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Upper Cretaceous Farmington Sandstone of Northeastern San Juan County, New Mexico

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UPPER CRETACEOUS FARMINGTON SANDSTONE

DILWORTH

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By

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This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

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ABSTRACT

The Upper Cretaceous Farmington sandstone is found only in northwestern New Mexico and southwestern Colorado. The Farmington sandstone is the middle member of the Kirtland shale, there being a Kirtland shale member above and below it. This sandstone unit appears as an extensive wedge in the Kirtland shale and thins northward, southward, and southeastward from Townships 30-31 North, Ranges 9-13 West. The thickness of the Farmington sandstone ranges from 27 to 818 feet within the area of this thesis. The unit is correlative with parts of the Vermejo formation of the Raton basin and the Fox Hills formation of the Great Plains. Paleontological evidence indicates that the Farmington sandstone is of Montanan age.

The type locality for the Farmington sandstone lies along the San Juan river from Farmington, New Mexico westward about six miles to within approximately three miles of Kirtland, New Mexico. The Farmington member consists of sandstone strata with some interbedded shale and siltstone lentils. The sandstones are usually some shade of tan, fine-to medium-grained, angular to sub-rounded, poorly to fairly well-sorted, and have a chloritic-argillaceous cement and matrix. The shale is gray to greenish-gray and usually sandy to silty and the siltstone is greenish-gray, micaceous, and hard.

A thin-section and heavy-mineral study of the sandstones indicates that the sediments which make up the Farmington sandstone were derived from an intermediate (diorite-monzonite) to more

silicic (granitic-granodioritic) igneous source and that they are feldspathic graywacke; however, there is a possibility that some of the sediments which make up the Farmington sandstone may have been derived from a metamorphic and volcanic terrane. The petrographic study further revealed that the Farmington sands were derived from a nearby source and that they are immature, inasmuch as they contain more feldspar than quartz.

A study of cross-bedding in the five measured surface sections suggest a southern to southwestern source for the major part of Farmington sediments. The discovery of microfossils in one shale unit suggests that the Farmington sediments are of marine or marine-brackish, probably lagoonal, origin. It is postulated that these conditions were brought about by the continued subsidence of the "Kirtland basin" which caused a temporary reversal in the withdrawal of the Lewis sea from the Cuba area.

High gravity (50° to 59° A. P. I.) oil has been produced from three Farmington sandstone pools and gas from four fields. Economically the Farmington sandstone is only of local interest, inasmuch as it has produced only about 82,587 barrels of oil and 338,885 MCF of gas. Wells producing oil and gas from the Farmington sandstone range from about 600 to 1,800 feet in depth.

silicic (granite-gneiss-[illegible]) [illegible] [illegible] [illegible] [illegible]

spathic graywacke, however, there is a [illegible] [illegible] [illegible] the

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derived from a [illegible] [illegible] [illegible] [illegible]. [illegible]

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Farmington sandstone. The [illegible] [illegible] [illegible] [illegible] [illegible]

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[illegible], [illegible] [illegible] [illegible]. [illegible] [illegible] [illegible] [illegible] [illegible]

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High gravity (58^{o} to 59^{o} [illegible]) [illegible] has been [illegible] from

three Farmington sandstone pools and gas from [illegible] [illegible].

Economically the Farmington sandstone is only of local interest,

inasmuch as it has produced only about [illegible] [illegible] [illegible] and

336,885 MCF of gas. [illegible] producing [illegible] [illegible] [illegible] [illegible]

sandstone range from [illegible] [illegible] to [illegible] [illegible] [illegible].

INTRODUCTION

Geography

The area covered by this thesis is located on the west side of the San Juan basin in northwestern New Mexico (Fig. 1). It is roughly rectangular in shape, 50 miles long and 38 miles wide, and lies in northeastern San Juan County, New Mexico. The area is bounded on the north by the New Mexico - Colorado state line, on the east by the San Juan - Rio Arriba County line, on the south by Township 26 North, and on the west by Range 15 West.

Aztec is the only city in this area. Other population centers are: Bloomfield, Farmington, Fruitland, Kirtland, and La Plata. A branch of the Denver and Rio Grande Railroad serves the area. This narrow gauge railroad extends southward from Durango, Colorado, through Aztec, New Mexico and terminates in Farmington. The area may also be reached by paved roads from the south, north, east, and west. In addition, there are numerous unpaved county, oil field, and Indian roads throughout the area.

The western part of the San Juan basin is drained westward by the San Juan, Animas, and La Plata rivers and their tributaries. The San Juan and Animas rivers are perennial. The lower end of the La Plata river usually is ephemeral during the hot dry summers. These rivers are maintained to a great extent by the melting snows at their sources in the San Juan and La Plata mountains of Colorado. Intermittent washes such as Largo and Carrizo carry large amounts of water during the thaw and rainy seasons.

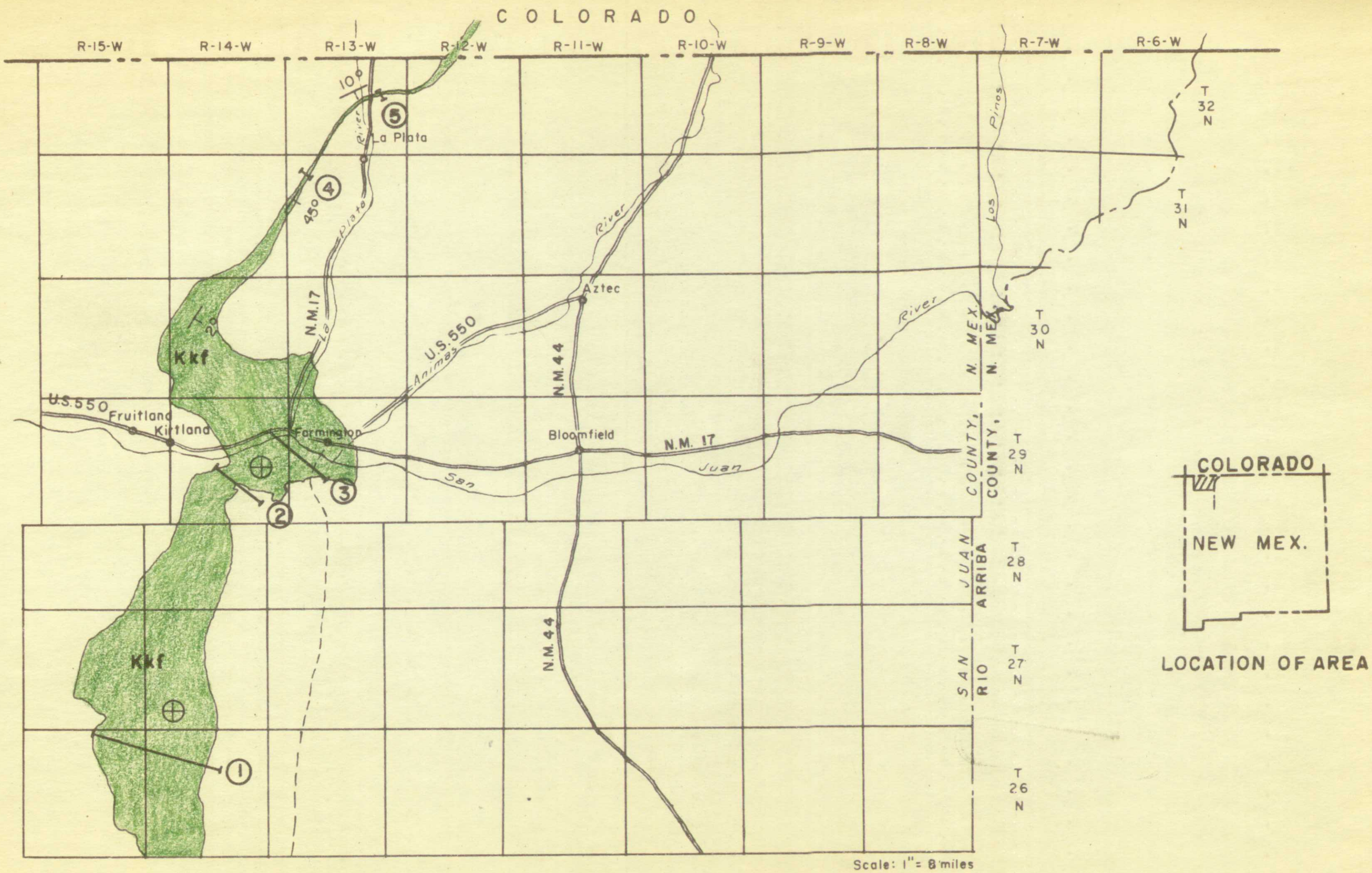


Figure 1: Index map of area showing location of sections measured along the outcrop of the Farmington sandstone.

The region is semi-arid and stands from 5,200 to 7,200 feet above sea level. Sage brush, rubber weed, Russian thistle, different varieties of cacti and grasses, and juniper, pine, cottonwood and scrub oak trees are the chief types of plant life in the area. The region comprises some ranching and farming lands, with the best arable lands being located along the rivers. The oil and gas boom during the past few years has resulted in a great influx of population and, in general, has made this area highly prosperous.

Previous Work

The Farmington sandstone member (Pl. I) of the Kirtland shale (Pl. II), present in northwestern New Mexico and southwestern Colorado, crops out along the northwestern and northern part of the San Juan basin, but is absent as a recognizable unit along the southern and eastern margins of the San Juan basin.

Bauer (1916, p. 274-275) named the Farmington sandstone and noted its medial position in the Kirtland shale. In the words of Bauer:

> The shale, so far as is known, is of fresh water origin, although possibly it was formed in deltas and lagoons. It is divided, as shown in the San Juan river section, into three parts—a lower shale 271 feet thick, a sandy part, here named the Farmington sandstone member, and an upper shale 110 feet thick.
>
> The sandstone member forms a prominent bluff on the San Juan river, where it is 455 feet thick, but toward the south it is gradually replaced by lenses of shale. On the head of Coal Creek the member disappears as a mappable unit, and farther south it is represented only by isolated sandstone lenses in the Kirtland shale. A study of the sandstone lenses making up the Farmington shows that they are irregular in thickness, cross-bedded, and composed almost invariably of two parts—at the base an easily eroded yellowish sandstone carrying clay pellets of various sizes and in

The region is [illegible]-arid and stands about [illegible] feet above sea level. Sage brush, saltbush, grease[illegible], Russian thistle, [illegible] varieties of grama and [illegible], and juniper, pinon, [illegible] and scrub oak trees are the chief types of plant life in the area. [illegible] com-prise some ranching and farming lands, with [illegible] lands [illegible] located along the rivers. The oil and gas development [illegible] the last few years has resulted in a great influx of population and [illegible] has made this area highly prosperous.

Previous Work

The Farmington sandstone member [illegible] (Pl. II), present in [illegible] crops out along the [illegible] part of the San Juan Basin but is absent [illegible] margins of the San Juan Basin.

Bauer (1916, p. [illegible]) named the Farmington [illegible] noted its [illegible] position in the Kirtland shale. In the words of Bauer:

> The shale, so far as is known, is of fresh water origin, although possibly it was [illegible] lagoons. It [illegible] in the San Juan [illegible] section [illegible] a sandy part [illegible] the Farmington sandstone [illegible] and [illegible] their [illegible].
>
> The sandstones [illegible] are [illegible] on the San Juan River [illegible] toward the [illegible] replaced by [illegible] of shale. [illegible] the [illegible] predominantly [illegible] Kirtland shale. [illegible] up the [illegible] that they are irregular [illegible] thickness [illegible] are [illegible] rather [illegible]

some lenses sandstone pebbles similar to the matrix, as large as 4 inches in diameter, and at the top a markedly resistant brownish sandstone whose upper portion is commonly of a dark chocolate-brown color on the exposed surface and dark gray on the fresh surface. All the lenses in the Farmington sandstone member lie on more or less irregular surfaces of interbedded shale and exhibit the characteristics of channel and floodplain deposits. An individual lens will usually have a maximum thickness of 20 feet, a lateral extent of 15 or 20 yards, and a length of several hundred yards.

Bauer's study included the area from Hogback mountain to about 30 miles east, and from the San Juan river to about 30 miles south. He included the McDermott formation with the upper Kirtland shale member.

The following excerpts, concerning the Kirtland shale and Farmington sandstone, are from a paper by Reeside (1924, p. 21, 22, and 23):

> * * * The formation has been traced around the west side of the San Juan basin but is overlapped on the north side by the Animas formation and on the south side by the Ojo Alamo sandstone. Whether it can be recognized on the east side of the basin the writer cannot say. It has not been recognized definitely outside of the San Juan basin, though there are certainly sediments of the same age over wide areas.
>
> At the type locality the Kirtland shale may be divided into three groups of beds forming distinct members, all of fresh water origin. * * *
>
> Southward from the typical locality the Farmington sandstone member thins and is completely replaced by soft beds between Coal Creek and Kimbetoh Arroyo, the lower shale member thickening at its expense, while the upper shale varies but little. Northward from San Juan river the sandstone member and the upper shale member vary irregularly in thickness, and the lower shale changes little. The lighologic constitution of these members remains the same as at the typical locality. * * *

[illegible] ... [illegible] ... [illegible]
[illegible]
several hundred years.

Emerson's study included the area from [illegible] about 30 miles east, and [illegible] river to about [illegible] miles south. He included [illegible] land shale member.

The following [illegible]

Farmington [illegible] (Figures 22, and 23):

[illegible]

[illegible]

[illegible]

The writer has not anywhere found pebbles in the Farmington sandstone. The sandstones of the Farmington member make marked benches where the dip of the beds is low and a ridge where the dip is high. * * *

On San Juan river the lower shale member is 271 feet thick, the Farmington sandstone member 459 feet thick, and the upper shale member 80 feet. Toward the south the lower shale member increases, in the sections measured, to 368 feet, 550 feet, and 1,031 feet and then decreases to 975 and 830 feet. In the same sections the Farmington sandstone member measures 432, 450, 99, 87, and 20 feet. The upper shale member ranges from 12 to 44 feet in thickness. North of San Juan river the lower shale member maintains at most places a thickness of 300 to 350 feet. The Farmington sandstone member, however, ranges from 162 to 480 feet and the upper shale member from 150 to 475 feet. These variations seem to indicate simply differences in sedimentation, as the beds form everywhere an unbroken sequence of deposits.

Reeside measured the Farmington sandstone type section for Bauer in 1915, but the type section was not published until 1924. The type section description is included in the Appendix of this paper and is graphically depicted on Plate III.

Economic Considerations

The Farmington sandstone is important chiefly as an oil and gas reservoir. Official records show that 82,587 barrels of high gravity oil and 333,885 MCF of flammable gas had been produced from the Farmington sandstone as of November 30, 1959 (Emery C. Arnold, written communication, December 8, 1959).

A few shallow water wells are producing from this member of the Kirtland shale, however, the water in the majority of these wells has a high sulphur content and in most cases is barely potable.

The writer has not [illegible] Farmington sandstone. [illegible] ington sandstone [illegible] that rocks [illegible]

On San Juan River [illegible] teen miles, the Farmington sandstone [illegible] thick, and the [illegible] the south the [illegible] section measured [illegible] feet and then decreases to [illegible] and [illegible] feet. In the [illegible] Farmington [illegible] sures [illegible] of San Juan River the lower shale [illegible] most places a thickness [illegible] ington sandstone [illegible] 400 feet and the upper shale [illegible] feet. These variations [illegible] ences in sedimentation [illegible] an unbroken sequence of [illegible]

Reeside measured the Kirtland [illegible] type section [illegible] Bauer in 1915, but the type section was not designated until [illegible]. The type section description is included in the [illegible] and is graphically depicted on Plate [illegible].

Economic Considerations

The Farmington sandstone [illegible] gas reservoir [illegible] gravity oil and [illegible] the Farmington sandstone as oil [illegible] written communication [illegible]

A few small oil [illegible] of the Kirtland shale, however, the [illegible] wells has a high [illegible]

Purpose of Investigation

Very little information, excepting that presented by Bauer (1916) and Reeside (1924), appears in the literature concerning the Farmington sandstone member of the Kirtland shale. This thesis is an attempt to present the regional structure and stratigraphy, lithology, paleontology, source areas of sediments, environment of deposition, correlation, oil and gas production statistics, core descriptions, and descriptions of measured sections. In addition, a thin-section, heavy-mineral, and grain-size analysis for one section is included.

Method of Investigation

Six days were spent in the field during the spring and summer of 1959 in measuring sections, collecting samples, searching for fossils, taking photographs, walking the outcrops, and studying the local and regional setting and surface exposures. The rest of the work was done in the office and laboratory. Several samples from Measured Section No. 3 were sent to the El Paso Natural Gas Company Research Laboratory in Salt Lake City, Utah, for a thin-section, heavy-mineral, grain-size, and paleontologic study.

Acknowledgments

Appreciation is expressed to Sherman A. Wengerd for suggesting such an interesting geological study in the immediate area where the writer is employed and for directing the study and writing of this thesis; to Wolfgang E. Elston who was so kind as to read and correct the thesis; and to Roger Y. Anderson who kindly read and

corrected the thesis and made suggestions as to the depositional environment of the Farmington sandstone after examining foraminifera found therein.

Thanks are due the New Mexico Geological Society for financial assistance in helping defray the expenses connected with this thesis; to El Paso Natural Gas Company for the use of time, facilities, and equipment; and to the management of El Paso Natural Gas Company for permission to submit this thesis. Further thanks are due the following personnel of El Paso Natural Gas Company: Roy L. Pritchard who offered constant encouragement toward the completion of the project; Allan J. Loleit for reading the entire manuscript and making many valuable suggestions; Edward R. Woodside for finding and identifying the microfossils in Measured Section No. 3; Dean L. Eige for helping to measure the cross-bedding in Measured Section No. 4; Del A. Talley and Edward D. Leuppe for assisting with the drafting; and Miss Betty Ferrick for typing the manuscript.

Special thanks are due William J. Barrett, petrographer, El Paso Natural Gas Company Research Laboratory, Salt Lake City, Utah, who spent a great deal of time and effort in doing the thin-section, heavy-mineral, and grain-size analyses especially for this thesis.

corrected the thesis and made many suggestions concerning the depositional environment of the [illegible] and [illegible] foraminifera found therein.

Thanks are due the [illegible] for financial assistance in helping defray the expenses connected with this thesis; to El Paso Natural Gas Company for the use of its facilities and equipment, and to the management of El Paso Natural Gas Company for permission to submit this thesis. Further thanks are due the following persons of El Paso Natural Gas Company: Roy L. Pritchard who offered constant support and encouragement toward the completion of the thesis; Allen L. [illegible] for reading the manuscript and making many valuable suggestions; [illegible] for finding [illegible] No. 3; Dean L. Rice for [illegible] Measured Section No. 4; Don D. Talley and [illegible] for assisting with the drafting and [illegible] for typing the manuscript.

Special thanks are due Bob Whitehead, Research Geologist, El Paso Natural Gas Company Research Laboratory, Salt Lake City, Utah, who spent a great deal of time and effort in making the thin section, heavy-mineral and grain-size analysis, especially for this thesis.

REGIONAL SETTING

Structure

Regional Structure

The San Juan basin is located in the southeastern part of the Colorado Plateau province. The present structures of the Colorado Plateau province are due chiefly to deformation during the Laramide orogeny and late Tertiary time. The San Juan basin, surrounded by uplifts, is an ovate, frontal, intermontane, structural basin, about 20,000 square miles in area, encompassing almost 36,000 cubic miles of sedimentary rocks within the Dakota outcrop and above the Precambrian basement (Wengerd, 1958, p. 366).

Geographically, the San Juan basin is bounded on the north by the San Juan mountains, on the northeast by the Chama basin and Archuleta anticlinorium, on the east by the Nacimiento mountains, on the southeast by the Rio Grande trench, on the south by the Mount Taylor volcanic complex, on the southwest by the Zuni mountains, on the west by the Defiance uplift and Chuska mountains, and on the northwest by the Four Corners platform (Fig. 2).

The San Juan basin has undergone the following generalized tectonic history (Wengerd, 1959, p. 2221): (1) from Cambrian to early Pennsylvanian time this area was a high shelf of the Cordilleran geosyncline and was limited on the east by the San Luis positive area; (2) Paradox basinal subsidence with medial evaporitic conditions were prevalent during Pennsylvanian Cherokee time, as the San Luis and Penasco uplifts began to shed coarse clastics into the basin; (3) thorough marine ventilation and deposition of normal marine shelf to

REGIONAL SETTING

Structure

The San Juan Basin

The San Juan Basin is [illegible] the [illegible] Colorado Plateau province. Like [illegible] Plateau provinces [illegible] Laramide [illegible] orogeny and late Tertiary [illegible] uplifts, is an oval [illegible] 20,000 square miles in area, [illegible] of sedimentary rocks [illegible] Precambrian basement (Woodward, 1973, p. [illegible]).

Geographically, the San Juan Basin is bounded on the north by the San Juan Mountains, on the northeast [illegible] Archuleta anticlinorium, on the east by the Nacimiento [illegible], on the southeast by [illegible] [illegible] Taylor volcanic [illegible] the west by the Defiance uplift [illegible] and on the northwest by the Four Corners platform (fig. [illegible]).

The San Juan Basin has [illegible] tectonic history (Woodward, [illegible]): (1) [illegible] early Pennsylvanian [illegible] geosyncline [illegible] (2) Paradox basin [illegible] prevalent during Pennsylvanian [illegible] Penasco uplifts [illegible] the basin [illegible] through [illegible]

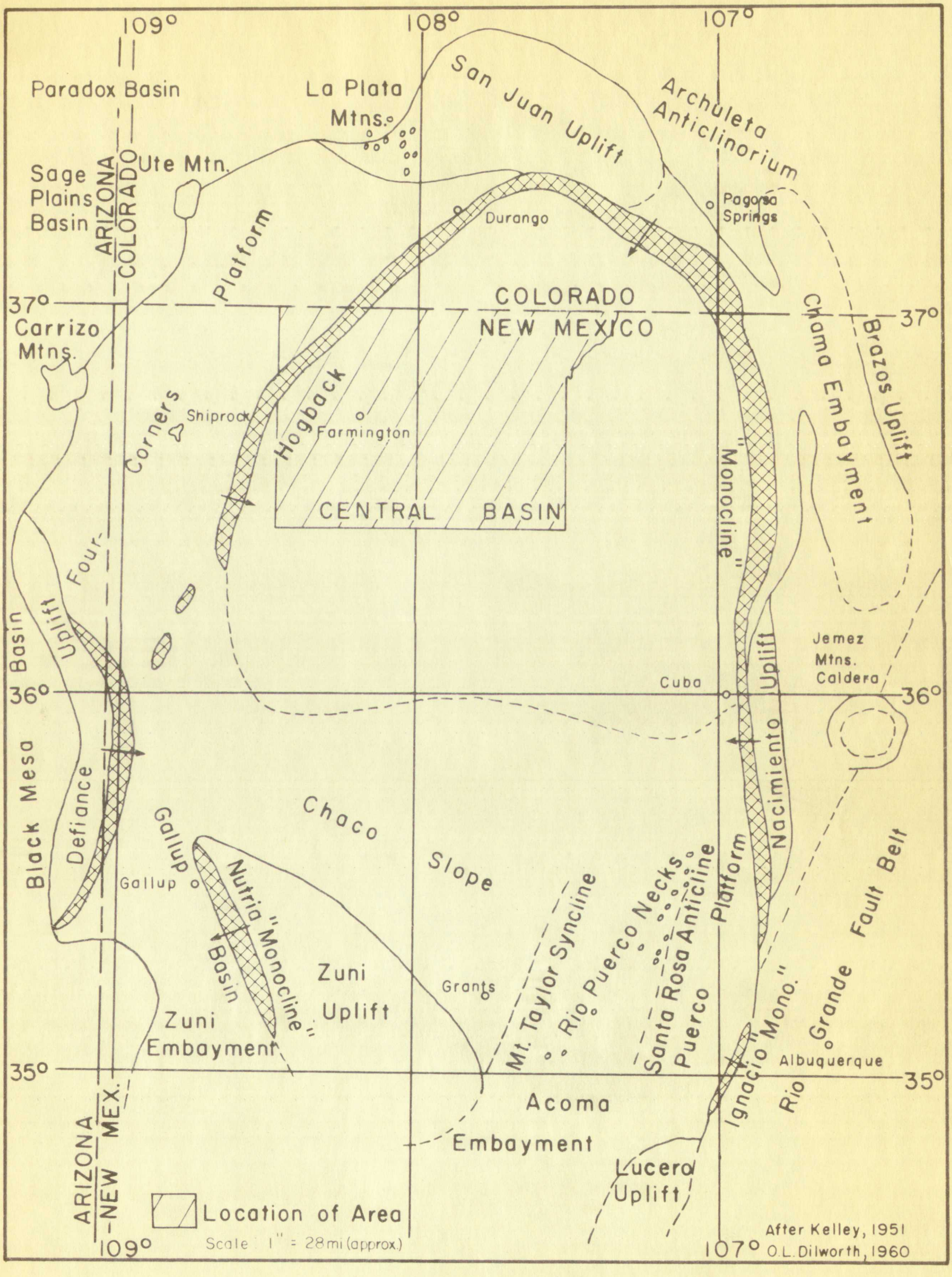


FIGURE 2 - STRUCTURAL ELEMENTS OF THE SAN JUAN BASIN

semi-basinal sediments during late Pennsylvanian time, as the reactivated positive elements shed many cubic miles of coarse arkosic sediments along the east side of the basin; (4) during Permian time the region was tilted westward and the marine waters retreated; (5) fine-to coarse-grained continental clastics were deposited over the area from Permian to early Mesozoic time; (6) during late Cretaceous time the region was tilted northeastward and marine waters inundated the region; (7) the area underwent regional uplift and local folding during the Laramide orogeny at the end of Cretaceous time; (8) during Tertiary time the San Juan basin became a separate tectonic feature as deep local subsidence and crowding-in of the ringing uplifts took place; (9) during mid-Cenozoic time the basin was uplifted more than 6,000 feet above sea level as the ringing uplifts became tectonically active; and (10) intrusion and extrusion of late Tertiary volcanic rocks into parts of the basin.

