GEOLOGY OF THE D CROSS MOUNTAIN QUADRANGLE
SOCORRO AND CATRON COUNTIES,
NEW MEXICO

APPROVED:

David V. LeMone
Chairman

APPROVED:

Dean of Graduate School

GEOLOGY OF THE D CROSS MOUNTAIN QUADRANGLE,
SOCORRO AND CATRON COUNTIES,
NEW MEXICO

by

BOB RUSSELL ROBINSON

Bachelor of Science; Master of Science

DISSERTATION

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

for the Degree of

DOCTOR OF GEOLOGICAL SCIENCES

IN GEOLOGY

THE UNIVERSITY OF TEXAS AT EL PASO

May, 1981

ACKNOWLEDGEMENTS

I thank Dr. David LeMone, my committee chairman, for his help in all phases of this undertaking, especially for his desire and demand that the job be completed. The other members of my committee were always available and cooperative in solving any problems that I encountered. Dr. C. Stuart was especially helpful with sedimentological interpretations. Dr. C. Chapin, Dr. S. Hook, D. Tabet and F. Campbell of the New Mexico Bureau of Mines and Mineral Resources provided both needed criticism and encouragement that enabled me to better understand and enjoy my work. Finally to R. Mills and a cast of thousands that insisted that this dissertation be completed, I give my sincerest kudos. Funding was provided for this study by the New Mexico Bureau of Mines and Mineral Resources as project number 816-246 NW.

ABSTRACT

Approximately 5000 ft (1525 m) of strata crop out in the D Cross Mountain quadrangle in west-central New Mexico. The oldest strata are red shales and sandstones of the Chinle Formation (Late Triassic) that accumulated on an extensive, low-lying, coastal plain in a meandering stream complex. Jurassic age strata, if deposited in the area, were subsequently eroded due to uplift of the Mogollon Highlands and north-northwest tilting of the area during the Jurassic.

The basal Dakota Sandstone was deposited by laterally planing, meandering streams before regional subsidence during the Cenomanian resulted in the initial encroachment of the mid-continent Cretaceous seaway into the Acoma embayment.

The area oscillated between paralic and coastal nonmarine environments for the remainder of the Cretaceous Period. As a result, a complex sequence of dark, offshore marine muds of the Mancos Shale interfinger to the west with coastal marine and fluvial sandstones and shales of the Dakota, Tres Hermanos, Gallup, and Crevasse Canyon Formations.

Northeast-directed compressional forces associated with the Laramide orogeny deformed the strata into a series of broad open folds at the close of Cretaceous time. Pebble conglomerates and arkosic sandstones of the Baca Formation (Eocene) were eroded from the Zuni Mountains, transported to

the southeast in a fluvial channel-floodplain complex, and accumulated in an east-trending, elongate, structural low.

A thick cover of volcanic and volcaniclastic rocks spread over the area during the Oligocene. Lithic-crystal and crystal-lithic tuffs and debris flows of the Spears Formation were derived from a major volcanic center located south of the D Cross Mountain quadrangle.

After cessation of volcanism, sediments were stripped from this volcanic highland and accumulated in a northward extending alluvial fan complex. The Miocene (?) conglomerate of Rock Tank Canyon is a fanglomerate that was derived principally from erosion of Spears tuffs.

The dominant structure of the area is a south-dipping homocline formed as the result of uplift of the Colorado Plateau. The continuity of the homocline is, however, broken by a series of Neogene normal faults that formed in response to the opening of the Rio Grande rift. Volcanic necks and plugs cropping out on D Cross Mountain and Blue Mesa were emplaced during the Late Tertiary and appear to post-date uplift of the Plateau.

CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

Page

INTRODUCTION

Location and Access

The study area is located approximately 40 mi (64 km) northwest of Magdalena, New Mexico, in the northeastern part of Catron County and the northwestern part of Socorro County (Figure 1). This 64 mi^2 area is included entirely on the D Cross Mountain 7 1/2' topographic sheet published by the United States Geological Survey. Access to the D Cross Mountain area is most easily obtained by a graded road to the Martin Ranch, which intersects State Highway 52, approximately 25 mi (65 km) north of Magdalena.

Climate and Vegetation

Precipitation in the study area is approximately 12 in. (30 cm) annually and occurs most frequently as downpours during the summer and early fall. Temperatures range from slightly over 100^{o}F (38^{o}C) on summer days to well below freezing during winter nights. The area is classifed as a semiarid desert.

Vegetation is typical of high elevation, semiarid regions of the southwest. Trees common to the area include: Pinyon Pine, Rocky Mountain Juniper, and Staghorn Cholla. Rio Grande Cottonwood and Bonpoland Willows are abundant along the courses of larger, sandy creeks and at higher elevations stands of Ponderosa Pine occur on sandstone dip slopes. Various shrubs, grasses, cacti, and small oak trees

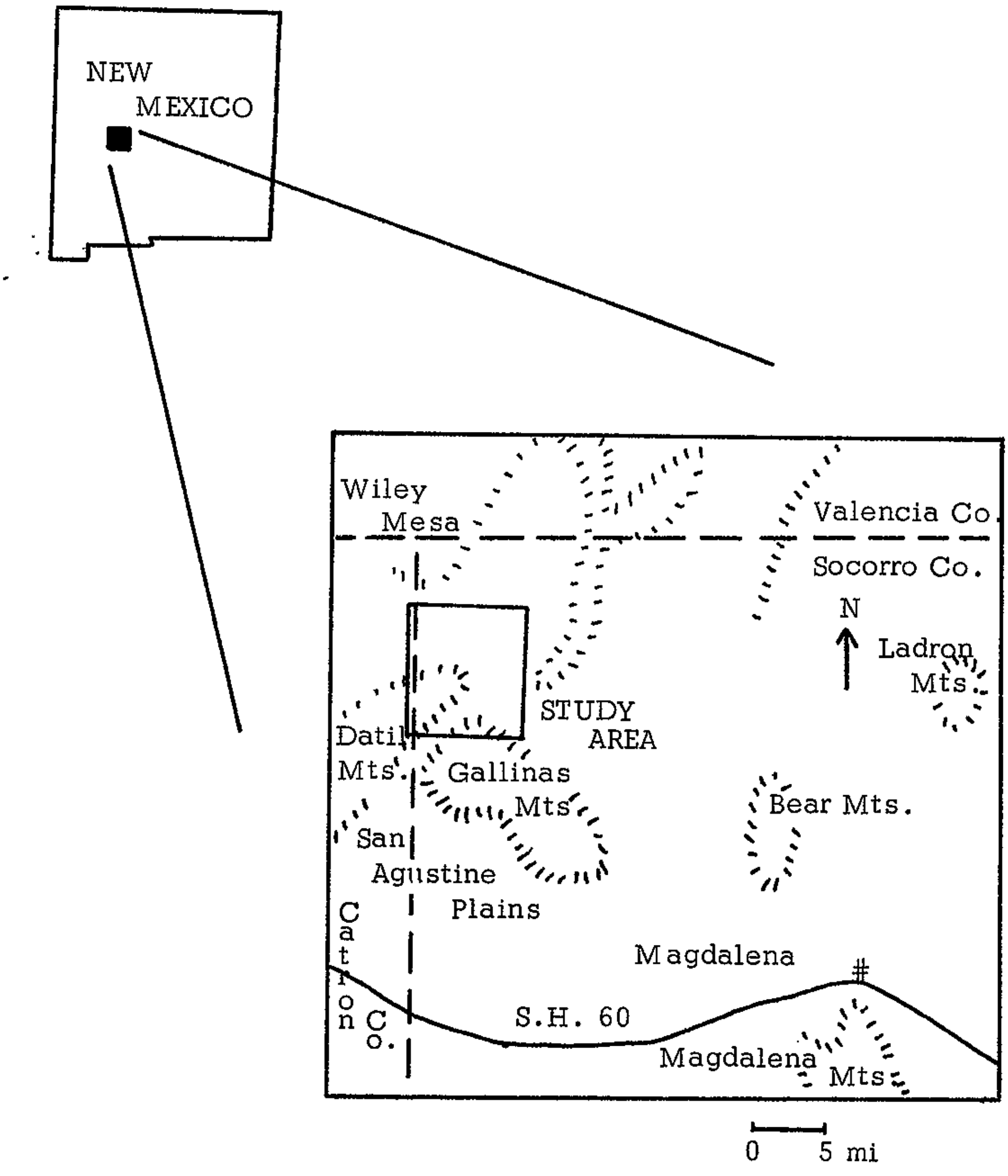


Figure 1. Map showing the location of the study area.

also flourish within the area. The vegetation is of the Upper Sonoran to Transition Life Zones.

Larger forms of wildlife are not abundant in the area. Rabbit, deer, snakes, rodents, and birds are most common. Fox, coyote, mountain lion, bobcat, and black bear are rare.

The area is used exclusively for domestic livestock grazing. Plentiful well-water and apparently adequate foliage support moderate-size herds of cattle.

Physiography

The D Cross Mountain quadrangle is within the Datil subdivision of the Basin and Range physiographic province (Hawley and others, 1976). Three prominent mountain ranges, the Gallinas Mountains, Datil Mountains (Blue Mesa), and D Cross Mountain, extend into the area (Plate 2). The Gallinas Range is composed of rounded hills of deeply incised quartz latite tuffs of the Spears Formation. Blue Mesa, with a maximum elevation of 8541 ft (2604 m), is the highest of the three ranges and is capped by a series of flat-lying basalt flows which have prevented development of, and subsequent downcutting by any major stream system. As a result, the northern end of Blue Mesa is a large monolithic rock mass. D Cross Mountain is a volcanic neck which has intruded into gently dipping Cretaceous age sandstones and shales. Differential erosion of the shales and sandstones has produced a series of benches and cliffs on the slopes of the mountain.

Plate 2. D Cross Mountain Area--view is to the northwest. The light colored hills in the left foreground are the Gallinas Mountains; darker mountain in left background is Blue Mesa; D Cross Mountain in right background.

Easily eroded Chinle and Crevasse Canyon strata form a rolling hill topography in the northeastern portion of the mapped area. On the east side of Blue Mesa and the north face of the Gallinas Mountains, pediment surfaces that dip away from the mountain fronts are the dominant landforms.

Alamocita Creek, a large sandy ephemeral stream, flows east and cuts obliquely across the structural grain of the area. Tributaries of the master stream are dominantly north-trending.

Local relief is approximately 2200 ft (670 m), ranging from 6380 ft (1945 m) in the bed of Alamocita Creek where it exits the study area, to 8541 ft (2603 m) on Blue Mesa. D Cross Mountain rises 8495 ft (2589 m) above sea level.

Purpose and Scope

The purpose of this study was to map and describe the geology of the D Cross Mountain quadrangle. The area was mapped during 1978-80 at a scale of 1:24,000 using United States Geological Survey (USGS) topographic sheets and United States Forest Service color aerial photographs.

Measured sections were used to integrate the area into the regional geologic setting and to determine the lateral extent, geometry, and relations of the mapped units. Environmental interpretations are based on unit geometry, fossil content, the type of unit contacts, and vertical and lateral sequences of sedimentary structures. Sixty five thin-sections were examined petrographically for grain size, sorting, grain morphology, mineralogy, and diagenetic changes to augment hand-specimen descriptions of the rock units. Additionally, 18 ultra-thin coal sections were examined for maceral components. Four coal samples were analyzed for B.T.U. value, and whole-rock analyses of the major oxides were obtained from two igneous rock units. Rock colors were determined in the field using the Geological Society of America rock color chart.

Previous Work

Herrick (1900) was the first geologist to report on the strata cropping out in the D Cross Mountain area. He produced a reconnaissance strip map along the course of Alamocita Creek and broadly differentiated Triassic, Cretaceous, and volcanic rock units.

Winchester (1920) studied the Cretaceous strata as a part of a coal evaluation program of the upper Rio Salado drainage basin. Based on stratigraphic sections measured in the study area, Winchester introduced several new formational names into the literature.

The oil and gas possibilities of the area were reported on by Wells (1919). In this report Wells briefly described the stratigraphy and structure of a portion of the D Cross Mountain quadrangle.

The area was mapped at a scale of approximately 1:126,000 by Givens (1957) as a part of the Dog Springs quadrangle. His map is, however, of a general nature.

Many geologists (Pike, 1947; Landis, Dane and Cobban, 1973; and Molenaar, 1973) have measured partial sections of the Cretaceous strata cropping out in the area in an attempt to construct regional stratigraphic cross-sections. The Cretaceous paleontology has been extensively discussed by Landis, Dane and Cobban (1973), Cobban (1977a and 1977b), Cobban and Hook (1979), Hook and Cobban (1977, 1979, 1980a, and 1980b), and Hook, Cobban and Landis (1980). Other reports that have briefly noted the geology of the area are referenced within the text.

Regional Setting

The D Cross Mountain quadrangle is located between the Acoma embayment and the Mogollon slope (Figure 2). The Acoma embayment, a regional synclinal structure composed of faulted and folded Mesozoic strata that dip gently to the southwest, grades northward into the San Juan Basin. The Mogollon slope is the southern boundary of the Colorado Plateau (Fitzsimmons, 1959) and is formed by southward dipping Tertiary volcanics and associated sedimentary rocks.

The Zuni Mountains are a northwest-trending, assymmetrical, doubly plunging anticline. The uplifted block is 50 mi (80 km) long and 20 mi (32 km) wide and has been structurally elevated approximately 5000 ft (1525 m) (Kelley, 1955). Precambrian granites and metamorphic rocks are exposed in the core of the structure. Paleozoic carbonate and clastic rocks dip away from the crest of the anticline.

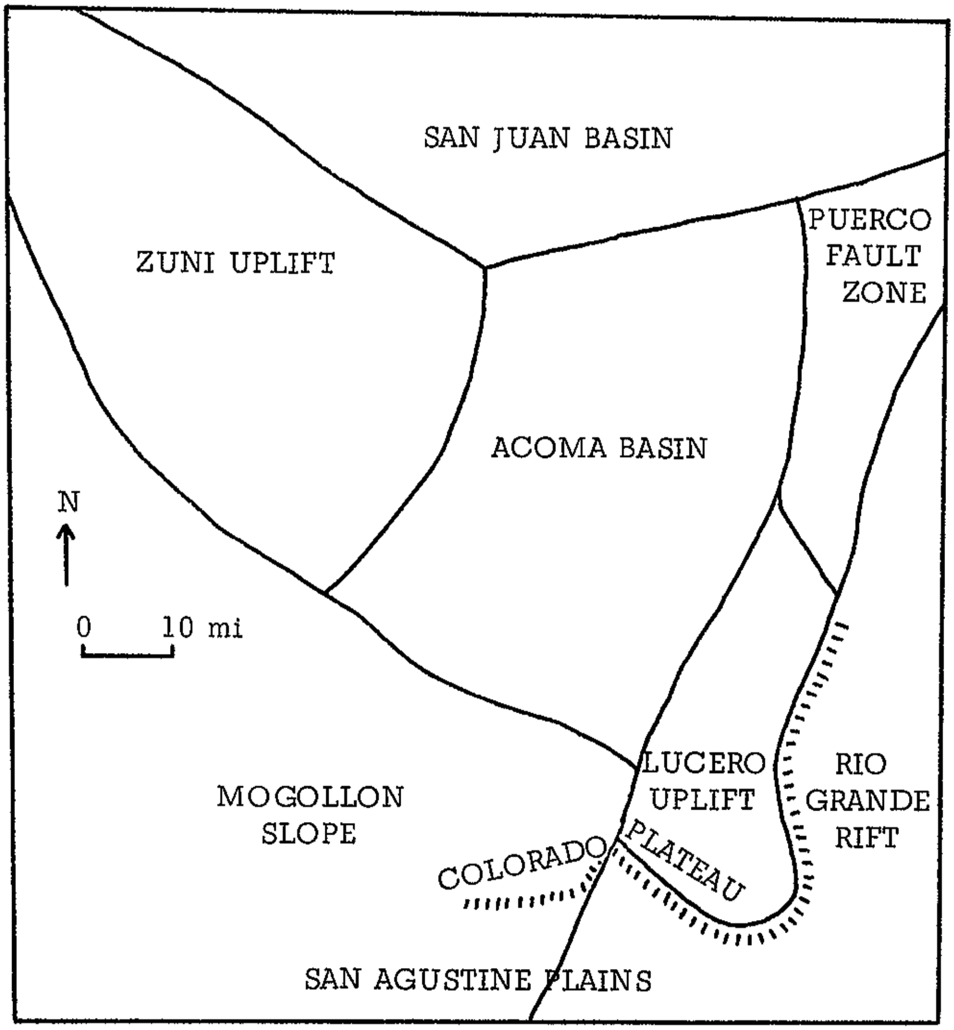


Figure 2. Map showing the location of the major structural elements in northwestern New Mexico.

The Lucero uplift and Puerco fault zone border the study area to the west. The Lucero uplift is a 10 mi (16 km) wide, 40 mi (64 km) long, asymmetrical, uplifted block that trends N 10° E. Strata involved in the uplift have undergone broad arching and overthrusting associated with the Laramide orogeny (Kelley and Wood, 1946) and the Southern Rocky Mountain deformation belt (Kelley, 1957).

The Puerco fault zone is a series of north-northeast-trending down-to-the-west normal faults. The fault zone is 7-22 mi (10-34 km) wide and 30 mi (48 km) long. Strata within the zone dip gently to the east. The major faults are of basin and range origin (Kelley, 1957), although basin formation within the Rio Grande rift has affected the area.

Southeast of the study area, opening of the Rio Grande rift has produced several graben structures. The Mulligan Gulch graben forms a north-trending topographic low between the Bear-Magdalena and Gallinas-San Mateo Mountains. This graben structure began to form approximately 26 m.y. B.P. (C. Chapin, oral commun., 1979). The San Augustine Plains, a flat, extensive surface located south of the Gallinas Mountains, is also a gravel-filled basin that is part of the southwest-trending graben complex that formed in response to opening of the Rio Grande rift (Chapin and other, 1975).

STRATIGRAPHY

Approximately 5000 ft (1525 m) of Triassic through Quaternary age strata crop out in the D Cross Mountain quadrangle (Figure 3). These rocks represent a plethora of depositional environments that reflect the evolving climatic, tectonic, volcanic and sedimentalogical conditions prevalent in the area during the past 200 million years.

Triassic System

The Triassic System is represented by the Chinle Formation in the D Cross Mountain area. Only a partial section of the formation is exposed in the study area. Younger Triassic or Jurassic strata, if deposited, were subsequently eroded from the area.

Chinle Formation

The term "Chinle" was originally applied by Gregory (1916) to "highly colored ... shales and sandstone" that are exposed in Chinle Valley, Arizona. At the reference section, Gregory divided the formation into four informal units. Correlatives of these are not recognized in the Acoma basin.

Tonking (1957) was the first person to use the Chinle terminology for strata cropping out in the Acoma basin. In the Puertecito area, he divided the formation into four informal units. Later, Givens (1957) applied the name

AGE			STRATIGRAPHIC UNIT		
CENOZOIC	QUAT	Holo.			unconsolidated gravels
		Pleis.			Blue Mesa Basalts
	TERTIARY	Plio.			
		Mio.			conglomerate of Rock Tank Canyon
		Oligo.			Spears Formation
		Eocene			Baca Formation
MESOZOIC	CRETACEOUS	Conia.	Mesa-verde Group		Crevasse Canyon Formation
					Gallup Sandstone
			Mancos Shale		D Cross tongue
				Tres Hermanos Sandstone	Fite Ranch Member
		Turonian			Carthage Member
					Atarque Member
					Rio Salado tongue
				Dakota Sandstone	Twowells tongue
					Whitewater Arroyo tongue
		Cenomaian		Dakota Sandstone	Paguate tongue
					INM Springs tongue
					Dakota Sandstone-main body
	Triassic				Chinle Formation

Figure 3. Stratigraphic column for the D Cross Mountain area, New Mexico.

Chinle Formation to a series of "red shales and mudstones" that crop out west of the Red Lake fault in the D Cross Mountain quadrangle. Winchester (1920) had earlier used only "Red Beds" to designate these same strata. Following the usage of Givens (1957), two informal divisions of the Chinle are recognized in the map area: an upper shale unit and a lower sandstone unit. Based on comparisons of the Chinle in the study area with Tonking's descriptions, the sandstone and shale units of D Cross Mountain probably correlate with Tonking's units three and four, respectively.

Regionally, the Chinle is discordantly overlain by the Cretaceous Dakota Sandstone. The unconformity between the two formations is not obvious locally. The basal contact of the Chinle is not exposed in the D Cross Mountain quadrangle and a complete stratigraphic section could not be measured. From well log data, Foster (1964) inferred that 1475 ft (450 m) of Chinle strata are present in the subsurface in the vicinity of D Cross Mountain. The Chinle appears to maintain a uniform thickness from north-central New Mexico southward until reaching the zero isopach line for Jurassic rocks in Valencia County, New Mexico (Foster, 1964). South of this line, the Chinle thins rapidly and pinches out along a west-northwest-trending line passing through Reserve, New Mexico (Foster, 1964). The southwest thinning of the Chinle is largely the result of post-Triassic erosion although some depositional thinning cannot be ruled out.

No diagnostic fossils were collected from the Chinle strata, although silicified wood fragments are present. In other areas, vertebrate fossils, "fossil forest", and fresh water bivalves have been reported (Daugherty, 1941). These fossils indicate a Late Triassic age for the Chinle (McKee, 1951).

The lower sandstone unit of the Chinle Formation consists of approximately 50 ft (15 m) of thin- to thick-bedded, white, red and lavender sandstones and siltstones (Plate 3). The sandstones are moderately indurated, very calcareous, fine- to very fine-grained, moderately to well-sorted, submature lithic arkoses. Subangular to subrounded grains of quartz are the most common framework constituent and comprise 65-70% of the rock. Vacuolized plagioclase, orthoclase, muscovite, opaque minerals, chert, subhedral zircon, and badly weathered volcanic (?) rock fragments occur in varying amounts (Appendix A).

The rock is cemented by large, 0.2 in. (51 mm)-diameter, equant calcite crystals and has a poikilitic texture. Partial replacement of the framework grains by the calcite cement is common. Fine- to coarse-textured chert and kaolinite are locally prominent cements.

The sandstone unit is composed of a series of large scale cut-and-fill deposits. Each cut-and-fill feature is bounded by an upper and lower curved truncation surface. Each sedimentation unit exhibits a characteristic sequence of sedimentary structures and is normally graded. The

Plate 3. Channel sandstone in the Chinle Formation--the sandstone unit occurs in the basal 50 ft (15 m) of the formation. Photograph was taken in Section 10, T. 3 N., R. 8 W.

sequence is, from the base upward: (1) a 0.5-1.0 ft (15-30 cm) thick, structureless or crudely cross-stratified, clay-clast conglomerate, (2) a 3-10 ft (1-3 m) thick zone of large-scale trough cross-stratified sandstone, and (3) a zone of variable thickness of small scale trough cross-stratifications and microcross-laminations. Paleocurrent flow direction as determined from the orientation of channel axes and maximum forset dip directions gave a mean flow direction of N 2^{o} E (Appendix B).

The shale unit is composed of approximately 150 ft (46 m) of intercalated shale and siltstone. The broad, low valley north of the INM Ranch is covered with red soil eroded from this nonresistant shale unit. Only the upper 25-30 ft (8-9 m) of the shale unit, immediately beneath a ridge capped by Dakota Sandstone, is exposed. In the cliff face the rock is dominantly a red to lavender, silty, slightly calcareous, bentonitic, mottled shale. The upper 0.5-2.0 ft (0.15-0.6 m) of the shale is white, probably the result of leaching by ground water which percolated through the porous Dakota Sandstone.

The Chinle strata represent a classic continental "red-bed" deposit that accumulated on a broad northeast-sloping coastal plain. The high shale to sandstone ratio and the sequence and type of sedimentary structures in the sandstone unit is suggestive of deposition as point-bars in laterally migrating, mixed-load, meandering streams as described by Galloway (1977). Wood fragments and root mottling, a lack of primary sedimentary structures in the shale member, and "oxidized" color are characteristics generally associated with subaerial terrestrial environments such as flood plains that develop adjacent to meandering stream channels. O'Sullivan (1977) has proposed a similar depositional model for much of the Chinle strata cropping out in New Mexico.

Cretaceous System

Approximately 1700 ft (520 m) of Cretaceous strata are exposed in the mapped area. The largest exposures of Cretaceous rocks are confined to a triangular-shaped segment west of the Red Lake fault (Plate 4). A small exposure of Crevasse Canyon Formation, north of Alamocita Creek, is the only Cretaceous strata that crops out on the east side of the Red Lake fault.

In earlier studies, correlations of Cretaceous strata between isolated outcrop areas were based primarily on counting the number of sandstones upward from the base of the sequence and attempting to match these on a one-to-one basis. Recent and ongoing investigations of the regional Cretaceous stratigraphy by staff members of the United States Geological Survey and the New Mexico Bureau of Mines and Mineral Resources have resulted in extensive revision of the lithostratigraphic terminology of Cretaceous strata cropping out in the San Juan, Acoma, and Zuni basins.

In the area mapped in this study, five distinct formations, ranging in age from Cenomanian to Coniacian, have

Plate 4. Cretaceous strata exposed on the east slope of D Cross Mountain--the section is composed of approximately 1700 ft (520 m) of interbedded cliff-forming sandstones and shales. The red shale unit in the foreground is Chinle shale.

been delineated. The Cretaceous stratigraphy is shown in Figures 4 and 5. These lithostratigraphic units represent sediments that accumulated in three depositional environments: (1) offshore marine, (2) coastal paralic and (3) continental fluvial.

Dakota Sandstone

The basal Cretaceous unit is the Dakota Sandstone. The reference section for the Dakota was described by Meek and Hayden (1861) in the vicinity of Dakota, Nebraska. Herrick (1900) was apparently the first to extend the Dakota terminology into the Acoma basin. Regional studies of the intertongued relations of marine and nonmarine Cretaceous rocks in northwestern New Mexico have shown that in the San Juan and Acoma basins the Dakota Sandstone is not a simple, single sandstone body, but is split into several discrete sandstone packages by intervening tongues of Mancos Shale. In general, the Dakota tongues merge to become a single unit near the New Mexico-Arizona border. In the map area three Dakota units are recognized, these are, in ascending stratigraphic order: (1) Dakota Sandstone (main body), (2) Paguate tongue, and (3) Twowells tongue.

Dakota Sandstone Main Body

Within the Acoma basin the main body of the Dakota Sandstone ranges from 6 ft (2 m) thick in the Puertecito area (Tonking, 1957) to 94 ft (29 m) thick in the

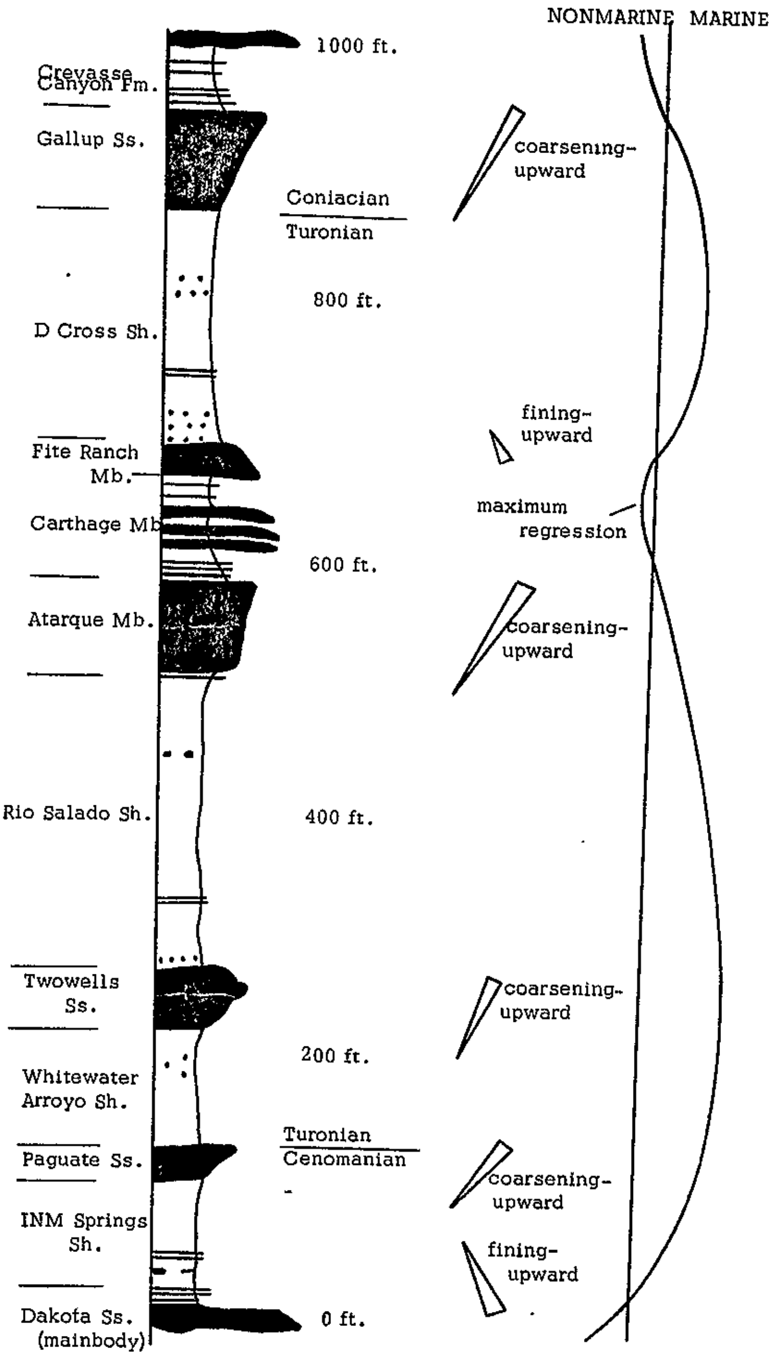


Figure 4. Generalized section of the marine, Cretaceous rocks cropping out in the D Cross Mountain area. Notice the close relation of coarsening upward sandstone packages to regressive episodes.

