AN INTERPRETATION OF THE DEPOSITIONAL SETTING FOR THE SUGARITE COAL ZONE OF THE RATON FORMATION, LOCATED NEAR THE CITY OF RATON, NEW MEXICO

by

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This thesis is accepted on behalf of the faculty at the New Mexico Institute of Mining and Technology by the following committee:

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To my Mom and Dad

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

Plate

ABSTRACT

The purpose of this study is to obtain a reasonable explanation for the existence of coal in the lowermost 200 ft. of the Raton Formation located within the vicinity of the city of Raton, New Mexico. This lowest portion of the Raton Formation is refered to as the 'lower, barren zone.' The 'Sugarite coal zone' is part of the lower 200 ft. of the Raton Formation and is of special interest because of the local, mineable coal seam found at this level.

The sandstone bodies making up the lowest portion of the Raton Formation have common characteristics which include: mineralogy, color, grain size, sorting, rounding, induration and matrix. Sandstone deposits display grain size and bed thickness that only slightly decrease vertically. Many sandstones contain plant impressions and carbonaceous debris especially at their bases. Other than fresh water plant impressions, no fossils were observed.

The sandstones vary in bed shape, thickness and nature of basal contacts. The internal structures also vary from trough, planar and convoluted cross beds, ripple and horizontal laminations. Only two sandstone deposits contain a quartz pebble lag at their bases.

The sandstones were observed to be vertically and laterally associated with siltstone, silty mudstone,

carbonaceous shales and coal. Most sandstones were observed as isolated, discontinuous bodies within interbedded lithologies. In the upper 2/3 of all measured sections, many sandstones appeared multistoried and somewhat laterally continuous.

This paper divides the 'lower, barren zone' into separate intervals in order to group vertical and lateral lithologic associations. The separation is based on percentage of observed associated thick to very thick sandstone, siltstone, carbonaceous shale and coal relative to interbedded siltstone, mudstone and thinly laminated to medium sandstone beds. Since the emphasis of this paper is to determine the depositional setting for the occurrence of coal in the lowest portion of the Raton Formation, significant coal and carbonaceous shale zones were used to determine the separation of intervals.

The study area could be divided into three separate intervals based on a carbonaceous rich zone located in the middle 1/3 of all measured sections. The lowest 1/3 of all measured sections is poor in sandstone and carbonaceous lithologies and rich in interbedded deposits. This is designated as interval 1. The middle 1/3 carbonaceous rich zone is designated as interval 2. The upper 2/3 of all measured sections is sandstone rich while the uppermost 1/3 of all measured sections, designated as interval 3, is again

poor in carbonaceous deposits. Mudstone is the dominant lithology in all three intervals.

Sandstone deposits of the Raton Formation are compared to sandstone deposits of six different environments: alluvial, tidal, marine-shelf, eolian, turbidite and barrier-island. Sandstone beds of the Raton Formation show characteristics similar to sandstone beds of alluvial origin.

Sandstones and related lithologies of the Raton Formation are also compared to several environments: back-barrier, lower delta plain, transitional lower delta plain, and fluvial-upper delta plain. Lithologies of the Raton Formation display characteristics similar to both lower delta plain to transitional lower delta plain and fluvial-upper delta plain environments.

The interpretation of lithologies of the Raton Formation as lower delta plain include distributary-mouth-bar sandstone, lower and upper bay fill deposits of active and abandoned distributary channels and interdistributary deposits of crevasse splay, natural levee and marsh. From interval 1 through 3, there is an overall coarsening-upward of lithologies as would be expected in a prograding deltaic environment.

An alternate interpretation for the deposits of the lower Raton Formation consists of the possible

existence of an unconformity overlain by deposits of an initial braided and subsequent meandering river systems. The lowest 20 ft. of the Raton Formation show characteristics of a mixed load, moderately sinuous fluvial system (Schumm, 1963, 1981 and Galloway, 1981). This is based on the substantial presence of sandstone to any other lithology at this lowest level. The basal sandstones found at the lowest 20 ft. of the Raton Formation show many of the characteristics associated with braided systems. A change in gradient and sediment may have produced channel stabilization (Beaumont, 1979). The subsequent environment may be interpreted as a northwest to southeast trending meandering river system. All measured sections are believed to be obtained adjacent to the main channel of this system.

The deposits of the Raton Formation interpreted to be produced by a meandering fluvial system include moderately well to well drained swamp, crevasse channel and crevasse splay deposits. Coals are interpreted as having formed on crevasse splay platforms which would explain their discontinuous and split nature.

It is concluded that the deposits of the lowermost Raton Formation located within the area of study are those of lower-delta plain origin. This is based on the absence of point bar accretion, the characteristics of the deposits more closely resemble those of

lower-delta plain and an overall coarsening-upward sequence of these deposits.

INTRODUCTION

Purpose

Coal is one of New Mexico's leading natural resources. The major coal producing areas of New Mexico are the San Juan and Raton Basins. The San Juan Basin produces subbituminous coal while the Raton Basin contains medium to high volatile bituminous coal.

Because of obvious social and economic interest in extracting coal, this study will add information on the geological occurrence of coal found in the vicinity of Raton. The purpose of this study is to place the Sugarite coal bed in its depositional context.

Location and Accessibility

The area of investigation is located north and east of Raton, New Mexico (Figures 1 and 2). It is contained within the Raton Quadrangle published by the U.S. Geol. Survey. The initial outcrops studied lie west of a point called Goat Hill within Climax Canyon; outcrops were followed north for approximately one and one half miles and then east across the lowest portion of Bartlett Mesa to the easternmost beds measured in Chicorica Creek Canyon to the northeast of Raton. Approximately eight linear miles were studied

FIGURE 1

INDEX MAP OF STUDY AREA

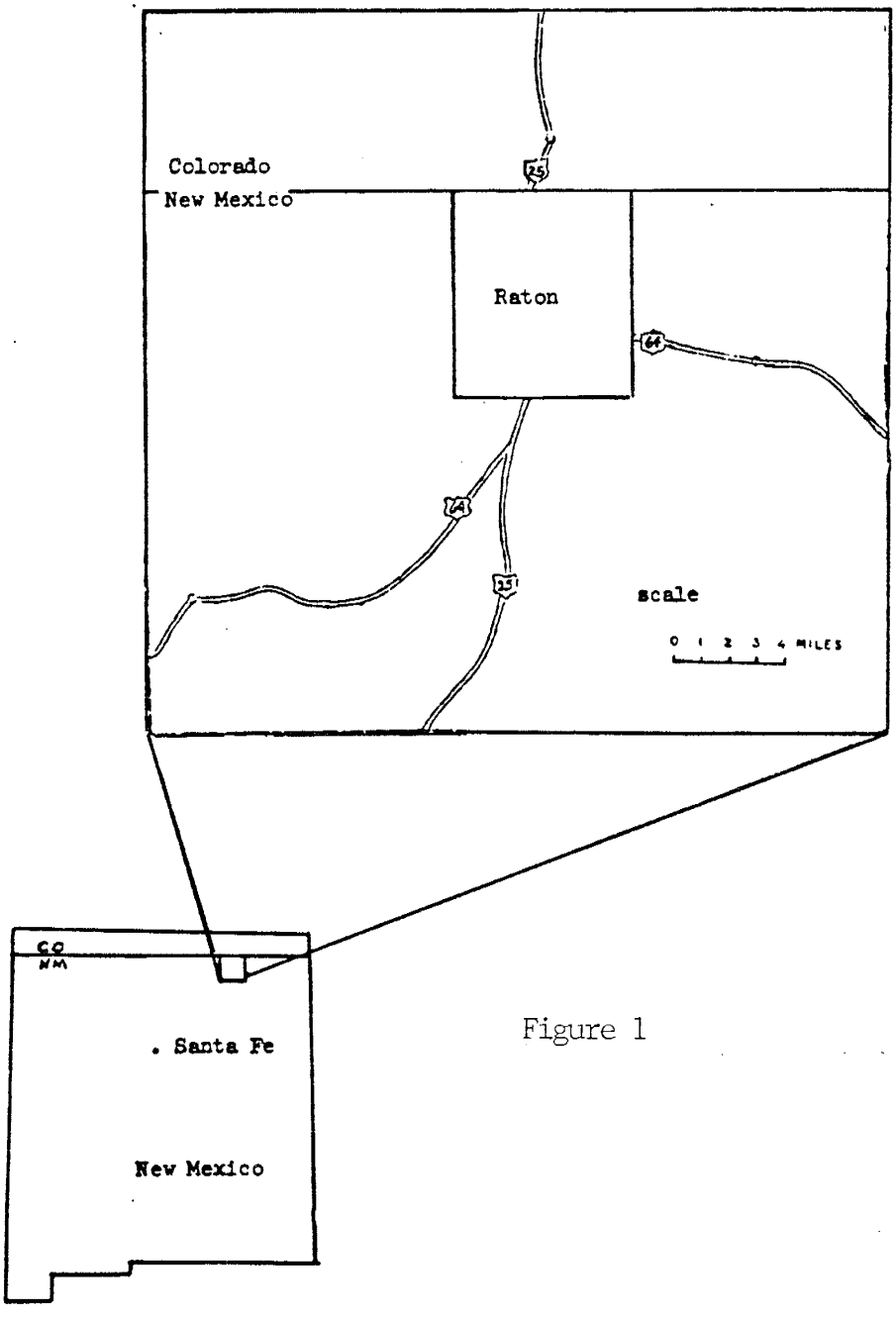

Colorado
New Mexico
Raton
64
25
scale
0 1 2 3 4 MILES
CO
NM
Santa Fe
New Mexico

Figure 1

FIGURE 2

VIEW OF STUDY AREA NEAR THE CITY OF RATON

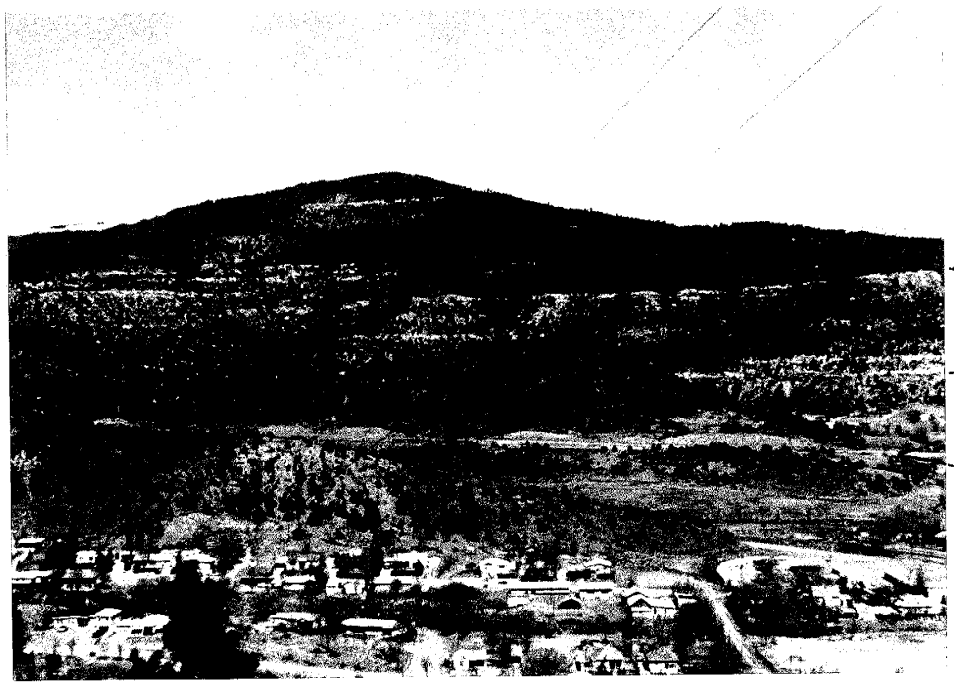


Figure 2

in detail.

The area is accessible by the old Raton Pass road (Scenic Road), Interstate Highway 25, and State Roads 72 and 526. Other county and private roads provide access to most of the area; although trails were needed to reach less accessible portions.

Methods of Investigation

The field work was carried out from mid August to the first of December of 1982. Tape and Jacob staff equipped with a hand level device were used for measuring stratigraphic sections. Representative rock samples were collected for laboratory analysis. The field work began behind a point called Goat Hill, just west of the city of Raton, where a section was measured up a gully in Climax Canyon. The work proceeded northward for approximately 1 1/2 miles, then eastward across the southern face of Bartlett Mesa ending in Chicorica Creek Canyon (Figure 3). All work began at the top of the Trinidad Sandstone and continued upward for approximately 200+ ft. A total of 17 complete sections were measured and additional shorter sections were measured in order to assure lateral correlation due to heavy vegetation and poor exposure throughout the area and to fill in as much additional information as possible. The top of the Trinidad Formation was determined from work of previous authors

FIGURE 3

FIELD AREA AND LOCATION OF SECTIONS MEASURED
(FROM USGS RATON QUADRANGLE, 1971)

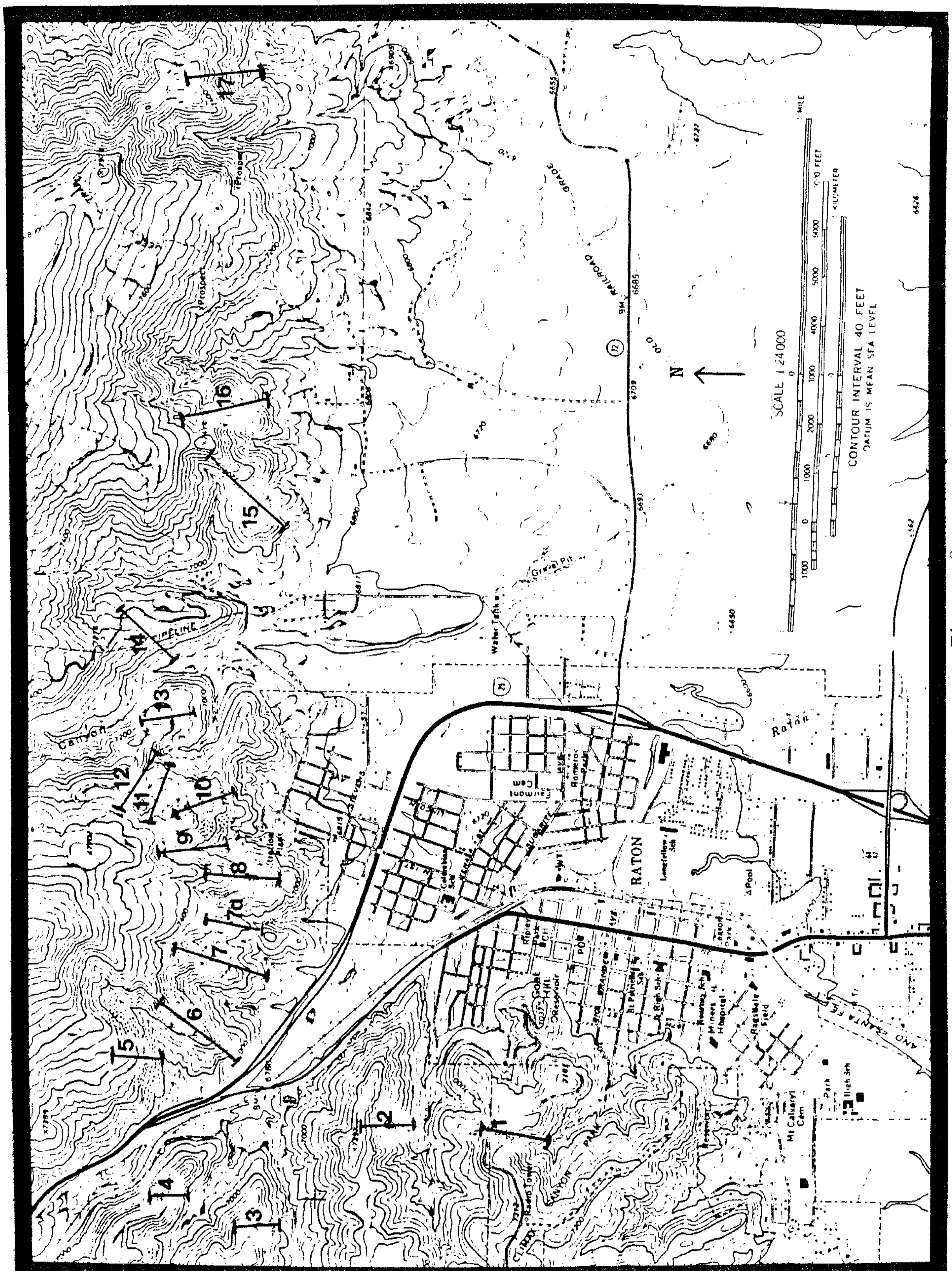

RATON
SCALE 1:24000
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
N

Figure 3

and field investigation. The Trinidad is a cliff former and a good marker bed throughout the field of study.

Field descriptions of component facies emphasize lithology, thickness, nature of contacts, grain size, lateral extent, sedimentary structures and fossil content. Due to the lack of deformation, no strike and dip measurements were recorded. All data recorded are compiled on east to west stratigraphic cross sections (Plates 1-6). The cross section datum is the top of the Trinidad Sandstone.

Petrographic study of representative sandstones involved examination of 9 thin sections. Using techniques suggested by Moorhouse (1959) and Folk (1980), thin sections were examined for grain size, mineral composition, cement and matrix, textural maturity, abundance of monocrystalline and polycrystalline quartz and diagenesis. Descriptions used in the field and incorporated within this text are based on standardized scales. Wentworth's (1922) scale is used for grain size determination, the Geological Society of America Rock Color Chart for color descriptions, Ingrams's (1954) classification for bed thickness, Folk's (1980) classification for sandstones and roundness, and Terry and Chilingar's (1955) transparency for estimating percentage of composition, and Compton (1962) and Lahee (1969) field geology

manuals were used as references for all other descriptions.

Geological Setting of the Raton Basin

The Raton Basin is a structural basin which lies in the western part of the Great Plains Province situated in Las Animas and Huerfano Counties of southern Colorado, and Colfax County of northeastern New Mexico (Figure 4). That part of the basin in New Mexico, is about 175 miles long and is 65 miles wide at the Colorado border (Clark, 1966).

The Basin is bounded on the west by the Sangre De Cristo Mountains, the northeast by the Apishapa Arch and the southeast by the Sierra Grande Arch. The structural axis of the Raton Basin roughly parallels the Sangre De Cristo Mountains. It is generally arcuate trending north in New Mexico and northwest in Colorado. The deepest part of the basin is in the Colorado portion. The basin is asymmetrical with a west limb dipping at an angle of about 50 degrees to the east and an east limb which dips at about 1 to 5 degrees to the west (Speer, 1976). Late upper Cretaceous and lower and middle Tertiary rocks fill the deepest part of the basin in the Raton Mesa region and Huerfano Park.

Within the study area of this paper, structures such as faulting, folding or intrusions were not

FIGURE 4

MAP OF THE STRUCTURAL RATON BASIN OF NEW MEXICO
(from Johnson et. al., 1966, p. 89)

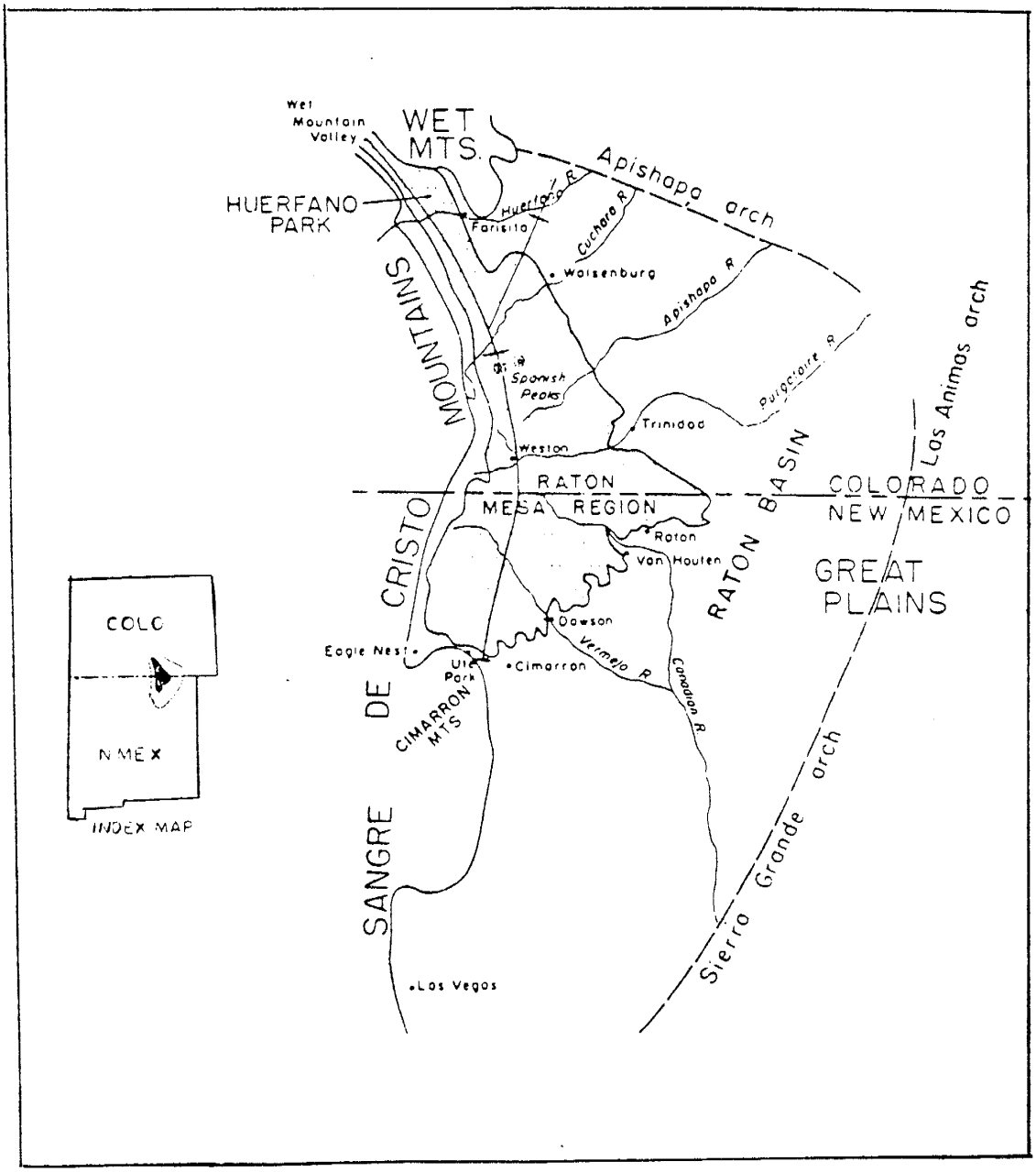

Wet Mountain Valley
WET MTS.
HUERFANO PARK
Huerfano R
Farisita
Cucharo R
Walsenburg
Apishapa arch
Apishapa R
Spanish Peaks
Purgatoire R
Trinidad
Weston
MOUNTAINS
CRISTO
DE
RATON MESA REGION
COLORADO
NEW MEXICO
Las Animos arch
RATON BASIN
GREAT PLAINS
Raton
Van Houten
Dawson
Vermejo R
Canadian R
Eagle Nest
Ute Park
Cimarron
CIMARRON MTS
SANGRE
Los Vegas
Sierra Grande arch
COLO
N MEX
INDEX MAP
0 10 20 30 40 50 Miles
Scale

Figure 4

observed; although some local faulting and intrusions were observed to the north and west of the field of study.

Raton Basin Stratigraphy

Rocks associated with the basin, range in age from Precambrian to recent deposits (Table 1). The Precambrian rocks are crystalline and are exposed in the Sangre De Cristo and Cimarron Uplifts on the west side of the Raton Basin. The Paleozoic is dominantly sandstones and limestones. Mesozoic rocks include mostly sandstones and shales. The early Tertiary is composed of clastic rocks (Raton and Poison Canyon Formations) derived from the Sangre De Cristo Uplift which rose during Laramide time. Downwarping of the Raton Basin continued during deposition of these strata and ended in Eocene or Oligocene time. Postorogenic rocks are late Tertiary to Quaternary in age. Andesitic and basaltic volcanic rocks are found mainly in the southern and eastern parts of the Raton Basin. Numerous sills and laccoliths occur on the Sierra Grande Uplift. Coarse, unconsolidated gravel overlies the volcanics in the Sangre De Cristo region.

The stratigraphic sequence, found within the study area, includes the Pierre, Trinidad, Vermejo and Raton Formations (Table 2). These formations are part of a regressive coastal system developed during the end of

Table 1. Composite stratigraphic column for Raton Basin, New Mexico and Colorado (in New Mexico Geol. Soc. Guidebook, Vermejo Park, 1976).

AGE	LITHOLOGIC UNITS	THICKNESS
RECENT	ALLUVIUM, DUNE SAND, LANDSLIDE DEBRIS	0-20'
PLIOCENE — PLEISTOCENE	BASALTS	
	OGALLALA FM. — PEDIMENT GRAVEL, VALLEY FILL, CALICHE	200-500'
MIOCENE ?	DEVIL'S HOLE FM. - CONGLOM., TUFFS (COLORADO ONLY)	25-1300'
	MONZONITE PROPHYRIES (COLORADO ONLY)	100-1500'
	RHYOLITES & ANDESITES (COLORADO ONLY)	1300-1500'
OLIGOCENE ?	FARASITA CONGLOM. (COLORADO ONLY)	0-1200'
EOCENE	HUERFANO FM. — SH & SANDS (COLORADO ONLY)	0-2000'
	CUCHARA FM. — SAND & SHALE (COLORADO ONLY)	0-5000'
PALEOCENE	POISON CANYON FM.	0-2500'
	RATON FM. CONGLOM., SS'S.	
	GRYWK'S., SILST., COAL	0-2075'
CRETACEOUS	VERMEJO FM. — SS., SH., CLAY, COAL	0-360'
	TRINIDAD SS.	0-255'
	PIERRE SH.	1300-2900'
	NIOBRARA FM. —	
	SMOKY HILL MARL MBR.	900'
	FT. HAYS LS. MBR.	0-55'
	BENTON FM.	
	CARLILE SH.	165-225'
	GREENHORN LS.	20-70'
	GRANEROS SH.	175-400'
	DAKOTA SS.	140-200'
	PURGATOIRE FM. - SS. & SH	100-150'
JURASSIC	MORRISON FM.	150-400'
	WANAKAH FM.	30-100'
	ENTRADA SS.	40-100'
TRIASSIC	DOCKUM GROUP - SH'S & SS'S	0-1200'
PERMIAN	BERNAL FM.	0-125'
	SAN ANDRES LS.	10-20'
	GLORIETA SS.	50-200'
	YESO FM.	200-400'
?	SANGRE DE CRISTO FM.	700-5300'
PENNSYLVANIAN	MAGDALENA GRP. — LS'S., SH. & SS.	4000-5000'
MISSISSIPPIAN	TERERRO FM. — LS'S.	40-50'
DEVONIAN ?	ESPIRITU SANTO FM. — DOL. LS.	25'
PRE-CAMBRIAN	MAFIC GNEISS GRP.	7000' ?
	METAQUARTZITE GRP.	5000' ?
	GRANITE & GRANITE GNEISS	4000' ?

Table 2. Generalized stratigraphic section of rocks in the Raton coal field (from Pillmore, 1976).

AGE		FORMATION	GENERAL DESCRIPTION	APPROXIMATE THICKNESS IN FEET
TERTIARY	PALEOCENE	POISON CANYON FORMATION	Sandstone, coarse to conglomeratic, beds 5 to more than 50 feet thick, interbeds of soft yellow-weathering clayey sandstone; thickens to west at expense of underlying rocks	500+
		RATON FORMATION	Sandstone, very fine grained to fine grained with interbeds of claystone, siltstone, and coal; commercial coal beds in upper part. Lower few feet conglomeratic; intertongues with Poison Canyon to the west. Generally sharp erosional contact with underlying Vermejo Formation	0-2000
CRETACEOUS	LATE CRETACEOUS	VERMEJO FORMATION	Sandstone, very fine grained to medium grained, interbedded with mudstone, carbonaceous shale, and coal; extensive thick coals top and bottom	0-380
		TRINIDAD SANDSTONE	Sandstone, very fine grained to medium grained, contains casts of *Ophiomorpha* sp.	0-130
		PIERRE SHALE	Black shale, limestone concretions, silty in upper part, grades up to sandstone	2500+

Cretaceous and beginning of Tertiary time. The shoreline of this system, in the vicinity of Raton, retreated to the southeast leaving a northeast trending coastal shore (Pillmore, 1976). The sediment source, originally some 400 miles to the west, shifted to the San Juan Mountains about 200-300 miles west of Raton.

Previous Work

The earliest recognition of coal in the Raton Basin was recorded by the Long Expedition about 1821. It was later mined for fuel by the local ranchers and to supply the garrison at Fort Union 50 miles to the south.

It wasn't until the late 1800's that St. John, a member of the Hayden Survey, began a geologic investigation of the basin. His work was directed at determining the extent and feasibility of mining the coal. From 1900 to 1923 Lee, a geologist for the U.S. Geol. Survey, compiled extensive stratigraphic information on the eastern Raton Basin. The purpose of his work was aimed at establishing the Cretaceous-Tertiary unconformity, which he placed at the top of the Vermejo and base of the Raton Formations. Lee (1917) noted that the Vermejo Formation pinched out in Linwood Canyon and did not exist east of this locale (Figure 5). It was during this period that Knowlton (1917) compiled the

FIGURE 5

PINCHOUT OF THE VERMEJO FORMATION IN LINWOOD CANYON AS MAPPED BY LEE (1917) (FROM ZEUSS, 1967).

