclair and Granger (1914, p. 305–306 and section *A*, fig. 2) near Ojo Alamo and Barrel Spring. The present writers found a few scraps of mammal bone in the tongue of the Nacimiento north of the locality of collection 2.

Collections 1 and 2 were examined by R. Y. Anderson and compared with previously described (Anderson, 1960) collections from the Ojo Alamo Sandstone and the Nacimiento Formation of the eastern part of the San Juan Basin. Collection 1 from the Ojo Alamo and collection 2 from the Nacimiento are similar to each other and contain common to abundant grains of *Ulmoideipites tricostatus* Anderson and *Podocarpus* sp. These are the two dominant types of grains in Anderson's (1960) Ojo Alamo florules from the eastern part of the basin. Several kinds of *Momipites* grains are present in collections 1 and 2; these also are common in Anderson's (1960) Ojo Alamo and Nacimiento florules from the eastern part of the basin. The florule of collection 1 contains many large inaperturate semihexagonal grains, some monosulcate grains, monolete and trilete spores, triporate pollen, and pinaceous conifer pollen. The florule of collection 2 contains *Quercus*? sp., *Arecipites* cf. *A. reticulatus* (Van der Hammen), *Cupaneidites* cf. *C. major* Cookson and Pike, *Paliurus triplicatus*? Anderson, and some spores, all of which are present in Anderson's (1960) Ojo Alamo or Nacimiento florules from the eastern part of the basin. Collection 2 also contains some grains that were not observed in Anderson's (1960) florules from the eastern part of the basin.

The palynology does not directly fix the age of the restricted Ojo Alamo Sandstone which, however, appears to be Paleocene on the basis of its gradational and intertonguing relation with the Nacimiento. Collections 1 and 2 and the Ojo Alamo 2 and Nacimiento florules of Anderson (1960) contain forms that are known to occur also in the Fort Union Formation and other formations generally considered to be of Palecene age (Leffingwell, 1962; Gerhard, 1958), but the ranges of these grains have not been discussed in the literature.

A florule (colln. 3) was obtained from a lignite bed in the upper part of the upper shale member of the Kirtland Shale at locality 6 in Ojo Alamo Arroyo (pl. 1). Collection 3 was examined also by R. Y. Anderson in order to compare the florule of these rocks of known Montana age with the florules of the Ojo Alamo and Nacimiento.

The florule of collection 3 from the Kirtland is strikingly different from collections 1 and 2 and from any of the Cretaceous and Tertiary florules described by Anderson (1960) from the eastern part of the basin. The dominant forms of collection 3 are polypodiaceous spores and a monosulcate grain with echinate-clavate sculpture. Pinaceous conifer pollen are common. Dicotyledon grains are much fewer than in any of the eastern florules, and the dominant form is a tricolpate, reticulate, brevaxial grain with intersemiangular to intersemilobate outline. Smooth and warty trilete spores are present in collection 3, and there are many cystlike structures with hollow processes that resemble some hystrichosphaerids. The florule contains *Liliacidites leei* Anderson which occurs in the Kirtland, Ojo Alamo, and Nacimiento florules of the eastern part of the basin, and *Liliacidites hyalacinatus?* Anderson which occurs in the Kirtland and Ojo Alamo 1 florules of the eastern part of the basin. *Proteacidites thalmanni* Anderson is the only really distinctive form in collection 3 that is found also in an eastern florule. It occurs in Anderson's (1960) Kirtland Shale and Lewis Shale florules and suggests a Cretaceous age for collection 3. The Cretaceous age of the Kirtland is, of course, established by its dinosaur fauna.

