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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

Chenoweth — The Variegated Member of the Morrison Formation

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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

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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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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.

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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° north between longitude 107°5' and longitude 107°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 Paguate 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

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

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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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The area is a land of steep-sided mesas and broad valleys. Some of the more important mesas are Mesa [illegible],

north of Correo; Mesa Redonda, southeast of Correo; Wheat Mountain, north of Laguna; Snowbird Mesa, southeast of Paguate; 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 Paguate 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

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

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.

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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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.

Vincent C. Kelley and Sherman A. Wengerd of the University of New Mexico gave much appreciated field and office counsel while the study was in progress. Stuart A. Northrop, also of the University of New Mexico, kindly aided in the identification and age determination of certain fossil 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

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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

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

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

the south and east the amount of sandstone and siltstone in the interval greatly increases. Locally it appears to intertongue 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

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.

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The Bluff 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

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: Westwater 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.

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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: Westwater 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 parts 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.

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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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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

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

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 Vermilion 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.

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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

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

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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

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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

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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

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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

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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-

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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.

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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.

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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, 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 interfinger 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. 19) replaced the Variegated shale member of Bailey 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 Bailey and Wood is very probably a Summerville equivalent and is tentatively called the Red Mesa formation of Hoover.

Craig, et al. (1955) 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

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

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Nomenclature as Applied to the Present Studies

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 Morrison has been restricted to 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 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.

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Direct correlation between the Morrison units of the

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 Zuni Uplift and in the [illegible] to the east in the Acoma and Laguna regions. In [illegible] the intervening McCartys syncline, however, the Morrison rocks disappear about 5 miles south of [illegible] and then reappear to the east near [illegible]. Outcrops are fairly continuous from the Acoma area to the [illegible]. Detailed work by Rapaport, et al. [illegible] and [illegible] by the writer and other members of the [illegible] of the Atomic Energy Commission has clearly demonstrated that the Variegated shale member of [illegible] and [illegible] is stratigraphically and lithologically equivalent to the [illegible] member of Smith (Recapture shale member of the [illegible]) of the Zuni Uplift.

North of the area studied by [illegible], the rocks immediately overlying their Variegated shale member form a resistant, [illegible], cliff-forming, cross-laminated, fine-grained sandstone belonging to the Morrison formation [illegible]. Because it was removed in the south part of the area, probably by pre-Dakota erosion, it has never formally been given a local name as have other members of the Morrison in this region. This sandstone may be correlative with the [illegible] sandstone [illegible] (USGS and AEC) on the northern flank of the Zuni Uplift. The presence of this [illegible] confirms the writer's opinion that the [illegible] member of

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.

<u>Outcrops</u>

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^{o}-3^{o} 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 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 comparatively rare within the member. In spite of the fact that this unit may be correlated with the recently designated [illegible] member on the north flank of the Zuni Uplift, field geologists of the Atomic Energy Commission and the Geological Survey currently designate the unit the tentative [illegible] 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. 7). Except in the Lucero Uplift and along the [illegible] the beds are nearly flat-lying as the regional dip is 1°-3° 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

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 underground as a result of the [illegible]. Outcrops form the [illegible] light-green, purple, green, and [illegible]. These slopes are littered with [illegible] from the overlying Dakota group. Complete [illegible] difficult to find due to the [illegible] that has taken place within the [illegible]. This [illegible] of landslide has been given the [illegible] Toreva-block by Reiche (1937). He described [illegible] north-central Arizona and noted [illegible] near the Laguna Indian Reservation [illegible] 1937, pp. [illegible]). [illegible] a Toreva-block as "a [illegible] a single large mass of [illegible] descent, has undergone [illegible] parent cliff about a [illegible] it". These blocks [illegible] the Variegated member [illegible] obscuring the outcrops of it.

Lithology

The member is a sequence of [illegible] with interbedded [illegible], sandstone and [illegible] stone beds (Pls. 9, 17 [illegible]).

Claystone comprises [illegible]. The beds are multicolored [illegible].

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

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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 Jurrassic 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 granules, pebbles, etc., [illegible] in scour zones.

The sandstone may be gray, grayish-white, or yellowish-brown and is usually composed of very fine to medium-grained, subrounded, moderately sorted quartz with minor 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 [illegible] are subrounded granules and pebbles of quartz, chert, quartzite, and granitic material. Many of these sandstones contain much interstitial kaolin. According to [illegible] (1951, pp. 61-62) kaolinization in the upper part of the [illegible] 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 that resulted from the decomposition of feldspar.