Local Structure

The Farmington sandstone is well exposed where it crops out on the western edge of the San Juan basin (Fig. 1). The dip of the Farmington sandstone ranges from a maximum of 45 degrees southeast in Township 31 North, Range 13 West, to zero in Township 26 North, Range 14 and 15 West. No faults were noted while doing field work. At its deepest point within the area of this report, near the San Juan and Rio Arriba County line, the Farmington member is covered by approximately 2,700 feet of younger, uppermost Cretaceous and Tertiary, strata.

semi-basinal sandstones. During late Pennsylvanian time, the basin [illegible] activated positive areas [illegible] and in [illegible] sediments along the east side of the basin; (4) during Permian time the region was tilted [illegible] marine [illegible] deposited; (5) fine-to coarse-grained continental clastic [illegible] deposited over the area from Permian to early Cretaceous time; (6) during late Cretaceous time the region was tilted [illegible] invaded the region; (7) the area [illegible] uplift and [illegible] during the Laramide orogeny at the end of Cretaceous time; (8) during Tertiary time [illegible] present structural features as deep basinal subsidence and [illegible] of the [illegible] uplift took place; (9) during mid-Cenozoic time the basin was [illegible] more than 4,000 feet above sea level to the [illegible] tectonically active; and (10) [illegible] Tertiary volcanic rocks into parts of the basin.

Local Setting

The Farmington [illegible] located on the western edge of the [illegible] Farmington [illegible] east in Township [illegible] North, Range [illegible] work. At its deepest point [illegible] San Juan and [illegible] covered by approximately [illegible] and Tertiary rocks.

No structure contour map was attempted owing to economic implications and the lensing nature of the Farmington sandstone; however, structure contour maps could be made on certain wide spread lenses of Farmington sandstone. Economic implications also prevented an investigation of possible structural terraces or noses to determine if folding, or subsidence of the "Kirtland basin" may have had an effect on sandstone distribution.

Stratigraphy

Regional

The San Juan basin includes rocks ranging from Precambrian through Recent in age. There are no known Ordovician or Silurian rocks in the San Juan basin (Cooper, 1955, p. 61).

Throughout early Paleozoic time the region of the basin was a high shelf area. Cambrian, Devonian, and Mississippian rocks represent high-shelf equivalents of the thick early Paleozoic sections of the Cordilleran geosyncline far to the west. It was not until late Paleozoic time, during the Pennsylvanian and Permian periods, that the area received sediments of great thickness. The remainder of the Paleozoic systems have been either partially removed by erosion or are absent. During Pennsylvanian time the San Juan basin area was a southeasterly part of the Paradox geosyncline. From zero to over 3,000 feet of carbonates and clastics were deposited in the resultant shelf to basinal area. The Pennsylvanian Hermosa group comprises the most complete record of deposition during Paleozoic time. During the Permian, Triassic, and Jurassic periods the area

No structural [illegible] was attempted [illegible] its economic
implications and the [illegible] for the [illegible] structure [illegible],
however, structure could [illegible] the wide
spread lenses of Paleozoic [illegible]
prevented an investigation of [illegible] to
determine if folding, or [illegible] may have
had an effect on sandstone distribution.

[illegible]

[illegible]

The [illegible] rocks [illegible] range from [illegible]
through Recent in age. [illegible]
rocks in the [illegible] (Figure 1, [illegible]).

Throughout early Paleozoic time the region of the [illegible] was
a high shelf area. [illegible]
represent high-shelf [illegible] of the [illegible]
of the Cordilleran geosyncline [illegible] late
Paleozoic time [illegible] that
the area received [illegible]. The [illegible] of
the Paleozoic systems [illegible]
or are absent. During [illegible]
was a comparatively [illegible]
over 1,000 feet of [illegible]
culmination [illegible]
comprises the [illegible]
time. During the [illegible]

received great thicknesses of continental sediments (Wengerd, 1959, p. 2214-16).

Regional unconformities occur between the Cambrian and Devonian strata; Devonian and Mississippian strata; Mississippian and Pennsylvanian strata; Permian and Triassic strata; and between Jurassic and Cretaceous strata.

Field evidence indicates thatthe area received virtually continuous deposition of sediments from late Cretaceous through Eocene time (Fig. 3). The upper Cretaceous section is represented chiefly by sandstone and shale with some coal present in the Dakota sandstone, Menefee, and Fruitland formations. The only true limestones younger than Pennsylvanian in age are found in the Jurassic Todilto and upper Cretaceous Greenhorn strata. The Sanastee member of the upper Cretaceous Mancos formation is a sandy limestone and calcareous sandstone.

The Upper Cretaceous stratigraphic section represents long and repeated transgressions and regressions of marine waters in the Rocky Mountain geosyncline. From Upper Cretaceous Dakota time to the final regression of the sea which deposited the Pictured Cliffs sandstone the sea was relatively shallow but fluctuated in depth. The resultant sedimentational environments caused intertonguing of sandstone, shale, and coal. The post-Pictured Cliffs strata are continental in origin, excepting the Farmington sandstone member of the Kirtland shale which may be partly or wholly marine or marine-brackish, probably lagoonal, and consist of conglomerate, sandstone, siltstone, shale, and coal.

receiving [illegible] sediments of continental [illegible] ([illegible], p. 224-16).

Regional unconformities [illegible] Devonian strata [illegible] and Pennsylvanian strata, [illegible] Jurassic and Cretaceous strata.

Field evidence indicates that the [illegible] continuous deposition of [illegible] time (Fig. 3). The upper Cretaceous [illegible] represented by sandstone and shale [illegible] present in the [illegible] Mancos, and Fruitland formations. [illegible] than Pennsylvanian [illegible] Jurassic [illegible] upper Cretaceous [illegible] Cretaceous Mancos [illegible] sandstone.

The Upper Cretaceous [illegible] repeated transgressions and [illegible] Mountain geosyncline. [illegible] regression of the sea [illegible] sea was relatively shallow [illegible] mentation [illegible] coal. [illegible] the [illegible] sandstone [illegible] partly or wholly [illegible] cumulative [illegible]

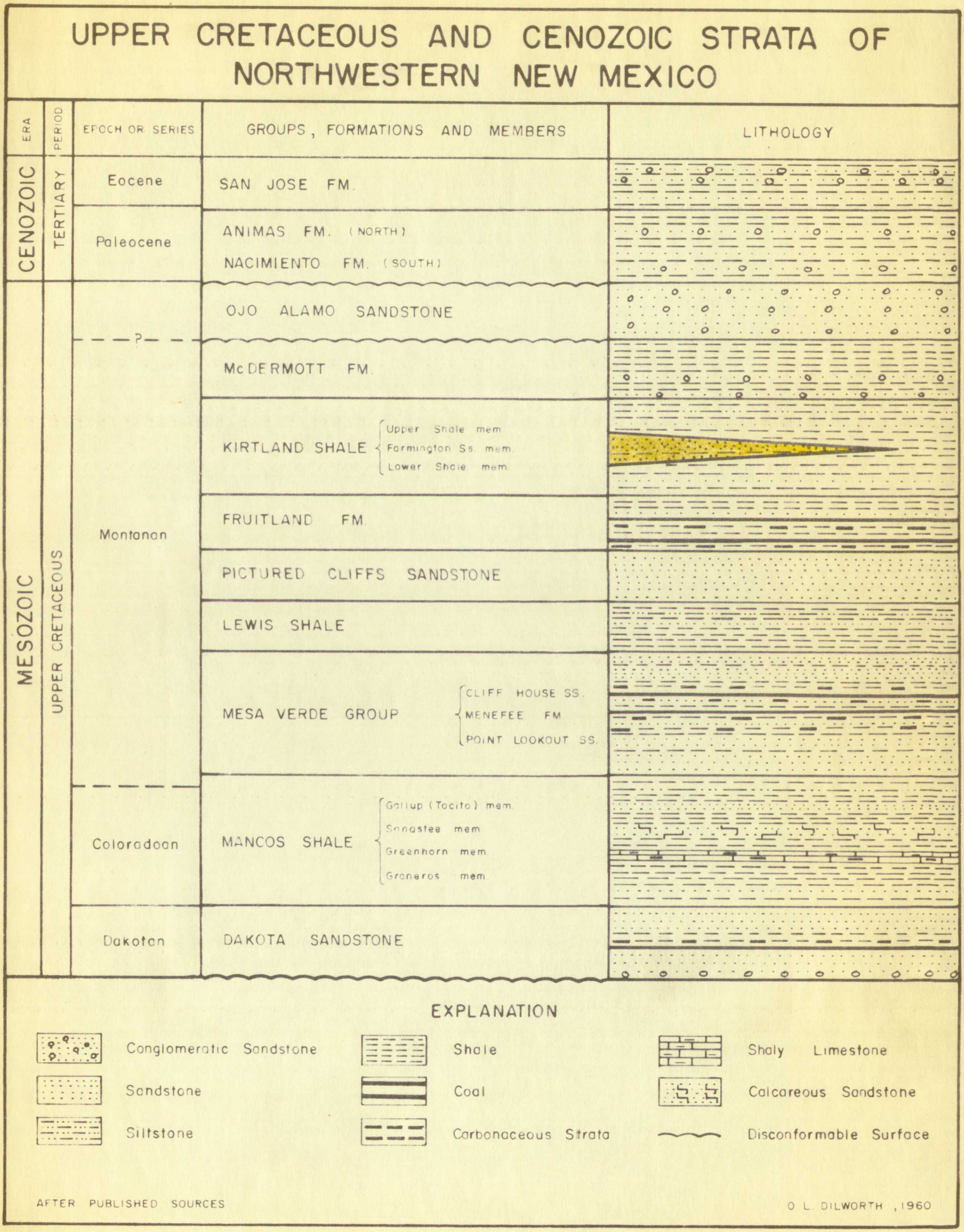

UPPER CRETACEOUS AND CENOZOIC STRATA OF NORTHWESTERN NEW MEXICO
ERA
PERIOD
EPOCH OR SERIES
GROUPS, FORMATIONS AND MEMBERS
LITHOLOGY
CENOZOIC
TERTIARY
Eocene
SAN JOSE FM.
Paleocene
ANIMAS FM. (NORTH)
NACIMIENTO FM. (SOUTH)
MESOZOIC
UPPER CRETACEOUS
OJO ALAMO SANDSTONE
?
McDERMOTT FM.
KIRTLAND SHALE
Upper Shale mem.
Farmington Ss. mem.
Lower Shale mem.
Montanan
FRUITLAND FM.
PICTURED CLIFFS SANDSTONE
LEWIS SHALE
MESA VERDE GROUP
CLIFF HOUSE SS.
MENEFEE FM.
POINT LOOKOUT SS.
Coloradoan
MANCOS SHALE
Gallup (Tocito) mem.
Sanastee mem.
Greenhorn mem.
Graneros mem.
Dakotan
DAKOTA SANDSTONE
EXPLANATION
Conglomeratic Sandstone
Sandstone
Siltstone
Shale
Coal
Carbonaceous Strata
Shaly Limestone
Calcareous Sandstone
Disconformable Surface
AFTER PUBLISHED SOURCES
O. L. DILWORTH, 1960

Figure 3

Lithologic Character

The Farmington sandstone member consists of a series of more or less resistant sandstone lenses interbedded with shale and siltstone beds (Fig. 4). The sandstone is usually some shade of tan, fairly well-consolidated, fine-to medium-grained, fairly well to poorly sorted, contains varying amounts of feldspar, and has a chloritic-argillaceous cement and matrix. The sandstone is feldspathic graywacke. In most cases the shale is gray to greenish-gray and silty to sandy. Varying amounts of chloritic material give the shale its greenish hue. The siltstone is usually greenish-gray, hard, and micaceous.

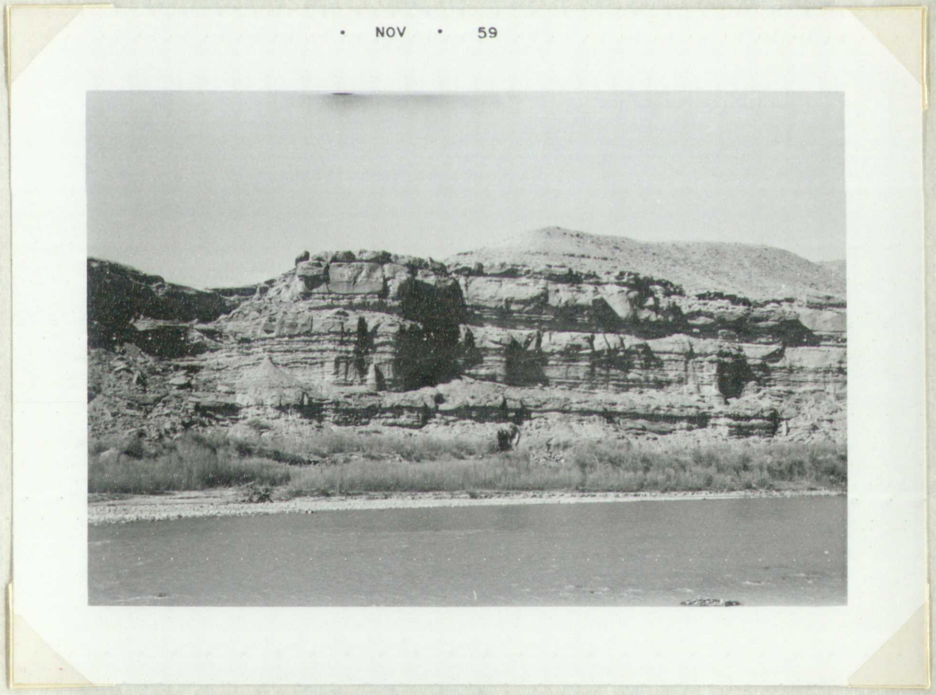


Figure 4. The middle part of the Farmington sandstone type section along the San Juan river, Section 12, Township 29 North, Range 14 West, and the lower part of Measured Section No. 3. Cliff approximately 200 feet high. View northward.

Environment of Deposition

Bauer (1916, p. 274) states that the Kirtland shale may possibly have been formed in deltas and lagoons. Foraminiferal evidence suggests that the Farmington sandstone was deposited in a shallow marine to marine-brackish, probably lagoonal, environment. A cross-bedding study indicates that the major source area, or areas, for the sediments which make up the Farmington sandstone member was to the south or southwest.

It is postulated that sediment-laden streams from the source area flowed down a gentle northeastward dipping regional slope into the lagoonal waters of the "Kirtland basin" (see p. 28). Current and wave action sorted and distributed these sediments to the deeper part of the lagoon. The sand was deposited as lentils and the clay settled out, on and around the sandstone lentils, to form shale, thus gradually a highly lenticular section was built up with the thicker part of the section being in the deeper part of the lagoonal basin. It is believed that basinal subsidence, pulsating uplift of the source area, seasonal rainfall in the source area, and current and wave action were the chief contributing factors to the highly lenticular nature of the Farmington sandstone member.

Local variations in the thickness of the Farmington sandstone appear to be due to lateral facies changes into shale rather than intraformational erosion.

Age and Correlation

The Kirtland shale and the Fruitland formation have usually been considered as a unit in various paleontological interpretations

[illegible]

[illegible] possibly have been formed in a lagoonal [illegible] evidence suggests that the [illegible] a shallow marine [illegible] ment. A cross-bedding [illegible] or areas, for the [illegible] stone member was [illegible].

It is postulated that [illegible] area flowed down [illegible] the lagoonal waters of the [illegible] wave action [illegible] of the lagoon. The [illegible] out, on [illegible] a highly lenticular [illegible] action being [illegible] basinal subsidence, [illegible] fall in the source area, and current and wave action [illegible] tributing factors to the highly lenticular nature of the [illegible] stone member.

Local [illegible] appear to be due to [illegible] intraformational erosion.

[illegible]

The [illegible] been considered [illegible]

of their ages, inasmuch as their lithologies, faunas, and floras are similar.

Holmes (1877, p. 244) believed the strata, which were later named the Kirtland shale, to be part of the so-called Laramie (?) group. Shaler (1907, p. 378-379) and Gardner (1909, p. 338) considered these strata to be in the Laramie formation. Gilmore (1916, p. 281), (1919, p. 8) determined conclusively, from his studies of reptilian faunas, that the Fruitland formation, Kirtland shale, and Ojo Alamo sandstone are of Montanan age and older than the Lance or Laramie formations. Knowlton (1916, p. 331) states that the flora of the Fruitland and Kirtland strata is Montanan in age. A study of non-marine invertebrates by Stanton (1916, p. 310) suggests that the Fruitland, Kirtland, and Ojo Alamo are equivalent to everything from Fox Hills to Lance, inclusive. Reeside (1924, pl. IV) correlates the Kirtland shale with the Vermejo formation of the Raton basin area.

Relationship to Adjacent Units

The Farmington sandstone member of the Kirtland shale appears to be conformable with the adjacent shale members, and is a concentration of sandstone beds, with some interbedded siltstone and shale, near the middle of the Kirtland shale (Fig. 5). Both the top and bottom of the sandstone member are arbitrary due to the lensing nature of the sandstone units. The thickening and thinning of the Farmington sandstone section appears to be due to lateral facies change into shale rather than intraformational erosion.

of their ages, although their lithologies [illegible]
are similar.

[illegible] Holmes (1877, p. [illegible]) [illegible]
later named the [illegible]
group. Shaler (1907, p. [illegible]) and [illegible] (1927, p. [illegible]) con-
sidered these strata to be [illegible]
p. 221), (1916, p. 9) [illegible] concluded [illegible]
reptilian faunas, that the Fruitland [illegible]
Ojo Alamo sandstone are of [illegible]
or Laramie formations. [illegible]
flora of the Fruitland and Kirtland [illegible]
study of non-marine [illegible] Stanton [illegible]
that the Fruitland, Kirtland, and Ojo Alamo are equivalent [illegible]
[illegible]
correlates the Kirtland shale [illegible]
Raton basin area.

Relationship to Adjacent Units

The Farmington sandstone member of the Kirtland shale [illegible]
to be conformable with the adjacent shale members, and is a concen-
tration of sandstone beds, with interbedded siltstone and shale,
near the middle of the Kirtland shale [illegible]
bottom of the sandstone member [illegible]
nature of the sandstone units [illegible]
Farmington sandstone section [illegible]
change into shale rather than [illegible]

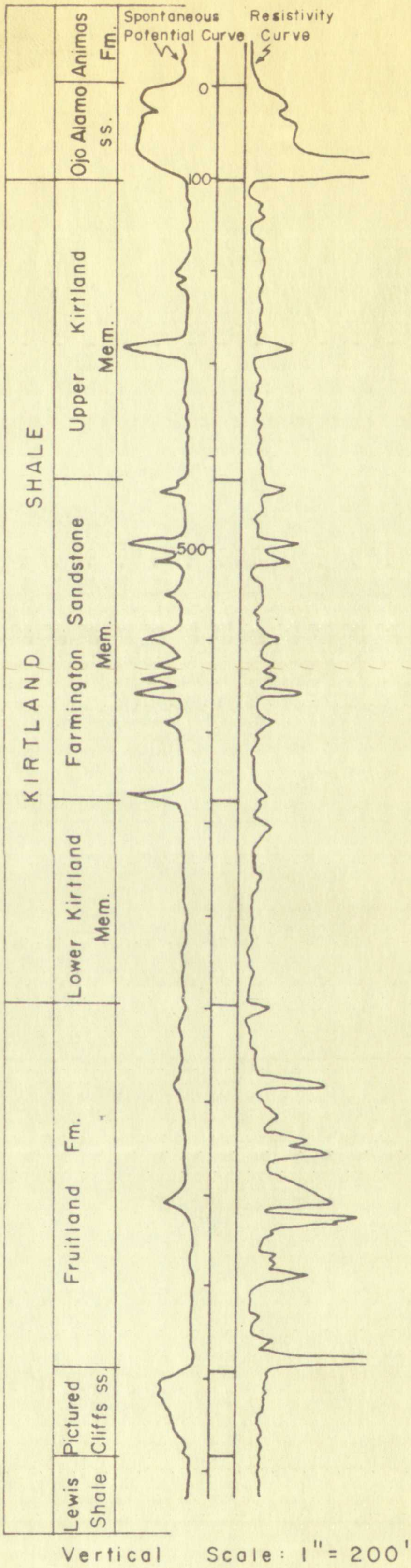


Figure 5 : Typical Electrical Log showing the Animas, Ojo Alamo, Kirtland, Fruitland, Pictured Cliffs and Lewis formations (log after Schlumberger's Typical No. 1 of the San Juan basin).

The Kirtland shale-Fruitland formation contact is conformable but also arbitrary; and for the purpose of this report, the bottom of the Kirtland shale is considered to be the point where carbonaceous strata become apparent on the resistivity curves of the electrical log. There are no coal beds interbedded with lentils of typical Kirtland shale.

The contact of the Kirtland shale-McDermott formation is chosen at that gradational zone where gray shales cease and purple shales are present in the section. The purple shale in most places contains varying amounts of volcanic glass and is thus believed to be volcanic in origin. The purple shale lentils are included in the lower part of the McDermott formation.

Sedimentary Structure

The majority of the sandstone lentils in the Farmington member display cross-bedding to some extent. In many sandstone lentils the cross-beds are too poorly exposed to facilitate measurement or photographing. Pettijohn (1957, p. 167) was used as a guide while studying the cross-laminations. According to Pettijohn:

> Only the scale, the mean direction, and the variability of the cross-bedding appear to be significant. The scale is a function of the current velocity, the orientation of the cross-bedding is a function of the direction of current flow; and the variability is a function of the stability of the current system. * * * In general the dip of the cross-bedding is the local direction of current flow. If such directions of current flow show a regionally consistent pattern, that is, one with a strong preferred orientation, instead of a random scatter, then the implied current movement was probably down the regional slope at the time of deposition of the bed in question. In general, therefore, the current flow is from source to site and hence from older rocks toward younger.

