GEOLOGY OF RILEY-PUERTECITO AREA, SOUTHEASTERN MARGIN OF COLORADO PLATEAU, SOCORRO COUNTY, NEW MEXICO

BY

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DISSERTATION

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GEOLOGY OF RILEY-PUERTECITO AREA, SOUTHEASTERN MARGIN OF COLORADO PLATEAU, SOCORRO COUNTY, NEW MEXICO

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ABSTRACT

Late Cretaceous and Cenozoic rocks crop out in south-dipping hogbacks north of the Bear Mountains along the drainage of the Rio Salado in northwestern Socorro County. The Cretaceous rocks are typically dark-gray shales and yellowish-gray sandstones that were deposited as marine and nonmarine sediments associated with two regional marine transgressions. Discontinuous coal seams up to 4 ft (1.2 m.) thick occur in the Mesaverde Formation. The inferred resources of bituminous and sub-bituminous coal are about 50 million tons (45.4 million metric tons).

The Baca Formation (Eocene) overlies the Cretaceous rocks unconformably. The Baca Formation is composed of arkosic sandstones, mudstones, and conglomerates that are largely products of fluvial deposition that occurred in a narrow east-trending basin. Several large sandstone channel deposits within the lower and middle portions of the Baca are bleached, contain abundant carbonaceous debris, and appear to be favorable for uranium mineralization. The Baca Formation has a gradational interfingering upper contact with the overlying Spears Formation (early Oligocene), the basal volcaniclastic apron of the Datil-Mogollon volcanic field. In turn, the Spears Formation was covered by the Hells Mesa and A-L Peak Tuffs (32-31 m.y. B.P.).

Several large, relatively gentle north-trending folds were produced during the Laramide Orogeny. In late

Oligocene to early Miocene time, the Riley area was cut by numerous north-trending, high-angle, normal faults, downthrown-to-the-west. Many of these faults served as the site of intrusion for mafic dikes that may have been feeders for basaltic andesite lavas related to the opening of the Rio Grande rift. Beginning in the early Miocene, uplift of the Colorado Plateau tilted the rocks southward, and subsequent erosion produced the present east-trending outcrop belt.

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INTRODUCTION

Location and Area

The abandoned settlement of Riley, previously called Santa Rita is about 18 mi (29.0 km) north of Magdalena, on the north bank of the Rio Salado (fig. 1). An improved dirt road, Forest Road 354, parallels the eastern edge of the Bear Mountains from Magdalena to Riley. On the western side of the Bear Mountains, Forest Road 123 leading to Puertecito crosses the northwestern edge of the area mapped.

The area mapped is about 12 mi (19.3 km) long and 4 to 5 mi (6.4 to 8.0 km) wide, elongate northwest to southeast. The Rio Salado roughly outlines the northern boundary. The 54 mi^2 (139.9 km^2) area is within the La Jara Peak 7.5' quadrangle, the Mesa Cencerro 7.5' quadrangle and the Riley 15' quadrangle.

About 35 percent of the area is in Cibola National Forest; the remaining 65 percent is equally divided between public domain controlled by the Bureau of Land Management and deeded property. Ranching is the dominant enterprise and much of the Bureau of Land Management and National Forest land is leased for grazing.

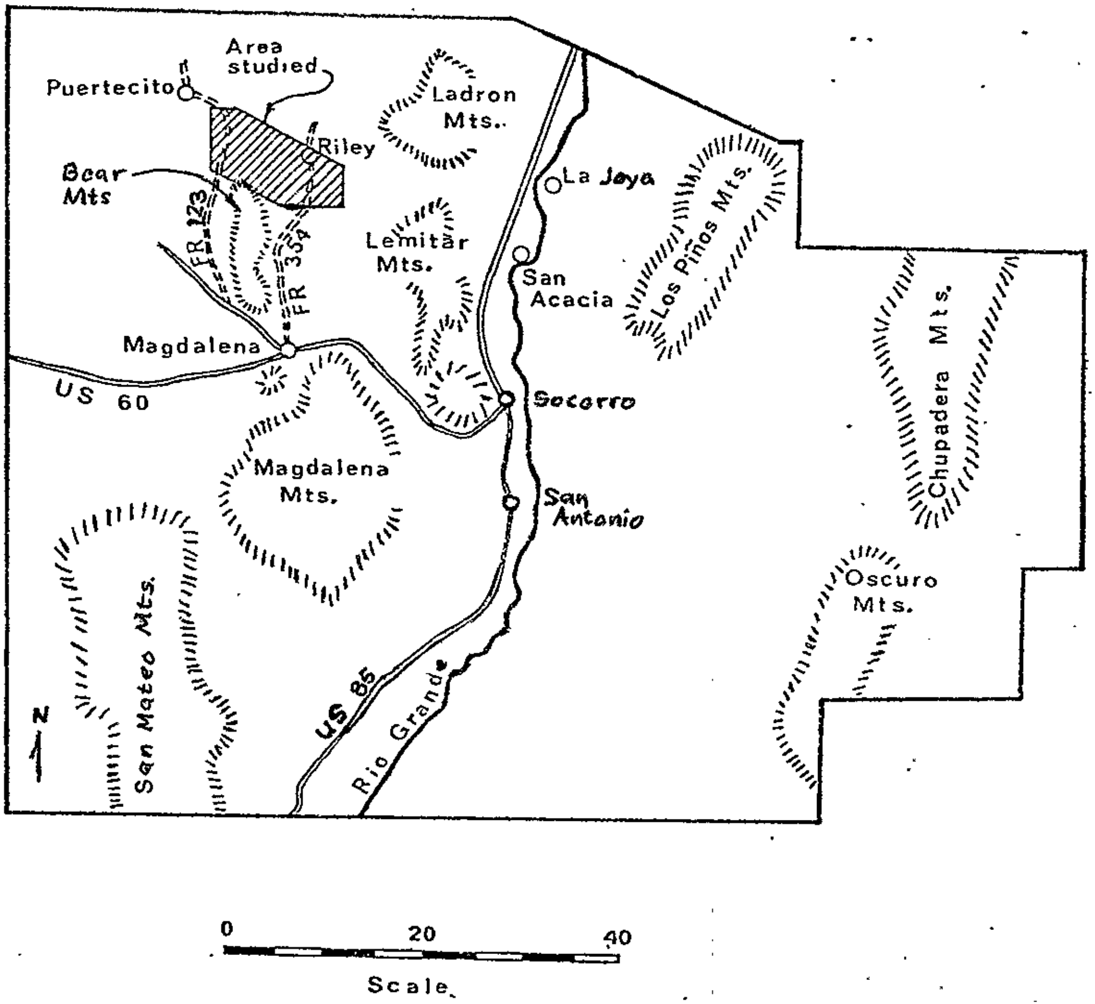
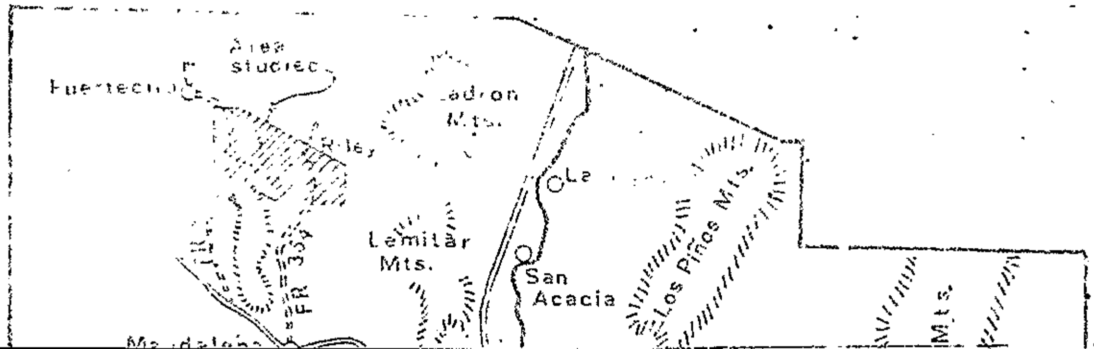


Figure 1. Socorro County with studied area indicated.



Physiography

The area of study is on the western edge of the Rio Grande depression within the Datil subdivision of the Basin and Range physiographic province (Hawley and others, 1976). Along the drainage of the Rio Salado erosion has exposed resistant sandstone beds and sill-like intrusives which cap numerous hogback and cuesta ridges. A multitude of vertical, north-trending dikes form parallel, symmetrical ridges which cross the hogbacks at various angles resulting in a complex drainage pattern. A gently dipping gravel-covered piedmont overlies the older rocks in the southeastern part of the area. The Bear Mountains, in the southwestern part of the area, consist of a thick pile of basaltic andesite flows and ash flow tuffs, which crop out in high, rounded ridges.

The maximum elevation of the area is 7812 ft (2381.1 m) at Hells Mesa, sec. 17, T. 1 N., R. 4 W. The minimum elevation is about 5400 ft (1645.9 m) along the Rio Salado where it leaves the area to the east. The local surface relief is about 2412 ft (735.2 m).

The Rio Salado, previously called Alamosa Creek, flows southeastward across the area, following less resistant shale units. Between Puertecito and Riley the river valley is developed in shale of the Chinle Formation. At Riley, the river cuts across the Dakota Sandstone where a fault has offset the resistant sandstone. Across the remainder of the studied area, the Rio Salado valley is in the Alamito Well Tongue of the Mancos Shale.

Runoff of the area drains into the Rio Grande via the Rio Salado and its tributaries which are largely intermittent, except for local spring-fed segments. Groundwater is present at shallow depths; numerous springs and shallow wind-powered wells are present throughout the area.

The climate of the region is semi-arid with a mean annual temperature around 53° F (11.7° C). The mean daily maximum temperature is about 70° F (21.1° C) and the mean daily minimum temperature is about 40° F (4.4° C). The annual precipitation is approximately 10 inches (25 cm) to 15 inches (38 cm) (U.S. Department of Commerce, 1965). Most of the rainfall occurs in short, violent thunderstorms during the early summer months. The runoff cuts deep arroyos, a characteristic of the American southwest since the 1800's (Malde and Scott, 1977).

The vegetation of the area is varied, dependent upon elevation, soil type, and proximity to water. Cottonwoods, willows, oak, tamarisk and other small trees and shrubs grow in creek bottoms. Locally, springs support lush vegetation including reeds, cat claws, and wild grape vines. The lower slopes and flats are covered with various grasses and moderately spaced cedar and cholla. Higher elevations in the Bear Mountains have reasonably thick growths of juniper, pine and cedar. Rabbits, rodents, birds, and lizards are extremely abundant, supporting a large population of coyote. Deer, bobcat, fox, and other small mammals are present in modest numbers.

Nature and Scope of Investigation

The purpose of this investigation was to map and interpret the geology of the outcropping Cretaceous and Eocene strata near Riley, New Mexico. The study was part of a geological investigation of the coal, uranium, and petroleum potential of the Riley-Puertecito area, Socorro County, New Mexico. The program was funded by the New Mexico Energy Resources Board and directed by Dr. Charles E. Chapin of the New Mexico Bureau of Mines and Mineral Resources. The field work was done from May to September, 1976, and from May to December, 1977. The topographic base map, scale 1:24,000, was compiled by joining portions of the La Jara Peak 7.5' quadrangle, Mesa Cencerro 7.5' quadrangle, and an enlarged Riley 15' quadrangle.

Several partial stratigraphic sections were measured to establish the stratigraphic framework of the area. Descriptions of rocks in stratigraphic sections follow a method outlined by Kottlowski and others (1956). Rock colors were determined by using the Geological Society of America's "Color Chart" (1963). Forty-seven samples of various sedimentary rocks units were examined in thin-section.

The study was conducted concurrently with biostratigraphic study of the marine portion of the Upper Cretaceous in northwestern New Mexico by Dr. Stephen C. Hook, New Mexico Bureau of Mines and Mineral Resources. Many of the fossils collected were sent to Dr. William A. Cobban, United States Geological Survey, and were subsequently assigned United States Geological Survey fossil locality numbers. The terminology applied to the Cretaceous strata was extensively researched and discussed with the Stratigraphic Names Committee, United States Geological Survey, by Dr. Stephen C. Hook.

Occurrences of coal were mapped and eight samples were analyzed by the United States Department of Energy. Channel trends, pebble imbrications and lithotypes in the Baca Formation were examined to determine provenance and transport directions. Similar determinations were made on the Mesaverde and Popotosa Formations. Primary sedimentary structures, grain sizes, sorting, rounding, and compositions were scrutinized to establish the mode of deposition of the Cretaceous and Baca rocks.

Fifty intrusives, mostly dikes, were sampled and 20 representative samples were thin-sectioned. One volcanic neck and two dikes were sampled for whole-rock chemical analysis and radiometric dating.

Previous Work

In 1899 C. L. Herrick reconnoitered the geology of western Socorro and Valencia Counties and in the report in 1900 he made a brief reference about the composition of the volcanic rocks in the Bear Mountains. D. E. Winchester, in 1913 and 1914 studied the coal resources of northern Socorro County and investigated the geology along the drainage of the Rio Salado. He published the results and a simple map in 1920.

N. H. Darton published a study of the "Red Beds" and associated formations in New Mexico in 1928. In the same publication he outlined the geology of the state and briefly described the geology of the studied area. Kelly and Wood (1946) reported on the structure and stratigraphy of the Lucero Uplift, adjacent to the studied area to the north.

With the exception of the eastern one-third the studied area was included in a study of the Puertecito quadrangle by W. H. Tonking in 1951 and 1952. Tonking made excellent initial determinations of the regional stratigraphy and structure. His findings and a map were published in 1957.

S. C. Potter (1970), measured and mapped portions of the Baca Formation along Baca Canyon to define its character and depositional environment. Previous works not specifically concerning the studied area but of a general stratigraphic nature will be discussed in the stratigraphy portion of this paper.

REGIONAL SETTING

General

Northwestern Socorro County is characterized by gently to moderately dipping sedimentary strata and extensive volcanic accumulations. Late Cenozoic block faulting and erosion has produced a series of north-trending ranges flanked by deep structural basins. The elevation varies from about 4500 ft (1371.6 m) along the Rio Grande to 10,785 ft (3287.3 m) at South Baldy in the Magdalena Mountains.

The major structural provinces of northwestern Socorro County (fig. 2) are the Colorado Plateau and the Rio Grande rift. The position of the boundary between these provinces is debatable because rift faulting is present in areas where the strata are tilted because of uplift by the plateau. The limit of rift characteristics can be defined by a margin that parallels the eastern side of the Lucero uplift, makes a westward bend west of the Ladron Mountains, passes north of the Bear Mountains, and turns southward along the east side of the Gallinas Mountains (fig. 2). The area of study includes aspects of both rift and plateau; the strata dip southward because of the uplift of the plateau but they are also broken by numerous north-trending fractures related to rifting.

In the past the boundary of the rift was considered to be east of the Socorro-Lemitar Range (Fitzsimmons, 1959).

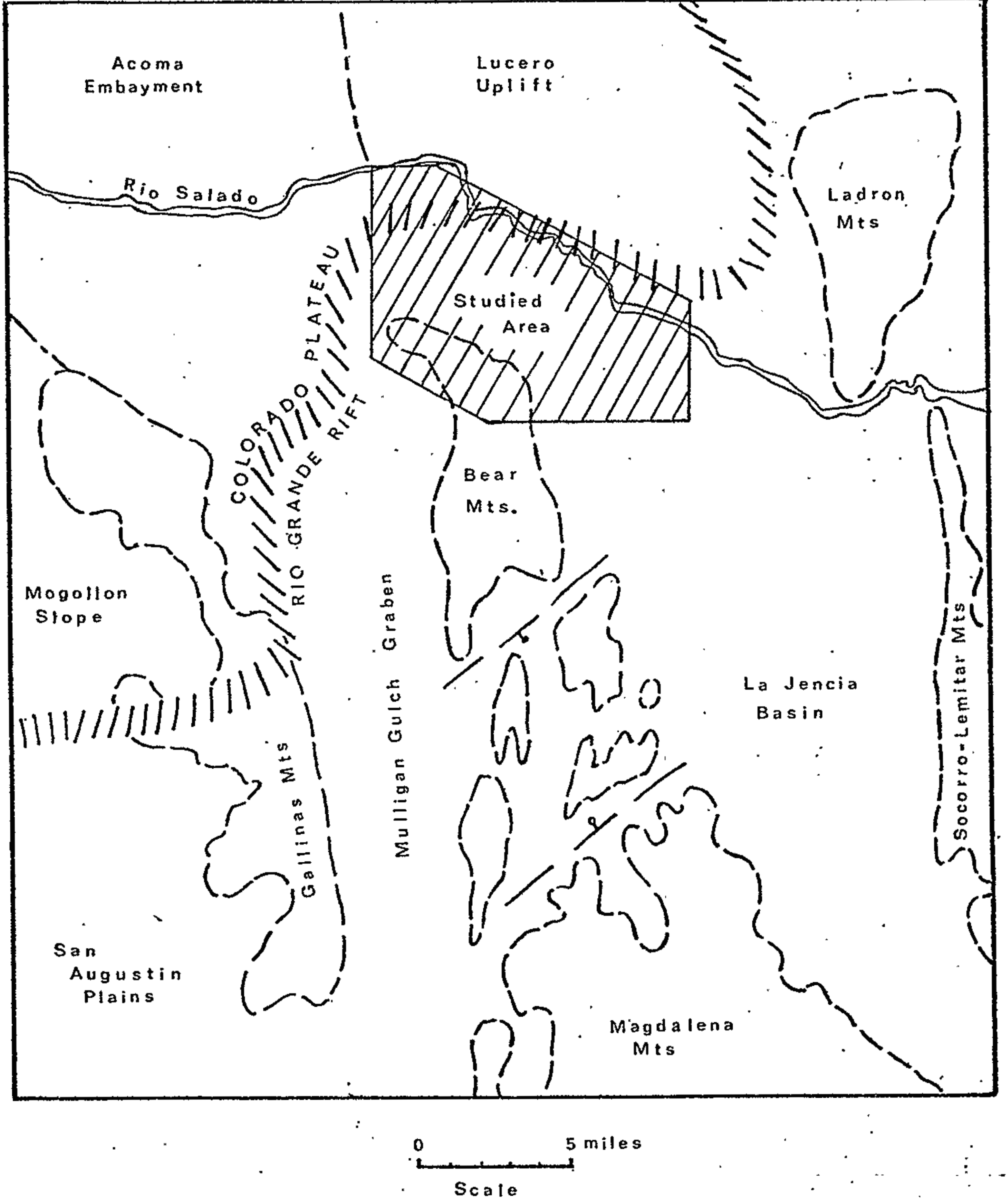


Figure 2. Structural subdivisions of northwestern Socorro County with studied area indicated. Boundary between Colorado Plateau and Rio Grande rift structural provinces is indicated by hatchured line. Modified after Chapin and Seager, 1975, Fitzsimmon, 1959, and Chapin, oral communication, 1978.

The "Socorro constriction" (Kelley, 1952), however, is an illusion and the Rio Grande rift actually widens in the Socorro area (Chapin, 1971 a).

Rio Grande Rift

The Rio Grande rift consists of a series of essentially parallel north-trending horsts and grabens which extend for about 600 mi (965.6 km) from near Leadville, Colorado, to near El Paso, Texas. In the Socorro region, the rift widens into a series of parallel basins separated by intrarift horsts (Chapin, 1971 a). The Rio Grande depression has evolved over a considerable period of time, beginning about 29 m.y. ago, and it is still subsiding (Chapin and Seager, 1975). Initially isolated, closed and continuously filled with sediments the separate basins were integrated in Pliocene time by the ancestral Rio Grande.

A large early-rift basin in which the Popotosa Formation accumulated once covered much of northwestern Socorro County. This basin, originally at least 40 mi (64.4 km) wide in an east-west direction, was progressively segmented by a series of north-trending fault-block uplifts. In order of their creation, the intrabasin uplifts include the Magdalena Mountains, Ladron Mountains, Socorro-Lemitar Range, and the Bear Mountains (Chapin and others, 1975).

The Bear Mountains are a north-northwest-trending, westward-tilted block composed of the volcaniclastic Spears Formation overlain by the Hells Mesa and A-L Peak Tuffs of Oligocene age; and the La Jara Peak Basaltic Andesite of late Oligocene-early Miocene age. The Bear Mountains are bordered on the north by the Lucero uplift and on the west by the Mulligan Gulch graben.

A southwest-trending arm of the Rio Grande rift, the San Augustin graben, dropped the southern half of the Bear Mountains about 2000 ft (609.6 m) and underwent about 4000 ft (1219.2 m) of apparent westward displacement on the southern boundary fault (Chapin and others, 1975). The San Augustin graben is a complex of several west-southwest-trending echelon grabens which probably range in age of development from Miocene to Pliocene. The San Augustin plain is probably the youngest and shallowest basin (Chapin and others, 1975). Topographic lows between the Bear and Magdalena Mountains and between the Gallinas and San Mateo Mountains are evidence of that graben.

Several pluvial lakes developed in the depression of the San Augustin arm of the rift during the Pleistocene. The ancient lake system covered a maximum of 255 mi^2 (660.4 km^2). The present day playa covers about 35 mi^2 (90.6 km^2) and is encircled by highlands of largely volcanic rock (Fitzsimmons, 1959).

The northern half of the Magdalena Mountains are a north-northwest-trending, westward-tilted fault-block uplift with about 4500 ft (1371.6 m) of topographic relief. They are composed of Precambrian granites, argillites and quartzites; late Paleozoic limestones, quartzites and shales; capped by middle Tertiary ash-flow tuffs, andesites, monzonites and granites (Chapin and others, 1975). The Bear Mountains are the structural extension of the Magdalena Mountains and both are bounded by the La Jencia Basin and Mulligan Gulch graben on the east and west, respectively.

The Socorro-Lemitar Mountains are a north-trending fault-block range composed of Precambrian granites, argillites and quartzites; late Paleozoic limestones, quartzites, and shales; and middle Tertiary volcanic strata and late Tertiary sedimentary rocks. The strata are tilted to the west and broken by a complex pattern of dominantly low-angle normal faults of varying inclinations that represent progressive rotation of originally high-angle, early-rift normal faults and fault blocks (Chamberlain, 1976). Socorro Peak at 7,243 ft (2207.7 m), is capped by a series of late Miocene silicic domes (12-7 m.y.) intruded along the northern margin of the late Oligocene Socorro cauldron (Chapin and others, 1978). The Socorro-Lemitar uplift is bounded on the west by La Jencia Basin.

The Ladron Mountains, the northern structural extension of the Socorro-Lemitar uplift, are small in area but stand impressively high with a maximum elevation of 9,176 ft (2796.8 m). The core of the range is composed of quartzites, granites, schists, and gneisses of Precambrian age (Condie, 1976). The mountains trend northward and are a westward-tilted fault block probably bounded by Cenozoic high-angle faults (Kelley, 1952). Strata of late Paleozoic and Mesozoic age crop out along the west flank of the Precambrian core (Black, 1964; Haederle, 1966).

The La Jencia Basin, located between the Socorro-Lemitar and Bear-Magdalena uplifts, is about 14 mi (22.5 km) long and 9 mi (14.5 km) wide. The major part of the north end of the basin is drained by the northeast-flowing La Jencia Creek. The La Jencia basin was originally part of the older Popotosa basin and contains portions of the Popotosa Formation of Miocene age and Upper Santa Fe Group of Pliocene age (Chapin and others, 1978). Bolson fill clastics of Quaternary age overlie these units. Southwest of the Ladron Mountains and northwest of the Lemitar Mountains an extensive Pliocene travertine unit accumulated over the bolson and Santa Fe Group sediments.

Between the Bear-Magdalena and Gallinas-San Mateo Mountains is a narrow trough, the Mulligan Gulch graben, which extends from San Marcial on the south to beyond Abbe Spring on the north. At the northwest end of the Bear Mountains, fanglomerates are interbedded with 26 m.y. old lava flows of the La Jara Peak Basaltic Andesite. These fanglomerates are the first record of bolson sedimentation (Chapin and Seager, 1975). As the large Miocene Popotosa Basin was broken into smaller parallel basins the Popotosa Formation became tilted and was subsequently covered by Upper Santa Fe clastics and Quaternary fanglomerates shed from the surrounding uplifts (Chapin and Seager, 1975).

Colorado Plateau

The Colorado Plateau is a broad, stable uplifted segment of the crust which embraces 130,000 to 150,000 mi^2 (209,215 to 388,498 km^2) in northwestern New Mexico, northeastern Arizona, southeastern Utah and western Colorado. The plateau is characterized by valleys, plains, mesas and buttes of generally flat-lying sedimentary strata, 6,000 to 10,000 ft (1,828.8 to 3,048.0 m) thick, overlying a Precambrian basement complex (Eardley, 1962). Locally, the nearly flat-lying strata are disturbed by large monoclinal flexures of Laramide age (Kelley, 1955).

The Lucero uplift is part of a north-trending arch which marks the eastern edge of the Colorado Plateau (Kelley and Wood, 1946). The boundary of the Colorado Plateau follows the eastern and southern sides of the Lucero arch, bending westward just north of Rio Salado. The Lucero uplift is considered an extension of the Rio Puerco fault zone and the Nacimiento uplift by Kelley and Wood (1946). However, the major tectonism of the Lucero uplift is Laramide in age, the Rio Puerco fault zone is the result of an Eocene tensional couple, and the Nacimiento uplift is a complex of normal and reverse faults, early to late Tertiary in age (Woodward and others, 1972; Slack, 1975; and Callender and Zilinski, 1976). Within the Lucero area is a sinuous belt of thrust faults, the Comanche thrust belt, which extends about 25 mi (40.2 km) along the eastern margin of the Acoma Basin. Movement was from west to east, with stratigraphic displacements of 3000 ft (914.4 m) or more. Normal faulting related to the subsidence of the Rio Grande depression was superimposed on the earlier uplift and thrusting (Kelley and Wood, 1946).

Between the Zuni uplift to the west and the Lucero uplift to the east, Cretaceous and older strata are present in the Acoma embayment or basin. The basin grades into the San Juan Basin to the north and the Mogollon slope to the south. Northwest-trending folds and faults have affected the Triassic and Cretaceous strata in the southeastern part of the Acoma Embayment. The average dip of the strata is about 20 degrees south and southwest. A major geomorphic surface of Pliocene age was covered in places by mafic flows which now cap prominent mesas. Several late Pliocene volcanic necks appear to be genetically related to this surface (Chapin, oral communication, 1977).

The Acoma embayment passes into the Mogollon slope to the south. The Mogollon slope is a rather non-descript structural unit composed of extensive volcanic flows and gently dipping sedimentary rocks. The prominent southward dip of these rocks suggests that the Mogollon slope represents the south flank of the uplifted Colorado Plateau (Fitzsimmons, 1959).

STRATIGRAPHY

Introduction

Strata mapped in the Riley-Puertecito area range in age from Triassic to Quaternary (fig. 3). The oldest rocks mapped are shales and sandstones of the Triassic Chinle Formation. Upper Cretaceous shales and sandstones unconformably overlie the Chinle Formation. Cretaceous rocks are broadly divided into the Dakota Sandstone, the Mancos Shale, and Mesaverde Formation.

The Baca Formation of Eocene age is separated from the underlying Cretaceous rocks by a regional unconformity and consists primarily of arkosic sandstones, mudstones, and conglomerates. Upper Baca strata are interbedded with the overlying Spears Formation. The Spears, dated at 37 m.y. B.P. is considered the basal volcaniclastic apron of the Datil-Mogollon volcanic field (Chapin and others, 1975). About 32 to 29 m.y. B.P. the Spears was covered by rhyolitic ash flow tuffs from cauldron centers in the Magdalena and San Mateo Mountains. These tuffs, the Hells Mesa and A-L Peak Tuffs, were buried about 26 to 24 m.y. B.P. by the La Jara Peak Basaltic Andesite (Chapin and others, 1975).

The upper beds of the La Jara Peak Basaltic Andesite intertongue with fanglomerates of the Miocene Popotosa Formation of the Santa Fe Group. Sierra Ladrones Formation, Upper Santa Fe Group, and younger sediment overlie many of

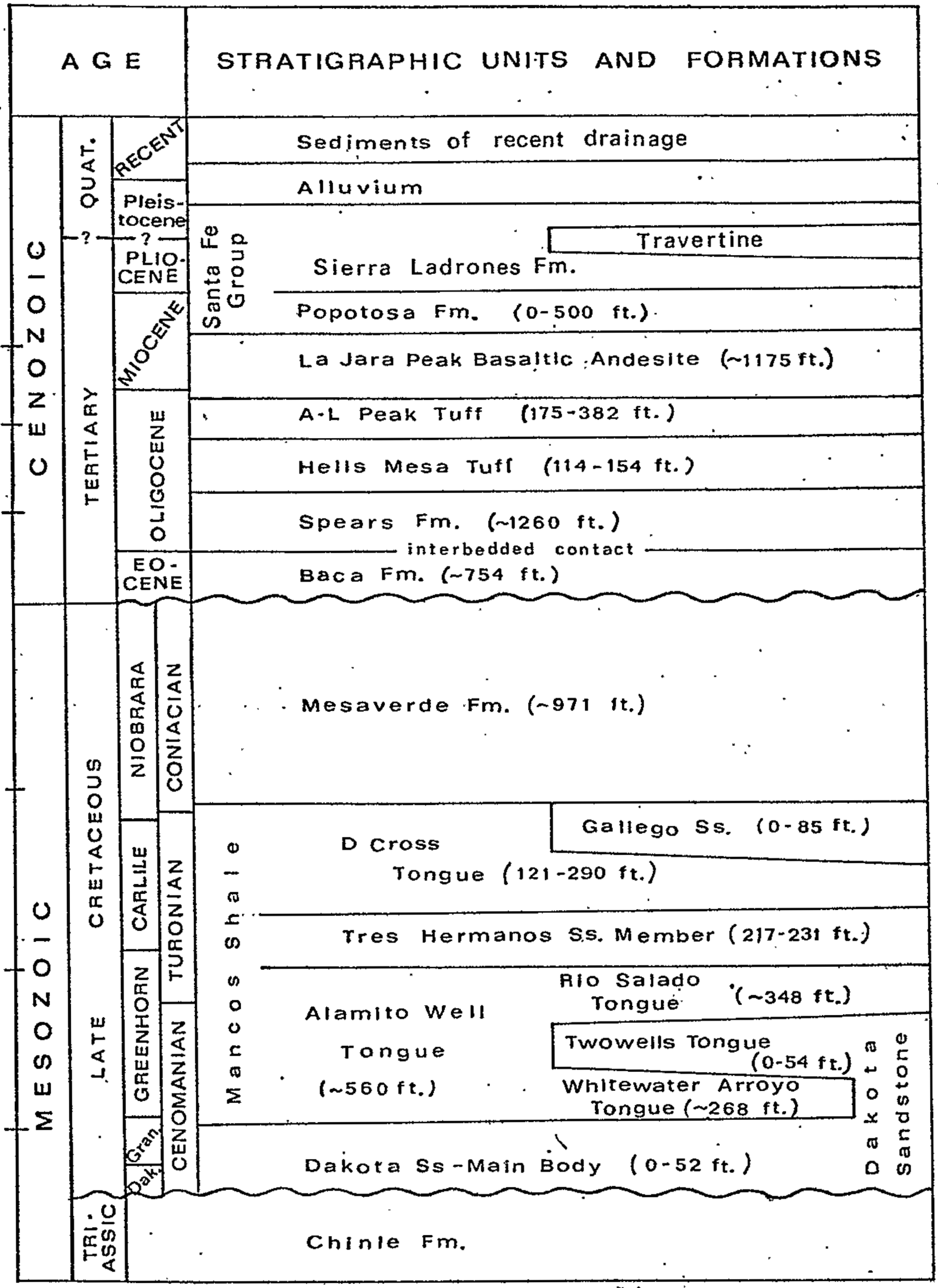


Figure 3. Stratigraphy of Riley-Puertecito area. Radiometric dates after Chapin and Seager, 1975 and Obradovich and Cobban, 1975.

the older rocks of the area.

Triassic Rocks

Winchester (1920) described the Triassic rocks of the region as "red beds." Prior to this, however, Wells (1919) had given the name Puertecito Formation to these rocks. Later Tonking (1957) assigned the "red beds" to the Chinle Formation, which is now the accepted usage. The Chinle Formation was first described by Gregory (1916) after Chinle Valley, Arizona, and was later shown to be Late Triassic in age (O'Sullivan, 1977).

The Chinle Formation was examined only near its upper boundary, because the project was limited to mapping Cretaceous and younger rocks. The Triassic rocks in the study area are estimated to be about 500 ft (152.4 m) thick. O'Sullivan (1977) reports in excess of 1312 ft (400.0 m) of Triassic rocks in the southwestern San Juan basin.

The contact of the Chinle Formation with the overlying Dakota Sandstone appears conformable when viewed in a small area but on a regional scale a slight angular unconformity is recognizable (Givens, 1957). Jurassic beds decrease in thickness from the San Juan Basin to the south and pinch out about 28 mi (45.1 km) northwest Riley (Green and Pierson, 1977, Jicha, 1958). In the Riley area, the Chinle Formation rests disconformally on the San Andres Limestone.

The Chinle Formation crops out as a broad valley east of Puertecito. The predominant lithology of the Chinle Formation is shale or mudstone containing variable amounts of silt. The shales have a characteristic red color that makes them easily distinguishable from the underlying limestones of the San Andres Formation and the overlying Dakota Sandstone. At various intervals within the red shales are gray-to-buff, coarse sandstone and conglomerate lenses. Most of the clasts are quartz, feldspar, limestone, and quartzite. The grains are poorly sorted, subangular, and cemented by calcite. Low-angle cross-stratification is common in the sandstone beds. Fossil wood and nonmarine vertebrate remains are occasionally present.

A persistent northwest-trending geosyncline existed in New Mexico throughout much of Triassic time (O'Sullivan, 1977). Within this basin sediments were deposited on a broad, nonmarine floodplain crossed by northward-flowing channels carrying sand and gravel.

Cretaceous Rocks

General

During the Late Cretaceous, a north-trending, elongate epicontinental sea divided North America into two landmasses. The basin of deposition was asymmetric, being deeper on the west than on the east (Kummel, 1970). An unstable mountainous landmass to the west gave rise to large volumes of clastic material, which varied in quantity due to sporadic tectonic and volcanic events. The clastic influx is probably the major causitive agent for Cretaceous regressions (Pike, 1947; Williams and Stelck, 1975).

Fluvial, deltaic, paludal, estuarine, and marine littoral and neritic environments are represented in Upper Cretaceous rocks of the Western Interior. Nonetheless, within the Cretaceous sequence subdivision of the rocks into the Dakota, Mancos, and Mesaverde units is possible. The definition of these units is not one of precise age limits or specific depositional environment, but rather one of a general lithologic and depositional framework within the major transgressive-regressive sequence (Sears and others, 1941). The basal unit of the Upper Cretaceous sequence is the Dakota Sandstone which is composed of fluvial, flood-plain, swamp, and lagoonal facies. The Dakota grades upward into marine dark shales and light-colored sandstones of the Mancos Shale. The Mesaverde Formation is composed of sandstones, shales, and coal beds predominately of continental origin. The Dakota, Mancos and Mesaverde, therefore, are units whose general characteristics persist over large areas, but whose composition, thickness, boundaries, age, and vertical position vary geographically (Sears and others, 1941).

The rocks in the Riley-Puertecito area record two transgressive-regressive episodes of the Cretaceous sea (fig. 4). The earliest transgression is recorded by the Dakota Sandstone and lower Alamito Well Tongue of the Mancos Shale. A thin, persistent limestone containing *Sciponoceras gracile*, a late Cenomanian ammonite, was deposited at the time of maximum advance of the Cretaceous sea into northwestern Socorro County (Hook and Cobban, 1977). At that time the sea probably covered most, if not all of New Mexico (fig. 5, line 1). The time of that event, about 89 m.y. B.P., can be determined from a Cretaceous time table established by Obradovich and Cobban (1973) which correlates ammonite zonation with radiometric dates (fig. 4). The regression that followed ended approximately in middle Turonian time (fig. 5, line 2); it is represented by the upper Alamito Well Tongue of the Mancos Shale and at least the basal half of the Tres Hermanos Sandstone Member of the Mancos Shale. The nonmarine beds in the central portion of the Tres Hermanos represent the culmination of

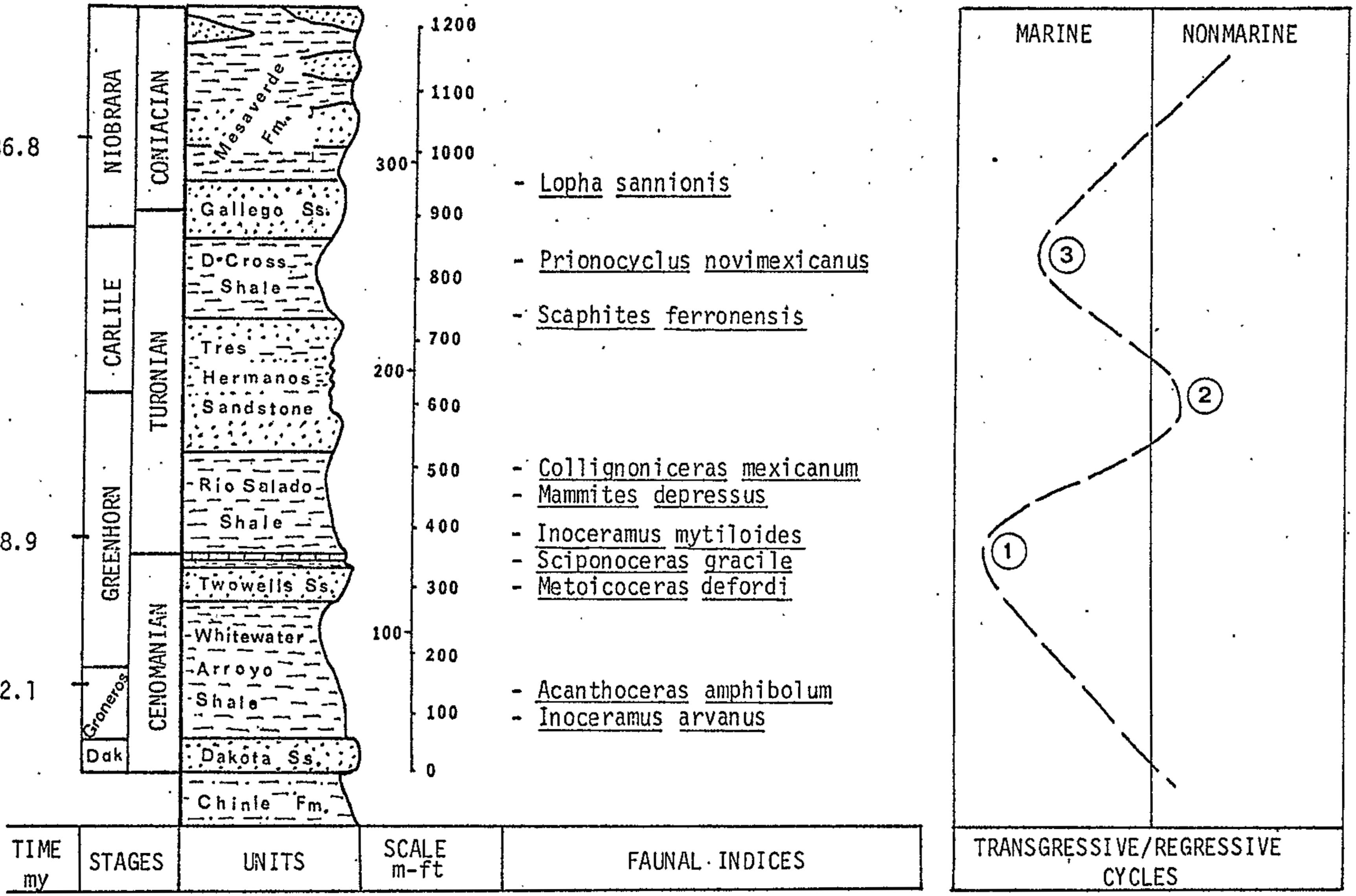


Figure 4 . Transgressive-regressive cycles with respect to time, lithologic units, and faunal indices of Riley-Puertecito area, Socorro County, New Mexico. Numbers on transgressive/regressive curve correspond to shoreline positions on Figure 5.

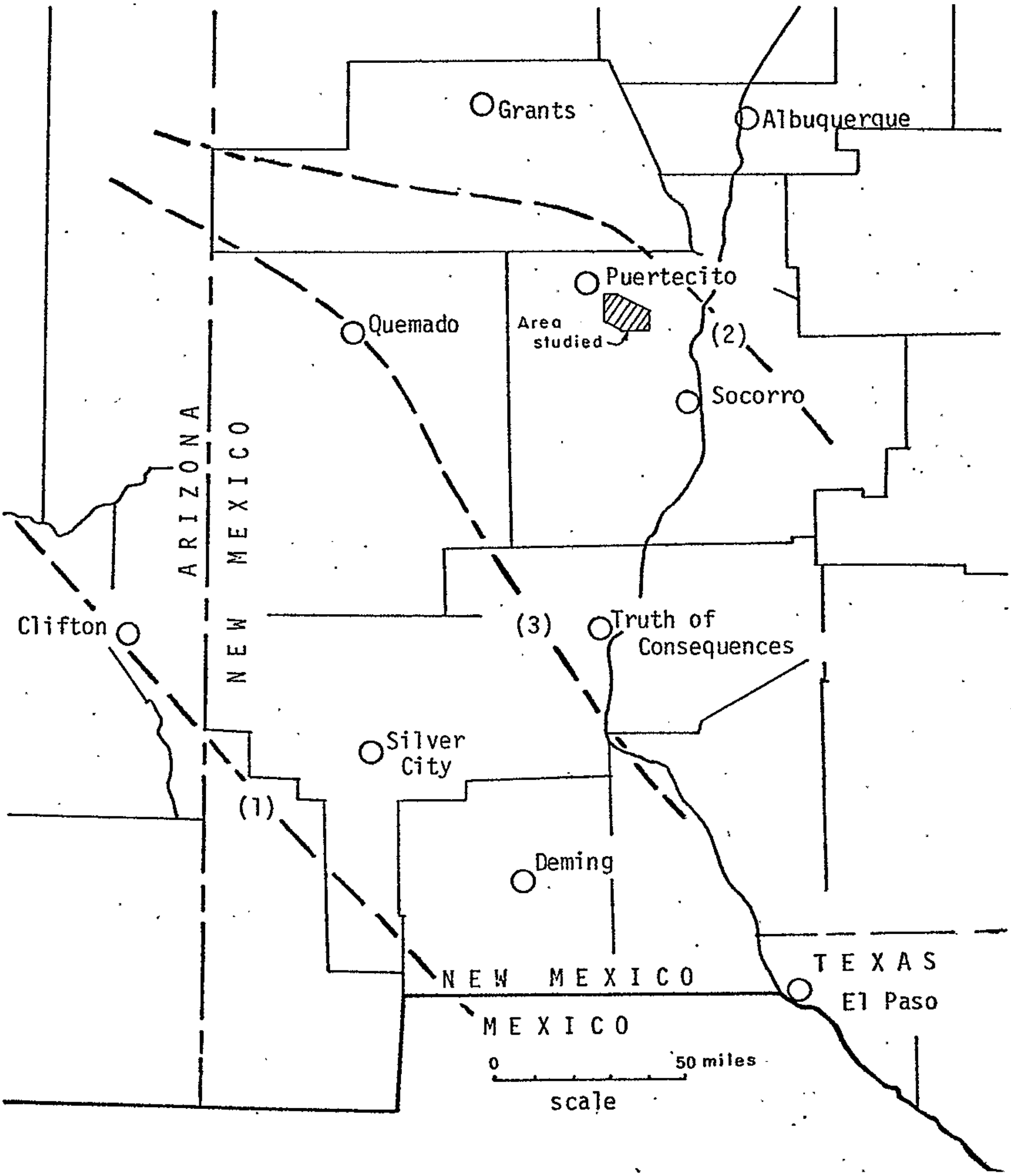


Figure 5. Approximate positions of shorelines at reversals from transgressive/regressive phases, Upper Cretaceous, southwest New Mexico: (1) apex of maximum transgression; Cenomanian-Turonian boundary, (2) apex of regression; middle Turonian, and (3) apex of lesser transgression; late Turonian (partially after Hook and Cobban, 1977; 1978). Numbers correspond to those on transgressive/regressive curve, figure 4.

this regression.

A transgression of lesser magnitude followed, as recorded by the upper portion of the Tres Hermanos Member of the Mancos Shale and the lower part of the D-Cross Tongue of the Mancos Shale. Hook (oral communication, 1978) believes the initial D-Cross transgression in the Riley-Puertecito area began in the Scaphites Ferronensis zone, i.e. within the upper Prionocylus Wyoningensis zone (fig. 5, line 3). The Cretaceous sea retreated to the northeast as the upper D-Cross Tongue of the Mancos Shale and the basal part of the Mesaverde Formation were deposited. After the sea departed, the region was subaerial for an unknown period of time.

A southeast to northwest cross section (fig. 6) from Riley to Puertecito roughly parallels the Cretaceous shoreline. The units are generally of constant thickness along the strike of the cross section with the exception of the Gallego Sandstone and the Twowells Tongue of the Dakota Sandstone. Both pinch out east of Puertecito. The names of the Cretaceous units in the area have evolved as shown in figure 7.

Rate estimates of Cretaceous sedimentation (Table 1) can be calculated by comparing time against thickness of rock for parts of the marine Cretaceous rocks using radiometric dates of Obradovich and Cobban (1975). The periods used, (A, B, and C), are delineated by ammonite zones and

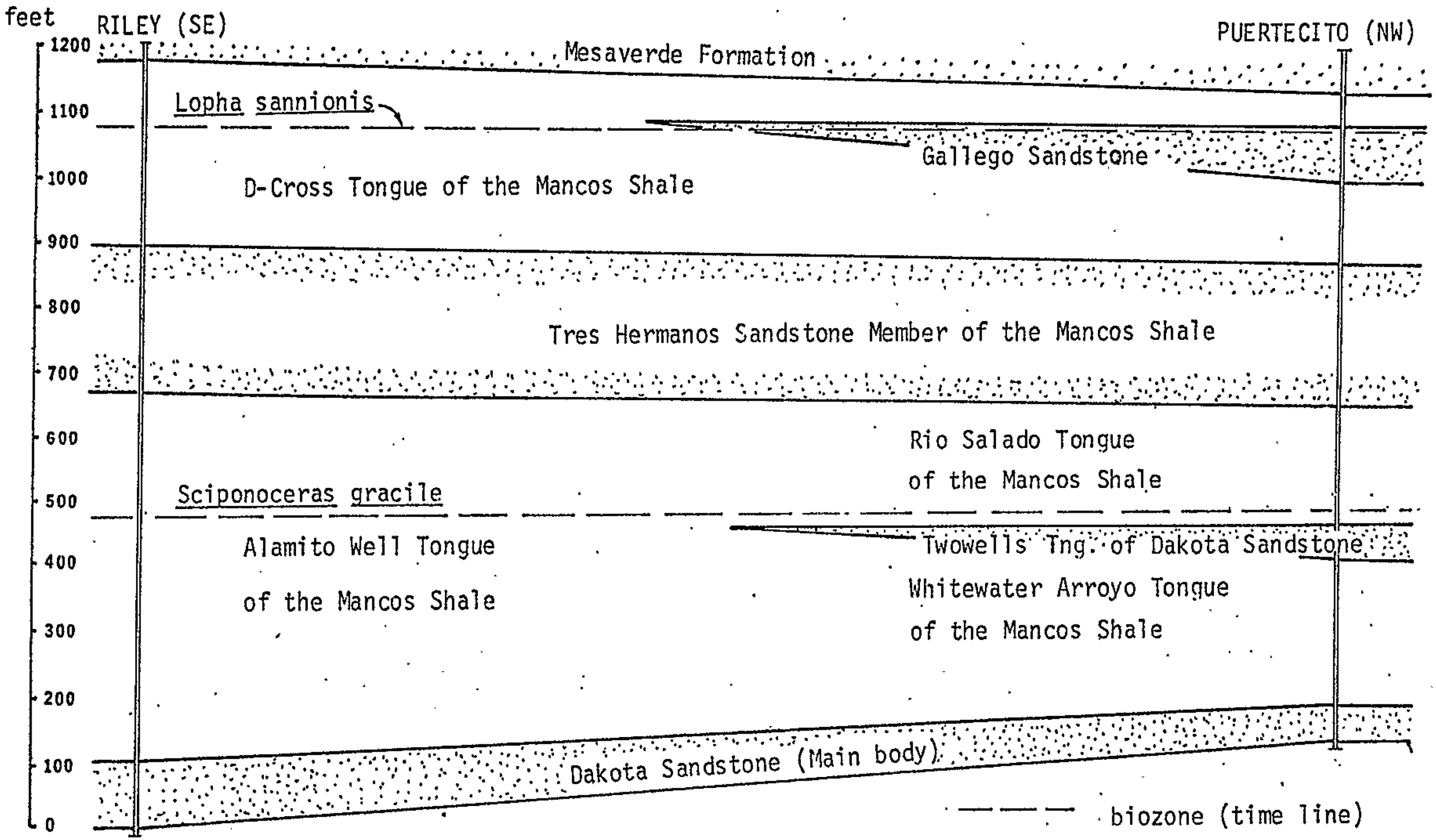


Figure 6. Cross section looking south from Riley to Puertecito, New Mexico illustrating relationships of Cretaceous rocks.