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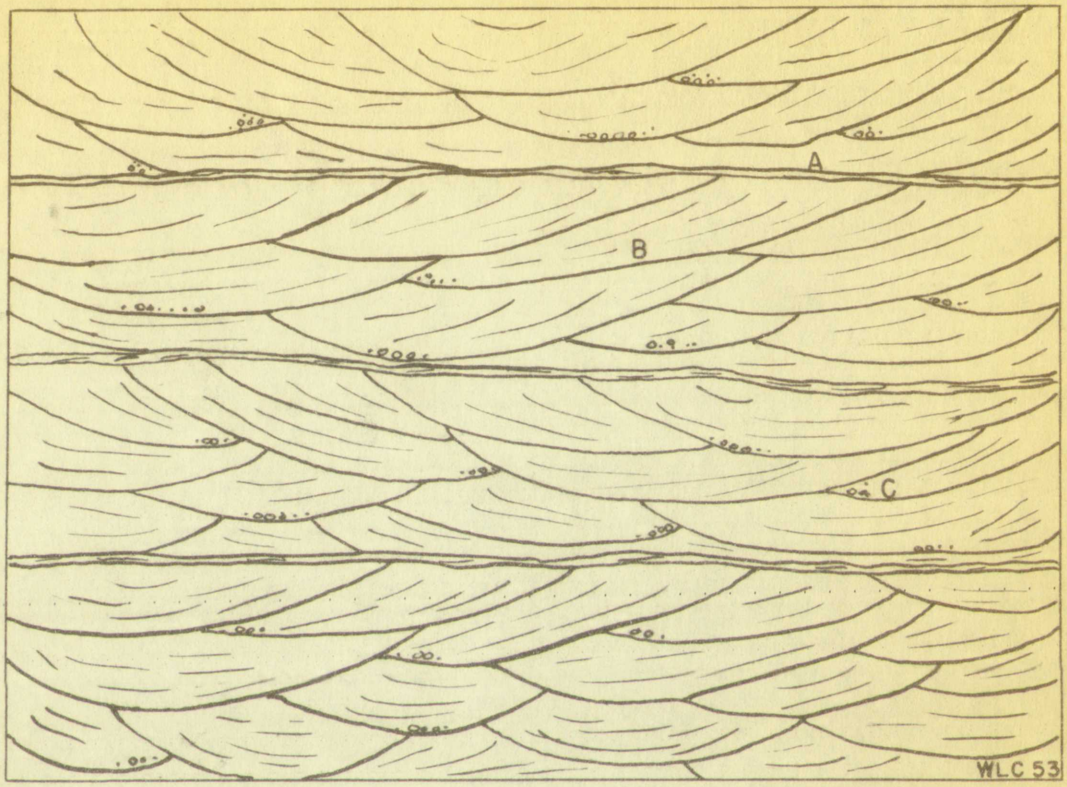

Figure 6. Diagrammatic bedding and cross-lamination in the sandstone in the Variegated member.

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 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. A small walk-out of many of the thick sandstone beds has, time and time again, established that these units lens out within a few hundred feet along the outcrop. However, a small, prominent, cliff-forming sandstone (no. 6) near the base of the Laguna section (Pl. 3A.) may have equivalents to the northeast in the [illegible] Springs (no. 2) and Herrera Ranch (no. 11) sections (Pl. 4). As a sandstone bed pinches out, there is both an increase in the thickness of the intercalated claystone stringers along the bedding planes and a gradation to siltstone and finally into claystone. As a rule these wedges out the lower units commonly lense out first so the beds appear 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 [illegible] is rare. Beds 6 to 12 inches thick are composed of dark gray, [illegible] crystalline and finely crystalline varieties which are commonly [illegible]

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.

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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 Dobrovolny, 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

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

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 Morrison is [illegible] gradation into sandstone similar to the underlying Bluff sandstone, as well as some pre-Dakota erosion (Fig. [illegible]).

The base of the Variegated member was drawn at the bottom of the first clay zone or siltstone above the Bluff sandstone. As the member [illegible] tends 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. 16, T. [illegible] N., R. 7 W., and Sec. 18, T. 9 N., R. 6 W.) the gradation is well exposed and could be examined. Between these two localities is an unscalable outlier of Bluff sandstone, the [illegible] Enchanted Mesa (Sec. 14, T. [illegible] N., R. [illegible] W.) [illegible] to be capped, not by Dakota sandstone, but by the sandstone facies of the Variegated member. [illegible] place the clay zone of the Variegated member [illegible] 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 [illegible], east of South Garcia (Sec. [illegible], T. [illegible] N., R. 7 W.) [illegible]

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

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

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

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

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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.

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A poor fragment of [illegible]

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Mold of a [illegible] bryozoan

Brachiopods

Fragmentary mold of [illegible], possibly [illegible]

Fragmentary mold of [illegible], possibly a productid.

Pelecypods?

Doubtful fragments not [illegible].

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

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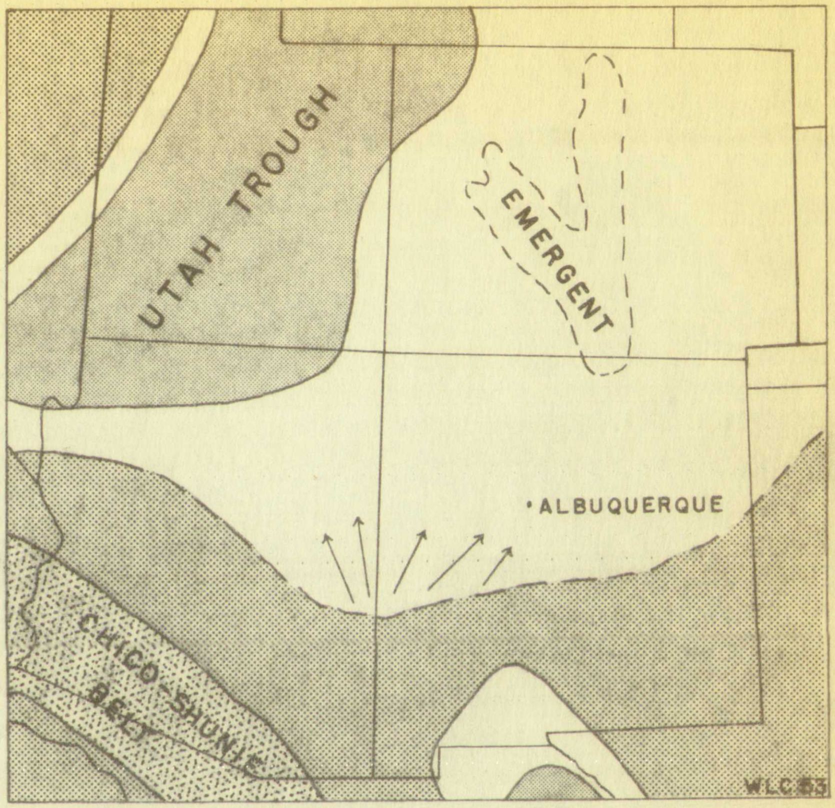