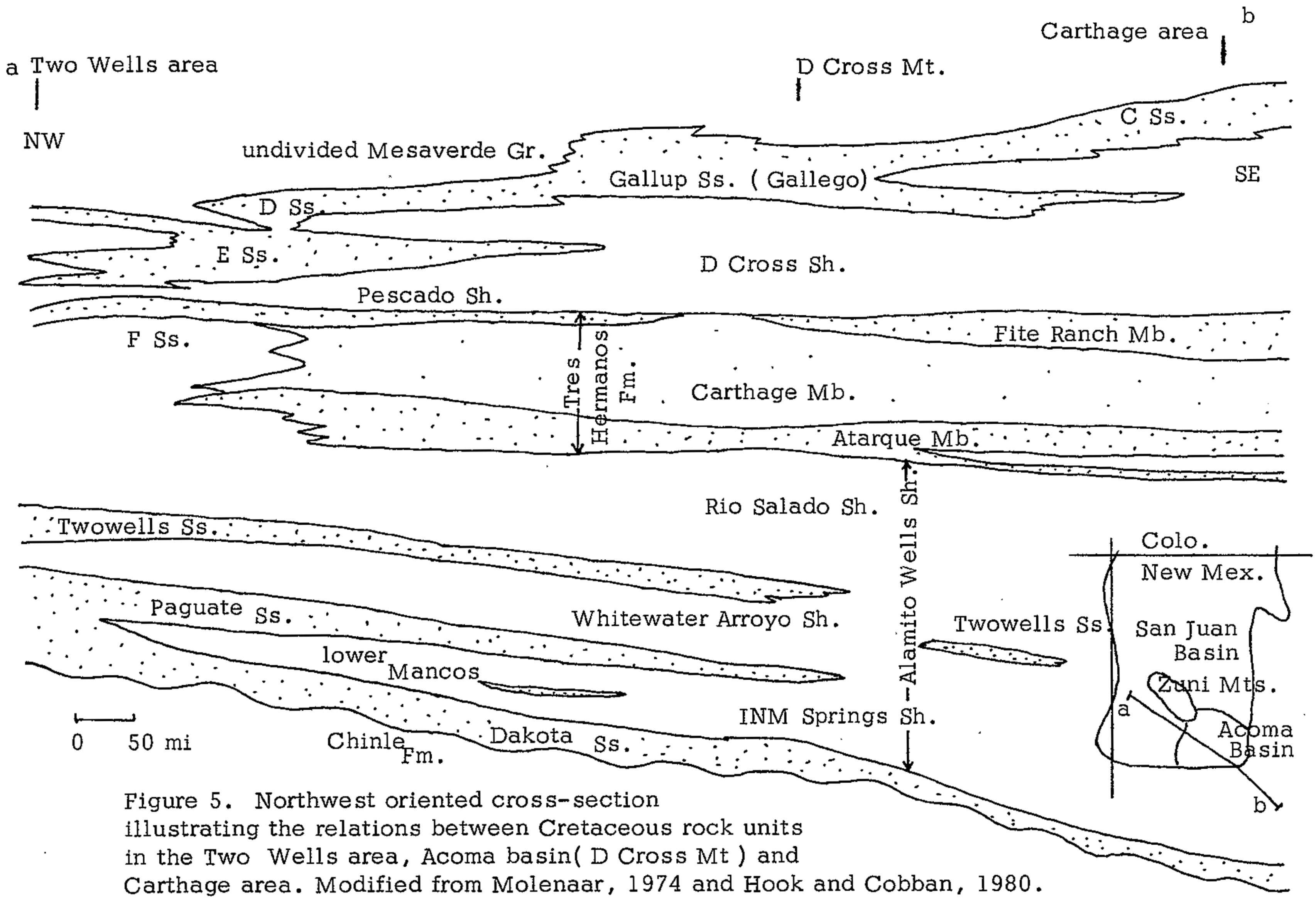


Figure 5. Northwest oriented cross-section illustrating the relations between Cretaceous rock units in the Two Wells area, Acoma basin(D Cross Mt) and Carthage area. Modified from Molenaar, 1974 and Hook and Cobban, 1980.

Huckleberry well (Foster, 1964). Variation in thickness, in part, reflects the lack of consistent placement of the upper boundary, though actual changes in thickness certainly occur. In the study area the main body of the Dakota Sandstone is uniformly 32 ft (10 m) thick.

In the D Cross Mountain quadrangle, the main body of the Dakota Sandstone (hereafter referred to only as the Dakota or Dakota Sandstone) directly overlies the Chinle Formation, and forms a resistant ridge that can be traced northward from the abandoned INM ranch house on the north bank of Alamocita Creek in Sec. 21, T. 3 N., R. 8 W. Due to the plastic behavior of the underlying Chinle shales, large blocks of detached Dakota sandstone have been "let down" as the incompetent shale below has been removed. As a result, a landslide-like topography is typically developed along the contact between the two formations.

A section of the Dakota was measured where a small arroyo cuts obliquely across the strata in Sec. 21, T. 3 N., R. 8 W. At this locality the erosional basal contact with the Chinle is well exposed. The Dakota is gradational into the overlying Mancos Shale tongue. The gradational change occurs over a stratigraphic interval of approximately 10 ft (3 m) and is the result of an increase in thickness and number of shale beds near the top of the unit.

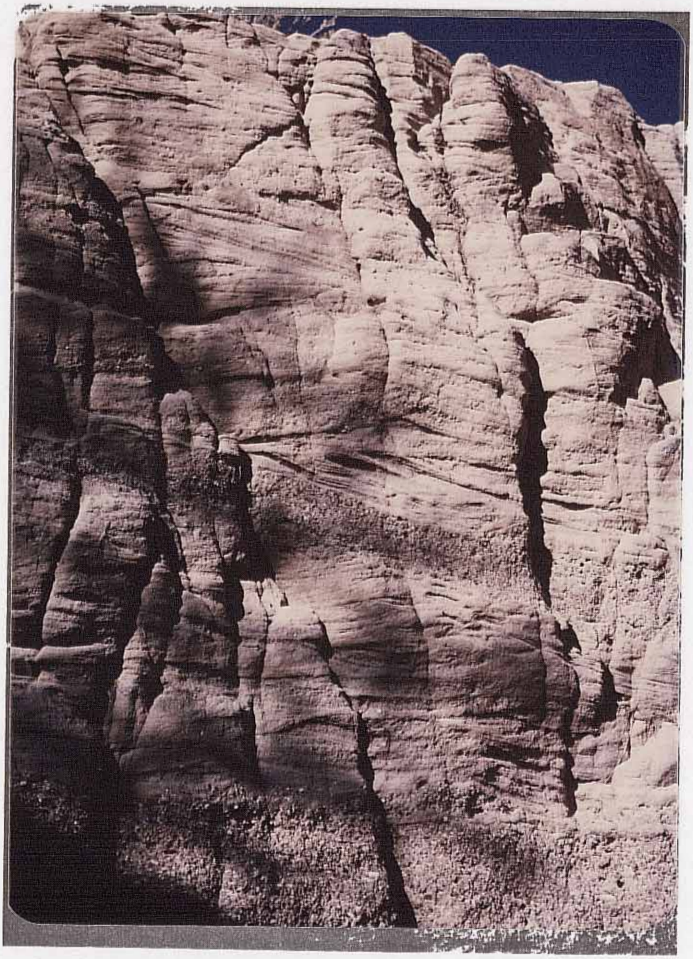
I chose to place the upper contact of the formation at the top of a predominantly sandstone interval which underlies dark-colored shale more typical of the Mancos. This lithologic definition is similar to that used by Foster (1964) for subsurface correlations and corresponds to a slight break in topography.

No fossils were collected from the main body of the Dakota Sandstone. Regional studies indicate that the basal Cretaceous unit is of earliest Late Cretaceous (Cenomanian) age. A Thatcher equivalent (middle Cenomanian) (Cobban, 1977a) was collected from nodular limestone concretions in the overlying Mancos Shale tongue 20 ft (6 m) above the top of the main body of the Dakota Sandstone. This is the stratigraphically lowest occurrence of a diagnostic fauna within the study area. The gradational Dakota-Mancos contact indicates a similar age for the Dakota.

The Dakota Sandstone can be divided into three parts: (1) a basal conglomeratic sandstone unit, (2) a middle shale unit, and (3) an upper sandstone unit. These divisions are used informally in this study.

The lower 16 ft (5 m) of the Dakota is a massively bedded, trough cross-stratified, well-indurated unit composed of small pebble conglomerates and slightly pebbly, medium-grained sandstones (Plate 5). Conglomerate beds are thicker and more numerous in the basal part of the exposure and the unit is graded.

Texturally, the lower part of the Dakota is composed of subequal amounts of sand and gravel, with sand the more common size-grade. The larger constituents are well-rounded, equant pebbles of black chert and variously-colored



'late 5. Basal chert pebble conglomerate in the main body of the Dakota Sandstone--the unit is a fining upward sequence. Photograph was taken in Section 21, T. 3 N., R. 8 W.

quartzite. Many of these clasts were probably reworked from Triassic or Jurassic strata. Gravel size material occurs in discrete lenticular beds that range in dimension from a single pebble to 1 ft (30 cm) or more in thickness. These conglomerate beds often grade laterally into sandstone over a distance of a few feet.

The coarse-grained beds are well stratified with large, shallow trough cross-stratification being the dominant sedimentary structure. Planar wedge-sets that range from 0.1 to 1.0 ft (3 to 30 cm) thick are the only cross-stratification type observed in the intervening sandstone beds.

Overlying the lower unit is a section composed predominantly of shales with a few thin sandstone beds. The shales are silty, black, very carbonaceous, nodular appearing, and thin- to medium-bedded. The intercalated sandstones are only a few inches thick, laterally continuous, silty, moderately carbonaceous, poorly sorted, fine-grained subarkoses.

The upper unit of the Dakota is composed of numerous 0.5-1.0 ft (15-30 cm) thick beds of limonite-stained, moderately indurated, calcareous, moderately sorted, fine-grained quartzarenites and subarkoses. These sandstones are separated by thin beds of black shale. The only structures present within these sandstones are branching burrows that resemble Planolites which occur as casts on the soles of the sandstone beds.

The sand size constituents are dominantly subrounded to rounded quartz grains (86-90%) that are generally single crystals with undulose extinction. Other sand size components include chert (10%), subrounded zircon (trace), and kaolinized potassium feldspar (trace) (Appendix A). The framework grains are closely packed and display crenulated or convex-concave boundaries. Pressure solutioning of the quartz and squashing of labile particles is common.

Cementation was accomplished primarily by silica precipitation as overgrowths on the quartz grains and by later infilling of intergranular voids with calcium carbonate in a passive pore-filling sequence. Authigenic clay minerals are also present within the matrix.

The Dakota strata represents sediment that accumulated in both paralic and fluvial environments. The transition from nonmarine fluvial conditions, represented by the basal unit, to nearshore marine conditions that prevailed during the accumulation of the upper unit developed as the result of the encroachment of a shallow Cretaceous sea into the D Cross Mountain area during the Cenomanian.

The lower conglomeratic strata overlie a regional unconformity. During the time represented by the unconformable surface, the action of laterally planing streams at or near base-level produced a near peneplane surface. During planation gravel-size components reworked from the underlying Triassic, and perhaps Jurassic, strata accumulated as a stream bottom lag and as gravel bars in the fluvial system. The basal conglomerate unit contains many of the characteristics commonly associated with braided stream deposits: (1) slightly erosional base, (2) coarse grain size, (3) moderate sorting, (4) dominance of unidirectional planar cross-laminations, and (5) lack of fossils (Doeglas, 1962).

Deposition of the fluvial sediments occurred as the Late Cretaceous seas began to transgress into the area, reducing the regional gradient. Judging from the widespread extent of the basal unit an extensive fluvial complex must have existed in the area. Stokes (1950), Reeside (1957), and McKnight (1968) have envisioned similar settings in interpreting thin, persistent basal conglomerates in the Rocky Mountain region. Paleocurrent data obtained from cross-stratification in the lower unit indicate a southwesterly paleoslope (Appendix B).

The middle shale unit is slightly bioturbated, very carbonaceous, and contains a few immature sandstone interbeds. No megafossils were observed in the shale interval. The upper sandstone unit is composed of numerous bioturbated sandstone and shale beds that grade vertically into offshore muds (Mancos Shale) containing open marine fossils. This mudstone and sandstone sequence represents a transgressive mud coastline and nearshore bar complex that accumulated on a sand-starved coastline during the earliest marine transgression into the area. Similar mud-dominated shorelines have been described by Fisher and Brown (1972) from the Louisiana Gulf Coast.

Paguate Tongue

Near the town of Paguate, New Mexico, Landis and others (1973) measured and described approximately 62 ft (19 m) of sandstone and siltstone to which they applied the name Paguate Sandstone tongue of the Dakota Sandstone. In this same study, they demonstrated that the Paguate merged with the main body of the Dakota Sandstone near Grants, New Mexico. In the D Cross area 32 ft (10 m) of sandstone crop out approximately 100 ft (30 m) above the main body of the Dakota Sandstone. Based on the stratigraphic position, lithology, and age, these strata were determined to be Paguate Sandstone equivalents. No Paguate strata crop out east of D Cross Mountain. Therefore, the outcrops at D Cross Mountain represent the southeasternmost extension of the sandstone.

The Paguate thickens and merges with the main body of the Dakota Sandstone in a northwestwardly direction. The geometry of the unit indicates the strata were derived from the west or northwest (Landis and others, 1973). Cross-stratification measurements in the D Cross Mountain and Pueblo Viejo areas show a unidirectional southerly paleo-current pattern (Appendix B)--oblique to the inferred Cretaceous shoreline at that time. This substantiates the conclusions of Landis and others (1973) that the Paguate prograded in a southeasterly direction.

The Paguate tongue is poorly exposed in the D Cross Mountain area, cropping out only as a low discontinuous ridge formed at the base of the slope beneath Twowells sandstone in Sec. 8, T. 3 N., R. 8 W. At this locality only a partial section composed of 15 ft (5 m) of strata is exposed; further to the south the Paguate is concealed beneath Quaternary alluvium. A complete section of Paguate does, however, crop out approximately 1 mi (1.6 km) north of the study area along the course of the Rio Salado, and there the Paguate is 32 ft (10 m) thick (Figure 6).

The age of the Paguate was determined from a well preserved ammonite collected from the middle of the unit in exposures along the Rio Salado. The ammonite was identified as Parxacsompsoceras landisi, a late middle Cenomanian form (S. Hook, oral commun., 1978). Landis and others (1973) have collected specimens of Acanthoceras amphibolum, also a Cenomanian ammonite, from the lower 25 ft (8 m) of the Paguate Sandstone near Laguna, New Mexico. As the Paguate is at least 100 ft (30 m) stratigraphically lower than the late Cenomanian Twowells tongue, a middle Cenomanian age for the Paguate appears reasonable.

The Paguate is a coarsening-upward sequence of fine- to medium-grained sandstone that is gradational from the underlying Mancos Shale (Plate 6). The lower 20 ft (6 m) of the unit is green-gray (10 GY 5/2), silty, moderately indurated, calcareous, and moderately sorted. This silty zone is massively bedded and, as the result of intense bioturbation,

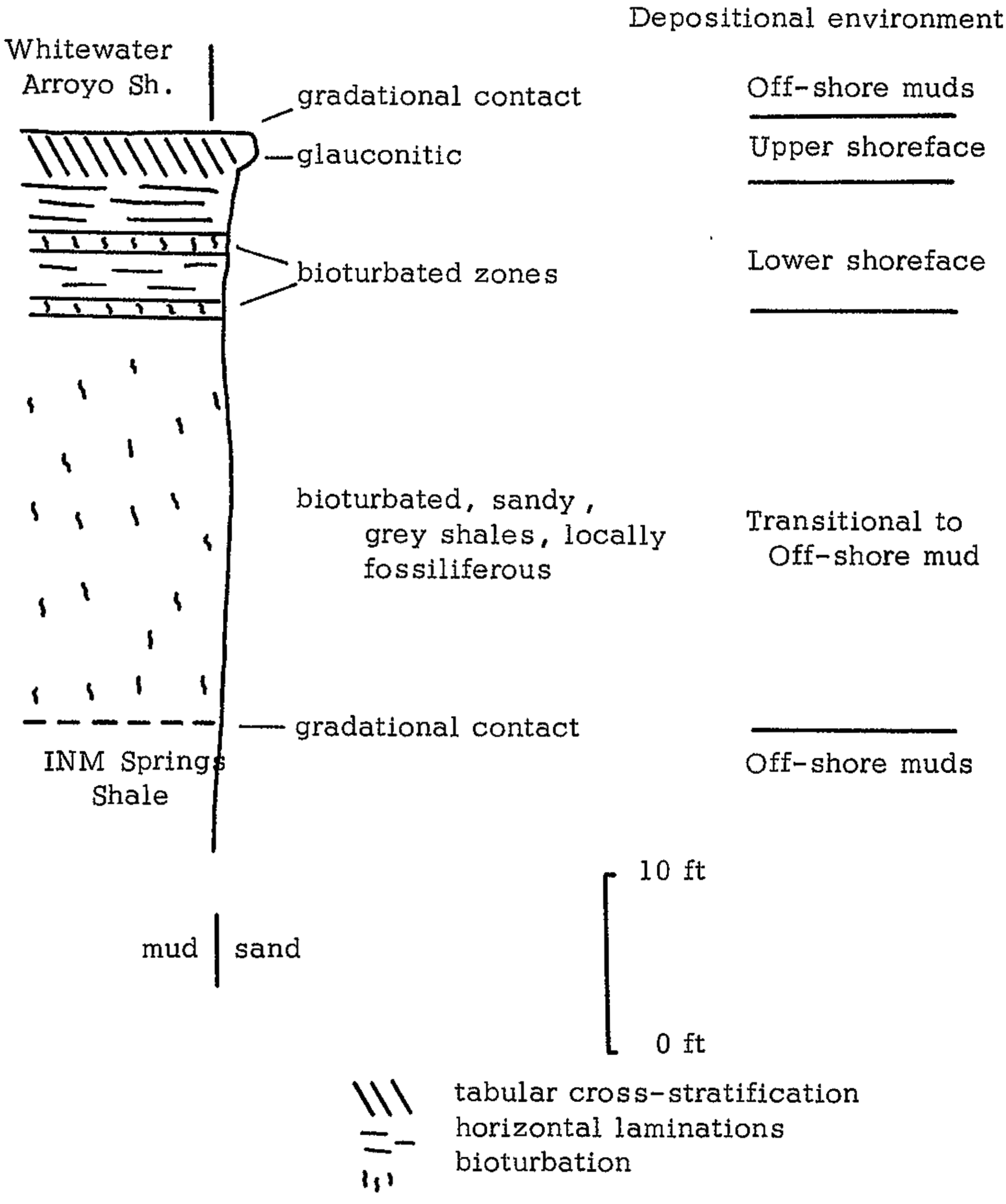


Figure 6. Stratigraphic section of the Paguate tongue of the Dakota Sandstone. The Paguate accumulated as an offshore bar sand.

Plate 6. Contact between Paguate tongue of the Dakota Sandstone and the underlying INM Springs tongue of the Mancos Shale--the contact is gradational. Lighter colored areas in the shale interval are bentonites. Photograph was taken in Section 5, T. 3 N., R 8 W., Wiley Mesa quadrangle.

has a swirled appearance. Due to the high clay content of the base of the unit, the rock is spheroidal weathering. Fossils are often present and include unabraded inoceramids and ammonites.

The lower part of the unit is overlain by 10 ft (3 m) of bioturbated, horizontally laminated to structureless, thin to thick wavy beds of medium-grained sandstone. Iron oxide within the burrowed zones imparts a reddish-orange (10 R 4/6) color to the strata.

The upper 2 ft (61 cm) of the Paguate is a resistant, white (N 9), cross-stratified, well-sorted, medium-grained glauconitic quartzarenite. The cross-stratifications occur in sets up to 1 ft (30 cm) thick and are of the planar wedge-shape type. The cross-laminae are inclined uniformly to the south-southeast.

Fine- to medium-grained quartz comprises from 94-95% of the framework constituents in the five thin-sections examined. The quartz grains are generally free of inclusions and have straight extinction; although grains with needle-shaped rutile inclusions and grains with undulose extinction are present. Most grains are subequant and subrounded to subangular. Other constituents that occur in amounts greater than 1% include: rounded, medium-green (5G 5/6) glauconite (2%), grey chert (2%), potassium feldspar (1%), and siltstone (1%). Trace amounts of partially degraded biotite and muscovite were also recorded (Appendix A).

The rock texture ranges from moderately overpacked, in which the grains have short straight contacts, to tightly packed in which sutured, concave-convex, or long, straight grain contacts are the dominant type. Soft grains of mica, glauconite, and mudstone are deformed because of the compaction.

Calcite and silica are the primary cementing agents. Silica was the earliest precipitant. The silica cement was derived from solution of quartz at grain contacts and reprecipitated as quartz overgrowths with crystal face terminations. Calcite cement is finely to coarsely crystalline with some crystals attaining a size up to 0.3 in. (7.6 mm) in diameter. The larger crystals encompass numerous framework grains and are the product of aggrading neomorphism. Partial replacement of framework constituents by the calcite cement is common.

The Paguate Sandstone is sandwiched between open marine Mancos Shale units and represents an offshore marine sand bar complex. Glauconite in the sandstone is generally ascribed to a normal marine environment (Cloud, 1955), and the presence of an open marine fauna provides strong supportive evidence for the marine origin of the rock. The sequence of primary and biogenic sedimentary structures and textures observed in the rock is similar to those produced during progradation of a shallow offshore marine sand bar as described by Carter (1978) and Reineck and Singh (1975). Migration of an offshore sand bar will produce a coarsening-upward sandstone package as bioturbated offshore muds are overridden by coarse-grained, cross-bedded bar crest sediments (Reineck and Singh, 1975). The observed characteristics of the Paguate closely approximate this model for a prograding offshore sand bar. Paleocurrent indicators, as well as regional geometric relations, indicate that progradation was to the southeast.

Twowells Tongue

The Twowells tongue was named by Pike (1947) for exposures near Two Wells, New Mexico, in the northwestern part of the state. Pike (1947) originally included the unit as a lentil of the Mancos Shale, but suggested that the sandstone body might be more closely related to the Dakota Sandstone. Subsequent investigations by Dane and others (1971) have demonstrated that the Twowells merges with the Dakota near Window Rock, Arizona. The unit is now considered to be a tongue of the Dakota.

Dane and others (1971) were the first to apply the Twowells terminology to strata in the D Cross-Alamo Day School area. Their usage supercedes the earlier designation of Tres Hermanos Sandstone utilized by Herrick (1900), Tonking (1957), Given (1958), and Jicha (1958).

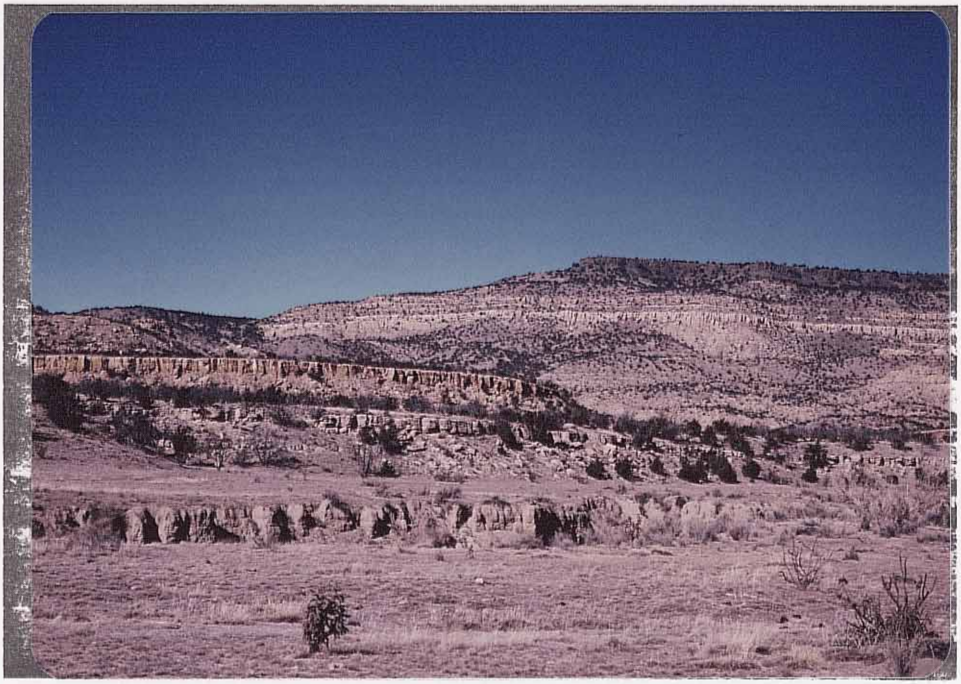
Regionally, the Twowells is a southeastward thinning sheet-sand. Dane and others (1971) reported that the sandstone package extends at least 140 mi (90 km) southeastward from Window Rock, Arizona, and has a maximum width of 200 mi

(125 km). In the southern Acoma basin, immediately east of D Cross Mountain, the Twowells consists of a series of discontinuous sandstone lentils (Tonking, 1957, and Givens, 1958). The Twowells is not present in the Riley area (Massingill, 1979).

In the D Cross Mountain quadrangle, the Twowells is the first resistant cliff-forming unit above the Dakota Sandstone (Plate 7). Stratigraphic separation of the Twowells and Dakota by an intervening Mancos Shale tongue and Paguate Sandstone is 209 ft (64 m) on the east side of D Cross Mountain. The Twowells is 44 ft (13 m) thick (Figure 7).

The upper contact of the Twowells with the Rio Salado Shale tongue of the Mancos Shale is poorly exposed. In most areas there appears to be a 4-6 ft (12-24 cm) thick zone of interbedded sandstones and dark shales near the top of the unit. The upper contact was placed at the top of the last resistant sandstone bed. The lower Twowells contact is gradational and conformable with the underlying Whitewater Arroyo tongue of the Mancos Shale and was drawn at the point where sand is greater than 50% by volume of the rock.

No diagnostic fossils were collected from the Twowells in the D Cross area. Extensive collecting from the top of the Twowells in the Puertecito area has yielded a late Cenomanian age fauna (S. Hook, oral commun., 1979). In the D Cross area <u>Pycnodonte newberri</u>, a late Cenomanian to early Turonian oyster, and <u>Scipnoceras gracile</u>, a late Cenomanian ammonite, occur within 10 ft (3 m) above the top of the



late 7. Cliff-forming outcrop of Twowells sandstone--the Twowells is the orange weathering unit forming the second cliff in the photograph. Photograph was taken in Section 5, T. 3 N., R. 8 W., Wiley Mesa quadrangle.

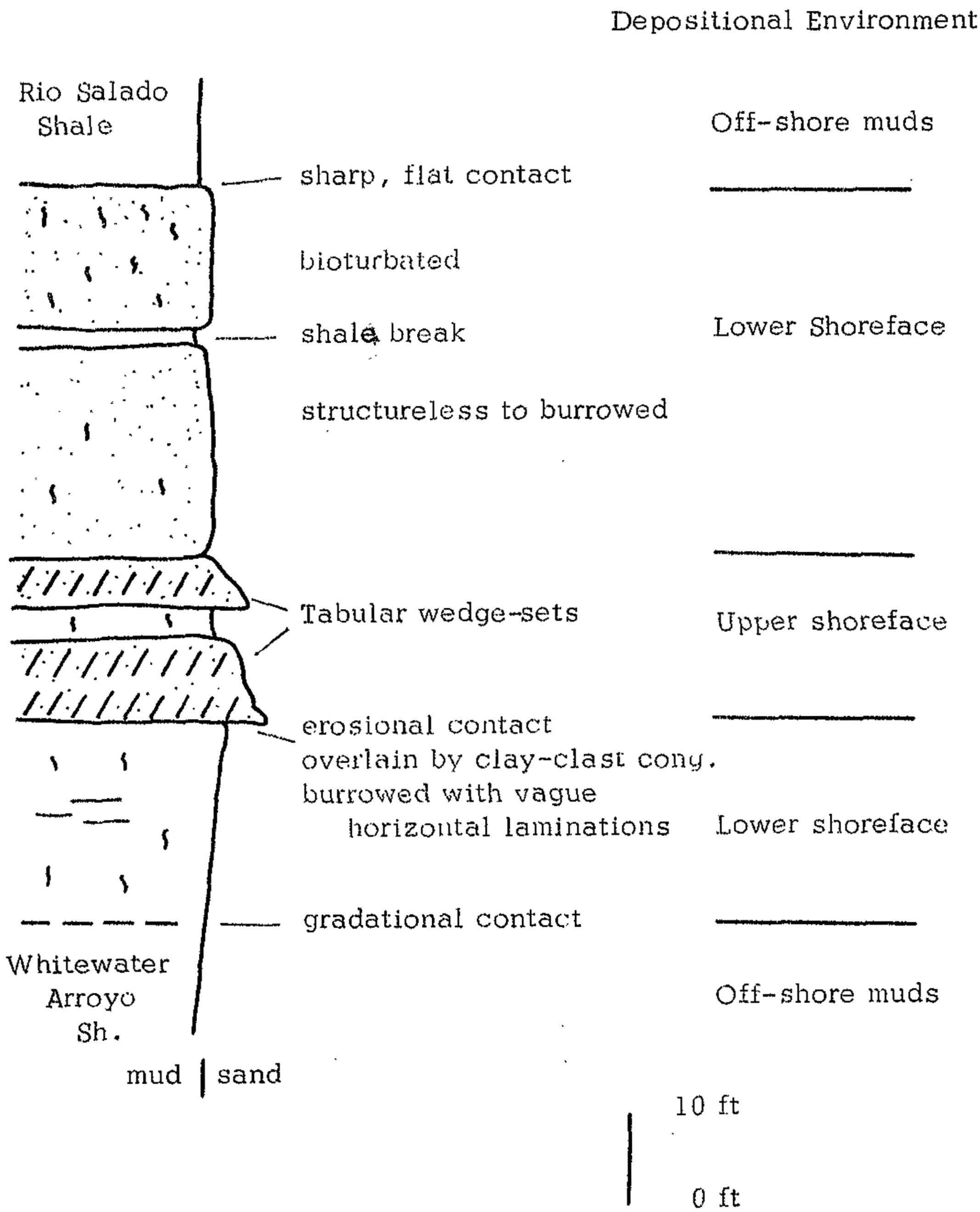


Figure 7. Stratigraphic section of the Twowells tongue of the Dakota Sandstone.

