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# The Variegated Member of the Morrison Formation in the Southeastern Part of the San Juan Basin, Valencia County New Mexico

William L. Chenoweth

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THE VARIEGATED MEMBER OF THE MORRISON  
FORMATION IN THE SOUTHEASTERN PART OF  
THE SAN JUAN BASIN, VALENCIA COUNTY  
NEW MEXICO

By

William L. Chenoweth

A Thesis

In partial fulfillment of the  
Requirements for the Degree of  
Master of Science in Geology

The University of New Mexico  
1953



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## ABSTRACT

The strata now designated as Morrison in western New Mexico have been known by a variety of names since the beginning of geological exploration in the West. The nomenclature has become confused due to the many facies that are present. Recent exploration for uranium has renewed interest in the stratigraphy of the Morrison formation.

Morrison rocks exposed in the southeastern part of the San Juan Basin are divided into two members,—the Variegated member and an overlying sandstone member. These members may be correlated respectively with the Chaves or Recapture shale member and the Prewitt or Westwater Canyon sandstone member in the northern flank of the Zuni Uplift.

The Variegated member is predominantly a sequence of varicolored claystone, lenticular, tan sandstone, and occasional thin, arenaceous, gray limestone beds. The member can not be recognized south of T. 8 N. Convergence is due to both truncation by a pre-Dakota erosion surface and gradation into the underlying Bluff sandstone.

Silicified dinosaur bone fragments were the only fossils encountered and are not uncommon on the slopes of outcrops of the member.

The Variegated member was derived from a mixed source



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formation.

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the San Juan Basin are divided into two members -- the  
Variegated member and an upper, sandstone member.  
These members may be correlated with the  
Chaves or Boscawen shale member and the  
Westwater Canyon sandstone member and the  
of the Sand Bluff.

The Variegated member is predominantly  
of variegated claystone, sandstone, and shale, with  
occasional thin, arenaceous, fossiliferous beds.  
member can not be recognized as a unit.  
is due to both truncation of a pre-existing member  
and gradation into the upper member.  
Bifoliated clastic and fossiliferous beds  
fossils encountered and are not to be confused  
of outcrops of the member.

The Variegated member is a unit of



of pre-existing sedimentary rocks and originated as part of a low-gradient, alluvial fan over which there were extensive playas. A coarsening of the member to the south and southwest indicates a source in that direction.

Late Jurassic-early Cretaceous movement, probably related to the Zuni Uplift, produced some gentle folding within the area. Throughout the broad Acoma Embayment, outcrops of the Variegated member are nearly horizontal and undeformed. However, in the eastern part of the area, there is pronounced deformation as the result of the Lucero Uplift and Ignacio monocline. Tertiary intrusions occur as basalt dikes and sills cutting through the Variegated member.

The clay within the member, used in small quantities by Indians of the region, may represent an untapped resource for cement and ceramics. Uranium deposits, of the type found in the overlying sandstone member, are to be expected in the larger sandstone lenses within the Variegated member.







## INTRODUCTION

### Geography

#### Location

The area in which outcrops of the Morrison formation were studied is located nearly wholly within the Acoma embayment of the San Juan Basin and only partly within the Lucero Uplift as designated by Kelley (1950, 1951). The irregular and discontinuous outcrops, within the area studied, form an uneven pattern on either side of latitude  $35^{\circ}$  north between longitude  $107^{\circ}5'$  and longitude  $107^{\circ}35'$  west (Fig. 1, in pocket). Most of the area lies within Valencia County, New Mexico but the extreme northeastern part is in Bernalillo County. About 155 miles of linear outcrops of the Variegated member occur within this area.

#### Culture

Located nearly midway between Albuquerque and Grants, the area contains the small settlements of Correo and Cubero, and numerous Indian villages. Prominent among the latter are the Pueblos of Acoma and Laguna. Other villages include Acomita, Seama, Paraje, New Laguna, and Mesita along the valley of the Rio San Jose, and Encinal and Pagate to the north of it. In the eastern part of the area studied is the Navajo Indian community of Cañoncito. To the north, outside the area studied, are the Spanish-American communities of



INTRODUCTION

Geography

Location

The area is within outcrops of the ...

were studied as isolated ...

embayment of the sea ...

Lucero ...

irregular and ...

form an ...

between ...

in pocket ...

New Mexico ...

Illinois ...

Variegated ...

Culture

located near ...

the area contains ...

and numerous ...

the people of ...

Asomita, ...

valley of the ...

north of it ...

Navajo Indian ...

the area ...



Bilbo, Cebolletita, Cebolleta, and Piedro Lumbre. Also outside the area but to the west is the settlement of San Fidel. Along the main line of the Atchison, Topeka and Santa Fe Railroad are the stock loading pens and stations of Suwanee, South Garcia, and North Garcia (Fig. 1).

Indian reservations of the Acoma and Laguna tribes and the Cañoncito Navajos comprise the majority of the land. Two Spanish land grants, Cubero and Antonio Sedillo, also lie within the area. In addition to the Indian reservations and land grants there is a small amount of private land occupied by a few ranchers.

Sheep raising is the main source of livelihood throughout the entire area.

#### Accessibility

Most outcrops of the Variegated member of the Morrison are easily accessible. U. S. Highway 66 crosses the area just south of the majority of the outcrops and many good exposures can be seen from it. State Highway 6 leads from U. S. Highway 66 near Correo to the southeast through the southeastern part of the area. The Atchison, Topeka and Santa Fe Railway roughly parallels State Highway 6. State Highway 53 traverses Acoma Valley for 14 miles between Acoma and Paraje, the latter being located on U. S. Highway 66. A good graveled road connects Laguna with the village of Paguate, 10 miles north of U. S. Highway 66. A few graded roads and numerous unimproved roads connect the scattered







habitations and abandoned sheep camps in the area.

Wind-blown sand and washouts of the roads after rains impede travel on many of the poor or secondary roads.

#### Climate and Vegetation

The climate of the area is semi-arid. The average annual rainfall is 12 inches. Almost one-half of the mean annual rainfall occurs in the summer months of July, August, and September. Much of this precipitation is torrential, of the cloud-burst type. In the summer the mean temperature is about 70° F. The days are hot, though tempered by cooling breezes; the nights are cool and pleasant. During the winter the mean temperature is about 35° F. The nights are cold but the days are generally sunny and warm. Prevailing winds are from the south and southwest.

The dryness of the climate is expressed in the types of vegetation. Rabbitbrush, sand sage, yucca, various grasses, cacti, and wildflowers are common in the lowlands. Greasewood and a few cottonwoods are found near springs and along water courses, Piñon and juniper grow at the foot of the slopes and on the mesas. Sheep grazing and wood hauling have greatly decreased the vegetation of the area.

#### Physiography

The area is a land of steep dissected mesas and broad valleys. Some of the more important mesas are Mesa Gigante,



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### Climate and Vegetation

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and September. Much of this rain is in the form of  
of the storm-burst type. In the winter the mean temperature  
is about 70° F. The days are hot, mostly over 80° F. by noon  
pressed; the nights are cool and pleasant. During the winter  
the mean temperature is about 55° F. The nights are cold  
but the days are generally sunny and warm. The winter months  
are free from the south and southwest.

The average of the climate is expected to be the same  
of vegetation. The vegetation is a dry grass, mostly  
grasses, cereals, and wildflowers and shrubs in the lowlands.  
Greensand and a few cottonwoods are found near the river and  
along water courses. The river and its tributaries are the best of  
the slopes and on the river. The slopes are mostly bare and  
ing have mostly bare slopes and the vegetation of the area.

### Vegetation

The area is a land of deep cultivated lands and some  
valleys. Some of the more important crops are wheat, alfalfa,



north of Correo; Mesa Redonda, southeast of Correo; Wheat Mountain, north of Laguna; Snowbird Mesa, southeast of Pagate; and a small mesa 2 miles northeast of Acoma called Enchanted Mesa. Prominent mesas in the region but not in the area are Cebolleta and Putney Mesas to the west, Mesa del Oro to the south, and Lucero Mesa to the southeast. Suwanee Peak, a small upfaulted block of Jurassic and Cretaceous rocks capped by Quaternary spring deposits (Pl. 1A) is a well-known landmark in the eastern part of the area.

Standing above these features to the northwest of the area, is Mount Taylor, one of the most prominent landmarks in northwestern New Mexico.

Drainage within the area is intermittent. The Rio San Jose, which is the main drainage, traverses the middle of the area from west to southeast. Important tributaries of the Rio San Jose are Acoma Creek and Rio Colorado on the south, and on the north the Rio Pagate and Arroyo Gigante (Concho Arroyo and Arroyo Verde of some maps) are important (Fig. 1). The east side of Mesa Gigante is drained by the Rio Puerco of which Arroyo Apache and Arroyo Cocino are important tributaries. Just outside the area, to the southeast, the Rio San Jose joins the Rio Puerco, so that on a regional basis the area is drained by the Rio Puerco.

Relief throughout the area averages about 500 feet, as the mesas are generally at the elevation of about



North of Dorsey, near the base of the mountain, south of  
Mountain, north of Dorsey, south of Dorsey, south of  
Pagosa; and a small mesa 2 miles northeast of Pagosa called  
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the area are Caballero and Antelope mesas to the west, Mesa  
del Oro to the south, and Antelope Mesa to the southeast.  
Swansee Peak, a small isolated block of Jurassic and  
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6,000 feet and the valleys average about 5,500 feet.

#### Previous Work

Early geologists who accompanied the various expeditions and survey parties which passed through the area described remarkably well the general geology they observed along their routes and some even went so far as to measure a few stratigraphic sections and construct cross sections. Notable among these pioneers were W. P. Blake and Jules Marcou (1856) with Lt. Whipple's railroad survey party in 1853, J. S. Newberry (1861) with Lt. Ives's Colorado River expedition in 1858, and G. K. Gilbert (1875) and E. E. Howell (1875) with the Wheeler Survey parties in 1873. C. E. Dutton (1885) roughly mapped and briefly described the general geologic features of the area but was largely concerned with the region to the north and west of it.

Herrick (1904), although primarily concerned with the gypsum deposits of New Mexico, briefly described the rocks overlying the gypsum along the valley of the Rio San Jose.

Darton (1922, pl. 48) published the first detailed map of the area after several earlier reconnaissances (1910; 1916) through the area while prospecting for water along the Atchison, Topeka and Santa Fe Railroad in New Mexico and Arizona. Later, Darton (1928a; pp. 109-137) described the general geology of the area including the extent and stratigraphic relationships of the Variegated member.



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Although Hunt (1936) was mainly concerned with the coal-bearing Cretaceous rocks, he included the Morrison formation and mapped the structure in the northern part of the area covered. Hunt (op. cit., pp. 33-35) included a detailed bibliography of previous work on the coal-bearing Cretaceous rocks in the northern part of the area.

Baker, Dane, and Reeside (1936) included a section measured by Darton (1928a, p. 119) on the west side of Mesa Gigante in their correlation of the Jurassic rocks of the Colorado Plateau. Reiche (1937) briefly cited examples of his newly defined landslide type, the Toreva-block, in and near the Laguna Indian Reservation. Leopold (1943) noted the occurrence of kaolin in the Morrison rocks underlying the Dakota sandstone in the Suwanee area. Kelley and Wood (1946) prepared a map of the Lucero Uplift in the southeastern part of the area and included three sections containing the Variegated member of the Morrison. Wright (1946) treated the Cenozoic geology of the area and was not primarily interested in the older formations.

Baker, Dane, and Reeside (1947), in their revised correlation of the Jurassic rocks, again used the Mesa Gigante section. Silver (1948) described in detail the Jurassic overlap that is excellently exposed in the area. Craig, et al. (1951) briefly visited the area and examined the Morrison formation in preparation of their paper on



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the regional aspects of the Morrison. Rapaport, et al. (1952) measured a few sections in the area in 1951. These were included in their report on the Jurassic rocks of the Zuni Uplift. Imlay (1952), in his correlation chart of the Jurassic formations of North America, included a generalized section representative of the area.

#### Present Work

Previous workers, with the exception of Kelley and Wood (1946) and Silver (1948), have, as a rule, included the Variegated member with whatever other lithologic units were included in the Morrison formation at the time of their reports, and have treated the whole formation in rather general terms.

This detailed study of the Variegated member of the Morrison formation is undertaken in order to describe it thoroughly and especially study its stratigraphic relationships and origin.

During the months of June, July, August, and September 1952, while the author was affiliated with the Grants District Office of the Atomic Energy Commission, eleven stratigraphic sections were measured at various localities throughout the area where the Variegated member was best exposed (Fig. 1). The localities were chosen so that complete stratigraphic sections, free from as much talus material as possible, could be measured accurately.



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Considerable attention was given to the lateral variations or changes in the various lithologic units comprising the member. Outcrops of the Variegated member, shown on the index map (Fig. 1) were compiled from aerial mosaics and AEC reconnaissance maps.

#### Acknowledgments

The author gratefully acknowledges the generous aid given him by numerous individuals. Special thanks are expressed to Ralph Wilpolt, Paul Melancon, and Arthur Mirsky of the Geologic Branch, Division of Exploration, of the Grand Junction Operations Office of the Atomic Energy Commission, who made several unpublished reports available as well as giving constructive criticism.

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Considerable attention was given to the lateral extent of or changes in the various lithologic units comprising the member. Outcrops of the Variegated member, shown on the index map (Fig. 1) were compiled from aerial photos and AEC reconnaissance maps.

#### Acknowledgments

The author gratefully acknowledges the generous aid given him by numerous individuals. Special thanks are expressed to Ralph Wilcox, Paul Johnson, and Arthur H. H. of the Geologic Branch, Director of Exploration, of the Grand Junction Operations Office of the Atomic Energy Commission, who made several unpublished reports available as well as giving constructive criticism. Vincent G. Kelley and Sherman A. Wenger of the University of New Mexico gave much appreciated field and office counsel while the study was in progress. Stewart A. Hartman, also of the University of New Mexico, kindly aided in the identification and age determination of certain fossils. Fragments collected by the author.



## STRATIGRAPHY

The Jurassic rocks of the Colorado Plateau are divided into three major units—the Glen Canyon group, the San Rafael group, and the Morrison formation, in ascending order. Baker, Dane, and Reeside (1936, 1947) have discussed the Jurassic stratigraphy of the Colorado Plateau and their papers cite the principal references dealing with this division.

### Pre-Morrison Jurassic Rocks

Although rocks of Glen Canyon and lower San Rafael age are present within the area (Silver, 1948, p. 74), the oldest formation considered here is the Entrada sandstone.

#### Entrada Sandstone

The Entrada sandstone is exposed on the south side of Mesa Gigante along the line of cliffs south of Mesa Gigante. It also crops out in a very small area near Suwanee Peak, along the Rio Colorado and on the east side of the Acoma Valley. Although the base is not usually exposed, a thickness of 165 feet was measured at one place on the south side of Mesa Gigante.

This sandstone consists of fine to very fine, subrounded, well-sorted quartz grains with very small amounts of dark-colored chert. It is a massive cross-laminated, cliff forming sandstone. Two color zones are distinguishable. The



## STRATIGRAPHY

The Jurassic rocks of the Colorado Plateau are divided into three major units--the Glen Rose group, the San Rafael group, and the Morrison formation, in ascending order. Baker, Leach, and Howell (1937) have discussed the Jurassic stratigraphy of the Colorado Plateau and their papers cite the principal references dealing with this division.

### Pre-Morrison Jurassic Rocks

Although rocks of Glen Rose and lower San Rafael are present within the area (Hilmer, 1935, p. 7), the formation considered here is the upper San Rafael.

### Entrada Sandstone

The Entrada sandstone is exposed on the northeast of Mesa Grande along the line of cliffs north of Mesa Grande. It also crops out in a very small area near Lower Mesa Grande along the Rio Colorado and on the east side of the Rio Valley. Although the sandstone is not usually exposed, a thickness of 100 feet was measured at one place on the south side of Mesa Grande.

This sandstone consists of fine to very fine, well-sorted quartz grains with very small amounts of dark colored chert. It is a massive cross-bedded, light-colored sandstone. Two color bands are distinguishable. The



lower zone is reddish-brown and the upper (about 1/3 of the total thickness) is white. Toward the south the upper bleached zone increases to about one-half of the entire thickness.

#### Todilto Formation

The Todilto limestone and gypsum are exposed along the same pattern as the Entrada sandstone. They are also exposed in a small area near Suwanee Peak and on the south and east sides of Mesa Redonda. The limestone commonly forms a rim capping the Entrada sandstone, with the overlying gypsum forming a slope or badlands topography. The thickness of the formation varies according to the amount of gypsum present. North of Mesita the gypsum is 80 feet thick but thins out rapidly to the south and west and is not present in the Acoma Valley. Throughout the area limestone is generally 15 feet thick. The limestone is generally dark gray on weathered surfaces, but is commonly light gray on fresh surfaces. It is thin bedded, fine to microcrystalline, slightly fetid, and in some places arenaceous, particularly in the lower part. Occasionally the limestone contains calcite seams. The lower part of the limestone contains sandstone lenses and thin beds of reworked Entrada.

#### Summerville Formation

The interval between the top of the Todilto and the base of the overlying Bluff sandstone in this area has been



lower zone is reddish-brown and the upper (about 1/3 of the total thickness) is white. Toward the south the weathered zone increases to about one-half of the entire thickness.

#### Toddite Formation

The Toddite limestone and gypsiferous are exposed along the same pattern as the Toddite sandstone. They are exposed in a small area near the base and on the south and east sides of Mesa Rancho. The limestone commonly forms a rim capping the Toddite sandstone, with the overlying gypsiferous forming a slope or pediment topography. The thickness of the formation varies according to the amount of sand present. North of Mesa Rancho the gypsiferous is 50 feet thick but thins out rapidly to the south and west and is not present in the lower valley. Throughout the area limestone is generally 15 feet thick. The limestone is generally dark gray on weathered surfaces, but is commonly light gray on fresh surfaces. It is fine grained, like the interstratified, slightly foliated, and in some places granular, partly in the lower part. Occasionally the limestone contains calcite seams. The lower part of the limestone contains sandstone lenses and thin beds of weathered sandstone.

#### Summerville Formation

The interval between the top of the Toddite and the base of the overlying River sandstone in this area has been



known by several different names (Fig. 2, in pocket). It was originally named the Buff shale member of the Morrison by Kelley and Wood (1946). Silver (1948, pp. 70, 80), after studying this interval, was undecided as to whether it should be included in the Todilto formation or in the Morrison. The New Mexico Geological Society (1951, p. 19) referred to this unit as the Red Mesa formation which was named by Hoover (1950, p. 77) in the northeastern part of Arizona and considered by him to be of Summerville age. In accordance with current usage by field geologists of the Atomic Energy Commission and the Geological Survey, the name Summerville is used in this thesis for this stratigraphic unit.

It ranges in thickness from 50 feet to 120 feet, being thickest in the Acoma Valley. It commonly forms a slope back of a bench eroded on the Todilto. It is exposed on the east, south, and west sides of Mesa Gigante, in the Suwanee Peak area, around the base of Mesa Redonda, along the line of cliffs south of Mesa Gigante along the Rio Colorado, and on both sides of the Acoma Valley.

It consists of thin sandstone, siltstone, and claystone beds which are banded buff, red, and reddish brown. The lower half is predominantly claystone and the upper consists of interbedded sandstone and siltstone. Toward



known by several different names (Fig. 2, in pocket). It was originally named the Bull shale member of the Morrison by Kelley and Wood (1946). Silver (1948, pp. 70, 80), after studying this interval, was undecided as to whether it should be included in the Tertiary formation or in the Morrison. The New Mexico Geological Society (1951, p. 12) referred to this unit as the Red Mesa formation which was named by Hoover (1950, p. 77) in the northeastern part of Arizona and considered by him to be of Sumnerville age. In accordance with current usage by field geologists of the Atomic Energy Commission and the Geological Survey, the name Sumnerville is used in this thesis for this stratigraphic unit.

It ranges in thickness from 50 feet to 130 feet, being thickest in the Acorn Valley. It commonly forms a step back of a bench eroded on the Tertiary. It is exposed on the east, south, and west sides of Mesa Grande, in the Sumner Peak area, around the base of Mesa Redonda, along the line of cliffs south of Mesa Grande along the Rio Colorado, and on both sides of the Acorn Valley.

It consists of thin sandstone, siltstone, and claystone beds which are banded buff, red, and reddish brown. The lower half is predominantly claystone and the upper consists of interbedded sandstone and siltstone. Toward



the south and east the amount of sandstone and siltstone in the interval greatly increases. Locally it appears to inter-tongue with the gypsum and limestone of the Todilto formation.

### Bluff Sandstone

The sandstone overlying the Summerville in this area has also been known by a variety of names (Fig. 2). Kelley and Wood (1946) divided this sandstone into two units--the Brown-buff sandstone and the White sandstone members of the Morrison. Recently the New Mexico Geological Society (1951, p. 19) considered only the lower (the Brown-buff member) as possibly equivalent to the Bluff sandstone of the Four Corners area. Although there has been some controversy as to the status of the Bluff sandstone of the Four Corners area, the Bluff, according to Eckel (1949, p. 29) is ranked as the youngest formation of the San Rafael group. Both the Brown-buff and the White sandstone members of Kelley and Wood (1946) are currently designated as the Bluff sandstone by field geologists of the Atomic Energy Commission and the Geological Survey and are so considered in this thesis.

The Bluff sandstone is exposed along the east, south, and west sides of Mesa Gigante, in the Suwanee Peak area, around the base of Mesa Redonda, and makes the line of cliffs along the Rio Colorado. It also is exposed along the north



tion.

## Bluff Sandstone

The sandstone overlying the limestone in this area has also been known by a variety of names. It is called and Wood (1946) divided this sandstone into two units—the Brown-bluff sandstone and the white sandstone members of the Morrison. Recently the New Mexico Geological Society (1951, p. 19) considered only the lower (the brown-bluff member) as possibly equivalent to the bluff sandstone of the lower Cornudas area. Although there has been some controversy as to the status of the bluff sandstone of the Cornudas area, the bluff, according to Leakey (1944, p. 10) is ranked as the youngest formation of the San Rafael group. Well, the Brown-bluff and the white sandstone members of Leakey and Wood (1946) are currently designated as the bluff sandstone in field geologists of the New Mexico Energy Commission and the Geological Survey and are so considered in this report. The bluff sandstone is exposed along the east, south, and west sides of Mesa Lagarto, in the Pecos River area, around the base of Mesa Lagarto, and takes the form of cliffs along the Rio Colorado. It also is exposed along the north



side of the Rio San Jose in the vicinity of Laguna and along both sides of the Acoma Valley. Most of the area between the cliffs along the Rio Colorado and the east side of the Acoma Valley consists of a very gentle dip slope formed by the Bluff sandstone.

The Bluff sandstone is a prominent cliff former throughout most of the area. However, in the eastern part of the area where Kelley and Wood made a two-fold division of it, the upper or White sandstone member erodes back and thus forms a bench on the lower unit. Where this bench is not formed the two units can be recognized easily by difference in color and bedding (Pls. 2A; 3B). It consists of medium to fine-grained, subrounded, well-sorted quartz which are moderately cemented. The color is variable. In Mesa Gigante the lower unit is banded buff, reddish-brown, and brown (Pl. 2B). This lower unit consists predominantly of parallel bedding although it does contain some cross-laminated units. The upper part is white to buff in color and is chiefly cross-laminated. To the south and west of the area, the Bluff, becomes a white massive, cross-laminated sandstone in which it is impossible to distinguish the two units.

The Bluff is quite variable in thickness, varying from 200 to 300 feet.



side of the Rio San Jose in the vicinity of Laguna and  
along both sides of the Acama Valley. Most of the area  
between one cliff along the Rio Colorado and the east  
side of the Acama Valley consists of a very gentle dip  
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The Binil sandstone is a prominent cliff former  
throughout most of the area. However, in the eastern part  
of the area where Hales and Wood make a two-fold division  
of it, the upper or white sandstone member extends back and  
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ference in color and bedding. The Binil is composed  
of medium to fine-grained, well-sorted quartz  
which are moderately cemented. The color is variable.  
In less distance the lower unit is banded buff, reddish-  
brown, and brown (Pl. 23). This lower unit contains ex-  
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and west of the area, the Binil becomes a white massive,  
cross-laminated sandstone in which it is impossible to  
distinguish the two units.  
The Binil is quite variable in thickness, varying from  
200 to 300 feet.



