GEOLOGY OF THE RATON AREA, COLFAX COUNTY, NEW MEXICO

by

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ABSTRACT

This study is a geologic description of an area of approximately 77 square miles, in the northern part of the Colfax County, New Mexico. Upper Cretaceous, Paleocene, and Quaternary strata were studied with emphasis on the former two; this study includes also a brief summary of the volcanic rocks of the area.

The strata of the study area are on the eastern side of the Raton basin and dip to the west. Late Tertiary volcanic rocks rest unconformably on older formations.

The pattern of sediment distribution, the study of the directions of sediment transport, the extreme variety in sediment structures and forms of the sand bodies, the presence of a great number of channels, the variations in grain size, and the approximate agreement with Weimer's (1965) criteria for the recognition of a delta and with Visher's (1965) vertical profile of a delta, all support a hypothesis for a deltaic sedimentation in the Raton area during the Late Cretaceous and Paleocene time.

The presence of the carbonaceous detrital materials in the upper Pierre and the Trinidad Sandstone indicate the possibility these beds are marine time-equivalents of the Vermejo and the Raton formations.

The Vermejo and the Raton formations were deposited in nearly similar environments of deposition, and their identification and separation in the Raton area is difficult. A marker bed, the "lower massive sandstone" of the Raton Formation, is used to define the Vermejo-Raton contact.

The Trinidad Sandstone, the Vermejo Formation, and especially the Raton Formation have been informally subdivided into distinctive units which have been traced throughout the mapped area.

Eastward extending tongues of the Trinidad Sandstone are interbedded with the upper Pierre Shale and may form potential stratigraphic traps for petroleum west of the city of Raton, where they are not exposed by erosion. The main body of the Trinidad is not considered as an oil prospect.

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INTRODUCTION

Purpose and Scope

The major purpose of this study is to present a detailed stratigraphic analysis of Upper Cretaceous and Paleocene rocks in the Raton, New Mexico area; this study includes a definition of the directions of sediment transport, an analysis of the environment of deposition, and a subdivision of the stratigraphic units into correlatable subunits. Several geologic markers have been identified in this study. Late Tertiary volcanic rocks and Quaternary sediments are also considered briefly.

Another subject of investigation is the study of the mineral resources of the area and the possibilities for the entrapment of hydrocarbons.

Location and Accessibility

The area discussed in this report is located in the Raton Quadrangle in the north-central part of Colfax County, New Mexico, and extends nine miles south from the Colorado-New Mexico boundary (fig. 1).

The area covers 77 square miles in townships: T 30 N, T 31 N, T 32 N, R 23 N, and R 24 N.

Interstate Highway U.S. 25 passes through the eastern and central part of the study area. Other roads such as U.S. highways 64, 85, 87, the state highway No. 72, the Old Raton Road (Scenic Road), and other county and private roads provide access to most of the area.

Population

Raton is the largest town in northeastern New Mexico, and had a population of 9,000 in 1967. It is the county seat of Colfax County and headquarters of commercial activities for neighboring communities. It is also the center of the largest coal mining region in New Mexico (Raton Chamber of Commerce).

Several ghost towns are located in the study area, among them Sugarite, Blossburg and Gardiner. According to Lee (1922):

> Sugarite had a population of 471 in 1920, consisting of men employed in the Sugarite Mine, one of the newer openings of the St. Louis, Rocky Mountain and Pacific Company.
>
> Blossburg, in Dillon Canyon west of Raton, is one of the oldest mining towns of New Mexico; it was established after the Atchison, Topeka, and Santa Fe Railway reached Raton. In 1890 its population was 1,171, but in 1920 it was only 292,[and in 1967 zero].

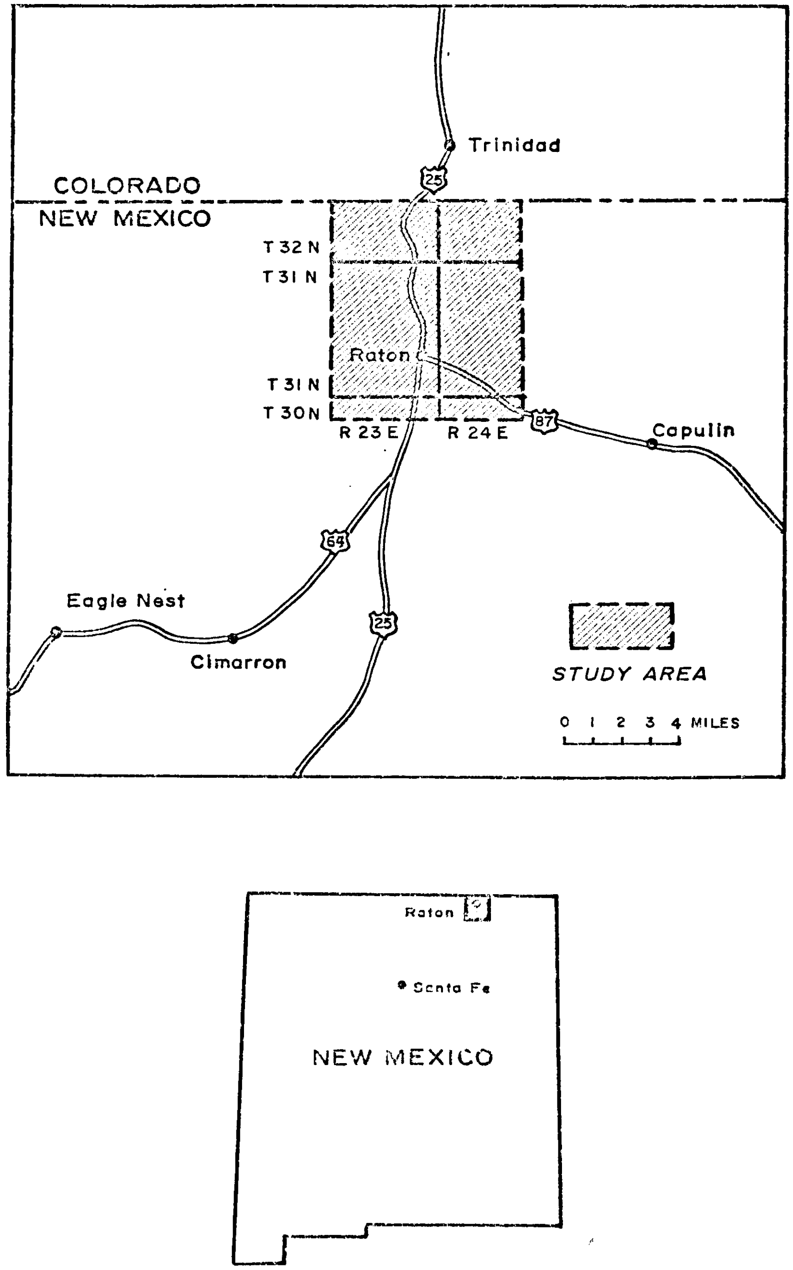

FIG. I. LOCATION OF THE STUDY AREA, RATON AREA, NEW MEXICO.

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> Gardiner, which had 985 inhabitants in 1900 had 373 in 1920.

A great part of the study area lies within the old Beaubien Maxwell Grant.

Field Methods

The field work was carried out from mid-June to about mid-September of 1965. Field observations were recorded on aerial photographs at a scale of 1:24,000 obtained from the Soil Conservation Service. The geologic data were transferred from the photos to a 1:15,850 scale topographic map prepared from a 1912 1:62,500 scale U.S. Geological Survey map of the Raton Quadrangle.

Tape and Jacob staff were used for four stratigraphic section measurements. The measured sections are composite, because a complete section of rocks exposed on the surface was not available at any one locality.

Previous Studies in the Area

The northeastern part of New Mexico was visited by Hayden as early as 1869. He made the first geological study in the vicinity of Raton, where he studied the continental deposits. Lee defined formally the Raton Formation in 1913.

Lee (1913, 1915, 1917, 1922, and 1924) made many detailed studies in the eastern side of the Raton Basin. He gave excellent and detailed descriptions of the general geology, geomorphology, igneous rocks and coal fields; the stratigraphy is treated in a more generalized manner. Lee's U. S. Geological Survey Folio 214 (1922) for the Raton-Brilliant-Koehler quadrangles, is the most detailed report available for the above mentioned area.

Knowlton (1917) made a very comprehensive study of the flora of the Vermejo and Raton Formations.

Johnson (1954, 1955, 1956) published many detailed articles between 1954 and 1961 on areas of the Raton Basin in Colorado. His detailed geologic and geographic descriptions can be partially applied to the Raton area.

Other references on the Raton area that proved valuable to this work are the following: Collins (1949), Stobbe (1949), Carter (1956), Cobban (1956), and Baltz (1956).

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GENERAL GEOLOGY

Exposed sedimentary rocks of the study area dip gently to the northwest and are mostly of Late Cretaceous and Paleocene age. Rocks of the Early Cretaceous, Jurassic, Triassic and Paleozoic age are present beneath the Late Cretaceous sequence. The whole sedimentary complex rests on a Precambrian igneous basement (Haun and Kent, 1965).

Seas invaded the area during the Paleozoic and Early Cretaceous. The sequence analyzed in the study represents the regressive phase of the Cretaceous sea; this phase is the subject of extensive discussions in the Stratigraphy Chapter.

The oldest exposed unit of the Raton area is the Pierre Shale of Late Cretaceous age. Overlying the Pierre Shale are the Late Cretaceous Trinidad Sandstone, Vermejo Formation, and the lower part of the Raton Formation (Brown, 1943); the upper part of the Raton is of Paleocene age (fig. 3 and 39). Thin Quaternary sediments and Late Tertiary igneous rocks occur also in the study area.

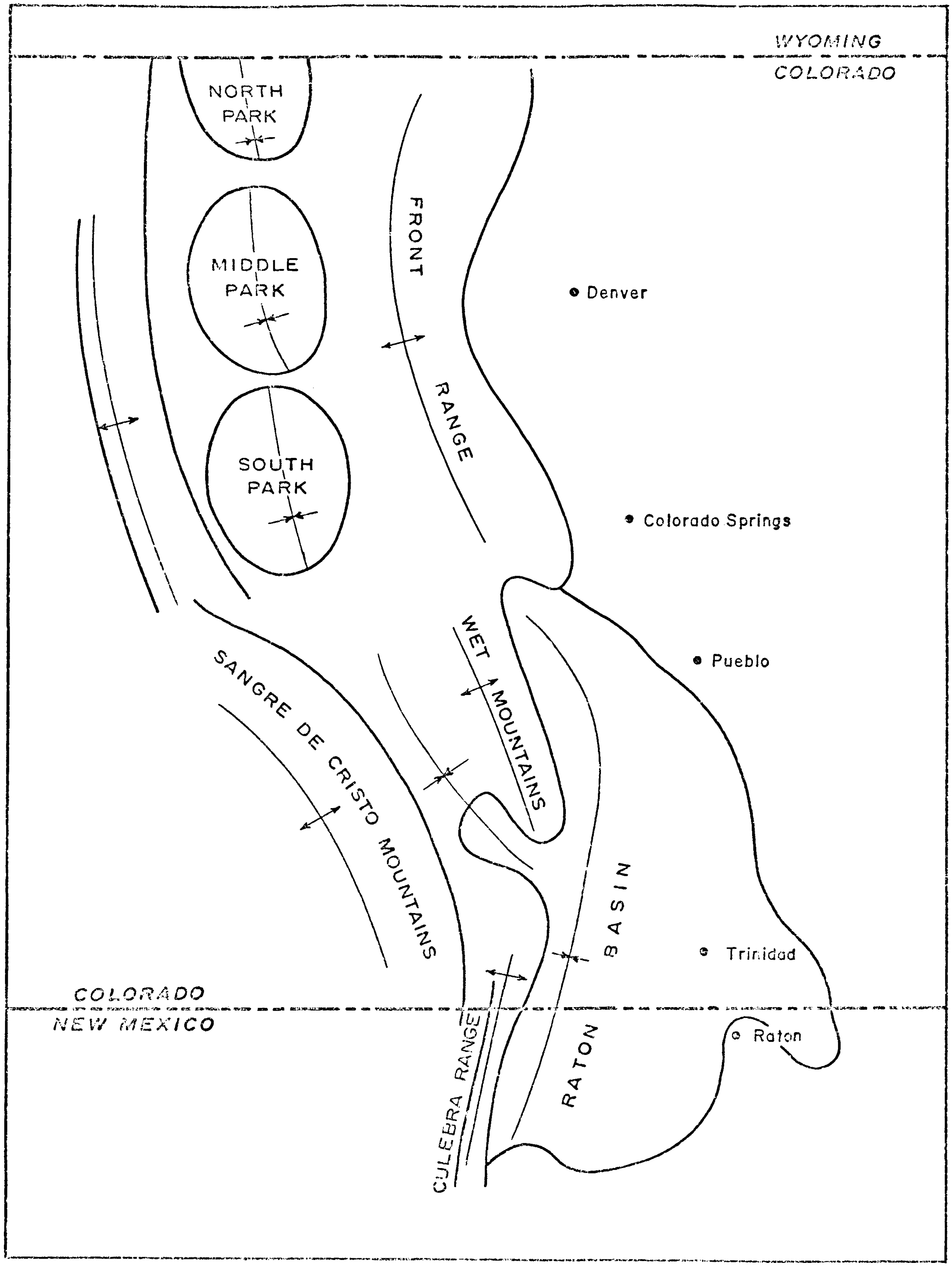

FIG. 2. PRINCIPAL STRUCTURES DEVELOPED DURING LATE CRETACEOUS TO EARLY TERTIARY TIME.

As the Ancestral Rocky Mountains emerged during the late Paleozoic, lower Pennsylvanian and older strata, which once extended over the Rocky Mountain area, were deformed. Another uplift followed during late Cretaceous and early Tertiary time; the present structural framework developed in that time (fig. 2). Four volcanic eruptive periods occurred during late Cenozoic. Only three of these volcanic episodes are represented in the Raton area.

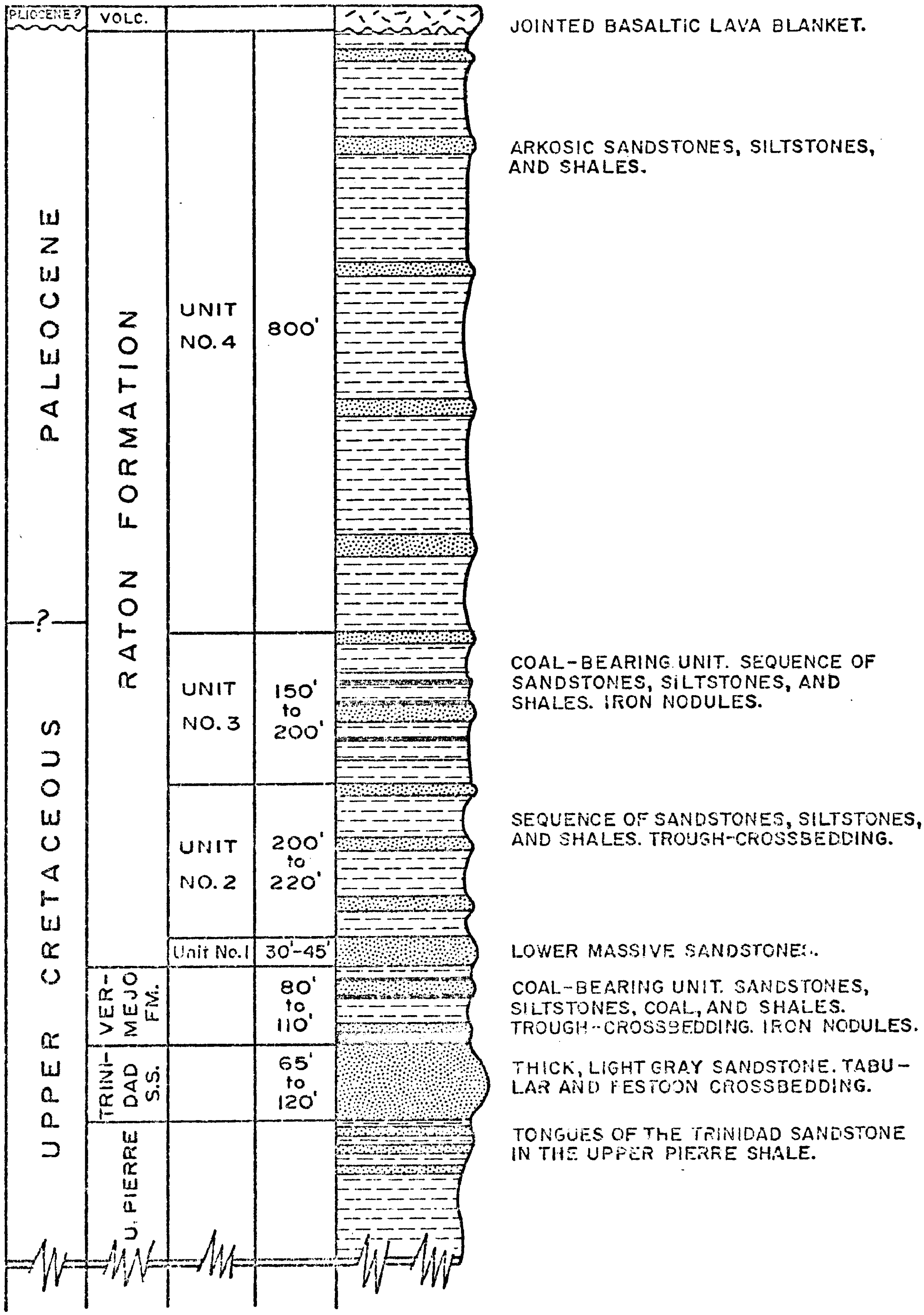

FIG. 3. GENERALIZED GEOLOGIC COLUMN OF THE RATON AREA, NEW MEXICO.

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GEOMORPHOLOGY

The study area lies in a transition zone between two geomorphic provinces, the Great Plains and the Rocky Mountains, and is from 6000 to 8860 feet above sea level. Several mesas rise to altitudes that range from a few hundred to more than 2000 feet above the general level of the plains. Large parts of the Raton area are smooth; others are characterized by low mesas, and still others by high mesas, rugged hills, and deep canyons (Lee, 1922).

The principal stream is the Canadian River, a tributary of the Mississippi River.

Three principal topographic features can be recognized: mesas, dissected highlands, and lowlands (fig. 4). Topographic relief has been influenced by the nature of the rocks. The high mesas of the study area have been protected by lava blankets. The surface on which the lavas were deposited is a remnant of a once continuous pediment which was still present in the late Tertiary. Since four eruptional periods can be traced through the Cenozoic, four different altitudes may be observed in the mesas of the Raton area (Lee, 1922). The lava blankets on the Raton, the Barrilla, and other mesas are of the first eruptive period; the Bartlett, Horse and Johnson mesas are covered by lavas of the second period; the third period is represented by the Yankee Valley lava flow, and the blankets on the Cunningham, Round and Black Mesas, to the southeast of the town of Raton; they are less than 300 feet above the general level of the plains.

Bartlett Mesa stands 2000 feet above the plain (Lee, 1922). There is one elevation on this mesa that marks clearly the location of a volcanic vent. This volcano stands near the north rim of the mesa and rises about 250 feet above the general level. A small crater can be observed at the top.

A great part of the study area consists of a dissected plateau that was still in existence during the late Tertiary. This plateau was developed upon Paleocene rocks that are more resistant than the soft Pierre Shale of the lowlands, but less resistant than the igneous rocks that cap the mesas. The western part of the study area is very dissected by streams in contrast to other parts.