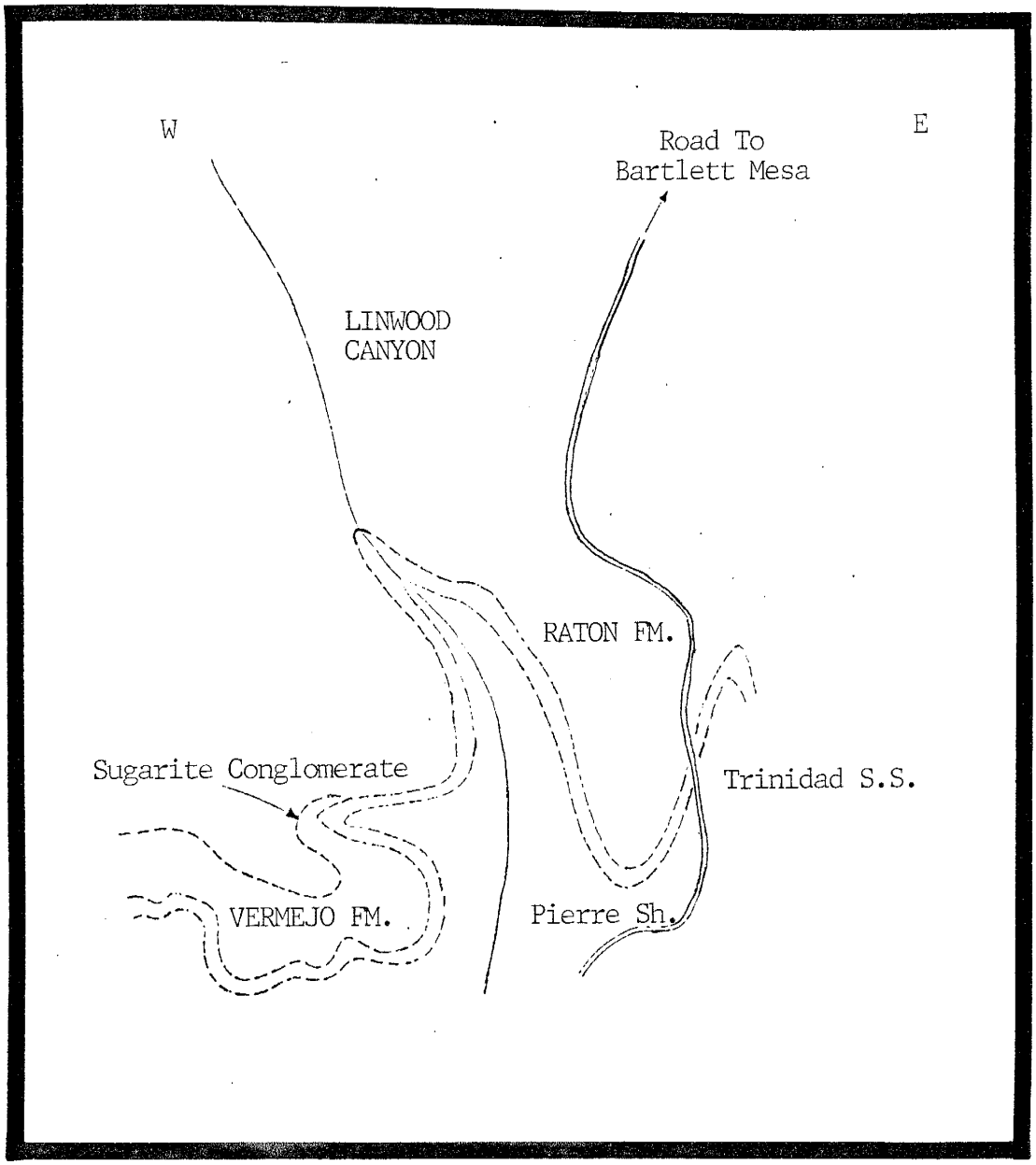

W
E
Road To
Bartlett Mesa
LINWOOD
CANYON
RATON FM.
Sugarite Conglomerate
Trinidad S.S.
VERMEJO FM.
Pierre Sh.

Figure 5

most comprehensive data to date of the fossil floras of the Vermejo and Raton Formations.

From 1924 to 1943, no serious coal exploration was conducted in the Raton Basin. Coal outcrops were identified; but continuity or quality of the coal was not established.

In 1948 to 1949 Van Lint, a geologist for the St. Louis, Rocky Mountain and Pacific Company (SLRMP) owners of the coal rights in the Vermejo Park area of the Raton Basin, estimated the coal reserves in two major Vermejo coal seams. Kaiser Steel bought the SLRMP holdings in 1955. Kaiser geologists began an exploration program from 1956 to 1957 in search of a high quality, low ash coal. Their work included estimates of reserves and thickness of coal. In the 1970's, drilling was done, but no additional field work. During the writing of this report, Kaiser has sold its holdings.

The U.S. Geol. Survey's interest in the Raton Basin was rekindled in 1948 with a regional investigation of the geology and fuel resources. In 1956, the Rocky Mountain Association of Geologists published a guidebook to the geology of the Raton Basin, and in 1966 the New Mexico Geological Society 17th Field Conference published a guidebook called "The Taos, Raton, Spanish Peaks Country". In that book, Clark (1966) and Johnson, Dixon and Wanek (1966)

described the structure and geology of the Basin.

The New Mexico Geological Society's 27th Field Conference published a guidebook called "Vermejo Park" in 1976. In it Fassett (1976) discussed late Cretaceous sedimentation in the San Juan and Raton Basins and Pillmore (1976) discussed the coal deposits of the Vermejo and Raton Formations in greater detail.

Interpretation of the Pierre-Trinidad-Vermejo stratigraphic succession has been reported by Pillmore and Mayberry (1976) to be an interdeltaic coastal system similar to that of present day South Carolina or Georgia. Detailed interpretation of this stratigraphic sequence, found within the study area of this paper, have been discussed in two M.S. theses: Zeuss (1967) and Leighton (1980). Zeuss (1967) uses the base of the lowest, very thick, cliff forming sandstone of the Raton Formation to designate the Vermejo-Raton contact within the vicinity of Linwood Canyon (see Figure 6). This is approximately 20-40 ft. higher than the same contact established by Lee (1917) within Linwood Canyon. Zeuss (1967) places the 'Sugarite' coal zone within the Vermejo Formation. He bases his interpretation on what he determined to be similar environments of deposition and calorific values for both the Vermejo and 'Sugarite' coal beds. He does not attempt a detailed description of the depositional setting for the 'Sugarite' coal. Zeuss does state that

FIGURE 6

INTERPRETATION OF VERMEJO-RATON RELATIONSHIP IN LINWOOD CANYON AS MAPPED BY ZEUSS (FROM ZEUSS, 1967).

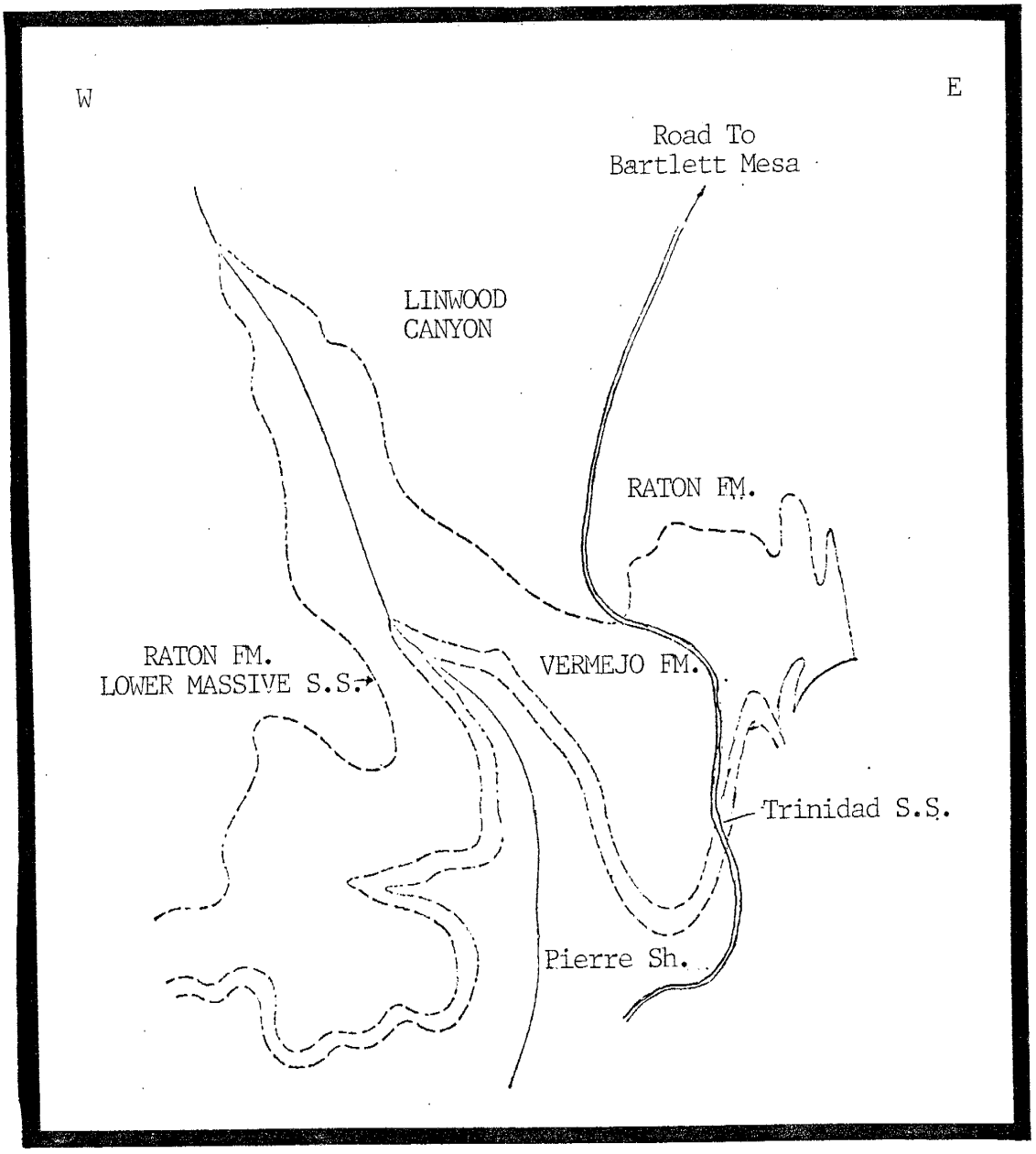

W
E
Road To
Bartlett Mesa
LINWOOD
CANYON
RATON FM.
RATON FM.
LOWER MASSIVE S.S.
VERMEJO FM.
Trinidad S.S.
Pierre Sh.

Figure 6

the study area was on the southern side of a delta with the average direction of transport to the northeast and east of Raton. Zeuss describes the environmental setting, in which both the Vermejo and 'Sugarite' coal beds were formed, as "swamps located in and behind a deltaic zone", or shallow lagoons "which were separated from the sea by thin strips of land".

Leighton (1980) presented the most detailed account of the depositional environment of the Pierre-Trinidad-Vermejo Formations touching lightly on the basal units of the Raton. His findings concurred with those of Pillmore and Mayberry (1976). Leighton (1981) suggested that the Pierre Shale represented quiet water depositional conditions in the shallow open marine shelf, while the Trinidad Sandstone was deposited under high energy, near-shore coastal conditions; the Vermejo Formation is interpreted as having formed in a coastal plain complex. Several environments were identified within the study area and Leighton (1981) reported them to include "lower and middle shoreface, river estuary-inlet, beach, splay, natural levee, and poorly to well drained swamps. It is an aerially restricted delta front and delta distributary channel environment of a small wave dominated and tidally influenced lobate delta area." Coals of the Vermejo Formation, within the vicinity of Raton, were reported by Leighton (1981) to be a product

of peat swamps forming directly behind a beach ridge chain. He pointed out that the Vermejo coals in the study area were thicker than would be expected of salt marsh derived coals and concluded that they formed dominantly in fresh water swamps. Leighton (1981) offered no explanation for the dominance of fresh water. Leighton also stated that the basal sandstone of the Raton Formation, as reported by Lee (1917), is a braided stream channel sandstone. The only evidence Leighton cited to support this conclusion is the lack of fining-upward sequences in the basal sandstones of the Raton Formation.

LITHOLOGIC DESCRIPTIONS

Sandstones

The sandstones making up the lowest 200 ft. of the Raton Formation have many characteristics in common. They are quartzose to subarkosic. The color is generally grayish orange (10 YR 7/4) in weathered surface to a very pale orange (10 YR 8/2) in fresh surface. The average grain size is medium and the sorting is moderate. The individual grains are subangular to angular. The textural maturity is submature. Rock samples are well indurated to indurated. The sandstones are composed mostly of quartz and feldspar. Petrographic inspection shows that most of the quartz is monocrystalline with some polycrystalline varieties. The shape of quartz grains is anhedral and the contacts are smooth. Microcline is the main feldspar with some plagioclase varieties being present. Deformed mica is present and the sandstones contain a matrix clay which may be kaolinitic. Lithic fragments are commonly sedimentary. The dominant cementing material is quartz. Quartz cement in the form of overgrowths is found to be common in the sandstones at or near the base of the Raton Formation.

Sandstone beds show a slight upward and lateral fining. The bases are marked by plant impressions and carbonaceous debris. Sandstone bodies could not be

traced laterally for any distance.

The following descriptions and divisions of sandstones, that are found within study area, are based on similarities of grain size, structures, overall bed shape, thickness and nature of their bases.

Type 1a

Type 1a sandstones are quartzose and exhibit a 'sugary' appearance. Structures observed range from structureless, planar to trough cross bedded to ripple and horizontal laminations and convolutions. Sandstone bed shapes vary from tabular to lenticular. The bases of type 1a sandstones vary from erosional, wavy or undulating scour to nonerosional and contain plant impressions, carbonaceous debris and load casts. The average thickness of all type 1a sandstones is approximately 4 ft. (Figure 7).

Type 1b

Type 1b sandstone description is the same as that of type 1a sandstones with the addition of a quartz pebble channel lag at the base. Size of the pebbles may range from approximately 0.5 mm to 1.0 mm. Type 1b sandstones are observed occurring as thick as 17.0 ft.

FIGURE 7

TYPE 1a SANDSTONE (SECTION R 14, UNIT 1).

Figure 7

Type 1c

Type 1c sandstones are subarkosic containing either lenses or bands of quartzose sandstone. The lenses or bands have sharp contacts with the surrounding arkosic sandstone. The subarkosic portion of the sandstone is generally fine grained while the quartzose portion is medium to coarse grained. Type 1c sandstones are generally observed to be structureless. Basal contacts vary from sharp to gradational and may possess plant impressions, carbonaceous debris and load casts. The average thickness of all type 1c sandstones is approximately 4.0 ft. The shape may be tabular or lenticular (Figures 8 and 9).

Type 1d

Type 1d sandstones have combined characteristics from types 1a, b and c (Figures 10 and 11).

Type 2

Type 2 sandstones range from lenticular to elongated in shape. The overall shape of the beds is lenticular. Structures include trough cross-bedding, convoluted bedding, planar cross-bedding, horizontal and ripple laminations. Basal contacts of type 2 sandstones are observed to be erosional scour and characterized by clay clasts, root impressions and

FIGURE 8

TYPE 1c SANDSTONE (SECTION R 9, UNIT 3).

FIGURE 9

TYPE 1c SANDSTONE BASAL LOAD CASTS (SECTION R 9, UNIT 3) (SCALE IN INCHES).

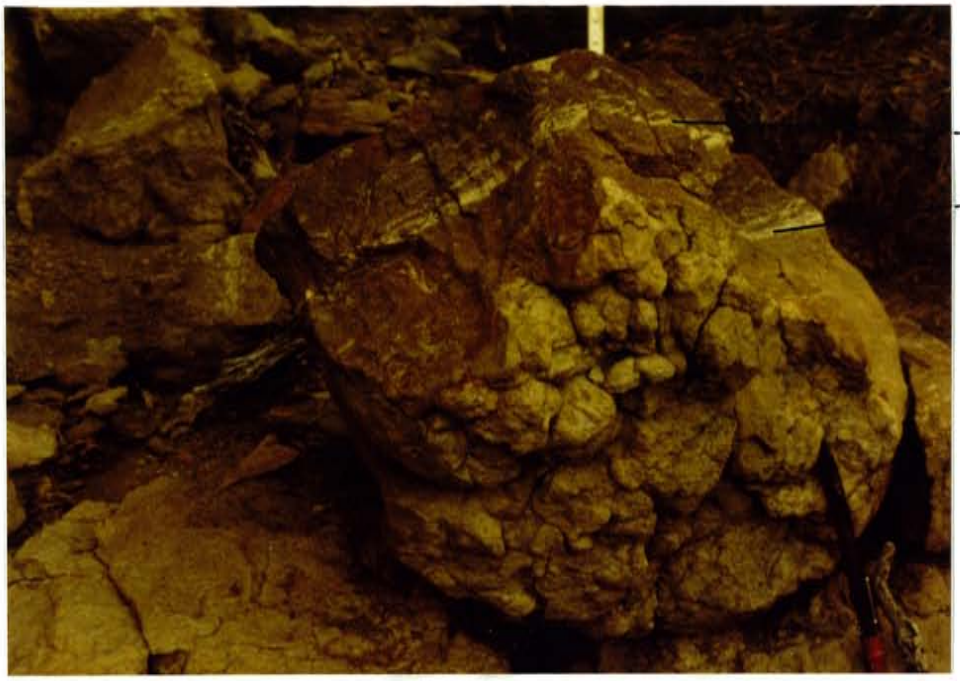


Figure 8

Figure 9

FIGURE 10

TYPE 1d SANDSTONE (SECTION R 16, UNIT 1)

Figure 10

FIGURE 11

TYPE 1d SANDSTONE (SECTION R 16, UNIT 1)
SKETCH OF STRUCTURES.

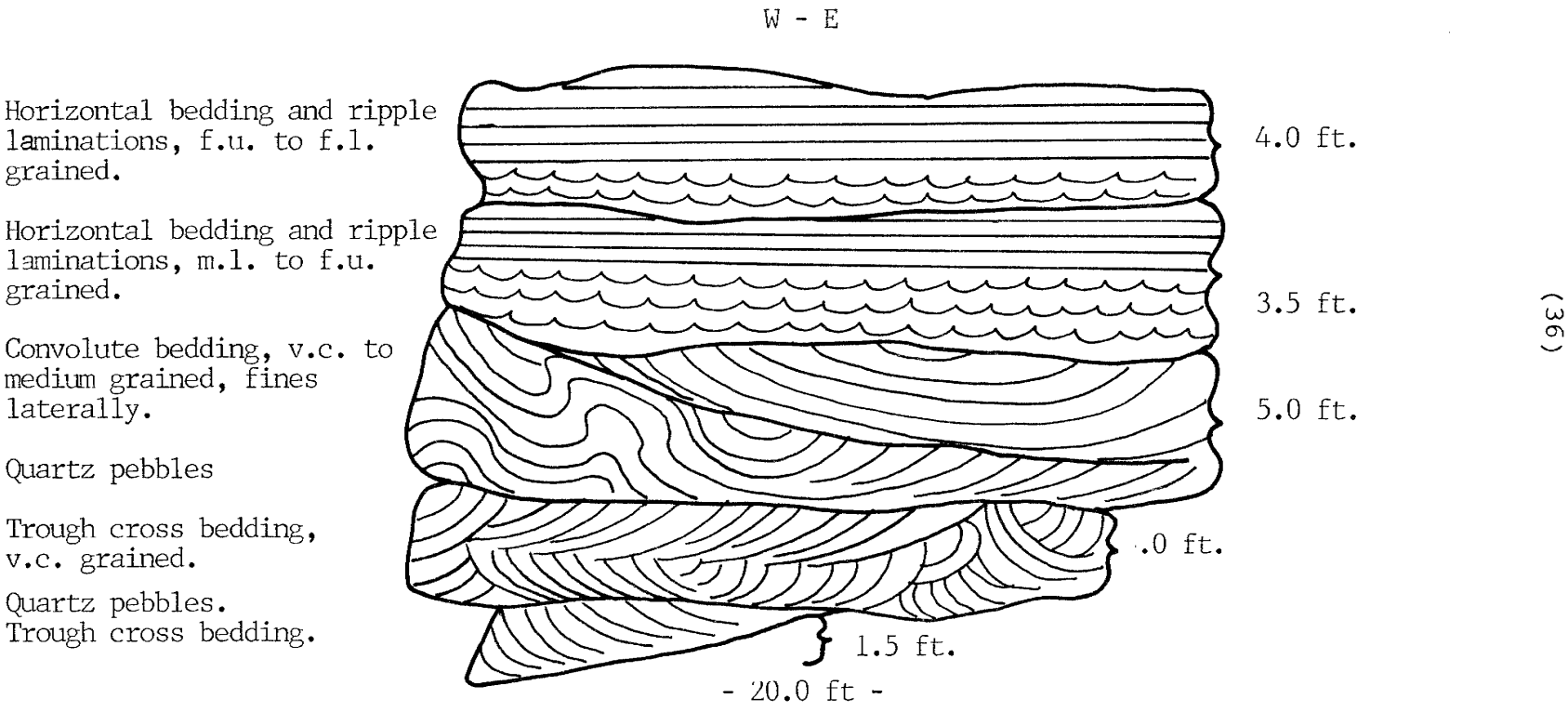

W - E
Horizontal bedding and ripple laminations, f.u. to f.l. grained.
Horizontal bedding and ripple laminations, m.l. to f.u. grained.
Convolute bedding, v.c. to medium grained, fines laterally.
Quartz pebbles
Trough cross bedding, v.c. grained.
Quartz pebbles.
Trough cross bedding.
4.0 ft.
3.5 ft.
5.0 ft.
.0 ft.
1.5 ft.
- 20.0 ft -

Figure 11

organic debris. Well indurated load casts often mark the base. Ironstone is frequently found throughout the beds and is observed to occur in bands or large concretions (Figure 12). Most type 2 sandstones are approximately 15.0 to 20.0 ft. thick and range from 1.5 ft. thick to a maximum accumulation of 60.0 ft. The elongated type 2 sandstone bodies may be laterally traceable while lenticular shaped type 2 sandstones are local features that break up laterally.

Type 3

Type 3 sandstones are tabular in shape and have internal structures which range from small to large scale trough crossbeds, parallel laminations and ripple laminations. The basal contacts are observed to be sharp nonerosional or gradational and are often characterized by clay clasts, root impressions and organic debris. Often well indurated load casts mark the base. Ironstone is found throughout the beds and is observed in bands or large concretions (Figure 13). The sandstones range in size from approximately 1.5 ft. to accumulations as great as 25.0 ft. Type 3 sandstones grade laterally into siltstone, mudstone, carbonaceous shale and coal deposits. These sandstones are also laterally associated with type 2 sandstones.

FIGURE 12

TYPE 2 LENTICULAR SHAPED SANDSTONE (SECTION R 4, UNIT 16a).

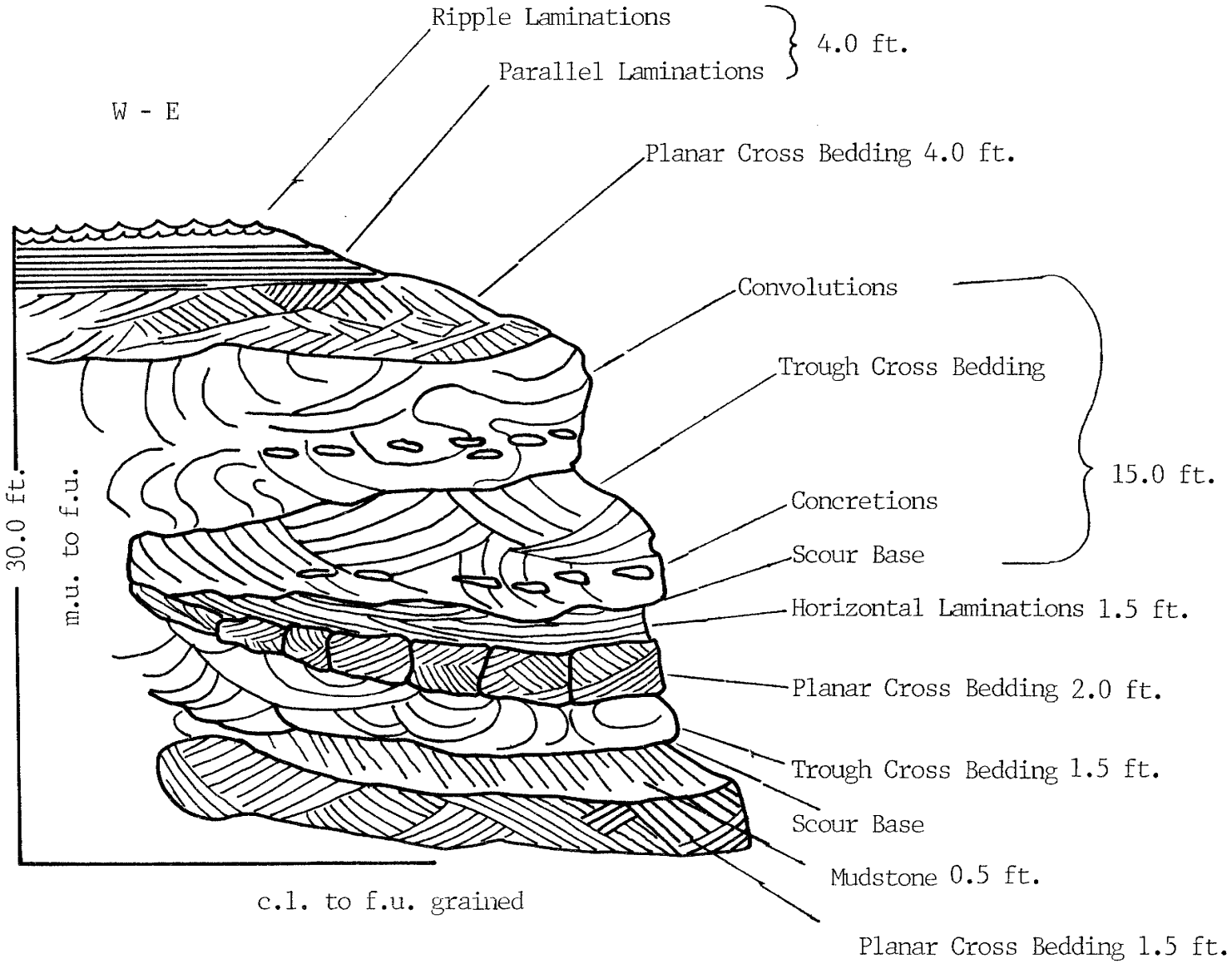

Ripple Laminations
Parallel Laminations
4.0 ft.
W - E
Planar Cross Bedding 4.0 ft.
Convolutions
Trough Cross Bedding
15.0 ft.
Concretions
Scour Base
Horizontal Laminations 1.5 ft.
Planar Cross Bedding 2.0 ft.
Trough Cross Bedding 1.5 ft.
Scour Base
Mudstone 0.5 ft.
Planar Cross Bedding 1.5 ft.
30.0 ft.
m.u. to f.u.
c.l. to f.u. grained

Figure 12

FIGURE 13

TYPE 3 SANDSTONE (SECTION R 7a, UNIT 12).

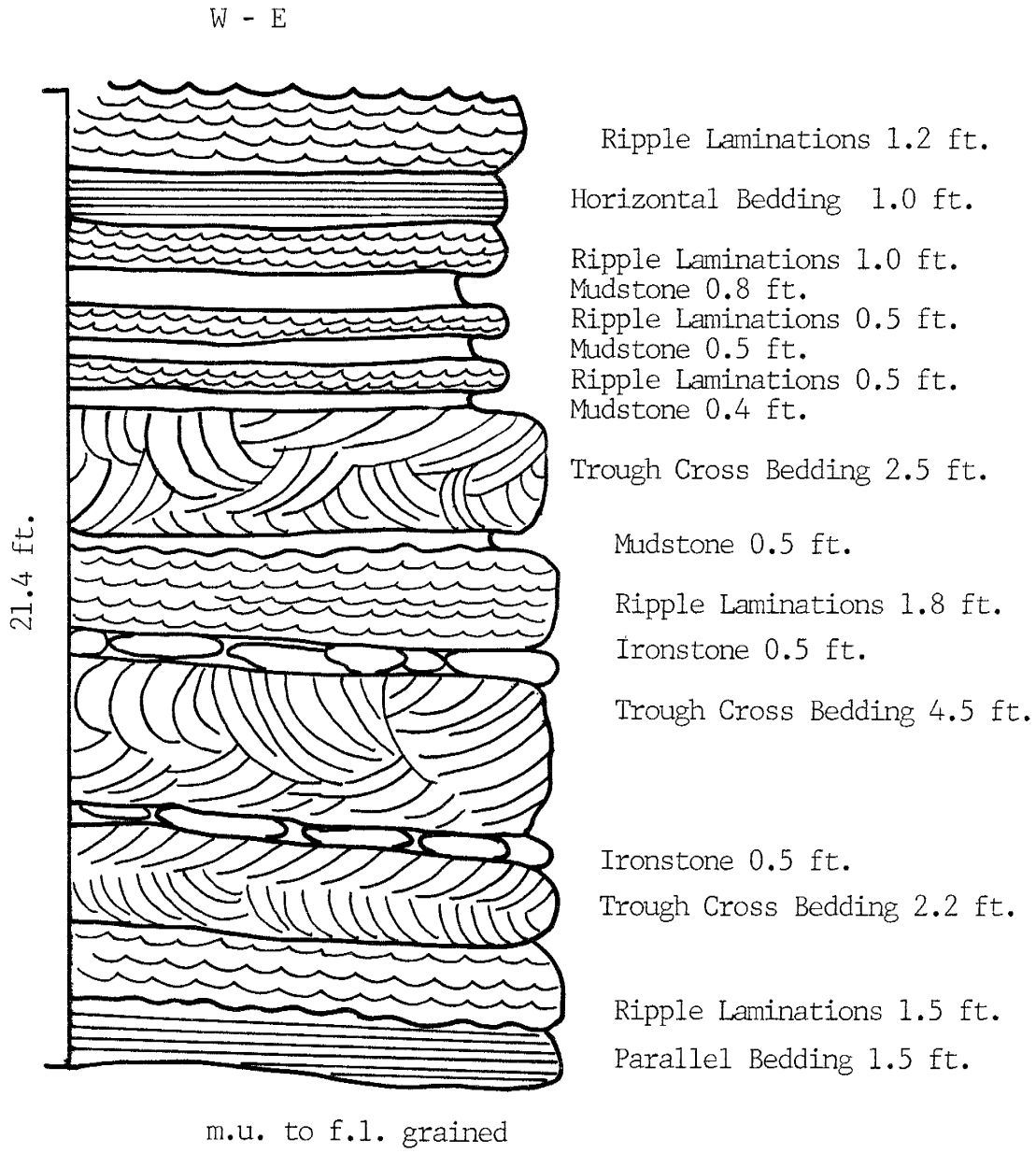

W - E
21.4 ft.
Ripple Laminations 1.2 ft.
Horizontal Bedding 1.0 ft.
Ripple Laminations 1.0 ft.
Mudstone 0.8 ft.
Ripple Laminations 0.5 ft.
Mudstone 0.5 ft.
Ripple Laminations 0.5 ft.
Mudstone 0.4 ft.
Trough Cross Bedding 2.5 ft.
Mudstone 0.5 ft.
Ripple Laminations 1.8 ft.
Ironstone 0.5 ft.
Trough Cross Bedding 4.5 ft.
Ironstone 0.5 ft.
Trough Cross Bedding 2.2 ft.
Ripple Laminations 1.5 ft.
Parallel Bedding 1.5 ft.
m.u. to f.l. grained

Figure 13

Type 4

Type 4 sandstones are medium to thinly laminated. The average bed thickness is less than 5.0 in. The basal contact ranges from gradational to sharp and is nonerosional. These sandstones have abundant organic debris, stem and leaf imprints and modern rootlets throughout. This sandstone type is found interbedded with siltstone, mudstone, carbonaceous shale and coal.

Siltstone

This rock type occurs as thick individual units or as thin interbedded units. The siltstone ranges in color from dark yellowish brown (10 YR 4/2), dusky yellow (5 Y 5/2) to light olive gray (5 Y 6/1) both in fresh and weathered surfaces. Siltstones vary from very well indurated to unconsolidated. The structures vary from structureless to horizontal and ripple laminations. The basal contacts are gradational to sharp nonerosional. Siltstones often contain abundant organic debris, stem and leaf imprints and modern rootlets throughout. Siltstones are found interbedded with type 4 sandstones and mudstones. They often occur as partings in carbonaceous shale and coal deposits. All types of sandstones may be vertically and laterally associated with siltstones. Type 2 sandstones most commonly grade vertically into siltstone deposits.