The base of the Bluff sandstone is difficult to distinguish, particularly in the Acoma area where it grades into sandstones of the Summerville formation.

### Morrison Formation

#### General Statement

The name Morrison formation is generally used as a "dump box" to include all Jurassic continental sediments that were deposited subsequent to the deposition of the San Rafael group. It has been applied to strata covering about 350,000 square miles and distributed over the greater part of the Western Interior of the United States. According to Reeside (Yen, 1952, p. 22) the Morrison is recognized as far south as northern New Mexico and northeastern Arizona, as far west as central Utah and west-central Wyoming, as far north as the Canadian border in Montana, and in the east under the high plains of western South Dakota, western Nebraska, western Kansas, and the Oklahoma Panhandle.

The type section of the Morrison was designated by Eldridge (Emmons, et al. 1896, pp. 60-62) from incomplete exposures at or near Morrison, Colorado. Later this section became the subject of some controversy (Lee 1920; 1927, p. 28) as the boundaries were thought to be too broad. Waldschmidt and Leroy (1944) redefined the type section from complete exposures north of the town of Morrison and their definition



The base of the bluff sandstone is difficult to distinguish, particularly in the areas where it grades into sandstones of the Chamberlain formation.

## Morrison Formation

### General Statement

The name Morrison formation is generally used as a "dump box" to include all Tertiary continental sediments that were deposited subsequent to the deposition of the San Rafael group. It has been applied to strata covering about 350,000 square miles and distributed over the greater part of the Western Interior of the United States. According to Reeside (Yon, 1922, p. 22) the Morrison is recognized as far south as northern New Mexico and northeastern Arizona, as far west as central Utah and west-central Wyoming, as far north as the Canadian border in Montana, and in the east under the high plains of western South Dakota, western Nebraska, western Kansas, and the Oklahoma Panhandle. The type section of the Morrison was designated by Hildridge (Hemans, et al., 1896, pp. 60-62) from incomplete exposures at or near Morrison, Colorado. Later this section became the subject of some controversy (see 1920, 1922, p. 28) as the boundaries were thought to be too broad. Waldo and Leroy (1944) redefined the type section from complete exposures north of the town of Morrison and their definition



includes essentially the same strata that were included by Eldridge.

In northeastern Arizona and southeastern Utah the Morrison can be separated into an upper and a lower part (Fig. 3, in pocket), each of which has two members: West-water Canyon sandstone and Brushy Basin shale\* in the upper, and Salt Wash sandstone and Recapture shale\* in the lower part. In western Colorado, eastern Utah, and part of northeastern Arizona the Morrison consists of an upper part of variegated mudstone and claystone (Brushy Basin shale member) and a lower part of lenticular cross-laminated sandstone and mudstone (Salt Wash sandstone member). Over most of the western part of the United States the Morrison cannot be divided into members and consists of irregularly distributed mudstone and claystone with a few interbedded sandstones.

#### Summary of the Nomenclature

The deposits which are now designated as belonging to the Morrison formation in northwestern New Mexico have, under various names (Fig. 2) been of interest to geologists since almost the beginning of the geologic exploration of the West.

William Blake and Jules Marcou, as geologists with Lt. Whipple's railroad survey party in 1853, were the first

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\*The term shale is actually a misnomer as these units are predominantly claystone.



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In northeastern Arizona and southeastern Utah the  
Morrison can be separated into an upper and a lower part  
(Fig. 3, in pocket), each of which has two members. The  
upper member consists of a lower part of reddish-brown  
sandstone and claystone and a lower part of reddish-brown  
sandstone and claystone. The lower member consists of an upper  
part of reddish-brown sandstone and claystone and a lower  
part of reddish-brown sandstone and claystone. The upper  
member is divided into two parts, a lower part of reddish-brown  
sandstone and claystone and an upper part of reddish-brown  
sandstone and claystone. The lower member is divided into two  
parts, a lower part of reddish-brown sandstone and claystone  
and an upper part of reddish-brown sandstone and claystone.  
The upper member is divided into two parts, a lower part of  
reddish-brown sandstone and claystone and an upper part of  
reddish-brown sandstone and claystone. The lower member is  
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#### Summary of the nomenclature

The deposits which are now designated as belonging to  
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William Hanks and James Watson, as geologists with  
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to map and describe the geology of northwestern New Mexico. Blake (1856, pp. 69-78) gave the name Gypsum formation to the red sandstone, clay, and marl containing gypsum and without fossils, to the interval between the rocks definitely Carboniferous and Cretaceous.

J. S. Newberry, geologist with Lt. Ives's Colorado River expedition in 1858, named the red beds immediately below the Cretaceous, the Marl series, from exposures in northeastern Arizona (Newberry, 1861, p. 78). Newberry (1861, pp. 96-97) used this term in describing sections near Fort Wingate and Laguna Pueblo. As a member of the Wheeler Survey parties in 1873, Gilbert (1875, pp. 551-552) measured a section near Fort Wingate but did not apply specific names to the exposed formations. Dutton (1885, pp. 136-137) gave the name Zuni sandstones to the interbedded sandstone and shale beneath the Dakota sandstone, and overlying the massive red cliff-forming sandstone which he named Wingate, near Fort Wingate.

In order to understand the use and limits of the names that are to be applied in northwestern New Mexico, it is necessary to summarize briefly the derivation of the nomenclature that was developed in Colorado.

In 1894, G. H. Eldridge named the Gunnison formation from exposures in Gunnison Canyon on the western slope of the Rocky Mountains (Eldridge, 1894, p. 6). It included the interval between the Dakota formation and the so-called



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J. S. Newberry, geologist with J. C. Ives's Colorado River expedition in 1878, named the red beds immediately below the Cretaceous, the Marl series, from exposures in northwestern Arizona (Newberry, 1881, p. 78). Newberry (1881, pp. 94-97) used this term in describing sections near Fort Wingate and Laguna Pueblo. As a member of the Wheeler Survey parties in 1873, Gilbert (1877, pp. 251-252) measured a section near Fort Wingate but did not apply specific names to the exposed formations. Patton (1887, pp. 136-137) gave the name sandstone to the interbedded sandstone and shale beneath the Dakota sandstone, and overlying the massive red cliff-forming sandstone which he named Wingate, near Fort Wingate. In order to understand the use and limits of the names that are to be applied in northwestern New Mexico, it is necessary to summarize briefly the derivation of the names of the formations that were developed in Colorado.

In 1894, G. B. Albridge named the Gunnison formation from exposures in Gunnison Canyon on the western slope of the Rocky Mountains (Albridge, 1894, p. 6). It included the interval between the Dakota formation and the so-called



Maroon conglomerate. In describing it, he (op. cit., p. 6) noted the similar stratigraphic and lithographic correspondence of Atlantosaurus beds of Marsh (1877, p. 516) on the eastern slope of the Rocky Mountains. A few months later Whitman Cross (1894, p. 2) applied the name Morrison formation to exposures near the town of Morrison, southwest of Denver, Colorado. This original Morrison formation included the Atlantosaurus beds of Marsh and was regarded by Cross (1894, p. 2) as occurring in the same stratigraphic interval immediately underlying the Dakota sandstone, as Eldridge's Gunnison formation. A detailed description of the Morrison formation, although omitted by Cross, was given by Eldridge in his description of the Mesozoic rocks of the Denver Basin (Emmons, et al. 1896, pp. 60-62).

Purington (1898, p. 759) restricted the thickness of Eldridge's Gunnison when he designated the Gunnison shale as the upper member of the Jurassic immediately below the Dakota sandstone on the western slope.

Cross (1899, p. 2) regarded the Gunnison formation of Eldridge in part or at least equal to the Atlantosaurus beds of the eastern slope. He (op. cit., pp. 2-3) also divided the Gunnison into an upper and a lower division. To the upper division, immediately beneath the Dakota sandstone (the Gunnison shale of Purington), he gave the name McElmo formation from exposures in the McElmo Valley



Harmon conglomerate. In describing it, he said:

p. 6) noted the similar stratigraphic and lithologic correspondence of Albion (Harmon, 1907).

p. 716) on the eastern slope of the Rocky Mountains, a few months later William Cross (1892, p. 2) applied the name Morrison formation to exposures near the town of Morrison, southwest of Denver, Colorado. This original Morrison formation included the Albion beds of Marsh and was regarded by Cross (1892, p. 2) as occurring in the same stratigraphic interval immediately underlying the Dakota sandstone, as Blair's Quinn formation.

A detailed description of the Morrison formation, although omitted by Cross, was given by Blair in his description of the Mesozoic rocks of the Denver basin (Blair, 1911, 1916, pp. 60-62).

Putnam (1906, p. 759) restricted the term to Blair's Quinn when he designated the Quinn as the upper member of the Tertiary immediately below the Dakota sandstone on the western slope.

Cross (1892, p. 2) regarded the Quinn formation of Blair in part or at least equal to the Albion beds of the eastern slope. He (op. cit., pp. 2-3) also divided the Quinn into an upper and a lower division. To the upper division, immediately beneath the Dakota sandstone (the Quinn of Putnam), he gave the name Albion formation from exposures in the Albion valley.



in southwestern Colorado; and to the lower he gave the name La Plata sandstone from exposures in the La Plata Mountains. The La Plata sandstone consisted of two massive sandstones separated by a thin discontinuous limestone. In naming these two formations, Cross thus elevated the Gunnison to the rank of a group.

In describing the gypsum deposits of the San Jose Valley, Herrick (1904, pp. 96-97) divided the Red Beds into a lower Red Division, a middle Chocolate Division containing the gypsum at the base, and an upper Vermillion Division. He (op. cit., p. 99) correlated somewhat incorrectly his Vermillion Division with the Wingate sandstone farther to the west.

In their regional correlations, Cross and Howe (1905, p. 479) stated that Dutton's Zuni sandstones probably represented the Gunnison group but his section was not detailed enough to suggest equivalents of the McElmo and La Plata formations.

Keyes (1905, p. 424) applied the name Zuni shale to the interval between the Dakota sandstone and Wingate sandstone in western New Mexico. The next year Keyes (1906, p. 298) discarded the name Zuni shale and replaced it with the term Zunian series.

Darton (1910, pp. 44-48) suggested no correlations but simply referred to the Dakota-Wingate interval in the



in southwestern Colorado and to the west to have the name La Plata sandstone from exposures in the La Plata Mountains. The La Plata sandstone consists of two massive sandstones separated by a thin siliceous limestone. In naming these two formations, Cross thus elevated the Guntur to the rank of a group.

In describing the type section of the San Juan Valley, Herrick (1904, pp. 30-32) divided the sandstone into a lower Red Division, a middle Yellow Division containing the typical type, and an upper Vermilion Division. He (pp. 31, p. 32) correlated somewhat incorrectly his Vermilion Division with the white sandstone farther to the west.

In their regional correlations, Cross and Ross (1905, p. 479) stated that Barton's Red sandstone probably represented the Guntur group but his section was not detailed enough to suggest equivalence of the yellow and La Plata formations.

Keyes (1905, p. 434) applied the name sandstone to the interval between the white sandstone and limestone sandstone in western New Mexico. The next year Keyes (1906, p. 296) discarded the name sandstone and replaced it with the term *San Juan series*.

Barton (1910, pp. 44-45) suggested no correlation but simply referred to the Keyes-*San Juan interval* in the



Zuni Uplift as the Zuni sandstone. East of Laguna, Darton (op. cit., pp. 49-50) referred to the rock units exposed, using Herrick's names of Vermilion, Chocolate, and Red divisions of the Red Beds. Later, he (1916, p. 93) considered the green shale beneath the Dakota sandstone in the Lucero Uplift to be a probable equivalent of the Morrison formation of the eastern slope of the Rocky Mountains. Seventy miles farther west, in the Zuni Uplift, he (op. cit., p. 100) made no mention of possible Morrison equivalents but divided the Zuni sandstone into three members: an upper green and purple shale member, a middle gray sandstone, and a lower limestone and gypsum member.

Gregory (1917, pp. 59-60) extended the McElmo formation south of the San Juan River into New Mexico. This replaced the upper part of Dutton's Zuni sandstone or the part Darton had previously called his upper shale member. To the lower part of Dutton's Zuni sandstone (Darton's sandstone member), he (Gregory, 1917, p. 52) designated the Navajo sandstone from exposures in the Navajo Indian Reservation in northeastern Arizona. Gregory arbitrarily correlated his Navajo with the upper sandstone of Cross's La Plata. This application of the name Navajo to the sandstones above the Wingate in New Mexico and northeastern Arizona was an error which hampered geologists for many years. To the limestone and gypsum member of Darton at the



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 years. To the limestone and gypsum member of Barton at the



base of Dutton's Zuni, Gregory (op. cit., pp. 53-55) applied the name Todilto formation and designated its type locality as Todilto Park, New Mexico. He correlated the Todilto with the limestone of the middle La Plata. Lee (1918, pp. 21-24) used the same nomenclature as Gregory and agreed that the Navajo, Todilto, and Wingate belonged to the La Plata group. He correlated the McElmo with the Morrison of northeastern New Mexico and the Todilto with "marine Jurassic" or Carmel of Utah.

Keyes (1920, p. 252) considered his Zunian series equivalent to his Morrison series of northeastern New Mexico.

Darton (1922, p. 177) in his paper on structures in New Mexico used Gregory's nomenclature of McElmo, Navajo, and Todilto. He (op. cit., p. 184) did not find the McElmo everywhere present and considered it essentially equivalent to the Morrison formation of northeastern New Mexico. A few years later, Darton (1928, p. 129) definitely concluded that the Zuni sandstone of Dutton was a sandy western extension of the Morrison, and as Gregory had found the McElmo equivalent to the upper Zuni sandstone, McElmo was, therefore, equivalent to the Morrison. After concluding that the Morrison was equivalent to the McElmo, Darton (1928, p. 145) designated all the shale formerly called McElmo by Gregory, Morrison. Darton considered



base of Patton's (1925, p. 21-22) and Gregory (1925, p. 21-22) applied the name Tobito formation and considered the locality as Tobito Park, New Mexico. The correlation of Tobito with the thickness of the middle of the series (1918, pp. 21-22) was the same as Gregory and agreed that the name Tobito, New Mexico, was applied to the place group. The correlation of the Tobito with Morrison of northeastern New Mexico and the Tobito with "Marine Unconformity" in Canyon of Death, New Mexico. Keyes (1920, p. 21-22) considered the Tobito series equivalent to his Morrison series of northeastern New Mexico.

Darton (1922, p. 21-22) in his paper on correlation in New Mexico used Gregory's nomenclature of Tobito, New Mexico and Tobito, New Mexico. He (1922, p. 21-22) considered it essentially equivalent everywhere present and considered it essentially equivalent to the Morrison formation of northeastern New Mexico. A few years later, Darton (1925, p. 21-22) definitely concluded that the Tobito sandstone of eastern New Mexico was a western extension of the Morrison, and Gregory had found the Tobito equivalent to the western Tobito sandstone, and was, therefore, equivalent to the Tobito. After concluding that the Morrison was equivalent to the Tobito, Darton (1925, p. 21-22) suggested that the name Tobito be called Tobito by Gregory, New Mexico. Darton considered



Gregory's names of Navajo sandstone and Todilto limestone quite valid, but felt that the Navajo sandstone was equivalent only to the lower La Plata, not the upper, as Gregory had originally concluded.

Reeside (1929, p. 50) did not consider the so-called "McElmo formation" of northwestern New Mexico the exact equivalent of the Morrison formation. To substantiate his opinion, he suggested two possible correlations of the northwestern New Mexico section with southern Utah and northeastern Arizona. The first correlation was that the "McElmo" was equivalent to the Summerville and Morrison formations, the local Navajo was equal to the Entrada sandstone, and the Todilto was equal to the Carmel formation. Reeside's second correlation suggested that the "McElmo" was equal to the San Rafael group; and the Morrison and the local Navajo, Todilto, and underlying Wingate were equivalent to the whole Glen Canyon group. Mathews (1931, p. 39), also, did not accept the Morrison as a valid equivalent of Gregory's McElmo in New Mexico.

Renick (1931, p. 34) considered the Navajo sandstone absent in western Sandoval County, New Mexico, and believed that the Morrison formation rested directly on the underlying Todilto formation. He (op. cit., pp. 32-34) divided the Morrison into three members: an upper shale member, a middle sandstone member, and a lower shale



Gregory's names of Navajo sandstone and Todilto limestone quite valid, but felt that the Navajo sandstone was confined only to the lower in Utah, and the upper, as Gregory had originally concluded.

Reeside (1929, p. 30) did not consider the so-called "Mexican formation" of northwestern New Mexico the exact equivalent of the northern formation. In his opinion, he suggested two possible correlations of the northwestern New Mexico section with the southern Utah and northeastern Arizona. The first correlation was that the "Mexican" was equivalent to the Navajo and sandstone formations, the local Navajo was equal to the Navajo sandstone, and the Todilto was equal to the Canyon sandstone. Reeside's second correlation suggested that the "Mexican" was equal to the San Rafael group, and the Navajo and the local Navajo, Todilto, and underlying strata were equivalent to the whole San Rafael group. Gregory (1931, p. 39), also, did not accept the correlation as valid. Equivalent of Gregory's Mexican in New Mexico. Reeside (1931, p. 34) considered the Navajo sandstone absent in western San Juan County, New Mexico, and believed that the northern formation rested directly on the underlying Todilto formation. In (1931, p. 34-35) divided the northern into three sections: an upper sandstone member, a middle sandstone member, and a lower sandstone member.



member.

Although Sears was primarily interested in the Cretaceous coal fields, he (1934, pp. 9-10) measured a section at Navajo Church, using Gregory's nomenclature of McElmo, Navajo, and Todilto, and noted that Baker, Dane, and Reeside planned to revise that terminology.

In 1936, Baker, Dane, and Reeside completely revised the correlation of Jurassic formations of the Colorado Plateau. In northwestern New Mexico they (1936, p. 44) considered the entire interval, from the base of the Dakota sandstone through the Todilto limestone, as belonging to the Morrison. They designated Gregory's McElmo as an upper shale member, the Navajo as a middle sandstone member, and classed the Todilto as a limestone member at the base of the formation.

Following this new definition of the Morrison, Gregory proposed names for the members he had mapped in southeastern Utah. He (1938, pp. 58-60) named the members, in descending order, as follows: Brushy Basin shale, Westwater Canyon sandstone, Recapture shale, and the Bluff sandstone. Previous to Gregory's work, Lupton (1914, p. 127) had found a prominent sandstone at the base of the McElmo formation in Grand County, Utah, which he named the Salt Wash sandstone member of the McElmo. Since the Salt Wash sandstone occurred at the base of a thick variegated shale



member.

Although Beers was primarily interested in the lower Tertiary coal fields, he (1934, pp. 2-10) measured a section at Navajo Church, using Gregory's nomenclature of Navajo, Havalto, and Tobilto, and noted that Havalto, Havalto, and Tobilto planned to revise that terminology.

In 1936, Baker, Lane, and Beardsley completely revised the correlation of Tertiary formations of the Colorado Plateau. In northwestern New Mexico they (1936, p. 1) considered the entire interval from the base of the Permian sandstone through the Tobilto limestone as representing the Morrison. They designated Gregory's Navajo as an upper shale member, the Havalto as a middle sandstone member, and classed the Tobilto as a massive member at the base of the formation.

Following this new definition of the Morrison, Gregory proposed names for the Navajo he had assigned in northern eastern Utah. He (1936, pp. 58-60) named the members, in descending order, as follows: (1) Havalto shale, (2) Havalto sandstone, (3) Havalto shale, and (4) Havalto sandstone. Previous to Gregory's work, Lipson (1914, p. 127) had found a prominent sandstone at the base of the Tobilto formation in Grand County, Utah, which he named the Wash sandstone member of the Havalto. Since the Havalto sandstone occurred at this base, it is fairly certain that



in the upper part of the Morrison, Gregory (op. cit., p. 59) concluded that the Salt Wash sandstone was included in what he called the Westwater Canyon sandstone. Actually, it was included in the base of his Recapture.

Goldman and Spencer, in studying the correlations of Cross's La Plata sandstone, described primarily the basal Morrison and underlying beds. They (1941, pp. 1749-1791) named the members of the basal Morrison in the San Juan Mountains in southwestern Colorado, in descending order: the Junction Creek sandstone, Wanakah marl, Bilk Creek sandstone, and the Pony Express limestone. Only Junction Creek and Bilk Creek were new terms. The name Pony Express beds had been used earlier by Irving (1905, p. 56) to designate the basal beds of the McElmo in the Ouray mining district. The Wanakah marl member was a restriction of Burbank's Wanakah member of the Morrison. As Burbank (1930, pp. 172-174) had originally defined the Wanakah, it consisted of the basal shale portion of Cross's McElmo, the entire Upper La Plata sandstone of Cross and the shale, limestone, and breccia known as the Pony Express beds. Goldman and Spencer's Wanakah marl included only the shale unit of the original description. At Navajo Church, New Mexico, Goldman and Spencer (op. cit., p. 1761) found, overlying the Todilto limestone, equivalents of their Wanakah marl and Junction Creek sandstone, which



in the upper part of the formation, Gregory (1911, p. 59) concluded that the 21st sandstone was included in what he called the Western Canyon sandstone. Actually, it was included in the base of the Hesperian. Goldsmith and Spencer, in studying the correlation of Cross's 13 plate sandstone, described initially the basal Morrison and then the 21st sandstone. They (1934, pp. 174-179) named the members of the basal Morrison in the San Juan Mountains in southwestern Colorado, in ascending order: the Junction Creek sandstone, Canyon Creek, Bill Creek sandstone, and the Pony Express limestone. The name Junction Creek and Bill Creek were new terms. The name Pony Express beds had been used earlier by Irving (1905, p. 56) to designate the basal beds of the Hesperian in the Gray mining district. The name was not used as a restriction of Cross's Hesperian member of the Morrison as Burruss (1910, pp. 172-174) had originally defined the Wenatchee, it consisted of the basal beds of the Hesperian. The entire upper 13 plate sandstone of Cross and McElme, the shale, limestone, and breccia known as the Pony Express beds. Goldsmith and Spencer's Hesperian sand included only the shale unit of the original description. At Navajo, Church, New Mexico, Goldsmith and Spencer (pp. 174-175) found, overlying the fossiliferous limestone, equivalents of their Wenatchee and Junction Creek sandstone, which



they considered the true equivalent of the Upper La Plata. In the extreme northwestern corner of New Mexico, at Beclabito Dome, Goldman and Spencer (op. cit., p. 1761) considered Gregory's Bluff sandstone member of the Morrison equivalent to their Junction Creek sandstone, and the underlying Summerville formation of Baker, Dane, and Reeside equivalent to their Wanakah marl. Because the so-called "Todilto" of Beclabito Dome rested on the Entrada sandstone instead of on the sandstone called Wingate farther south at the type locality, Goldman and Spencer considered it an equivalent of the Pony Express member and not Todilto.

Following the demand for uranium and vanadium brought on by World War II, a detailed mapping of Jurassic rocks of the Colorado Plateau took place. As many of the mineral deposits are in the Morrison and related strata, many stratigraphic relationships were worked out. Fischer (1942, p. 368), in a preliminary report, stated that the Summerville formation was, in part, equivalent to the Wanakah member in southwestern Colorado.

In 1944, Stokes found in his regional study of the Morrison that the Salt Wash sandstone member was not equivalent to the Westwater Canyon member as Gregory had assumed. Stokes (1944, pp. 962-965) found the Salt Wash sandstone at the base of the Recapture shale and was able to







differentiate the Brushy Basin shale, Westwater Canyon sandstone, Recapture shale, and Salt Wash members in the Beclabito Dome area. In the Beclabito Dome area (op. cit., pp. 958-960), he correlated Gregory's Bluff sandstone member of the Morrison with the upper part of the Entrada sandstone, and the underlying Summerville and Todilto formations with the rest of the Entrada and the Carmel formation.