Figure 7. Tectonic map of the late Jurassic.
(Modified after Eardley)

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

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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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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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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).

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

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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 sames as the Acoma fold. Such an alinement 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

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

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Small dikes and sills [illegible]

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.

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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

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. Masters, district geologist, Fourth Corners 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 Shinarump (Lower Kinsey 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 lenses less than 40 feet thick are generally not favorable for the 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.

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.

APPENDIX

(Descriptive Stratigraphic Sections)

Herrera Ranch Section

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

No.	Description	Thickness Unit	(Feet) Cumulative
	(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

No.	Description	Thickness Unit	(Feet) Cumulative
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

No.	Description	Thickness Unit	(Feet) Cumulative
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)		

East Mesa Gigante Section

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

No.	Description	Thickness Unit	(Feet) Cumulative
	(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.

No.	Description	Thickness Unit	(Feet) Cumulative
	(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

No.	Description	Thickness Unit	(Feet) Cumulative
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.

No.	Description	Thickness Unit	(Feet) Cumulative
	(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 subrounded; 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 subrounded; 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.

No.	Description	Thickness (Feet) Unit	Cumulative
	(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.

No.	Description	Thickness (Feet) Unit	Cumulative
	(Dakota group above)		
	Top of the Variegated member:		
7	SANDSTONE: medium bedded; cross laminated; white; fine to very coarse grained; grains angular to subrounded; 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	

Laguna Section

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

No.	Description	Thickness Unit	(Feet) Cumulative
	(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

No.	Description	Thickness Unit	(Feet) Cumulative
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)		

Wheat Mountain Section

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

No.	Description	Thickness Unit	(Feet) Cumulative
	(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; microcrystalline; 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; microcrystalline; 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 subangular to subrounded; intercalated light-green mudstone beds............	11	79

No.	Description	Thickness Unit	(Feet) Cumulative
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.

No.	Description	Thickness Unit	(Feet) Cumulative
	(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)		

Acoma Section

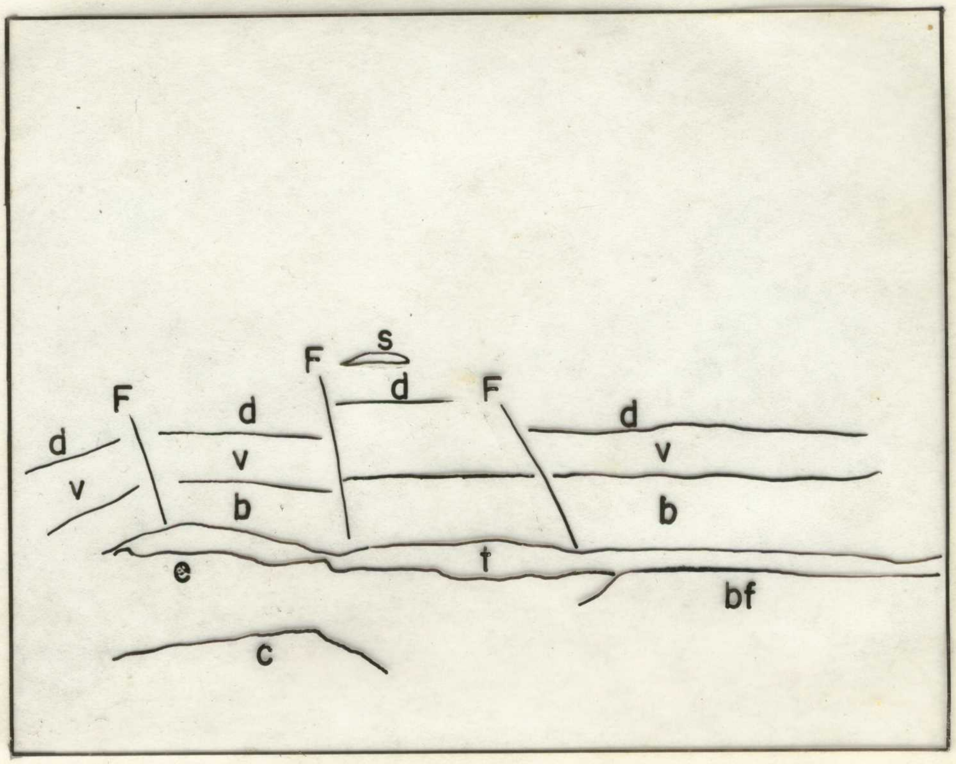
NW 1/4, Sec. 8, T. 8 N., R. 7 W.