Mudstone

Mudstone deposits are olive black (5 Y 2/1) to dusky yellowish brown (10 YR 2/2) when fresh and a pale yellowish brown (10 YR 6/2), dark yellowish brown (10 YR 4/2) to light olive gray (5 Y 6/1) when dry. They are structureless, poorly consolidated to unconsolidated, organic with abundant modern rootlets, and contain silt to coarse grained sand size particles. Mudstones comprise the greatest percent of the interbedded lithologies. Mudstones are often observed as drapes along bedding planes of type 2 and 3 sandstones. Mudstones are also seen as partings in carbonaceous shale and coal beds. These mudstones may possess a shaly appearance and become increasingly carbonaceous as they grade vertically into a shale or coal bed. Laterally mudstones grade into siltstone or become increasingly carbonaceous or coaly. Often the unconsolidated, structureless mudstones are observed expanded or swollen presumably due to the presence of a montmorillonite type clay mineral. Cherven (1978), while reporting on the lithology of the Sentinel Butte Formation in the Williston Basin, noted the presence of "blue-black, swelling, montmorillonite clay" in association with "dark-gray, organic silty to sandy clay and lignite lenses". Mudstones are associated both vertically and laterally with all previously mentioned sandstone types.

Carbonaceous Shale

Carbonaceous shales are black (N 1) when fresh, dark gray (N 3) when weathered. They often possess lenses or stringers of coal; usually this condition grades vertically into a coal bed. They are associated with and gradational to carbonaceous, unconsolidated mudstones. The shales may be silty or contain very fine to coarse sand grains. Often carbonaceous shale will grade vertically or laterally into a siltstone or silty mudstone. Modern rootlets are abundant. The shales are thinly laminated with total bed thickness as great as 8.0 ft.; generally they are less than 1.0 ft. thick. Structureless mudstones often separate individual shale beds.

Coal

Average coal bed thickness is 1.3 ft.; although individual beds may range from a few tenths of a foot up to 2.5 ft. reaching a maximum thickness of 6.0 ft. Coal beds may contain partings of carbonaceous shale, poorly consolidated mudstone and silt to coarse size sandstone particles. Modern rootlets are abundant within the coal beds.

A very light gray (N 8) clay, 0.1 in. in thickness, was observed as a parting in the coal bed. The clay partings were determined to be tonsteins based

on the descriptions, by Bohor and Pillmore (1976), of tonstein occurrences in the field. They have described tonsteins as being recognized by their "white to light gray weathering color, usually sharp contacts with the enclosing coal and blocky, massive appearance...they have a characteristic smoothness when chewed, as well as an irregular fracture and 'resinous' luster."

No fossil plant impressions were found in the coal beds measured; but Lee (1917) collected a large number of fossil plant impressions from the roofs of now abandoned coal mines located east of Raton and included in this study area. These plant impressions were studied by Knowlton (1917) who determined that three main genera existed in this lower portion of the Raton Formation: Palmacarpon, Sabalites and Palaeoester. Miners, still living in Raton who worked these mines, recall seeing palm leaf impressions having the same appearance as Sabalites covering the ceilings of the mines. A palm leaf resembling Sabalites was recovered from a type 2 sandstone body while measuring sections.

Individual coal beds are not laterally continuous. They are found to grade both vertically and laterally into unconsolidated mudstone, very fine to coarse grained, organic sandstone to siltstone and carbonaceous shale (Figure 14). Organic mudstone, siltstone and shale are the most abundant lithologies within the area studied. Coal beds may be laterally

FIGURE 14

CARBONACEOUS ZONE (SECTION R 1, UNIT 13a-h).

Figure 14

associated with type 2 lenticular or elongated sandstones. Often these sandstones appear to have a scour base resting directly upon a coal bed. In several instances, coal beds were observed to rest on top of either an elongated type 2 or tabular type 3 sandstone.

DESCRIPTION OF THE LOWERMOST 200 FT. OF THE RATON FORMATION

Introduction

What this paper calls intervals 1, 2 and 3, previous publications refer to as the 'lower, barren zone' of the Raton Formation. Within the Raton area, Pillmore (1976) places this zone from 200-300 ft. above the Vermejo Formation. This paper separates the 'lower, barren zone' into separate intervals in order to group vertical and lateral lithologic associations. The separation of this 'lower, barren zone' into three separate intervals is based on the percent of observed associated thick to very thick sandstone, shale and coal (carbonaceous lithologies) relative to interbedded siltstone, mudstone and thinly laminated to medium type 4 sandstone (see Table 3 and Appendix A). Since the emphasis of this paper is to determine a reasonable explanation for the occurrence of coal in the lowest 200-300 ft. of the Raton Formation, coal and carbonaceous shale zones were used to determine the top and bottom of an interval.

It was observed that the study area could be divided into three nearly equal parts based on the presence of a carbonaceous rich zone located in the middle 1/3 of all measured sections. The lowest 1/3 of all measured sections is poor in carbonaceous lithologies (1.2%), thick to thickly bedded sandstone

Table 3. Lithologic percentages for intervals 1, 2, and 3.

Sandstone = thick to thickly bedded.
Siltstone = thick to thickly bedded.
Carbonaceous = shale and coal.
Interbedded = medium to thinly laminated sandstone, siltstone, shale and mudstone.
Cover = areas covered by vegetation or rock debris. It is assumed to be composed of slope forming mudstone and interbedded lithologies.
s.d. = standard deviation.
Average = average percent of the three combined intervals.

Lithology	Interval 1	s.d. %	Interval 2	s.d. %	Interval 3	s.d. %
Sandstone	22.8 %	12.6	26.4 %	19.1	38.2 %	15.1
Siltstone	3.6 %	7.3	9.4 %	12.8	3.4 %	7.3
Carbonaceous	1.2 %	2.2	5.4 %	3.6	0.4 %	0.8
Interbedded	31.6 %	32.5	25.3 %	22.9	25.7 %	21.2
Cover	40.8 %	36.9	33.5 %	28.2	32.3 %	27.1

(22.8%), and siltstone (3.6%) in relation to interbedded medium to thinly laminated sandstone, siltstone and mudstone (31.6%) and cover(40.8%). The middle 1/3 of all measured sections contain a carbonaceous rich zone (5.4%) with sandstone (26.4%), siltstone (9.4%), interbedded (25.3%) and cover (33.5%) comprising the remaining lithologic content. The upper 1/3 of all measured sections is poor in carbonaceous lithologies (0.4%) and rich in sandstone (38.2%), siltstone (3.4%), interbedded lithologies (25.7%) and cover (32.3%) (Plates 7a, b and c).

Interval 1

Interval 1 refers to the basal 72.0 ft. of the Raton Formation which begins at the first recognizable sandstone from types 1a, b, c, d, 2 or 3. These sandstones are observed lying on top of an assemblage of Vermejo type rocks composed of carbonaceous mud, shale and coal. When no assemblage of Vermejo type rocks are observed, then the first sandstone from types 1a, b, c, 2 or 3 resting directly above the Trinidad Sandstone is designated as the base of interval 1. Lee (1917) established the contact between the Vermejo and the Raton Formations, west of the area of study, at a very well indurated, quartz pebble conglomerate resting unconformably on the Vermejo Formation. Within the area around Raton, the conglomerate was reported by Lee

(1917) to be absent at all but one locality, Linwood Canyon, where it appears to rest directly on top of the Trinidad Sandstone.

In the western part of the basin, where the conglomerate is most conspicuous, Pillmore (1976) identifies it as a sandstone consisting of "pebbles and cobbles composed mostly of quartzite, chert, and gneiss in a coarse-grained quartzose to arkosic sandstone matrix." He describes the rest of the 'lower zone' as composed of fine to coarse-grained sandstone, siltstone, mudstone and thin impure coal beds. In this 'lower zone', sandstone and mudstone are the dominant lithologic units.

The apparent absence of the basal conglomerate in the study area caused Zeuss (1967) to place, what this paper refers to as intervals 1 and 2, within the Vermejo Formation based on the reasons mentioned earlier (see 'Previous Work' section of this report). Leighton (1980) states that the basal sandstone of the Raton Formation is markedly different from the sandstones of the underlying Vermejo Formation. He describes the basal sandstone as trough cross-bedded commonly with convolutions, ripples and horizontal bedding, no significant vertical grain size changes, well indurated and having a 'sugary' texture, resulting from quartz overgrowths. He found only one location, that of Linwood Canyon, where this basal sandstone

possessed a definite quartz pebble conglomeratic channel lag at its base.

Basal sandstones of the Raton Formation, within the area of study, overly carbonaceous shale and coal sequences of the Vermejo Formation. These basal sandstones display characteristics of sandstone types 1a, b, c and d; although types 1b and d were observed only in the Linwood Canyon area where they rested directly upon the Trinidad Sandstone. In the vicinity of Linwood Canyon and eastward, the basal types 1b and d sandstones are at their thickest (17.0 ft.). Sandstone type 1a, b, c and d grade vertically and laterally into carbonaceous, sandy shale to poorly consolidated mudstone. Sandstone types 1a and c are found to grade laterally into each other.

Most of the type 2 sandstones, of interval 1, are lenticular in shape. Both type 2 and 3 sandstone units, of interval 1, are observed to be isolated within a sequence of dominantly muddy sediments. Most commonly a type 2 lenticular sandstone unit will be laterally associated with a type 3 sandstone. Both type 2 and 3 sandstones will grade laterally and vertically into siltstone and mudstone deposits. The siltstones will grade laterally and vertically into interbedded type 4 sandstones and mudstones.

Average thickness of all thick to very thickly bedded sandstone types of interval 1 is 7.3 ft.

Sandstones attain a maximum thickness of 25.0 ft. and a minimum thickness of approximately 1.0 ft. Thick to very thickly bedded sandstone of all types makes up 22.8 percent and siltstone 3.6 percent of the total thickness of interval 1, carbonaceous lithologies comprise 1.2 percent, interbedded type 4 sandstone, siltstone and mudstone 31.6 percent and cover 40.8 percent (see Plates 1 - 7a, b and c).

Interval 2

Interval 2 (~ 72.0 ft. thick) contains the 'Sugarite' coal zone and is part of the 'lower, barren zone' of the Raton Formation as previously described. The base of interval 2 is established where the first linear association of coal and carbonaceous shale occur. The association was observed at approximately 72.0 ft. above the base of interval 1. The carbonaceous zone is associated laterally with the beginnings of a thick to thickly bedded sandstone belt.

Thickly bedded, lenticular type 2 sandstone bodies of interval 2, are more laterally continuous than those of interval 1, and appear multistoried (Schumm, 1981), although they could be traced laterally for only up to 0.5 miles. Type 2 sandstones are observed to be vertically and laterally associated with type 3 sandstones. Type 3 sandstones grade laterally and vertically into siltstone and mudstone deposits.

Average thickness for all type 2 and 3 sandstone of interval 2 is approximately 16.0 ft.; single beds have a maximum thickness of 45.0 ft.

A second lateral association of carbonaceous shales, unconsolidated mudstones and coal is found at approximately 72.0 ft. above the base of interval 2 and near the top of the previously mentioned sandstone rich belt. This second carbonaceous rich zone is designated as the top of interval 2.

Carbonaceous rich zones of interval 2 contain siltstone and thinly laminated type 4 sandstone partings. These zones may grade laterally into type 2 or 3 sandstone, siltstone or mudstone deposits. Individual coal beds of interval 2 are not continuous. Only in the vicinity of the filter plant north of the city of Raton, could an individual coal bed be traced laterally, for approximately 1450.0 ft., based on the existence of a 0.1 in. very light gray (N 8) clay (tonstein) parting. The average thickness of this bed is 1.5 ft.

The amount of thick to thickly bedded type 2 and 3 sandstone bodies is 26.4 percent and siltstone 9.4 percent of the total thickness of interval 2. Carbonaceous lithologies make up 5.4 percent of the total interval, with the remaining consisting of interbedded siltstones, mudstones and medium to thinly laminated type 4 sandstones (25.3%) and cover (33.5%).

Interval 3

The base of interval 3 was established near the top of the shale, mudstone and coal assemblage previously described as the top of interval 2. Interval 3 is carbonaceous poor (0.4%) and rich in thick to very thickly bedded type 2 and 3 sandstone (38.2%) and siltstone (3.4%). The dominant lithologies remain interbedded siltstone, unconsolidated mudstone and thinly laminated to medium bedded type 4 sandstone (25.7 %) and cover (32.3 %).

The average thickness of type 2 and 3 sandstone is 15.3 ft., and ranges from 1.5 ft. to a maximum thickness of 60.0 ft. Thick to very thickly bedded type 2 sandstone bodies of interval 3 appear to be more multistoried and elongate than those of the previous two intervals; and laterally traceable for up to 0.7 miles. Coal and shale are nearly nonexistent in interval 3. The top of interval 3 was established at approximately 72.0 ft. above its base in order to equal the thickness of the two previous intervals (see Plates 1 - 7a, b and c).

SUMMARY OF INTERVAL DESCRIPTIONS

For the purpose of examining the changing vertical and lateral relationships of all the lithologies that constitute the lowest 200-300 ft. of the Raton Formation within the study area, this paper divides the lowest zone into 3 intervals. The divisions were attained by observing vertical changes in the percent of associated lithologies and the lateral continuity of the lithologies especially those of coal and carbonaceous shale beds.

It was noted that the lowest 1/3 of all measured sections is rich in interbedded lithologies while poor in carbonaceous shale, coal and thick to thickly bedded sandstone. This lowest 1/3 is referred to as interval 1. The base of this interval is established at the first recognizable sandstone from types 1a, b, c, d, 2 and 3 found resting on top of a Vermejo type assemblage of rocks containing coal and carbonaceous shale or found resting directly on top of the Trinidad Sandstone. All previously described types of sandstones were observed in this interval. Types 1a, b, c and d sandstones are generally found at or near the base of the interval. All sandstones, including types 2, 3, 4 and siltstone, are observed to be laterally discontinuous and isolated within interbedded lithologies.

The middle 1/3 of all measured sections contains a carbonaceous shale and coal rich zone. This middle 1/3 of the study area is approximately 72.0 ft. thick and designated as interval 2. The first and last linear association of carbonaceous shale and coal were picked as the bottom and top of this interval. Between the upper and lower associations of coal and carbonaceous shale of interval 2 is a sandstone rich zone. Thick to very thickly bedded type 2 and 3 sandstone of interval 2 are laterally discontinuous and generally isolated within interbedded lithologies. Many of the type 2 sandstone bodies are multistoried. The sandstones of intervals 2 and 3 comprise a sand rich final 2/3 of all measured sections.

Interval 3 is the upper 1/3 of the sections measured. It is poor in carbonaceous shale and coal but rich in sandstone. The base of this interval is at the previously described upper coal and carbonaceous shale zone of interval 2. The thick to very thick bedded sandstones are those of types 2 and 3. These sandstones are multistoried and somewhat laterally traceable. The top of the interval is 72.0 ft. above its base. This measurement was established in order to equal the thickness of the previous two intervals.

PRESENTATION OF MODELS

Introduction

It is generally accepted (Fassett, 1976 and Blatz, 1965), that during the latest Cretaceous and early Tertiary Periods, shallow seas covering this portion of New Mexico withdrew due to epeirogenic movements west of the Raton Basin. As a result of a prograding shoreline, continental deposits of the Raton Formation overlie those of a coastal system. Johnson, Dixon and Wanek (1966) stated that the main record of the earliest orogenic phase of the late Cretaceous epeirogenic uplift is the basal coarse sand and gravel of the Raton Formation, eroded from metamorphic and igneous rocks of Precambrian age. This uplift continued throughout the Tertiary Period with several orogenic episodes. It is at this time that the fluvial, continental sediments of the Raton Formation were deposited.

Possible environments of deposition to be considered for the sandstones of the lowest portion of the Raton Formation are given in Table 4. The descriptions are based on Potter's (1967) six major origins for sandbodies. The origins include alluvial, tidal, turbidite, barrier-island, shallow-water marine and desert eolian. These are general environments and further subdivisions are not made. The sandstone

Table 4. Depositional settings for sandstone deposits (from Potter, 1967).

Environment	Petrology	Texture	Sedimentary Structures	Internal Organization	Size and Shape	Associated Lithology
Alluvial Sand Bodies	Detrital. Abundant shale pebbles. Carbonaceous debris. Immature to submature. Faunal content low to absent.	Poor to moderate sorting. Low grain-matrix ratio. Poorly rounded. High variability.	Ripple marks and well-oriented cross bedding. Deformation structures are common. Beds are lenticular with erosional scour.	Upward decrease in grain size and bed thickness. Possible conglomerate at the base. Larger channel fill sandstone bodies tend to be coarser grained than smaller ones.	Commonly very elongate. Wide variation in widths. Dendritic, bifurcating and anastomosing patterns.	Vertical: silty shales, often peat and coal. Basal contact is usually sharp and disconformable. Multistoried sandstone bodies. Lateral: silty shale, siltstone with abundant carbonaceous debris and modern rootlets. Multilateral sandstone bodies. Correlation is difficult.
Tidal Sand Bodies	Detrital. Argillaceous rock fragments, skeletal debris and collophane and argillaceous material. Some glauconite and authigenic feldspar. Detrital and chemical cements.	Fair sorting, moderate to high grain matrix ratio. Possibly shell conglomerate at base. Very similar to alluvial sandstones. Peat, clay galls, and wood common.	Ripple marks are common. Abundant cross bedding of variable thickness. Lenticular bedding common. Tracks, trails and burrows abundant. Channels and washouts.	Strong vertical decrease in grain size and bedding thickness, may have conglomerate at base.	A few tens of ft. to more than 1,000 ft. wide, mostly very elongate. Straight to moderate meandering, dendritic patterns, the latter as tidal inlets. Also lunate bars in passes between barrier islands. Cross bedding is parallel with elongation.	Vertical: variable. Assoc. with interlaminated shale and sandstone of tidal origin and marine sediments. Disconformable basal contact. Lateral: interbedded siltstone and shale of tidal flat origin commonly with mollusks, worms, crustaceans and possibly algae as well as marine sedoments.

Table 4. (continued)

Environment	Petrology	Texture	Sedimentary Structures	Internal Organization	Size and Shape	Associated Lithology
Turbidite Sand Bodies	Detrital. Rock fragments and immature minerals abundant as well as marine skeletals of both deep water origin. Carbonaceous material generally present. Shale pebble congl. Cements are very largely detrital.	Very poor to fair sorting and low grain matrix ratio. Rhythmic alternation of beds produces abrupt juxtaposition of shale and sandstone.	Graded beds rhythmically interbedded with shale. Absence of large scale cross beds. Sole marks, ripple marks, and laminated and convoluted beds are common. Trails and tracks are generally present.	Not given.	Elongated sandstone bodies up to many miles; fairly straight but dendritic and bifurcating. Sheet and blanket like deposits dominate.	Vertical: other marine shale and turbidite sandstone. Multistory sandstone bodies possible. Lateral: except for lower sandstone shale ratio, little lithologic contrast. Mixed benthonic and pelagic faunas in shale and reworked shelf faunas in sandstone.
Barrier Island Sand Bodies	Detrital. Heavy-mineral concentrates common. Skeletal debris, collophane, and glauconite. Mostly chemical cements.	Commonly excellent sorting and very high grain matrix ratio. Low variability of textural parameters. Commonly good rounding.	Ripple marks. Abundant gently dipping beds. Lamination and lineation conspicuous on beach. Cross bedding moderately abundant and may be eolian as well as water laid. Variability of cross bedding orientation, moderate to large. Burrows and channeling common.	Not given	Variable widths. Thickness 20-60 ft. Very elongate parallel with strand line. Sandstone bodies generally straight to gently curved. Grain fabrics and cross bedding are variable.	Vertical: variable according to origin. Basal contact is even and may be transitional. Lateral: separates marine from lagoonal or terrestrial deposits. Multilateral sandstone bodies are common.

Table 4. (continued)

Environment	Petrology	Texture	Sedimentary Structures	Internal Organization	Size and Shape	Associated Lithology
Marine-Shelf Sand Bodies	Detrital. Few argillaceous fragments and micas. Feldspar and glauconite and some detrital carbonate may be present. Mostly chemical cements.	Good to excellent sorting and high grain matrix ratio. Low variability of textures. Well rounded.	Ripple marks. Abundant cross beds. Trails and burrows. Minor channels and washovers.	Not given	Highly variable in size and shape, ranges from irregular, small pods to elongate, and sheet like deposits. Bifurcating and dendritic patterns absent.	Vertical: variable according to regressive or transgressive origin, but mostly marine shale and carbonates. Basal contact may be disconformable, but generally not of great magnitude. Lateral: relatively uniform silt free shales or carb. commonly with rich and varied marine fauna.
Eolian Sandstone Bodies	Micaceous minerals are absent. Cementing agents are generally chemical. Gravel is rare, although shale chips can be abundant.	High grain matrix ratio, good sorting, well rounded, immature.	Principal structure is cross beds. Variability of cross beds is small to moderate. Ripple marks are also found. Fossils, tracks, and trails are scarce.	Not given	Dunes may reach enormous sizes in modern deposits but are not found in ancient record. Most consist of widespread thick sheets of cross bedded sandstone.	Associated rock types are difficult to generalize because units tend to be separated by an unconformity. Laterally a sheet deposit may grade either into marine or continental deposits.

Table 4. (continued)

Environment	Petrology	Texture	Sedimentary Structures	Internal Organization	Size and Shape	Associated Lithology
Lower Raton Formation Sandstone Bodies	Detrital. Subarkosic, abundant clay pebble lag, carbonaceous debris. Submature Faunal content is low. Dominant cementing material is quartz.	Moderate sorting, subangular grains Moderate to low grain-matrix ratio.	Ripple marks, horizontal laminations, trough cross beds, and convoluted beds are common. Beds are lenticular with both erosional scour and nonerosional bases.	Upward decrease in grain size and bed thickness. Pebble conglomerate was observed in two locations. Large sandstones are coarser grained than smaller sandstone bodies.	Variable in size and shape. The sandstones range from elongate, tabular and lenticular in shape. Generally the sandstones cannot be traced laterally for any distance. The size ranges from a few tenths of an inch to greater than 50 ft.	Vertical: grades into siltstone, silty mudstone, carbonaceous shale and coal. This same sequence is found laterally. Often the sandstone bodies are multistoried. Generally correlation of the sandstones is difficult. Erosional scour bases are dominant in the larger sandstone deposits.

bodies of each environment are described in terms of petrology, texture, sedimentary structures, internal organization, size, shape and associated lithologies.

A further comparison of the sandstone bodies and associated deposits of the lower Raton Formation with those of fluvial-upper delta plain, transitional lower delta plain, lower delta plain and back-barrier environments (Figure 15) is found in Table 5. Criteria for recognizing these environments are based on data published by Horne, Ferm, Caruccio and Baganz (1978).

The characteristics of the sandstones of the lower Raton Formation are compared to the six major origins of sandbodies and to those of a delta plain. The conclusion, based upon these comparisons, is that the deposits of the lower Raton Formation are alluvial in origin. Due to the vertical association of the Raton deposits with those of a coastal system, some barrier island-strand plain deposits will be considered.

Barrier Island-Strand Plain Complex

Horne, Ferm, Caruccio and Baganz (1978) define barrier island-strand plain complex as including such systems as beach, shoreface, tidal channels, tidal deltas, washover fans, marshes and lagoons. In a barrier island-strand plain complex, the sandstones become finer grained in a seaward direction and grade

FIGURE 15

DEPOSITIONAL MODEL FOR PEAT-FORMING ENVIRONMENTS IN COASTAL REGIONS (FROM HORNE, 1978).

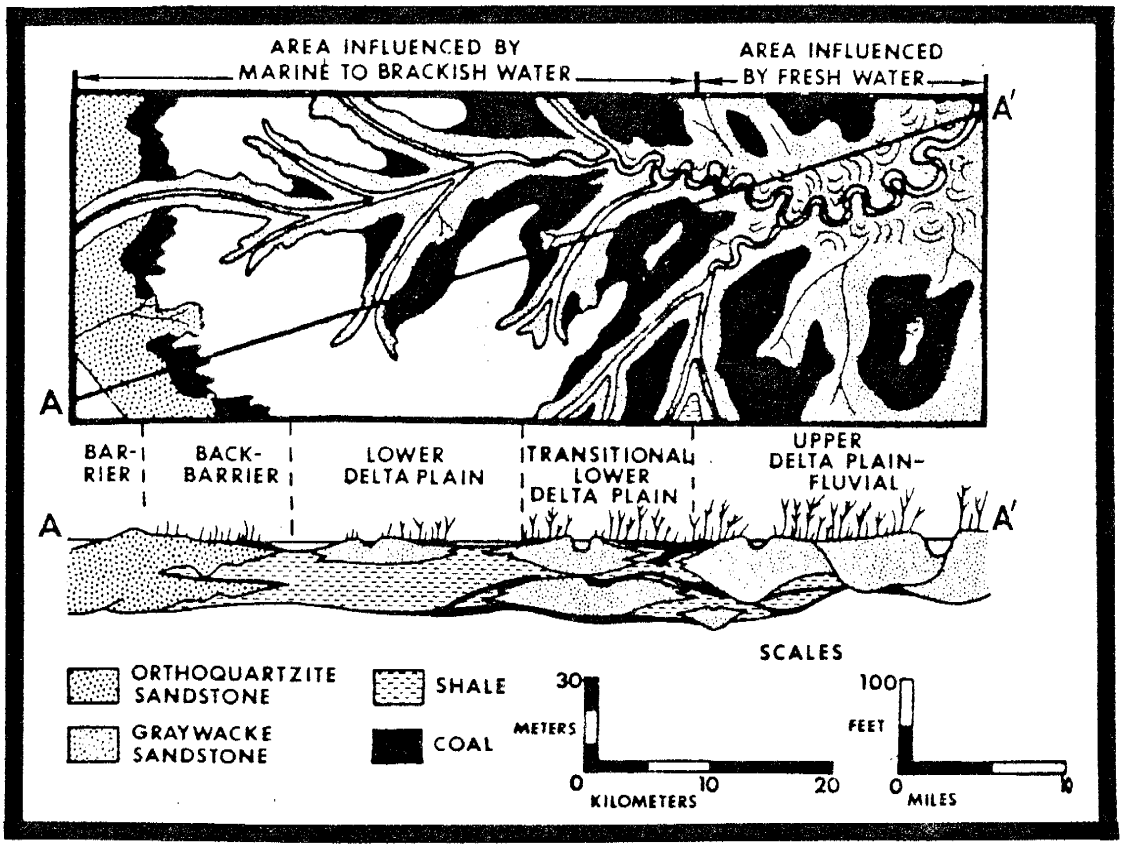

AREA INFLUENCED BY
MARINE TO BRACKISH WATER
AREA INFLUENCED
BY FRESH WATER
A'
A
BAR-
RIER
BACK-
BARRIER
LOWER
DELTA PLAIN
TRANSITIONAL
LOWER
DELTA PLAIN
UPPER
DELTA PLAIN-
FLUVIAL
A
A'
ORTHOQUARTZITE
SANDSTONE
GRAYWACKE
SANDSTONE
SHALE
COAL
SCALES
30
METERS
0
10
20
KILOMETERS
100
FEET
0
MILES

Figure 15

Table 5. Comparison of deltaic deposits with deposits of the lower Raton Formation found within the area of study (modified from Horne, 1978).

Characteristics	Fluvial/ Upper Delta Plain	Transitional/ lower Delta Plain	Lower Delta Plain	Back-Barrier	Interval		
					1	2	3
I. Coarsening Upward							
A. Shale and siltstone sequences	2-3	2	1	2-1	1	1	2
1. 50 ft. +	4	3-4	2-1	2-1	2-1	2-1	2
2. 5 to 25 ft.	2-3	2-1	2-1	2-1	2-1	2-1	2
B. Sandstone sequences	3-4	2-3	2-1	2	2-1	2-1	2
1. 50 ft. +	4	4	2-1	3	2	2	2
2. 5 to 25 ft.	3	2-3	2-1	2	2	2	2
II. Channel Deposits							
A. Fine grained abandoned fill	3	2-3	1-2	2	2	1	2
1. Clay and Silt	3	2-3	1-2	2	1	1	2
2. Organic debris	3	2-3	1-2	3	1	1	2
B. Active sandstone fill	1	2	2-3	2-3	2	2	2
1. Fine grained	2	2	2-3	2-3	2	2	2
2. Medium and coarse grained	1	2-3	3	3	3	3	3-2
3. Pebble lags	1	1	2	2-3	2	2	2
4. Coal spars	1	1	2	2-3	2	2	2
III. Contacts							
A. Abrupt (scour)	1	1	2	2	2	2	1
B. Gradational	2-3	2	2-1	2	2-1	2-1	2
IV. Bedding							
A. Cross bedding	1	1	1	1-2	1	1	1
1. Ripples	2	2-1	1	1	1	1	1
2. Ripple drift	2-1	2	2-3	3-2	3	3	3
3. Trough	1	1-2	2-1	2	1	1	1
4. Graded	3	3	2-1	3-2	2	2	2
5. Point bar accum.	1	2	3-4	3-4	4	4	4
6. Irregular	1	2	3-2	3-2	2	2	2
V. Levee Deposits							
A. Irregularly interbedded sandstones and shales, rooted	1	1-2	3-2	3	3	3	3
VI. Mineralogy of sandst.							
A. Arkose - subarkose	1	1	1-2	3	1	1	1
B. Orthoquartzites	4	4	4-3	1-2	4	4	4
VII. Fossils							
A. Marine	4	3-2	2-1	1-2	4	4	4
B. Brackish	3	2	2	2-3	4	4	4
C. Fresh	2-3	3-2	3-4	4	3-4	3-4	3-4
D. Burrow	3	2	1	1	4	4	4
VIII. Coal							
A. Thick mineable	3	2	4	2	4	4	4
B. Thin discontinuous	2	2	2	3	2	2	2
IX. Clay rich zones	1	2-1	2	3-2	2	2	2
X. Sandstone channels enclosed in shales	2-3	2	1-2	1	1-2	1-2	1-2
XI. Non-bedded mudstone	2-3	2-1	1-2	1-2	1	1	1
XII. Conglomerate and/or plant debris lag	2-3	2-1	1-2	1-2	2	2	2

Explanation: 1. Abundant 2. Common 3. Rare 4. Not present - or not observed

into marine calcareous shales. In a landward direction, they grade into lagoonal shales. Barrier system sandstones are generally more quartzose and better sorted than those of surrounding environments. Previous authors have demonstrated that the deposits of the Trinidad and Vermejo Formations represent this type of complex.

Tidal channels and tidal deltas connect lagoonal areas to the sea and the resulting sand bodies are similar in internal sedimentary structures and textures. A tidal channel deposit is described by Reinson (1979) as having an erosional base often with a basal lag: deep channels consist of large scale planar and medium scale trough crossbeds. Shallow channel deposits consist of small scale trough and planar cross beds. Reinson (1979) describes tidal delta sandstone deposits as consisting of planar and trough cross beds.