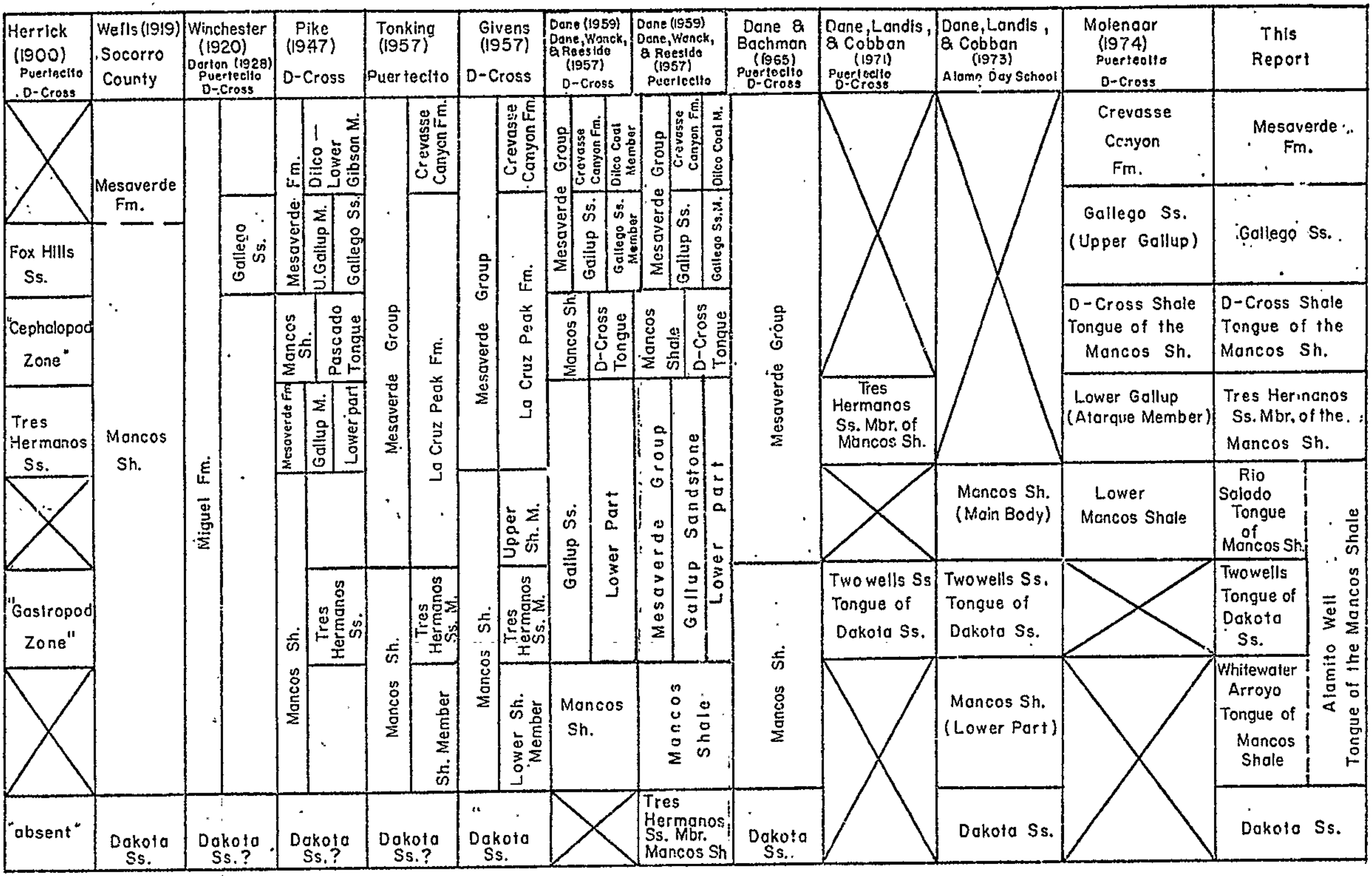


Figure 7. Progression of stratigraphic terminology for Cretaceous rocks, Riley-Puertecito area, New Mexico (modified from Hook and Cobban, in prep).

	PERIOD MILLIONS OF YEARS BEFORE PRESENT	SEDIMENTS DEPOSITED	YEARS MILLIONS	SEDIMENTS DEPOSITED PER MILLION YEARS	SEDIMENTATION RATE PER 1000 YEARS
(A)	92	235 ft	3	78.3 ft	0.94 inches
	to				
	89	72 m		23.9 m	2.39 cm
(B)	89	635 ft	2	317.5 ft	3.81 inches
	to				
	87	194 m		96.8 m	9.68 cm
(C)	92	870 ft	5	174.0 ft	2.09 inches
	to				
	87	266 m		53.0 m	5.30 cm

Table 1 Sedimentation rates for marine Cretaceous rocks, Puertecito, New Mexico. Radiometric dates after Obradovich and Cobban (1975).

are not representative of any systematic time interval. The radiometric dates for these intervals were obtained by K-Ar dating of ash beds intercalated with strata of known faunal position (Obradovich and Cobban, 1975).

Although the data of table 1 are limited, one conclusion can be drawn. Sedimentation rate B is about three times as fast as rate A. Period A represents only a portion of a transgressive phase, whereas period B contains a transgressive phase and two episodes of regression. As regression may have resulted from vast quantities of clastic influx, a higher sedimentation rate during regression would be reasonable. Period C is an average of periods A and B.

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Dakota Sandstone

By accepted usage, the basal sandstone of the Upper Cretaceous in New Mexico is called the Dakota Sandstone. The term "Dakota" was first used near Dakota, Nebraska, to describe the basal sandstone of the Cretaceous (Meek and Hayden, 1861). Early workers in New Mexico and Arizona often suffixed the term "Dakota" with a questionmark to indicate that the relationship to the type locality was poorly understood. Current usage, however, is to delete the questionmark.

Although no fossils, other than wood fragments, are found in the Dakota Sandstone in the Riley-Puertecito area, the age of the Dakota is thought to be early Graneros (Cenomanian). This conclusion stems from the lack of any apparent break in the transgressive sequence into the overlying Mancos. The age of the lower Mancos beds by marine fossils (see discussions of Alamito Well and White-water Arroyo Tongues of Mancos Shale) is Graneros (Cenomanian) in age (Hook, oral communication, 1978).

The Dakota Sandstone ranges from 0 to 200 ft (60.1 m) in thickness across the Colorado Plateau and consists of a diverse assemblage of sandstones, conglomerates, shales, and coal measures (Young, 1975; Pike, 1947). In the area studied, the Dakota Sandstone fluctuates from 0 to 52 ft (16.0 m) in thickness, and averages about 30 ft (9.1 m) thick.

The Dakota thins, disappears, and reappears within a distance of about 1 mi (1.6 km), along a northwest-trending outcrop north of La Jara Peak, sec. 3, T. 2 N., R. 5 W.

The upper formational boundary of the Dakota is marked by the last clean non-calcareous quartz sandstone above which are the dark-gray shales of the Mancos. The Dakota is well consolidated and resistent to erosion and commonly forms a prominent ridge above the slope-forming red shales of the Chinle Formation.

The dip slope of the Dakota Sandstone is crenulated and irregular due to thin resistant sandstones blocks overlying soft shales (fig. 8). Therefore, dip determinations are best generalized from a distance rather than from observations made directly on the irregular dip surface. Due to the resistant nature of the Dakota, the slopes beneath an outcrop are in many places mantled with large scree blocks.

The Dakota Sandstone fractured readily during folding, probably because of its brittle nature and position between the ductile shales of the Chinle Formation and Mancos Shale. This may also explain why the dip of the Dakota Sandstone is often inconsistent with the dips of adjoining strata involved in the same fold.

The lower two-thirds of the Dakota Sandstone, unit 1-4 (fig. 9), is thick, cross-stratified sandstone. On a fresh surface the color is yellowish white (5 Y 9/1), but weathers

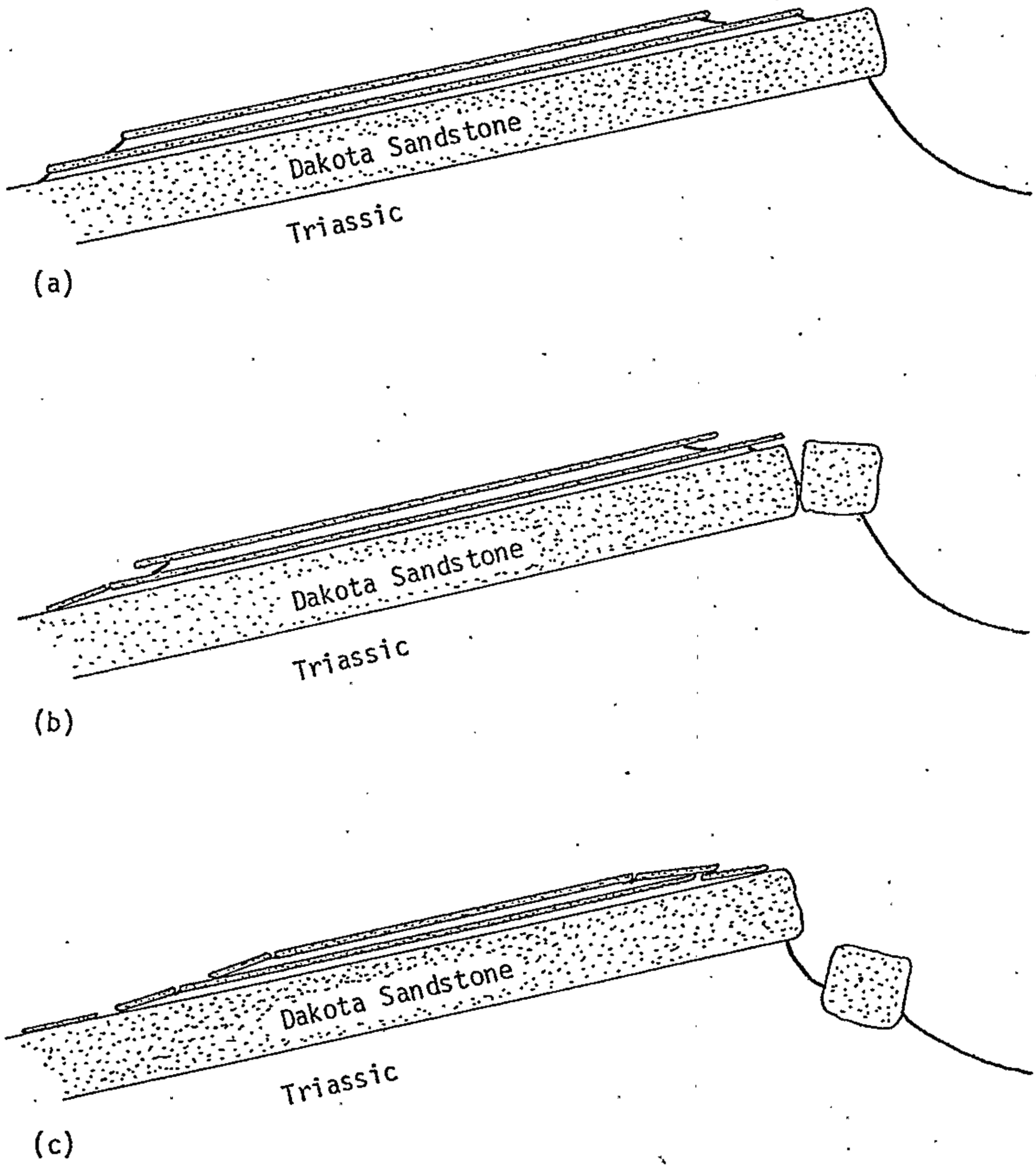


Figure 8. Diagrammatic representation of development of the irregular upper surface which is characteristic of outcrops of Dakota Sandstone.

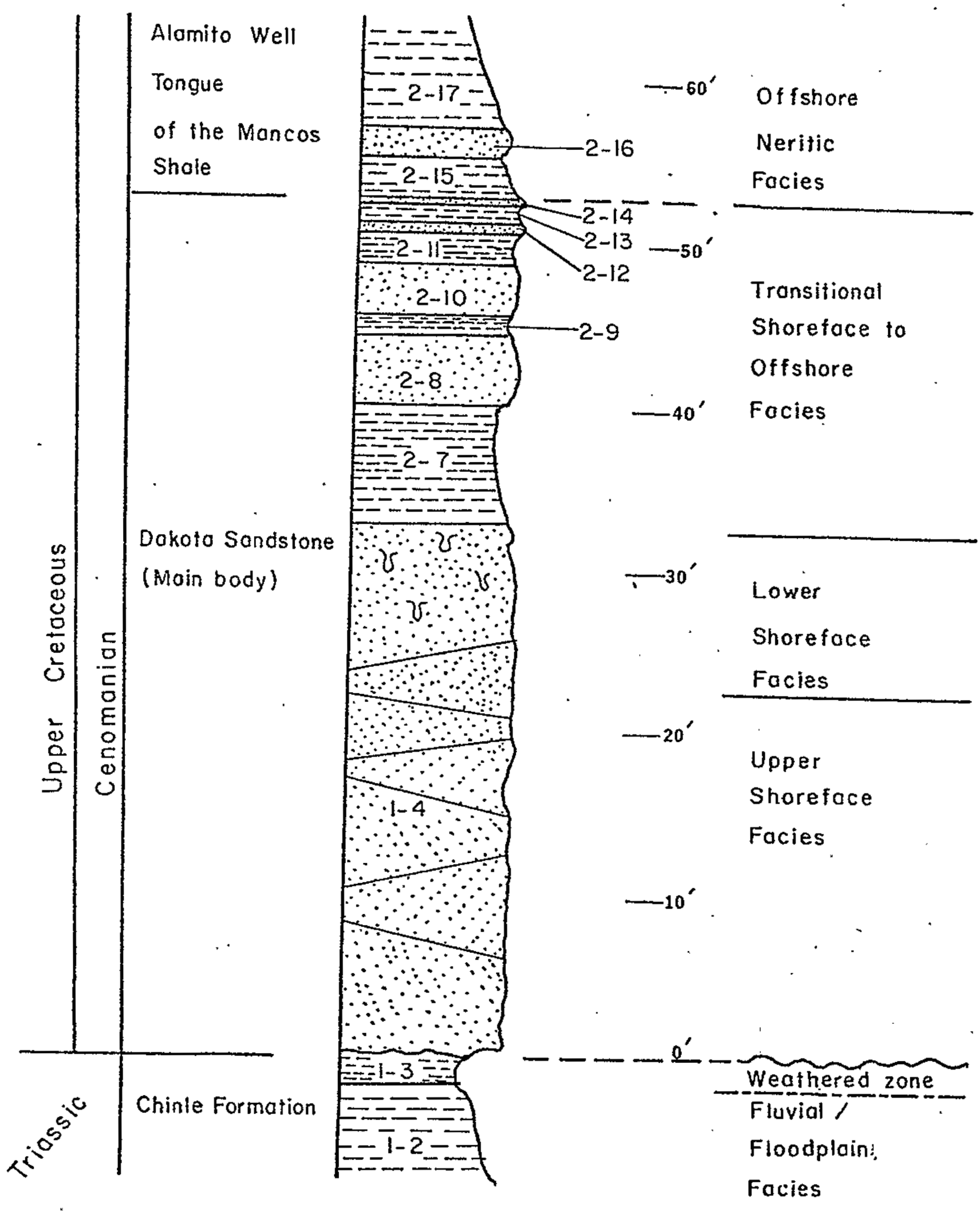


Figure 9. Dakota Sandstone, measured thickness 52 ft (16.0 m).

grayish orange (10 YR 7/4) with light-brown (5 YR 5/7) mottling. The mottling is attributed to areas of concretionary iron oxide and to burrowing. Weathered surfaces are often covered by a dark coating of desert varnish. The rock is composed largely of quartz grains of medium sand size, rounded to well rounded, and well sorted. The grains commonly have quartz overgrowths and are cemented by silica.

The upper one-third of the formation, units 2-7 through 2-17 (fig. 9), is composed of thin, non-calcareous sandstones interbedded with dark, carboniferous shales. These thin sandstones consist largely of well-sorted, subrounded, fine-grained quartz sand. The sandstones become thinner and finer grained toward the top of the formation. The beds are generally yellowish white (5 Y 9/1) with dark-yellowish-orange (10 YR 6/6) mottling. Unlike the thicker lower bed, unit 1-4, these beds are not cross-stratified but are medium bedded and break into plates. The weathered appearance of the thin sandstones, however, is similar to the lower bed.

The Dakota Sandstone in the Riley-Puertecito area was deposited in a transgressive littoral environment. Variation in the thickness of the formation is largely attributed to the uneven nature of the erosion surface over which the water encroached. From bottom to top, unit 1-4, is interpreted to change from an upper shoreface to a lower shoreface deposit (fig. 9). The lower two-thirds of unit

1-4 is characterized by tabular cross-bed sets. Burrowing is absent at the base but is common in the upper part of the unit. The upper portion of unit 1-4 has long, low-angle cross-stratification. The vertical sequence of sedimentary structures is similar to features displayed by the beach profile at Licola, Gulf of Gaeta, Italy (Reineck and Singh, 1975). At Licola, in a seaward direction, the shoreface changes from tabular cross-bed sets to long, low-angle cross-stratifications. Burrowing is common in the lower shoreface. Tidal currents at Licola are minimal but strong longshore coastal currents develop during unusual weather conditions (Reineck and Singh, 1975). The upper zone of interbedded sandstone and shales, units 2-7 to 2-17, is considered a transitional environment from shoreface to offshore facies.

Twowells Tongue

The name "Twowells" originally referred to a sandstone lentil in the Mancos Shale exposed near Twowells, New Mexico (Pike, 1947). Owen (1963) later considered the Twowells to be a member of the Dakota. Landis and others (1973) subsequently called the Twowells a tongue of the Dakota Sandstone which is the accepted usage at present. The age of the Twowells at Puertecito, as suggested by the presence of marine fossils, (i.e. *Pycnodonte* sp., *Exogyra levis*, and *Metoicoceras defordi*) in the upper portion, is middle Greenhorn (middle to late Cenomanian) (Hook, oral communication, 1978).

The Twowells splits from the Dakota near Shiprock and is traceable as a lentil from that area to Puertecito. Near La Jara Peak, the Twowells Tongue of the Dakota Sandstone wedges out and is absent throughout the eastern two-thirds of the studied area. The thickness varies from 0 to 54 ft (16.5 m) within a few miles of Puertecito, New Mexico (fig. 10).

The upper contact of the Twowells Tongue of the Dakota Sandstone with the Rio Salado Tongue of the Mancos Shale is sharp. The base of the Twowells is transitional into the underlying Whitewater Arroyo Tongue of the Mancos Shale. Generally the Twowells crops out as a low hogback, but where it is the thickest, it forms a prominent ledge.

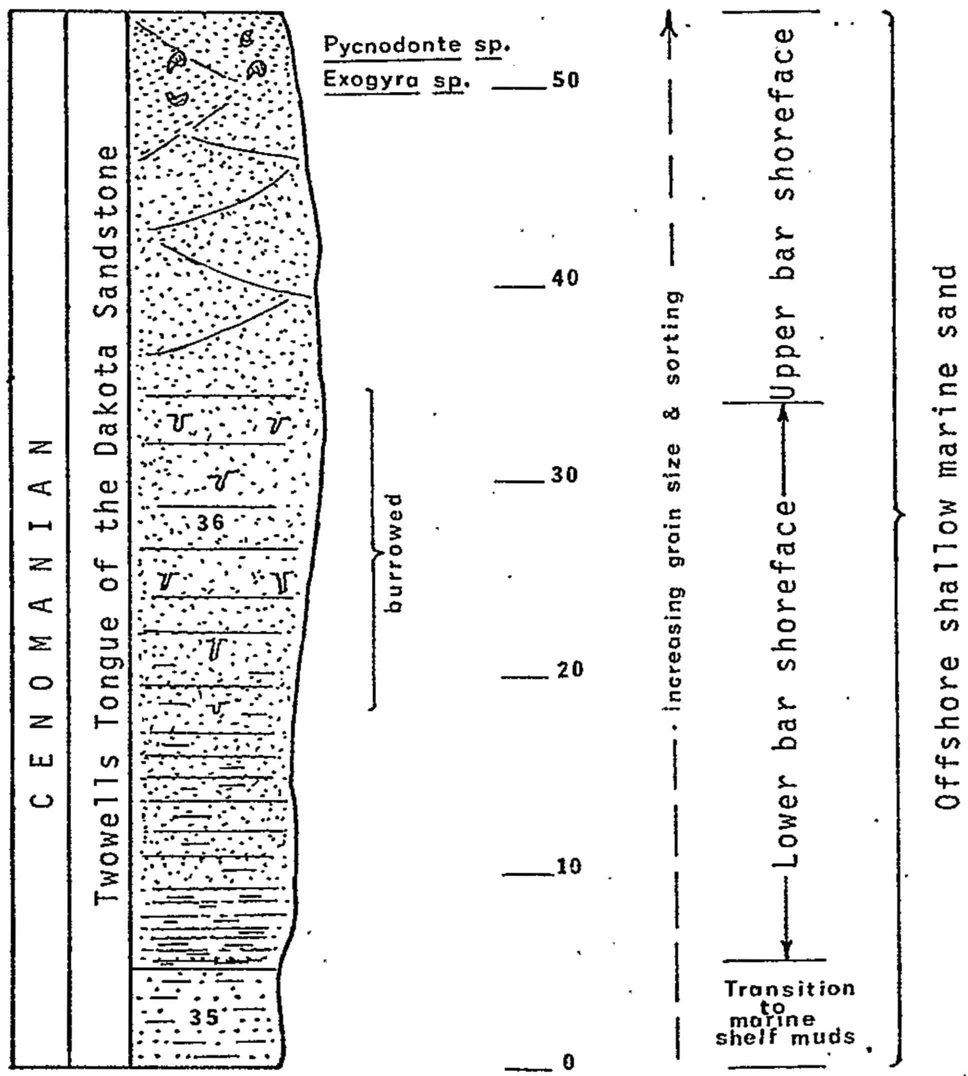


Figure 10. Twowells Tongue of the Dakota Sandstone, an offshore shallow marine sand, measured thickness 54 ft (16 m).

Near the base, the Twowells is composed of a clayey, calcareous, subrounded, fine-grained, moderately sorted, moderately consolidated quartz sand. Because the base of the unit is transitional to a clean shale, the clay content is greatest at the base and decreases upward. The upper portion of the Twowells is composed of medium-grained, rounded, and well-sorted sand. The upper one-third of the unit is extensively burrowed. Tabular and trough cross-stratification is common in the upper portion of the Twowells. Bedding changes vertically from thin at the base to very thick near the top.

The Twowells Tongue of the Dakota Sandstone is interpreted to have accumulated as an offshore marine bar. The position of marine shales, both over and under the Twowells, with no appreciable hiatus recognized at the contacts suggests a marine mode of deposition. In addition, the Twowells contains marine fossils in the upper portion. The vertical sequence of textures and sedimentary structures are compatible with "typical" shallow marine sands. Harms and others (1975) interpreted the Upper Cretaceous Shannon Sandstone of the southwestern Powder River basin, Wyoming, as a shallow marine sand and a comparison of the Twowells with the Shannon Sandstone shows a striking similarity.

Owen (1966), Dane and others (1971), and Landis and others (1973) reported the Twowells to be an extensive, offshore, shallow-marine shelf sandstone. Sediment was derived from a source area to the southwest. Their conclusion about the source area was based upon the variation in age and thickness of the unit and changes in provenance-related metamorphic-type heavy minerals. The Twowells near Puertecito wedges out to the southwest, northeast, and southeast, but can be traced northwestward along the strike of the Cretaceous shoreline. It is probably a spit-like offshore marine sand generated by longshore currents moving southeastward.

Mancos Shale

General

The name "Mancos" was first applied by Cross (1899) for approximately 1200 ft (365.8 m) of dark shale exposed in the Mancos River valley near Mancos, southwestern Colorado. Dark-gray, predominately marine, shales of the lower part of the Upper Cretaceous in northeastern Arizona, western Colorado, eastern Utah, and northwestern New Mexico are also commonly referred to as the Mancos Shale.

In Socorro County, the Mancos is separated into two or three tongues by intervening sandstone units. At Riley there are two tongues, the Alamito Well and D-Cross, separated by the Tres Hermanos Sandstone Member of the Mancos Shale. At Puertecito, the lower shale (Alamito Well), is further divided into two shale tongues, the Whitewater Arroyo and Rio Salado, by the Twowells Tongue of the Dakota Sandstone.

Intertonguing of the Dakota, Mancos, and Mesaverde units suggests the lateral migration of facies as the shoreline shifted. The sediments of a particular environment plotted in a two dimensional scheme migrate vertically and laterally. Traditionally, the Cretaceous rocks have been shown by various authors to "zig-zag" across a cross-section. Due to the lack of exposures to the

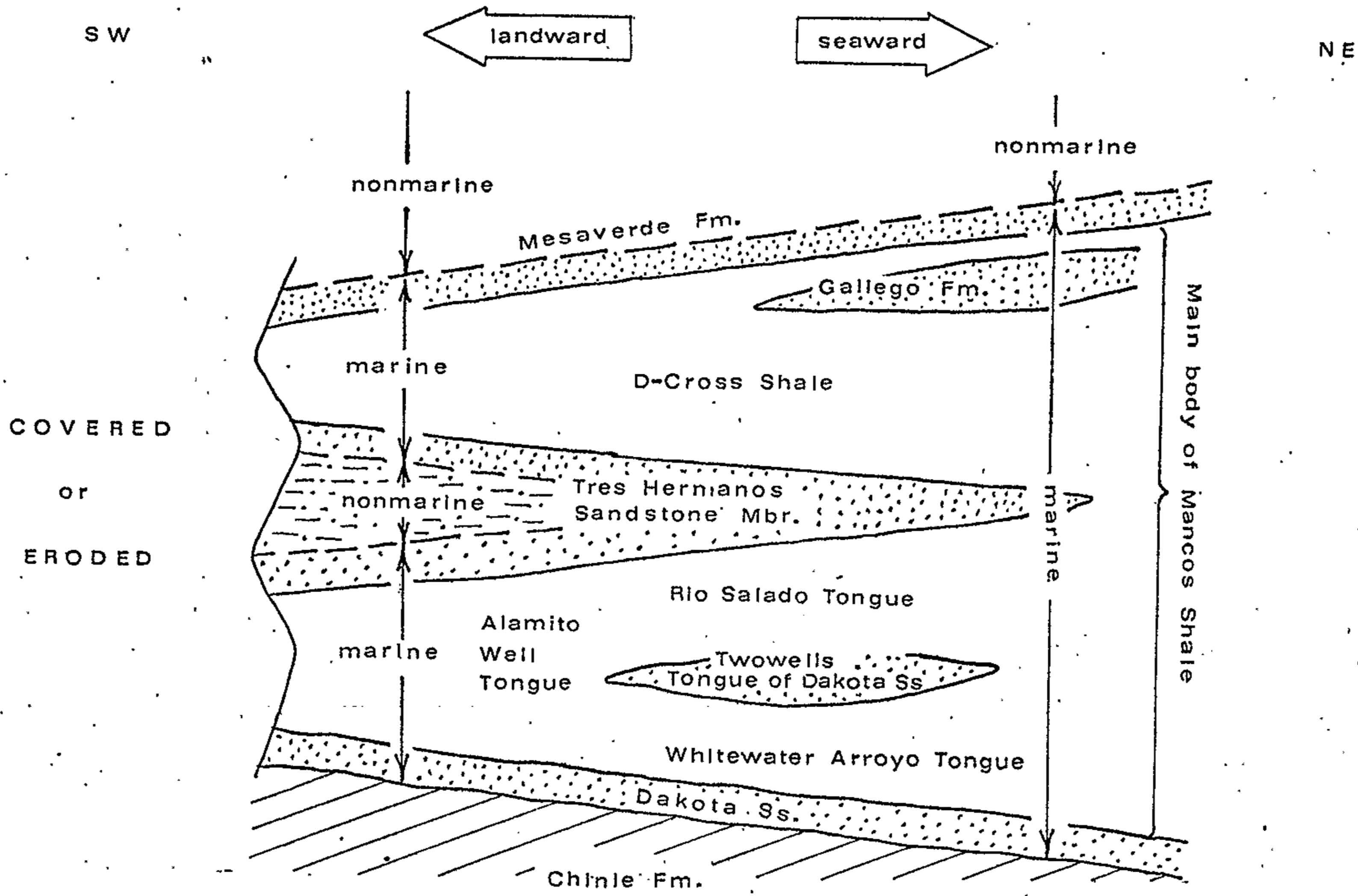


Figure 11. Diagrammatic illustration of tonguing relationships of marine and nonmarine rocks of Cretaceous age in northwestern Socorro County.

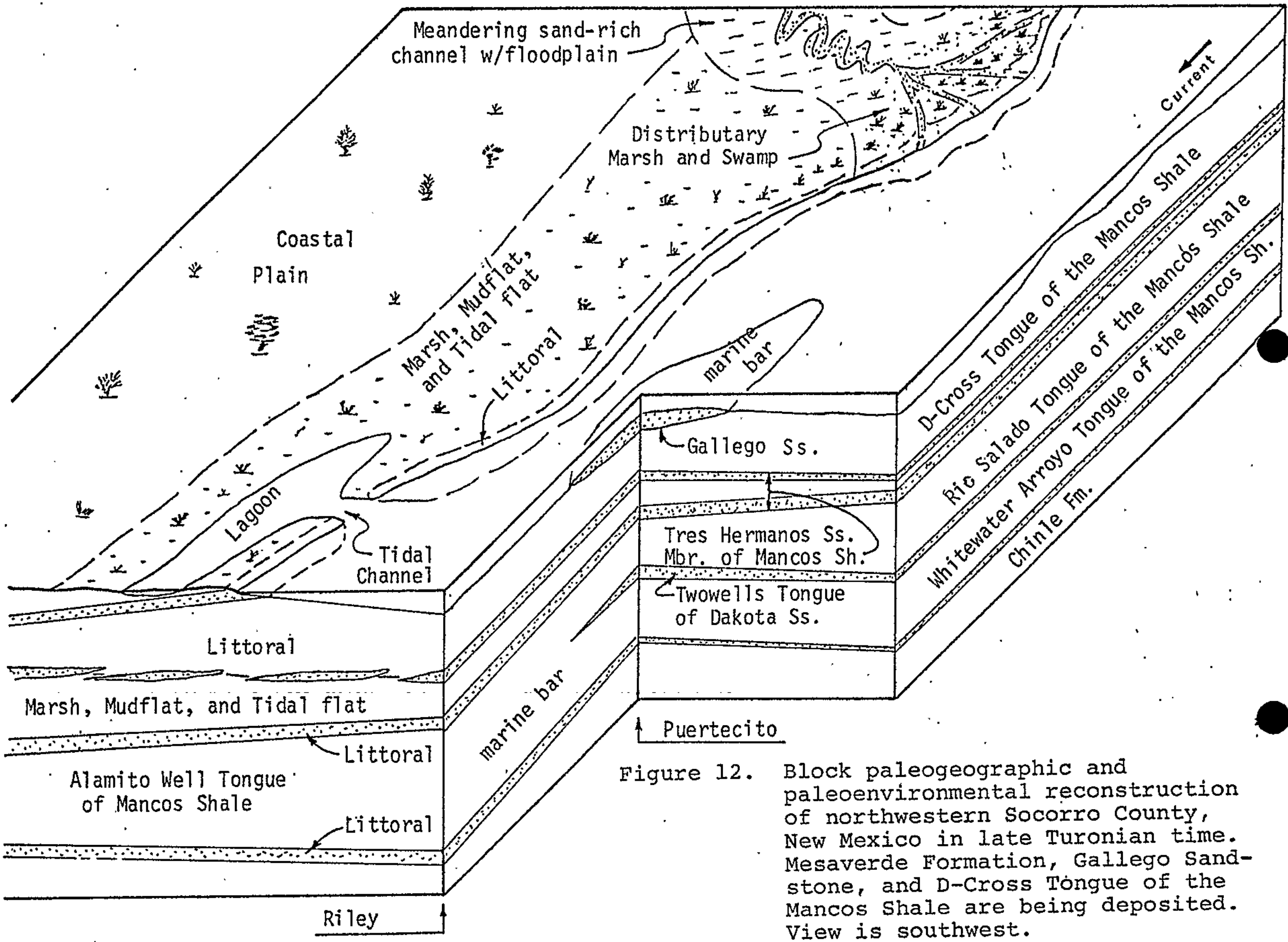


Figure 12. Block paleogeographic and paleoenvironmental reconstruction of northwestern Socorro County, New Mexico in late Turonian time. Mesaverde Formation, Gallego Sandstone, and D-Cross Tongue of the Mancos Shale are being deposited. View is southwest.

southwestward, intertonguing can only be demonstrated northeastward, which was the seaward direction during the late Cretaceous (fig. 11). Figure 12 is a block paleogeographic and paleoenvironmental representation of northwestern Socorro County in late Turonian time. The Mesaverde Formation, Gallego Formation, and D-Cross Tongue of the Mancos Shale were being deposited.

Alamito Well Tongue

The Alamito Well Tongue (new name) of the Mancos Shale lies between the Dakota Sandstone and the Tres Hermanos Sandstone Member of the Mancos Shale. The name is taken from Alamito Well, which is located in Cañon del Alamito, sec. 20, T. 2 N., R. 4 W., about 2.3 mi (3.7 km) northwest of the settlement of Riley, New Mexico. The Alamito Well Shale is exposed along Cañon del Alamito, but faulting has cut the unit in several places making detailed stratigraphic interpretation difficult. The shale is also well exposed in an unnamed canyon 1.5 mi (2.4 km) southeast of Alamito Well, sec. 21 and 22, T. 2 N., R. 4 W. In this unnamed canyon two partial sections of the Alamito Well Shale were measured and integrated to establish a composite type section for the Alamito Well Tongue.

Faunal evidence indicates that the Alamito Well Tongue of the Mancos Shale was being deposited throughout most of Greenhorn time (Hook, oral communication, 1978). The Cenomanian-Turonian boundary is within the Alamito Well Tongue.

To the northwest, the Alamito Well Tongue of the Mancos Shale is split into the Whitewater Arroyo and Rio Salado tongues by the Twowells Tongue of the Dakota Sandstone. The Alamito Well Tongue of the Mancos Shale is also recognized at Carthage, New Mexico (Hook, oral communication, 1977).

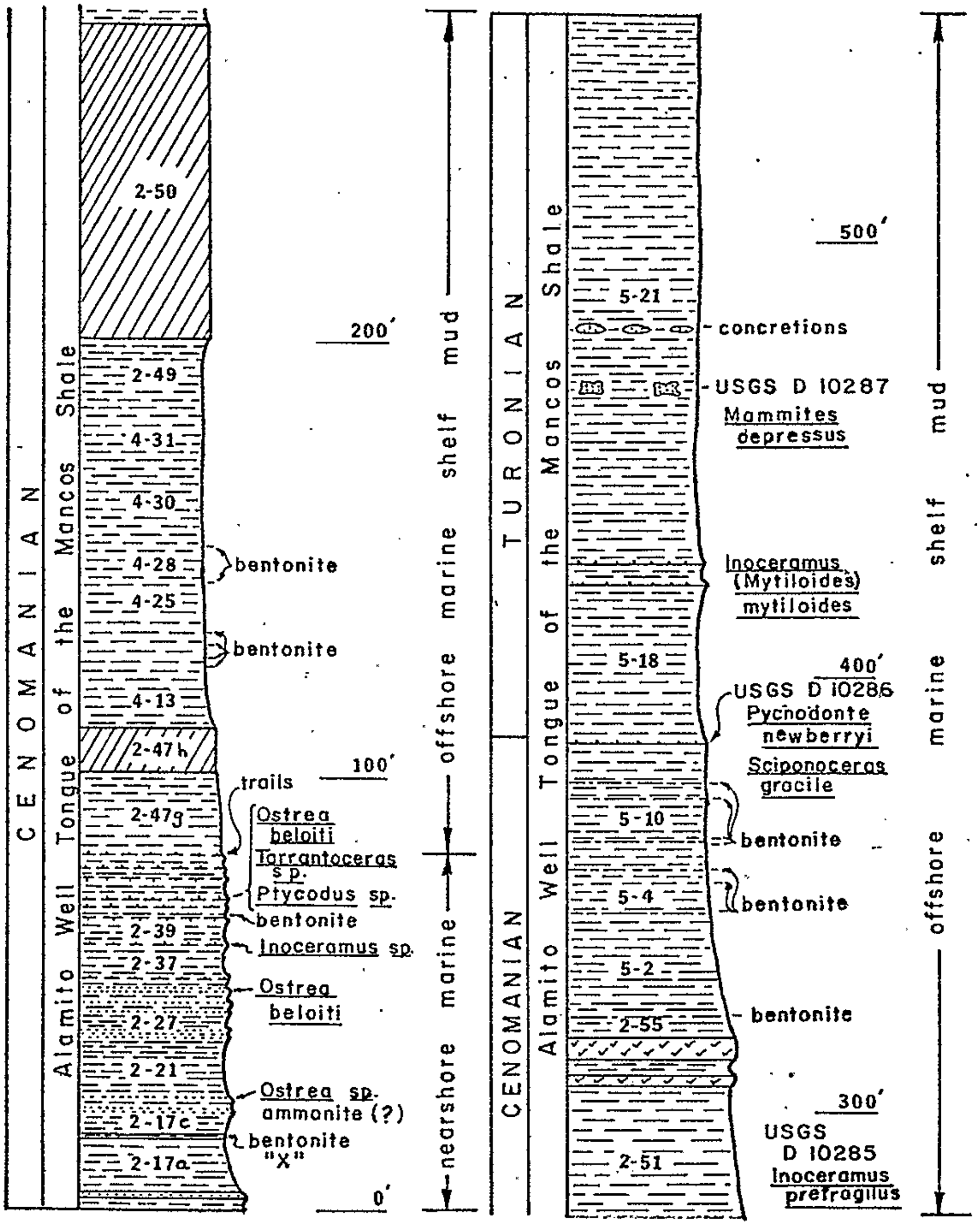


Figure 13. Alamito Well Tongue of the Mancos Shale, measured thickness 555 ft (169.4 m) includes 7 ft (2 m) of intrusive rock and 81 ft (25 m) of covered interval.

are subrounded and moderate to well sorted. The cement is clay and calcite. These beds are light gray (5 Y 5/2) to pale yellowish brown (10 YR 6/2) on a fresh surface and weather very pale orange (10 YR 6/2). The siltstones are well consolidated and form small breaks in slopes of the softer shale.

The limestone beds are about the same thickness as the siltstones and are generally composed of silty or sandy micrite. The fresh color is grayish dusky blue (5 PB 4/2) to olive gray (5 Y 4/1) and moderate brown (5 YR 4/4) where weathered. Fossils common to the beds include _Ostrea beloiti_, _Ostrea_ sp., _Inoceramus rutherfordi_., _Tarrantoceras_ sp., and _Ptychodus_ sp., (Hook, oral communication, 1978). The limestones stand out as subtle benches in the softer shale.

Thin bentonite beds occur throughout the Alamito Well Tongue. A typical bentonite layer is about 1 inch (3 cm) thick, very thin bedded and very pale orange (10 YR 8/2). The bentonites are generally obscured by a clay coating washed off the darker shale. The bentonite beds are detected on slopes by a slight color change in the clay coating and in places by selenite crystals. Selenite is normally associated with bentonite beds and also occurs in discordant veins unrelated to bentonite accumulations. One bentonite bed, unit 2-17 b (fig. 13), is 1 ft 2 inches (36 cm) thick. It occurs near the base of the Alamito

Well Tongue and may represent the so-called "X" bentonite used for subsurface correlation in the San Juan basin (Hook, oral communication, 1977).

A limestone, unit 5-17, about 7 inches (18 cm) thick occurs about 165 ft (50.3 m) below the top of the Alamito Well. The bed is a lithographic, fossiliferous, medium-gray (N 5) limestone that weathers a distinctive grayish orange (10 YR 7/4). The limestone contains the ammonite <u>Sciponoceras gracile</u> and the pelecypod <u>Pycnodonte newberryi</u> (Hook, oral communication, 1978).

As many as six limestone beds can be associated with the <u>Sciponoceras gracile</u> biozone (Hook, oral communication, 1978). Individually the limestone beds are thin, but despite their thinness they are widespread and correlatable over a large part of the four corners states. Hook (oral communication, 1978) regards the <u>Sciponoceras gracile</u>-bearing limestones as chronostratigraphic units because: 1) they are lithologically distinct and have essentially the same characteristics over a large area; 2) they are thin; and 3) they contain the same faunal assemblage everywhere. The <u>Sciponoceras gracile</u> biozone is an excellent stratigraphic marker across the region (Hook and Cobban, 1977).

About 40 to 45 ft (12.2 to 13.7 m) above the <u>Sciponoceras gracile</u> zone is a distinct 2 inch (51 cm) thick, clayey, fossiliferous, medium-light-gray (N 5) calcarenite bed (unit 5-20 b, fig. 13). This bed weathers to very pale orange (10 YR 8/2), forms a slight ledge, and contains *Inoceramus* (*Mytiloides*) *mytiloides* (Hook, oral communication, 1978).

In the uppermost shale of the Alamito Well, unit 5-21 (fig. 13), are large limestone concretions. The concretions are often fossiliferous and contain *Mammites depressus* (Hook, oral communication, 1978). The concretionary zone occurs about 80 ft (24.4 m) below the base of the overlying Tres Hermanos Sandstone Member of the Mancos Shale near Riley.

The Alamito Well Tongue of the Mancos Shale is believed to be the marine portion of the initial marine inundation of the region which began during the mid-Cenomanian (Hook, oral communication, 1978). The lower three-fourths of the Alamito Well represents the transgressive phase of the cycle. The maximum advance of the Cretaceous sea in New Mexico occurred about the time of the *Sciponoceras gracile* ammonite zone (Hook and Cobban, 1977). The Cretaceous sea retreated from the region after *Sciponoceras gracile* time and during deposition of the uppermost one-quarter of the Alamito Well Tongue of the Mancos Shale. Based on rates of deposition (table 1) the regression was probably caused by a massive influx of clastic sediments.

The lower 74 ft (22.6 m) of the Alamito Well Tongue are interpreted to have been deposited in a nearshore marine environment because of the marine fossils and thin siltstone beds. The remaining 481 ft (146.6 m) of the Alamito Well rocks are interpreted to have been deposited farther off-shore in a deeper marine environment because of their stratigraphic position and cleaner shale. The abrupt contact of the Alamito Well with the Tres Hermanos Sandstone Member of the Mancos Shale was probably due to massive sand influx during progradation or to a shift in longshore currents giving rise to a change from marine shelf muds to lower shoreface sands in a short stratigraphic interval.

Whitewater Arroyo Tongue

West of Riley in the vicinity of La Jara Peak, the Alamito Well Tongue of the Mancos Shale is split into two lesser tongues by the Twowells Tongue of the Dakota Sandstone. The lower of these tongues, the Whitewater Arroyo Tongue, was originally described as a member of the Dakota near Twowells, New Mexico (Owen, 1966). The Whitewater Arroyo is presently defined as the shale body between the Paguate and Twowell Tongues of the Dakota Sandstone (Landis and others, 1973). In this report, the term Whitewater Arroyo is used with some latitude as the Paguate Sandstone is absent. The lower portion of the Whitewater Arroyo at Puertecito is time equivalent to the Paguate (Hook, oral communication, 1978), thus the lower contact of the Whitewater Arroyo Shale is with the basal Dakota Sandstone and not the Paguate Tongue of the Dakota Sandstone.

The Whitewater Arroyo Tongue of the Mancos Shale, based on biozonation, is correlatable to approximately the lower 240 ft (73.2 m) of the Alamito Well Tongue of the Mancos Shale. The age is lower Greenhorn (middle Cenomanian) (Hook, oral communication, 1978).

The distribution of the Whitewater Arroyo Tongue of the Mancos Shale is, by definition, dependent on the distribution of the Twowells Tongue of the Dakota Sandstone.

North and east from the type locality where the Twowells pinches out, the Whitewater Arroyo Shale is incorporated into larger shale units. The thickness of the Whitewater Arroyo Tongue of the Mancos Shale is about 60 ft (18.3 m) in the Gallup area but is 187 ft (57.0 m) in the vicinity of Puertecito.

The upper contact of the Whitewater Arroyo Tongue of the Mancos Shale is gradational, changing upward into the distinct sand of the Twowells Tongue of the Dakota Sandstone. The lower contact of the Whitewater Arroyo Tongue is transitional into the Dakota Sandstone through a zone of interbedded siltstones and shales. The Whitewater Arroyo Tongue normally forms a valley between the ridges of the basal Dakota Sandstone and the Twowells Tongue of the Dakota Sandstone.

Lithologically, the Whitewater Arroyo Tongue is similar to the lower portion of the Alamito Well Tongue with which it is correlative. The shales of the Whitewater Arroyo are generally calcareous, thin to very thin bedded, fissile, olive gray (5 Y 3/2) where fresh, and light-olive-gray (5 Y 5/2) where weathered. The basal 70 to 80 ft (21.3 to 24.4 m) is a zone of interbedded shales, siltstones, and limestones. The siltstones and limestones are about 1 to 5 inches (3 to 13 cm) thick and stand out as slight ridges in the softer shale. The siltstones and limestone beds are generally light brown (5 YR 5/6) on a fresh

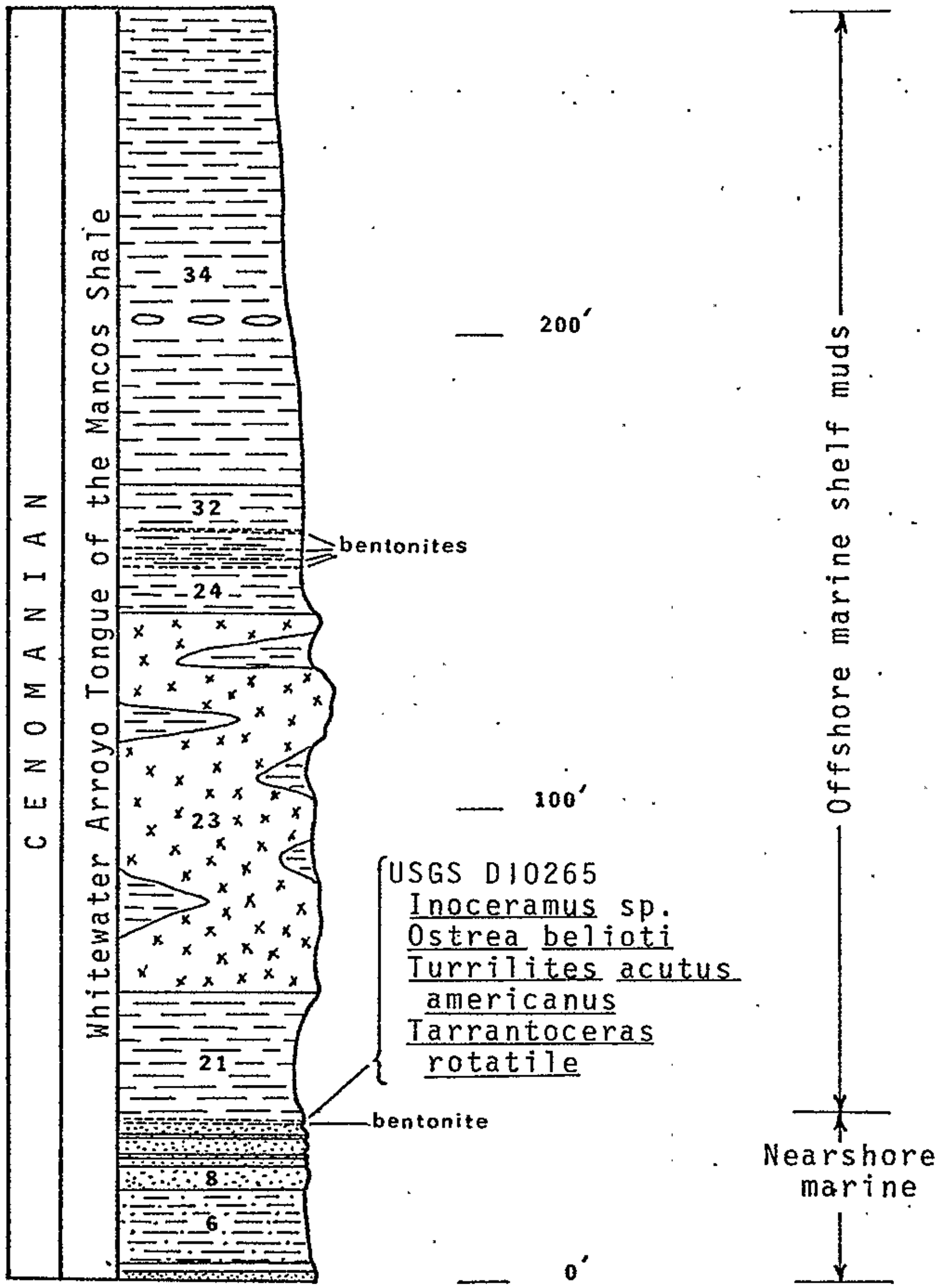


Figure 14. Whitewater Arroyo Tongue of the Mancos Shale, measured thickness 187 ft (57.2 m) excluding 80 ft (24 m) intrusive complex.

fracture and weather pale yellowish brown (5 YR 6/2). Unit 10, (fig. 14) is fossiliferous, containing *Inoceramus* sp., *Ostrea belioti*, *Turrilites acutus americanus*, and *Tarrantoceras rotatile* (Hook, oral communication, 1978).