Kelley and Wood (1946), working in an area remote from any named member of the Morrison, proposed local lithologic names for members of the Morrison in the Lucero Uplift area. They designated the members, in descending order, as the Variegated shale, White sandstone, Brown-buff sandstone, and Buff shale members and regarded the Todilto as a separate formation and not a member of the Morrison.

As a result of the work by Heaton (1939), Goldman and Spencer (1941), Stokes (1944) and other workers, Baker, Dane, and Reeside found that Dutton's type Wingate sandstone was equivalent to the Entrada sandstone of Utah and Colorado. Although Dutton's name, Wingate, clearly had priority over the name Entrada they believed it would be unfortunate and confusing to replace the Wingate sandstone of Utah and Arizona belonging to the Glen Canyon group with a new name. Therefore, Baker, Dane, and Reeside abandoned the Fort Wingate type locality of Dutton and named the "Wingate" sand-



differentiate the Brushy Basin shale, Westwater Canyon sandstone, Bessemer shale, and Salt Wash members in the Bessemer Dome area. In the Bessemer Dome area (pp. 211, pp. 228-260), he correlated Gregory's Flint sandstone member of the Morrison with the upper part of the Hagerman sandstone, and the underlying Hagerman and Toddlite formations with the rest of the sandstone and gravel layers.

Kelley and Wood (1946), working in an area remote from any named member of the Morrison, proposed local lithologic names for members of the Morrison in the Lower Ogallala area. They designated the members, in descending order, as the Variegated shale, white sandstone, brown-buff sandstone, and buff shale members and regarded the Toddlite as a separate formation and not a member of the Morrison.

As a result of the work by Hooton (1939), Goldman and Spencer (1941), Beckes (1944) and other workers, Baker, Dane, and Hooton found that Hooton's type Winkate sandstone was equivalent to the Hagerman sandstone of Utah and Colorado. Although Hooton's name, Winkate, clearly was inferior over the name Hagerman they believed it would be unfortunate and confusing to replace the Winkate sandstone of Utah and Arizona belonging to the Glen Canyon group with a new name. Therefore, Baker, Dane, and Hooton abandoned the term Winkate type locality of Hooton and named the "Winkate" sand-



stone of New Mexico the Entrada. Baker, Dane, and Reeside (op. cit., p. 1668) also regarded the Todilto not as a limestone member of the Morrison but as a limestone member of the Wanakah which they raised to formation rank.

Webber (1949) who, as chief geologist for the Union Mines Development Corporation, headed the evaluation of the uranium resources of the Salt Wash sandstone member of the Morrison, during 1943 through 1946 for the Manhattan Project, used Gregory's members of Brushy Basin shale, Westwater Canyon sandstone, Recapture shale, in addition to the Salt Wash sandstone in the part of the exploration which extended into the extreme northwestern corner of New Mexico. However, Union Mines geologists incorrectly mapped the Bluff sandstone as Entrada and the Summerville, Todilto, Entrada, and Carmel formations as all Carmel in the same area.

Eckel (1949, p. 29) considered the Junction Creek sandstone as a separate formation and not as a member of the Morrison. Soon afterwards, Read, Wood, Wanek, and Mackee (1949) considered the Junction Creek sandstone a member of the Wanakah instead of a separate formation or as belonging to the Morrison.

Smith (1952), while supervising the New Mexico School of Mines summer geology field camps in the Zuni Mountains in 1949 and 1950, mapped the members of the



stone of New Mexico the latter, Baker, Baker, and Henshaw  
(op. cit., p. 1968) also regarded the formation as a  
limestone member of the Morrison and as a limestone member  
of the Kanab which they related to limestone.  
Webster (1949) who, as chief geologist for the United  
States Development Corporation, headed the expedition of  
the uranium resources of the Salt Lake area, considered  
the Morrison, during 1948 through 1950 for the uranium  
project, used Webster's name for the formation.  
Westwater Canyon sandstone, Kanab area, is related  
to the Salt Lake sandstone in the part of the formation  
which extended into the extreme northwest corner of  
Mexico. However, other than geologists, Webster and  
the Salt Lake sandstone as a whole and the Kanab area,  
Kanab, and Capitol Reef formations as a whole in the  
area.

Rebel (1949, p. 29) considered the Kanab area  
sandstone as a separate formation and not as a member of  
the Morrison. Some of the same, but not all, and  
Mackee (1949) considered the Kanab area sandstone as  
member of the Kanab which is a separate formation of  
as belonging to the Morrison.

Smith (1952), while describing the Kanab area  
School of Mines summer geological field party in the  
Morrison in 1949 and 1950, named the member of the



Morrison as the Brushy Basin shale, the Prewitt sandstone, and the Chaves member. The latter two were local names applied because Gregory's members were not recognizable. To the remaining interval between the base of the Morrison and the Todilto formation, Smith applied the name Thoreau formation and considered it a possible Summerville equivalent.

The editors (Colbert, Northrop, Romer, and Simpson) of the guidebook of the fourth field conference of the Society of Vertebrate Paleontology preferred to retain the name Wingate as originally designated, rather than use the name Entrada (Northrop, 1950, p. 36). They also (Northrop, op. cit.) regard the Todilto of northwestern New Mexico as of formational rank.

Hoover (1950, pp. 77-80), in the Four Corners area, likewise found a Summerville equivalent. To the interval between the Bluff sandstone and the Entrada sandstone Hoover gave the name Red Mesa formation and considered it equivalent to the Pony Express limestone, Bilk Creek sandstone, and the Wanakah marl of Goldman and Spencer. Wright and Becker (1951, pp. 611-613) also found a Summerville equivalent quite extensive in the Defiance Monocline. Here, the Todilto is quite well developed and they considered it a separate formation below their Summerville formation.



Morrison as the primary Basin stage, the Prowler and the Chaves member. The latter two were local names applied because Gregory's reports were not recognizable. To the remaining interval between the base of the Morrison and the Tobilite formation, Smith applied the name Thompson formation and considered it a distinctively Thompsonian lent.

The editors (Colbert, Leachman, and others) of the *Guidebook of the Fourth Great American Desert* of the Society of Vertebrate Paleontology preferred to retain the name Wingate as originally designated, rather than use the name Laramie (Morrison, 1900, p. 10). They also (Morrison, 1900, p. 11) regard the Tobilite of northwestern New Mexico as of Tobilite rank.

Hoover (1950, pp. 75-80), in the *Four Corners area*, likewise found a summary of evidence. To the interval between the Tobilite and the Laramie, Hoover gave the name Red Mesa formation and considered it equivalent to the Fort Laramie formation. Williston and Stone, and the Wankarem of Goldman and Brown, and Becker (1951, p. 61-62) also found a summary of evidence. Here, the Tobilite is quite well developed and they considered it a separate formation below the Laramie formation.



Recently, Harshbarger, et al. have extended Gregory's other members of the Morrison--Westwater Canyon sandstone, Recapture shale, and Bluff sandstone--into the Fort Wingate-Thoreau area by continuous mapping along the Defiance Monocline. In doing this mapping, they (Harshbarger, et al., 1951, pp. 97-98) incorporated a new formation because of the sand facies to the west. This sandstone has been named the Cow Springs sandstone from exposures near Cow Springs, Arizona. It has been found to intertongue in the lower part with Summerville equivalents, in the middle with the Bluff sandstone member of the Morrison, and in the upper part with the Recapture shale member of the Morrison.

The New Mexico Geological Society (1951, p. 13) replaced the Variegated shale member of Kelley and Wood with the name Brushy Basin, and retained the names White and Brown-buff sandstone members. It is thought, however, (op. cit., p. 19) that the Brown-buff sandstone may be equivalent to the Bluff sandstone of the Four Corners area and that the Buff shale member of Kelley and Wood is very probably a Summerville equivalent and is tentatively called the Red Mesa formation of Hoover.

Craig, et al. (1951) in their regional study of the Morrison formation extended the use of Gregory's nomenclature of the Brushy Basin shale, Westwater Canyon sandstone, Recapture shale, and Bluff sandstone members rather



Recently, Hatcher, et al. have extended Gregory's

other members of the Morrison--Westonian Canyon sandstone,

Receptance shale, and Bitter sandstone--into the Fort Union

gate-threshold area by continuous mapping along the Helina

Monocline. In doing this mapping, they (Hatcher, et al.,

1951, pp. 97-98) incorporated a new formation because of

the sand facies of the west. This sandstone has been

named the Cow Springs sandstone. It is named after Cow

Springs, Arizona. It is here found to interdigitate in the

lower part with Summerville sandstone, in the middle with

the Bitter sandstone member of the Morrison, and in the

upper part with the Receptance shale member of the Morrison.

The New Mexico Geological Society (1951, p. 13) has

placed the variegated shale member of the Fort Union and west with

the name Shinarump Basin, and retained the name Bitter and

Brown-bell sandstone members. It is thought, however,

(op. cit., p. 13) that the Brown-bell sandstone may be

equivalent to the Bitter sandstone of the Fort Union area

and that the Bitter shale member of the Fort Union is very

probably a Summerville equivalent and is tentatively called

the Red Mesa formation of Hoover.

Craig, et al. (1952) in their regional study of the

Morrison formation extended the use of Gregory's nomen-

clature of the Shinarump Basin shale, Receptance shale, and

stone, Receptance shale, and Bitter sandstone members rather



arbitrarily to include all of western New Mexico. Following Eckel (1949, p. 29) they consider the Bluff sandstone a separate formation.

Very recently, Imlay (1952), in his Jurassic correlation chart of North America, referred to the sandy phase of the Morrison in the Fort Wingate area as the Zuni sandstone and to the interval between the base of the Morrison and the top of the Entrada as the Wanakah formation which contains the basal Todilto limestone member.

As this summary of the nomenclature indicates, continual interest in the Morrison formation has resulted in the accumulation of a large amount of literature concerning it. Mook (1916) reviewed the previously published literature on the Morrison. Baker, Dane, and Reeside (1936) reviewed all the Jurassic literature of the Colorado Plateau and the southern Rocky Mountains, which included the Morrison literature of northwestern New Mexico. Stokes (1944) continued the review and evaluation of the literature. Since 1944 no general summary of the literature has been published.

#### Nomenclature as Applied to the Area Studied

The names of the various Jurassic formations, particularly the members of the Morrison in northwestern New Mexico, has always been a subject of much controversy. Detailed mapping of the formations has resulted from the



arbitrarily to include all of the ...  
ing (1949, p. 29) they consider the ...  
a separate formation.

Very recently, (1951), in his ...  
chart of North America, ...  
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and to the interval between the base of the ...  
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As this summary of the ...  
of interest in the ...

accumulation of a large amount of ...  
Book (1956) reviewed the ...  
on the ...

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continued the review ...  
Since 1944 no general ...

published.

Homocidus as applied to ...

The names of the various ...  
whatly the members of the ...  
Mexico, has always been a ...  
Detailed mapping of the ...



exploration for uranium. In the Zuni and Lucero Uplifts, as well as in the Acoma embayment which lies between the two uplifts, the controversy centers upon what to designate as members of the Morrison. Federal geologists with the Geological Survey and the Atomic Energy Commission who usually have had experience in the Four Corners area of the Colorado Plateau have used Gregory's Utah nomenclature for convenience in field work and mapping because of the similarity of the lithologic units in the Grants area of northwestern New Mexico.

Stratigraphers within the state, such as Smith, Kelley, Wood, and others, believe that although lithologic divisions are similar in southeastern Utah and northwestern New Mexico, the relationships are not such as to warrant the use of Utah nomenclature in New Mexico, and hence wish to apply local names. Along the northern flank of the Zuni Uplift, Smith (1952) has divided the Morrison; in descending order, into the Brushy Basin shale, Prewitt sandstone member, and the Chaves member. Because the Brushy Basin is the most widespread member of the Morrison it was retained, whereas the other two are local names. Geologists of the Geological Survey and the Atomic Energy Commission call Smith's Prewitt sandstone member the Westwater Canyon sandstone member and his Chaves member the Recapture shale member.

Direct correlation between the Morrison units of the



exploration for uranium. In the past the uranium industry  
as well as in the geologic surveys which have been made  
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have as members of the geologic surveys, the geologic surveys  
the geologic surveys and the geologic surveys, the geologic surveys  
who usually have had experience in the geologic surveys  
of the Colorado Plateau have made the geologic surveys  
elaborate for convenience in the geologic surveys, the geologic surveys  
of the similarity of the geologic surveys, the geologic surveys  
area of northwestern New Mexico.  
Geologists within the geologic surveys, the geologic surveys  
Wood, and others, believe that a geologic survey of the geologic surveys  
are similar in northwestern New Mexico and northwestern New Mexico  
the relationships are not such as to warrant the geologic surveys  
Utah nomenclature in northwestern New Mexico and northwestern New Mexico  
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Smith (1952) has divided the geologic surveys, the geologic surveys  
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whereas members of the geologic surveys, the geologic surveys  
the other two are local names. The geologic surveys, the geologic surveys  
can survey and the geologic surveys, the geologic surveys  
Preston and others, the geologic surveys, the geologic surveys  
member and the geologic surveys, the geologic surveys  
Direct correlation between the geologic surveys, the geologic surveys



northern flank of the Zuni Uplift and those exposed to the east in the Acoma and Lucero regions is hampered by the intervening McCartys syncline, where the Morrison rocks disappear about 6 miles southeast of Grants and then reappear to the east near Acomita. Outcrops are fairly continuous from the Acoma area to the Lucero region. Detailed work by Rapaport, et al. (1952) and later by the writer and other members of the Grants office of the U. S. Atomic Energy Commission has clearly demonstrated that the Variegated shale member of Kelley and Wood is stratigraphically and lithologically equivalent to the Chaves member of Smith (Recapture shale member of the USGS and AEC) of the Zuni Uplift.

North of the area studied by Kelley and Wood and overlying their Variegated shale member is a massive, white, cliff-forming, cross-laminated, fluviatile sandstone belonging to the Morrison formation (Pl. 3 A.). Because it was removed in the south part of the area, probably by pre-Dakota erosion, it has never actually been given a local name as have other members of the Morrison in this region. This sandstone may be correlated with the Prewitt sandstone member of Smith (Westwater Canyon member of the USGS and AEC) in the northern flank of the Zuni Uplift. The presence of this sandstone definitely substantiates the writer's opinion that the Variegated shale member of



northern flank of the ...  
the east in the ...  
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rocks disappear about ...  
then respond to the ...  
fairly continuous ...  
Detailed work by ...  
writer and other ...  
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Variegated shale ...  
only and lithologically ...  
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cliff-forming, cross-bedded ...  
length to the ...  
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pre-Dakota ...  
local name ...  
region. This ...  
sandstone ...  
USGS and ...  
The presence of ...  
the writer's opinion ...



Kelley and Wood is older than the Brushy Basin shale to which some writers thought it was equivalent. Further aspects of this sandstone will be discussed later in this thesis.

#### Variegated Member

The Variegated member was originally designated as a shale member of the Morrison by Kelley and Wood (1946), although fissile shale is conspicuously rare within the member. In spite of the fact that this unit may be correlated with the recently designated Chaves member in the north flank of the Zuni Uplift, field geologists of the Atomic Energy Commission and the Geological Survey currently designate it as the Recapture shale member. However, in this thesis the unit is referred to as the Variegated member in order to have some means of identification without adding more to the confusion of the nomenclature.

#### Outcrops

Outcrops of the Variegated member occur in an irregular pattern throughout the area studied (Fig. 1). Except in the Lucero Uplift and along the Ignacio monocline the beds are nearly flat-lying as the regional dip is  $1^{\circ}$ - $3^{\circ}$  NNW. Hence the outcrops are usually along mesa slopes instead of valley bottoms as would be the case with steeper dips. In the northern part of the area studied the Variegated



Kelley and Wood is older than the Variegated member which some writers thought it was younger than the Variegated member. This conclusion will be discussed later in the thesis.

#### Variegated Member

The Variegated member was originally designated as shale member of the formation by Kelley and Wood (1932) although fissile shale is characteristic of the Variegated member. In spite of the fact that this shale may be correlated with the recently designated Variegated member of the North Line of the Appalachian Field, the Variegated Atomic Energy Commission and the Geological Survey are recently designated as the Variegated member. However, in this thesis the Variegated member is referred to as the Variegated member in order to have uniformity of designation with out adding more to the confusion of the nomenclature.

#### Outcrops

Outcrops of the Variegated member occur in an irregular pattern throughout the area studied (Fig. 1). The Variegated member is the lacustrine shale and along the Variegated member are nearly flat-lying in the region of the Variegated member. Hence the outcrops are vertically elongated near the Variegated member and are vertically elongated near the Variegated member. In the northern part of the area studied the Variegated member is the Variegated member.



member dips underground as a result of the regional dip. Outcrops form steep convex outward slopes consisting of light-green, purple, cream, and maroon color-banding. These slopes are littered with talus material from the overlying Dakota group. Complete exposures are exceedingly difficult to find due to the large amount of slumping that has taken place within the shale. This particular kind of landslide has been given the name Toreva-block by Reiche (1937). He described them from large examples in north-central Arizona and noted their occurrence in and near the Laguna Indian Reservation in New Mexico (Reiche, 1937, pp. 546-547). Reiche (op. cit., p. 538) described a Toreva-block as a "landslide consisting essentially of a single large mass of unjostled material which, during descent, has undergone a backward rotation toward the parent cliff about a horizontal axis which roughly parallels it". These blocks are extremely common, occurring wherever the Variegated member is exposed in the area and greatly obscuring the outcrops of it.

### Lithology

The member is a sequence of claystone and siltstone with interbedded lenticular sandstone and a few thin limestone beds (Fig. 4, in pocket).

Claystone comprises the greater part of the member. The beds are multicolored in shades of cream, light-green,



member dips northward at an angle of about 10° to 15°. Outcrops form the top of the hill, and are light-green, purple, and brown. These slopes are covered with a thin layer of overlying Dakota sand. It is difficult to find any trace of the sandstone which has taken place within the hill. This part of the of landslide has been given the name of "Helm's (1937)". The described sandstone is north-central Arizona and was found in 1937 near the Laguna Indian Reservation. (1937, pp. 240-241). A 1000-foot thick sandstone block is a single large mass of sandstone, and is described as being underlain by a sandstone parent cliff about 100 feet high. This block is about 100 feet high. The Variegated member is composed of sandstone and siltstone obscuring the outcrop of the sandstone.

Lithology

The member is composed of sandstone and siltstone with interbedded sandstone and siltstone. The sandstone beds (No. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100) are composed of sandstone and siltstone. The beds are well-bedded and are composed of sandstone and siltstone.



greenish-gray, purple, and maroon. The color bands grade imperceptibly into one another. Shades of maroon and purple are more common in the lower part of the member and the cream, green, and gray are found in the upper part (Pl. 3A.). A few of the beds, particularly in the upper part, are bentonitic. The claystone produces a variegated outcrop for which the member is well known throughout the area. Where the claystone is bentonitic, weathering produces a slope commonly called "elephant hide" because of its rough, irregular, hard character.

The sandstone within the member generally constitutes about 20-25 per cent of the total thickness of the unit, but toward the south the sandstone makes up as much as 50 per cent of the total thickness. Sandstone beds in the member are generally obscured by the slope cover produced on the claystones. Where they are exposed they stand as small ledges in the slope. Following the current usage among many field geologists, who are working on the continental Triassic and Jurassic sediments of the Colorado Plateau, the sandstone may be described as cross-laminated instead of cross-bedded. The term bedding is thus restricted to the total nearly horizontal, layer (Fig. 6). Bedding planes are commonly marked by very thin seams of light-green or purple claystone. At the base of many of the cross laminations are "pockets" of coarse material



greenish-gray, purple, and brown. The color is  
imperfectly into one another. The color is  
purple and brown and the color is  
and the green, green, and gray and brown and brown and  
(Pl. 3A.). A few of the beds, particularly in the lower  
part, are banded. The strata are banded and  
outcrop for which the member is well known. The  
area. The strata are banded and the  
duces a slope commonly called a "steep" and  
the rough, irregular, and irregular.  
The sandstone within the member is generally  
about 20-25 per cent of the total thickness of the  
but toward the south the sandstone is more  
per cent of the total thickness. The sandstone is  
member are generally composed of the same  
on the claystone. The sandstone is composed of  
small beds in the slope. The sandstone is  
among the field geologists, who are working on the con-  
mental Triassic and Jurassic beds of the  
Platte, the sandstone may be described as a  
instead of cross-bedded. The sandstone is  
attributed to the local (local) sandstone, and is  
Bedford planes are commonly marked by thin  
light-green or white sandstone. At the base of each of  
the cross sandstone is a bed of sandstone.



consisting of granules, pebbles, etc. which are called scour zones.

The sandstone may be tan, grayish-white, or yellowish-brown and is usually composed of very fine to medium-grained, subrounded, moderately sorted quartz with some feldspar. Graded bedding in which the size of the material decreases upward is also common. In the scour zones within the sandstone may be found coarse, to very coarse, angular and subangular quartz and feldspar grains and subangular and subrounded granules and pebbles of quartz, chert, feldspar, and granitic material. Many of these sandstone beds contain much interstitial kaolin. According to Leopold (1943, pp. 61-62) kaolinization in the upper part of the Morrison indicates that a moist climate prevailed during a part, at least, of the time between the deposition of the Jurassic and the overlying Cretaceous, and has resulted from the decomposition of feldspar.

Cementation of the sandstone varies considerably. The majority of the sandstone beds are well cemented with calcite. Other cements, although somewhat uncommon, include silica, limonite, and clay. The coarser beds, particularly those containing granules and pebbles, are practically unconsolidated and show almost no cementation.

The sandstone beds within the Variegated member are characterized by their lenticular nature. In thicker



consisting of granular, reddish-brown, and  
some zones.

The sandstone may be of two kinds, one of which is  
brown and is usually composed of rounded grains, and the other  
is unrounded, more or less angular, and is usually  
graded bedding in which the size of the grains increases  
upward is also common. In the second case, the sandstone  
may be found coarse, to very coarse, angular and  
angular grains and is often called a "conglomerate"  
subrounded granules and pebbles of quartz, feldspar,  
and granitic material. Some of these pebbles may be  
seen much interstitially. In some cases, the pebbles  
pp. 61-62) (localization in the upper part of the section  
indicates that a major change occurred during the  
at least, of the time between the deposition of the  
massic and the overlying conglomerate, and the period of  
the decomposition of the latter.