Washover fans result from eroded barrier sands being transported into the lagoon during storm periods. Structures include parallel laminations and small to medium scale planar cross beds. The washover deposits are generally thin and are composed of fine to medium grained sand.

Alluvial Models

Lower Delta Plain

Lower delta plain deposits, especially those of a river dominated delta (Miall, 1981), contain thick coarsening-upward sequences of bay-fill deposits.

Lower bay-fill deposits are characterized by interbedded mudstone, siltstone, fine sandstone and distributary-mouth-bar or sheet sands. These sands are coarse and characterized by planar and trough crossbeds and ripple marks.

Upper bay-fill deposits consist of sandstone and siltstone alternating with thin, silty mudstone laminations. Small scale ripple and other current related structures are the most common laminations. Other deposits include fine-grained sediment and marsh deposits. Within the upper bay fill, the coarsening upward pattern is broken by tongues of crevasse-splay deposits. Ironstone is found in bands or as large concretions along bedding plains. The upper bay-fill deposits contain marine and brackish water fossils and burrow structures. These deposits are overlain by and laterally equivalent to very thick sandstone accumulations.

The environments and resulting deposits making up the lower delta plain are distal bar, distributary-mouth-bar, active and abandoned

distributary channel, crevasse splay, natural levee and marsh.

Distal bar deposits

Distal bars are located seaward of the distributary-mouth-bar deposits and are composed of laminated silts and muds. It is the seaward sloping margin of the delta front. Common sedimentary structures include cross bedding, ripple marks, scour and fill and erosional surfaces. This zone is burrowed, bioturbated and contains marine fossils.

Distributary-mouth-bar deposits

Sandstone and silt deposited at the mouths of active distributaries are referred to as the distributary-mouth-bar. In river dominated deltas, these sands form a nearly continuous deposit extending laterally for some distance. Thin laminations of plant debris are often present. Trough cross bedding is the most common structure. These deposits are overlain by bay fill sediments as the delta progrades seaward.

Active distributary channel deposits

According to Horne et al. (1978), active distributary channels of the lower delta plain are straight and do not laterally migrate; therefore no

point bar accretion beds are developed. Elliot (1978) noted that distributary channels of the Mississippi River, a modern fluvial-dominated delta, have a low sinuosity pattern and are not braided. Within active distributary channels structures include scour-and-fill, trough cross bedding in the lower part and ripple drift in the upper. Slump structures are commonly found. A pebble lag often occurs at the base of the channel. The basal scour surface is undulating or wavy. Active distributary channels vary in size but most are not over 10 ft. thick. These channel deposits grade vertically into siltstone and mudstone.

Abandoned distributary channel deposits

Elliot (1978) distinguished active fluvial distributary channels from other alluvial channels by the frequency of avulsion. This process produces abandoned distributary channel deposits of the lower delta plain. Horne et al. (1978) describes abandoned distributary deposits of the lower delta plain as consisting of poorly sorted sands and silts with abundant organic debris in the lowest portion. The overlaying portion consists of fine grained muds, silts and poorly sorted organic debris. The uppermost part of the fill includes organic rich clays with intense root burrowing. Coal is associated with these deposits. Structures include ripple laminations and

small scale cross beds. Sand bodies may show convoluted laminations. Some fining upward sequences are observed; although deposits may show no change in grain size.

Interdistributary channel deposits

Coleman and Prior (1982) note that environments between distributary channels make up the largest percentage of the lower delta plain. Interdistributary areas of the lower delta plain are shallow water environments in which sediments from distributary channels are deposited during periods of flooding. The resulting features include levees, crevasse channels and crevasse splay deposits. These deposits in turn provide a platform for subsequent vegetation growth.

Levee deposits of the lower delta plain consist of poorly sorted, irregularly interbedded, partially rooted siltstones and sandstones. These beds dip away from the associated channel.

Crevasse splay deposits are characterized by their tabular shape, coarsening-upward sequence, small to large scale cross beds and parallel, rippled and convoluted laminations. Rippled and convoluted laminations may be repeated throughout the bed. Crevasse splay deposits generally consist of fine to very fine grained sand. They have gradational to sharp bases. Thickness of crevasse deposits vary from a few

feet to very thick accumulations. These sandstones are laterally extensive. Crevassing may be produced by numerous small, anastomosing streams. This process produces small channel lenses each separated by a thin, fine sediment drape (Elliot, 1981). Crevasse deposits often grade upward into well-drained swamp deposits. They fine away from the breached levee and grade laterally into interdistributary bay-fill sequences.

Coals of the lower delta plain are generally thin and discontinuous. The coal beds roughly parallel distributary channels. Often coals are overlain by silty mudstones that contain abundant rootlets.

Transitional Delta Plain

The transition zone (Horne, Ferm, Caruccio and Baganz, 1978) has characteristics of both the lower and upper delta plains. Bay fill sequences are thinner than those of the lower delta plain. This zone contains marine and brackish faunas and is extensively burrowed. The transition zone contains point bar accretion beds; but they are finer grained than those of the upper delta plain. The point bar accretion beds are single storied and have one direction of lateral migration. Levees are thicker than those of the lower delta plain. Splay sandstones are common but less so than lower delta plain and more common than in the upper delta plain. Coals are thicker and more

widespread than either the lower or upper delta plains.

Upper Delta Plain

The upper delta plain consists of fluvial deposits typically of a meandering or braided river system. Classification of braided and meandering rivers is based on channel sinuousity (Schumm, 1981, p.25, and Galloway, 1981, p.134) (Figure 16 and Table 6), sediment load (Schumm, 1963, p.8) (Table 7) and river discharge.

Meandering river deposits

Meandering rivers form deposits primarily by the action of lateral accretion on point bars within concave sides of meanders, coupled with a lesser amount of vertical accretion on floodplains resulting from overbank flooding. The main deposits associated with meandering rivers include point bar deposits, natural levee, crevasse splay, flood-basin and channel-fill deposits (Coleman and Prior, 1982; and Cant, 1982).

Channel sandstone deposits of meandering rivers are described by Horne et al. (1978) as elongate in shape and multistoried with many directions of lateral migration. These units may attain great thicknesses. The bases are scoured and may truncate units below. The sandstone bodies intertongue laterally with shale,

FIGURE 16

RANGE OF ALLUVIAL CHANNEL PATTERNS (FROM SCHUMM, 1981)

A. BED-LOAD CHANNEL PATTERNS
B. MIXED LOAD CHANNEL PATTERNS
C. SUSPENDED-LOAD CHANNEL PATTERNS

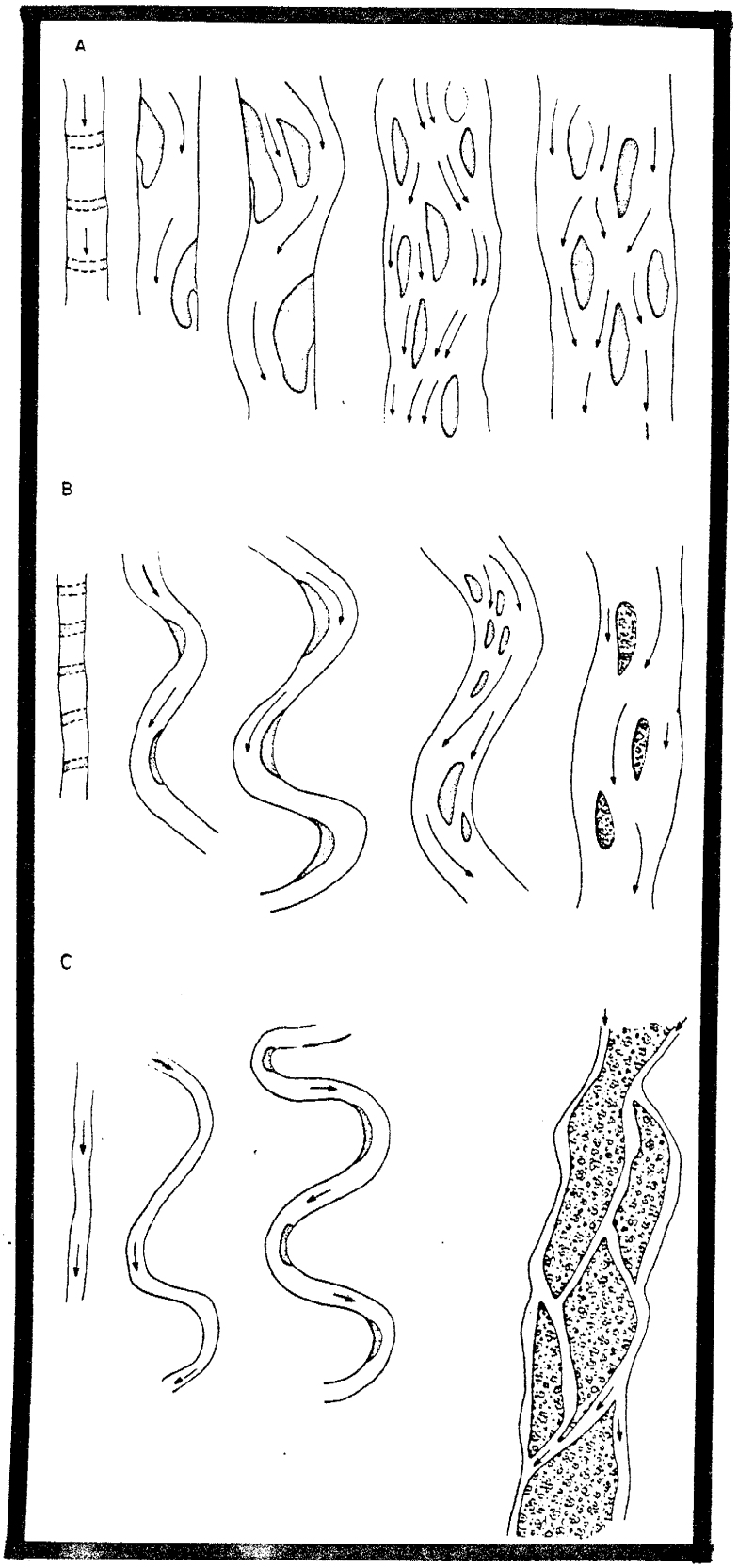


Figure 16

Table 6. Geomorphic and sedimentary characteristics of bedload, mixed-load, and suspended sediments (Galloway, 1981).

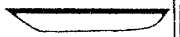
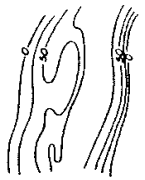
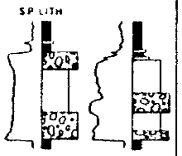
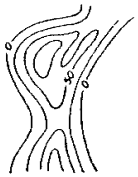
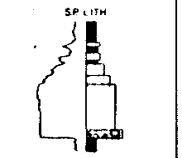
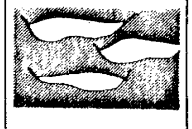
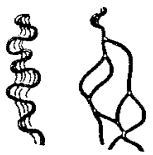
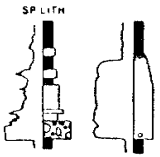
CHANNEL TYPE	COMPOSITION OF CHANNEL FILL	CHANNEL GEOMETRY			INTERNAL STRUCTURE		LATERAL RELATIONS
		CROSS SECTION	MAP VIEW	SAND ISOLITH	SEDIMENTARY FABRIC	VERTICAL SEQUENCE	
BEDLOAD CHANNEL	 Dominantly sand	 High width / depth ratio Low to moderate relief on basal scour surface	 Straight to slightly sinuous	 Broad continuous belt	 Bed accretion dominates sediment infill	 Irregular, fining-up poorly developed	 Multilateral channel fills commonly volumetrically exceed overbank deposits
MIXED LOAD CHANNEL	 Mixed sand, silt, and mud	 Moderate width / depth ratio High relief on basal scour surface	 Sinuous	 Complex, typically "beaded" belt	 Bank and bed accretion both preserved in sediment infill	 Variety of fining-up profiles well developed	 Multistory channel fills generally subordinate to surrounding overbank deposits
SUSPENDED LOAD CHANNEL	 Dominantly silt and mud	 Low to very low width / depth ratio High-relief scour with steep banks, some segments with multiple thalwegs	 Highly sinuous to anastomosing	 Shoestring or pod	 Bank accretion (either symmetrical or asymmetrical) dominates sediment infill	 Sequence dominated by fine material, thus vertical trends may be obscure	 Multistory channel fills encased in abundant overbank mud and clay

Table 7. Classification of alluvial channels (from Schumm, 1963).

Mode of sediment transport	Channel sediment (M) percent	Proportion of total sediment load		Channel stability		
		Suspended load percent	Bedload percent	Stable (graded stream)	Depositing (excess load)	Eroding (deficiency of load)
Suspended load	30–100	85–100	0–15	Stable suspended-load channel. Width-depth ratio less than 7; sinuosity greater than 2.1; gradient relatively gentle.	Depositing suspended load channel. Major deposition on banks cause narrowing of channel; streambed deposition minor.	Eroding suspended-load channel. Streambed erosion predominant; channel widening minor.
Mixed load	8–30	65–85	15–35	Stable mixed-load channel. Width-depth ratio greater than 7 less than 25; sinuosity, less than 2.1 greater than 1.5; gradient moderate.	Depositing mixed-load channel. Initial major deposition on banks followed by streambed deposition.	Eroding mixed-load channel. Initial streambed erosion followed by channel widening.
Bedload	0–8	30–65	35–70	Stable bedload channel. Width-depth ratio greater than 25; sinuosity, less than 1.5; gradient relatively steep.	Depositing bedload channel. Streambed deposition and island formation.	Eroding bedload channel. Little streambed erosion; channel widening predominant.

siltstone and coal beds. Mineralogies may vary from graywackes to arkoses. Grain size is generally medium to coarse. Above the scoured base, grain size decreases. The base may have a pebble lag and coal spars. Bedding is massive with thick festoon cross beds in the lowest. Upward these massive beds merge into point bar accretion beds. Accretion beds often contain small scale festoon cross beds overlain by rooted sandstone, siltstone and climbing ripples. Sandstone channel deposits may display an en echelon arrangement and have wide variations in current direction indicators due to the sinuous nature of the channels.

Point bar deposits are recognized by abrupt lower boundaries and fining-upward sequences. Grain size ranges from fine to coarse. Sedimentary structures range from medium to large scale cross beds to horizontal laminations. Basal contacts are sharp and nonerosional. Point bar deposits can be recognized by their longitudinal accretion surfaces (epsilon cross-stratification).

The descriptions of crevasse splay and levee deposits of a meandering river by Horne et al. (1978) are the same as those given for crevasse splay and levee deposits of the lower delta plain.

Floodplain deposits associated with a meandering river contain the finest suspended sediments and

abundant organic debris. Coal is generally formed in poorly-drained swamp deposits. Ethridge, Jackson and Youngberg (1981) describe well-drained swamp deposits as those consisting of mudstone having relatively high percentages of silt and low percentages of organic debris; and poorly-drained swamp deposits as those consisting of carbonaceous mudstone, shale and coal. Well-drained swamp and crevasse splay deposits grade into poorly-drained swamp deposits. Primary sedimentary structures are rare in both types of deposits. Coal deposits associated with floodplain deposits of meandering rivers may be locally thick, but are generally thin and discontinuous.

Braided river deposits

Braided rivers are laterally unstable and form by the division of a main channel into a network of smaller channels, which flow around elevated alluvial bars or islands at low flow. The development of braided patterns is related to three factors : 1) the presence of erodible banks; 2) an abundant volume of bed load being transported; and 3) rapid and frequent variations in discharge. Braided systems accumulate their deposits by growth of longitudinal transverse and cross-channel bars. Because each channel of a braided system has a different depth, lateral migration of the channel results in scouring to different depths.

Multiple fining-upward sequences, which are commonly truncated, occur within the resulting sand bodies. Lateral migration together with aggradation, leads to sheet sandstones or conglomerates with thin shales enclosed within coarser sediments. Often coalesced channels will produce sand deposits of great thickness with only minor shale lenses scattered throughout.

Typical braided channel deposits include large scale cross bedding, overlain by trough shaped cross bedding and finally ripple drift bedding separated by parallel laminations. Braided river deposits in general have more planar cross beds within a sand body, more irregularities in grain size and has less fine overbank material than meandering river deposits.

DEPOSITIONAL INTERPRETATIONS

Barrier Island-Strand Plain

Type 1a, b, c, and d quartzose sandstones, which make up some of the basal sandstones of interval 1, show characteristics associated with a barrier island-strand plain complex. These sandstones may represent tidal delta, tidal channel and washovers. They are associated with lagoonal Vermejo and strand-plain Trinidad deposits (Figures 17 and 18).

Lower Delta Plain

The deposits of the lowermost 200 ft. of the Raton Formation, when compared to deposits associated with a deltaic system, display characteristics similar to those of lower delta plain environments. The specific environments and resulting deposits include: lower bay-fill, upper bay-fill, distributary-mouth-bar, distributary channel, crevasse splay and swamp.

The lower portion of interval 1 may represent lower bay-fill and distributary-mouth-bar deposits due to the dominance of silty mudstone and interbedded silt and type 4 sandstone beds. Type 1a, b, c and d sandstones may also be interpreted as distributary mouth sandstone sheet deposits.

The upper portion of interval 1 and all of

FIGURE 17

GENERALIZED VERTICAL SEQUENCE THROUGH BACK-BARRIER DEPOSITS IN CARBONIFEROUS OF EASTERN KENTUCKY AND SOUTHERN WEST VIRGINIA (FROM HORN, 1978).

FIGURE 18

INTERPRETATION OF THE VERTICAL SEQUENCE THROUGH BACK-BARRIER DEPOSITS OF THE VERMEJO FORMATION INCLUDING THE LOWERMOST SANDSTONE TYPE 1a-d (SECTION R 7, UNITS 1-7).

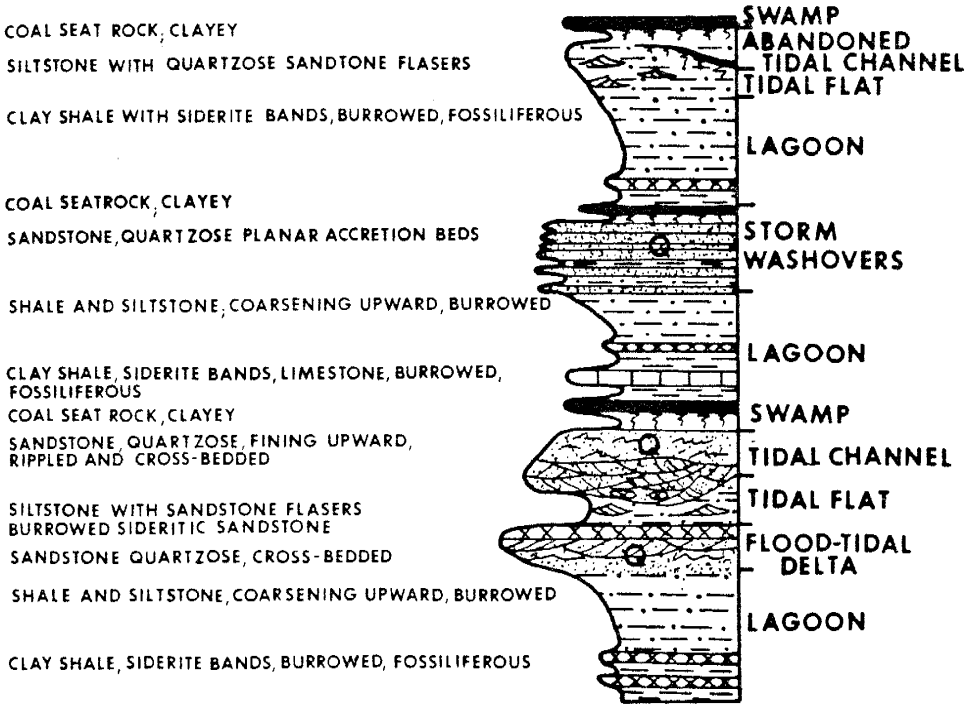


Figure 17

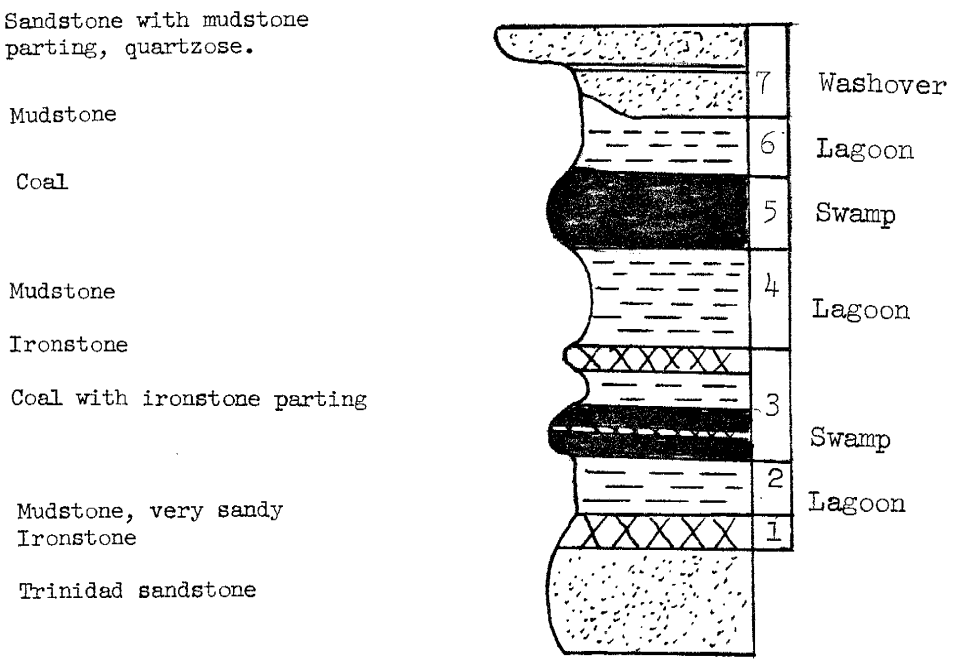


Figure 18

interval 2 may represent upper bay-fill deposits due to the presence of type 2 lenticular and increased frequency of type 3 tabular sandstone and siltstone beds and carbonaceous lithologies. The deposits include active and abandoned distributary channel, crevasse channel and crevasse splay, interdistributary channel and marsh.

Lenticular type 2 sandstones may be distributary channel deposits. They are basically single storied, straight, contain scour and wavy bases, trough cross beds, ripple and horizontal laminations, pebble lag and coal spars. There is little variation in grain size; although slight internal fining-upward sequences were detected. The smaller, less continuous, isolated lenticular type 2 sandstone deposits may be interpreted as crevasse splay channel sandstones. These sandstone beds are laterally and vertically associated with interbedded lithologies, coal and carbonaceous shale.

Type 3 sandstones are interpreted to be crevasse splay deposits of an interdistributary environment. These sandstones are tabular in shape, fine grained and have coarsening-upward sequences. They contain trough cross beds and ripple laminations. Sequences of sandstone, siltstone and silty muds are frequently observed. These deposits are laterally associated with type 2 sandstones.

The carbonaceous zone of interval 2 appears to

have been formed in a well drained environment. The lateral association of coal with type 3 crevasse splay sandstones accounts for the numerous splits and discontinuous nature of the coal bed. The coal and carbonaceous zone, found near the top of interval 2, may represent final stages of bay-fill. Coals also could have formed in abandoned distributary channels or on crevasse splay platforms in an interdistributary environment (Figures 19 and 20).

The abundant mudstone and interbedded lithologies may have formed in abandoned distributary channels or an interdistributary environment.

Transitional Delta Plain

Interval 3 may represent the transitional zone of the lower delta plain. Type 2 sandstones of interval 3 are elongate, multistoried and display some of the internal and morphological characteristics of a meandering river channel sand. This interval may represent very early stages of the transitional zone since its characteristics are more like those of the lower delta plain than of a meandering fluvial system (Figures 21 and 22).

FIGURE 19

GENERALIZED COARSENING-UPWARD SEQUENCE THROUGH LOWER DELTA-PLAIN DEPOSITS IN EASTERN KENTUCKY (FROM BAGANZ, 1975).

FIGURE 20

INTERPRETATION OF THE VERTICAL SEQUENCE THROUGH LOWER DELTA-PLAIN DEPOSITS OF INTERVALS 1 AND 2 (SECTION R 7, UNITS 8-16).

Coal
Rooted Sandstone
Sandstone, fine-grained, climbing ripples
Sandstone, fine to medium-grained
Sandstone, med.-grained, festoon cross-beds
Congl. Lag, siderite pebble, coal spar
Sandstone, Siltstone, graded beds

Sandstone, flow rolls
Sandstone, Siltstone, flaser-bedded
Siltstone and Silty Shale thin-bedded, burrowed
Burrowed sideritic Sandstone
Sandstone, fine-grained
Sandstone, fine-grained, rippled

Silty Shale and Siltstone with calcareous concretions, thin-bedded, burrowed

Clay Shale with siderite bands burrowed, fossiliferous

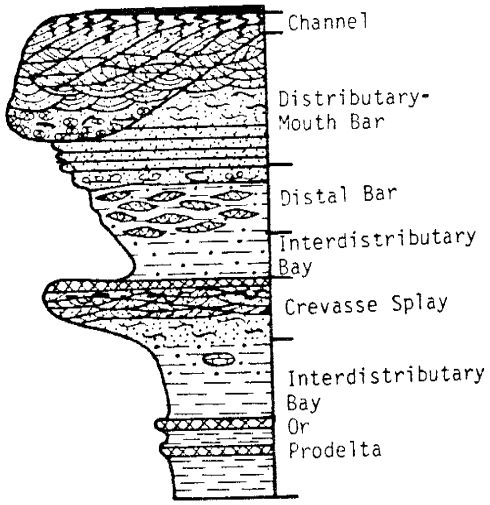


Figure 19

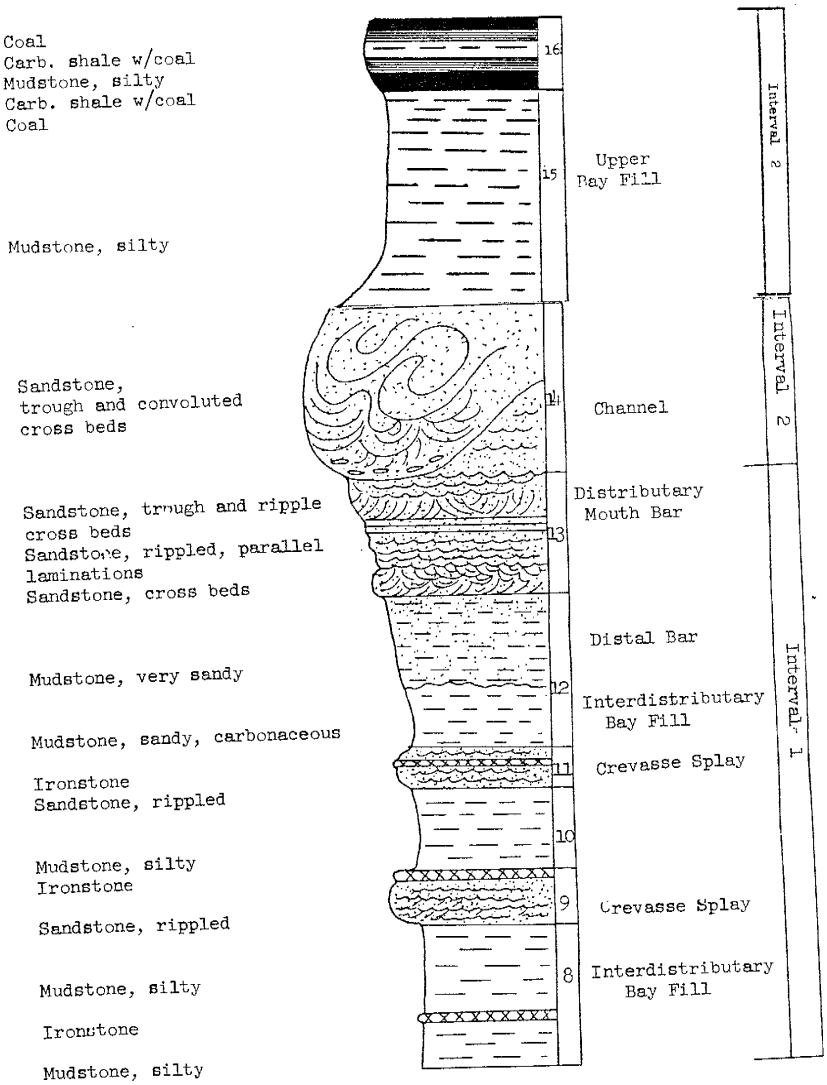


Figure 20

FIGURE 21

GENERALIZED VERTICAL SEQUENCE THROUGH TRANSITIONAL LOWER DELTA-PLAIN DEPOSITS OF EASTERN KENTUCKY AND SOUTHERN WEST VIRGINIA (FROM HORNE, 1978).

FIGURE 22

INTERPRETATION OF THE VERTICAL SEQUENCE THROUGH TRANSITIONAL LOWER DELTA-PLAIN DEPOSITS OF INTERVALS 2 AND 3 (SECTION R 7, UNITS 17-24).