Bentonites are scattered throughout the tongue. They are typically less than 1 inch (3 cm) thick, fissile, and dark yellowish orange (10 YR 6/6). Limestone concretions scattered throughout the upper 90 ft (27.4 m) of the Whitewater Arroyo are generally about 10 inches (25 cm) in diameter with irregular calcite centers. The concretions weather yellowish gray (5 Y 8/1).

The Whitewater Arroyo Tongue of the Mancos Shale contains a normal transgressive progression from near-shore marine muds and silts to off-shore marine shelf muds. The lower contact is transitional to the shoreface sands of the Dakota and the upper contact is gradational into the off-shore marine sand of the Twowells. The Whitewater Arroyo shales contain several species of open marine fossils.

Rio Salado Tongue

The Rio Salado Tongue of the Mancos Shale, named for exposures along the Rio Salado near Puertecito, is defined as the shale between the Twowells Tongue of the Dakota Sandstone and the Tres Hermanos Sandstone Member of the Mancos Shale (Hook and Cobban, in preparation). The type locality is north of the Rio Salado, approximately 2 mi (3.2 km) northeast of Alamo Mission. The Rio Salado Tongue was deposited during late Greenhorn (very late Cenomanian through early Turonian) time based on faunal evidence (Hook, oral communication, 1978).

The Rio Salado Tongue of the Mancos Shale is present throughout most of the Acoma basin. The maximum measured thickness of the Rio Salado Tongue of the Mancos Shale is 238 ft (72.5 m). The Rio Salado Tongue is a slope-forming, silty, medium-dark-gray (N 4) to light-olive-brown (5 Y 5/6), shale that weathers yellowish gray (5 Y 7/2).

A massive, finely crystalline limestone (fig. 15, unit 4) occurs from 10 to 35 ft (3.0 to 10.7 m) above the Twowells Tongue of the Dakota Sandstone. The rock is pale yellowish brown (10 YR 7/2) on fresh surfaces, but weathers pale yellowish orange (10 YR 8/6). The limestone contains _Hemiaster jacksoni_, _Sciponoceras gracile_, _Allocrioceras annulatum_, _Psuedocalycoceras dentonense_, _Kanabiceras septemscriatum_, _Metoicoceras whitei_, and

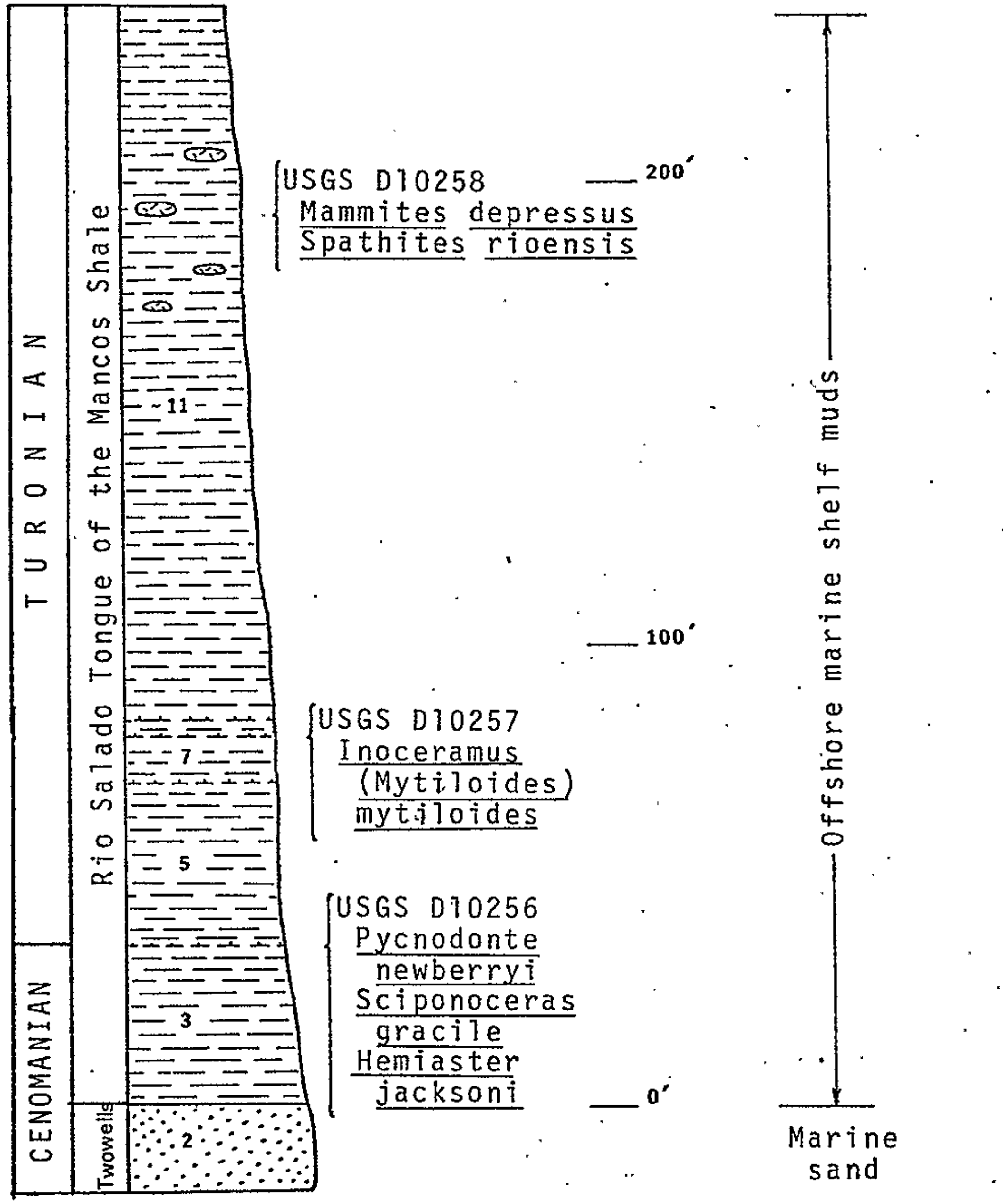


Figure 15. Rio Salado Tongue of the Mancos Shale at type locality of Tres Hermanos Sandstone Member of the Mancos Shale, measured thickness 237 ft (72.4 m)

Pycnodonte newberryi (Hook, oral communications, 1978).

The sea reached maximum transgression at the time of the Sciponoceras gracile biozone and began to recede during the deposition of the Rio Salado Tongue of the Mancos Shale as shown by faunal distributions (Hook, oral communication, 1978). The Rio Salado was deposited largely as offshore or shelf marine mud. It is correlatable with approximately the upper 170 ft (52 m) of the Alamito Well Tongue of the Mancos Shale.

Tres Hermanos Sandstone Member

The Tres Hermanos was named by Herrick (1900) for exposures near the three basaltic peaks of Tres Hermanos. The type locality specified by Herrick is, in his words,

> "East of Tres Hermanos . . . The Dakota Sandstone appears to be absent and the so-called gastropod zone is within a hundred feet of the bottom with fossils of Fort Benton age followed by a band of sandstone with enormous concretions."

Herrick's description fits an area where Cottonwood Draw joins the Rio Salado, sec. 34, T. 3 N., R. 5 W. Dane (1959) states concerning the Tres Hermanos Sandstone, "that there is no reason for doubt as to the type locality and little reason for misidentification of the specific sandstone defined." Near Tres Hermanos Peaks, a section from the Twowells through the basal Tres Hermanos, which carries large concretions is easily accessable and well exposed. This section was measured as a partial reference locality for the Tres Hermanos Sandstone Member of the Mancos Shale (Hook and Cobban, in preparation).

Tonking (1957) and Givens (1957) incorrectly identified the Twowells Tongue of the Dakota Sandstone in the D-Cross Puertecito area as the Tres Hermanos following a mistake initiated by Pike (1947) at D-Cross Mountain (Dane and others, 1971). The Tres Hermanos has been referred to in the past as the lower part of the Gallup Sandstone at D-Cross Mountain (Dane and others, 1957). The Tres Hermanos is partly late Greenhorn and largely early Carlile (early to middle Turonian) in age as shown by the occurrence of _Collignoniceras_ _mexicanum_ near the base and, _Scaphites_ _Ferronesis_ and _S_. Whitfieldi a few feet above the top (Hook, oral communications, 1978).

The Tres Hermanos crops out extensively in the valley of the Rio Salado near Carthage and throughout the Acoma basin. The Atarque Member of the Mesaverde in the Gallup (Zuni) basin is probably equivalent to the Tres Hermanos Sandstone Member of the Mancos. The Tres Hermanos crops out in discontinuous but traceable ridges from a few miles east of Riley to Tres Hermanos Peaks. The Tres Hermanos Sandstone is 231 ft (70.4 m) thick at Riley and 217 ft (66.1 m) thick at Puertecito.

In the Riley-Puertecito area, the Tres Hermanos is composed of thin sandstones and siltstones interbedded with shales (fig. 16). A topographic profile across the Tres Hermanos consists of a central zone of low benches and troughs between two prominent ridges. The basal sandstones of the Tres Hermanos, units 6-2 through 6-7 are characterized by platy-weathering fragments and abundantly fossiliferous concretionary zones. They vary from thin to medium bedded and are slightly to well consolidated. The sandstone units commonly are cross-

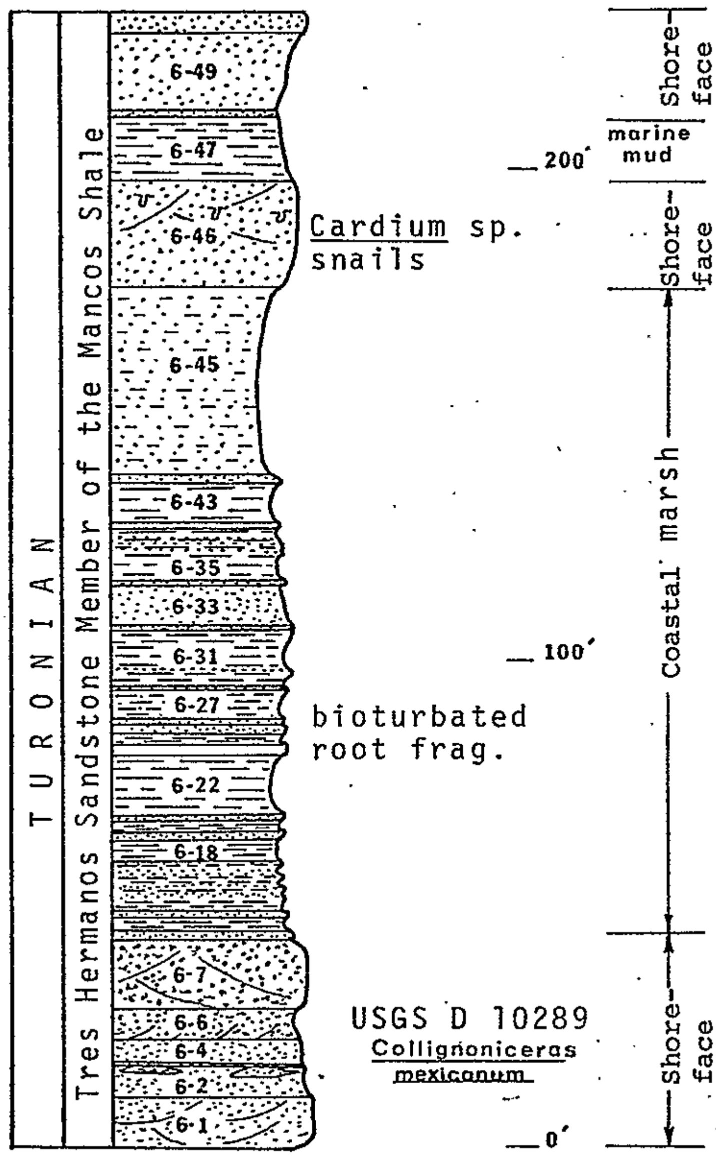


Figure 16. Tres Hermanos Sandstone Member of the Mancos Shale, measured thickness 231 ft (70.5 m).

stratified or bioturbated with linguoid ripples on isolated bedding planes. Sandstones are composed of medium-grained, subrounded, moderately sorted, yellowish-gray (5 Y 8/1) to grayish-orange (10 YR 7/4) quartz grains. The cement is calcite.

Richly fossiliferous areas within the sandstone beds are spheroidal to lenticular, yellowish brown (10 YR 4/2), and very calcareous. The fauna includes Collignoniceras mexicanum, Baculites yokoyami, Proplacenticeras pseudoplacenta, Cardium pauperculum, and Gyrodes depressus (Hook and Cobban, in preparation).

The central part of the Tres Hermanos consists of siltstones and sandstones interbedded with shales, units 6-8 through 6-45. The shales are normally about 5 ft (1.5 m) thick and of two types. One type is a medium-dark-gray (N 4) to light-gray (N 7) shale that weathers light gray (N 6) to yellowish gray (5 Y 8/1). This type, the most common, is slightly silty, thin bedded, and poorly consolidated.

The second type of shale is typically greenish yellow (5 YR 8/4) where fresh, weathers to various shades of brownish black (5 YR 2/1) to grayish yellow (5 Y 8/4), and contains varying amounts of organic debris. Coal and lignite is present in the central part of the Tres Hermanos SE¼ SE¼ sec. 6, T. 2 N., R. 5 W. The lenticular seams are less than 1 ft (0.3 m) thick.

The sandstones and siltstones in the middle Tres Hermanos are commonly about 1 ft (0.3 m) thick and form resistant, repetitive low benches. Bedding is thin to medium unless disturbed by intense burrowing. Bioturbation is common and gives the beds a mottled appearance. The rocks are composed of subangular to subrounded, moderately sorted silt to fine quartz sand cemented by quartz and limonite. The color ranges from pale olive (10 Y 6/2) to moderate brown (5 YR 4/4). Organic fragments are represented by carbonaceous streaks and iron-stained impressions.

Sandstones in the upper Tres Hermanos, units 6-46, 6-48, 6-49, and 6-50, are commonly about 10 ft (3.1 m) thick but thicken and thin laterally. Induration of the units varies, producing slopes and low ridges. The units are thin bedded, commonly cross-stratified, and often bioturbated. The beds are composed of poorly sorted, subangular grains of coarse-to fine-grained quartz, cemented by hematite and clay. The sandstones are very light gray (N 8) when fresh and yellowish gray (5 Y 8/1) with light-brown (5 YR 6/4) mottling when weathered. Unit 6-46 contains *Cardium* sp. and snails.

At Puertecito, the upper portion of the Tres Hermanos consists of 8 ft (2.4 m) of fine-grained, subangular, moderately sorted quartz sandstone. This unit is medium to thick bedded, well consolidated, cross-stratified, and bioturbated. The color is moderately orange pink where fresh, (5 YR 8/4) light brown (5 YR 5/6) where mottled, and dusky brown (5 YR 2/2) where weathered.

The lower sandstones units, 6-1 through 6-7, were deposited as shoreface and foreshore sands of a regressive, prograding, shoreline. In support of this hypothesis are: 1) the upward coarsening of grain size, 2) the upward thickening of bedding, and 3) the vertical change from marine shales below to nonmarine silts and shales above. The abundance of cross-stratification varies throughout the segment but is more common in the upper part. Similar changes are known in the Gallup Sandstone in the San Juan basin; the Gallup was deposited as a prograding sandy shoreline (Harms and others, 1975). The fossiliferous lentils in the Tres Hermanos are possibly intercalated layers of shells that collected on a beach. Reineck and Singh (1975) discuss similar shell layers at Sapelo Island, Georgia.

The middle nonmarine beds of the Tres Hermanos, units 6-8 through 6-45, overlie, and are in turn overlain by, marine deposits. This close association indicates that beds of the middle Tres Hermanos are probably lower coastal plain deposits and that regression changed to transgression during that time.

Subenvironments represented in the lower coastal plain deposits of the Tres Hermanos are coastal marsh, mud flat, crevasse splay, washover fan, distributary channel, and lagoon. These environments are recognized based on their geometry, vertical succession, and other criteria listed. Coastal marsh deposits are bioturbated (rooted), organic rich shales containing lenticular lignites and coals. Mud flat deposits are variegated shales. Thin, lenticular, ripple-bedded sands are either crevasse splays or washover fans. Crevasse splays are poorly sorted, fine-to medium-grained sand. Washover fans are well-sorted, medium-grained sand. Distributary channels are thick, broadly lenticular, moderately sorted, medium-grained sand. Distributary channels have deep-cut bases and large trough and tabular cross-stratification. Lagoonal deposits are calcarenites and contain brackish water oysters.

The upper sands, units 6-46 through 6-50, of the Tres Hermanos are transgressive coastal sands. During transgression, coastal sands were generally reworked within the littoral zone as demonstrated by their mature sorting and rounding, compared to the moderately sorted sands of similar environments during progradation. The result is that the shoreface sands are lenticular and shingled, or absent. Transgression can be a nondepositional shift in the shoreline (Asquith, 1974); a concept that may explain the incomplete depositional record and increased sorting of the upper sands of the Tres Hermanos.

The timing of the regression of the basal Tres Hermanos can be documented by comparing ammonite zones at various locations. The base of the Tres Hermanos is in the *Mammites nodosoides* zone near Truth or Consequences; in the *Collignoniceras mexicanum* zone at Riley; and in the *Prionocyclus hyatti* zone where it wedges out south of Cuba (Hook and Cobban, in preparation). Regression across this region crosses four ammonite zones (about 0.5 million years duration), and culminates within the *Prionocyclus hyatti* zone (Hook and Cobban, in preparation). The transgression that followed, was rapid as indicated by the top of the Tres Hermanos Sandstone being in the *Prinocyclus macombi* zone from Puertecito to Acoma (Hook and Cobban, in preparation).

D-Cross Tongue

Dane and others (1957) named the D-Cross Tongue of the Mancos Shale for exposures at D-Cross Mountain, New Mexico and defined it as the shale body between the Gallego Sandstone and the lower part of the Gallup Sandstone (recognized now as the Tres Hermanos Sandstone Member of the Mancos Shale). Dane and others (1957) believed the D-Cross tongue, at the type locality, to be a distant and higher tongue of the Mancos rather than correlatable with the Pescado tongue of the Gallup-Zuni basin as proposed by Pike (1947). However, the lower half of the D-Cross Tongue is directly equivalent to the Pescado Tongue (Molenaar, 1974). The age of the D-Cross is late Carlile (late Turonian) (Hook, oral communication, 1978). Near Riley the change from Carlile to Niobrara (Turonian to Coniacian) is near the top of the D-Cross.

The D-Cross Tongue of the Mancos Shale is 175 ft (53.3 m) thick at D-Cross Mountain (Dane and others, 1957). At Puertecito, the main body of the D-Cross Tongue is 121 ft (36.8 m) thick. Above the Gallego Sandstone at Puertecito is approximately 40 ft (12.2 m) of shale. Near Riley the D-Cross Shale is 290 ft (88.4 m) thick and is stratigraphically equivalent to the D-Cross Tongue, Gallego Sandstone and

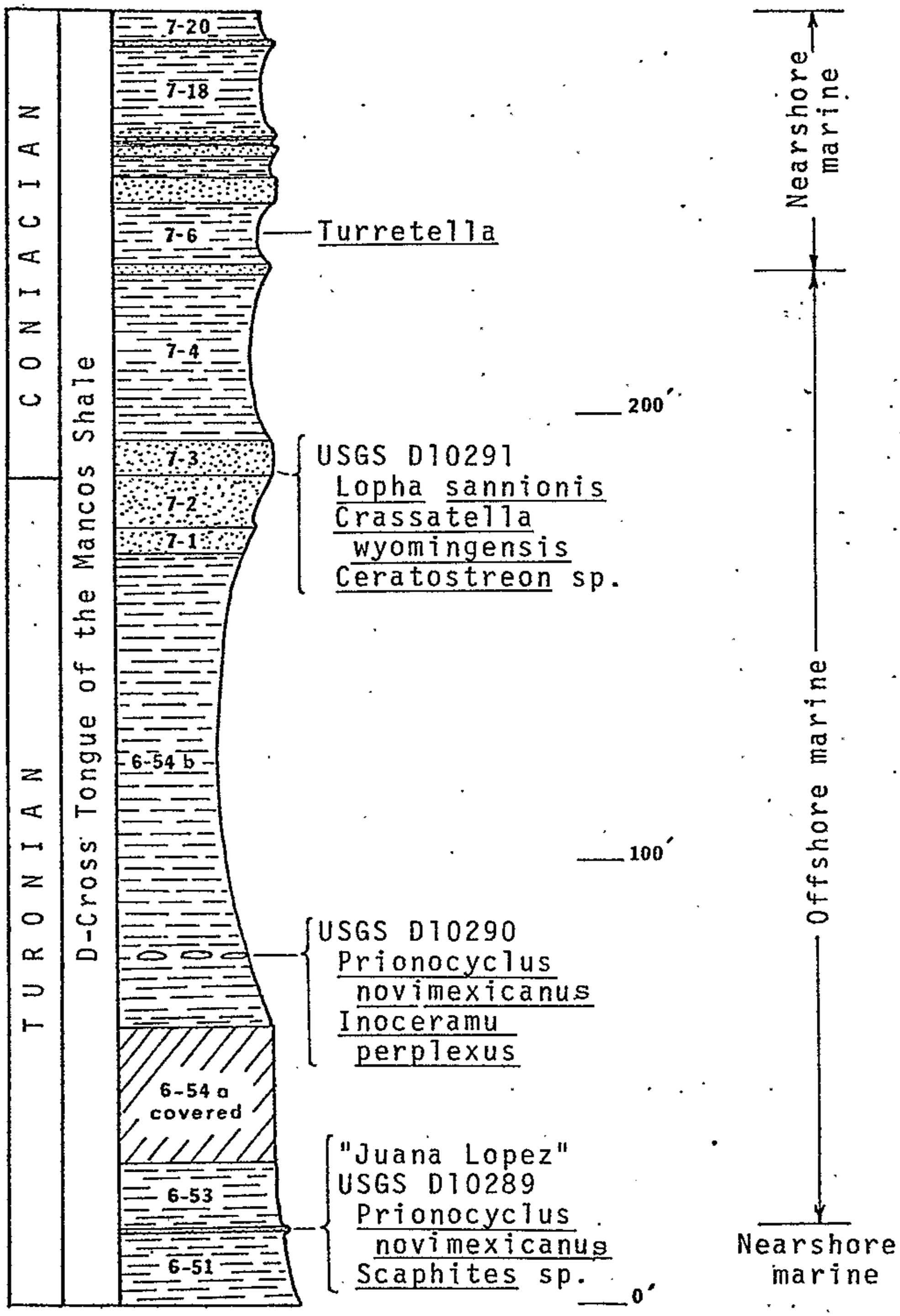


Figure 17. D-Cross Tongue of Mancos Shale, near Riley, measured thickness 290 ft (88.4 m); includes 30 ft (9 m) covered interval.

upper shale at Puertecito.

The D-Cross Tongue is generally a medium-dark-gray (N 4) to medium-gray (N 5) shale; the weathered surface of the rock is light gray (N 7). The shale is thinly to very thinly bedded with variable amounts of sand and silt.

Approximately 20 ft (6.1 m) of the basal D-Cross is time equivalent to the Juana Lopez Member of the Mancos Shale; in this segment is a 7 inch (19 cm) thick, dark-yellowish-orange (10 YR 6/6) calcarenite, unit 6-52, that contains *Inoceramus* sp., *Scaphite* sp., and *Prinocyclus* sp. (Hook, oral communication, 1978). The calcarenite is distinctive and persistent enough to be useful as a stratigraphic marker.

Shale beds above the base of the D-Cross are usually concretionary. The concretions are 6 to 36 inches (15 to 91 cm) in diameter and of two basic types. One type is a nonfossiliferous, botryoidal aggregate of acicular calcite. The second type is oblate-shaped limestone with a smooth outer surface. The centers of these concretions commonly contain either septa of brown calcite or ammonites. The concretions are concentrated along stratigraphic horizons and in places form irregular discontinuous beds. The concretionary portion of the D-Cross shale contains *Prionocyclus* sp., *Inoceramus* sp., *Baculites yokoyami*, *Prionocyclus novamexicanus* and *Inoceramus perplexus* (Hook, oral communication, 1978). Near Riley the upper

100 ft (30.5 m) of D-Cross shale is very sandy.

Intercalated with the shale are thin to thick beds of loosely consolidated sandstone whose contacts are gradational into the enclosing shale. These sandstones contain Cardium pauperculum, Lopha sannionis, Placenticeras sp., Exogyra sp., Ptychodus sp., and Crassotella sp. (Hook, oral communication, 1978). Bentonite beds less than 1 inch (30 cm) thick occur in the central part of the D-Cross at Puertecito.

The D-Cross Tongue of the Mancos Shale accumulated during a marine transgressive-regressive cycle. The shales were deposited as marine shelf muds based on the fact that they are clean and contain marine fossils. The sandstones also contain marine fossils. They may represent storm events when sand was carried out onto the marine shelf where clean muds normally accumulated. Ripple laminae and coarser grain size indicate the influence of a current or wave activity uncommon to the normal mud regime of the enclosing shales. The change from transgression to regression occurred prior to the deposition of the Gallego Sandstone, or while the upper D-Cross was being deposited, as shown by ammonite distribution (Hook, oral communication, 1978).

Gallego Sandstone

The type section of the Gallego Sandstone, named from "Gallego" (Gallegos) Creek, is at Pueblo Viejo Mesa (Winchester, 1920). Winchester (1920) originally considered the Gallego Sandstone a member of the Miguel Formation; Pike (1946) considered the Gallego Sandstone a member of the Mesaverde Formation; and, Molenaar (1974) raised the unit to formational rank. The Gallego is now thought to be correlatable to the upper Gallup Sandstone (Molenaar, 1974).

The Gallego Sandstone at D-Cross Mountain splits eastward into two sandstone tongues divided by shale. In this report only the lower of the two tongues is called Gallego and the upper sandstone tongue is included with the Mesaverde Formation. Future workers may find it convenient to include the basal sandstone of the Mesaverde of this report with the Gallego Sandstone.

The Gallego Sandstone is late Carlile (late Turonian) in age (Hook, oral communication, 1978). It is 86 ft (26.1 m) thick at the Puertecito reference section and 93 ft (28.3 m) thick at D-Cross Mountain (Winchester, 1920). The upper 85 ft (25.9 m) of D-Cross Shale at Riley probably correlates to the Gallego Sandstone at Puertecito.

The basal unit of the Gallego, unit 98, coarsens upward from the underlying D-Cross shale (fig. 18). It is a dusky-yellow (5 Y 6/4) medium-grained quartz sandstone

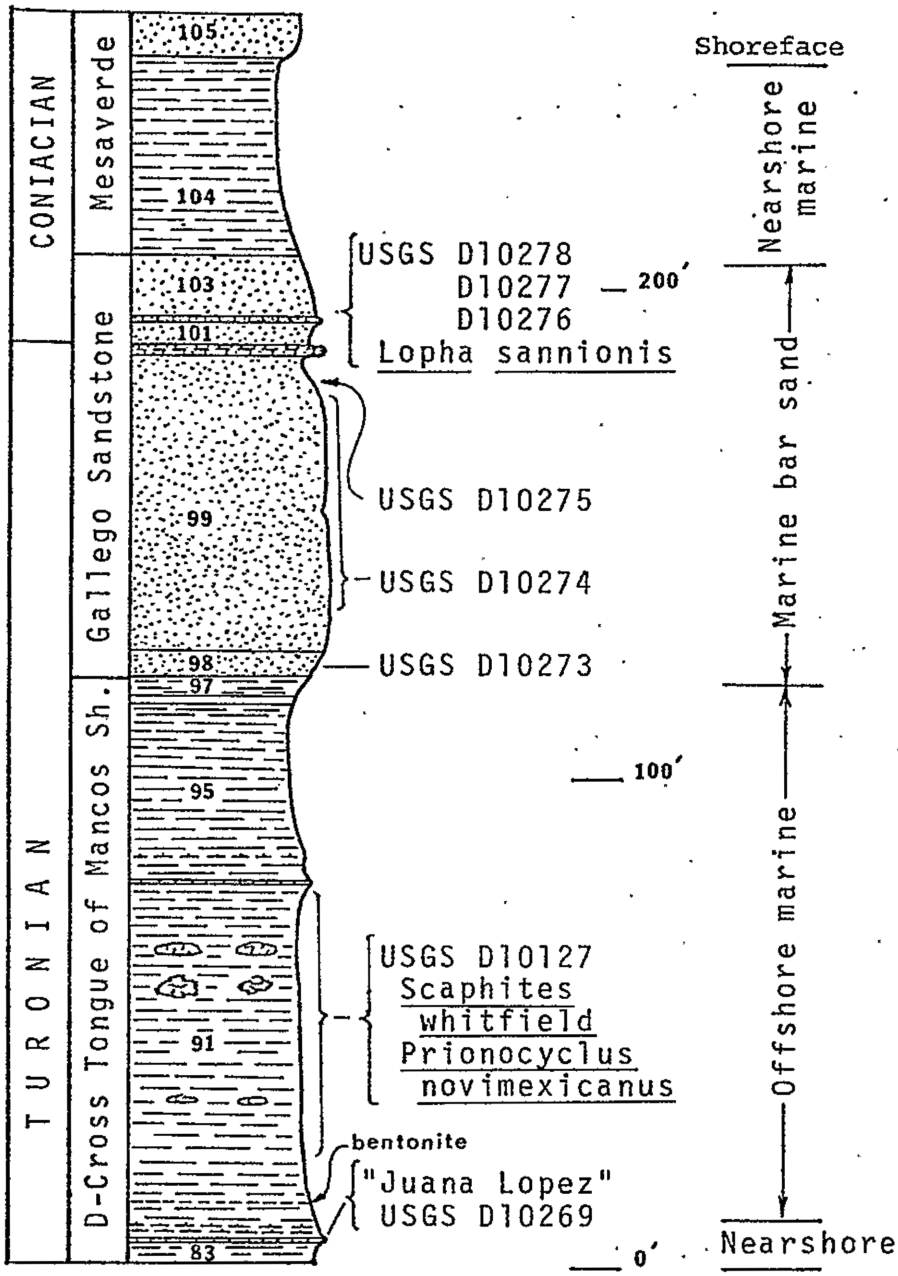


Figure 18. D-Cross tongue of the Mancos Shale and Gallego Sandstone, near Puertecito, measured thickness 121 ft (37.0 m) and 85 ft (26.1 m) respectively.

containing _Prionocyclus_ sp., _Inoceramus_ n. sp., and _Baculites Yokoyami_ (Hook, oral communication, 1978). Unit 99 is a yellowish-gray (5 Y 7/2) sandstone that forms a prominent cliff. The bed contains _Prionocylus quadratus_, _Baculites yokoyami_, _Inoceramus rotundatus_, _Inoceramus_ sp., _Eutrephoceras_ sp., gastropods, and echinoderms (Hook, oral communication, 1978).

Above the massive, cliff-forming sandstone is an interval of interbedded sandstones and shales, units 100 to 103. These sandstones are composed of medium-grained, subangular, moderately sorted quartz grains cemented by calcite. They are yellowish gray (5 Y 8/1) to dusky yellow (5 Y 6/4) on a fresh surface. Weathered specimens are yellowish orange (10 YR 6/6) to moderate yellowish brown (10 YR 5/4). Two of the five beds, units 100 and 102, are fossiliferous and, locally, are almost a coquina. These contain _Lopha sannionis_, _Cardium curtum_, and _Inoceramus_ sp. (Hook, oral communication, 1978). The fossiliferous beds are generally slightly darker colored and more resistant than the other sandstone beds and form slight benches.

The Gallego Sandstone is marine as it contains marine fossils throughout. The upward coarsening of grain size and bedding in the lower Gallego follows the expected change related to shoaling (Reinick and Singh, 1975). The lack of grain gradation and lack of sedimentary structures in the upper part of the Gallego is compatible with the massively bioturbated portion of a marine bar (Conybeare and Crook, 1968). Molenaar (1974) considered the Gallego Sandstone to have been deposited as one or several coastal barrier bars.

Mesaverde Formation

Holmes (1877) named the "Mesa Verde group" from exposures on Mesa Verde, Montezuma County, southwestern Colorado. South of the type locality, the Mesaverde is often considered a formation where individual formations are not differentiated. Throughout the Western Interior the term "Mesaverde" is applied extensively, often loosely, to the coal-bearing portion of the middle part of the Upper Cretaceous.

Tonking (1957) and Givens (1957) mapped much of the Mesaverde in the Puertecito and Dog Springs quadrangles, respectively, as the Crevasse Canyon Formation. Givens (1957) states that, "This name was chosen because of the similarity of the beds . . . to the type Crevasse Canyon Formation." However, the Crevasse Canyon Formation is defined precisely by Allen and Balk (1954) as, "the sedimentary units which lie between the top of the Gallup sandstone and the base of the Point Lookout sandstone . . . ." Because neither the Gallup nor the Point Lookout sandstones are present in the Riley-Puertecito area, the term Crevasse Canyon does not strictly fit; therefore, the nonmarine coal-bearing strata above the Mancos Shale in the Riley area is called the Mesaverde Formation. A general environmental and lithological correlation, on the other hand, conforms closely to the Crevasse Canyon.

The Mesaverde Formation rests on early Niobrara (early Coniacian) age Mancos Shale. The formation is probably no younger than late Niobrara (late Coniacian) age based on the abundance and variety of triporate and tricopate forms of pollen in coals of the upper Mesaverde (Chaiffetz, oral communication, 1978). If the rocks were younger, both the varieties and numbers of each form would be greater.

The Mesaverde Formation can be traced westward to north of Pietown where it is covered by basalt. Across the outcrop area, the strata dip generally south; therefore the Mesaverde has been removed to the north and dips under younger rocks to the south. Sandstone, shale and coal beds of the Mesaverde Formation comprise about one-third of the surface of the map area. South of Riley, the Mesaverde is 971 ft (296.0 m) thick.

Stratigraphically, the Mesaverde Formation is composed of three intervals of lithologic similarity. From bottom to top, these are 1) a basal sandstone, 2) an interval of shale with interbedded thin sandstones and siltstones containing lentils of coal and 3) an interval of shale with thick ribbons of sandstone.

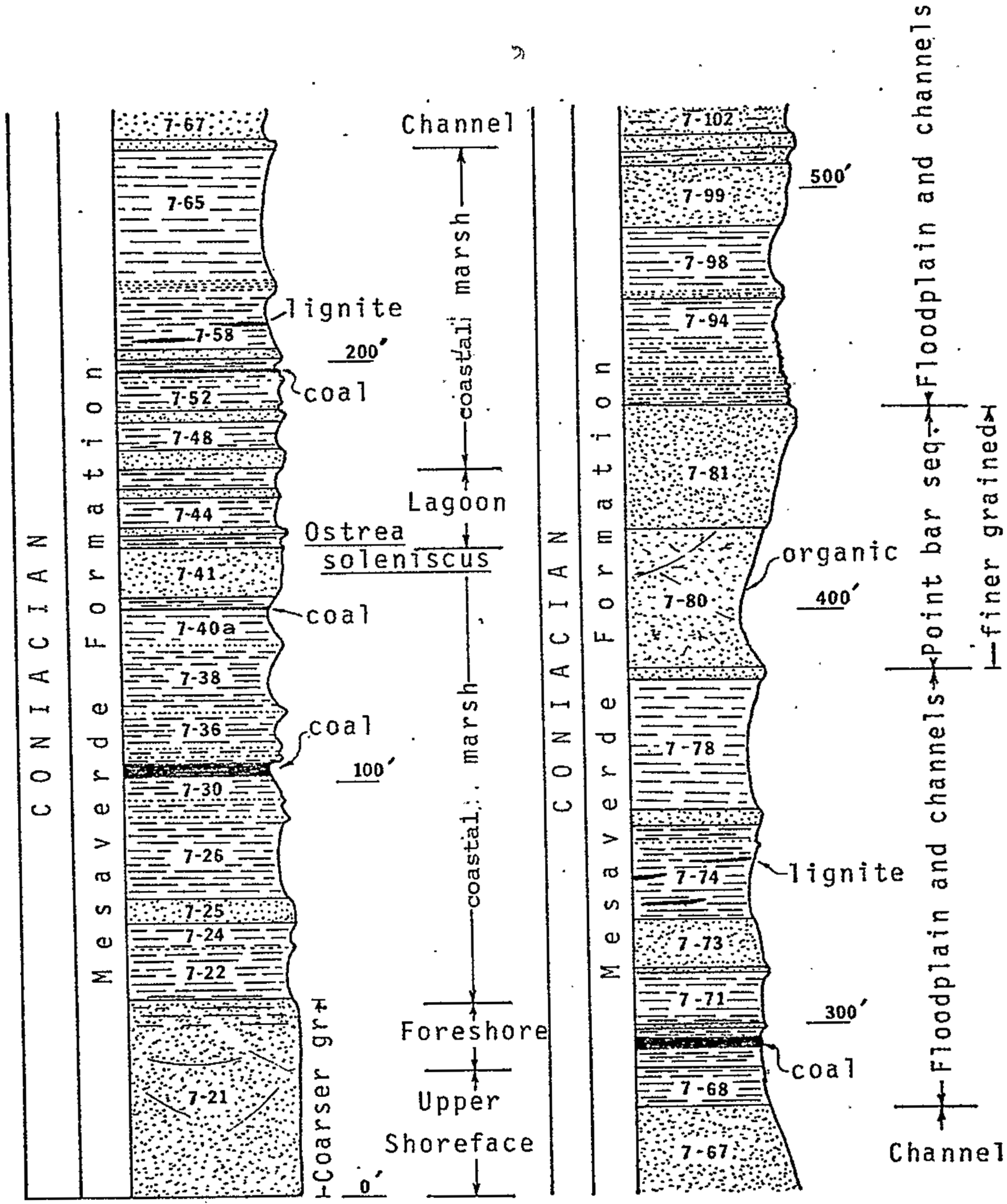


Figure 19. Lower 520 ft (159 m) of Mesaverde Formation.

First interval - The basal sandstone, unit 7-21, is 47 ft (14.3 m) thick (fig. 19). The sandstone is medium to thick bedded and cross-stratified near the top. It is moderately consolidated and forms a cliff or prominent ledge. The framework constituents grade upward from fine sand at the base to coarse sand at the top. The grains are rounded, well-sorted to moderately sorted quartz. The cement is calcite. The fresh color is very light gray (N 8) and weathers light brown (5 YR 6/4) to very pale orange (10 YR 8/2). The bed also contains scattered organic debris.

Second interval - An interval consisting of shale and interbedded thin sandstones, and also a few thin, local lenses of limestone and coal (fig. 20). This interval, units 7-22 through 7-65, is about 220 ft (67.1 m) thick near Riley (fig. 19). The shales are poorly consolidated and form slopes and troughs between more resistant sandstones. The dominant lithology is shale in beds typically about 5 ft (1.5 m) thick, but ranging from 1 to 30 ft (0.3 to 9.1 m) in thickness. The color of the shales is either medium light gray to dark gray (N 6), pale olive (10 Y 6/2), or grayish yellow green (5 GY 7/2). Some of the shale beds are calcareous and may contain silt, organic debris, or hematitic concretions.

The sandstones are commonly 1 to 2 ft (30 to 61 cm) thick but may be as much as 12 ft (3.7 m) thick. Where

Figure 20. Coal bed, about 14 inches (35 cm) thick, about 70 ft (21.3 m) above base of Mesaverde Formation in lower zone of paludal shales and coals. Thin siltstones are crevasse splay deposits. Photo was taken looking east along Forest Road 354 about 1 mi (1.6 km) south of Riley NE¼ SW¼ sec. 26, T. 2 N., R. 4 W.

fresh, the sandstones are light gray (N 7) or yellowish gray (5 Y 8/1); where weathered, they are dark yellowish orange (10 YR 8/6) to moderate brown (5 YR 4/4). The framework grains of these sandstones are principally subrounded, well-sorted quartz. They are moderately cemented by clay and hematite. The sandstones, like the shales, are calcareous and locally contain organic material or limonitic concretions. The concretions are spheroidal and about 1 inch (3 cm) in diameter. Unit 7-43 is almost a calcarenite, and contains _Ostrea soleniscus_ and _Cardium_ sp., (fig. 21). The upper surface of unit 7-43 locally has well-developed cone-in-cone structures (fig. 22). In this interval, lenticular beds of sub-bituminous coal are common and occur in seams that are typically about 12 to 14 inches (30 to 36 cm) thick but can be as much as 5 ft (1.5 m) thick.

Third interval - The upper 720 ft (219.5 m) of the Mesaverde Formation consists of interbedded shales and sandstones with some coal. This portion of the Mesaverde, units 7-66 to 7-157, is composed dominantly of sandstones that range from a few inches to as much as 50 ft (15.2 m) in thickness (figs. 19 & 23). The sandstone bodies are morphologically ribbon-like in a northeast to southwest direction and lenticular perpendicular to that direction. The sandstones are moderately consolidated and the thicker sands form prominent ledges.

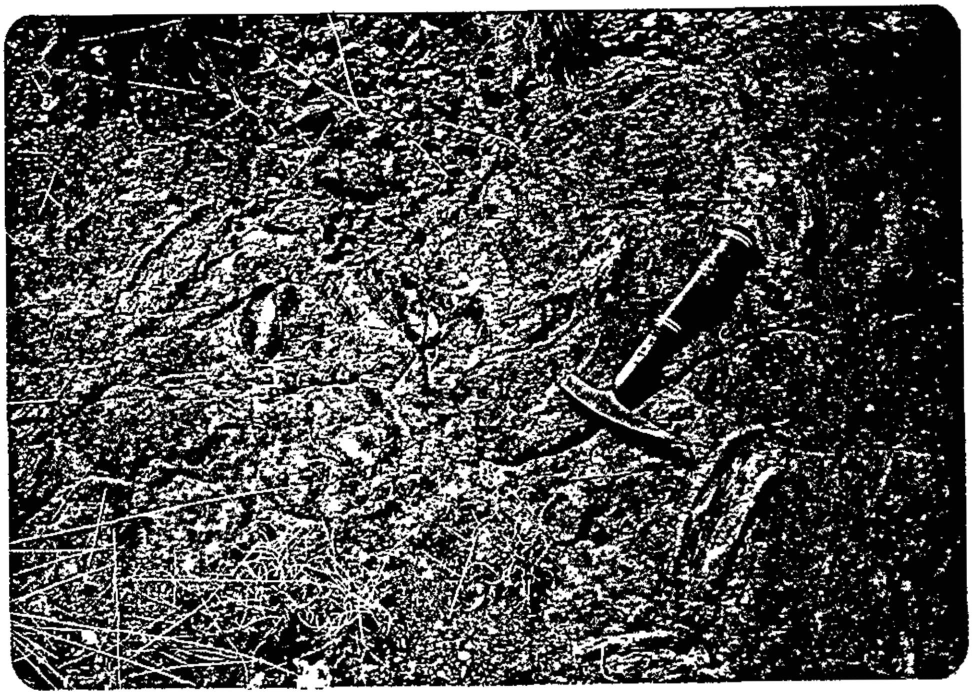


Figure 21. Limestone containing Ostrea soleniscus in basal Mesaverde Formation. View is down, location is NW¼ SE¼ sec. 26, T. 2 N., R. 4 W.

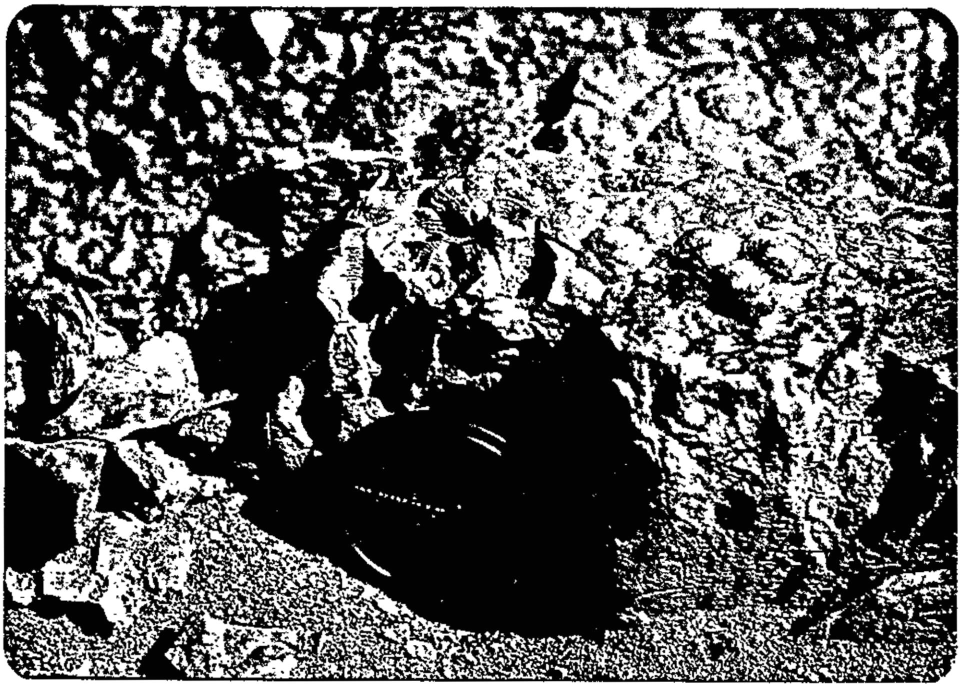


Figure 22. Cone-in-cone structures on upper surface of limestone in basal Mesaverde Formation. Location is NW¼ SW¼ sec. 26, T. 2 N., R. 4 W.

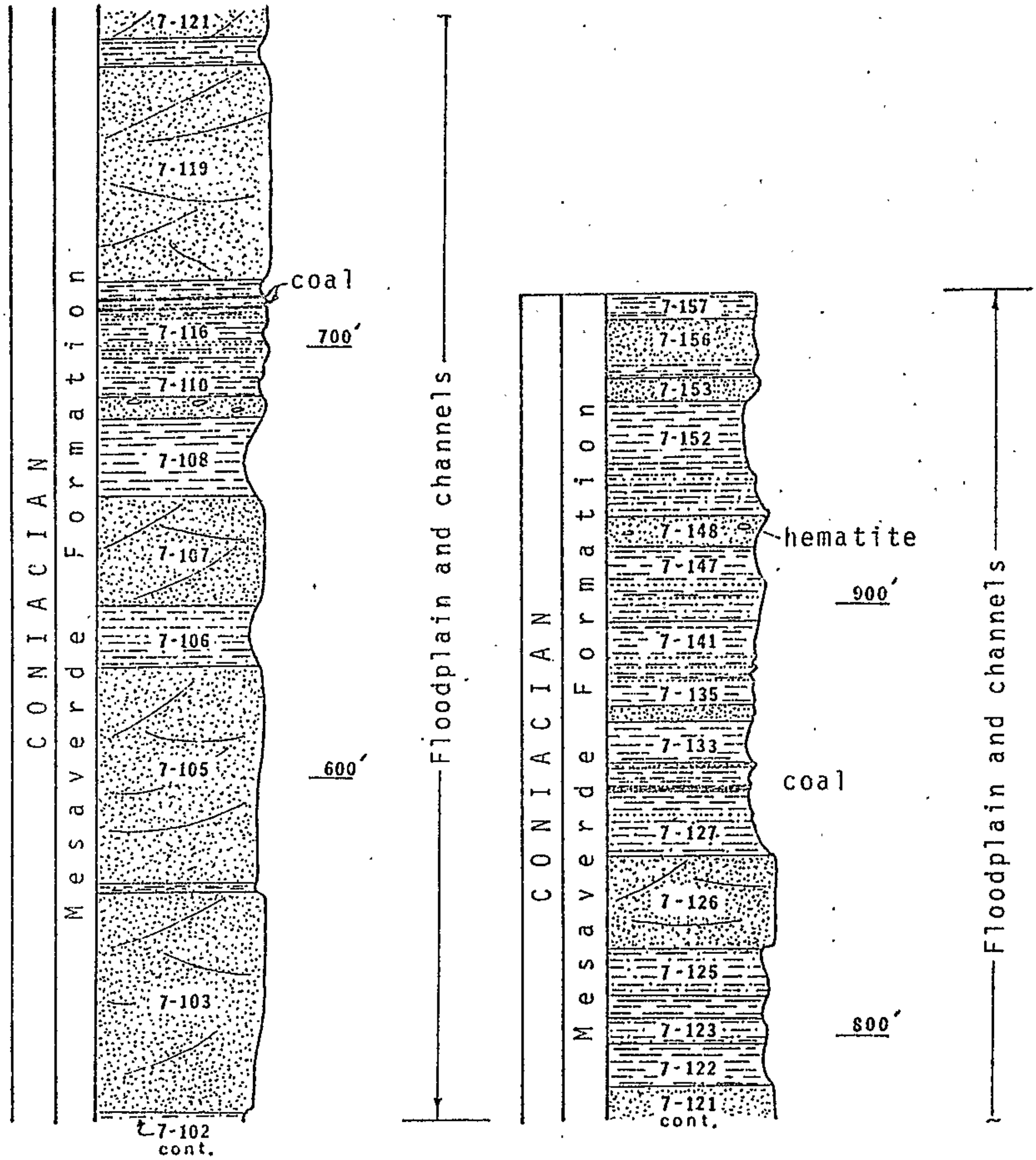


Figure 23. Upper 451 ft (137.5 m) of Mesaverde Formation.