Some cross-laminations were studied and measured in each of the five measured sections; twenty-six such measurements were made. The minimum and maximum dip, strike, and thickness of each unit measured is shown on Table 1. The thickness of the cross-beds are usually six to eighteen inches with a mean thickness of about twelve inches. The horizontal lengths of the cross-beds are usually from 1 1/2 to 2 1/2 feet with a mean length of two feet.

The cross-bedding (Figs. 6 and 7) was found to be the normal tabular type (Shrock, 1948, p. 245). Dunbar and Rodgers (1957, p. 105) are of the opinion that the evenness of tabular type cross-bedding is almost certain proof that it was formed not by torrents but by steady broad currents in rivers, lakes, or seas, especially by currents carrying sediments into shallow standing water. The cross-bedding displays a constant northeastward direction of dip, except on the south where it is eastward (Fig. 8). This suggests a south to southwest source for the sediments of the Farmington sandstone. A more detailed study of the cross-bedding would be required before a more definite conclusion could be reached as to the source areas of the Farmington sandstone.

PALEONTOLOGY

The writer was unable to find any macrofossils in the Farmington sandstone while collecting rock samples from five surface sections. Thirty-five samples from Measured Section No. 3 were sent to Edward R. Woodside, El Paso Natural Gas Company paleontologist, who found and tentatively identified the following microfossils:

[illegible] of the [illegible] with [illegible]

of the [illegible] sand [illegible] the [illegible] grooves [illegible] the sands. The [illegible] are [illegible] each unit [illegible] by [illegible]. The thickness [illegible] beds are usually [illegible] twelve inches. [illegible] the lengths of the [illegible] from 1 1/2 to [illegible] feet [illegible]

The cross-bedding [illegible] tabular type (Krumbein, [illegible], [illegible] and [illegible] (1949, p. 107) are of the opinion that the [illegible] of [illegible] type of cross-bedding is almost certain proof that it was [illegible] by [illegible] broad currents in [illegible], [illegible] by streams carrying sediments into shallow [illegible]. The cross-bedding displays a constant [illegible] where it [illegible] (Fig. [illegible]). This suggests a [illegible] source for the sand [illegible]. A [illegible] study of the cross-bedding would be [illegible] conclusion could be reached as to the [illegible] sandstone.

[illegible]

The writer was unable to [illegible] any [illegible] in the [illegible] sandstone while collecting [illegible] samples [illegible] the [illegible] sequence. Thirty-five samples [illegible] to [illegible] R. Woodside [illegible] geologist, who [illegible] and tentatively identified [illegible]

Table 1

Cross Bed Statistics

Measured Section No.	Unit No.	Thickness of unit	Minimum dip	Maximum dip	Direction of dip
1	2	12"	5°	18°	N85E
	6	30"	7°	18°	N82E
	8	8"	5°	15°	N87E
	10	12"	5°	15°	N80E
	13	8"	4°	10°	N70E
	15	8"	5°	15°	S80E
	17	12"	2°	10°	S85E
2	6	12"	5°	20°	N40E
	10	36"	10°	20°	N55E
	19	12"	5°	25°	N40E
	21	12"	10°	20°	N36E
	23	12"	5°	10°	N25E
	29	36"	5°	15°	N30E
3	20-22	8"	5°	20°	N10E
	28	6"	5°	25°	N 5W
	31	6"	5°	20°	N35E
4	16	15"	2°	13°	N20E
	18	12"	2°	16°	N30E
	30	11"	5°	19°	N37E
	32	12"	5°	25°	N30E
	36	12"	5°	18°	N45E
5	12	18"	5°	15°	N42E
	20	8"	15°	35°	N64E
	30	12"	15°	38°	N60E
	33	12"	2°	15°	N55E
	36-37	30"	15°	35°	S65E

Figure 6: Cross-bedding in Unit No. 8, Measured Section No. 1. View northwestward.

Figure 7: Weathered cross-bedding in Unit No. 13, Measured Section No. 1. View northwestward.

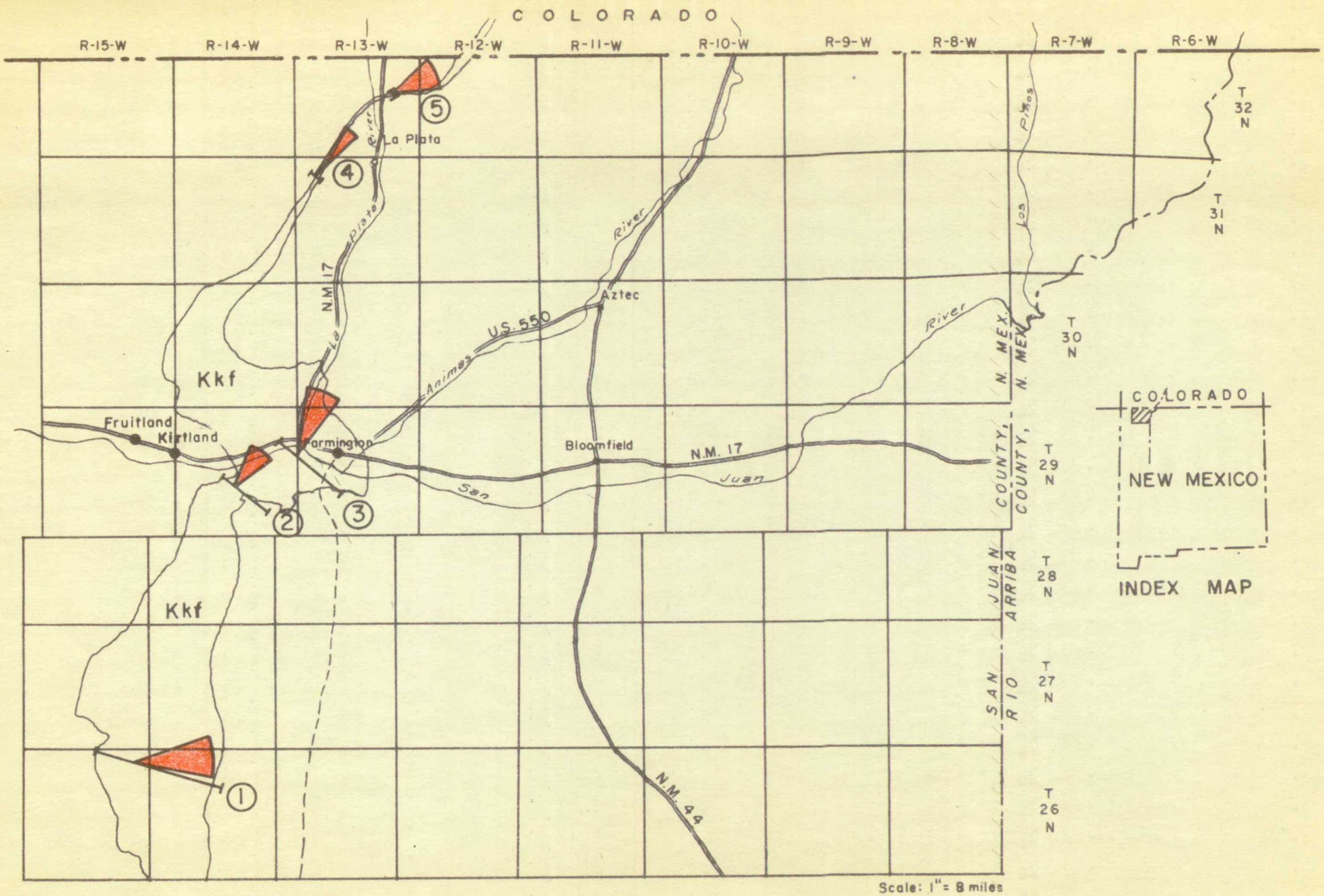


Figure 8: Map showing Farmington sandstone outcrop, locations of measured sections, and the maximum and minimum true bearings of directions of cross-bedding dips.

Outcrop pattern after Reeside, 1924

Bathysiphon sp.
Haplophragmoides sp.
Robulus sp.
Ostracoda (fragments)

These fossils were found in a grayish-buff, micaceous, silty, shale unit somewhat near the center of the Farmington sandstone member. All of these fossils have been replaced by iron compounds and are of too poor quality to photograph. It cannot be said with certainty that these foraminifera do not represent a reworked fauna; however, it will be assumed in this paper that these microfossils were in place.

Roger Y. Anderson (written communication, March 30 1960) examined the above fossils and verified that they are foraminifera. He declined however to identify the genus of the fossils, owing to their poor state of preservation. Both Anderson and Woodside state that these foraminifera represent a shallow marine or marine-brackish assemblage.

Several collections of fossils have been made in the Kirtland shale, and at least six of these collections were from the Farmington sandstone (Bauer, 1916, pl. LXV). The majority of these collections were made in New Mexico and described by Gilmore, Stanton, and Knowlton. According to Reeside (1924 p. 23) all of these fossils indicate a fluviatile origin for the Kirtland shale.

Gilmore (1919, p. 8) made the following vertebrate collection but the list given includes faunas from both the Kirtland shale and McDermott formation:

[illegible]

[illegible]

Paleontology

Foraminifera [illegible]

These fossils were found in a [illegible]

shale and somewhat [illegible] the [illegible]

member. [illegible]

and are of [illegible] preservation. [illegible]

certainly [illegible]

however, it [illegible] the [illegible]

were in place.

Roger R. Anderson [illegible]

examined the [illegible]

He declined [illegible]

poor state of preservation [illegible]

these foraminifera [illegible]

assemblage.

Several [illegible]

shale, and at [illegible]

sandstone (Bauer, 1916, [illegible]). [illegible]

were made [illegible]

Knowlton. [illegible]

indicated [illegible] for the [illegible]

Cobban (1948) [illegible]

but the [illegible]

McBarron [illegible]

Dinosauria

Kritosaurus sp.
Crested trachodonts
Carnivorous dinosaurs
Ceratops ? sp.

Scelidosauridae (Armoured dinosaur)

Chelonia

Baena nodosa Gilmore
Baena sp. undetermined
Neurankylus baueri Gilmore
Adocus bassi Gilmore
Adocus kirtlandius Gilmore
Plastomenus robustus Gilmore
Plastomenus sp. undetermined
Aspideretes sp.

Crocodilia

Crocodylus sp.
Brachychampsa sp.

Pisces

Lepidosteus sp.
Myledaphyus sp.

Stanton (1916, P. 310) made the following invertebrate collection from the Kirtland shale:

Unio pyramidatoides Whitfield ?
Unio baueri Stanton
Unio sp. undetermined
Viviparus sp.

Knowlton (1916, p. 330) described the following plants collected from the extreme top and bottom of the Kirtland shale, but the list includes also species from the McDermott formation:

[illegible]

[illegible] sp.
[illegible]
[illegible]
[illegible]

[illegible]

[illegible]

[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

[illegible]

[illegible] sp.
[illegible]

[illegible]

Leptogenys sp.
[illegible] sp.

[illegible] (1916, [illegible]) [illegible]

from the Kirtland [illegible]

[illegible]
[illegible]
[illegible]
[illegible]

[illegible]

from the [illegible]

cludes also species. [illegible]

Geinitzia formosa Herr
Salix sp.
Ficus praetrinervis ? Knowlton
Ficus leei Knowlton

Knowlton identified the following plant fossils which were collected from the Farmington sandstone member in the SE/4 SE/4 Section 13, Township 35 North, Range 7 West, five miles north of Bayfield, Colorado (Reeside, 1924, p. 23):

Ficus curta Knowlton
Phyllites petiolatus ? Knowlton
Several undescribed leaves

GEOLOGIC HISTORY

To facilitate understanding of the sedimentational history of the Farmington sandstone it is necessary to briefly review the geologic history of a part of Montanan time.

In middle Montanan time Cretaceous marine waters retreated northeastward across the northwestern part of the San Juan basin. The beach sands and off-shore bars of the Pictured Cliffs sandstone were deposited on top of the Lewis shale during this marine retreat. The Pictured Cliffs sandstone appears stratigraphically higher and is younger northeastward.

The sand, shale, and coal of the Fruitland formation and the carbonaceous strata of the lowermost Kirtland shale were deposited in the coastal swamps and on the slightly inclined northeastward-dipping coastal plains left by the retreating Cretaceous marine waters. The character of the sediments and the intertonguing relationship led Baltz (1953) to suggest a southwestern source for the Pictured Cliffs sandstone, Fruitland formation, and possibly part of the Kirtland shale.

[illegible]
[illegible]
[illegible]
[illegible]

[illegible] collected from the [illegible] Section 13, Township 35 North, Range 7 West, five miles [illegible] Bayfield, Colorado [illegible]:

[illegible]
[illegible]
Several [illegible]

[illegible]

To [illegible] of the [illegible] the Farmington [illegible] necessary to briefly [illegible] history of [illegible].

In [illegible] northeastward [illegible]. The beach [illegible] were deposited [illegible]. The Pictured Cliffs [illegible] is younger northeastward.

The sand, shale, and coal [illegible] carbonaceous [illegible] in the coastal [illegible] dipping coastal [illegible]. The character of the [illegible] Bates (1933) to [illegible] sandstone, Kirtland [illegible].

Silver (1950a, p. 112, and 119 to 121) believes that a late Cretaceous basin of deposition was formed after the retreat of marine waters from the area. This basin was termed "Kirtland basin", by Silver, after the sediments which best define it. The " Kirtland basin" lay to the west of the present area of Tertiary outcrop in northwest New Mexico. Its possible axis crossed the Colorado - New Mexico line in Range 14 West. Silver based his assumption for the presence of the "Kirtland basin" on a lithofacies and isopach map of the total interval of the Fruitland formation and Kirtland shale.

Silver suggests that the Kirtland shale is largely fluviatile in origin and was derived from the same southwestern source area as older marine Cretaceous strata. While lower Kirtland sediments were being deposited, early orogenic movements of the Laramide Revolution caused the western half of the present basin to be relatively depressed in relation to the eastern half. A thick wedge of sand, the Farmington sandstone member, was deposited in the newly formed continental basin of deposition.

Foraminifera found in the Farmington sandstone member during this study, suggest that part or all of the Farmington sandstone is marine or marine-brackish, probably lagoonal, in origin. It is postulated that the continued subsidence of the "Kirtland basin" caused a temporary reversal in the withdrawal of the Lewis sea from the Cuba area. This created marine-lagoonal conditions in the "Kirtland basin" (Roger Y. Anderson, written communication, March 30, 1960).

[illegible]

[illegible]

[illegible]

After the deposition of the Farmington sandstone, the Lewis sea retreated and the continental upper Kirtland sediments were deposited. The eastern part of the "Kirtland basin" remained relatively close to the base level of deposition inasmuch as little or no sediment was deposited there. The source which supplied sediments for the Farmington sandstone was apparently worn down enough by upper Kirtland time to contribute mostly fine-grained sediments. As the final sediments of the upper Kirtland were being deposited, volcanism occurred to the north and contributed siliceous pebbles and andesitic debris of the McDermott formation. Following McDermott deposition, the coarse sediments of the Ojo Alamo sandstone were deposited. Mountains began to rise to the northwest and the western part of the "Kirtland basin" began to receive coarse-grained sand and volcanic material, which masked further contribution of sediments from the southwest (Silver, 1950a, p. 121).

LITHOLOGIC COMPONENTS

Measured Sections

Five sections were measured and sampled and are described in the Appendix. A stratigraphic cross section of these sections and the type section is shown on Plate III. At least one sample was collected for each change in lithology. In some cases, where a bed was thicker than usual or where there was a suspected change of lithology within the bed, more than one sample was collected. Over 3,600 feet of section was measured and 211 samples collected. This is an average of one sample for each 17 feet of section. The samples were carefully studied and described with the aid of the binocular microscope.

Where practicable, the measured sections include samples from the upper part of the Upper Cretaceous Fruitland formation through the lower part of the Upper Cretaceous Ojo Alamo sandstone.

Although the samples are described in detail in the Appendix, in order to hold repetition to a minimum, the following general statements are presented as being applicable to all sections:

(1) the sandstones are feldspathic graywacke,

(2) most of the sand grains appear to be sub-angular to sub-rounded under the binocular microscope,

(3) in most cases the sandstone beds contain variable amounts of feldspar,

(4) interstratal inclusions of clay "galls" or "blebs" are present in each section. They are usually tan, soft, 1/4 to 1/2 inch in length, and often appear in roughly horizontal planes (Fig. 9),

Figure 9: Clay galls in Unit No. 15 of Measured Section No. 1. View northwestward.

(5) purple to purplish-brown concretions were noted in most sections. These are spheroidal, oblate, or flattened in shape and are from two inches to four feet in diameter (Fig. 10). The concretions appear to have been formed after the sediments were deposited, since there is no evidence of bending or draping of the strata immediately around them. Only in rare cases is concentric banding noted within the concretions when they are broken open. One concretion was noted in Measured Section No. 1, which has a piece of petrified wood as a nucleus (Fig. 11). The typical concretion has the same rock description as its host rock except for its outer purple to purplish-brown rim and its high percent of calcareous cement. The concretions may usually be described as follows: sandstone, purple to purplish-brown rim up to one inch in thickness; tan or light-gray inside; well-consolidated; very fine-to fine-grained; sub-angular to sub-rounded; well-sorted; tight; and having highly calcareous, slightly argillaceous cement. The concretions are more resistant to weathering than the beds which enclose them. None of the concretions appear to be of volcanic origin,

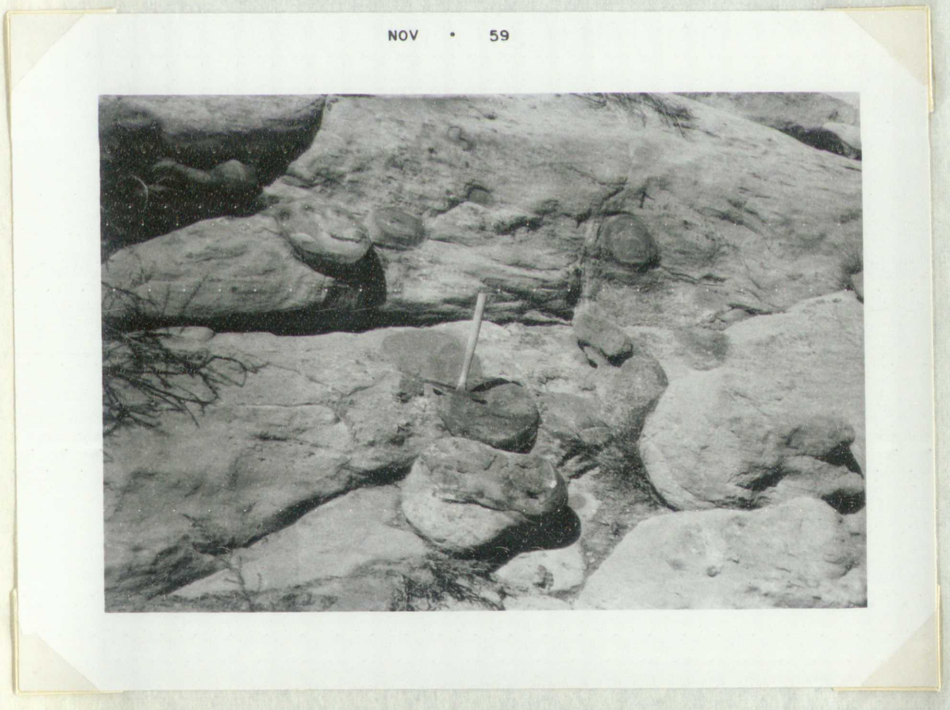


Figure 10: Purple to purplish-brown concretions in Unit No. 36 of Measured Section No. 4. View northwestward.

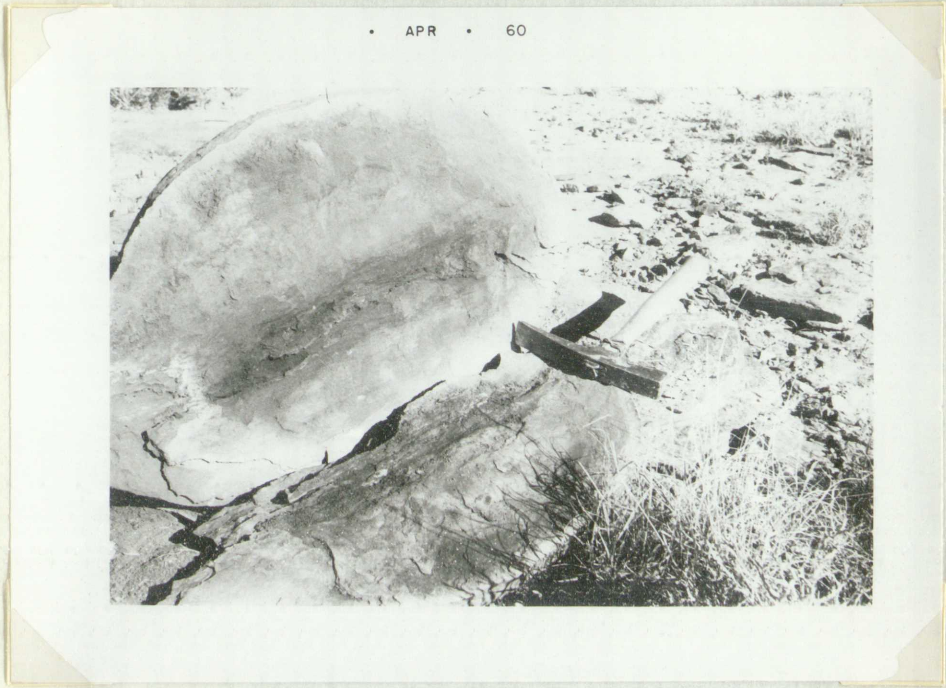


Figure 11: Large purplish-brown concretion, with piece of petrified wood as a nucleus, from top of Unit No. 15, Measured Section No. 1. View northwestward.

(6) the pea-size concretions or pisolites, found in Measured Section No. 1, are usually somewhat darker in color and more calcareous than their host rock, and composed of essentially the same sediments. They are more resistant to weathering than their host rock (Fig. 12).

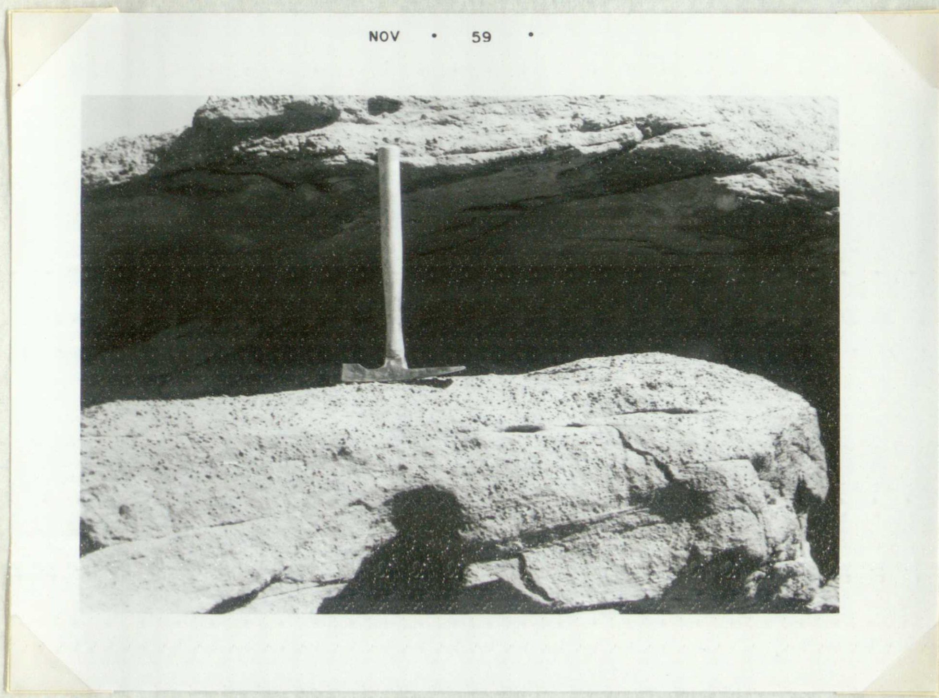


Figure 12: Pea-sized concretions or pisolites in Unit No. 8, Measured Section No. 1. View northwestward.