Lowlands occupy the southeastern part of the study area.

They owe their existence mainly to the presence of soft, easily eroded shale. Degradation is now progressing rapidly with the increase of steep-walled gorges or arroyos.

All the above mentioned geomorphological features can be observed on the attached geologic-topographic map and cross-sections.

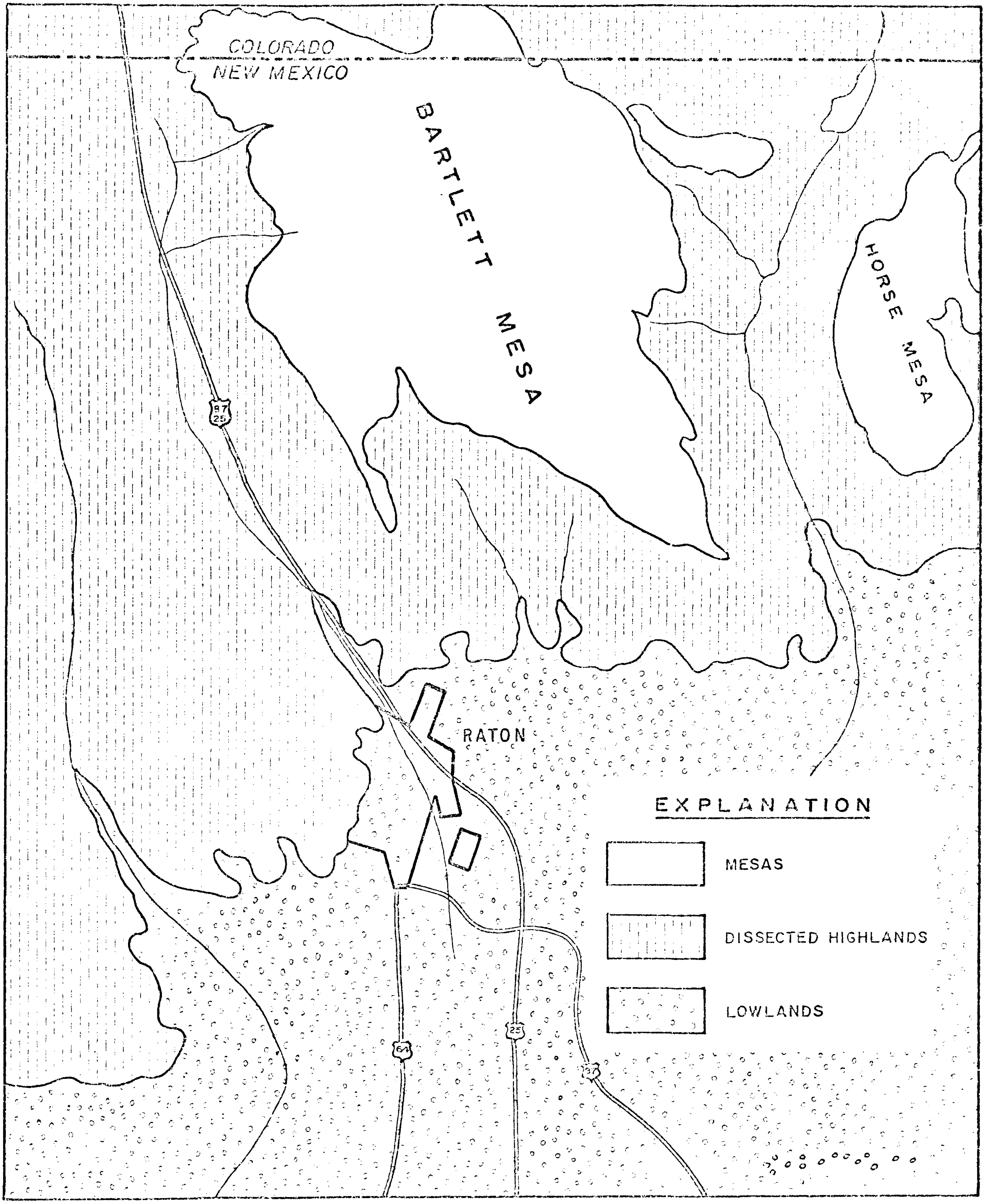

FIG. 4. PRINCIPAL TOPOGRAPHIC FEATURES OF THE AREA: MESAS, DISSECTED HIGHLANDS AND LOWLANDS.

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STRATIGRAPHY

Pierre Shale

The upper part of the Pierre Shale (Upper Cretaceous) is present in the southeastern part of the study area. This unit is approximately 2000 feet thick in northeastern New Mexico, but is 5000 feet at the southern side of the Denver Basin, (Guidebook to the Geology of the Raton Basin, 1957).

The formation was first described in the vicinity of Old Fort Pierre, Stanley or Hughes County, South Dakota, by Meek and Hayden (1862). The Pierre Shale is widely distributed throughout South and North Dakota, eastern Wyoming, eastern Montana, eastern Colorado, Nebraska, western Minnesota, and northeastern New Mexico.

The Pierre Shale consists of dark gray and bluish, sometimes fossiliferous shales. Small sandstone and siltstone lenses, and calcareous concretions are present in different parts. Where indications of sudden deposition of clastics are present fossils may occur in great numbers.

Many fossils are present approximately 80-100 feet below the top of the formation. Ammonites, corals, and worm-tubes are abundant, especially in the Sugarite Canyon. According to Lee (1922) these marine invertebrates have a wide stratigraphic range, none of them restricted to definite zones.

The upper 40-90 feet of the formation are brownish, because of the presence of iron oxides and detrital carbonaceous materials in the sequence of shale, sandstone and siltstone beds. It is possible that the carbonaceous materials originated from the Vermejo and Raton coals which were being formed at the same time in a transitional environment, in the landward direction.

The most important features of the brown part of the Pierre Formation are the sandstone tongues and lenses embedded in the shale (fig. 5 and 6). The sandstone tongues are very abundant and spread out from the lowermost Trinidad into the upper part of the Pierre Shale (pl. 5). Pierre-type shales with thin sandstones are interbedded with the lowest part of the Trinidad Sandstone. These relationships have been studied on the southern side of the Bartlett Mesa (pl. 5) where the Trinidad Sandstone thins gradually to the east. The thinning of the Trinidad Sandstone is compensated for by the increase in thickness in the transitional zone of the Pierre Shale. This is interpreted

Figure 5. Sequence of thin sandstones, siltstones and shales. Upper Pierre. Sugarite Mine.

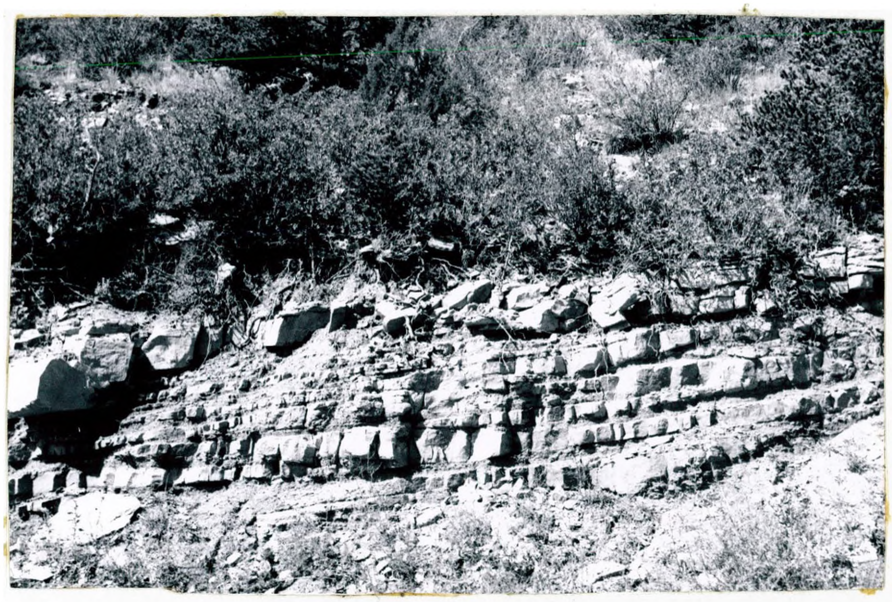

Figure 6. Sandstones in the upper Pierre. Sugarite Canyon.

as indicating that at least the lower part of the Trinidad Sandstone is contemporaneous with the marine shales of the upper Pierre to the east. Johnson and Wood (1956, p. 710) illustrate the same pattern of intertonguing between Dawson and Cimarron, New Mexico. It is very probable that intertonguing of the Trinidad and Pierre exist beneath the transition and continental types of sediments, in areas of former marine environments.

The interfingering of porous sandstones with impermeable shales may form stratigraphic traps and should be considered for oil exploration. The sandstone tongues have a maximum thickness of eight feet in the Sugarite Canyon. Greater thicknesses can be observed to the southwest of Raton, in the vicinity of Dawson. The tongues are oriented to the northeast.

Trinidad Sandstone

The Trinidad Sandstone is present in southeastern Colorado and northeastern New Mexico. It was first described by Hills (1899) in the vicinity of the town of Trinidad, Las Animas County, Colorado. He included the "transitional zone" of the upper Pierre in the Trinidad Sandstone. The "transitional zone" was labeled as lower Trinidad, whereas the massive, light gray sandstone overlying the former was defined as "Upper Trinidad". Lee (1917, p. 48) redefined the name, leaving the upper, massive sandstone in the Trinidad and assigning the lower, transition zone to the upper Pierre.

The above mentioned massive sandstone and the "transition zone" can be recognized in the Raton area; they form nearly vertical escarpments and the outcrops are, generally, fairly well preserved. The Trinidad Sandstone as defined by Lee, is an excellent geologic and stratigraphic marker in Raton basin.

The upper contact with the Vermejo Formation is transitional. Many olive-green and brown, more resistant Vermejo-type tongues are present in the light colored and non-resistant uppermost Trinidad.

The Trinidad Sandstone is a massive, feldspathic, light colored sandstone. The thickness varies between 65 and 120 feet, in the Raton area (pl. 1, 2, 3, and 4). Very thin, slightly carbonaceous shales may be present. The Trinidad usually forms cliffs that rise abruptly above the less precipitous slopes of the upper Pierre Shale.

The Trinidad Sandstone of the Raton area can be subdivided into five units, on the basis of sedimentary structures. These structures are better developed when they are at a short lateral distance from tongues that penetrate the uppermost Pierre. The Trinidad Sandstone is more massive toward the northwest and the sedimentary structures are less conspicuous in this direction. Goat Hill and the Scenic Road (see map) are the best localities to study the subdivisions of the Trinidad Sandstone (pl. 1). These units from bottom to top are:

Vermejo Formation: Sequence measured on Goat Hill and Scenic Road:

Top Trinidad Formation

Unit	Thickness (feet)	Description
5	12	This unit is principally a gray to olive-green, friable sandstone but is white in color in a few outcrops. The sorting and the porosity are variable, but generally poor. Subangular plagioclase and orthoclase feldspar grains are abundant; the matrix is kaolinitic. Some detritic carbonaceous material can be observed and a small amount of heavy minerals, such as magnetite, hematite, hornblende, biotite, staurolite, garnet and zircon are present. In many cases this unit has the aspect of a reworked material. Vermejo-type tongues are present and the sedimentary structures are generally poorly developed or missing. A few observations from tabular cross bedding indicate an average dip of 15° NE, and a direction of transport of N 70° E. Fossils are very rare in this unit.

Unit	Thickness (feet)	Description
4	17	The color of this sandstone is not as uniform as in the lower units. It is white, gray, buff and green. Fine-sized grains predominate in the white parts, but medium sized grains as well as a greater proportion of feldspar grains are more common in the green Vermejo-type tongues, which occur in the upper part of the unit; the amount of feldspars is greater in the latter. Some heavy mineral grains such as magnetite, illmenite, biotite, hornblende, garnet, zircon and hematite are present throughout the unit. Sorting and porosity of the sandstones are poor, and the matrix is kaolinitic. Small amounts of carbonaceous detritic materials are present in some outcrops, mainly in the western part of the study area. Tongues of Vermejo-type sandstone are a feature of the upper Trinidad at the eastern side of the Raton Basin. Tabular sets with a slight tendency to trough cross bedded foresets are dominant in unit four. Attitudes of cross bedding show

a greater variation than the lower units. The average dip of these structures is 17° NE; the mean value for the directions of transport is N 70° E (table 1).

Ophiomorpha sp. tubes and algae are rare.

Unit	Thickness (feet)	Description
3	10	The middle part of the Trinidad Sandstone is white to light gray in color and has, basically, the same lithology as Unit No. 2. A slightly carbonaceous shale of 1/2 to 3 feet is present in some outcrops, but this is not consistent throughout the study area. Tabular cross bedding sets are typical of the middle and upper parts of the Trinidad Sandstone and do not appear in other formations of the eastern part of the Raton Basin. These sedimentary structures of the Raton area can be best observed on Goat Hill and on the Scenic Road (fig. 7 and 8), and also appear in the middle part of the Trinidad Sandstone southwest of Trinidad, Colorado (fig. 12). In some cases, the tabular cross bedding is combined with a very low angle, almost imperceptible, trough cross-bedding. The average dip of the tabular sets is 22° NE, and the mean direction of transport point is to N 80° E. Some of the measurements of cross bedding directions are given on table 1. *Ophiomorpha* sp. tubes, and pelecypod molds are fairly abundant.

Table 1

Directions of sediment transport in tabular, crossbedded foresets, measured in Units No. 5, No. 4, and No. 3 of the Trinidad Sandstone, Goat Hill.

Unit No. 5:

N 85° E	
N 55° E	Average dip: 15° NE
N 72° W	
N 73° E	

Unit No. 4:

N 65° E	
N 72° E	Average dip: 17° NE
N 79° W	
N 69° E	

Unit No. 3:

N 70° E	
N 80° W	
N 78° E	Average dip: 22° NE
N 65° E	
N 71° E	
N 82° W	
N 74° E	

Figure 7. Tabular cross bedding cosets of Unit No. 3 of the Trinidad Sandstone. These structures are typical of this formation. Scenic Road.

Figure 8. Tabular cross bedding cosets of Unit No. 3 of the Trinidad Sandstone. Scenic Road.

Unit	Thickness (feet)	Description
2	23	This sandstone is light gray to white, with fine quartzitic grains that are subrounded, fairly sorted, very poorly cemented, more friable than in Unit No. 1; some orthoclase and plagioclase feldspar grains which alter to kaolinite are present. Insignificant amounts of magnetite, zircon and carbonaceous materials are present. The matrix is quartzitic and kaolinitic. Thin carbonaceous shales are present toward the east. Very low angle festoon cross bedding, which approaches the horizontal position may be confused with horizontal strata. Directions of sedimentary transport determined from sedimentary structures show great variation in orientation both laterally in the same horizon and vertically through the unit. Unit No. 2 has been divided into three subunits in order to measure the current directions. The average directional tendency in the lowest part was toward the southwest, and to the northeast in the middle and upper subunits (table 2).

Figure 9. Thin bedded sandstone is common in the lower Middle Trinidad (Unit No. 2). Goat Hill.

Figure 10. Festoon cross bedded coset. Unit No. 2, Trinidad Sandstone, Goat Hill.

Unit	Thickness (feet)	Description
1	25	The lowest part of the Trinidad Sandstone consists of sandstone which is light gray to white, poorly cemented, friable, with poorly to fairly sorted, fairly porous, very fine grained, subrounded, with mainly quartzitic grains, but also with a few orthoclase and plagioclase feldspar grains. The feldspar grains are altered to kaolinite and are generally smaller than their siliceous counterparts. Heavy minerals are few; some magnetite, hornblende, zircon and hematite grains are present; also some carbonaceous material may be observed. The matrix is quartzitic and kaolinitic; some siliceous cement may be present in some localities. Some gray and brown, thin shales similar in lithology to the underlying Pierre Shale are located in the lower part of the unit; these shales are more numerous in the eastern part of the study area (pl. 5). This unit is massive on Goat Hill at the western side of the study area, but toward the east it is more laminated. The fauna is represented by _Ophiomorpha_ sp. tubes (fig. 11) and shell casts of pelecypods.

Total Thickness of the Trinidad Sandstone 87 feet

Base of the Trinidad Sandstone

Figure 11. *Ophiomorpha* sp. is abundant in Trinidad Sandstone. Sugarite (ghost town).

Table 2

Directions of sediment transport measured in the festoon cross bedding foresets of Unit No. 2, Trinidad Sandstone, Goat Hill.

Lowest Part (Major tendency to the southwest)	Middle Part (Major tendency to the northeast)	Upper Part (Major tendency to the northeast)
S 4° W	N 48° E	N 71° E
S 30° E	N 60° E	N 65° E
S 2° W	N 40° E	N 40° E
S 40° W	S 29° W	S 17° E
S 61° W	N 47° E	N 64° E
N 18° E	N 2° W	N 78° E
S 28° W	N 41° E	N 43° E
S 17° W	N 5° W	N 4° W
S 7° W	N 18° E	N 62° E
S 26° W	N 51° E	N 67° E
N 7° E	N 72° E	N 11° W
S 21° E	N 81° E	S 23° W
S 45° W	N 39° E	
S 65° W	N 57° E	
S 21° E	S 38° W	
S 38° W		
S 44° W		

Figure 12. Tabular cross bedding in the middle part of the Trinidad to the southwest of the town of Trinidad, Colorado. Approximately 15 miles to the north of the study area.

Figure 13. Shale layers in the lower part of the Trinidad Sandstone, Blossburg Road.

The Trinidad Sandstone of the Raton area probably was deposited in a transitional environment partly as beach deposits and partly as shallow marine sediments; the environment of deposition is indicated by the relative position of the Trinidad between the marine Pierre Shale and the non-marine Vermejo Formation. The fauna as the *Ophiomorpha* sp. and beach mollusks, the tabular cross bedding which indicates transverse waves and the lithological characteristics of the unit support all together the above mentioned definition of the environment of deposition of the Trinidad Sandstone.

Vermejo Formation

The Vermejo Formation is the most controversial unit in the study area. The formation was first described in Vermejo Park, New Mexico, by Lee (1913).

The lower contact is transitional with the underlying Trinidad Sandstone and the distinction of the lithologic types is not difficult. The upper contact of the Vermejo Formation as defined by Lee (1922), is almost impossible to locate, especially in the vicinity of Raton. Instead, the writer has used the bottom of the "lower massive sandstone" of the Raton Formation as the most practical marker for the base of the Raton. This sandstone is the best geologic and topographic marker of the area, and is approximately twenty to forty feet higher than the contact as defined by Lee. Based on this interpretation the Vermejo is present east of Linwood Canyon, where it was not mapped by Lee (fig. 14A). According to Lee, there is an unconformity and a conglomerate that define the top of the Vermejo Formation. Nevertheless, the regional importance of the unconformity and of a conglomerate are questionable, especially in the Raton area. If the unconformity concept should be used to separate the Vermejo from the Raton, hundreds of other unconformities of the eastern part of the Raton Basin have to be taken into consideration.

Since the sediments of the Vermejo and Raton Formations were deposited in nearly similar environments of deposition their separation and identification may be difficult in the Raton area. The merger of the Vermejo and the Raton Formations into a single unit would be probably desirable in light of the mentioned facts.