The reconnaissance nature of Anderson's (1960) palynologic study in the eastern side of the basin and the limited number of collections from the western side do not permit positive statements concerning correlation based on the occurrence of pollen and spores. However, the abundance in collections 1 and 2 of ulmaceous pollen and the presence of podocarpaceous grains and *Momipites*, none of which were observed in collection 3 or in Anderson's (1960) collections from the Kirtland Shale, suggest that the florule of collections 1 and 2 are more closely related to the eastern Ojo Alamo and Nacimiento florules than to the florules from the Kirtland Shale. This suggested correlation is substantiated by the physical tracing of the Ojo Alamo Sandstone and Nacimiento Formation from the Hunter Wash-Coal Creek area to the eastern part of the basin.

In summary, the palynologic and physical-stratigraphic evidence of age of the restricted Ojo Alamo Sandstone are in agreement. Although collection 3 from the Kirtland Shale is dissimilar to Anderson's (1960) eastern Kirtland florule, both contain *Proteacidites thalmanni* Anderson. The restricted Ojo Alamo Sandstone and the lower (Puerco) part of the Nacimiento contain florules that have the same dominant species and other similar forms in common in both the western and eastern parts of the basin.

CRETACEOUS-TERTIARY BOUNDARY IN THE SAN JUAN BASIN

Because the restricted Ojo Alamo Sandstone is early Paleocene and rests with erosional unconformity on Cretaceous rocks, the Cretaceous-Tertiary boundary in the southern part of the Central basin is slightly lower than the boundary which pervious workers placed at the top of the Ojo Alamo. Also, since the Kirtland Shale (including the newly named Naashoibito Member) is of Montana age, the unconformity at the base of the restricted Ojo Alamo Sandstone represents a hiatus during which rocks of latest Cretaceous (Lance) age either were not deposited or were eroded from parts of the basin.

The present writers traced the Ojo Alamo Sandstone, as restricted in this report, southeastward from the type locality across most of the southern part of the Central basin to the vicinity of Cuba. The restricted Ojo Alamo was found to be, at most places, the Ojo Alamo Sandstone of Dane (1936) and the Ojo Alamo Sandstone of Baltz (1962). At the many places where the base of the Ojo Alamo was observed, it is a channeled unconformity similar in all respects to the unconformity in the Hunter Wash-Coal Creek area. At places the Ojo Alamo rests on lenticular ledge-forming sandstone beds of the Kirtland that are similar in topographic expression to the Ojo Alamo. At these places the base of the Ojo Alamo can be determined by careful tracing of individual beds.

In the eastern part of the Central basin the Ojo Alamo Sandstone rests with erosional unconformity on rocks that Baltz (1962, p. 57–59) called the undivided Fruitland Formation and Kirtland Shale. The combined thickness of the Fruitland and Kirtland is locally only 120–225 feet in contrast to the combined thickness of more than 1,600 feet for these formations in the west-central part of the basin. This eastward decrease in thickness of the Fruitland and Kirtland might have been the result of depositional thinning to the east as postulated by Dane (1936, p. 120–121); or the eastward decrease in thickness might have been the result of one or more stages of westward tilting and erosion of the Fruitland and Kirtland before deposition of the Ojo Alamo.

Anderson's (1960) Kirtland florule and collection 3 from Ojo Alamo Arroyo, taken from the Kirtland Shale beneath the unconformity in the eastern and western parts of the basin, are quite different. It is not known how the two florules are related stratigraphically, but their different compositions allow for the possibility that rocks equivalent in age to the upper shale member of the Kirtland (colln. 3) at Ojo Alamo may be absent from the eastern part of the basin. This interpretation would be consistent with the physical evidence for a hiatus between the deposition of the Kirtland and the Ojo Alamo.

Silver (1950, p. 112) and Baltz (1962, p. 98–99) indicate that subsurface correlations also suggest a regionally angular unconformity at the base of the Ojo Alamo in the eastern part of the Central basin.