Cores and Samples

There are very few well samples and cores available from wells drilled through the Farmington sandstone; however, the writer had access to cores and/or samples through the Farmington section on the following El Paso Natural Gas Company wells:

Huerfano No. 92	Section 6, T 26N, R 9W	Samples only
Phillips No. 2	Section 32, T 28N, R 8W	Sidewall cores only
Woolley No. 1	Section 8, T 29N, R 11W	Conventional cores and samples only

These samples and cores were described with the aid of a binocular microscope. Information was also available concerning oil, gas, and/or water "bleeding" as the core was pulled at the well site (Jack A. Cole, written communication, 1959). The cores are described in detail in the Appendix. Samples and/or core descriptions for the Huerfano No. 92 and the Woolley No. 1 wells have been plotted on the depth tracts of the appropriate cross section. The sidewall-core descriptions for the Phillip's No. 2 well have not been plotted on a depth tract since this well does not fall in any line of cross section.

Petrographic Analyses

W. J. Barrett accomplished the thin-section, heavy-mineral, and grain-size analyses especially for this paper. The writer has assembled Barrett's information and added ideas and conclusions of his own.

The petrographic study reveals that the sediments of the Farmington sandstone were derived predominantly from a plutonic source. The heavy-mineral suite indicates a silicic (granite to granodiorite) to intermediate (diorite to monzonite) igneous source whereas the abundance of plagioclase, predominantly andesine, suggests an intermediate igneous source. It has been suggested (Wolfgang E. Elston, written communication, March, 1960) that the source area(s) for the Farmington sandstone could, for instance, be a mixed volcanic and metamorphic terrane rather than an igneous plutonic one, inasmuch as most of the heavy-minerals found in this member have a wide distribution.

Thin sections were cut from eleven sandstone units in Measured Section No. 3. This section was chosen inasmuch as it is the upper part of Bauer's (1916) type section for the Farmington sandstone. Unit numbers referred to on the following pages may be identified under "Measured Section No. 3" in the Appendix.

Heavy-mineral analyses were made on Unit No. 22 and a composite was run on the sandstone beds in the first 32 units of Measured Section No. 3. Grain-size analyses were run on Units No. 4, 13, and 22.

The petrographic study was based on the following basic concepts of sedimentation:

(1) mineral suites are indicative of the type of source rock or rocks of a sediment,

(2) angular grains, poor sorting, and abundance of argillaceous cement and matrix are indicative of rapid deposition and proximity to the source area,

(3) maturity of a sandstone is expressed by its ratio of quartz to feldspar; the more feldspar present the more immature the sandstone (Pettijohn, 1957, p. 287),

(4) presence or absence of a detrital clay-sized matrix in a sandstone is an index of the effectiveness of the sorting ability of the transporting medium and therefore to the sediment-fluid ratio of that medium (Pettijohn, 1957, p. 288).

Thin Sections

Most of the detrital grains are angular and poorly sorted, and there is an abundance of argillaceous cement and matrix. The percentage of the feldspar in the sandstones is much higher than the

This section [illegible] eleven [illegible] units in [illegible] Section No. [illegible]. This section was [illegible] part of [illegible]'s (1934) type section [illegible] numbers [illegible] the following pages may be [illegible] "Measured Section No. [illegible]"

[illegible] analyses were [illegible] Unit No. [illegible] was run on the [illegible] No. 3. [illegible]

The petrographic study was [illegible] cepts of sedimentation:

(1) [illegible] of a sediment.

(2) [illegible] of [illegible] rocks.

(3) [illegible] p. [illegible]

(4) [illegible]

[illegible]

[illegible] there is [illegible]

[illegible]

percentage of quartz (Table 2). A small percentage of heavy-minerals is present in each sample. The mineralogy of the Farmington sandstone, based on thin-section analyses, is given in Table 2. Six photomicrographs of thin-sections follow:

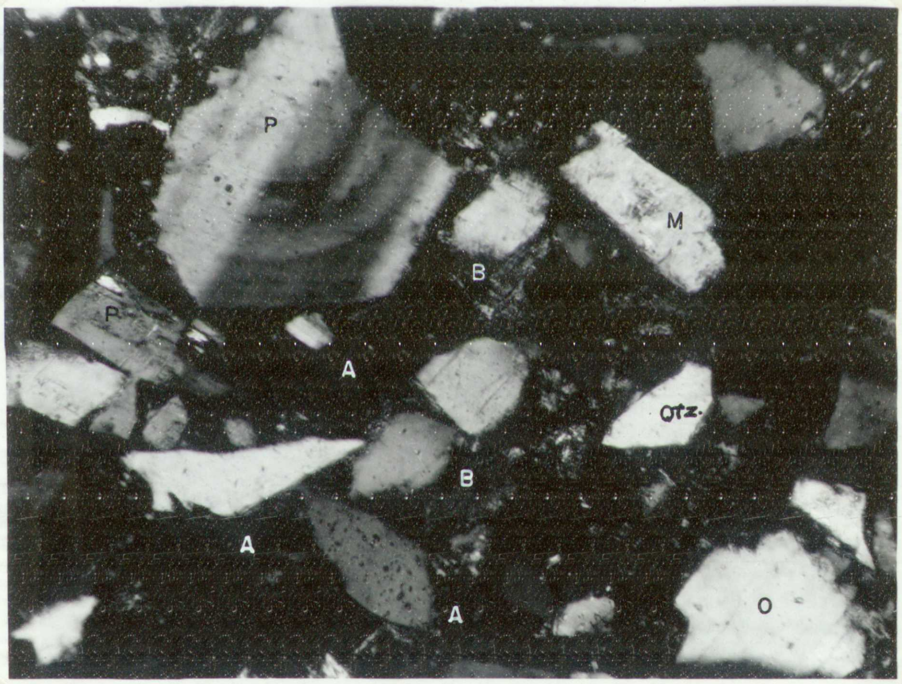


Figure 13: Thin section of Unit No. 1, Measured Section No. 3. A-Siliceous - argillaceous cement, B-Biotite, M-Microcline, O-Orthoclase, and P-Plagioclase. Note poor sorting and angularity of some grains. Grain size ranges from silt to 0.30 mm. Crossed nicols, approximately 144 X.

Table 2

Mineralogy of the Farmington Sandstone
in Measured Section No. 3

	Mineral Name	Unit No. 1	5	8	13	14	16	18	20	22	28	31
		%	%	%	%	%	%	%	%	%	%	%
	Quartz	25	30	10	15	15	30	25	25	25	15	20
	Chert	T	T	T	T	T	5	5	5	5	5	5
	Orthoclase	5	10	5	10	5	10	10	10	10	5	5
	Microcline	5	5	5	5	5	5	5	5	5	T	T
	Plagioclase	30	30	35	40	30	20	25	25	25	33	37
	Rock Fragments	0	0	0	0	0	0	0	5	T	0	T
	Muscovite	T	T	0	T	0	T	T	0	0	T	T
	Chlorite	10	5	0	10	0	0	5	0	0	0	0
	Biotite	5	5	10	5	15	15	5	5	5	15	15
Cement	Argillaceous	20	15	30	10	30	15	20	20	25	23	15
	Barite	0	0	0	5	0	0	0	0	0	0	0
	Silica	0	0	5	0	0	0	0	0	0	0	0
Heavy Minerals	Zircon	T	0	T	T	0	T	T	0	0	T	0
	Tourmaline	T	0	0	0	0	0	0	0	0	0	0
	Garnet	0	T	0	0	0	0	0	0	0	0	0
	Apatite	0	0	0	0	0	0	T	0	0	0	0
	Sphene	0	0	0	0	0	0	T	0	0	T	T
	Monazite	0	0	0	0	0	0	0	0	0	T	0
Opaques	Limonite	T	T	0	T	0	0	0	0	T	4	3
	Hematite	T	0	0	0	0	0	0	0	0	T	0
	Magnetite	0	0	0	T	0	0	0	0	0	T	0

Figure 14: Thin section of Unit No. 5, Measured Section No. 3. A-Siliceous - argillaceous - chloritic cement and matrix, B-Biotite, C-Chlorite, O-Orthoclase, and P-Plagioclase, some zoned. Note poor sorting. Grain size ranges from silt to 0.24 mm. Crossed nicols, approximately 144 X.

Figure 18: Thin section of [illegible]

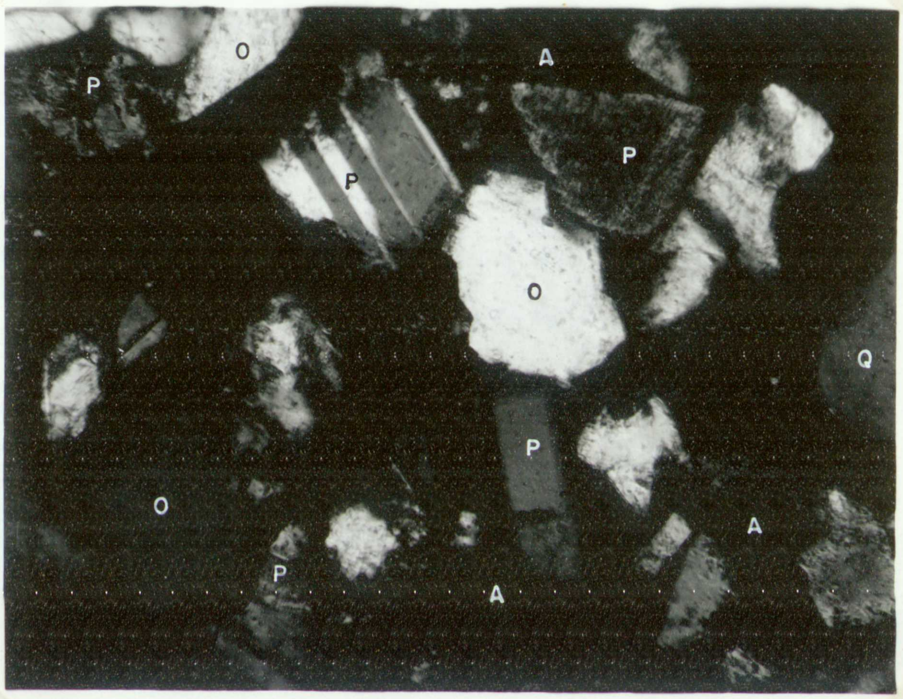


Figure 15: Thin section of Unit No. 13, Measured Section No. 3. A-Siliceous - argillaceous cement and matrix, O-Orthoclase, P-Plagioclase, and Q-Quartz. Note poor sorting and angularity of detrital grains. Grain size ranges from silt to 0.30 mm. Crossed nicols, approximately 144 X.

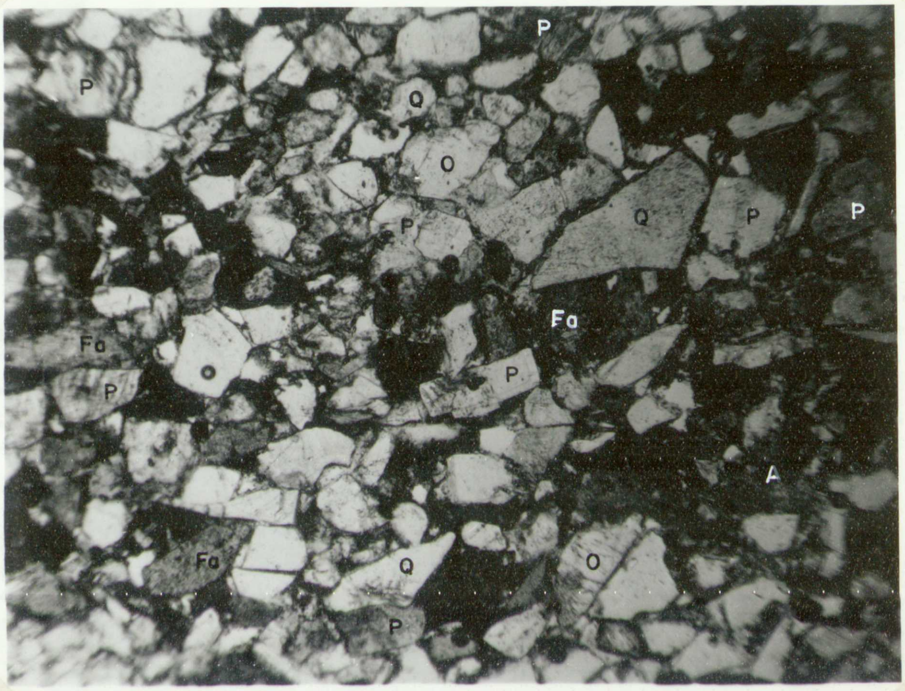


Figure 16: Thin section of Unit No. 18, Measured Section No. 3. A-Siliceous - argillaceous cement and matrix, Fa-Feldspar, highly altered, O-Orthoclase, P-Plagioclase, and Q-Quartz. Note sharp angularity of grains and poor sorting. Grain size ranges from silt to 0.32 mm. Plain light, approximately 40 X.

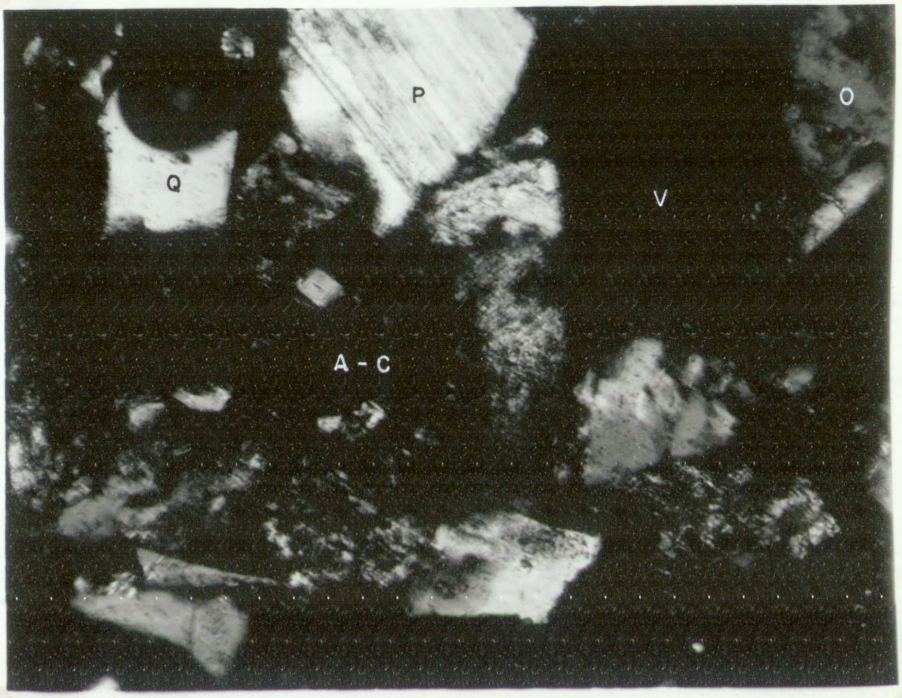


Figure 17: Thin section of Unit No. 22, Measured Section No. 3. A-C-Chloritic - argillaceous cement and matrix, O-Orthoclase, P-Plagioclase, Q-Quartz, and V-Void or pore space. Note poor sorting and pore space. Grain size ranges from 0.40 to 0.50 mm. Crossed nicols, approximately 144 X.

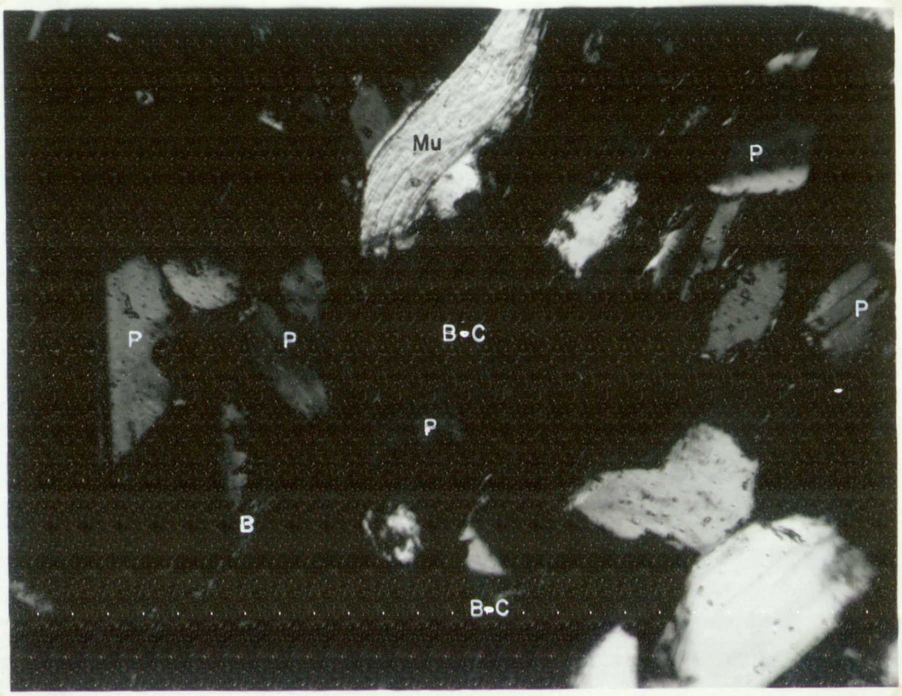


Figure 18: Thin section of Unit No. 31, Measured Section No. 3. B-Biotite, B-C-Chloritic, biotitic-argillaceous cement and matrix, Mu-Muscovite, and P-Plagioclase. Note poor sorting. Grain size grades from silt to 0.24 mm. Crossed nicols, approximately 144 X.

Heavy Minerals

Heavy minerals, in order of abundance, with descriptions and possible source rocks are described below:

Biotite:	green, brown, and golden; highly altered to chlorite in some grains; possible source rocks are granite and gneiss.
Sphene:	fresh and clear; euhedral grains abundant; when abundant, sphene may be authigenic; however, this sphene is believed to be detrital inasmuch as some grains are irregular in shape, and show slight rounding; possible source rocks are granite, intermediate igneous rocks, and metamorphic rocks such as gneiss, schist, and altered limestone.
Apatite:	fresh and clear; euhedral to subhedral grains abundant; suggested source rocks are granite and syenite.
Zircon:	fresh and angular; euhedral grains common; occurs in pink, clear, and golden color tinges; possible source rocks are acidic and intermediate igneous rocks.
Monazite:	angular and fresh appearing; subhedral to anhedral grains common; possible source rocks are acidic igneous rocks, especially granite.
Garnet:	angular and pink to clear; detrital garnet common; suggested source rocks are igneous and metamorphic rocks.
Tourmaline:	euhedral with a trace of subrounding; prismatic appearing tourmaline rare to common; possible source rocks are acidic igneous rocks, pegmatites, schists, gneisses, and phyllites.
Leucoxene:	trace to common; alters from ilmenite; a secondary mineral.
Ilmenite:	trace to common; suggested source rocks are granite, syenite, diabase, and some metamorphic rocks.
Magnetite:	primary type; abundant locally; magnetite is a primary constituent of mafic igneous rocks and is also present in certain metamorphic rocks.

Photomicrographs:

Following are two photomicrographs of heavy minerals in the Farmington sandstone:

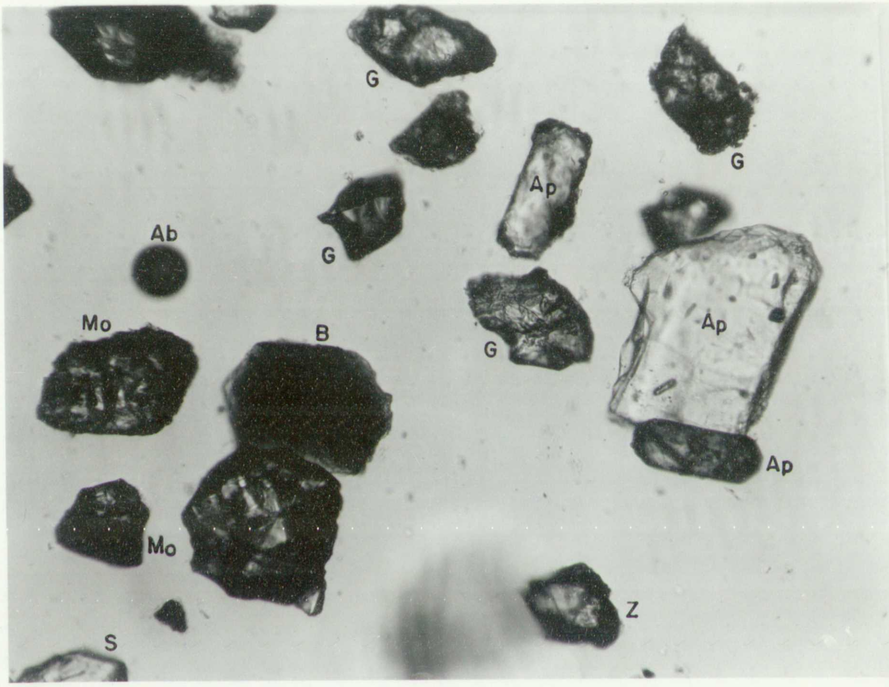


Figure 19: Heavy minerals of Unit No. 22, Measured Section No. 3. Ab-Air bubble, Ap-Apatite, B-Biotite, G-Garnet, Mo-Monazite, S-Sphene, and Z-Zircon. Note angularity of prismatic apatite, and euhedral biotite grains. Magnification approximately 144 X.

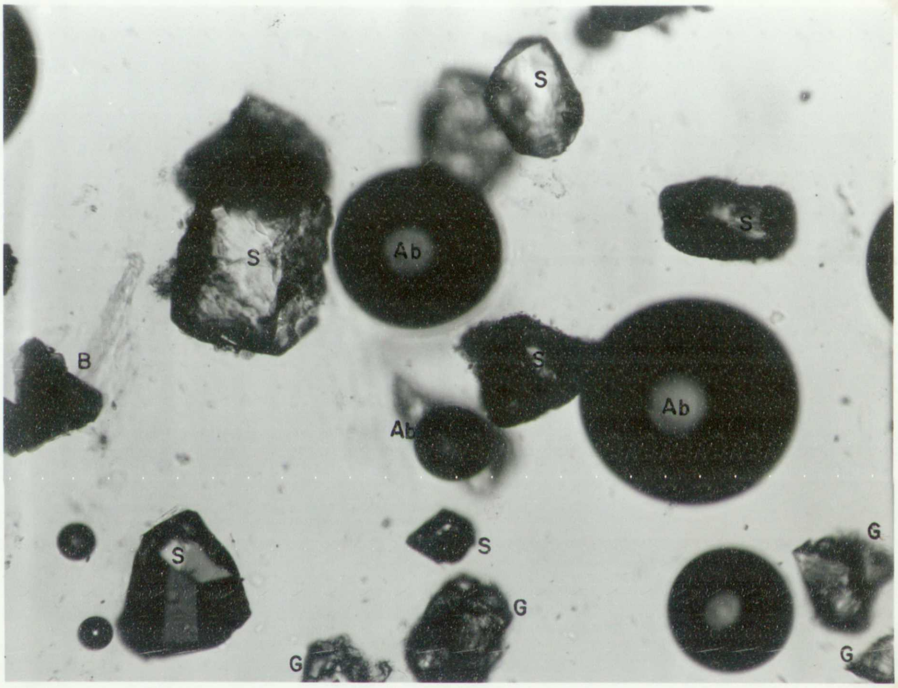


Figure 20: Heavy minerals of composite of sandstone beds in first 32 units of Measured Section No. 3. Ab-Air bubble, B-Biotite, G-Garnet, and S-Sphene. Magnification approximately 144 X.