Twowells. This indicates a late Cenomanian age for the sandstone unit. In a northwesterly direction, the Twowells is essentially synchronous (S. Hook, oral commun., 1978). Dane and others (1971) have reported that toward the southwest the Twowells rises slightly stratigraphically.

In the D Cross Mountain area the Twowells is a coarsening-upward sequence composed predominantly of bioturbated, thick beds of calcareous, moderately sorted, mature, silica cemented, fine-grained glauconitic chertarenites and subarkoses (Appendix A). The bioturbated zones consist of sparse burrows within depositional units, or of abundant circular, flat-lying, branching, 0.1 in. (2.5 mm) diameter burrows that are concentrated along bedding planes. The difference in type and abundance of the burrows probably reflects rate of sedimentation. Near the middle of the unit, a zone that is composed of one or more beds of dark-brown (5 YR 2/1), tabular cross-stratified, medium- to coarse-grained sandstone, containing squashed clay clasts, imparts a banded appearance to the strata. The upper 10 ft (3 m) of the Twowells is composed of medium beds of fine-grained, bioturbated sandstone. Mineralogically the Twowells is similar to the Paguate Sandstone.

The geometry and the presence of a marine fauna and glauconite within the Twowells suggests that the strata accumulated as an extensive offshore marine sheet sand that developed during a/marine regression. Thinning of the sandstone package to the southeast, the distribution of a suite of metamorphic minerals (Owens, 1963), and the dip direction of tabular cross-laminations suggest that the sediments were derived from the northwest (Appendix B).

Characteristics of the rock closely resemble those produced in the lower and upper shoreface environments of recent shallow marine offshore bars (Reineck and Singh, 1975) and ancient shoreface deposits (Molenaar, 1973). The lower part of the unit represents lower shoreface to transitional, bioturbated, silty sands that accumulated below wave base. The upper part of the unit is cross-stratified and contains mud rip-up clasts. These sediments accumulated in agitated waters above normal wave base, perhaps on a bar crest. Fossils and burrows are, expectedly, not common in this high energy environment.

The Twowells appears to represent a shoreface sandstone that accumulated during a regressive sequence (Peterson and Kirk, 1977). However, several factors lend evidence to a different origin for the strata. First, the Twowells is "time-flat" from Puertecito, New Mexico, to Shiprock, New Mexico, in a direction oblique to the Cretaceous shoreline; this phenomenon is not generally attributed to transgressive-regressive cycles. Second, the Twowells contains glauconite in considerable quantities, which is suggestive of long periods of slow or nondeposition. Third, there is no lithologic evidence which would support a shift of the shoreline during the accumulation of the Twowells strata. An alternative depositional model, which has less conjectural qualities, is that the Twowells sandstone accumulated as an offshore bar complex that prograded parallel to the shoreline. This would explain the transitional lower contact with open marine shales, the regional "time-flat" nature of the sandstone unit in a direction perpendicular to the paleoshoreline, and the lack of laterally related regressive deposits.

Mancos Shale

Mancos Shale was the name applied by Cross (1899) to approximately 1200 ft (366 m) of dark shale that crop out near the town of Mancos, Colorado. In the San Juan, Zuni, and Acoma basins of New Mexico, the Mancos Shale is split into numerous tongues by intervening sandstone units. The intertonguing is to the west and southwest (Pike, 1947; Sears and others, 1941; and Molenaar, 1974). Four Mancos Shale tongues were mapped in the D Cross Mountain quadrangle. In stratigraphic order these are: INM Springs (new name), Whitewater Arroyo, Rio Salado, and D Cross.

INM Springs Tongue

On the eastern slope of D Cross Mountain, approximately 90 ft (27 m) of Mancos shale separate the Paguate and Dakota sandstones. This shale is laterally equivalent to the Clay Mesa tongue of the Mancos Shale as described by Landis and others (1973). At the Clay Mesa stratotype, the shale section is bounded by the Cubero Member and Paguate Sandstone tongue of the Dakota Sandstone. However, the Cubero wedges-out within the Mancos Shale south of the Laguna area (Hook and others, 1980) and the Clay Mesa terminology cannot be extended from the reference section into the D Cross Mountain area. In this report the lowest shale tongue of the Mancos is named the INM Springs tongue of the Mancos Shale. The name is derived from INM Springs located in Sec. 28, T. 3 N., R. 8 W.

Regionally, the INM Springs tongue thins to the north-west (Landis and others, 1973) and west (Hook and others, 1980) as the bounding Dakota Sandstone tongues merge. Pinchout points of the shale tongue occur along a line passing through Mount Powell, Two Wells, and Atarque, New Mexico. North of D Cross Mountain, at the reference section of the Clay Mesa Shale, the INM Springs equivalent is 70 ft (21 m) thick and consists "...mostly of medium- to dark-gray clay shale, silty in part, but has bentonites, limey concre-tions, and thin limestone beds" (Landis and others, 1973). East of D Cross Mountain, where the Paguate Sandstone is absent and the lowest Mancos shale and overlying Whitewater Arroyo tongue of the Mancos Shale merge, the shale interval has been loosely referred to as the Whitewater Arroyo tongue of the Mancos Shale (Massingill, 1979).

The INM Springs tongue is poorly exposed in the study area. Erosion of the shale generally results in the devel-opment of a low grass covered flat between the Paguate and Dakota sandstones. For descriptive purposes a "composite" section was constructed from isolated exposures of the shale within and adjacent to the study area. The lower contact between the INM Springs and the main body of the Dakota Sandstone is one of interbedding and was arbitrarily placed at the top of the last sandstone bed that is greater than 2 ft (61 cm) thick. The contact between the INM Springs and Paguate Sandstone is also gradational. The gradational change is, however, the result of an increase in median grain size near the top of the INM Springs and not of an interbedded nature. Therefore, the upper contact was placed at the point where the rock is texturally a sandstone.

Cobban (1977a) has collected a Thatcher age (middle Cenomanian) fauna from concretions in the lower part of the INM Springs shale. Identified invertebrates include: *Plicatula arenaria*, pectenids, and *Ostrea beloiti*.

The INM Springs consists predominantly of black (N1) to grey (N5) shale with minor intercalations of limestone, bentonite, and calcareous siltstone. The lower 20 ft (6 m) is primarily dark-black (N1), nodular weathering, very calcareous, silty shales and interbedded, 0.3-1.0 ft (.75-2.5 cm) thick, very calcareous, moderately indurated, light-yellow (10 Y 4/2), very fine-grained lithicarenites and siltstones. Feeding tracks and trails are common on the soles of the sandstone and siltstone beds. The upper 60 ft (18 m) of the INM Springs is a moderately calcareous, splintery weathering, silty, medium-grey (N5) shale.

Near the base of the INM Springs, a zone of large, 3 ft (1 m)-diameter, ellipsoidal, limestone nodules form a nearly continuous bed that forms a weak bench in some areas. The nodules are medium-brownish-grey (5 YR 5/1) micrite and contain megafossils.

Bentonites occur in the INM Springs at approximately 10 ft (3 m), 26 ft (8 m), and 43 ft (13 m) above the base of the unit. These bentonites are 0.1 ft (1 cm), 0.5 ft (15 cm), and .25 ft (7.5 cm) thick respectively. The bentonites weather greenish-orange (5 Y 6/6); on a fresh surface they are very light-grey (N8).

Gypsum crystals are common in the upper part of the shale tongue. The gypsum is confined to post-depositional fractures within the rock that cut obliquely across bedding surfaces.

The INM Springs Shale accumulated in an offshore, shelf mud environment during the initial Cretaceous marine transgression. The shale tongue is gradational into lower shoreface sandstones of the underlying Dakota Sandstone and into offshore bar deposits of the overlying Paguate Sandstone. The presence of an unabraded open marine fauna and the high silt content of the shales indicate that nearshore, yet normal, marine conditions prevailed during deposition of the sediments.

Whitewater Arroyo Tongue

Owens (1966) first applied the term Whitewater Arroyo tongue to a section of dark shales that separate the main body of the Dakota Sandstone and Twowells Sandstone tongue in the Zuni basin. He, however, considered the Whitewater Arroyo to be a member of the Dakota Sandstone. Landis and others (1973) later included the shale unit as a tongue of the Mancos as had Moench (1963), and Moench and Schlee (1967). The Whitewater Arroyo is used in this report in the sense of Landis and others (1973). This usage requires a correlation of approximately 40 mi (64 km) from the nearest Whitewater Arroyo outcrop in the Narrows area.

The Whitewater Arroyo is 92 ft (28 m) thick in Sec. 17, T. 3 N., R. 8 W. on the east side of the D Cross Mountain. The shale interval appears to maintain a uniform thickness in a northward direction at least as far as Laguna, New Mexico, where Landis and others reported a thickness of 90 ft (27 m).

Northwest of D Cross Mountain, the Whitewater Arroyo thins to a 60 ft (18 m) thick in the vicinity of Gallup, New Mexico (Owens, 1963). East of D Cross Mountain the Paguate Sandstone is not present and the Whitewater Arroyo of Massingill (1979) is 187 ft (57 m) thick. This section includes, however, the lateral equivalent of the INM Springs tongue of the Mancos Shale and the Paguate tongue of the Dakota Sandstone as described in the D Cross area; thus, no more than 100 ft (30 m) of the interval is Whitewater Arroyo equivalents.

The Whitewater Arroyo is similar in lithology and weathering characteristics to the INM Springs Shale. In the D Cross Mountain area, the incompetent shales are typically poorly exposed and the contact between the Whitewater Arroyo and Paguate Sandstone is concealed beneath Quaternary alluvium. However, in the bed of the Rio Salado, approximately 1 mi (1.6 km) north of the study area in Sec. 5, T. 3 N., R. 8 W., the contact between the two units is gradational. The contact between the Whitewater Arroyo and the overlying Twowells Sandstone is also gradational, and is the result of an increase in silt and sand content in the upper part of the shale unit.

Fossils are rare in the Whitewater Arroyo. Occasionally, unabraded specimens of an Exogyra and Inoceramus species occur as float in the upper part of the section. A fossil assemblage collected by Landis and others (1973) indicates a Cenomanian age for the shale strata.

The Whitewater Arroyo is dominantly a silty, very calcareous, dark-grey (N4) shale that weathers yellowish-grey (5 Y 7/2). Sandy zones occur sporadically throughout the unit and small, 0.2 ft (6 cm)-diameter, equant, micrite nodules are abundant in the upper 10 ft (3 m) of the unit.

Several white (N9) bentonites occur within the shale section. The stratigraphically lowest of these is 0.5 ft (15 cm) thick, and occurs approximately 35 ft (11 m) above the top of the Paguate Sandstone tongue. Hook and others (1980) believe this bentonite bed may be equivalent to the "X" bentonite "...which lies within the *Acanthoceras amphibolum* Zone and has been dated at 92.1 m.y." by Obradovich and Cobban (1975). The second bentonite occurs a few feet below the Whitewter Arroyo-Twowells contact. This bed is only 3 in. (7.6 cm) thick.

The Whitewater Arroyo grades above and below into offshore bar sandstones and represents sediments deposited below wave base. The presence of a sparse, unabraded, open marine fauna and the absence of appreciable quantities of silt and sand in the shale suggest deposition in an offshore open marine shelf-mud environment.

Rio Salado Tongue

The Rio Salado Shale tongue of the Mancos Shale was the name applied by S. Hook and W. Cobban (oral commun., 1979) to a thick, black shale sequence that separates the Twowells and Tres Hermanos sandstones in the Puertecito area. At the stratotype, along the course of the Rio Salado, Massingill (1979) measured 238 ft (73 m) of Rio Salado strata. The shale tongue maintains a uniform thickness eastward as far as the outcrop can be traced and is 229 ft (70 m) thick on the eastern slope of D Cross Mountain. The Rio Salado is probably correlative with the upper 170-200 ft (52-61 m) of Massingill's Alamito Well tongue of the Mancos Shale.

The age of the Rio Salado is established as late Cenomanian to early Turonian based on the contained fossils. Sciponoceras gracile, a standard zone ammonite of the Western Interior Cretaceous (Cobban and Reeside, 1952; and Cobban and Scott, 1972), occurs a few feet above the lower Rio Salado contact. This ammonite zone marks the Cenomanian-Turonian boundary. The upper Rio Salado is of early to middle Turonian age as indicated by the presence of Mammites depressus (Plate 8). A change from calcareous shale to noncalcareous shales within the Rio Salado is considered by many workers to mark the Carlile-Greenhorn boundary. In the D Cross Mountain area, this boundary occurs approximately 70 ft (21 m) below the Rio Salado-Tres Hermanos contact.

Exposures of the shale unit are extremely poor due to calving of huge blocks of Tres Hermanos sandstone onto the Rio Salado slope. Where exposures of the rock can be found, it is a dark-grey (N3), noncalcareous to moderately calcareous, splintery weathering, silty shale.

Thin, light-brownish-grey (5 YR 4/1) calcarenites occur throughout the shale unit. Thicker zones of calcarenites crop out at 33 ft (10 m) and 80 ft (24 m) above the Twowells-Rio Salado contact. The calcarenites are platy weathering, bioturbated, silty, thinly laminated, current-lineated, and form poorly developed benches in the otherwise smooth slope. Fossil hash is common in the calcarenite beds. The most common fossil constituents are Mytiloides

Plate 8. Specimen of Mammites depressus--this specimen was collected from the center of a large concretion 60 ft (18 m) below the Rio Salado-Tres Hermanos contact.

mytiloides; shark teeth and other bioclasts are also recorded.

Limestone concretions occur in two stratigraphic horizons within the shale section. The lower unit is composed of light-grey (N7) to olive grey (5 Y 5/2), massive, micrite nodules that are elongate and parallel to bedding. This zone is within 10 ft (3 m) of the Twowells-Rio Salado contact. Fossils are very abundant in the concretionary zone and include: *Pycnodonte newberryi*, unidentified echinoids, and the ammonite *Sciponoceras gracile*. The upper concretionary zone is 2-3 ft (30-61 cm) thick and occurs approximately 60 ft (18 m) below the Tres Hermanos Sandstone. The concretions are yellowish-brown (10 YR 5/2), as much as 2 ft (.7 m) in diameter, septarian-like, and spaced 70-100 ft (21-30 m) apart. The nuclei of the concretions often consist of the large ammonite *Mammites depressus*. The fossil-bearing concretions are of particular interest in that (1) the concretions are confined to a narrow stratigraphic zone and (2) the oysters are attached in growth position to the ammonite cast. S. Hook (oral commun., 1980) has observed similar occurrences of oysters attached on both the upper and lower surfaces of casts of *M. depressus* in other areas.

The position of the Rio Salado shales between paralic shoreface sandstones of the Atarque Member of the Tres Hermanos Sandstone and Twowells Sandstone, and the presence of a largely unabraded, open marine fauna suggest that the

Rio Salado was deposited below wave base as offshore, marine shelf-muds during a transgressive-regressive sequence.

The Sciponoceras gracile-bearing limestone nodules may have accumulated seaward of the offshore marine mud facies in deeper, clear waters and could represent maximum transgression in the area. Seaward progression from sands to clastic muds to carbonates is a well known model for epeiric sea deposits (Shaw, 1964).

Calcarenites, composed of fine sand size carbonate bioclasts, may either represent sediments that were accumulated through reworking of the marine muds during storm events, or that were transported offshore by storm-related currents. The offshore movement of sand size material by storm-generated currents is well known from the Recent (Hayes, 1967).

The presence of oyster shells, attached in growth position on ammonite casts, suggests an erosional surface exists in the strata that is not lithologically apparent. This assumption is based on the fact that the oysters occur attached to ammonite casts and not to original skeletal material. The following history is suggested: (1) deposition of ammonite shells, (2) burial and internal filling of the ammonite shells, (3) lithification of the mold-filling sediments, (4) dissolution of the original ammonite skeletal material, (5) erosion and accumulation of the fossil casts in a single horizon, and (6) attachment and growth of oysters on the casts. Regionally, the presence of an erosional conglomerate within the same time-stratigraphic interval supports the presence of an unconformity within the strata (S. Hook, oral commun., 1980). Other minor hiatuses and erosional vacuities may exist in the Mancos shale units that cannot be identified without detailed study.

D Cross Tongue

The D Cross tongue was defined by Dane and others (1957) as the shale that crops out on the eastern flank of D Cross Mountain in Sec. 30, T. 3 N., R. 8 W. between the "Gallego" (upper Gallup) and a "lower Gallup sandstone" (Tres Hermanos Sandstone). At the stratotype the D Cross tongue is 173 ft (53 m) thick. East of the D Cross area, Massingill (1979) reported thicknesses of the D Cross Shale of 121 ft (37 m) near Puertecito, and 290 ft (88 m) near Riley, New Mexico, where the "Gallego" sandstone is not present. In the Jornada del Muerto area, the D Cross is 363 ft (111 m) thick. West and north of D Cross Mountain, the D Cross Shale tongue is split into two units by an intervening sandstone: the "E" sandstone of Molenaar (1973 and 1974).

Pike (1947), in a regional study of the Cretaceous, correlated the, as of then unnamed, D Cross tongue with the Pescado tongue of the Mancos Shale in the Zuni basin. At the time the D Cross Shale was formally defined, Dane and others (1957) believed the D Cross was a stratigraphically higher shale tongue than the Pescado. Molenaar (1974) later partially substantiated Pike's original correlation by demonstrating that at least the lower half of D Cross Shale is equivalent to the Pescado tongue.

The D Cross Shale is late Turonian to early Coniacian in age (S. Hook, oral commun., 1979). Hook believes that sandier zones in the lower part of the unit are time equivalent to the Juana Lopez Member of the Mancos Shale (Carlile Shale of the Raton and Denver basins) as defined by Dane and others (1966) in the San Juan Basin.

The D Cross tongue is the highest prominent slope-forming unit in the D Cross Mountain area. The rock is a medium-grey (N3 to 5 Y 5/2), chunky weathering, slightly to noncalcareous, moderate-olive grey (5 Y 4/1), bioturbated, silty shale containing numerous fossil-bearing concretion zones. Identifiable fossils collected from the lower part of the unit include: Prionocyclus wyomingensis, Prionocyclus novimexicanus, Coilopoceras inflatum, and Lopha bellaplicata.

The middle portion of the unit is generally very silty, moderately calcareous, and contains abundant oyster hash, Prionocyclus novimexicanus, and various microfossils. The upper 40 ft (12 m) of D Cross shale is slightly calcareous and contains the following fossils: Lopha sannionis, Inoceramus perplexus, Prionocyclus novimexicanus, P. quadratus, and Baculites yokoyami.

Concretionary zones are common in the D Cross shale; occurring at 1 ft (30 cm), 9 ft (3 m), 22 ft (7 m), 134 ft (41 m), and 143 ft (44 m) above the formation base. The concretions vary from isolated, solid, small, subequant, grey (N5) micrite nodules to large, 3 ft (1 m)-diameter, subequant to elongate, yellowish-grey (5 Y 7/2), septarian-like concretions that form near-continuous beds. Fossil ammonites often form the nuclei of the concretions in the lower two concretion zones.

The lower contact of the D Cross shale with the Tres Hermanos Sandstone is sharp and flat or, locally undulatory. The upper contact with the Gallup Sandstone is gradational; sandstone and shale beds are interbedded over a stratigraphic interval of 5-6 ft (1.5-1.8 m). The upper contact was placed at the base of the first sandstone that was greater than 1 ft (30 cm) thick.

The D Cross shales accumulated in a nearshore marine mud environment during a regional transgressive-regressive sequence as documented by the shale unit containing an open marine fauna and grading into overlying marine shoreface sandstones. The silty character of the shale, presence of abraded shell hash, and abundant fossils suggest shallow water depths and deposition in a transitional zone between typical "clean" offshore muds and lower shoreface environments.

Tres Hermanos Sandstone

The name Tres Hermanos was first used by Herrick (1900) for the Cretaceous age strata that crop out along the course of the Rio Salado in west-central New Mexico. Herrick's failure to adequately designate a type locality for the formation has led to considerable confusion among later workers as to his intended usage. In the D Cross Mountain area, both Pike (1947) and Givens (1957) used the Tres Hermanos terminology for what is now considered the Twowells Sandstone.

S. Hook and W. Cobban (oral commun., 1979) have recently redefined and elevated the Tres Hermanos to formational status and defined three formal members; these are, in ascending order: (1) a lower sandstone - the Atarque Member, (2) a middle coal-bearing sandstone and shale section - the Carthage Member, and (3) an upper concretionary sandstone - the Fite Ranch Member. The combined thickness of the three members is 230 ft (70 m) in Sec. 19, T. 3 N., R. 8 W. on the southeastern slope of D Cross Mountain (Figure 8). The formation, as a package, is probably correlative with the Atarque member of the Gallup Sandstone and F sandstone (or equivalent) of Molenaar (1973) in the Zuni basin of western New Mexico.

Regionally, the Tres Hermanos Sandstone thins to the northeast. The thinning occurs in the Carthage Member, and is due to the stratigraphic rise of the Atarque Member in a northeastward direction. The rise of the Atarque results in a wedging-out of the Carthage Member along a line extending northwest-southeast from the vicinity of Grants, New Mexico, to Carrizozo, New Mexico. At Carthage the Tres Hermanos is 244 ft (74 m) thick. East of Grants an offshore marine

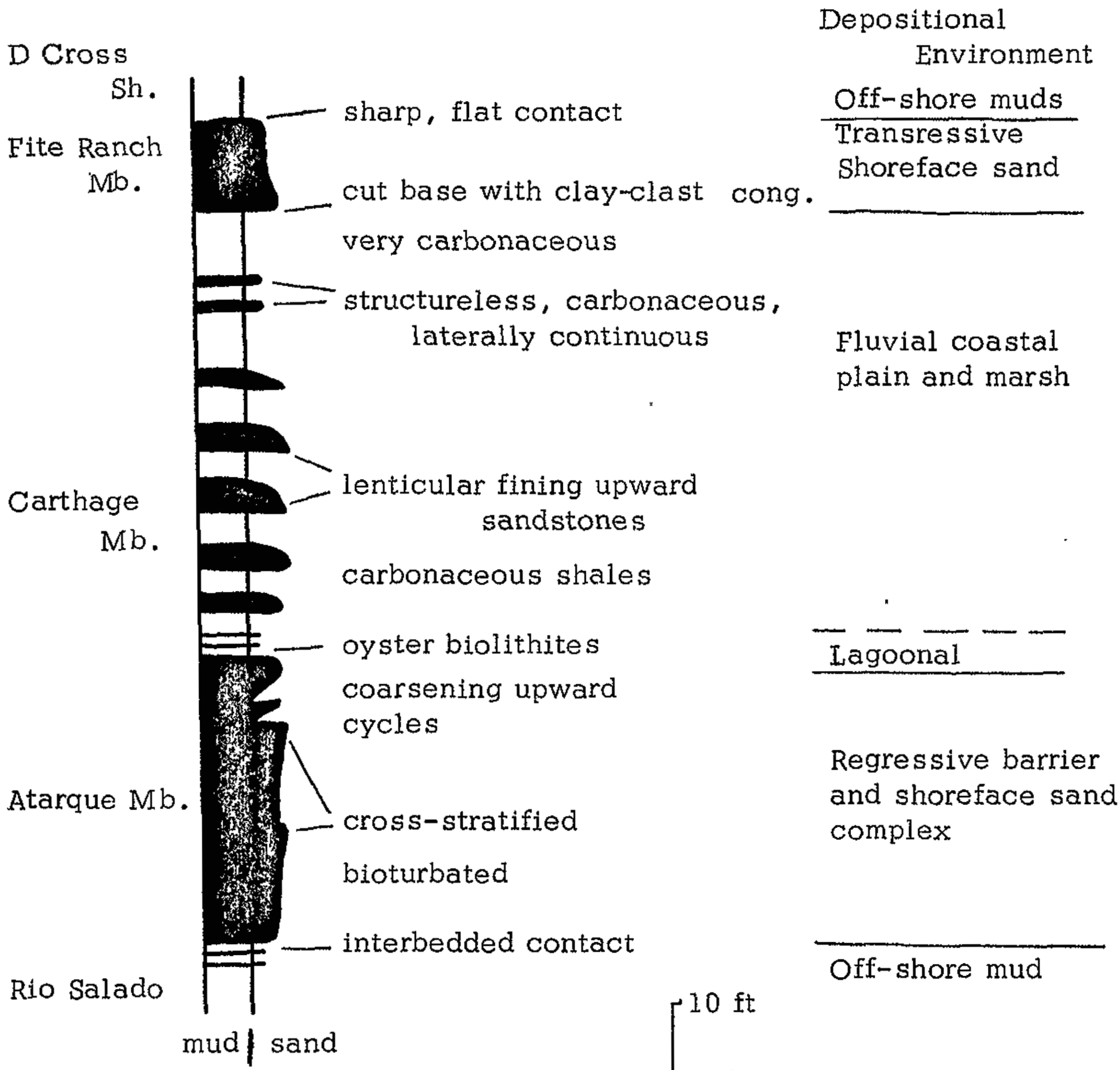


Figure 8. Stratigraphic section of the Tres Hermanos Sandstone. The Tres Hermanos accumulated during a regressive-transgressive episode.

sandstone, the Semilla Sandstone of Dane and others (1968), is of Tres Hermanos age (Molenaar, 1973).

The Tres Hermanos is assigned a middle Turonian age based on the presence of *Collignoniceras woollgari woollgari* at the base of the formation and *Scaphites ferronensis*, *S. whitfieldi*, *Prionocyclus novamexicanus*, and *Coilopoceras inflatum* within a few feet above the Tres Hermanos-D Cross Shale contact. The age of the base of the Tres Hermanos becomes younger from southeast to northwest along a line from Truth or Consequences, New Mexico, to Cuba, New Mexico. The top of the formation appears to be "time-flat" between the same areas as denoted by the presence of *Prionocyclus maconbi* at both localities (S. Hook and W. Cobban, oral commun., 1979). This suggests either a very rapid rate of marine transgression or a northwest-striking shoreline. Rapid marine transgressions appear to have been common during the Cretaceous in the southern Rocky Mountains, and a northwest-trending paleoshoreline fits well into the paleogeography as discussed by Hook and others (1980).

The base of the Tres Hermanos is gradationally interbedded with the underlying Rio Salado Shale tongue of the Mancos Shale. Along the base of the scarp-forming outcrop, bioturbated thin to very thin beds of horizontally laminated, silty sandstone and siltstone are interbedded with dark organic-rich Mancos shales over a stratigraphic interval of approximately 5 ft (1.5 m). The contact between the

Tres Hermanos and the overlying D Cross Shale is sharp and flat.

Atarque Member

The Atarque Member forms the bold cliff that is prominent on the east side of D Cross Mountain. This sandstone unit is composed of 83 ft (25 m) of intercalated sandstone and thin shale beds (Plate 9). The frequency and thickness of the shale beds increases towards the top of the unit. The Atarque is characterized by medium to thick beds of hummocky laminated, bioturbated and cross-stratified, fine- to medium-grained subarkoses.

Numerous large, up to 3 ft (1 m) diameter, poorly developed, spherical, calcareous concretions are present at the base of the Atarque Member. Similar concretions were noted by Herrick (1900) in his original definition of the Tres Hermanos. The concretions are only slightly more resistant to weathering than the surrounding rock and appear as vague brown zones at the outcrop.

The Atarque, in general, exhibits cyclic sedimentation. A typical coarsening upward cycle consists of (1) thin, dark, structureless shale or siltstone at the base of the sequence, (2) a middle unit of structureless, horizontally laminated or low angle cross-laminated, fine-grained sandstone containing Ophiomorpha burrows (Plate 10) and (3) an upper sequence of planar cross-stratified sandstone. The wedge-planar sets average less than 1 ft (30 cm) in

Plate 9. Cliff-forming outcrop of the Atarque Member of the Tres Hermanos Sandstone--the Atarque is a coarsening-upward sequence of cross-stratified subarkoses. Photograph was taken in Section 29, T. 3 N., R. 8 W.

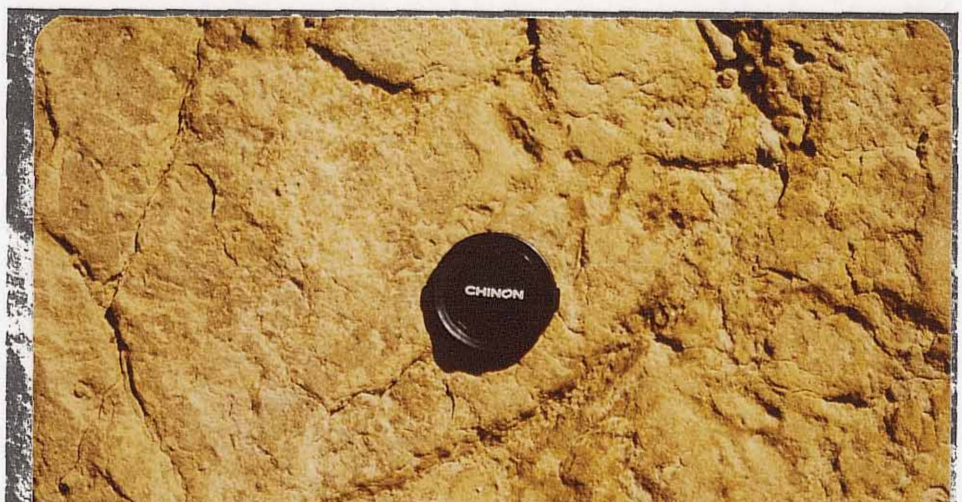


Plate 10. Ophiomorpha burrows--these trace fossil, which are characteristic of shoreface environments, are common in the Atarque Member of the Tres Hermanos Sandstone.

thickness, and foreset stratifications are inclined to the southeast (Appendix B).