No.	Description	Thickness Unit	(Feet) Cumulative
	(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)		

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.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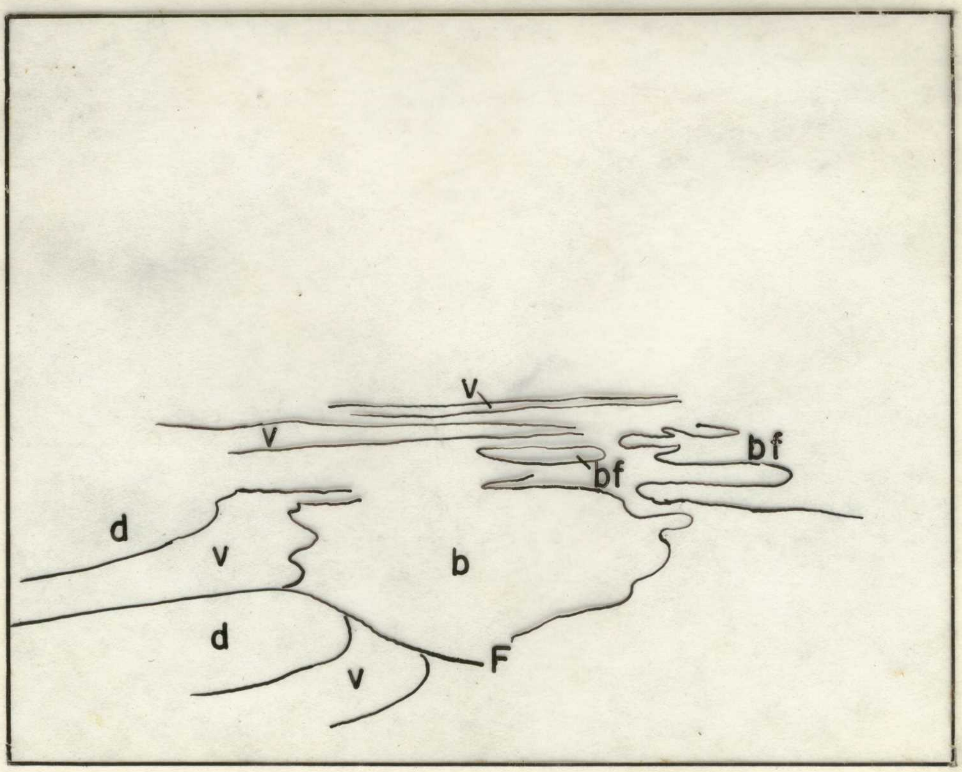
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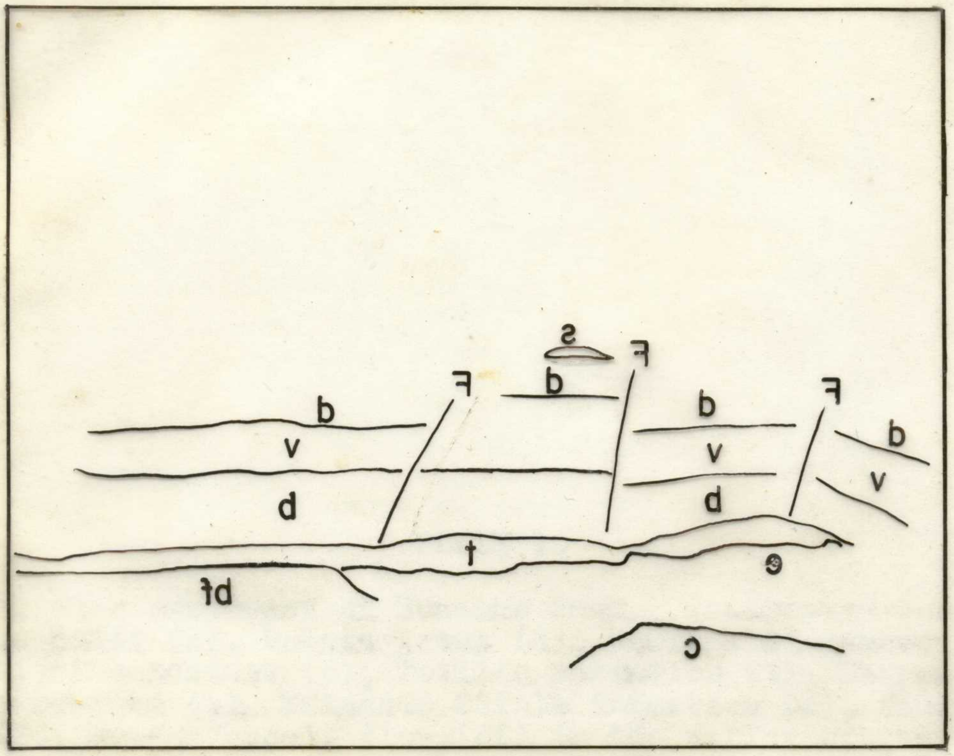