Composition of the sandstone varies considerably. The  
majority of the sandstone beds are well cemented and contain  
Other cements, all of which are unknown, including silica,  
limonite, and clay. The cement is usually brownish, and  
contains granules and pebbles, and is usually  
dated and shows almost no cementation.  
The sandstone beds are also well cemented and are  
characterized by their limonitic nature, and are



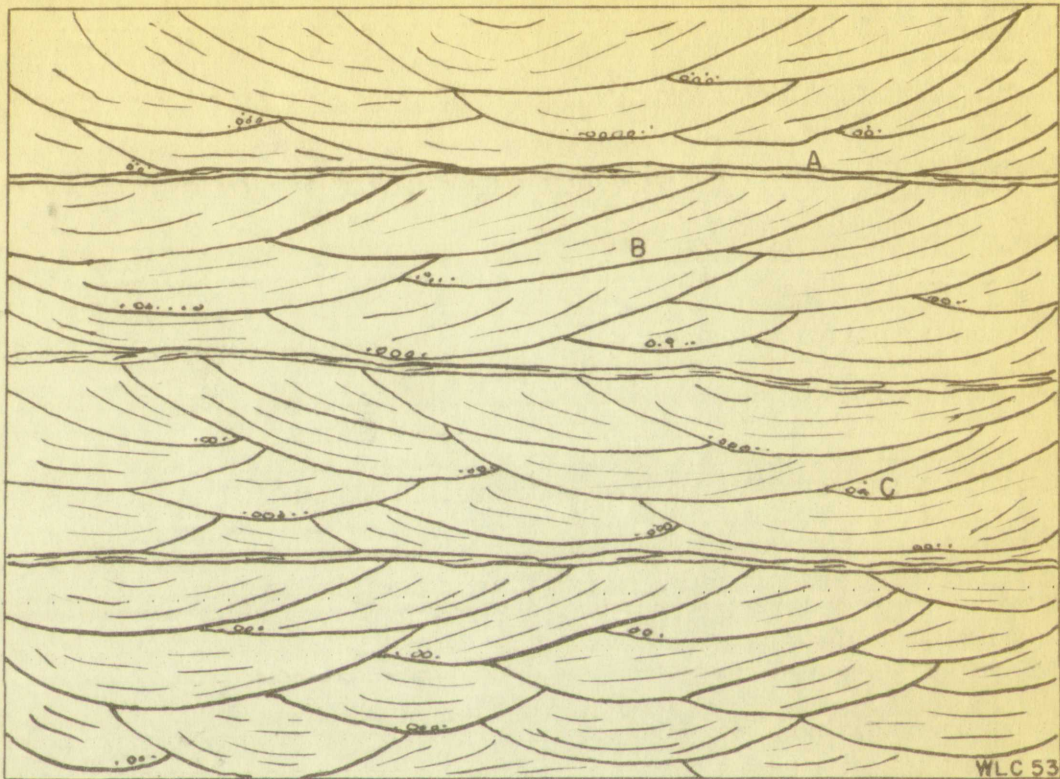
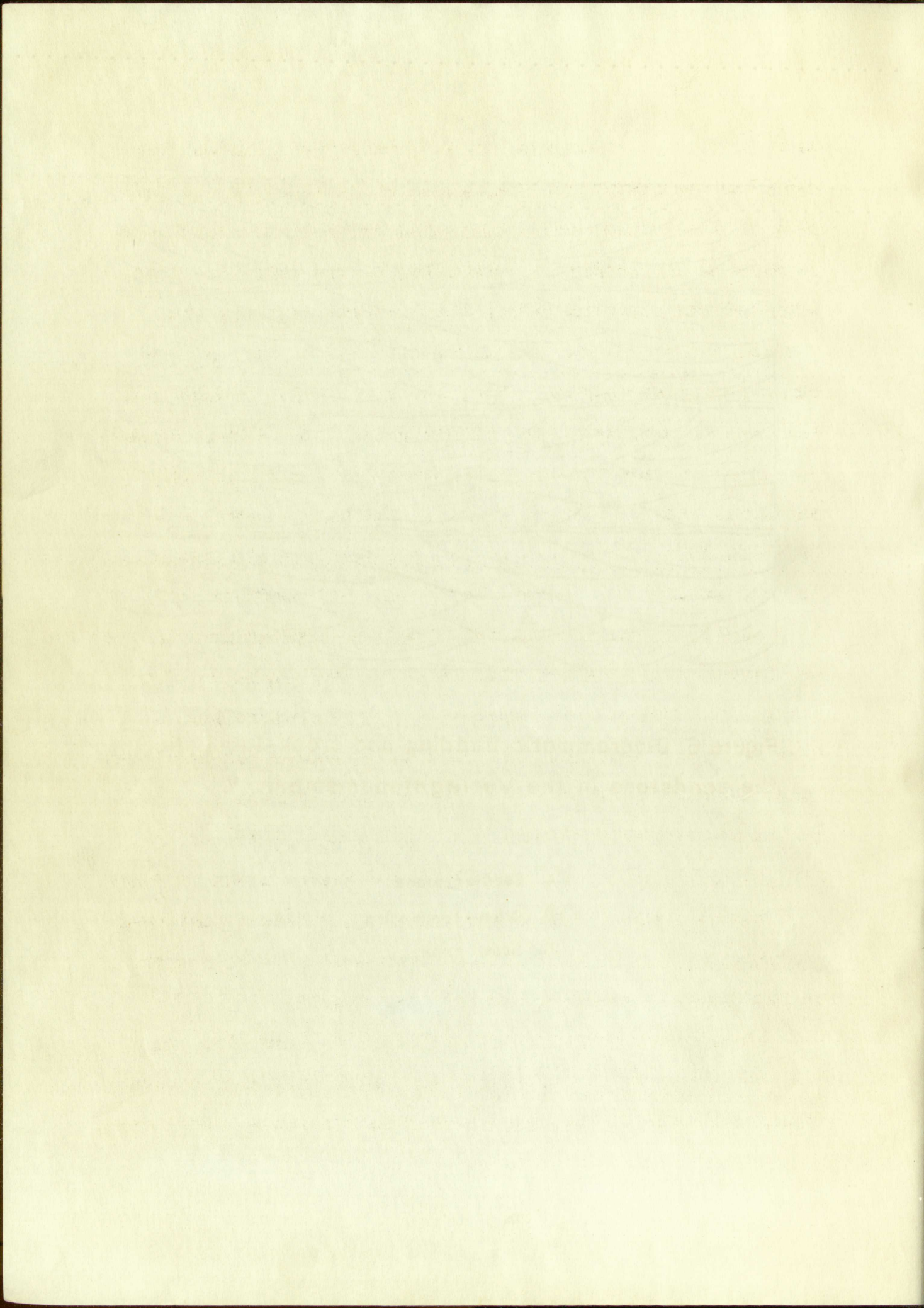


Figure 6. Diagrammatic bedding and cross-lamination in the sandstone in the Variegated member.

- A. Bedding plane
- B. Cross-lamination
- C. Scour zone







sandstone units there are almost always intercalated green claystone stringers and clay galls which separate the bedding of the thicker cross-laminated units of the sandstone. Because of the lenticular character of the sandstone units detailed correlations within the measured sections are virtually impossible. Actual walking out of many of the thick sandstone beds has, time and time again, established that these units lense out within a few hundred feet along the outcrop. However, a small, prominent, cliff-forming sandstone (no. 8) near the base of the Laguna section (Pl. 3A.) may have equivalents to the northeast in the Concho Springs (no. 2) and Herrera Ranch (no. 11) sections (Fig. 4). As a sandstone bed pinches out, there is both an increase in the thickness of the interbedded claystone stringers along the bedding planes and a gradation into siltstone and finally into claystone. As a sandstone wedges out the lower units commonly lense out first so the bed appears to rise in the section as it lenses out. Where the pinch out is abrupt, the exposure is probably a transverse cross section of a stream channel, but where the pinch out is gradational the exposure may be more or less longitudinal with respect to the trend or course of the stream deposit.

Limestone within the member occurs as individual beds 6 to 12 inches thick and consists of dark gray microcrystalline and finely crystalline arenaceous limestone. Weathering



sandstone units found and which have been  
claystone stringers and clay shale which separate the sand-  
stone of the higher order-laminated units of the sandstone.  
Because of the fossiliferous character of the sandstone units  
detailed correlations within the measured section are  
virtually impossible. It will be one of the  
thick sandstone beds in the measured section, estimated  
that these units extend out within a few hundred feet along  
the outcrop. However, a small, fragmentary, fossiliferous  
sandstone (no. 3) near the base of the measured section (no.  
3A.) may have equivalence to the measured section in the  
Springs (no. 2) and between sections (no. 1) and (no. 4).  
As a sandstone bed pinches out, there is both an increase in  
the thickness of the interbedded claystone and siltstone along  
the bedding planes and a general increase in the thickness  
finally into claystone. As a sandstone bed pinches out, the lower  
units commonly pinch out first on the bed planes and then  
in the section as it pinches out. Thus the thin bed is  
abrupt, the exposure is marked by a sharp, irregular section  
of a stream channel, but there is a general increase in the thickness  
the exposure may be marked by a sharp, irregular section  
to the trend of course of the stream bed.

Limestone with a fossiliferous character, 6 to 12 inches thick and occurs on the surface of the measured  
line and finely crystalline and fossiliferous limestone.



commonly bleaches the exterior of the limestone to a very light chalky color. Calcite seams and clusters are common along bedding planes and joints in many of the exposures. Where the limestone is argillaceous it is commonly purple or grayish-purple and more lenticular. When more limestone than usual is found in a section, it is usually present near the base of the member.

### Thickness

The Variegated member ranges from a maximum measured thickness of 379 feet in the Concho Springs section (Sec. 14, T. 10 N., R. 4 W.)\* to a featheredge in T. 8 N., 14 miles to the south. This thinning is due to truncation by a pre-Dakota erosion surface and gradation into the underlying Bluff sandstone (Fig. 5, in pocket). As would be expected, greater thicknesses occur where the overlying sandstone member is present. The thinning of the member to the northeast appears to be due to over-all decrease of deposition that would normally be expected farther from the source area, rather than from the thinning or lensing out of individual units. Irregularities on the top of the Bluff and differential compaction of the finer constituents of the member account for some variations in the thickness of the Variegated member.

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\*All locations in this thesis refer to the New Mexico Principal Meridian and Baseline.



commonly places the extent of the limestone a very light chalky color. Caliche veins and clasts are common along bedding planes and joints in many of the exposures. Where the limestone is argillaceous it is commonly pinkish or grayish-purple and more lustrous. Thin beds of limestone than usual is found in a section, it is usually not sent near the base of the member.

# Thickness

The Variegated member ranges from a maximum measured thickness of 375 feet in the Genoa Shinarump section (Sec. 14, T. 10 N., R. 4 E., S. 37) to a thickness of 100 feet in the south. This change is due to truncation by a fault. Dakota erosion surface and gradation. Bluff sandstone (Fig. 2, in pocket). In some places greater thicknesses occur where the overlying sandstone member is present. The thinning of the member to the northeast appears to be due to over-all decrease of deposition that would normally be expected farther to the north. This is rather than from the thinning or lessening out of individual units. Irregularities on the top of the Bluff sandstone differential compaction of the thin sandstone of the member account for some variations in the thickness of the Variegated member.

\*All locations in this report are in the Shinarump section, principal section and standard.



### Stratigraphic Relationships

The convergence of the Variegated member within the area was first mapped by Darton (1922, pl. 48), who later (1928a, pp. 121-122) briefly described it. He considered this feature, in the western part of the area, to be due, probably, to pre-Dakota erosion. Near Suwanee, because the Variegated member varied in thickness, Darton (1928a, p. 122) noted that it "appears to grade down into a soft white sandstone 30 to 80 feet thick". Although no specific locality was mentioned, it is quite possible that Darton had in mind the Mesa Redonda section where only 18 feet of claystone was measured overlying a white sandstone which is indistinguishable from the underlying Bluff. This section appears to be somewhat anomalous as 2.5 miles to the east-southeast at the Ojo Escondido section, 126 feet of typical Variegated was measured. Silver (1948, p. 78) stated that the convergence was due to a facies change into the underlying Bluff sandstone besides some pre-Dakota erosion. A similar convergence of the Morrison formation has been noted in Quay County, New Mexico, by Dobrovolsky, Summerson, and Bates. They (1947, sheet 2) stated that it is due to a facies change into an underlying sandstone and also some pre-Lower Cretaceous erosion.

After a detailed examination of the available outcrops, it may be concluded that the convergence of the



## Stratigraphic Relationships

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Variegated member of the Morrison is due primarily to a gradation into sandstone similar to the underlying Bluff sandstone, as well as some pre-Dakota erosion (Fig. 4).

The base of the Variegated member was chosen at the bottom of the first claystone or siltstone above the Bluff sandstone. As the member becomes sandier and begins to grade into sandstone the contact becomes more difficult to distinguish. At two localities within the area, on either side of the Acoma Valley (Sec. 18, T. 8 N., R. 7 W.; and Sec. 18, T. 8 N., R. 6 W.) the gradation is well exposed and could be examined. Between these two localities is an unscalable outlier of Bluff sandstone called Enchanted Mesa (Sec. 14, T. 8 N., R. 7 W.) which appears to be capped, not by Dakota sandstone, but by the sandstone facies of the Variegated member. Where the gradation takes place the claystone of the Variegated member grades into siltstone which in turn grades into very fine grained sandstone. This very fine grained sandstone grades into a fine-grained sandstone which cannot be differentiated from the underlying Bluff sandstone except that it still contains a few reddish-brown bands which disappear with the coarsening of the quartz grains.

At a third locality within the area covered, west of South Garcia (Sec. 31, T. 8 N., R. 2 W.) convergence takes



Variegated member of the sandstone is...  
gradation into sandstone...  
sandstone, as well as...  
The base of the Variegated member...  
bottom of the first claystone...  
sandstone. As the member...  
grade into sandstone...  
to distinguish...  
either side of the...  
and Sec. 18, T. 6 N., R. 6 E., the...  
posed and could be...  
is an uncalcareous...  
channeled mass (Sec. 18, T. 6 N., R. 6 E.)...  
be capped, not by...  
facies of the Variegated member...  
place the clay...  
sandstone which...  
stone. This very fine...  
graded sandstone...  
underlying...  
a few reddish...  
ing of the quartz...  
At a third locality...  
South Dakota (Sec. 18, T. 6 N., R. 6 E.)



place but is not well exposed because it is obscured by Quaternary spring deposits. Southeast of Grants, New Mexico, along the west side of Cebolleta Mesa (Sec. 22, T. 10 N., R. 9 W.) convergence similar to that which takes place in the Acoma Valley is poorly exposed. On the isopachous map (Fig. 5) the zero line refers to the point where the Variegated member can no longer be recognized but does not mean that is the margin of the deposition of the Variegated member as the upper part probably was deposited some distance farther to the south but was removed by post-Morrison pre-Dakota erosion.

#### Age and Paleontology

The age of the Morrison has been the subject of much disagreement among stratigraphers and paleontologists for over seventy years. The age of the formation was alternately shifted from Jurassic to Cretaceous and back again. The reason for this uncertainty was a lack of diagnostic fossils. Darton (1928a) in the last comprehensive summary of New Mexico geology and on the state geologic map (1928b), listed the Morrison as Cretaceous in age. Baker, Dane, and Reeside (1936, pp. 58-63) reviewed the discussions up to 1936, and although little has been added since that time, it is now generally accepted that deposition of the Morrison started in the Upper Jurassic time and may extend into the Lower Cretaceous as its exact upper age limit is



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not known. Overlying the Morrison formation in many parts of the Colorado Plateau are rocks similar to the Morrison, which have been demonstrated to be Lower Cretaceous in age such as the Burro Canyon formation of southwestern Colorado (Stokes, 1952, pp. 1174-1175)

The Morrison formation of the Western Interior is probably best known because it contains the remains of giant reptiles. This dinosaur fauna is the most varied and distinctive of any known. In addition to these and other vertebrates a large number of invertebrates is also present. These include fresh-water pelecypods, gastropods, and ostracodes. Plant remains are also abundant, including microfossils of charophyte oogonia.

Identifiable vertebrate fossils and invertebrates of any sort are so far unknown in the Morrison formation of New Mexico. Darton (1928a, p. 38) noted that the only fossils so far reported were the unidentified scattered bones of several kinds of saurians. Colbert (1950, p. 65) stated that no vertebrates had as yet been described from the New Mexico Morrison but there is every reason to suspect that identifiable bones will be found.

The only fossils that were encountered in this study of the Variegated member were disarticulated dinosaur bone fragments. These were usually found loose on the talus slopes and occasionally embedded in the channel sandstones. They



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were fairly well distributed over the whole area but there is a localization of these fossils on the west side of Mesa Gigante. These bones were frequently encountered because they were radioactive and were easily detected by a Geiger counter or a scintillometer. Inasmuch as teeth or other skull materials were not encountered, identification of the remains was not undertaken.

A small bone fragment assayed by the Technical Services Laboratory of the U. S. Atomic Energy Commission in Grand Junction, Colorado showed .07 per cent of  $U_3O_8$ .

It was suggested to the writer by L. C. Craig that a hand lens examination of the limestone beds, particularly on their weathered surfaces, might disclose some charophyte oogonia but none was found.

#### Source and Environment

Throughout much of the Western Interior, the Morrison is characterized by a thick, varicolored claystone and mudstone sequence. The origin of this sequence has intrigued and puzzled geologists for many years. It was long thought to represent a type of terrestrial sedimentation not found elsewhere. However, similar lithology and sedimentation have been described from the Tertiary Nacimiento formation of the San Juan Basin and the Cretaceous McRae formation of southern New Mexico. The Morrison is now generally regarded as having been deposited in extensive playa-like basins that



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were surrounded by vast floodplains. Locally within the claystone facies of the Morrison are clastic members that represent the incursion of coarse material of the surrounding alluvial plains.

The Variegated member appears to have originated both on the low-gradient alluvial plains and in extensive playas. Being of such origin, the member contains two main types of sedimentation associated with such a depositional environment—fluviatile and lacustrine. The claystone and mudstone originated both as floodplain deposits and water-laid deposits in playas. Differentiation of these two types of deposits is virtually impossible. The sandstone is fluviatile in character and was deposited along the channels of the aggrading streams and their small tributaries. The thin limestone beds were formed in small bodies of standing water, such as lakes in abandoned stream valleys, and playas. Some reworking by wind of the stream deposits occurred. However, no deposits were recognized in the mapped area, but they have been recognized elsewhere. The coarsening to the south of the beds making up the Variegated member indicates a source in that direction. Either a decrease in gradient or a decrease in the size of the streams or a combination of both would produce a decrease in the transporting capacity of the material. The coarsening of



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the beds is not of such magnitude as to suggest a decrease in gradient. The decrease in the size of the streams could have resulted from evaporation, absorption by pre-deposited sediments, or by the subdivision of the streams which disperse into smaller and smaller streamlets outward across the fan or plain.

Lack of significant evidence in the rocks makes the climatic conditions under which the Variegated member was deposited difficult to evaluate. Probably it was of a semi-arid climate but there was sufficient moisture present to support dinosaurs. With the mountainous source area to the south and southwest, the semi-aridity of this region to the north might have been partially caused by the rain shadow of the mountains. With the amount of water which must have been present (small lakes, playas, streams, etc.) the general lack of plant material in the beds is rather surprising. It can be concluded that the climate at the time of the deposition of the Variegated member was more moist and thus more favorable for the existence of terrestrial vertebrates than during the earlier part of the Jurassic in this area.

The relationship between the source of the Jurassic rocks of the area to the size of the material involved has already been discussed by Silver (1948, pp. 79-80). He postulated a positive area to the south which, as eroded, shifted southward during Jurassic time. Such a source



The beds in fact of such magnitude as to suggest a decrease in gradient. The decrease in the size of the stream could have resulted from evaporation, absorption by pre-deposited sediments, or by the subduction of the streams which pass into smaller and smaller streams towards the base of the plain.

Lack of significant evidence in the rocks in the elastic conditions under which the Variscan movement was deposited difficult to evaluate. Probably it was a local and elastic but there was sufficient resistance present to support dinosaurs. With the mountains some level to the south and southwest, the east-northeast of this region of the north might have been partially covered by the rain water of the mountains. With the amount of water which has been present (small lakes, swamps, etc.) the general lack of plant material in the beds is rather surprising. It can be concluded that the climate at the time of the deposition of the Variscan member was more moist and thus more favorable for the existence of terrestrial vegetation than during the earlier part of the Jurassic in this area. The relationship between the source of the beds in rocks of the area to the site of the material involved has already been discussed by Elvert (1943, pp. 78-83). He postulated a positive area to the south which, as indicated, shifted southward during Tertiary time. Such a source



area of the Variegated member appears to be valid in part, at least.

The Variegated member appears to have been derived from a mixed source consisting mainly of pre-existing sedimentary rocks. Granules and pebbles of quartz, feldspar, and granitic material in the scour zones of many of the sandstone lenses could indicate a minor contribution from igneous rocks or metamorphic rocks, or both, but may be better attributed to pre-existing conglomerates. Orographic relationships in the source area possibly account for the variety of materials comprising the sandstone and conglomerate. Fragmentary and poorly preserved fossil fragments in chert pebbles found in a poorly consolidated pebble bed about midway in the Variegated member on the west side of Mesa Gigante (SW 1/4, Sec. 23, T. 10 N., R. 4 W.) have been tentatively identified by S. A. Northrop as follows:

Corals

Lophophyllidium? sp.

A poor fragment of another tetracoral?

Bryzoan?

Mold of a fenestelloid bryzoan?

Brachiopods

Fragmentary mold of a brachiopod, possibly Spirifer.

Fragmentary mold of another brachiopod, possibly a productid.

Pelecypod?

Doubtful fragment; may not be a pelecypod at all.







With the exception of the coral (Lophophyllidium? sp.) the fossil fragments are in dark chert pebbles. The coral, nearly a complete specimen, is white and silicified. According to Northrop (January 12, 1953, Personal communication) this small lot suggests a late Paleozoic age. If the specimen identified as Lophophyllidium? sp. is excluded, the age might be Devonian, Mississippian, Pennsylvanian or Permian. The Lophophyllidium? sp. suggests Pennsylvanian or Permian.

Eardley (1951, pl. 13), in his tectonic map of the late Jurassic, indicates an area subject to erosion throughout the entire southern half of the State and extending into Arizona where it gradually shifts northwestward toward southern Nevada. The only other possible source, as indicated by Eardley, is in central Colorado where the Uncompahgre and Front Range elements stood as an emergent area (Fig. 7).

The late Paleozoic age of the fossils suggests a source area to the south where Paleozoic sediments were deposited over a widespread area.

Along the northern flank of the Zuni Uplift the Chaves member of the Morrison together with the underlying Bluff sandstone and Summerville formation (both included in Smith's Thoreau formation; see Fig. 3) coarsen perceptibly to the west until they become indistinguishable from each other







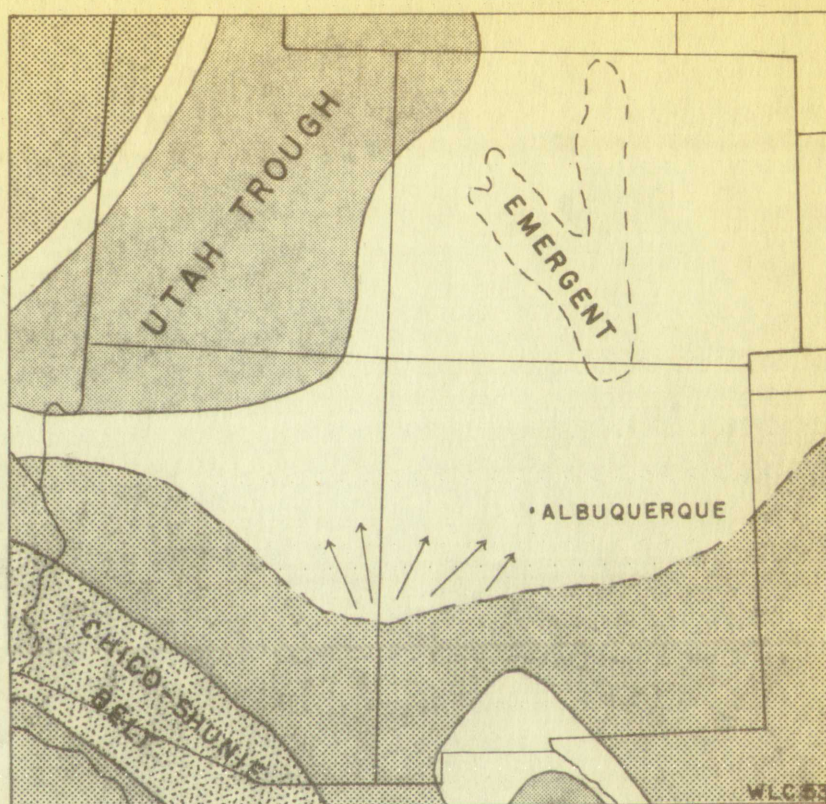




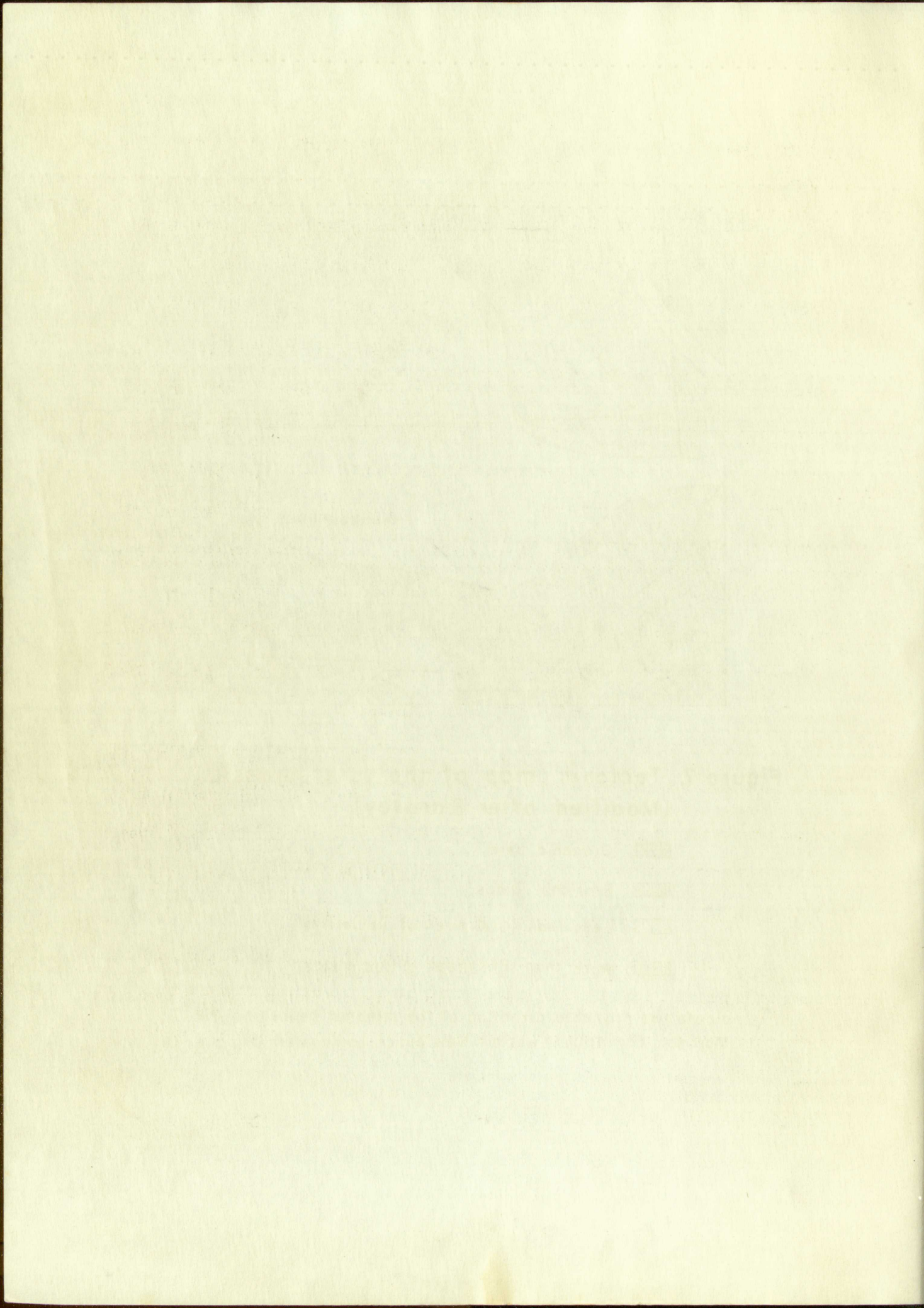


Figure 7. Tectonic map of the late Jurassic.  
(Modified after Eardley)

-  Orogenic belts
-  Erosional areas
-  Less than 1000 feet of sediments
-  More than 1000 feet of sediments

↑ indicate the probable direction of the streams depositing the Morrison formation in western New Mexico and eastern Arizona.