The upper part of the Atarque is composed of rippled, microcross-laminated, bioturbated, thin-bedded, fine-grained sandstone, dark-colored, fossiliferous, bioturbated shale, and rare bioturbated biomicrites and rippled biosparites. Cymbophora sp., Cardium paraeculum, Laternula sp., Gyrodes despresus, and oysters are common at the top of the Atarque Member. The skeletal material is generally unabraded. The Atarque grades vertically into the overlying Carthage Member.

Carthage Member

The Carthage Member is 123 ft (38 m) thick and consists of numerous 3-5 ft (0.9-1.5 m)-thick, lenticular, light-yellow to olive green (5 Y 8/3 to 56 Y 3/2), silty, poorly sorted, trough and tabular cross-stratified, and rippled, fine-grained feldspathic litharenites. These sandstones have sharp, undulatory cut bases and contain a basal clay-clast congomerate. Bioturbation features are rare.

The sandstone packages become cleaner and more persistent toward the top of the member and the shale intervals increase in both thickness and in organic content. The shale intervals are dark, organic-rich, silty, and contain small, 0.1 ft (3 cm)-diameter, subequant, dark-red (5 R 3/4) ironstone concretions.

Several thin, dark-reddish-brown (10 R 3/4) zones in the higher part of the Carthage contain approximately 50%

carbonaceous matter. No coal is, however, developed in the Carthage Member. Unusual rock types associated with the carbonaceous interval are a thin, laterally persistent, 3 ft (1 m)-thick, structureless, grey (N7), silty subarkose, which contains abundant disseminated organic fragments and a lenticular zone of red (5 R 4/6) claystone clinkers formed as the result of in situ combustion.

The carbonaceous Carthage Member is overlain by the Fite Ranch Member. The contact between the Fite Ranch Member and Carthage is sharp and slightly erosional.

Fite Ranch Member

The Fite Ranch is 24 ft (7 m) thick throughout the study area. Regionally, the Fite Ranch (F sand of Molenaar, 1973) averages 5 ft (1.5 m) in thickness, but it is not present everywhere, such as in the Nutria monocline.

At the base of the section the rock is a structureless, spheroidal weathering, yellowish-grey (5 Y 7/2), slightly calcareous, bioturbated, moderately-sorted, medium fine-grained subarkose. Dark organic streaks and coal fragments occur locally within the base of the sandstone unit. The upper part of the unit is a medium fine-grained, calcite cemented subarkose.

Large, moderate-brown (5 YR 3/4) concretions, that are as much as 5 ft (1.5 m) in diameter, are common in the Fite Ranch Member. These concretions are very conspicuous and weather out as huge spherical boulders.

Eight thin-sections, of seven sandstones and a lime stone, from the Tres Hermanos were examined petrographically. A wide variety of rock types are represented in the Tres Hermanos strata. Sandstones from the Atarque Member generally contain less than 80% quartz grains and are subarkoses. The quartz grains are mostly subrounded, single grains with undulose extinction and are free of inclusion, although grains with microlites, bubbles and bubble trains are present. Sparry calcite is the chief cementing agent.

Feldspars are the second most abundant mineral constituent. Potassium feldspars, mostly orthoclase and lesser amounts of microcline, are the dominant feldspar types recorded, comprising up to 11% of the grains in some samples. Many of the grains are microperthite as exhibited by the characteristic alteration pattern of the grains. The feldspars are subangular to subrounded, and are generally smaller than the quartz grains. Both unweathered grains and grains that have undergone varying degrees of kaolinization and/or vacuolization are present. Sodic plagioclases are rarely observed and are poorly preserved. Other constituents that occur in small quantities, but which may be abundant locally, include: muscovite, biotite, glauconite, skeletal carbonate material, opaque minerals (iron oxides and organic material), chert, siltstone grains, phosphatic skeletal material, and anisotropic heavy minerals (Appendix A).

Sandstones in the Carthage Member are very calcareous, silty, contain no glauconite, have a higher percentage of organic debris, mica, and mudstone clasts than the Atarque sandstones. Sandstones in the Fite Ranch Member are mineralogically similar to those of the Atarque. The high organic content, lack of glauconite and presence of a clay-cast conglomerate at the base of the Fite Ranch sandstone is noteworthy.

The Tres Hermanos is composed of a thick section of marshy coastal plain sediments (Carthage Member) that are sandwiched between regressive (Atarque Member) and transgressive (Fite Ranch Member) sandstones. These strata accumulated during one of two major fluctuations in the position of the Upper Cretaceous shoreline in central New Mexico.

The Atarque Member represent sediments that accumulated as a near-shore submerged bar or barrier island complex during a late Greenhorn-early Carlile regression. The sandstone exhibits variations in texture and sedimentary structures that are similar to that interpreted by Molenaar (1973) as a prograding sand bar. These characteristics include: (1) coarsening-upward grain size, (2) vertical decrease in bioturbation, (3) prevalence of parallel laminations (lower shoreface) in the lower part of the unit, and (4) gradation from offshore marine muds at the base into coal-bearing coastal plain sediments at the top. As many as three vertically stacked bars exist in the D Cross area.

Near the top of the Atarque Member, a series of thin, immature, bioturbated and cross-stratified, oyster-bearing sandstones, biomicrites, and intercalated dark-colored bioturbated shales are interpreted as lagoonal in origin.

Lenticular sandstones in the Carthage Member represent channel-fill deposits that accumulated in channels that were cut into root-mottled organic-rich shale and "coals" that accumulated in a flood plain and interdistributary environment on a fluvially-constructed lower coastal plain. Similar channel sands, peat-bearing flood plain and interdistributary deposits are presently accumulating on the Mississippi River delta plain complex (Gould and Morgan, 1962) and are well known from the rock-record (Erpenbeck and Flores, 1979).

The Fite Ranch sandstone represents a single depositional environment in the D Cross Mountain quadrangle. This sandstone is a, moderately bioturbated, fining-upward sequence. The unit has a slightly erosional base and is overlain by marine shales of the D Cross tongue. Similar sand sequences are presently accumulating on the southeast Texas Gulf Coast as a result of a marine transgression caused by local subsidence and a deficiency of sand entering the shoreline system. The thinness of the Fite Ranch Member, its absence in some areas, and its synchronous age in widespread outcrops indicate that the sand represents an onlap sandstone that was deposited on a rapidly subsiding sand-starved coastline.

MESAVERDE GROUP

The name "Mesaverde Group" was first applied by Holmes (1877) to a thick sequence of Cretaceous sandstones and shales that crop out in Montezuma County, Colorado. Since Holmes' original work the term "Mesaverde" has been used inconsistently to connotate either group or formational rank. Two formations of the Mesaverde Group crop out in the study area. These are, in ascending order, the Gallup Sandstone and the Crevasse Canyon Formation.

Gallup Sandstone

The name Gallego was first used by Winchester (1920) for a thick, cliff-forming sandstone that crops out along the Rio Salado and the Alamocita Creek beds in west-central New Mexico. Winchester (1920) originally considered the Gallego to be a part of the now obsolete Miquel Formation. Later, Pike (1947), in a regional study of the Cretaceous of New Mexico, included the Gallego as the basal member of the Mesaverde Formation. The Gallego was raised to formational rank by Molenaar (1974) who suggested that the sandstone is correlative with the upper Gallup sandstone of the San Juan Basin. The Gallup terminology is now used throughout the Acoma basin for Winchester's Gallego Sandstone.

In the Riley-Puertecito area, the Gallup is divided into two units by an intervening tongue of the Mancos Shale (Molenaar, 1974). Massingill (1979) opted to apply the

"Gallego terminology" only to the lower of these two sandstones; including the upper unit in his undivided Mesaverde Formation (sic).

In the D Cross area the Gallup is a single, 80 ft (24 m) thick, sandstone that forms the stratigraphically highest laterally persistent cliff on the east face of D Cross Mountain (Plate 11). The upper part of the Gallup is bleached white and is very distinctive when viewed from a distance.

Fossils are not abundant in the Gallup Sandstone. In the D Cross area Prionocyclus novimexicanus, Baculites yokoyami, Inoceramus perplexus, and Lopha sannionis occur in the underlying D Cross shale within 10 ft (3 m) of the base of the Gallup. Lopha sannionis is common in the upper few feet of the Gallup Sandstone and Inoceramus sp. fragments occur throughout the unit. Massingill (1979) has reported Prionocyclus sp. and Baculites yokoyami from the base of the Gallup in the Puertecito area. Based on the contained fossil assemblage, the Gallup is late Turonian in age.

In the D Cross Mountain quadrangle, the Gallup is composed of a coarsening-upward sequence of subarkoses (Figure 9). At the base of the unit thin, very fine-grained sandstones are interbedded with shales over a vertical distance of 2-5 ft (0.6-1.5 m). The contact between the Gallup Sandstone and overlying Crevasse Canyon Formation is sharp and irregular but poorly exposed.

The greatest part of the Gallup is composed of alternating beds of fine- to medium-grained, moderately sorted

Plate 11. Cliff-forming outcrop of Gallup Sandstone--the unit is a coarsening upward sandstone package measuring 80 ft (24 m) thick. The contact with the underlying D Cross shale is gradational.

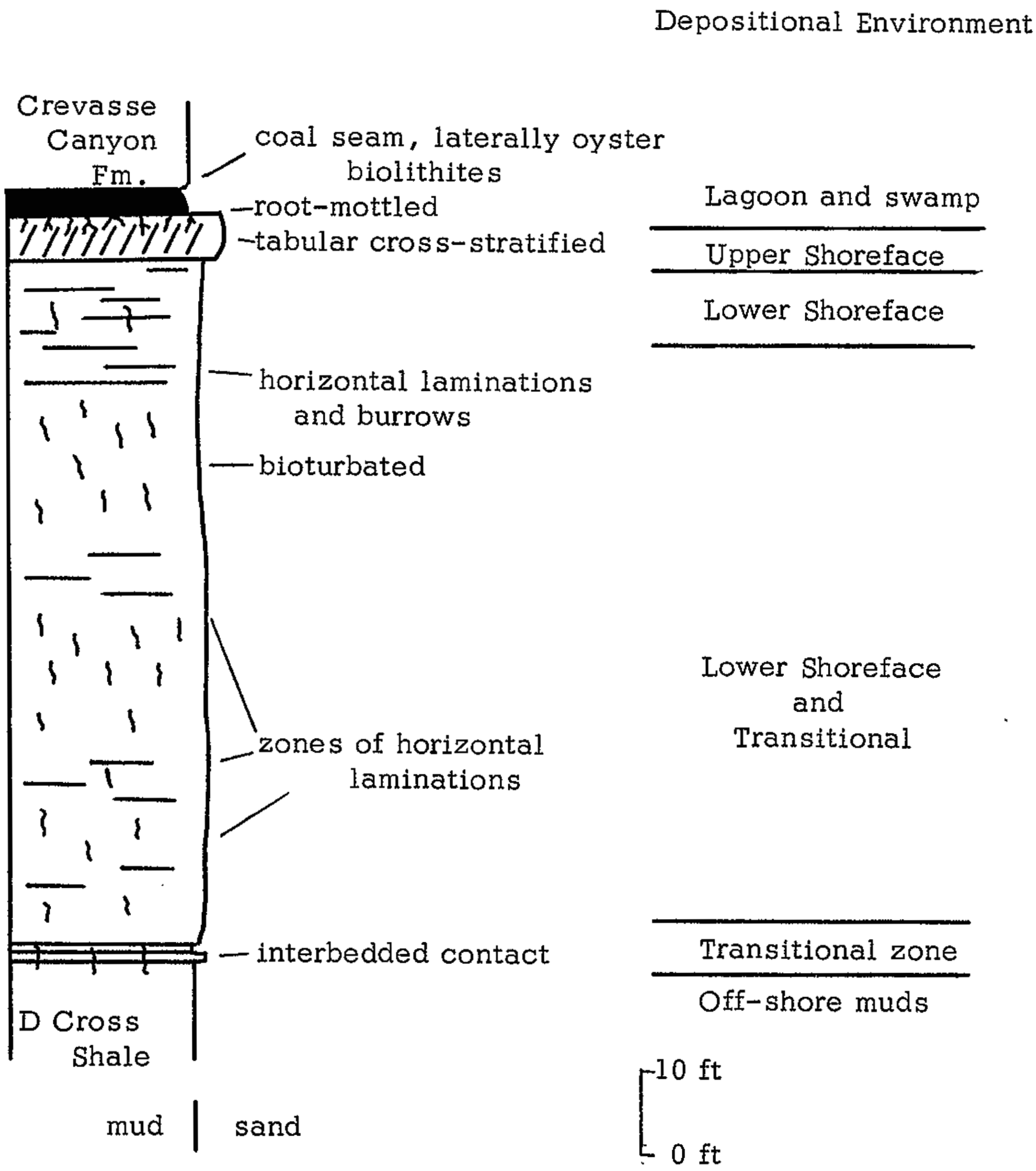


Figure 9. Stratigraphic section of the Gallup Sandstone. The Gallup sandstone represents a coastal barrier bar deposit.

subarkoses that are horizontally laminated and sparsely bioturbated, or intensely bioturbated and structureless. Abraded pelecypod shell hash occurs along bedding planes throughout the unit, but it is more common at the base of the formation.

Grain size increases rapidly near the top of the unit where the rock is a medium-grained, white (N8), mature, well sorted, tabular cross-stratified sandstone (Plate 12). Tabular cosets comprise an interval that is approximately 15 ft (5 m) thick. The cross-laminae are high angle, inclined uniformly to the southeast (Appendix B), and occur in sets that are as much as 1 ft (30 cm) thick. Laterally, small sand-filled channels occur at the top of the cliff-forming unit.

A series of thin-bedded, dark-colored, bioturbated shales and intercalated medium-bedded, bioturbated, structureless to horizontally laminated, and ripple cross-stratified sandstones occur in the upper few feet of the Gallup. The sandstones are moderately sorted, calcite cemented subarkoses. Locally, small, lenticular oyster bioherms occur in the shale intervals. The fossiliferous zones are dark-brown (5 YR 2/4) and stand out conspicuously against the white Gallup sandstones (Plate 13). The oysters are long, slender, black (N1) Ostera soleniscus that occur in growth position.

Long, 0.3 in. (7.6 mm)-diameter, circular, branching root-tubes are present in the upper part of the unit in many

Plate 12. Cross-stratified, upper shoreface deposits at the top of the Gallup Sandstone. Photograph was taken along the north bank of Alamocita Creek in Section 30, T. 3 N., R. 8 W.

Plate 13. Oyster bioherm in the upper Gallup Sandstone--the oysters are Ostera soleniscus that occur in growth position. Brown weathering of the bioherm is distinctive against the white Gallup strata. Photograph was taken in Section 30, T. 3 N., R. 8 W.

areas. The tubes are best exposed in outcrops along the north bank of the Alamocita Creek due south of D Cross Mountain.

Examination of the Gallup sandstones in five thin-sections show the rock to be a subarkose or lithic arkose. The dominant mineral constituent is quartz which comprises 60-75% of the rock. The quartz grains are uniformly sub-rounded, single crystals with slightly undulose extinction and are free of inclusions. Feldspar comprises approximately 19% by volume of the framework grains. The feldspar grains are mostly intensely weathered orthoclase that are smaller than quartz grains. Only a trace of plagioclase and microcline were noted. Other minerals, present in varying quantities, include: muscovite (trace), chert (as much as 3%), glauconite (trace), opaque constituents (1-2%), and mudstone clasts (1-3%) (Appendix A).

The rock varies from loosely packed, with grains in point contact, to tightly packed, with grains having multiple concave-convex or straight boundaries. Squashing of labile mineral constituents in the more tightly packed fabric is common.

The primary cement in the rock is calcite. The calcite crystals are large, up to 0.1 in. (2.5 mm) in diameter, equant, and enclose numerous framework grains. The cement is of an aggrading, neomorphic origin as shown by the presence of framework grains floating in the sparry calcite cement. Finely crystalline silica cement occurs in most rock specimens, but it is more common in the tightly packed rocks. Silica is subordinate to calcite in total volume. Minor amounts of clay matrix were observed in most samples. Some of this "matrix" may be squashed clay-clasts.

The Gallup strata accumulated as a nearshore, regressive, marine sand body and in related environments. Sorting, grain size, and mineralogy (glauconite), as well as stratigraphic relations and the contained fauna, support the concept of a marine origin for the unit. The lower part of the unit is composed of bioturbated and structureless or horizontally laminated sandstone that grades into marine mud of D Cross Shale. Bioturbated, structureless to horizontally laminated sands grade into marine muds in typical Holocene lower shoreface environments (Bernard and others, 1970). Sorting and grain size increase toward the top of the unit and tabular cross-stratifications are well developed. These deposits resemble upper shoreface sediments that accumulate above wave-base as described by Reineck and Singh (1975).

Locally, black, oyster patch reefs and bioturbated black shales and small tidal channels document a coexisting lagoonal environment for at least part of the Gallup. Thin structureless to horizontally laminated sands associated with the lagoonal sediments are similar to washover fan deposits (Hayes, 1967) or the distal portions of tidal deltas (Bernard and others, 1970).

In the Alamo Day School area a classic sequence from lower shoreface through dune deposits is exposed in the Gallup Sandstone. This section is overlain by coal-bearing sediments of the Crevasse Canyon Formation. In the D Cross area the close relations of the Gallup sand body to non-marine environments is well documented by coals that overlie the Gallup and by the presence of mangrove-like root tubes (Chaiffetz, oral commun., 1977) within the upper part of the sandstone. No beach or dune deposits separate these swamp and shoreface deposits. However, due to contemperaneous erosion, dune and beach deposits often are not preserved in the rock-record (Dickerson and others, 1972).

Crevasse Canyon Formation

Givens (1957) extended the Crevasse Canyon terminology of Allen and Balk (1954) into the D Cross area; applying the formational name to a thick sequence of coal-bearing sandstones and shales that overlie the Gallup (Gallego) Sandstone. Givens, however, made no attempt to define any of the formal members of the formation that are recognized in the San Juan Basin. I have recognized three distinct units within the Crevasse Canyon Formation; these are, in ascending order: (1) basal sandstone, (2) interbedded shale and sandstone, and (3) upper sandstone. These divisions are used informally and cannot, as yet, be correlated with the members described by Allen and Balk (1954). In the Riley-Puertecito area, Massingill (1979) recognized three informal divisions of his undifferentiated Mesaverde Formation (sic) (Crevasse Canyon Formation). These units correspond roughly to the divisions I have utilized in the D Cross Mountain area.

The Crevasse Canyon Formation dips gently to the southwest and is exposed in almost continuous outcrop along an east-west line from Pietown, New Mexico, to Puertecito, New Mexico. North of this line, the strata have been eroded due to uplift of the Colorado Plateau. South of the outcrop belt, the Crevasse Canyon is present only in the subsurface. In general, the Crevasse Canyon thickens to the east and pinches-out within the Mancos Shale north of D Cross Mountain (Molenaar, 1974).

In the D Cross Mountain quadrangle an incomplete section of Crevasse Canyon, 793 ft (242 m) thick (Figure 10) was measured on the north face of Blue Mesa. The formation may be appreciably thicker, but the lack of marker beds, variable dips, and rugged terrain make accurate thickness determinations difficult.

The Crevasse Canyon crops out in the southwestern and northeastern parts of the mapped area on opposite sides of the Red Lake fault. The strata, where not protected by a resistant cap rock such as the basalt flows on Blue Mesa, erodes to form a series of low cuesta-like hills.

No diagnostic megafossils were observed in the Crevasse Canyon strata, although a few poorly preserved pelecypods were collected from the lower part of the formation. The Crevasse Canyon rests conformably on the late Turonian to

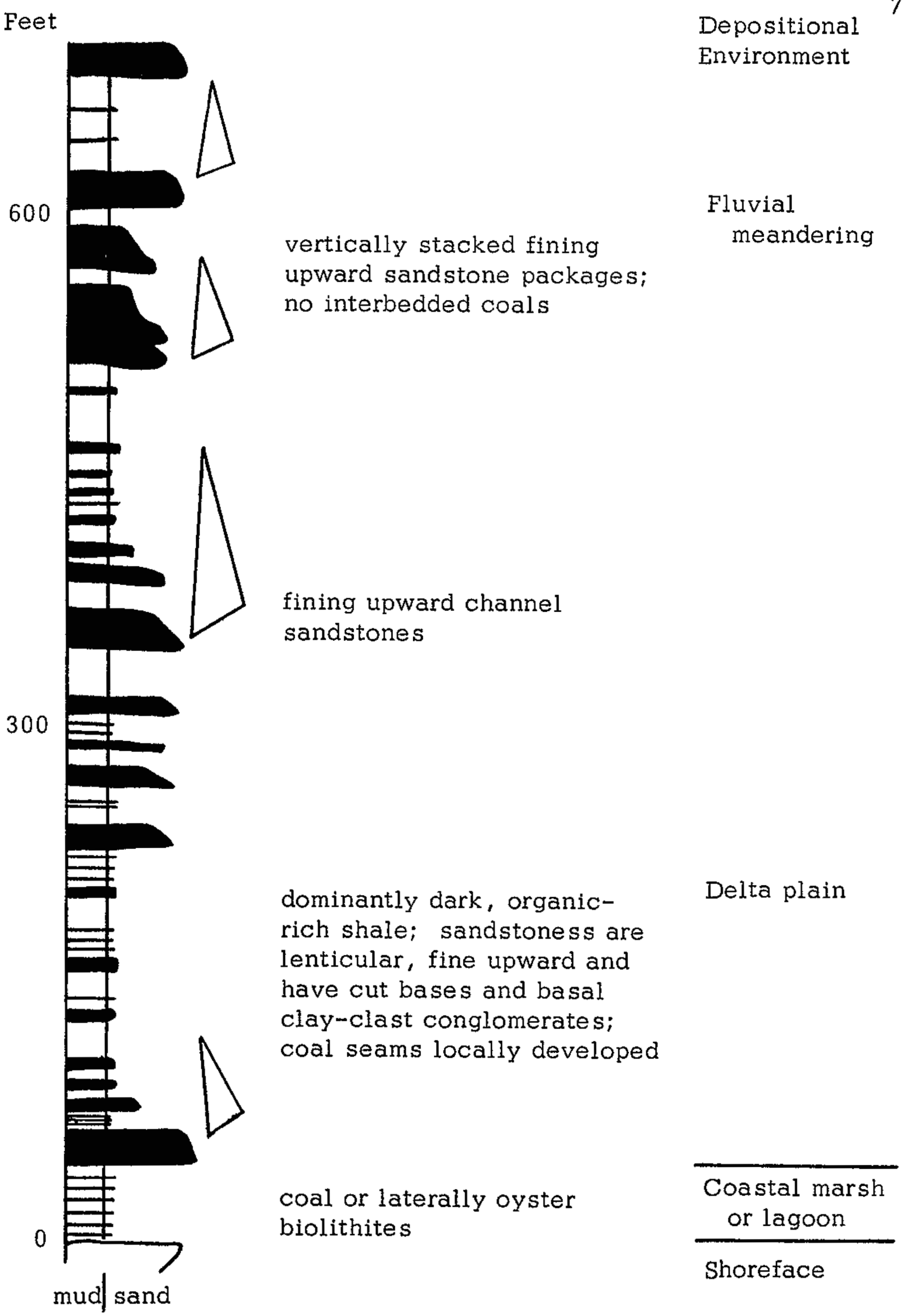


Figure 10. Stratigraphic section of the Crevasse Canyon Formation. Note fining upward sandstone units.

early Coniacian Gallup Sandstone and is unconformably overlain by the Eocene Baca Formation. A late Coniacian to early Eocene age appears reasonable for the Crevasse Canyon strata. Pollen from Crevasse Canyon shales partially substantiates this age determination (Chaiffetz, oral commun., 1977).

The basal sandstone sequence of the Crevasse Canyon Formation consists of approximately 50 ft (15 m) of silty shale and a single laterally persistent, 30 ft (9 m)-thick sandstone. The middle unit of the Crevasse Canyon is approximately 500 ft (152 m) thick and consists of a monotonous repetition of interbedded shales and sandstone. The upper sandstone sequence is 250 ft (76 m) thick, and is composed predominantly of sandstone with thin shale interbeds. Individual sandstone bodies of the upper sequence are not thicker than those in the middle unit but, packages of vertically stacked sandstones comprise intervals of considerable thickness. The lack of an appreciable thickness of shale and the absences of coal is the basis for differentiation between the upper and middle units of the Crevasse Canyon. The upper sequence crops out as a series of poorly developed cliffs on the north and east sides of Blue Mesa and probably represents the strata shown as Point Lookout Sandstone in the 1965 edition of the New Mexico State Geologic Map.

Sandstones within the three members are very similar (Plate 14). In general they are lenticular, and they are in

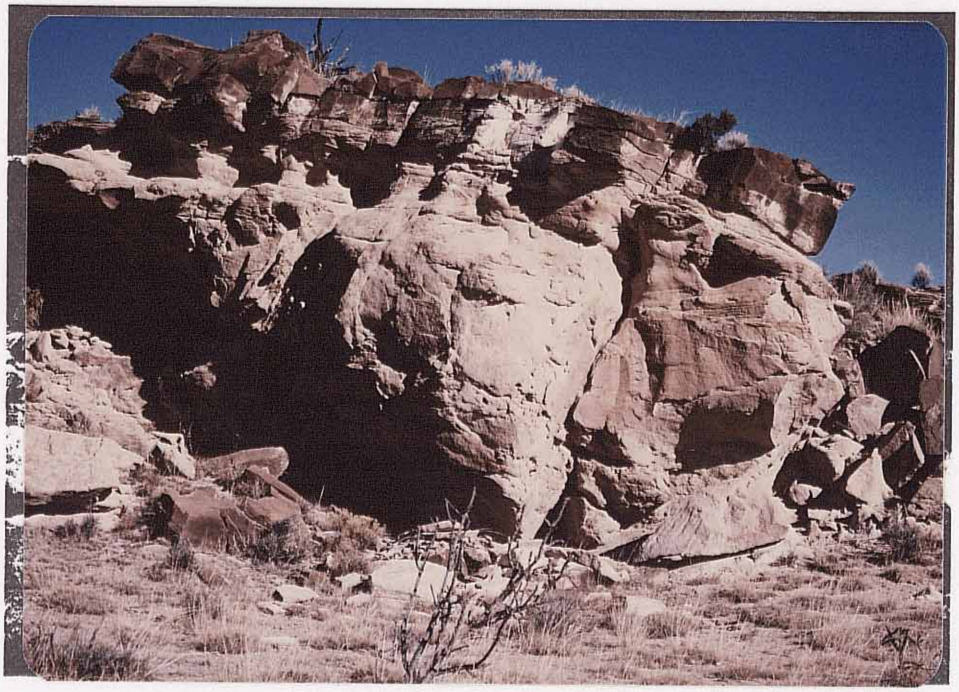


Plate 14. Channel sandstone in the Crevasse Canyon Formation--the sandstone unit has a cut base, lenticular geometry, and is a fining upward sequence. Photograph taken in Section 22, T. 3 N., R. 8 W.

erosional contact with either an underlying shale unit or another sandstone. Gravel-size clay rip-up clasts are common in the base of the sandstone packages. The sandstones are light-yellow (5 Y 8/6), well indurated, concretionary, cross-stratified subarkose that grades from coarse sand at the base to fine sand at the top. The following vertical sequence of sedimentary structures is present: (1) structureless to crudely trough cross-stratified zone, (2) trough cross-stratified zone, (3) tabular cross-stratified interval with sets of cross-laminae as much as 1.5 ft (46 cm) thick, (4) zone of interbedded, fine-grained, traction-current-type rippled sandstones and shales with tracks and trails on bed soles. The dip direction of cross-lamination foresets indicate a northeast paleo-flow direction (Appendix B).

Generally the upper few inches of each sandstone is moderate-brown (5 YR 3/4) and very calcareous. The calcite cemented zone results in the development of a resistant dip-forming cap on which a karren-type weathering surface develops. Hickory-nut size, brown (5 YR 4/4), carbonate or iron oxide cemented concretions occur sporadically within the sandstones.

Mineralogically, the sandstone framework grains are moderately sorted and rounded to subrounded quartz and as much as 17% potassium feldspar. Rarer mineral constituents include grey chert (3-4%), plagioclase (3-10%), micas (2%), and a trace of rounded zircon (Appendix A). The grains are loosely bound by silica and hematite cement or have a clay pore-filling matrix.

Intervening shale units are poorly exposed, dusky yellow-green to light-olive (5 GY 5/2 to 10 Y 5/4), silty, splintery weathering, organic rich, and contain wood impressions, rare pelecypods and irregular calcium carbonate and siderite cemented concretions. Locally, thin, structureless, fine-grained, iron oxide cemented sandstones with tracks and trails on bed soles, 0.5 ft (15 cm)-thick, lenticular coal seams (Plate 15), and cone-in-cone limestone occur in the shale units. The thickest coal seam in the D Cross area is 2 ft (61 cm) thick and occurs within the shale interval in Sec. 30, T. 3 N., R. 8 W.

Deposition of the Crevasse Canyon strata took place in coastal marsh, fluvial channel and flood plain environments. Dark colored shales that overlie the marine shoreface and lagoonal Gallup sandstones contain thick laterally persistent Classopollis pollen-bearing coals and fine sandstones. These deposits accumulated in a coastal brackish to fresh water marsh environment behind the strandline sandstone. Similar accumulations of peat are known in Recent coastal environments and from the rock-record (Roehler, 1977; Shomaker and others, 1971; Young, 1955; Gould and Morgan, 1962; and Fisk, 1960). The presence of mangrove-like root-casts extending into the upper parts of the Gallup sandstone indicates that rooted trees or shrubs flourished in the swamp.