The sandstones are typically capped by a belt of moderate-brown, calcareous (5 YR 4/4) sandstone. The capping differs from the remainder of the unit only in color and amount of calcareous material. The sandstones are very light gray (N 8) where fresh and weather yellowish gray (5 Y 8/1). The framework grains are medium-grained, sub-rounded and moderately sorted quartz. The cement is largely quartz and lesser amounts of clay and hematite. Chlorite is a common accessory mineral. These strata are thin to medium bedded with trough and tabular cross-stratification. In places, the sandstones contain spherical, about 1 inch (3 cm) in diameter, limonite concretions.

Shales and siltstones of this interval are gradational into each other, very thin bedded, slightly calcareous, and poorly consolidated. The fresh and weathered color is typically grayish yellow green (5 GY 7/2). Locally, these beds are rich in hematite nodules. The nodules are moderate red (5 R 4/6) to grayish red (10 R 4/2) and are oblate with septa of calcite and hematite. Isolated lenses of sub-bituminous coal and lignite occur randomly.

Rocks of the Mesaverde Formation compare favorably to a depositional setting like the Niger Delta area, Nigeria, in geometry, vertical sequence, and internal characteristics. In a wave dominated environment, like the Niger Delta region, shoreline and delta-center sands are continuously reworked (Allen, 1965) so that distinction between the two environments is difficult. The recognition of delta centers is based on the following:

1) thickening of the sand body
2) a basal erosional contact
3) evidence of rapid sedimentation (e.g., ball and pillow structures)
4) dominance of basinward current indicators (cross-stratification)
5) the abundance of organic debris.

Marine portions of distributary channels are rarely preserved because they are usually destroyed by waves. Both shoreface (including foreshore) and delta-center sands contain oscillatory ripples and longshore cross-stratification.

The basal sandstone of the Mesaverde Formation, unit 7-21, is thought to be a shoreline sand because it is sheet-like and separates marine and nonmarine rocks. The grain size and bedding coarsen upward like a shoreface sequence. Areas where the basal sandstone thickens along its trend are probably deltaic buildups. In an area just south of Riley, the basal Mesaverde sandstone is thicker than average and may represent a delta center. There the basal sandstone contains all of the basic criteria listed above for a delta center.

Along a wave-dominated coastline, large lagoons do not develop; therefore, fresh water vegetation grows very near the open-marine environment. Swamps develop adjacent and parallel to the shoreline. Small tidal-filled lagoons can develop inland from fresh water swamps. The lower coastal plain is essentially delineated by the presence of the coastal marsh (swamp) and by the initial bifurcation of large river channels. Delta plains are an extension of the lower coastal plain but are wider because large rivers disperse into numerous distributary channels. Swamps, and therefore coal, are more extensive on delta plains.

Above the delta (shoreface) sandstone at Riley are organic shales, coals, thick cross-stratified sandstones, thin rippled sandstones, and oyster-bearing limestones. Coals and organic shales, units 7-31, 7-34, and 7-36, probably were deposited in swamps on the lower coastal plain (delta plain). This conclusion is substantiated by the presence of rooting and pollen of Classopollis. Classopollis is analagous to mangroves in habit and indicates a swamp environment (Chaiffetz, oral communication, 1978). Iron nodules, like those found in these shales, also infer a paludal origin (Pettijohn 1975). Sandstones, unit 7-41, that are greater than 10 ft (3.0 m) thick, have a channel shape, and contain large trough and tabular cross-stratification are probably distributary channels. Thin, widespread wedges of sandstone, like units 7-35 and 7-39; are probably crevasse-splay deposits. They are characterized by poor sorting and rippling. Lagoonal sediments, like of silt-to coarse-sand-sized quartz and gray-colored potassium feldspar. The grains are moderately sorted and subrounded to subhedral. Yellow limonite halos commonly encircle organic debris and fossilized tree trunks in this member (fig. 27). Conglomeratic cross-bedded sand lenses, as well as limestone beds are present locally, secs 9 and 11, T. 1 N., R. 4 W.

The red mudstone member, units 33 through 51, is 244 ft (74.5 m) thick and composed mostly of grayish-red (10 R 4/2) to reddish-brown (10 R 4/4) silty mudstone. Thin sandstones, about 3 inches (8 cm) thick, are interbedded in the lower portion of this segment. The sandstones are very light gray (N 8), composed of rounded, well sorted, very-fine-sand-to silt-sized grains. In the upper portion of the member pale-red (10 R 6/2) sandstones as much as 25 ft (8.6 m) thick are interbedded with mudstones. The sandstones consist of moderately sorted, loosely consolidated coarse arkosic sand. Numerous veins of satin spar gypsum and one thin vein of light blue celestite was observed in the upper portion of the Baca at the type locality.

The sand-and silt-sized constituents of the Baca are about 30 percent quartz, 20 percent microcline, 20 percent quartzite, 10 percent chert, and the remaining 20 percent divided among plagioclase, potassium feldspar, carbonate, muscovite, and mudstone grains. The cement of

Figure 27. Fossilized tree trunk in gray sandstone segment of the middle Baca Formation. Yellow limonite halo encircles tree trunk. Location is NE¼ NE¼ sec. 16, T. 1 N., R. 4 W.

the sandstones is partly an early generation of silicia but is largely a later generation carbonate. The grains are commonly coated by a thin layer of hematite. Fine-grained hematite and carbonate occurs in shales of the Baca Formation.

The Baca accumulated in one of many basins produced by the Laramide orogeny. The dimensions and shape of the Baca basin are unknown but judging from the present outcrop belt the basin probably was elongate east to west and slightly sinuous between highland masses. Highlands bordering the basin during Baca depositon include: Zuni, Defiance and Lucero uplifts on the north, Joyita Hills uplift on the east, Magdalena uplift to the south, and Mogollon highlands to the southwest. Undoubtedly, smaller, local uplifts also influenced Baca sedimentation.

Snyder (1971) interpreted the climate during Baca deposition to be arid to semiarid, and gave the following as evidence: 1) coarse-grained sediments in deeply entrenched channels; 2) reddish color of the finer grained rocks; 3) lack of abundant organic trash (believed by Snyder to be due to the paucity of vegetation); and 4) presence of continental limestones thought to be caliche. Johnson (1978) advocates a wetter climate, in the range of semiarid to subhumid. As evidence he cites the following: 1) lack of obvious indicators or aridity, such as primary evaporites, wind reworked sand, and carbonates; 2) the fact that caliche, described by Potter (1970), develops best in semiarid rather than arid climates; 3) abundance of root mottling even if actual organic debris is scarce; and 4) humid tropical floras and faunas of neighboring Eocene basins.

Although the writer concurs with Johnson's conclusion that the climate was wet and hot during Baca deposition, certain points should be made. First, limestones found in the Baca north of the Bear Mountains are associated with gray shales and have yielded lacustrine algae (Chaiffetz, in preparation). A lacustrine origin, not soil-profile caliche, is postulated for these beds. Mudcracks in the Baca (Tonking, 1957), suggests alternate wetting and drying.

Second, the MacRae basin that Johnson (1978) advances as proof of a wet climate for the middle Eocene is in part late Cretaceous in age, older than the Baca. The San Jose Formation of the San Juan Basin is unquestionably (Bridger) middle Eocene as in the Baca in New Mexico from the limited faunal evidence available. The fauna of the San Jose Formation are typical of savanna-like upland assemblages (Lucas, 1977).

Thirdly, only the clay constituents of the Baca sediments are characteristically red. Silt and sand clasts are shades of gray with only a few grains with coatings of iron oxides. Magnetite and other iron-bearing minerals in the Baca are mainly unaltered, indicating that the red pigment is not a product of in situ alteration of iron-bearing detrital grains, a process described by Walker (1967). Because the red pigment is almost exclusively in the clay fraction of the rocks the origin of the red color is probably due to the weathering of a soil rich in brown ferric material. The sediment is transported in the brown hydrated form, and converted to a bright red by dehydration and oxidation after deposition (Van Houten, 1968). The oxidation probably was close to the depositional interface because after deeper burial clayey-sediments could not oxidize easily. A seasonally rainy, hot, savanna-like climate is an ideal setting for drying ferric hydroxide to hematite (Schmalz, 1968).

Baca clasts are varied and Snyder (1971) concluded that the Baca sediments were derived from multiple source areas. The clasts in the area studied were derived primarily from granitic, metamorphic and limestone sources. The distance from the source rock must have been short for the following reasons: 1) large size of granitic boulders in the Baca; 2) angularity of some of the constituents; 3) occurrence of euhedral and unaltered feldspars, and 4) presence of limestone clasts. Potter (1970) concluded that "some of the constituents of the Baca were transported no more than a few miles." Blatt and others (1972) state that feldspar grains are fairly durable and can be transported great distances without significant reduction in total volume percentage, but are greatly reduced in size when transported distances of only 20 to 25

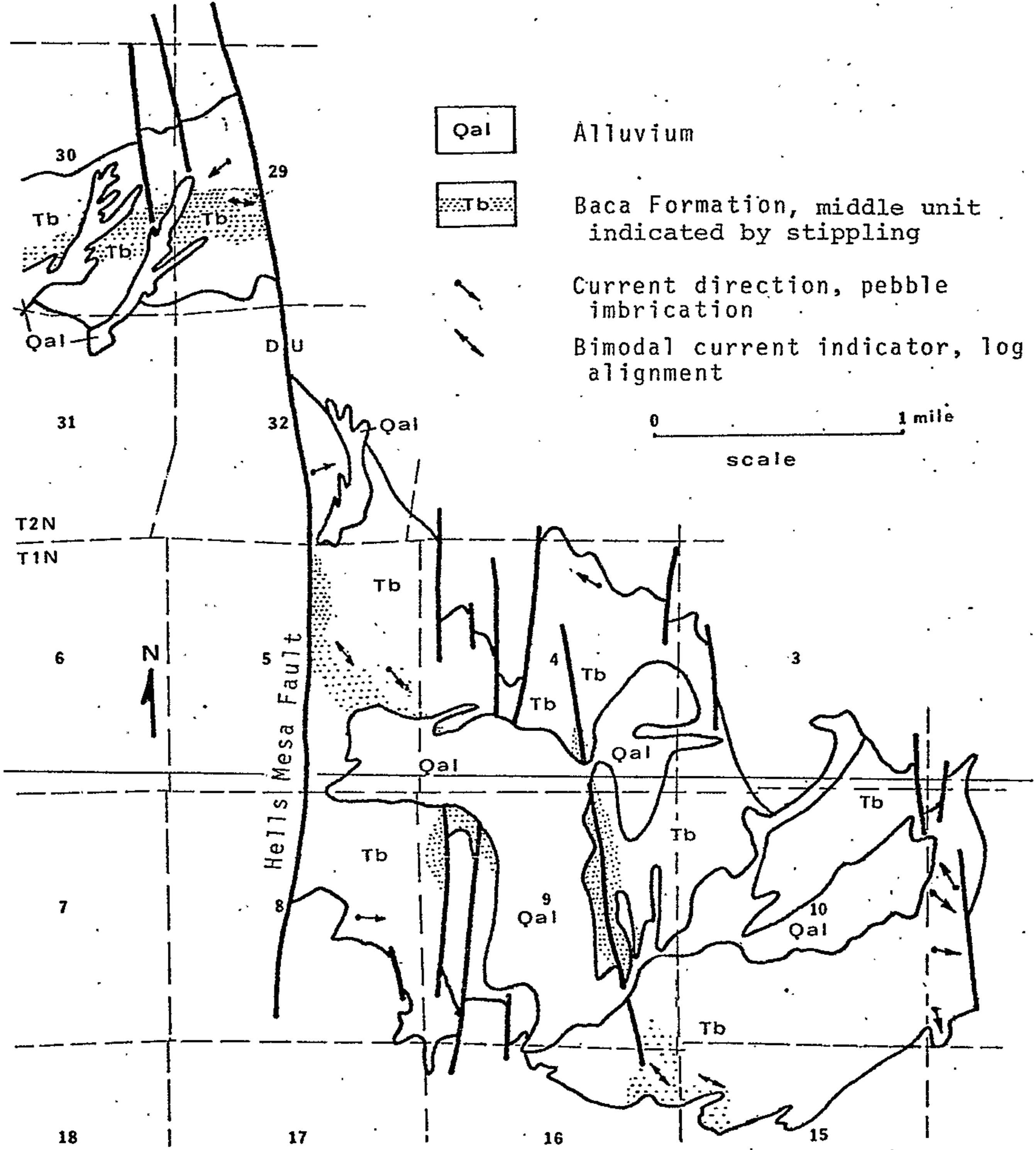


Figure 28. Map showing Baca outcrop belt, northeast of Bear Mountains, with current directions indicated.

mi (32.2 to 40.2 km). Judging from the granite boulders in the lower Baca, a nearby source for at least this material is indicated. Other constituents of boulder size, principally limestone and quartzite, are more rounded and could have come from more distant sources.

Pebble imbrications, cross-bedding, ripples, and long axis of tree trunks in the conglomeratic and gray sandstone members of the Baca indicate a southeastward flowing current (fig. 28). Therefore, the source area probably was to the northwest. Potter (1970) and Johnson (1978) proposed the Lucero uplift and Snyder (1971) the Zuni uplift as the source of the Baca sediments in the area studied. Although the Lucero uplift is closer and could have provided Paleozoic limestone to the Baca, no granites or quartzites were exposed in that area during the Eocene or at present. The Ladron Mountains, with a Precambrian granitic and quartzite core, is a Miocene uplift (Bruning, 1973) and could not have contributed to Eocene Baca sedimentation. The Zuni is the closest known uplift to the northwest that could have been the source of granitic and quartzitic material, but as the Zuni uplift is 60 mi (96.6 km) northwest of the area studied, it seems unlikely that boulders of granite and large angular feldspars could have came from such a distant source. Yet, no alternate source area to the northwest can be suggested.

Until 1978, most workers have considered the Baca as a fluvial channel and floodplain sequence (Potter, 1970; and Snyder, 1971). However, Johnson (1978) interpreted the Baca, from west to east, to be generally a progression of facies from humid alluvial fan, fluvial-meander belt, to lacustrine delta. In the area studied Johnson (1978) calls the lower conglomeratic member, a lacustrine fan delta; the middle gray sandstone member, a distal humid alluvial fan; and the upper red mudstone-sandstone member, a lacustrine fine-grained fan delta.

The writer believes the Baca to be largely a fluvial sequence. The disagreement with Johnson is based on the following reasons. First, evidence for a large lake in this area is lacking. There are no shoreline deposits or supportive faunal evidence. Second, the red color of the sediments is more suggestive of subaerial than subaqueous exposure. Johnson (1978) defends this point by suggesting a shallow, polymictic (frequent overturn) lake or lakes; the frequent overturn would allow oxidation and cause the red coloration. However, because the thicknesses of deltaic sand bodies described by Johnson are as much as 30 ft (9.1 m) thick they therefore require similar water depths. Thirdly, the fan delta complex is composed of many small deltaic sand bodies that would require an extensive fluvial system to supply the material. However, the fluvial facies tract is only a small segment of Johnson's (1978) interpretation. For example, on the west side of the Bear Mountains Johnson (1978) shows the entire Baca section, about 500 ft (152.3 m) of lacustrine deltaic facies, without associated facies. Fourthly, according to Johnson (1978) evidence for a deltaic origin for parts of the Baca are the upward coarsening of grain size per sedimentary package; extensive burrowing; convolute bedding; high mud to sand ratio; and vertical sequence of sedimentary structures. In opposition, the writer points out that convolute bedding, burrowing and root mottling are common in fluvial sequences (Reineck and Singh, 1975). In the Baca the sand:mud ratio is estimated to be about 1:1. This ratio is not outside the realm of fluvial systems. Also, the coarsening upward depositional package that Johnson (1978) promotes may not represent a true depositional cycle. Additionally Bluck (1971) has shown that the head portion of point bars in a coarse-grained meanderbelt can coarsen upward. Also, the writer has found the sandstone bodies in the Baca to be variable in both grain size and sedimentary structures throughout and a typical vertical sequence difficult to document.

Based on the data above the writer concludes that the Baca in the area studied was deposited by streams carrying coarse-grained sediment. The floodplain was savanna-like and the climate subhumid. In the studied area the southeast flowing streams carried granite, quartzite and Paleozoic limestone debris from the Zuni Uplift.

Spears Formation

The terminology of the Spears Formation has evolved in the following way. Winchester (1920) named the Datil Formation after the Datil Mountains. However, the type locality is at the north end of the Bear Mountains, about 25 mi (40.2 km) east of the Datil Mountains. Tonking (1957) separated all but the basal Baca portion of the Datil Formation into three members. In ascending order, the members are the Spears, Hells Mesa, and La Jara Peak. Chapin and others (1978) upgraded the Spears to formational rank. In addition, Elston (1976) recommends the abandonment of the term Datil as it has been stratigraphically and geographically extended to cover all mid-Tertiary rocks of the Mogollon-Datil Province.

Tonking (1957) named the Spears after the Guy Spears ranch, the abandoned headquarters of which is approximately 1 mi (1.6 km) north of the type section on the northeast slope of Hells Mesa. The Spears crops out continuously along the northern and eastern flanks of the Bear Mountains and can be traced westward into the foothills of the Gallinas Mountains. The Spears Formation is 37 to 33 m.y. old (Chapin and others, 1978).

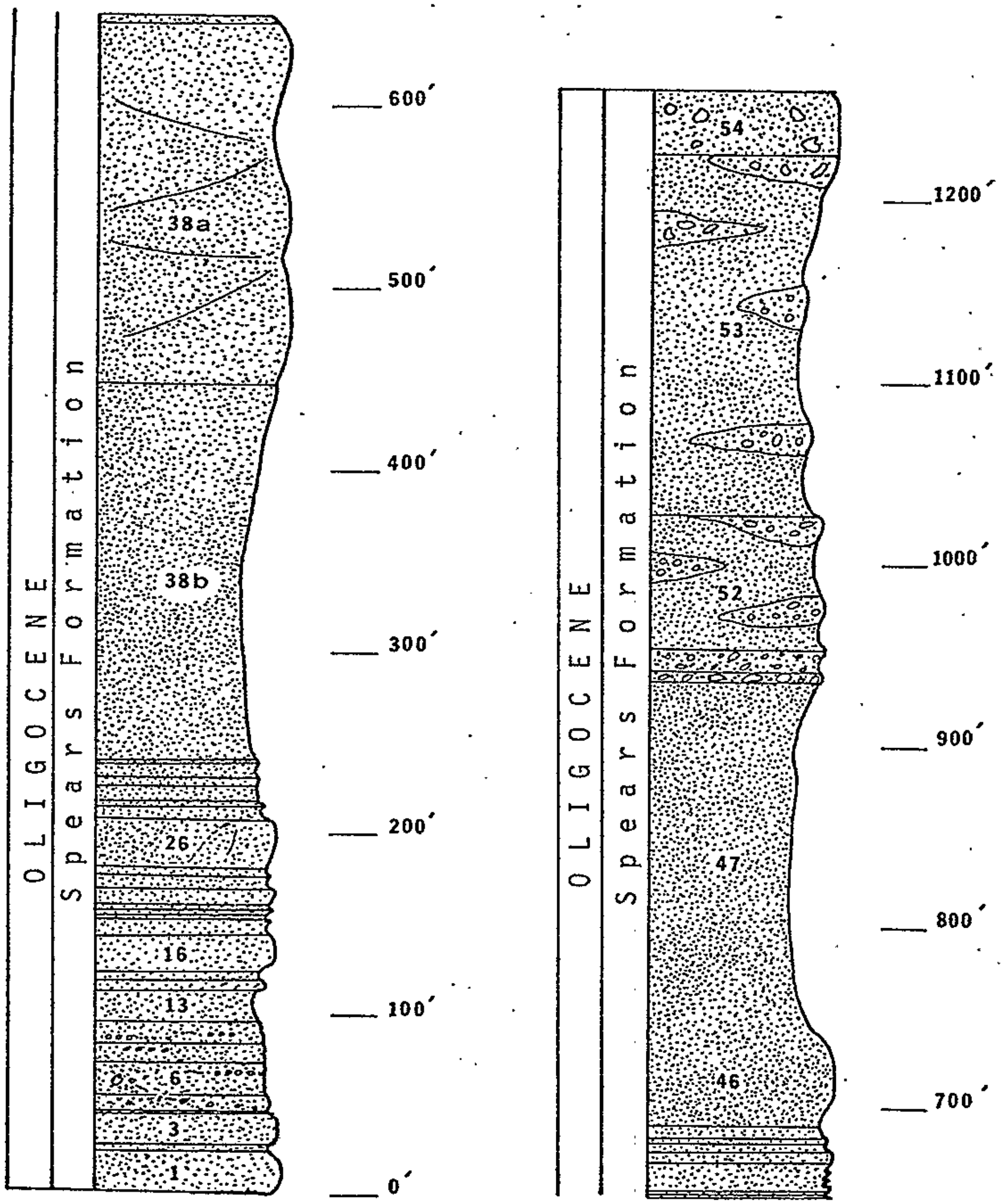


Figure 29. Spears Formation, measured thickness 1259 ft (383.9 m).

The Spears Formation is 1259 ft (383.9 m) thick at the type location (fig. 29). Tonking (1957) measured 1340 ft (408.4 m) of Spears at the same location. The basal Spears in the studied area is conformable and in places is interbedded with the upper Baca. The Spears is overlain by the Hells Mesa Tuff.

The Spears in the Riley area is composed predominately of sandstone with conglomerate lenses. Individual beds are a few inches to several feet thick and exhibit large, low-angle cross-stratification. The color varies from brownish gray (5 YR 4/1) to grayish red purple (5 RP 6/2). The sandstones are composed of a mixture of sanidine and plagioclase grains. The conglomerates are lenticular, increasing in number near the top of the formation, and have a multicolored appearance due to assorted lithic fragments. The conglomerates contain lithic cobbles of several types of andesites and some vesicular basalt fragments plus grains of biotite, pyroxene, and amphibole.

Grain sizes vary from clay to cobble, but the average size is medium sand. Sorting is poor and clay is the dominant matrix material. The larger clasts are commonly angular. Sand-sized plagioclase grains are subhedral to euhedral. Subtle vertical changes in grain size and consolidation produce alternating rounded slopes and cliffs. Unit 36 is a thin, pale-red (5 R 6/2) claystone and stands out in contrast with the overall dull-brownish-purple color unit 7-43, are carbonates and contain brackish water fossils. A common brackish water oyster of Cretaceous time is *Ostrea soleniscus*.

The upper coastal plain is recognized by large channel sands and yellowish gray shales. Sinuous sandstone lenses of the upper Mesaverde have a thick, blocky cross-sectional morphology and typically have the same grain size throughout. These sandstones may be the product of a river choked with sand crossing a low gradient such as the Ganges-Brahmaputra, Bangladesh (Coleman, 1969).

Coal seams associated with the upper part of the Mesaverde were deposited in marshes on the upper coastal plain. An inland marsh origin for these coals is corroborated by the lenticular nature of the seams and the lack of marine palynological indicators. Angiosperm forms are the most abundant type of pollen in coals of the upper Mesaverde in contrast to the dominance of mangrove-like forms in the coals of the lower Mesaverde (Chaiffetz, oral communication, 1978). Upper Mesaverde coals contain about 4 to 6 species of tricopate forms. Second in abundance in the coals are spores of the fern families, Gleicheniidaceae, Cyathaceaceae, and Schizaeaceae, with monosulcate angiosperm pollen, perhaps related to the modern palms. The assemblage most closely resembles those reported for the Straight

Cliffs Sandstone, Utah (Orlansky, 1971) and Frontier Formation, Wyoming (Upshaw, 1964).

The moderate-brown (5 YR 4/4) capping of the sandstone units of the Mesaverde probably originated subsequent to deposition by groundwater moving through the beds. The darker color of these zones is due to oxidation of iron present in the rock. Oxidation could have occurred as oxygen and carbonate-rich pore water passed through them. This would also explain the increased interstitial calcium carbonate in these zones.

Spherical limonite concretions in the sandstones have cores of organic material and are similar to those found in beach ridges of San Diego County, California (Emory, 1950). They may have undergone a complex diagenetic history, however, and may have begun as marcasite or pyrite. Marcasite commonly replaces wood in modern freshwater environments (Pettijohn, 1975). Some sandstones near Riley contain limonite concretions that surround hematite pseudomorphs after pyrite.

Iron nodules are of differing morphologies and may represent diverse origins. Usually, the iron is concentrated in areas rich in clay; hematite nodules and lenses in the shales of the Mesaverde probably evolved from iron carbonate or sulfide-rich muds. Siderite and black amorphous iron sulfide are present in modern paludal muds and many ironstone concretions or nodules have cores of sideritic clay (Pettijohn, 1975). Septa of calcite are common in the iron nodules and, if they represent shrinkage fractures, also imply a mud origin of the nodules. The presence of cone-in-cone structures on hematitic beds, implies a carbonate association, as cone-in-cone normally develops only on muddy carbonates which are, in part, ankeritic or sideritic (Pettijohn, 1975).

Tertiary and Quaternary

Baca Formation

The Datil Formation (Winchester, 1920), a name now abandoned (Elston, 1976, p. 134), has been separated into the Baca Formation, Spears Formation, Hells Mesa Tuff, A-L Peak Tuff and La Jara Peak Basaltic Andesite. Wilpolt and others (1946) designated the basal 684 ft (208.5 m) of Winchester's (1920) measured section of the Datil Formation as the type section for the Baca Formation. This section was measured in the upper portion of Baca Canyon, secs. 4, 5, 8, and 9, T. 1 N., R. 4 W., and is the only published measured section of the Baca Formation at the type locality. Of that section, 365 ft (111.3 m) was "covered" or "not exposed".

At Carthage, Gardner (1910) recovered a tooth of *Palaeosyops*, a small rhinoceras-type animal of Bridger (Middle Eocene) age from the Baca Formation. North of Datil, teeth and bone fragments of *Protoreodon pumilus*, a late Eocene relative of the modern-day sheep, were found in Baca strata (Snyder, 1970). Fossil wood from the Baca has been identified as *Palmoxylon sp.* and *Leguminoxylon sp.* which supports the Eocene age assignment (Snyder, 1971). *Tilia*-type pollen, Jugladaceous forms, and others also indicate the Baca to be at least as young as Eocene (Chaiffetz, in preparation).

Potter (1970), in an unpublished thesis, reported making several partial measurements which he compiled, in his own words, by "somewhat questionable correlations" into a complete section. Potter (1970) found the Baca to be 697 ft (212.5 m) thick at Baca Canyon, secs. 4, 5 and 8, T. 1 N., R. 4 W. The thickness of the Baca is 2500 ft (762.0 m) as indicated by drilling, but in outcrop it does not exceed 1150 ft (350.5 m); typically the thickness is about 600 ft (182.9 m) (Snyder, 1971).

Wilpolt and others (1946) correlated rocks of the Carthage and Joyita Hills areas with those in Baca Canyon. Other formations that are of similar lithologies and close to time equivalent to the Baca include the Eagar, McRae, Cub Mountain, and Galisteo. The age of the Eagar Formation, a westward continuation of the Baca in Arizona (Snyder, 1971), is uncertain but it contains a Cretaceous fauna and coal in the basal portion (Sirrine, 1956). The McRae Formation, Elephant Butte dam area, contains Triceratops and is therefore Cretaceous in part (Lee and Knowlton, 1917). The Cub Mountain Formation, Capitan-Ruidoso area, is post-Laramide to pre-Oligocene in age (Kelley, 1971). The Galisteo Formation, south of Santa Fe, is of uncertain age within a range from Paleocene to Eocene based on limited plant remains (Lee and Knowlton, 1917). Sedimentation in the San Juan and Raton basins continued throughout the late Cretaceous and early Tertiary. Faunal evidence indicates a Eocene age for the San Jose Formation (Lucas, 1977).

Because early Tertiary rocks are similar lithologically, separated geographically, and differing ages, it is reasonable to conclude that sedimentation in New Mexico and western Arizona occurred from the Cretaceous through the Eocene in isolated but somewhat genetically related basins (Tonking, 1957). The times and rates of subsidence and sediment accumulation undoubtedly fluctuated from basin to basin. The stratigraphic position and duration of gaps in the sediment record are difficult to establish because of sparse paleontological control.

The base of the Baca rests unconformably on the Mesaverde, a relationship that can be demonstrated regionally but is difficult to ascertain at a single location. The boundary between the formations changes character laterally and in places is difficult to delineate. In general, the lower Baca boundary is placed at the first occurrence of red shale or sandstone that contains pink-colored potassium feldspar. Often the shales and sandstones of the uppermost Mesaverde take on a greenish hue and this color change is useful in distinguishing the formations.

The contact of the Baca and overlying Spears Formations is marked by alternating beds of Baca and Spears lithologies and was mapped at the lowest bed containing volcanic detritus. Beds of the Baca are arkosic and rich in granitic rock fragments. Beds of the Spears, on the other hand, contain abundant volcanic material. At a distance the Baca and Spears can generally be differentiated on the basis of color and weathering. The Baca strata are various hues of red, generally forming low plains with isolated light-gray conglomerate or sandstone ledges, whereas the Spears crops out as rounded, light-purple, rough-textured sandstone hills.

Potter (1970) divided the Baca into three informal members. These members are, in ascending order: a lower red mudstone-sandstone member, an arkosic sandstone member, and an upper red mudstone-sandstone member. In the study area three informal members of the Baca are easily distinguished. Potter's (1970) terminology of these members, however, lacks descriptive viability and therefore a slightly modified version of terminology is proposed. The lower red mudstone could more accurately be called the conglomeratic member as conglomerates in the Baca are largely restricted to this portion. The arkosic sandstone member is misleading as arkosic sandstones are found throughout the Baca. A more descriptive name for this subdivision would be the gray sandstone member as this portion differs from the rest of the Baca by its characteristic gray-yellow color. The upper red mudstone-sandstone member of Potter's is sufficiently descriptive. Therefore, the terminology the writer prefers is, from bottom to top: conglomeratic, gray sandstone, and red mudstone members.

An excellent exposure of the Baca Formation 753 ft (229.7 m) thick was measured north of the type locality, W½ sec. 29, T. 2 N., R. 4 W. There a complete section of Baca dips at about 6 degrees south and has the tripartite division discussed above. The conglomeratic member, units 3 through 28, is 319 ft (97.4 m) thick (figs. 24 & 25). The member consists of reddish-brown (10 R 4/4) mudstone with numerous lentils of conglomerate and coarse, arkosic sandstone. The lentils range from 50 to 200 ft (15.2 to 61.0 m) in length and 10 to 30 ft (3.0 to 9.1 m) in thickness. The mudstones are thin to medium bedded and break into small chunks. The sandstone and conglomerate beds are composed of poorly sorted, subangular to rounded, coarse sand and cobbles. The clasts are commonly quartz, pink- and gray-colored potassium feldspar, and lithic fragments. Limestone, several varieties of granites, pegmatitic quartz, several types of quartzites, and occasional gneisses compose the bulk of the lithic fragments found in the lower Baca. The granite pebbles are generally coarse-grained, angular, and often pegmatitic. Three types of granite clasts are present, namely: 1) cream-colored potassium feldspars and quartz, 2) pink-colored potassium feldspars and quartz, and 3) graphic-textured granite. The quartzite clast vary in color and are generally rounded. Granitic

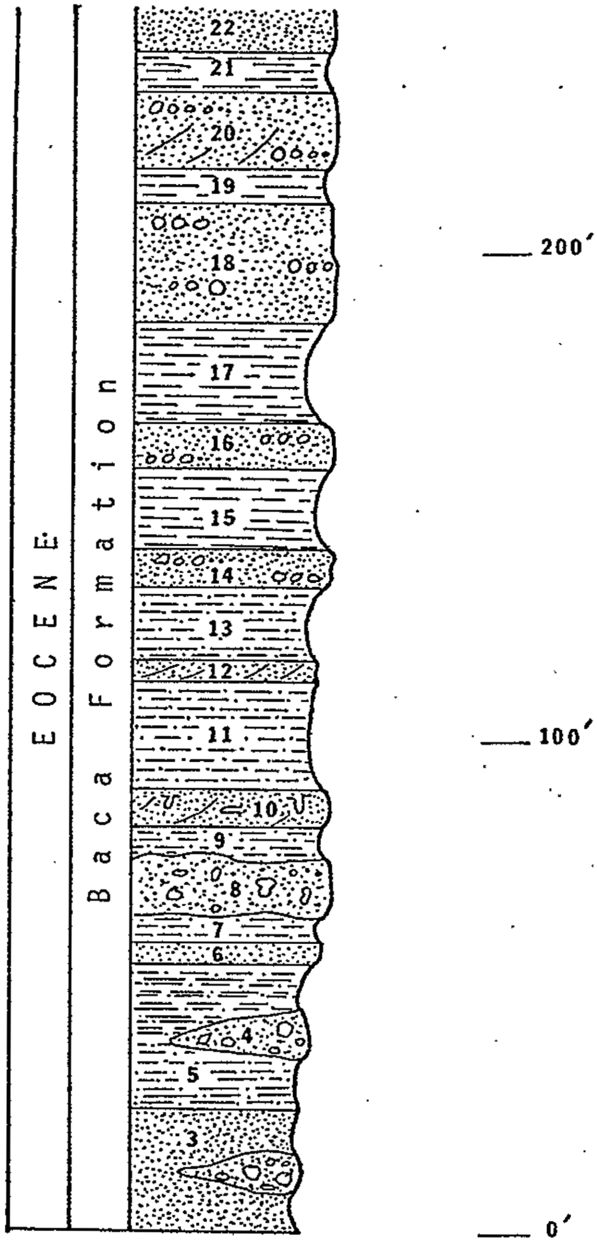


Figure 24. Lower 250 ft (76.2 m) of Baca Formation.

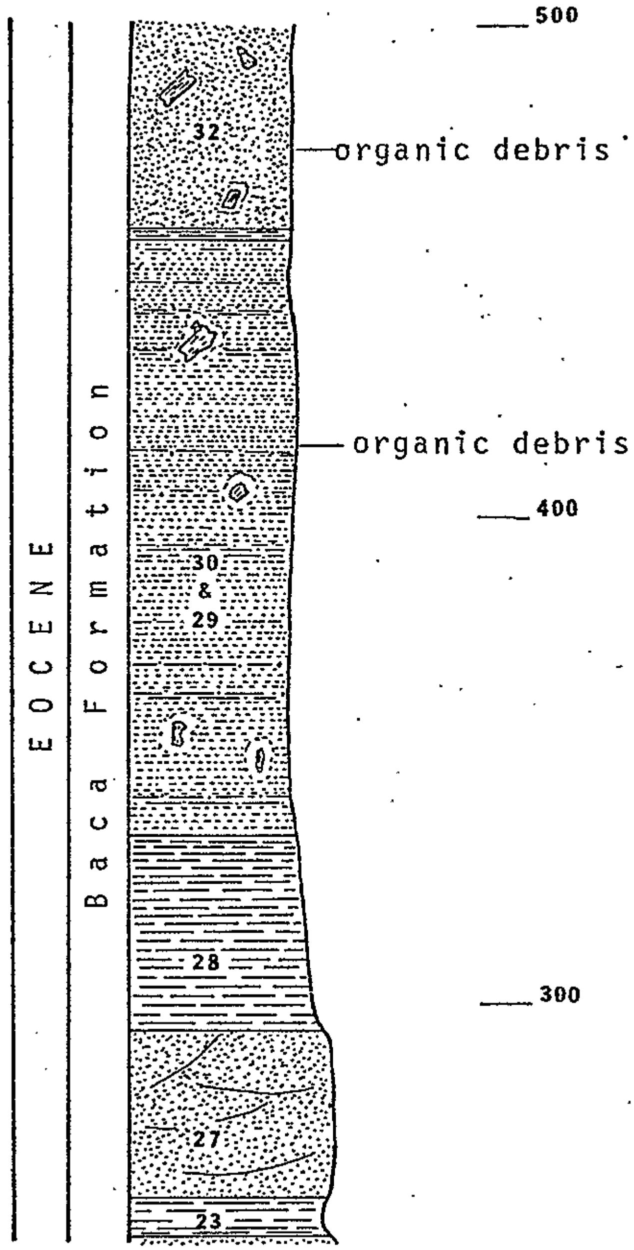


Figure 25. Middle 250 ft (76.2 m) of Baca Formation.

and quartzite fragments are considered to be derived from Precambrian rocks. Rounded limestone fragments are commonly fossiliferous, containing crinoid stems, brachiopods, bryzoans and other fossils of Mississippian to Permian age. Two types of fossilized wood occur in the Baca; one type is unrounded and genetically related to the Baca, and a second type is darker in color, rounded, and presumed to have been reworked from the Triassic (Potter, 1970).

Conglomeratic strata are generally a grayish color in contrast to the reddish hue of the mudstone. The sandstones and conglomerates are more resistant to erosion than the mudstone and form stepped ledges that vary in thickness due to their lenticular nature. Trough and very-low-angle cross-stratification is common in the sandstones. The thickest sandstone or conglomerate unit measured, unit 27, is 35 ft (10.7 m) thick. Siltstones and claystones are burrowed in many places. The burrows are non-branching, vertical and horizontal, about ¼ inch (6 mm) in diameter, and several inches long.

The gray sandstone member, units 29 through 32, is composed almost entirely of interbedded, light-greenish-gray (5 GY 8/1) and thin-bedded yellowish-gray (5 Y 8/1), clayey, sandstones and siltstones (fig. 25 & 26). No red shales occur in this interval. The gray sandstone member is 176 ft (53.6 m) thick, loosely consolidated, and forms slopes or level plains. The rock is composed predominately

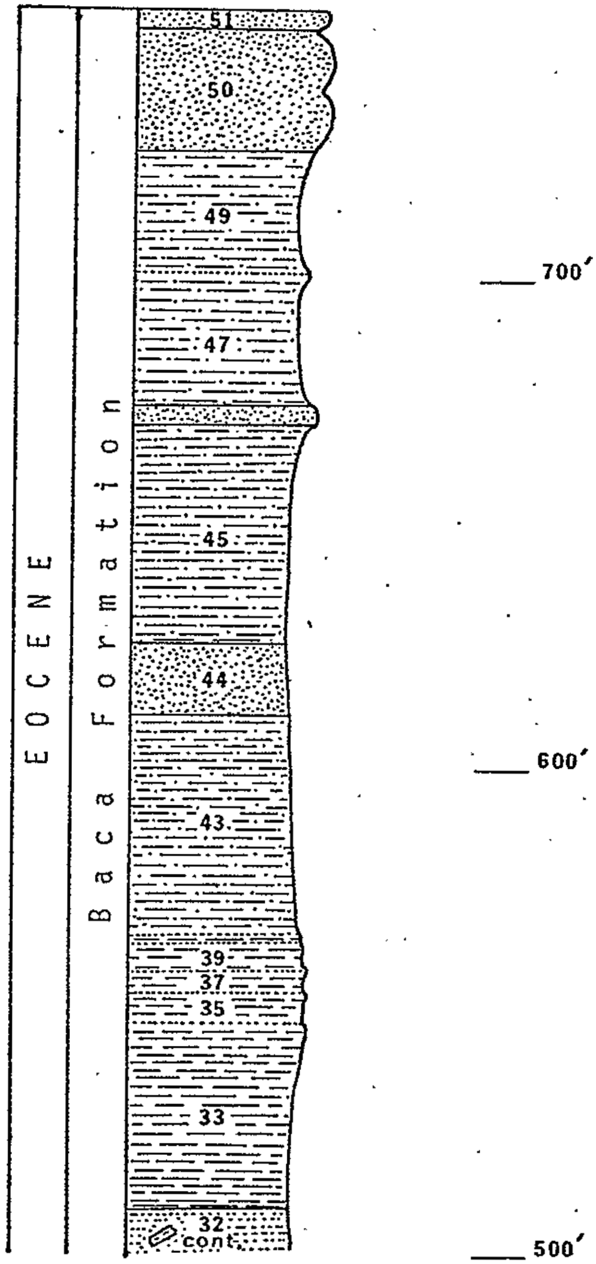


Figure 26. Upper 253 ft (77.3 m) of the Baca Formation

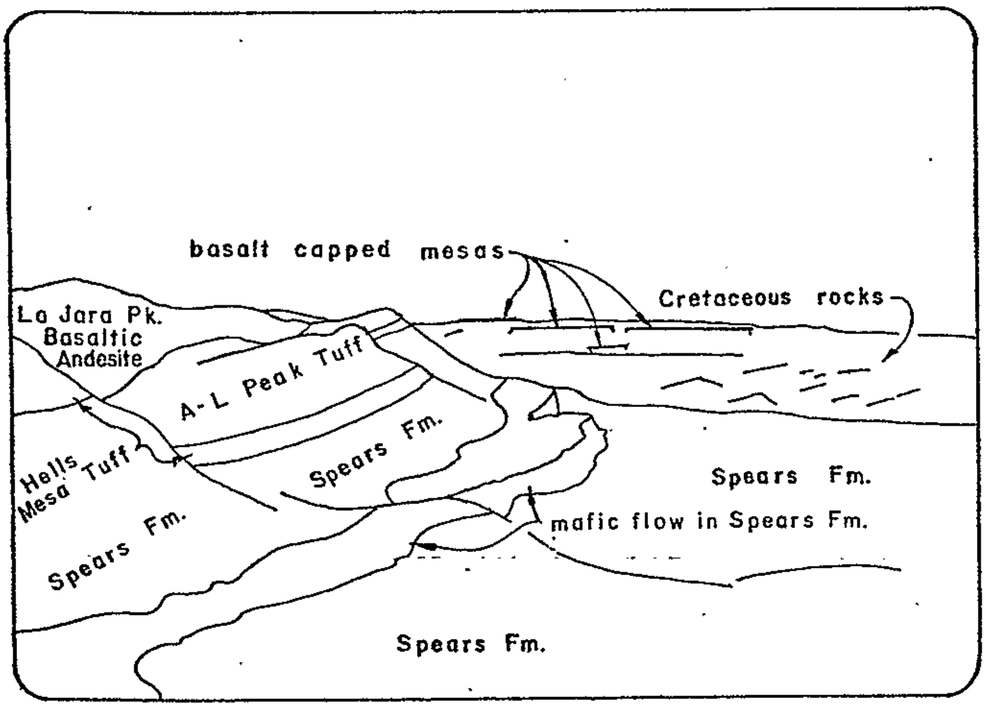
of the formation. This bed crops out at the type section, and north of Fall Springs, sec. 5, T. 1 N., R. 4 W.

Also at Fall Springs is a basaltic andesite flow estimated to be about 40 ft (12.2 m) thick (fig. 30). The andesite is porphyritic, containing phenocrysts of lath-shaped, light-colored plagioclase. The flow is concordant with sedimentary strata and contains fragments of the underlying rock at its base. Along the northeastern front of the Bear Mountains, the flow forms a prominent ledge which wedges out to the west. It was mapped as a member of the Spears; however, Tonking (1957) mapped it as a sill. The existence of a basal auto-brecciated zone and abundant vesicules indicate that the unit is a lava flow. A slight baking of sediments is visible along the lower contact of the unit. A good exposure of the upper contact was not found. The flow is about 30 ft (9.1 m) below the top of the Spears.

The Spears of the northern Bear Mountains is a volcaniclastic pile of sandstones, conglomerate, siltstones, and one andesitic flow. The sedimentary rocks of the Spears probably were deposited by a fluvial system flowing northward. Volcanic debris was derived from latite-andesite breccia and flows associated with the early intermediate phase (37-32 m.y.) of volcanism in the Datil-Mogollon volcanic field (Chapin and Seager, 1975).

The general upward coarsening of the Spears may be due to northward encroachment of eruptive centers as the volcanic field grew in size. As volcanism progressed, the peripheral volcaniclastic apron transgressed outward and coarsened upward. The number and variety of andesite cobbles, also increase upward in the formation, suggesting that more and varied flows served as sources of sediment as time progressed. To the south, the Spears contains more volcanic flows, indicating eruptive centers in that direction (Chapin, 1974).

Figure 30. View looking northwest across north end of the Bear Mountains. Spears Formation, including mafic flow, takes up large portion of slope in foreground. Hells Mesa and A-L Peak Tuffs overlie Spears. La Jara Peak Basaltic Andesite makeup the summit of the Bear Mountains in the center.



basalt capped mesas
La Jara Pk. Basaltic Andesite
Cretaceous rocks
A-L Peak Tuff
Spears Fm.
Hells Mesa Tuff
Spears Fm.
Spears Fm.
mafic flow in Spears Fm.
Spears Fm.
Spears Fm.

Hells Mesa Tuff

The Hells Mesa Member of the Datil Formation was named by Tonking (1957) for resistant, cliff-forming, ash-flow tuffs that form Hells Mesa, sec. 17, T. 1 N., R. 4 W. Tonking's type section, however, trends southward across the north face of the northernmost Bear Mountains several miles north of Hells Mesa, sec. 31, T. 2 N., R. 4 W. Tonking's original Hells Mesa Member has since been split into the Hells Mesa and A-L Peak Tuffs and upgraded to formational rank (Chapin and others, 1978). Brown (1972) mapped in the southern Bear Mountains and referred to the Hells Mesa Tuff informally as the tuff of Goat Springs. The Hells Mesa Tuff is the basal crystal-rich, quartz-rich ash-flow sheet in the region that crops out in bold palisades along the eastern and northern fronts of the Bear Mountains. At the type locality, the part of Tonking's (1957) original section that is now the Hells Mesa is 114 ft (34.8 m) thick. The average of four K/Ar dates gives an approximate age of 32 m.y. (Weber and Bassett, 1963; Weber 1971).

The Hells Mesa Tuff is 154 ft (46.9 m) thick on the northeastern side of Hells Mesa, sec. 17, T. 1 N., R. 4 W. The contact with the underlying Spears is a distinct, sharp surface where visible but in many places is covered by large volumes of rubble from the overlying Hells Mesa and A-L Peak Tuffs.

The Hells Mesa is a densely welded, pale-brown (5 YR 5/2) to grayish-pink (5 R 8/2) tuff that weathers to chunky blocks. It is crystal-rich, containing abundant phenocrysts of quartz, feldspar, and biotite accounting for 40 to 50 percent of the rock. The quartz is clear to smokey and comprises 1 to 16 percent of the total rock. The feldspars in a fresh hand sample are clear, and cloudy in a weathered sample. Colorless, subhedral plagioclase and sanidine occur in about equal abundance and together make up to 30-35 percent of the rock. The rock is characterized by a seriate texture with large crystals 3 mm in diameter down to fragments 0.01 mm or less in diameter. The matrix consists of abundant small fragments grading from phenocryst size down to microscopic. The types of determinable matrix constituents are quartz, feldspar, biotite, and devitrified glass shards.

The Hells Mesa Tuff is a multiple flow, simple cooling unit that originated from the North Baldy cauldron in the northern Magdalena Mountains (Chapin and others, 1978). The map area is on the northern edge of present outcrop distribution and the unit undoubtedly extended northward beyond present outcrops (Chapin and Seager, 1975). Between the writer's and Tonking's sections, the Hells Mesa thins at a rate of about 14 ft/mi (2.8 m/km). Using this projection, the Hells Mesa extended at least another 8 mi (12.9 km) northward from Tonking's measured section.

A-L Peak Tuff

The A-L Peak Tuff was informally named the tuff of Bear Springs by Brown (1972). Deal and Rhodes (1976) formally named the unit from exposures on the northeast flank of A-L Peak in the northern San Mateo Mountains. Throughout the Bear Mountains the upper crystal-poor portion of Tonking's (1957) Hells Mesa Member of the Datil Formation is correlative with the A-L Peak Tuff (Brown, 1972; Chapin and others, 1978).

Near Magdalena, the A-L Peak is intruded by quartz monzonitic stocks dated at about 28 m.y. The A-L Peak is, therefore, younger than the 32 m.y. old Hells Mesa but older than these stocks. A fission-track date of 31.8 $\pm$ 1.7 m.y. obtained from the A-L Peak Tuff at the type locality (Smith and others, 1976) suggests that it is only slightly younger than the Hells Mesa Tuff.

The A-L Peak rests conformably on the Hells Mesa Tuff in the northern Bear Mountains. The A-L Peak Tuff is overlain by the La Jara Peak Basaltic Andesite. The writer measured an incomplete section of A-L Peak Tuff on the summit of Hells Mesa; there the unit is at least 382 ft (116.4 m) thick. According to Tonking (1957) the A-L Peak Tuff in the northern Bear Mountains is 175 ft (53.3 m) thick.