(Cow Springs sandstone) on the Hogback east of Gallup, New Mexico.

Distribution diagrams of the Recapture and Westwater Canyon members of the Morrison by Stokes (1944, p. 96) and Smith (1951, fig. 3) show a remarkably similar tongue-shaped distribution along the New Mexico-Arizona boundary, extending into a southeastern Utah and barely into southwestern Colorado. Craig, et al. (1951, pp. 26 and 47) also have a similar tongue-shaped distribution in the coarser clastics of the lithofacies of the Recapture and Westwater Canyon members but extended their distribution much farther east into New Mexico than previous workers. It appears from the nature of the distribution that the major source of these members was south and slightly west of Gallup, New Mexico in the Apache Uplift of Arizona.

Since the Variegated member can be correlated with the Chaves member of the Morrison in the Zuni Uplift and since this unit coarsens to the southwest, the deposition of the Variegated member must have been affected by sources not only to the south but also to the southwest.

The sources of the material were fairly uniform during deposition of the Variegated member as noted by its fine consistency. Fresh pink feldspar in many of the sandstones may indicate a slight rejuvenation from time to time, but it is probably due to the erosion of feldspathic or arkosic



(Cow Springs sandstone) on the west side of Salina, New Mexico.

Distribution diagram of the sandstone and water-

Canyon members of the Morrison by Smith (1951, p. 96) and Smith (1951, fig. 3) show a remarkably similar tongue-shaped distribution along the New Mexico-Arizona boundary, extending into a wedge-shaped belt and partly into south-western Colorado. Craig, et al. (1951, pp. 26 and 27) also have a similar tongue-shaped distribution in the canyon classics of the lithologies of the Escabedron and water-Canyon members but extended their distribution much farther east into New Mexico than the western authors. It is clear from the nature of the distribution that the canyon members of these members was south and slightly west of Salina, New Mexico in the Apache Basin of Arizona.

Since the Variegated member can be correlated with the Chavez member of the Morrison in the San Joaquin River this unit corresponds to the southwest, the deposition of the Variegated member must have been affected by sources not only to the south but also to the southwest.

The sources of the material were fairly well limited deposition of the Variegated member as noted by Smith (1951, p. 96). From the fact that it is a sandstone may indicate a slight rejuvenation from the south, but it is probably due to the erosion of the sandstone of the



sandstones whose grains normally would be carried by the streams. The slight bentonitic content of some of the claystone indicates that volcanic ash falls which were exceedingly common during the later part of Morrison deposition throughout the Western Interior contributed to the formation of the Variegated member.

After the deposition of the Variegated member a major rejuvenation of at least part of the source area occurred, resulting in the deposition of the coarse material composing the sandstone which overlies the Variegated member.

#### Sandstone Member

As previously mentioned in this report, above the Variegated member of the Morrison lies a prominent sandstone which was not named by Kelley and Wood as it was removed, probably by pre-Dakota erosion, in the area where they worked. This sandstone may be correlated with Smith's Prewitt sandstone member of the Morrison in the northern part of the Zuni Uplift. For convenience, field geologists of the U. S. Atomic Energy Commission and the Geological Survey commonly refer to this sandstone as the Westwater Canyon sandstone member of the Morrison. It is exposed along the northern part of the east and west sides of Mesa Gigante, along the line of cliffs between Piedra Lumbre and Paguate, and southwest from Paguate along the cliffs on the west side of the Rio Paguate toward Laguna. From Laguna it is exposed



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stone member of the Morrison in the northern part of the  
Zuni uplift. For convenience, Field geologists on the U. S.  
Atomic Energy Commission and the Geological Survey commonly  
refer to this sandstone as the "western Canyon sandstone  
member of the Morrison. It is exposed along the northern  
part of the east and west sides of Mesa Blanca, along the  
line of cliffs between Paganito and Santa Fe, and  
southwest from Paganito along the cliffs on the west side of  
the Rio Paganito toward Paganito. From Paganito it is exposed



along the cliffs north of U. S. Highway 66 as far west as Cubero. The present extent of this sandstone to the south, although not studied in detail, is inferred in Figure 5.

It commonly forms massive vertical cliffs, the bases of which are covered by talus material. In the area two miles east of Paguate where the Anaconda Copper Mining Company was core drilling during the months of July and August, an average thickness of 100 feet of this sandstone was regularly encountered (James Kelly, July 1952, Oral communication). The interval between the top of this sandstone and the base of the Dakota sandstone consists of 10 to 25 feet of pale-green mudstone (James Kelly, *ibid.*).

This sandstone consists of fine to coarse-grained, angular to subrounded, poorly sorted, poorly cemented quartz with some feldspar. It contains low-angle fluviatile type of cross lamination, and as a whole, the individual beds are very lenticular and contain clay galls and green mudstone stringers locally. The white color of the sandstone is due to the great amount of interstitial kaolin. Silicified logs are locally common in channel fills and scour zones. Carnotite type of uranium mineralization is known at several localities in this sandstone and is currently being mined east of Paguate.



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communication). This sandstone consists of a poorly cemented, coarse-  
grained to subrounded, poorly sorted, poorly cemented coarse-  
grained sandstone. It contains low-angle, horizontal beds  
of cross lamination, and as a whole, the individual beds  
are very lenticular and contain clay, silt and green mud-  
stone stringers locally. The white color of the sandstone  
is due to the great amount of iron-oxide staining. Thin-  
bedded logs are locally common in channel fills and some  
zones. Characteristic type of weathering is known  
at several localities in this sandstone and is apparently  
being mined east of Paguate.



## Post-Morrison Upper Cretaceous Rock

Rocks representing the Dakota group, Mancos shale, and Mesaverde formation are widespread throughout the area. Inasmuch as the Dakota group overlies the Morrison formation, it is the only unit that will be briefly discussed.

### Dakota Group

The Dakota group is the most widespread formation in the area studied. It forms the rims and generally the tops of the mesas and buttes under which the Morrison formation is exposed. The sandstone members are very resistant and are conspicuous by their blocky, much jointed, cliff-forming nature. They weather to a dark, rusty brown. The sandstone consists of very fine grained to fine-grained, round to subrounded, well-sorted and well-cemented quartz. Although the sandstone weathers rusty brown, on a fresh surface it is buff and has a vitreous luster. Interbedded with the sandstone in the basal part of the Dakota are dark-gray, arenaceous, siltstone and mudstone beds. At the base of the Dakota is a marked unconformity. Silver (1948, p. 79) noted as much as 30 feet of relief locally along this unconformity. Carnotite type of uranium mineralization has recently been found in a sandstone bed at Piedra Lumbre (Arthur Mirsky, March 30, 1953, Oral communication).



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## STRUCTURE

Regionally, the area studied shows little deformation as it consists largely of the broad Acoma embayment of the San Juan Basin. However, in the southeastern part of the area Jurassic rocks are greatly deformed by the Lucero Uplift and in the northern part of this eastern area there is a small amount of deformation along the Ignacio monocline. For convenience, structural deformations reflected in the Variegated member are classed either as late Jurassic-early Cretaceous or post-Dakota.

### Late Jurassic-Early Cretaceous Deformation

Following the deposition of the Morrison, epeirogenic warping of the whole area occurred. This warping was of greater intensity to the south and because erosion was greater in the southern part of the area, it stripped older and older formations. Therefore, when the Dakota was deposited it truncated older formations toward the south. During the epeirogenic uplifting of the area, a small amount of gentle folding took place throughout the area. One such fold of late Jurassic age is excellently exposed on the northwestern side of the Acoma Valley in Sec. 19, T. 9 N., R. 6 W. (Pl. 3B.). Here the Variegated member is greatly thinned both against and over a gentle fold in the Bluff sandstone, whereas the overlying Dakota group shows no evidence of deformation. The thinning of the Variegated







member near the fold is quite obvious on the isopachous map (Fig. 5). The trend of the fold, although rather difficult to establish, appears to be to the northwest. In the large valley south of Seama, talus material prevented the recognition of the continuation of the fold from the Acoma Valley to the east, however, the outcrop pattern of the Variegated member (Fig. 1) suggests it is present.

Throughout the area the pinch-out line of the Variegated member is east-west. From the locality on the west side of the Acoma Valley (Sec. 18, T. 8 N., R. 7 W.) to the locality on the west side of Cebolleta Mesa (Sec. 22, T. 10 N., R. 9 W.) the pinch-out line trends northwest, the same as the Acoma fold. Such an alignment suggests that late Jurassic movement in the Zuni Uplift influenced the deposition of the Variegated member as well as producing small compressional folds as the one exposed in the Acoma Valley. Undoubtedly, there are other similar folds within the area but the large amount of talus material and slump blocks which commonly cover the slopes of the Variegated member obscure them.

#### Post-Dakota Deformation

Two areas of severe post-Dakota deformation were encountered within the region studied. In the vicinity of Suwanee Peak the Jurassic cliffs which form the bluffs along the east side of the Rio San Jose are complexly



member near the fold is quite obvious on the topographic map (Fig. 5). The trend of the fold, although rather difficult to establish, appears to be to the northwest. In the large valley south of Seneca, talus material revealed the recognition of the continuation of the fold from the Seneca Valley to the east, however, the outcrop pattern of the Variegated member (Fig. 1) suggests it is present. Throughout the area the pinch-out line of the Variegated member is east-west. From the locality on the west side of the Seneca Valley (Sec. 18, T. 8 N., R. 7 W.) to the locality on the west side of Cebollero Mesa (Sec. 22, T. 10 N., R. 9 W.) the pinch-out line trends northwest, the axis of the Seneca fold. Such an alignment suggests that late Jurassic movement in the San Juan Mountains is responsible for the Variegated member as well as producing small compressional folds as the one exposed in the Seneca Valley. Undoubtedly, there are other similar folds within the area but the large amount of talus material and slumps blocks which commonly cover the slopes of the Variegated member obscure them.

#### Post-Dakota Deformation

Two areas of severe post-Dakota deformation were encountered within the region studied. In the vicinity of Seneca Peak the thrust faults which form the bluffs along the east side of the Rio San Jose are complexly



faulted by a series of northeast-trending, high-angle normal faults (Pls. 1A., 1B.). This faulting occurred in such a manner as to form a series of jostled faulted blocks which are mostly downthrown on the west. A large fault of this same system is very obvious as it bisects Mesa Redonda. For more detailed description of this particular area the reader should refer to the works of Hunt (1936), Kelley and Wood (1946), and Wright (1946).

The second area where the Variegated member is greatly deformed is in the Cañoncito area. Here the rocks, trending northeast, dip steeply to the southeast as a reflection of the Ignacio monocline. Here these steeply dipping rocks are broken by a series of parallel northeast-trending faults. Of each long slender fault block the northwest side is upthrown and the southeast side is down dropped. Since the formations involved are the Variegated member, the sandstone overlying it and belonging to the Morrison, and the Dakota group, the over-all picture is a series of northeast-trending cuestas which dip to the southeast. For a more detailed description, see Hunt (1936) and Wright (1946).

#### Igneous Intrusions

Igneous intrusions of Tertiary age are not uncommon throughout the area, but only the ones which are associated with the Variegated member are discussed here.

Small dikes and sills of basaltic material have



labeled by a series of numbers... normal faults (Fig. 1). This is... such a manner as to form a series of... which are mostly... this case system is very... For more detailed... reader should refer to the work of... Wood (1946), and others (1947).

The second area... deformed is in the... any northeast, dip... of the igneous... are broken by a series of... Of each long... thrown and the... formations involved... stone overlying it... Dakota group, the... trending... detailed description...

Igneous intrusions... Igneous intrusions... throughout the area... with the Variscan... Small dikes and...



intruded the Variegated member at several localities throughout the area. Sills are most numerous northeast of Laguna on the southeastern projection of Wheat Mountain (Secs. 29, 31, T. 10 N., R. 6 W.). A dike was noted northwest of Acoma (Sec. 7, T. 8 N., R. 7 W.); another dike is northeast of Paraje (Sec. 32, T. 10 N., R. 6 W.). More sills and dikes are located south and east of Paguate (Secs. 1, 2, 11, 15, T. 10 N., R. 5 W.). A small volcanic plug south of Piedra Lumbre (Sec. 34, T. 11 N., R. 4 W.) is exposed within the Morrison strata. The sills exposed in the vicinities of Laguna and Paguate are unique due to the fact that they traverse the older rocks in an irregularly oblique pattern. During intrusion when the material reached a more competent bed it migrated laterally before rupturing the strata and continuing in a vertical direction. Joints in the underlying Bluff sandstone appear to have been important in the introduction of intrusive material into the Variegated member. Only slight metamorphism was noted along the contacts of the intrusive material and the Variegated member.



intruded the Variegated member at several localities throughout the area. Dikes are most numerous northward of Laguna on the southeastern projection of West Mountain (secs. 29, 31, T. 10 N., R. 6 W.). A dike was noted north-west of Acorn (sec. 7, T. 8 N., R. 7 W.); another dike is northeast of Paraje (sec. 32, T. 10 N., R. 6 W.). More sills and dikes are located south and east of Laguna (secs. 1, 2, 11, 12, T. 10 N., R. 7 W.). A small volcanic plug south of Piedra Inmura (sec. 34, T. 11 N., R. 4 W.) is exposed within the Morrison strata. The sills exposed in the vicinities of Laguna and Paraje are unique due to the fact that they traverse the older rocks in an irregularly oblique pattern. During intrusion when the material reached a more competent bed it migrated laterally before rupturing the strata and continuing in a vertical direction. Joints in the underlying Elbert sandstone appear to have been important in the introduction of intrusive material into the Variegated member. Only slight metamorphism was noted along the contacts of the intrusive material and the Variegated member.



## ECONOMIC CONSIDERATIONS

The Morrison has long been known to be very important economically for uranium and vanadium minerals found in it. The principal deposits were known to be in the Salt Wash sandstone member. As the result, however, of the recent intensive search for uranium on the Colorado Plateau, deposits have been found in the Permian Cutler formation, the Upper Triassic Shinarump conglomerate and Chinle formation, the Todilto limestone, other members of the Morrison, and in the Dakota group.

### Uranium

The Variegated member of the Morrison was studied primarily for its mineralization possibilities, although its stratigraphic relationships were also given detailed consideration. Prospecting was undertaken due to the fact that in the northern flank of the Zuni Uplift, northwest of Thoreau, New Mexico (Sec. 8, T. 14 N., R. 14 W., and Sec. 2, T. 14 N., R. 14 W.) mineralized zones of the carnotite type are known in sandstone lenses in the upper part of the Chaves (Recapture) member of the Morrison. Mineralization in similar occurrences has been found in the Recapture member in the Sanastee area along the New Mexico-Arizona boundary in the Four Corners area, according



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### Uranium

The Variegated member of the Morrison was studied primarily for its mineralization possibilities, although its stratigraphic relationships were also given detailed consideration. Prospecting was undertaken due to the fact that in the northern flank of the East Uplift, northwest of Thoreau, New Mexico (Sec. 8, T. 14 N., R. 14 W., and Sec. 9, T. 14 N., R. 14 E.), mineralized zones of the carnotite type are known in sandstone lenses in the upper part of the Chaves (Receptum) member of the Morrison. Mineralization in similar occurrences has been found in the Receptum member in the Salinas area along the New Mexico-Arizona boundary in the town Cornudas area, according



to John A. Masters, district geologist, North Chuska Mountain Area, Atomic Energy Commission (Oral communication, October 1952).

In spite of the fact that no mineralization of any kind has been found so far in the sandstone channel deposits in the Variegated member, there seems to be no reasonable doubt that mineralization does exist somewhere in it. In the Paguate area, a considerable amount of carnotite type mineralization occurs in the sandstone (Westwater Canyon of the USGS and AEC) overlying the Variegated member. Inasmuch as these sandstone channel deposits contain the same type of sedimentational structures, and have been exposed to similar mineral-bearing solutions that percolated through the permeable sandstone beds before regional deformation took place, mineralization should be expected in the Variegated member. The lack of uranium mineralization within the sandstone lenses of the Variegated member may be attributed to the absence of large amounts of carbonaceous material which are normally associated with uranium mineralization on the Colorado Plateau. Because of the lenticular nature and irregular extent of these channel sands, the expected mineralization probably will not be in any large quantities. Weir (1952, p. 18) states that sandstone beds less than 40 feet thick are generally not favorable for the deposition of ore bodies.



to John A. Mather, District Engineer, New York  
Mountain Area, Federal Energy Commission, New York  
Office, October 1953.

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kind has been found to date in the sandstone channel re-  
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in it. In the Variegated member, a considerable amount of coarse-  
grained type mineralization occurs in the sandstone (assumed  
Canyon of the USGS and 1953) overlying the Variegated member.  
Inasmuch as these sandstone channel deposits contain the  
same type of sedimentation, structure, and have been ex-  
posed to similar mineralizing solutions that permeated  
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nature and irregular extent of these channel sand, inter-  
bedded mineralization probably will not be in any large  
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deposition of ore bodies.



## Clay

The Variegated member is predominantly made up of claystone and mudstone. This material represents an untapped resource as it is suitable for ceramics and probably for the manufacture of cement. It is used by both the Acoma and the Laguna Indians to make a good type of pottery—both for their own use and for the tourist trade. During the progress of this study no actual quarries were observed but Indian women were seen collecting clay from a slump block of the Variegated member north of U. S. Highway 66 near Seama.

## Other Resources

Although they contain the necessary porosity and permeability, the sandstone channel deposits are of such lenticular shape and irregular extent that they are of no economic importance in the accumulation of any fluids such as petroleum, natural gas, or ground water. Water has been found in fractured shales of the Mancos and Chinle formations but none has been found in the Morrison (T. O. Meeks, January 13, 1953, Oral communication). Such wells which produce from fractured shales are extremely rare and should be regarded as a geological anomaly. A few small landslide-type springs were noted seeping out from beneath Toreva-blocks consisting of the Dakota formation and the Variegated member in the Acoma Valley.



The Variegated member is predominantly made up of  
claystone and sandstone. This material is considered an un-  
tapped resource as it is suitable for cement and probably  
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Other Resources

Although they come in the necessary quantity and qual-  
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economic importance in the production of oil. This is  
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Tobaya-bloom formation of the Agona formation and the  
Variegated member in the Agona (115).



## PRINCIPAL CONCLUSIONS

The principal conclusions in this study of the Variegated member of the Morrison formation are listed as follows:

(1) The Variegated member of the Morrison of the southeastern part of the San Juan Basin may be correlated with the Chaves member of the Zuni Uplift, which may have equivalents in the Recapture member of the Morrison in southeastern Utah.

(2) A northwest-trending late Jurassic fold exposed in the Acoma Valley suggests movement of the Zuni Uplift during that time.

(3) Southward convergence of the Variegated member is due both to truncation by a pre-Dakota erosion surface and gradation into the underlying Bluff sandstone.

(4) Large sandstone lenses within the Variegated member are favorable for carnotite type of uranium deposits.

(5) The abundance of fragments of vertebrate remains in the Variegated member suggests the possibility of finding complete forms.



# PHILOSOPHY OF SCIENCE

The principal conclusion in this study is that the Variegated member of the Morrison formation is related to the following:

(1) The Variegated member of the formation of the southeastern part of the San Juan basin may be correlated with the Chaves member of the East Unit, which may have equivalents in the Mesquite member of the formation in southeastern Utah.

(2) A northwest-trending late Jurassic fold exposed in the Acoma Valley suggests movement of the East Unit during that time.

(3) Southward movement of the Variegated member is due both to truncation by a pre-Paleocene erosion surface and gradation into the underlying West Unit.

(4) Large sandstone lenses within the Variegated member are favorable for sandstone type of uranium deposits.

(5) The abundance of fragments of vertebrate remains in the Variegated member suggests the possibility of finding complete forms.



# APPENDIX

## (Descriptive Stratigraphic Sections)

### Herrera Ranch Section

Center, Sec. 14, T. 11 N., R. 3 W.

<u>No.</u>	<u>Description</u>	<u>Thickness</u>	<u>(Feet)</u>
		<u>Unit</u>	<u>Cumulative</u>
	(Dakota group above)		
	Top of the sandstone member:		
15	SANDSTONE: thick bedded; cross laminated; white; medium grained; grains subrounded; calcareous cement; kaolinitic.....	32	307
	Total: sandstone member:	32	
	Top of the Variegated member:		
14	CLAYSTONE: pale green; slightly bentonitic, with occasional limestone lenses 4-6 inches thick.....	151	275
13	SANDSTONE: medium bedded; cross laminated; tan; fine to medium grained; grains angular to rounded; poorly cemented; limonitic.....	23	124
12	CLAYSTONE: maroon.....	5	101
11	SANDSTONE: thick bedded; cross laminated; tan; fine to medium grained with coarse grains in scour zones 1-3 inches thick; grains angular to rounded, with some feldspar in scour zones; poorly cemented; limonitic.....	43	96
10	MUDSTONE: purple.....	5	53
9	LIMESTONE: single bed; dark gray; weathers light gray; microcrystalline; arenaceous; calcite seams and clusters.....	1	48
8	MUDSTONE: purple and maroon.....	10	47
7	LIMESTONE: single bed; dark gray, weathers light gray; microcrystalline; slightly arenaceous.....	1	37
6	CLAYSTONE: maroon.....	4	36



(Descriptive section)

Horroba Ranch section

Center, 28.14, 1.11, 1.11, 1.11

No.