In the western part of the basin, the Ojo Alamo Sandstone as shown on the map of O'Sullivan and Beikman (1963) is the restricted Ojo Alamo of the present report. Mapping by O'Sullivan and Baltz in the western part of the Central basin (from San Juan River to Pinyon Mesa—see O'Sullivan and Beikman, 1963) indicates that the Ojo Alamo Sandstone of that region is unconformable on the Kirtland Shale and the McDermott Member of the Animas Formation. Possibly the McDermott Member and the lower part of the upper member of the Animas Formation in the northwestern and northern parts of the Central basin are latest Cretaceous (Lance) in age (Reeside, 1944), but this has not been substantiated by fossils. The fragments of dinosaur and turtle bones collected from the McDermott Member and the upper member of the Animas in Colorado were indeterminate (Reeside, 1924, p. 26, 34). *Triceratops*, which characterizes the Hell Creek and Lance Formations of latest Cretaceous age (the "zone of *Triceratops*"), has not been found anywhere in the San Juan Basin.

Hayes and Zapp (1955) and O'Sullivan and Baltz found that near La Plata River northwest of Pinyon Mesa the Ojo Alamo Sandstone wedges out northward into shale and soft sandstone assigned to the Nacimiento Formation by O'Sullivan and Beikman (1963). North of this wedge out, the nature of the contact of the Nacimiento and the Animas Formation in New Mexico is not known with certainty because of poor exposures.

Although the lower part of the Animas Formation of the northern part of the Central basin contains dinosaur fossils (Reeside, 1924, p. 34) and is of Cretaceous age, much of the Animas Formation of the northern and northeastern parts of the basin is known to be Paleocene because of its stratal equivalence to the Nacimiento Formation (Dane, 1946; Baltz, 1953; Barnes, Baltz and Hayes, 1954) and because Torrejon fossils have been found in it (Reeside, 1924; Dane, 1946). At Bridge Timber Mountain, on the Hogback monocline southwest of Durango, Colo., the lower part of the upper member of the Animas Formation is overlain with angular unconformity by overstepping beds which Baltz (1953, p. 37–38) and Barnes, Baltz, and Hayes (1954) assigned to the upper part of the Animas and to the Nacimiento Formation. Regional structural relationships suggest that the unconformity within the Animas near the Hogback monocline may be equivalent to the unconformity at the base of the Ojo Alamo in New Mexico, and thus may represent the Cretaceous-Tertiary boundary near the margins of the northwestern part of the Central basin (fig. 5). However, no fossils have been reported from either the Animas or the Nacimiento in the Bridge Timber Mountain area to confirm this suggestion. Possibly the Cretaceous-Tertiary boundary is conformable in the subsurface of the northwestern and northern parts of the basin where the Kirtland Shale and Animas Formations are thickest.

Further detailed mapping and searching for fossils in the northern and northeastern parts of the basin will be necessary to establish the position and the nature of the Cretaceous-Tertiary boundary in those parts of the basin.

MEASURED STRATIGRAPHIC SECTIONS

Localities and descriptions of stratigraphic sections measured by the authors are given below.

Localities of measured stratigraphic sections

Locality — *Description*

1. West side of a shallow western branch of Hunter Wash, sec. 32, T. 25 N., R. 12 W.
2. West side of eastern branch of Hunter Wash. Southeast-facing cliff on east side of a point of a broad cuesta, sec. 3, T. 24 N., R. 12 W. About 300 yd east of Bauer's (1916, pl. 69) section *J*.
3. Cliffs west of long western branch of Ojo Alamo Arroyo, sec. 2, T. 24 N., R. 12 W. Near Bauer's (1916, pl. 69) section *K*.
4. Cliffs west of long western branch of Ojo Alamo Arroyo, about 1,000 ft northeast of stratigraphic section 3, sec. 2, T. 24 N., R. 12 W. Locality of Bauer's (1916, pl. 69) section *L*.
5. See description of stratigraphic section.
6. North side of Ojo Alamo Arroyo at a small butte beside the road about ¾ mile northwest of spring and abandoned Ojo Alamo store, sec. 6, T. 24 N., R. 11 W.