The A-L Peak Tuff normally forms a sloping-bench above the high cliffs of the Hells Mesa Tuff. The rock weathers to large blocks or more commonly to thick plates. An average rock of the A-L Peak is moderately to densely welded and light gray (N 7) to pale red (10 R 6/2). Flattened pumice fragments and a paucity of crystals are characteristic of the unit. Flattened pumice gives the rock a prominent foliation. The ash flows are fine-grained and contain only 7 to 10 percent phenocrysts, consisting of perthitic sanidine (1-8 percent), less frequently quartz (< 1 percent), and traces of biotite and iron oxides.

The A-L Peak at Hells Mesa is composed of four units. The basal unit does not contain the characterisitic flattened pumice and is light gray (N 7). The unit contains visible quartz phenocrysts, but in lesser abundance than the underlying Hells Mesa. It is 160 ft (48.7 m) thick. The second unit is a light-gray (N 7), crystal-poor tuff with lineated pumice fragments. This unit is 86 ft (26.2 m) thick. The third unit is a brownish-gray (5 YR 4/1) basaltic andesite that exhibits small red spots on a weathered surface. It is 91 ft (27.7 m) thick. The upper unit caps Hells Mesa and is incomplete, therefore, only 45 ft (13.7 m) of the unit was measured. It is pale red (10 R 6/2), is crystal-poor and contains flattened pumice.

Chapin and others (1978) describe the A-L Peak Tuff as a composite sheet composed of basal gray-massive, middle flow-banded, and upper pinnacles members, with a tongue of the La Jara Peak Basaltic Andesite that usually separates the flow-banded and pinnacles members. The units recognized at Hells Mesa are considered correlative with Chapin and others' (1978) sequence. Brown (1972) divided the tuff of Bear Springs into three subdivisions, lower tuff, andesite flows, and upper tuff. The lower tuff is probably correlative with the basal gray-massive and middle flow-banded members of Chapin and others (1978) and the lower two units described in this report. The tongue of La Jara Peak Baslatic Andesite and pinnacles member of Chapin and others (1978) correlate with the andesite flows and upper tuff of Brown's (1972) respectively. The A-L Peak Tuff in many places is separated from the Hells Mesa Tuff by basaltic andesite flow rocks (Brown, 1972; Chapin and others, 1978) that are not found in the studied area.

In the Bear Mountains the A-L Peak is a composite outflow sheet of rhyolitic ash-flow tuffs with interbedded andesite flows. Eruption of each ash-flow unit caused cauldron collapse (Chapin, oral communication, 1978). The cauldrons responsible for tuffs of the A-L Peak are the Mt. Withington cauldron - gray massive member, Magdalena cauldron - flow banded member, and Sawmill Canyon cauldron - pinnacles member (Chapin and others, 1978). At the type locality in the northern San Mateo Mountains, the A-L Peak Tuff is over 2000 ft (610 m) thick (Deal and Rhodes, 1976). The A-L Peak Tuff in the northern Bear Mountain is sufficiently thick to suggest that the tuff may have extended several miles further north.

La Jara Peak Basaltic Andesite

La Jara Peak Andesite was named as a member of Winchester's (1920) Datil Formation by Tonking (1957) and elevated to formational status by Chapin (1971 b). Based on chemical analyses the La Jara Peak was later called a basaltic andesite (Chapin and Seager, 1975). The type locality for the La Jara Peak Basaltic Andesite is about 3 mi (4.8 km) south of La Jara Peak volcanic neck in the northern Bear Mountains, secs. 27 and 34, T. 2 N., R. 5 W. Note that the topographic feature, La Jara Peak, is not made up of Miocene basaltic andesite of the La Jara Peak rock unit, but is instead a Pliocene basaltic neck. K-Ar dates of La Jara Peak Basaltic Andesite range from 26 to 24 m.y. in age (Chapin, 1971 b; Bachman and Mehnert, 1978).

The high central portion of the Bear Mountains is composed of La Jara Peak Basaltic Andesite. It is 1175 ft (358.1 m) thick at the type locality. Individual flows are usually lenticular and about 10 to 30 ft (3 to 9.1 m) thick (Chapin and Seager, 1975). The lower La Jara Peak is interbedded with the A-L Peak Tuff. Several hundred feet of the upper La Jara Peak is interbedded with conglomerates of the overlying Popotosa Formation, sec. 34, T. 2 N., R. 5 W.

The La Jara Peak weathers to denuded, rough, rounded hills separated by steep-sided, V-shaped canyons. Individual flows tend to be more vesicular near the tops, are lenticular, and are about 10 to 30 ft (3.0 to 9.1 m) thick (Chapin and Seager, 1975). The rocks are medium to dark gray (N 5 to N 8) where fresh and weather brownish gray (5 YR 4/1) to dark yellowish brown (10 YR 4/2). They are porphyritic, vesicular basalts to basaltic andesites (Tonking, 1957). Phenocrysts consist of pyroxene and possibly olivine altering to reddish iron oxides. The oxidation products make identification of the phenocrysts difficult and give the La Jara Peak a characteristic red-speckled appearance. Plagioclase phenocrysts are notably absent (Chapin, 1974). Amygdules of calcite or quartz are common in vesicular flow-rocks. The groundmass consists mainly of plagioclase, clinopyroxene, and iron oxides with a trachytic texture (Tonking, 1957).

Basaltic andesite flows of the La Jara Peak erupted from an extensive dike swarm during late Oligocene to early Miocene time (Chapin and Seager, 1975). Basaltic-andesite flows, including the La Jara Peak, accumulated along the boundary of the Datil volcanic field and what is now the Colorado Plateau from the Riley area west into central Arizona (Elston, 1976). The flows are coincident with early stages of regional extension. Numerous normal faults developed during regional extension and became conduits for the extrusion of basaltic andesite magmas. Dikes, emplaced along vertical fractures, have been dated at 23.6 to 25.0 m.y.

(Chapin, unpublished dates). Some may have been feeders for the flows of La Jara Peak.

The lavas flowed out over an irregular surface developed by erosion and faulting. During erosion several stocks dated at 28 m.y. were breached (Chapin and Seager, 1975). Faulting and outpouring of lava may have been synchronous.

The upper A-L Peak is interbedded with the La Jara Peak between the northern Bear and Gallinas Mountains; also, younger ash flows (i.e., tuff of Lemitar Mountains and tuff of South Canyon) are missing in the Bear Mountains. The La Jara Peak volcanism may have formed a broad shield accumulation over the dike swarm so that the tuffs wedged out against the shield volcano and were never deposited in the Bear Mountains (Chapin, oral communication, 1978).

Popotosa Formation

The Popotosa Formation was named by Denny (1940) for exposures along Cañada Popotosa south of the Ladron Mountains, T. 2 N., R. 2 W., about 13 mi (20.8 km) due east of Riley. Denny (1940) described the Popotosa as well-cemented, volcanic-rich alluvial fan and playa deposits of the Santa Fe Formation, north-central Socorro County, New Mexico. Spiegel and Baldwin (1963) formally raised the Santa Fe to group status.

The age of the Popotosa is believed to be early to late Miocene (Denny, 1940; Bruning, 1973; Chapin and Seager, 1975; Machette, 1978). The basal portion of the formation, northwest Bear Mountains, is interbedded with the 24-30 m.y. old La Jara Peak Basaltic Andesite (Chapin and others, 1978). Deposition of the Popotosa continued at least to late Miocene time because silicic domes, flows, and tuffs of Socorro Peak, 12 to 7 m.y. old, are interbedded with the upper Popotosa (Bruning, 1973; Chapin and others, 1978).

The Popotosa crops out as discontinuous faulted exposures along the northeast edge of the Mogollon-Datil volcanic field (Bruning, 1973). Tonking (1957) assigned a conglomerate that crops out in the northwest Bear Mountains, sec. 3 and 34, R. 5 W., to the Santa Fe Group, suggesting that it might be equivalent to the Popotosa

Formation. He estimated a minimum thickness of 500 ft (152.4 m). Chapin and Seager (1975) also considered these rocks correlative to the Popotosa Formation. The basal Popotosa, at this location, is interbedded with the underlying La Jara Peak Basaltic Andesite. The beds dip southward and the outcrop is bounded by the Carrizozo and Cottonwood Spring faults on the east and west, respectively.

The Popotosa in the northwest Bear Mountains contains a high percentage of clasts derived from the La Jara Peak Basaltic Andesite. Boulders of basaltic andesite as large as 2 ft (0.6 m) in diameter dominate the lower beds. The upper beds, however, are finer grained and contain about equal proportions of clasts of each of the underlying volcanic formations. Pebbles in the Popotosa at this location are commonly imbricated giving an average south-southeast transport direction (Bruning, 1973).

The Popotosa was deposited as bolson sediments in an arid to semi-arid climate (Denny, 1940). Gravels were moved by sheetfloods, streams and debris flows off nearby highlands and deposited on bordering alluvial fans (Bruning, 1973). The lower part of the Popotosa represents detritus shed southeastward into this area off the rising Colorado Plateau (Bruning, 1973). The original shape and size of the basin of accumulation can only be partially reconstructed. It was at least 30 mi (48.2 km) wide north to south and extended eastward from the Gallinas Mountains well into the present valley of the Rio Grande (Bruning, 1973). In late Miocene time the Popotosa Basin was broken up by several north-trending uplifts (Bruning, 1973).

Santa Fe Group Undifferentiated

On the eastern side of the map area, secs. 20, 29, and 32, T. 2 N., R. 4 W.; and secs. 5, 7, 8, 17, and 18, T. 1 N., R. 4 W., a well-cemented conglomerate is part of an apparently continuous outcrop of Santa Fe from the north end of the Ladron Mountains (Denny, 1940). This outcropping of rocks can be seen to wedge-out on the escarpment north of the Rio Salado, sec. 20 and 29, T. 2 N., R. 3 W. There Santa Fe conglomerate rests on Triassic rocks and further south, on Cretaceous rocks. Because the volcanic rocks on which the basal Santa Fe (Popotosa) normally rests were stripped off, probably during early Popotosa time, the rocks at this location are thought to be younger. They closely resemble the Fanglomerate of Ladron Peak, upper Popotosa, of Bruning (1973) but could also belong to the Sierra Ladrones Formation, upper Santa Fe Group. Because sedimentation in the La Jencia basin was essentially continuous throughout the Neogene the distinction between Popotosa and upper Santa Fe beds is difficult. For that reason the rocks at this location are designated as undifferentiated Santa Fe Group, but are probably largely equivalent to the Sierra Ladrones Formation.

The Sierra Ladrones Formation was named by Machette (1978) for exposures east of the Ladrone Mountains. The Sierra Ladrones is early Pliocene to middle Pleistocene in age and consist of alluvial fan, piedmont slope, alluvial flat and flood plain deposits related to the axial stream system of the late Rio Grande depression. In the northern La Jencia Basin, the time equivalent sediments to the Sierra Ladrones Formation are fanglomerates and related finer-grained bolson fill and not specifically related to the ancient axial Rio Grande.

The rock of the Santa Fe Group undifferentiated is composed of conglomerates and coarse sandstones that are well-cemented by very-light-gray (N 8), fine-grained carbonate. The overall color of the rock is grayish pink (5 R 8/2). The color is attributed to a large concentration of volcanic clasts. Pebble counts made in this unit gave the following: Hells Mesa Tuff (19 percent), A-L Peak Tuff (19 percent), La Jara Peak Basaltic Andesite (29 percent) and quantities of less than 5 percent each, of quartzite, andesite, and basalt. An average clast is wedge shaped, about 1 inch (2.5 cm) thick with a long dimension of about 3 inches (7.5 cm). The matrix is coarse sand to silt composed predominantly of quartz and volcanic fragments. Cross-stratification and lenticular beds are common. Bruning (1973) found variable transport directions upward through the section at this location. North of the Rio

Salado, pebbles in this outcrop show southeast transport through most of the section, however, near the top of the section some beds have pebbles that suggest southwest transport. In these upper beds the constituents generally contain higher proportions of quartzite and schist. South of the Rio Salado, pebbles in the Popotosa show northeast transport. These transport directions generally agree with Bruning (1973).

Rocks of the upper Santa Fe in the studied area were deposited in the closed La Jencia basin continuously since its inception. The La Jencia basin is one of several subbasins that formed as the original Popotosa basin was segmented by north-trending uplifts. Sedimentation in each basin was synchronous but the varieties of source rocks, basin shapes, and basin histories gave each an individual signature. For example, the rocks in the La Jencia, which has a largely volcanic source and closed basin history, contrasts greatly to the Socorro basin which lies adjacent to it and only a few miles away. The Socorro basin has a variety of source rocks and an open basin history.

Piedmont Gravel

In the northwestern La Jencia basin a thick piedmont gravel was deposited by the aggradation of coalescing alluvial fans off the flank of the Bear Mountains. Lithologically the gravels are dominantly composed of clasts of the Hells Mesa Tuff, A-L Peak Tuff, and La Jara Peak Basaltic Andesite in approximately equal proportions. The matrix is a calcareous silt and the overall color of the rock is light brownish gray (5 YR 6/1). These rocks are probably equivalent to upper Santa Fe rocks but may be younger.

The incision of the Rio Salado drainage system post-dates the deposition of the piedmont gravel as the river has cut a valley several miles wide and at least 600 ft (182.8 m) deep through this and other strata. The eastward sloping plain in the northernmost La Jencia Basin, east of the Bear Mountains is principally an erosional surface. As base level lowered, erosion advanced southward, exposing Cretaceous and Eocene rocks and reconstructing the slope of the upper surface of the piedmont gravels in the northern La Jencia basin. The southeastern outcrop boundary of the Cretaceous and Eocene rocks of the mapped area is formed by the southward receding erosional escarpment of piedmont gravels.

Travertine

In the northeast corner of the map area, part of an extensive carbonate unit was mapped. The carbonate strata wedge out westward, just within the map boundary, and cap the tilted outcrops of Santa Fe rocks from this location eastward to the canyon referred to as "The Box." Detritus from the Ladron Mountains covers the carbonate strata to the north. South of the Rio Salado the travertine is overlain by younger Santa Fe rocks. The thickness of the unit was not measured but is estimated to be as great as 50 ft (15.2 m) thick in places.

The carbonate unit is older than youngest Santa Fe because it overlies upper Santa Fe rocks northwest of the Lemitar Mountains. Also, because it appears to lie at a similar elevation and to be genetically related to a widespread paleogeomorphic surface on which 3.5 m.y. old basalts rest, the travertine may be younger than late Pliocene.

The rock is composed dominantly of calcium carbonate with some sand and silt fractions. Rock fabric ranges from banded, porous-spongy, to dense-structureless. In places laminated, algal-like and oncolite-like textures were observed.

The carbonate strata probably were deposited in a spring-fed lake. The banded travertine-like appearance infers that the waters probably were warm, and perhaps conducive to the growth of algae. Manganiferous zones in the Popotosa underlie the travertine. In some areas, the finer matrix of the Popotosa has been removed leaving a highly porous rock in which the voids were filled and grains recemented by pyrolusite and psilomelane. These mineralized zones give the appearance of vertical alignment, as would be expected if they represent conduits for surface springs.

Pleistocene and Quaternary Alluvium

Gravels, sands and silts crop out on benches at a distinctly lower level than the Santa Fe rocks. These sediments, generally found below the 6000 ft (1828.8 m) elevation, have also been dissected by the present drainage. They probably accumulated as valley fill and small alluvial fans immediately adjacent to the north end of the Bear Mountains. The sediment is composed of fine-grained, very-light-gray (N 8) sandstone and conglomerate. The clasts of this strata, like the Sierra Ladrones rocks, are dominately volcanic fragments of Tertiary age.

The present Rio Salado is obviously in an erosional phase and may have been since the accumulation of the aforementioned gravels. Stream sediments filling the existing drainage paths are largely sands, silts and clays, derived from all the presently exposed strata. Large quantities of valley fill are interpreted to be equal to the older alluvial gravel because the present drainage dissects them. The contact between the older gravels and present stream gravels is indistinct and the mapped boundaries are, to some extent, arbitary. The distinction between the two types of gravels was generally made with reference to topographic position to the present drainage, i.e., thick alluvial cover cut by present drainage was interpreted to be older and lumped with the older gravels.

INTRUSIVE ROCKS

Dikes

One of the most noticeable features of the eastern half of the area studied is a major swarm of north-trending dikes. The dikes vary from about 2 to 61 ft (0.6 to 18.6 m) wide and range from a few feet to several miles long. The widest dike, mentioned above, runs the length of secs. 26 and 35, T. 2 N., R. 4 W. Another large dike worthy of note, forms a prominent ridge that is clearly visible on Skylab photography. It is more than 4 miles (6.4 km) long; it crops out in sec. 4, T. 1 N., R. 4 W., secs. 28 and 33, T. 2 N., R. 4 W.

The greatest density of dikes in the swarm is in a zone about 8 mi (12.9 km) wide in the eastern half of the map area; the density decreases westward. The eastern edge of the dike field is covered and not delineated by a decrease in number of dikes. The dikes have a fan-like distribution of trends that change from N 8° W on the west side of the field to N 15° E on the east side. A point of convergence of these two trends is about 5 mi (8.0 km) due north of Magdalena, sec. 27, T. 1 S., R. 4 W.

The dikes were emplaced along faults produced by the opening of the Rio Grande rift. Potassium/argon dates of two dikes (table 2) are 24.3 $\pm$ 0.8 and 24.8 $\pm$ 0.6 m.y. B.P years (Chapin, unpublished dates). Wide, brecciated areas

Sample Number	Location	K/Ar Date in m.y.	SiO_2	Al_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	Total
			Chemical Analyses (%)									
77-4-2	Old Spears Ranch, Sec. 4, T1N, R4W	24.8 $\pm$ 0.6	53.13	14.06	9.05	6.44	4.99	3.06	4.94	1.24	0.13	97.04
77-11-1	Baca Canyon Sec. 2, T1N, R4W	24.3 $\pm$ 0.8										
77-11-4	La Jara Peak Sec. 11, T2N, R5W	3.60 $\pm$ 0.18										

Table 2 Potassium/argon dates for two dikes and one neck; chemical analyses for one dike rock. Locations plotted on geologic map. Chemical analyses (x-ray fluorescence) by David W. White and dating by Charles E. Chapin, New Mexico Bureau of Mines and Mineral Resources.

are present at places along some of the thicker dikes and may represent roots of vents from which basaltic andesite flows of the La Jara Peak emerged.

Petrographically the dike rocks in the Riley area are basaltic andesites. The color of the rocks varies from greenish-black (5 G 2/1) to dusky-yellowish-green (10 GY 3/2). Plagioclase is generally present only in the matrix and ranges from An 50 to 60 (labradorite). The dike rocks contain as much as 20 percent phenocrysts of pyroxene and/or olivine. Magnetite and biotite are abundant accessory minerals. All thin sections examined revealed strong hydrothermal alteration. Chlorite, epidote, iron oxides and calcite are common replacement minerals. Much of the alteration appears deuteric in origin. Calcite is an abundant secondary mineral, up to 25 percent. A chemical analysis of one dike is shown in Table 2.

The dike rocks range in texture from aphanitic porphyritic to very-fine-grained holocrystalline. The groundmass usually consists of .01 to .2 mm lathes of trachytically aligned plagioclase with some iron oxides and pyroxene.

Weathering affects dikes in the area studied in two distinct ways. One type of weathered dike is a dusky-yellow-green (5 GY 5/2) earthy rubble (fig. 31). Chilled margins are more resistant than the cores and morphologically these dikes form a low sag between two narrow ridges.

Figure 31. Mafic dike weathered to a dusky-yellow-green (5 GY 5/2) earthy rubble except for thin chilled margins. View is north; location is NE¼ NE¼ sec. 5, T. 1 N., R. 4 W.

Other dikes, however, are less affected by weathering and stand as brownish-gray (5 YR 4/1) ridges, commonly with the appearance of a man-made rock fence (fig. 32). The weathering characteristics of dikes are related mainly to variations in hydrothermal alteration. The lithologies of the two types are similar and a single dike may weather both ways at different positions along its length. The type and water content of rock that the magma intruded, may have influenced the alteration and weathering. For example, there seems to be a correlation to the earthy variety of dikes to the Baca Formation.

Sills

Sills in the area vary in thickness from a few feet to a few tens of feet. Single bodies can be traced more than 2 mi (3.2 km) along an outcrop, secs. 3, 4 and 10, T. 2 N., R. 5 W. (fig. 33). The lateral subsurface dimension is indeterminate but is probably similar to the outcrop length. The sills are concentrated in the Mancos shales or lower paludal shales of the Mesaverde. No sills crop out above or below that stratigraphic interval. Many sills, are closely conformable with bedding and can be used as stratigraphic horizons for short distances. Others are irregular masses which wedge out, change stratigraphic position, and have erratic apophyses.

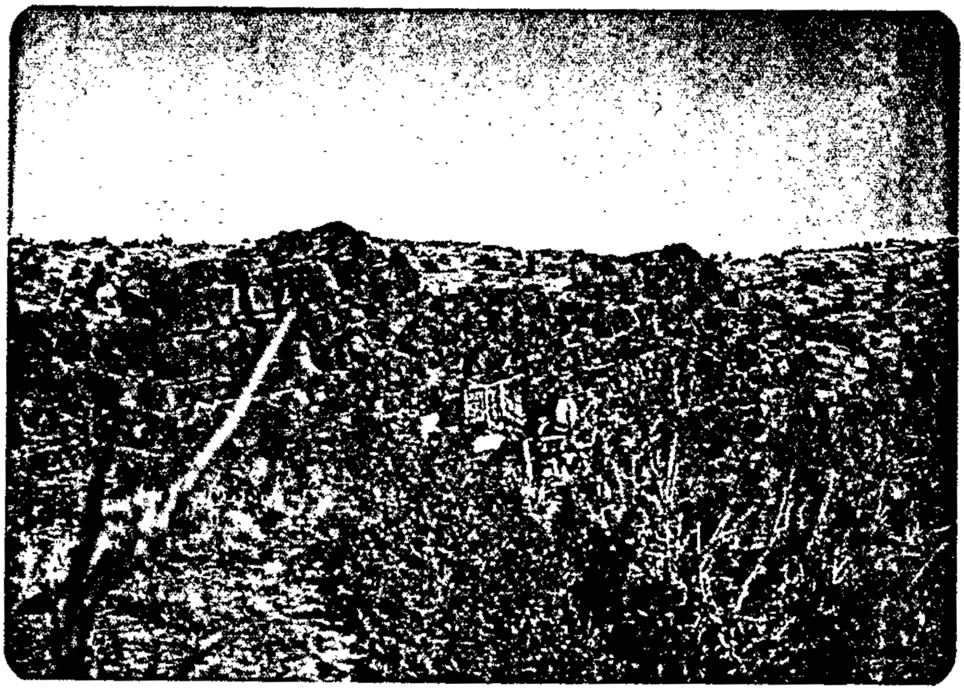
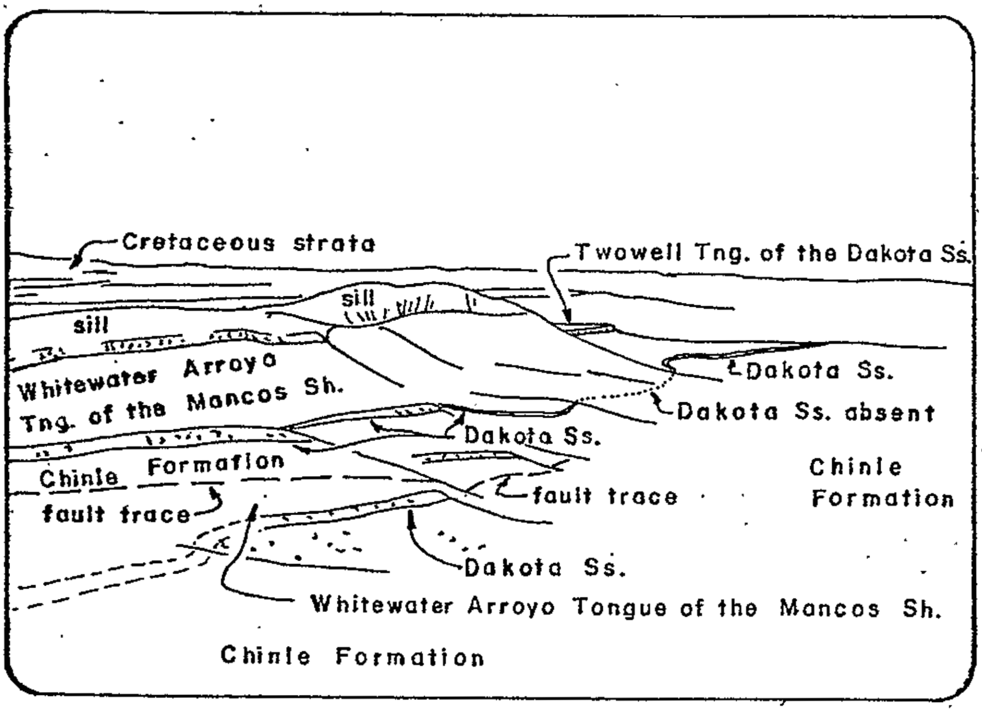


Figure 3.2. Ridge with a blocky man-made appearance formed by a mafic dike that is relatively resistant to weathering. View is northwest, location is SW¼ NW¼ sec. 3, T. 1 N., R. 4 W.

Figure 33. View north from summit of La Jara Peak volcanic neck, SE$\frac{1}{4}$ SW$\frac{1}{4}$, sec. 11, T. 2 N., R. S. W. Valley floor is Triassic Chinle Formation. Two low hogbacks in foreground are capped by Dakota Sandstone, repeated by faulting. The major ridge formed because of a thick sill that is close to the top of the ridge. Skyline is basalt-capped Mesa del Oro which stands at a slightly higher level as La Jara Peak neck.



Cretaceous strata
Twowell Tng. of the Dakota Ss.
sill
sill
Whitewater Arroyo
Tng. of the Mancos Sh.
Dakota Ss.
Dakota Ss. absent
Dakota Ss.
Chinle Formation
fault trace
fault trace
Chinle
Formation
Dakota Ss.
Whitewater Arroyo Tongue of the Mancos Sh.
Chinle Formation

The sills are generally similar in composition to the dike rocks, except they are more pervasively altered. For that reason no radiometric dates were obtained for them.

Dioritic sills were noted at two locations. In sec. 17, T. 2 N., R. 4 W. a small neck and wedge-like sill, 0 to 20 ft (0 to 6.1 m) thick, were intruded along a fault zone. Another sill, about 20 ft (6.1 m) thick, intrudes the D-Cross Tongue of the Mancos Shale in sec. 28, T. 2 N., R. 4 W. Silification and dolomitization are present in the host rock at each location.

Necks

The most prominent volcanic feature of the area studied is La Jara Peak, 6406 ft (1952.5 m), in sec. 11, T. 2 N., R. 4 W. It is a basaltic volcanic neck dated at 3.6 $\pm$ 0.18 m.y. (Chapin, unpublished date). Cooling columns flare outward toward the base suggesting that the neck is an erosional remnant of a lava-filling of a crater. Bedded agglomerates, believed to represent remnants of the underlying cinder cone, are present on the southwest side of the neck (Chapin, oral communication, 1978). The diameter of the neck ranges from 200 ft (61.0 m) to 300 ft (91.4 m).

Temporal and Spatial Relationships

Although sills were not dated radiometrically, the common basaltic andesite petrology and spatial relationship of sills and dikes infer that the sills in this region are synchronous with the 24-25 m.y. old dikes. Many sills pre-date faulting as they are cut by faults and, in rare cases, cut by dikes. This does not suggest, however, that all sills pre-date faulting or dike emplacement because an equal number of sills appear to have been fed by dikes. Faulting and the intrusion of dikes and sills may have been concurrent and may have spanned an appreciable time interval.

The depth at which sills were emplaced is estimated to have been between 3000 to 3800 ft (914.4 to 1158.2 m), based on the estimated thickness of the overlying strata at that time. The sills favored the Mancos and lower Mesaverde shales as hosts, although equally ductile units are present both above and below this stratigraphic interval. Perhaps the depth of emplacement is linked to a combination of the stress field and magma pressure.

Basaltic magmatism occurred much later than the basaltic andesite event related to the opening of the Rio Grande ift. The La Jara Peak neck (3.6 m.y. -old) is part of a widespread Pliocene basaltic magmatic event related to late stage development of the Rio Grande rift (Chapin and Seager, 1975).

STRUCTURE

General

The area of study is within a transition zone between the Colorado Plateau to the northwest and the Rio Grande rift to the southeast. Three major episodes of structural development have modified the region. They are in chronological order: 1) Laramide folding; 2) Neogene normal faulting and drag folding; and 3) Neogene epeirogenic uplift of the Colorado Plateau. Gentle folds and numerous normal faults are the dominant structural elements of the area (fig. 34). Conspicuous mafic dikes now occupy many of the north-trending Tertiary faults in the eastern half of the map area.

Laramide Folding

Two folds of Laramide age in the study area are the Baca Canyon syncline and the Monument anticline. These folds are broad and each several miles wide. Maximum dip produced during folding was probably less than 12 degrees. Modification by Tertiary faulting makes determination of the exact axial trend of the folds difficult, however the approximate axial trend of each is close to north. The folds now plunge southward, the result of regional uplift to the north.

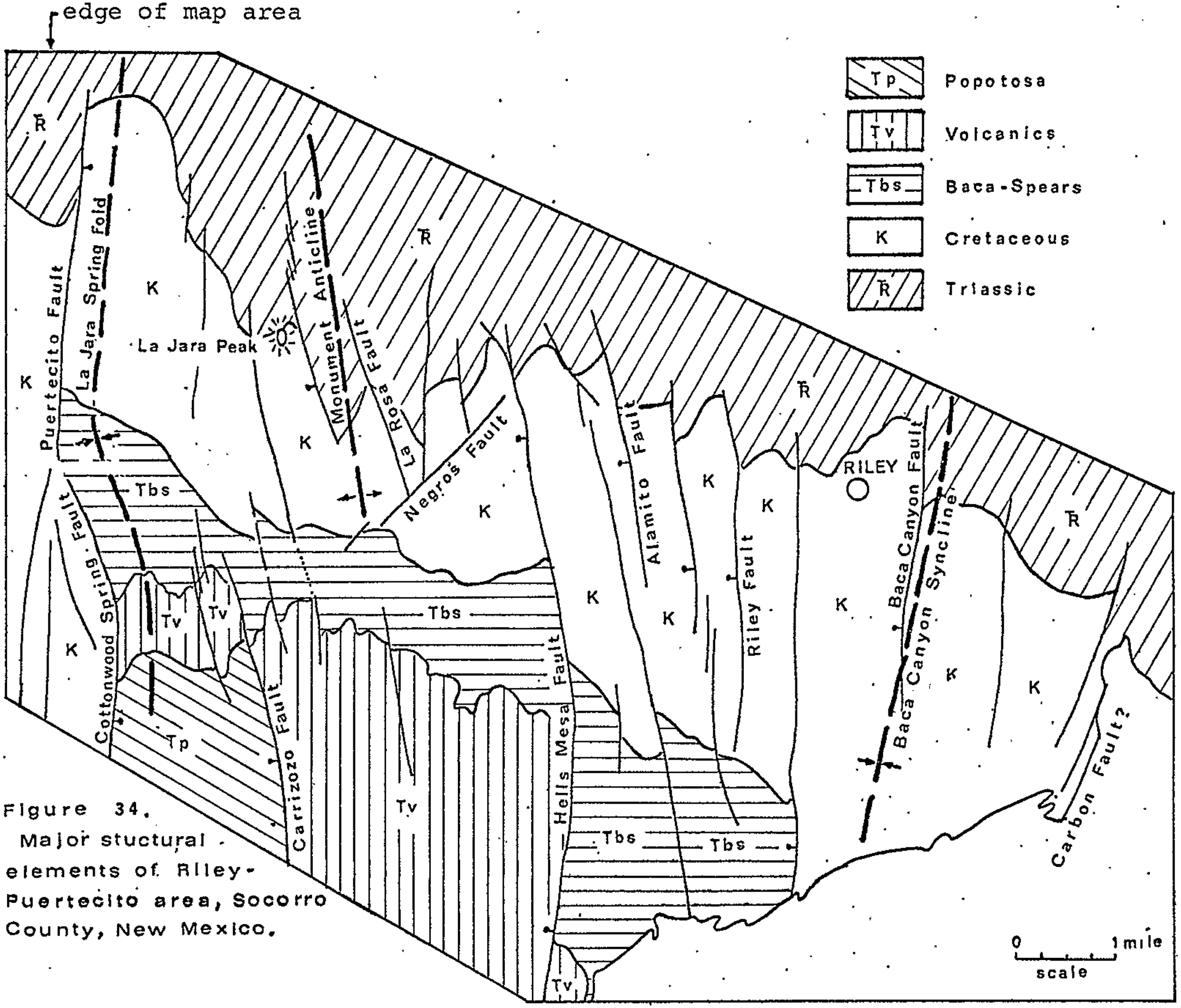


Figure 34. Major stuctural elements of Riley-Puertecito area, Socorro County, New Mexico.

Early Rift Fault and Dike Swarm

A multitude of faults, especially abundant in the eastern half of the map area, strike within a few degrees of north. The faults developed during the initial or early stages of opening of the Rio Grande rift. Dikes, emplaced along many of the faults during this same period, are dated at 24-25 m.y. B.P. (Chapin, unpublished dates, table 2).

Most of the faults are down-to-the-west and dip about 80 degrees westward. More than 70 percent of the 76 fault planes measured dip at 75 degrees or greater and none of the faults dip less than 51 degrees. Slickensides are rare, but where present indicate vertical movement with little or no horizontal component. The blocks between faults are rotated eastward close to the complement of the dip to the fault planes, i.e. ~ 10 degrees. Horsts and grabens are present but are subordinate to the unidirectional faulting and tilted fault-block structures.

The vertical throw is generally only tens of feet, but some faults, such as the Hells Mesa fault, have as much as 1700 ft (518.2 m) of throw. The apparent horizontal separation of the outcropping strata along a fault trace is usually greater than the throw. This is due to erosion of beds with low dips cut by high-angle faults trending perpendicular to the strike of the beds. For example, the apparent horizontal separation of the Baca Formation by the Hells Mesa fault is about 6000 ft (1828.8 m), whereas the vertical throw in the same area is only about 630 ft (192.0 m).

The Puertecito and Cottonwood Spring faults are the only faults in the studied area with several hundred feet of down-to-the-east throw. The Puertecito fault has a minimum throw of 1400 ft (427 m) and a maximum throw of 3400 ft (1036 m). The Cottonwood Spring fault has a minimum throw of 1100 ft (335.3 m). In the northwest part of the studied area, the Puertecito fault is a zone about 100 ft (30.5 m) wide, parallel to the western map boundary. South of La Jara Creek, the zone spreads into a complex of faults several miles wide. The Cottonwood Spring fault is the easternmost fault of that complex. The Cottonwood Spring and Carrizozo faults are obviously younger than the 24-25 m.y. old faults as they offset strata as young as the Popotosa.

The La Jara Spring fold is a large asymmetric fold, elongate north-south along the western edge of the map area. This and another north-trending fold are both aligned parallel to the Puertecito fault. The general strike of the strata in this area is northwest but near the Puertecito fault the strike changes to southwest on the east side of the fault and northeast on the west side. Both folds plunge southward; the La Jara Spring fold is synclinal and the other fold is anticlinal. The fold configuration corresponds to deformation produced by drag along a fault with major down-to-the-east movement, such as the Puertecito fault.

Tonking (1957) observed that the Baca strata were folded with the Cretaceous in the La Jara Spring fold but interpreted the Spears Formation to be uninvolved. The Spears at that location, however, is mostly covered and the writer was unable to determine bedding attitudes. Farther south, the Cottonwood Spring fault offsets the Popotosa and older rocks. The beds are inclined at angles up to 80 degrees adjacent to the fault. The steeply tilted beds represent rotated blocks of brittle rock rather than the more plastic deformation producing the folds observed in the older rocks.. The ability of faults of the region to change the attitude of strata is demonstrable along both the Puertecito and Cottonwood Spring faults. Other small tight folds in the map area are also attributed to drag on faults rather than to Laramide folding (e.g. in secs. 33, 34, and 35, T. 2 N., R. 4 W. and sec. 2, T. 1 N., R. 4 W.).

Thicknesses of 46 dikes along an east-trending line 5.9 mi (9.5 km) long were measured to account for the amount of crustal extension now represented by dikes. The 46 dikes have a total thickness of 428 ft (130.5 m); an average dike is 9.3 ft (2.8 m) thick. This represents 1.4 percent extension accountable to dikes.

Crustal extension due to normal faulting, i.e. the heave of each fault, was calculated using an average dip of 80 degrees and an average throw of 18 ft (5.5 m) for 42 faults along an east-trending line through the center of the map area. The extension was 131 ft (39.9 m) across the area or 0.3 percent of the 8.24 mi (13.3 km) long traverse. Fault and dike extension totals 559 ft (170.4 m) or about 1.7 percent.

Colorado Plateau Uplift

Uplift of the Colorado Plateau, beginning in the early Miocene (Chapin and Seager, 1975), tilted La Jara Peak Basaltic Andesite and older strata southward. Across the southern noses of tilted, southward-plunging Laramide folds, Cretaceous and older beds strike from about N 45^{o} W to N 50^{o} E. The average direction and angle of dip of Cretaceous beds are south and 12 degrees, respectively. Modification of the original plunge is probably about 6 degrees, the same as the average dip of beds younger than the Laramide episode. The Tertiary beds generally strike east-west and dip southward, except where localized faulting has modified their attitude.

The actual uplift of the Colorado Plateau relative to the adjacent area to the south is manifested by a broad monoclinal flexure. The rocks on the Colorado Plateau proper dip eastward or westward at low angles, whereas, the rocks along the southern margin of the plateau dip as much as 20 degrees southward. Rocks as young as Popotosa in the northern Bear Mountains stand at similar elevations as Triassic rocks less than 20 mi (32.2 km) to the north, or Cretaceous rocks to the northwest. Therefore, since the beginning of uplift, the Colorado Plateau has risen about 5450 ft (1661.2 m). This figure is based on the thickness of stratigraphic section between Triassic and Miocene rocks.

Near the north end of the Bear Mountains two volcanic necks, La Jara Peak and La Cruz Peak, have outward flaring columns and are thought to be lava lakes associated with cinder cones built upon a widespreas Pliocene geomorphic surface. The two necks have been dated at about 3.5 m.y. (Chapin, unpublished dates). Gravels of the same Pliocene surface cap Mesa del Oro and are, in turn, covered by 3.1 m.y. old basalt (Bachman and Mehnert, 1978). The base of the outward flaring cooling columns of La Jara Peak and the top of the gravels of Mesa del Oro are inferred to represent the position of the surface during the Pliocene. The difference between the present elevations of these points, about 700 ft (213.4 m) should, therefore, measure the amount of uplift since the development of La Jara Peak (3.6 ± 0.18 m.y. B.P.; Chapin, unpublished data).

Northeast-Trending Lineament

The effect that uplift of the Colorado Plateau may have had on pre-existing faults is not obvious. North-trending fault blocks may have undergone some rotation and differential movement parallel to their length because of uplift to the north, but this effect was not documented. A northeast-trending fault, divergent from the common trend, may represent activation of an older basement structure by uplift of the Colorado Plateau. This fault, the Negros fault (fig. 34), is a segment of the major northeast-trending Tijeras lineament that can be traced both southwest and northeast of this area (Chapin, oral communication, 1978).

The Tijeras lineament is probably a reactivated Precambrian structure and is well exposed in the Tijeras Canyon area southeast of Albuquerque. The Los Lunas volcano may be a surficial reflection of the buried lineament where it crosses the Rio Grande rift (Chapin, oral communication, 1978). The deflection of the western margin of the Albuquerque Basin to form the Monte Largo embayment may also be due to the lineament. The lineament manifests itself in the Carrizozo Spring area by a change in dip directions in the Spears and younger rocks. Southwest of the study area, near Abbe Springs, the western edge of the Mulligan Gulch graben is deflected along a northeast-trending structure which may be a continuation of the Tijeras lineament (Chapin, oral communication, 1978).

Northern Bear Mountains and Mulligan Gulch Graben

The north end of the Bear Mountains is within the Mulligan Gulch graben with the Puertecito and Hells Mesa faults bounding the west and east sides, respectively. The graben is apparently dying out within the study area against the Colorado Plateau uplift. The Hells Mesa fault has about 1700 ft (518.1 m) of throw near Hells Mesa, about 630 ft (192.0 m) of throw midway across the map, and only 60 ft (18.3 m) of throw near the upper border of map. The Puertecito fault, however, still has a minimum of 1400 ft (426.7 m) of throw in the northwest corner of the study area.

The Hells Mesa, Puertecito, Carrizozo, and other faults offset rocks as young as Popotosa and therefore continued to move well into the Miocene. These faults may have begun to form somewhat later than other faults as indicated by the absence of dikes intruded along their length.

ECONOMIC GEOLOGY

Coal

General

Coal in the Mesaverde Formation occurs in two stratigraphic intervals: 1) a basal interval containing numerous coal beds, and 2) a thick upper interval containing sparcely scattered lentils of coal. Although the upper Cretaceous nonmarine strata near Riley are formally designated the Mesaverde Formation, informally they are probably correlative to the Crevasse Canyon Formation. The lower and upper coal divisions may be equivalent to the Dilco Coal Member and Bartlett Barren Member of the Crevasse Canyon, respectively.

baloney; formally by whom, definitely KCC

Coal beds are numerous in a stratigraphic interval about 200 ft (61.0 m) thick, beginning about 60 ft (19.3 m) above the base of the Mesaverde. The thicknesses of the coal beds in the basal coal interval are generally about 14 inches (0.4 m). The thickest bed observed was 4 ft 8 inches (1.4 m). thick at an abandoned mine in the SW¼ SW¼, sec. 26, T. 2 N., R. 4 W. Near the mine, about four coal beds, although displaced by faulting, can be traced for about 2 mi (3.2 km) in secs. 26 and 27, T. 2 N., R. 4 W. (fig. 35).

EXPLANATION

Cenozoic	Mesozoic
Qal Alluvium	Kmv Mesaverde
Qpg Piedmont Gravels	Km Mancos Shale
Tv Volcanics	Kd Dakota Ss.
Ts Spears Fm.	Trc Chinle Fm.
Tb Baca Fm.	

0 1 mile

0 1 kilometer

coal outcrops

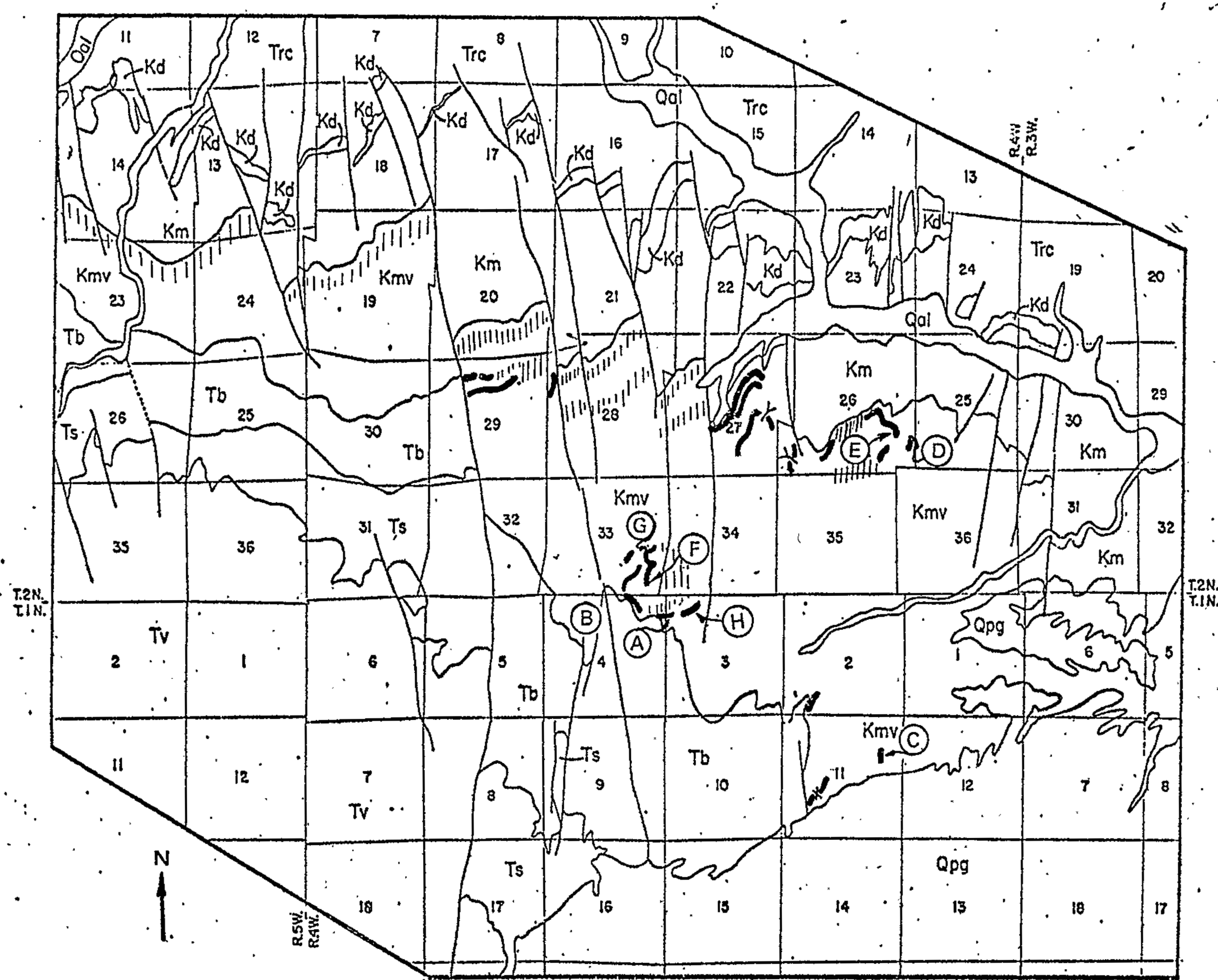
potentially coal bearing areas

coal mine

coal prospect

sample locations (Table 3)

Figure 35. Simplified geologic map of most of the area studied showing coal outcrops, coal mines, and sample locations.


Qal
Kd
Trc
Km
Kmv
Tb
Ts
Tv
Qpg
A
B
C
D
E
F
G
H
T.2N.
T.1N.
R.4W.
R.3W.
R.5W.
R.4W.
N

Coal beds higher in the Mesaverde Formation are usually separated both stratigraphically and geographically. A notable exception is in sec. 33, T. 2 N., R. 4 W. where several coal beds occur within a 60 ft (18.3 m) thick interval of the upper Mesaverde. Coal beds at this location, as well as other isolated single coal beds in the upper Mesaverde, are lenticular and change thickness radically within tens of feet.

Paleoenvironments

The coal in the Mesaverde Formation was deposited in two types of environments. The coal-bearing interval near the base of the Mesaverde Formation accumulated in coastal/delta plain swamps. Evidence in support of a coastal/delta plain origin of coals in the lower Mesaverde include: 1) stratigraphic position and proximity to marine shales of the Mancos; 2) presence of pollen of Classopollis, brackish-water mangrove-like plant, in the coals; 3) more and thicker coal beds associated with deltaic sand-bodies; 4) association of swamp-like ironstone accumulations; and 5) stratigraphic proximity, both above and below, to lagoonal sediments. Low sulfur content in the coals (table 3) suggests a greater influence of fresh versus marine water (Stach and others, 1975).

Coals at stratigraphically higher levels in the Mesaverde occur in generally isolated, lenticular beds.

They accumulated in localized marshes on the coastal plain. Evidence in support of this hypothesis includes: 1) thick stratigraphic separations of coastal sediments and the coal beds; 2) intimate association of coal beds and fluvial channels; 3) single, isolated coal beds; and 4) abundant angiosperm pollen and the lack of marine palynological indicators.