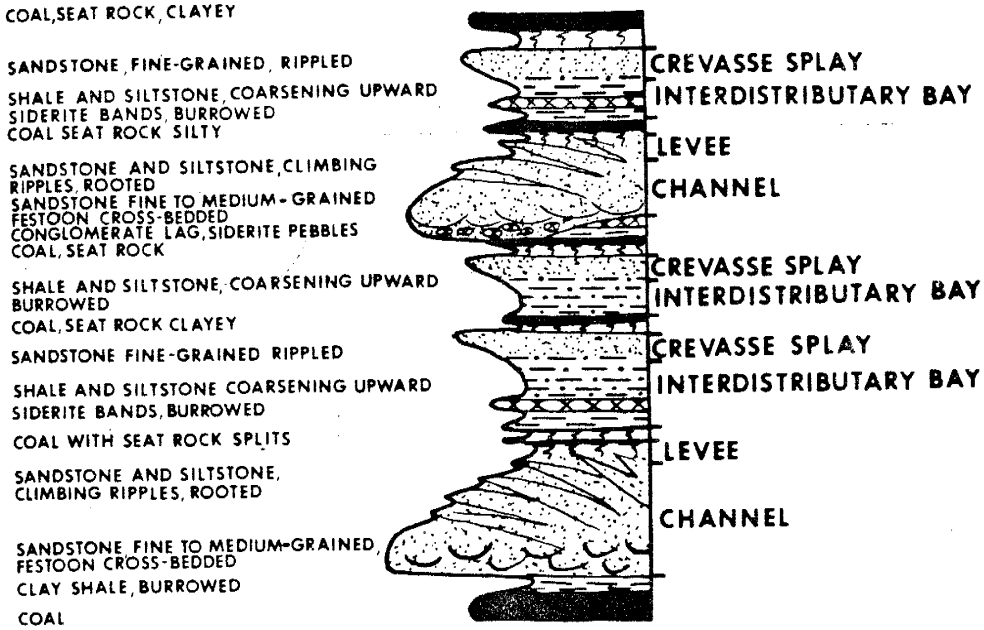


Figure 21

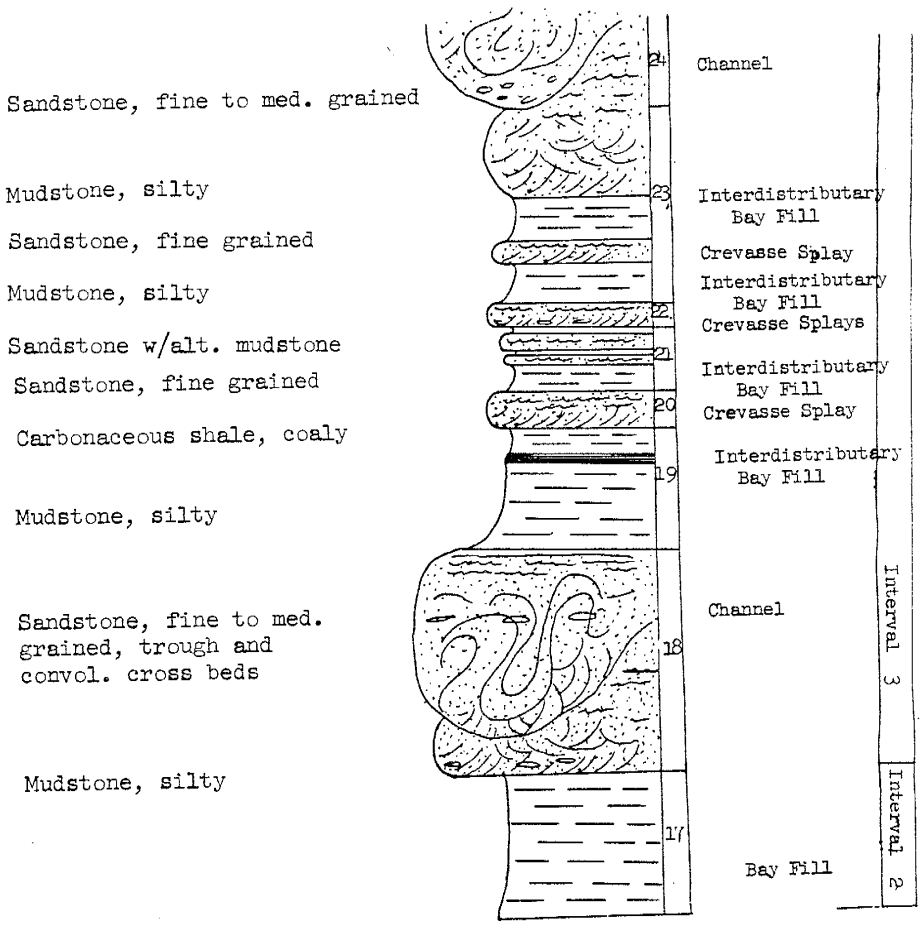


Figure 22

Upper Delta Plain (Braided-Meandering)

The characteristics of a braided system do not apply to the majority of the deposits comprising intervals 1, 2 and 3 except for the basal 20 ft. of interval 1. Types 1a, b, c, and d basal sandstones of interval 1 may be braided channel deposits based on: excessive amounts of sandstone in relation to any other lithology present at the lowest stratigraphic level of interval 1; the lack of fining upward sequences within a given basal sandstone bed; the presence of a quartz pebble lag; and sheet-like tabular deposits.

All the lithologic units of intervals 1, 2 and 3 have characteristics similar to both a lower delta plain and upper delta plain-fluvial systems. The deposits of the lower Raton Formation do not contain any marine influence as might be found associated with a lower delta plain. Two factors add credence to the possibility of a lower delta-plain depositional setting for the lower Raton Formation: 1) point bar accretion, which is characteristic of an upper delta plain-fluvial sandstone, was not observed in any of the sandstone units comprising intervals 1, 2 and 3; 2) intervals 1, 2 and 3 combined, display an overall coarsening-upward sequence which is characteristic of deltaic deposits.

Alternate Interpretation for Braided Meandering Systems

An alternate interpretation for the deposits of the lower Raton Formation consists of the possible existence of an unconformity overlain by braided and meandering river deposits.

The base of interval 1, which is the lowest portion of the 'lower barren zone' of the Raton Formation, is composed almost entirely of medium to coarse grained types 1a, b, c and d, quartzose to arkosic sandstone. As established previously, these sandstones may be interpreted as deposits associated with low sinuosity, mixed load (Schumm, 1963 and 1981) fluvial system.

The basal sandstone of the Fort Union Formation is referred to by Beaumont (1979) as a low sinuosity, mixed load stream deposit. Beaumont noted a quartz pebble, channel lag at the base of these sandstones and an excessive sandstone to shale ratio found at that stratigraphic level. Beaumont (1979) concluded that the initial stream system of the Fort Union Formation shifted extensively over its flood basin. This condition may have existed for the development of the basal types 1a, b, c and d sandstones of the Raton Formation.

Vertical and lateral variations of fluvial deposits within a stratigraphic unit have been noted and discussed by Schumm (1981, p. 24). Beaumont (1979,

p. 214) and Miall (1977, p. 52) also discuss fluvial "metamorphosis" through time. Beaumont (1979) stated, that as the basin fills and the gradient and sediment size decrease, the stream becomes more sinuous; and as more clay is introduced, the system tends toward channel stabilization, due to the cohesiveness of the clay particles and their resistance to erosion. The sediments found in interval 1 display this type of "metamorphosis." The lithologies immediately above the basal types 1a, b, c and d sandstones of interval 1, reflect a clay rich setting in which overbank lithologies exceed sandstone deposits, thus encasing the associated sandstone units.

Interval 1, above the basal 20 ft. , displays characteristics of a mixed sediment load, moderately sinuous fluvial system (Schumm, 1963, 1981 and Galloway, 1981). The lack of carbonaceous shale and coal, and the substantial presence of interbedded, thinly laminated to medium bedded type 4 sandstone, siltstone and very sandy to silty mudstone indicate a well-drained environment as would be found on a floodplain adjacent to a stream channel (Figure 23).

In intervals 1, 2 and 3 type 2 elongate shaped sandstone units, especially those observed in interval 3, may be interpreted as deposits associated with fluvial channels. This is based on the presence of similar internal and morphological characteristics as

FIGURE 23

DEPOSITIONAL SETTING FOR THE SUGARITE COAL ZONE (MODIFIED FROM BEAUMONT, 1979).

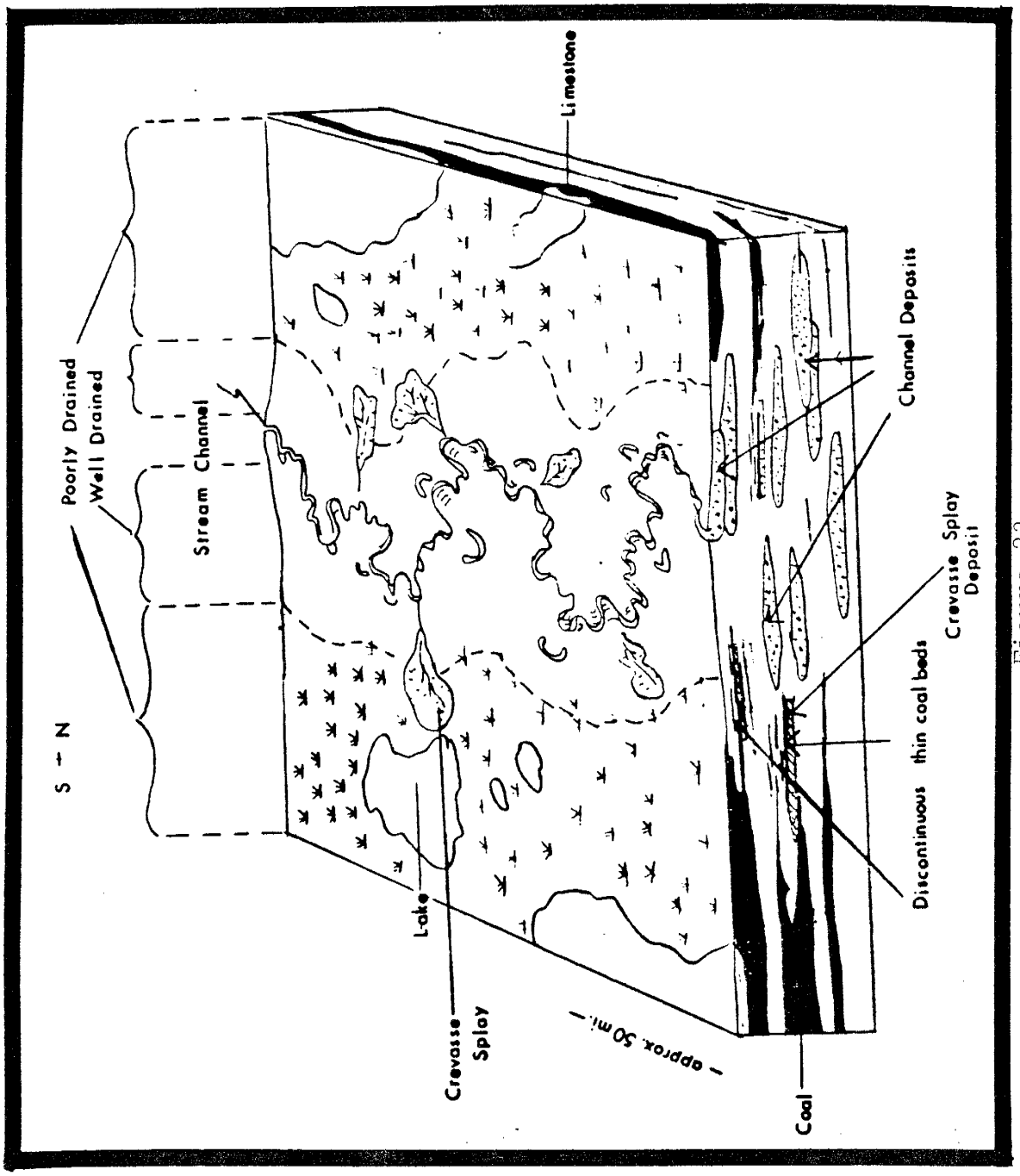

Limestone
Poorly Drained
Well Drained
Stream Channel
Channel Deposits
Crevasse Splay Deposit
S — N
Discontinuous thin coal beds
Lake
Crevasse Splay
approx. 50 mi.
Coal

Figure 23

the previously described meandering channel sandstone. The main channel of the fluvial system is determined to have a northwest to southeast trend. It is interpreted that sections were measured roughly parallel and to the south of the main channel system (Figure 24).

Lenticular shaped type 2 sandstone units, especially observed in intervals 1 and 2 isolated within interbedded sediments, are interpreted as low sinuosity channels of crevasse-splay deposits or possibly channels formed during avulsion (Cant, 1982, p. 120). Tabular shaped type 3 sandstone units, also isolated within a dominantly muddy lithology, are most likely crevasse splay deposits.

Within interval 2, the increased amount of carbonaceous shale and coal over that of interval 1, indicates a change from a well-drained to a poorly-drained swamp environment. The coal and carbonaceous shale deposits contain many partings and are not as thick and laterally continuous as would be expected in a low lying, poorly-drained or lacustrine area. All the lithologies, including the carbonaceous shale and coal beds, contain a substantial amount of sand and silt. The coals of interval 2 are interpreted as having formed in a moderately well drained swamp setting. The environment would have allowed for plant accumulation, yet would not have protected the swamp from periodic inundation of sediments by flooding and

FIGURE 24

DEPOSITIONAL SETTING FOR THE DEPOSITS OF INTERVAL 1 (MODIFIED FROM BEAUMONT, 1979).

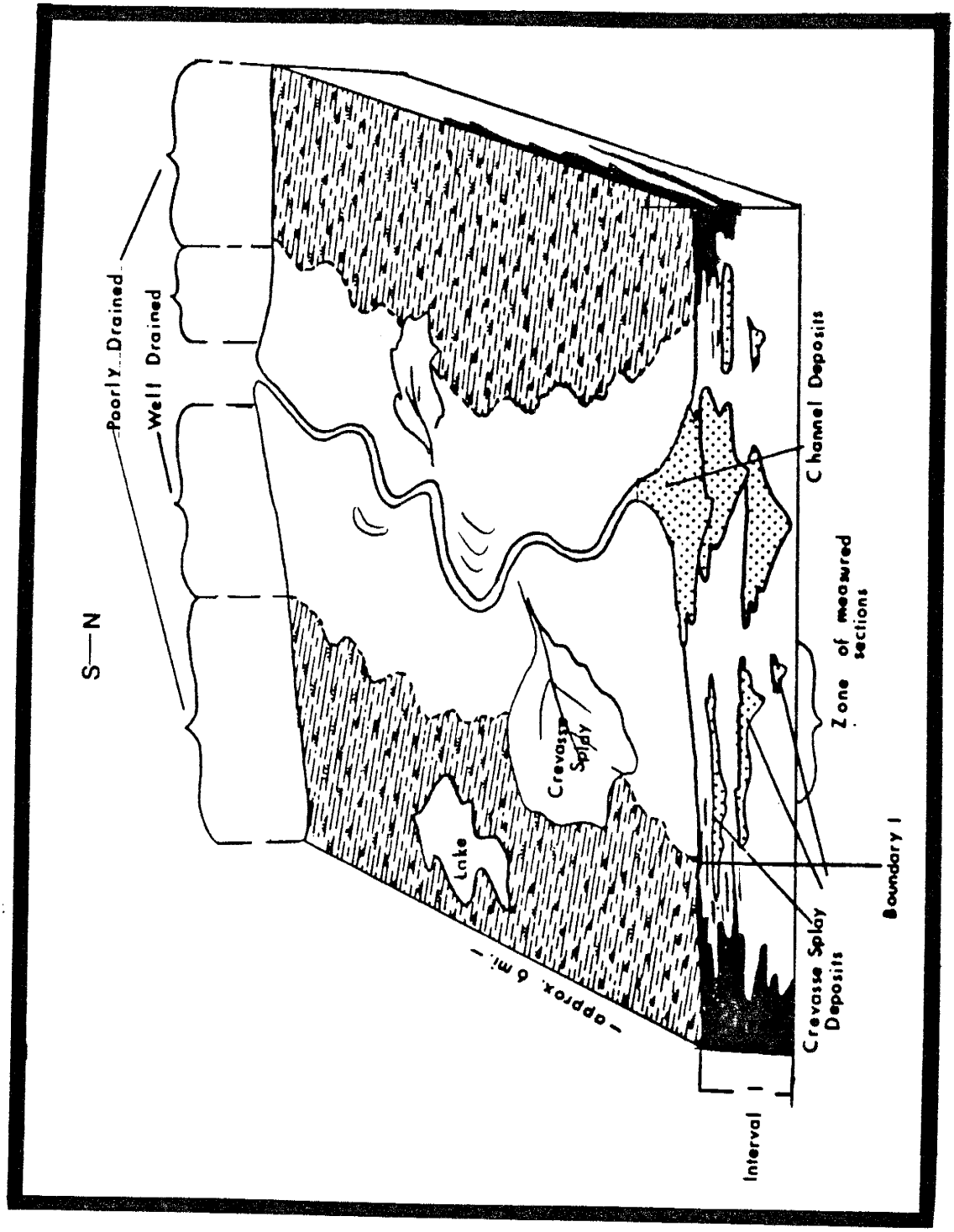

S—N
Poorly Drained
Well Drained
Lake
Crevasse Splay
Channel Deposits
Zone of measured sections
Crevasse Splay Deposits
Boundary I
Interval
— approx. 6 mi. —

Figure 24

crevassing and thus interrupting plant growth. Additional plant growth would begin over splay and overbank deposits. This may be demonstrated in interval 2 by the close vertical association of several thin, discontinuous coal beds to thickly bedded tabular type 3 and lenticular type 2 sandstone units.

Flores (1981) and Ethridge, Jackson and Youngberg (1981) noted the presence of thin discontinuous coal beds similar in character to those found in interval 2. Ethridge, Jackson and Youngberg (1981) hypothesized that these coals were developed as "small interchannel peat swamps on slightly better drained crevasse splay platforms rather than in low lying poorly-drained areas where lakes may have formed." Flores (1981) referred to these coals as formed in a "transition zone" where they were split by overbank and crevasse splay deposits. The moderate well drained swamp setting, reflected in the coal and carbonaceous shale zone of interval 2, most likely represents a slight lateral shifting of the fluvial system over that of the well drained swamp setting of interval 1 (Figure 25).

The very thick coal beds of interval 2, found in the mining district of Chicorica Creek Canyon, are believed to have been formed in a relatively poorer drained swamp setting than that of the thinner coal beds found within the same interval. The character of the thick coal beds does not differ significantly from

FIGURE 25

DEPOSITIONAL SETTING FOR THE DEPOSITS OF INTERVAL 2 (MODIFIED FROM BEAUMONT, 1979).

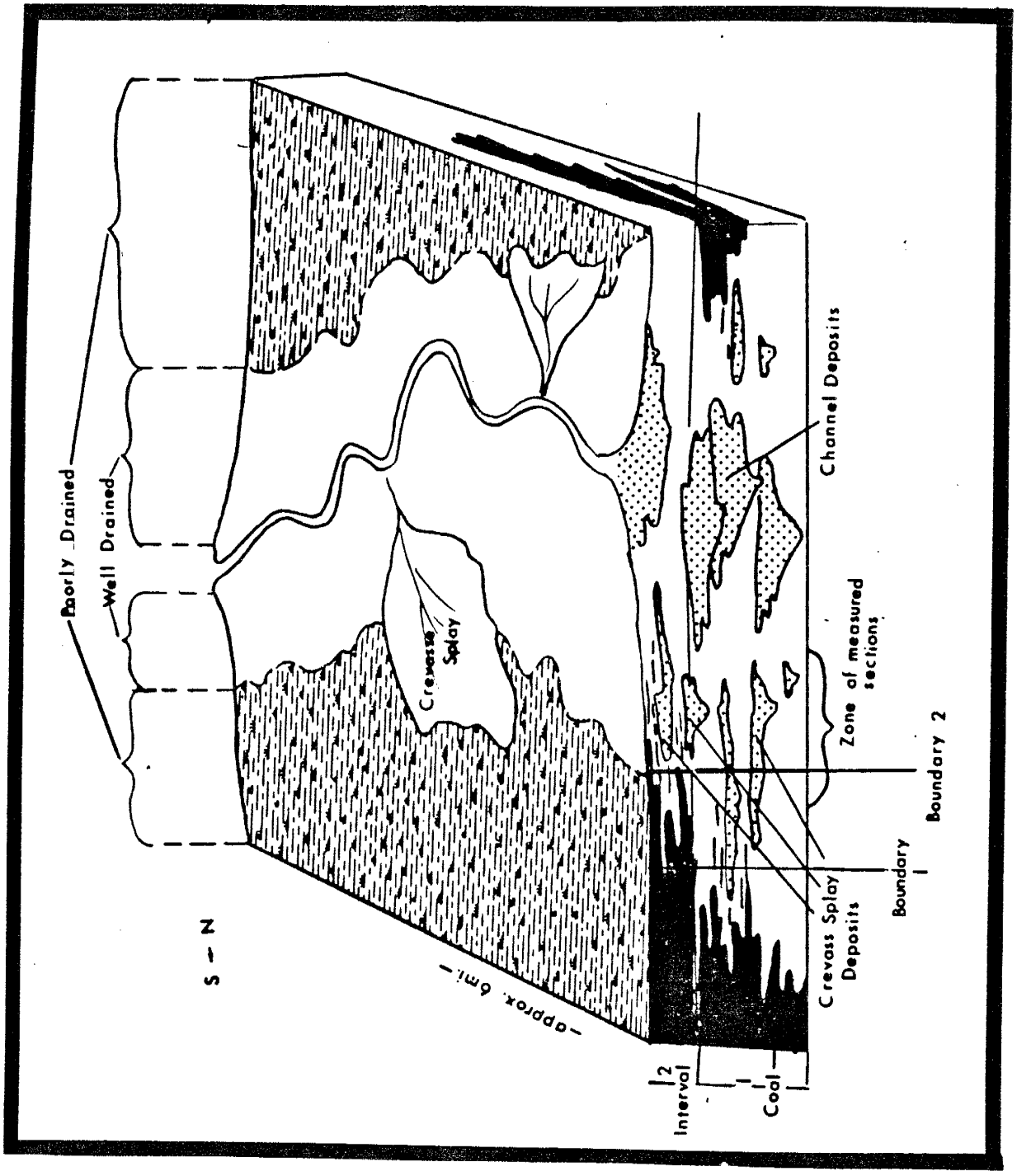

Poorly Drained
Well Drained
Crevasse Splay
Channel Deposits
Zone of measured sections
Boundary 2
Boundary 1
Crevass Splay Deposits
Coal
Interval
S — N
approx. 6mi.

Figure 25

the thinner coal deposits except for an increased thickness. The mineable coal of interval 2 is considered thin by comparison to the very thick coal deposits described by Flores (1981), Beaumont (1979) and Ethridge, Jackson and Youngberg (1981). The relative increase in coal bed thickness, that is encountered laterally between thin, non-mineable coal beds of interval 2, may represent an irregular to gradational nature that existed between the moderately drained and poorly drained swamp settings parallel to the stream channel. As the outcrop of the coal to carbonaceous shale zone of interval 2 is followed from west to east, which roughly parallels the direction of the stream channel, the undulatory nature of the moderately well-drained to moderate poorly-drained contact is reflected in the thickening and thinning of the coal beds.

Stach (1975) reports that most all mineable coal seams are autochthonous. He states that stump horizons or upright stems above the seams are evidence for autochthony. Hacquebard and Donaldson (1969) add to Stach's criteria the preservation of leaves and fern imprints in the roof of many seams, wide distribution and uniform seam thickness over large areas. Stach's (1975) definition for allochthonous coals is that they formed from plant remains which were transported long distances from their original site. He states that

allochthonous coals are too rich in mineral matter for economic use.

Hacquebard and Donaldson (1969) state that these coals occur in areas where the water table was too high to permit any plant growth. Bell (1940) reported that allochthonous coals show variability in quality and thickness which grade laterally and vertically into carbonaceous shales; they commonly lack rooted zones, upright trees and plant remains in the roof of the coal seams.

Stach (1975) reports that "unimportant rearrangementing of plant remains take place repeatedly within a peat swamp during times of flooding. Consequently 'hypautochthonous' coals result and these are commonly characterized by a finely detrital composition..." Hypautochthonous coals are therefore formed from plant remains transported within the area of its growth.

Beaumont (1979) found that the hypautochthonous origin best described the character of the Fort Union coals. His conclusions were based on the the lack of upright fossil trees, excellent and abundant preservation of fossil leaves in surrounding lithologies, variability in quality and thickness and low sulfur content.

The coals of interval 2 are believed to be hypautochthonous in origin. The coals of this

interval, located within a sand rich zone, would be subjected to periodic reworking by floodwaters and show characteristics of both allochthonous and autochthonous nature.

Interval 3 is possibly composed of sediments derived from a moderately sinuous, mixed load, well-drained system. The sandstone rich lithology of interval 3 over that of intervals 1 and 2 may represent a lateral migration of the fluvial system across previously deposited carbonaceous shales and coals of a moderately well drained setting (Figure 26). These sandstones are multistoried, elongate, laterally traceable and found within a dominant overbank lithology and may represent channel sand deposits. Interrupted, rhythmic internal structures may be a result of a cut and fill process. Tabular sandstones of interval 3, within an overbank lithology, are most likely crevasse-splay deposits.

FIGURE 26

DEPOSITIONAL SETTING FOR THE DEPOSITS OF INTERVAL 3 (MODIFIED FROM BEAUMONT, 1979).

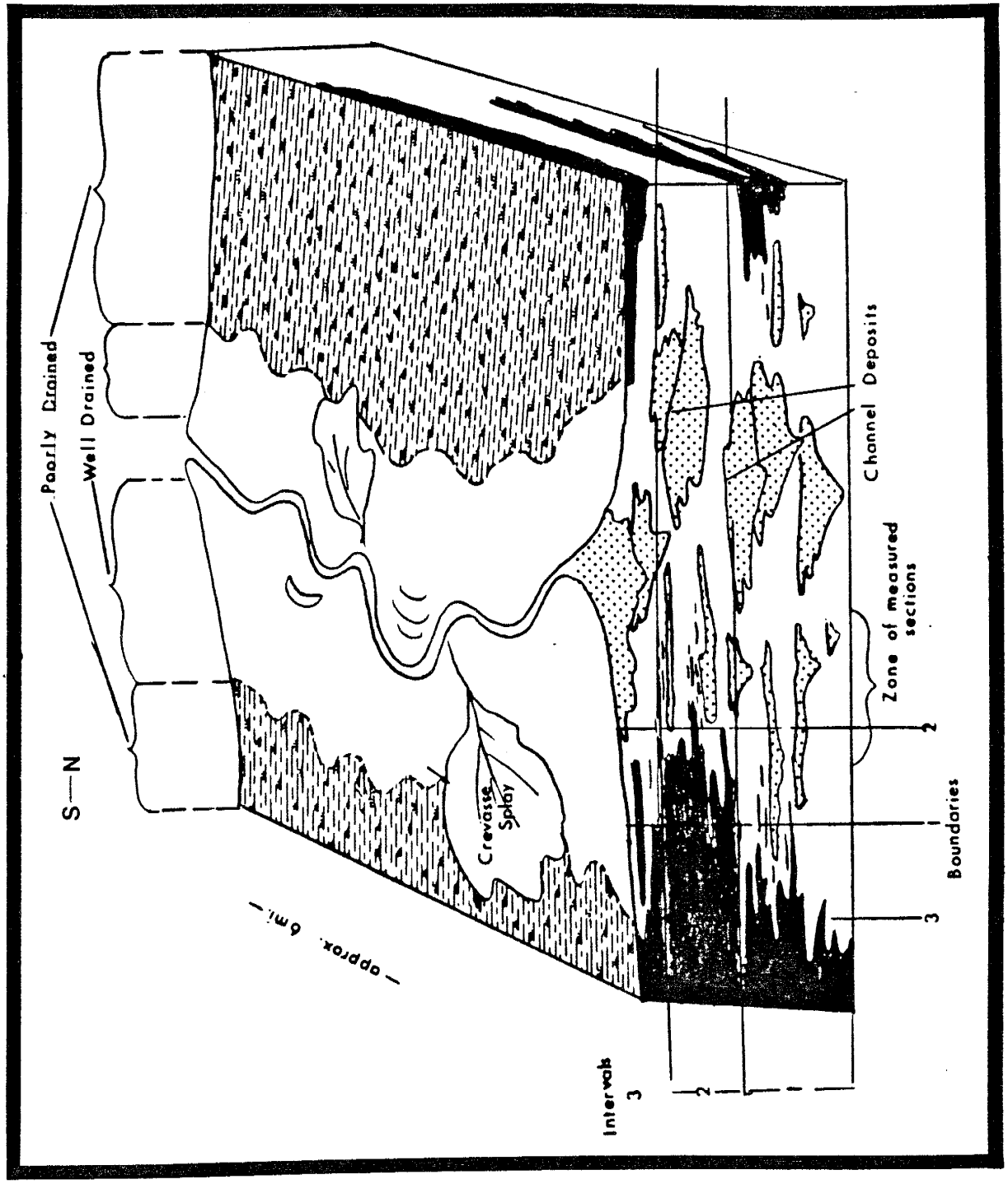

Poorly Drained
Well Drained
S—N
Crevasse Splay
approx. 6 mi.
Channel Deposits
Zone of measured sections
Boundaries
Intervals
3
2
1
2
3

Figure 26

SUMMARY OF DEPOSITIONAL INTERPRETATIONS

The deposits of the lowermost 200 ft. of the Raton Formation show characterstics that are most similar to those of lower delta plain environments.

The quartzose sandstone, which makes up sandstone types 1a, b, c and d that are found near the base of interval 1, may represent tidal delta, tidal channel and washover deposits which are associated with a barrier island, strand-plain complex. These sandstones are observed in both lateral and vertical association with lagoonal Vermejo and strand-plain Trinidad deposits.

The lower portion of interval 1, due to the dominance of silty mudstone and interbedded lithologies, may represent lower bay-fill and distributary-bay-mouth deposits. Sandstone types 1a, b, c and d may also be interpreted as distributary mouth sandstone sheet deposits.

The upper portion of interval 1 and all of interval 2 may be made up of upper bay-fill deposits due to the increased amount of sandstone and carbonaceous lithologies over that of interval 1. In both intervals 1 and 2, type 2 sandstones display most of the characteristics of distributary channel deposits; while type 3 sandstones show characteristics of crevasse splay deposits. Small lenticular type 2

sandstones may be crevasse splay channel deposits. The thin discontinuous carbonaceous zones of interval 2 may represent deposits found in association both vertically and laterally with distributary channels and crevasse splay deposits.

Interval 3 may represent the very early stages of a transitional zone of a delta plain complex due to type 2 sandstones becoming slightly more elongate and multistoried than those of interval 2. Interval 3 is interpreted to have characteristics more like those of the lower delta plain than those of a meandering-fluvial system.

The lithologies of intervals 1, 2 and 3 do not show characteristics that represent a braided fluvial system. Only the lowest 20.0 ft. of interval 1 could be compared to a braided system based on: excessive amounts of sandstone compared to any other lithology present at the lowest 20.0 ft. of interval 1; the lack of fining-upward sequences; the presence of a quartz pebble lag; and sheet like tabular nature of many of the sandstone deposits.

Although the deposits of intervals 1, 2 and 3 show characteristics similar to both lower and upper delta-plain fluvial deposits, they do not contain any marine influence. Two factors that add credence to the possibility of a lower delta-plain depositional setting for the lower Raton Formation are the lack of point bar

accretion and the overall coarsening-upward sequence.

An alternate interpretation of the lithologies of intervals 1, 2 and 3 consists of the existence of an unconformity overlain by braided-meandering river deposits.

The basal 20.0 ft. may represent mixed load, low sinuosity stream deposits (Schumm, 1963 and 1981). Through time, a fluvial metamorphosis (Beaumont, 1979, p. 214 and Miall, 1977, p. 52) may have occurred as the basin filled and the gradient and sediment size decreased, the stream may have become more sinuous; and as more clay was introduced, the system tended toward channel stabilization.

Interval 1 deposits may be a result of a mixed sediment load, moderately sinuous, fluvial system (Schumm, 1963, 1981 and Galloway 1981). The lack of carbonaceous lithologies and the abundance of interbedded lithologies indicate a well-drained environment as would be found on a floodplain adjacent to a stream channel.

Interval 2 may represent a slight lateral shifting of the system to a more poorly-drained environment due to the increased presence of carbonaceous lithologies.

Interval 3 may again represent a lateral migration back to a well-drained environment as would be found near the main channel of a fluvial system.