It is possible that some conglomerates of the Raton basin were not deposited as a consequence of regional uplifts, but because of the rise in energy of the streams, which was due, probably, to an increase in the precipitation regime. Local conglomerate sandstone lenses as Linwood Canyon conglomerate may be of the mentioned origin. Only geologists of a great experience in the eastern part of the basin can make use of the basal conglomerate which is absent in several parts of the basin, including the Raton area. Even in areas, as to the southwest of Walsenburg, Colorado, where the conglomerate is more conspicuous, the pebble-sized grains form less than 10 percent of the sample in the best samples, but in most cases they contain less than 2 percent; it is, therefore, difficult to locate in the field. Due to the low percentage of the pebble-sized grains, it is questioned if the term "conglomerate" should be used, as it is employed in the geologic literature, or if the more appropriate terms as "conglomeratic sandstone" or simply "sandstone" should be applied.

According to Lee, the Vermejo Formation of the study area, pinches out in Linwood Canyon, and the Raton Formation rests on the Trinidad Sandstone east of that locality (fig. 14A). It is believed that the Vermejo Formation is present in areas east of Linwood Canyon for the following reasons: commercial coals are absent in the lowest portion of the Raton Formation, in contrast to the Vermejo Formation which is very carbonaceous. In this case no coal beds would exist to the east of Linwood Canyon if Lee's interpretation is considered as valid (fig. 14A). Nevertheless, according to him the Raton Formation begins to have commercial coals to the east of the mentioned canyon. To the writer, the lowest part of the Raton, as mapped by Lee (1922), is the Vermejo Formation (fig. 14B). Even if Lee included this carbonaceous zone in the lower Raton, he gave a special map color to this portion, indicating that it is different from the rest of the Raton Formation.

Lee paid no attention to the fact that the coals of the Wagon and Sugarite Mines have the same properties as the Vermejo coals. The calorific values of the Raton coals (Lee, 1924) fluctuate between 12,000 and 13,000 BTU and the Vermejo coals are close to 15,000 BTU (Lee, 1917); the average calorific value for the Sugarite Mine coals is 15,020 BTU. To the writer, Lee's (1917) "Sugarite Zone" of the lowest part of his Raton Formation belongs, actually, to the Vermejo Formation. Where Lee discovers a "basal conglomerate" below a commercial coal bed he classifies the unit as belonging to the Raton Formation, but at the same time he accepts the fact that with the exception of the local conglomerate in Linwood Canyon, this conglomerate is practically undetectable in the Raton Quadrangle.

As mentioned before, the writer places the contact of the Raton and Vermejo Formations at the base of the lower massive sandstone of the Raton Formation, which has the best topographic expression on the eastern side of the basin.

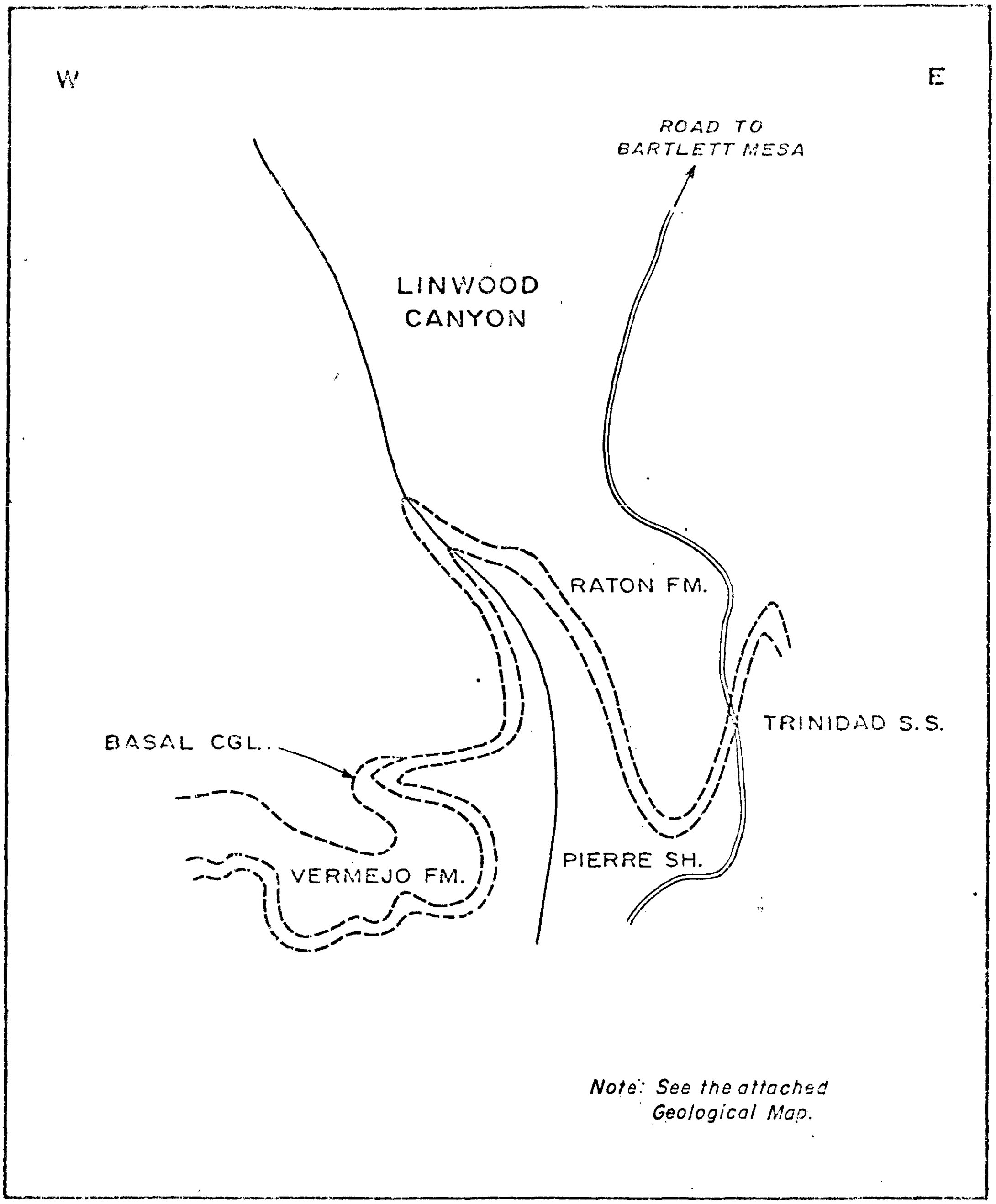

FIG. 14A. PINCHOUT OF THE VERMEJO FORMATION IN LINWOOD CANYON AS MAPPED BY LEE (1922).

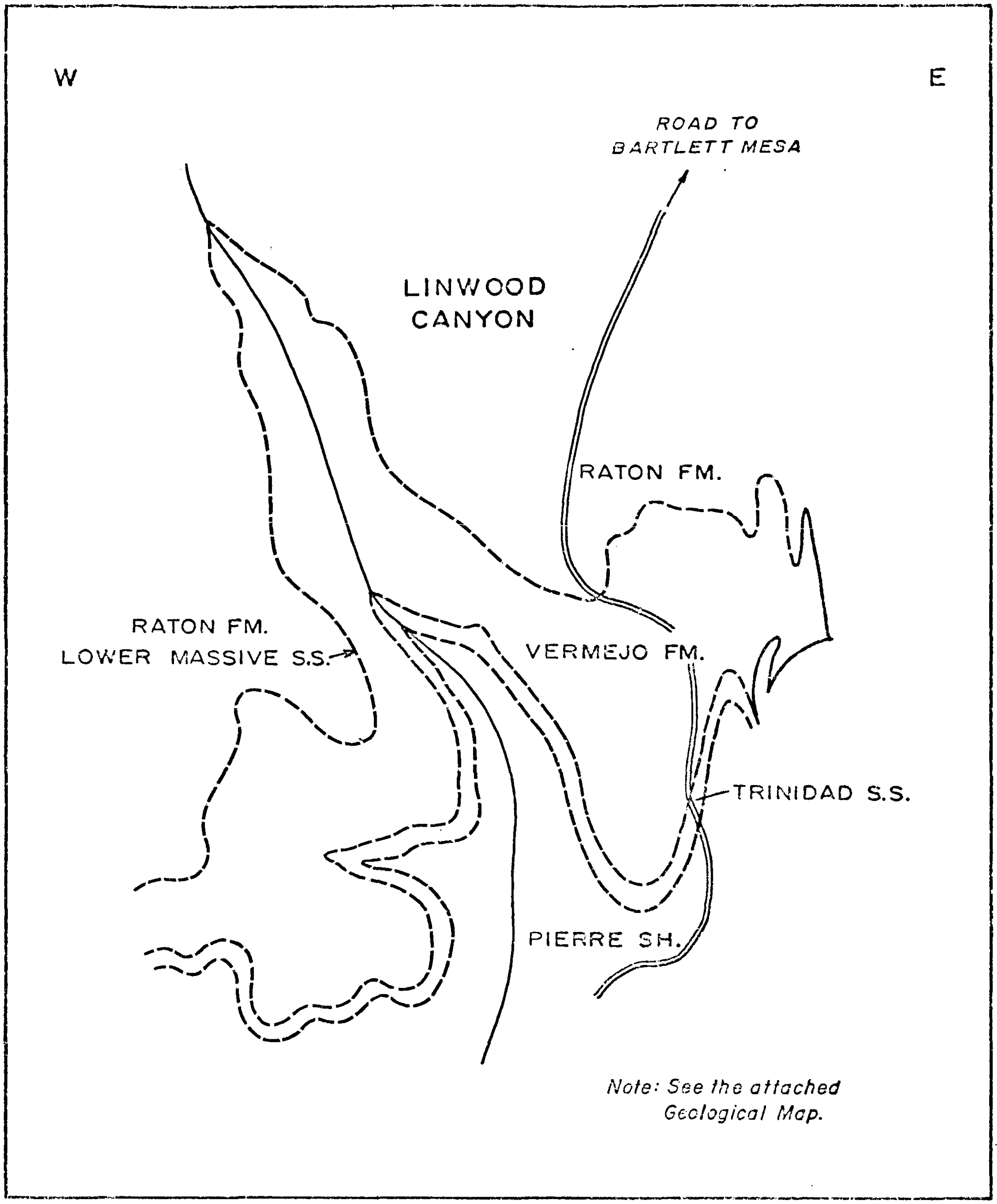

FIG. 14 B. INTERPRETATION OF VERMEJO – RATON RELATIONSHIP IN LINWOOD CANYON (THIS PAPER).

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This sandstone is probably 20 to 40 feet higher than Lee's formational boundary.

The writer believes that in the U. S. Geological Survey Bulletin 752, plate III, Lee uses the "lower massive sandstone" of the Raton Formation (Koehler area) to define the limit between the formations under discussion.

Sideritic nodules, very abundant in the Vermejo of the Raton area, can be located very easily to the east of Linwood Canyon. The mentioned nodules are very important for correlation purposes in the Raton area, because the next zone, rich in sideritic nodules is Unit No. 3 of the Raton Formation, 300 to 400 feet higher, stratigraphically.

The Vermejo Formation is 80 to 110 feet thick in the area and the lower contact, as mentioned before, is transitional. The lithologic description of this unit is basically from the outcrops exposed on the Scenic Road and on Goat Hill (pl. 1) and is as follows:

Vermejo Formation: (Sequence measured on Goat Hill and Scenic Road):

Top Vermejo Formation

Unit	Thickness (feet)	Description
7	17.5	This unit is a very carbonaceous shale, especially at the lower part where many coal beds exist. This unit is the principal producer in the Blossburg coal mining district (fig. 18). Plant structures can be observed in the coals. Thin interstratifications of sandstones and siltstones are present.
6	14	Gray to brown colored, massive sandstone with fine to medium sized, subrounded grains, fairly cemented, medium hard and poorly to fairly porous. More ferrous "lenses" than nodules and some cross bedding that is distorted by slumping, may be observed.
5	12	Soft, very carbonaceous shale, with a few siltstone layers and many coal layers are present.

Unit	Thickness (feet)	Description
4	8	Gray to light brown colored sandstone. Fine to medium grained, and poor to fair sorting. The matrix is silicic and feldspathic. Great numbers of sideritic features, mainly nodules. Also some trough cross bedding disturbed by slumping can be observed.
3	7.5	Soft gray and brown shale. No coal layers are present.
2	8	Well bedded, buff, fine-grained, poorly to fairly sorted, friable sandstone, with interlaminations of siltstones and shales; high content of orthoclase and plagioclase feldspars. Some grains of hematite, garnet, hornblende and biotite are present. Sideritic nodules are abundant.
1	29	The Vermejo has a thin, dark brown, poorly sorted, arkosic, fine-grained sandstone at the base, with many sideritic features, plant remains and worm tracks; this bed is followed by a thick, very carbonaceous shale, with thin coal layers and small siltstone and sandstone lenses.

Total Thickness of the Vermejo Formation: 101.5 feet

Base of Vermejo Formation

Three carbonaceous zones have been described; they have a regional importance in the eastern part of the basin. The individual coal beds cannot be correlated for great distances, but a carbonaceous zone of a medium thickness is more useful as a semi-regional geologic marker.

Trough cross bedding and slump structures are widely distributed throughout the study area (fig. 20). Paleo-current measurements indicate directions of transport from N-S to E-W, with an average of N 40° E for the Raton area. Ripple marks are well developed in some outcrops of the upper Vermejo (see figs. 15, 16, and 17). Channels cutting older strata are common (fig. 19).

Most of the Vermejo fossils consist of impressions of leaves that occur in shales. They are of Montanan age, according to Knowlton (1917).

Figure 15. The ripple marks were formed by current action in shallow lakes in the upper part of the Vermejo Formation.

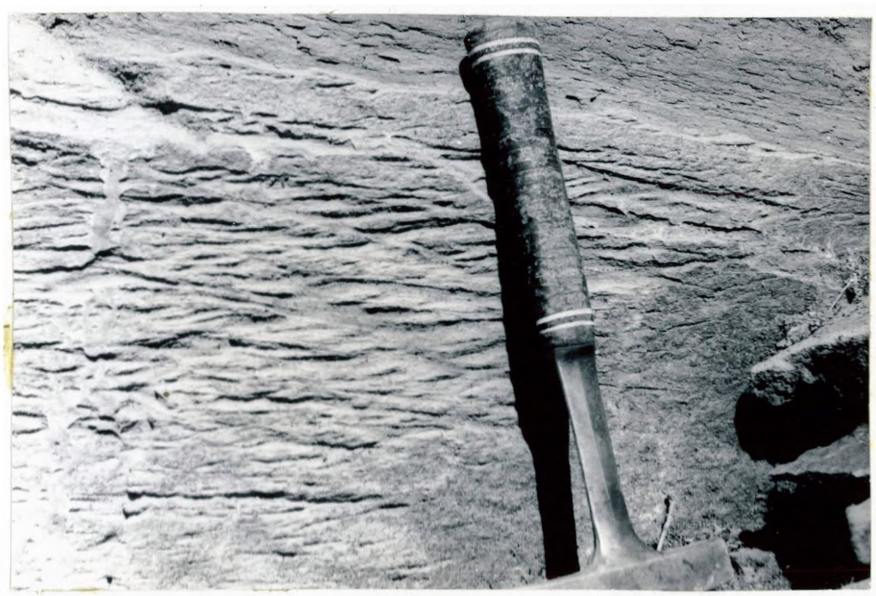

Figure 16. Ripple marks in the upper Vermejo Formation, Sugarite Canyon.

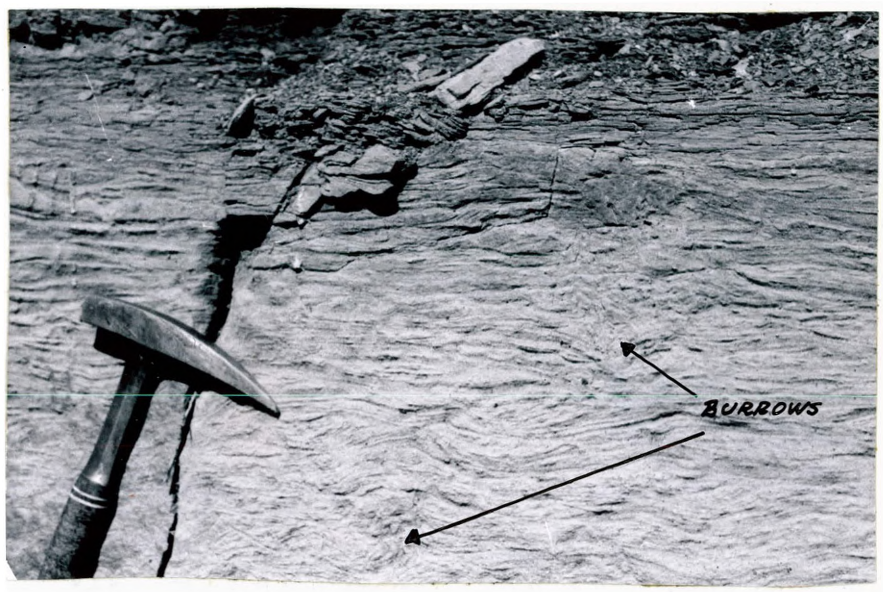

Figure 17. Ripple marks on the upper Vermejo modified partly by animal burrows. Sugarite Canyon.

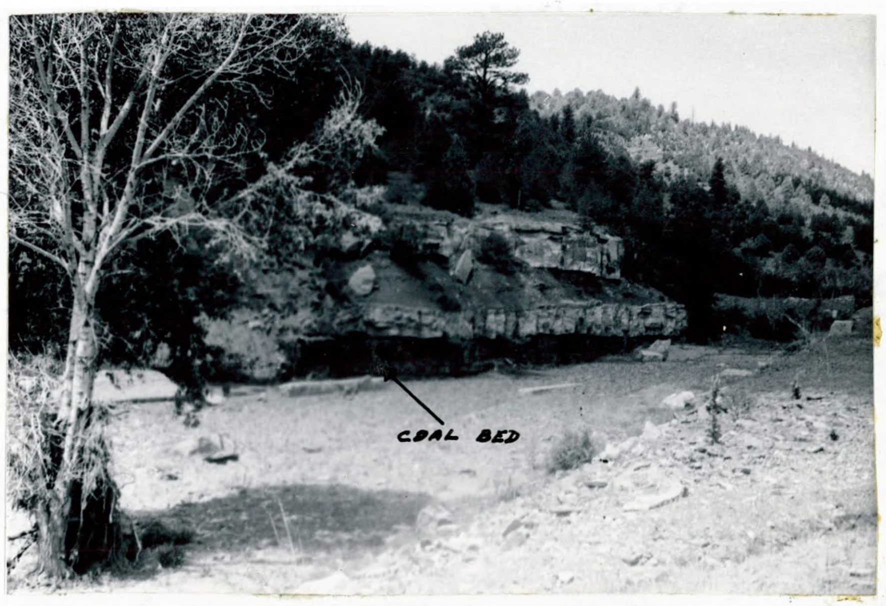

Figure 18. Principal coal bed in the Vermejo Formation. Blossburg Coal District, New Mexico.

Figure 19. This illustration shows how channels destroyed older strata in the Vermejo Formation. These channel deposits are a common feature in both the Vermejo and Raton. The structures show lateral shifting depositional processes.

Figure 20. Trough cross bedding distorted by slump processes. Middle Vermejo. Scenic Road.

Raton Formation

The continental-type deposits of the Raton area were first described by Hayden (1869) in the Raton basin. This formation was formally defined by Lee (1922). The unit consists of sandstones, shales, carbonaceous shales, coals, and some conglomerates which weather to yellowish-brown. The lower portion is considered as Upper Cretaceous, whereas the rest is Paleocene (Brown 1943).