15	Dark gray sandstone, fossiliferous, thin bedded, cross laminated, slightly irregular, grain somewhat, calcareous cement, lenticular.
14	Top of the Variegated member. CLAYSTONE: pale green, slightly lenticular, with some small lenticles.
13	lenses 4-6 inches thick, cross laminated, thin line to medium, grain, similar to rounded, poorly cemented, lenticular.
12	CLAYSTONE: brown, cross laminated, thin line to medium, grain, similar to rounded, poorly cemented, lenticular.
11	CLAYSTONE: thin bedded, cross laminated, thin line to medium, grain, similar to rounded, poorly cemented, lenticular.
10	CLAYSTONE: thin bedded, cross laminated, thin line to medium, grain, similar to rounded, poorly cemented, lenticular.
9	CLAYSTONE: thin bedded, cross laminated, thin line to medium, grain, similar to rounded, poorly cemented, lenticular.
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6	CLAYSTONE: thin bedded, cross laminated, thin line to medium, grain, similar to rounded, poorly cemented, lenticular.



<u>No.</u>	<u>Description</u>	<u>Thickness</u> <u>Unit</u>	<u>(Feet)</u> <u>Cumulative</u>
5	SANDSTONE: thin bedded; white; fine to medium grained; grains subrounded to rounded.....	2	32
4	CLAYSTONE: maroon.....	3	30
3	LIMESTONE: like 7.....	1	27
2	CLAYSTONE: purple.....	2	26
1	COVERED: probably maroon and purple claystone.....	24	
	Total: Variegated member:	275	
	(Bluff sandstone below)		

### Concho Springs Section

NW 1/4, Sec. 14, T. 10 N., R. 4 W.

(Dakota group above)

Top of the sandstone member:

15	SANDSTONE: thick bedded; cross laminated; white; medium to coarse grained; grains angular to sub-rounded; poorly cemented; kaolinitic..	59	438
	Total: sandstone member:	59	

Top of the Variegated member:

14	CLAYSTONE: light green, slightly bentonitic, with several dark gray; light gray weathering; microcrystalline; slightly arenaceous limestone beds 4-6 inches thick.....	62	379
13	SANDSTONE: thin bedded; cross laminated; grayish white; very fine to medium grained; grains angular to subrounded; moderately cemented; slightly kaolinitic.....	11	317
12	CLAYSTONE: light green; lower 6 feet purple; color gradational.....	24	306
11	SANDSTONE: thin bedded; cross laminated; grayish white; fine grained; grains subrounded, with coarse, angular grains in scour zones up to 3 inches thick; calcareous cement.....	21	282
10	CLAYSTONE: light green.....	52	261







<u>No.</u>	<u>Description</u>	<u>Thickness</u> <u>Unit</u>	<u>(Feet)</u> <u>Cumulative</u>
9	SANDSTONE: thin bedded; cross laminated; grayish white; medium grained; grains subrounded; calcareous cement; basal foot very calcareous and well cemented.....	11	209
8	CLAYSTONE: light green; calcareous with several limestone lenses 3-4 inches thick.....	22	198
7	LIMESTONE: single bed; dark gray, weathers light gray; finely crystalline; arenaceous.....	1	176
6	CLAYSTONE: light green, bentonitic....	26	175
5	SANDSTONE: medium bedded; grayish-white; medium grained; grains subrounded to rounded; moderately cemented; middle portion intruded by several sill-like basaltic tongues 2-4 inches thick.....	13	149
4	SANDSTONE: thick bedded; gray; fine to medium grained; grains subangular to subrounded; well cemented; highly calcareous.....	4	136
3	CLAYSTONE: light green; lower portion maroon; color gradational; silicified dinosaur bone fragments on slope.....	11	132
2	SANDSTONE: thick bedded; cross laminated; tan; fine to medium grained; grains subrounded to rounded; 3 per cent feldspar; 30 feet below the top is a prominent 6-inch thick, green shale seam, top contains abundant limonite concretions and nodules.....	108	121
1	LIMESTONE: thin bedded, in beds 6-12 inches thick; dark gray, weathers light gray; microcrystalline; arenaceous; seams and clusters of calcite; intercalated purple mudstone beds 2-3 inches thick.....	13	
Total: Variegated member:		379	
(Bluff sandstone below)			

379  
121  
258



No.	Description	Thickness	Remarks
9	SANDSTONE: thin bedded, cross laminated; grayish white; medium grained; grains subrounded; calcareous cement; basal 100 feet	100	
8	GRAYSTONE: light gray; calcareous with several liassic fossils; 1-4 inches thick	25	
7	LIMESTONE: single bed; dark gray; weathers light gray; finely crystalline; microporous	5	
6	GRAYSTONE: light gray; microporous; thin bedded	20	
5	SANDSTONE: medium bedded; cross laminated; rounded to rounded; microporous; cemented; fossils; rounded by several silty fine liassic boulders	15	
4	SANDSTONE: thin bedded; gray; fine to medium grained; grains subangular to subrounded; well cemented; light calcareous	10	
3	GRAYSTONE: light gray; lower portion microporous; color transitional; microporous; some fragments on slope	15	
2	SANDSTONE: thin bedded; cross laminated; tan; fine to medium grained; grains rounded to rounded; 50 feet thick; below 100 feet a prominent columnar structure; some sandstone and sandstone fragments	100	
1	LIMESTONE: thin bedded; in beds 6-12 inches thick; dark gray; microporous; light gray; microporous; some sandstone and some liassic fossils; 1-4 inches thick	15	
	(Bluff section below)		



# East Mesa Gigante Section

SW 1/4, Sec. 9, T. 9 N., R. 3 W.

<u>No.</u>	<u>Description</u>	<u>Thickness</u> <u>Unit</u>	<u>(Feet)</u> <u>Cumulative</u>
	(Dakota group above)		
	Top of the Variegated member:		
4	CLAYSTONE: light green; slightly bentonitic; several 1-3 feet thick; tan; medium to coarse grained; poorly cemented, sandstone beds.....	146	181
3	CLAYSTONE: maroon.....	10	35
2	SANDSTONE: thick bedded, cross laminated; tan; fine to medium grained.....	8	25
1	CLAYSTONE: maroon; calcareous with an occasional dark-gray limestone lens 6-8 inches thick.....	17	
	Total: Variegated member:	181	
	(Bluff sandstone below)		

# West Mesa Gigante Section

SW 1/4, Sec. 2, T. 9 N., R. 4 W.

	(Dakota group above)		
	Top of the Variegated member:		
10	CLAYSTONE: light green.....	10	229
9	CLAYSTONE: light gray; arenaceous.....	1	219
8	CLAYSTONE: light green.....	10	218
7	SANDSTONE: medium bedded; cross laminated; tan; fine grained; grains subrounded; lower 8 inches contains chert pebble conglomerate.....	4	208
6	CLAYSTONE: light green; slightly bentonitic; silicified dinosaur bone fragments on slope.....	20	204
5	SANDSTONE: medium bedded; cross laminated; tan; fine grained; grains subrounded; calcareous cement.....	20	184
4	CLAYSTONE: light green.....	15	164



East West Cigarette

SW 1/4, Sec. 2, T. 2 N., R. 4 E.

No.	Description	Thickness	Feet
	(Dakota group above)		
	Top of the variegated member		
4	CLAYTON: light green, slightly bentonitic; several 1-3 foot thin	10	10
	tan; medium to coarse grained		
	poorly cemented, sandstone beds	10	10
3	CLAYTON: medium to coarse grained	10	10
2	CLAYTON: thin-bedded, green	10	10
	laminated; tan to medium		
	grained		
1	CLAYTON: medium to coarse grained, with an occasional dark-gray limestone lens	10	10
	6-8 inches thick		
	Total variegated member	10	10
	(Dakota group below)		

East West Cigarette

SW 1/4, Sec. 2, T. 2 N., R. 4 E.

	(Dakota group above)		
	Top of the variegated member		
10	CLAYTON: light green, slightly bentonitic	10	10
9	CLAYTON: light green, slightly bentonitic	10	10
8	CLAYTON: light green, slightly bentonitic	10	10
7	CLAYTON: medium to coarse grained	10	10
	laminated; tan to medium		
	subrounded; lower 2 inches bentonitic		
	green, partly concretionary		
6	CLAYTON: light green, slightly bentonitic; slightly bentonitic	10	10
	limestone as a whole		
5	CLAYTON: medium to coarse grained	10	10
	laminated; tan to medium		
	subrounded; lower 2 inches bentonitic		
4	CLAYTON: light green, slightly bentonitic	10	10



<u>No.</u>	<u>Description</u>	<u>Thickness</u> <u>Unit</u>	<u>(Feet)</u> <u>Cumulative</u>
3	SANDSTONE: thin bedded; cross laminated; light gray; very fine to fine grained; grains subrounded .....	4	149
2	CLAYSTONE: light green.....	20	145
1	CLAYSTONE: maroon, purple and cream colored, containing several sandstone lenses up to 8 inches thick.....	125	
	Total: Variegated member	229	
	(Bluff sandstone below)		

### Suwanee Peak Section

SE 1/4, Sec. 2, T. 8 N., R. 3 W.

	(Dakota group above)		
	Top of the Variegated member:		
7	CLAYSTONE: light green and cream; bentonitic; occasional dark-gray limestone lenses 6-8 inches thick....	78	161
6	SANDSTONE: thin bedded; cross laminated; grayish white; very fine grained; grains subangular to sub-rounded; poorly cemented.....	5	83
5	CLAYSTONE: light green.....	11	78
4	SANDSTONE: thick bedded; cross laminated; grayish white; very fine to fine grained; grains subangular to subrounded; calcareous cement.....	24	67
3	CLAYSTONE: light green.....	4	43
2	SANDSTONE: thin bedded; cross laminated; grayish white; very fine grained; grains subangular to sub-rounded; poorly cemented.....	3	39
1	CLAYSTONE: maroon and cream colored; with a few limestone lenses 3-6 inches thick.....	36	
	Total: Variegated member:	161	
	(Bluff sandstone below)		







# Mesa Redonda Section

SE 1/4, Sec. 14, T. 8 N., R. 3 W.

<u>No.</u>	<u>Description</u>	<u>Thickness</u> <u>Unit</u>	(Feet) <u>Cumulative</u>
	(Dakota group above)		
	Top of the Variegated member:		
2	CLAYSTONE: purple and maroon.....	18	82
1	SANDSTONE: thick bedded; cross laminated; tan; very fine grained; grains subrounded; mostly talus covered; base obscured; may contain some claystone.....	64	
	Total: Variegated member:	82	
	(Bluff sandstone below)		

# Ojo Escondido Section

SW 1/4, Sec. 20, T. 8 N., R. 2 W.

	(Dakota group above)		
	Top of the Variegated member:		
7	SANDSTONE: medium bedded; cross laminated; white; fine to very coarse grained; grains angular to sub- rounded; poorly cemented; very limonitic and kaolinitic.....	2	126
6	CLAYSTONE: light green and cream; color gradational; bentonitic.....	44	124
5	SANDSTONE: thin bedded; grayish white; fine grained; grains subrounded.....	3	80
4	CLAYSTONE: purple.....	37	77
3	SANDSTONE: medium bedded; cross laminated; grayish white; fine grained; grains subrounded to rounded.....	8	40
2	SANDSTONE: thin bedded, cross laminated; grayish white; fine grained; grains subrounded with coarse grains and angular chert pebbles in scour zones up to 4 inches thick; scour zones poorly cemented....	5	32
1	CLAYSTONE: purple grading upward to light green; slightly bentonitic.....	27	
	Total: Variegated member:	126	



SW 1/4, Sec. 14, T. 3 N., R. 3 W.

No.	Description	Thickness Feet	Remarks
	(Dakota group above)		
	Top of the Variegated member		
2	CLAYSTONE: purple and brownish, cross	18	
1	SANDSTONE: thick bedded, cross		
	laminated; tan; very fine grained;		
	grains subangular; mostly fine		
	covered; base obscured; grayish brown		
	some claystone	12	
	Total Variegated member	30	
	(Bluff sandstone below)		

Upper sandstone section

SW 1/4, Sec. 14, T. 3 N., R. 3 W.

	(Dakota group above)		
	Top of the Variegated member		
7	SANDSTONE: medium bedded, cross		
	laminated; white; fine to very fine		
	grained; grains angular to sub-		
	rounded; poorly cemented; very		
122	limestone and dolomite	1	
	CLAYSTONE: light green and cream		
124	color gradational; dolomitic	44	
	SANDSTONE: thin bedded, grayish white		
30	fine grained, grains subangular	3	
37	CLAYSTONE: purple	37	
	SANDSTONE: medium bedded, cross		
	laminated; grayish white; fine		
	grained; grains subangular to		
	rounded		
2	SANDSTONE: thin bedded, cross		
	laminated; grayish white; fine		
	grained; grains subangular to		
	coarse grains and angular		
	pebbles in some zones up to 4 inches		
38	shale; some roots poorly cemented	3	
	CLAYSTONE: purple grading brown to		
	light green; slightly dolomitic	11	
	Total Variegated member	120	



# Laguna Section

NW 1/4, Sec. 28, T. 10 N., R. 5 W.

<u>No.</u>	<u>Description</u>	<u>Thickness</u> <u>Unit</u>	<u>(Feet)</u> <u>Cumulative</u>
	(Dakota group above)		
	Top of the sandstone member:		
23	SANDSTONE: thick bedded; cross laminated; white; very fine to medium grained; grains subrounded; scour zones containing coarse to very coarse, angular grains, up to 8 inches thick; kaolinitic.....	103	387
	Total: sandstone member:	103	
	Top of the Variegated member:		
22	CLAYSTONE: light green and light gray.	21	284
21	SANDSTONE: medium bedded; cross laminated; tan; fine grained; grains subrounded; calcareous cement; intercalated thin light-green shale beds.....	21	263
20	CLAYSTONE: light green.....	7	242
19	SANDSTONE: medium grained; cross laminated; light gray; very fine grained; grains subrounded; scour zones containing very coarse grains to pebble size angular chert fragments and fragments of silicified dinosaur bones; well cemented with silica; 15 per cent feldspar.....	9	235
18	LIMESTONE: single bed; dark gray, weathers light gray; finely crystalline; slightly arenaceous.....	1	226
17	CLAYSTONE: light green; bentonitic....	39	225
16	LIMESTONE: single bed; dark gray, weathers light gray; micro-crystalline; slightly arenaceous.....	1	186
15	CLAYSTONE: light green; bentonitic....	25	185
14	SANDSTONE: medium bedded; cross laminated; tan; fine grained; grains subrounded; well cemented with calcareous cement; two light green claystone seams divide this sandstone into three units which were observed to lense out to a feather edge within 200 feet.....	10	160
13	CLAYSTONE: light green; bentonitic....	27	150



# Logans Section

NW 1/4, Sec. 28, T. 10 N., R. 5 W.

No.	Description	Unit	Thickness	Cumulative (feet)
23	(Dakota group above) Top of the sandstone member: SANDSTONE: thin bedded; cross laminated; white; very fine to medium grained; grains subrounded; some zones containing coarse to very coarse, angular grains, up to 5 inches thick; radiolitic. Total: sandstone member: 103	103	387	
22	Top of the variegated member: CLAYSTONE: light green and light gray. 21	21	384	
21	SANDSTONE: medium bedded; cross laminated; tan; fine grained; grains subrounded; calcareous cement; interbedded thin light-green shale beds..... 21	21	363	
20	CLAYSTONE: light green..... 7	7	342	
19	SANDSTONE: medium grained; cross laminated; light gray; very fine grained; grains subrounded; some zones containing very coarse grains to pebble size angular chert fragments and fragments of silicified dinosaur bones; well cemented with silice; 15 per cent talciferous..... 9	9	333	
18	LIMESTONE: single bed; dark gray; weathers light gray finely crystalline; slightly arenaceous..... 1	1	332	
17	CLAYSTONE: light green; bentonitic..... 39	39	322	
16	LIMESTONE: single bed; dark gray; weathers light gray; micro- crystalline; slightly arenaceous..... 1	1	186	
15	CLAYSTONE: light green; bentonitic..... 32	32	187	
14	SANDSTONE: medium bedded; cross laminated; tan; fine grained; grains subrounded; well cemented with calcareous cement; two light green claystone seams divide this sand- stone into three units, which were observed to pass out to a farther edge within 200 feet..... 10	10	160	
13	CLAYSTONE: light green; bentonitic..... 27	27	150	



<u>No.</u>	<u>Description</u>	<u>Thickness</u> <u>Unit</u>	<u>(Feet)</u> <u>Cumulative</u>
12	SANDSTONE: thin bedded; tan; fine grained; grains subangular; well cemented with calcareous cement.....	4	123
11	CLAYSTONE: light green.....	16	119
10	LIMESTONE: like 16.....	1	103
9	CLAYSTONE: purple and light green.....	11	102
8	SANDSTONE: thick bedded; cross laminated; yellowish brown; very fine to fine grained; grains subangular to subrounded; poorly cemented with calcareous cement; grains coated with limonite; slightly kaolinitic; 20 feet above the base is an arenaceous, maroon limestone lense 2 feet thick; top contains abundant limonite concretions and nodules.....	65	91
7	CLAYSTONE: light green.....	5	26
6	LIMESTONE: three 8-inch beds; purplish gray, weathers light gray; microcrystalline; highly arenaceous; contains 20 per cent fine to medium, angular to round, frosted quartz grains; cross cut by calcite seams and clusters.....	2	21
5	CLAYSTONE: light green.....	4	19
4	SANDSTONE: thin bedded; light gray; fine grained; grains subrounded; well cemented with calcareous cement.....	1	15
3	CLAYSTONE: light green.....	5	14
2	LIMESTONE: thin bedded; dark gray, weathers very dark gray; microcrystalline; slightly arenaceous.....	1	9
1	SHALE: purple.....	8	
Total: Variegated member:		284	
(Bluff sandstone below)			



No.	Description	Thickness Feet	Cumulative
12	SANDSTONE: thin bedded; tan; fine grained; grains subangular; well cemented with calcareous cement	8	123
11	CLAYSTONE: light green	10	103
10	LIMESTONE: like 10	1	103
9	CLAYSTONE: gray and light green	11	102
8	SANDSTONE: thick bedded; cross laminated; yellowish brown; very fine to fine grained; grains sub-angular to subrounded; poorly cemented with calcareous cement; grains coated with limonite; slightly kaolinized; 20 feet above the base is an irregular, carbon limestone lens 2 feet thick; top contains abundant limonite concretions and nodules	52	51
7	CLAYSTONE: light green	2	50
6	LIMESTONE: thin bedded; grayish gray; weathered light gray; microporous; slightly micaceous; contains 20 per cent lime to nodules angular to round, frosted quartz grains; cross cut by vertical seams and cleavages	2	48
5	CLAYSTONE: light green	4	44
4	SANDSTONE: thin bedded; light gray; fine grained; grains subangular; well cemented with calcareous cement	1	40
3	CLAYSTONE: light green	2	38
2	LIMESTONE: thin bedded; dark gray; weathers very dark gray; micro-crystalline; slightly micaceous	1	36
1	SHALE: purple	3	33
	(Bluish sandstone below)		



# Wheat Mountain Section

W 1/2 Sec. 32, T. 10 N., R. 5 W.

<u>No.</u>	<u>Description</u>	<u>Thickness</u> <u>Unit</u>	<u>(Feet)</u> <u>Cumulative</u>
	(Dakota group above)		
	Top of the sandstone member:		
20	SANDSTONE: thick bedded; cross laminated; white to tan; fine grained; grains subrounded to rounded; scour zones of coarse grains to pebbles of varicolored chert and small clay galls, up to 8 inches in thickness; upper 30 feet generally without these scours; limonite staining and kaolinitic throughout.....	132	410
	Total: sandstone member:	132	
	Top of the Variegated member:		
19	CLAYSTONE: purple.....	4	278
18	LIMESTONE: single bed; dark gray, weathers bluish gray; micro-crystalline; slightly arenaceous.....	1	274
17	CLAYSTONE: light green; bentonitic....	12	273
16	SANDSTONE: medium bedded; cross laminated; tan; fine grained; grains rounded; calcareous cement.....	4	261
15	CLAYSTONE: light green; bentonitic....	4	257
14	LIMESTONE: single bed; dark gray, weathers light gray; micro-crystalline; slightly arenaceous.....	1	253
13	CLAYSTONE: light green, bentonitic....	32	252
12	SANDSTONE: medium bedded; cross laminated; tan to white; fine to coarse grained; decreasing upward; grains angular to rounded; slightly feldspathic.....	25	220
11	CLAYSTONE: cream colored.....	16	195
10	LIMESTONE: like 13.....	1	179
9	CLAYSTONE: cream colored.....	43	178
8	SANDSTONE: thin bedded; cross laminated; grayish white; very fine grained; grains subrounded.....	5	135
7	CLAYSTONE: cream and light green.....	51	130
6	SANDSTONE: thin bedded; tan; very fine to fine grained; grains sub-angular to subrounded; intercalated light-green mudstone beds.....	11	79



# Wheat Mountain Section

W 1/2 Sec. 35, T. 10 N., R. 5 W.

No.	Description	Thickness Feet	Comments
20	(Dakota group above) Top of the sandstone member: SANDSTONE, thick bedded; cross laminated; white to tan; fine grained; grains subrounded to rounded; occur zones of coarse grains to pebbles of varicolored chert and small clay galls, up to 8 inches in thickness; upper 30 feet generally without fossils occur; limonite staining and kaolinitic throughout. Total sandstone member: 132	410	
19	Top of the variegated member: CLAYSTONE, purple.....	4	378
18	LIMESTONE, single bed; dark gray, weathered bluish gray; micro- crystalline; slightly arenaceous.....	1	374
17	CLAYSTONE, light green; bentonitic.....	12	373
16	SANDSTONE, medium bedded; cross laminated; tan; fine grained; grains rounded; calcareous cement.....	4	361
15	CLAYSTONE, light green; bentonitic.....	4	357
14	LIMESTONE, single bed; dark gray, weathered light gray; micro- crystalline; slightly arenaceous.....	1	353
13	CLAYSTONE, light green, bentonitic.....	32	322
12	SANDSTONE, medium bedded; cross laminated; tan to white; fine to coarse grained; zones and nodules of chert, irregular to rounded, slightly fossiliferous.....	25	320
11	CLAYSTONE, cream colored.....	10	317
10	LIMESTONE, like 11.....	10	313
9	CLAYSTONE, cream colored.....	5	313
8	SANDSTONE, thin bedded; cross laminated; grayish white; very fine grained; grains subrounded.....	2	312
7	CLAYSTONE, green and light green.....	21	310
6	SANDSTONE, thin bedded; tan; very fine to fine grained; grains sub- angular to subrounded; intercalated light-green claystone beds.....	11	29



<u>No.</u>	<u>Description</u>	<u>Thickness</u> <u>Unit</u>	<u>(Feet)</u> <u>Cumulative</u>
5	CLAYSTONE: purple; with several very thin sandstone lenses; silicified fragments of dinosaur bones on slope; bentonitic.....	32	68
4	SANDSTONE: medium bedded; tan; very fine grained; grains subrounded; calcareous cement; abundant limonite concretions and nodules.....	26	36
3	CLAYSTONE: maroon.....	2	10
2	LIMESTONE: thin bedded; dark gray, weathers bluish gray; micro-crystalline, with large calcite crystals; slightly arenaceous.....	2	8
1	CLAYSTONE: reddish brown.....	6	
	Total: Variegated member:	278	
	(Bluff sandstone below)		

#### Acoma Valley Section

Center, Sec. 19, T. 9 N., R. 6 W.

(Dakota group above)

Top of the Variegated member:

5	CLAYSTONE: light green, with some light-gray siltstone near the top.....	11	90
4	SANDSTONE: thick bedded; cross laminated; tan; fine grained; grains subrounded; scour zones up to 4 inches containing very coarse, angular quartz and some feldspar grains; intercalated light-green thin mudstone beds; poorly cemented with calcareous cement; kaolinitic throughout.....	29	79
3	CLAYSTONE: purple grading upward into light green; bentonitic.....	27	50
2	SANDSTONE: medium bedded; cross laminated; light gray to tan; grains coarse to very coarse, angular, grading upward into very fine sub-rounded grains; calcareous cement increases with decrease in grain size.	22	23
1	SILTSTONE: purple; locally thin as this unit was observed to thicken laterally to a thickness of 4 feet.....	1	
	Total: Variegated member:	90	
	(Bluff sandstone below)		



No. Description

- 5 CLAYSTONE: grayish; with several very thin sandstone lenses. In places fragments of thin sandstone bones are visible. ...
- 4 SANDSTONE: medium bedded; fine grained; ...
- 3 CLAYSTONE: massive; ...
- 2 LIMESTONE: thin bedded; dark gray; ...
- 1 CLAYSTONE: reddish brown; ...