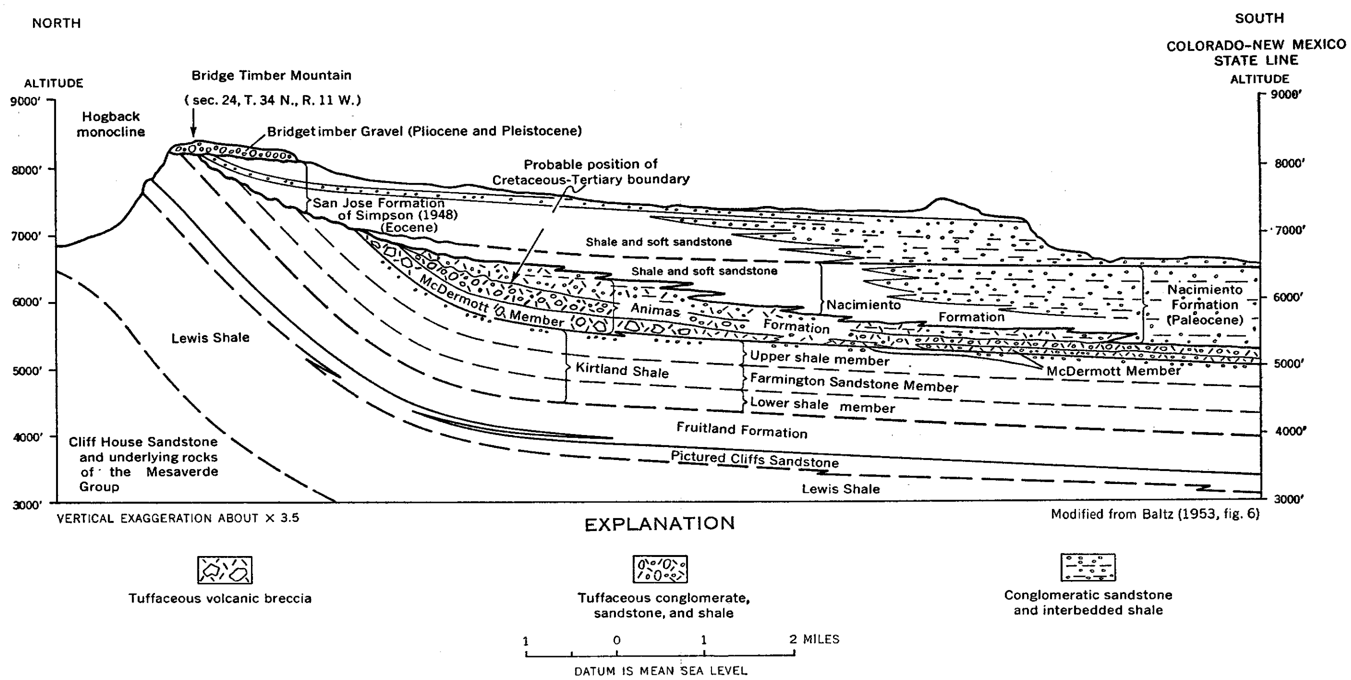

FIGURE 5.—Diagram showing stratigraphic relationships of Upper Cretaceous and lower Tertiary rocks in the northwestern part of the San Juan Basin in Colorado. The relationships are partly those observed along the Hogback monocline west of Bridge Timber Mountain.

Localities of measured stratigraphic sections—Continued

Locality *Description*

7. See description of stratigraphic section.
8. Southern branch of Ojo Alamo Arroyo, on south side of long spur, sec. 7, T. 24 N., R. 11 W. Locality of Bauer's (1916, pl. 69) section *P*.
9. South-facing slopes in erosional amphitheater at south side of the broad cuesta between Ojo Alamo and Barrel Spring, sec. 18, T. 24 N., R. 11 W.
10. See description of stratigraphic section.
11. See description of stratigraphic section.
12. Point of mesa south of the side canyon in which Barrel Spring is situated, about ⅛ mile south of the spring, sec. 17, T. 24 N., R. 11 W.
13. South-facing cliff about ¾ mile southeast of Barrel Spring and west of county road. Base of section is in a deep arroyo near the brass-capped stake at SE cor. sec. 17, T. 24 N., R. 11 W.
14. In a small canyon near the western point of a large cuesta, sec. 2, T. 23 N., R. 11 W., about 3 miles southeast of the main stem of Coal Creek.
15. East side of valley and west-facing slopes just west of county road, between the easternmost tributaries of Coal Creek, secs. 17 and 18, T. 23 N., R. 10 W.