There is a great lack of lateral continuity and a great lithologic variation in the different parts of the Raton Formation. This formation is 1,300 feet thick in the vicinity of the Colorado-New Mexico state line and 750 feet on the southern side of the Bartlett Mesa. This difference in thickness was caused by the erosion that took place before the lava blanket that covers the Raton, was spread over the area. The variations in the lava thicknesses at the rim of the mesas show that the relief was not smooth and that erosional features, such as small valleys, were present before the Tertiary volcanic eruptions took place. Lithologic descriptions are based on information gathered in Railroad and Sugarite Canyons, and the study of rock samples (pl. 2 and 4).

The sediments are similar to the swampy environment described by Krumbein and Sloss (1951). Four general subdivisions of the Raton Formation can be recognized in the Raton area. The units from bottom to top are:

Raton Formation (Sequence measured in Sugarite Canyon).

Top of Raton Formation

Unit	Thickness (feet)	Description
4	830	This unit is a sequence of sandstones, shales and claystones, which are slightly carbonaceous in some places. Several sandstones are almost 30 feet thick, locally, but most of them form lenses; the sandstones are light brown, with subangular, fine to medium sized grains. Their sorting is generally poor. Quartzitic grains predominate, but the amount of orthoclase and plagioclase feldspars, and kaolinitic materials is very high. Heavy minerals such as magnetite, biotite, zircon, hematite, hornblende and pyrite, are present in insignificant amounts. Poorly developed trough cross bedded structures are usually deformed by slump processes. The percentage of sandstones is lower than in Unit No. 3.

Unit	Thickness (feet)	Description
		The soft shales at the bottom, change gradually to claystones. In most cases Unit No. 4 is covered by Quaternary landslides and the identification of the different beds is very difficult and probably incomplete.
3	150-200	This is a very continuous, dark, coal-bearing zone. Unit No. 3 is a sequence of thin to medium thick-bedded sandstones, siltstones, slightly to very carbonaceous shales, and coal beds ranging from ¼-inch to 15 inches in thickness. It contains a great number of sideritic concretions with plant remnants in their interior; they range from 1/8-foot to 7 feet in diameter. In the mapped area, these sideritic concretions were observed in the Vermejo Formation and Unit No. 3 of the Raton Formation, only. This unit is well represented on plates 2 and 4. The sandstones are gray to light brown, with fine subangular, poorly sorted grains; they are friable to medium hard. A high amount of orthoclase and plagioclase feldspar grains and kaolinitic material and also some

Unit	Thickness (feet)	Description
		heavy minerals, such as magnetite, hornblende, garnet, pyrite, biotite, and hematite are also present. The thin sandstones are generally well bedded and have interlaminations of carbonaceous shales and siltstones. The more massive sandstones have a poorly developed trough cross bedding deformed by slump processes. Sediment transport measurements in the Lake Malloya area indicate a change from an average N 40° E in the western part of the study area to E-W and S-E directions in the northeast (pl. 6). Sandstone lenses and a great number of beds that have been destroyed by new channel patterns are characteristic of this unit. The energy of the streams was very high during this period and great quantities of reworked materials are present, especially along Highway U.S. 25 (see figs. 21, 26, 27, and 28).
2	200-220	This is a sequence consisting of thin to medium-bedded sandstones, siltstones, shales and thin carbonaceous shales. In rare occasions, there are thin noncommercial coal

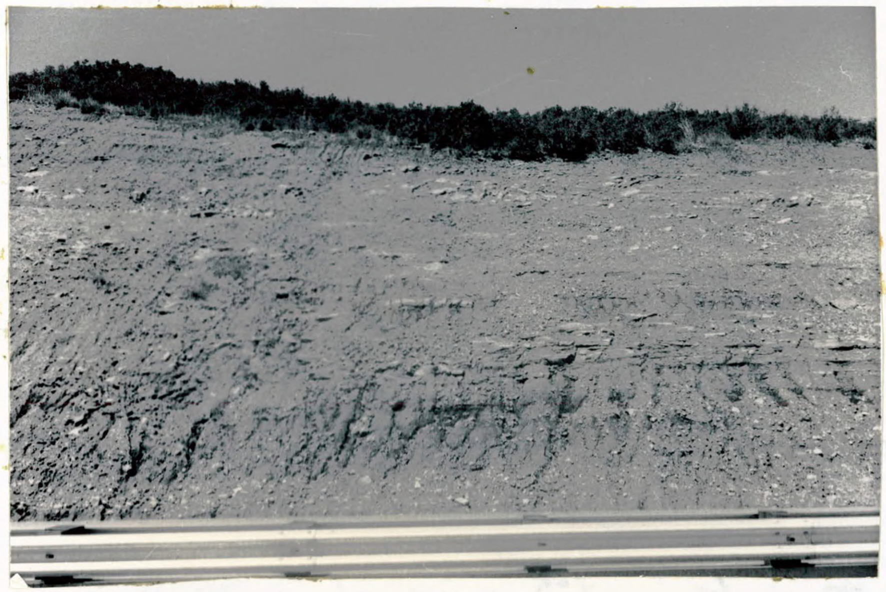

Figure 21. Unit No. 3, Raton Formation. Railroad Canyon.

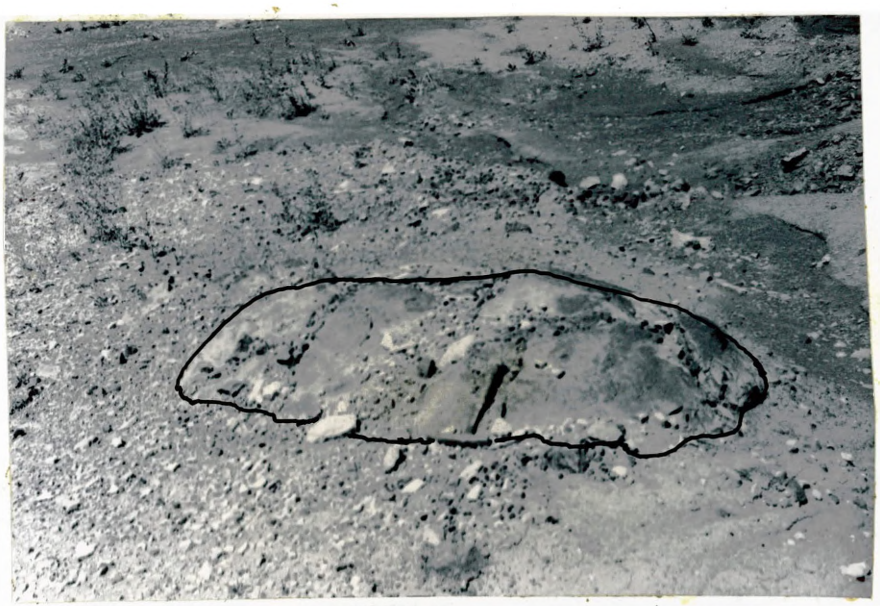

Figure 22. Large sideritic concretions characteristic of Unit No. 3 of the Raton Formation. Vicinity of Lake Malloya.

Figure 23. Sideritic concretions with concentrations of plant remains. Unit No. 3, Raton Formation, Lake Malloya.

Figure 24. Sideritic concretions near Wooton Ranch, Unit No. 3, Raton Formation. Interstate 25 Highway.

Figure 25. Sub-parallel strata probably formed in quiet lakes where current action was negligible. Unit No. 2, Raton Formation. Railroad Canyon.

Figure 26. Unit No. 3 of the Raton Formation is characterized by many coal layers and channels. Outcrop in Railroad Canyon.

Figure 27. Unit No. 3, Raton Formation. Depression of underlying strata as a result of deposition of large sandstone boulders. Penecontemporaneous compression. Interstate Highway 25.

Figure 28. Carbonaceous shale unit eroded by fluvial currents during the Late Cretaceous. Interstate Highway 25.

Unit Thickness (feet) Description

beds at the bottom of this unit.

The sandstones are darker than in Unit No. 1. They have fine and subrounded grains; the sorting and porosity are poor to fair, and some siliceous cement is present. The amount of orthoclase and plagioclase feldspars is high; they are partially altered to kaolinite. Iron concretions are practically absent from this unit.

Some laterally discontinuous fairly massive sandstones ranging from 1 to 30 feet are characteristically found on the southern side of the Bartlett Mesa. The lateral extent of the individual sand bodies is two miles along the face of the mesa. These sandstones are present in other parts of the area but are not so conspicuous.

The best-developed trough cross bedding structures of the Raton area are in this unit; in many cases they are distorted by slump processes (figs. 31 and 32). Trough cross bedding is also present in other units of the Raton and the Vermejo Formations, but

Unit	Thickness (feet)	Description
		is absent in the Trinidad Sandstone. Lenticular sand patterns are very frequent in this unit (see figs. 29 and 30). The subparallel horizontal strata (fig. 25) suggest that these sediments were deposited in low energy environments.
1	30-45	"Lower massive sandstone": This sandstone is 30 to 50 feet thick, light gray to light buff, with medium sized, subrounded, medium sorted, fairly well cemented, quartzitic grains but with a high percentage of feldspars; it is a massive cliff-forming unit which can be consistently recognized throughout the eastern part of the Raton Basin (fig. 21). Very poorly developed trough cross bedding and some slump structures are present (figs. 33, 34, 35 and 36). The mineralogical composition is fairly constant throughout the area; the amount of feldspars decreases slightly toward the east. The sandstone is moderately jointed in many outcrops (figs. 50 and 51).

Total Thickness: 1,300 feet

Base of Raton Formation

The flora is very abundant in the Raton Formation. It has been well covered by Knowlton (1917). The fauna is poorly preserved, but it was, undoubtedly, very abundant, especially in the swampy environment of the Raton time.

Figure 29. The lenticular sand pattern is common in a low energy environment of deposition (Unit No. 2), Raton Formation. Railroad Canyon.

Figure 30. Compaction of underlying strata may influence the thickness of the sand lenses, Unit No. 2, Raton Formation. Railroad Canyon.

Figure 31. Trough cross bedding modified by slump processes. These structures are better developed in Unit No. 2 of the Raton Formation, but are also present in other zones of the Raton and Vermejo Formations. Outcrop on Scenic Road.

Figure 32. Outcrop with overturned foreset beds. Scenic Road.

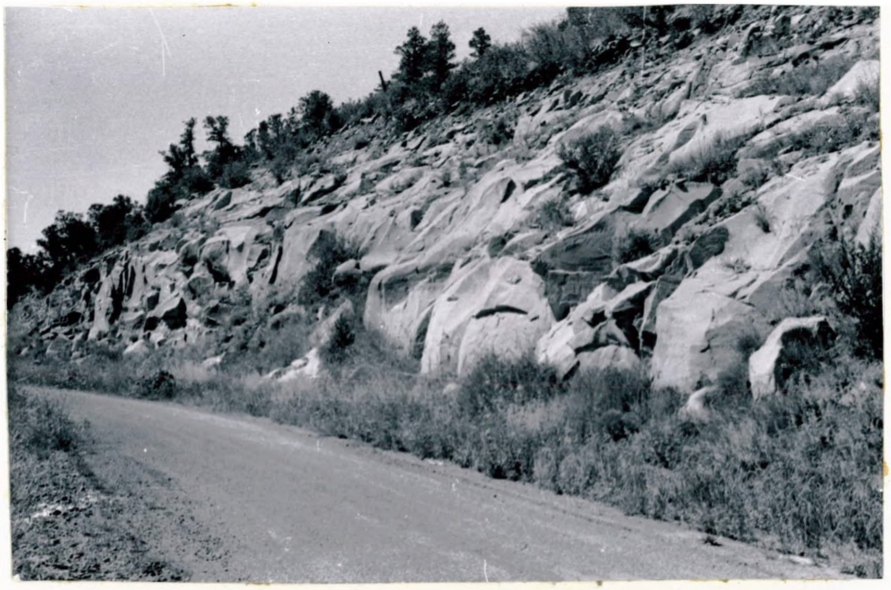

Figure 33. Lowest massive sandstone of the Raton Formation (Unit No. 1). It is the best topographic and geologic marker of the area. Outcrop on the Scenic Road.

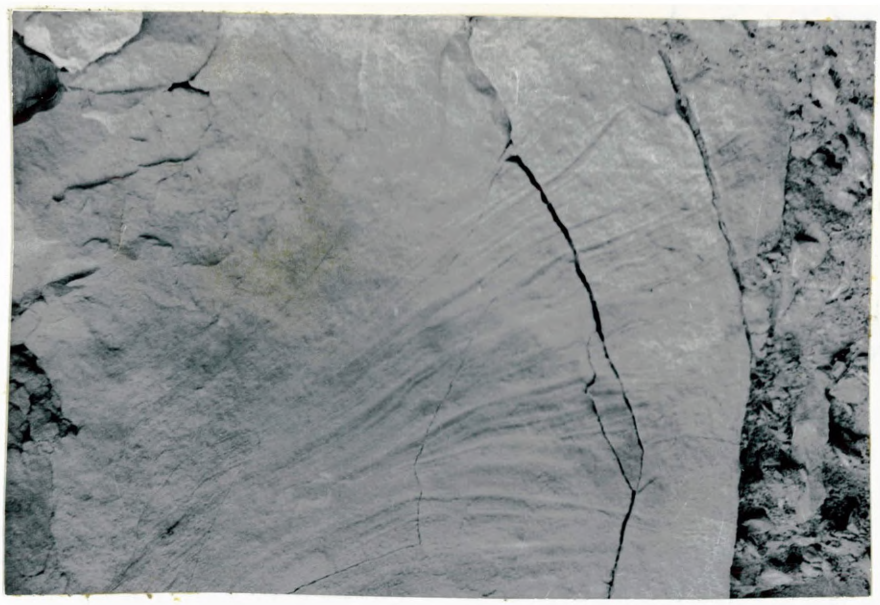

Figure 34. Contorted bedding in the "lower massive sandstone" (Unit No. 1) of the Raton Formation. Railroad Canyon.

Figure 35. Contorted bedding in the "lower massive sandstone" of the Raton Formation. Railroad Canyon.

Figure 36. Contorted sedimentary structures in the same sandstone. Railroad Canyon.

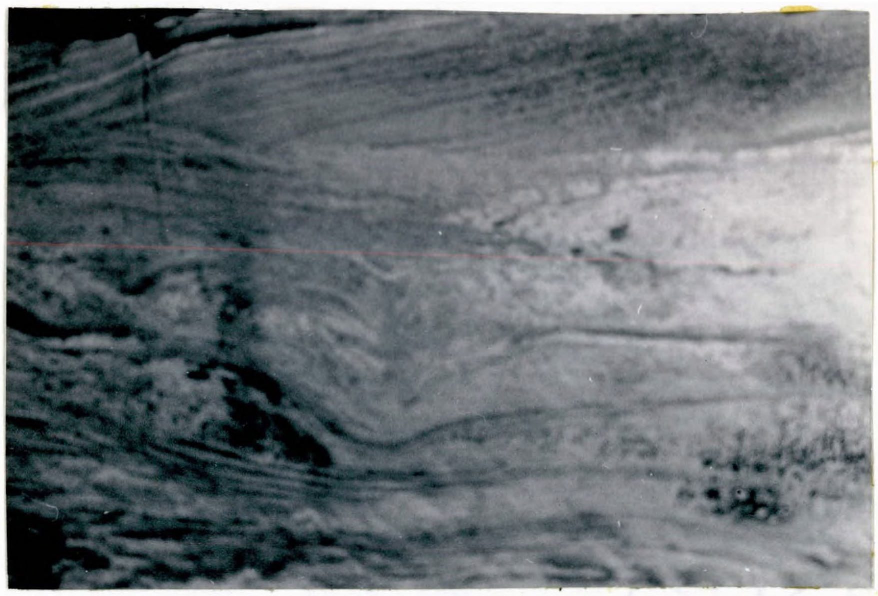

Figure 37. Sedimentary structures in the "lower massive sandstone". Railroad Canyon.

Environment of Deposition

Upper Cretaceous and Paleocene Sediments

The most important criteria which have been used to develop interpretations of the environments of deposition are the following: the lithologies of the sediments, the relative position of the different stratigraphic units, the sedimentary structures and, to some extent, the fossil remains in the rocks. From this evidence it is believed that the Upper Cretaceous and Paleocene sediments of the Raton area represent the products of deposition in three basic sedimentary environments: marine, transitional and continental.

Sediments deposited in marine and transitional environments are widely represented in the study area; non-marine sediments of the Poison Canyon Formation outcrop two or three milys west of Blossburg.

Deposition of the Upper Cretaceous and Paleocene units took place in a broad, shallow trough or geosyncline (Lee, 1922). The shale-sandstone sequence of the upper Pierre Shale is the result of deposition during a time of minor oscillations of the sea level. At the time of deposition of the upper Pierre the sediment depositional pattern was one of rapid seaward progradation, especially to the northeast of the present town of Raton. Figure 38 indicates a body of continental and

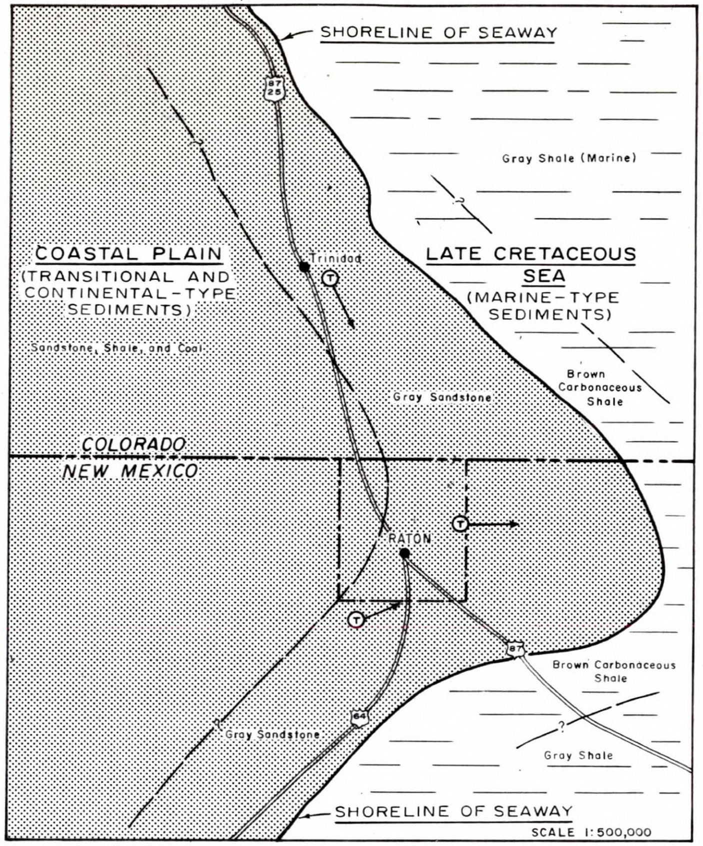

FIG. 38A. PALEOGEOGRAPHIC AND LITHOFACIES INTERPRETATION OF THE EASTERN SIDE OF THE RATON BASIN AT THE TIME OF DEPOSITION OF THE TRINIDAD SANDSTONE.

AN ARCUATE LITHOFACIES PATTERN OF COASTAL PLAIN STRATA (NON-MARINE AND TRANSITIONAL TYPE) PROTRUDING INTO THE MARINE BASIN;

THE AVERAGE DIRECTIONS OF SEDIMENT TRANSPORT INDICATE THAT THE MAIN DRAINAGE OUTLET OF THE REGION WAS TO THE NORTHEAST AND TO THE EAST OF RATON, NEW MEXICO, DURING THE LATE CRETACEOUS AND THE PALEOCENE.