Grain-Size Analyses

Grain size was checked in three samples, Units 4, 13 and 22 of Measured Section No. 3, by use of Tyler sieves. Samples from these three sandstone units were chosen for grain-size analyses inasmuch as they appear to represent typical sandstone lentils in the Farmington sandstone type section. The Wentworth scale was used for grain sizes, and sorting, skewness, and median grain sizes were calculated for each sample. Table 3 shows the results of size analyses which are graphically shown in Figures 21, 22, and 23. Accumulative curves and histograms were constructed for each sample.

The median grain size (M), sorting value (So), and skewness (Sk) values for each of the units are listed below:

	Unit No. 4	Unit No. 13	Unit No. 22
M	0.125 mm	0.0244 mm	0.035 mm
So	1.73	1.73	1.46
Sk	1.50	0.75	0.84

Units 4 and 13 show poor-sorting while Unit 22 shows fair-sorting. Unit 4 is skewed toward the coarse admixture while Units 13 and 22 are skewed toward the fine-grain sizes. The distribution of the size grades may be noted on the histograms (Figs. 21, 22, and 23).

FLUIDS

There are three Farmington sandstone oil pools and four Farmington sandstone gas fields, three of which are undesignated

Table 3

Results of Size Analyses Graphically Shown in Figures 21, 22, and 23

Measured Section No. 3 Unit No. 4

Mesh.	mm	Weight in Grams.	Percentage	Accumulative Percentage
60	0.246	19.9	15.0	15.0
100	0.147	47.6	35.8	50.8
150	0.104	20.6	15.5	66.3
200	0.074	17.4	13.1	79.4
250	0.061	7.6	5.7	85.1
325	0.046	5.5	4.1	89.2
cup	Less than 0.046	14.5	10.9	100.1

Total 133.1 grams.

Measured Section No. 3 Unit No. 13

Mesh.	mm	Weight in Grams.	Percentage	Accumulative Percentage
60	0.246	28.6	19.9	19.9
100	0.147	56.0	38.9	58.8
150	0.104	13.9	9.7	68.5
200	0.074	14.8	10.3	78.8
250	0.061	7.0	4.9	83.8
325	0.046	4.4	3.1	86.8
cup	Less than 0.046	19.3	13.4	100.6

Total 144.0 grams.

Measured Section No. 3 Unit No. 22

Mesh.	mm	Weight in Grams.	Percentage	Accumulative Percentage
0.5 mm	0.5	0.1	0.1	0.1
60	0.246	32.3	19.5	19.6
100	0.147	86.8	52.4	72.0
150	0.104	20.4	12.3	84.3
200	0.074	9.3	5.6	89.9
250	0.061	3.9	2.4	92.3
325	0.046	2.5	1.5	93.8
cup	Less than 0.046	10.5	6.3	100.1

Total 165.8 grams.

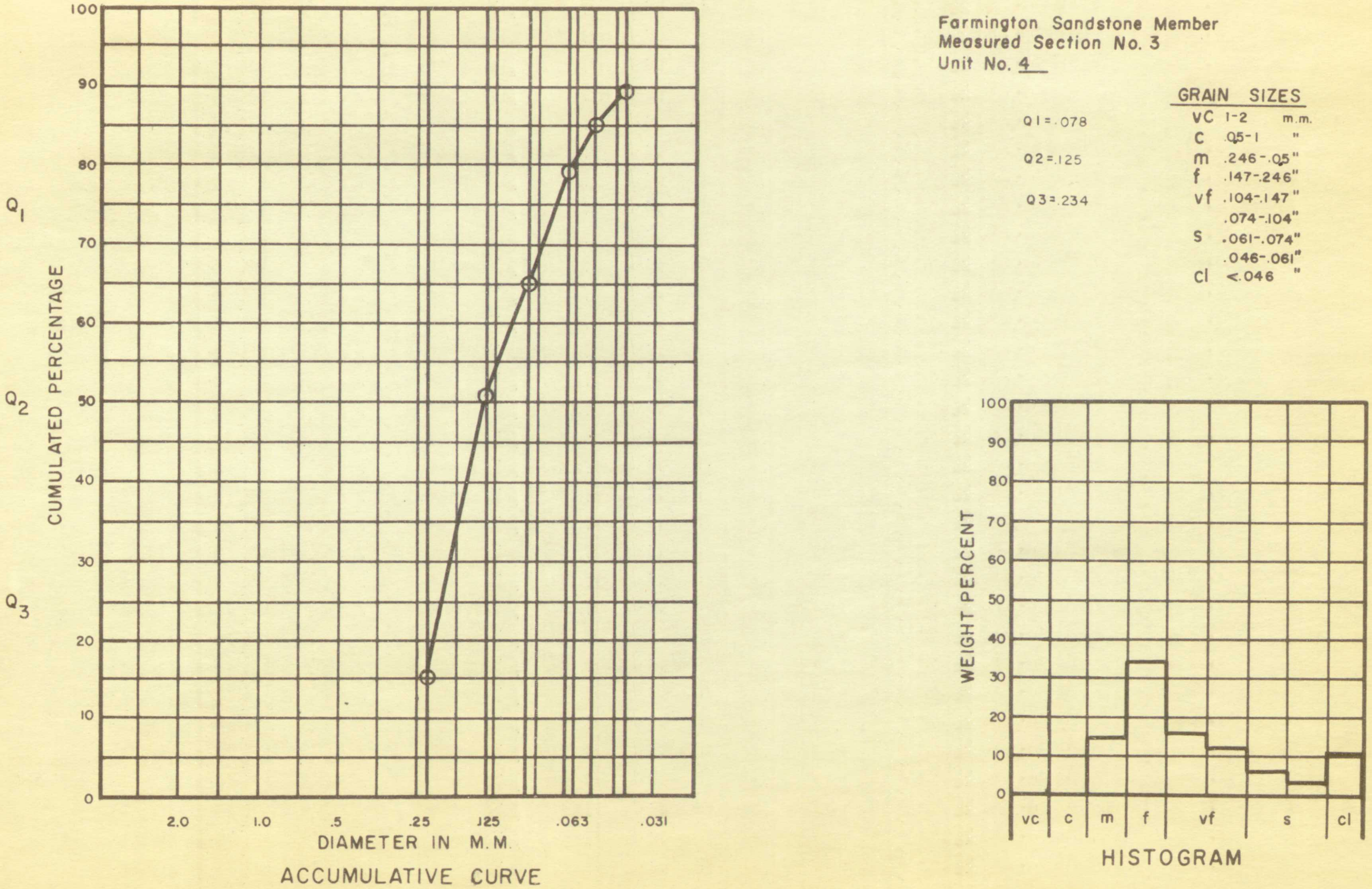


Figure 21: Accumulative curve and histogram for Unit No. 4, Measured Section No. 3.

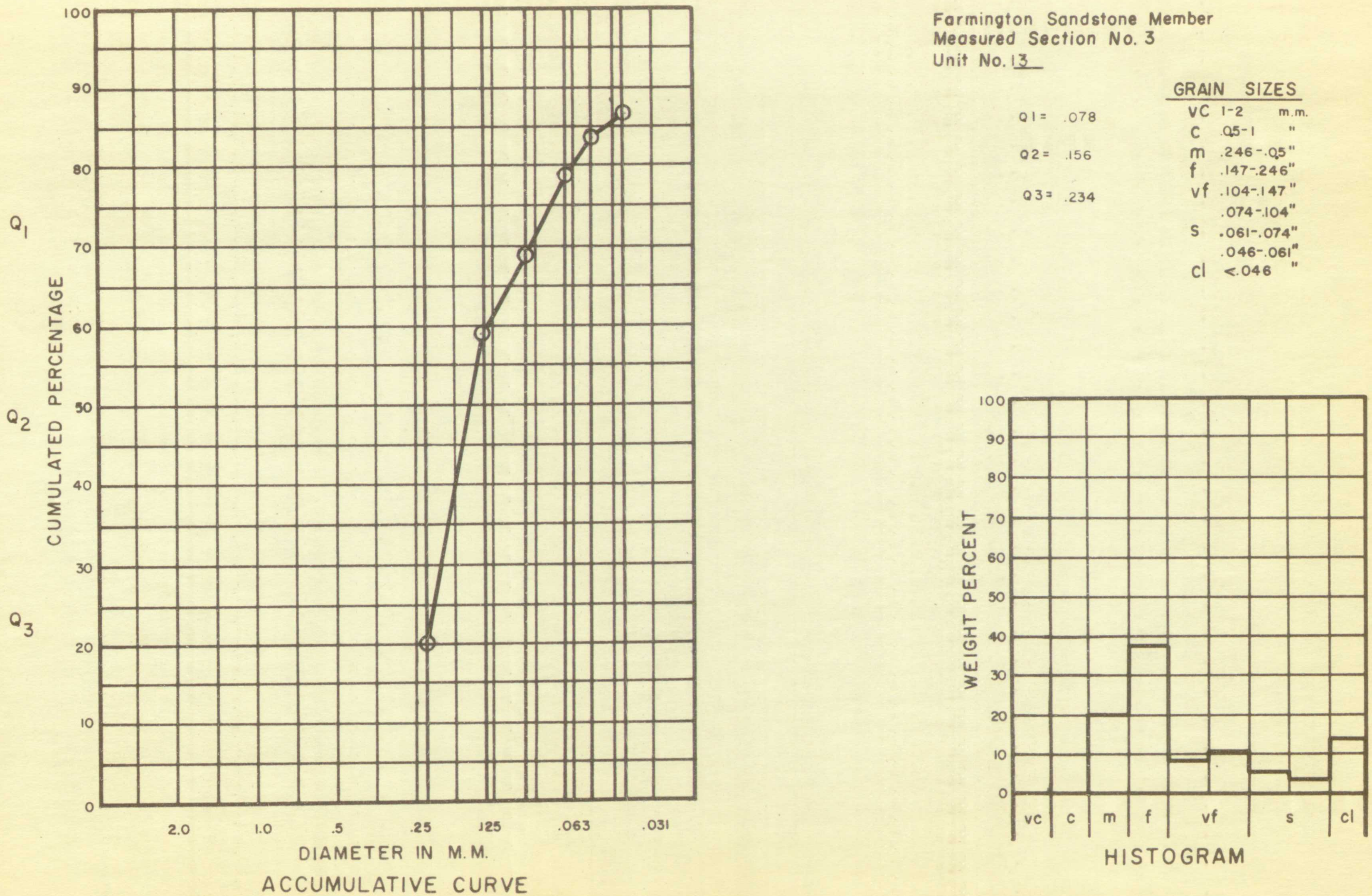
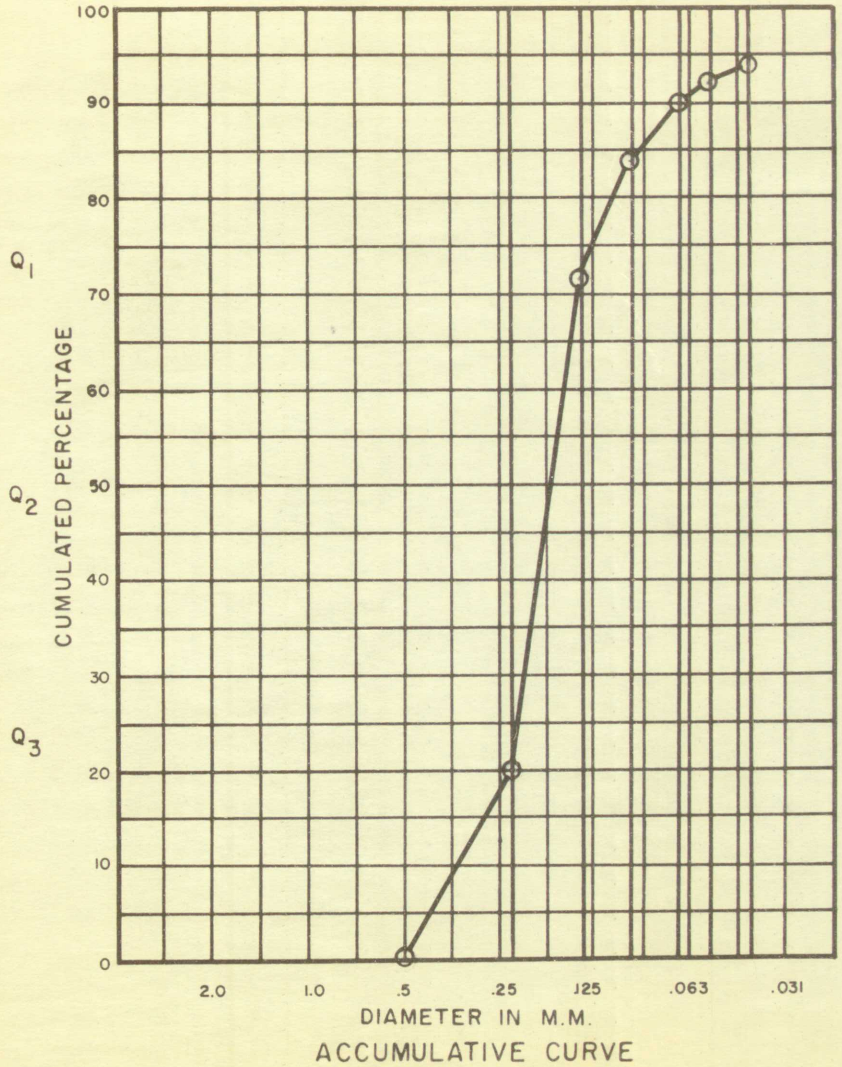


Figure 22: Accumulative curve and histogram for Unit No. 13, Measured Section No. 3.



Farmington Sandstone Member
Measured Section No. 3
Unit No. 22

Q1 = .117

Q2 = .188

Q3 = 0.25

GRAIN SIZES

VC 1-2 m.m.
C .05-1 "
m .246-.05"
f .147-.246"
vf .104-.147"
.074-.104"
S .061-.074"
.046-.061"
cl <.046 "

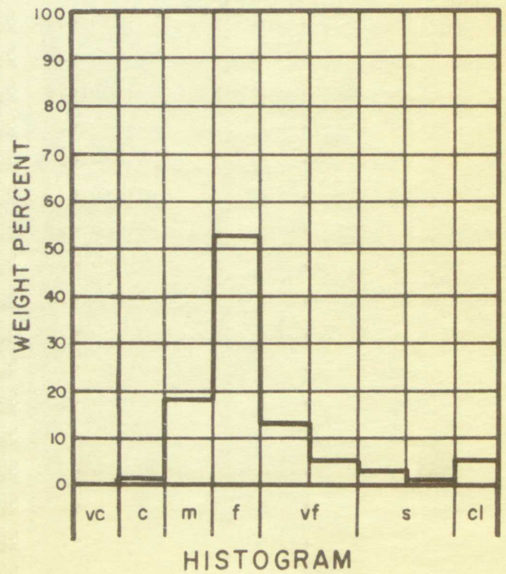


Figure 23: Accumulative curve and histogram for Unit No. 22, Measured Section No. 3.

(Table 4). Fields and pools in which exact locations are known are outlined on PlateI. Pertinent information (Emery C. Arnold, written communication, December 8, 1959) concerning these fields and pools is listed in Table 4. Arnold emphasizes that the accumulative production figures in Table 4 are probably inaccurate inasmuch as considerable production took place prior to the time that the New Mexico Oil Conservation Commission was established. Much of the early production was not reported.

Available information (Bates, 1942; New Mexico Oil and Gas Engineering Committee, 1957; and written communication, George H. Peacock, El Paso Natural Gas Company, San Juan Division Laboratory, August 21, 1959) reveal the following pertinent information concerning fluids in the Farmington sandstone:

(1) oils range from 50°-59° A. P. I. gravity,

(2) waters are brackish to saline,

(3) gases are flammable and consist of 63 to 70 percent methane and 20 to 28 percent ethane.

DISCUSSION OF MAJOR ILLUSTRATIONS

Stratigraphic Cross Sections

Four stratigraphic cross-sections were constructed. Where possible, measured sections and lithologies from samples and core descriptions through the Kirtland shale section were included in these cross-sections. An attempt was made to cover as much of the area of this report as possible by constructing south-north, southwest-northeast, west-east, and northwest-southeast cross-sections. One or

(Table 4). [illegible] and [illegible] in which [illegible] [illegible] [illegible] [illegible] outlined [illegible] [illegible] Petroleum Information, [illegible], Colorado, written communication, December [illegible] [illegible] [illegible] [illegible] is listed in Table 4. [illegible] [illegible] the [illegible] production figures in Table 4 are [illegible] [illegible] [illegible] considerable production [illegible] [illegible] to [illegible] [illegible] the New Mexico Oil Conservation Commission was established. Much of the early production was not reported.

Available [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] Engineering Committee, [illegible] and written communication, [illegible] [illegible] J. Pascoe, El Paso Natural Gas Company, San Juan Division Laboratory, August [illegible] [illegible] [illegible] [illegible] [illegible] concerning [illegible] in the [illegible] [illegible]

(1) [illegible] [illegible]

(2) [illegible] [illegible] [illegible] [illegible]

(3) [illegible] [illegible] [illegible] [illegible] [illegible] percent [illegible] [illegible] [illegible] percent [illegible].

[illegible] OF [illegible] [illegible]

[illegible] [illegible] [illegible] [illegible]

Four [illegible] [illegible] [illegible] [illegible] constructed. [illegible] possible, [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] descriptions through the [illegible] [illegible] [illegible] [illegible] [illegible] these [illegible] sections. [illegible] [illegible] [illegible] [illegible] [illegible] area of this report [illegible] [illegible] [illegible] [illegible] [illegible] northern [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

Table 4

Oil and Gas Production
Farmington Sandstone - Northwest New Mexico*
(Cumulative to November 30, 1959)

Oil Production

Pool	Location	No. wells producing as of November 30, 1959	Production (bbls)
Bloomfield	T 29N, R 11W	3	37,146
Oswell	T 29 & 30N, R 11W	2	38,589
Wyper	T 30N, R 12W	0	6,852
TOTAL		5	82,587

Gas Production

Field	Location	No. of wells producing as of November 30, 1959	Production (MCF)
Kutz	T 28N, R 11W	3	150,533
Undesignated	T 28N, R 10W	1	188,352 (combined)
Undesignated	T 29N, R 10W	1	
Undesignated	T 29N, R 11W	1	
TOTAL		6	338,885

*Courtesy of Emery C. Arnold, New Mexico Oil Conservation Commission.

more wells were selected in each township in the lines of cross-section. Cross-sections intersect as one or more common wells and in most cases the cross-sections intersect recognized Farmington sandstone oil pools or gas fields.

Electrical logs showing the spontaneous potential and resistivity (short normal) curves were the only curves used in the construction of these lines of section.

The datum surface for the cross-sections is the bottom of the Ojo Alamo sandstone and/or the Animas formation. An attempt has been made to differentiate between the bottom of the Ojo Alamo sandstone and the Animas formation on the cross-sections.

Differentiation between the upper Kirtland shale member and the McDermott formation was possible on the outcrops. All purple shales, sandstones, and conglomeratic sandstones are considered to be in the McDermott formation. There does not appear to be any good method of differentiating between the McDermott formation and the upper Kirtland member on electrical logs; therefore, the McDermott formation is included in the upper Kirtland shale member in this paper.

Correlation becomes difficult in area northward from Township 31 North where the Ojo Alamo sandstone is replaced by the Animas formation. An attempt has been made to correlate from logs where the Ojo Alamo sandstone is easily identified to logs where the Animas formation appears, and thereby obtain a fairly accurate thickness for the upper Kirtland shale and consequently the entire Kirtland shale.

more wells were selected [illegible] in the four cross-sections. Cross-sections [illegible] interest, as [illegible] wells [illegible] the cross-sections [illegible] oil pools or gas fields.

Electrical [illegible] (short normal) curves [illegible] these lines of section.

The author [illegible] Ojo Alamo [illegible] been made to [illegible] and [illegible] section.

Differentiation [illegible] the McDermott formation [illegible] shales, [illegible] upon the [illegible]. [illegible] method of differentiation between the McDermott formation and the upper Kirtland [illegible] formation [illegible] paper.

Correlation [illegible] 32 North [illegible] formation. [illegible] the Ojo Alamo [illegible] formation [illegible] upper Kirtland [illegible]

Dashed lines are used to correlate the tops of the Farmington sandstone member, the lower Kirtland shale member, and the Fruitland formation inasmuch as these tops are gradational and arbitrary. An attempt has been made in this paper to adhere as closely as possible to the original sub-division of the Kirtland shale as set up by Bauer (1916) and later expounded upon by Reedside (1924, p. 21 to 24 and 62-63). In this report the bottom of the Kirtland shale is selected at the point where the strata becomes carbonaceous enough to cause an appreciable "kick" on the resistivity curves of the electrical log. There are no coal beds in the Kirtland shale. The Farmington sandstone member appears on the cross-sections as a sequence of sandstone lentils somewhat near the center of the Kirtland shale, similar to their disposition on the outcrop. The Farmington sandstone ranges in thickness from 27 to 818 feet in the area of this report. Both the upper and lower Kirtland shale members contain some sandstone lenses; however, these lenses are usually less resistant on the outcrop than those in the Farmington sandstone member.

Cross Section A-A' (South-North)

Eleven wells were used in this electrical log cross-section (Pl. IV). No measured sections were included in this cross-section inasmuch as the Farmington sandstone does not crop out in the line of section. This cross-section shows the general thinning of the Kirtland shale and its members from north to south. It further demonstrates that the Kirtland shale and its members are the thickest in Township 31 North, Range 11 West, which lies near the axis of the San Juan basin.

Dashed lines are used to correlate the top of the Farmington sandstone member, the lower Kirtland shale member, and the Kirtland formation (sandstones in the upper) are questionable and arbitrary. An attempt has been made in this paper to adhere as closely as possible to the original sub-division of the Kirtland shale as set up by Bauer (1916) and later expounded upon by Reeside (1924, p. 21 to 25 and 62-65). In this report the bottom of the Kirtland shale is selected at the point where the strata becomes carbonaceous enough to cause an appreciable "kick" on the resistivity curves of the electrical log. There are no coal beds in the Kirtland shale. The Farmington sandstone member appears on the cross-sections as a sequence of sandstone lentils somewhat near the center of the Kirtland shale, similar to their disposition on the outcrop. The Farmington sandstone ranges in thickness from 22 to 813 feet in the area of this report. Both the upper and lower Kirtland shale members contain some sandstone lenses; however, these lenses are usually less resistant on the outcrop than those in the Farmington sandstone member.

Cross Section A-A' (South-North)

Eleven wells were used in this electrical log cross-section (Pl. IV). No measured sections were included in this cross-section inasmuch as the Farmington sandstone does not crop out in the line of section. This cross-section shows the general thinning of the Kirtland shale and its members from north to south. It further demonstrates that the Kirtland shale and its members are thickest in Township 31 North, Range 11 West, which lies near the axis of the San Juan basin.

The Farmington sandstone member ranges in thickness from 232 feet in Township 26 North, Range 11 West, to 628 feet in Township 31 North, Range 11 West. This line of section is normal to or near normal to most Farmington sandstone isopachous lines except on the south (Pl. I).

Cross Section B-B' (Southwest-Northeast)

Twelve electric logs and one measured section were used in this cross-section (Pl. V). This cross-section indicates the general thickening of the Kirtland shale and its members from both the southwest and northeast parts of the cross-section toward the center.

The Farmington sandstone member ranges from 228 feet in thickness in Township 26 North, Range 14 West, to 425 feet in Township 30 North, Range 9 West. This line of section is sub-parallel to the 300-400 foot Farmington sandstone isopachous lines (Pl. I).

Cross Section C-C' (West-East)

Twelve wells and one measured section were used in this line of section (Pl. VI). This cross-section shows a general thinning of the Kirtland shale and its members from west to east.