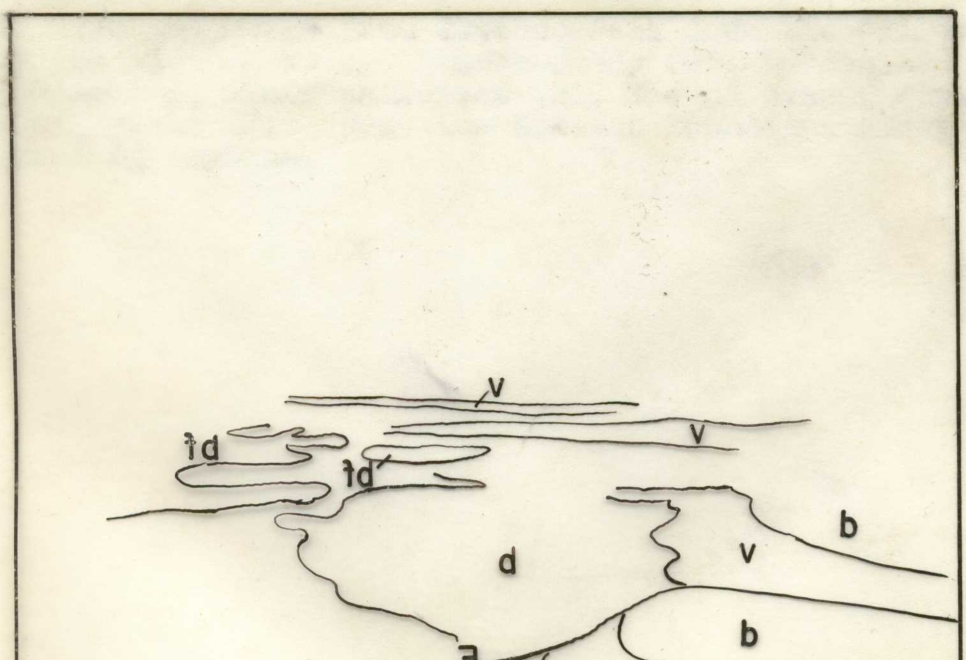
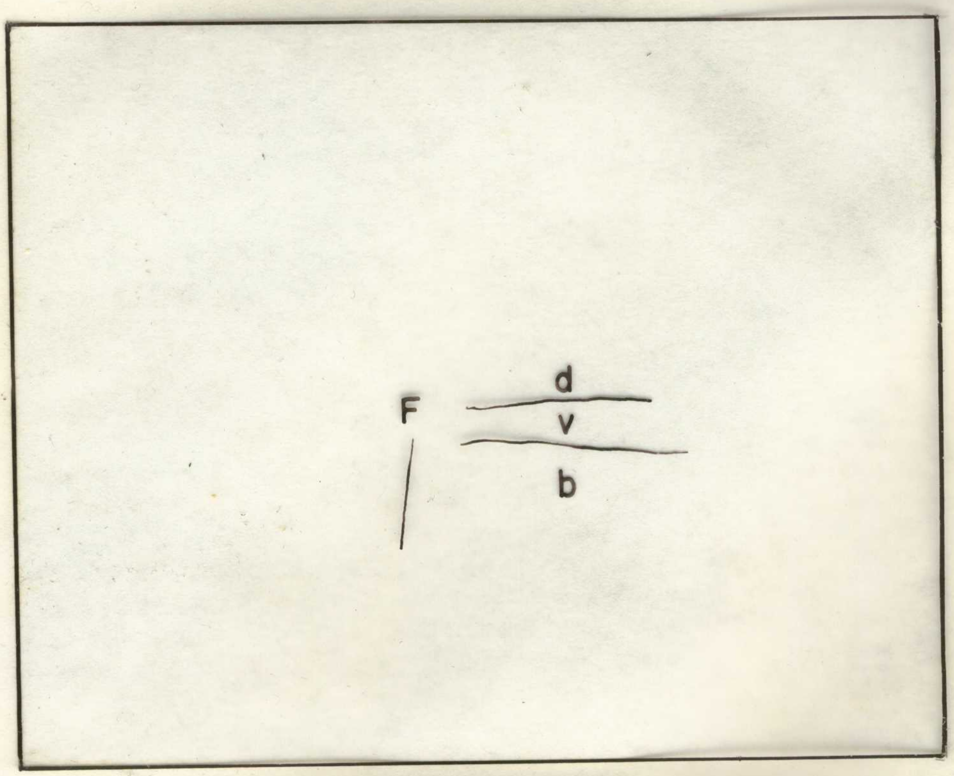


PLATE 1.