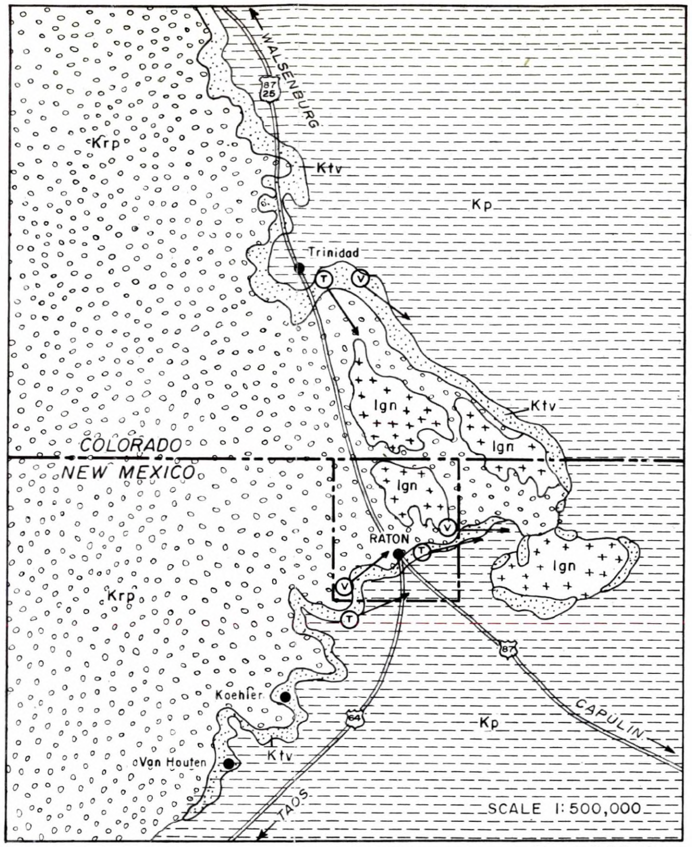

FIG. 38B. GEOLOGIC MAP OF PART OF THE EASTERN SIDE OF THE RATON BASIN.

LITHOLOGY

Kp	PIERRE SHALE & OLDER UNITS
Krp	RATON AND POISON CANYON FORMATIONS
Ktv	TRINIDAD SANDSTONE AND VERMEJO FORMATION
Ign	IGNEOUS ROCKS

AVERAGE DIRECTIONS OF SEDIMENT TRANSPORT:

(T) → IN THE TRINIDAD SANDSTONE
(V) → IN THE VERMEJO SANDSTONE

BY H. ZEUSS

transitional sediments protruding into marine sediments that might have been a delta.

The fossil remains, the sedimentary structures and the lithology indicate that the upper part of the Pierre Shale and Trinidad Sandstone were deposited in epineritic and beach environments. At the same time that the upper Pierre Shale was being deposited to the east in the sea, transitional and non-marine type deposits were deposited landward, to the west. The writer believes that the Trinidad Sandstone, the Vermejo Formation, the Raton Formation and probably the Poison Canyon Formation are more landward time-stratigraphic equivalents of the Pierre Shale. At the time the Pierre Shale was deposited it is logical to assume that certain, more continental facies existed in the landward direction. Field observations of the intertonguing relationships of the upper Pierre with the Trinidad indicate that at least partly, both units have been deposited at the same time (pl. 5). Vermejo-type tongues 20 feet below the top of the Trinidad Sandstone suggest a same formation age for both units. It is difficult to find traces of any possible carbonaceous units other than those of the Vermejo and the Raton in the Raton Basin, that existed during the deposition of the Pierre Shale. It is believed, therefore, that the carbonaceous debris that are present in the Trinidad Sandstone and the

Pierre Shale indicate the existence of carbonaceous units in the landward direction which might have been the Vermejo and the Raton Formations.

The above discussion supports the hypothesis of a time-equivalence of the Raton, the Vermejo, the Trinidad and the Upper Pierre. Lee (1922, p. 6, fig. 14) and Johnson and Wood (1956, p. 76, fig. 3), also believe in the time-equivalence of the above mentioned units. Figure 39 of this study indicates the development of the stratigraphic pattern, during the Late Cretaceous in the Raton area.

It is believed that the study area was on the southern side of a delta. Different data, such as the above mentioned continental sediments that protrude into the Pierre Shale at the eastern side of the Raton basin, the study of the directions of sediment transport, the extreme variety in sedimentary structures and shape of the sand bodies, the presence of many channels, the variations in grain size, and the approximate agreement of the stratigraphic section of the Raton area with Weimer's (1965) criteria for the recognition of a delta and with Visher's (1965) "deltaic vertical profile", are a great support for a hypothesis of a deltaic outlet for the area.

The wide range of conditions of a deltaic environment is largely dependent upon water depth and supply of clastic

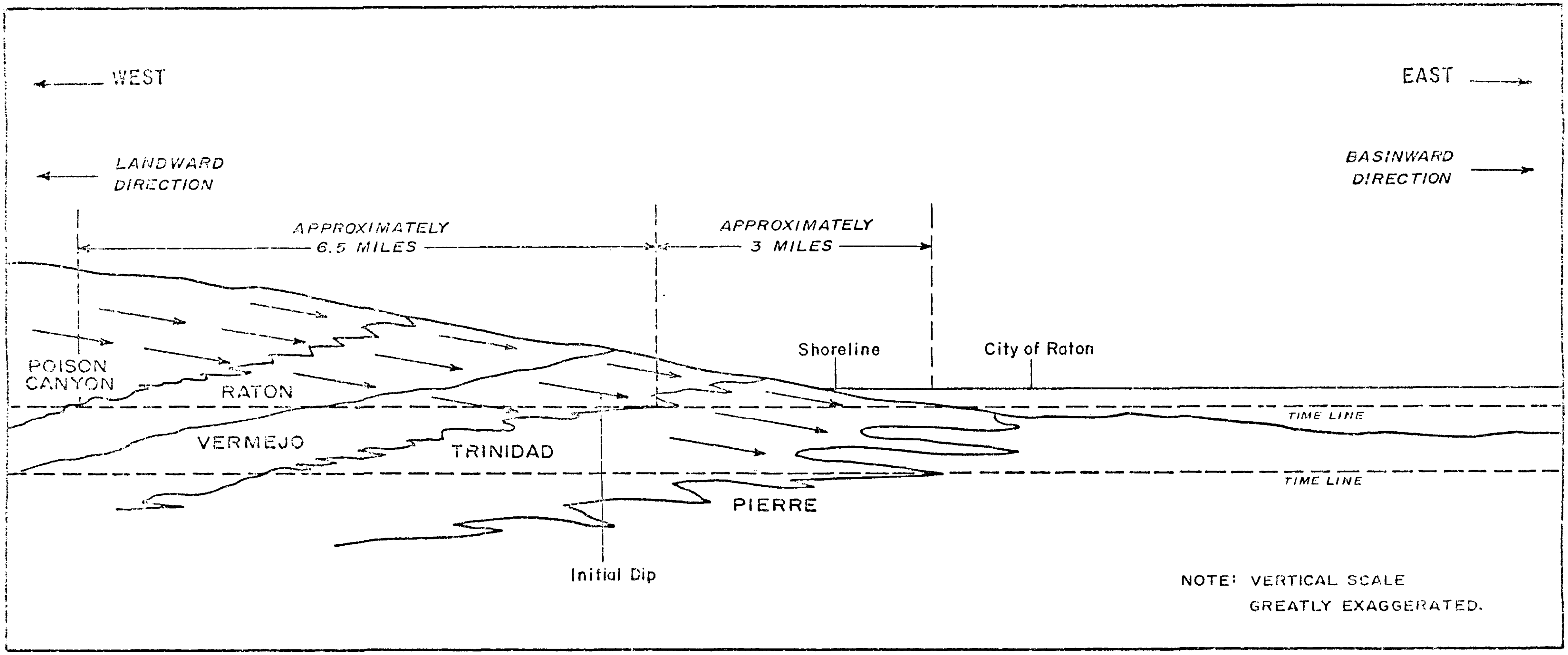

FIG. 39. LATERAL RELATIONSHIPS OF THE UPPER PIERRE, TRINIDAD, VERMEJO, AND RATON FORMATIONS DURING THE TIME OF DEPOSITION.

BY H. ZEUSS

material. According to Krumbein and Sloss (1951), the deltaic environment is a composite of several, including alluvial, lacustrine, eolian, lagoonal, swamp and beach environments of deposition.

Weimer (1961, 1965) indicates that the development of deltas was a very common feature in the Western Interior during the Late Cretaceous.

Weimer (1965) gives a summary of several criteria that may be used for the recognition of deltas:

> "1) An arcuate lithofacies pattern ~~protruding~~ of coastal plain strata (non-marine) protruding into the marine basin; 2) for a designed time-stratigraphic unit, thickest deposits in the general shore line zone (area of topset and foreset strata associated with this lithofacies pattern); 3) a complex intertonguing of marine (foreset and bottomset strata) and non-marine (topset) strata; 4) rapidly changing shore line sandstone trends from one time-stratigraphic unit to another; 5) abundance of stream deposits over deposits of other environments of coastal plain; 6) biological criteria in marine strata, especially lack of fossils (absence of pelagic calcareous foraminifera); arenaceous bentonic forms tend to dominate; 7) persistence of above criteria in vertical sequence indicating semipermanency of drainage system responsible for deltaic deposits."

All points of the deltaic pattern defined by Weimer (1965) can be applied to the Raton Mesa area of the Raton basin. The sedimentary sequence is especially thick, and continental deposits protrude very definitely into marine deposits (fig. 38). The average directions of sediment transport in the Raton and Trinidad area indicate that the main drainage outlet for the region was to the northeast and east of Raton.

Indications of the presence of a deltaic complex in the study area are:

a) The average directions of sediment transport are to the southeast in the Trinidad area, Colorado, and to the northeast in the Raton area, New Mexico; this is an indication that the principal outlet of the area was to the northeast and to the east of the city of Raton.

b) The different streams of the delta shift very frequently but there is also a general consistence in the average direction of the currents. Many channels, coal beds and sandstones have been eroded away continuously by new currents.

c) The energy of the streams was not always uniform. At times of greater stream energy bodies such as the Linwood Canyon conglomerate lens were formed.

d) The biological complex is very variable. Figure 39 shows stratigraphic units at relatively small horizontal distances, which have been formed in different environments of deposition. In a short horizontal segment, ammonites, beach fauna and remains of palms and trees (Knowlton, 1917) are present.

e) The oxidation-reduction conditions vary extremely in very short distances. A reducing environment may have lain less than one mile from a well-oxygenated area.

f) The vertical section through the delta shows great variations, especially in the sedimentary structures. Weimer's (1965) criteria for the recognition of a delta can be applied to the upper Cretaceous and Paleocene sediments of the Raton Mesa region. Visher's vertical profile for a delta can be applied to this case.

j) Crossbedding, cut and fill structure, and current ripples are common structures in the sediments.

k) Abundant detrital carbonaceous material in the upper Pierre Shale may suggest a prodelta deposit.

l) Krumbein (1951) states, "Away from the delta, some one of the individual environments in the deltaic complex begin to dominate. Oceanward, the delta merges into typical marine environment, and, along the coast on both sides of the delta, it may display a normal beach environment or combination of lagoonal and beach environment."

As the delta was being developed, a great number of swamps were present in and behind the deltaic zone; this was the environment where the Vermejo and Raton Formations originated. These units were deposited in shallow lagoons which were separated from the sea by thin strips of land. The lakes received fresh water sediments mainly although some sea-water might have been poured-in for short intervals of time. High energy acted along the stream patterns, where many sedimentary structures took their origin.

The above discussion indicates, clearly, that there are many evidences that give support to the presence of a deltaic complex in upper Cretaceous and Paleocene sediments of the Raton Mesa area. Deltaic sediments have a great, practical interest especially for petroleum exploration.

Quaternary Rocks

Four varieties of unconsolidated sediments of recent origin are present in the study area. They are alluvium and wind deposits, stream gravel, landslides and talus deposits. All these rocks are in an unconformable relation with more ancient rocks.

According to Lee (1922, p. 13), sheets of alluvium have been distributed by streams along their courses through the lowlands and also in the broad mouths of the canyons. At present, most of the streams occupy deep cut trenches in these sheets.

Another type of Quaternary sediments is the stream gravel terraces, which are well developed to the south of the study area. Smaller terraces can be observed in the different canyons. Some of the gravels are fairly well cemented.

A few landslides are located on the slopes of the mesas of the area. Considerable masses of sedimentary rocks leave good exposures of fresh outcrops of rocks.

The talus deposits are formed by the fall of large basaltic masses from the rim of the lava blankets on the mesas. The masses are scattered down the slopes and a great part of the material reaches the plains. In some places of the Sugarite Canyon the talus is so abundant that it is almost impossible to study the underlying Raton Formation, especially Unit No. 4.

IGNEOUS ROCKS

The igneous rocks of the area rest unconformably on the underlying strata. Two general types are present in the study area: extrusive lava blankets, and intrusive dikes.

Very detailed descriptions of igneous rocks have been given by Lee (1922), Stobbe (1949) and Collins (1949). According to Lee, four successive general periods of volcanism that took place from the late Tertiary to the Quaternary, can be identified in northeastern New Mexico when the relative positions of the lava blankets are analyzed. During every period many flows of lava made their appearance, but at short intervals of time. No appreciable erosional surfaces were formed between lava flows.

Lavas of the first phase, the oldest phase, are absent in the study area. Only lavas of the second phase are present in the study area, and a lava flow in the Yankee Canyon, immediately to the east, is a representative of the third phase (fig. 46). The difference in elevation of the mentioned lava bodies is a valid criterion to distinguish the younger phase from the older.

Eruptive Rocks

Lavas of the second eruptive period (late Tertiary) cover Bartlett, Horseshoe and Horse mesas. The lavas were highly fluid and spread rapidly over the area. During the second period there were few separate flows (Lee, 1922). Fissure eruptions were frequent but volcanic cover were also formed. A 250 foot late Tertiary volcano is well preserved on the northern side of the Bartlett Mesa.

The average thickness of the lava blanket varies between 30 and 45 feet. Greater thicknesses can be found in local erosional depressions of the Raton Formation. The blanket is 110 feet thick in the vicinity of the volcanic cone. The thicknesses are greater on Horse Mesa but less uniform than on Bartlett Mesa. The pre-existing topography influenced the lava blanket thicknesses when they were spread over the area.

At the rim of the lava blankets form columnar joints. The precipitation waters are carried down along the joint planes to form springs at the base of the blanket (figs. 40, 41, 42 and 43).

At the time of the cooling, the lava was subjected to shrinkage processes that developed structures that resemble

Figure 40. Bartlett Mesa lava blanket with columnar joints.

Figure 41. The tendency to form columnar joints is accentuated at the borders of the lava blankets. Bartlett Mesa.

Figure 42. The cracks associated with the columnar joints in the lava are, frequently, 2 to 3 feet wide. Bartlett Mesa.

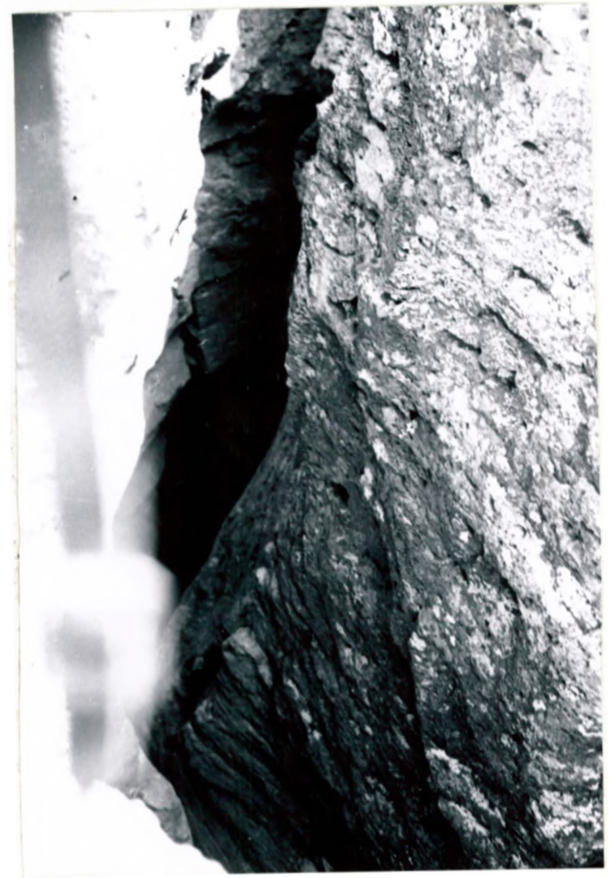

Figure 43. The cracks extend through the lava blanket. Bartlett Mesa.

stratification (figs. 44 and 45). Joints also probably formed by shrinkage.

Lee gives the following petrographic summary for the lavas of the second period.

> "The lavas of the second period of eruption, like those of the first period, are very much alike in appearance, composition, and habit. Like those of the first period, they range in color from light gray to dark gray and include both compact and vesicular varieties. They are universally porphyritic, but in the hand specimens the only phenocrysts commotly visible are crystals of altered olivine. The groundmass is aphanitic."
>
> "....The following tables show the average mineral composition." (Lee, 1922):

Percentage of principal minerals in lavas of second period of eruption.

	Maximum	Minimum	Average
Labradorite	57	36	46
Augite	38	26	33
Magnetite	17	5	9
Altered Olivine	20	8	12

According to Lee (1922) the lavas of the second period are olivine basalts.

Lavas of the third period are close to the eastern limit of the study area. They are more than 1000 feet lower than the blankets of the second period. Their source is the "Yankee Volcano" in the eastern part of the canyon of the same name (Lee, 1922).

The Black Mesa, Cunningham Butte, and Round Mesa to

Figure 44. Tabular features developed in the Bartlett Mesa lava blankets during the cooling process.

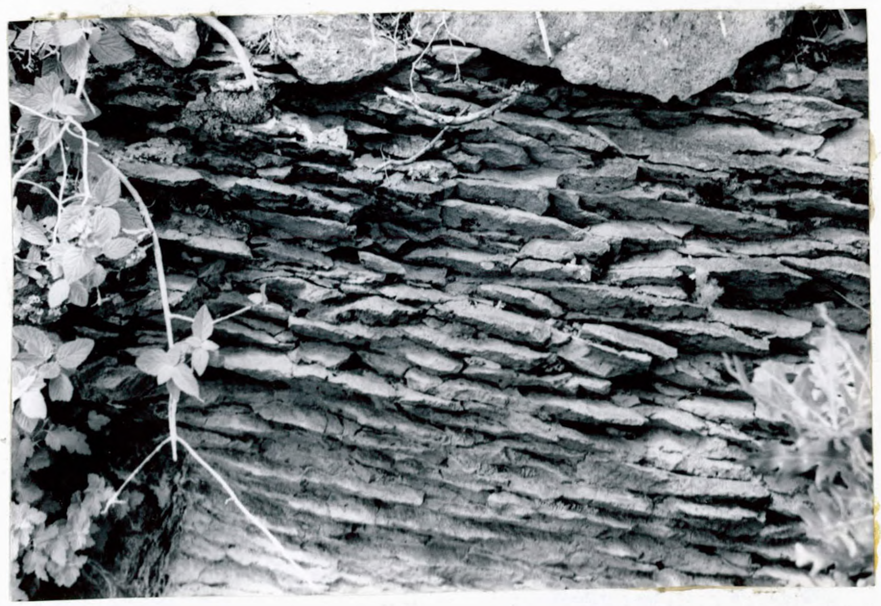

Figure 45. Forms developed during the cooling of the lava. Bartlett Mesa.