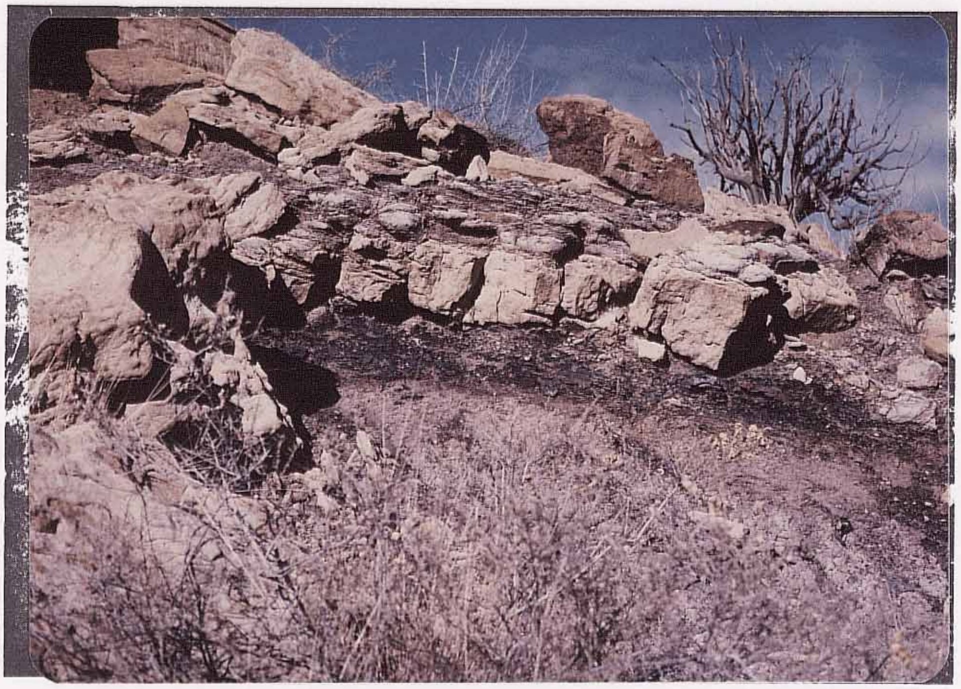


Plate 15. Coal seam in the Crevasse Canyon Formation--this seam is less than 1 ft (30 cm) thick and cannot be traced laterally. Sandstone unit directly above the coal is a crevasse splay. Photograph was taken in Section 21, T. 3 N., R. 8 W.

Sandstone and shale in the lower and middle part of the Crevasse Canyon exhibit features that are similar to deposits that accumulate in the lower reaches of meandering stream systems that develop on a low relief, coastal plain. The sandstones are characterized by erosional bases, basal clay-clast conglomerates, fining-upward textures, lenticular geometry, traction-current-type cross-bedding, and a distinctive sequence of sedimentary structures that is generally associated with meandering stream point-bar deposits (Maberry, 1971). The thinness of the sandstone packages suggests that a series of small anastomosing channels existed; similar to the Niger (Allen, 1965) and parts of the Mississippi River (Coleman and Gagliano, 1965) delta plains. Genetically-related dark shales, coal seams containing angiosperm pollen, and thin dirty sandstones, that are laterally associated with the channel sandstones represent interdistributary deposits that accumulated between sand-fill channels. These interdistributary areas probably fluctuated between open water lakes characterized by deposition of clean shales and a fresh water fauna, and vegetation-clogged, stagnant, chemically-reducing swamps in which thin coals developed. Similar genetic sequences are well documented on the delta plain of the Mississippi River (Fisk, 1960). Thin "dirty" sandstones interbedded with the flood-basin sediments are probably crevasse splay in origin.

The upper part of the Crevasse Canyon is composed primarily of thick, lenticular sandstone packages that consist of a series of vertically stacked channel sandstones. Flood plain clays and silts are noticeably absent. The sandstones exhibit characteristics similar to the fluvial sandstones in the middle unit and differ only in size and number. No coals occur in the upper sequence of the Crevasse Canyon Formation. The massive sandstones resemble those that accumulate in the upper reaches of a meandering stream system, in an area of slow subsidence, perhaps beyond the hinge-line of coastal subsidence. Here the channels would migrate laterally over great distances reworking and redistributing flood plain muds while depositing only a thin point-bar sand sequence. Each sweep of the river system across the area would then deposit another point-bar channel-fill sequence above the last. The result is a series of vertically stacked channels sands. Thick Tertiary sandstone packages from the upper Texas Gulf Coast have been ascribed to a similar mode of deposition (Fisher, 1968).

In conclusion, the strata of the Crevasse Canyon represent a transition from coastal marsh and lagoonal condition, through delta plain conditions, into a "normal" meandering fluvial system. This vertical sequence is typical of a low relief, clastic, prograding shoreline.

Tertiary System

Strata that accumulated during the Cenozoic document periods of fluvial deposition, widespread volcanism, and associated erosion. The oldest Tertiary rocks exposed in the D Cross area are Eocene red beds of the Baca Formation that disconformably overlie Cretaceous age Crevasse Canyon strata. During the Oligocene, a thick pile of quartz latite tuffs and related rocks were derived from a volcanic center located in the Gallinas Mountains. Following the eruptive events the detritus stripped from the volcanically constructed highlands accumulated as a Miocene alluvial fan apron. During the Pliocene, a second eruptive event spread thin basaltic lavas over a rolling hill topography. The late Pliocene was a time of erosion and pediment construction associated with regional lowering of base-level.

Baca Formation

The term Baca Formation was originally used in the Riley-Puertecito area by Wilpolt and others (1946) for the lower 687 ft (208 m) of Winchester's (1920) Datil Formation. Givens (1957) extended the Baca terminology into the D Cross Mountain area. Well data indicate that 2500 ft (760 m) of Baca strata are present in the subsurface, although in the Datil Mountains maximum exposures are less than 1100 ft (335 m) thick (Snyder, 1971). In the D Cross Mountain quadrangle, a minimum of 670 ft (204 m) of red (5 R 4/6) shales and siltstones, and red to white (5 R 5/4 to N8) lithic arkoses constitute the Baca Formation (Plate 16).

Regionally, Baca, or Baca equivalents, are exposed from Carthage, New Mexico, westward into Arizona. Strata corre-

Plate 16. Exposure of the Baca Formation--Section 35, T. 3 N., R. 8 W. The section is 640 ft (195 m) thick and composed of interbedded red shale and white sandstone.

lative with the Baca include the Eager Formation (Johnson, 1978) and Mogollon Rim gravels in Arizona (Cather, 1980).

No diagnostic fossils were recovered from the Baca strata. Silicified wood is, however, present in a few conglomerate beds, and a few small bone fragments were collected from exposures of Baca below the prospect on the north face of Blue Mesa. In the Socorro area, Garner (1910) collected middle Eocene rhinoceros-like remains from the Baca and <u>Protoreondon pumilus</u> has been described from Baca outcrops exposed west of the study area (Snyder, 1971). Vertebrate remains of Eocene to early Oligocene age are known from the Datil Mountains and Quemado areas, Tiliaceous and Juglandaceous (Linden-walnut) pollen have been identified from the basal Baca shales in the D Cross Mountain area (M. Chaiffetz, oral commun., 1978).

The contact of the Baca with the underlying Crevasse Canyon Formation has been concluded locally to be: erosional, angularly unconformable, or conformable by various workers. The nature of the contact cannot be physically demonstrated from the limited exposures in the study area.

The upper contact between the Baca and Spears Formation is erosional along the north face of the Gallinas Mountains. Approximately 0.5 mi (1 km) south of Sec. 34, T. 2 N., R. 8 W., Spears tuffs crop out approximately 100 ft (30 m) below the projected Spears-Baca contact as observed in the Gallinas Mountains. No faulting is evident but a thick sequence of gravels obscure the field relations.

The base of the Baca was placed at the first occurrence of variegated shales. In the D Cross area, variegated shales occur in a zone that is approximately 50 ft (15 m) thick (Plate 17). The shales are silty, horizontally laminated to structureless, slightly calcareous, root-mottled, olive grey (5 Y 6/1) to medium-dark grey (N4), light-brown (5 YR 6/4), greyish-purple (5 P 6/2), and yellow (5 Y 7/4). Ironstone nodules and 0.5-1.0 ft (15-30 cm)-diameter, black to yellow (N2 to 5 Y 7/4), septarian-like carbonate concretions are locally abundant. This basal zone is considered "transitional" to the Crevasse Canyon and is composed of, in part, reworked Cretaceous strata. Johnson (1978) reported a similar transition zone, as much as 250 ft (76 m) thick, between the Baca and Crevasse Canyon in the Datil Mountains. D. Chamberlin (oral commun., 1980) believes this "transition zone" may be actually a weathered zone in the top of the Crevasse Canyon Formation. Another possibility is that the variegated shales are of Paleocene age.

The Baca consists principally of silty shales in which numerous 4-30 ft (1.2-9.1 m)-thick, lenticular sandstone beds occur. The shales are red (5 R 4/6), silty, noncalcareous to slightly calcareous, and vaguely laminated or structureless. Thin, irregular ironstone layers, isolated, 0.1-.02 in. (.25-.50 cm)-diameter, botryoidal iron oxide nodules, and pea-size, white (N7), calcium carbonate nodules or thin caliche beds occur sporadically within the section.

Plate 17. Shale strata in the base of the Baca Formation--the shale interval is approximately 50 ft (15 m) thick and composed of variegated, concretionary shale of possible Paleocene age.

Thin structureless or horizontally laminated, muddy, slightly calcareous, fine-grained, red (5 R 5/4) lithic arkoses are common in the shale unit. The sandstones range from 0.1-3.0 ft (.25 cm-1 m) thick and have erosional or gradational contacts with the enclosing shales.

Thicker sandstone packages are fining-upward sequences composed of medium- to coarse-grained, moderately sorted, indurated, calcite cemented arkoses. These sandstones are as much as 30 ft (9 m) thick but pinch-and-swell laterally. The base of a typical sandstone is erosional into either shale or another sandstone unit. The lower half of a typical sandstone is structureless, horizontally laminated or trough cross-stratified and may contain zones of tabular wedge-sets that are up to 1 ft (30 cm) thick. Large, red shale rip-up clasts are common at the base of the sandstones. The upper part of a typical sandstone is medium-grained and exhibits the following vertical sequence of sedimentary structures: (1) horizontal lamination, (2) zones of small asymmetrical ripples; locally climbing, and (3) horizontal lamination with rare contorted laminae. The sandstone body may be gradationally or sharply overlain by shale, or it may be in erosional contact with an overlying sandstone.

A single, 6 ft (3 m) thick, dip-slope forming conglomerate crops out approximately 70 ft (24 m) above the base of the Baca Formation. The conglomerate is continuous throughout the D Cross Mountain area and I have observed a similar conglomerate west of D Cross Mountain in the Cal Ship Mesa quadrangle. The conglomerate has an erosional base and is composed of randomly oriented, equant to bladed, rounded pebbles and cobbles of variously colored quartzite and chert, arkosic sandstone, grey (N6) fossiliferous Paleozoic limestone, and granite. The larger clasts are as much as 6 in. (15 cm) in diameter. This conglomerate may separate the Eocene Baca from the underlying, perhaps Paleocene, variegated shale zone. Abundant gravel-size clasts litter the slope higher in the section; but, a source for the material could not be located.

Mineralogically the Baca sandstones are lithic arkoses and arkoses. Quartz is the most abundant constituent but comprises only 50-60% of the rock. The grains are a mixture of single grains and composite grains which have either undulose or straight extinction. Most are inclusion free although grains with bubbles, bubble trains, and microlite inclusions do occur. The quartz grains are generally subrounded.

Feldspars comprise 20% of the framework grains (Appendix A). Most are potassium feldspars (13%). Orthoclase is the most abundant K-feldspar, microcline is common, and perthite grains are rare. Most of the K-feldspars grains are subrounded, moderately weathered, and due to vacuolization and kaolinization, appear cloudy in plain-light, although the spectrum from fresh to intensely weathered grains are present. Plagioclase grains comprise 8% of the sand fraction. Partial alteration of these grains to sericite or illite is common. Selective alteration of plagioclase to illite or sericite within perthite grains is also noted.

Other constituents comprise approximately 12% of the rock. These include grey (N4) microcrystalline chert (6%), limestone (2%), muscovite (1%), granite and quartz schist (3%), chlorite (trace), biotite (trace), and heavy minerals (trace).

The rock is cemented by blocky sparry calcite. The carbonate crystals are as large as 0.3 in. (8 mm) in diameter. Other cementing agents are rarely present, although fine-grained, poorly sorted sandstones may have a clay matrix.

In the D Cross Mountain area, the Baca strata accumulated in a series of southeast flowing meandering streams, as channel-fill and flood plain deposits. Vertebrate fossil remains and association with other continental environments are strong evidence for the continental origin of the rock unit.

Regionally, many local sources existed for the Baca Formation (Johnson, 1978; and Cather, 1980). The lithology of pebble-sized clasts in the Baca suggests a Precambrian to Paleozoic granitic, metamorphic, and sedimentary provenance. Rounding of the largest clasts indicates on the order of 100 mi (160 km) of transport and cross-laminae in the upper part of the formation give a southeasterly paleo-flow direction

(Appendix B). This data suggests that the Baca sediments were derived from rocks that crop out in the Zuni Mountains of New Mexico. Influx of sediments from the Mogollon highlands, however, is documented by the presence of sand-sized volcanic rock fragments and cross-laminae that indicate a more northerly paleo-flow direction in the lower 1/3 of the unit. Cather (1980) has documented that much of the Baca exposed in the Gallinas Mountains southeast of the D Cross area was deposited in north-flowing streams and in an associated lake-delta complex. The source for these sediments was strongly influenced by the Mogollon highlands.

Lenticular, fining-upward sandstones that have cut bases and basal clay-clast conglomerates are interpreted to be channel-fill deposits. These sandstones exhibit a sequence of sedimentary structures that is similar to a typical meandering stream point-bar sand as described by Allen (1964), Visher (1972), and Bernard and others (1970). Vertical stacking of genetic units is common. Horizontally laminated and rippled fine-grained sandstones that are laterally associated with the channel-fill sequences are similar to natural levee deposits of the Brahmaputra River (Coleman, 1969).

The high clay content of the Baca is evidence of a high suspended-load meandering stream system, because extensive mud-covered flood plains are required for bank stabilization before meandering can occur (Bernard and others, 1970). Mudstones make up 60% of the Baca Formation. The mudstones are red, exhibit desiccation features, contain caliche nodules and vertebrate fossil remains, and are root mottled. Similar deposits accumulate on interfluvial flood plains along the courses of many large meandering streams (Bernard and others, 1970). Thin sandstones within the dominantly mud interval may be of crevasse splay origin.

Cather (1980) believes that the red coloration of the Baca strata is a diagenetic phenomenon and that the Baca accumulated under a "hot, semiarid, possible savanna-like climate." The extensive meandering stream complexes developed in the D Cross Mountain area suggest that a wetter, perhaps subhumid climate existed.

Spears Formation

The Spears Member was originally separated from Winchester's (1920) Datil Formation by Tonking (1957). Givens (1957) extended the Spears terminology into the Dog Spring quadrangle but used the term Spears Ranch Member of the Datil Formation. The unit was elevated to formational rank and renamed the Spears Formation by Chapin (1974).

The Spears is an extensive unit cropping out in the Datil, Bear, Lemitar, Gallinas, Magdelena, and Chupadera Mountains, and Joyita Hills. The Spears is probably equivalent to the Rubio Peak Formation in the east-central part of the Datil-Mogollon volcanic field (C. Chapin, oral commun., 1980). At the reference section, in the northern Bear Mountains, the Spears consists of approximately 1200 ft

(365 m) of sandstone and conglomerate that accumulated as a volcaniclastic apron around an Oligocene volcanic field (Chapin and Seager, 1975; and Massingill, 1979). In the D Cross Mountain quadrangle, the Spears is approximately 2000 ft (610 m) thick and is composed predominantly of tuff breccias and volcaniclastic sedimentary rocks.

The northern face of the Gallinas Mountains and southern part of Blue Mesa (northern Datil Mountains) are primarily underlain by Spears lithology. The resistance to weathering of the rock results in the development of smooth-sided hills and valleys in which exposures are poor.

Throughout the D Cross area, the Spears disconformably overlies the Baca Formation and is separated by an angular unconformity from younger strata. South of the mapped area however, the Spears is conformably overlain by a thick pile of ash-flow tuffs and flow rocks (Givens, 1957; and Harrison, 1980).

In the study area, the Spears is composed of a suite of rock types that includes lithic-crystal and crystal-lithic tuffs and volcaniclastic sedimentary rocks. Volcaniclastic rocks are the most abundant rock types. The lower part of the unit is predominantly light-grey (N7) tuff (Plate 18) which grades vertically into volcaniclastic rocks. Due to poor exposures, lack of distinctive marker beds, structural complication, and the lenticularity of the lithotypes, members were not delineated during mapping.

Plate 18. Crystal-lithic tuffs in the Spears Formation. The tuffs are quartz-rich and pumice poor. Devitrification of the groundmass is extensive. Photograph taken on the west side of Dog Springs Canyon approximately 1 mi (1.6 km) south of the Martin Ranch house.

Generally, the tuffs are light-grey (N7), lithic-crystal and, due to extensive devitrification, show little evidence of welding or compaction. The lithic fragments range from sand to small pebble size, and are composed predominantly of rounded to angular volcanic rock fragments that are lithologically similar to the enclosing tuff matrix. Sand size clasts of quartzarenites, fossiliferous limestones, granites, and gneisses are also present (0-10%).

Phenocrysts within the tuffs include strongly embayed quartz (rare), zoned, euhedral or broken andesine (abundant) that exhibits multiple growth stages and have a more calcic core, euhedral amphibole (common), opaque minerals (common), and a trace of augite and sanidine. Devitrification of the groundmass makes detailed study of the rock difficult. X-ray fluorescence analysis of a Spears tuff indicates approximately 68% silica (Table 1).

Debris flows are common in the Spears section. Both monomictic and polymictic debris flows are present. Generally the clasts are either uniformly rounded or angular, and are volcanic in origin. Occasional cobbles or boulders of sedimentary or intrusive igneous origin are also encountered. Debris flows containing enormous blocks of fossiliferous Paleozoic limestone are common in the base of the formation.

Rare rock types within the unit include black (N1) basaltic autobreccias and thin, cross-stratified, moderate-yellow (5 Y 7/6) volcanicarenites. The latter rock types

OXIDE	Spears Tuff	Blue Mesa Basalt
SiO_2	67.905	47.384
TiO_2	0.741	2.614
Al_2O_3	14.649	14.079
Fe_2O_3	4.766	11.464
MgO	2.081	8.902
CaO	3.888	9.409
Na_2O	3.883	2.971
K_2O	2.784	1.110
MnO_2	0.076	0.186
P_2O_5	0.413	0.706
Total %	101.186	98.826

TABLE 1

X-ray Fluorescence Analyses of Volcanic Rocks from the D Cross Mountain Area are confined to the southernmost exposures in the quadrangle.

Bedding within the Spears Formation is relatively chaotic with dips changing every few tens of feet, although the general dip is to the southwest. An unusual structure occurs in the tuffs approximately 0.5 mi (0.8 km) south of the Fred Martin Ranch. There, light-grey crystal-lithic tuffs dip as much as 80° and have strikes that curve through a 180° arc.

Several crystal-rich tuff samples were collected for radiometric dating. Unfortunately thin-section analyses indicated the presence of small xenoliths and possible xenocrysts in all specimens (G. Osborn, oral commun., 1979). Therefore, no radiometric dates were attempted. The Spears overlies Eocene Baca strata and is laterally equivalent to rocks of the Bear Mountains-Joyita Hills area, that have been dated as 33 to 37 m.y. old (C. Chapin, oral commun., 1980).

The Spears strata accumulated in numerous genetically related environments in close proximity to a suspected Tertiary cauldron complex. Mapping in the D Cross Mountain and Dog Springs quadrangles has not, however, delineated either a structural or geomorphic cauldron margin. In the D Cross Mountain quadrangle the Spears unconformity overlies the Baca Formation. South of the mapped area, the Spears is covered by younger ash-flow tuffs (Harrison, 1980). It is conceivable that a cauldron center is concealed in the southern Gallinas Mountains.

The thick accumulation of mudflows in the D Cross area suggests deposition in close proximity to a large eruptive center. Although the tectonic framework associated with deposition of the Spears is not fully understood, the strata are similar to mudflow aprons that accumulate around cauldron centers in other areas. Large blocks of Paleozoic limestone in the Spears Formation probably represent debris that was transported into the area from a Laramide high as clasts within debris flows.

Attitudes of the Spears strata are erratic, changing every few hundred feet. Lateral variations in lithology are also pronounced. The chaotic dips are due to both penecontemporaneous soft sediment deformation and to the original dips of debris flows that were deposited in an entrenched channel system.

Conglomerate of Rock Tank Canyon

Approximately 290 ft (88 m) of coarse sandstone and conglomerate crop out east of the Red Lake fault. The best exposures of the unit occur in Rock Tank Canyon and the unit is here referred to as the conglomerate of Rock Tank Canyon. These same strata were earlier designated Santa Fe Formation by Givens (1957).

An attempt to restrict the Santa Fe terminology by Galusha and Blick (1971) has not been well received and most "late Tertiary valley fill of Atlantic drainage" in New Mexico is presently considered to be Santa Fe Formation (Elston, 1976). Because the relations of the conglomerate of Rock Tank Canyon to other conglomerate units, or to the regional drainage pattern during deposition are not fully understood, I have opted not to apply a formal lithostratigraphic name to the unit.

The conglomerate of Rock Tank Canyon is exposed in discontinuous outcrop adjacent to the Red Lake fault from the vicinity of Blue Mesa Tank northward beyond the mapped area. Isolated outcrops of a similar conglomerate have been reported south of the study area and from Tres Hermanos Mesa and Table Mountain Mesa (Givens, 1957).

The conglomerate rests with angularity on older strata of the Spears, Baca (Plate 19), and Crevasse Canyon Formations, from south to north, and appears to have been deposited on a north-sloping surface. The thickest and best exposed sections occur in Sec. 35, T. 3 N., R. 8 W., along the north end of the north-trending ridge. At that locality, the base of the conglomerate is in erosional contact with Baca strata. Local relief on the contact is only 1-2 ft (30-61 cm).

The conglomerate of Rock Tank Canyon is thought to be of late Miocene to Pliocene age. No fossils were collected from the strata and the age is therefore based on structural and stratigraphic relations. The unit angularly overlies the Oligiocene Spears Formation but is cut by the Red Lake

Plate 19. Conglomerate of Rock Tank Canyon. The light-grey hills in the background are composed of 290 ft (88 m) of volcanic pebble conglomerates. This conglomerate is in erosional contact with red Baca Formation strata. Photograph was taken looking southwest from Section 36, T. 3 N., R. 8 W

fault. Latest movement along the fault has been tentatively established as late Pliocene.

The conglomerate unit is a fining-upward sequence composed of light-grey (N7) structureless to horizontally laminated conglomerates and interbedded pinkish-grey (5 YR 8/1) sandstones. Near the base of the unit, thin- to medium-thick lenticular beds of moderately to poorly sorted, indurated, large-pebble conglomerates are the dominant rock type. The larger clasts are as much as 8 in. (20 cm) diameter but average only 0.5 in. (1.3 cm) in diameter.

The clasts are generally platy to compact, imbricated, subangular to subrounded pebbles and cobbles of quartz latite tuff. Black (N1) basalt, limestone, and sandstone clasts occur in trace amounts. The rock is grain supported and has a light-grey (N7) to faint-pink (5 YR 8/1) calcareous, muddy, volcanicarenite matrix.

The upper part of the conglomerate of Rock Tank Canyon is composed of light-pink (5 YR 8/1), very pebbly, coarse-grained horizontally and tablular cross-stratified volcanicarenites (Appendix A). The sandstones are moderately sorted and are composed of volcanic rock fragments, feldspars, and quartz grains that are cemented by calcite or, locally, by an unidentified zeolite. Placers of dark-colored heavy minerals occur along individual laminae. Often the sandstones grade laterally and vertically into conglomerates and occasionally, thin, discontinuous, mudstones that exhibit dessication cracks and thin, white (N9) caliche horizons occur in the sandstone sequence.

The conglomerate of Rock Tank Canyon accumulated in a large northward extending alluvial complex that deposited a sedimentary apron around the flanks of the Spears volcanic pile. Locally derived volcanic pebbles within the unit and the decrease in grain size toward the top of the unit suggest derivation from erosion of the Spears Formation during a period of tectonic quiescence. The presence of large, angular, locally derived clasts, oxidized color, mud-cracks, caliche horizons, rapid textural changes, and relations to other continental strata are characteristics commonly associated with alluvial fan complexes (Bull, 1972). Lenticular bedding, prevalence of cross-stratifications and rapid lateral changes in texture bear close resemblance to sediments deposited as fluvial channel-fill and sheet-flood deposits of the proximal and midfan portions of Holocene and rock-record humid alluvial fan complexes as described by Blissenbach (1954), McGowen and Groat (1971), and Robinson (1976).

Blue Mesa Basalt

Several basalt flows crop out on Blue Mesa and D Cross Mountain Mesa. These flows discordantly overlie tuffs of the Spears Formation at the southern end of Blue Mesa and progressively younger rocks to the north. On D Cross Mountain Mesa the flows overlie Crevasse Canyon strata.

Two flows are present on D Cross Mountain Mesa and as many as three flows may be present on Blue Mesa. Individual flows average less than 50 ft (15 m) thick and exhibit well-developed vertical columnar jointing. Typically, a 1-10 ft (0.3-3.0 m)-thick dark-yellowish-orange (10 YR 6/6) zone of ash and vesicular basalt breccia is overlain by black (N1), blocky weathering, dense, porphyritic basalt that comprises the bulk of the unit.

The basalts are dense, black (N1), prophyritic, and dotted with faint-white (N8) spots on weathered surfaces. The phenocrysts are oriented, lath shaped, subhedral, unaltered andesine-labradorite (45-55%) (Plate 20) that exhibit albite and carlsbad twinning and rare zoning, euhedral to subhedral, equant olivine (20-25%) crystals that always have alteration rims of reddish-brown (10 R 4/6) iddingiste, and anhedral to subhedral pyroxene crystals (20-25%). The phenocrysts are surrounded by a felty groundmass composed of small feldspar laths and microlites of augite, olivine (?), and magnetite. Volcanic glass is rare. A chemical analysis of the basalt is given in Table 1.

The source of the flows on D Cross Mountain Mesa was the volcanic neck which forms D Cross Mountain. The source for the flows on Blue Mesa was the problematical Blue Mesa vent. On the mesas the flows dip 1-2° radially away from the source but dips steepen abruptly to 9-10° near the vents (Plate 21). A small segment of a collapsed lava tube on the north face of Blue Mesa is oriented N 10° E.

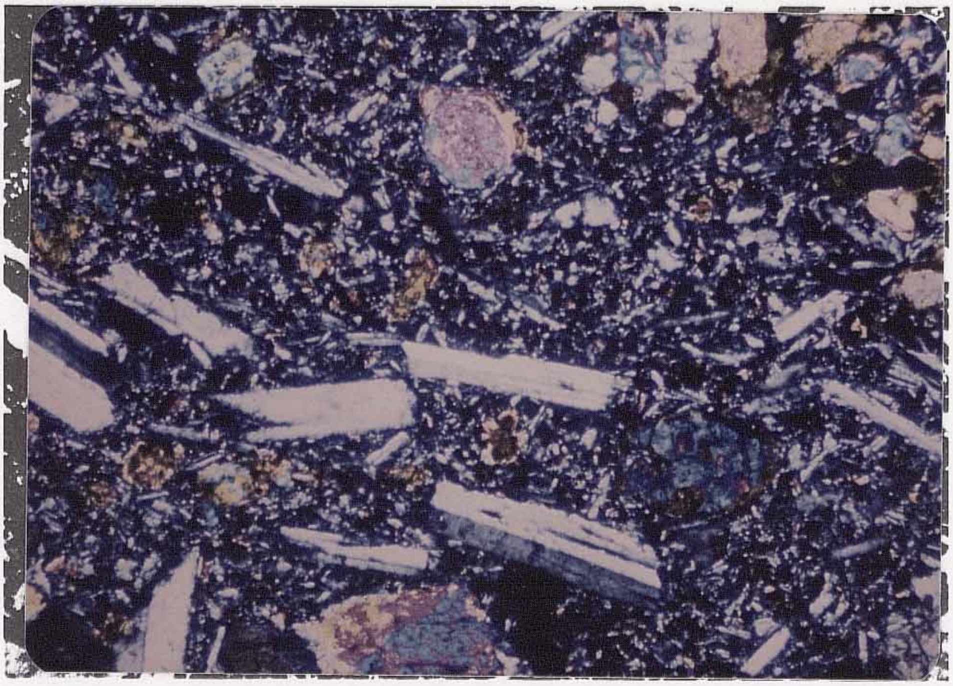


Plate 20. Photomicrograph of thin-section of Blue Mesa basalt. The large lath shaped crystals are andesine-labordorite, high birefrengence crystals are olivine and pyroxene. Felty groundmass is composed of feldspars, olivine, pyroxene and magnetite (cross Nichols, low power).

Plate 21. Flows of Blue Mesa basalt capping D Cross Mountain Mesa. Two flows, each approximately 50 ft (15 m) thick can be seen. Notice how the dips of the flow rocks increase (from left to right) near the D Cross vent.

Several basalt samples were collected for radiometric dating; none, however, proved adequate for analysis. Stratigraphic, topographic, and regional relations suggest that the flows are approximately 3-4 m.y. old. The flows are younger than the conglomerate of Rock Tank Canyon based on the relation of the two units to the Red Lake fault. In Secs. 28 and 33, T. 3 N., R. 8 W., the Miocene (?) conglomerate has been tilted to the east by movement along the fault. This same fault is covered by the flows several miles to the south.

In surrounding areas, volcanic necks with associated flows that are lithologically, stratigraphically, and topographically similar to those of the D Cross Mountain area have been dated at 3.4-3.6 m.y. B. P. (C. Chapin, oral commun., 1980) and 3.1 m.y. B.P. (Bachman and Mehnert, 1978). A similar age appears likely for the D Cross Mountain basalt flows.

Quaternary System

Pediment Gravels

Three gravel covered pediments have been mapped in the study area: Q_{g1}, Q_{g2}, and Q_{g3}. Differentiation of the gravels is based on elevation and degree of induration. In general, the sediment cover is less than 10 ft (3 m) thick and is composed of poorly sorted gravel and cross-stratified volcanicarenites that are locally loosely cemented by caliche. These sediments were derived from the erosion of Datil volcanics in the surrounding mountains and rest with angularity above older strata.