Type 2 elongate sandstone deposits of intervals 1,

2 and 3 may be deposits associated with a northwest to southeast trending main river channel. It is interpreted that these sandstone beds were measured parallel and to the south of the main channel. Lenticular type 2 sandstones of all intervals may be crevasse splay channel deposits; while tabular type 3 sandstones may be interpreted as crevasse splay deposits. The carbonaceous lithologies may have been formed in a moderately well-drained swamp environment. This environment would have been subjected to periodic inundation of sediments by flooding and crevassing. The carbonaceous lithologies of interval 2 are interpreted to be hypautochthonous (Stach, 1974) in origin. These would have formed in a well-drained setting and have been subjected to flooding and reworking.

The lithologies of the intervals 1, 2 and 3 are compared to models, especially those of alluvial deposits of the lower delta plain and upper delta plain. These deposits show characteristics most like those of lower delta-plain active distributary channel, abandoned distributary and crevasse splay deposits.

CONCLUSIONS

When the lithologies of the lowest 200 ft. of the Raton Formation and the vertical and lateral associations of these lithologies are compared to various fluvial environments, they strongly resemble those of a lower delta plain. The study conducted for this research did not prove the existence of an unconformity as established by Lee (1917) existing between the Raton and Vermejo Formations nor were point bar deposits, which are characteristic of a meandering system, observed in any of the measured sections. What is interpreted to exist are deposits resulting from the transition from marine, strand-plain, lagoonal systems to lower delta plain fluvial system.

COAL RESOURCES

The Raton Basin's coal resources are modest compared to some fields being developed in the western U.S.; however, the coal from the Raton field is of high rank, and produces a high quality coke. Average heating values of coals from the Raton Field are almost twice those of lower rank coals from the Fort Union region and nearly 1.5 times those from the Powder River region. At the present rate of production, estimated resources in the Raton Field will last for several thousand years.

Much of the Raton Basin is underlain by coal beds of mineable thickness, but in some places thick overburden exists and hampers mining. Only the southwesternmost part of the basin (~ 80-100 square miles) is devoid of coal.

The coal is all high volatile A to B bituminous rank (Pillmore, 1976). The thickest (~14.5 ft) and most extensive coal bed in the Raton Field is the Raton coal bed of the Vermejo Formation. The 'Raton' bed name is commonly applied to commercial coal beds found at or near the base of the Vermejo Formation. This is the coal bed seen within the study area. Where two or more beds are present, the thickest bed is called the Raton bed. The coal may rest directly on the Trinidad Sandstone or occur 30 ft. or more above it. This is

the coal bed described as having been deposited in a back-barrier swamp environment.

Another coal, formed in large swamps on a river floodplain and irregular in thickness and distribution, is the Vermejo coal bed of the Vermejo Formation. It is as thick as 15 ft. and mined in the Castle Rock Park District. The bed is restricted to areas where the Vermejo Formation is thicker than 250 ft.

In the Raton Formation, coal beds are common, but are less extensive and not as widely distributed as coal beds in the Vermejo Formation. The Raton Formation is divided into two zones; an upper zone from which all commercial quality coals are mined, and a lower barren zone. The upper Left Fork and York Canyon beds (Kaiser Steel) in the central part of the Raton Formation, in the 'coal-bearing zone', are the only beds being mined. There are coal beds in the 'lower, barren zone' of the Raton Formation, but for the most part they are lenticular, impure, bony and less than 2 ft. thick (Pillmore, 1976). Sugarite is the lowest coal bed of the 'lower, barren zone' that is of commercial quality. It occurs 80-100 ft. above the base of the Raton Formation (Pillmore, 1976). Due to its high heating value it was mined as a domestic fuel.

SUGGESTIONS FOR FURTHER WORK

Paleocurrent measurements of the sandstones of intervals 1, 2 and 3 will determine the direction of channel flow. If this is dominantly a meandering fluvial system, there would exist a a wide variance in paleocurrent measurements. What most likely would be observed, since the evidence strongly supports that of a lower delta plain system, is a smaller variance in paleocurrent direction and a dominant northeast direction of flow.

Additional petrological investigation, especially that of the coal deposits, to determine the maceral content will add information to the depositional setting.

If the system is meandering fluvial, it is possible that west of the study area, coals that are time equivalent to those found in interval 2, may produce thick mineable seams such as that found in Chicorica Creek Canyon. Further study of the depositional environment to the west will determine this probability.

Additional stratigraphic measurements, both laterally and vertically, will provide information on a broader scope. This study dealt with a relatively small area, therefore more stratigraphic information is needed to understand the total system and intervals 1,

2 and 3 relationship to it.

APPENDICES

APPENDIX A

LITHOLOGIC PERCENTAGES FOR INTERVALS 1, 2 AND 3 OF EACH MEASURED SECTION.

APPENDIX A

Lithologic Percentages

Percentage = total percent of a given lithology within an interval.
Sandstone = thick to thickly bedded.
Siltstone = thick to thickly bedded.
Carbonaceous = shale and coal.
Interbedded = medium to thinly laminated sandstone, siltstone, shale and mudstone.
Cover = areas covered by vegetation or rock debris. It is assumed to be composed of slope forming mudstone and interbedded lithologies.
/ = undetermined.
Thickness = interval thickness (ft.).
t = total percent of each lithology for the section.

Section no.	Interval no.	Thickness ft.	Sandstone %	Siltstone %	Carb. %	Interb. %	Cover %
	3	72.0	57.0	0.0	0.0	43.0	0.0
(1)	2	72.0	30.0	0.0	8.0	62.0	0.0
	1	62.0	23.0	0.0	0.0	14.0	63.0
	(t)	206.0	36.6	0.0	2.7	39.7	21.0
	3	72.0	42.0	0.0	0.0	58.0	0.0
(2)	2	72.0	20.0	0.0	7.7	58.3	14.0
	1	62.0	33.0	0.0	0.0	30.0	37.0
	(t)	206.0	25.2	0.0	8.0	49.0	17.0

Section no.	Interval no.	Thickness ft.	Sandstone %	Siltstone %	Carb. %	Interb. %	Cover %
	3	72.0	30.0	0.0	0.3	36.7	33.0
(3)	2	72.0	54.0	0.0	4.9	41.1	0.0
	1	60.0	23.0	0.0	0.0	1.0	76.0
	(t)	204.0	35.6	0.0	1.7	26.4	36.3
	3	72.0	40.3	0.0	0.0	0.0	59.7
(4)	2	72.0	15.3	0.0	4.2	9.7	70.8
	1	60.0	46.4	0.0	0.0	53.6	0.0
	(t)	204.0	34.0	0.0	1.5	21.0	43.5
	3	72.0	56.0	0.0	0.0	0.0	44.0
(5)	2	72.0	34.7	0.0	0.6	0.0	64.7
	1	50.0	44.0	0.0	0.0	56.0	0.0
	(t)	194.0	44.9	0.0	0.2	18.7	36.2
	3	72.0	11.0	0.0	0.0	32.0	57.0
(6)	2	72.0	62.5	0.0	2.1	14.4	21.0
	1	53.0	14.0	0.0	3.0	0.0	83.0
	(t)	194.7	29.2	0.0	1.7	15.5	53.6
	3	72.0	60.0	0.0	0.5	39.5	0.0
(7)	2	72.0	44.0	0.0	6.0	50.0	0.0
	1	60.0	43.0	0.0	0.8	56.2	0.0

Section no.	Interval no.	Thickness ft.	Sandstone %	Siltstone %	Carb. %	Interb. %	Cover %
	(t)	204.0	49.0	0.0	2.4	48.6	0.0
	3	72.0	31.0	0.0	0.0	69.0	0.0
(7a)	2	72.0	20.0	17.5	7.4	55.1	0.0
	1	61.0	25.0	9.2	0.8	65.0	0.0
	(t)	205.0	25.3	8.9	2.8	63.0	0.0
	3	72.0	63.0	0.0	0.0	37.0	0.0
(7b)	2	72.0	30.0	4.1	0.0	4.9	61.0
	1	27.0	26.0	0.0	0.0	0.0	74.0
	(t)	171.0	39.6	1.4	0.0	14.0	45.0
	3	73.0	22.0	26.7	0.0	51.3	0.0
(8)	2	73.0	21.0	11.0	7.0	12.0	49.0
	1	62.0	2.3	9.7	0.0	88.0	0.0
	(t)	208.0	15.1	15.8	2.4	50.4	16.3
	3	73.0	38.0	0.0	0.0	0.0	62.0
(8a)	2	73.0	27.4	12.3	2.0	24.7	33.6
	1	/	/	/	/	/	/
	(t)	146.0	33.0	6.2	1.0	12.0	47.8

Section no.	Interval no.	Thickness ft.	Sandstone %	Siltstone %	Carb. %	Interb. %	Cover %
	3	74.0	54.0	0.0	0.0	0.0	46.0
(8b)	2	/	/	/	/	/	/
	1	/	/	/	/	/	/
	(t)	74.0	54.0	0.0	0.0	0.0	46.0
	3	72.0	18.0	0.0	0.0	82.0	0.0
(9)	2	72.0	0.0	17.5	13.1	69.4	0.0
	1	61.0	12.0	10.0	0.0	78.0	0.0
	(t)	205.0	10.0	9.2	4.3	76.5	0.0
	3	71.0	30.0	0.0	2.8	8.2	59.0
(9a)	2	74.0	0.0	6.8	5.5	4.1	83.6
	1	/	/	/	/	/	/
	(t)	145.0	15.0	3.4	4.2	6.2	71.2
	3	72.0	29.2	2.8	0.0	22.2	45.8
(9b)	2	75.0	3.3	42.7	12.0	33.4	8.6
	1	/	/	/	/	/	/
	(t)	147.0	16.3	22.7	6.0	27.8	27.7
	3	72.0	37.5	16.7	0.0	45.8	0.0
(9c)	2	75.0	16.0	26.7	12.0	45.3	0.0

Section no.	Interval no.	Thickness ft.	Sandstone %	Siltstone %	Carb. %	Interb. %	Cover %
	1	/	/	/	/	/	/
	(t)	147.0	26.8	21.6	6.1	45.5	0.0
	3	71.0	35.0	0.0	0.0	17.0	48.0
(9d)	2	/	/	/	/	/	/
	1	/	/	/	/	/	/
	(t)	71.0	35.0	0.0	0.0	17.0	48.0
	3	71.0	44.0	0.0	0.0	56.0	0.0
(10)	2	75.0	16.0	0.0	2.7	41.3	40.0
	1	62.0	19.4	1.0	0.0	79.6	1.0
	(t)	152.0	26.5	0.3	0.9	58.9	13.4
	3	70.0	44.0	14.0	0.0	8.0	34.0
(11)	2	75.0	51.0	3.0	3.3	2.7	40.0
	1	88.0	19.0	1.5	2.0	4.5	73.0
	(t)	233.0	38.0	6.2	1.7	5.1	49.0
	3	70.0	56.0	0.0	0.0	44.0	0.0
(12)	2	77.5	55.0	22.0	6.0	17.0	0.0
	1	91.0	27.0	14.0	0.0	59.0	0.0
	(t)	238.5	46.0	12.0	2.0	40.0	0.0

Section no.	Interval no.	Thickness ft.	Sandstone %	Siltstone %	Carb. %	Interb. %	Cover %
	3	68.5	57.0	2.0	2.0	7.0	32.0
(12a)	2	73.0	14.0	37.0	4.0	8.0	37.0
	1	/	/	/	/	/	/
	(t)	141.5	36.0	19.0	3.0	8.0	34.0
	3	67.0	40.5	15.0	1.5	18.0	25.0
(12b)	2	/	/	/	/	/	/
	1	/	/	/	/	/	/
	(t)	67.0	40.5	15.0	1.5	18.0	25.0
	3	71.0	49.0	0.0	0.0	27.0	24.0
(12c)	2	/	/	/	/	/	/
	1	/	/	/	/	/	/
	(t)	71.0	49.0	0.0	0.0	27.0	24.0
	3	70.0	41.0	20.0	0.0	0.0	39.0
(12d)	2	73.0	43.0	16.0	0.0	0.0	41.0
	1	/	/	/	/	/	/
	(t)	143.0	42.0	18.0	0.0	0.0	40.0
	3	70.0	30.0	0.0	2.0	12.0	56.0
(13)	2	72.0	43.0	0.0	1.0	0.0	56.0
	1	72.0	12.0	0.0	0.0	2.0	86.0

Section no.	Interval no.	Thickness ft.	Sandstone %	Siltstone %	Carb. %	Interb. %	Cover %
	(t)	214.0	28.0	0.0	1.0	5.0	66.0
	3	70.0	37.0	0.0	1.0	39.0	23.0
(14)	2	72.0	45.0	0.0	8.0	11.0	36.0
	1	79.0	20.0	0.0	0.0	0.0	80.0
	(t)	221.0	34.0	0.0	3.0	17.0	46.0
	3	/	/	/	/	/	/
(14a)	2	72.0	0.0	28.0	6.0	2.0	64.0
	1	/	/	/	/	/	/
	(t)	72.0	0.0	28.0	6.0	2.0	64.0
	3	70.0	9.0	0.0	0.0	0.0	91.0
(15)	2	72.0	46.0	0.0	7.0	4.0	43.0
	1	81.0	31.0	0.0	7.0	0.0	62.0
	(t)	223.0	29.0	0.0	4.0	1.0	66.0
	3	70.0	31.0	0.0	0.0	29.0	40.0
(16)	2	71.0	25.0	0.0	3.0	56.0	16.0
	1	81.0	12.0	0.0	0.0	0.0	88.0
	(t)	222.0	23.0	0.0	1.0	28.0	48.0

Section no.	Interval no.	Thickness ft.	Sandstone %	Siltstone %	Carb. %	Interb. %	Cover %
	3	70.0	26.0	0.0	1.0	46.0	27.0
(17)	2	70.5	0.0	0.0	8.0	31.0	61.0
	1	82.0	24.0	0.0	4.0	42.0	30.0
	(t)	222.5	17.0	0.0	4.0	40.0	39.0

APPENDIX B

LITHOLOGIC DESCRIPTIONS OF MEASURED SECTIONS FOR THE LOWER-MOST 200 FT. OF THE RATON FORMATION.

Appendix B

Lithologic Descriptions of Measured Sections

Lithologic description for measured sections 1-17. The descriptions and numbered units are related to the graphic descriptions of the sections as depicted in Plates 1-6.
Unless otherwise indicated, the grain size descriptions of fine, medium and coarse refer to the size of sand grains. Silt size grains are those determined to be smaller than the very fine classification for sand.

SECTION R 1 - This section is located above Goat Hill in a gully located in Climax Canyon off the old Raton Pass Highway just west of the city of Raton, New Mexico.

Unit	Unit Thickness ft.	Bed Thickness ft.	Descriptions
Top of the measured section:			
16	30.0	30.0	This unit is a cliff forming arkosic to subarkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor and the sandstone is indurated. The outcrop shape is elongated to lenticular. The base is sharp and erosional. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the

			bed. The beds are lenticular in shape. The top of the bed is a gradational contact.
			(Type 2)
15	17.9	17.9	Interbedded; see unit 2c for description.
14	4.2	4.2	This is a cliff forming arkosic sandstone. It is grayish orange (10 YR 7/4)in both fresh and weathered surfaces. The grain size is fine, the sorting is moderate and it is indurated. The shape is elongate and the bed is laterally discontinuous. The base is erosional with clay clasts, organic debris and plant impressions. Trough cross bedding is the dominant structure. The top contact is gradational. (Type 2)
13	26.1	(j) 10.2	Interbedded; see unit 2c for description.
		(i) 0.6	Coal bed.
		(h) 7.0	Interbedded; see unit 2c for description.
		(g) 0.8	Coal bed.
		(f) 0.7	Coaly carbonaceous shale; see unit 1b for description.
		(e) 2.5	Mudstone; see unit 1a for description.

		(d)	0.1	Coaly carbonaceous shale; see unit 1b for description.
		(c)	2.2	Coal bed.
		(b)	0.2	Coaly carbonaceous shale; see unit 1b for description.
		(a)	1.8	Mudstone (sandy); See unit 1a for description.
12	3.0		3.0	This is a cliff forming arkosic sandstone. The color is very pale orange (10 YR 8/2) in both fresh and weathered surfaces. The grain size ranges from fine to medium, the sorting is moderate and the bed is indurated. The shape of the bed is tabular. The base is nonerosional. The structures include small scale cross beds and horizontal laminations. The top and bottom contacts are sharp. (Type 3)
11	21.2	(c)	19.2	Interbedded; see unit 2c for description.
		(b)	1.2	Coaly carbonaceous shale; see unit 1b for description.
		(a)	1.0	Mudstone; see unit 1a for description.
10	19.3	(c)	3.0	Sandstone; see unit 5 for description.

		(b)	16.3	This is a cliff forming arkosic sandstone. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. The grain size ranges from medium to fine grained, the sorting is moderate and the bed is indurated. Quartzose lenses are observed within the lower portion of this unit. The bed is lenticular in shape and not laterally continuous. The base is gradational to the underlying sandstone. The structures include trough cross beds, planar cross beds and horizontal and ripple laminations. The top contact is gradational. (Type 2)
		(a)	1.0	Sandstone; see unit 2b for description.
9	41.6	(e)	12.9	Interbedded; see unit 2c for descriptions.
		(d)	0.7	Sandstone; see unit 2b for descriptions.
		(c)	0.1	Mudstone; see unit 1a for descriptions.
		(d)	0.9	Sandstone; see unit 2b for descriptions.
		(a)	27.0	Covered slope.
8	3.1	(b)	1.6	This is a cliff forming, quartzose sandstone. The weathered surface is dark yellowish orange (10 YR

			6/6) and the fresh surface is very pale orange (10 YR 8) in color. The grain size ranges from coarse to medium grained, the sorting is poor and the bed is well indurated. The shape is tabular. The base is erosional with abundant clay clasts, plant impressions, organic debris and load casts. Trough to planar cross bedding are the dominant structures. The basal contact is sharp while the top contact is gradational. (Type 3)
		(a) 1.5	This is a cliff forming, arkosic sandstone. The color is grayish orange both in fresh and weathered surfaces. The grain size ranges from medium to fine grained. It is moderately sorted and indurated. Quartzose lenses are observed within the lower portion of this unit. The shape is tabular. The base is gradational to the unit below. The dominant structures are trough and planar cross beds. The top contact is gradational. (Type 3)
7	5.0	5.0	Interbedded; see unit 1a for description.
6	10.6	10.6	Covered slope.
5	10.2	10.2	This is a cliff forming, quartzose sandstone. The color ranges from grayish

				orange (10 YR 7/4) in weathered surface to very pale orange (10 YR 8/2) in fresh surface. The grain size ranges from medium to fine grained, the sorting is moderate and the bed is well indurated. It is lenticular in shape and not laterally continuous. The base is erosional and contains abundant clay clasts, organic debris, plant impressions and very well indurated load casts. Trough cross bedding is the dominant structure. The basal contact is sharp and the top contact is gradational. (Type 2)
4	1.6		1.6	Mudstone; see unit 1a for description.
3	3.5		3.5	Coal bed.
2	8.6	(c)	6.0	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and

				ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are the same as described for unit 1a.
		(b)	0.6	This is a cliff forming arkosic sandstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and gradational to the sandstone below while the top contact sharp. (Type 4)
		(a)	2.0	Mudstone (sandy); see unit 1a for the description.
1	3.2	(e)	0.6	Coaly carbonaceous shale; see unit 1b for the description.

(d)	0.2	Mudstone (coaly); see unit 1a for the description.
(c)	1.9	Coal bed.
(b)	0.2	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to very fine sand grains are observed in the beds.
(a)	0.3	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium to very fine sand grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.

Top of the Trinidad Sandstone.

SECTION R 2 - This section is located 1/2 mile north of Section R 1.

Unit	Unit Thickness ft.		Bed Thickness ft.	Descriptions
Top of the measured section:				
13	30.0		30.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor and the sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional with clay clasts and organic debris. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. The top of the bed is a gradational contact. Ironstone concretions are seen as bands or large lenses throughout the bed. (Type 2)
12	35.3		35.5	Interbedded; see unit 2 for description.
11	11.4	(d)	0.6	Coaly carbonaceous shale; see unit 11 b for description.

		(c)	2.0	Coal bed.
		(b)	6.2	This is a carbonaceous shale. It is black (N 1) when fresh and dark gray (N 8) when weathered. It is thinly laminated. The bed contains coarse sand to silt size grains and abundant modern rootlets.
		(a)	2.6	Coal bed (thinly laminated).
10	10.2		10.2	Covered slope.
9	6.1	(d)	0.7	Carbonaceous shale; see 1b for description.
		(c)	0.6	Coal bed.
		(b)	2.8	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
		(a)	2.0	Coaly carbonaceous shale; see unit 1b for description.
8	36.7		36.7	Covered interval.
7	3.0		3.0	This is a cliff forming arkosic to subarkosic

				sandstone. The color is yellow gray (5 Y 7/2) and a grayish orange (10 YR 7/4) when fresh. The grain size ranges from very fine to medium and fining upward sequences are present. The grains are subangular and the sorting is moderate and the bed is indurated. The shape of the bed is tabular and thickly bedded. The base is nonerosional. The structures include planar cross beds, horizontal and ripple laminations. The top and bottom contacts are sharp. (Type 3)
6	9.7		9.7	Interbedded; see unit 2 for description.
5	15.0	(b)	7.0	This is a cliff forming arkosic sandstone. The color ranges from grayish orange (10 YR 7/4) when weathered and very pale orange (10 YR 8/2) when fresh. The grain size ranges from coarse to medium, and fining upward sequences are observed, the sorting is moderate, the grains are subangular and it is indurated. It is medium to thickly bedded and the dominant structures are trough cross beds and horizontal laminations. The shape is tabular. It has a scoured, erosional base with clay clasts, plant impressions and organic debris. (Type 3)
		(a)	8.0	This is a slope forming

				arkosic to subarkosic sandstone. The color is grayish orange (10 YR 7/4) on both weathered and fresh surfaces. It is fine to very fine grained, moderately sorted, the grains are subangular and it is poorly indurated and contains abundant modern rootlets. The structures were not detectable due to the weathered nature of the bed. All contacts are gradational. (Type 2)
4	21.0		21.0	Covered slope.
3	5.2		5.2	A quartzose, medium grained sandstone, not well exposed, is observed to have a sharp, erosional base with clay clasts and root impressions. (Type 1a)
2	12.2		12.2	Covered slope.
1	3.4	(b)	0.5	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
		(a)	2.9	Coal bed.

Top of Trinidad Sandstone

SECTION R 3 - This section is located 1/2 mile north of Section R 2.

Unit	Unit Thickness ft.	Bed Thickness ft.	Descriptions
Top of the measured section:			
20	10.0	10.0	This unit is a cliff forming arkosic to subarkosic sandstone. The weathered surface color is grayish orange (10 YR 7/4) and the fresh surface is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The grains are subangular and sorting is moderate to poor. The sandstone is indurated to well indurated. The bedding ranges from very thickly to thinly bedded. The beds have a lenticular shape. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional with clay clasts and organic debris. The top of the bed is a gradational contact. (Type 2)
19	39.5	39.5	Covered slope.
18	0.2	0.2	Coaly carbonaceous shale; see unit 1a for

				description.
17	8.5		8.5	Mudstone; see unit 1g for description.
16	7.5	(b)	5.5	This is a slope forming arkosic to subarkosic sandstone. The color is grayish orange (10 YR 7/4) both weathered and fresh. It is medium to fine grained, with a fining upward sequence, moderately sorted, poorly indurated. The structures include planar cross beds and horizontal laminations. It is thinly bedded. All contacts are gradational. (Type 3)
		(a)	2.0	This is a cliff forming arkosic to subarkosic sandstone. The color is grayish orange (10 YR 7/4) both weathered and fresh. It is medium grained, moderately sorted, the grains are subangular and it is indurated. The structures include trough cross beds and planar cross beds. It is thickly bedded and lenticular in outcrop shape. It has a scour base with clay clasts, plant impressions and organic debris. The top contact is gradational. (Type 2)
15	18.6		18.6	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and

			mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
14	42.0	42.0	This unit is a cliff forming arkosic sandstone. The weathered

			color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous and the base is sharp and erosional with clasts and organic debris. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. The beds are lenticular in shape. The top of the bed is a gradational. (Type 2)
13	10.0	10.0	Mudstone; see unit 1g for description.
12	1.2	1.2	Coal bed.
11	10.5	10.5	Mudstone (silty); see 1g for description.
10	13.5	13.5	This is a slope forming subarkosic sandstone. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is very fine grained, unconsolidated, containing abundant organic debris, modern rootlets and is structureless. All contacts are gradational. (Type 3)

9	11.0		11.0	Mudstone (silty); see unit 1g for description.
8	2.0	(e)	0.4	Coaly carbonaceous shale; see unit 1a for description.
		(d)	0.5	Mudstone (silty); see unit 1g for description.
		(c)	0.3	Coaly carbonaceous shale; see unit 1a for description.
		(b)	0.4	Mudstone (silty); see unit 1g for description.
		(a)	0.4	Coaly carbonaceous shale; see unit 1a for description.
7	40.0		40.0	Covered slope.
6	1.0		1.0	This is a cliff forming arkosic sandstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and gradational to the sandstone below while the top contact sharp. (Type

				3)
5	3.0		3.0	Covered slope.
4	6.0		6.0	This is a slope forming arkosic to subarkosic sandstone. The color is grayish orange (10 YR 7/4) both weathered and fresh. It is medium to fine grained, with a fining upward sequence, moderately sorted, poorly indurated. The structures include planar cross beds and horizontal laminations. It is thinly bedded. All contacts are gradational. (Type 3)
3	6.0		6.0	Covered slope.
2	8.1	(c)	4.0	This is a cliff forming arkosic to subarkosic sandstone. It is very pale orange (10 YR 8/2) in both fresh and weathered surfaces. It is medium grained, moderately sorted and indurated. The beds are thin and the structures are planar and trough cross bedding. It is tabular in shape and contains abundant organic debris and modern rootlets. All contacts are gradational. (Type 3)
		(b)	1.0	Mudstone (sandy); see unit 1g for description.
		(a)	3.1	This is a cliff forming quartzose sandstone. It is medium grained, well indurated, moderately

				sorted and thickly bedded. The unit is tabular in shape. Trough cross beds are the dominant structure. The base is scour, erosional with clay clasts and the top is sharp. (Type 1a)
1	14.7	(r)	3.9	Mudstone; see unit 1g for description.
		(q)	1.2	Coaly carbonaceous shale; see 1a for description.
		(p)	0.5	Mudstone; see unit 1g for description.
		(o)	0.3	Coal bed.
		(n)	0.2	Carbonaceous shale; see unit 1a for description.
		(m)	0.5	Coaly carbonaceous shale; see unit 1a for description.
		(l)	0.9	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine grained, moderately sorted and indurated. The main structure is horizontal laminations. It contains plant impressions and modern rootlets. The contacts are nonerosional and gradational. The shape is tabular. (Type 3)
		(k)	0.1	This is a cliff forming arkosic sandstone. The

		weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, moderately and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and gradational to the sandstone below while the top contact sharp. (Type 4)
(j)	1.5	Mudstone; see unit 1g for description.
(i)	0.5	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine grained, moderately sorted and indurated. The main structure is horizontal laminations. It is thinly laminated. The contacts are nonerosional and sharp. It contains plant impressions and modern rootlets. The shape is tabular. (Type 4)
(g)	1.0	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris

		and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
(f)	0.5	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
(e)	0.5	Coal bed.
(d)	0.3	Coaly carbonaceous shale; see unit 1a for descriptions.
(c)	1.2	Coal bed.
(b)	0.4	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine grained, moderately sorted and indurated. The main structure is horizontal laminations. It is thinly laminated. The contacts are nonerosional and sharp. It contains plant impressions and modern rootlets. The shape is tabular. (Type 4)
(a)	0.5	This is a coaly carbonaceous shale. The

coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds. All contacts are gradational.

Top of Trinidad Sandstone

SECTION R 4 - This section is located 1/2 mile north of Section R 3.

Unit	Unit Thickness ft.	Bed Thickness ft.	Descriptions
Top of the measured section:			
21	4.8	4.8	Sandstone; see unit 17 for description.
20	2.8	2.8	Mudstone (sandy); see unit 6 for description.
19	19.6	(b) 2.8	Sandstone; see unit 17 for description.
		(a) 7.1	Sandstone; see unit 11 for description.
18	46.0	46.0	Covered slope.
17	7.2	7.2	This is a cliff forming arkosic sandstone. The color ranges from grayish orange (10 YR 7/4) when weathered and very pale orange (10 YR 8/2) when fresh. The grain size is medium, sorting is moderate, the grains are subangular and it is indurated. It is medium to thickly bedded and the dominant structures are trough cross beds and horizontal laminations. The shape is tabular. It has a sharp nonerosional base. (Type 3)
16	15.5	15.5	Covered slope.

15	30.0		30.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional with clasts and organic debris. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. The structures are rhythmic and the beds are lenticular in shape. The top of the bed is a gradational contact. (Type 2)
14	52.0		52.0	Covered slope.
13	2.5	(c)	1.0	Carbonaceous shale; see unit 1d for description.
		(b)	1.0	Coal bed.
		(a)	0.5	Carbonaceous shale; see unit 1d for description.
12	9.0		9.0	Mudstone; see unit 1a for description.
11	15.9	(c)	7.1	This is a cliff forming

				arkosic to subarkosic sandstone. It is very pale orange (10 YR 8/2) in both fresh and weathered surfaces. It is medium grained, moderately sorted and indurated. The beds are thin and the structures are planar and trough cross bedding. It is tabular in shape and contains abundant organic debris and modern rootlets. All contacts are gradational. (Type 3)
		(b)	0.9	Mudstone (silty); see unit 1a for description.
		(a)	7.0	This is a cliff forming arkosic to subarkosic sandstone. It is medium grained, well indurated, moderately sorted and thickly bedded. The unit is tabular in shape. Trough cross beds are the dominant structure. The base is scoured, erosional with clay clasts and the top is sharp. (Type 3)
10	13.5		13.5	Interbedded; see unit 4 for description.
9	10.9		10.9	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone

				is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional with clasts and organic debris. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. The beds are lenticular in shape. The top of the bed is a gradational.(Type 2)
8	13.0		13.0	Interbedded; see unit 4 for description.
7	0.8		0.8	This is a cliff forming quartzose sandstone. It is medium grained, well indurated, moderately sorted and thickly bedded. The unit is tabular in shape. Trough cross beds are the dominant structure. The base is sharp and nonerosional. (Type 1a)
6	7.4		7.4	Interbedded; see unit 4 for description.
5	5.1	(e)	2.0	Carbonaceous shale; see unit 1d for description.
		(d)	0.7	Mudstone; see unit 1a for description.
		(c)	0.9	Coal bed.
		(b)	0.6	Coaly Carbonaceous shale; see unit 1c for description.