Mining

Coal was mined near Riley at two localities (fig. 35). Coal was removed from the lower Mesaverde Formation about 1 mi (1.6 km) south of Riley in sec. 26, T. 2 N., R. 4 W., about 2000 ft (609.6 m) west of Forest Road 354. The workings (fig. 36) appear to be about 20 years old; record of the operation was not found. Judging from the size of the workings, mining was sustained for at least a year, perhaps longer. There is also evidence to suggest that local inhabitants still use coal from two small stock piles at this location. Several small excavations probably yielded small amounts of coal, but most of the coal produced came from an adit driven along a bed, 4 ft 8 inches (1.4 m) thick. It is estimated that a few hundred tons were taken from the adit. The adit trends S 80° E into the hillside. Track is still in place. Timber braces and the overall condition of the adit is poor, therefore the writer only

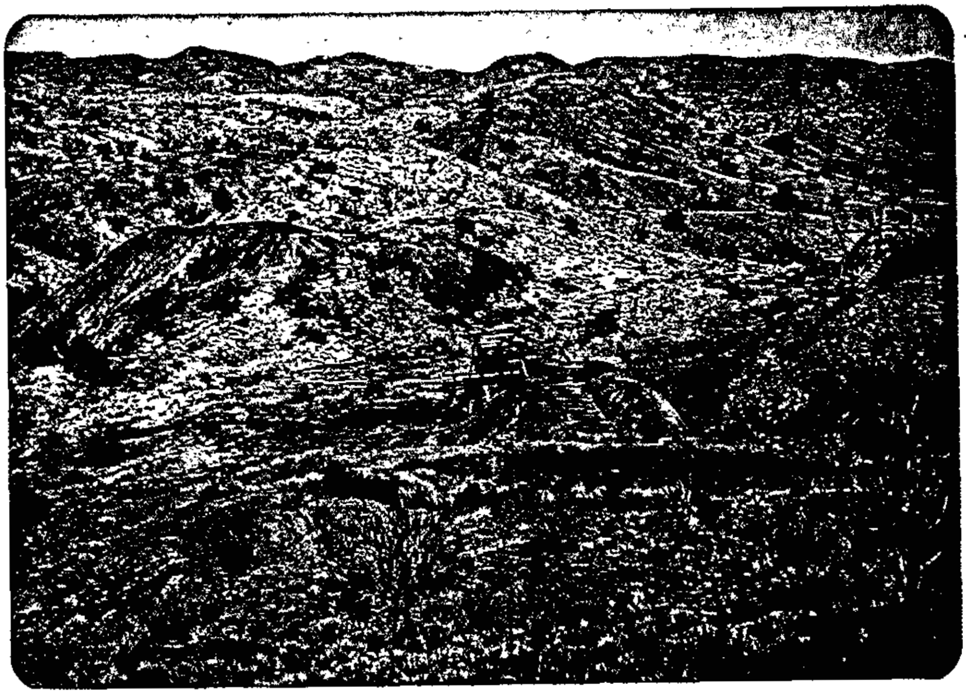


Figure 36. View of abandoned coal mine looking north-northwest in SE¼ SW¼ sec. 26, T. 2 N., R. 4 W. Coal bed is in the lower Mesaverde Formation. It is 4 ft 8 inches (1.4 m) thick and extends toward the point of origin of photo. An unknown amount of coal was produced at this location.

ventured a few feet inside the opening. The adit is estimated to be about 150 to 200 ft (45.7 to 61.0 m) long at which point the tunnel would intersect a major north-trending fault. Crosscuts are not visible from the entrance but probably exist, judging from the size of the spoil pile.

Mining was also done south of Cañon del Tanque Hondo SE¼ SW¼, sec. 33, T. 2 N., R. 4 W. There coal was removed from an isolated coal-bearing zone in the upper Mesaverde Formation by the El Cerro Coal Mining Company, managed by G. Romero and E. R. Sanchez. A 2 ft (0.6 m) coal bed was mined from a 100 ft (30.5 m) long adit and a 30 ft (9.1 m) cross cut to the right. Total production from this mine was 788 tons (715 metric tons) (Frost and Nickelson, in preparation). T. Scartaccini, worked a property in sec. 34, T. 2 N., R. 4 W., in 1945 and 1949. State records indicate that this mine was a two-man operation but the production figures are not given (New Mexico State Inspector of Mines, 1923-1965).

Analysis

Analysis of eight coal samples from the Riley area show that the coals are assignable to the high-volatile C bituminous and the sub-bituminous B classes based on standard specifications for the classification of coal established by the American Society for Testing and Materials (1967). The class separations of lower ranks of coals is based on the caloric value in BTU per pound where samples are free of moisture and mineral matter. The average dry-matter-free caloric value of the samples analysed is 11,188 BTU.

Table 3 shows proximate and ultimate analysis of the eight samples of the Mesaverde Formation as received. British Thermal Units (BTU) are shown with and without natural moisture and mineral matter. Mineral matter in the coals analyzed contains low concentrations of all the trace elements tested, except for 1000 ppm manganese in sample A and 300 ppm manganese in sample B. Sulfur content is low and ranges from 0.3 to 0.4 percent of the total sample. The agglomerating character of the coal is unknown.

Resources

Resource calculations were made using United States Geological Survey Bulletin 1450-B, "Coal Resource Classification System of the U.S. Bureau of Mines and U.S. Geological Survey," as a guide. Indicated resources were computed from data points generally less than 0.5 mi (0.8 km) apart and projected 0.25 mi (0.4 km) down dip from the outcrop. Inferred resources were computed from data points less than 2 mi (3.22 km) apart and only 0.5 mi

TABLE 3. Analyses of Eight Coal Samples, Riley Area.
(Analyses by U.S. Bureau of Mines)

	Sample	Location	Moisture	Volatile	Carbon	Ash
PROXIMATE ANALYSIS	A	NE¼ NE¼ 4 T1N, R4W	8.4	31.9	27.0	32.7
	B	NE¼ NE¼ 4 T1N, R4W	14.3	30.0	32.5	23.2
	C	SE¼ SE¼ 11 T1N, R4W	16.7	24.3	22.4	36.6
	D	NE¼ SE 26 T2N, R4W	11.9	28.4	20.7	39.0
	E	NW¼ SE¼ 26 T2N, R4W	19.0	30.9	35.9	14.2
	F	SE¼ SE¼ 33 T2N, R4W	9.1	35.3	42.7	12.9
	G	NE¼ SE¼ 33 T2N, R4W	7.6	25.9	26.2	40.3
	H	NW¼ NW¼ 3 T1N, R4W	13.6	35.1	41.5	9.8

	Sample	H	C	N	O	S	BTU
ULTIMATE ANALYSIS	A	3.8	41.7	0.8	20.6	0.4	6854 *11621
	B	4.2	44.4	0.9	26.8	0.4	7280 *11642
	C	3.5	30.5	0.8	28.2	0.3	4578 *9821
	D	3.4	32.5	0.7	23.8	0.6	5137 *10467
	E	4.7	46.1	1.0	33.6	0.5	7179 *10740
	F	4.7	56.9	1.1	24.0	0.4	9315 *11951
	G	3.7	36.9	0.8	17.9	0.4	6083 *11672
	H	4.8	54.7	1.1	29.2	0.3	8876 *11591

1. Content values in percent
2. BTU values in calories
3. Samples analyses as received; except where asterisk (*)-dry, mineral matter free
4. See Figure 35 for sample locations

(0.8 km) from the outcrop because of the average 12 degree dip of beds in the region.

The inferred coal resource of the Riley area was computed from coal outcrops in secs. 20, 26, 27, 28, 29, and 33, T. 2 N., R. 4 W., and secs. 3 and 4, T. 1 N., R. 4 W. From fifteen data points in these sections, 48,622,727 tons (44,109,796 metric tons) of coal are inferred.

Indicated resource computations were made in two locations. The first location, secs. 33 and 34, T. 2 N., R. 4 W. and secs. 3 and 4, T. 1 N., R. 4 W., is the site of the El Cerro coal mine. Indicated coal resource at that site is 428,636 tons (388,852 metric tons). The second location is spread across secs. 26 and 27, T. 2 N., R. 4 W. The indicated resource at this site is 2,759,091 tons (2,503,005 metric tons). A portion of this resource is in four beds, two of which are 3 to 4 ft (0.9 to 1.2 m) thick and crop out continuously for 4000 ft (1219.2 m) along a ridge trending N 35° E. The beds dip southeastward at about 12 degrees. From this ridge, an estimated 694,000 tons (629,586 metric tons) of coal could be extracted using a 10:1 stripping ratio.

Summary

The inferred coal resource of the Riley region is about 50 million tons (45.4 million metric tons) of low-sulfur, bituminous and sub-bituminous coal. One area has an indicated resource of about 700,000 tons (635,029 metric tons) of bituminous coal easily recoverable at a 10:1 stripping ratio. The mining problems are numerous and include: 1) thin, multiple beds; 2) discontinuous lenticular beds; 3) numerous faults that are in many places filled with dikes; 4) alternating hard and soft beds as overburden; and 5) a shallow water table.

Uranium

Several lines of evidence suggest a good potential for uranium deposits in the Riley area. First, known uranium mineralization is near. Yellow uranium minerals are present in lenticular sandstone beds of the Baca Formation west of the Bear Mountains along Jaralosa Creek, secs. 13, 18, and 24, T2N, R5W (Bachman, Baltz & Griggs, 1957). Uranium minerals also occur along the low-angle Jeter fault which separates Precambrian rocks from basin-fill fanglomerates northeast of Ladron Peak, sec. 35, T. 3 N., R. 2 W. (Collins and Smith, 1956; Black, 1964; and Condie, 1976). Pods of uranium mineralization are also localized in rocks near the contact between the Cretaceous Mesaverde Formation and the Eocene Baca Formation at the Red Basin claims north of Datil, T. 2 N., Rs. 10 and 11 W. (Griggs, 1954). Gulf Minerals Inc. has outlined several ore bodies in this area.

Second, there are several stratigraphic units that could be favorable host rocks for uranium mineralization in the Mesaverde and Baca Formations. These include sandstone channels and coal-bearing strata in the Mesaverde and coarse-grained channels and gray-bleached,organic-rich sandstones of the Baca. Organic matter, working as a reductant, could facilitate uranium deposition in these beds. Fossilized logs found in the middle gray sandstone member of the Baca invariably have a yellow-stained halo about them. Channels of the Mesaverde increase in size upward in the section and trend northeastward with moderate sinuosity.

Third, Oligocene ash-flow tuffs overlie the Eocene and Cretaceous beds and could act as source rocks. In places the tuffs are radioactive and contain traces of uranium (Griggs, 1954). North of Datil, where uranium mineralization is prevalent across a broad area, early Oligocene tuffs rest directly on the Eocene Baca Formation. At other locations, the Baca is separated from late Oligocene tuffs by a thick section of volcaniclastic rocks.

Fourth, Laramide compression produced north-trending folds that have been subsequently tilted south and broken by north-trending, normal faults. As a result, numerous conduits and barriers for uranium-bearing solutions are present. Also, favorable host rocks have been downwarped or dropped by faulting and preserved from oxidation and leaching. For example, the selenium-indicator plants *Astragalus pattersoni* and *Astragalus* sp. grow on outcrops of the gray sandstone member of the middle Baca on the downthrown side of the Hells Mesa fault. At this location, the gray sandstone member dips 6 degrees southward under the Bear Mountains.

In summary, exploration for uranium in the Riley area should be conducted with several points in mind. Channel sands, which are potential targets, trend about N 30^{o} E to S 30^{o} E in the Baca and N 10^{o} E to N 40^{o} E in the Mesaverde. The middle gray member of the Baca is a favorable sandstone unit which contains abundant carbonaceous material and is large enough to contain major deposits. North-trending folds have been tilted south and broken by north-trending normal faults. Oligocene ash-flow tuffs are probable source rocks.

Oil and Gas

The area north of the Bear Mountains has not been drilled for oil and gas. However, to the northwest, in the Acoma basin, a few dry wells have been drilled. The spacing of these wells is varied and wide, leaving the majority of the area virtually untested.

Below the surface exposures of Triassic and Cretaceous rocks are about 4500 ft (1371.6 m) of Paleozoic sedimentary section which contains both source rocks and potential reservoir rocks (Wengerd, 1959). Shows of petroleum and limited production of distillate in Socorro County have been from the Magdalena Group of Pennsylvanian age (Anonymous, 1963), probably from the Madera or Sandia Formations. Other strata regarded as promising targets are the San Andres and Yeso Formations of Permian age.

Studies of thermal maturation of palynomorphs have shown that the effect of intrusive bodies on the country rock in this area is minimal (Chaiffetz, personal communication, 1978). Within a few feet of an intrusive body the country rock is relatively unaffected (Pannel, personal communication, 1978). A relatively high heat flow, about 29° C/km is reported for the northern Bear Mountains (Shearer and Reiter, 1978). Sedimentary rocks at depths less than 12,000 ft (3657.6 m) have probably never been heated above 120° C. Oil and some gas is produced and preserved within this temperature range. Orange coloration of spores, caloric values ($\sim$ 11,000 B.T.U.) and vitrinite refectance values ($\sim$ 0.5 R_o) of Cretaceous coals suggest that these rocks are in the initial stage of organic maturity. The age and depth of the Pennsylvanian rocks should increase the maturation of hydrocarbons but not beyond the zone of oil generation. In fact, the high temperature gradient may have served to increase the hydrocarbon potential. Dark carbonaceous shales in the Sandia Formation of Pennsylvanian age are the most logical source rocks.

Laramide folds in northwest Socorro County are generally broad, gentle flexures that could provide structural traps. However, Tertiary faulting and uplift of the Colorado Plateau changed the original character and attitude of the folds. Anticlines, generally plunge south, and are commonly broken by north-trending, high-angle normal faults. Closures, if present, are now at the north end of these folds. Faults may have created traps or produced conduits that released fluids from pre-existing traps. The eastern portion of the mapped area may have been too faulted to be favorable for oil and gas. Northwestward across the area, however, the intensity of faulting and dike injection decreases. West of Puertecito, the folds are largely unfaulted and constitute potentially significant traps.

Stratigraphic traps may result from the regional westward pinch out of Pennsylvanian rocks. Also, Permian sandstones are lenticular and locally may form traps. Because the Cretaceous shoreline trended northwestward, marine bar sandstones are continuous in that direction but generally pinch out northeastward or southwestward. Shoreface sandstones of the Cretaceous, although, generally considered sheetlike, are composed of imbricated lenses. As the regional dip is southward, the nature of these sandstones is conducive for the development of stratigraphic traps.

Because of the sparcity of drill data, the petroleum potential of the Acoma basin must be based largely on surface geology. Outlining possible structural and stratigraphic traps indicates that many promising areas have not been tested. The region has good potential for commercial petroleum accumulations if one projects what is known, against the few negative tests drilled.

Other Minerals

Barite, chrysocolla, pyrolusite, psilomelane, dolomite, pyrite, celestite, gypsum, and hematite are present in varying amounts in the Riley-Puertecito area. The occurrence of gypsum in thin veins of satin spar is common in the Baca Formation but not considered commercial anywhere in the area. Also one thin vein of a very pale-blue (5 B 8/2) celestite is present in the upper Baca Formation south of the abandoned Spear's ranch, NW¼ NW¼, sec. 16, T. 1 N., R. 4 W.

Light-blue (5 B 7/6) chrysocolla mineralization occurs at two locations along the Hells Mesa fault, sec. 8, T. 1 N., R. 4 W. Small prospect pits expose several thin discontinuous veins in fractured rock of the A-L Peak Tuff. South of the mapped area, in sec. 30, T. 1 N., R. 4 W., open cuts have exposed thin veins of chrysocolla along the Hells Mesa Fault. No economic potential is foreseen for such minor copper deposits.

Barite mineralization occurs in the area of the Helen and Katherine mines SE¼ sec. 12, T. 2 N., R. 5 W.; and NE¼ sec. 8 and NW¼ sec. 9, T. 2 N., R. 4 W. Both deposits are located in fractured and sheared Paleozoic limestones. The limestone host rocks, at both locations, dip southward moderately and are broken by closely-spaced, nearly-parallel, north-trending fractures. The mineralization is sporadic along the fissures. The ore is silicic and contains about 40 percent $BaSO_4$ (Williams and others, 1964). Zones of mineralization range from 10 to 40 ft (3.1 to 12.2 m) in width and 100 to 1000 ft (30.5 to 304.8 m) in length.

Pyrolusite and psilomelane occur as intergranular fillings in the Popotosa Formation, sec. 20, T. 2 N., R. 4 W. The mineralization is concentrated in vertical zones about 40 ft (12.2 m) wide. The intergranular cement has been dissolved and partly replaced by manganese minerals. The overall effect is to leave a rather porous, conglomeratic rock containing concentrations of manganese minerals along the boundaries of the voids. The manganese minerals are generally soft and earthy but in places are extremely porous and spongy.

A small manganese mining venture was attempted in the late 1950's (Guy Spears, oral communication, 1978). A local inhabitant removed an unknown, but minor, quantity of manganiferous material. The mining was done using small tunnels that follow irregular pockets of mineralization.

Dolomite and pyrite mineralization was observed at two locations, secs. 17 and 28, T. 2 N., R. 4 W. The mineralization consists of pyritic, siliceous fault gouge with euhedral dolomite along small fissures. The north-trending fault zones in both cases are about 5 ft (1.5 m) wide and the mineralized segments of the faults are adjacent to dioritic intrusions. Two west-trending adits, now inaccessible, once intersected the fault zone, sec. 17, T. 2 N., R. 4 W. The object of the mining is unknown but may have been to recover silver or gold. The size of the dumps suggest that each of the tunnels is about 100 ft (30.5 m) long.

Iron-bearing nodules are common in parts of the Mesaverde Formation. In places the ground is strewn with flattened 6 inch (15 cm) long nodules composed primarily of hematite (identified by x-ray difraction). These nodules are exceptionally abundant at a locality sec. 3, T. 1 N., R. 4 W., however, the amount of iron recoverable from these nodules is far from commercial.

REGIONAL GEOLOGIC HISTORY

Precambrian rocks, largely argillite and quartzite, crop out in the Ladron, Lemitar and Magdalena mountains. These rocks were deposited as sediments on a broad shelf which covered most of central New Mexico during Precambrian time (Smith, 1963). Gabbroic to granitic stocks and diabase dikes intruded the sedimentary rocks during the Precambrian (Chapin and others, 1975).

Following the Precambrian the region probably was positive during much of the early Paleozoic and erosion removed substantial portions of Cambrian to Devonian rocks, if they were ever deposited. Sedimentary rocks of Mississippian age, the Caloso Formation and Kelly Limestone, were subsequently deposited on the Precambrian basement complex as a sea transgressed from the south across the area. The Caloso Formation of Kinderhookian or lower Osagian age is composed of a basal conglomerate and a sandy limestone (Armstrong, 1958). The Kelly Limestone is a crinoidal biosparite of upper Osagian age. These two units, the Kelly Limestone and the Caloso Formation, have a combined thickness of 125 ft (38.1 m) in the Magdalena Mountains (Gordon, 1907 a), and extend at least as far north as the southern end of the Ladron Mountains (Kelley and Wood, 1946).

About 600 ft (182.8 meters) of dark carbonaceous shales and siltstones of the Sandia Formation, and about 1800 ft (548.6 m) of micritic limestones of the Madera Limestone, lie unconformably on either Precambrian or Mississippian rocks (Gordon, 1907 b). These early Pennsylvanian rocks comprise the Magdalena Group; they are composed of marine sediments deposited in a sea that covered most of central New Mexico. The deepest part of the basin lay to the north in the southern part of the Lucero region, as indicated by a thickness of more than 2400 ft (731.5 m) of Pennsylvanian rocks in that region (Kelley and Wood, 1946). The Lucero and San Mateo basins were a continuous basin that shoaled abruptly to the southeast and shoaled gradually to the south, southwest, and west, and shallowed only slightly to the north and northeast (Kelley and Wood, 1946).

The overlying paralic and continental shales, limestones and sandstones of the Abo Formation are Permian in age. As the previous basin became shallower continental conditions succeeded the marine environment, giving rise to transitional interbedding of arkosic terrigenous material with red, gray, and green shales and gray nodular micritic limestones (Kelley and Wood, 1946; Kottlowski and others, 1956). Marine conditions again prevailed in Yeso and San Andres time. About 1700 ft (518.2 m) of clastic sediments, gypsum and marine limestone of the Yeso and San

Andres Formation were deposited in the basin under restricted marine conditions (Kelley and Wood, 1946). By the close of the Paleozoic Era as much as 5000 ft (1524.0 m) of accumulated sediments were broadly uplifted with only slight deformation (Kelley and Wood, 1946).

Throughout lower Triassic time central New Mexico was a positive area with no known deposition and probably only minor erosion (O'Sullivan, 1977). The region was relatively stable during the early Triassic and consequently the upper Triassic Chinle Formation rests nearly concordantly on the underlying Paleozoic strata (Kelley and Wood, 1946). The Chinle rocks are 1500 ft (457.2 m) thick in the Lucero area and consist of shales, siltstones, and sandstones, deposited on a floodplain crossed by channels carrying coarse sand and gravel (Kelley and Wood, 1946). The Chinle crops out north of the Bear Mountains along the Rio Salado and in the Ladron Mountains.

Rocks of Jurassic age, the Entrada Sandstone and Morrison Formation, are present to the north in the Lucero and Mesa del Oro areas (Kelley and Wood, 1946, Jicha, 1958). They are thought to have been deposited in an arid environment as fluvial, deltaic, floodplain and lacustrine sediments (Kelley and Wood, 1946). Jurassic sediments in most of central New Mexico either were never deposited (Silver, 1948) or were removed by erosion.

In Early Cretaceous time, the area was relatively stable and probably only minor deposition or erosion occurred (Kelley and Wood, 1946). In Late Cretaceous time, a shallow, broad epicontinental sea encroached Socorro County from the northeast. The rocks deposited are medium-grained, yellowish sandstone and dark-gray and yellowish-gray shales. Oscillations of the shore line resulted from variations in the rate of subsidence of the continually sinking basin and in the rate of supply of detritus (Pike, 1947). Many workers recognized the intertonguing of marine and nonmarine rocks of Upper Cretaceous time in the Western Interior of the United States (Sears and others, 1941; Pike, 1947; Beaumont, 1968; Young, 1973; and Molenaar, 1974). Lithostratigraphic units of the Dakota, Mancos or Mesaverde formations, therefore, are based on facies rather than time relationships.

Rocks of Cretaceous age crop out north of the Bear Mountains along the drainage of the Rio Salado and form a continuous outcrop belt northward and westward into the main portion of the San Juan Basin. South and east of Riley only isolated outcrops of Upper Cretaceous strata are present. These exposures are in the Joyita Hills, Carthage area, Carrizozo area, Fra Cristobal Mountains, Cutter sag, Jornado del Muerto, Caballo Mountains, and the Cooke's Range. The Deming axis apparently represented some type of barrier, south of which the rocks of Cretaceous age are older and of a different character.

The Laramide orogeny is minifested in the region by low, broad folds with a dominant, north-trending orientation. Upwarps and downwarps were formed; erosion stripped highlands and simultaneously filled the basins. In central New Mexico, the basin in which the Baca Formation was deposited was 50 to 100 mi (80.5 to 160.9 km) wide and extended westward past the Arizona border (Snyder, 1971). Arkosic red shales, sandstones and conglomerates accumulated in that basin by an aggrading fluvial-floodplain system. The Baca varies from 0 to 1000 ft (304.8 m) in thickness throughout its outcrop belt (Snyder, 1971).

Beginning about 37 m.y. B.P., widespread volcanism blanketed southwestern New Mexico (Chapin and Seager, 1975). In the studied area, this volcanic activity is represented by the Spears Formation, a volcaniclastic apron of sandstones, conglomerates, laharic breccias and basaltic andesite lavas. The lower part of the Spears Formation is interbedded with the upper Baca Formation near the center of the basin of accumulation, but near the margins of the basin, the Spears rests unconformably on older rocks (Chapin, oral communication, 1977). The Spears varies from 0 to 2000 ft (609.6 m) in thickness.

Between about 32 m.y. and 26 m.y. B.P., eruptive centers in the San Mateo and Magdalena ranges expelled tremendous volumes of rhyolitic ash-flow tuffs (Chapin and others, 1978). Ash-flow tuffs represented in the area studied are, in ascending order, the Hells Mesa Tuff and A-L Peak Tuff. The area studied is distal to the centers of eruptive activity, as indicated by only 490 ft (149.4 m) of ash-flow accumulation, compared to more than 5000 ft (1524.0 m) near Magdalena. The flow units moved down an inferred north-sloping drainage and were deposited across the southern edge of the Colorado Plateau (Chapin and Seager, 1975). During the Oligocene the flow units may have extended 10 to 20 mi (16.1 to 32.2 km) further north than the northern margins of present outcrops.

About 29 m.y. B.P., regional extension produced numerous north-trending normal faults. Apparently these faults tapped a magma source and allowed the emplacement of numerous mafic stocks and dikes (Chapin and Seager, 1975). After the beginning of block faulting, more than 1000 ft (304.8 m) of basaltic andesite lavas of the La Jara Peak Formation issued from fractures. The La Jara Peak Basaltic Andesite built a major shield area against which younger ash flows pinched out (Chapin, oral communication, 1978).

The upper La Jara Peak Formation is interbedded with the overlying Popotosa Formation. The Popotosa Formation of the Santa Fe Group is composed in the Bear Mountain area of fanglomerates built by materials shed off the rising Colorado Plateau into the subsiding Popotosa Basin beginning about 24 m.y. B.P. (Chapin and Seager, 1975). The original Popotosa basin was greatly modified by late Tertiary tectonic adjustments which created several intra-basin horsts. Uplifts, such as the Socorro-Lemitar and Bear Mountains disrupted and tilted the Popotosa beds (Bruning, 1973). Fanglomerates from the Ladron and Magdalena Mountains contributed to the Popotosa Formation. The broad Popotosa basin was disrupted by north-trending intrabasin horsts during the interval 7-4 m.y. ago (Chapin and Seager, 1975). During late Pliocene time basaltic lavas covered parts of a widespread geomorphic surface. These lavas presently cap mesas west of Puertecito where they are at elevations about 700 ft (213.4 m) above the La Jara Peak and La Cruz Peak necks that are also believed to have developed on this surface. Thus the Colorado Plateau appears to have risen about 700 ft (213.4 m) relative to the Riley area since about 3.5 m.y. ago. High seismicity and Pleistocene and recent fault scarps indicate that deformation is still active in this region (Bruning, 1973).

SUMMARY

Significant aspects of this investigation of the Riley area are outlined as follows:

(A) Stratigraphic

1) A more finely divided set of stratigraphic names for the Cretaceous rocks was applied to the area. The new names are reserved by the United States Geological Survey Stratigraphic Names Committee. At Riley and vicinity these units are, from oldest to youngest, the Dakota Sandstone, Alamito Well Tongue of the Mancos Shale, (new name, see next paragraph). Tres Hermanos Sandstone Member of the Mancos Shale, D-Cross Tongue of the Mancos Shale, and Mesaverde Formation. At Puertecito, west of Riley, the Twowell Tongue of the Dakota Sandstone separates the Alamito Well Tongue of the Mancos Shale into the Whitewater Arroyo and Rio Salado (new name, see next paragraph) Tongues of the Mancos Shale.

2) Two new stratigraphic names are used in this report. The Alamito Well Tongue of the Mancos Shale is named herein from exposures near Alamito Well on Cañon del Alamito, sec. 20, T. 2 N., R. 4 W. The

name, Rio Salado Tongue of the Mancos Shale, is adopted from Hook and Cobban (in preparation). This tongue was named for exposure along the Rio Salado near Puertecito.

3) The environments of deposition of the Cretaceous units are as follows: Dakota Sandstone-paralic; Alamito Well Tongue of the Mancos Shale-marine; Tres Hermanos Member of the Mancos Shale-marine, paralic and nonmarine; D-Cross Tongue of the Mancos Shale-marine; and Mesaverde-paralic and fluvial-floodplain. The Twowells Tongue of the Dakota Sandstone is an offshore marine bar and the Gallego Sandstone is a nearshore marine bar. The Whitewater Arroyo and Rio Salado Tongues of the Mancos Shale are both marine.

4) A complete section of the Baca was measured near the type location. Heretofore, measured sections of the Baca at the type location were largely covered or compiled from several partial sections, e.g. those of Winchester (1920) and Potter (1970). Note that Wilpolt and others (1946) named the Baca and designated

Winchester's (1920) measured section as the type locality, but did not measure a section.

5) Three members of the Baca, first differentiated by Potter (1970), were recognized. These were informally designated, from oldest to youngest, the conglomeratic, gray sandstone, and red mudstone members.

(B) Structural

1) Two broad, low folds in the area studied are attributed to the Laramide compressional event. These folds, the Baca Canyon syncline and Monument anticline, have north-trending axes and originally dipped only about 12 degrees on the flanks.

2) In the Oligocene and early Miocene, 29 to 20 m.y. ago, the eastern half of the studied area was broken by numerous high-angle normal faults. The majority of the faults dip west with down-to-the-west displacement. Blocks between faults have been rotated eastward close to the complement of the dip of the faults.

3) Many of the faults were intruded by basaltic-andesite magmas which emplaced dikes and sills. Samples from two of the

dikes yielded potassium-argon dates of 23.6 and 25.0 m.y. B.P.

4) Uplift of the Colorado Plateau tilted the rocks south-southwestward. Rocks not involved in Laramide folding, e.g. Baca and younger, dip generally in a south-southwestward direction. Rocks involved in Laramide folding dip southeast to southwest around the flanks of south-plunging folds.

5) Several younger faults have affected rocks as young as the Popotosa Formation. Drag is obvious along the Puertecito fault, e.g. the La Jara Spring fold. Small, tight folds throughout the area are largely attributed to drag along faults.

(c) Relationships of Formational Contacts

1) The Cretaceous Dakota Sandstone rests peneconcordantly on the Triassic Chinle Formation.

2) The Mesaverde Formation is overlain unconformably by the Eocene Baca Formation.

3) The upper Baca Formation is interbedded with the lower Spears Formation.

4) The upper La Jara Peak Basaltic Andesite is interbedded with the lower Popotosa Formation.

(D) Economic

1) Coal beds as much as 4 ft 8 inches (1.4 m) thick occur in the Cretaceous Mesaverde Formation. The beds are discontinuous and lenticular. The coal is assignable to the high volatile C bituminous and sub-bituminous B classes. The inferred coal resource of the Riley region is about 50 million tons (45.4 million metric tons).

2) Large channels in the Mesaverde and Baca Formations are potential hosts for uranium deposits. The middle sandstone segment of the Baca is especially favorable. This unit is bleached and contains abundant organic trash; selenium indicator plants of the genus <u>Astragalus</u> grow on outcrops.

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APPENDIX

CONTENTS OF APPENDIX

METHODS OF MEASURED SECTIONS

Many locations were visited while compiling partial sections of the stratigraphic sequence in the studied area. The exact locations of these partial sections are given in prefix to the individual sections. In general, however, the locations of the sections were near either Riley or Puertecito, New Mexico. Near Riley nine separate lines across segments of the stratigraphic sequence were measured and used to compile a complete stratigraphic section from the base of the Dakota Sandstone to the top of the Spears Formation (fig. 28). The accuracy of the correlations from one line to another is considered to be good. Near Puertecito a single line of section was measured from the base of the Dakota Sandstone to the base of the Mesaverde Formation. This line of section is being prepared by Hook and Cobban as a reference section for the marine interval of the Upper Cretaceous for the region.

The unit numbers of the rock descriptions correlate with those used on the columnar sections in the stratigraphic portion of this report. Some numbers of the columnar sections were deleted due to space limitations. Rock units which were thin sectioned are indicated by an asterisk (*) under the unit number.

The format of the rock descriptions is modified from Kottlowski and others (1956, p. 89). Nine characteristics

EXPLANATION

Cenozoic	Mesozoic
Qal — Alluvium	Kmv — Mesaverde
Qpg — Piedmont Gravels	Km — Mancos Shale
Tv — Volcanics	Kd — Dakota Ss.
Ts — Spears Fm.	Trc — Chinle Fm.
Tb — Baca Fm.	

0 1 mile

0 1 kilometer

Measured sections:

1 Dakota & Alamito Well

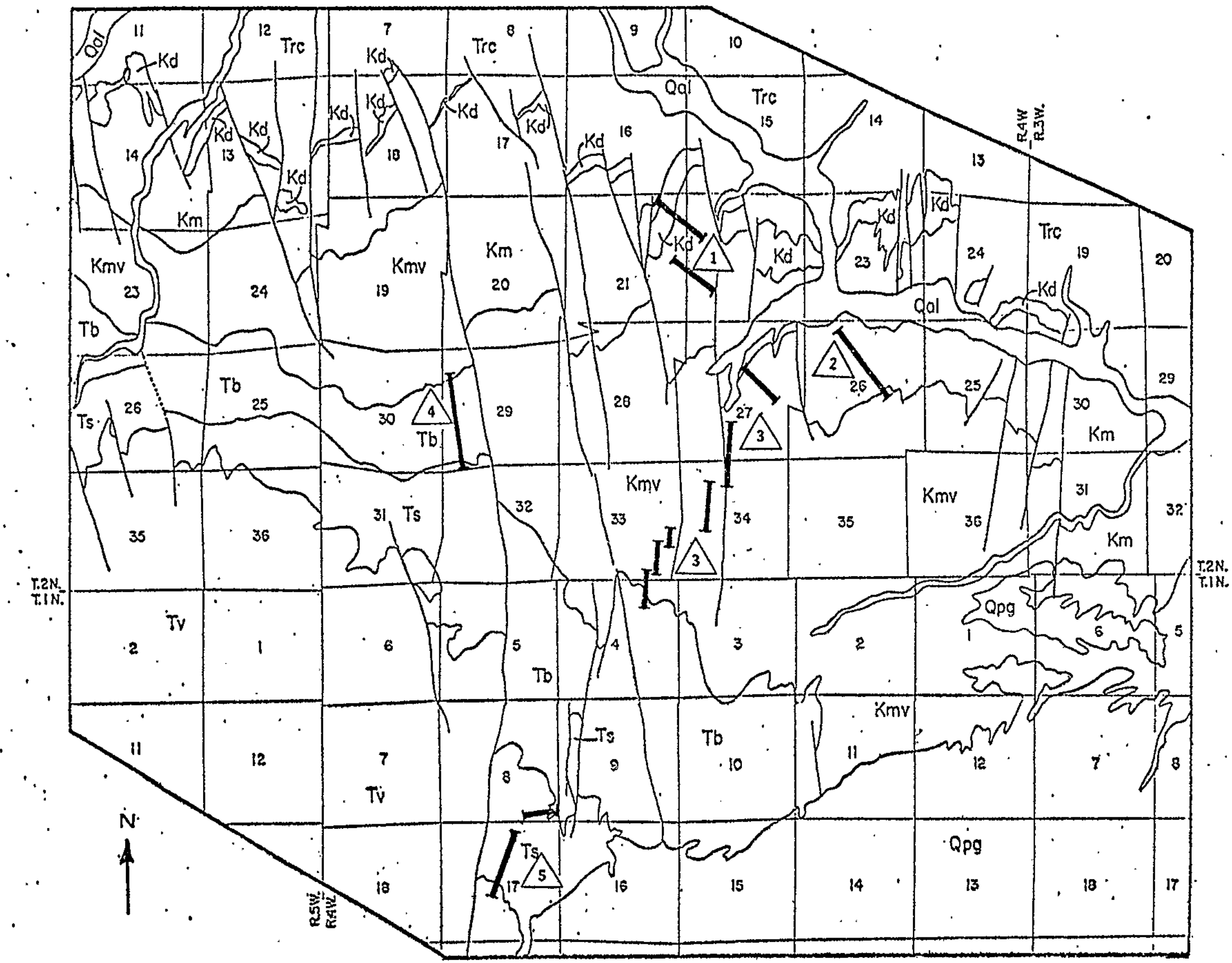
2 Tres Hermanos & D-Cross

3 Mesaverde

4 Baca

5 Spears

Figure 37. Simplified geologic map of most of the area studied showing locations of lines of sections that were measured.


Qal
Kd
Trc
Km
Kmv
Tb
Ts
Tv
Qpg
R.4W.
R.3W.
R.5W.
R.4W.
T.2N.
T.1N.
N
1
2
3
4
5

of the rocks are listed, if pertinent. These are: (1) rock name; (2) compositional adjective, mineral composition, and cements; (3) dry color on fresh fracture, as well as banding and mottling; (4) grain size, shape, and roundness (or crystallinity); (5) bedding, as to thickness and mode; (6) weathering color, not listed if same as color on fresh fracture; (7) topographic expression, hardness, and degree of consolidation; (8) special characteristics, such as concretions, burrows, and cross-laminations; (9) fossils (with United States Geological Survey Mesozoic Fossil Locality Numbers, if applicable).

All samples were tested for $CaCO_3$ and when present the term calcareous was applied. If the term "calcareous" was not included in the description, a lack of effervescence was noted. Cross-stratification was labeled as low or high angle; low angle cross-stratification, as used in this report is less than 20 degrees from horizontal.

MEASURED SECTIONS NEAR RILEY

Spears Formation

The Spears Formation was measured along a line striking N 40° E in the northeast corner of sec. 17, T. 1 N., R. 4 W., Mesa Cencerro 7.5' quadrangle, Socorro County, New Mexico. The section was measured using a Jacob Staff, Brunton compass and tape by Gary Massingill on 24 September 1977.

UNIT	DESCRIPTION	FT	IN	METERS
54	Sandstone and Conglomerate; lithic feldspar, slightly calcareous; pale-red (10 R 6/2); very coarse grained sand to cobble - mostly pebble, rounded to subangular; thin-to thick-bedded; well-consolidated, ledge; andesite clasts well-rounded, other clasts including vesicular basalt mostly well-rounded.	37		11.28
53	Sandstone and Conglomerate; feld-spar; green-pyroxene (10 GY 414), black (N 1) biotite, grayish-yellow-green (5 GY 7/2), black (N 1) and grayish-green (5 G 5/2)	197		60.05

UNIT		FT	IN	METERS
	porphyritic andesite; coarse-grained sand to cobbles, rounded to angular, poorly sorted; thin-to thick-bedded; moderate-consolidation, smooth uncovered to covered steep slope.			
52 *	Sandstone and conglomerate; lithic, feldspar; dark-yellowish-green (10 GY 4/4) shiny pyroxene, grayish-green (10 GY 5/2) dull chlorite, black (N 1) hornblende; coarse-grained sand to cobble, becoming coarser upward; grayish-yellow-green (5 YR 6/1); thin-to thick-bedded; well-indurated, steep slope and ledges.	75		22.86
51 *	Conglomerate; quartz, lithic, feldspar; very-pale-orange (10 YR 8/2); fine-grained sand to pebble, poorly sorted, subangular; well-consolidated, slight break in slope.	12		3.66
50	Conglomerate; lithic, slightly calcareous; light-gray (N 7) matrix, various colors of crystal rich andesites; coarse-grained sand to cobbles, poorly sorted,	5	-	1.52

UNIT		FT	IN	METERS
	rounded; very thick bedded; well-indurated, base of ledge.			
47	Sandstone with conglomeritic lenses; feldspar, very clayey, calcareous; brownish-gray (5 YR 4/1) white speckled appearance due to feldspar grains in clay matrix; medium to coarse-grained sand, angular, very poorly sorted; thin to thick bedded; moderate-to loose-consolidation, slope.	194	-	59.13
46	Sandstone; biotite, hornblende, calcareous; light-brownish-gray (5 YR 6/1); medium-to rounded, moderate-sorting; thick-bedded; well-consolidated, slope.	7	-	2.13
45	Sandstone, feldspar, biotite, moderate-red (5 R 5/4) to pale-red (10 R 6/2); medium-grained, subangular, moderately sorted; thin-bedded; friable, slope.	1	-	0.61

UNIT		FT	IN	METERS
44	Sandstone; refer to 46.	2	-	0.61
43	Sandstone; refer to 45.	5	-	1.52
42	Sandstone; refer to 46.	7	-	2.13
41	Sandstone; zone of beds about 1 ft (.3 m) thick, compositions like units 46 and 45.	13	-	3.96
40	Sandstone; refer to 46.	3	-	0.92
39	Sandstone; refer to 45.	5	-	1.52
38a	Sandstone; feldspar, biotite, slightly clayey, calcareous; light-brownish-gray (5 YR 6/1) matrix, white (N 9) feldspar; mostly coarse-grained sand with larger lithic clasts, as large as pebble size, moderate to very poorly sorted, some euhedral feldspar grains; thin- to thick-bedded; moderate-consolidation, talus covered and uncovered rounded slopes and ledges; low-angle cross-stratification.	198	-	60.35
38b	Sandstone; feldspar, very clayey, calcareous; brownish-gray (5 YR 4/1); white speckled appearance due to feldspar grain	206	6	62.94

UNIT		FT IN	METERS
	in clay matrix; medium-to coarse-grained, angular, very poorly sorted; thin-to thick-bedded; moderate-to poor-consolidation, slope.		
37	Sandstone; feldspar, very clayey calcareous; grayish-red-purple (5 RP 6/2); very fine grained sand and silt, angular, poorly sorted; thin-bedded; loosely consolidated, slope.	3 -	0.92
36	Siltstone; feldspar, clayey; pale-red (5 R 6/2); silt, some coarse-grained sand, subangular to angular, poorly sorted; thin-bedded; well-to moderate-consolidation, slope; breaks chunky.	6 -	0.15
35	Sandstone; refer to 37.	2 -	0.61
34	Sandstone; feldspar, clayey, brownish-gray (5 YR 4/1) white speckled appearance due to feldspar grains in clay matrix; medium-to coarse-grained, angular, very poorly sorted; thin-to thick-bedded; moderate to loose	4 -	1.22

UNIT		FT	IN	METERS
	consolidation, slope.			
33	Sandstone; refer to 37.	2	-	0.61
32	Sandstone; refer to 34.	1	-	0.30
31	Sandstone; refer to 37.	3	-	0.92
30	Sandstone; refer to 34.	9	-	2.74
29	Sandstone; refer to 37.	2	-	0.61
28 *	Siltstone; refer to 36.	3	-	0.92
27	Sandstone; refer to 34.	5	-	1.52
26	Sandstone; refer to 36.	30	-	9.15
25 *	Sandstone; refer to 34.	1	-	0.30
24	Sandstone; refer to 36.	1	6	0.46
23	Sandstone; refer to 34.	5	-	1.52
22	Sandstone; refer to 36.	7	-	2.13
21	Sandstone; refer to 34.	5	-	1.52
20	Sandstone; refer to 36.	3	-	0.92
19	Sandstone; refer to 34.	2	-	0.61
18	Sandstone; refer to 36.	2	-	0.61
17	Sandstone; refer to 34.	8	-	2.44
16	Sandstone; refer to 36.	20	-	6.10
15	Sandstone; refer to 34.	4	6	1.37
14	Sandstone; refer to 36.	5	-	1.52
13	Sandstone; refer to 34.	18	6	5.64
12	Sandstone; refer to 36.	6	-	1.83
11	Sandstone and conglomerate;	5	-	1.52

UNIT		FT	IN	METERS
	lithic, volcanic and clay clasts, calcareous, clayey; brownish-gray (5 YR 4/1); coarse-grained sand to cobbles, angular to rounded, very poorly sorted; medium-bedded; moderate-consolidation, resistant ridge capping slope; low-angle cross-stratification.			
10	Sandstone; refer to 34.	4	-	1.22
9	Sandstone; refer to 36.	3	6	1.07
8	Sandstone; refer to 34.	2	-	0.61
7	Sandstone; refer to 36.	2	-	0.61
6	Sandstone and conglomerate; refer to 11	19	-	5.79
5	Sandstone; refer to 36.	8	6	2.59
4	Sandstone; refer to 34.	1	6	0.46
3	Sandstone; refer to 36.	17	-	5.18
2	Sandstone; refer to 34.	3	6	1.07
1	Sandstone; refer to 36.	24	-	7.32

Measured thickness of Spears Formation = 1,259 ft 6 inches (383.90 m).

Baca Formation

The Baca section was measured along a line striking N 10^{O} W across the west side of sec. 29, T. 2 N., R. 4 W., Mesa Cencerro 7.5' quadrangle. Section was measured using a Jacob Staff, Brunton compass, and tape by Gary and Linda Massingill on 25-26 May 1977.

UNIT		FT	IN	METERS
51	Sandstone; lithic, ferrigunous, quartz; pale-reddish-brown (10 R 5/4); very coarse grained, good-to moderate-sorting, sub-rounded; thick-bedded; blocky ridge, well-consolidated.	4	-	1.22
50 *	Sandstone; ferruginuous, quartz; pale-red (10 R 6/2); very coarse grained sand to silt, poorly sorted, subangular; thick-bedded; bluff, well-consolidated spheroidal weathering to large boulders.	25	-	7.62
49	Shale; ferruginuous, silty; grayish-red (10 R 4/2); thin-to medium-bedded; weathers moderate-reddish-brown (10 R 4/6); loosely consolidated, slope to level plain; contains thin	25	-	7.62

UNIT		FT	IN	METERS
	sandy beds.			
48	Arkose; quartz, feldspar; yellowish-white (5 Y 9/1); coarse-grained sand, moderate-sorting, subangular; thick-bedded, loosely consolidated, slope.	-	2	0.05
47	Shale; ferruginous, silty; grayish-red (10 R 4/2); thin-to medium-bedded; weathers moderate-reddish-brown (10 R 4/6); loosely consolidated, slope to level plain; contains thin sandy beds.	27	-	8.23
46	Arkose; quartz, feldspar; yellowish-white (5 Y 9/1); coarse-grained sand, moderate-sorting; loosely consolidated, slope.	3	6	1.07
45	Shale; ferruginous, silty; grayish-red (10 R 4/2); weathers moderate-reddish-brown (10 R 4/6); thin-to medium-bedded; loosely consolidated, slope to level plain; contains thin sandy beds.	45	-	13.71
44	Arkose; quartz, feldspar; yellowish-white (5 Y 9/10); coarse-grained sand, moderate-sorting, subangular; thick-bedded; slope, loosely	15	-	4.57

UNIT		FT	IN	METERS
	consolidated.			
43	Shale; ferruginous; silty; grayish-red (10 R 4/2); weathers moderate-reddish-brown (10 R 4/6); thin-to medium-bedded; loosely consolidated, slope to level plain; contains thin sandy beds.	45	-	13.71
42	Sandstone; quartz, very light gray (N 8); very fine grained sand to silt, well-sorted, rounded; very thin bedded; rise, loosely consolidated.	-	4	0.10
41	Shale; ferruginous, silty; grayish-red (10 R 4/2); weathers moderate-reddish-brown (10 R 4/6); thin-to medium-bedded; loosely consolidated, slope to level plain, contains thin sandy beds.	1	-	0.30
40	Sandstone; quartz; very light gray (N 8); very fine grained sand to silt, well-sorted, rounded; very thin bedded; rise, loosely consolidated.	-	3	0.08
39	Shale; ferruginous, silty; grayish-red (10 R 4/2); weathers moderate-reddish-brown (10 R 4/6), thin-to	5	-	1.62

UNIT		FT	IN	METERS
	medium-bedded; loosely consolidated, slope to level plain; sandy beds.			
38	Sandstone, quartz; very light gray (N 8); very fine grained sand to silt, well-sorted, rounded; very thin bedded; rise, loosely consolidated	-	3	0.08
37	Shale; arkosic, ferruginous; reddish-brown (10 R 4/4); weathers pale-reddish-brown (10 R 5/4); thick-bedded; loosely consolidated, slope.	4	-	1.22
36	Sandstone; quartz; very light gray (N 8); very fine grained sand to silt; well-sorted, rounded; very thin bedded; rise, loosely consolidated.	-	2	0.05
35	Shale, arkosic, ferruginous; reddish-brown (10 R 4/4); weathers pale-reddish-brown (10 R 5/4); thick-bedded; loosely consolidated, slope.	5	-	1.52
34	Sandstone; quartz; very light gray (N 8); very fine grained sand to silt, well-sorted, rounded, very thin bedded, rise, loosely consolidated.	1	6	0.46

UNIT		FT	IN	METERS
33	Shale; arkosic, ferruginous; reddish-brown (10 R 4/4); weathers pale-reddish-brown (10 R 5/4); thick-bedded; loosely consolidated, slope.	37	6	11.43
32	Sandstone; micaceous; quartz, yellowish-gray (5 Y 8/1); coarse-grained, moderate-to well-sorted; subrounded; weathers yellowish-gray (5 Y 8/1); very loosely consolidated, slope; wood fragments.	52	-	15.85
31	Shale; silty; grayish-yellowish-green (5 GY 6.2); thick-bedded; very pale green (10 G 8/2); loosely consolidated, slight slope.	2	-	0.61
30 & 29	Interbedded sandstone and siltstone. Siltstone; shaley, chloritic, quartz, light-greenish-gray (5 GY 8/1); silt and clay, well-sorted, rounded; slope, loosely consolidated; wood. Sandstone; micaceous, quartz; yellowish-gray (5 Y 8/1); coarse-grained, moderate-to well-sorted,	122	-	37.19

UNIT		FT	IN	METERS
	subrounded; slope, very loosely consolidated; wood fragments.			
28	Shale; arkosic, ferruginous, reddish-brown (10 R 4/4); thick-bedded; weathers pale-reddish-brown (10 R 5/4); loosely consolidated, slope.	40	-	12.19
27 *	Arkose; quartz, feldspar, lithic; grayish-orange-pink (5 YR 7/2); coarse-grained sand to cobbles, very poorly sorted; subangular to rounded; thin-bedded; weathers grayish-orange-pink (10 R 8/2); moderate-consolidation, ledge; cross-stratified.	35	-	10.67
23	Shale, ferruginous; reddish-brown (10 R 4/4); thin-bedded; weathers pale-reddish-brown (10 R 5/4); poorly consolidated, slope.	8	-	2.44
22 *	Sandstone; lithic, quartz, light-brownish-gray (5 YR 6/1); very coarse grained, poorly sorted, subangular; thin-bedded; weathers pale-yellowish-brown (10 YR 6/2); moderate-consolidation, slight terrace.	10	-	3.05

UNIT		FT	IN	METERS
21	Shale; ferruginous, reddish-brown (10 R 4/4); thin-bedded; weathers pale-reddish-brown (10 R 5/4); poorly consolidated, slope.	8	-	2.44
20	Sandstone; ferruginous, quartz feldspar; light-brownish-gray (5 YR 6/1); medium-to coarse-grained, moderately sorted; sub-angular to rounded; medium-bedded; weathers pale-red (10 R 6/2); moderate to well consolidated, ledge and slope; conglomeratic in parts, low-angle cross-stratification.	16	-	4.88
19	Shale; ferruginous; reddish-brown (10 R 4/4); thin-bedded; weathers pale-reddish-brown (10 R 5/4); poorly consolidated, slope.	7	-	1.83
18	Sandstone; ferruginous, quartz feldspar; light-brownish-gray (5 YR 6/1); medium-to coarse-grained, moderately sorted, sub-angular to rounded, medium-bedded; weathers pale-red (10 R 6/2); moderate-to well-	24	-	7.31

UNIT		FT	IN	METERS
	consolidated, ledge and slope; conglomeratic in parts, low-angle cross-stratification.			
17	Shale; ferruginous; dark-reddish-brown (10 R 3/4); medium-bedded; weathers pale-reddish-brown (10 R 5/4); poorly consolidated, slope; breaks into chunks.	21	-	6.40
16 *	Sandstone; quartz; pinkish-white (5 YR 9/1); medium-to coarse-grained, moderate-sorting, subangular to subrounded; thick-bedded; weathers pale-red (10 R 4/2); well-consolidated, ledge; conglomeratic in parts.	9	-	2.74
15	Shale; ferruginous; reddish-brown (10 R 4/4); thin-bedded; pale-reddish-brown (10 R 5/4); poorly consolidated, slope.	17	-	5.18
14	Sandstone; ferruginous, quartz; light-brownish-gray (5 YR 6/1); coarse grained, moderate-sorting, subangular; thin-bedded; weathers pale-red (10 R 6/2); well-consolidated, ledge; conglomeratic in parts.	7	6	2.29

UNIT		FT	IN	METERS
13	Sandstone; ferruginous, quartz; light-brownish-gray (5 YR 6/1); medium-to fine-grained, well-sorted, subrounded; very thin bedded; weathers pale-red (5 R 6/2); moderately consolidated, slight terrace; low-angle cross-stratification.	4	6	1.37
11	Shale; silty, ferruginous; reddish brown (10 R 4/4); massive; weathers pale-reddish-brown (10 R 5/4); loosely consolidated, slope.	22	-	6.71
10 *	Sandstone; quartz, ferruginous; light-brownish-gray (5 YR 6/1); coarse-grained, moderately sorted, subangular; very thin bedded; weathers pale-reddish-brown (10 R 5/4); moderately consolidated, terrace; conglomeratic lenses, horizontal and vertical burrows, low-angle cross-stratification.	8	-	2.44
9	Shale; lithic, ferruginous; reddish-brown (10 R 4/4); massive; weathers pale-reddish-brown (10 R 5/4); poorly consolidated,	12	-	3.66

UNIT		FT	IN	METERS
	slope; breaks into chunks.			
8	Conglomerate; arkosic, lithic; pinkish-white (5 YR 9/1); very poorly sorted, subangular; thin to very thick bedded, weathers grayish-orange-pink (5 YR 7/2); moderate-to well-consolidated, terrace; low-angle cross-stratification.	12	-	3.66
7	Shale; arkosic, feldspar, quartzite sandy; grayish-red (10 R 4/2); thin to very thin bedding; weathers pale-red (5 R 6/2); loosely consolidated; slope; fissile.	5	6	1.68
6	Sandstone; conglomeratic, quartz some pink feldspar; pinkish-white (5 YR 9/1); very coarse grained, poorly sorted, subangular; well-consolidated, ridge.	4	6	1.37
5 & 4	Interbedded conglomerate and shale Conglomerate; quartz, feldspathic; very-light-gray (N 8); large cobble to fine-grained sand, poorly sorted, pebbles rounded, smaller fragments rounded to angular; thick-bedded	29	-	8.84

with vague bedding planes; weathers light-brownish-gray (5 YR 6/1); moderate-consolidation; slope.