The Farmington sandstone member ranges in thickness from 522 feet in Township 29 North, Range 14 West, to 133 feet in Township 29 North, Range 8 West. This line of section is normal to almost parallel with the Farmington sandstone isopachous lines (Pl. I).

Cross Section D-D' (Northwest-Southeast)

Fourteen wells and one measured section were used in this cross-section (Pl. VII). In addition, cores and/or samples of the Kirtland

shale were available on the El Paso Natural Gas Company Huerfano No. 92 and Woolley State No. 1 wells. These cores and samples were examined and plotted within the depth tract of these two wells.

This cross-section is probably the most informative and interesting of the four cross-sections inasmuch as it demonstrates a gradual thinning both to the north and south from Township 31 North, Range 12 West which lies near the axis of the San Juan basin.

The Farmington sandstone ranges from 818 feet in thickness in Township 31 North, Range 12 West, to 325 feet thick in Township 32 North, Range 13 West, to 27 feet thick in Township 26 North, Range 8 West. This line of section is almost normal to all Farmington sandstone isopachous lines along its course (Pl. I).

Isopachous Maps

Isopachous maps have been constructed for the total Farmington sandstone interval (Pl. I) and the total Kirtland shale interval (Pl. II). Inasmuch as it is almost impossible to differentiate between the McDermott formation and the upper Kirtland shale member on electrical logs, the McDermott interval, by necessity, has been included with that of the Kirtland shale interval. Approximately 200 electrical logs and five measured sections were used in the construction of these maps. The Kirtland shale has been stripped off by erosion to the west; hence, the ancient trend of the thickness of this unit cannot be resurrected. The maps are not intended to show great detail but rather to show general trends in thicknesses.

bale were available on the [illegible] Inc. [illegible] (Lindsay [illegible]

No. 92 and Kindley State No. 1 well. [illegible] and [illegible] were

examined and placed within the [illegible]

This cross-section [illegible] and [illegible]

esting of the [illegible] sandstone [illegible]

thinning [illegible] to the north and [illegible] Range [illegible]

West which lies near the [illegible] basin.

The Farmington sandstone [illegible]

In Township 32 North, Range 11 West, [illegible]

32 North, Range 11 West, [illegible] 32 North, Range

8 West. The line of section [illegible] Farmington sand-

stone isopachous lines along [illegible]

Isopachous Maps

Isopachous maps have been constructed for the total Farmington

sandstone interval (Pl. 1) and [illegible] (Pl. [illegible]).

Inasmuch as it is [illegible] the [illegible]

McDermott formation and the upper [illegible]

logs, the McDermott [illegible] the area [illegible]

of the Kirtland shale [illegible] approximately [illegible]

five measured sections were used in the construction of these maps.

The Kirtland shale [illegible] to [illegible]

the ancient trend of [illegible]

The maps are [illegible] to show

general trends in thicknesses.

Isopachous Map of the Farmington Sandstone

This map (Pl. I) indicates:

(1) a gradual thinning of section from northwest to southeast,

(2) the thickest area of Farmington sandstone deposition to be in the general area of Township 30-31 North, Ranges 9-13 West. This general area of thickening is nearly coincident with the axis of the present day San Juan basin,

(3) the thickness of the Farmington sandstone interval varies from 27 feet in Township 26 North, Range 8 West, to 818 feet in Township 31 North, Range 12 West.

Isopachous Map of the Kirtland Shale (and McDermott Formation)

This map (Pl. II) shows the following:

(1) a general thinning of interval from northwest to southeast,

(2) the thickest interval of Kirtland shale appears to be in the general area of Township 31 North, Ranges 9-13 West. This area is nearly coincident with the axis of the present day San Juan basin,

(3) the thickness of the Kirtland shale interval ranges from 398 feet in Township 26 North, Range 8 West, to 1,405 feet in Township 31 North, Range 12 West.

CONCLUSIONS

The Farmington sandstone member of the Kirtland shale thins northward, southward, and southeastward from Township 30-31 North, Range 9-13 West, San Juan County, New Mexico.

A thin-section study of sandstone strata in the Farmington sandstone indicates that they are feldspathic graywacke. The study of cross-bedding in five measured sections strongly suggest that the major source areas, for the sediments which make up the Farmington sandstone, were to the south and southwest.

Isopachous map of the [illegible]

This map [illegible] illustrates:

(1) [illegible]
[illegible]

(2) [illegible]
[illegible]

(3) [illegible]
[illegible]

Isopachous map of the [illegible]

This map (Pl. [illegible]) illustrates:

(1) [illegible]

(2) The [illegible] in the general area of Township [illegible] North, Range [illegible]
[illegible]

(3) The thickness of the Kirtland [illegible]
[illegible]

CONCLUSIONS

The [illegible]

northward, southward [illegible] Township 21-31 North,

Range 9-13 West, San Juan County, New Mexico [illegible]

A [illegible]

stone indicated [illegible]

bedding [illegible]

areas [illegible]

to the south [illegible]

The discovery of foraminifera in the Farmington sandstone infers that a part or all of the Farmington sandstone was deposited under marine or marine-brackish, probably lagoonal, conditions. It appears to have been deposited in a fleeting lagoonal basin (formed by subsidence of the "Kirtland basin") which was flooded with marine waters, probably from the Cuba area, during a temporary reversal in the withdrawal of the Lewis sea.

The heavy-minerals found in the Farmington sandstone have a wide distribution and may indicate an igneous plutonic terrane or even a volcanic and metamorphic terrane. The heavy-mineral and thin-section study together suggest that the source rocks for the Farmington sandstone were predominantly igneous rocks, ranging from intermediate (diorite to monzonite) to silicic (granite to granodiorite) types.

The sediments which make up the Farmington sandstone were either deposited close to the source area or underwent little transportation and reworking prior to deposition inasmuch as most of the detrital grains are angular to sub-angular and poorly-sorted, the percentage of feldspar is higher than that of quartz, and there is an abundance of argillaceous cement and matrix. The high percentage of clay material indicates that the Farmington sandstone was deposited from fluids with a high sediment-fluid ratio.

The Farmington sandstone is considered immature inasmuch as it contains more feldspar than quartz. Rapid uplift of the source area or a pulsating uplift with basin subsidence leads to high relief with the result that weathering is incomplete, transport is brief, and burial takes place with little reworking. If the relief of the source

The discovery of [illegible]

infers that a [illegible] of the Farmington [illegible]

under [illegible] marine [illegible] conditions. [illegible]

It appears to have [illegible] (1960) [illegible]

by subsidence of the [illegible]

waters, probably [illegible]

in the [illegible]

The heavy minerals [illegible]

a wide [illegible]

even a volcanic [illegible]

thin-section study [illegible]

Farmington sands [illegible]

from [illegible]

detrital) types.

The sediment [illegible]

either [illegible]

portation and [illegible]

detrital grains [illegible]

percentage of feldspar, [illegible]

abundance of [illegible]

clay material [illegible]

from [illegible]

The [illegible]

as it contains [illegible]

area of [illegible]

with the result that [illegible]

[illegible]

area had been low it would have lead to more complete destruction of the feldspars and unstable heavy minerals and the formation of concentrates of orthoquartzite sandstone.

Ecomonically the Farmington sandstone is only of local interest inasmuch as it has produced only about 82, 587 barrels of oil and 338, 885 M. C. F. of gas.

APPENDIX

Descriptive Stratigraphic Sections

Type Section

(After Reeside, Jr., 1924). Section measured for C. M. Bauer in 1915 along the San Juan River west of Farmington, New Mexico. The description of the Kirtland shale appears exactly as in the literature but the descriptions of the Torrejon formation, Ojo Alamo sandstone, Mc Dermott and Fruitland formations have been condensed from the literature.

Top of Section	Feet
Torrejon formation: Shale, olive and gray with minor white to yellow sandstone containing siliceous pebbles----------	250
Ojo Alamo sandstone: Sandstone, gray-white to yellow and brown; medium-to coarse-grained (contains pebbles up to six inches in diameter); massive; cross-bedded; and minor, brown, green and greenish-gray shale---------	397
McDermott formation (unconformable contact): Gray shale; purple shale containing volcanic debris; and coarse, gray-white soft sandstone----------------------------	30
Kirtland shale:	
Upper shale member: Shale, yellowish, sandy, stained with limonite in irregular patches, and gray to drab shale, with platy dark-brown concretions one foot or less in diameter, alternating irregularly; dinosaur bone from horizon near top of unit---------------------------	80
Farmington sandstone member: Sandstone, brown, massive, fine grained; contains lenses of grit with fine black chert and clay galls but consists mostly of quartz--	15
Sandstone, friable, buff, stained locally by limonite--	16

Descriptions of [illegible]

Type Section

(After [illegible], 19[illegible]). [illegible] section measured [illegible] in 1949 along the [illegible] River [illegible]. [illegible] description of [illegible] and [illegible] the descriptions of the Torrejon formation, [illegible] Dermott and Fruitland formations have been [illegible] in the literature.

Top of section [illegible]

Torrejon formation: [illegible] yellow sandstone [illegible] [illegible]

Ojo Alamo sandstone: [illegible] brown, and [illegible] to six inches in [illegible] [illegible] colors, brown, green and [illegible] [illegible]

McDermott formation: [illegible] purple [illegible] gray-white [illegible] [illegible]

Kirtland shale

Upper shale [illegible] with [illegible] in [illegible] [illegible] horizon [illegible] [illegible]

Farmington sandstone member: [illegible] [illegible] of [illegible] [illegible]

[illegible] [illegible]

	Feet
Shale, drab, sandy, locally carbonaceous--------	33
Shale, sandy, salmon-colored------------------	5
Sandstone, brown, rather coarse, cross-bedded; contains crusts of limonite------------------------	12
Shale, drab, clayey, and light-brown sandy shale, alternating irregularly. Contains lenses of friable sandstone and dark-brown sandstone concretions-----	98
Sandstone, light brown, coarse, hard; fresh surface gray with fine white specks; much cross-bedded; locally pisolitic--------------------------------	4
Shale, drab, sandy----------------------------	5
Sandstone, light gray, fine grained, friable with a number of platy brown concretions; small limonitic crusts abundant-----------------------------------	10
Shale, gray, sandy----------------------------	8
Sandstone, fine grained, reddish brown on weathered surface, light gray on fresh surface, micaceous, massive, resistant; locally contains clay galls and ferruginous concretions; impressions of stems of plants and parallel-veined leaves abundant-----------	4
Shale, light brown, sandy, with some drab streaks--	19
Sandstone, reddish brown, fine grained, hard, with platy concretions of dark-brown sandstone; clay galls numerous; lower part lighter and softer---------	5
Shale, olive, sandy---------------------------	22
Sandstone, reddish brown, fine grained, massive; fresh surface light gray---------------------------	12
Shale, gray and buff, sandy, alternating irregularly and inclosing a few thin sandstones; gypsum present locally--------------------------------	84
Sandstone, reddish brown on weathered surface; mottled brown and white on fresh surface; massive, resistant unit------------------------------------	35
Shale, gray and buff, sandy, alternating at about five-foot intervals with thin brown sandstones--------	28

	Feet
Sandstone, yellowish, coarse, friable-------------	19
Shale, gray, sandy-------------------------------	16
Sandstone, buff, friable, cross-bedded; dinosaur bone observed---	9
Total Farmington sandstone member-------------	459
Lower shale member: Shale, clayey; light gray on weathered surface, drab on fresh exposure; contains a few thin sandstone layers-------------------------	14
Shale, sandy, chocolate-brown, filled with carbonized plant fragments; much gypsum in small crystals present-------------------------------------	4
Sandstone, buff, friable; stained with limonite----	2
Shale, drab, very sandy; a few dark sandstone concretions present----------------------------------	10
Shale, dark bluish-gray, stained along seams with limonite and containing gypsum on joint planes; plant fragments abundant---------------------------	4
Shale, light gray--------------------------------	11
Shale, somewhat sandy, black to dark brown, filled with comminuted plant fragments---------------	2
Shale, sandy, micaceous, light gray on weathered surface, mottled drab and brown on fresh surfaces----	13
Sandstone, shaly, yellowish, soft; contains large crystals of gypsum and scattered lignitic material; large concretions of platy dark-brown sandstone--	10
Shale, light gray--------------------------------	20
Shale, black, carbonaceous---------------------	1/2
Shale, dark gray--------------------------------	18
Shale, dark brown, carbonaceous----------------	1/2
Shale, light gray on weathered surface, drab on fresh surface--------------------------------------	23

Sandstone, [illegible] ----------

Shale, gray, sandy ----------

Sandstone, [illegible] ----------

Total thickness [illegible] ----------

Lower lake beds [illegible]

[illegible]

Shale, [illegible]

[illegible]

Sandstone, [illegible] ----------

Shale, [illegible]

[illegible]

[illegible]

Shale, [illegible] ----------

Shale, [illegible]

[illegible] ----------

Shale, [illegible]

[illegible] ----------

[illegible]

[illegible] ----------

Shale, [illegible] ----------

Shale, [illegible] ----------

Shale, [illegible] ----------

Shale, [illegible] ----------

Shale, [illegible]

[illegible] ----------

	Feet
Shale, yellowish, sandy; perhaps really a soft sandstone; contains much disseminated gypsum and a few thin lenses of dark-green indurated shale-------	17
Sandstone, buff, soft, with a line of dark-brown platy concretions at top------------------------------	5
Shale, yellowish, very sandy, grading upward into the unit above--------------------------------------	16
Shale, black, carbonaceous, with much gypsum---	1
Shale, gray to yellow, very sandy---------------	6
Shale, chocolate-colored, with carbonized plant remains---	2
Shale, gray to yellow, sandy--------------------	13
Shale, black, carbonaceous---------------------	1 1/2
Shale, gray------------------------------------	5.0
Shale, brown, carbonaceous, with carbonized vegetable debris---------------------------------	2.0
Shale, drab, sandy in part---------------------	35
Shale, black, carbonaceous---------------------	1
Shale, drab, sandy-----------------------------	35
Total lower shale member---------------------	271
Total Kirtland shale-------------------------	810
Fruitland formation: Carbonaceous shale, gray to brown shale, coal, and carbonaceous sandstone-------------	246

Bottom of Section

Measured Section No. 1

Section measured in northeast quarter of Township 26 North, Range 15 West and in the northwest quarter of Township 26 North,

Shale, [illegible], [illegible] sandstone, [illegible] a [illegible] ---

Sandstone, [illegible] platy [illegible] ---

Shale, [illegible] into the [illegible] ---

Shale, black, carbonaceous, [illegible] ---

Shale, gray to yellow, very sandy ---

Shale, chocolate-colored, [illegible] carbonaceous plant remains ---

Shale, gray to yellow, sandy ---

Shale, black, carbonaceous ---

Shale, [illegible] ---

Shale, brown, carbonaceous, with abundant vegetable [illegible] ---

Shale, [illegible] ---

Shale, black, carbonaceous ---

Shale, [illegible] ---

Total [illegible] ---

Total thickness of [illegible] ---

Fruitland formation: [illegible] shale, coal, [illegible] ---

Bottom of section.

Measured section No. [illegible]

Section measured [illegible]

Range 13 West [illegible]

Range 14 West, San Juan County, New Mexico. The beds are essentially horizontal hence strike or dip were not taken. Started measuring section near or at the bottom of the Farmington sandstone.

Top of Section

Unit No.	Description	Thickness (Feet)
21.	Ojo Alamo sandstone: Sandstone, conglomeratic; white to tan; well-consolidated; fine-to very coarse-grained with pebbles up to two inches in diameter; poorly-sorted; argillaceous cement----	25.0 plus
	Total thickness of Ojo Alamo sandstone measured-	25.0 plus
	McDermott formation (unconformable contact):	
20.	Shale, purple to purple-tan; soft; very sandy----	53.0
19.	Sandstone, grayish-white; loosely-consolidated; very fine-to medium-grained; sub-angular to sub-rounded with a few angular grains; fairly well-sorted; traces of green, black and orange grains and biotite; highly calcareous, bentonitic cement; traces of clay galls; cross-bedded; contains purple concretions up to two feet in diameter; unit weathers like a shale slope------------------	15.0
	Total thickness of McDermott formation---------	68.0
	Kirtland shale (apparent conformable contact):	
18.	Upper shale member: Shale, light-gray; soft (disintegrates slowly in water); slightly waxy; traces of sand laminations. Sandstone, white; friable; fine-to medium-grained; fairly well-sorted; traces of biotite and clay galls; bentonitic cement------------------------------------	53.0
	Total thickness of upper Kirtland member-------	53.0
17.	Farmington sandstone member (conformable contact): Sandstone, tannish-brown; consolidated; very fine-to fine-grained; well-sorted; traces of biotite, clay galls and tiny one-fourth inch concretions throughout; argillaceous cement; cross-bedded--	18.0

Unit No.	Description	Thickness (Feet)
16.	Shale, tan, soft; sandy; with traces of sand laminations at top. Sandstone; light-brown; friable; very fine-to fine-grained; fairly well-sorted; traces of biotite; argillaceous cement----	24.0
15.	Sandstone, light-brown; well-consolidated; very fine-to fine-grained; well-sorted; traces of biotite; argillaceous cement; good porosity; prominent cliff-former; cross-bedded. Unit contains sandy clay galls (Fig. 9) up to three inches in diameter, purple concretions (Fig. 11) up to two feet in diameter, and numerous pea size concretions------------------------------------	20.0
14.	Siltstone, light-green, highly argillaceous; traces of biotite; sandy with a trace of eight to twelve inch thick sand laminations in the upper nine feet of the unit. Sandstone, tan; consolidated; very fine-to fine-grained; well-sorted; traces of biotite; argillaceous bentonitic cement----------------	29.0
13.	Sandstone, light-brown; well-consolidated; very fine-to fine-grained; traces of biotite; argillaceous cement; good porosity; cross-bedded (Fig. 7); tiny pea size concretions and clay galls throughout; few purple concretions up to three feet in diameter at top; cliff-former----------------------------	9.0
12.	Sandstone, brownish-tan; slightly friable; very fine-to medium-grained (chiefly fine-grained); fairly well-sorted; traces of biotite, clay galls and gypsum (in fractures); slope former---------	7.0
11.	Shale, tan; soft to medium-hard; sandy; bentonitic--	16.0
10.	Sandstone, brownish-tan; well-consolidated; very fine-to fine-grained; well-sorted, traces of biotite; argillaceous cement; good porosity; cross-bedded; traces of pea size concretions throughout------------------------------------	8.0
9.	Shale, light-gray; soft; traces of biotite; very bentonitic------------------------------------	7.0
8.	Sandstone, tan; well-consolidated; very fine-to fine-grained (predominantly fine-grained); well-sorted; traces of mica, clay galls, pea size concretions (Fig. 12) and purple concretions up to sixteen inches in diameter; argillaceous cement, good porosity, cross-bedded (Fig. 6)---------	11.0

Unit No.	Description	Thickness (Feet)
7.	Shale, light-gray; soft; sandy; highly bentonitic; traces of biotite----------------------------------	11.0
6.	Sandstone, tan; slightly friable; very fine-to medium-grained; fairly well-sorted; traces of biotite, clay galls and pea size concretions; argillaceous cement; cross-bedded-------------	3.0
5.	Shale, tan; soft; sandy; traces of biotite; appears bentonitic---------------------------------------	14.0
4.	Sandstone, tan; friable; very fine-to fine-grained; well-sorted; traces of biotite and clay galls; argillaceous cement------------------------------	10.0
3.	Siltstone, tan; very argillaceous; traces of mica and tan, fine-grained sand laminations from six to ten inches thick----------------------------------	31.8
2.	Sandstone, tan; friable; very fine-to fine-grained; sub-angular to sub-rounded with a trace of angular grains; well-sorted; traces of biotite, clay galls and carbonaceous matter; argillaceous cement; cross-bedded; good porosity-------------------	10.0
	Total thickness of Farmington sandstone measured---	228.8
1.	Shale, light-gray; very hard; siliceous (?); slightly silty. Bottom covered. This unit is probably the top of the lower Kirtland shale----	32.0 plus

Bottom of Section

	Total thickness of Lower Kirtland measured-----	32.0 plus
	Total thickness of section measured------------	406.8 plus

Measured Section No. 2

Measured in Sections 21, 22, 27 and 26, Township 29 North, Range 14 West, San Juan County, New Mexico. Measurement was begun at the foot of a mesa about five miles west of Farmington, south of the San Juan River and the old Shiprock highway, and proceeded

Unit No.	Description	Thickness (feet)
7.	Shale, light-gray, soft [illegible]; contains [illegible] traces of [illegible]-----------	[illegible]
6.	Sandstone, [illegible]; [illegible] medium-grained; [illegible] [illegible] [illegible] slightly [illegible]-------------	[illegible]
5.	Shale, tan-gray, silty [illegible] concretions [illegible]----------	[illegible]
4.	Sandstone, tan-gray, very [illegible]; well-sorted; [illegible] calcareous cement----------	[illegible]
3.	Siltstone, [illegible]; gray, [illegible] and tan, fine-grained sandstone [illegible] in two [illegible]-----------	[illegible]
2.	Sandstone, tan [illegible]; sub-angular [illegible] grains; well-sorted; [illegible] [illegible] cross-bedded [illegible]-----------	[illegible]
	Total thickness [illegible] measured----------	[illegible]
1.	Shale, light-gray, very [illegible] slightly silty. [illegible] probably the top of the [illegible]----------	[illegible]

Bottom of section

Total thickness of [illegible] measured----- [illegible]

Total thickness of section measured----- [illegible]

[illegible]

Measured [illegible]

Range [illegible] [illegible]

began at [illegible]

south of the [illegible]

in a south 45 degree east direction for about two miles. The beds are horizontal. Started measuring section at the top of the lower Kirtland shale.