The oldest gravel, which is also topographically the highest, is north-sloping and was deposited on a widespread, 3-4 m.y.-old geomorphic surface. Remnants of the gravel-covered surface occur in the extreme south-central portion of the quadrangle and are approximately 200 ft (61 m) above the present drainage.

An extensive northeast-sloping surface was developed by the lateral planing action of streams flowing at a lower elevation than those that deposited the Q_{g1} gravels. This gravel-covered surface (Q_{g2}) slopes to the northeast away from the Datil Mountains and is less than 100 ft (30 m) higher than the present drainage. The gravels are similar to those of Q_{g1} but contain a larger proportion of angular, black (N2) basalt clasts that were derived principally from erosion of the basalt flows cropping out on the mesa surface. Cross-stratification measurements indicate a northeast paleoslope during deposition of the gravels. The Q_{g2} gravel deposit is appreciably thicker than those of either Q_{g1} or Q_{g3}, and may represent a coalesced bajada complex that built outward from the mountain front.

The lowest and most extensive gravel-covered surface is a few tens of feet above the present drainage. The surface on which the gravels accumulated is north-sloping and cut on weakly resistant Baca and Crevasse Canyon strata. The most extensive exposure is in the east-central portion of the mapped area. Sediment cover is only a few feet thick in most areas and composed dominantly of unconsolidated sand and pebble size volcanic clasts.

The gravel-covered surfaces range in age from latest Pliocene to Holocene and were developed by the action of laterally planing streams during a step-like lowering of base-level. For this reason the older surfaces are the more dissected and stand at a higher elevation.

Alluvium, Colluvium, Landslide, and Eolian Deposits

The ephemeral creek beds in the area are floored with locally derived gravel, sand and mud. Unconsolidated sediments deposited along the course of Alamocita Creek have been mapped as: Qals, recent stream deposits; Qalt, flood plain deposits; and Qs, dune deposits. Qals sediments are moderately to poorly sorted and crudely cross-stratified. Petrology of the deposits reflects the local geology of the Alamocita Creek drainage basin. Flood plain deposits are poorly sorted muds and sands and, locally, gravels which form the banks of Alamocita Creek and its tributaries.

Cross-stratified dune deposits, formed by the accumulation of sand blown from the bed of Alamocita Creek, locally form thick accumulations. The dunes are composed dominantly of quartz sand and reach 30 ft (9 m) in height in some areas. The larger dunes occur on the south side of the creek as a result of the prevailing northwest to southeast winds.

Undifferentiated water-lain gravels, sands, and muds have been mapped as Qal. These deposits include locally developed, isolated pediment gravels or alluvial fan deposits on Blue Mesa, and slope-wash covered areas such as the Cretaceous shale valleys north of Alamocita Creek.

Colluvium (Qc) was mapped only where talus and other locally derived debris were so thick as to conceal the underlying rock. Larger areas of colluvium are associated with the D Cross Mountain vent and the flows capping Blue Mesa and D Cross Mountain Mesa.

Landslide blocks have been mapped as Qls. Two such areas were delineated. The largest landslide feature occurs on the east side of Blue Mesa. There numerous blocks of basalt have slid down the east side of the mesa. The blocks appear to have slid along steeply inclined shale units in the Baca Formation. A zone of jumbled Dakota Sandstone and Chinle Formation in Sec. 9, T. 3 N., R. 8 W. has also been mapped as a landslide terrain.

Intrusive Rocks

A single volcanic neck, D Cross Mountain, was mapped in the study area. The vent rock at D Cross Mountain is a basaltic ventagglomerate that has intruded into Crevasse Canyon strata (Plate 22). Due to the resistant nature of the intrusive rock, the neck now stands 300 ft (91 m) above

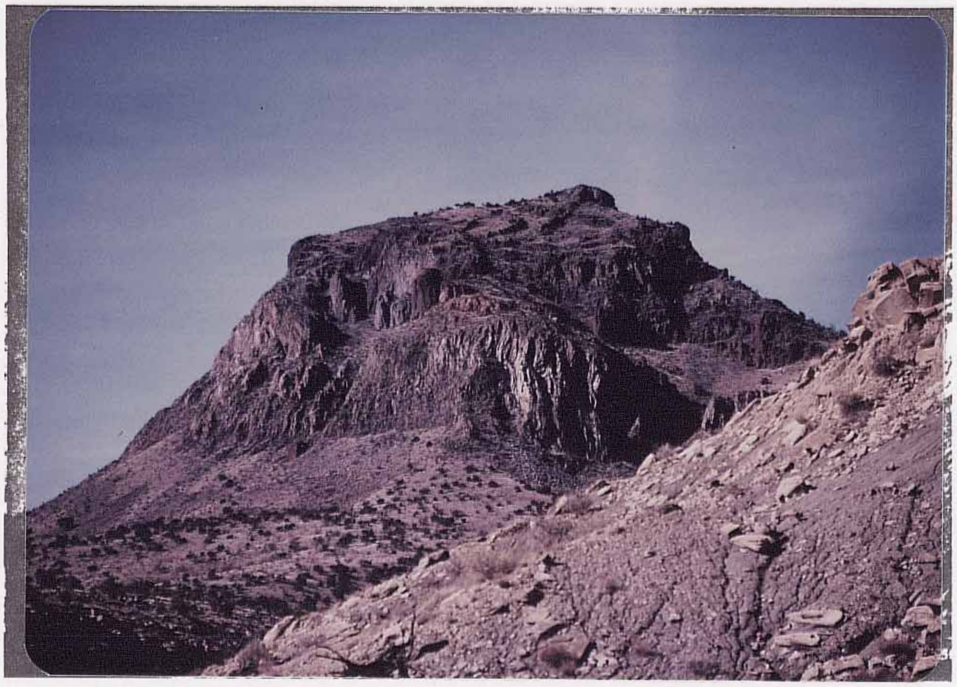


Plate 22. D Cross Mountain. Formerly called Turtle Mountain. D Cross Mountain is a volcanic vent, columnar jointing is well developed in the lower part of the exposure. The vent rock is capped by a series of flat lying lava flows that solidified in a lava lake. The "DX" visible on top of the mountain is a natural rock formation.

the intruded strata. The D Cross neck is semicircular in plan and approximately 1500 ft (460 m) in diameter. Due to the accumulation of colluvium at the base of the cliff, the intrusive contact is not exposed.

Columnar jointing is well developed within the intrusion. The joints are generally vertical or near vertical at the base of the exposure, but flare wildly from place to place. In the upper third of the neck, the cooling columns flatten out and are overlain by horizontal lavas. These flat-lying basalt rocks probably represent a lava lake that solidified in the volcanic vent.

Mineralogically the D Cross Mountain intrusive rock is similar to the flows capping Blue Mesa and D Cross Mountain Mesa. The rock is, however, more vesicular and contains abundant large to small xenoliths of sandstone, shale, and various types of igneous rocks.

A probable, less well-exposed, vent exists beneath the basalt flows on Blue Mesa. Here the magma has intruded Spears tuffs at approximately the same elevation as the D Cross Mountain neck. Criteria for the existence of the Blue Mesa vent include: thickening of the lava section, alteration of the Spears tuffs, and the radial dips of lava flows away from the suspected vent area. The geometry of the intrusion cannot be ascertained.

Three small, irregular intrusions measuring less than 100 ft (30 m) in diameter were mapped. Lithologically, the plugs are similar to the D Cross Mountain vent rock. These small intrusions probably represent finger-like intrusions of magma that originated from a buried magma chamber but solidified before reaching the surface.

In surrounding areas intrusions and associated flow rocks that are related to a widespread geomorphic surface have been dated at 3.4-3.6 m.y. B.P. (C. Chapin, oral commun., 1980) and 3.1 m.y. B.P. (Bachman and Mehnert, 1978). Vents and plugs in the study area were also probably emplaced during this period of volcanic activity.

Two northwest-trending dikes crop out on the southwest side of D Cross Mountain. These tabular intrusions can be traced intermittently for at least 5 mi (8 km) and maintain a relatively uniform thickness of between 6-10 ft (1.8-3.0 m). Two miles (3.2 km) north of the D Cross Mountain quadrangle, one or both of the dikes thicken to form a large, irregular intrusive body. The trace of the dikes is only slightly deflected by topography; a very steep dip to the east is indicated.

Alteration along the dike margins is minimal. Generally, a thin, reddish-orange (10 R 6/6) baked zone extends a few inches into the host rock and a 1-2 in. (2.5-5 cm) thick, black (N1) glassy chilled zone is developed at the dike margin. The dike rock is nonresistant to weathering and forms a slight topographic depression along its trace.

The rock is sugary weathering, aphanitic, olive green (5 GY 3/2), and porphyritic. In two thin-sections examined, brown, pleochloric, euhedral biotite is the dominant phenocryst. The biotite crystals range from 0.01 mm to 1 mm in diameter, are fresh to slightly altered, and are arranged subparallel to the dike margins. Many of the biotite crystals exhibit a dark-red alteration rim. Opaque minerals comprise less than 1% of the rock.

Other phenocrysts in the rock have been altered to clay minerals (?) and zeolites, or have been replaced by calcite and silica. These altered phenocrysts are euhedral to subhedral but positive identification could not be made. Based on the crystal form, they are speculatively either hornblende or, perhaps, pyroxene. The phenocrysts are set in a silicified or zeolitized matrix. The rock may have originally been a basaltic andesite.

The dikes cross-cut strata as young as the Crevasse Canyon Formation. Relations to post-Crevasse Canyon strata are based on relative relations to tectonic events. The two dikes crop out adjacent to, and on opposite sides of, the D Cross fault and are thought to be repeated parts of a single dike that has been cut by the down-to-the-east fault. If this relation is correct, the dikes are at least as young as Oligocene. The dikes, furthermore, appear to be offset on the north face of Blue Mesa by Miocene (?) movement along the Red Lake fault.

North-trending, basaltic andesite dikes in the Riley-Puertecito area that are associated with Rio Grande rifting are dated at 24-25 m.y. old (C. Chapin, oral commun., 1980). A similar age appears likely for the dikes in the D Cross

Mountain area. Based on the composition and age of the dikes, they are thought not to be genetically related to the vents and associated flow rocks of Blue Mesa and D Cross Mountain, but to have formed during an older event, perhaps related to extrusion of the post-Spears volcanics of the southern Datil Mountains.

STRUCTURAL GEOLOGY

The general structure of the D Cross Mountain area is a southwest dipping homocline. The continuity of the structure is, however, broken by a series of north-northwest trending normal faults and by a broad northeast-oriented anticline the crest of which is cut by a major northeast-striking normal fault. Tectonic events that are well documented in the area include: Laramide folding, Basin and Range faulting, and the uplift of the Colorado Plateau.

Little can be gleaned concerning pre-Cretaceous tectonism in the area. However, there is an angular unconformity separating the Triassic Chinle Formation from the Cretaceous Dakota Sandstone. Regionally, the Chinle pinches out against the erosional surface to the south. The gentle uplift and northward tilting of the Chinle probably occurred during the Jurassic Period.

Broad, open, northeast-trending anticlines and synclines are prominent features north of the study area. One of the more impressive structures, the Red Lake anticline, has a maximum width of 4 mi (6 km) and can be traced southward for a minimum of 10 mi (16 km) to a point near the abandoned INM Ranch headquarters in Sec. 21, T. 3 N., R. 8 W. The crest of the Red Lake anticline is cut by the Red Lake fault which partially masks the anticlinal signature in the D Cross Mountain quadrangle.

The Red Lake anticline is asymmetrical and south-plunging. The axis of the structure trends N 30° E and plunges southward at 10°. Strata at least as young as Crevasse Canyon are involved in the folding. Dips of strata on the western limb are 5-8° to the west. The eastern limb dips as much as 47° to the east-southeast. These higher dips occur in close proximity to the Red Lake fault and drag along the down-to-the-east normal fault is responsible for the higher dips.

The nose of the Red Lake anticline is broken by several small west-northwest-trending tear faults and the strata have locally been deformed into a series of small anticlines and synclines. These subsidiary folds involve Dakota (main body) and Twowells strata and were produced by movement along the fault. Folding occurred during the Late Cretaceous to early Eocene as the result of northeast-directed compressional forces associated with the Laramide orogeny.

As many as 20 subparallel northwest-trending normal faults were mapped in the D Cross Mountain quadrangle. The faults are mostly down-to-the-east in a step-like fashion. A few faults, however, are down-to-the-west and several have dips of less than 70°. Horst and graben structures are rare and no reverse faulting was demonstrated. In general the fault blocks are tilted to the east-southeast at angles only a few degrees greater than that of the regional dip. Displacement along the normal faults is generally less than 75 ft (23 m) and the faults cannot be traced laterally for great distances.

Most of the down-to-the-east movement is concentrated along D Cross fault. The D Cross fault trends northwestward, has a maximum displacement of 700 ft (213 m), and can be traced for a minimum of 7 mi (11 km). The fault plane dips 80-85° to the east. In most areas upper and lower Crevasse Canyon strata are juxtaposed across the fault plane. In topographically lower areas along Alamocita Creek, exposed middle Crevasse Canyon strata have been dropped down against the Carthage Member of the Tres Hermanos Sandstone.

The D Cross fault can be traced from the northwest corner of the quadrangle as far south as Sec. 6, T. 2 N., R. 8 W. before being lost in Crevasse Canyon strata. The fault must continue southward because displacement on the fault is still on the order of 500 ft (152 m) in that area. A large fault, on the north face of Blue Mesa, east of the Red Lake fault, has a similar sense and magnitude of displacement and it probably is an off-set segment of the D Cross fault. This unnamed fault continues southeastward and is concealed beneath Quaternary gravels in the valley east of Blue Mesa.

Faults in the D Cross fault zone offset strata as young as the Spears Formation. Miocene (?) conglomerates in Secs. 11 and 14, T. 3 N., R. 8 W. post-date movement along several northwest-trending faults. Therefore, the northwest-trending faults are of late Oligocene to Miocene age. This suggests a Basin and Range origin for the faults, although the fault-zone-trend is parallel to Laramide structures of the Zuni Mountains. The orientation of the faults may have been in part controlled by older planes of weakness.

Several northeast-trending faults were mapped in the southeastern portion of the study area. These faults cut the Spears tuff. Due to the chaotic dips of the Spears strata and the lack of marker beds, relative displacements could not be ascertained and many small faults probably exist in the tuff section which were not mapped.

The Red Lake fault is a prominent northeast-trending, high angle, down-to-the-east normal fault that can be traced throughout the study area. Dip angles of the fault plane vary from 70° in Sec. 10, T. 3 N., R. 8 W. to 85° on the southwest side of Blue Mesa. Displacement along the Red Lake fault is more than 1200 ft (365 m) and is either concentrated along a single fault plane, or is distributed in several fault splays. North of Alamocita Creek, Chinle strata have been juxtaposed against Crevasse Canyon strata by movement along the Red Lake fault. In the northwest quarter of Sec. 33, T. 3 N., R. 8 W., the fault splits into two major segments. One segment continues to the southwest where it cuts across the west side of Blue Mesa and extends beyond the southern limit of the study area. Locally, this fault is concealed by the basalt flows that cap the mesa. The eastern segment of the Red Lake fault is concealed beneath Quaternary gravels in the valley east of Blue Mesa and it is not exposed south of Sec. 33, T. 3 N., R. 8 W.

Drag on the downthrown block of the Red Lake fault has locally tilted the strata as much as 90°. The dips, however, decrease rapidly away from the fault plane and strata within 0.5 mi (0.8 km) of the fault appear to be unaffected by the movement. Blue Mesa is a fault-bound block that has been caught up between the two major segments of the Red Lake fault. The entire mountain has been tilted, and perhaps rotated, 30-35° to the east-southeast.

Strata as young as the Miocene (?) conglomerate of Rock Tank Canyon are cut by the Red Lake fault; the 3-4 m.y.-old basalt flows on Blue Mesa overlie the fault trace, and are therefore younger. Thus the latest movement along the Red Lake fault is of Miocene or Pliocene age.

An unusual structure occurs in the Spears tuff approximately 1 mi (1.6 km) south of the Fred Martin Ranch. On the east side of Dog Springs Canyon, the tuffs have dips of as much as 80° and have been folded into a 180°, 0.3 mi (0.5 km)-diameter semicircular arc. The faulting, fracturing, and folding of the Spears may be related to collapse, or subsidence of the overlying strata into a depleted magma chamber from which the tuffs emanated. However, no cauldron structure has been recognized.

The Colorado Plateau is a high standing, dissected crustal block that measures nearly 500 mi (800 km) in diameter (King, 1977). Uplift along the margins of the

Plateau, beginning in the early Miocene (Chapin and Seager, 1975), has been dominantly along monoclinal flextures that may in part reflect older crustal weaknesses.

The D Cross area occupies a portion of the southeastern margin of the plateau. In the study area, strata that have been affected by Laramide and Basin and Range tectonic events dip between 10-19° to the southwest. The conglomerate of Rock Tank Canyon (Miocene ?) post-dates these earlier deformation events, but is tilted as much as 8° to the south. Tilting of these strata represent the rising of the Colorado Plateau. Massingill (1979) has reported 700 ft (213 m) of Colorado Plateau-associated uplift in the Riley-Puertecito area since the Pliocene (3-4 m.y. B.P.) based on the elevation of a regional geomorphic surface. Uplift along the margins of the Plateau may still be active.

GEOMORPHOLOGY

Alamocita Creek is a large east-flowing ephemeral stream which cuts across the structural fabric of the D Cross Mountain quadrangle. Field evidence suggests the stream was superposed onto the underlying structures. Downcutting of over 2000 ft (610 m) in the past few million years has been episoidic, oscillating between periods of base-level stability and periods of rapid downcutting.

Three pediment surfaces were formed during periods of temporary stability of the local base-level by laterally planing tributaries of the master stream. These gravel-covered surfaces are mapped, from oldest to youngest: Q_{g1}, Q_{g2}, and Q_{g3}. A fourth, older surface was not mapped but is defined by the distribution of basalt flows on Blue Mesa and on D Cross Mountain Mesa. The Q_{g1} and Q_{g3} surfaces slope gently to the north from the Gallinas Mountains at 100 ft (30 m) per mile and were graded to Alamocita Creek when it flowed at a higher elevation. The Q_{g2} surface slopes eastward away from Blue Mesa and was cut to grade to a north-oriented tributary of Alamocita Creek that worked its way by headward erosion into Rock Tank Canyon. This surface, if traced to the south beyond the readjustment effect to this sidestream, merges with the Q_{g1} surface. Alamocita Creek is currently in a degradational phase and recent erosion has resulted in dissection of the older geomorphic surfaces.

ECONOMIC GEOLOGY

Coal

The D Cross Mountain quadrangle is within the Datil Mountain coal field that covers 765 mi^2 (1958 km^2) in Socorro, Catron, and Valencia counties, New Mexico (Figure 11). No mines are presently operating within the field. Five underground mines operated sporadically between the early 1900's and 1949 during which time more than 900 tons of coal were removed. Read and others (1950) estimated that more than a billion tons of reserves exist in the field. Recent exploratory drilling by the New Mexico Bureau of Mines and Mineral Resources suggests that commercial coal deposits are present in the Datil Mountain coal field (Frost and others, 1979).

Coal seams in the Datil Mountain field average less than 2 ft (61 cm) thick but range up to 5 ft (1.5 m) in thickness. The Coal-bearing interval occurs in the lower 200 ft (60 m) of the Crevasse Canyon Formation (Dilco Member ?). The thicker seams are, however, confined to a zone within 60 ft (18 m) above the top of the Gallup Sandstone.

In the D Cross Mountain quadrangle the thickest seam is approximately 2 ft (60 cm) thick and occurs in the lower 5 ft (1.5 m) of the Crevasse Canyon Formation (Plate 23). This seam is probably correlative with the seam that Winchester (1920) mapped in the Pasture Canyon and Wild

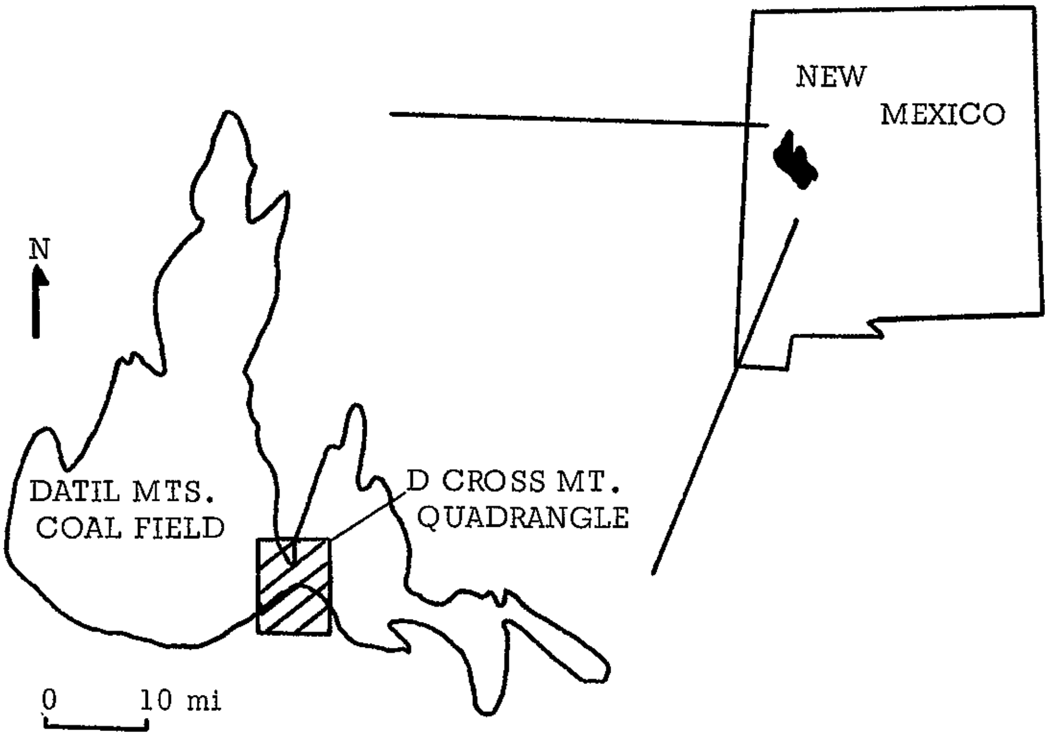


Figure 11. Map showing the location and extent of the Datil Mountain coal field.

Plate 23. Coal seam at the base of the Crevasse Canyon Formation. This seam occurs within a few feet above the Gallup Sandstone and can be traced almost continuously into the Pasture Canyon and Wild Horse Mesa quadrangles. The seam is 2 ft (60 cm) thick. Dark shale unit at base of photograph represents coastal marsh deposits.

Horse Canyon quadrangle and the seam cored by the New Mexico Bureau of Mines and Mineral Resources in the Pueblo Viejo Mesa and Wild Horse Canyon quadrangles (Frost and others, 1979). Numerous thin coal seams that do not have great lateral extent occur stratigraphically higher in the Crevasse Canyon Formation.

Coals in the D Cross Mountain area accumulated in both coastal marsh and interdistributary swamps on a low-lying coastal plain during a major marine regression. The thicker coal seams are closely associated with coastal sandstone bodies, they are laterally continuous, and contain brackish water _Classopollis_ pollen. Mangrove-like root casts commonly extend from the coal horizon into the underlying Gallup Sandstone. These coals accumulated in an environment similar to the Dismal Swamp of North Carolina and Virginia. Accumulations of mangrove-peat swamps above marine sandbodies are well known from coastal swamps of southeastern Florida (Teichmuller and Teichmuller, 1975).

Coals higher in the stratigraphic section are more closely related to fluvial sandstone bodies. As a result of the lateral migration of the stream channels and over bank flooding, these coal seams are thin and discontinuous. Similar deposits have been documented from the Mississippi River delta plain (Gould and Morgan, 1962).

The D Cross Mountain coals are classified as high-volatile C bituminous. On a "fresh" surface, the coals are of the semisplint variety and cleat faces are well developed. The face cleats strike N 25° W and the butt cleats strike N 70° E. On the outcrop, secondary mineralization along the cleats is rare, although pyrite crystals are common in cored samples (Frost and others, 1979).

Transparent attritus is the dominant maceral constituent (Plate 24). Antraxylon and opaque attritus are common and fusain is rare. Clay, calcium carbonate, and silica occur along microfractures and as void-filling precipitants. Most samples also contain wind blown (?) quartz grains. In a few interfluvial coals, quartz grains comprise as much as 40% of the rock volume. Cored samples yield calorimetric values ranging from 11,700 to 12,600 B.T.U. (Table 2); ash (9-16%) and sulfur (less than 1%) content is low. Sulfur is most frequently encountered in organic form (Frost and others, 1979).

The lower coal seam in the D Cross Mountain area would appear to be thick enough and continuous enough to be mined commercially. Several factors, however, limit the feasibility of economic mining of coal in the D Cross Mountain quadrangle. Unfavorable conditions include: (1) structural complications; (2) rugged topography; (3) limited access; (4) nature and thickness of overburden; and (5) lack of local market. Many of these limitations do not apply to areas surrounding the study area (e.g. Red Lake Valley) in which coal possibly could be commercially mined.

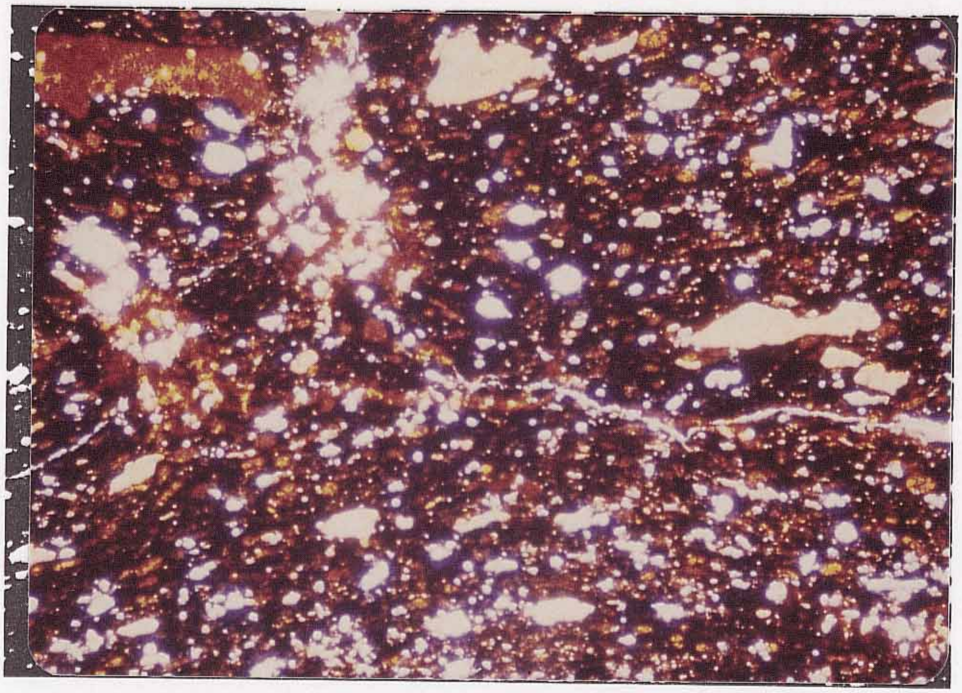


Plate 24. Photomicrograph of coal thin-section. Large yellow and red fragments are anthraxylon; small yellow and red constituents are transparent attritus; black material is opaque matter and white areas are quartz grains.

TABLE 2

Coal Analyses from the Datil Mountain Field
New Mexico

	Moist.	Ash	Vol.	F.C.	Sulfur	BTU	Type
I	0.6	16.0	35.8	48	2.7	12,238	C
	1.4	16.4	40.0	42	0.8	11,725	C
	2.5	9.6	41.0	47	0.5	12,646	C
	4.1	8.9	41.3	46	0.5	12,017	C
II	8.4	32.7	31.9	27	0.4	11,621	W
	14.3	23.2	30.9	33	0.4	11,642	W
	16.7	36.6	24.3	22	0.3	9,821	W
	11.9	30.0	28.4	21	0.6	10,467	W
	19.0	14.2	30.9	36	0.5	10,740	W
	9.1	12.9	35.3	43	0.4	11,951	W
	7.6	40.3	25.9	26	0.4	11,672	W
	13.6	9.8	35.1	41	0.3	11,591	W
III	25.9	9.1	30.3	34	0.4	7,430	W
	9.1	11.1	37.2	43	0.3	9,120	W
	NA	12.2	40.9	47	0.5	10,030	W
	NA	NA	46.6	53	0.6	11,430	W
IV	6.5	7.1	34.5	52	0.5	11,990	W
	5.3	7.2	34.9	53	0.5	12,150	W

	Moist.	Ash	Vol.	F.C.	Sulfur	BTU	TYPE
	NA	7.6	36.9	56	0.5	12,820	W
	NA	NA	39.9	60	0.6	13,870	W
	18.5	10.8	31.7	39	0.4	8,480	W
	12.6	11.6	34.0	42	0.5	9,090	W
	NA	13.2	38.9	48	0.5	10,400	W
	NA	NA	44.8	55	0.6	11,990	W
V	6.6	6.4	32.0	54	NA	11,555	M

I Frost and others, 1979; as received bases

II Massingill, 1979; BTU, dry mineral matter free

III Campbell and Clark, 1915

IV Campbell, 1912

V Tabet and Frost, 1978

C - core sample
W - weathered surface or mine sample
M - mine sample

Uranium

The Baca Formation is a well known uranium host rock in west-central New Mexico and crops out extensively in the D Cross Mountain quadrangle. A small uranium prospect is located on the north face of Blue Mesa in the "transition zone" between Crevasse Canyon and Baca strata. The prospect occurs near the intersection of the D Cross and Red Lake faults and it is not known if the anomaly was associated with these faults or if it is stratigraphically controlled. However, uranium prospects west of the study area in the Red Basin district have been centered on the Baca-Crevasse Canyon "transition zone."