Shale; arkosic, quartzitic, sandy; grayish-red (10 R 4/2); thin to very thin bedding; weathers pale-red (5 R 6/2); loosely consolidated, slope; fissile.

UNIT		FT	IN	METERS
3 *	Sandstone; quartzite, shaley, feld-spathic; light-bluish-gray (5 B 9/1); medium-grained, moderate to very poorly sorted, rounded to very angular; thick-bedded; weathers light-brownish-gray (5 YR 6/1); variable hardness; bank; more purplish upward, burrowed.	25	-	7.62

Measured thickness of Baca Formation = 753 ft 8 inches (229.72 m).

Locations of Cretaceous Units

The Cretaceous formations described are a composite of several locations south of Rio Salado near Riley, New Mexico. The Dakota Sandstone and the lower part of the Alamito Well of the Mancos Shale were measured on a line striking N 40^{O} W across the extreme northeast corner of sec. 21 and the northwest corner of sec. 22; T. 2 N., R. 4 W., La Jara Peak 7.5' quadrangle and Riley 15' quadrangle, respectively. The remaining portion of the Alamito Well Shale Tongue of the Mancos Shale was measured on a line striking N 40^{O} W across the east-central portion of sec. 21 and the west central portion of sec. 22; T. 2 N., R. 4 W., La Jara Peak 7.5' quadrangle. The Tres Hermanos Sandstone Member of the Mancos Shale and the D-Cross Tongue of Mancos Shale were measured along offsetting lines striking N 40^{O} W across the central portion of sec. 26, with additional information from a partial section striking N 60^{O} W across the W½ SW¼ sec. 26, T. 2 N., R. 4 W., Riley 15' quadrangle. The second, third and fourth lines were across the Mesaverde Formation. The second and third lines strike N 85^{O} W across the SW¼ sec. 27 and NW¼ sec. 34, T. 2 N., R. 4 W. The fourth line strikes N 85^{O} W across the SW¼ sec. 33; T. 2 N., R. 4 W. and the NE¼ sec. 4; T. 1 N., R. 4 W., Mesa Cencerro 7.5'quadrangle. Sections were measured by Brunton compass, Jacob staff and tape. The section from the Dakota Sandstone to the base of the Tres

Hermanos Member of the Mancos Shale were measured by Gary and Linda Massingill on 12-15 June, 1976. The remaining section was measured by Gary Massingill on 26 June, 1976 and 2-6 July, 1976.

Mesaverde Formation

UNIT		FT	IN	METERS
7-157	Shale; silty; dusky-yellow (5 Y 6/4); medium-bedded; weathers grayish-yellow (5 Y 8/4); slope, moderate-consolidation; crumbles into about 1/4 inch pieces.	3	-	.91
7-156	Sandstone; quartz, very silty, calcareous; light-greenish-gray (5 GY 8/1); fine-to medium-grained, subangular, moderate-sorting; thin bedded; weathers grayish-yellow-green (5 GY 7/2); poorly consolidated, slope.	6	6	1.98
7-155	Sandstone; quartz, very silty, calcareous; light-greenish-gray (5 GY 8/1); fine-to medium-grained, subangular, moderate-sorting; thin-bedded; weathers grayish-yellow-green (5 GY 7/2); moderate-consolidation, slight ridge on slope.	-	-	0.10
7-154	Shale; silty, slightly calcareous, micaceous; pale-olive (10 Y 6/2); very thin bedded; weathers grayish-yellow-green (10 GY 7/2); loosely	4	-	1.22

UNIT		FT	IN	METERS
	consolidated, slope.			
7-153	Sandstone; quartz; very light gray (N 8); fine-grained, subrounded, well-sorted; thin-bedded; moderate-consolidation, ledge; spherical hematite concretions about 1/4 inch across.	5	-	1.53
7-152	Shale, light-olive-gray (5 Y 5/2); thin-bedded; weathers pale-olive (10 Y 6/2); poorly consolidated, slope.	18	-	5.49
7-151	Siltstone; light-olive (10 Y 5/4); subangular, moderately to poorly sorted; thin-to medium-bedded; weathers pale-olive (10 Y 6/2); medium to poorly consolidated, slope.	1	-	0.30
7-150	Shale; organic; brownish-black (5 YR 2/1); very thin bedded; weathers medium-dark-gray (N 4); moderate-consolidation, slope.	3	6	1.07
7-149	Siltstone; quartz; very light gray (N 8); subrounded, well-sorted; thin-bedded; very loosely consolidated, slope.	3	-	0.92

UNIT		FT	IN	METERS
7-148	Sandstone; quartz; very light gray (N 8); fine-grained, subrounded, well-sorted; thin-bedded; moderate consolidation, ledge; spherical hematite concretions up to 3 inches across.	7	-	2.13
7-147	Shale; light-olive-gray (5 Y 5/2); thin-bedded; weathers pale-olive (10 Y 6/2); poorly consolidated, slope.	9	-	2.74
7-146	Siltstone; light-olive (10 Y 5/4); subangular, moderately to poorly sorted; thin-to medium-bedded; weathers pale-olive (10 Y 6/2); medium to poorly consolidated, slope.	1	-	0.30
7-145	Shale; light-olive-gray (5 Y 5/2); thin-bedded; weathers pale-olive (10 Y 6/2); poorly consolidated, slope.	1	6	0.46
7-144	Siltstone; light-olive (10 Y 5.4); subangular, moderately to poorly sorted; thin-to medium-bedded; weathers pale-olive (10 YR 6/2); medium to poorly consolidated, slope.	-	2	0.05

UNIT		FT	IN	METERS
7-143	Shale; light-olive-gray (5 Y 5/2); thin-bedded; weathers pale-olive (10 Y 6/2); poorly consolidated, slope.	2	11	0.89
7-142	Siltstone; light-olive (10 Y 5/4); subangular, moderately to poorly sorted; thin-to medium-bedded; weathers pale-olive (10 YR 6/2); medium to poorly consolidated, slope.	2	-	0.61
7-141	Shale; light-olive-gray (5 Y 5/2); thin-bedded; weathers pale-olive (10 Y 6/2); poorly consolidated, slope.	8	-	2.44
7-140	Siltstone; light-olive (10 YR 5/4); subangular, moderately to poorly sorted; thin-to medium-bedded; weathers pale-olive (10 YR 6 /2); medium to poorly consolidated, slope.	-	8	0.20
7-139	Shale; light-olive-gray (5 Y 5/2); thin-bedded; weathers pale-olive (10 Y 6/2); poorly consolidated, slope.	2	-	0.61
7-138	Siltstone; light-olive (10 YR 5/4); subangular, moderately to poorly	-	6	0.15

UNIT		FT	IN	METERS
	sorted; thin-to medium-bedded; weathers pale-olive (10 YR 6/2); medium to poorly consolidated, slope.			
7-137	Shale; light-olive-gray (5 Y 5/2); thin-bedded; weathers pale-olive (10 Y 6/2); poorly consolidated, slope.	2	6	0.76
7-136 *	Sandstone; quartz, calcareous; grayish-green (5 GY 6/1); fine-to medium-grained, subangular, moderately well sorted; medium-bedded; weathers grayish-yellow-green (5 GY 7/2); moderate-consolidation, slight rise on slope; plant fragments.	1	-	0.30
7-135	Shale; light-olive-gray (5 Y 5/2); thin-bedded; weathers pale-olive (10 Y 6/2); poorly consolidated, slope.	2	6	0.76
7-134	Sandstone; quartz; very light gray (N 8); medium-grained, subrounded, well-sorted; very thin bedded; moderate-consolidation, slope.	4	-	1.22

UNIT		FT	IN	METERS
7-133	Shale; light-olive-gray (5 Y 5/2); thin-bedded; weathers pale-olive (10 Y 6/2); poorly consolidated, slope.	9	-	2.74
7-132	Sandstone; quartz, calcareous, very light gray (N 8); medium-grained, subrounded, well-sorted; thin-bedded; moderate-consolidation, slope; organic debris, hematite staining.	2	-	0.60
7-131	Shale; organic; brownish-black (5 YR 2/1); very thin bedded, weathers medium-dark-gray (N 4); moderate-consolidation, slope.	3	6	1.07
7-130	Coal; bituminous; thin-bedded with brownish-black (5 YR 2/1); and light-brown (5 YR 5/6) iron staining; usually covered slope.	1	-	0.30
7-129 *	Shale; organic; brownish-black (5 YR 2/1); very thin bedded; weathers medium-dark-gray (N 4); moderate-consolidation, slope.	3	6	1.07
7-128	Sandstone; quartz; very-light-gray (N 8); fine-grained, subrounded, well-sorted, very thin bedded with wavy texture; moderate-consolidation,	1	9	0.53

UNIT		FT	IN	METERS
	slope; organic layers.			
7-127 *	Siltstone; light-olive (10 Y 5/4); subangular, moderately to poorly sorted; thin-to medium-bedded; weathers pale-olive (10 Y 6/2); medium to poorly consolidated, slope.	8	6	2.59
7-126 *	Sandstone; quartz; very light gray (N 8); fine-grained; subrounded; well-sorted; thin-bedded; weathers yellowish-gray (5 Y 8/1); moderate consolidation, ledge; mud-lump impressions on some surface, cross-stratification.	21	-	6.40
7-125	Sandstone; quartz, calcareous; pale-greenish-yellow (10 Y 8/2); fine-grained; subrounded; moderately sorted; thin-bedded; poorly consolidated, slope; grading upward into a siltstone.	11	-	3.35
7-124	Shale; light-olive-gray (5 Y 5/2); thin-bedded; weathers pale-olive (10 Y 6/2); poorly consolidated, slope.	5	-	1.53
7-123	Siltstone; pale-olive (10 Y 6/2); subrounded, moderately sorted;	5	6	1.68

UNIT		FT	IN	METERS
	thin-bedded, moderate-consolidation, slight ridge; organic fragments, some layers very shaley.			
7-122	Shale; grayish-yellow-green (5 GY 7/2); thin-bedded; (5 GY 7/2); poorly consolidated, slope.	0	-	3.05
7-121	Sandstone; quartz; very light gray (N 8); medium-grained, subrounded, moderate-to well-sorted; thin-to medium-bedded; weathers yellowish-gray (5 Y 8/1); moderate-consolidation, prominent ledge and ridge where thickest, slope where thinner; large low-angle cross-stratification.	15	-	4.57
7-120	Siltstone; clayey; pale-olive (10 Y 6/2); subrounded, poorly sorted; medium-bedded; weathers yellowish-gray (5 Y 7/2); poorly consolidated, slope.	7	-	2.13
7-119	Sandstone; quartz; very light gray (N 8); medium-grained, subrounded, moderate-to well-sorted; thin-to medium-bedded; weathers yellowish-gray (5 Y 8/1); moderate-consolidation, prominent ledge and	50	-	15.24

UNIT		FT	IN	METERS
	ridge where thickest, slope where thinner; large low-angle cross-stratification.			
7-188e	Shale; silty; pale-olive (10 Y 6/2); medium-bedded; weathers yellowish-gray (5 Y 7/2); poorly consolidated, slope.	4	-	1.22
7-188d	Coal; bituminous; thin-bedded with brownish-black (5 YR 2/1) and light-brown (5 YR 5/6) iron staining; usually covered slope.	-	8	0.20
7-188c	Shale; silty; pale-olive (10 Y 6/2); medium-bedded; weathers yellowish-gray (5 Y 7/2); poorly consolidated, slope.	1	6	0.46
7-118b	Coal; bituminous; thin-bedded with brownish-black (5 YR 2/1) and light-brown (5 YR 5/6) iron staining; covered slope.	-	9	0.23
7-118a	Shale; silty; pale-olive (10 Y 6/2); medium-bedded; weathers yellowish-gray (5 Y 7/2); poorly consolidated, slope.	1	-	0.30

UNIT		FT	IN	METERS
7-177	Sandstone; quartz; very light gray (N 8); fine-grained, subrounded, well-sorted; thin-bedded; moderate-consolidation, ledge; spherical hematite concretions about 1/4 inch across.	1	8	0.51
7-166	Shale; grayish-yellow-green (5 GY 7/2); thin-bedded; poorly consolidated, slope.	4	6	1.37
7-115	Sandstone; quartz; very light gray (N 8); fine-grained, subrounded, well-sorted; thin-bedded; moderate-consolidation, ledge; spherical hematite concretions about 1/4 inches across.	1	6	0.46
7-114	Shale; grayish-yellow-green (5 GY 7/2); thin-bedded; poorly consolidated, slope.	1	3	0.38
7-113	Sandstone; quartz; very light gray (N 8); fine-grained, subrounded, well-sorted; thin-bedded; moderate-consolidation, ledge; spherical hematite concretions about 1/4 inch across.	1	-	0.30

UNIT		FT	IN	METERS
7-112	Shale; grayish-yellow-green (5 GY 7/2); thin-bedded; poorly consolidated, slope.	3	6	1.07
7-111	Sandstone; quartz, calcareous, pale-greenish-yellow (10 Y 8/2); fine-grained, subrounded, moderately sorted; medium-bedded; moderate-consolidation, slope.	1	-	0.30
7-110	Shale; grayish-yellow-green (5 GY 7/2); thin-bedded; poorly consolidated, slope.	5	6	1.68
7-109	Sandstone; quartz; very light gray (N 8); medium-grained, subrounded, moderate-to well-sorted; thin-to medium-bedded; weathers yellowish-gray (5 Y 8/1); moderate-consolidation, ledge; spherical hematite concretions about 1/4 inch across.	4	6	1.37
7-108	Shale; grayish-yellow-green (5 GY 7/2); thin-bedded; poorly consolidated, slope.	18	-	5.49
7-107	Sandstone; quartz; very light gray (N 8); medium-grained, subrounded, moderate-to well-sorted; thin-to	25	-	7.62

UNIT		FT	IN	METERS
	medium-bedded; weathers yellowish-gray (5 Y 8/1); moderate-consolidation, prominent ledge and ridge where thickest, slope where thinner; large low-angle cross-stratification.			
7-106	Siltstone; clayey; pale-olive (10 Y 6/2); silt, subrounded, poorly sorted; medium-bedded; weathers yellowish-gray (5 Y 7/2); poor-consolidation, slope.	15	-	4.57
7-105	Sandstone; quartz; very light gray (N 8); medium-grained, subrounded, moderate-to well-sorted; thin-to medium-bedded; weathers yellowish-gray (5 Y 8/1); moderate-consolidation, prominent ledge and ridge where thickest, slope where thinner; large low-angle cross-stratification.	51	-	15.55
7-104	Siltstone; shaley, slightly calcareous; grayish-yellow-green (5 GY 7/2); very thin bedded; poor consolidation, slope.	2	-	0.61
7-103 *	Sandstone; quartz; very light gray (N 8); medium-grained, subrounded,	50	-	15.24

UNIT		FT	IN	METERS
	moderately to well sorted; thin-to medium-bedded; weathers yellowish-gray (5 Y 8/1); moderate-consolidation, prominent ledge and ridge where thickest, slope where thinner; large low-angle cross-stratification.			
7-102	Siltstone; clayey; pale-olive (10 Y 6/2); subrounded, poorly sorted; medium-bedded; weathers yellowish-gray (5 Y 7/2); poor-consolidation, slope.	11	-	3.35
7-101	Sandstone; quartz, calcareous; yellowish-gray (5 Y 8/1); medium-grained, subangular, poorly sorted; thin-bedded; moderate-consolidation, slope; organic debris.	3	6	1.07
7-100	Siltstone; clayey; pale-olive (10 Y 6/2); subrounded; poorly sorted; thin-bedded; weathers yellowish-gray (5 Y 7/2); poor-consolidation, slope.	3	6	1.07
7-99 *	Sandstone; quartz, calcareous; pale-greenish-yellow (10 Y 8/2); fine-grained, subrounded, moderately sorted; thin-bedded; moderate-	15	-	4.57

UNIT		FT	IN	METERS
	consolidated, prominent ledge.			
7-98	Shale; silty, concretionary, slightly calcareous; grayish-yellow-green (5 GY 7/2); very thin bedded; poorly consolidated, slope; weathers grayish-black (N 2) to light-brown (5 YR 5/6) hematite concretion zone at base.	14	-	4.27
7-97	Sandstone; quartz; grayish-yellow-green (5 GY 7/2); fine-grained, subrounded, well-sorted; thin-bedded; moderate-consolidation, slope to ledge; hematitic in places making weathering color pale-yellowish-brown (10 YR 6/2).	-	8	0.20
7-96	Shale; refer to 7-98.	-	8	0.20
7-95	Sandstone; refer to 7-97.	1	-	0.30
7-94	Shale; refer to 7-98.	10	-	3.05
7-93	Sandstone; refer to 7-97.	1	3	0.38
7-92	Shale; refer to 7-98.	2	9	0.69
7-91	Sandstone; refer to 7-97.	-	4	0.10
7-90	Shale; refer to 7-98.	2	9	0.84
7-89	Sandstone; refer to 7-97.	1	11	0.59
7-88	Shale; refer to 7-98.	-	10	0.25
7-87	Sandstone; refer to 7-97.	-	6	0.15

UNIT		FT	IN	METERS
7-86	Shale; refer to 7-98.	2	2	0.66
7-85	Sandstone; refer to 7-97.	-	7	0.18
7-84	Shale; refer to 7-98.	2	7	0.76
7-83	Sandstone; refer to 7-97.	-	3	0.08
7-82	Shale; refer to 7-98.	1	9	0.53
7-81 *	Sandstone; quartz, grayish-yellow-green (5 GY 7/2); medium-grained at base to fine-grained at top, subangular to subrounded, moderate- to well-sorted; thin-bedded; weathers grayish-yellow-green (5 GY 7/2) and pale-yellowish-brown (10 YR 6/2); moderate-consolidation, ledge.	30	-	9.15
7-80	Sandstone; quartz, calcareous at base, micaceous; very light gray (N 8), mottled light-brown (5 YR 5/6); medium-grained, subangular, moderate-sorting; thin to very thin bedded; weathers pale-yellowish-brown (10 YR 6/2); moderate to poorly consolidated, ledge; large low-angle cross-stratification; grades upward to fine-grained sand, well-sorted, with medium-gray (N 5) shale lenses and stringer, micaceous, organic debris.	33	-	10.06

UNIT		FT	IN	METERS
7-79	Sandstone; calcareous, quartz; grayish-orange-pink (5 YR 7/2); medium-grained, moderately sorted, subrounded; medium-bedded; weathers pale-yellowish-brown (10 YR 6/2); moderate-consolidation, ridge and slope.	3	-	0.91
7-78	Shale; silty; yellowish-gray (5 Y 7/2); thin-to medium-bedded; moderate-consolidation, slope.	31	6	9.60
7-77	Sandstone; refer to 7-79.	4	0	1.22
7-76	Shale; refer to 7-78.	3	6	1.07
7-75	Sandstone; refer to 7-79.	-	6	0.15
7-74	Shale; medium-light-gray (N 6); thin-bedded; crumbly, covered slope; organic debris, coal and lignite lenses.	19	-	5.79
7-73	Sandstone; quartz; yellowish-gray (5 Y 8/1); medium-grained, sub-angular, moderate-sorting; thin-bedded; weathers yellowish-gray (5 Y 7/2); very loosely consolidated with moderately consolidated light-brown (5 YR 5/6) lenses, slope.	12	-	3.66

UNIT		FT	IN	METERS
7-72 *	Sandstone; calcareous, quartz; grayish-orange-pink (5 YR 7/2); medium-grained, subangular, moderately sorted; thin-to medium-bedded; weathers pale-yellowish-brown (10 YR 6/2); moderate-consolidation, ridge and slope; symmetrical ripples.	1	3	0.38
7-71	Shale; same as 7-78.	12	-	3.66
7-70	Sandstone; quartz; yellowish-gray (5 Y 8/1); medium-grained, sub-angular, moderate-sorting; thin-bedded; weathers yellowish-gray (5 Y 7/2); well-consolidated, slight ridge.	1	2	0.35
7-69c	Shale; silty; medium-light-gray (N 7) to brownish-gray (5 RY 4/1); thin-bedded; loosely consolidated, slope.	1	6	0.46
7-69b	Coal; bituminous; thin-bedded; brownish-black (5 YR 2/1) and light-brown (5 YR 5/6) iron staining; usually covered slope.	3	-	0.91
7-69a	Shale; refer to 7-69c.	4	6	1.37

UNIT		FT	IN	METERS
7-68	Shale; refer to 7-78.	9	6	2.90
7-67	Shale; refer to 7-74.	28	-	8.53
7-66	Sandstone; refer to 7-70.	2	6	0.76
7-65	Shale; silty; pale-olive (10 Y 6/2); very thin to thin bedded; weathers yellowish-gray (5 Y 7/2); loosely consolidated, slope; grayish zone high in organic content.	30	-	9.15
7-64	Sandstone; quartz, pale-olive (10 Y 6/2); fine-grained, moderate-sorting, subangular; thin-bedded; weathers yellowish-gray (5 Y 7/2); moderate-consolidation, slope.	-	9	0.23
7-63	Shale; refer to 7-78.	-	10	0.26
7-62	Sandstone; refer to 7-64.	-	9	0.23
7-61	Shale; refer to 7-78.	-	4	0.10
7-60	Sandstone; refer to 7-64.	-	6	0.15
* 7-59	Shale; refer to 7-78.	4	7	1.37
7-58	Shale; medium-light-gray (N 6); thin-bedded; covered slope; crumbly, organic debris, coal and lignite lenses.	9	-	1.37
7-57	Sandstone; quartz, calcareous; yellowish-gray (5 Y 7/2); fine-	2	-	0.61

UNIT		FT	IN	METERS
	grained, subrounded, well-sorted; thin-bedded; well-consolidated, ridge; hematitic and concretionary at base.			
7-56	Shale; slightly calcareous; medium-light-gray (N 6); thin-bedded; weathers yellowish-gray (5 Y 8/1); loosely consolidated, slope.	2	6	0.76
7-55	Coal; same as 7-69b.	-	11	0.28
7-54	Shale; refer to 7-56.	1	6	0.46
7-53	Sandstone; quartz; yellowish-gray (5 Y 8/1); medium-grained, sub-angular, moderate-sorting; thick-bedded; weathers yellowish-gray (5 Y 7/2); well-consolidated, slight ridge; organic debris.	-	6	0.15
7-52	Shale; slightly calcareous, medium-light-gray (N 6); thin-bedded; weathers yellowish-gray (5 Y 8/1); loosely consolidated, slope; hematite lenses in zone 2 ft from base.	6	6	1.98
7-51 *	Siltstone; quartz; grayish-yellow-green (5 GY 7/2); silt and fine sand, well-sorted, subrounded; medium-bedded; well-consolidated, slight slope; cross-stratification.	1	6	0.46

UNIT		FT	IN	METERS
7-50	Shale; silty; pale-olive (10 Y 6/2); very thin to thin bedded; weathers yellowish-gray (5 Y 7/2); loosely consolidated, slope.	1	-	0.30
7-49	Sandstone; quartz, calcareous; yellowish-gray (5 Y 8/1), mottled light-brown (5 YR 5/6); medium-grained, subangular, moderate-sorting; thin-bedded; moderate-consolidation; slight slope; cross-stratification.	2	6	0.76
7-48	Shale; medium-dark-gray (N 4); thin-bedded; weathers medium-light-gray (N 6); crumbly; some organic debris.	6	6	1.98
7-47 *	Sandstone; refer to 7-49.	5	6	1.68
7-46	Shale; refer to 7-56.	5	-	1.53
7-45	Sandstone; very calcareous; medium-dark-gray; silt to fine-grained sand, subrounded, well-sorted; medium-bedded, weathers dark-yellowish-orange (10 YR 8/6); moderate-consolidation, ridge; cross-stratified in parts.	2	-	0.61
7-44	Shale; medium-light-gray (N 6); very thin bedded; weathers light-olive-	7	-	2.13

UNIT		FT	IN	METERS
	gray (5 Y 6/1); loosely consolidated, slope; fissile.			
7-43	Sandstone; very calcareous, fossiliferous; medium-dark-gray (N 4); silt to fine-grained sand, subrounded, well-sorted; massive; weathers dark-yellowish-orange (10 YR 8/6); moderate-consolidation, moderate ridge. *Oystera soleniscus* *Cardium* sp.	2	-	0.61
7-42	Shale; refer to 7-56.	3	-	0.92
7-41 *	Sandstone; quartz; yellowish-gray (5 Y 8/1); fine-grained, moderately sorted, subangular; medium-bedded; moderate-consolidation, moderate ridge.	12	-	3.66
7-40c	Shale; slightly calcareous; medium-light-gray (N 6); thin-bedded; weathers yellowish-gray (5 Y 8/1); loosely consolidated, slope.	3	6	1.07
7-40b	Coal; refer to 7-69b.	-	6	0.15
7-40a	Shale; slightly calcareous; medium-light-gray (N 7); thin-bedded; weathers yellowish-gray (5 Y 8/1); loosely consolidated, slope.	7	-	2.13

UNIT		FT	IN	METERS
7-39	Sandstone; quartz; very light gray (N 8), mottled light-brown (5 YR 5/6); fine-grained, subangular, moderately sorted; medium-bedded; weathers moderate-yellowish-brown (10 YR 5/4); moderate-consolidation, slight ridge.	1	3	0.38
7-38	Shale; refer to 7-56.	15	6	4.73
7-37	Sandstone; refer to 7-39.	-	8	0.21
7-36	Shale; silty; pale-olive (10 Y 6/2); very thin to thin bedded; weathers yellowish-gray (5 Y 7/2); loosely consolidated, slope; sandy lenses, some rich in blackish-red (5 R 2/2) to light-gray (N 7) organic debris.	8	6	2.59
7-35	Sandstone; quartz, calcareous; yellowish-gray (5 Y 8/1); fine-to medium-grained, moderately sorted, subangular; medium-bedded; weathers very-light-gray (N 8); moderate-consolidation, slope to slight ridge.	1	1	0.30
7-34	Shale; pale-olive (10 Y 6/2); very thin bedded; loosely consolidated,	1	6	0.46

UNIT		FT	IN	METERS
	slope; fissile; hematitic limestone bed at top with cone-in-cone surface.			
7-33	Sandstone; quartz, hematitic in places; pale-yellowish-brown (10 YR 7/2); medium-grained, well-sorted, subrounded; thin-bedded; weathers moderate-brown (5 YR 4/4); well-consolidated, slight ridge.	1	3	0.38
7-32	Shale; silty; grayish-yellow-green (5 GY 7/2); very thin bedded; loosely consolidated, slope; fissile.	1	-	0.30
7-31	Coal; refer to 7-69b.	3	6	1.07
7-30	Shale; decreasing silt upward; grayish-yellow-green (5 GY 7/2) to medium-gray (N 5); very thin bedded; loosely consolidated; slope; fissile.	5	-	1.52
7-29	Sandstone; same as 7-33.	-	6	1.07
7-28	Shale; dark-gray (N 3); very thin bedded; weathers light-gray (N 7); loosely consolidated slope; fissile.	3	6	1.07
7-27	Sandstone; refer to 7-33.	-	6	0.15
7-26 *	Shale; refer to 7-36.	20	-	6.10

UNIT		FT	IN	METERS
7-25	Sandstone; light-gray (N 7); medium-grained, poorly sorted, subangular; thin-bedded; weathers yellowish-gray (5 Y 8/1); moderate-consolidation, ridge; organic debris, hematitic zone about 12 inches from top, wavy bedded weathering texture.	6	6	1.98
7-24	Shale; medium-light-gray (N 7); thin-bedded; weathers light-olive-gray (5 Y 6/1); loosely consolidated, slope; organic debris.	5	6	1.68
7-23	Sandstone; refer to 7-33.	-	4	0.10
7-22	Shale; refer to 7-24.	13	6	4.11
7-21	Sandstone; quartz; very light gray (N 8); fine-to coarse-grained, subrounded, well to moderately sorted; medium-to thick-bedded; weathers light-brown (5 YR 6/4) to very pale orange (10 YR 8/2); moderate-induration, cliff or prominent ridge; hematite staining, some speckled appearance due to hematite, grayish under coarser grained material, fine-grained at bottom coarsening upward,	47	-	14.33

UNIT	FT IN	METERS

cross-stratified at top with organic debris.

Measured thickness of Mesaverde Formation 971 ft, 1 inch, (295.98 m).

Mancos Shale

D-Cross Tongue

UNIT		FT	IN	METERS
7-20	Shale; silty; medium-dark-gray (N 4); thin-to medium-bedded; weathers yellowish-gray (5 Y 7/2); loosely consolidated, slope, organic material.	8	6	2.60
7-19	Sandstone; quartz; grayish-orange (10 YR 7/4); medium-grained, well-sorted, subangular; medium-bedded; weathers dark-yellowish-brown (10 YR 4/2); well-consolidated, slight ledge; burrowed.	1	-	0.30
7-18	Shale; refer to 7-20.	19	-	5.90
7-17	Sandstone; refer to 7-19.	-	6	0.15
7-16	Shale; refer to 7-19.	-	10	0.25
7-15	Sandstone; refer to 7-19.	-	8	0.20
7-14	Shale; very sandy; medium-dark-gray (N 4); thin-to medium-bedded; weathers yellowish-gray (5 Y 7/2); loosely consolidated, slope; organic material.	1	7	0.48
7-13	Sandstone; refer to 7-19.	2	3	0.69

UNIT		FT	IN	METERS
7-12	Shale; refer to 7-20.	4	6	1.37
7-11	Sandstone; refer to 7-19.	1	3	0.38
7-10	Shale; refer to 7-20.	-	6	0.15
7-9	Sandstone; refer to 7-19.	1	-	0.30
7-8	Shale; fossiliferous; medium-dark-gray (N 4); thin-bedded; loosely consolidated, slope; streaked appearance. *Turretella* sp.	14	-	4.28
7-5	Sandstone; quartz, calcareous, magnetite (?); grayish-orange (10 YR 7/4); medium-grained, well-sorted, subangular; medium-bedded; weathers dark-yellowish-brown (10 YR 4/2); well-consolidated, slight ledge.	2	-	0.61
7-4	Shale (with sandy and silty portions); calcareous, micaceous; greenish-gray (5 GY 6/1) to medium-gray (N 5) shale; very thin bedded; weathers grayish-yellow-green (5 GY 7/2); loosely consolidated, slope; organic debris; contains light-gray (N 7) thin, very fine sandstone beds.	37	-	11.28

UNIT		FT	IN	METERS
7-3	Sandstone; quartz, very calcareous, fossiliferous; medium-light-gray (N 6); very fine grained, well-sorted, rounded; medium-bedded; weathers yellowish-gray (5 Y 7/2); moderate-consolidation, slight ridge. USGS Mesozoic locality D 10291. *Lopha sannionis* *Crassatella wyomingensis* *Ceratostereon* so.	8	-	2.44
7-2	Sandstone; quartz, calcareous; light-olive-gray (5 Y 6/1); fine-grained, well-sorted, rounded; thin-bedded; weathers yellowish-gray (5 Y 7/2); loosely indurated, slope.	12	-	3.66
7-1 *	Sandstone; fossiliferous, quartz, calcareous; yellowish-gray (5 Y 8/1); fine-to medium-grained, moderately sorted, subrounded; medium-bedded; weathers moderate-yellowish-brown (10 YR 5/4); increasing induration toward top, gradational contact at base, slight ridge; wood fragments.	5	-	1.52

UNIT		FT	IN	METERS
	Cardium sp.			
6-54b	Shale; slightly silty, concretionary, fossiliferous; light-gray (N 7); thin bedded; weathers yellowish-gray (5 Y 8/1); slope loosely consolidated; fossiliferous carbonate concretions with siderite septa, and zone of concretions radiating calcite. USGS Mesozoic locality D 10290 *Inoceramus perplexus* *Prionocyclus novimexicanus*	107	-	32.61
6-54a	Covered.	30	-	9.14
6-53	Shale; slightly silty, fossiliferous; light-gray (N 7); thin-bedded weathers yellowish-gray (5 Y 8/1); slope, loosely consolidated. *Prionocyclus novimexicanus*			
6-52 *	Limestone; arenaceous, fossiliferous; light-gray (5 Y 7/2); massive; weathers dark-yellowish-orange (10 YR 6/6); slight ridge. USGS Mesozoic locality D 10289 *Scaphites* sp. *Prionocyclus* sp. *Inoceramus* sp.	-	7	0.18

UNIT		FT	IN	METERS
	Note: "Juana Lopez" equivalent.			
6-51	Shale; slightly silty, fossiliferous; light-gray (N 7); thin-bedded; yellowish-gray (5 Y 8/1); slope, loosely consolidated.	16	-	4.88
	Cardium sp.			

Minimum Measured Thickness of D-Cross Tongue of Mancos Shale is 290 ft 2 inches (88.44 m). Includes 30 ft (9 m) covered interval.

Tres Hermanos Sandstone Member

UNIT		FT	IN	METERS
6-50	Sandstone; quartz, calcareous; very light gray (N 8); mottled light-brown (5 YR 6/4); coarse-grained, subrounded, moderately sorted; thin-bedded; moderately consolidated; ridge; bioturbated, vertical and horizontal burrows up to 8 inches long, tough and tabular cross-stratification.	4	-	1.22
6-49	Sandstone; fossiliferous, quartz; very light gray (N 8); coarse-to fine-grained, poorly sorted, subangular; weathers yellowish-gray (5 Y 8/1); thin-bedded; very loosely consolidated; ridge; burrowed, zone of nodules of very light gray (N 8) sandstone 5 ft from base. <u>Lopha</u> <u>bellaplicata</u>	15	-	4.57
6-48	Sandstone; clayey; quartz, very light gray (N 8); coarse to fine grained, poorly sorted, subangular; thin-bedded; weathers light-brown (5 YR 6/4); loosely	1	-	0.30

UNIT		FT	IN	METERS
	consolidated, cross-stratified.			
6-47	Shale; slightly silty; light-gray (N 7); thin-bedded; weathers yellowish-gray (5 Y 8/1); slope, poorly consolidated.	11	-	3.35
6-46 *	Sandstone; clayey in parts, quartz fossiliferous; gray (N 8); coarse- to fine-grained, poorly sorted, subangular; thin-bedded; weathers yellowish-gray (5 Y 8/1); poorly consolidated; filled vertical and horizontal burrows, cross-stratified. _Cardium_ sp. snails	22	-	6.71
6-45	Siltstone; very clayey; medium-dark-gray (N 4); thin-to medium-bedded; weathers grayish-yellow (5 Y 8/4); slope, poorly consolidated.	38	-	11.58
6-44	Sandstone; quartz; very pale orange (10 YR 8/2); mottled light-brown (5 YR 5/6); fine-grained, subangular, well-sorted; medium-bedded; ledge, well-consolidated.	1	6	0.46

UNIT		FT	IN	METERS
6-43	Shale; refer to 6-47.	7	6	2.29
6-42	Sandstone; refer to 6-44.	1	6	0.46
6-41	Shale; refer to 6-47.	3	-	0.91
6-40	Siltstone; pale-olive (10 Y 6/2); subrounded; moderately sorted; thin-bedded; moderately consolidated.	1	-	0.30
6-39	Shale; refer to 6-47.	1	3	0.38
6-38 *	Sandstone; quartz, chloritic, hematitic; moderate-brown (5 YR 4/4) and grayish-yellow-green (5 GY 7/2); fine-grained sand and silt, subrounded, moderately consolidated; organic debris.	-	5	0.13
6-37	Shale; refer to 6-47.	1	1	0.33
6-36	Siltstone; medium-light-gray (N 6); subangular, well-sorted; medium-bedded; well-consolidated; wood fragments.	-	9	0.23
6-35	Shale; silty; light-gray (N 7); thin-bedded; weathers yellowish-gray (5 Y 8/1); slope, poorly consolidated.	6	-	1.83
6-34	Sandstone; quartz; very pale orange (10 YR 8/2); fine-grained,	1	-	0.30

UNIT		FT	IN	METERS
	subangular, well-sorted, medium-bedded; ledge; bioturbated.			
6-33	Sandstone; yellowish-gray (5 Y 8/1); medium-grained, sub-angular, moderately sorted; slope, very poorly consolidated.	8	-	2.44
6-32	Sandstone, refer to 6-34.	2	-	0.61
6-31	Shale; light-gray (N 7); thin-bedded; yellowish-gray (5 Y 8/1); slope, poorly consolidated.	7	6	2.29
6-30	Sandstone; quartz; very pale orange (10 YR 8/2) mottled light-brown (5 YR 5/6); fine-grained, subangular, well-sorted; medium-bedded; ledge; well-consolidated; fractured, blocky appearance.	-	3	0.08
6-29	Shale; greenish-yellow (5 Y 8/4); thin-bedded; weathers to colors varying from brownish-black (5 YR 2/1) to grayish-yellow (5 Y 8/4); slope; poorly consolidated; contains thin sandstones; very-pale-orange (10 YR 8/2); fine sand; sub-angular; well-sorted; bioturbated.	2	6	0.76

UNIT		FT	IN	METERS
6-28	Sandstone; refer to 6-44.	1	3	0.38
6-27	Shale; organic at top; grades from greenish-yellow (5 Y 8/4) at base to medium-dark-gray (N 4) at top; thin-bedded; weathers to colors varying from brownish-black (5 YR 2/1) to grayish-yellow (5 Y 8/4); slope, poorly consolidated; contains thin sandstones; very-pale-orange (10 YR 8/2); fine sand; subangular; well-sorted; bioturbated.	5	6	
6-28	Sandstone; refer to 6-44.	1	3	0.38
6-27	Shale; organic at top; grades from greenish-yellow (5 Y 8/4) at base to medium-dark-gray (N 4) at top; thin-bedded; weathers to colors varying from brownish-black (5 YR 2/1) to grayish-yellow (5 Y 8/4); slope, poorly consolidated.	5	6	
6-26	Sandstone; quartz; very pale orange (10 YR 8/2) mottled light-brown (5 YR 5/6); fine-grained, subangular, well-sorted; medium-bedded; ledge, well-consolidated;	1	6	0.46

UNIT		FT	IN	METERS
	massive bioturbation destroys bedding in parts, wispy bedding.			
6-25a *	Siltstone; very light gray (N 8); subangular, well-sorted; massive; well-indurated; root fragments and tubes.	1	6	0.46
6-25b *	Shale; organic; medium-gray (N 5); thin-bedded; weathers dark-gray (N 3); abundant grayish-yellow (5 Y 8/4) organic debris.			
6-24	Shale; refer to 6-47.	2	6	0.76
6-23	Sandstone; refer to 6-26.	2	-	0.61
6-22	Shale; refer to 6-47.	12	6	3.81
6-21	Sandstone; quartz; very pale orange (10 YR 8/2) mottled light-brown (5 YR 5/6); fine-grained, subangular, well-sorted; medium-bedded; ledge, well-consolidated; bioturbated, vertical burrows.	1	-	0.30
6-20	Shale; refer to 6-47.	2	6	0.76
6-19	Sandstone; quartz; very pale orange (10 YR 8/2) mottled light-brown (5 YR 5/6); fine sand; subangular; well-sorted; medium-bedded; ledge, well-consolidated; wispy bedding, bioturbated.	1	6	0.46

UNIT		FT	IN	METERS
6-18	Shale; refer to 6-47.	4	6	1.37
6-17	Sandstone; refer to 6-44.	1	9	0.53
6-16	Shale; refer to 6-47.	2	9	0.84
6-15	Sandstone; refer to 6-44.	-	3	0.08
6-14	Sandstone; refer to 6-47.	1	3	0.38
6-13 *	Sandstone; refer to 6-44.	1	6	0.46
6-12	Shale; calcareous, silty; light-gray (N 7); thin-bedded; weathers yellowish-gray (5 Y 8/1); slope, poor-consolidation.	2	-	0.61
6-11 *	Sandstone; quartz, ferruginous; grayish-brown (5 YR 3/2); medium-grained, subrounded, moderately sorted; thin-bedded; weathers grayish-brown (5 YR 7/4); ledge, moderate-consolidation.	1	6	0.46
6-10	Shale; slightly silty; light-gray (N 7); thin-bedded; weathers yellowish-gray (5 Y 8/1); slope; poorly consolidated.	2	3	0.69
6-9	Sandstone, refer to 6-11.	-	8	0.20
6-8	Siltstone; clayey; very light gray (N 8); thin to very thin bedded; weathers grayish-orange (10 YR 7/4); slope; poor-to moderate-consolidation;	2	-	0.61

UNIT		FT	IN	METERS
	organic material.			
6-7	Sandstone; quartz, ferruginous, clay balls in parts; yellowish-white (5 Y 9/1) with varying amount of light-brown (5 YR 5/6) mottling; medium-to coarse-grained, subrounded, poorly sorted; medium-bedded; varying colors on weathered surface from medium-dark-gray (N 4) to moderate-reddish-brown (10 R 4/6); ridge; varying consolidation from moderate to well; cross-stratification.	14	-	4.26
6-6	Sandstone; calcareous, quartz, yellowish-gray (5 Y 8/1); medium-to fine-grained, rounded, well-sorted; thin to very thin bedded; slope; poorly consolidated.	4	-	1.22
6-5	Sandstone; quartz; very pale orange (10 YR 8/2) mottled light-brown (5 YR 5/6); fine-grained, subrounded, moderate-sorting; thin-bedded; weathers yellowish-gray (5 Y 8/1); ridge and slope; moderate-consolidation, cross-	2	6	0.76

UNIT		FT	IN	METERS
	stratification.			
6-4	Sandstone; quartz, ferruginous; grayish-orange (10 YR 7/4); very fine grained, subangular, well-sorted; thin to very thin bedded; weathers moderate-yellowish-brown (10 YR 5/4); slope, poor-to moderate-consolidation; cross- and planar-laminations; breaks into very thin plates.	4	10	1.47
6-3 *	Limestone; very fossiliferous in parts; silty; pale-yellowish-brown (10 YR 6/2); medium-bedded; weathers dark-yellowish-brown (10 YR 4/2); slope and ridge; well-consolidated.	-	11	0.28
6-2 *	Sandstone; fossiliferous, concretionary calcareous, quartz; yellowish-gray (5 Y 8/1); medium-to fine-grained, rounded, well-sorted; thin to very thin bedded; weathers yellowish-gray (5 Y 8/1); slope, poorly consolidated.	6	6	1.98

USGS Mesozoic fossil locality D 10288

Collignoniceras mexicanium

Cardium sp.

UNIT		FT	IN	METERS
6-1	Sandstone; calcareous, quartz; very pale orange (10 YR 8/2); fine-grained, subrounded, moderate-sorting; thin-bedded; weathers moderate-yellowish-brown (10 YR 5/2); moderate-consolidation; cross- and planar-laminations.	10	-	3.04

Measured thickness of Tres Hermanos is 231 ft 2 inches (70.46 m).