Top of Section

Unit No.	Description	Thickness (Feet)
48.	Ojo Alamo sandstone: Conglomerate, tan; cliff-former--	20.0 plus
47.	Sandstone, tannish-brown; friable; fine-to very coarse-grained with a trace of quartz pebbles; poorly-sorted; micaceous; argillaceous cement--	6.0
	Total thickness of lower part of Ojo Alamo sandstone-------------------------------------	26.0 plus
46A.	McDermott formation (unconformable contact): Shale, white; hard (disintegrates in water); micaceous; sandy; bentonitic------------------	12.0
	Total thickness of McDermott formation------	12.0
46 & 45.	Kirtland shale (apparent conformable contact): Upper Kirtland member: Shale, greenish-gray, hard; traces of biotite; slightly waxy------	40.0
	Total thickness of upper Kirtland member------	40.0
44.	Farmington sandstone member (conformable contact): Sandstone, dark-tan; friable; very fine-to fine-grained (predominantly fine-grained); sub-angular to sub-rounded with a trace of angular grains; well-sorted; traces of biotite; argillaceous cement; excellent porosity--------------------	16.0
43.	Sandstone, white; friable; very fine-to fine-grained; well-sorted; argillaceous cement-------	16.0
42.	Sandstone, light-gray; well-consolidated; very fine-to fine-grained (predominantly very fine-grained), well-sorted; argillaceous cement; nodular; slightly shaly; traces of gypsum in fractures------------	7.0

Unit No.	Description	Thickness (Feet)
41.	Shale, tan; soft (disintegrates in water); silty----	2.0
40.	Sandstone, white; very loosely-consolidated; weathers like a shale slope; very fine-to fine-grained; well-sorted; traces of biotite; bentonitic cement---	16.0
39.	Sandstone, tan; loosely-consolidated; very fine-to fine-grained; well-sorted; traces of biotite; argillaceous cement------------------------------	6.0
38.	Sandstone, white; loosely-consolidated; very fine-to fine-grained; well-sorted; traces of biotite; bentonite cement------------------------	4.0
37.	Sandstone, tan; loosely-consolidated; very fine-to medium-grained (predominantly medium-grained); poorly-sorted; argillaceous cement; few clay galls throughout; cross-bedded---------	24.0
36.	Shale, tan; sandy; traces of biotite--------------	6.0
35 & 34.	Siltstone, tan; sandy; traces of biotite; clayey----	8.0
33.	Sandstone, dark-tan; consolidated; very fine-to fine-grained (dominantly very fine-grained); well-sorted; traces of biotite; argillaceous cement; traces of shale laminations. Shale is tan, soft (disintegrates in water), micaceous and sandy----	4.0
32.	Siltstone, light-gray to tan; soft; slightly sandy; highly micaceous; nodular----------------------	6.0
31.	Shale, light-gray; soft (disintegrates in water); gypsiferous----------------------------------	42.0
30 & 29.	Sandstone, tan; well-consolidated; medium-to very coarse-grained (dominantly coarse-grained); sub-rounded; poorly-sorted; argillaceous cement; clay galls throughout--------------------------	17.0
28.	Shale, light-gray; soft to hard; sandy (some shale contains sub-rounded sand grains up to coarse grain size); traces of biotite------------------	4.0
27.	Sandstone, brownish-tan; friable; very fine-to fine-grained (chiefly fine-grained); sub-rounded; well-sorted; traces of biotite; calcareous-argillaceous cement; clay galls throughout, many of these appear in one-half inch layers----------	3.0

Unit No.	Description	Thickness (Feet)
26.	Shale, orange to tan; soft; sandy, contains sub-rounded, quartz grains up to very coarse-grain size--	11.0
25.	Sandstone, tannish-brown; friable; very fine- to medium-grained (predominantly fine-grained); sub-angular with a few angular grains; well-sorted; traces of biotite; limonitic (?) argillaceous cement--------------------------------	24.0
24.	Shale, tan; medium-hard; highly arenaceous; micaceous. Sand grains are very fine in size and sub-angular to sub-rounded----------------	5.0
23.	Sandstone, orangish-brown, friable; fine-to medium-grained; fairly well-sorted; traces of biotite; limonitic-argillaceous cement. Contains occasional purple concretions up to ten inches in diameter-------------------------------------	8.0
22.	Shale, greenish-gray; hard; sandy; traces of biotite--	17.0
21.	Sandstone, tannish-brown; friable; fine to coarse-grained (predominantly medium-grained); poorly-sorted; traces of biotite, argillaceous cement----	10.0
20.	Sandstone (40%) and shale (60%) interbedded. Sandstone, olive-tan; friable; fine-to medium-grained; well-sorted; traces of biotite; calcareous argillaceous cement; highly porous. Shale, tan to greenish-gray; soft; becomes sandy toward top---	20.0
19.	Sandstone, tannish-brown; slightly friable; fine- to medium-grained; sub-angular; fairly well-sorted; traces of biotite; argillaceous cement. The upper part of this unit contains purplish sandstone concretions up to two feet in diameter------	12.0
18.	Sandstone (50%) and shale (50%) interbedded. Sandstone, tannish-brown; friable; fine-to medium-grained; sub-angular; well-sorted; calcareous-argillaceous cement. Purplish concretions up to ten inches in diameter are present in a four foot sand bed about midway in this unit. Shale, greenish-gray and soft-----------------	20.0

Unit No.	Description	Thickness (Feet)
17.	Sandstone, brownish-tan; slightly friable; very fine-to fine-grained; well-sorted; micaceous; argillaceous cement; contains traces of clay "blebs"--	15.0
16.	Sandstone (50%) and shale (50%) interbedded. Sandstone, tan; well-consolidated; very fine-grained; sub-rounded; well-sorted; micaceous; argillaceous cement. Shale grayish-tan; soft; bentonitic--	9.0
15.	Shale (90%) and siltstone (10%) interbedded. Shale, greenish-gray; soft; bentonitic; micaceous; sandy. Siltstone, medium-green; hard; micaceous; argillaceous, sandy---------------	22.0
14.	Sandstone, dark-tan; well-consolidated; very fine-to fine-grained; fairly well-sorted; argillaceous-siliceous cement; contains some petrified wood--	6.0
13.	Shale, purplish-brown; soft; bentonitic; traces of biotite and gypsum; slightly carbonaceous-----	4.0
12.	Sandstone, tan; well-consolidated; very fine-to fine-grained; sub-angular; fairly well-sorted, traces of biotite, clay galls and carbonaceous specks; argillaceous cement; cross-bedded; thinly laminated at top-----------------------	3.0
11.	Shale, light-gray; soft to hard; traces of biotite; bentonitic--	6.0
10.	Sandstone, light-brown; friable; fine- to coarse-grained (predominantly medium-grained), sub-rounded with some sub-angular grains; poorly-sorted; traces of biotite, gypsum and clay galls; highly argillaceous cement-------------------	22.0
9.	Sandstone (90%) and shale (10%). Sandstone, tan; well-consolidated; very fine-to fine-grained; fairly well-sorted; slightly carbonaceous; traces of biotite; highly argillaceous cement. Shale, light-gray; medium-hard; carbonaceous---------	27.0
8.	Sandstone, friable; greenish-tan; very fine-grained; slightly carbonaceous; highly argillaceous cement; traces of tan, soft, carbonaceous shale laminations---------------------	11.0

Unit No.	Description	Thickness (Feet)
7.	Shale, grayish-green; hard; slightly silty-------	6.0
6.	Shale (50%) and siltstone (50%). Shale, light-gray; soft; micaceous; sandy. Siltstone, tan; hard; highly argillaceous; slightly sandy; traces of biotite--	10.0
5.	Shale, light-gray; soft; micaceous; sandy; fissile--	12.0
4.	Sandstone, slightly friable; dark-tan; very fine- to fine-grained (dominantly fine-grained); fairly well-sorted; traces of biotite; calcareous-argillaceous cement--	5.0
3.	Shale (80%) and sandstone (20%) interbedded. Shale, tan; soft; traces of biotite and sand grains. Sandstone, greenish-tan; well-consolidated; very fine-to fine-grained; fairly well-sorted; traces of biotite; argillaceous cement--------------------	42.4
2.	Sandstone, reddish-tan; friable; very fine-to fine-grained; fairly well-sorted; few clay galls; carbonaceous; highly argillaceous cement; slightly cross-bedded-------------------------	16.0
1.	Sandstone, tan; slightly friable; very fine-to fine-grained; sub-rounded; fairly well-sorted; carbonaceous in part; argillaceous cement; traces of tan, soft, shale laminations. Unit partially covered throughout and completely covered at the bottom-------------------------	31.8

Bottom of Section

	Total thickness of Farmington sandstone measured-------------------------------------	556.2
	Total thickness of measured section-----------	634.2

Measured Section No. 3

Section measured in Section 12, Township 29 North, Range 14 West and Sections 17 and 18, Township 29 North, Range 13 West, San Juan County, New Mexico. Lower part of section measured about

one-fourth mile west of the La Plata and San Juan River confluence. The upper part of the section was measured on the bluffs south of the San Juan River behind the hospital. The beds are essentially horizontal. Started measuring section near middle of Farmington sandstone.

Top of Section

Unit No.	Description	Thickness (Feet)
44.	Ojo Alamo sandstone: Conglomerate white to light-gray; well-consolidated; fine-grained to pebble size particles; poorly-sorted; argillaceous cement--	100 plus
	Total thickness of Ojo Alamo sandstone----------	100 plus
	McDermott formation (unconformable contact):	
43.	Shale, purple; soft (disintegrates in water); sandy--	16.0
42.	Sandstone, white to light-gray; well-consolidated; very fine-to medium-grained; angular to subrounded; poorly-sorted; argillaceous, bentonitic cement. About 30% of this unit consists of purple, soft, sandy shale laminations up to six inches thick--	13.00
	Total thickness of McDermott formation--------	29.00
	Kirtland shale (unconformable contact):	
41.	Upper Kirtland member: Sandstone, dark-tan; consolidated; very fine-to medium-grained; fairly well-sorted; argillaceous cement; good porosity. This sandstone appears as a large lens over 200 yards long and grades into shale on either side----------------------------------	27.0
40.	Shale, greenish-gray; soft (disintegrates in water); slightly sandy; traces of biotite. Contains a thin, carbonaceous, sandy, purple shale lamination---	28.0
39.	Sandstone, white; loosely-consolidated; very fine-	

[illegible] in Fish [illegible] [illegible]

The upper part of the section [illegible]

the [illegible] alluvial [illegible]

horizontal, [illegible]

sandstone.

Top of Section

Unit No. Description

14. [illegible] sandstone: [illegible] light-gray [illegible] [illegible] [illegible] [illegible]

Total thickness of [illegible]

Sandstone [illegible] [illegible]

43. [illegible]

42. Sandstone, [illegible] [illegible] [illegible] [illegible] [illegible]

Total [illegible]

[illegible] (Upper Fish [illegible] [illegible]

41. [illegible] [illegible] [illegible] [illegible] [illegible]

40. Shale, [illegible] [illegible] [illegible]

39. Limestone, [illegible]

Unit No.	Description	Thickness (Feet)
	grained; well-sorted; white argillaceous cement; traces of biotite; good porosity----------------	1.0
38.	Shale, grayish-tan; soft (disintegrates in water); silty and contains a trace of very fine sand grains--------------------------------------	27.0
	Total thickness of upper Kirtland member------	83.0
37.	Farmington sandstone member (conformable contact): Sandstone, tan; friable (weathers like a shale slope); very fine-to medium-grained; poorly-sorted; traces of biotite, calcareous-argillaceous cement; cross-bedded------------	16.0
36.	Shale, tan; hard; sandy (very fine-to fine-grained, sub-rounded sand grains); traces of biotite------	16.0
	NOTE: Samples 44 - 36 were collected on the bluff south of San Juan Hospital.	
35.	Sandstone, tan; slightly friable; very fine-to fine-grained; well-sorted; traces of biotite; argillaceous cement; good porosity------------------	3.0
34.	Shale, tan; soft (disintegrates in water); traces of biotite. This unit contains a six inch layer of sand about two-thirds of the way up. Sandstone, greenish-tan; loosely-consolidated; very fine-to fine-grained; fairly well-sorted; traces of biotite; argillaceous cement---------------------------	9.0
33.	Sandstone, tan; slightly friable; very fine-to fine-grained; well-sorted; traces of biotite and clay galls; argillaceous cement; fair porosity----	3.0
32.	Shale, light-gray to tan; soft; silty and sandy-----	8.0
31.	Sandstone, tan; friable; very fine-to fine-grained; traces of biotite; argillaceous cement-----------	11.0
30.	Mudstone, light-gray; hard; silty; contains traces of biotite, sand and carbonaceous matter---------	8.0
29.	Shale, light-gray; soft; very silty; fissile, traces of sand and biotite-----------------------------	12.0

Unit No.	Description	Thickness (Feet)
28.	Sandstone, tan; slightly friable; very fine-to medium-grained; poorly-sorted; calcareous-argillaceous cement; slightly porous------------	3.0
27.	Interbedded shale and siltstone. Shale, grayish-green; hard; appears siliceous. Siltstone, tan; hard, traces of biotite-----------------------	8.0
26.	Shale, dull-red; medium-soft; slightly sandy; carbonaceous. Sandstone is fine-to medium-grained and sub-angular---------------------	4.0
25.	Interbedded siltstone and shale. Siltstone, greenish gray; hard; contains about 1% biotite. Shale, greenish-gray; hard; silty, sandy; traces of biotite---	8.0
24.	Shale, orangish-tan; soft; silty and sandy; traces of biotite-------------------------------------	1.0
23.	Mudstone, greenish-gray; hard; silty; traces of biotite--	6.0
22 - 20.	Sandstone, friable; tan; fine-to medium-grained; fairly well-sorted; traces of biotite; argillaceous cement---------------------------------------	18.0
19.	Mudstone, greenish-gray; hard; slightly silty----	13.0
18.	Sandstone, light-brown; slightly friable; sub-angular; fine-to medium-grained; traces of biotite; calcareous; limonitic-argillaceous cement; highly porous; cross-bedded-------------------	3.0
17.	Mudstone, greenish-gray; hard; slightly silty----	8.0
16.	Sandstone, tan; consolidated; very fine-to fine-grained; fairly well-sorted; traces of biotite; argillaceous cement; excellent porosity---------	2.0
15.	Mudstone, tannish-gray; hard, silty; traces of biotite; nodular----------------------------	10.0
14.	Interbedded sandstone and shale. Shale, tan; silty; soft; traces of biotite. Sandstone, tan; well-consolidated; very fine-to fine-grained (dominantly very fine-grained); sub-rounded;	

Unit No.	Description	Thickness (Feet)
	well-sorted; traces of biotite and muscovite; argillaceous cement; poor porosity------------	10.0
13.	Sandstone, tan; well-consolidated; very fine-to medium-grained (chiefly medium-grained); fairly well-sorted; traces of green grains, biotite and carbonaceous matter; limonitic-argillaceous cement; good porosity; cross-bedded-----------	3.0
12.	Shale, light-gray; medium-hard; slightly sandy; nodular------------------------------------	3.0
11.	Sandstone, light-gray; slightly friable, very fine-to fine-grained; sub-rounded; fairly well-sorted; traces of biotite; highly argillaceous cement; fair porosity------------------------------------	2.0
10.	Siltstone, light-gray; sandy; highly argillaceous; traces of biotite------------------------------	5.0
9.	Shale, tan; soft; slightly carbonaceous----------	0.50
8.	Sandstone, dark greenish-gray; slightly friable; very fine-to medium-grained; poorly-sorted; traces of biotite; highly argillaceous cement; nodular; fair porosity-------------------------	4.0
7.	Sandstone, greenish-gray; well-consolidated; very fine-to fine-grained; well-sorted; traces of biotite; argillaceous cement; fair porosity--------------	4.0
6.	Mudstone, greenish-gray; hard; traces of biotite-	5.0
5 & 4.	Sandstone, light-gray to tan; well consolidated; very fine-to medium-grained; poorly-sorted; up to 3% biotite; argillaceous-siliceous (?) cement; cross-bedded-------------------------------	10.0
3.	Shale, grayish-buff; medium-hard; slightly calcareous; slightly silty; traces of biotite and hematite specks; foraminiferal zone-----------	1.0
2.	Siltstone, greenish-gray; soft; calcareous; highly argillaceous; traces of biotite and sand--	2.0
1.	Sandstone, greenish-tan; slightly friable; very fine-to fine-grained; fairly well-sorted; up to 3% biotite; slightly calcareous-argillaceous cement. Section begins at San Juan River level---------	1.5

Unit No.	Description	Thickness (Feet)
Bottom of Section		
	Total thickness of Farmington sandstone measured------------------------------------	221.0
	Total thickness of section measured------------	433.0 plus

Measured Section No. 4

Section measured in SE/4 of Section 5, and NW/4 of Section 9, Township 31 North, Range 13 West, San Juan County, New Mexico. Strike and dip of beds: N 28 E 45° SE. Thicker sandstone beds form prominent hogbacks. This section measured immediately north of the Standard of Texas, Federal 12-5 location. Started measuring section in Fruitland formation.

Top of Section

Unit No.	Description	Thickness (Feet)
43.	McDermott formation: Sandstone, white; friable; very fine-to coarse-grained, poorly-sorted; bentonitic cement; traces of biotite; contains laminations of purple, sandy, slightly carbonaceous shale. The remainder of the section, 100 feet plus or minus, is mostly covered friable sandstone and shale. There is no Ojo Alamo sandstone present but there is a great deal of conglomerate float on the surface---------------------	24.8
42.	Sandstone, white to tan; friable; very fine-to medium-grained; poorly-sorted; bentonitic cement; traces of biotite. This bed weathers like a shale slope--------------------------------	7.2
41.	Shale, tan, sandy, and bentonitic; partially covered------------------------------------	15.4
40.	Sandstone, tan to white; friable; very fine-to coarse-grained; highly calcareous cement; cross-bedded--	6.0

Unit No.	Description	Thickness (Feet)
	Total thickness of lower part of McDermott formation------------------------------------	53.4 plus
	Kirtland shale (apparent conformable contact):	
39.	Upper Kirtland member: Shale, grayish-green; hard; sandy; traces of biotite------------	114.0
38.	Sandstone, dark-tan; well-consolidated; very fine-to fine-grained; poorly-sorted; up to 5% biotite; argillaceous cement; poor porosity; cross-bedded----------------------------------	10.0
37.	Shale, tannish-gray; soft; disintegrates in water; traces of biotite------------------------	113.0
	Total thickness of upper Kirtland member-----	237.0
	Farmington sandstone (conformable contact):	
36.	Sandstone, tan; friable; very fine-to fine-grained; fairly well-sorted; traces of biotite; argillaceous cement, excellent porosity; contains a few clay galls, and purplish concretions (some of which display poor concentric growth rings when broken open) up to two and one-half feet in diameter (Fig. 10); cross-bedded-----------------------	15.4
35.	Shale, dark-tan, soft; probably bentonitic (disintegrates in water); with few six inch sandstone laminations. Sandstone, tan; well-consolidated; fine-to medium-grained; sub-angular to sub-rounded; fairly well-sorted; traces of biotite and clay galls; tight; argillaceous cement----	35.6
34.	Sandstone, tan; slightly friable; very fine-to medium-grained (chiefly fine-grained); fairly well-sorted; traces of biotite; argillaceous cement; fair porosity; cross-bedded------------	3.0
33.	Shale, dark-tan; soft; appears bentonitic (disintegrates in water)----------------------	15.9
32.	Sandstone, tan; slightly friable; very fine-to medium-grained (chiefly fine-grained); fairly well-sorted; traces of biotite and clay galls; argillaceous cement; good porosity; traces of purplish concretions up to two feet in diameter; cross-bedded, traces of gray shale laminations--	24.9

Unit No.	Description	Thickness (Feet)
31.	Shale, tan; soft; pure-------------------------	42.7
30.	Sandstone, tan; friable; very fine-to medium-grained; fairly well-sorted; traces of brown and black mica; calcareous-argillaceous cement; excellent porosity; cross-bedded; traces of clay galls; purple concretions up to four feet in diameter and non-calcareous iron concretions up to four inches in diameter---------------------	24.9
29.	Shale, greenish-gray; medium-hard; slightly sandy; traces of biotite----------------------	31.9
28.	Sandstone, whitish-tan; friable; very fine-to medium-grained; fairly well-sorted; traces of biotite, green, black and orange grains; calcareous-argillaceous white cement; good porosity; few purple concretions up to three feet in diameter------------------------------------	12.5
27.	Shale, greenish-gray; soft; slightly sandy-------	28.9
26.	Sandstone, tan; well-consolidated; very fine-to fine-grained; well-sorted; traces of brown and black mica; argillaceous cement; tight----------	3.0
25.	Shale, tan; medium-hard----------------------	35.6
24.	Sandstone, tan; friable; very fine-grained; well-sorted; traces of biotite; argillaceous cement----	1.0
23.	Shale, greenish-gray; medium-hard; traces of biotite; partially covered---------------------	21.4
22.	Sandstone, dark-tan; friable; very fine-to fine-grained; well-sorted; argillaceous cement; good porosity, traces of purple concretions up to two feet in diameter------------------------	10.7
21.	Shale, light-gray; medium-hard----------------	7.1
20.	Sandstone, tan; consolidated; very fine-to fine-grained; well-sorted; traces of biotite, argillaceous cement; fair porosity; cross-bedded; few purple concretions up to four feet in diameter---	7.2
19.	Shale, tan; medium-hard; slightly sandy; traces of biotite; partially covered------------------	24.8

Unit No.	Description	Thickness (Feet)
18.	Sandstone, tan; friable; very fine-to fine-grained; well-sorted; traces of biotite; argillaceous cement; cross-bedded; few clay galls throughout; few purple concretions up to two and one-half feet in diameter noted; some concretions display concentric growth lines when broken open----------------------------------	16.0
17.	Shale, tan; hard; sandy; traces of biotite--------	24.8
16.	Sandstone, tan; consolidated; very fine-to fine-grained; well-sorted; traces of biotite and green grains; argillaceous cement; contains few purple concretions up to ten inches in diameter--------	7.0
15.	Shale, light-gray; soft; contains few purple, calcareous sand concretions up to four inches in diameter--------------------------------------	12.0
14.	Sandstone, grayish-tan; slightly friable; very fine-to fine-grained (chiefly fine-grained); well-sorted; traces of biotite and green grains; calcareous-argillaceous cement; good porosity; cross-bedded------------------------------------	5.0
13.	Shale, greenish-gray; medium-hard; slightly sandy; traces of biotite------------------------	8.0
12.	Sandstone, tan; consolidated; very fine-to medium-grained; fairly well-sorted; traces of biotite; argillaceous cement; good porosity; cross-bedded; few clay galls scattered throughout---	13.0
11.	Shale, tannish-brown; soft; carbonaceous; sandy--	7.0
10.	Sandstone, light-brown; consolidated; very fine-to fine-grained, (predominantly fine-grained); well-sorted; fair porosity; traces of carbonaceous matter; contains many clay galls at bottom-------	8.0
	Total thickness of Farmington sandstone---------	446.3
	Lower Kirtland member (conformable contact):	
9.	Shale, tan; soft; trace sandstone-----------------	8.0

Unit No.	[illegible]	[illegible]
18.	[illegible] gray [illegible] cross[illegible] [illegible] con[illegible] [illegible] and one [illegible] [illegible] [illegible] [illegible]	[illegible]
17.	Shale, tan [illegible] [illegible]	[illegible]
16.	Sandstone, tan [illegible] [illegible] grained [illegible] con[illegible]	[illegible]
15.	Shale, [illegible] [illegible] purple, calcareous [illegible] in [illegible]	[illegible]
14.	Sandstone, [illegible] [illegible] [illegible]	[illegible]
13.	Shale, [illegible] [illegible] sandy [illegible]	[illegible]
12.	Siltstone, tan [illegible] [illegible] of [illegible] [illegible]	[illegible]
11.	Shale, [illegible] sandy [illegible] sandy [illegible]	[illegible]
10.	Sandstone, [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]	[illegible]
	Total [illegible]	[illegible]
9.	[illegible]	[illegible]

Unit No.	Description	Thickness (Feet)
8.	Sandstone, light-gray; consolidated; fine-grained; well-sorted; argillaceous cement; fair porosity---	6.0
7.	Shale, light-gray; soft; waxy; mostly covered-----	35.6
6.	Sandstone, light-gray (salt and pepper appearance); well-consolidated; very fine-to fine-grained; well sorted; calcareous-argillaceous cement-----	3.0
5.	Shale, light-gray; soft; waxy; slightly silty with many layers of brown, soft, carbonaceous shale; partially covered-------------------------------	178.0
	Total thickness of lower Kirtland member------	230.6
	Total thickness of Kirtland shale---------------	913.9
	Fruitland formation (conformable contact):	
4.	Sandstone, light-gray (salt and pepper appearance); consolidated; very fine-to fine-grained; well-sorted; highly calcareous-argillaceous cement--	4.0
3.	Shale, greenish-gray; medium-hard; slightly carbonaceous; calcareous; sandy; partially covered-------------------------------------	53.4
2.	Sandstone; whitish-gray (salt and pepper appearance); well-consolidated; very fine-to fine-grained; well-sorted; calcareous-argillaceous cement; thin bedded----------------------------	15.0
1.	Coal, brown to black; shaly--------------------	10.0
	Total thickness of upper part of Fruitland formation measured--------------------------	82.4

Bottom of Section

	Total thickness of section measured-----------	1,049.7

Measured Section No. 5

Section measured in south half of Section 23, Township 32 North, Range 13 West, San Juan County, New Mexico. Strike and dip of beds; N 45 E 10° SE. Measured section begins approximately two miles south of New Mexico - Colorado state line just east of Highway 17 and proceeding approximately one mile in the direction of dip. Started measuring section in Fruitland formation.