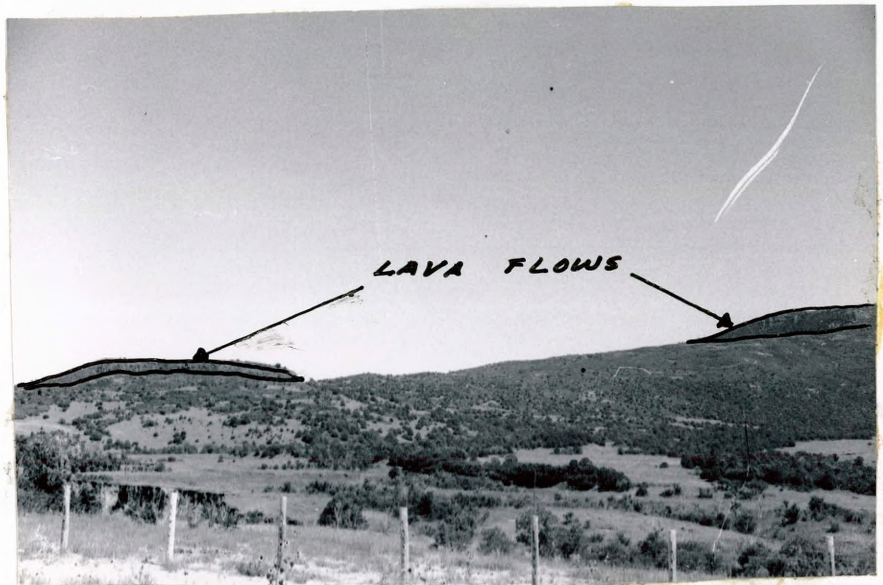

Figure 46. The lavas of the third phase, almost on the bottom of Yankee Canyon, are 1000 feet lower than the second phase lavas of the Johnson Mesa to the southeast of the study area.

Figure 47. Basaltic dikes crossing the Vermejo Formation, to the north of the study area.

the south of the study area, are covered by third phase, late Tertiary, lavas.

During the fourth phase, that lasted until one thousand years ago in the Capulin area, there were no eruptions in the area of Raton (Stobbe, 1949).

Intrusive Rocks

Intrusive rocks are present in the study area in the form of dikes (fig. 48). They are intruded into sedimentary rocks (see attached geologic map).

According to Lee (1922) the dikes are sodic vogesites. The petrographic description is the following:

> "The sodic vogesites are dark-gray to dark greenish-gray compact rocks, some of them rather coarse grained and others almost aphanitic. Almost without exception they are nonporphyritic. Their fabric is in some places almost ophitic or diabasic. More commonly, perhaps, it is granular,..."

Figure 48. Dikes cutting the Pierre Shale, one mile northeast of Raton, New Mexico.

STRUCTURE

Lee (1922) mentions two major uplifts that affected the geologic units in the Raton basin; these movements are labeled as post-Vermejo uplift and the post Raton uplift. According to Lee (1922) great part of the Vermejo Formation was removed after the former uplift. This erosion resulted in an unconformity between the Vermejo and the Raton Formation; since the "lower massive sandstone" of the Raton Formation is used in this study as the formation boundary, the mentioned unconformity would be located in the upper part of the Vermejo Formation.

The most important structural features of the area were produced by the post-Raton uplift. The Rocky Mountains, to the west of the study area, were lifted, upturning the sedimentary formations, including the Raton Formation, along the foothills. The bending of the strata was so regular on the eastern side of the basin, that it produced only few faults, with a very small displacement. The Morley and

Mesa de Maya domes were formed by the emplacement of intrusive bodies. Lee believes that the volcanic activity in the area is related to the post-Raton uplift and the doming effects. Lee suspects that volcanism took place in the Early Tertiary, but that the lava flows had been eroded away. Several younger lava blankets that are preserved are in unconformable relation with Upper Cretaceous and Paleocene rocks.

The study area is on the eastern side of the Raton structural basin. The strata dip approximately 3° to the west, toward the structural axis of the basin.

Small direct faults can be observed, which indicate a slight tension stress in the area. Some of the faults seem to be due to surface movements similar to slumping.

Columnar jointing is very extensive at the edges of the lava blankets. Some of the joint planes are more than two feet apart.

Several joint systems can be observed throughout the area. They are almost always vertical and the average strikes of the main systems are as follows: N 80° W and N 10° E (see figs. 49 and 50).

The dikes of the area follow the direction of the main joint system. The dikes, themselves, are irregularly jointed in most cases.

Figure 49. The massive sandstones of the Raton area are fractured by several joint systems. Railroad Canyon.

Figure 50. The joint planes are accompanied by swarms of subparallel cracks. Railroad Canyon.

Many intraformational unconformities are present in the Vermejo and Raton Formations.

ECONOMIC GEOLOGY

The Upper Cretaceous and Paleocene rocks of the Raton area contain large deposits of coal, stone, clay, water, and probably commercial amounts of petroleum and gas. In the area mapped, only coal has been mined economically. Exploration for petroleum in the area has been unsuccessful, although several wells were drilled. Because of this failure the area has not been the object for further exploration programs.

Coal

Coal has been mined in the vicinity of Raton since the early eighteen seventy's. The mentioned area is part of the Raton Mesa region, which extends about 90 miles from north to south and 50 miles or more from east to west; it includes both the Trinidad Coal Field of Colorado and the Raton Coal Field of New Mexico. The coal of the Raton area is classified as a medium rank bituminous coal and compares favorably in quality with the best bituminous coals of the United States. Great part of the coal can be converted to coke, and in many places it is sufficiently thick to be easily mined (Lee, 1924).

The coal production of the Raton Coal Field has been in small mines in the vicinity of the town of Raton since the early eighteen seventy's, but the first large mines have been operated near Blossburg since the late eighteen eighty's in the western part of the study area.

Very soon, several mining operations were opened at Koehler, Van Houten, and Dawson, all to the southwest of the town of Raton. Around the turn of the century the most recent mines of the region have been developed at Brilliant, Swastica, Yankee, Gardiner and Sugarite, the latter two in the study area.

The coals are located in the Vermejo and the Raton formations. The coals of the former are more regular in thickness, physical character, and have less quantities of shaly interstratifications. The older coal units are less lenticular than the younger. In general, it is very difficult to estimate the coal reserves for the entire area (Lee, 1924). Certain carbonaceous zones can be correlated at long distances, but the individual coal beds are very local.

The lowest coal bed of the region is the Raton Coal Bed of the Vermejo Formation. This coal has been mined more extensively in the area than the upper ones, which have been opened in only a few places. There are many indications of lenticularity and much evidence that separate beds are grouped under the name of Raton Coal, but this term is used to designate the coals of the Vermejo Formation in a general way (Lee, 1924). The Raton Coal Bed is mined in several separate districts of the eastern part of the Raton Basin. These districts are Koehler, Willow (or Van Houten), Dawson and Blossburg. This report includes the coal bed of the Sugarite Mine as belonging to the same group.

Some coal beds are partly destroyed by igneous intrusions in the western part of the study area. The Raton Coal Bed of this area consists almost always of three coal beds. The combined thickness of all coal zones is seldom greater than 12 feet.

According to the writer, Lee's (1924) "Sugarite Zone" belongs to the Vermejo Formation and not to the Raton Formation. For more details see page 35. All the coals between the "lower massive sandstone" of the Raton Formation and the Trinidad Formation, belong to the Vermejo Formation. This is the case for the Wagon and Sugarite Mines in the study area.

The Sugarite Mine, to the northeast of the study area, was opened in 1912. The coal bed was very thick in this point. This location marks the center of the swamp, where the coal was formed. The coal bed disappears toward the sides, within a short distance. The mine has openings on both sides of the canyon and was worked by the room and pillar system. The amounts of gas in the mine are negligible.

The Wagon Mine, on the southern side of the Bartlett Mesa, was opened in 1902, and was in operation until 1912. The roof shale of the mine has many impressions of leaves and tree trunks, large palm leaves being especially abundant (Knowlton, 1917). This mine is known by this name because the coal was transported by wagon from it to Raton.

The Raton Formation has two well defined groups of coal beds. Lee (1924) includes the "Sugarite Zone" in the lowest group, and not in the Vermejo Formation, as the writer does.

Two carbonaceous zones which have no specific names in the study area can be recognized in Unit No. 3 of the Raton Formation; they have not been exploited in the area. The lowest of the mentioned carbonaceous beds is equivalent to the Yankee Coal Bed to the east of the study area, and to the Tin Pan Coal in the west; the upper zone, approximately 65 feet higher, is equivalent to the Kellog Bed in the east, and to the Potato Canyon Coal Bed west of the study area.

It is important to emphasize that the above mentioned beds are not completely continuous throughout the Raton Coal Field; they are parts of stratigraphic zones which have been deposited in a time when environment of deposition was favorable to the formation of coal.

The coals of Unit No. 3 of the Raton Formation have not been studied very extensively in the Raton area, except by Lee in some places, outside the study area.

The only mine currently in operation is the Koehler Coal Mine, operated by the Kaiser Steel Co.; the mine is completely mechanized.

Finally it is important to add that small amounts of graphite have been mined in the Cottonwood Canyon since 1889, close to the Canadian River.

Petroleum

The first wildcat well of the Raton Basin was drilled 67 years ago but the area has received only minor attention from the petroleum industry for any further exploration. Very few subsurface data are available, but if reconstruction derived from surface and subsurface data were made, a considerable complexity in stratigraphic conditions could be expected (Baltz, 1965). This is particularly encouraging for the eastern part of the basin, where structural traps do not exist.

Many oil shows have been located in Upper Cretaceous rocks of the Raton Basin. Shows of oil and gas have been encountered in fractured Pierre Shale, in the northern Raton Basin and two miles southeast of the town of Raton. Oil has been found in fractures of a basalt dike intruded in the Pierre Shale, 7 miles south of Raton.

Good shows have been discovered in the Trinidad Sandstone in several wells of Colorado and oil seeps and asphaltic residues have been reported from the Cimarron River Canyon in New Mexico, and also on Alamo Dome (Johnson and Stephens, 1954; Creely and Saterdal, 1956; Baltz and Bachman, 1956).

The writer does not believe that the main body of the Trinidad Sandstone is an attractive drilling objective, because of hydrodynamic considerations. Only the intertonguing of the lower part of the Trinidad with Pierre Shale can be considered to form fair prospects. There are some possibilities for oil accumulation at the western side of the basin, close to the Sangre de Cristo Mountains, where the Trinidad is moderately faulted.

The Trinidad Sandstone is fairly regular and porous throughout the basin. The writer believes that precipitation waters, very common along the Sangre de Cristo Range, enter the Trinidad Sandstone from the western side and

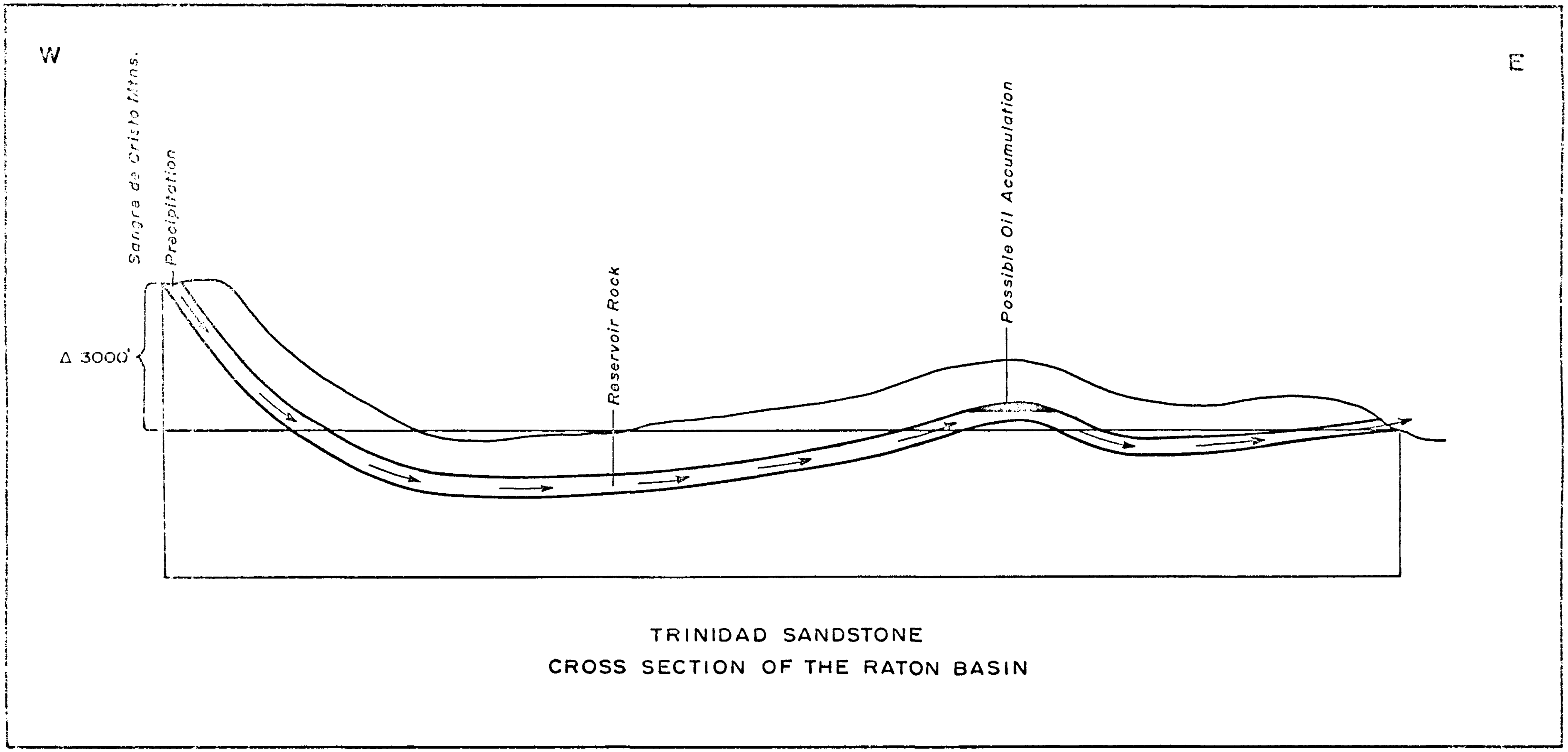

FIG. 51. HYDRODYNAMIC EXPLANATION FOR THE ABSENCE OF OIL AT THE MAIN STRUCTURES IN THE RATON BASIN.

BY H. ZEUSS

travel hydrodynamically through the basin without any obstruction; the waters run out from the eastern side, where the Trinidad is exposed. The mechanism of this system can be observed on figure 51; the water head is 3,000 feet higher at the west than the outcrops on the eastern side. Oil could have been accumulated at some anticlinal folds, but their upper parts are always lower than the water head, and the possible oil was flushed out by hydrodynamic forces.

The Vermejo and Raton sandstones are separated from the great Trinidad Sandstone "channel", where movements of oil and water took place. The separation is provided by shale beds, but in many cases fractures or sandstone bodies are in direct contact with the Trinidad. In this case some oil could have been accumulated in these formations.

While the front of sediments was advancing into the sea during the Late Cretaceous time, the Pierre-Trinidad tongues were continuously formed. This is the reason why innumerable sandstone tongues can be expected below the present Raton Basin. Some of the tongues and sand lenses have a width and longitude of several miles. A close examination of the outcropping tongues indicates that many of them are fairly porous and that the maximum thickness is of eight feet.

The NE-SW trend of the intertonguing has to be taken into account for oil exploration programs.

Only stratigraphic traps for oil can be expected in the Raton area. Some possibility to find oil exists in the vicinity of dike intersections. Several shows have been found in such places; this possibility is not very encouraging, because the dikes are jointed and the principal oil migration period took place before they were intruded.

The deltaic pattern of the sediments of the area is very encouraging for petroleum exploration.

Gas

Occurrences of two varieties of gases can be located in the vicinity of Raton. One of them originated with the petroleum that was formed during the Upper Cretaceous. The second variety was derived from coal beds, especially after mining operations started to take place. In several cases the coal gas migrated to close lying sandstone lenses and originated small reservoirs of coal gas.

Lee (1922) does not specify the varieties of gases when he makes reference to the gas emanations of Van Houten, Barilla Mesa and other locations; these emanations are always in the vicinity of coal mines and it is very probable that they are coal gas.

There is a gas well close to the Wooton Ranch, one mile to the north of the study area in Colorado; its chemical analysis indicates that it contains coal gas, probably derived from the very gasiferous Morley Coal Mine. The daily production of this shallow well is of 50,000 standard cubic feet (Mr. Berg, Wooton Ranch owner).

Several wells of the same variety are located a few miles from the northeastern corner of the study area.

Many coal zones considered as noncommercial for ordinary purposes may be suitable for underground gasification and liquification. This can especially be applied to poor coal zones with many shale interlaminations, such as Unit No. 3 of the Raton Formation of the study area.

Groundwater

Important quantities of groundwater are available in the vicinity of Raton. Some small springs are located in the Pierre Shale, which has some sandstones and many fractures in the shale. The Pierre water is strongly charged with sulphates and other substances, that are objectionable to drinking (Lee, 1922).

In addition, many springs are located at the base of the jointed lava blankets of the area. The springs located in the vicinity of the Bartlett Mesa Road intersection of the lava blanket of the mesa, were considered sufficient for the water necessities of the town of Raton, at the turn of the century, when water supply sources were under investigation.

Springs also occur at many places in areas occupied by the Raton Formation, especially on the western side of the Sugarite Canyon.

The Quaternary alluvium is very porous. Streams such as the Canadian River disappear completely in the alluvium, especially in seasons when water supply from the mountains is short. Shallow water-wells are very productive, when drilled in the mentioned alluvium.

Miscellany

The main source for clay has been developed from the Pierre Shale. Bricks are produced for the local market. The shales of the Vermejo and Raton Formations have never been much utilized.

There are many stone quarries in the area. The pink lava stones are used for decoration purposes. The Trinidad Sandstone has been used extensively in Raton and in neighboring towns. The massive sandstones of the Raton Formation seem to be suitable for building stone.

The lowlands of the Raton area are covered by alluvium soils, washed down from the mountains, and by adobe soil derived from the alteration of the Pierre Shale. The former are better suited for farming, especially when water can be impounded for irrigation. Both varieties are widely used for grazing.

The soils of the mesas, derived partly from basalts, are very rich, but because of the high altitude the growing season is very short.

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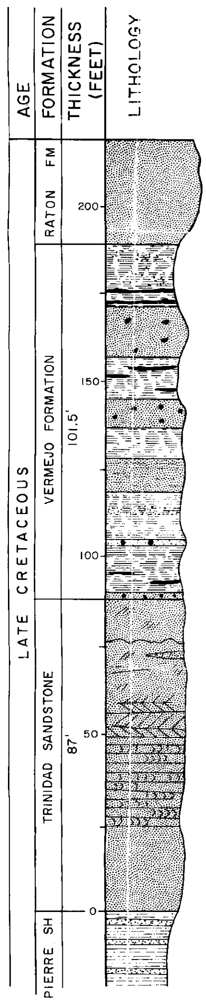
COMPOSITE STRATIGRAPHIC COLUMN (A)

GOAT HILL - COLFAX CO., NEW MEXICO

T. 31 N. - R. 23 E.



DESCRIPTION

"LOWER MASSIVE SANDSTONE": LIGHT GRAY TO WHITE, MEDIUM GRAIN SIZE, SUBANGULAR, MEDIUM HARDNESS, POOR TO FAIR SORTING, FAIR POROSITY, VERY MASSIVE, SILICEOUS CEMENT, QUARTZ, FELDSPARS, MODERATELY JOINTED, GOOD TOPOGRAPHIC EXPRESSION, ARKOSIC.