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).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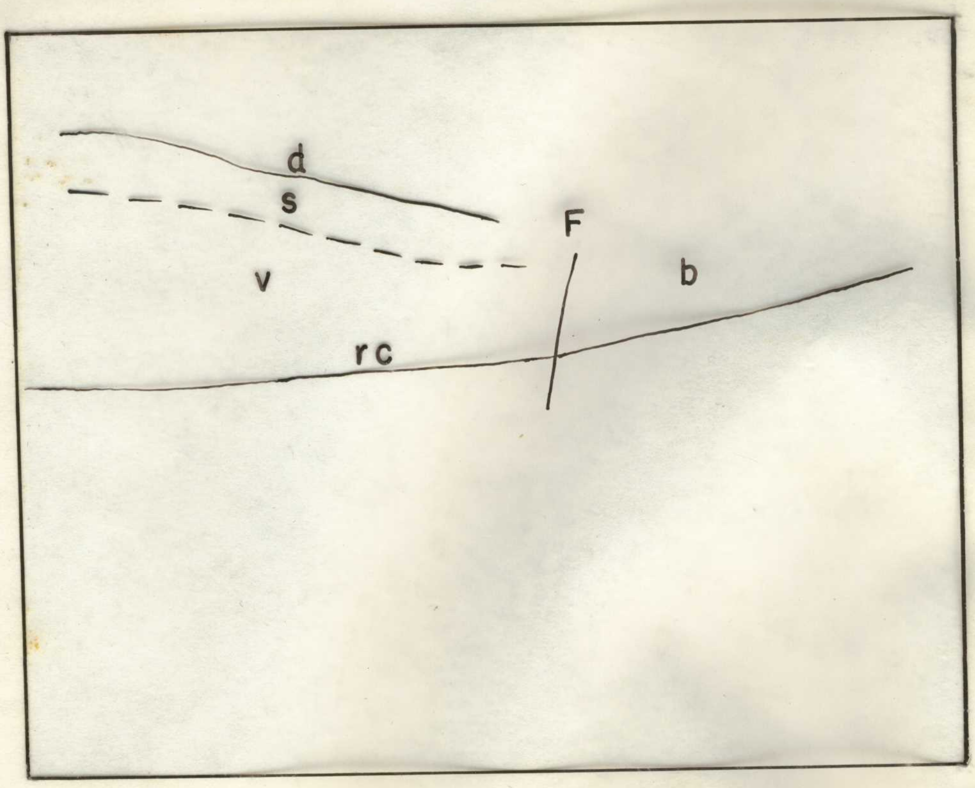
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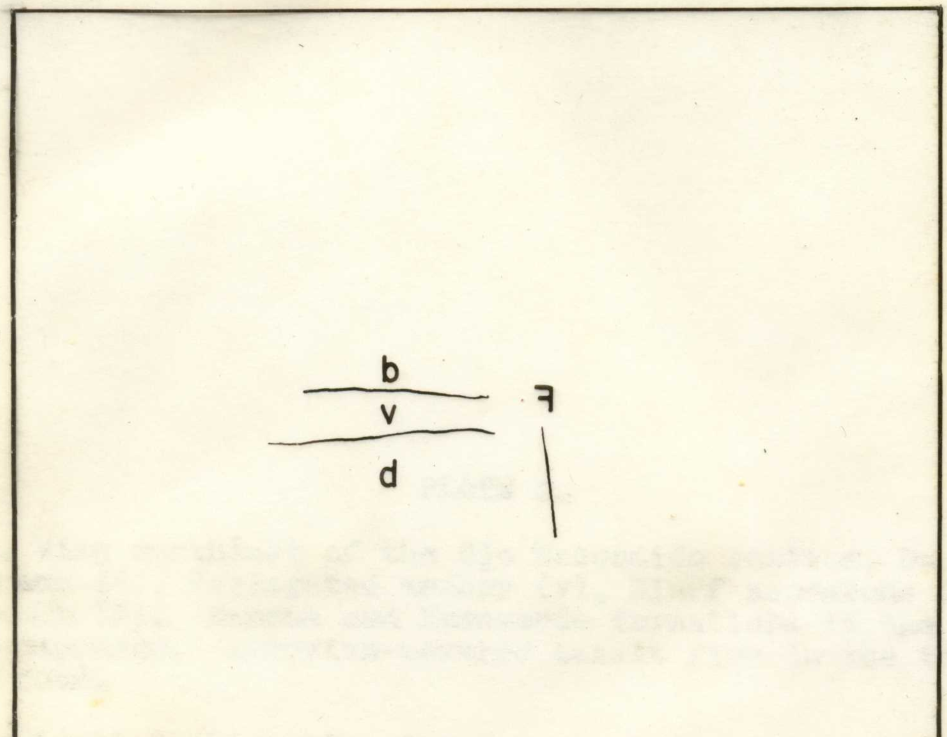