Alamito Well Tongue

UNIT		FT	IN	METERS
5-21	Shale; fossiliferous, concretionary; light-olive-gray (5 Y 5/2), very thin bedded; weathers pale-olive (10 Y 6/2); loosely consolidated; fissile. USGS Mesozoic fossil locality D 10287 *Mammites depressus* *Placenticeras* sp. *Placenticeras* sp.	130	-	39.62
5-20b	Calcarenite; clayey, fossiliferous; medium-light-gray (N 5); medium-bedded; weathers very pale orange (10 YR 8/2); moderate-consolidation, slight rise. *Inoceramus (Mytiloides) mytiloides*	-	2	0.05
5-20a	Shale; calcareous, silty; medium-gray (N 5); thin-to medium-bedded; loosely consolidated, slope.	4	3	1.30
5-19	Calcarenite; same as 5-20b.	-	5	0.13
5-18	Shale; same as 5-20a. USGS Mesozoic fossil locality D 10286 *Pycnodonte newberryi*	35	-	10.67
5-17	Limestone; lithographic,	-	7	0.18

UNIT		FT	IN	METERS
	fossiliferous; medium-gray (N 5); massive-bedded; weathers grayish-orange (10 YR 7/4); well-consolidated, break in slope; burrowed. *Sciponoceras gracile* *Pycnodonte newberryi*			
5-16	Shale; refer to 5-20a.	4	6	1.37
5-15	Shale; very calcareous; medium-gray (N 5); medium-bedded; weathers grayish-orange (10 YR 7/4); well-consolidated, break in slope.	-	8	0.20
5-14	Shale; refer to 5-20a.	3	2	0.96
5-13	Shale; bentonitic, gypsiferous, slightly silty; pale olive (10 Y 6/2); very thin bedded; weathers very light gray (N 8); loosely consolidated, slope.	-	3	0.08
5-12	Shale; refer to 5-20a.	2	9	0.84
5-11	Shale; refer to 5-13.	10	-	3.05
5-10	Shale; refer to 5-20a.	1	1	0.33
5-9	Shale; refer to 5-13.	1	1	0.33
5-8	Shale; fossiliferous, calcareous, silty; pale-olive (10 Y 5/2); medium-bedded; loosely consolidated, slope.	5	6	1.68

UNIT		FT	IN	METERS
5-7	Shale; bentonitic, gypsiferous; dark-yellowish-orange (10 YR 6/6), thin to very thin bedded; weathers very pale orange (10 YR 8/2); loosely consolidated, slope.	-	1/2	0.01
5-6	Shale; refer to 5-8.	3	3	0.99
5-5	Shale; refer to 5-7.	-	1/2	0.01
5-4	Shale; refer to 5-20a.	5	7	1.70
5-3	Shale; bentonitic, calcareous, gypsiferous; light-gray (N 7); thin-bedded; loosely consolidated, slope.	1	-	0.30
5-2	Shale; refer to 5-20a.	23	4	7.11
5-1	Shale; refer to 5-7.	-	4	0.10
2-55	Shale; silty, calcareous, light-olive-gray (5 Y 5/2); thin-bedded; weathers dusky-yellow (5 Y 6/4); loosely consolidated, slope.	5	10	1.77
2-54	Sill	5	-	1.52
2-53	Shale; refer to 2-55.	3	6	1.07
2-52	Sill	2	-	0.61
2-51	Shale; refer to 2-55. USGS Mesozoic fossil locality D 10285 *Inoceramus prefragilis*	33	6	10.21

UNIT		FT	IN	METERS
2-50	Covered.	72	-	21.95
2-49	Shale; silty, calcareous, olive-black (5 Y 2/1); thin-to medium-bedded; weathers dusky-blue (5 PB 4/2); moderately consolidated; slightly fissile; slope; lumpy appearance, shrinkage fractures, selenite veins.			
4-31	Shale; silty; calcareous; ferruginous; olive-black (5 Y 2/1) to light-olive-gray (5 Y 6/1), stringy mix of colors; medium-bedded, mix of softer and harder beds; loose-to medium-consolidation, slope.	10	-	3.05
4-30	Shale; refer to 2-49.	19	-	5.79
4-29	Shale; bentonitic, silty, gypsiferous, very pale orange (10 YR 8/2); thin-to medium-bedded; poorly consolidated, slope.			
4-28	Shale; refer to 2-49.	8	7	2.62
4-27	Siltstone; micaceous, gypsiferous; light-gray (N 7); thin-to medium-bedded; weathers very light gray	-	6	0.15

UNIT		FT	IN	METERS
	(N 8); slope, loosely consolidated; salt and pepper texture.			
4-26	Shale; refer to 4-29.	1	1/2	0.01
2-25	Shale; refer to 2-49.	9	6	2.90
2-24	Shale; refer to 4-29.	-	6	0.15
2-23	Shale; refer to 2-49.	-	11	0.28
4-22	Shale; refer to 4-29.	-	5	0.13
4-21	Shale; refer to 2-49.	1	10	0.56
4-20	Shale; refer to 4-29.	-	5	0.13
4-19	Shale; refer to 2-49.	-	7	0.18
4-18	Shale; refer to 4-29.	-	1½	0.04
4-17	Shale; refer to 2-29.	2	4	0.71
4-16	Shale; refer to 4-29.	1	1½	0.04
4-15	Shale; refer to 2-49.	1	9	0.53
4-14	Shale; refer to 4-29.	-	1½	0.04
4-13	Shale; refer to 2-49.	14	-	4.27
2-47h	Covered.	9	2	2.79
2-47g	Shale; silty; grayish-orange (10 YR 7/4), irregular medium-dark-gray (N 4) areas; thin-bedded; weathers yellowish-gray (5 Y 8/1); loosely consolidated, slope.	20	-	6.10
2-47f	Limestone; sandy; very light gray (N 8); thin-bedded; weathers	-	1	0.03

UNIT		FT	IN	METERS
	yellowish-gray (5 Y 7/2); slope; platy breakage; trace fossils-trails.			
2-47e	Shale; refer to 2-47g.	3	-	0.91
2-47d	Limestone; sandy; very light gray (N 8); thin-bedded; weathers light-brownish-gray (5 YR 6/1); slope; platy breakage.	-	1	0.03
2-47c	Shale; same as 2-47g.	2	6	0.76
2-47b	Limestone; grayish-dusky-blue (5 PB 4/2); medium-bedded; weathers moderate-brown (5 YR 4/4); well-consolidated, slight ridge.	-	2	0.05
2-47a	Shale; refer to 2-47g.	5	-	1.52
2-46	Limestone; fossiliferous, grayish-dusky-blue (5 PB 4/2); medium-bedded weathers light-brown (5 YR 4/4), slight ridge, well consolidated. *Ostrea beloiti* *Tarrantoceras* sp. ammonite?	-	2	0.05
2-45	Shale; slightly silty; grayish-orange (10 YR 7/4), irregular medium-dark-gray (N 4) areas; thin-bedded; weathers yellowish-gray (5 Y 8/1); interbedded with thin,	2	6	0.76

UNIT		FT	IN	METERS
	hard calcareous beds; loosely consolidated.			
2-44	Limestone; refer to 2-46.	-	3	0.08
	<u>Tarrantoceras</u> sp.			
	<u>Ostrea</u> <u>beloiti</u>			
2-43c	Shale; refer to 2-45.	-	7	0.18
2-43b	Shale; bentonitic, gypsiferous; very pale orange (10 YR 8/2); very thin bedded; poorly consolidated, slope.	-	1	0.03
2-43a	Shale; refer to 2-45.	-	8	0.20
2-42	Shale; refer to 2-43b.	-	1	0.03
2-41	Shale; refer to 2-45.	-	6	0.15
2-40	Limestone; refer to 2-46.	-	2	0.05
	USGS Mesozoic Locality D 10284			
	<u>Ostrea</u> <u>beloiti</u>			
	<u>Inoceramus</u> <u>rutherfordi</u>			
	<u>Tarrantoceras</u> sp.			
2-39	Shale; refer to 2-45.	6	-	1.83
2-38	Limestone; fossiliferous; olive gray (5 Y 4/1); medium-bedded; weathers moderate-brown (5 YR 4/4), well-consolidated.	-	2	0.05
	<u>Inoceramus</u> sp.			
2-37	Shale; refer to 2-45.	7	-	2.13

UNIT		FT	IN	METERS
2-36	Limestone; refer to 2-38.	-	2	0.05
* 2-35	Shale; silty, calcareous; light-olive-gray (5 Y 5/2); moderate-sorting; thin-to medium-bedded, weathers greenish-gray (5 Y 8/1), slope, loosely consolidated.	2	-	0.61
2-34	Siltstone; fossiliferous, carbonaceous; light-olive-gray (5 Y 6/1); fine sand and silt, moderate-sorting, subrounded; medium-bedded, weathers yellowish-gray (5 Y 8/1); slight rise, moderate-consolidation; bioturbated. *Ostrea beloiti*	-	3	0.08
2-33	Shale; refer to 2-35.	2	-	0.61
2-32	Siltstone; refer to 2-34.	-	2	0.05
2-31	Shale; refer to 2-35.	2	-	0.61
2-30	Siltstone; refer to 2-34.	-	3	0.08
2-29	Shale; refer to 2-35.	2	6	0.76
2-28	Siltstone; refer to 2-34.	-	3	0.08
* 2-27	Shale refer to 2-38.	4	-	1.22
2-26	Limestone; refer to 2-38.	-	4	0.10
2-25	Shale; refer to 2-35.	1	6	0.46
2-24	Sandstone; very calcareous, quartz; light-olive-gray (5 Y 5/2); fine sand and silt, moderate-consoli-	-	3	0.08

UNIT		FT	IN	METERS
	dation; bioturbated; organic fragments.			
2-23	Shale; refer to 2-35.	-	9	0.23
2-22	Sandstone; refer to 2-24.	-	3	0.08
2-21	Shale; refer to 2-35.	14	-	4.27
2-20	Siltstone; fossiliferous, calcareous; pale-yellowish-brown (10 YR 6/2); silt, very well sorted, rounded; massive-bedded; weathers very pale orange (10 YR 8/2), slight ledge, well-indurated; platy breakage. Ostrea sp. Ammonite-poorly preserved			
2-19	Shale; beds of varied colors--some pale-yellowish-orange (10 YR 8/6) to medium-gray (N 5); weathers very thin bedded; weathers yellowish-gray (5 Y 8/2), loosely consolidated; fissile, calcite veins, thin bentonitic shale about 1 ft 6 inches from base.	2	6	0.76
2-18	Siltstone; calcareous; pale-yellowish-brown (10 YR 6/2); silt, very well sorted, rounded; massive-bedded; weathers very pale orange	-	5	0.13

UNIT		FT	IN	METERS
	(10 YR 8/2), slight ledge; well-indurated; bioturbated.			
2-17c	Shale; very silty, calcareous; medium-dark-gray (N 4); silt and clay, well-sorted, subangular; very thin bedded; weathers dark-gray (N 5); slope, loosely consolidated; fissile.	5	4	1.62
2-17b	Shale; bentonitic; very pale orange (10 YR 8/2); very thin bedded; poorly consolidated, slope.	1	2	0.35
2-17a	Shale; very silty; medium-dark-gray (N 4); very thin bedded; slope; weathers medium-gray (N 5), loosely consolidated; fissile, contains selenite.	12	-	3.66
2-16 *	Siltstone; calcareous; medium-dark-gray (N 4); very well sorted, rounded; massive-bedded; weathers pale-yellowish-orange (10 YR 8/6) and yellowish-gray (5 Y 7/2); slight ledge, well-indurated; bioturbated.	1	6	0.46
2-15	Shale; carboniferous; medium-light-gray (N 6); moderate-consolidation; fissile; with 1/2 to 2 inch beds of sandstone; quartz; weathers light-brown	2	6	0.76

(5 YR 5/6); well-cemented.

Minimum measured thickness of Alamito Well Tongue of the Mancos Shale is 555 ft 10.5 inches, 164.43 m. Includes 7 ft (2 m) sill and 81 ft (25 m) of covered interval.

Dakota Sandstone

UNIT		FT	IN	METERS
2-14	Sandstone; quartz, ferruginous; yellowish-white (5 Y 9/1), mottled dark-yellowish-orange (10 YR 6/6); fine-grained, well-sorted, sub-rounded; medium-bedded; hematite concretions; platy-weathering, moderate-consolidation; fractured, slight ridge.	-	4	0.10
2-13	Shale; carboniferous medium-light-gray (N 6) mottled light-brown (5 YR 5/6); thin-bedded; moderately consolidated, covered slope; contains sandstone beds, 1/2 to 2 inches thick.	1	2	0.35
2-12	Sandstone; refer to 2-14.	-	6	0.15
2-11	Shale; refer to 2-13.	2	-	0.61
2-10	Sandstone; refer to 2-14.	3	-	0.91
2-9	Shale; refer to 2-13.	1	6	0.46
2-8	Sandstone; refer to 2-14.	4	-	1.22
2-7	Shale; refer to 2-13.	7	6	2.29
1-4 *	Sandstone; quartz, some hematite, some magnetite; yellowish white (5 Y 9/1), mottled light-brown	32	6	9.91

(5 YR 5/6) to moderate-brown (5 YR 3/4), weathers grayish-orange (10 YR 7/4); medium-grained, very well rounded; medium-bedded; weathers grayish-orange (10 YR 7/4), prominent ledge, well-consolidated; hematite concretions, planar burrows near top, cross-stratification, desert varnish.

Measured thickness of Dakota Sandstone is 52 ft 6 inches (16.00 m).

PUERTECITO REFERENCE SECTION

South of Rio Salado, approximately 1 mi (1.6 km) due south of Puertecito, New Mexico, secs. 5, 7, and 7 T. 2 N., R. 5 W., Puertecito 7.5' quadrangle, a section of Cretaceous rocks from the base of the Dakota Sandstone to the base of the Mesaverde Formation was measured using a Jacob Staff, Abney hand level, and tape. The section was originally measured by Stephen Hook and Gary Massingill on 8-10 June 1976 and remeasured on 19-21 July 1977.

Mesaverde Formation

Top of measured section

UNIT		FT	IN	METERS
105	Sandstone; very pale orange (10 YR 8/2) subangular, medium-grained, medium-bedded; weathers yellowish-orange (10 YR 7/6); hard.	8+	-	2.44
104	Shale; silty, sandy; moderate yellowish brown (10 YR 5/4); soft, slope.	40	-	12. 19

Measured thickness of Mesaverde Formation (incomplete) is 48 + ft (14.63 m).

Gallego Sandstone

UNIT		FT	IN	METERS
103	Sandstone; slightly calcareous; yellowish-gray (5 Y 8/1); fine-grained, subangular, burrowed; weathers pale-yellowish-orange (10 YR 8/7) and dark-yellowish-orange (10 YR 6/6); slope. USGS Mesozoic locality D 10278 (float from 2 ft above base of unit): *Inoceramus deformis*	12	-	3.66
102	Sandstone; highly fossiliferous (almost on oyster coquina), calcareous, concretionary; dusky-yellow (5 Y 6/4); medium-grained, subangular; weathers moderate-yellowish-brown (10 YR 5/4); resistant. USGS Mesozoic locality D 10277 *Lopha sannionis* *Cyrimeria* sp. *Cardium* sp.	1	6	0.46
101	Sandstone; calcareous, friable; yellowish-gray (5 Y 7/2); medium-grained, subangular; weathers	5	-	1.52

UNIT		FT	IN	METERS
	mottled, dark-yellowish-brown (10 YR 4/2); and yellowish-gray (5 Y 7/2); slope.			
100	Sandstone; abundantly fossiliferous (in places is almost an oyster coquina), calcareous; grayish-orange (10 YR 7/4); medium-grained, subangular; weathers moderate-yellowish-brown (10 YR 5/4); hard, resistant.	2	-	0.61
	USGS Mesozoic locality D 10276			
	Lopha sannionis			
	Cyrimeria sp.			
	Cardium sp.			
	Inoceramus rotundatus			
	Baculites yokoyami			
99	Sandstone; fossiliferous, calcareous; yellowish-gray (5 Y 7/2); fine-to medium-grained, rounded; bold massive cliff.	60	-	18.29
	USGS Mesozoic locality D 10275 (from 3 ft below top of unit)			
	Inoceramus rotundatus			
	USGS Mesozoic locality D 10274			

UNIT		FT	IN	METERS
	(float from throughout unit) *Baculites yokoyami* *Prionocyclus quadratus*			
98	Sandstone; fossiliferous, calcareous, micaceous; dusky-yellow (5 Y 6/4); medium-grained, subrounded, thin-to medium-bedded; moderately resistant. USGS Mesozoic locality D 10273 *Carota*? sp. *Inoceramus incertus* *Baculites yokoyami* *Prionocyclus quadratus*	5	-	1.52

Measured thickness of Gallego Sandstone is 85 ft 6 inches (26.06 m).

Mancos Shale

D-Cross Tongue

UNIT		FT	IN	METERS
97	Shale; concretionary, silty, calcareous; yellowish-gray (5 Y 7/2); slope; fossiliferous concretions like unit 91 (in places concretions form a discontinuous bed approximately 1 ft above base of unit).	3	6	1.07
96	Mudstone; fossiliferous, silty, sandy, slightly calcareous, slightly micaceous; medium-gray (N 5) weathering bluish-gray (5 N 6/1) with iron staining; resistant; gradational contact as base distinct contact at top. USGS Mesozoic locality D 10272 *Inoceramus incertus* *Inoceramus* n. sp. *Baculites yokoyami* *Prionocyclus quadratus*	1	3	0.38
95	Shale; fossiliferous, concretionary, silty, slightly calcareous;	32	-	9.76

UNIT		FT	IN	METERS
	olive-gray (5 Y 4/4); slope; concretions like those in unit 92. USGS Mesozoic locality D 10271 Inoceramus n. sp.			
94	Limestone; concretionary, silty and sandy; olive-gray (5 Y 4/4) weathers mottled yellowish-orange (10 YR 7/7); slightly concretionary in places but in general forms continuous, resistant beds.	-	6	0.15
93	Shale; silty, micaceous, concretionary, fossiliferous; slope; limestone concretions like those in unit 91.	5	0	1.52
92	Limestone; concretionary, silty; weathers grayish-orange (10 YR 7/4) to moderate yellowish-brown (10 YR 6/4); discontinuous resistant bed; concretions are oblate and up to 4 ft long.	1	-	0.30
91	Shale; silty, concretionary, fossiliferous; limestone concretions scattered throughout that are either solid or septarian oblate spheriods, concretions are finely	65	-	19.81

UNIT		FT	IN	METERS
	crystalline and range from a few inches to 3 ft in diameter, unit also contains large (up to 3 ft across) botryoidal concretions of acicular calcite; soft, slope-forming unit. USGS Mesozoic locality D 10127 *Scaphites whitfield* *Prionocyclus novimexicanus*			
90	Bentonite; gypsiferous; pale-yellowish-orange (10 YR 8/6); weathers very pale orange (10 YR 8/2).	-	2	0.05
89	Shale; olive-gray (5 Y 4/1), weathers light-olive-gray (5 Y 6/1), slope.	5	-	1.52
88	Calcarenite; fossiliferous; pale-brown (5 YR 5/2); fine-grained, subangular, moderate-sorting; thin-bedded; weathers light-brown (5 YR 5/6); moderately consolidated, slight break in slope; weathers to platy fragments. USGS Mesozoic locality D 10270	-	0.5	0.01

UNIT		FT	IN	METERS
	Scaphites whitfield			
87	Shale; calcareous, silty; medium-dark-gray (N 4) to brownish-gray (5 YR 4/1); weathers very pale orange (10 YR 8/2); slope.	1	3	0.38
86	Calcarenite; fossiliferous; pale-yellowish-brown (10 YR 7/2); fine-grained, subangular, moderate-sorting; weathers dark-yellowish-brown (10 YR 4/2); relatively hard; break in slope; weathers to platy fragments.	-	1	0.03
	USGS Mesozoic locality D 10126			
	Inoceramus dimidius			
85	Shale; calcareous; dark-yellowish-brown (10 YR 4/2); weathers yellowish-gray (5 Y 7/2).	1	6	0.46
84	Limestone; fossiliferous, finely crystalline; light-gray (N 7); weathers dark-yellowish-orange (10 YR 6/6); hard, resistant unit.	-	9	0.23
	USGS Mesozoic locality D 10269			
	Scaphites ferronensis			
	Inoceramus sp.			

UNIT		FT	IN	METERS
83	Shale; (partly covered) upper 2 ft is slightly calcareous; dark-yellowish-brown (10 YR 4/2) to pale-yellowish-brown (20 YR 5/4); weathers pale-yellowish-brown (10 YR 6/2), mottled moderate-yellowish-brown (10 YR 5/4); soft, slope.	4	3	1.30

Measured thickness of D-Cross Tongue is 121 ft 3.5 inches (36.97 m).

Tres Hermanos Sandstone Member

UNIT		FT	IN	METERS
82	Sandstone; slightly calcareous; moderate-orange-pink (5 YR 8/4), mottled light-brown (5 YR 5/6); fine-grained, subangular, moderate-sorting, medium-to thick-bedded, weathers dusky-brown (5 YR 2/2); hard, resistant; borrowed and bioturbated, assymmetric ripples, low-angle cross-stratification.	8	-	2.44
81	Covered.	5	-	1.53
80	Sandstone; calcareous; pinkish-gray (5 YR 7/1); fine-grained, subangular, moderate-sorting, weathers moderate-yellowish-brown (10 YR 5/4); well-consolidated, break in slope; burrowed.	-	3	0.08
79	Covered.	4	6	1.37
78	Sandstone; calcareous; dark-yellowish-orange (10 YR 6/6), mottled yellowish-gray (5 Y 8/1); fine-grained, subrounded, well-sorted; medium-bedded; weathers yellowish-orange (10 YR 6/6);	-	4	0.10

UNIT		FT	IN	METERS
	well-consolidated, break in slope; burrowed.			
77	Covered.	14	-	4.27
76	Sandstone; calcareous; moderate-brown (5 YR 3/4); very fine grained, subrounded, moderate-sorting; weathers pale-yellowish-orange (10 YR 8/6); well-consolidated, break in slope.	-	1	0.03
75	Shale; calcareous; medium-light-gray (N 7); soil covered slope.	6	-	1.83
74	Sandstone; calcareous; mottled light-brown (5 YR 6/4), yellowish-gray (5 YR 6/1) and grayish-orange (10 YR 7/4); fine-grained, subrounded, well-sorted; thin-bedded; weathers moderate-brown (5 YR 4/4); well-consolidated, break in slope.	2	6	0.76
73	Shale; medium-dark-gray (N 4); weathers light-gray (N 6); slope.	4	6	1.37
72	Sandstone; light-brown (5 YR 6/4) with very light gray (N 8) and grayish-red (5 YR 4/2) spots and streaks; medium-grained, sub-	-	3	0.08

UNIT		FT	IN	METERS
	angular, moderate-sorting; thin-bedded; weathers light-brown (5 YR 5/6); well-consolidated, break in slope.			
71	Shale; medium-dark-gray (N 4); weathers medium-light-gray (N 6); slope.	19	-	5.79
70	Sandstone; calcareous; moderate-brown (5 YR 4/4); medium-grained, subrounded, moderate-sorting; thin-bedded; weathers moderate-brown; well-consolidated, break in slope.	-	6	0.15
69	Shale; olive-gray (5 Y 4/1); weathers light-olive-gray (5 Y 6/1); slope.	7	6	2.29
68	Sandstone; slightly calcareous; medium-dark-gray (N 4); weathers medium-light-gray (N 6), mottled light-brown (5 YR 5/6); very fine grained, subrounded, well-sorted; thick-bedded; weathers pinkish-gray (5 YR 8/1); well-consolidated, break in slope.	13	6	4.11
67	Shale; slightly calcareous; medium-dark-gray (N 4); weathers	13	6	4.11

UNIT		FT	IN	METERS
	medium-light-gray (N 6); slope.			
66	Sandstone; very light gray (N 6) mottled light-brown (5 YR 5/6); very fine grained, subrounded, well-sorted; thick-bedded; weathers pinkish-gray (5 YR 8/1); well-consolidated, break in slope.	2	-	0.61
65	Sandstone; calcareous; very light gray (N 8) mottled dark-yellowish-orange (10 YR 6/6); fine-grained, subrounded, well-sorted; medium-bedded; weathers light-brown (5 YR 5/6) to dark-yellowish-orange (10 YR 6/6); well-consolidated, break in slope.	1	6	0.46
64	Covered.	14	-	4.27
63	Sandstone; calcareous; very light gray (N 8) mottled dark-yellowish-orange (10 YR 6/6); fine-grained, subrounded, well-sorted; medium-bedded; weathers light-brown (5 YR 5/6); to dark-yellowish-orange (10 YR 6/6); well-consolidated, break in slope; wood fragments.			

UNIT		FT	IN	METERS
62	Covered.	10	6	3.20
61	Sandstone; calcareous; very light gray (N 8); very fine grained, subrounded, well-sorted; thin-bedded; weathers light-brown (5 YR 6/4); moderately consolidated, break in slope.			
60	Covered; large concretions (up to 3 ft across) of calcareous, yellowish-gray (5 Y 8/1) sandstone that weather moderate-brown (5 Y 8/1) to moderate-brown (5 Y 4/4) near top of unit.	10	-	3.05
59	Sandstone; calcareous, very pale-orange (10 YR 8/2) mottled grayish-orange (10 YR 7/4); fine-grained, subangular, moderate-sorting; massive, moderate-consolidation, hummocky break in slope; burrowed.	2	9	0.84
58	Covered.	13	0	3.96
57	Sandstone; calcareous; yellowish-orange (10 YR 7/6); fine-grained, subangular, moderate-sorting; medium-bedded; weathers grayish-orange (10 YR 7/4); break in slope.	-	1	0.03

UNIT		FT	IN	METERS
56	Covered.	5	6	1.68
55	Sandstone; calcareous; light-gray (N 8), mottled light-brown (5 YR 5/6); medium-grained, subangular, moderate-sorting; thin-bedded; moderate-consolidation, break in slope.	-	3	0.08
54	Sandstone; (partly covered), slightly calcareous; light-gray (N 8); thin-bedded; very loosely consolidated, slope.	6	6	1.98
53	Sandstone; calcareous; light-gray (N 8), mottled light-brown (5 YR 5/6); medium-grained, subangular, moderate-sorting; thin-bedded; break in slope.	1	0	0.30
52	Shale; calcareous, light-bluish-gray (5 B 7/1); slope.	1	-	0.30
51	Sandstone; calcareous; light-gray (N 8), mottled light-brown (5 YR 5/6); medium-grained, subangular, moderate-sorting; thin-bedded; moderate-consolidation, slight break in slope.	-	1	0.30

UNIT		FT	IN	METERS
50	Shale; calcareous; light-bluish-gray; slope.	1	0	0.38
49	Sandstone; very light gray (N 8), mottled light-brown (5 YR 6/4); thin-bedded; weathers light-brown (5 YR 6/4); moderate-consolidation, break in slope; bioturbated, oscillation ripples.	1	3	0.38
48	Sandstone; (partly covered), calcareous; very light gray (N 8); medium-grained, subangular, moderate-sorting; weathers yellowish-gray (5 Y 8/1); moderate-to loose-consolidation, slope.	6	6	1.98
47	Sandstone; calcareous; yellowish-gray (5 Y 8/1); fine-grained, well-sorted, subrounded; thin-bedded; weathers yellowish-gray (5 Y 8/2); moderately indurated; burrowed.	6	6	1.98
46	Sandstone; calcareous; yellowish-gray (5 Y 8/1); fine-grained, well-sorted, subrounded; thin-bedded; weathers yellowish-gray (5 Y 8/2); moderate-induration, caps ridge; breaks to platy fragments, low-angle	5	-	1.52

UNIT		FT	IN	METERS
	cross-stratification.			
45	Sandstone; fossiliferous, concretionary, calcareous; yellowish-gray (5 Y 8/1); fine-grained, well-sorted, subrounded; weathers yellowish-gray (5 Y 8/2); resistant; large (up to 4 ft across) yellowish-brown (10 YR 4/2), fossiliferous concretions. USGS Mesozoic locality D 10268: <u>Collignoniceras</u> <u>mexicanum</u>	9	-	2.74
44	Sandstone; calcareous; yellowish-gray (5 Y 8/1); fine-grained, subrounded, well-sorted; thin-bedded; weathers yellowish-gray (5 Y 8/2); moderate-induration; breaks to platy fragments.	3	-	0.91
43	Sandstone; calcareous; yellowish-gray (5 Y 8/1) fine-grained, subrounded, well-sorted; thin-bedded; weathers yellowish-gray (5 Y 8/2); well-indurated; low-angle cross-stratification.	4	6	1.37
42	Sandstone; calcareous; yellowish-gray (5 Y 8/1); fine-grained,	4	-	1.22

UNIT		FT	IN	METERS
	subrounded, well-sorted; thin-bedded; weathers yellowish-gray (5 Y 8/2); moderate induration, break in slope; platy.			
41	Shale; calcareous; light-olive-gray (5 Y 5/1); slope.	13	-	3.96
40	Sandstone; calcareous; yellowish-gray (5 Y 7/2); fine-grained, subangular, moderate-sorting, thin-to thick-bedded; weathers grayish-orange (10 YR 7/4); well-consolidated; breaks to plates ¼ to ½ inch thick, contains plant fragments, feeding trails along bedding surfaces.	6	6	1.98

Measured thickness of Tres Hermanos Sandstone Member of Mancos Shale is 217 ft 5 inches (66.26 m).

Rio Salado Tongue

UNIT		FT	IN	METERS
39	Shale; (partly covered), slightly silty; medium-dark-gray (N 4) and light-olive-brown (5 Y 5/6); weathers yellowish-gray (5 Y 7/2); slope.	53	-	16.16
38	Covered.	65	-	19.81
37	Covered (thickness only approximate)	230	-	70.10

Measured thickness of Rio Salado tongue, including 230 ft (70.10) covered interval, is 348 ft (106.07 m).

Whitewater Arroyo Tongue

UNIT		FT	IN	METERS
34	Shale; partly covered, calcareous, slightly silty; olive-gray (5 Y 4/1); weathers medium-light-gray (N 6); slope; scattered medium-dark-gray (N 4) limestone concretions with irregular ovoids as large as 12 inches in diameter.	100	0	30.47
33	Bentonite; gypsiferous; weathers dark-yellowish-orange (10 YR 6/6).	-	1	0.03
32	Shale; calcareous, gypsiferous; olive-black (5 Y 2/1); weathers olive-gray (5 Y 3/1); slope; olive-black limestone concretions weather grayish-orange (10 YR 7/4).	9	-	2.74
31	Bentonite; gypsiferous; weathers dark-yellowish-orange (10 YR 6/6).	-	10	0.25
30	Shale; calcareous, gypsiferous; olive-black (5 Y 2/1); weathers olive-gray (5 Y 3/1); limestone concretions like unit 32.	3	6	1.07
29	Bentonite; gypsiferous; weathers dark-yellowish-orange (10 YR 6/6).	-	0.5	0.01

UNIT		FT	IN	METERS
28	Shale; calcareous, gypsiferous; olive-black (5 Y 2/1); weathers olive-gray (5 Y 3/1).	2	-	0.61
27	Bentonite; gypsiferous; weathers dark-yellowish-orange (10 YR 6/6).	-	1	0.03
26	Shale; calcareous, gypsiferous; olive-black (5 Y 2/1); weathers olive-gray (5 Y 3/1).	1	6	0.46
25	Bentonite; gypsiferous; weathers dark-yellowish-orange (10 YR 6/6).	-	1	0.03
24	Shale; calcareous, gypsiferous; olive-black (5 Y 2/1); weathers olive-gray (5 Y 3/1) scattered olive-black (5 Y 2/1) limestone concretions that weather grayish-orange (10 YR 7/4) and ovoid, as much as 12 inches in diameter.	10	0	3.05
23	Tertiary intrusive-shale complex; intrusives are andesitic; phenocrysts; pale-olive (10 Y 6/2); weathering olive-gray (5 Y 5/2).	80	-	24.38
22	Shale; calcareous; light-olive-gray (5 Y 6/1) weathers dark-yellowish-brown (10 YR 4/2).	2	-	7.31

UNIT		FT	IN	METERS
21	Shale; slightly calcareous; olive-gray (5 Y 3/2); weathers light-olive-gray (5 Y 5/2); slope.	24	-	7.31
20	Sandstone; fossiliferous, calcareous; pale-yellowish-brown (10 YR 6/2); fine-grained, subangular, well-sorted; thin-bedded; weathers pale-yellowish-brown (10 YR 6/2); well-consolidated, break in slope; burrowed. USGS Mesozoic locality D 10265 *Inoceramus* sp. *Ostrea belioti* *Turrilites acustus americanus* *Tarrantoceras rotatile*	-	5	0.31
19	Shale; calcareous; olive-gray (5 Y 4/1); weathers light-olive-gray (5 Y 6/1) slope.	-	2	0.05
18	Bentonite; weathers dark-yellowish-brown (10 YR 6/6).	-	1	0.03
17	Shale; calcareous; olive-gray (5 Y 4/1); weathers light-olive-gray (5 Y 6/1); slope.	2	10	0.86
16	Sandstone; calcareous, clayey; light-brownish-gray (5 YR 6/1);	-	1	0.03

UNIT		FT	IN	METERS
	fine-grained subangular, poorly sorted; weathers medium-gray (N 5); slope.			
15	Sandstone; calcareous; light-brown (5 YR 5/6); fine to very fine grained, subangular, well-sorted; thin-bedded; weathers dark-yellowish-orange (10 YR 6/6); well-consolidated, break in slope; burrowed.	1	-	0.30
14	Sandstone; calcareous, clayey; light-brownish-gray (5 YR 6/1); fine-grained, subangular, poorly sorted; very thin bedded; weathers medium-gray (N 5); very loosely consolidated, slope.	3	6	1.07
13	Sandstone; calcareous; light-brown (5 YR 5/6); fine to very fine grained, subangular, well-sorted; thin-bedded; weathers dark-yellowish-orange (10 YR 6/6); well-consolidated, break in slope; burrowed.	-	1	0.03
12	Sandstone; calcareous, clayey; olive-black (5 Y 2/1); fine-grained, subangular, poorly sorted; weathers	1	-	0.30

UNIT		FT	IN	METERS
	medium-gray (N 5); slope.			
11	Sandstone; calcareous; light-brown (5 YR 5/6); fine to very fine grained, subangular, well-sorted; thin-bedded; weathers dark-yellowish-orange (10 YR 6/6); break in slope.	-	1	0.03
10	Sandstone; calcareous, clayey; olive-black (5 Y 2/1); fine-grained, subangular, poorly sorted; very thin bedded; slope.	1	6	0.46
9	Sandstone; calcareous; light-brown (5 YR 5/6) fine to very fine grained, subangular, well-sorted; thin-bedded; weathers dark-yellowish-orange (10 YR 6/6); well-consolidated, break in slope; burrowed.	-	2	0.05
8	Sandstone; calcareous, clayey; olive-black (5 Y 2/1); fine-grained, subangular, poorly sorted; very thin bedded; weathers medium-gray (N 5); slope.	5	-	1.52
7	Sandstone; calcareous; dark-yellowish-brown (10 YR 6/6) with patches of medium-dark-gray (N 4); fine-grained, subrounded, well-sorted;	-	8	0.20

UNIT		FT	IN	METERS
	medium-bedded; weathers yellowish-gray (5 Y 7/2); break in slope.			
6	Siltstone with interbedded shales; calcareous; dark-gray (N 3); thin to very thin bedded; weathers yellowish-gray (5 Y 7/2); slope.	15	-	4.57
5	Siltstone; calcareous; pale-yellowish-brown (10 YR 6/2); covered with white (N 9) caliche.	1	6	0.46
4	Sandstone; calcareous; dark-yellowish-orange (10 YR 6/6) medium-dark-gray (N 4) patches; medium-grained, subangular, moderate-sorting; medium-bedded; loosely consolidated; change in slope or soil covered slope.	2	-	0.61

Measured thickness of Whitewater Arroyo Tongue of Mancos Shale, including intrusive complex 80 ft (24.38 m), is 268 ft 2.5 inches (81.76 m).

UNIT FT IN METERS

scattered limestone; concretions like those in unit 34; transitional into overlying and underlying units.

Measured thickness of Twowells Tongue of Dakota Sandstone is 54 ft (16.46 m).

Twowells Tongue of the Dakota Sandstone

UNIT		FT	IN	METERS
36	Sandstone; fossiliferous, calcareous; very light gray (N 8), irregular dark-yellowish-orange (10 YR 6/6) and medium-gray (N 4) patches; medium-grained, subrounded, well-sorted, massive-to thick-bedded; weathers yellowish-gray (5 Y 8/1); resistant, ridge; burrowed; uppermost bed is a medium-grained, rounded, well-sorted, saccharoidal sandstone that weathers to a distinctive light-brown (5 YR 5/6). USGS Mesozoic locality D 10267 *Metoicoceras defordei* *Pycnodonte* sp. *Exogyra levis*	49	-	14.94
35	Sandstone; concretionary, calcareous, clayey; light-olive-gray (5 Y 6/1); fine-grained, subrounded, moderate-sorting; weathers yellowish-gray (5 Y 8/1); moderate-consolidation;	5	-	1.52

Dakota Sandstone

UNIT		FT	IN	METERS
3	Sandstone; (largely rubble covered slope) calcareous; yellowish-gray (5 Y 7/2); weathers grayish-orange (10 YR 7/4) with brownish-black (5 YR 2/1) desert varnish; medium-grained, rounded, moderate-sorting; thick-bedded; well-indurated.	5	-	1.52
2	Sandstone; slightly calcareous; very light gray (N 8); fine-grained, subrounded, moderate-sorting; massive; weathers light-brown (5 YR 5/7) with brownish-black (5 YR 2/1) desert varnish; well-indurated, ridge.	17	-	5.18
1	Sandstone; very light gray (N 8); very fine grained, subrounded, well-sorted; thin-bedded; weathers very light gray (N 8); moderate-consolidation.	1	6	0.46

Measured thickness of main body of Dakota Sandstone is 23 ft 6 inches (7.16 m).

VITA

Gary Lee Massingill was born in Snyder, Texas on August 8, 1946. He received both his primary and secondary education in the Snyder public school system. After graduation from Snyder High School in 1964, he attended Howard County Junior College at Big Spring, Texas until December, 1966. He then transferred to West Texas State University in Canyon, Texas, where he received a Bachelor of Science degree in Geology in July, 1969. After graduation he entered Officer's Training School at Lackland Air Force Base, Texas and received a commission as Second Lieutenant on March 11, 1970. As an officer in the United States Air Force he served as a Vehicle Maintenance Officer at Bergstrom Air Force Base, Texas and Osan Air Force Base, Korea until honorably discharged at the rank of Captain in June, 1972. In June, 1975 he graduated with a Master of Science degree from West Texas State University. He entered the graduate program for a Doctor of Geological Science degree at the University of Texas at El Paso in September, 1975. He is currently employed by the New Mexico Bureau of Mines and Mineral Resources at Socorro, New Mexico.

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GEOLOGIC MAP OF THE RILEY AREA, SOCORRO COUNTY, NEW MEXICO

GEOLOGY by GARY MASSINGILL
Summers of 1976 and 1977

CARTOGRAPHY by D. L. KUHFAL

Department of Geological Sciences
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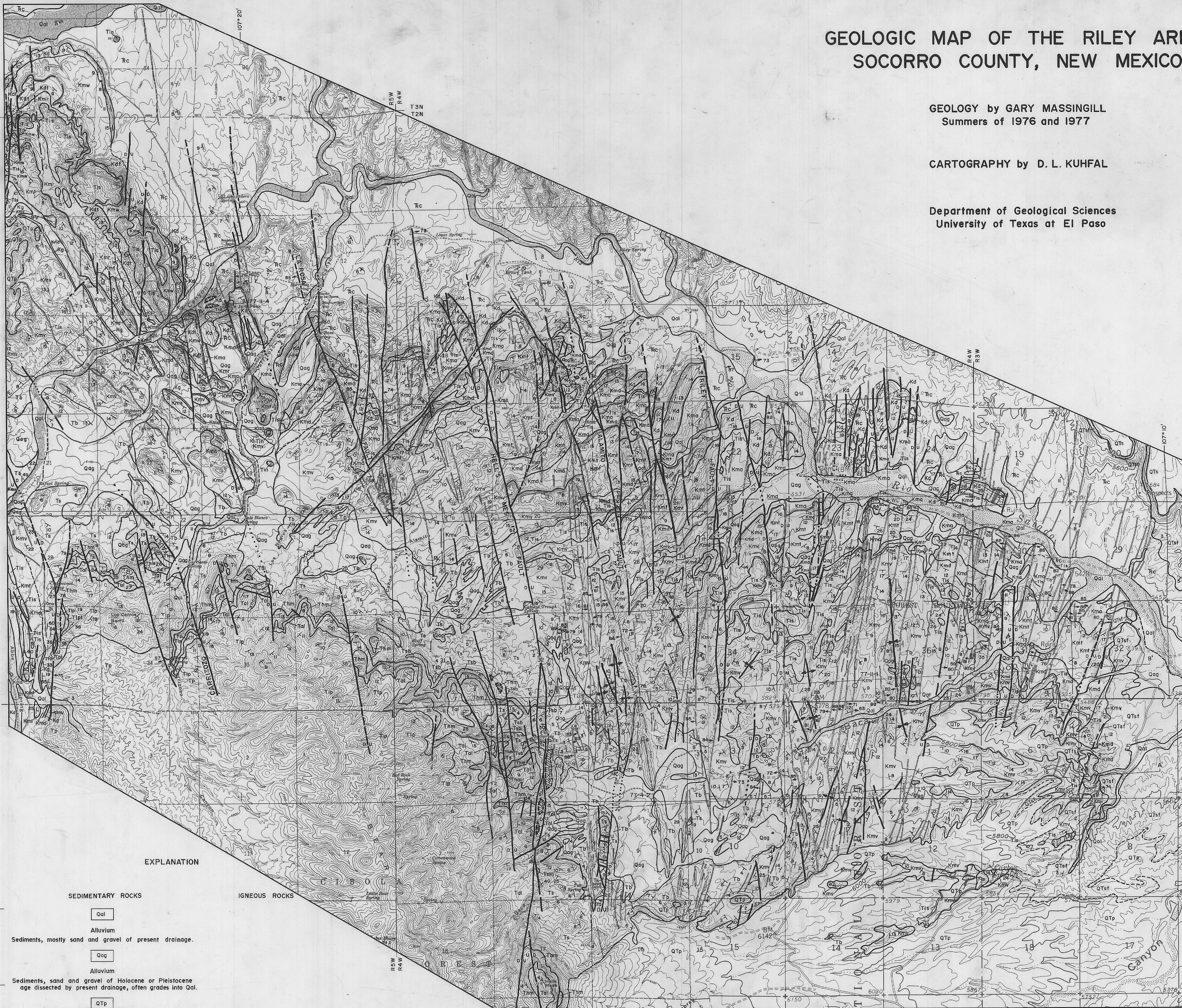

EXPLANATION

SEDIMENTARY ROCKS

HOLOCENE

Qal

Alluvium
Sediments, mostly sand and gravel of present drainage.

Qag

Alluvium
Sediments, sand and gravel of Holocene or Pleistocene age dissected by present drainage, often grades into Qal.

PLIO-PLEISTOCENE

QTp

Piedmont Gravels (upper or post Santa Fe Group); fanglomerate, grayish-purple

Tp — QTsf — QTs

QTs- Spring deposit (upper Santa Fe Group); travertine

QTsf- Santa Fe Group undivided (Sierra Ladrones Formation and possibly in part upper Popotosa Formation) conglomerates, sandstones, and siltstones

Tp- Popotosa Formation (lower Santa Fe Group); conglomerate

MIOCENE

Tlp — Tlpt

Tlp - La Jara Peak Basaltic Andesite
Basaltic-andesite flows, interbedded with Popotosa Formation in upper part.

Tlpt - Lithic tuff, interbedded with La Jara Peak Basaltic Andesite

UNCONFORMITY

OLIGOCENE

Tal

A-L Peak Tuff
Ash-flow tuffs, rhyolitic, crystal-poor, basaltic-andesite flow interbedded near middle.

Thm

Hells Mesa Tuff
Ash-flow tuffs, rhyolitic, crystal-rich, quartz-rich.

Ts — Tsb

Spears Formation
Ts-Volcaniclastic sands, conglomerates, silts, and mudstones.
Tsb-Basaltic-Andesite flow

GRADATIONAL, INTERBEDDED CONTACT

EOCENE

Tb

Baca Formation
Arkosic conglomerates, sandstones, and red mudstones.

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UPPER CRETACEOUS

Kmv

Mesaverde Formation
Grayish-yellow sandstones and silty, grayish-yellow shales, gray shales and coal beds, contains ironstone nodules.

Kg

Gallego Sandstone
Light-gray weathering to yellow-gray, fossiliferous sandstone, contains *Lopha sannionis* at top.

Kmd
Kmt
Kmr
Kma — Kdt
Kmw

Mancos Shale

Kmd-D-Cross Tongue of the Mancos Shale
Dark-gray weathering to olive-gray, fossiliferous, concretionary shale, contains *Scaphites whitfieldi* and *Prionocyclus novimexicanus*.

Kmt-Tres Hermanos Sandstone Tongue
Interbedded light-gray weathering to yellowish-gray sandstones and dark-gray weathering to light-gray organic shales, contains *Collignoniceras mexicanum* at base.

Kma-Alamito Well Tongue
Dark-gray weathering to medium-gray, silty, fossiliferous, concretionary shale, contains *Pycnodonte newberryi*, *Sciponoceras gracile*, and *Mammites depressus*.

Kmr-Rio Salado Tongue
Shale, dark-gray weathering to medium-gray, silty, fossiliferous, concretionary, contains *Pycnodonte newberryi*, *Sciponoceras gracile* and *Mammites depressus*.

Kmw-Whitewater Arroyo Tongue
Shale, dark-gray weathering to olive-gray, several bentonite beds; includes Paguate Sandstone time-equivalent, interbedded light-gray weathering to yellowish-gray, calcareous, fossiliferous sandstones and olive-gray, shales, contains *Ostrea beloiti*.

Kd — Kdt

Dakota Sandstone
Kd-Sandstone, yellowish-gray, iron-stained
Kdt-Twowells Tongue
Sandstone, light-gray weathering to yellow-gray.

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TRIASSIC

₮c

Chinle Formation
Grayish-red, reddish-brown, and greenish-gray shales, silts, sands and conglomerates.

IGNEOUS ROCKS

Tin

Necks
Basalt and diorite intrusions.

Tis Ti
Sills Dikes
Basaltic andesite and basalt intrusions.

Formation contact. Dashed where uncertain.

U
D

Fault. U represents upthrown side, D represents downthrown side. Dashed where uncertained, dotted concealed.

Synclinal axes.

Anticlinal axes.

Kd$_L$

Slump.

4

Strike and dip of beds.

78

Strike and dip of faults and dikes.

Intermittent stream.

Dirt road. Dashed where unimproved.

Mine adit.

× 7812

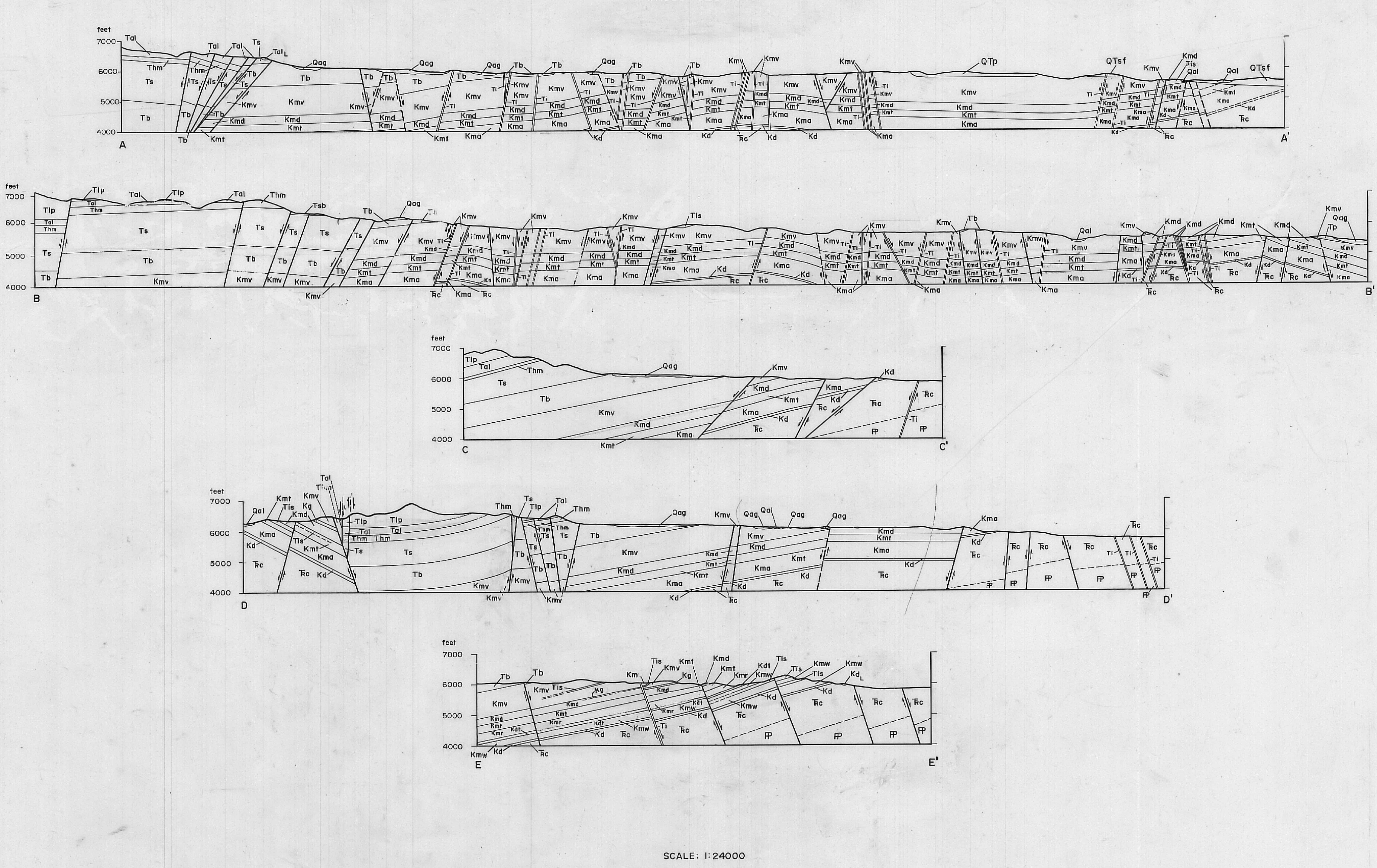
Point elevation

Building

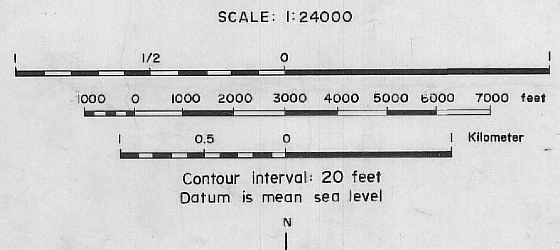
77-4-2

Sample location

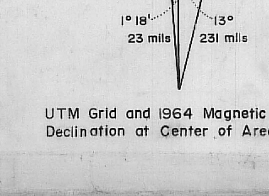
CROSS-SECTIONS



SCALE: 1:24000

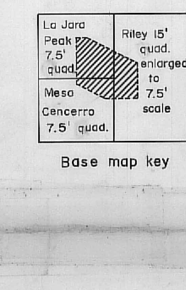


Contour interval: 20 feet
Datum is mean sea level



UTM Grid and 1964 Magnetic North
Declination at Center of Area

Study Area Location



Base map key