SHALE, SANDSTONE, SILTSTONE, AND COAL: DARK SHALES, VERY CARBONACEOUS AT THE BOTTOM, VERY SOFT; GRAY SANDSTONES, FINE GRAIN SIZE, SUBANGULAR, POOR SORTING, THIN, SILICEOUS CEMENT, POOR IN SEDIMENTARY STRUCTURES, ARKOSIC; THIN COAL LAYERS WITH PLANT MATERIAL.

SANDSTONE: GRAY TO BROWN, FINE TO MEDIUM GRAIN SIZE, SUBANGULAR, FAIR TO MEDIUM HARDNESS, POOR TO MEDIUM SORTING, SILICEOUS CEMENT, POOR TROUGH CROSS BEDDING, IRON NODULES AND LENSES, ARKOSIC.

SHALE: DARK GRAY, CARBONACEOUS, SOFT; WITH SMALL SANDSTONE LENSES AND THIN COAL LAYERS.

SANDSTONE: GRAY TO BROWN, FINE TO MEDIUM GRAIN SIZE, MEDIUM HARDNESS, FAIR POROSITY, SILICEOUS CEMENT. QUARTZ, FELDSPARS, POOR TROUGH CROSS BEDDING, IRON NODULES, ARKOSIC.

SHALE: GRAY AND BROWN SHALE, SOFT, WELL-BEDDED, ESSENTIALLY NON-CARBONACEOUS.

SANDSTONE, SILTSTONE, SHALE: GRAY TO BROWN SANDSTONES, FINE TO MEDIUM GRAIN SIZE, MEDIUM HARDNESS, FAIR POROSITY, SILICEOUS CEMENT, QUARTZ, FELDSPARS, POOR TROUGH-CROSS BEDDING, IRON NODULES, ARKOSIC SANDSTONE; SOME INTERLAMINATIONS OF SILTSTONES AND SHALES.

SHALE: DARK GRAY TO BLACK, CARBONACEOUS, SOFT; THIN SILTSTONE AND SANDSTONE LENSES.

SANDSTONE: BROWN, FINE TO MEDIUM GRAIN SIZE, FRIABLE, POOR SORTING AND POROSITY, SILICEOUS CEMENT, QUARTZ, FELDSPARS, IRON NODULES, ARKOSIC.

SHALE, COAL, SILTSTONE, SANDSTONE: DARK GRAY TO BLACK, CARBONACEOUS, SOFT SHALES; THIN COAL LAYERS; THIN SILTSTONE AND SANDSTONE LENSES.

SANDSTONE: BROWN, FINE, POOR SORTING, IRON NODULES, POORLY PRESERVED FOSSILS, WORM TRACKS, LEAF IMPRINTS AND ALGAE (?).

SANDSTONE (TRANSITION ZONE): GRAY TO OLIVE, FINE GRAIN SIZE, POOR SORTING, VERY FRIABLE, PROBABLY REDEPOSITED MATERIAL, SOME CROSS-BEDDING, QUARTZ, FELDSPARS, SOME CARBONACEOUS DETRITIC MATERIALS, ARKOSIC.

SANDSTONE: LIGHT GRAY TO WHITE, WITH SOME OLIVE VERMEJO TYPE INTERTONGUES, FINE TO MEDIUM GRAIN SIZE, SUBROUNDED, FRIABLE, POOR TO MEDIUM SORTING, FAIR POROSITY, TABULAR AND PLANAR CROSS-BEDDING, ARKOSIC.

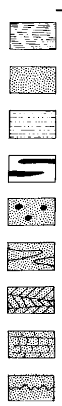
SANDSTONE: LIGHT GRAY TO WHITE, FINE GRAIN SIZE, SUBROUNDED, FRIABLE, FAIR SORTING AND POROSITY, VERY WELL DEVELOPED TABULAR CROSS-BEDDING, ARKOSIC.

SANDSTONE: LIGHT GRAY TO WHITE, FINE GRAIN SIZE, SUBROUNDED, FRIABLE, FAIR SORTING AND POROSITY, IN FORM OF THIN LAMINAE OR LOW-ANGLE FESTOON CROSS-BEDDING.

SANDSTONE: LIGHT TO GRAY, FINE GRAIN SIZE, SUBROUNDED, POOR TO FAIR SORTING, POORLY CEMENTED, QUARTZ, SOME FELDSPARS AND DETRITIC CARBONACEOUS MATERIAL, MASSIVE, SOME SHALY INTERLAMINATIONS.

SHALE, SANDSTONE, SILTSTONE: BROWN TO GRAY SHALES; GRAY SANDSTONES, FINE GRAIN SIZE, SUBROUNDED, COMPACT, CARBONACEOUS DETRITIC MATERIALS; ALSO WELL-BEDDED SILTSTONES.

SYMBOLS



SHALE

SANDSTONE

SILTSTONE

COAL BEDS

IRON NODULES IN SANDSTONE

SANDSTONE TONGUES

CROSS-BEDDING

FESTOON CROSS BEDDING

LOCAL UNCONFORMITY

PLATE I T-1146

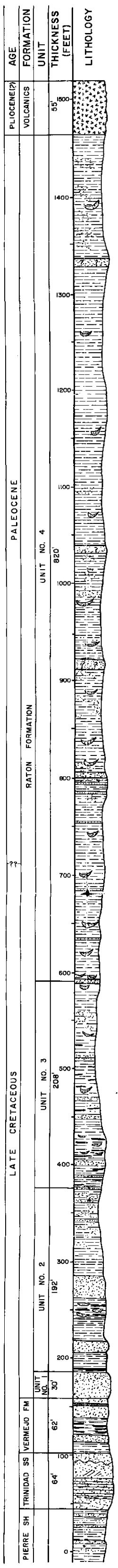
By: HILARIO ZEUSS
1967

SCALE: 1 INCH = 25 FEET

COMPOSITE STRATIGRAPHIC COLUMN (B)

RAILROAD CANYON (ALONG INTERSTATE 25) COLFAX CO., NEW MEXICO

T. 31 N., T. 32 N. – R. 23 E.



DESCRIPTION

LAVA: DARK PINK TO GRAY, COMPACT AND VESICULAR VARIETIES, SOME PHENOCRYSTS IN APHANITIC GROUNDMASS, TENDENCY TO FORM COLUMNAR JOINTS, BASALTIC LAVA BLANKET.

SHALE, SANDSTONE: BROWN, SOFT SHALE; SMALL ARKOSIC SANDSTONE LENSES.

SANDSTONE: LIGHT BROWN TO GRAY, FINE TO MEDIUM GRAIN SIZE, POOR TO MEDIUM SORTING, SUBANGULAR, SILICEOUS CEMENT, SOME TROUGH CROSS BEDDING, ARKOSIC.

SHALE: LIGHT BROWN, SOFT, WELL-BEDDED; PROBABLY SOME SMALL LOCAL SANDSTONE LENSES.

SANDSTONE: LIGHT GRAY, FINE GRAIN SIZE, SUBANGULAR, MEDIUM HARD, SOME TROUGH CROSS BEDDING, WEATHERS TO BROWN, ARKOSIC.

SHALE, SANDSTONES: BROWN SHALES, SOFT, WELL-BEDDED; LIGHT BROWN SANDSTONES, FINE TO MEDIUM SIZE, POOR SORTING, SUBANGULAR, MEDIUM HARDNESS, QUARTZ, ORTHOCLASE AND PLAGIOCLASE FELDSPARS, KAOLINITIC MATERIALS, POOR IN HEAVY MINERALS, POORLY DEVELOPED TROUGH-CROSS BEDDING, DEFORMED BY SLUMP PROCESSES, ONLY IN LOCAL LENSES, ARKOSIC.

SANDSTONE: GRAY TO LIGHT BROWN, FINE GRAIN SIZE, SUBANGULAR, POOR SORTING, POOR TO MEDIUM HARDNESS, QUARTZ, FELDSPARS, KAOLINITIC MATERIALS, POOR IN HEAVY MINERALS, JOINTED, ARKOSIC.

SHALE; SANDSTONE: BROWN SHALES, SOFT, WELL-BEDDED; LOCAL ARKOSIC SAND LENSES.

SANDSTONE: LIGHT BROWN, FINE TO MEDIUM GRAIN SIZE, SUBANGULAR, POOR TROUGH-CROSS BEDDING, JOINTED, ARKOSIC.

SHALE, SANDSTONES, SILTSTONES: BROWN, SLIGHTLY CARBONACEOUS, SOFT SHALE; SEQUENCES OF THIN SANDSTONES, SILTSTONES AND SHALES; LOCAL SANDSTONE LENSES.

SANDSTONE, CARBONACEOUS SHALE: LIGHT BROWN SANDSTONE, FINE TO MEDIUM GRAIN SIZE, SUBANGULAR, POOR SORTING, FRIABLE, QUARTZ, FELDSPARS, KAOLINITIC MATERIALS, TROUGH CROSS BEDDING, ARKOSIC SANDSTONE; DARK GRAY, SOFT WELL-BEDDED, CARBONACEOUS SHALE.

SHALE, SANDSTONE, COAL, SILTSTONE: LIGHT GRAY, BROWN AND BLACK SHALES, PREDOMINANTELY CARBONACEOUS, SOFT AND WELL-BEDDED; LIGHT BROWN SANDSTONES, FINE TO MEDIUM GRAIN SIZE, SUBROUNDED, POOR SORTING, QUARTZ, FELDSPARS, KAOLINITIC MATERALS, TROUGH CROSS BEDDING, LENTICULAR, ARKOSIC SANDSTONES; THIN COAL BEDS WITH PLANT STRUCTURES; WELL-BEDDED SILTSTONES INTERBEDDED WITH SHALES AND SANDSTONES.

COAL, SANDSTONE, SHALE: SEVERAL COAL LAYERS, SOME OF THEM MORE THAN ONE FOOT THICK. SOME COAL BEDS HAVE BEEN PARTLY DESTROYED BY CURRENT ACTIONS; REDEPOSITED COAL IS ALSO PRESENT; LIGHT GRAY AND BROWN SANDSTONE, POORLY SORTED, POOR TO MEDIUM HARDNESS, SOME TROUGH CROSS BEDDING, LINTICULAR, ARKOSIC SANDSTONES; THE SHALES ARE CARBONACEOUS.

SHALE, SANDSTONE, SILTSTONE: POORLY PRESERVED SHALEY UNIT WITH THIN LOCAL SANDSTONES AND SILTSTONES.

SANDSTONE: LIGHT GRAY TO BROWN SANDSTONE, FINE TO MEDIUM GRAIN SIZE, SUBANGULAR, POOR SORTING, MEDIUM HARDNESS, SOME TROUGH CROSS BEDDING, MASSIVE, QUARTZ, FELDSPARS, KAOLINITIC MATERIALS, ARKOSIC.

SANDSTONE, COAL, SHALE: VERY VARIABLE SEQUENCE OF SANDSTONE, THIN COAL LAYERS AND CARBONACEOUS SHALE.

SHALE: GRAY AND BROWN, SLIGHTLY CARBONACEOUS.

SANDSTONE: LIGHT GRAY TO BROWN, FINE GRAIN SIZE, SUBANGULAR, MEDIUM HARDNESS, SILICEOUS CEMENT, QUARTZ, FELDSPARS, KAOLINITIC MATERIALS, ARKOSIC.

SHALE, SILTSTONE, SANDSTONE, COAL: SEQUENCE OF SHALES AND SILTSTONES, WITH THIN LINTICULAR SANDSTONES; COAL BED AT THE BOTTOM.

"LOWER MASSIVE SANDSTONE": LIGHT GRAY, MEDIUM GRAIN SIZE, SUBROUNDED, MEDIUM HARDNESS, POOR TO FAIR POROSITY, VERY MASSIVE, SILICEOUS CEMENT, QUARTZ, ORTHOCLASE AND PLAGIOCLASE FELDSPARS, MODERATELY JOINTED, GOOD TOPOGRAPHIC EXPRESSION, ARKOSIC.

SHALE, COAL, SANDSTONE: DARK GRAY AND BLACK, SOFT SHALE; THIN COAL LAYERS AND THIN LOCAL SANDSTONE LENSES.

SANDSTONE: LIGHT BROWN, FINE TO MEDIUM GRAIN SIZE, SUBROUNDED, POOR TO FAIR SORTING, SILICEOUS CEMENT, IRON NODULES.

SHALE, COAL: DARK GRAY TO BLACK SHALE, CARBONACEOUS; THIN COAL LAYERS WITH PRESERVED VEGETABLE STRUCTURES.

SANDSTONE: LIGHT BROWN, FINE TO MEDIUM GRAIN SIZE, TROUGH CROSS BEDDING, IRON CONCRETIONS.

SHALE: DARK GRAY TO BLACK, CARBONACEOUS, SOFT; THIN COAL LAYERS.

SANDSTONE: OLIVE TO GRAY, FINE GRAIN SIZE, VERY FRIABLE, TRANSITIONAL AND PARTLY REDEPOSITED UNIT; PROBABLY AN UNCONFORMITY AT THE BOTTOM.

SANDSTONE: GRAY, FINE GRAIN SIZE, POORLY CEMENTED, SOME TABULAR CROSS-BEDDING.

SANDSTONE: GRAY TO WHITE, FINE GRAIN SIZE, POORLY CEMENTED, THIN LAMINATED.

SANDSTONE, SHALE: GRAY TO WHITE, FINE GRAIN SIZE, POOR TO MEDIUM HARDNESS, MASSIVE; THIN SHALE UNIT AT THE TOP.

SHALE, SANDSTONE, SILTSTONE: BROWN TO GRAY SHALES; GRAY SANDSTONES, FINE GRAINED, SUBROUNDED, COMPACT, QUARTZITIC, CARBONACEOUS DETRITIC MATERIALS, SOME RESEMBLANCE TO THE TRINIDAD SANDSTONES, IN MANY CASES; ALSO INTERSTRATIFICATIONS OF SILTSTONES.

SYMBOLS

- SHALE
- SANDSTONE
- SILTSTONE
- COAL BEDS
- IRON NODULES IN SANDSTONE
- SANDSTONE TONGUES
- CROSS-BEDDING
- LOCAL UNCONFORMITY
- SANDSTONE LENS IN SHALE
- VOLCANICS

PLATE 2 T-1146

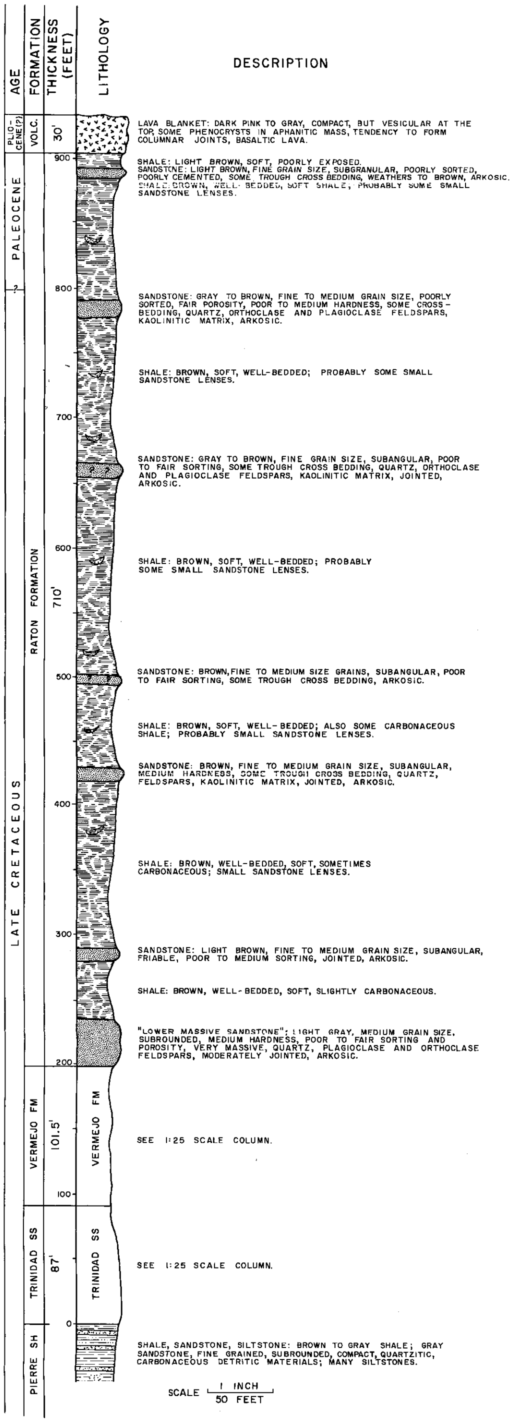
By: HILARIO ZEUSS
1967

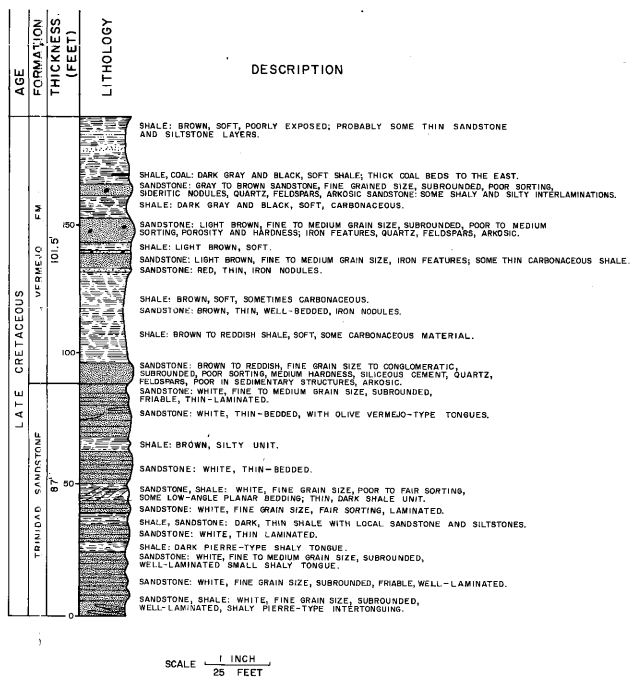
SCALE: 1 INCH = 50 FEET

COMPOSITE STRATIGRAPHIC COLUMN (C)

ROAD TO BARTLETT MESA COLFAX CO., NEW MEXICO

T. 31 N. -- R. 23 E.





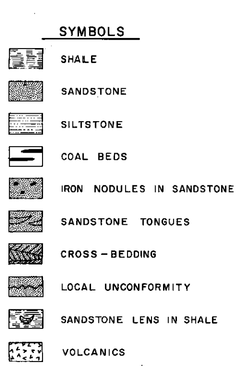


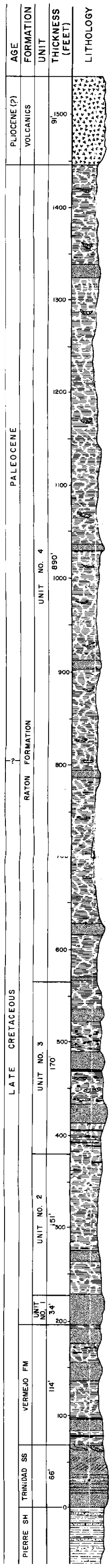
PLATE 3 T-1146

By: HILARIO ZEUSS
1967

COMPOSITE STRATIGRAPHIC COLUMN (D)

SUGARITE CANYON - COLFAX CO., NEW MEXICO

T. 31 N., T. 32 N. - R. 24 E.



DESCRIPTION

LAVA: DARK PINK TO GRAY, COMPACT, VESICULAR AT THE TOP, SOME PHENOCRYSTS IN APHANITIC GROUNDMASS, TENDENCY TO FORM COLUMNAR JOINTS, BASALTIC LAVA BLANKET.