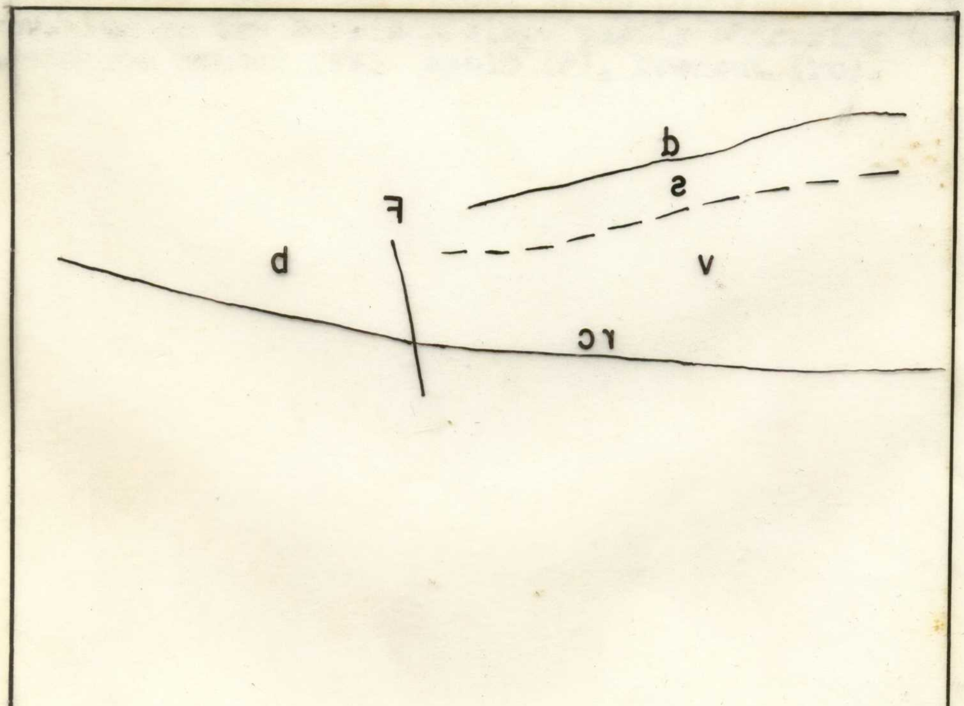
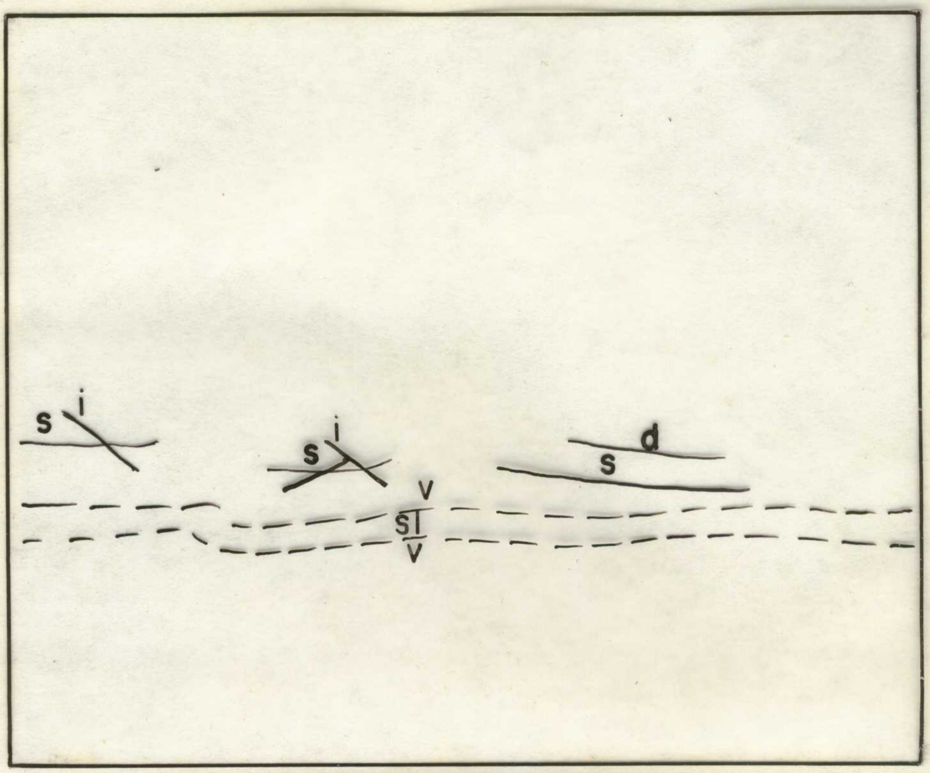


PLATE 2.

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.



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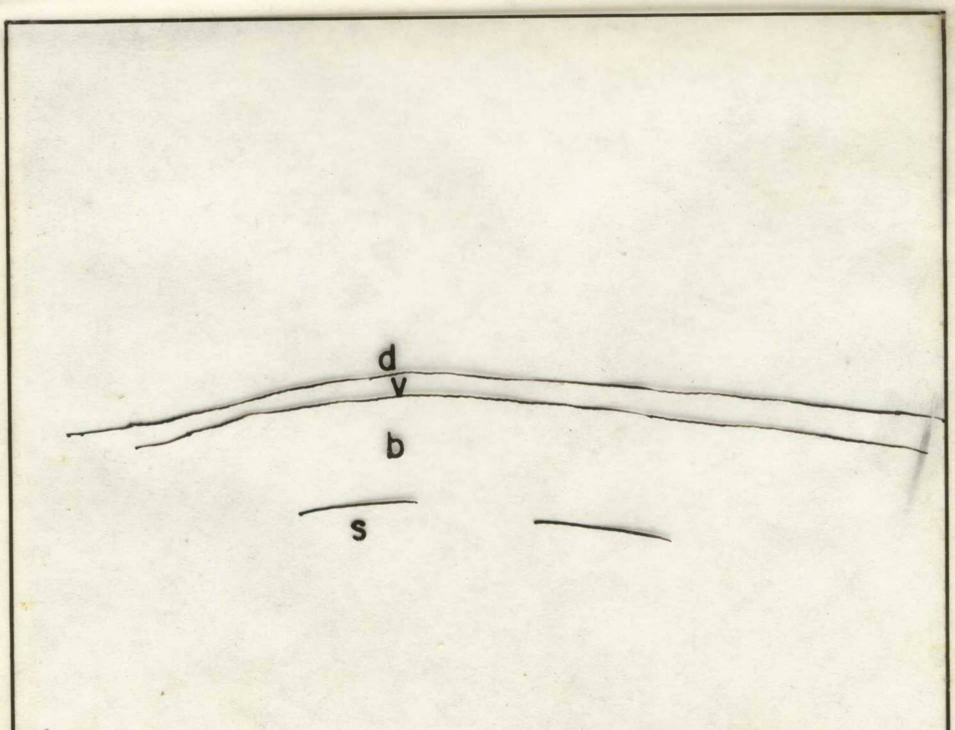