Descriptions of stratigraphic sections

Locality 5

[Measured on north side of Ojo Alamo Arroyo, just west of the first major northern tributary, at Naashoibito which is a small spring with a small cottonwood tree, sec. 1, T. 24 N., R. 12 W. Locality is on southeast-facing cliffs below a cuesta that is capped by sand dunes. Near Bauer's (1916, pl. 69) section *M*, about 1½ miles west of Ojo Alamo. Type section of Naashoibito Member of Kirtland Shale]

	Thickness (feet)
Top.	
8. Stabilized sand dunes of Quaternary age that cap a broad gently northeast sloping cuesta	7–15
Unconformity, erosional.	
Ojo Alamo Sandstone restricted:	
7. Sandstone, light-tan to yellowish-gray, coarse-grained, arkosic. Contains lenses of pebbles and large silicified logs. Bedding is highly irregular; some beds are highly ferruginous and hard. Unit weathers to form low irregular ledges. Basal contact is a locally irregular erosional surface. (Unit 7 is the upper conglomerate of Bauer's Ojo Alamo Sandstone.)	16.0
6. Sandstone, buff to pale-orange, coarse-grained; contains siliceous pebbles and clay and sandstone pebbles near the base. Bedding is irregular, and the beds near the edges of this stream-channel deposit dip in toward the center. The basal beds are highly ferruginous and form thin hard local ledges. Bedding is more massive near the top. This unit is a local stream-channel deposit, about 600 ft wide, that thins and wedges out to the southwest and northeast of loc. 5. Naashoibito spring issues from the base of the topographically lowest part of the sandstone. The unit rests on a deeply channeled erosion surface cut in the underlying Naashoibito Member of the Kirtland Shale. The local relief on this surface is 25–30 ft	25.0
Unconformity, erosional.	

Descriptions of stratigraphic sections—Continued

	Thickness (feet)
Kirtland Shale, Naashoibito Member:	
5. Shale, silty clay, light-gray to light olive-green; forms a slope. (A stratigraphically higher unit of gray shale and interbedded soft sandstone that contains "cannonball" concretions also is assigned to the Naashoibito where these beds are present northeast and southwest of the wedgeouts of unit 6. These upper shale and sandstone beds of the Naashoibito are 25–30 ft thick in this vicinity.)	5–8
4. Sandstone, white-weathering, fine- to coarse-grained, soft; contains concretionary "cannonballs." Weathers to rounded slopes	13.0
3. Shale, plastic clay, olive-green. (This unit and units 4 and 5 comprise the medial part of Bauer's Ojo Alamo Sandstone at this locality.)	2.0
2. Sandstone, light-gray; locally stained orange by limonite. Sand is coarse to granule size and contains numerous siliceous pebbles that are as large as 2 in. in maximum dimension. Bedding is irregular stream-channel type. Unit is soft at loc. 5, but forms a small bench to the northeast. Basal contact is a slightly channeled surface. (This unit is the lower conglomerate of Bauer's Ojo Alamo Sandstone.)	2–4
Kirtland Shale, upper shale member (in part):	
1. Shale, sandy clay, purplish-weathering. Forms slope. Not measured.	