Lower Yellow Section

Center, sec. 18, T. 2 N., R. 10 E., S. 1

- (Dakota group above)
- 5 CLAYSTONE: light gray; ...
- 4 SANDSTONE: thin bedded; ...
- 3 CLAYSTONE: ...
- 2 SANDSTONE: ...
- 1 CLAYSTONE: ...



# Acoma Section

NW 1/4, Sec. 8, T. 8 N., R. 7 W.

<u>No.</u>	<u>Description</u>	<u>Thickness</u> <u>Unit</u>	<u>(Feet)</u> <u>Cumulative</u>
	(Dakota group above)		
	Top of the Variegated member:		
14	SANDSTONE: thin bedded; cross laminated; grayish white; medium grained; grains subrounded; scour zones up to 8 inches thick, containing angular to subangular, coarse grains to pebble size quartz and chert fragments; intercalated thin, light-green claystone and siltstone beds.....	9	173
13	CLAYSTONE: light green; slightly bentonitic.....	11	164
12	SANDSTONE: thin bedded; tan; fine grained.....	1	153
11	CLAYSTONE: like 13.....	5	152
10	SANDSTONE: like 12.....	1	147
9	CLAYSTONE: like 13.....	25	146
8	SANDSTONE: medium bedded; cross laminated; tan; fine grained; grains subrounded; calcareous cement; slightly kaolinitic.....	11	121
7	CLAYSTONE: purple and light green; bentonitic.....	17	110
6	SANDSTONE: medium bedded; cross laminated; tan; fine grained; grains subrounded; scour zones up to 12 inches thick containing subangular to subrounded, coarse grains to pebbles; 5 per cent feldspar in scours; unit grades upward into argillaceous siltstone.....	9	93
5	CLAYSTONE: purple grading upward into light green; bentonitic.....	33	84
4	LIMESTONE: single bed; dark gray, weathers pinkish gray; microcrystalline; arenaceous.....	1	51
3	CLAYSTONE: purple; silicified dinosaur bone fragments and "gastroliths" on slope.....	30	50
2	SANDSTONE: thin bedded; cross laminated; tan; very fine grained; grains subrounded; calcareous cement..	4	20
1	CLAYSTONE: purple and maroon.....	16	
	Total: Variegated member:	173	
	(Bluff sandstone below)		



NW 1/4, Sec. 8, T. 2N., R. 7E.

No.	Particulars	Feet	Notes
	(Birl's sandstone below)		
1	CLAYSTONE: purple and yellowish, thin bedded, cross laminated; top very fine grained; grains somewhat coarser than average; some small pebbles of quartz and chert fragments; interbedded with light green claystone and thin, light green claystone and siltstone beds.	10	
2	SANDSTONE: thin bedded, cross laminated; top very fine grained; grains somewhat coarser than average; some small pebbles of quartz and chert fragments; interbedded with light green claystone and thin, light green claystone and siltstone beds.	10	
3	CLAYSTONE: purple and yellowish, thin bedded, cross laminated; top very fine grained; grains somewhat coarser than average; some small pebbles of quartz and chert fragments; interbedded with light green claystone and thin, light green claystone and siltstone beds.	10	
4	CLAYSTONE: purple and yellowish, thin bedded, cross laminated; top very fine grained; grains somewhat coarser than average; some small pebbles of quartz and chert fragments; interbedded with light green claystone and thin, light green claystone and siltstone beds.	10	
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6	SANDSTONE: thin bedded, cross laminated; top very fine grained; grains somewhat coarser than average; some small pebbles of quartz and chert fragments; interbedded with light green claystone and thin, light green claystone and siltstone beds.	10	
7	CLAYSTONE: purple and yellowish, thin bedded, cross laminated; top very fine grained; grains somewhat coarser than average; some small pebbles of quartz and chert fragments; interbedded with light green claystone and thin, light green claystone and siltstone beds.	10	
8	SANDSTONE: thin bedded, cross laminated; top very fine grained; grains somewhat coarser than average; some small pebbles of quartz and chert fragments; interbedded with light green claystone and thin, light green claystone and siltstone beds.	10	
9	CLAYSTONE: purple and yellowish, thin bedded, cross laminated; top very fine grained; grains somewhat coarser than average; some small pebbles of quartz and chert fragments; interbedded with light green claystone and thin, light green claystone and siltstone beds.	10	
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13	CLAYSTONE: purple and yellowish, thin bedded, cross laminated; top very fine grained; grains somewhat coarser than average; some small pebbles of quartz and chert fragments; interbedded with light green claystone and thin, light green claystone and siltstone beds.	10	
14	SANDSTONE: thin bedded, cross laminated; top very fine grained; grains somewhat coarser than average; some small pebbles of quartz and chert fragments; interbedded with light green claystone and thin, light green claystone and siltstone beds.	10	
	Top of the Variegated member (Dakota group above)		



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1. The first part of the report is a general statement of the work done during the year. It is divided into two main parts, (a) the work done in the field, and (b) the work done in the laboratory. The first part is divided into three sections, (i) the work done in the field, (ii) the work done in the laboratory, and (iii) the work done in the office. The second part is a detailed account of the work done in the field, and is divided into three sections, (i) the work done in the field, (ii) the work done in the laboratory, and (iii) the work done in the office.

2. The second part of the report is a detailed account of the work done in the field. It is divided into three sections, (i) the work done in the field, (ii) the work done in the laboratory, and (iii) the work done in the office. The first section is a detailed account of the work done in the field, and is divided into three sections, (i) the work done in the field, (ii) the work done in the laboratory, and (iii) the work done in the office.

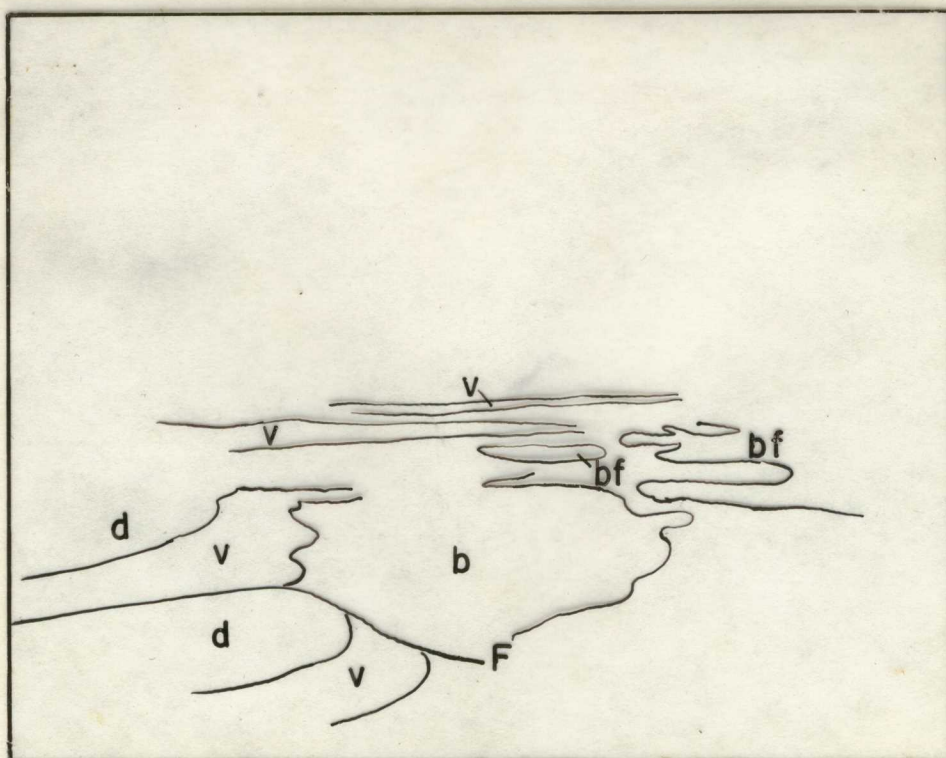
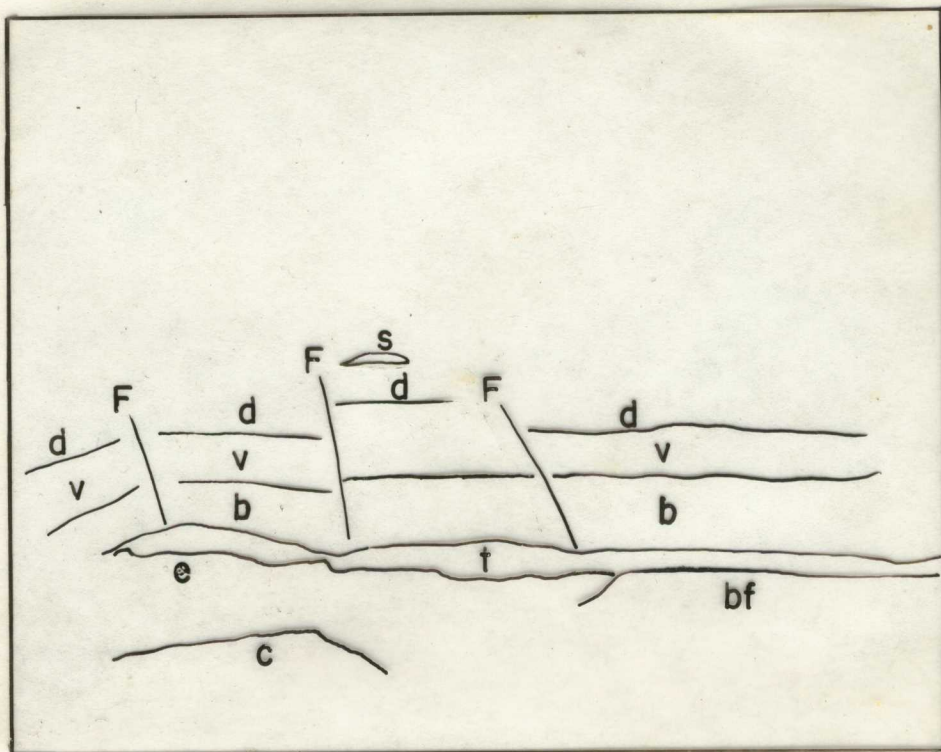


PLATE 1.

A. View northeast of Suwanee Peak. Quaternary spring deposits (s), Dakota group (d), Variegated member (v), Bluff sandstone (b), Todilto formation (t), Entrada sandstone (e), Triassic Chinle formation (c), faults (F), Recent basalt flow (bf) in the valley of the Rio San Jose.

B. View southeast from Suwanee Peak down the valley of the Rio San Jose. Dakota group (d), Variegated member (v), Bluff sandstone (b), Recent basalt flow (bf), fault (F). Note the Manzano Mountains along the left skyline.







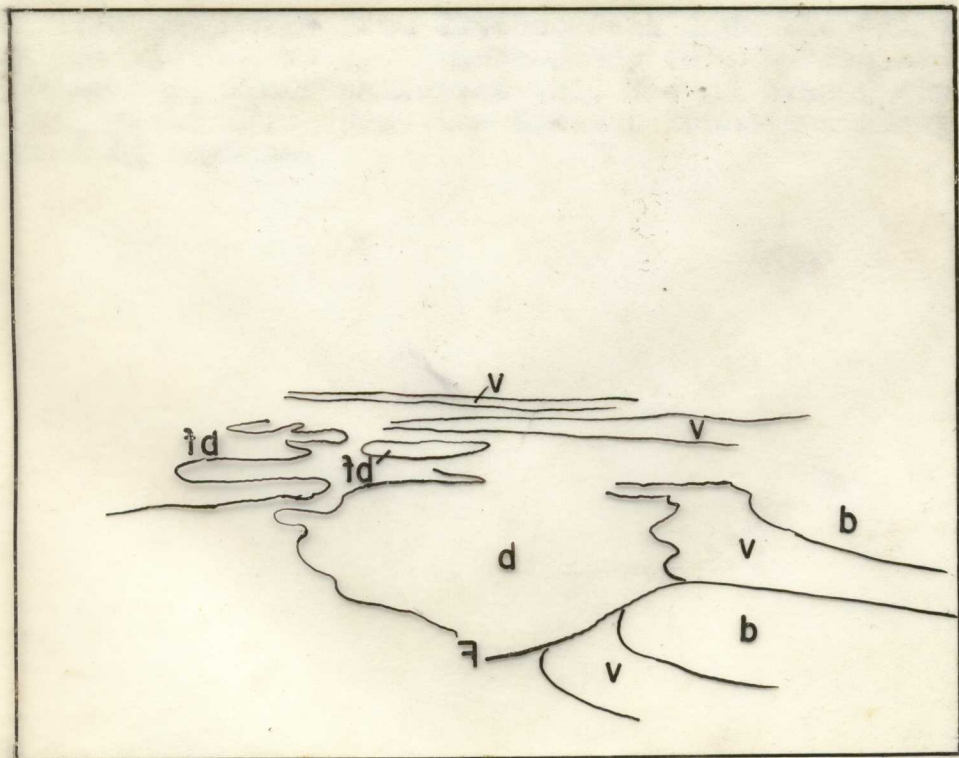
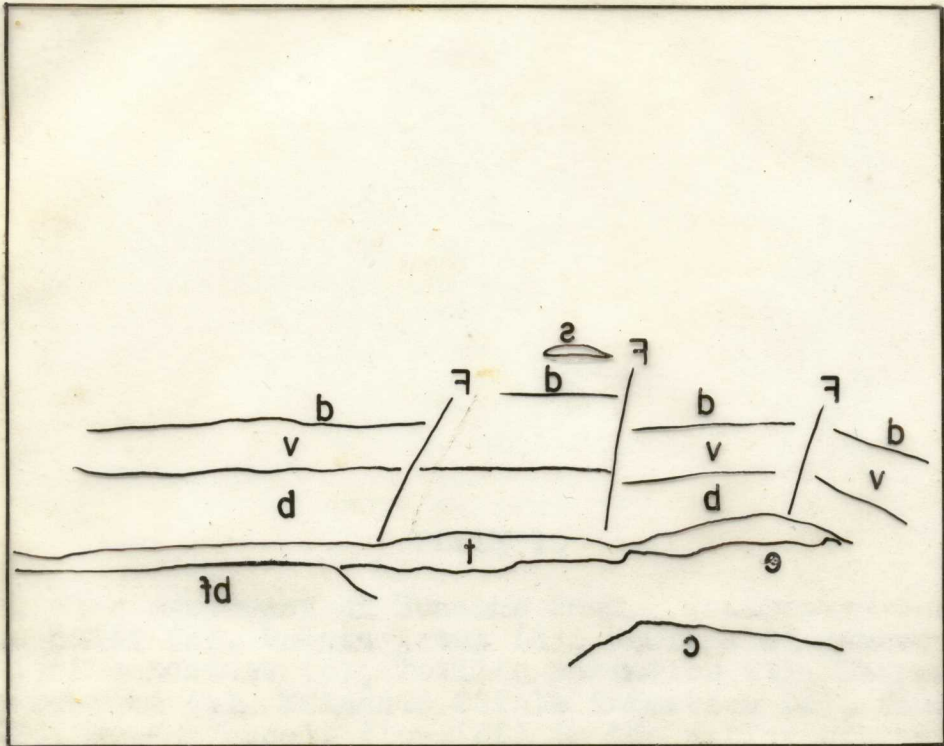




PLATE 1.





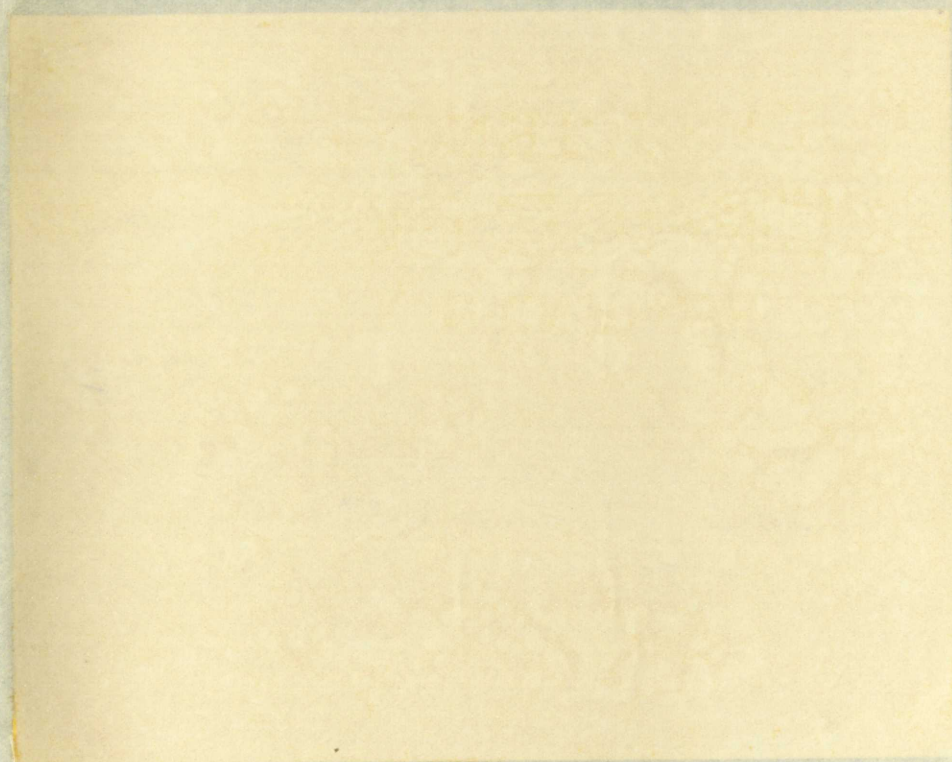






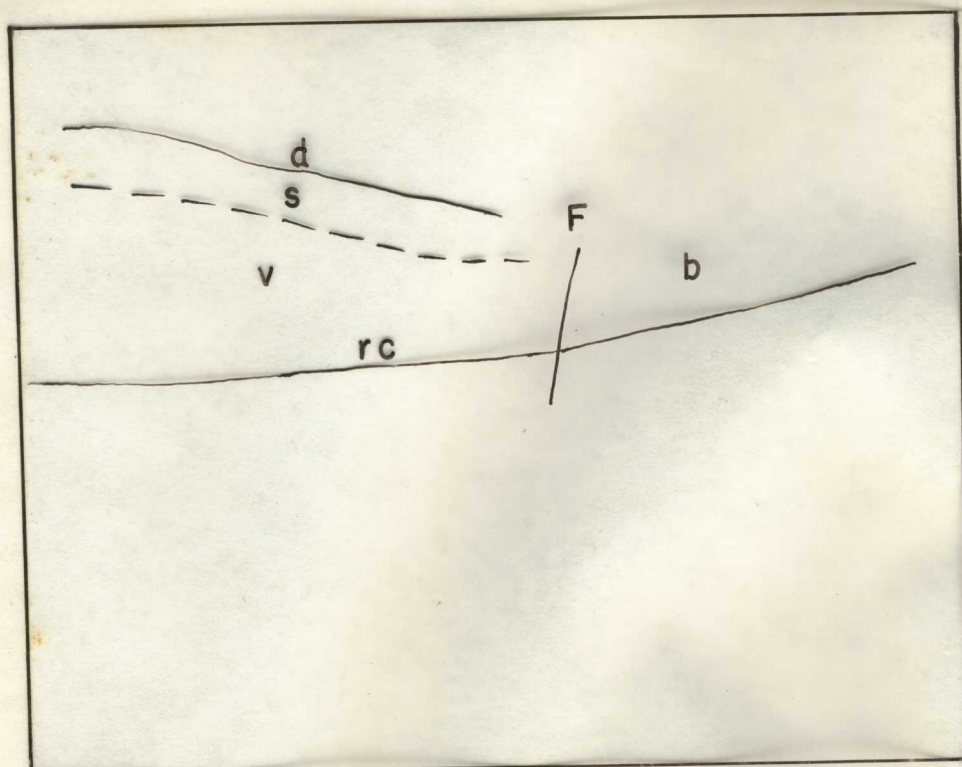
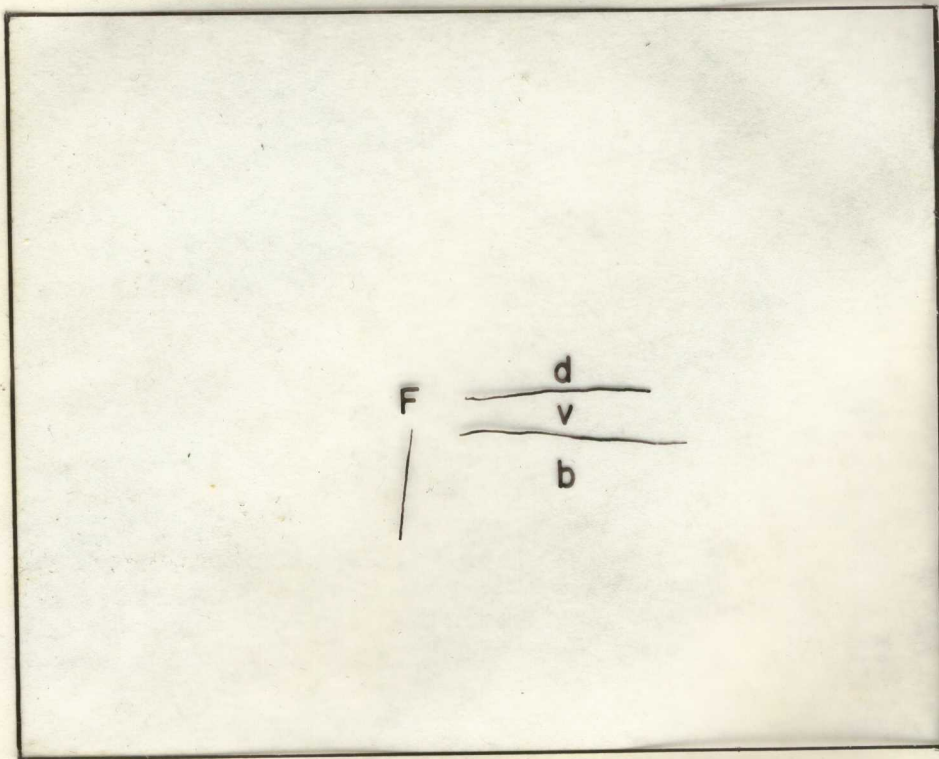


PLATE 2.

A. View northeast of the Ojo Escondido section. Dakota group (d), Variegated member (v), Bluff sandstone (b), fault (F). Mancos and Mesaverde formations in the left background. Alluvium-covered basalt flow in the foreground.

B. Small fault north of Cañoncito bringing the lower Bluff sandstone (b) in contact with the Variegated member (v). Note the Dakota group (d) forming a talus covering on the Morrison slope partly obscuring the sandstone member (s). Fault (F), roadcut (rc).