Top of Section

Unit No.	Description	Thickness (Feet)
54.	McDermott formation: Sandstone, tan; friable; very fine-to granule-size grains; conglomeratic; poorly-sorted; calcareous-argillaceous cement. A few small pebbles are present. There is conglomerate float on the surface here. No Ojo Alamo sandstone present--	3.0
53.	Shale, purple; soft; sandy---------------------	7.8
52.	Sandstone, tan; friable; very fine-to granule-size grains; poorly-sorted; argillaceous cement. A few black and orange grains are scattered throughout the unit---------------------------	3.0
51.	Shale, grayish-purple; soft; sandy-------------	15.6
50.	Sandstone, tan; friable; very fine-to medium-grained; conglomeratic (with a few granules and pebbles scattered throughout); poorly-sorted; argillaceous cement------------------	3.0
49.	Shale, tan; soft; waxy------------------------	26.0
48 & 47.	Sandstone, white; well-consolidated; fine-to very coarse-grained; poorly-sorted; bentonitic cement-	5.2
46.	Sandstone, orange to tan; friable; fine-to pebble-size grains; poorly-sorted; argillaceous cement--	5.2

Unit No.	Description	Thickness (Feet)
45.	Sandstone, white to grayish-purple; friable; fine-to coarse-grained; conglomeratic (a few sub-angular quartz pebbles up to one-half inch in diameter were noted); angular to sub-rounded; poorly-sorted; argillaceous cement-----	13.0
44.	Sandstone, white; friable; fine-to very coarse-grained; angular to sub-rounded; poorly-sorted; calcareous-argillaceous cement; platy structure--	6.0
43.	Siltstone, grayish-purple; soft; highly argillaceous; traces of biotite and green grains throughout--	6.0
42.	Sandstone, white; slightly friable; very fine-to medium-grained; poorly-sorted; calcareous-bentonitic cement; platy structure--------------	2.0
41 & 40.	Shale, purple; soft------------------------------	20.8
	Total thickness of lower part of McDermott formation--------------------------------------	116.6
	Kirtland shale (conformable contact):	
39 & 38.	Upper Kirtland member: Shale, tan to light-gray; silty; traces of carbonaceous matter. Shale occurs in a valley and is mostly covered---	280.8
	Total thickness of upper Kirtland member-------	280.8
37 & 36.	Farmington sandstone member (conformable contact): Sandstone, orange to tan; friable; very fine-to medium-grained (predominantly medium-grained); fairly well-sorted; traces of biotite; calcareous-argillaceous cement; cross-bedded; contains a few purple concretions up to four feet in diameter------------------------------------	11.0
35.	Shale, medium-green; soft, silty; sandy; highly micaceous------------------------------------	26.0
34.	Sandstone, purple coated; well-consolidated; very fine-to fine-grained; traces of green grains and carbonaceous matter; highly calcareous, argillaceous cement. This is a two foot layer of purple coated sandstone lying on top of 33 below-------	2.0

Unit No.	Description	Thickness (Feet)
33.	Sandstone, tan; well-consolidated; very fine- to fine-grained; fairly well-sorted; traces of biotite and clay galls; fair porosity; cross-bedded--	6.0
32.	Siltstone, tan; medium-hard; sandy-------------	2.0
31.	Shale, tan; soft; silty and sandy; traces of biotite--	20.8
30.	Sandstone, orangish-tan; friable; very fine-to medium-grained (predominantly fine-grained); fair-sorted; traces of biotite; calcareous-argillaceous cement; slightly cross-bedded; contains a few purple concretions up to eight inches in diameter. This unit contains two layers, about one-fourth and one-half way up from the bottom, of purple coated sandstone, very similar to the type which makes up the concretions, each of which is two feet thick-------------------------------	10.2
29.	Shale, light-gray; soft; sandy------------------	13.0
28.	Sandstone, tan; friable; very fine-to fine-grained; fairly well-sorted, calcareous-argillaceous cement; contains a few purple concretions up to two feet in diameter; good porosity--------------	2.0
27.	Shale, light greenish-gray; soft; silty to sandy; traces of biotite-------------------------------	8.2
26.	Sandstone, tan; friable; very fine-to fine-grained (predominantly fine-grained); well-sorted; traces of biotite; argillaceous cement; good porosity----	3.0
25.	Shale, medium gray-green; soft; slightly silty---	26.0
24.	Sandstone, orangish-tan; silty; friable; very fine-to fine-grained; well-sorted; traces of biotite; limonitic-argillaceous cement; contains a few purple concretions up to two and one-half feet in diameter-------------------------------	6.0
23.	Shale, medium greenish-gray; soft-------------	8.0
22.	Sandstone, orange-tan; well-consolidated; very fine-to medium-grained (chiefly fine-grained); fairly well-sorted; traces of biotite; limonitic-argillaceous cement; fair porosity--------------	4.0

Unit No.	Description	Thickness (Feet)
21.	Shale, light greenish-gray; soft----------------	36.4
20.	Sandstone, orangish-tan; friable; very fine-to fine-grained; fairly well-sorted; traces of biotite and clay galls; argillaceous cement; highly cross-bedded-----------------------------------	10.0
19.	Shale, tan; soft; silty; slightly sandy-----------	7.0
18.	Sandstone, tan; slightly friable; very fine-to fine-grained; fairly well-sorted; argillaceous cement; few clay galls and purple concretions, up to two and one-half feet in diameter throughout--	8.0
17.	Shale, tan; soft; silty-------------------------	26.0
16.	Sandstone, tan; friable; very fine-to fine-grained (chiefly fine-grained); well-sorted; traces of biotite; argillaceous cement; slightly cross-bedded; few scattered iron concretions----------------	3.0
15.	Shale, tan; soft; sandy; traces of biotite--------	10.4
14.	Sandstone, orangish-tan; friable; very fine-to medium-grained (predominantly fine-grained); fairly well-sorted; traces of biotite; argillaceous cement; good porosity; thin-bedded; traces of small iron concretions------------------------	8.0
13.	Shale, light greenish-gray; soft; silty; traces of biotite--------------------------------------	72.8
12.	Sandstone, orangish-tan; slightly friable; fine-to medium-grained (dominantly medium-grained); fairly well-sorted; traces of carbonaceous matter; argillaceous cement; good porosity; slightly cross-bedded; few clay galls throughout---------------	5.0
	Total thickness of Farmington sandstone---------	324.8
	Lower Kirtland member (conformable contact):	
11.	Shale, greenish-gray; soft; traces of carbonaceous matter; partially covered near bottom------------	182.0
	Total thickness of lower Kirtland member-------	182.0

Unit No.	Description	Thickness (Feet)
	Total thickness of Kirtland shale----------------	787.6
	Fruitland formation (conformable contact):	
10.	Sandstone, tan; well-consolidated; very fine-to medium-grained (predominantly fine-grained); fairly well-sorted; coal specks and biotite throughout; calcareous-argillaceous cement; good porosity; highly cross-bedded; traces of clay galls---------	5.0
9.	Shale, medium-gray; soft; purple; carbonaceous streak in middle-----------------------------------	36.4
8.	Sandstone, dark orange-gray; well-consolidated; very fine-to fine-grained (chiefly very fine-grained); well-sorted; small amount of biotite and carbonaceous matter throughout; argillaceous-siliceous cement; slightly cross-bedded; few clay galls present; good porosity; mammillary weathering; unit is thick-bedded at the bottom and thin-bedded at the top-----	12.0
7.	Shale, medium-gray; soft; carbonaceous specks throughout; two carbonaceous streaks present near middle of unit------------------------------	62.4
6 & 5.	Sandstone, tan; friable; very fine-to fine-grained (dominantly fine-grained); sub-rounded; well-sorted; coal specks throughout; highly calcareous; argillaceous cement; good porosity; cross-bedded; unit is thick-bedded at the bottom and thin-bedded at the top--	8.0
4.	Shale, orange; very soft; carbonaceous----------	18.4
3.	Sandstone, grayish-tan; slightly friable; very fine-grained; sub-rounded; well-sorted; coal specks throughout; very calcareous-argillaceous cement; very thin-bedded unit------------------	9.0
2.	Shale, light-gray; soft; silty; slightly carbonaceous--	46.8
1.	Shale, hard, dark-gray; highly calcareous; slightly carbonaceous; slightly silty-------------	2.0

Bottom of Section

	Total thickness of upper part of Fruitland measured--	200.0

Unit No.	Description	Thickness (feet)
	Total thickness [illegible] ------------	[illegible]
10.	Fruitland formation (lower part [illegible]): [illegible], well-[illegible] medium-grained [illegible]; [illegible] cross-bedded [illegible] ------	[illegible]
9.	Shale, [illegible] gray, [illegible] ------------	[illegible]
8.	Sandstone, [illegible] gray [illegible]; very fine-grained, [illegible]; well-sorted; [illegible] of [illegible]; [illegible]; slightly [illegible]; [illegible] bedded at the bottom, and [illegible] at the top ------	[illegible]
7.	Shale, [illegible] gray, [illegible] throughout; [illegible] near middle of unit ------------	[illegible]
6 & 5.	Sandstone, tan, friable, very fine- to fine-grained (dominantly very fine-grained), sub-angular; well-sorted; [illegible] throughout [illegible]; argillaceous cement [illegible]; cross-bedded; unit is [illegible] at the bottom and [illegible] at the top ------------	6.
4.	Shale, [illegible] very soft; [illegible] ------------	[illegible]
3.	Sandstone, grayish-tan, silty, [illegible]; very fine-grained, subangular, well-sorted; [illegible] specks throughout; very [illegible] cement; [illegible] ------------	[illegible]
2.	Shale, [illegible] gray, soft, [illegible] ------------	[illegible]
1.	Shale, hard, [illegible] ------------	[illegible]

Bottom of Section

Total thickness of [illegible] ------------

Unit No.	Description	Thickness (Feet)
	Total thickness of section measured----------	1,104.2

Core Descriptions

El Paso Natural Gas Company, Woolley No. 1
NE Section 8, Township 29 North, Range 11 West
San Juan County, New Mexico

Core No. 1: 774-834, Recovered 60 feet

Eight feet of conglomerate, light-gray, well-consolidated, fine grain to pebble size, sub-angular to sub-rounded, poorly-sorted, abundant siliceous cement, contains pyrite pebbles up to 1/2 inch in diameter; twenty-two feet of shale, grayish-green, hard, sandy and micaceous (biotite); three feet of sandstone, grayish-green, well-consolidated, very fine-to medium-grained, sub-angular to sub-rounded, poorly-sorted, argillaceous and highly micaceous (biotite); four feet of shale, grayish-green, hard, relatively pure clay; four feet of sandstone, light gray-green, well-consolidated, very fine-to fine-grained, sub-angular to sub-rounded, fairly well-sorted, argillaceous cement, slightly micaceous; five feet of shale, grayish-green, hard, slightly micaceous; two feet of sandstone, greenish-gray, well-consolidated, very fine-grained, sub-angular to sub-rounded, well-sorted, argillaceous and micaceous; two feet of shale, light-gray, medium-hard, silty, micaceous, contains green clay galls; ten feet of sandstone, light-gray, well-consolidated, very fine-to medium-grained (a few coarse grains are present toward the bottom), sub-angular to sub-rounded, poorly-sorted, highly argillaceous and micaceous, many accessory green grains are present, trace of poor porosity.

Core No. 2: 834-850, Recovered 16 feet

Eight feet of sandstone, as above, plus bleeding oil and gas; six feet of shale, grayish-green, hard, silty, traces of carbonaceous matter; two feet of sandstone, grayish-green, very fine-grained, well-consolidated, sub-angular to sub-rounded, well-sorted, traces of biotite and shale laminations, argillaceous cement.

Core No. 3: 885-941, Recovered 55 feet

Four feet of sandstone, light-gray, friable, very fine-to medium-grained (dominantly fine-grained), sub-angular to sub-rounded, fairly well-sorted, bentonitic cement, traces of green and black mica, poor porosity, heavy gas bleeding; three feet of sandstone, greenish-gray, well-consolidated, very fine-grained, slightly carbonaceous, argillaceous cement, slight gas bleeding; eighteen feet of shale, grayish-green, hard, slightly silty, traces of sand and biotite; five feet of siltstone, greenish-gray, hard, micaceous; six feet of sandstone, light-gray, well-consolidated, very fine-to fine-grained, sub-angular to sub-rounded, fairly well-sorted, highly bentonitic cement, slightly porous, traces of mica and green sand grains, heavy gas bleeding, a few medium to coarse sand grains were noted and one granule was noted at 920 feet; four feet of siltstone, grayish-green, hard, sandy, slightly carbonaceous and micaceous, traces of pyrite; nine feet of sandstone, greenish-gray, very fine-to medium-grained, sub-angular to sub-rounded, fairly well-sorted, highly bentonitic cement, traces of mica, poor porosity, slight gas bleed, traces of oil, and water saturated; six feet of shale, greenish-gray, medium-hard, slightly silty and sandy.

Core No. [illegible]

Five feet of sandstone, [illegible] six feet of shaly, [illegible] matter; two feet of sandstone, [illegible] consolidated, sub-angular to sub-rounded, well-sorted, [illegible] tite and chalcedony, [illegible]

Core No. 3: [illegible]

Four feet of sandstone, [illegible] grained (dominantly very-fine grained), [illegible] well-sorted, [illegible] porosity, [illegible] well-consolidated, very [illegible] cement, [illegible] slightly silty, [illegible] gray, hard, [illegible] dated, very [illegible] well-sorted, [illegible] and green [illegible] sand grains were [illegible] of siltstone, [illegible] micaceous, trace [illegible] very fine-to medium-grained, [illegible] sorted, [illegible] gas odor, [illegible] gray, medium-hard, slightly silty [illegible]

Core No. 4: 941-1000, Recovered 58 feet

Twenty-four feet of shale, as above, with traces of carbonaceous matter from 947-952 and 960-963 feet; six feet of siltstone, grayish-green, hard, traces of mica and carbonaceous matter; four feet of sandstone, light-gray, friable, very fine-to fine-grained, sub-angular to sub-rounded, fairly well-sorted, traces of biotite and green grains, slightly calcareous, bentonitic cement, poor porosity, water wet; two feet of shale, grayish-green, hard, traces of mica and sand grains; three feet of sandstone, grayish-green, well-consolidated, very fine-grained, sub-angular to sub-rounded, very argillaceous cement, clay galls at 977 feet, bleeding gas; twelve feet of shale, grayish-green, hard, micaceous, silty, traces of carbonaceous matter, becomes very sandy at 983-85 and 988-90 feet; two feet of sandstone, light greenish-gray, well-consolidated, very fine-to medium-grained, sub-angular to sub-rounded, poorly-sorted, traces of mica and carbonaceous matter, highly bentonitic cement, no porosity noted, water wet and bleeding gas; five feet of shale, light-gray, hard, silty and sandy.

Core No. 5: 1000-1060, Recovered 60 feet

Thirty-seven feet of shale, medium-gray, silty, hard, slightly carbonaceous and micaceous, becomes very sandy at 1,006 feet; two feet of sandstone, grayish-green, well-consolidated, very fine-grained, well-sorted, argillaceous cement, traces of mica; two feet of shale, as above; one foot of sand, as above; eighteen feet of shale as above, carbonaceous stick imprints noted at 1,051 and 1,054 feet.

Core No. 4: [illegible]-1000, Recovered [illegible] feet

Twenty-four feet of shale, as above, with traces of carbonaceous matter from 937-952 and 960-963 feet; [illegible] feet of [illegible], gray-green, hard, traces of mica and carbonaceous matter; [illegible] feet of sandstone, light gray, friable, quartzite-[illegible], sub-angular to sub-rounded, fairly well-sorted, traces of [illegible] and mica grains, slightly calcareous, bentonitic cement, poor porosity, water wet; [illegible] feet of shale, grayish-green, hard, traces of [illegible]; three feet of sandstone, grayish-green, well-consolidated, very fine-grained, sub-angular to sub-rounded, very argillaceous, [illegible] gas at 977 feet, bleeding gas; twelve feet of shale, [illegible], hard, micaceous, silty, traces of carbonaceous matter, [illegible] sandy at 963-68 and 965-97 feet; two feet of [illegible], gray, well-consolidated, very fine-grained, [illegible], sub-angular to sub-rounded, poorly sorted, [illegible] highly bentonitic cement, no porosity [illegible] gas; five feet of shale, light gray, [illegible]

Core No. 5: 1000-[illegible], Recovered [illegible] feet

Thirty-seven feet of shale, as above, [illegible] carbonaceous and micaceous [illegible]; [illegible] feet of sandstone, gray, [illegible] well-sorted, argillaceous cement, traces of [illegible] above; one foot of sand, [illegible] bentonite stick [illegible] and 1,037 feet.

Core No. 6: 1060-1120, Recovered 60 feet

Twenty-three feet of shale, light greenish-gray, hard, silty, slightly carbonaceous, unit very sandy at 1,065 feet; two feet of sandstone, light greenish-gray, very fine-to fine-grained, sub-rounded to sub-angular, fairly well-sorted, slightly micaceous and carbonaceous, argillaceous cement, poor porosity, traces of oil, and water wet; six feet of sandstone, light-gray, slightly friable, very fine-to medium-grained, sub-rounded to sub-angular, fairly well-sorted, calcareous bentonitic cement, traces of green grains and mica, poor to good porosity, traces of oil, and water wet; twenty-nine feet of shale, greenish-gray, hard, silty, traces of biotite.

Core No. 7: 1141-1201, Recovered 59 feet

Five feet of sandstone, grayish-green, well-consolidated, very fine-to medium-grained, sub-angular to sub-rounded, fairly well-sorted, argillaceous cement, fair porosity at 1,145 feet; two feet of shale, grayish-green, hard, silty, traces of mica; two feet of siltstone, grayish-green, hard, sandy, traces of mica; two feet of sandstone, grayish-green, very fine-to fine-grained, well-consolidated, sub-angular to sub-rounded, fairly well-sorted, argillaceous cement, traces of mica; three feet of shale, light-gray, medium-hard, sandy; thirteen feet of sandstone, light grayish-green, well-consolidated, very fine-to fine-grained, sub-angular to sub-rounded, well-sorted, calcareous, bentonitic cement, traces of mica, fair porosity, traces of shale laminations, water wet; six feet of sandstone, light-gray, well-consolidated to friable, very fine-to medium-grained, sub-angular to sub-rounded, fairly well-sorted,

Core No. 6: [illegible] feet

Twenty-three feet of [illegible] shale, greenish-gray, silty, slightly calcareous, [illegible] very sandy [illegible]; one foot of sandstone, light greenish-gray, very fine- to fine-grained, sub-rounded to sub-angular, fairly well-sorted, slightly micaceous, slightly calcareous, argillaceous cement, poor porosity, traces of oil, and [illegible] feet of sandstone, light-gray, slightly [illegible], very fine- to fine-grained, sub-rounded to sub-angular, fairly well-sorted, calcareous bentonitic cement, traces of green grains and [illegible], poor to good porosity, traces of oil, [illegible] nine feet of shale, greenish-gray, hard, silty, traces of [illegible].

Core No. 7: [illegible] feet

Five feet of sandstone, gray-green, well-consolidated, very fine- to medium-grained, sub-angular to sub-rounded, fairly well-sorted, argillaceous cement, fair porosity at [illegible]; two feet of shale, grayish-green, hard, silty, traces of [illegible] of siltstone, grayish-green, hard, sandy, [illegible] of sandstone, grayish-green, very fine- to fine-grained, well-[illegible], sub-angular to sub-rounded, fairly well-sorted, argillaceous [illegible], traces of [illegible] feet of shale, light-gray, [illegible], [illegible] of sandstone, light grayish-green, well-consolidated, very fine- to fine-grained, sub-angular to sub-rounded, well-sorted, [illegible] cement, traces of [illegible], traces of [illegible], six feet of sandstone, light-gray, well-consolidated, very fine- to medium-grained, [illegible], fairly well-sorted.

highly calcareous-argillaceous cement, traces of biotite and green grains, fair to good porosity, gas odor; three feet of shale, light-to dark-gray, sandy, hard; four feet of sandstone, light-gray, fine-to medium-grained, sub-angular to sub-rounded, fairly well-sorted; twelve feet of shale, light-gray, hard, traces of sand laminations; seven feet of shale, medium-to dark-gray; medium-hard.

<u>Core No. 8: 1201-1261, Recovered 58 feet</u>

Six feet of sandstone, light-gray, well-consolidated, very fine-to fine-grained, sub-angular to sub-rounded, well-sorted, traces of mica and green grains, argillaceous cement, tight; five feet of sandstone, greenish-gray, well-consolidated, very fine-to medium-grained, sub-angular to sub-rounded, well-sorted, argillaceous cement, traces of mica and green grains, fair porosity, bleeding gas and water; twenty-four feet of shale, light-gray, medium-hard, sandy; eight feet of sandstone, light-gray, very fine-to medium-grained, sub-angular to sub-rounded, poorly-sorted, traces of mica, some very carbonaceous layers, poor porosity, bleeding gas; fifteen feet of shale, light-to medium-gray, medium-hard.

<u>Core No. 9: 1261-1306, Recovered 44 feet</u>

Eight feet of shale, light greenish-gray, hard, traces of carbonaceous matter and silt; two feet of sandstone, grayish-green, well-consolidated, very fine-grained, highly argillaceous, traces of mica, tight, trace gas bleed; twenty feet of shale, medium gray-green, hard, traces of mica, and carbonaceous matter, silty (becomes very silty at 1275, 1278, 1283 and 1288 feet); ten feet of sandstone, light-gray, well-

highly calcareous-argillaceous cement [illegible] grains, [illegible] porosity; [illegible] feet of shale, [illegible] to dark-gray, [illegible] to medium-grained, sub-angular to [illegible]; twelve feet of shale, [illegible]; seven feet of shale, medium- to dark-gray, [illegible] hard.

Core No. [illegible]

Six feet of sandstone, light-gray, [illegible], very fine- to fine-grained, sub-angular to sub-rounded, well-sorted, [illegible] mica and green grains, argillaceous cement, [illegible] sandstone, greenish-gray, well-consolidated, very fine-grained, sub-angular to [illegible], traces of mica and green grains, fair porosity, bleeding [illegible]; twenty-four feet of shale, light-gray, [illegible] of sandstone, light-gray, very fine- to fine-grained, sub-angular to sub-rounded, poorly-sorted, traces of mica, [illegible] layers, poor porosity, bleeding gas; fifteen feet of shale, [illegible] medium-gray, [illegible].

Core No. [illegible]

Eight feet of sandstone, [illegible] argillaceous [illegible] consolidated, with [illegible] tight, [illegible] traces of mica, and carbonaceous matter, [illegible] 1275, 1276, [illegible]

consolidated, very fine-to fine-grained, sub-angular to sub-rounded, well-sorted, traces of mica, argillaceous cement, tight, fair gas bleed; four feet of shale, greenish-gray, hard, silty, slightly carbonaceous.

Sidewall Core Descriptions

El Paso Natural Gas Company, Phillips No. 2
NW Section 32, Township 28 North, Range 8 West
San Juan County, New Mexico

Footage	Description
2193	Sandstone, light-gray to white; loosely-consolidated; very fine-to medium-grained; angular to sub-rounded; fairly well-sorted; calcareous; highly bentonitic cement; frosted sand grains; traces of biotite, green and orange grains, and porosity.
2198	Sandstone, as 2193 above.
2346	Sandstone, greenish-white; well-consolidated; sub-angular to sub-rounded;fairly well-sorted; bentonitic cement; traces of green grains throughout, traces of porosity.
2390	Sandstone, very light-gray; well-consolidated; very fine-to fine-grained; sub-angular to sub-rounded; fairly well-sorted; argillaceous cement; traces of green grains and greenish-white mica; fair to good porosity.
2474	Sandstone, greenish-gray; well-consolidated; very fine-to fine-grained; sub-angular to sub-rounded; fairly well-sorted; argillaceous cement; many green grains throughout; fair to good porosity.
2505	Sandstone, very light-gray; well-consolidated; very fine-grained; well-sorted, slightly calcareous-argillaceous cement; traces of mica, carbonaceous matter and green grains; highly bentonitic; traces of porosity.

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