Locality 7

[Measured on south side of Ojo Alamo Arroyo about ¼ mile southeast of Ojo Alamo (spring and ruins of store) in sec. 6, T. 24 N., R. 11 W. Units 1–3 were measured on slopes and cliffs just west of the sandstone bench on which several Navajo hogans are situated. Units 4–7 were measured in badlands just south of the hogans. Type section of Ojo Alamo Sandstone restricted]

	Thickness (feet)
Top.	
7. Stabilized sand dunes and soil of Quaternary age that cap a gently sloping cuesta south of Ojo Alamo Arroyo	10–20
Unconformity, erosional.	
Nacimiento Formation (in part):	
6. Claystone, green, purple-blotched; appears to be dull greenish gray when viewed from a distance. Clay is compact and weathers to a rounded slope	5.0
5. Claystone, reddish, green-mottled. Contains barite concretions. Clay is compact and forms a rounded slope. This unit and unit 4 probably correlate with unit 8 of loc. 10	6.0
4. Shale, silty, sandy, olive-green. Grades into overlying and underlying units. Forms a rounded slope	3.0
Ojo Alamo Sandstone restricted, upper part:	
3. Sandstone, light-tan to light-gray. Coarse-grained but finer than underlying unit; contains a few scattered small pebbles. Bedding planes are broad and concave upward and are similar to dune-sand crossbeds. Upper one-quarter of unit contains several 2- to 3-in. bands of orange-brown-weathering argillaceous sandstone. Grades into overlying unit through	

Descriptions of stratigraphic sections—Continued

	Thickness (feet)
Ojo Alamo Sandstone restricted, upper part—Continued	
a 1-ft-thick transition zone. Forms a smooth steep slope set back from underlying unit. Unit 7 correlates with the upper part of the Ojo Alamo on the divide between Ojo Alamo and Barrel Spring Arroyos (fig. 4) and with unit 6 at loc. 10	15.5
Ojo Alamo Sandstone restricted, lower part:	
2. Sandstone, light-tan, coarse-grained, arkosic. Contains lenses of gravel and scattered pebbles. Bedding is highly irregular and of stream-channel type. Some beds are brown and highly ferruginous. Contains large prone petrified logs. The unit forms an irregular cliff; the brown ferruginous beds are particularly resistant to weathering, form strong ledges, and cap pinnacles (hoodoos), whereas other parts are soft. This unit correlates generally with unit 2 at loc. 10. At the base of the unit is an erosional unconformity that has at least 10 ft of relief in the vicinity of this section. (Units 2 and 3 are the upper conglomerate of Bauer's Ojo Alamo Sandstone.)	20.0
Unconformity, erosional.	
Kirtland Shale, Naashoibito Member (in part):	
1. Sandstone, very light gray to nearly white, medium-grained; contains a few "cannonball"-like concretions. Forms rounded hills with steep cliffs. Locally the sandstone is overlain by olive-gray silty clay shale which is cut out by the unconformity at the base of the restricted Ojo Alamo. (Unit 1 is the upper part of the medial unit of Bauer's Ojo Alamo Sandstone.) Not measured.	

Locality 10

[Measured on east wall of narrow part of Barrell Spring Arroyo about 500 ft south of wagon road to Ojo Alamo that crosses the arroyo in sec. 9, T. 24 N., R. 11 W. Reference section of Ojo Alamo Sandstone restricted]

	Thickness (feet)
Top.	
12. Stabilized sand dunes and soil of Quaternary age that cap a gently sloping cuesta east of Barrel Spring Arroyo	10–20
Unconformity, erosional.	
Nacimiento Formation (in part):	
11. Sandstone, gray, medium-grained, soft	3.0+
10. Clay, very dark gray	2.0
9. Clay, olive-green, silty	1.0
8. Shale, clay, olive-green; weathers pastel red and forms a conspicuous red band which persists in the badlands to the north. This is probably the "second" red clay of Sinclair and Granger (1914, p. 305) that contains Puerco fossils in the badlands. Locally, this unit contains manganiferous concretions near its base. Forms a gentle slope	7.5
Ojo Alamo Sandstone restricted, upper part:	
7. Sandstone, very light olive-gray, coarse-grained at base but medium-grained and argillaceous in upper half of unit. Contains several interbeds of soft plastic clay. Unit is soft and forms a slope. Upper contact poorly exposed; lower part of unit grades into underlying unit	5.5