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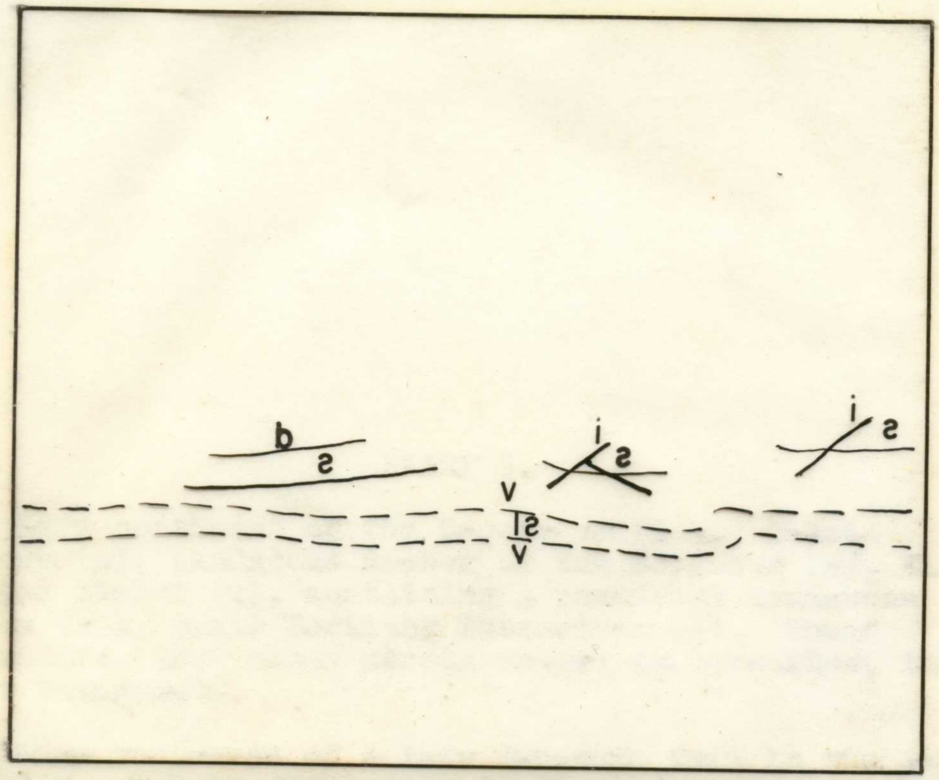

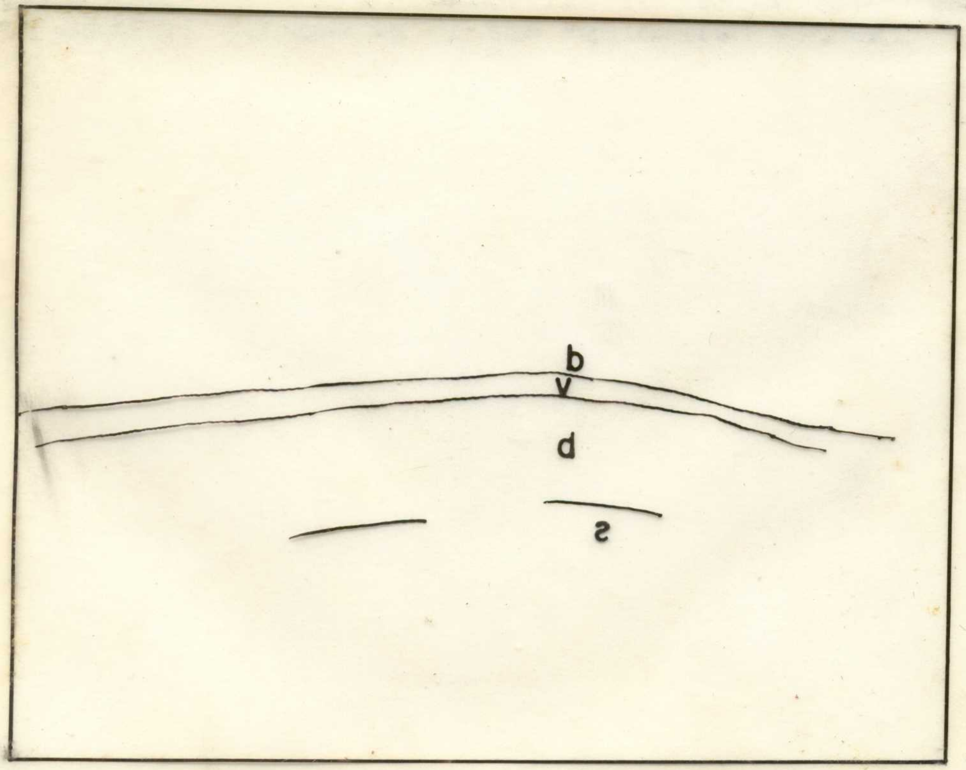

PLATE 3.

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5 Maps, folded charts, plates, etc.

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