Within the study area the Baca Formation appears to be a potential uranium host rock. The sandstone bodies are of fluvial origin, they resemble other host rocks of the Colorado Plateau region and they have a bleached white color which is often associated with uranium mineralization. The thick pile of silicic tuffs in the Gallinas Mountains could provide a source of uranium. Unfortunately, organic debris is scarce within exposed Baca channel sandstones.

Oil and Gas

Wells (1919), Winchester (1920), and Foster (1964) have discussed the oil and gas potential of the D Cross Mountain area. They concluded that structural traps involving Pennsylvanian or Permian carbonates or Cretaceous sandstones had potential as oil and gas reservoirs. Several oil wells drilled prior to 1964 in the vicinity of D Cross Mountain did not detect significant shows of either oil or gas (Foster, 1964).

SUMMARY OF GEOLOGIC HISTORY

Red shales and sandstones of the Chinle Formation accumulated on an extensive low-lying coastal plain in a meandering stream complex during the Upper Triassic. Jurassic strata, if deposited in the area, were subsequently eroded due to uplift of the Mogollon Highlands and north-northwest tilting of the area.

For most of the Lower Cretaceous the area remained in an erosional state during which laterally planing streams beveled the area and deposited the basal Dakota Sandstone. Regional subsidence during the Coniacian brought encroachment of the mid-continent Cretaceous seaway into the Acoma embayment from the southeast.

For the remainder of the Cretaceous, the area fluctuated between paralic and coastal non-marine environments. The oscillatory nature of the shoreline was the result of an interplay of sporadic uplift in the Cordilleran highlands and slow subsidence of the depositional basin. As a result, a complex sequence of dark offshore marine muds of the Mancos Shale interfinger to the west with coastal and fluvial sands and muds, and paludal coals of the Dakota, Tres Hermanos, Gallup, and Crevasse Canyon Formations.

Near the end of the Cretaceous, northeast-directed compressional forces associated with the Laramide orogeny produced a series of broad open folds and uplifted blocks such as the Zuni Mountains and Mogollon Highlands, and resulted in the final eastward regression of the marine seas from the area. Pebble conglomerates and arkosic sands eroded from the Zuni Mountains were transported to the southeast in a fluvial channel-floodplain complex and accumulated in a west-trending, elongated structural basin forming the Eocene Baca Formation.

Deposition of the Baca Formation was followed by a period of erosion before a thick cover of volcanic and volcaniclastic rocks spread over the area during the Oligocene. Lithic-crystal and crystal-lithic tuffs, and debris flows of the Spears Formation were derived from an eruptive center located along the southern boundary of the D Cross Mountain quadrangle. Eruption of the tuffs was followed by the extrusion of a thick pile of ash-flow tuffs from other volcanic centers, intrusion of basaltic andesite dikes and normal faulting. The conglomerate of Rock Tank Canyon (Miocene ?) was derived principally from erosion of Spears tuff upon cessation of volcanism and was deposited in an alluvial fan complex that extended northward from the Gallinas Mountains.

Uplift of the Colorado Plateau, beginning in the early to middle Miocene, tilted all older strata as much as 8° to the south. East-west oriented extensional forces during the latest Miocene to Pliocene, perhaps related to renewed opening of the Rio Grande rift resulted in the formation of a large down-to-the-east normal fault with as much as 1200 ft (365 m) of displacement.

Volcanic necks and plugs cropping out on D Cross Mountain and Blue Mesa were emplaced during the Late Tertiary. During the Pleistocene, Alamocita Creek began downcutting and was superposed across the structural grain of the area. During periods of base-level stability, pediment and terrace surfaces were constructed by laterally planing tributaries of the master stream. The present physiography of the area is related to continued lowering of base level and incision of streams into the complexly faulted sequence of sediments and volcanic rocks.

REFERENCES CITED

Allen, J. R. L., 1964, Studies in fluviatile sedimentation: six cyclothems from the Lower Old Red Sandstone, Anglo-Welsh Basin: Sed., vol. 3, p. 163-198.

Allen, J. R. L., 1965, Late Quaternary Niger delta and associated areas: Am. Assoc. Petroleum Geologist Bull., vol. 49, no. 5, p. 547-600.

Allen, J. E., and Balk, R., 1954, Mineral resources of Fort Defiance and Tohachi Quandrangles, Arizona and New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 36, 192 p.

Bachman, G. O., and Mehnert, H. H., 1978, New K-Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: Geol. Soc. American Bull., vol. 85, p. 283-292.

Bernard, H. A., Majors, C. F., Jr., Parrott, B. S., and LeBlanc, R. J., Sr., 1970, Recent sediments of South-east Texas - A field guide to the Brazos alluvium and delta plains and the Galveston barrier island complex: Texas Bureau of Econ. Geology, Guidebook 11, 16 p., and reprint append.

Blissenbach, E., 1954, Geology of alluvial fans in semi-arid regions: Geol. Soc. America Bull., vol. 65, p. 175-190.

Bull, W. B., 1972, Recognition of alluvial fan deposits in the stratigraphic record; <u>in</u> Recognition of Ancient Sedimentary Environments, J. K. Rigby and W. K. Hamblin eds.: Soc. Econ. Paleontologist and Mineralogist spec. pub. no. 16, p. 63-83.

Campbell, M. R., 1912, Analyses of coal samples from various fields in the United States: U. S. Geol. Survey Bull. 541, 499 p.

Campbell, M. R., and Clark, F. R., 1915, Analyses of coal samples from various parts of the United States: U. S. Geol. Survey Bull. 621, 332 p.

Carter, C. H., 1978, A regressive barrier and barrier-protected deposits: Depositional environments and geographical setting of the Late Tertiary Cohansey Sand: Jour. Sed. Petrology, vol. 48, p. 933-950.

Cather, S. M., 1980, Petrology, Diagensis, and Genetic Stratigraphy of the Eocene Baca Formation, Alamo Navajo Reservation and Vicinity, Socorro County, New Mexico: Univ. Texas Austin, unpub. M.S. thesis, 243 p.

Chapin, C. E., 1974, Composite stratigraphic column, Magdalena area: New Mexico Bureau of Mines and Mineral Resources, open-file report no. 46.

Chapin, C. E., Blakestead, R. B., and Seimers, W. T., 1975, Geology of the Magdalena area, Socorro County, New Mexico; _in_ Field trips to central New Mexico; part 2: Am. Assoc. Petroleum Geologist Guidebook, Rocky Mtn. Sect. Ann. Mtg. June, 1975, p. 43-49.

Chapin, C. E., and Seager, W. R., 1975, Evolution of the Rio Grande rift in the Socorro and Las Cruces areas: New

Mexico Geol. Soc. Guidebook 26th field conference, p. 297-321.

Cloud, P. E., Jr., 1955, Physical limits of glauconite formation: Am. Assoc. Petroleum Geologist Bull., vol. 39, p. 484-492.

Cobban, W. A., 1977a, Fossil mollusks of the Dakota Sandstone and intertongued Mancos Shale of west-central New Mexico: New Mexico Geol. Soc. Guidebook 28th field conference, p. 213-220.

Cobban, W. A., 1977b, Characteristic marine molluscan fossils from the Dakota Sandstone and intertongued Mancos Shale, west-central New Mexico: U. S. Geol. Survey Prof. Paper 1009, 74 p.

Cobban, W. A., and Hook, S. C., 1979, Collignoniceras woollgari woollgari (Mantell) ammonite fauna from the Upper Cretaceous of Western Interior, United States: New Mexico Bureau of Mines and Mineral Resources, Mem. 37, 51 p.

Cobban, W. A., and Reeside, J. B., Jr., 1952, Correlation of the Cretaceous formations of the Western Interior of the United States: Geol. Soc. America Bull., vol. 63, no. 10, p. 1011-1044.

Cobban, W. A., and Scott, G. R., 1972, Stratigraphy and ammonite fauna of the Graneros Shale and Greenhorn Limestone near Pueblo, Colorado: U. S. Geol. Survey Prof. Paper 645, 108 p.

Coleman, J. M., 1969, Brahmaputra River: channel processes and sedimentation: Sed. Geology, vol. 3, p. 129-239.

Coleman, J. M., and Gagliano, S. M., 1965, Sedimentary structures: Mississippi River Deltaic Plain; _in_ Primary sedimentary structures and their hydrodynamic interpretation: Soc. Econ. Paleontologist and Mineralogist spec. pub. no. 12, p. 113-148.

Cross, W., 1899, Description of the Telluride quadrangle (Colorado): U. S. Geol. Survey Atlas, Telluride folio no. 57.

Dane, C. H., Waneck, A. A., and Reeside, J. B., Jr., 1957, Reinterpretation of section of Cretaceous rocks in Alamosa Creek Valley area, Catron and Socorro Counties, New Mexico: Am. Assoc. Petroleum Geologist Bull., vol. 41, no. 2, p. 181-196.

Dane, C. H., Cobban, W. A. and Kauffman, E. G., 1966, Stratigraphy and regional relationships of a reference section for the Juana Lopez Member, Mancos Shale, in the San Juan Basin, New Mexico: U. S. Geol. Survey Bull. 1224-H, 15 p.

Dane, C. H., Kauffman, E. G., and Cobban, W. A., 1968, Semilla Sandstone, a new member of the Mancos Shale in the southeastern part of the San Juan Basin, New Mexico: U. S. Geol. Survey Bull. 1254-F, 21 p.

Dane, C. H., Landis, E. R., and Cobban, W. A., 1971, The Twowells Sandstone Tongue of the Dakota Sandstone and the Tres Hermanos Sandstone as used by Herrick (1900), western New Mexico: U. S. Geol. Survey Prof. Paper 750-B, p. B17-B22.

Daugherty, L. H., 1941, The Upper Triassic Flora of Arizona, Carnegie Inst. Wash. Pub., 526, 108 p.

Dickerson, K. A., Berryhill, H. L., Jr., and Holmes, C. W., 1972, Criteria for recognizing ancient barrier coast-lines; in Recognition of ancient sedimentary environ-ments, J. Rigby and W. Hamblin eds.: Soc. Econ. Paleontologist and Mineralogist spec. pub. no. 16, p. 192-214.

Doeglas, D. J., 1962, The structure of sedimentary deposits of braided rivers: Sed., vol. 1, p. 167-190.

Elston, W. E., 1976, Glossary of stratigraphic terms of the Mogollon-Datil Volcanic Provence, New Mexico; in Cenozoic Volcanism in Southwestern New Mexico: New Mexico Geol. Soc. spec. pub. no. 5, 151 p.

Erpenbeck, M. F., and Flores, R. M., 1979, Stratigraphy and depositional environments of the Upper Cretaceous Pictured Cliffs Sandstone and Fruitland Formations in the southwestern San Juan Basin, New Mexico: (abstract) Geol. Soc. America Abstracts with Programs, Rocky Mtn. Sect. 32nd Ann. Mtg., May, 1979, p. 271.

Fisher, J. J., 1968, Barrier island formation: discussion: Geol. Soc. America Bull., vol. 79, p. 1421-1426.

Fisher, W. L. and Brown, L. F., Jr., 1972, Beach and Barrier System, in Clastic Depositional Systems - A Genetic

Approach to Facies Analysis: Texas Bureau of Economic Geology, 211 p.

Fisk, H. N., 1960, Recent Mississippi River sedimentation and peat accumulation: Cong. Av. Estudes de Stratigraphie et de Geologie du Carbonifere, 4th, September, 1958, Heerlen, Compte rendu, p. 187-199.

Fitzsimmons, J. P., 1959, The structure and geomorphology of west-central New Mexico - A regional setting: New Mexico Geol. Soc., Guidebook 10th field conference, p. 112-116.

Folk, R. L., 1968, Petrology of Sedimentary Rocks: Hemphill Press, Austin, Texas, 170 p.

Foster, R. W., 1964, Stratigraphy and petroleum possibilities of Catron County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bull. 85, 55 p.

Frost, S. J., Tabet, D. E., and Campbell, F. W., 1979, Coal exploratory drilling in the Datil Mountain Coal Field: New Mexico Bureau of Mines and Mineral Resources, open-file report no. 111, 49 p.

Galloway, W. E., 1977, Catahoula Formation of the Texas Coastal Plain - Depositional systems, composition, structural development, ground-water flow history, and uranium distribution: Univ. of Texas Bureau of Econ. Geol., 59 p.

Galusha, T., and Blick, J. C., 1971, Stratigraphy of the Santa Fe Group, New Mexico: Am. Mus. Nat. History Bull., vol. 144, art. 1, 127 p.

Gardner, J. H., 1910, The Carthage coal field, New Mexico: U. S. Geol. Survey Bull. 381, p. 461-473.

Givens, D. B., 1957, Geology of the Dog Springs Quadrangle: New Mexico Bureau of Mines and Mineral Resources Bull., 58, 40 p.

Gould, H. R., and Morgan, J. P., 1962, Coastal Louisiana swamps and marshland; in Geology of the Gulf Coast and central Texas and guidebook of excursions: Houston, Texas: Houston Geological Soc., p. 287-341.

Gregory, H. E., 1916, The Navajo country; a geographic and hydrographic reconnaissance of parts of Arizona, New Mexico, and Utah: U. S. Geol. Survey, Water-Supply Paper 380.

Harrison, R. W., 1980, Geology of the northeast Datil Mountains, Socorro and Catron Counties, New Mexico: New Mexico Inst. Mining and Tech., unpub. M. S. thesis, 137 p.

Hawley, J. W., Bachman, G. O., and Manley, K., 1976, Quaternary stratigraphy in the Basin and Range and Great Plains Provinces, New Mexico and western Texas; in Quaternary Stratigraphy of North America, W. Mahaney ed.: Dowden, Huthicson and Ross, Inc., Stroudsburg, Penn., p. 235-275.

Hayes, M. O., 1967, Hurricanes as geological agents: case studies of hurricanes Carla 1961, and Cindy 1963: Texas Bureau of Econ. Geology Rept. Invest. 61, 54 p.

Herrick, C. L., 1900, Report on a geological reconnaissance in western Socorro and Valencia Counties, New Mexico: Am. Geologist, vol. 25, p. 331-346.

Holmes, W. H., 1877, Report on the San Juan district: U. S. Geol. Survey Terr., 9th Ann. Rept., p. 237-276.

Hook, S. C., and Cobban, W. A., 1977, Pycnodonte newberryi (Stanton) - common guide fossil in Upper Cretaceous of New Mexico: New Mexico Bureau of Mines and Mineral Resources Ann. Rept., 1976-77, p. 48-54.

Hook, S. C., and Cobban, W. A., 1979, Prionocyclus novimexicanus (Marcou) - common Upper Cretaceous guide fossil in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Ann. Rept., 1977-78, p. 34-42.

Hook, S. C., and Cobban, W. A., 1980a, Some guide fossils in Upper Cretaceous Juana Lopez, Mancos and Carlile Shales, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Ann. Rept., 1978-79, p. 38-42.

Hook, S. C., and Cobban, W. A., 1980b, Reinterpretation of type section of Juana Lopez Member of Mancos Shale: New Mexico Geology, vol. 2, no. 2, p. 17-22.

Hook, S. C., Cobban, W. A., and Landis, E. R., 1980, Extension of the intertongued Dakota Sandstone-Mancos Shale terminology into the southern Zuni Basin: New Mexico Geology, vol. 2, no. 3, p. 42-44 and 46.

Jicha, H. L., Jr., 1958, Geology and mineral resources of Mesa del Oro Quadrangle, Socorro and Valencia Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 56, 67 p.

Johnson, B. D., 1979, Genetic stratigraphy and provenance of the Baça Formation, New Mexico, and Eagar Formation, Arizona: Univ. Texas at Austin, unpub. M. S. thesis, 150 p.

Kelley, V. C., 1955, Regional tectonics of the Colorado plateau and relationships to the origin and distribution of uranium: Univ. of New Mexico Press, no. 5, 120 p.

Kelley, V. C., 1957, Tectonics of the San Juan Basin and surrounding areas: Four Courners Geological Soc. Guidebook, second field conf., Geology of the southwest San Juan Basis, p. 44-52.

Kelley, V. C., and Wood, G. H., 1946, Lucero Uplift, Valencia, Socorro, and Bernalillo Counties, New Mexico: U. S. Geol. Survey, Oil and Gas Invest. Prelim. Map 47.

King, P. B., 1977, The evolution of North America: Princeton Univ. Press, Princeton, New Jersey, 197 p.

Landis, E. R., Dane, C. H., and Cobban, W. A., 1973, Stratigraphic terminology of the Dakota Sandstone and Mancos Shale, West-Central New Mexico: U. S. Geol. Survey, Bull. 1372-J, p. J1-J42.

Maberry, J. O., 1971, Sedimentary features, Blackhawk formation (Cretaceous) Sunnyside District, Carbon County, Utah: U. S. Geol. Survey, Prof. Paper 688.

Massingill, G. L., 1979, Geology of the Riley-Puertecito area, southeastern margin of Colorado Plateau, Socorro County, New Mexico: Univ. Texas El Paso, unpub. D.G.S., 301 p.

McGowen, J. H., and Groat, C. G., 1971, Van Horn Sandstone, West Texas: An Alluvial fan model for mineral exploration: Texas Bureau of Econ. Geology, Rept. Invest. no. 72, 57 p.

McKee, E. D., 1951, Triassic deposits of the Arizona-New Mexico border area, New Mexico Geol. Soc. Guidebook of the south and west sides of the San Juan basin, New Mexico and Arizona, p. 85-92.

McKnight, J. F., 1968, Geology of the Bofecillos Mountain area, Trans-Pecos Texas: Univ. Texas Austin, unpub. Ph.D., 198 p.

Meek, F. B., and Hayden, F. V., 1861, Description of new Lower Silurian, Jurassic, Cretaceous, and Tertiary fossils collected in Nebraska Territory with some remarks on the rocks from which they were obtained: Academy Nat. Sci., Philadelphia, Penn., p. 415-447.

Moench, R. H., 1963, Geology and uranium deposits of the Laguna quadrangle, New Mexico: U. S. Geol. Survey, Geol. Quad. Map GQ-207.

Moench, R. H., and Schlee, J. S., 1967, Geology and uranium deposits of the Laguna district, New Mexico: U. S. Geol. Survey, Prof. Paper 519, 117 p.

Molenaar, C. M., 1973, Sedimentary facies and correlation of the Gallup Sandstone and associated formations, northeastern New Mexico: Four Corners Geol. Soc. Memoir Book, p. 85-110.

Molenaar, C. M., 1974, Correlation of the Gallup Sandstone and associated formations, Upper Cretaceous, eastern San Juan and Acoma basins, New Mexico: New Mexico Geol. Soc., Guidebook 25th field conference, p. 251-258.

Obradovich, J. D., and Cobban, W. A., 1975, A time-scale for the Late Cretaceous of the western interior of North America: Geol. Assoc. Canada, spec. pub. 13, p. 33-54.

O'Sullivan, R. B., 1977, Triassic rocks in the San Juan Basin of New Mexico and adjacent areas: New Mexico Geol. Soc., Guidebook 28th field conference, p. 139-146.

Owens, D. E., 1963, The Dakota Formation of the San Juan Basin, New Mexico and Colorado: Univ. Kansas, unpub. Ph.D. Thesis, 353 p.

Owens, D. E., 1966, Nomenclature of Dakota Sandstone (Cretaceous) in San Juan Basin, New Mexico and Colorado: Am. Assoc. Petroleum Geologist Bull., vol. 50, no. 5, p. 1023-1028.

Peterson, F., and Kirk, A. R., 1977, Correlation of the Cretaceous rocks in the San Juan Basin, Black Mesa, Kalparowits and Henry Basins, southern Colorado

Plateau: New Mexico Geol. Soc., Guidebook 28th field conf., p. 167-178.

Pike, W. S., 1947, Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geol. Soc. Am., Mem. 24, 103 p.

Read, C. B., Duffer, R. T., Wood, G. H., and Zapp, A. D., 1950, Coal resources of New Mexico: U. S. Geol. Survey, Circ. 89, 24 p.

Reeside, J. B., 1957, Paleoecology of the Cretaceous seas of the Western Interior of the United States: in Treaties on marine ecology and paleoecology: Geol. Soc. Am. Mem. 67, vol. 2, p. 505-542.

Reinech, H. E., and Singh, I. B., 1975, Depositional sedimentary environments: Springer-Verlag, New York, New York, 439 p.

Robinson, B. R., 1976, Stratigraphy and environment of deposition of member 9 of the Rawls Formation, Presidio County, Texas: Univ. of Houston, unpub. M.S. thesis, 151 p.

Roehler, H. W., 1977, Depositional environments of the Almond Formation in the Rock Springs Uplift: Geol. Rocky Mtn. Coal, Proc., 1976 Sympos., p. 87.

Sears, J. D., Hunt, C. B., and Hendricks, T. A., 1941, Transgressive and regressive Cretaceous deposits in southern San Juan Basin, New Mexico: U. S. Geol. Survey, Prof. paper 193 F, p. 101-121.

Shaw, A. B., Time in stratigraphy: McGraw-Hill Book Co., New York, 365 p.

Shomaker, J. W., Beaumont, E. C., and Kottlowski, F. E., 1971, Strippable low-sulfur coal resources of the San Juan Basin in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources, Mem. 25, 189 p.

Snyder, D. O., 1971, Stratigraphic analysis of the Baca Formation west-central New Mexico: Univ. of New Mexico, unpub. Ph.D. thesis, 160 p.

Stokes, W. L., 1950, Pediment concept applied to Shinarump and similar conglomerates: Geol. Soc. Am. Bull., vol. 61, no. 2, p. 91-98.

Tabet, D. E., and Frost, S. J., 1978, Coal fields and mines of New Mexico: New Mexico Bureau of Mines and Mineral Resources, Resources Map 10, map with text.

Teichmuller, M., and Teichmuller, R., 1975, The Geological basis of coal formation; in Coal Petrology, E. Stach ed., Berlin-Stuttgart, 428 p.

Tonking, W. H., 1957, Geology of the Puertecito quadrangle, Socorro County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bull. 41, 67 p.

Visher, G. S., 1972, Physical characteristics of fluvial deposits: in Recognition of ancient sedimentary environments: Soc. Econ. Paleontologist and Mineralogist spec. pub. no. 16, p. 84-97.

Wells, E. H., 1919, Oil and gas possibilities of the Puertecito district, Socorro and Valencia Counties, New Mexico: New Mexico School of Mines (New Mexico Bureau of Mines and Mineral Resources), Mineral Resources Survey, Bull. 3, 47 p.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L., and Vorbe, G., 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains and northern Chupadera Mesa, Valencia, Torrence, and Socorro Counties, New Mexico: U. S. Geol. Survey, Oil and Gas Invest., Map 61.

Winchester, D. E., 1920, Geology of Alamosa Creek Valley, Socorro County, New Mexico, with special reference to the occurrence of oil and gas: U. S. Geol. Survey, Bull. 716, p. 1-15.

Young, R. G., 1955, Sedimentary facies and intertonguing Upper Cretaceous Book Cliffs Formation, Utah and Colorado: Geol. Soc. Am. Bull., vol. 66.

APPENDIX A

APPENDIX A

Point-count Mineralogy of Selected Thin-sections

	Sample Number			
	4	6	7	9
Quartz	90	86	78	70
K spar	T	T	6	17
Plagioclase	0	0	1	0
Mica	T	T	1	T
Glauconite	T	0	4	2
Sed. Rx. Frags.	10	12	5	11
Meta. Rx. Frags.	0	0	0	0
Ign. Rx. Frags.	0	0	0	0
Others	T	T	5	T

	Sample Number			
	11	12	17	19
Quartz	94	95	75	64
K spar	2	1	11	10
Plagioclase	0	0	1	2
Mica	T	T	1	2
Glauconite	1	2	1	T
Sed. Rx. Frags.	3	2	10	31
Meta. Rx. Frags.	0	0	0	0
Ign. Rx. Frags.	0	0	0	0
Others	T	T	2	1

	Sample Number 21	23	93	45
Quartz	60	75	7	60
K spar	24	15	1	13
Plagioclase	2	1	15	8
Mica	1	T	1	1
Glauconite	T	T	0	0
Sed. Rx. Frags.	10	4	0	7
Meta. Rx. Frags.	0	0	0	6
Ign. Rx. Frags.	0	0	71	2
Others	5	5	5	3

	Sample Number 62	63	41	94
Quartz	70	65	56	69
K spar	17	10	11	4
Plagioclase	3	10	8	8
Mica	1	2	1	1
Glauconite	0	0	0	0
Sed. Rx. Frags.	7	11	11	12
Meta. Rx. Frags.	0	0	4	0
Ign. Rx. Frags.	0	0	1	T
Others	2	3	1	4

	Sample Number 95
Quartz	69
K spar	8
Plagioclase	10
Mica	2
Glauconite	0
Sed. Rx. Frags.	15
Meta. Rx. Frags.	0
Ign. Rx. Frags.	T
Others	4

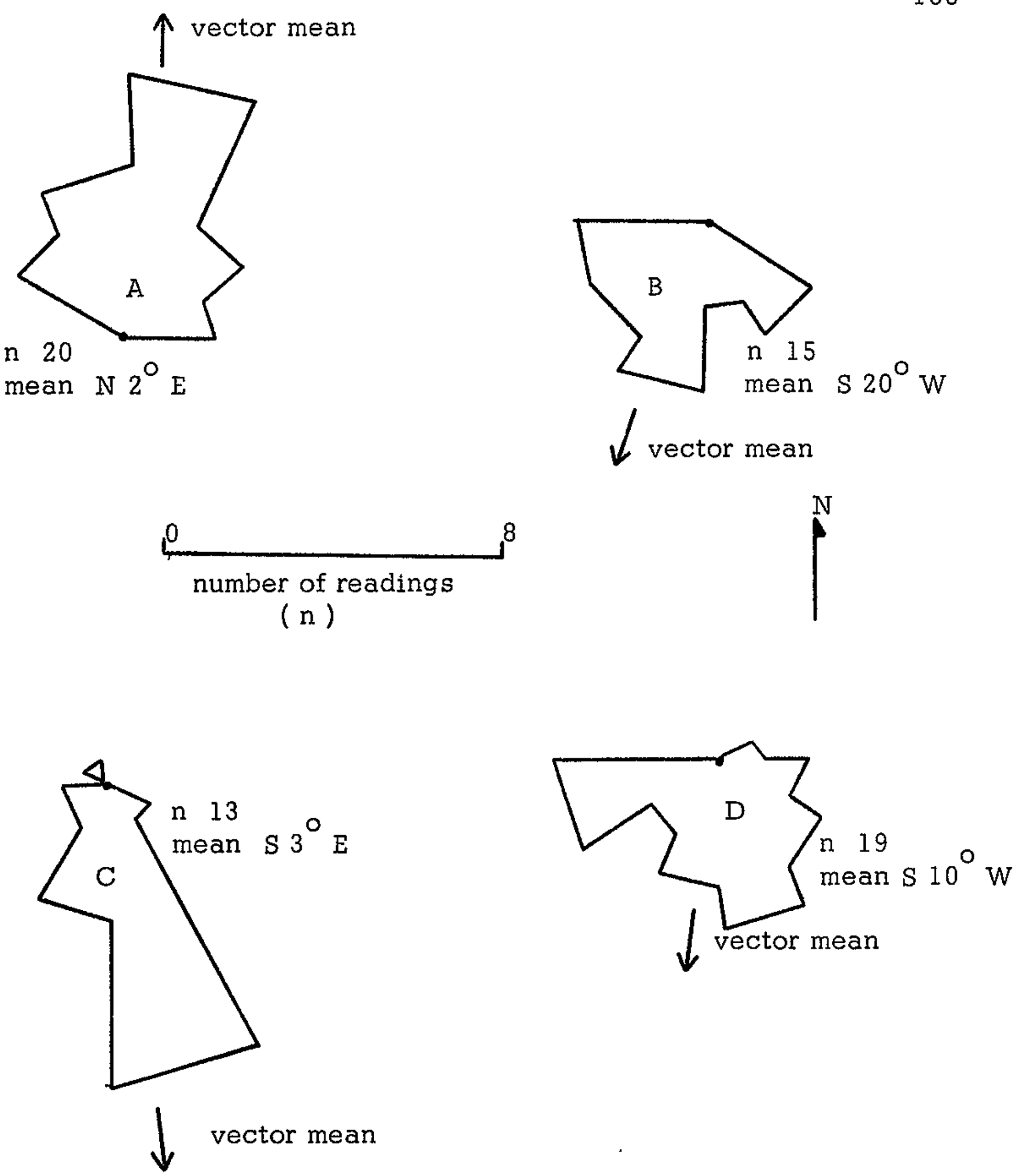
Code to sample numbers in Appendix A

Sample Code	Rock Unit	Rock Name
4	Dakota- main body	Sublitharenite
6	Dakota- main body	Sublitharenite
7	Twowells tongue	Subarkose
9	Twowells tongue	Lithic arkose
11	Paguate tongue	Sublitharenite
12	Paguate tongue	Quartzarenite
17	Tres Hermanos Sandstone	Subarkose

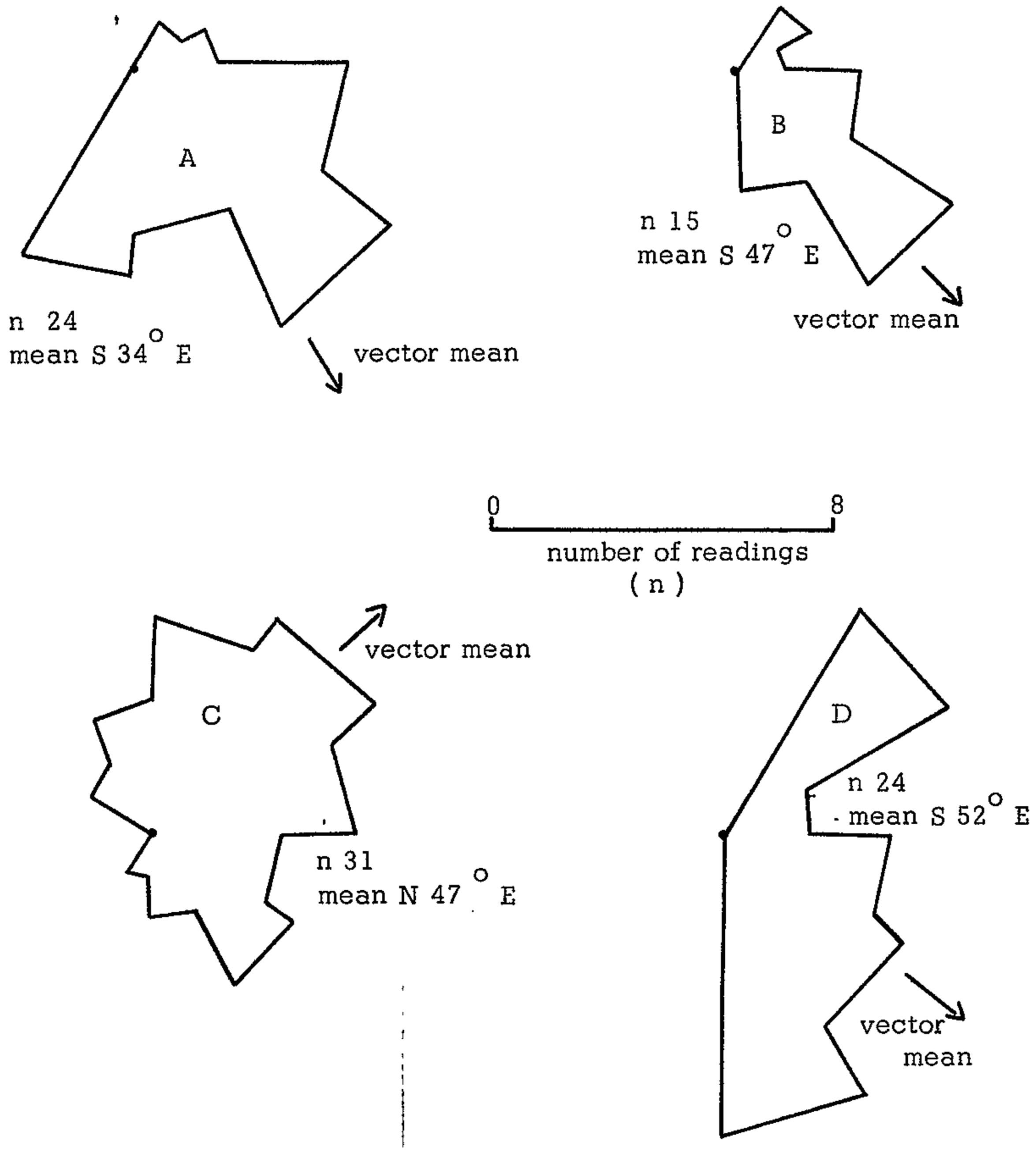
Sample Code	Rock Unit	Rock Name
19	Tres Hermanos Sandstone	Feldspathic Litharenite
21	Gallup Sandstone	Lithic arkose
23	Gallup Sandstone	Subarkose
41	Baca Formation	Lithic arkose
45	Baca Formation	Lithic arkose
62	Crevasse Canyon Fm.	Arkose
63	Crevasse Canyon Fm.	Lithic arkose
93	Conglomerate of Rock Tank	Volcanicarenite
94	Chinle Formation	Lithic arkose
95	Chinle Formation	Lithic arkose

The mineralogy is based on 200 grain-count. All samples were stained for potassium. Sedimentary rock fragments include locally derived clay-clasts. Rock names are after Folk (1968).