Descriptions of stratigraphic sections—Continued

	Thickness (feet)
Ojo Alamo Sandstone restricted, upper part—Continued	
6. Sandstone, light-tan to buff, medium- to coarse-grained. Grains are subrounded and consist mainly of quartz. About 25 percent of the grains are gray and red rock fragments and feldspar. Bedding planes are broad and concave upward and are similar to dune crossbeds. Locally, the unit is friable and weathers to loose sand. The unit forms a smooth rounded ledge and grades into the underlying unit. Units 6 and 7 wedge out northward into shale of Nacimiento Formation in the badlands about ¼ mile north of the wagon road in Barrel Spring Arroyo. (See fig. 4.)	20.0
Nacimiento Formation, tongue:	
5. Sandstone and olive-gray shale, interbedded. Sandstone is fine- to coarse-grained and contains lenses of small pebbles. Unit forms a slope. About 100 yd northeast of loc. 10, this unit grades laterally into reddish-banded and olive-drab clay shale and interbedded sandstone. This is probably the lower red clay of Sinclair and Granger (1914, p. 305). (See fig. 4.)	7.0
4. Sandstone, buff to yellowish orange, coarse-grained, soft. Forms a rounded slope	5.0
3. Clay, gray, and interbedded sandy shale and shaly coarse-grained sandstone. Soft; forms a notch. This unit and unit 4 persist northward where they become the lignite-bearing lower part of the Nacimiento Formation from which pollen and spore colln. 2 was made in the badlands north of the wagon road in Barrel Spring Arroyo. Farther south, unit 3 is the lignitic shale (unit 17) from which pollen and spore colln. 1 was made within the Ojo Alamo at loc. 11	3.0±
Ojo Alamo Sandstone restricted, lower part:	
2. Sandstone, buff to yellowish-brown, arkosic, conglomeratic, fine- to coarse-grained; grains are angular to subrounded. Numerous pebbles occur near the base and scattered throughout the unit; distinct lenses of pebbles occur locally. Unit is strongly crossbedded. Brown "cannonball"-like concretions occur about 15 ft above base. Unit contains numerous large prone petrified logs. Forms ledges and rounded slopes; ferruginous zones along bedding planes are particularly resistant to weathering and form strong ledges, whereas much of the sandstone is soft. These differences in cementation cause highly irregular "hoodoo"-like outcrops. Base of unit is an erosional unconformity with at least 6 ft of relief in the vicinity of this section. (Units 2–7 are the upper conglomerate of Bauer's Ojo Alamo Sandstone)	22.0
Unconformity, erosional.	
Kirtland Shale, Naashoibito Member (in part):	
1. Claystone, dark-blue-gray, bentonitic, compact; no bedding visible. Unit is soft and easily eroded. Base of unit not exposed. Forms a gentle rounded slope near the bottom of the narrow gully in Barrel Spring Arroyo. (Unit 1 is the upper part of the medial unit of Bauer's Ojo Alamo Sandstone)	6+

Descriptions of stratigraphic sections—Continued

Locality 11

[Measured on the west-facing cliffs and on the slopes above and below the cliffs, east side of Barrel Spring Arroyo, about ⅛ mile north of Barrel Spring, sec. 16, T. 24 N., R. 11 W. Reference section of the Naashoibito Member of the Kirtland shale]