	(a) 0.9		Coal bed (shaly).
4	4.6	4.6	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are the same as described for unit 1a.
3	0.6	0.6	This is a cliff forming arkosic sandstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh

				surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and gradational to the sandstone below while the top contact sharp. (Type 4)
2	2.5		2.5	Sandstone; see unit 1b for description.
1	3.8	(d)	1.0	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
		(c)	2.0	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds. All contacts are gradational.
		(b)	0.2	This is a slope forming arkosic to subarkosic

sandstone. The color is grayish orange (10 YR 7/4) both weathered and fresh. It is medium to fine grained, with a fining upward sequence, moderately sorted, poorly indurated. The structures include planar cross beds and horizontal laminations. It is thinly bedded. All contacts are gradational. (Type 4)

(a) 0.6 This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.

Top of the Trinidad Sandstone

SECTION R 5 - This section is located 1/4 mile east of Section R 4.

Unit	Unit Thickness ft.	Bed Thickness ft.	Descriptions
Top of the measured section:			
18	43.8	43.8	Sandstone; see unit 11 for description.
17	37.2	37.2	Covered slope.
16	41.9	41.9	Sandstone; see unit 11 for description.
15	46.5	46.5	Covered Slope.
14	25.0	25.0	Sandstone; see unit 11 for description.
13	2.0	(b) 0.4	Carbonaceous shale, see unit 3a for description.
		(a) 1.6	Mudstone (silty and organic), see unit 6 for description.
12	9.0	9.0	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.

11	13.0		13.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional with clasts and organic debris. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. The beds are lenticular in shape and the structures are rhythmic. The top of the bed is a gradational contact. (Type 2)
10	1.8	(c)	0.5	Mudstone, see unit 6 for description.
		(b)	0.8	This is a slope forming arkosic to subarkosic sandstone. The color is grayish orange (10 YR 7/4) both weathered and fresh. It is medium to fine grained, with a fining upward sequence, moderately sorted, poorly indurated. The structures include planar cross beds and horizontal laminations. It is thinly bedded. All

			contacts are gradational. (Type 3)
	(a)	0.5	Sandstone, see unit 3c for description.
9	8.2	8.2	Mudstone, see unit 6 for description.
8	5.0	5.0	Interbedded, see unit 2 for description.
7	3.7	3.7	This is a cliff forming arkosic sandstone. The color is very pale orange (10 YR 8/2) in both fresh and weathered surfaces. The grain size ranges from fine to medium, the sorting is moderate and the bed is indurated. The shape of the bed is tabular. The base is nonerosional. The structures include small scale cross beds and horizontal laminations. The top and bottom contacts are sharp.(Type 3)
6	6.0	6.0	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
5	2.8	2.8	This is a cliff forming

				quartzose sandstone. It is dark yellow orange (10 YR 6/6) in weathered surfaces and grayish orange (10 YR 7/4) when fresh. It is medium grained, well indurated, moderately sorted and thickly bedded. The unit is tabular in shape. Trough cross beds are the dominant structure. The base is nonerosional, the top is sharp. (Type 1a)
4	12.0		12.0	Interbedded, see unit 2 for description.
3	3.4	(d)	0.4	Carbonaceous shale, see unit 3b for description.
		(c)	0.8	Sandstone, see unit 3a for description.
		(b)	1.0	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
		(a)	1.2	This is a cliff forming subarkosic sandstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found

			throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and the top contact sharp. (Type 3)
2	7.5	7.5	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It

				contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
1	3.8	(c)	0.3	Coaly carbonaceous shale, see unit 1a for description.
		(b)	3.3	Coal bed.
		(a)	0.2	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.

Top of the Trinidad Sandstone

SECTION R 6 - This section is located 1800 ft. east of Section R 5.

Unit	Unit Thickness ft.	Bed Thickness ft.	Descriptions
Top of the measured section:			
21	30.0	30.0	Sandstone, see unit 12 for description.
20	55.0	55.0	Covered slope.
19	5.0	5.0	Interbedded, see unit 9 for description.
18	5.0	5.0	This is a slope forming arkosic to subarkosic sandstone. The color is grayish orange (10 YR 7/4) both weathered and fresh. It is medium to fine grained, with a fining upward sequence, moderately sorted, poorly indurated. The structures include planar cross beds and horizontal laminations. It is thinly bedded. All contacts are gradational. (Type 3)
17	35.0	35.0	Covered slope.
16	24.0	24.0	Interbedded, see unit 9 for description.
15	30.5	30.5	Covered slope.
14	3.6	(d) 0.5	Coal bed.

		(c)	1.3	Mudstone (carbonaceous), see unit 1a for description.
		(b)	0.5	Coal bed.
		(a)	1.3	Mudstone (sandy and carbonaceous), see unit 1a for description.
13	11.2		11.2	Interbedded, see unit 9 for description.
12	30.0		30.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional with clasts and organic debris. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. The beds are lenticular in shape and the structures are rhythmic. The top of the bed is a gradational contact. (Type 2)
11	13.5		13.5	Covered slope.

10	5.5	(f)	0.6	Mudstone (carbonaceous), see unit 1a for description.
		(e)	0.9	Coal bed (shaly).
		(d)	1.5	Mudstone (carbonaceous), see unit 1a for description.
		(c)	0.2	Coaly carbonaceous shale, see unit 1b for description.
		(b)	2.1	Mudstone (carbonaceous), see unit 1a for description.
		(a)	0.1	Coaly carbonaceous shale, see unit 1b for description.
9	45.0		45.0	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain

				abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
8	5.4	(d)	1.0	Carbonaceous shale, see unit 1d for description.
		(c)	2.0	Mudstone (silty), see unit 1a for description.
		(b)	1.6	Carbonaceous shale, see unit 1d for description.
		(a)	0.8	Mudstone (silty and carbonaceous), see unit 1d for description.
7	4.5		4.5	This is a cliff forming quartzose sandstone. It is dark yellow orange (10 YR 6/6) in weathered surfaces and grayish orange (10 YR 7/4) when fresh. It is medium

				grained, well indurated, moderately sorted and thickly bedded. The unit is lenticular in shape. Trough cross beds are the dominant structure. The base is erosional and the top is sharp. (Type 1a)
6	7.2		7.2	Mudstone (silty and carbonaceous), see unit 1a for description.
5	0.5	(b)	0.3	Coal bed (shaly).
		(a)	0.2	Carbonaceous shale (silty), see unit 1d for description.
4	3.5		3.5	Mudstone, see unit 1a for description.
3	4.0	(e)	0.1	Coaly carbonaceous shale, see unit 1b for description.
		(d)	0.6	Coal bed.
		(c)	0.1	Sandstone, see unit 2a for description.
		(b)	3.0	Coal bed.
		(a)	0.2	Carbonaceous shale, see unit 1d for description.
2	3.4	(h)	0.5	Mudstone, see unit 1a for description.
		(g)	0.5	Sandstone, see unit 2a for description.

		(f)	0.5	Mudstone, see unit 1a for description.
		(e)	0.1	Sandstone, see unit 2a for description.
		(d)	0.1	Carbonaceous shale (sandy), see unit 1d for description.
		(c)	0.7	Mudstone (carbonaceous and sandy), see unit 1a for description.
		(b)	0.4	Mudstone (sandy), see unit 1a for description.
		(a)	0.6	This is a cliff forming arkosic sandstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and gradational to the sandstone below while the top contact sharp. (Type 4)
1	3.9	(e)	0.2	Mudstone (carbonaceous), see unit 1a for description.
		(d)	0.6	This is a carbonaceous shale. The color is

		black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
(c)	2.4	Coal Bed.
(b)	0.2	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.
(a)	0.5	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.

Top of the Trinidad Sandstone

SECTION R 7 - This section is located 2250 ft. to the east of Section R 6.

Unit	Unit Thickness ft.		Bed Thickness ft.	Descriptions
Top of the measured section:				
24	31.4		31.4	Sandstone, see unit 14 for description.
23	22.3	(d)	10.0	Sandstone, see unit 23b for description.
		(c)	5.0	Mudstone, see unit 3a for description.
		(b)	2.8	Sandstone, see unit 23b for description.
		(a)	4.5	Mudstone (silty), see unit 3a for description.
22	3.0		3.0	Sandstone (base has clay clasts, root impressions and abundant organic debris), see unit 13c for description.
21	6.5	(d)	1.5	Sandstone, see unit 23b for description.
		(c)	0.5	Mudstone (silty), see unit 8f for description.
		(b)	1.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to

				medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick contacts are nonerosional and sharp. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
		(a)	3.5	Mudstone (silty), see unit 3a for description.
20	4.0		4.0	Sandstone, see unit 13a for description.
19	13.3	(c)	3.0	Mudstone (silty), see unit 3a for description.
		(b)	0.3	Coaly carbonaceous shale, see unit 16b for description.
		(a)	1.0	Mudstone (silty), see unit 3a for description.
18	25.0		25.0	Sandstone, see unit 14 for description.
17	16.5		16.5	Mudstone (silty), see unit 3a for description.
16	7.4	(f)	0.6	Mudstone (carbonaceous), see unit 3a for description.
		(e)	0.8	Coal bed.
		(d)	1.0	Coaly carbonaceous shale, see 16b for description.

		(c)	2.5	Mudstone (silty), see unit 3a for description.
		(b)	1.5	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.
		(a)	1.0	Coal bed.
15	25.0		25.0	Mudstone (sandy to silty), see unit 3a for description.
14	20.0		20.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional with clasts and organic debris. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. The

				beds are lenticular in shape. The top of the bed is a gradational contact. (Type 2)
13	14.7	(c)	4.7	This is a cliff forming arkosic to subarkosic sandstone. It is very pale orange (10 YR 8/2) in both fresh and weathered surfaces. It is medium grained, moderately sorted and indurated. The beds are thick and the structures are planar and trough cross bedding. It is tabular in shape and contains abundant organic debris and modern rootlets. All contacts are gradational. (Type 3)
		(b)	8.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine grained, moderately sorted and indurated. The main structure is planar cross beds. It is thinly laminated. The contacts are nonerosional and gradational. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
		(a)	2.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine grained, moderately sorted and indurated. The main structure is

			horizontal laminations. It is thinly bedded. The contacts are gradational. The shape is tabular. (Type 3)
12	19.0	19.0	Mudstone (carbonaceous and sandy), see unit 3a for description.
11	5.0	5.0	Sandstone, see unit 9 for description.
10	10.0	10.0	Mudstone (silty to sandy), see unit 3a for descriptions.
9	5.3	5.3	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine grained, moderately sorted and indurated. The structures are small scale trough cross beds and horizontal laminations. It is thinly bedded. The contacts are gradational. The shape is tabular. (Type 3)
8	18.0	(f) 14.5	Mudstone (silty to sandy and carbonaceous), see unit 3a for description.
		(e) 0.4	Mudstone (well indurated), see unit 3a for description.
		(d) 2.0	Mudstone (silty and carbonaceous), see unit 3a for description.

		(c)	0.3	Mudstone (well indurated), see unit 3a for description.
		(b)	0.4	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
		(a)	0.4	Mudstone (silty and carbonaceous), see unit 3a for description.
7	3.6	(c)	1.0	This is a cliff forming quartzose to subarkosic sandstone. It is dark yellow orange (10 YR 6/6) in outcrop and very pale orange (10 YR 8/2) when fresh. It is medium to fine grained, well indurated, moderately sorted and thickly bedded. The unit is tabular in shape. The quartzose nature is observed in bands throughout the subarkosic unit. Structures were not observed. The base is scoured, erosional with clay clasts, organic debris and load structures. (Type lc)
		(b)	0.2	Mudstone (sandy), see unit 3a for description.
		(a)	2.4	This is a cliff forming quartzose sandstone. It

			is dark yellow orange (10 YR 6/6) in weathered surfaces and grayish orange (10 YR 7/4) when fresh. It is medium grained, well indurated, moderately sorted and thickly bedded. The unit is lenticular in shape. Trough cross beds are the dominant structure. The base is erosional and the top is sharp. (Type 1a)
6	3.0	3.0	Interbedded, see unit 4 for description.
5	4.1	4.1	Coal bed.
4	8.0	8.0	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional

				and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
3	4.4	(f)	0.2	Siltstone, see unit 1 for description.
		(e)	1.3	Mudstone, see unit 3a for description.
		(d)	1.4	Coal bed.
		(c)	0.2	Sandstone, see unit 1 for description.
		(b)	1.1	Coal bed.
		(a)	0.2	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The

			contacts above and below are gradational.
2	2.8	2.8	This is a slope forming quartzose sandstone. The grain size is medium to fine, moderately sorted, unconsolidated, organic and containing abundant modern rootlets. It is very pale orange (10 YR 8/2) in fresh and weathered surfaces. All contacts are gradational. Structures could not be detected due to the weathered nature of the outcrop. (Type 1a)
1	1.0	1.0	This is a cliff forming arkosic sandstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and gradational to the sandstone below while the top contact sharp. (Type 3)

Top of the Trinidad Sandstone

SECTION R 7a - This section is located 800 ft. east of section R 7.

Unit	Unit Thickness ft.		Bed Thickness ft.	Descriptions
Top of the measured section:				
26	30.0		30.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional with clasts and organic debris. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. The beds are lenticular in shape. The top of the bed is a gradational contact. (Type 2)
25	5.0		5.0	Mudstone (sandy) see unit 3a for description.
24	4.2		4.2	Sandstone, see unit 20 for description.
23	9.4	(e)	2.9	Mudstone (sandy) see unit

				3a for description.
		(d)	1.0	Mudstone (carbonaceous) see unit 3a for description.
		(c)	3.0	Mudstone (sandy) see unit 3a for description.
		(b)	0.5	Coal bed.
		(a)	2.0	Mudstone (sandy) see unit 3a for description.
22	3.0		3.0	Sandstone, see unit 20 for description.
21	3.3		3.3	Mudstone (sandy) see unit 3a for description.
20	3.5		3.5	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is medium to fine grained and fining-upward sequences are observed. It is moderately sorted and indurated. The structures include planar cross beds and horizontal and ripple laminations. It is tabular in shape and all contacts are nonerosional and sharp. (Type 3)
19	5.0		5.0	Mudstone (sandy) see unit 3a for description.
18	16.5	(c)	3.5	This is an arkosic to subarkosic sandstone

		cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces and it has a salt and pepper appearance. It is fine grained, moderately sorted and indurated. The structures include horizontal and ripple laminations. The beds are thin. It is tabular in shape and all contacts are nonerosional and gradational. (Type 3)
(b)	8.0	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces and it has a salt and pepper appearance. It is medium grained, moderately sorted and indurated. The main structure is trough cross beds. It is very thickly bedded. It is tabular in shape and all contacts are nonerosional and gradational. (Type 3)
(a)	5.0	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces and it has a salt and pepper appearance. It is fine grained, moderately sorted and indurated. The main structure is planar cross beds. It is medium to thinly bedded. It is tabular in shape and the basal contact is nonerosional and sharp while the top contact is gradational. (Type 3)

17	45.2	(k)	10.0	Mudstone (sandy), see unit 3a for description.
		(j)	0.5	Sandstone, see unit 14d for description.
		(i)	3.0	Mudstone (silty) see unit 3a for description.
		(h)	0.7	Siltstone, see unit 7f for description.
		(g)	14.4	Mudstone (silty), see unit 3a for description.
		(f)	2.2	Siltstone, see unit 7f for description.
		(e)	1.5	Mudstone (silty), see unit 3a for description.
		(d)	2.7	Mudstone (carbonaceous), see unit 3a for description.
		(c)	4.1	Siltstone, see unit 7f for description.
		(b)	1.4	Mudstone (carbonaceous), see unit 3a for description.
		(a)	4.7	Siltstone, see unit 7f for description.
16	8.6	(l)	0.4	Coaly carbonaceous shale, see unit 2a for description.

		(k)	0.8	Mudstone (carbonaceous), see unit 3a for description.
		(j)	1.1	Coal bed.
		(i)	1.2	Mudstone (carbonaceous and shaly), see unit 3a for description.
		(h)	0.1	Coal bed.
		(g)	1.1	Mudstone (carbonaceous and silty), see unit 3a for description.
		(f)	0.2	Siltstone, see unit 1 for description.
		(e)	0.5	Carbonaceous shale, see unit 2c for description.
		(d)	0.7	Coaly carbonaceous shale, see unit 2a for description.
		(c)	1.4	Mudstone (carbonaceous and silty), see unit 3a for description.
		(b)	0.7	Coal bed.
		(a)	0.4	Coaly carbonaceous shale, see unit 2a for description.
15	4.1	(c)	1.0	Siltstone, see unit 7f for description.
		(b)	0.3	Sandstone, see unit 1 for description.

		(a)	2.8	Mudstone (silty), see unit 3a for description.
14	5.6	(e)	1.4	Siltstone, see unit 7f for description.
		(d)	1.2	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces and it has a salt and pepper appearance. It is fine grained, moderately sorted and indurated. The main structure is ripple laminations. It has abundant plant impressions and organic debris. It is tabular in shape and the contacts are nonerosional. (Type 3)
		(c)	1.2	Sandstone, see unit 1 for description.
		(b)	0.6	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine grained, moderately sorted and indurated. The main structure is horizontal and ripple laminations and it is thin to thinly laminated. It has abundant plant impressions and organic debris. It is tabular in shape and the contacts are nonerosional and sharp. (Type 4)

		(a)	1.2	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine grained, moderately sorted and indurated. The structures are small scale trough cross beds and horizontal laminations. It is thinly bedded. The contacts are nonerosional and sharp. The shape is tabular. (Type 3)
13	11.0	(f)	0.4	Mudstone, see unit 3a for description.
		(e)	2.0	Mudstone (carbonaceous), see unit 3a for description.
		(d)	3.4	Mudstone (silty), see unit 3a for description.
		(c)	1.8	This is an arkosic to subarkosic siltstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is indurated and the main structure is ripple laminations. It has abundant plant impressions, organic debris and modern rootlets. It is tabular in shape and the contacts are nonerosional and sharp.
		(b)	1.0	Coaly carbonaceous shale, see unit 2a for description.

		(a)	2.4	Mudstone (carbonaceous), see unit 3a for description.
12	21.4		21.4	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It

				is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
11	19.0	(k)	0.4	Mudstone (carbonaceous), see unit 3a for description.
		(j)	0.5	This is a cliff forming mudstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very organic with abundant plant impressions and very well indurated. Structures are not observed. Contacts are nonerosional and sharp.
		(i)	1.5	Mudstone (carbonaceous), see unit 3a for description.
		(h)	1.1	Siltstone, see unit 7f for description.
		(g)	0.5	Mudstone (carbonaceous), see unit 3a for description.
		(f)	1.0	Siltstone, see unit 7f for description.
		(e)	0.4	Coaly carbonaceous shale, see unit 2a for description.
		(d)	1.4	Mudstone (carbonaceous and sandy), see unit 3a

				for description.
		(c)	5.1	Siltstone, see unit 7f for description.
		(b)	2.1	Mudstone (carbonaceous), see unit 3a for description.
		(a)	5.0	Mudstone (silty), see unit 3a for description.
10	14.8	(g)	1.0	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is medium grained, moderately sorted and indurated. The main structure is planar and horizontal cross beds. It is thin to medium bedded, tabular in shape and all contacts are nonerosional and sharp. (Type 3)
		(f)	0.3	Sandstone, see unit 1 for description.
		(e)	2.0	Mudstone (sandy), see unit 3a for description.
		(d)	3.0	This is an arkosic to subarkosic sandstone cliff. It is very pale orange (10 YR 8/2) in both fresh and weathered surfaces. It is medium grained, moderately sorted and indurated. The main structures are planar and horizontal cross beds. It is thin to medium bedded, tabular in shape and all contacts

				are nonerosional and gradational. (Type 3)
		(c)	3.0	Mudstone (sandy), see unit 3a for description.
		(b)	0.5	Sandstone, see unit 1 for description.
		(a)	5.0	This is an arkosic to subarkosic sandstone cliff. It is very pale orange (10 YR 8/2) in both fresh and weathered surfaces. It is fine grained, moderately sorted and poorly indurated. The main structures are planar and horizontal cross beds. It is thin to medium bedded, tabular in shape and all contacts are nonerosional and gradational. (Type 3)
9	11.0	(e)	0.4	Sandstone (quartzose lenses), see unit 1 for description.
		(d)	2.0	Mudstone (silty), see unit 3a for description.
		(c)	2.2	Siltstone, see unit 7f for description.
		(b)	1.4	Mudstone (silty), see unit 3a for description.
		(a)	5.0	Mudstone (sandy), see unit 3a for description.
8	3.2		3.2	This is an arkosic to subarkosic sandstone

				cliff. It is very pale orange (10 YR 8/2) in both fresh and weathered surfaces. It is medium grained, moderately sorted and indurated. The main structures are planar cross beds and horizontal and ripple laminations. It is thin to medium bedded, tabular in shape and all contacts are nonerosional and gradational. (Type 3)
7	11.3	(f)	1.8	This is an arkosic to subarkosic siltstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is indurated and the main structures are planar and ripple laminations. It has abundant plant impressions, organic debris and modern rootlets. It is tabular in shape and the contacts are nonerosional and sharp.
		(e)	0.3	Carbonaceous shale, see unit 2c for description.
		(d)	0.4	Siltstone, see unit 1 for description.
		(c)	3.4	Mudstone (silty), see unit 3a for description.
		(b)	0.4	Siltstone, see unit 1 for description.
		(a)	5.0	Mudstone (silty), see unit 3a for description.

6	4.0	(c)	2.2	Sandstone, see unit 6a for description.
		(b)	0.3	Mudstone (silty), see unit 3a for description.
		(a)	1.5	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and indurated. Incomplete fining- upward sequences are observed. Quartzose lenses are distributed throughout the bed. The quartz grains are coarse and have abrupt contacts with the surrounding arkosic matrix. The main structures are planar cross beds and horizontal and ripple laminations. It is thickly bedded, lenticular in outcrop shape and the basal contact is an erosional scour with clay clasts, plant impressions, abundant organic debris and load casts. The top contact is sharp. (Type 1c)
5	6.3	(c)	3.0	Mudstone (sandy), see unit 3a for description.
		(b)	1.0	Carbonaceous shale, see unit 2c for description.
		(a)	2.3	Mudstone (sandy), see unit 3a for description.

4	1.5		1.5	Coal bed.
3	4.9	(d)	1.0	Mudstone (sandy), see unit 3a for description.
		(c)	1.0	Carbonaceous shale, see unit 2c for description.
		(b)	0.5	Mudstone (very sandy), see unit 3a for description.
		(a)	2.4	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
2	4.0	(e)	1.0	Carbonaceous shale, see unit 2c for description.
		(d)	1.0	Coal bed (shaly).
		(c)	0.3	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.

		(b) 1.2	Coal bed.
		(a) 0.5	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.
1	1.0	1.0	This is a cliff forming arkosic sandstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and gradational to the sandstone below while the top contact is sharp. (Type 3)

Top of the Trinidad Sandstone

SECTION R 8 - This section is located 1200 ft. east of Section R 7a.

Unit	Unit Thickness ft.		Bed Thickness ft.	Descriptions
Top of the measured section:				
15	49.0		49.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional. The structures are rhythmic and include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. The beds are lenticular in shape. The top of the bed is a gradational contact. (Type 2)
14	11.0	(b)	6.0	Mudstone (organic and sandy), see unit 2b for description.
		(a)	5.0	Mudstone (organic and silty), see unit 2b for description.

13	2.5		2.5	Sandstone, see unit 11 for description.
12	6.1	(b)	0.1	Coaly carbonaceous shale, see unit 5b for description.
		(a)	6.0	Mudstone (sandy), see unit 2b for description.
11	3.2		3.2	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces and it has a salt and pepper appearance. It is fine to very fine grained, moderately sorted and indurated. The main structures are planar cross beds and horizontal and ripple laminations. It is medium to thinly bedded. It contains abundant organic debris throughout the bed. It is tabular in shape and the basal contact is nonerosional and sharp while the top contact is gradational. (Type 3)
10	5.0		5.0	Mudstone (sands), see unit 2b for description.
9	4.6		4.6	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces and it has a salt and pepper appearance. It is fine to very fine grained, moderately sorted and indurated. The main

				structure is trough cross beds. It is medium bedded. It contains abundant organic debris throughout the bed. It is tabular in shape and the basal contact is nonerosional and sharp while the top contact is gradational. (Type 3)
8	5.0		5.0	Mudstone (sandy), see unit 2b for description.
7	6.8	(e)	1.8	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and indurated. The main structure is ripple laminations. It is thickly bedded. It contains organic debris throughout the bed. It is tabular in shape and all contacts are nonerosional and gradational. (Type 3)
		(d)	1.7	This is a slope forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and poorly indurated. The main structures are horizontal and ripple laminations. It is thin to thinly bedded. It contains organic debris throughout the bed. All contacts are nonerosional and gradational. (Type 3)

		(c)	1.3	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is medium to fine grained, moderately sorted and indurated. The main structure is ripple laminations. It is thickly bedded and contains organic debris and modern rootlets throughout the bed. It is tabular in shape and all contacts are nonerosional and gradational. (Type 3)
		(b)	1.2	Mudstone (sandy), see unit 2b for description.
		(a)	0.8	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is medium to fine grained, moderately sorted and indurated. The main structure is ripple laminations. It is medium bedded and contains organic debris and modern rootlets throughout the bed. It is tabular in shape and all contacts are nonerosional and gradational. (Type 3)
6	40.0		40.0	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones

				are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
5	8.5	(g)	1.6	Coal bed (shaly).
		(f)	0.8	Coaly carbonaceous shale,

				see unit 5b for description.
		(e)	3.1	Mudstone (carbonaceous), see unit 2b for description.
		(d)	0.6	Coaly carbonaceous shale, see unit 5b for description.
		(c)	1.0	Mudstone (carbonaceous), see unit 2b for description.
		(b)	0.2	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.
		(a)	1.2	Coal bed.
4	36.0		36.0	Covered slope.
3	15.0		15.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is

				lenticular and the bed is not laterally continuous. The base is sharp and erosional with clay clasts and organic debris. The structures are rhythmic and include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. Ironstone concretions are seen in bands or as large lenticular bodies within the sandstone unit. The beds are lenticular in shape. The top of the bed is gradational. (Type 2)
2	67.6	(n)	7.5	Mudstone (sandy), see unit 2b for description.
		(m)	1.0	Mudstone (carbonaceous), see unit 2b for description.
		(l)	6.0	Mudstone (sandy), see unit 2b for description.
		(k)	1.0	Mudstone (carbonaceous), see unit 2b for description.
		(j)	26.0	Mudstone (sandy), see unit 2b for description.
		(i)	2.1	Siltstone, see unit 2c for description.
		(h)	1.0	Mudstone (silty), see unit 2b for description.
		(g)	0.6	Mudstone (carbonaceous),

see unit 2b for description.

(f)	15.0	Mudstone (sandy), see unit 2b for description.
(e)	1.9	Siltstone, see unit 2c for description.
(d)	1.0	Mudstone (carbonaceous with lenses of coal), see unit 2b for description.
(c)	1.3	This is an arkosic to subarkosic siltstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is indurated and the main structures are planar and ripple laminations. It has abundant plant impressions, organic debris and modern rootlets. It is tabular in shape and the contacts are nonerosional and sharp. (Type 3)
(b)	0.8	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It often contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.

		(a)	2.4	This is a slope forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and poorly indurated. The main structures are horizontal and ripple laminations. It is thin to thinly bedded. It contains organic debris throughout the bed. All contacts are nonerosional and gradational. (Type 3)
1	4.8	(d)	2.5	Carbonaceous shale, see unit 1b for description.
		(c)	0.6	Coal bed.
		(b)	0.5	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
		(a)	1.2	Coal bed.

Top of Trinidad Sandstone

SECTION R 9 - This section is located 1200 ft. east of Section R 8.

Unit	Unit Thickness ft.	Bed	Thickness ft.	Descriptions
Top of the measured section:				
19	34.1	(c)	20.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional. The structures are rhythmic and include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the bed. The beds are lenticular in shape. The top of the bed is a gradational contact. (Type 2)
		(b)	4.7	Mudstone (sandy), see unit 1b for description.
		(a)	9.4	Sandstone, see unit 8a for description.

18	35.4	(h)	15.0	Mudstone (sandy), see unit 1b for description.
		(g)	2.0	Sandstone, see unit 18a for description.
		(f)	2.4	Mudstone (sandy), see unit 1b for description.
		(e)	1.5	Sandstone, see unit 18a for description.
		(d)	5.0	Mudstone (sandy), see unit 1b for description.
		(c)	0.6	Sandstone, see unit 14c for description.
		(b)	4.4	Mudstone (sandy), see unit 1b for description.
		(a)	4.5	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are trough and planar cross beds and horizontal laminations. The bedding ranges from thick to very thick and contacts are nonerosional and sharp. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
17	45.0		45.0	Interbedded, see unit 4c

				for description.
16	10.0		10.0	Mudstone (silty), see unit 1b for description.
15	7.6	(g)	1.0	Coaly carbonaceous shale, see unit 1f for description.
		(f)	0.1	This is a consolidated clay. It is very light gray (N 8). It has a greasy feeling and is powdery like talcum powder. The contacts are sharp.
		(e)	1.3	Coal bed.
		(d)	1.4	Mudstone (carbonaceous), see unit 1b for description.
		(c)	2.2	Carbonaceous shale, see unit 1a for description.
		(b)	1.0	Mudstone (carbonaceous), see unit 1b for description.
		(a)	0.6	Carbonaceous shale, see unit 1a for description.
14	8.6	(d)	2.5	Siltstone, see unit 4b for description.
		(c)	0.5	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine grained, moderately sorted and indurated.

				The structures are small scale planar cross beds and horizontal laminations. It is thinly bedded. The contacts are gradational. The shape is tabular. (Type 3)
		(d)	3.3	Mudstone (silty), see unit 1b for description.
		(a)	2.3	Siltstone, see unit 4b for description.
13	1.0		1.0	Coal bed.
12	16.0		16.0	Interbedded, see unit 4c for description.
11	1.7	(b)	1.2	Coal bed.
		(a)	0.5	Mudstone (carbonaceous and coaly), see unit 1b for description.
10	18.0		18.0	Interbedded, see unit 4c for description.
9	0.6		0.6	Carbonaceous shale (silty), see unit 1a for description.
8	7.0		7.0	Interbedded, see unit 4c for description.
7	4.0	(e)	0.5	Mudstone (carbonaceous and silty), see unit 1b for description.
		(d)	0.5	Mudstone (silty), see unit 1b for description.