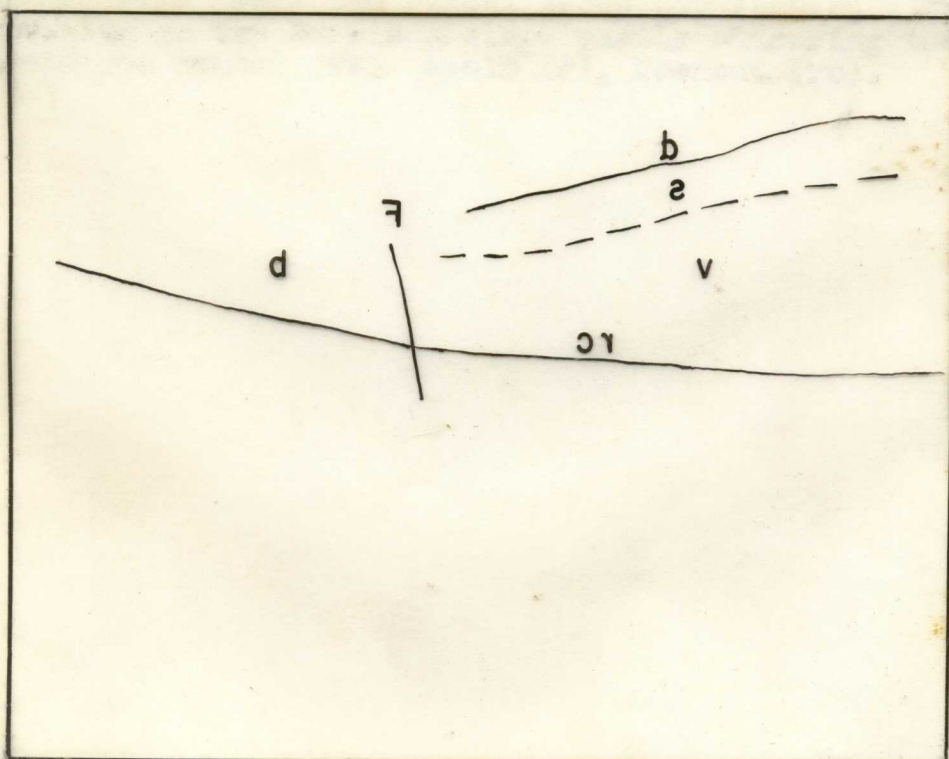
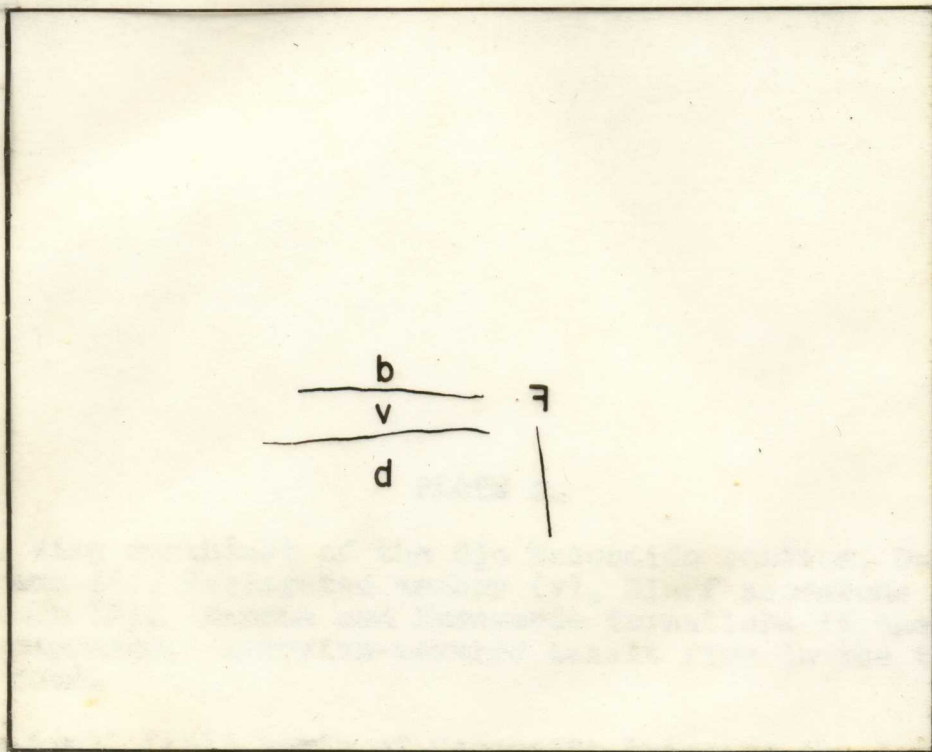


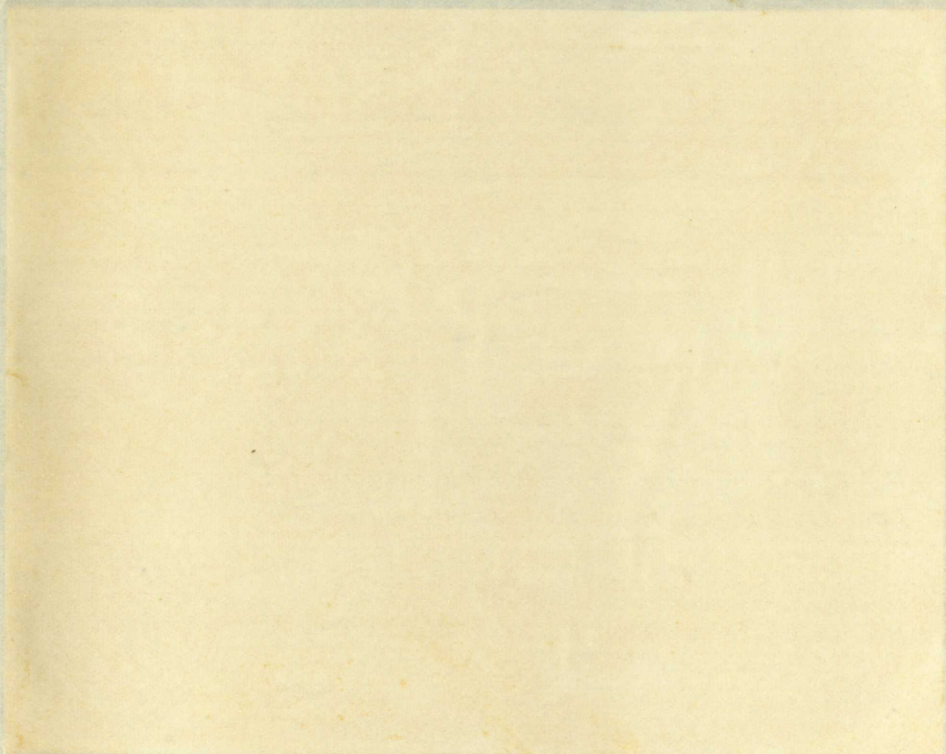
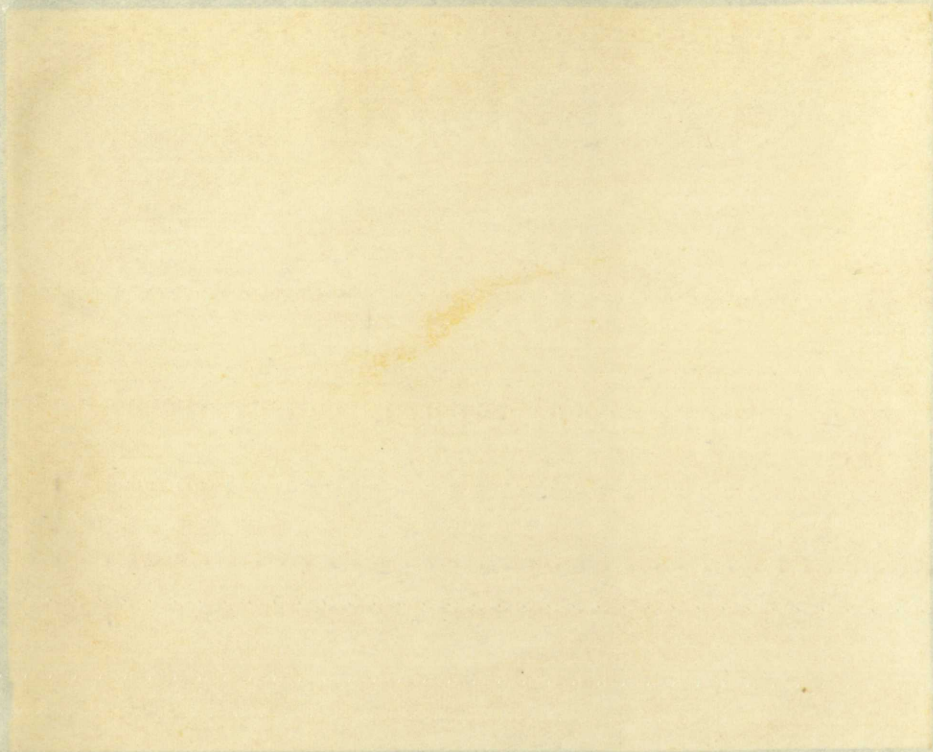


PLATE 2.





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1. The first part of the report is a general introduction to the project. It describes the purpose of the project, the scope of the work, and the organization of the report. It also includes a list of the main results of the project.

2. The second part of the report is a detailed description of the project. It describes the methods used, the results obtained, and the conclusions drawn. It also includes a list of the main results of the project.

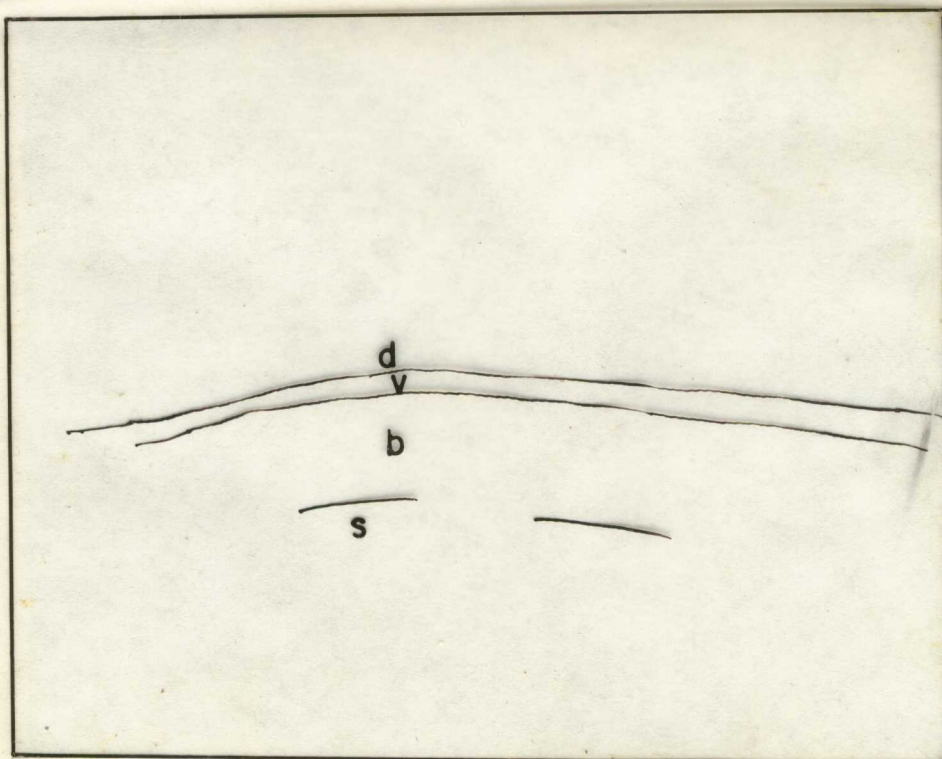
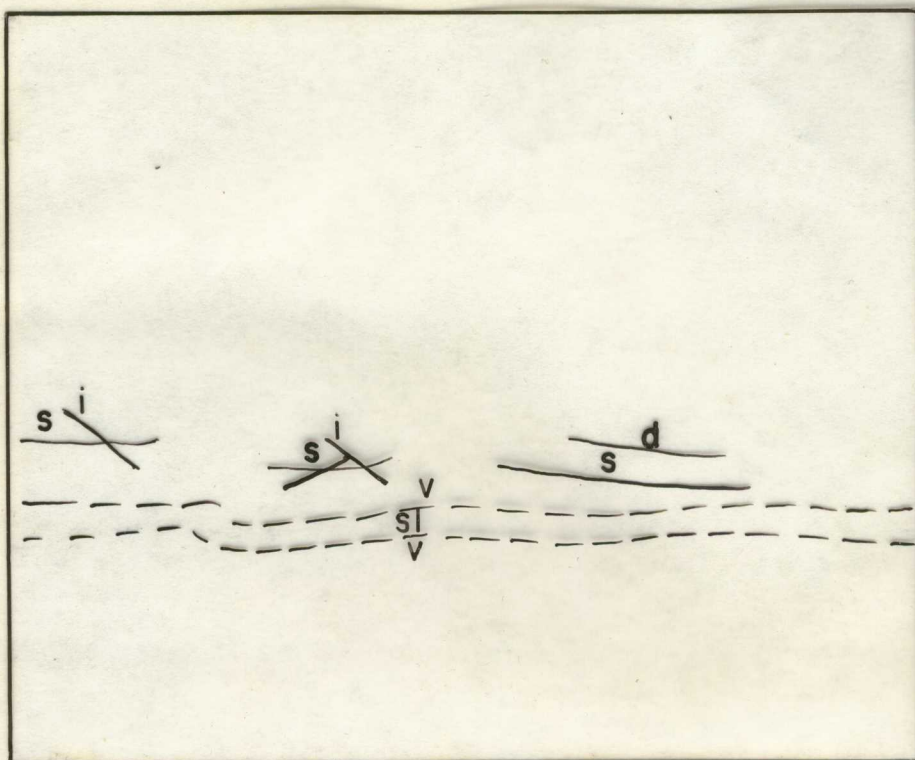


PLATE 3.

A. View northwest of the Laguna section. Dakota group (d), sandstone member of the Morrison (s), Variegated member (v), containing a prominent sandstone lens (sl), small Tertiary intrusives (i). Wheat Mountain, Cretaceous strata capped by lava flow, in the background.

B. View northwest of a late-Jurassic fold in the Acoma Valley. Dakota group (d), Variegated member (v), Bluff sandstone (b), Summerville formation (s). Note the lateral thickening of the Variegated member.







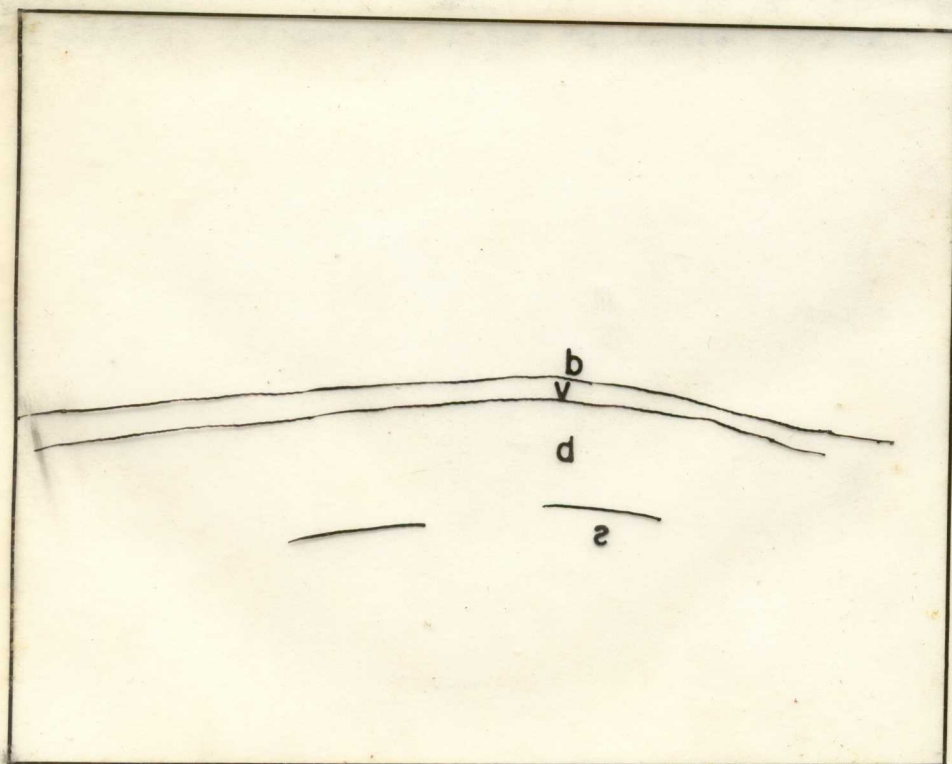
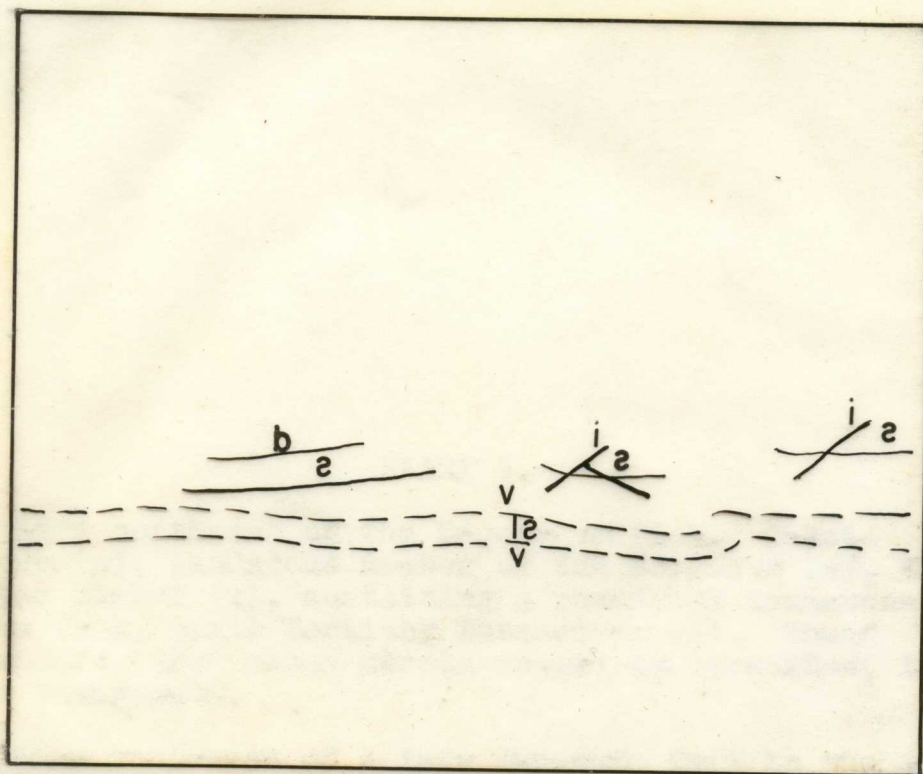
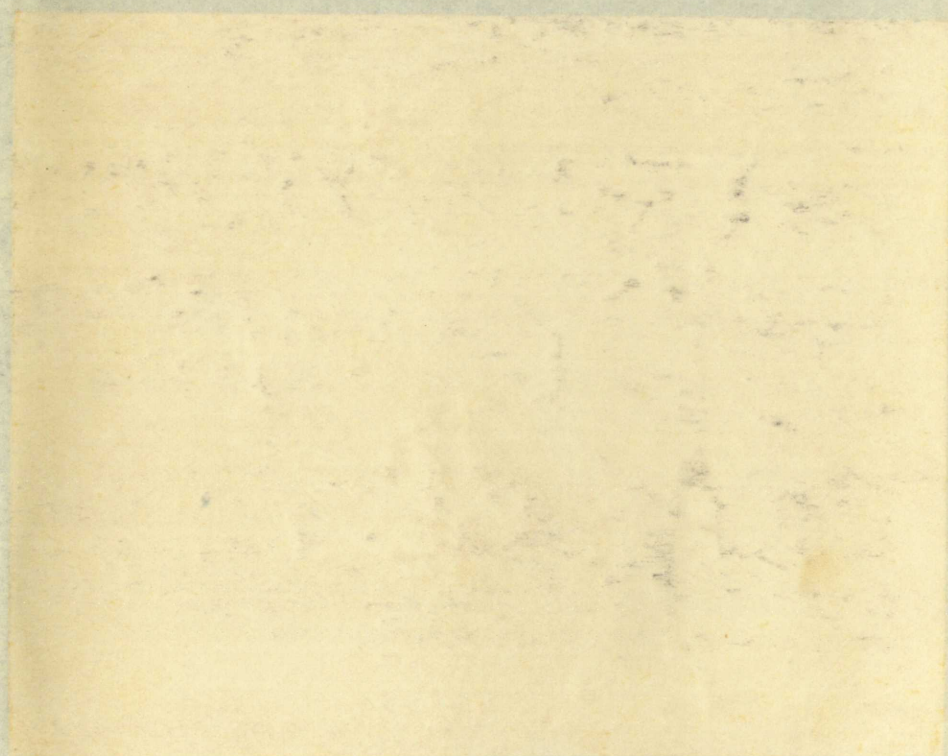




PLATE 3.









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REPORT OF THE  
COMMISSIONER OF THE  
LAND OFFICE  
FOR THE YEAR 1900

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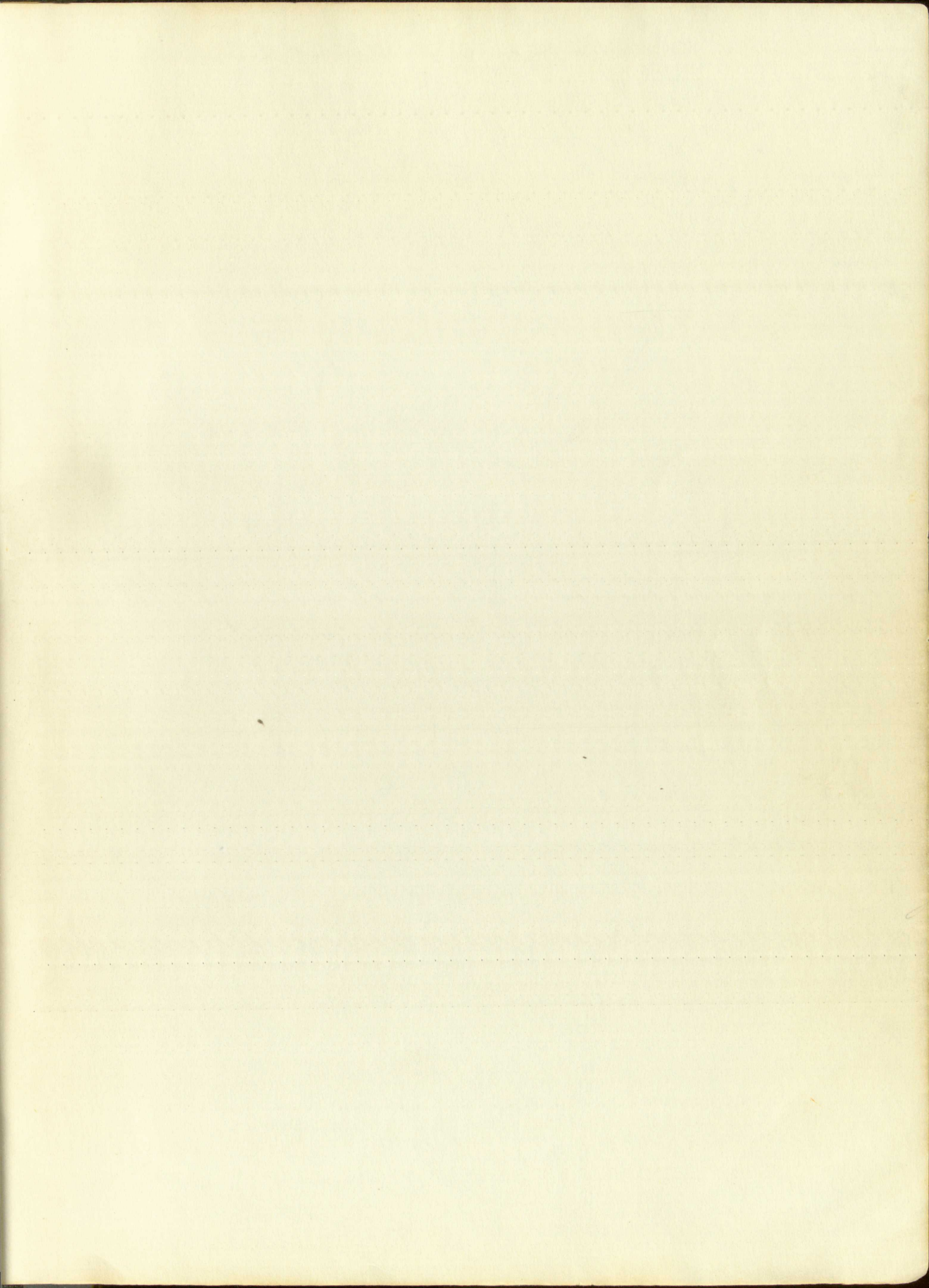


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5 Maps, folded charts, plates, etc.

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