Top.	*Thickness (feet)*
19. Stabilized sand dunes and soil of Quaternary age that cap the cuesta near Barrel Spring	0–10+
Unconformity, erosional.	
Ojo Alamo Sandstone restricted:	
18. Sandstone, light-tan, coarse-grained, soft; contains a few pebbles. Forms gentle slopes northeast of cliffs. Lower part contains several thin interbeds of olive-green sandy clay shale	16+
17. Shale, sandy clay, light olive-gray; contains lignitic laminae and carbonized plant fragments. Pollen and spore colln. 1 was taken from this unit. Forms a soft slope northeast of cliffs	1–3
16. Sandstone, buff, very coarse grained. Contains scattered pebbles and lenses of pebbles. The pebbles are mostly siliceous and are 1–3 in. in maximum dimension. The composition of the pebbles is similar to that of the pebbles in unit 3. Contains large silicified logs. Parts of the unit are highly crossbedded. Some beds are highly ferruginous and resistant to erosion, causing the unit to weather to irregular cliffs. Generally, the upper half of the unit is more resistant to erosion than the lower half. The base of the unit is a highly irregular erosional surface having local relief of 15–20 ft. Barrel Spring issues from the lower part of this unit. (Units 16–18 are the upper conglomerate of Bauer's Ojo Alamo Sandstone.)	12+
Unconformity, erosional.	
Kirtland Shale, Naashoibito Member:	
15. Sandstone, light-gray, fine-grained, soft; and interbedded gray plastic clay shale. Upper half is mostly clay shale. Forms a gentle slope	5.5
14. Shale, plastic clay, light-olive-gray. Forms a slope	4.5
13. Sandstone, buff to nearly white, fine- to medium-grained. Contains a few concretionary "cannonballs." Forms a steep slope	12.5
12. Claystone, olive-gray, silty, compact; upper half weathers purple. Forms a slope	2.5
11. Sandstone, buff, fine-grained, argillaceous. Forms a slope	2.0
10. Claystone, silty, gray, compact, purple-weathering	2.5
9. Claystone, purple-weathering, compact. To the south this unit thickens and grades laterally into "cannonball"-bearing sandstone. The base of this unit is, locally, a channeled surface	5.0
8. Claystone, gray, compact. Forms a steep slope set back slightly from the underlying unit	5.0
7. Claystone, purple-weathering, compact. Contains patches of green-weathering clay and numerous concretionary nodules of barite and calcite which litter the slopes below unit 7	9.0
6. Claystone, greenish-gray, compact. Weathers to large angular chips and forms a gentle slope	5.0
5. Sandstone, light-buff to white, fine- to medium-grained; contains some coarse grains. Contains numerous dark-brown-weathering concretionary "cannonballs" as much as 3 ft in diameter. Contains scraps of dinosaur bones. Sandstone is soft, and the unit forms rounded cliffs. The unit is persistent and conspicuous in this area, and locally it contains a few thin beds of purplish clay	17.0
4. Shale, plastic clay, sandy, greenish-gray. Forms a poorly exposed rounded slope. (Units 4–15 are the medial part of Bauer's Ojo Alamo Sandstone.)	4.5
3. Sandstone, buff; weathers yellow because of contained limonite; fine grained to coarse grained and gravelly. Contains numerous well-rounded pebbles that are as much as 3 in. in largest dimension. The pebbles are mostly pinkish and gray quartzite, but many pebbles are sandstone, volcanic rocks, and gray to red chalcedony. Pebbles are largest and most numerous near the base of the unit, but they are present throughout. Most of the sandstone is poorly cemented, but locally in the vicinity of Barrel Spring Arroyo it forms a resistant bench. Base of the unit is an irregular channeled surface. (Unit 3 is the basal conglomerate of Bauers' Ojo Alamo Sandstone.)	9.0±
Kirtland Shale, upper shale member (in part):	
2. Lignite and lignitic clay shale, black to dark-brown. This unit is persistent in the vicinity of Barrel Spring Arroyo, but its thickness varies	8.0
1. Mudstone, gray. Forms gentle slopes just above the channel of Barrel Spring Arroyo at loc. 11. To the southwest in the banks of the arroyo, unit 1 is underlain by dinosaur-bearing highly lenticular sandstone and lignitic clay shale. Not measured.	

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