		(c)	1.0	Mudstone (carbonaceous), see unit 1b for description.
		(b)	1.0	Mudstone (silty), see unit 1b for description.
		(a)	1.0	Mudstone (carbonaceous), see unit 1b for description.
6	18.2	(e)	3.0	Interbedded, see unit 4c for description.
		(d)	1.6	Siltstone, see unit 4b for description.
		(c)	11.0	Interbedded, see unit 4c for description.
		(b)	0.6	This is a cliff forming arkosic siltstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The contacts are nonerosional and sharp.
		(a)	2.0	Siltstone, see unit 4b for description.
5	3.0		3.0	This is a cliff forming

			arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick and the basal contact is erosional. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
4	35.0	(c) 22.5	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone

				is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
		(b)	0.5	This is an arkosic to subarkosic siltstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is indurated and the main structures are planar and ripple laminations. It has abundant plant impressions, organic debris and modern rootlets. It is tabular in shape and the contacts are nonerosional and sharp.
		(a)	12.0	Mudstone (carbonaceous and silty), see unit 1b for description.
3	3.5	(c)	0.4	This is a cliff forming arkosic to subarkosic sandstone. It is very pale orange (10 YR 8/2) in both fresh and weathered surfaces. It is fine grained, moderately sorted and indurated. The beds are

				thick and the structures are planar and trough cross bedding. It is tabular in shape and contains abundant organic debris and modern rootlets. All contacts are gradational. (Type 4)
		(b)	0.1	Mudstone (silty), see unit 1b for description.
		(a)	3.0	This is a subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and indurated. Incomplete fining- upward sequences are observed. Quartzose bands are distributed throughout the bed. The quartz grains are coarse and have abrupt contacts with the surrounding arkosic matrix. It is thickly bedded, lenticular in outcrop shape and the basal contact is an erosional scour with clay clasts, plant impressions, abundant organic debris and load casts. The top contact is sharp. (Type 1c)
2	12.0	(b)	1.0	Mudstone (carbonaceous and sandy), see unit 1b for description.
		(a)	11.0	Mudstone (sandy), see unit 1b for description.

1	10.6	(j)	0.3	Coaly carbonaceous shale, see unit 1f for description.
		(i)	0.7	Coal bed.
		(h)	0.3	Carbonaceous shale, see unit 1a for description.
		(g)	0.6	Coal bed.
		(f)	0.2	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.
		(e)	1.0	Mudstone (carbonaceous, sandy and shaly), see unit 1b for description.
		(d)	2.1	Mudstone (very sandy), see unit 1b for description.
		(c)	2.0	This is a slope forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and poorly indurated. The main structures are horizontal and ripple laminations. It is very thinly bedded. It contains organic debris throughout the bed. All

		contacts are nonerosional and gradational. (Type 3)
(b)	2.8	This is a slope forming organic mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It often contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
(a)	0.6	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.

Top of the Trinidad Sandstone

SECTION R 10 - This section is located 1200 ft. east of Section R 9.

Unit	Unit Thickness ft.	Bed Thickness ft.	Descriptions
Top of the measured section:			
21	30.0	30.0	Sandstone, see unit 13 for description.
20	22.0	22.0	Interbedded, see unit 2a for description.
19	21.9	21.9	Sandstone, see unit 13 for description.
18	23.0	23.0	Interbedded, see unit 2a for description.
17	9.0	9.0	Sandstone, see unit 13 for description.
16	18.8	18.8	Interbedded, see unit 2a for description.
15	3.0	3.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick and the basal contact is erosional. It contains plant impressions and modern rootlets. The shape is tabular. (Type

			3)	
14	30.0		30.0	Covered slope.
13	7.5		7.5	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional. The structures are rhythmic and include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the bed. The beds are lenticular in shape. The top of the bed is a gradational contact. (Type 2)
12	32.0		32.0	Interbedded, see unit 2 for description.
11	1.8	(c)	0.5	Coaly carbonaceous shale, see unit 3c for description.
		(b)	0.8	Mudstone (carbonaceous), see unit 6 for description.

		(a)	0.5	Carbonaceous shale, see unit 3b for description.
10	7.6		7.6	Interbedded, see unit 2 for description.
9	3.5		3.5	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are trough and planar cross beds and horizontal laminations. The bedding ranges from thick to very thick and contacts are nonerosional and sharp. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
8	43.0		43.0	Interbedded, see unit 2 for description.
7	1.5		1.5	This is a subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and indurated. Incomplete fining- upward sequences are observed. Quartzose bands are distributed throughout the bed. The quartz grains are coarse and have abrupt contacts with the surrounding arkosic matrix. It is thickly bedded, lenticular in

				outcrop shape and the basal contact is an erosional scour with clay clasts, plant impressions, abundant organic debris and load casts. The top contact is sharp. (Type lc)
6	2.9		2.9	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It often contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
5	4.0		4.0	This is an arkosic to subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces and it has a salt and pepper appearance. It is fine to very fine grained, moderately sorted and indurated. The main structure is trough cross beds. It is medium bedded. It contains abundant organic debris throughout the bed. It is tabular in shape and the basal contact is scour. (Type 3)
4	10.9		10.9	Interbedded, see unit 2 for description.
3	2.9	(d)	0.8	Coal bed.

		(c)	0.5	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.
		(b)	0.9	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
		(a)	0.7	Coal bed.
2	4.2		4.2	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures

			range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
1	2.1	2.1	This is a cliff forming siltstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The siltstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and sharp.

Top of the Trinidad Sandstone

SECTION R 11 - This section is located 200 ft. east of Section R 10.

Unit	Unit Thickness ft.		Bed Thickness ft.	Descriptions
Top of the measured section:				
13	32.0		32.0	Sandstone, see unit 1a for description.
12	15.0		15.0	Siltstone, see unit 9a for description.
11	34.4		34.4	Sandstone, see unit 7 for description.
10	45.0	(c)	5.0	Mudstone (sandy), see unit 9b for description.
		(b)	10.0	Siltstone, see unit 7 for description.
		(a)	30.0	Covered slope.
9	7.5	(h)	1.0	This is a cliff forming sandstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and sharp.

(g)	1.0	Mudstone (carbonaceous), see unit 9b for description.
(f)	0.6	Coal bed.
(e)	0.1	Tonstein clay.
(d)	0.9	Coal bed.
(c)	0.5	Mudstone (silty), see unit 9b for description.
(b)	1.0	This is a slope forming organic mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It often contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
(a)	2.4	This is an arkosic to subarkosic siltstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is indurated and the main structures are planar and ripple laminations. It has abundant plant impressions, organic debris and modern rootlets. It is tabular in shape and the contacts are nonerosional and sharp.

8	27.0		27.0	Covered slope.
7	46.7		46.7	Sandstone, see unit 1a for description.
6	56.0		56.0	Covered slope.
5	1.0		1.0	Sandstone, see unit 1c for description.
4	11.0		11.0	Covered slope.
3	1.5	(b)	0.5	Coal bed.
		(a)	1.0	Carbonaceous shale, see unit 1b for description.
2	4.0		4.0	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris,

				modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
1	9.0	(c)	2.0	This is a slope forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and poorly indurated. The main structures are horizontal and ripple laminations. It is very thinly bedded. It contains organic debris throughout the bed. All contacts are nonerosional. (Type 3)
		(b)	1.0	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1)

		when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.
(b)	0.9	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
(a)	6.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional. The structures are rhythmic and include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the bed. The beds are lenticular in shape. The top of the bed is a gradational

contact. (Type 2)

Top of the Trinidad Sandstone

SECTION R 12 - This section is located 800 ft. east of Section R 11.

Unit	Unit Thickness ft.	Bed Thickness ft.	Descriptions
Top of the measured section:			
13	32.0	32.0	Sandstone, see unit 7 for description.
12	13.0	13.0	Interbedded, see unit 3 for description.
11	13.0	13.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick and the basal contact is erosional. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
10	43.0	(d) 20.0	Interbedded, see unit 3 for description.
		(c) 2.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are trough and

				planar cross beds and horizontal laminations. The bedding ranges from thick to very thick and contacts are nonerosional and sharp. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
		(b)	18.0	Interbedded, see unit 3 for description.
		(a)	3.0	Siltstone (muddy), see unit 8a for description.
9	5.2	(f)	0.5	Coal bed.
		(e)	1.0	Mudstone (silty), see unit 6d for description.
		(d)	1.0	Siltstone (muddy), see unit 8a for description.
		(c)	1.0	Carbonaceous shale, see unit 1a for description.
		(b)	1.0	Coal bed.
		(a)	0.7	Carbonaceous shale, see unit 1a for description.
8	16.5	(e)	2.0	Mudstone (silty), see unit 6d for description.
		(d)	5.5	Siltstone, see unit 8a for description.
		(c)	1.0	Siltstone (shaly), see unit 8a for description.

		(b)	1.0	Carbonaceous shale, see unit 1a for description.
		(a)	7.0	This is an arkosic to subarkosic siltstone slope. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is indurated and the main structures are planar and ripple laminations. It has abundant plant impressions, organic debris and modern rootlets. It is tabular in shape and the contacts are nonerosional and gradational.
7	25.5		25.5	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional. The structures are rhythmic and include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the bed. The beds are lenticular in shape. The top of the

				bed is a gradational contact. (Type 2)
6	12.5	(d)	2.0	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It often contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
		(c)	5.0	Sandstone slope (ripple bedding), see unit 4 for description.
		(b)	5.0	Sandstone slope (horizontal laminations), see unit 4 for description.
		(a)	5.5	Sandstone slope (ripple bedding), see unit 4 for description.
5	28.0		28.0	Interbedded, see unit 4 for description.
4	15.0		15.0	This is a slop forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and poorly indurated. The main structures are horizontal and ripple laminations. It is very

			thinly bedded. It contains organic debris throughout the bed. All contacts are nonerosional and gradational. (Type 3)
3	32.0	32.0	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to

				silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
2	16.0	(e)	1.0	This is a subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and indurated. Incomplete fining- upward sequences are observed. Quartzose bands are distributed throughout the bed. The quartz grains are coarse and have abrupt contacts with the surrounding arkosic matrix. It is thickly bedded, lenticular in outcrop shape and the basal contact is an erosional scour with clay clasts, plant impressions, abundant organic debris and load casts. The top contact is sharp. (Type lc)
		(d)	2.0	This is a cliff forming quartzose sandstone. It is dark yellow orange (10 YR 6/6) in weathered surfaces and grayish orange (10 YR 7/4) when fresh. It is medium grained, well indurated, moderately sorted and thickly bedded. The unit is lenticular in shape. No structures were observed. The base is erosional and the top is sharp. (Type la)

(c)	7.0	This is a subarkosic sandstone cliff. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and indurated. Incomplete fining- upward sequences are observed. Quartzose bands are distributed throughout the bed. The quartz grains are coarse and have abrupt contacts with the surrounding arkosic matrix. It is thickly bedded, lenticular in outcrop shape and the basal contact is an erosional scour with clay clasts, plant impressions, abundant organic debris and load casts. The top contact is sharp. (Type 1c)
(b)	2.5	This is a cliff forming quartzose sandstone. It is dark yellow orange (10 YR 6/6) in weathered surfaces and grayish orange (10 YR 7/4) when fresh. It is medium grained, well indurated, moderately sorted and thickly bedded. The unit is lenticular in shape. Trough cross beds are the dominant structure. (Type 1a)
(a)	3.5	This is a cliff forming quartzose sandstone. It is dark yellow orange (10 YR 6/6) in weathered surfaces and grayish orange (10 YR 7/4) when fresh. It is

				medium grained, well indurated, moderately sorted and thickly bedded. The unit is lenticular in shape. Trough cross beds are the dominant structure. The base is erosional and the top is sharp and contains abundant clay clasts. (Type la)
1	1.5	(b)	1.0	Coal bed.
		(a)	0.5	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.

Top of the Trinidad Sandstone

SECTION R 13 - This section is located 2050 ft. east of Section R 12.

Unit	Unit Thickness ft.	Bed Thickness ft.	Descriptions
Top of the measured section:			
21	30.0	30.0	This unit is a cliff forming arkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated and the bed is not laterally continuous. The base is sharp and erosional. The structures are rhythmic and include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the bed. The beds are lenticular in shape. The top of the bed is a gradational contact. (Type 2)
20	18.2	18.2	Sandstone (slope, thin bedded), see unit 4b for description.

19	2.0	2.0	Sandstone (cliff, trough bedded), see unit 4b for description.
18	5.6	5.6	Sandstone (slope, horizontal bedding), see unit 4b for description.
17	6.6	6.6	Sandstone (cliff, tabular, trough cross bedding), see unit 15 for description.
16	11.7	11.7	Covered slope.
15	4.6	4.6	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick and the basal contact is erosional. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
14	22.8	22.8	Covered slope.
13	7.3	7.3	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine grained, moderately sorted and indurated. The structures are small scale planar cross beds and horizontal

			laminations. It is thinly bedded. The contacts are gradational. The shape is tabular. (Type 3)
12	1.6	1.6	Mudstone (sandy), see unit 2b for description.
11	0.9	0.9	Coaly carbonaceous shale, see unit 6 for description.
10	7.6	7.6	Interbedded, see unit 1b for description.
9	0.7	0.7	Coaly carbonaceous shale, see unit 6 for description.
8	8.5	8.5	Covered slope.
7	3.5	3.5	Sandstone (cliff, med to fine), see unit 4a for description.
6	0.6	0.6	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.
5	24.5	24.5	Covered slope.
4	27.7	(b) 19.5	This is a slope forming arkosic to subarkosic sandstone. It is grayish

				orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and poorly indurated. The main structures are horizontal and ripple laminations. It is very thinly bedded. It contains organic debris throughout the bed. All contacts are nonerosional and gradational. (Type 3)
		(a)	8.2	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick and the basal contact is erosional. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
3	74.5		74.5	Covered slope.
2	10.2	(c)	3.0	Sandstone, see 2a for description.
		(b)	1.5	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It often contains medium sand to silt size grains, abundant organic debris and modern

				rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
		(a)	5.7	This is a cliff forming quartzose sandstone. It is dark yellow orange (10 YR 6/6) in weathered surfaces and grayish orange (10 YR 7/4) when fresh. It is medium grained, well indurated, moderately sorted and thickly bedded. The unit is lenticular in shape. Trough cross beds are the dominant structure. The base is erosional and the top is sharp. (Type 1a)
1	7.3	(c)	2.0	Coal bed.
		(b)	4.3	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The

sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.

(a) 1.0 This is a cliff forming sandstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and sharp.

Top of the Trinidad Sandstone

SECTION R 14 - This section is located 6000 ft. east of Section R 13.

Unit	Unit Thickness ft.		Bed Thickness ft.	Descriptions
Top of the measured section:				
9	20.0		20.0	Sandstone (cliff), see unit 3 for description.
8	27.3	(c)	23.0	Interbedded, see unit 4a for description.
		(b)	0.3	Coaly carbonaceous shale, see unit 5a for description.
		(a)	4.0	Interbedded, see unit 4a for description.
7	2.0		2.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are ripple laminations. The bedding is thick and the basal contact sharp. The shape is tabular. (Type 3)
6	2.0		2.0	Interbedded, see unit 4a for description.
5	4.2		4.2	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both

				in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick and the basal contact is erosional. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
4	14.9	(f)	4.4	Carbonaceous shale (see unit 4b)
		(e)	1.5	Mudstone (silty)
		(d)	0.5	Carbonaceous shale (see unit 4b)
		(c)	1.0	Coal
		(b)	0.5	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
		(a)	7.0	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color

			ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
3	32.0	32.0	This unit is a cliff forming arkosic to subarkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2)

			with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated to lenticular The base is sharp and erosional. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the bed. The beds are lenticular in shape. The top of the bed is a gradational contact. (Type 2)
2	94.0	94.0	Covered slope.
1	16.3	16.3	This is a cliff forming quartzose sandstone. It is dark yellow orange (10 YR 6/6) in weathered surfaces and grayish orange (10 YR 7/4) when fresh. It is medium grained, well indurated, moderately sorted and thickly bedded. The unit is lenticular in shape. Trough cross beds are the dominant structure. The base is erosional and has a quartzose pebble lag, clay clasts and organic debris. (Type 1a)

Top of the Trinidad Sandstone

SECTION R 15 - This section is located 2000 ft. east of Section R 14.

Unit	Unit Thickness ft.		Bed Thickness ft.	Descriptions
Top of the measured section:				
8	30.0		30.0	Sandstone (lenticular cliff), see unit 3 for description.
7	6.2	(d)	1.0	Coaly carbonaceous shale, see unit 1a for description.
		(c)	3.0	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It often contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
		(b)	0.3	Carbonaceous shale, see unit 1c for description.
		(a)	1.9	Coal (shaly).
6	20.0		20.0	Covered slope.
5	0.4		0.4	Carbonaceous shale, see unit 1c for description.

4	34.0	(c)	8.0	Covered slope.
		(b)	9.0	Sandstone, shaley, fine grained.
		(a)	17.0	Covered slope.
3	24.7		24.7	This unit is a cliff forming arkosic to subarkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated to lenticular The base is sharp and erosional. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the bed. The beds are lenticular in shape. The top of the bed
2	38.2		38.2	Covered slope.
1	4.8	(e)	0.5	Carbonaceous shale, see unit 1c for description.
		(d)	1.2	Coal bed.
		(c)	1.3	This is a carbonaceous shale. The color is

		black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
(b)	0.8	Coal bed (shaly).
(a)	1.0	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.

Top of the Trinidad Sandstone

SECTION R 16 - This section is located 7000 ft. east of Section R 15.

Unit	Unit Thickness ft.	Bed Thickness ft.	Descriptions
Top of the measured section:			
13	30.0	30.0	Sandstone (cliff), see unit 9 for description.
12	40.0	40.0	Covered interval.
11	0.6	0.6	Coal bed.
10	9.0	9.0	Interbedded, see unit 4 for description.
9	15.0	15.0	This unit is a cliff forming arkosic to subarkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from medium to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated to lenticular The base erosional. The structures include trough cross bedding, horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the bed. The beds are lenticular in shape. The top of the bed is a

				gradational contact. (Type 2)
8	18.0		18.0	Interbedded, see unit 4 for description.
7	2.0	(c)	0.5	Coaly carbonaceous shale, see unit 7a for description.
		(b)	1.0	Coal bed.
		(a)	0.5	This is a coaly carbonaceous shale. The coal is observed as lenses and stringers throughout the shale. The shale is black (N 1) when fresh and dark gray (N 3) when weathered. Coarse to silt size sand grains are observed in the beds.
6	11.0		11.0	Interbedded, see unit 4 for description.
5	5.0		5.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick and the basal contact is erosional. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)

4	11.0	11.0	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below

			are gradational.
3	8.0	8.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick and the basal contact is erosional. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
2	83.0	83.0	Covered slope.
1	10.0	10.0	This is a sandstone cliff. It is quartzose to subarkosic. It is grayish orange (10 YR 7/4) in both fresh and weathered surfaces. It is fine to very fine grained, moderately sorted and indurated. Incomplete fining- upward sequences are observed. Quartzose bands are distributed throughout the bed. The quartz grains are coarse and have abrupt contacts with the surrounding arkosic matrix. It is thickly bedded, lenticular in outcrop shape and the basal contact is an erosional scour with clay clasts, plant impressions, abundant organic debris and load casts. The top contact is sharp. (Type 1c)

Top of the Trinidad Sandstone

SECTION R 17 - This section is located at the Chicorica Creek Canyon entrance.

Unit	Unit Thickness ft.		Bed Thickness ft.	Descriptions
Top of the measured section:				
17	30.0		30.0	Sandstone (cliff), see unit 15 for descriptions.
16	32.0	(c)	32.0	Mudstone (silty), see unit 1b for description.
		(b)	2.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick and the basal contact is nonerosional and sharp. It contains plant impressions and modern rootlets. The shape is tabular. (Type 3)
		(a)	10.0	Mudstone (silty), see unit 1b for description.
15	15.0		15.0	This unit is a cliff forming arkosic to subarkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain

			size ranges from coarse to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is elongated to lenticular The base is sharp and erosional. The structures include trough cross bedding, convoluted bedding, planar cross bedding and horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the bed. The beds are lenticular in shape. The top of the bed is a gradational contact. (Type 2)
14	15.0	15.0	Interbedded, see unit 2 for description.
13	0.6	0.6	Coal bed.
12	4.0	4.0	Interbedded, see unit 2 for description.
11	20.0	20.0	Covered slope.
10	5.0	5.0	This is a cliff forming arkosic to subarkosic sandstone. It is grayish orange (10 YR 7/4) both in fresh and weathered surfaces. It is fine to medium grained, moderately sorted and indurated. The main structures are planar and horizontal laminations. The bedding is thick and the basal contact is erosional. It contains

				plant impressions and modern rootlets. The shape is tabular. (Type 3)
9	29.0		29.0	Interbedded, see unit 2 for description.
8	1.0		1.0	Coal bed.
7	44.0		44.0	Covered slope.
6	14.0	(d)	1.5	Coal bed.
		(c)	1.5	Carbonaceous shale, see unit 1c for description.
		(b)	0.5	Coal bed.
		(a)	0.6	Carbonaceous shale, see unit 1c for description.
5	17.0		17.0	Interbedded, see unit 2 for description.
4	24.0		24.0	Covered slope.
3	8.0		8.0	This unit is a cliff forming arkosic to subarkosic sandstone. The weathered color is grayish orange (10 YR 7/4) and when fresh it is yellowish gray (5 Y 7/2) with a salt and pepper appearance. The grain size ranges from medium to fine and fining upward sequences are observed. The sorting is moderate to poor. The sandstone is indurated. The outcrop shape is

			lenticular. The base is sharp and erosional. The structures include trough cross bedding, and horizontal to ripple laminations. Ironstone concretions are seen as large bands or lenses throughout the bed. The beds are lenticular in shape. The top of the bed is a gradational contact. (Type 2)
2	16.9	16.9	This bed consists of slope forming interbedded lithologies. The lithologies include sandstone, siltstone and mudstone. The sandstones are medium to very fine grained (Type 4) arkosic to subarkosic. The color ranges from yellowish gray (5 Y 7/2) to dark, yellowish brown (10 YR 6/6) both in fresh and weathered surfaces. The sorting is moderate and the cementing is generally poor to unconsolidated although thin beds of very well indurated sandstones are observed. The structures range from planar cross beds, horizontal and ripple laminations to structureless. The sandstones contain abundant organic debris, modern rootlets and plant impressions are observed when the sandstone is very well indurated. The bases are nonerosional and the contacts are sharp when the sandstone is very well indurated, and gradational when it is unconsolidated. Siltstones display the

				same characteristics as the sandstones. The mudstones are olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 RY 2/2) when dry. It contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.
1	4.2	(e)	0.6	Carbonaceous shale, see unit 1c for description.
		(d)	1.0	Coal bed.
		(c)	1.0	This is a carbonaceous shale. The color is black (N 1) when fresh and dark gray (N 3) when weathered. It is thinly laminated and contains abundant modern rootlets and plant debris. Coarse sand to silt size grains are found within the beds. The top and bottom contacts are gradational.
		(b)	1.0	This is a slope forming mudstone. It is olive black (5 Y 2/1) when fresh and dusky yellowish brown (10 YR 2/2) when dry. It often contains medium sand to silt size grains, abundant organic debris and modern rootlets. It is unconsolidated, structureless and appears swollen or expanded. The contacts above and below are gradational.

(a)	0.6	This is a cliff forming sandstone. The weathered surface is a dark yellowish brown (10 YR 4/2) and the fresh surface is a light olive gray (5 Y 5/2). It is very fine grained, well sorted and very well indurated. The sandstone is very organic and plant impressions are found throughout the bed. Horizontal and ripple laminations are the dominant structures. The basal contact is nonerosional and sharp.

Top of the Trinidad Sandstone

References

Allen, J. R. L., 1965, Late Quaternary Niger Delta, and adjacent areas: Sedimentary environments and lithofacies: Am. Assoc. Petroleum Geologists, Bull., v. 49, no. 5, p. 547-600.

Beaumont, E. A., 1979, Depositional environments of Fort Union sediments (Tertiary, northwest Colorado) and their relation to coal: Am. Assoc. Petroleum Geologists Bull., v. 63, no. 2, p. 194-217.

Bell, W. A., 1940, The Pictou coalfield, Nova Scotia: Canada Geol. Survey Mem. 225, 160 p.

Blatz, E. H., 1965, Stratigraphy and history of the Raton Basin and notes on San Luis Basin, Colorado-New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 49, no. 11, p. 2041-2075.

Bohor, B. F. and Pillmore, C. L., 1976, Tonstein occurrences in the Raton coal field, Colfax Cop., New Mexico: in Ewing, R. C., and Kues, B. S., eds., New Mexico Geol. Soc. Guidebook, 27th Field Conf., Vermejo Park, p. 177-183.

Cant, D. J., 1982, Fluvial facies models and their application: in Scholle, P. A., and Spearing, D., eds., Sandstone Depositional Environments, Am. Assoc. Petroleum Geologists Spec. Publ., p. 115-137.

Cherven, V. B., 1978, Fluvial and deltaic facies in the Sentinel Butte Formation, central Williston Basin: Jour. of Sed. Petrology, vol. 48, no. 1, p. 159-170.

Clark, F. K., 1966, Geology of the Sangre de Cristo Mountains and adjacent areas: in Northrop, S. A., and Read, eds., C. B., New Mexico Geol. Soc. Guidebook, 17th Field Conf., Taos-Raton-Spanish Peaks, p. 57-65.

Coleman, J. M. and Prior, D. B., 1982, Deltaic environments of deposition: in Scholle,

P. A., and Spearing, D., eds., Sandstone Depositional Environments, Amer. Assoc. of Petroleum Geologists Spec. Publ., p. 139-178.

Compton, R. C., 1962, Manual of Field Geology: John Wiley and Sons, Inc., 378 p.

Elliot, T., 1974, Interdistributary bay sequences and their genesis: Sedimentology, v. 21, p. 611-622.

Ethridge, F. G., Jackson, T. J. and Youngberg, A. D., 1981, Floodbasin sequence of a fine-grained meander belt subsystem: The coal-bearing lower Wasatch and upper Fort Union Formations, southern Powder River Basin, Wyoming: in Ethridge, F. G., editor; et al., Recent and Ancient Nonmarine Depositional Environments: Models for Exploration, SEPM Spec. Publ., no. 31, p. 191-209.

Fassett, J. E., 1976, What happened during late Cretaceous time in the Raton and San Juan Basins with some thoughts about the area in between: in Ewing, R. C., and Kues, B. S., eds., New Mexico Geol. Soc. Guidebook, 27th Field Conf., Vermejo Park, p. 177-183.

Flores, R. M., 1981, Coal deposition in fluvial paleoenvironments of the Paleocene Tongue River Member of the Fort Union Formation, Powder River area, Powder River Basin, Wyoming and Montana: in Ethridge, F. G., editor, et al., Recent and Ancient Nonmarine Depositional Environments: Models for exploration, SEPM Spec. Publ., no. 31, p. 169-190.

Folk, R. L., 1980, Petrology of Sedimentary Rocks: Austin, Tx., Hemphill's, 182 p.

Galloway, W. E., 1981, Coal deposition in fluvial paleoenvironments of the Paleocene Tongue River Member of the Fort Union Formation, Powder River area, Powder River Basin, Wyoming and Montana: in Ethridge, F. G., editor, et al., Recent and Ancient Nonmarine Depositional Environments: Models for exploration, SEPM

Spec. Publ., no. 31, p. 127-155.

Hacquebard, P. A. and Donaldson, S. A., 1969, Carboniferous coal deposition associated with floodplain and limnic environments in Nova Scotia: in Dapples, E. C., and Hopkins, M. E., eds., Environments of Coal Deposition: Geol. Soc. America Spec. Paper no. 114, p. 143-192.

Horne, J. C., Ferm, J. C., Caruccio, F. T. and Baganz, B. P., 1978, Depositional models in coal exploration and mine planning in Appalachian region: Am. Assoc. Petroleum Geologists Bull., v. 62, no. 12, p. 2379-2411.

Ingram, R. L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks: Geol. Soc. of America Bull. vol. 65, p. 937-938.

Johnson, R. B., Dixon, G. H. and Wanek, A. A., 1966, Late Cretaceous and Tertiary stratigraphy of the Raton Basin of New Mexico and Colorado: in Northrop, S. A., and Read, C. B., eds., New Mexico Geol. Soc. Guidebook, 17th Field Conf., Taos-Raton-Spanish Peaks, p. 88-98.

Knowlton, F. H., 1917, Fossil floras of the Vermejo and Raton Formations of Colorado and New Mexico: in Washington, Govt. print. off., Geology and Paleontology of the Raton Mesa and other Regions in Colorado and New Mexico, U.S. Geol. Surv. Prof. Paper 101, 450 p.

Lahee, F. H., 1969, Field Geology: McGraw-Hill Book Company, Inc., 926 p.

Lee, W. T., 1917, Geology of the Raton Mesa: in Washington, Govt. print. off., Geology of the Raton Mesa and other Regions in Colorado and New Mexico, U.S. Geol. Surv. Prof. Paper 101, 221 p.

Leighton, V. L., 1980, Depositional environments and petrography of the Trinidad Sandstone and related formations, Raton area, New Mexico: Unpubl.

M. S. Thesis, Colo. State Univ., 97 p.

Maill, A. D., 1977, A review of the braided river depositional environment: Earth Sci. Review, v. 13, p. 1-62.

_____, 1979, Deltas, in Facies Models, Geological Assoc. of Canada publ., p. 43-56.

Moorhouse, W. W., 1959, The Study of Rocks in Thin Section: Harper and Row Publ., 514 p.

Pettijohn, F. H., Potter, P. E. and Seiver, R., Sand and Sandstone: Springer-Verlag, p. 618.

Pillmore, C. L., 1976, Commercial coal beds of the Raton coal field, Colfax County, New Mexico: in Ewing, R. C., and Kues, B. S., eds., New Mexico Geol. Soc. Guidebook, 27th Field Conf., Vermejo Park, p. 227-247.

_____, and Mayberry, J. D., 1976, The depositional environment and trace fossils of the Trinidad Sandstone, southern Raton Basin, New Mexico: in Ewing, R. C., and Kues, B. S., eds., New Mexico Geol. Soc. Guidebook, 27th Field Conf., Vermejo Park, p. 191-195.

Potter, P. E., 1967, Sand bodies and sedimentary environments: Am. Assoc. Petroleum Geologists Bull., v. 51. no. 3, p. 337-365.

Reinson, G. E., 1979, Barrier island systems: Facies Models, Geological Assoc. of Canada publ., vol. 6, no. 2, p 63-66.

Schumm, S. A., 1963, A tentative classification of alluvial river channels: U.S. Geol. Survey Circ. 477, p. 1-9.

_____, 1981, Evolution and response of the fluvial system, sedimentologic implications: in Ethridge, F. G., editor, et al., Recent and Ancient Nonmarine Depositional Environments: Models for

Exploration, SEPM Spec. Publ,. no. 31, p. 19-29.

Shelton, J. W. and Nobil, R. L., 1974, Depositional features of braided-meandering stream: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 4, p. 742-752.

Speer, W. R., 1976, Oil and gas exploration in the Raton Basin: in Ewing, R. C., and Kues, B. S., eds., New Mexico Geol. Soc. Guidebook, 27th Field Conf., Vermejo Park, p. 217-226.

Stach, E., 1975, The Study of Coal Petrology: Gebruder Borntraeger, Berlin, Stuttgart, 250 p.

Terry, R. D. and Chilingar, G. V., 1955, Summary of "Concerning some additional aids in studying sedimentary formations" by M.S. Shvetsov: Jour. Sed. Petrology, v. 25, p. 229-234.

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, p. 377-392.

Zeuss, H., 1967, Geology of the Raton area Colfax Co., New Mexico: Unpubl. M.S. Thesis no. 1146, Colo. Sch. Mines, 108 p.