SHALE: BROWN, SOFT SHALE; PROBABLY SMALL SANDSTONE LENSES.

SANDSTONE: LIGHT BROWN TO GRAY, FINE TO MEDIUM GRAIN SIZE, POOR TO MEDIUM SORTING, SUBANGULAR, SILICEOUS CEMENT, SOME TROUGH CROSS BEDDING, ARKOSIC.

SHALE: BROWN, SOFT SHALE; THIN SANDSTONES AND SILTSTONES.

SANDSTONE: LIGHT GRAY TO BROWN, FINE TO MEDIUM GRAIN SIZE, POOR SORTING, POOR TO FAIR HARDNESS, SOME TROUGH CROSS BEDDING, ARKOSIC.

SHALE: BROWN, SOFT; SMALL SANDSTONE LENSES.

SANDSTONE: LIGHT BROWN, FINE GRAIN SIZE, SUBANGULAR, POOR SORTING, FRIABLE, SOME TROUGH CROSS BEDDING, QUARTZ, FELDSPARS, KAOLINITIC MATRIX, JOINTED, ARKOSIC.

SHALE: BROWN, SOFT, WELL-BEDDED. PROBABLY SOME SMALL SANDSTONE LENSES.

SANDSTONE: LIGHT GRAY TO BROWN, FINE TO MEDIUM GRAIN SIZE, SUBANGULAR, POOR TO MEDIUM HARDNESS, TROUGH CROSS BEDDING, QUARTZ, FELDSPARS, KAOLINITIC MATRIX, FAIRLY JOINTED, ARKOSIC.

SHALE: LIGHT GRAY TO BROWN, SOFT, WELL-BEDDED, SOMETIMES SLIGHTLY CARBONACEOUS; LOCAL SMALL SANDSTONES.

SHALE: GRAY TO BROWN, SLIGHTLY CARBONACEOUS, SILTY SHALE.

SANDSTONE: LIGHT BROWN, FINE TO MEDIUM GRAIN SIZE, SUBANGULAR, POOR TO MEDIUM HARDNESS, SOME TROUGH CROSS BEDDING, FAIRLY JOINTED, ARKOSIC.

SHALE: BROWN, SOFT, WELL-BEDDED; THIN SANDSTONE LENSES.

SANDSTONE: BROWN, THIN.

SHALE: BROWN, SOFT, WELL-BEDDED; THIN WELL-BEDDED SILTSTONES.

SANDSTONE: LIGHT BROWN, FINE TO MEDIUM GRAIN SIZE, SUBANGULAR, POORLY SORTED, POOR TO MEDIUM HARDNESS, MASSIVE, FAIRLY JOINTED, ARKOSIC.

SHALE, COAL: BLACK, SOFT, CARBONACEOUS SHALE, WITH LARGE SIDERITIC CONCRETIONS; THIN COAL BEDS.

SANDSTONE: LIGHT BROWN, FINE, POORLY SORTED, MEDIUM HARDNESS, SOME TROUGH CROSS BEDDING, ARKOSIC SANDSTONE.

COAL: THICK BED, WITH PRESERVED PLANT STRUCTURES.

SHALE, SANDSTONE: BLACK, SOFT CARBONACEOUS SHALES, WITH VERY LARGE SIDERITIC CONCRETIONS. SOME LIGHT GRAY AND BROWN LENTICULAR SANDSTONES.

SANDSTONE: LIGHT BROWN, FINE TO MEDIUM GRAIN SIZE, POORLY SORTED, POOR TO MEDIUM HARDNESS, SOME TROUGH CROSS BEDDING, SILICEOUS CEMENT, QUARTZ, ORTHOCLASE AND PLAGIOCLASE FELDSPARS, ARKOSIC.

SHALE, COAL: BLACK, SOFT, CARBONACEOUS SHALE; SEVERAL THIN COAL BEDS.

SHALE, SILTSTONES: BLACK, SOFT CARBONACEOUS SHALE; THIN SILTSTONE LAYERS.

SANDSTONE: LIGHT BROWN, FINE TO MEDIUM GRAIN SIZE, POOR TO MEDIUM SORTING AND HARDNESS, SOME TROUGH CROSS BEDDING, ARKOSIC.

SHALE, SILTSTONE, SANDSTONE: BROWN AND DARK GRAY, SLIGHTLY CARBONACEOUS SHALES; THIN WELL-BEDDED SILTSTONE AND SANDSTONE.

"LOWER MASSIVE SANDSTONE": LIGHT GRAY, MEDIUM GRAIN SIZE, SUBROUNDED, MEDIUM HARDNESS, SILICEOUS CEMENT, QUARTZ, FELDSPARS, MODERATELY JOINTED, ARKOSIC.

SHALE: BLACK, SOFT, THIN CARBONACEOUS SHALE WITH IRON CONCRETIONS.

SANDSTONE: LIGHT GRAY, FINE TO MEDIUM, SUBROUNDED, MEDIUM HARDNESS, RIPPLE MARKS, SOME IRON CONCRETIONS, ARKOSIC.

SHALE, COAL: BLACK, CARBONACEOUS SHALE; THICK COAL LAYERS, WHICH WERE MINED IN THE SUGARITE MINE.

SANDSTONE: GRAY TO BROWN, FINE TO MEDIUM GRAIN SIZE, MEDIUM HARDNESS, MASSIVE, FAIRLY JOINTED, ARKOSIC.

SHALE, COAL: DARK GRAY AND BLACK SHALE, CARBONACEOUS; COAL BED AT THE BOTTOM OF THE UNIT.

SANDSTONE: BROWN, FINE TO MEDIUM GRAIN SIZE, POORLY SORTED, ARKOSIC.

SHALE, COAL: DARK GRAY TO BLACK, SOFT SHALE; THIN COAL BED.

SANDSTONE: OLIVE, FINE TO MEDIUM GRAIN SIZE IN VERMEJO-TYPE TONGUES THAT PENETRATE INTO THE UPPER PART OF THE TRINIDAD SANDSTONE.

SANDSTONE: WHITE TO GRAY, FINE TO MEDIUM, SUBROUNDED, FRIABLE, SOME TABULAR CROSS-BEDDING.

SANDSTONE: WHITE TO GRAY, FINE TO MEDIUM, SUBROUNDED, FRIABLE, VERY LAMINATED.

SANDSTONE: WHITE TO GRAY, FINE TO MEDIUM, SUBROUNDED, MEDIUM HARDNESS, MASSIVE, NO PIERRE-TYPE SHALE TONGUES.

SHALE, SANDSTONE, SILTSTONE: BROWN TO GRAY SHALES; GRAY SANDSTONES, FINE GRAIN SIZE, SUBROUNDED, COMPACT, QUARTZITIC, CARBONACEOUS DETRITIC MATERIALS; WELL-BEDDED SILTSTONES.

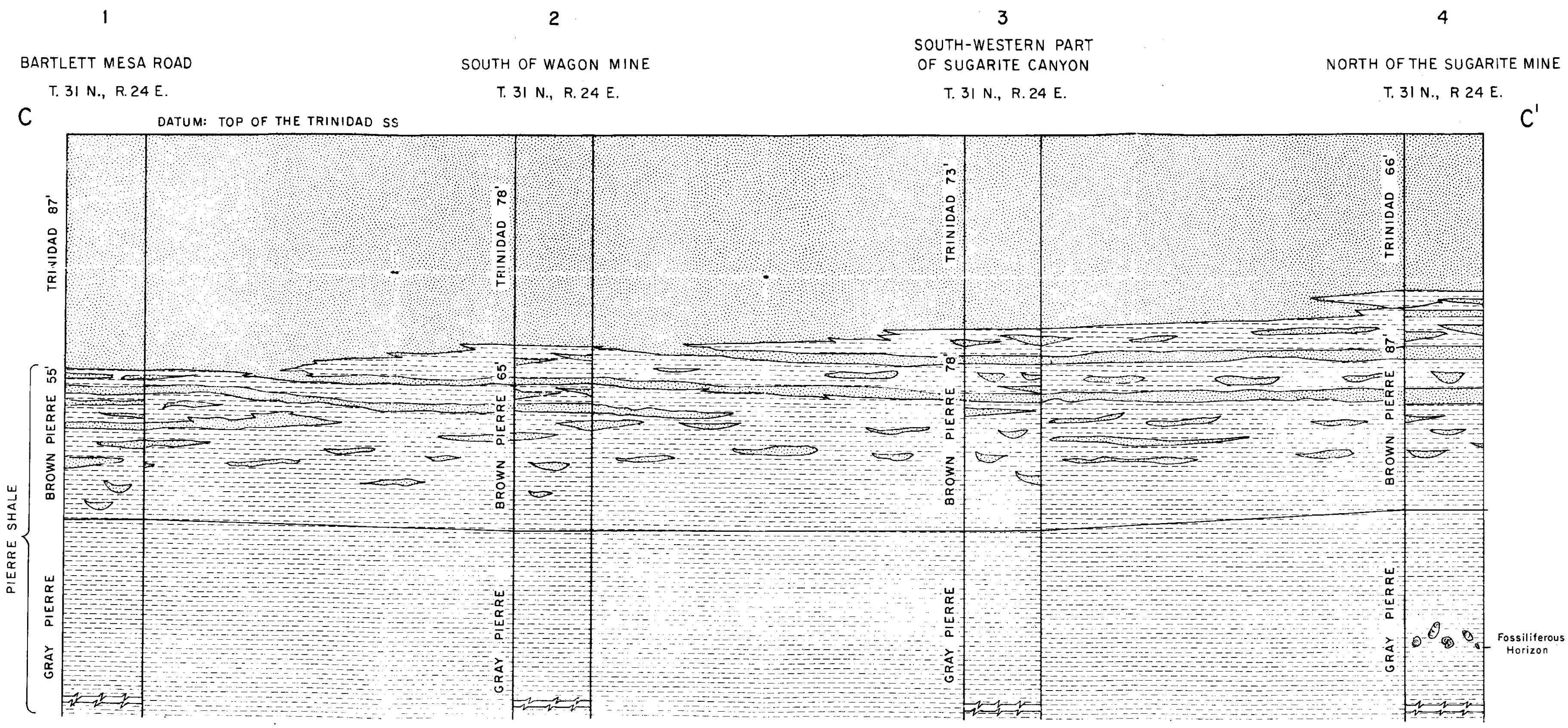
SYMBOLS

- SHALE
- SANDSTONE
- SILTSTONE
- COAL BEDS
- IRON NODULES IN SANDSTONE
- SANDSTONE TONGUES
- CROSS-BEDDING
- LOCAL UNCONFORMITY
- SANDSTONE LENS IN SHALE
- VOLCANICS

PLATE 4 T-1146

By: HILARIO ZEUSS
1967

SCALE: 1 INCH = 50 FEET



CROSS SECTION C-C'

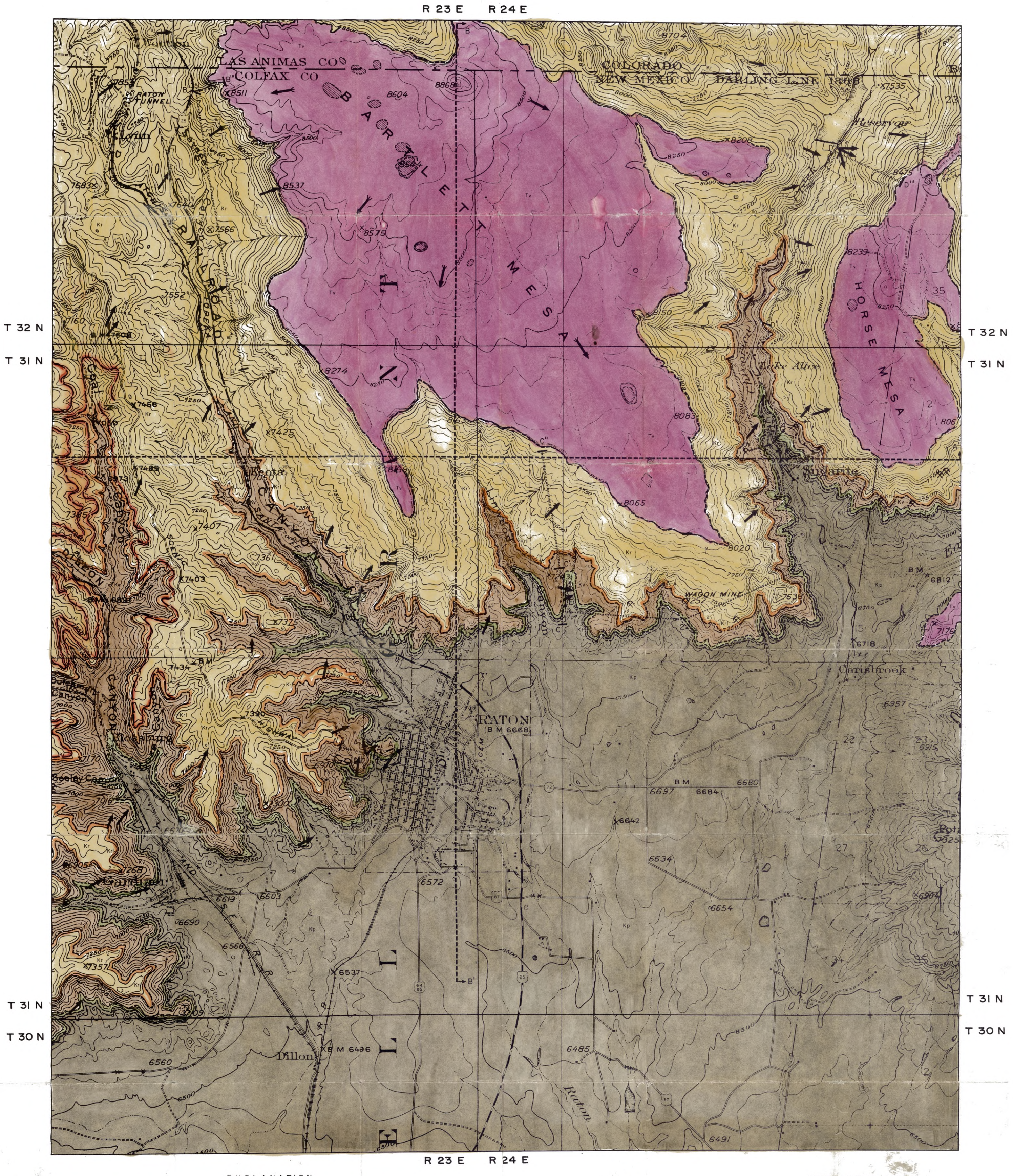
INTERTONGUING OF PIERRE SHALE AND TRINIDAD SANDSTONE

BY: HILARIO ZEUSS

1967

T-1146

PLATE 5



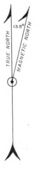
EXPLANATION

SYMBOLS

Contact	Four lane highway
Strike and dip of bed	Two lane highway
Strike and dip of joint	Other roads
Directions of sediment transport	Railway
Structural cross section (Plate 7)	Stream
Detailed cross section (Plate 5)	Lake or reservoir
Measured stratigraphic sections (Plates 1-4)	Topographic contour
Directions of lava flow	

FORMATIONS

TERTIARY	Late Tertiary	Tv; Intrusions	IGNEOUS
TERTIARY	Paleocene	Kr; Krl (L. massive ss.)	RATON FORMATION
UPPER CRETACEOUS		Kv	VERMEJO FORMATION
UPPER CRETACEOUS		Kt; Kt (Intertonguing of Trinidad Sandstones with Pierre Shales)	TRINIDAD SANDSTONE
UPPER CRETACEOUS		Kp	PIERRE SHALE



BASE MAP COMPILED FROM U.S.G.S. 1:62,500 RATON QUADRANGLE TOPOGRAPHIC MAP

GEOLOGIC MAP OF THE RATON AREA

COLFAX COUNTY, RATON QUADRANGLE
NEW MEXICO

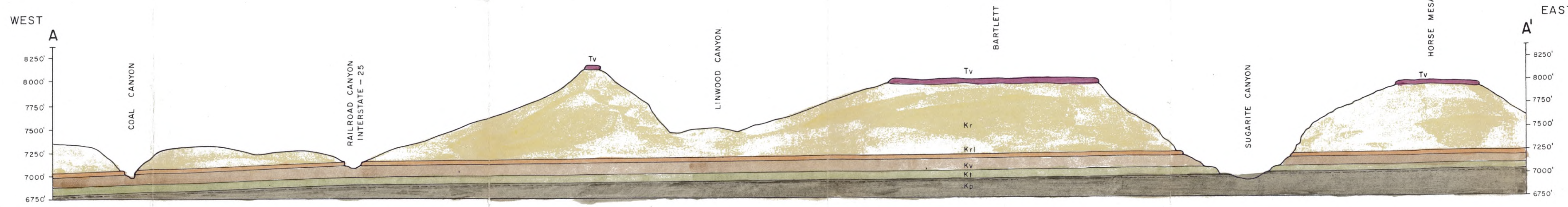
BY: HILARIO ZEUSS
1967

SCALE: 1:15,840

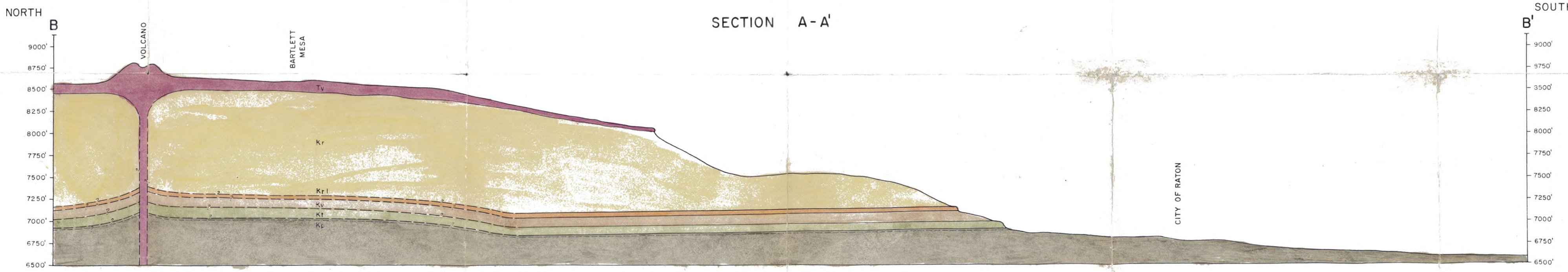
0 1/4 1/2 3/4 1 MILE

CONTOUR INTERVAL: 20 FEET; DATUM: SEA LEVEL

PLATE T-114



SECTION A-A'



SECTION B-B'

EXPLANATION

TERTIARY — Late Tertiary — Volcanics — Tv

Paleocene — Raton Fm — Kr — Krl Lower Massive SS

Upper Cretaceous — Vermejo Fm — Kv

Trinidad SS — Kt — Kt Trinidad Tongues

Pierre Fm — Kp

Scales: Horizontal 1:15,840
Vertical 1:500

STRUCTURAL CROSS-SECTIONS

RATON AREA, COLFAX COUNTY

NEW MEXICO

By: HILARIO ZEUSS

1967

T- 1146

PLATE 7