APPENDIX B



Paleocurrent Rose Diagrams: A) Chinle Formation
B) Dakota Sandstone - main body C) Paguate Sandstone
D) Twowells Sandstone.



Paleocurrent Rose Diagrams; A) Atarque Member
B) Gallup Sandstone C) Crevasse Canyon Formation
D) Baca Formation.

APPENDIX C

MEASURED SECTION 1

Dakota Sandstone (Main Body) and INM Springs Shale

Measured along an east-west line starting in the NW 1/4 Section 21, T. 3 N., R. 8 W. on July 24, 1978, with Jacob staff and Brunton compass.

Unit	Description	Thickness Feet	Meters
INM SPRINGS (partial section)			
8	Composite. Sandstone and shale: 0.1 to 0.3 ft thick siltstones and very fine-grained subarkoses (10 Y 4/2), moderately indurated, very calcareous, fossiliferous. Abundant burrows on bedding planes. Shales are silty, moderate to very calcareous, thin-bedded, and nodular appearing (10 Y 7/4).	10.1	3.1
7	Siltstone: Similar to siltstones of unit 8. Contains large, 3.0 ft diameter, sub-spherical yellow red (5 YR 5/1) micrite concretions containing sparse megafossils. Thatcher fauna.	0.5	0.1
6	Composite. Sandstone and shale: Same as unit 8. One-half inch		

Unit	Description	Thickness Feet	Meters
	bentonite bed at 4.7 ft above base.	10.7	3.3
5	Covered. Contains INM Springs-Dakota (Main Body) contact.	5.1	1.5
	TOTAL INM SPRINGS TONGUE	26.4	7.9
DAKOTA SANDSTONE (MAIN BODY)			
4	Sandstone: Thin, wavy and flat beds separated by thin shale partings. Limonite stained, indurated. Moderately sorted, calcareous. Burrow casts abundant along bedding planes. Grades to unit below. (5 YR 6/1 to N 7)	9.3	2.8
3	Composite. Sandstone and shale: Interbedded thin calcite cemented sandstones as unit 2 and very silty fine-grained sandstones (10 YR 6/6) with abundant disseminated organic debris. Shales occur in irregular thin to medium beds and are nodular weathering (N 6 to N 8). Grades to unit below. Slope-former. . . .	7.1	2.2

Unit	Description	Thickness Feet	Meters
2	Sandstone: Moderately resistant, noncalcareous, very fine-grained, well sorted, chert-arenite (10 YR 8/2) with black (N 4) carbonaceous streaks. Siltier, more carbonaceous, and less resistant at base. Abundant burrows. Limonite staining (5 YR 5/6) along fractures and burrows. Sharp, flat base.	1.2	0.4
1	Sandstone: Indurated, calcite and silica-cemented, well-sorted, medium- to coarse-grained chert-arenite. Lenses of quartz-pebble and chert-pebble conglomerate abundant in lower part of unit. Base is trough cross-stratified, top is tabular cross-stratified. Massively bedded, fines upward. Upper few inches are limonite-stained. Sharp erosional contact with Chinle shales.	15.2	4.6
	TOTAL DAKOTA SANDSTONE	32.8	10.0
	TOTAL MEASURED SECTION	59.2	18.0

MEASURED SECTION 2

INM Springs and Twowells Tongues

Measured along an east-west line starting in the SW 1/4 of Section 8, T. 3 N., R. 8 W. on July 25, 1978, with Jacob staff and Brunton compass.

Unit	Description	Thickness Feet	Meters
TWOWELLS TONGUE			
13	Covered. Landslide block of Tres Hermanos Sandstone. Abundant _P. newberryi_ as float at base of unit.	3.0	0.9
12	Sandstone: Fine-grained chert-arenite with squashed mud clasts. Moderately resistant, slightly to moderately calcareous. Lower 6.0 ft thick-bedded, poorly sorted, strongly bioturbated. Burrows are 0.2 in. in diameter and horizontal. Pale yellowish-orange (10 YR 8/6). Upper 2.0 ft form weak bench.	8.2	2.5
11	Covered. Probably shale.	1.5	0.5
10	Sandstone: Medium fine-grained, moderately calcareous, moderately		

Unit	Description	Thickness Feet	Meters
	to poorly sorted, massive to vaguely medium-bedded. Strongly bioturbated. Small circular burrows concentrated along bedding planes.	11.6	3.5
9	Sandstone: Well indurated, silica cemented chertarenite. Fines upward from medium coarse pebbly sandstone to lower medium-grained cross-bedded or horizontally laminated sandstone. Sharp upper contact. Limonite stained. Light grey (N 7) to dark yellowish-orange (10 YR 6/6)	2.3	0.7
8	Sandstone: As unit 10.	1.3	0.4
7	Sandstone: Indurated, silica cemented chertarenite. Fines upward to medium coarse pebbly sandstone. Tabular cross-stratified or horizontally laminated. Slightly calcareous, medium thick-bedded. Moderate brown (5 YR 4/4) to light grey (N 7).	4.9	1.5
6	Sandstone: Base of cliff-former. Massively bedded, fine-grained		

Unit	Description	Thickness Feet	Meters
	chertarenite. Moderately to well sorted, clay, silica and calcite cements. Strongly bioturbated in upper part. Liesegang banding pronounced. Grades to unit below. Greyish-orange (10 YR 7/4).	11.2	3.4
	TOTAL TWOWELLS	44.0	13.4
WHITEWATER ARROYO TONGUE			
5	Shale: Silty, very calcareous, dark-grey (N 3 to N 5). Lower half of unit poorly exposed. Contains two bentonite beds; the lowest stratigraphically is 0.6 ft thick and occurs 13.0 ft above the base of the unit. The second bentonite is 0.2 ft thick and occurs 87.0 ft above base of the unit. Float of cone-in-cone limestone and micrite nodules. Grades to unit 6.	91.8	28.0
	TOTAL WHITEWATER ARROYO TONGUE	91.8	28.0
PAGUATE TONGUE			
4	Covered. Base of slope. Laterally sandstone.	21.8	6.6

Unit	Description	Thickness Feet	Meters
3	Sandstone: Coarsening upward from silty, poorly sorted, very fine-grained quartzarenite to moderately sorted, indurated, bioturbated, dusky yellow (5 Y 6/4) fine-grained sandstone. Limonite stained. Lower part organic-rich. Forms weak bench. Base not exposed.	14.2	4.3
	TOTAL PAGUATE TONGUE	36.0	11.0
INM SPRINGS TONGUE			
2	Shale: Moderately calcareous, splintery weathering, silty, common megafossil float and gypsum crystal. Medium-grey (N 5). Two bentonites; the stratigraphically lower unit is 0.2 ft thick and occurs at 26.0 ft above the base of the unit; the other is 0.3 ft thick and occurs at 43.0 ft above unit base. Bentonites are pale greenish-yellow (10 Y 8/2) and weather greyish-orange (10 YR 7/4).	57.2	17.4

Unit	Description	Thickness Feet	Meters
1	Covered. Forms grassy flat. Laterally shale	30.1	9.2
	TOTAL INM SPRINGS TONGUE	87.3	26.2
	TOTAL MEASURED SECTION	259.1	79.0

MEASURED SECTION 3

Paguate Sandstone

Measured in the bed of Rio Salado in Section 5, T. 3 N., R. 8 W. Wiley Mesa quadrangle on July 30, 1978 with Jacob staff and Brunton compass.

Unit	Description	Thickness Feet	Meters
PAGUATE TONGUE			
3	Sandstone: Medium-grained, slightly glauconitic quartzarenite. Well sorted, calcite cemented, bioturbated, tabular cross-stratified. Knobby weathering, light-grey (N 7). Scarce inoceramids. Grades to unit below	2.5	0.8
2	Sandstone: Upper fine- to lower medium-grained, moderately sorted, calcite cemented quartzarenite. Horizontally laminated. Bioturbated zones. Light-olive grey (5 Y 6/2). Grades to unit below. .	14.5	4.4
1	Sandstone: silty very fine-grained quartzarenite. Hard, indurated, light-olive grey		

Unit	Description	Thickness Feet	Meters
	(5 Y 5/2) to medium-grey (N 6). Extremely bioturbated. Isolated lenses of inoceramids and rare ammonites; *P. landisi*. Grades to unit below	15.5	4.7
	TOTAL PAGUATE TONGUE	32.5	9.9
	TOTAL MEASURED SECTION	32.5	9.9

MEASURED SECTION 4

Rio Salado Shale

Measured along an east-west line starting from the top of the Twowells Sandstone in the SW 1/4 Section 20, T. 3 N., R. 8 W. on August 29, 1978 with Jacob staff and Brunton compass.

Unit	Description	Thickness Feet	Meters
RIO SALADO TONGUE			
13	Covered to base of Tres Hermanos. .	26.8	8.2
12	Shale: Greyish-olive green (5 GY 3/2), silty, splintery weathering, noncalcareous	41.6	12.7
11	Concretion zone: 2.0 ft diameter, subsperical, carbonate concretions, containing Mammites depressus . . .	2.3	0.7
10	Shale: Olive green to moderate-grey (5 GY 4/2 to N 6), very calcareous, silty.	79.1	24.1
9	Bentonite: White (N 8), weathers greyish-orange (10 YR 7/4).	0.2	0.1
8	Shale: As unit 10.	11.1	3.4
7	Sandstone: Calcarenite, grey to brown (N 5 to 5 YR 5/2), thinly		

Unit	Description	Thickness Feet	Meters
	laminated, lineated, *Mytiloides mytolodies* hash abundant.	0.9	0.3
6	Shale: As unit 10, shark teeth as float.	32.5	10.0
5	Sandstone: Calcarenite, as unit 7	1.2	0.4
4	Shale: Poorly exposed, grey (N 6), silty, non-calcareous	3.4	1.0
3	Covered. Probably shale as unit 4	10.1	3.0
2	Bentonite: Covered in line of section exposed laterally	0.1	0.1
1	Covered. Across grassy flat, probably shale as unit 4.	20.1	6.1
	TOTAL RIO SALADO TONGUE	229.4	69.9
	TOTAL SECTION MEASURED	229.4	69.9

MEASURED SECTION 5

Tres Hermanos Sandstone

Measured along an east-west line starting in the SW 1/4 Section 19, T. 3 N., R. 8 W. on July 30, 1978 with Jacob staff and Brunton compass.

Unit	Description	Thickness Feet	Meters
	TRES HERMANOS SANDSTONE		
	FITE RANCH MEMBER		
17	Sandstone: Fining upward sequence. Base is massive, spheroidal weathering, bioturbated, medium fine-grained silty, moderately sorted subarkose containing common mud clast. Upper part of unit is fine-grained, slightly calcareous and carbonaceous. Large, 5.0 ft diameter, brown (5 YR 4/2) carbonate cemented concretions are common at top. Erosional base, sharp flat upper contact with D Cross.	24.1	7.3
	TOTAL FITE RANCH MEMBER	24.1	7.3

Unit	Description	Thickness Feet	Meters
	CARTHAGE MEMBER		
16	Shale: Black (N 2), non-calcareous carbonaceous, silty Contains several muddy very fine-grained subarkoses	27.2	8.3
15	Sandstone: Fines upward. Fine-grained, noncalcareous, moderately to poorly sorted, subarkose. Common coal fragments. Greyish-yellow green (5 GY 7/2). Sharp basal contact	3.1	0.9
14	Shale: Grey to black (N 6 to N 2), silty, noncalcareous, carbonaceous.	3.9	1.2
13	Sandstone: Moderately resistant, punky weathering, noncalcareous. Muddy fine-grained subarkose. Moderately sorted at top. Weak bench-former. Light-grey to greyish-yellow green (N 6 to 5 GY 7/2)	4.0	1.2
12	Covered. Probably shale.	7.2	2.2
11	Shale: Black (N 3), non-calcareous, blocky to splintery		

Unit	Description	Thickness Feet	Meters
	weathering, clean, trace carbonaceous material	17.6	5.4
10	Composite. Sandstone and shale: Shales are pale olive (10 Y 6/2), poorly exposed. Rare ironstone concretions and lignite zones; Sandstones are noncalcareous, moderately resistant, (5 GY 6/1) and discontinuous. Pebble-sized clay clast abundant at base. Fine-grained lithic arenites. Clay pore-fill and limonite cement. Sharp lower contact, gradational upper contact	44.2	13.5
7	Sandstone: Resistant, sorted, horizontally laminated to structureless, thin-bedded, bioturbated, fine-grained subarkose. Light-grey to greenish-yellow (N 8 to 5 Y 7/2).	1.0	0.3
	TOTAL CARTHAGE MEMBER	123.2	37.6
	ATARQUE MEMBER		
6	Sandstone: Lower part; light grey (N 7), moderately resistant, very calcareous, fine-		

Unit	Description	Thickness Feet	Meters
	grained, subarkose. Moderately bioturbated. Upper part; Lower fine-grained, moderately sorted, horizontally laminated, slightly calcareous (N 8 to NY 7/2). Grades to unit below. Top of cliff-forming sandstone	4.9	1.5
5	Composite. Sandstone and shale: Three cyclical units as follows; non-resistant, slightly calcareous mudstone, carbonaceous, (5 Y 4/2), blocky weathering, grades to punky weathering, noncalcareous, (5 Y 7/2), silty fine-grained, moderately resistant carbonaceous subarkose. Top of unit is lower medium-grained, salt and pepper with orange pinpoints, irregular medium-bedded, well-sorted, horizontally laminated, moderately bioturbated subarkose. Each subunit is inversely graded.	15.0	4.6
4	Sandstone: Thick to very thick beds, moderately calcareous subarkoses. Base is punky, silty		

Unit	Description	Thickness Feet	Meters
	and fine-grained, with vague horizontal laminations. Middle part is fine-grained, medium-bedded, slightly bioturbated, horizontally laminated. Minor tabular cross-laminae. Poorly developed carbonate concretions near top. (N 8) with orange specks.	24.4	7.4
3	Covered. Laterally slope-forming, very calcareous, bio-turbated, coarse siltstone to fine sandstone. (5 Y 7/2).	13.1	4.0
2	Sandstone: Sharp irregular base with sole markings. Low angle cross-laminae at base and rare rippled zones. Medium- to thick-bedded. (10 YR 7/4). Moderately calcareous resistant. Fine-grained, moderately sorted sub-arkose. Upper part of unit is thin to medium-bedded, trough or tabular cross-stratified, flaggy, very calcareous, con-cretionary lower medium-grained		

Unit	Description	Thickness Feet	Meters
	subarkose, rounded weathering outcrop	30.8	9.4
1	Composite. Sandstone and shale: Sandstones are thin, horizontally laminated, slightly calcareous carbonaceous and very fine-grained. (5 YR 5/1). Micaceous. Sharp irregular bases and flat sharp upper contacts. Slightly bio-turbated, groove cast on soles. Shales are dark grey (N 3), slightly calcareous, silty and carbonaceous.	5.0	1.5
	TOTAL ATARQUE MEMBER	83.2	25.4
	TOTAL TRES HERMANOS SANDSTONE	230.5	70.3
	TOTAL SECTION MEASURED	230.5	70.3

MEASURED SECTION 6

D Cross Shale

Measured along an east-west line starting in the NW 1/4 Section 30, T. 3 N., R. 8 W. on August 3, 1978 with Jacob staff and Brunton compass.

Unit	Description	Thickness Feet	Meters
D CROSS TONGUE			
4	Shale: Slightly to moderately calcareous. Breaks chunky. Broken oyster fragments and microfossils common. Dark-grey to light-olive grey (N 3 to 5 Y 5/2). Gypsum common in fractures and along bedding planes. Concretionary zones at 143.0 ft and 134.0 ft above base of formation. Concretions are; carbonate, two to four feet in diameter and subspherical and often have fossil (ammonite) nuclei. (5 Y 4/1 to 5 Y 7/2), olive grey to yellowish-grey. Interbedded with Gallup Sandstone	107.1	32.6

Unit	Description	Thickness Feet	Meters
3	Shale: Silty, noncalcareous, chunky weathering, fossiliferous. Medium-dark grey to olive grey (N 4 to 5 Y 5/1).	44.0	13.4
2	Limestone: Concretion zone, undulatory bed. Sandy micrite containing fossil debris. A few isolated septarian concretions. Common gypsum vein-filling. Yellowish-brown weathering (10 YR 5/6).	2.1	0.6
1	Shale: Silty, noncalcareous, dark-olive grey (5 Y 4/1). Contains thin beds of very fine sandstone and sandstone-filled burrows. Prominent concretionary zones 1.0 ft and 9.0 ft above base of unit. Concretions often contain ammonites as nuclei: _Prionocyclus_ _sp._, _Coilopoceras collecti_. Sharp flat to undulatory lower contact.	20.0	6.1
	TOTAL D CROSS TONGUE	173.2	52.8
	TOTAL MEASURED SECTION	173.2	52.8

MEASURED SECTION 7

Gallup Sandstone

Measured along an east-west line starting from the SE 1/4 Section 30, T. 3 N., R. 8 W. on August 6, 1978, with Jacob staff, steel tape and Brunton compass.

Unit	Description	Thickness Feet	Meters
GALLUP SANDSTONE (Partial Section)			
6	Sandstone: Massive to thickly bedded, structureless. Non-calcareous, medium fine-grained, sorted, moderately bioturbated subarkose with clay pore-fill matrix. One to 5.0 ft thick strongly bioturbated zones, pale yellowish-brown (10 YR 7/2)	20.1	6.1
5	Sandstone: Parallel laminated, moderately calcareous, resistant, sorted, subarkose, calcareous cement, pale-orange (10 YR 8/2).	3.1	0.9
4	Sandstone: Thickly bedded, generally structureless with minor elongate, light-brown		

Unit	Description	Thickness Feet	Meters
	(5 YR 6/4) burrows. Locally intensely bioturbated near base of unit. Sorted, upper fine-grained, noncalcareous to slightly calcareous, resistant, subarkose.	24.8	7.6
3	Sandstone: Very calcareous, moderately sorted, friable, yellowish-grey (5 Y 7/2), subarkose. Forms base of cliff. Upper fine-grained and thickly bedded. Each bed fines upward. Tops of beds strongly bioturbated. Minor parallel lamination. Sharpe flat base.	31.2	9.5
2	Shale: Silty, slightly calcareous, chunky weathering, dark-grey to pale-brown (N 3 to 5 YR 5/2). Similar to underlying D Cross shales. . . .	1.5	0.5
1	Sandstone: Very calcareous, greyish-orange (5 Y 7/2), carbonaceous. Horizontally branching burrows on bedding		

Unit	Description	Thickness Feet	Meters
	planes. Resistant, poorly sorted, very fine-grained subarkose. Laterally discontinuous. Minor low angle cross-laminae at top of unit	0.6	0.2
	TOTAL GALLUP SANDSTONE	81.3	24.8
	TOTAL MEASURED SECTION	81.3	24.8

MEASURED SECTION 8

Gallup Sandstone

Measured along the north bank of Alamocita Creek starting in the SE 1/4 Section 30, T. 3 N., R. 8 W. on August 10, 1978 with Jacob staff and Brunton compass.

Unit	Description	Thickness Feet	Meters
GALLUP SANDSTONE (Partial Section)			
3	Composite. Sandstone, shale, limestone: Sandstones are bioturbated, vaguely laminated, poorly sorted, fine-grained subarkoses. Shales are grey (N 6), silty, organic rich, slightly calcareous, chunky weathering. Limestones are elliposoidal, biolithites: *Ostrea soleniscus*. Coal developed laterally	15.4	4.7
2	Sandstone: Medium-bedded, sorted, tabular cross-stratified, root-mottled subarkoses. Root cast are long, circular, branching		

Unit	Description	Thickness Feet	Meters
	and most common at top of unit.	10.1	3.1
1	Sandstone: Thickly bedded, greyish-orange pink (10 YR 7/2), moderately sorted, horizontally laminated, slightly bioturbated, sub-arkose. Resistant.	23.2	7.1
	TOTAL GALLUP SANDSTONE	48.7	14.8
	TOTAL SECTION MEASURED	48.7	14.8

MEASURED SECTION 9

Crevasse Canyon Formation

Measured along a north-south line starting in the SE 1/4 Section 31, T. 3 N., R. 8 W. on August 21, 1978 with Brunton compass and Jacob staff.

Unit	Description	Thickness Feet	Meters
CREVASSE CANYON FORMATION (Partial Section)			
50	Sandstone: Fining upward sequence. Two subunits; coarse-grained at base, with clay clast conglomerate above erosional lower contact. Structureless to crudely cross-stratified. Upper parts of subunits are fine-grained, moderately sorted, microcross-laminated and rippled. Moderately calcareous.	18.2	5.5
49	Shale: Poorly exposed, medium-grey (N 5), very slightly calcareous, contains several 6 in. thick greyish-olive		

Unit	Description	Thickness Feet	Meters
	(10 Y 4/2), structureless, dirty sandstones.	90.2	25.5
48	Sandstone: Two subunits separated by erosional surface. Rock is very similar in texture, composition and type and sequence of sedimentary structures to unit 50.	20.1	6.1
47	Covered. Probably shale.	10.0	3.0
46	Sandstone: Cut base overlain by small pebble clay clast conglomerate. Base structureless, top cross-bedded and ripple-laminated, flaggy, poorly sorted. Large brownish-grey (5 YR 4/1) carbonate concretions common.	15.1	4.6
45	Sandstone: Friable, silty, flaggy, moderately sorted, medium-grained subarkose to lithic subarkose. Cut base. Yellowish-grey (5 Y 8/4).	6.5	2.0
44	Sandstone: Pale-greenish-yellow (10 Y 8/2). Fines		

Unit	Description	Thickness Feet	Meters
	upward from medium to fine-grained at top. 0.1 ft diameter clay clast common at base. Trough cross-stratified at base. Slightly calcareous.	8.6	2.6
43	Shale: Poorly exposed, pale-olive (10 Y 6/2), silty	5.8	1.8
42	Sandstone: Generally as unit 50. .	30.9	9.4
41	Sandstone: Slightly calcareous, massive, flaggy, poorly sorted, clayey subarkose. Fines upward, contains hickory-nut-size concretions. Pale-greenish-yellow (10 Y 8/2).	15.2	4.6
40	Sandstone: Cut base. As unit above	15.1	4.6
39	Shale: Silty, very slightly calcareous sparce root-mottling, pale-olive (10 Y 6/2)	10.1	3.1
38	Sandstone: Fines upward, cut base. Trough cross-stratified moderately sorted upper fine-grained, calcareous cement.	0.7	0.2
37	Shale: Poorly exposed.	25.8	8.2

Unit	Description	Thickness Feet	Meters
36	Sandstone: Very calcareous, trough cross-stratified, fine-grained, moderately sorted. Yellowish-grey (5 Y 7/2).	4.1	1.3
35	Shale: Poorly exposed. Slope-former. Contains a few dirty sandstone interbeds. Grades to unit 36.	25.9	7.9
34	Shale: Silty, noncalcareous, chunky weathering, carbonaceous. Contains numerous thin, discontinuous dirty light-olive green (5 Y 5/2) sandstones.	30.6	9.3
33	Composite. Sandstone and shale: Shales are similar to unit 34: sandstones are 2.0-3.0 ft thick, structureless and contain wood impressions. Pale-greenish-yellow (10 Y 8/2)	12.1	3.7
32	Sandstone: Slightly calcareous, medium-grained moderately sorted, fines upward to upper fine-grained cross-laminated concretionary subarkose. Cut base with clay clast conglomerate	10.1	3.1

Unit	Description	Thickness Feet	Meters
31	Shale. Pale-olive (10 Y 6/2), silty, slightly calcareous.	18.0	5.5
30	Sandstone: Cut base overlain by clay clast conglomerate. Lower part; massive, lower medium-grained, upper part; upper fine-grained, cross-stratified with small brown (5 YR 4/4) carbonate concretions. Very calcareous top. Grades to unit above.	25.0	7.6
29	Shale: Poorly exposed.	36.5	11.1
28	Sandstone: As unit 32.	10.0	3.0
27	Shale: Light-green, noncalcareous, silty containing two thin structureless sandstones in middle part.	15.1	4.6
26	Sandstone: As unit 24.	5.1	1.5
25	Shale: As unit 23.	17.0	5.2
24	Sandstone: Cut base with clay clast conglomerate. Fines upward. Base is structureless to crudely trough cross-stratified, medium-grained, moderately sorted, calcite		

Unit	Description	Thickness Feet	Meters
	cemented subarkose. Upper part is lower medium-grained pale-yellowish-orange (10 YR 8/4) and has small scale cross-laminae. Grades to unit above. . .	12.1	3.7
23	Shale: Olive green (10 Y 6/2), silty, noncalcareous. Contains a 0.5 ft thick coal seam.	15.5	4.7
22	Covered. Probably shale.	5.1	1.5
21	Shale: Silty, moderate-yellowish-green (10 Y 7/4) noncalcareous, contains one 0.5 ft thick, moderately sorted, calcareous very fine-grained sandstone at top . . .	10.0	3.0
20	Sandstone: Cut base with clay clast conglomerate. Fines upward. Medium-grained, very calcareous, moderately sorted, medium-grained subarkose. Thinly laminated. Pale-olive (10 Y 6/2) weathers brown.	12.0	3.7
19	Shale: Moderate-greenish-yellow (10 Y 7/2), silty, noncalcareous, contains rare one to three inch diameter greyish-olive (10 Y 4/2),		

Unit	Description	Thickness Feet	Meters
	brownish black weathering iron-stone concretions and thin sand-stone interbeds	28.9	8.8
18	Sandstone: Poorly exposed, very pale orange (10 YR 8/2), flaggy, calcareous cement. Brown (5 YR 4/1) weathering top	7.8	2.4
17	Shale: Poorly exposed, con-cretionary.	20.1	6.1
16	Shale: Poorly exposed, medium grey (N 5), containing a thin very sandy limestone with cone-in-cone structures near top, laterally coally.	7.0	2.1
15	Shale: Poorly exposed, contains one 0.5 ft thick fine-grained clayey, poorly sorted lithi-carenite; rippled upper surface, common invertebrate tracks and trails. Pale-greenish-olive (5 Y 5/4)	13.2	4.0
14	Sandstone: Flaggy, slightly calcareous, clayey, crudely cross-stratified. Thin limey zones. Brown (5 YR 4/1).	9.5	2.9

Unit	Description	Thickness Feet	Meters
13	Shale: Silty, moderate-olive brown (5 Y 4/4) homogenous, wood impressions and small carbonate concretions	2.1	0.6
12	Sandstone: Light-brown (5 YR 5/6), fine-grained very calcareous. Grades to sandy limestone at top. Karren surface	2.1	0.6
11	Shale: Poorly exposed.	4.9	1.5
10	Sandstone: Lower part; cross-stratified, thin-bedded, flaggy, non to moderately calcareous, fine-grained, clayey, moderate-yellowish-brown (10 YR 5/4). Upper part; very sandy limestone, pale orange (10 YR 8/2) containing angular quartz grains, clay clasts wood and dark carbonate concretions. Wood is silicified. .	8.0	2.4
9	Shale: Poorly exposed, carbonaceous, (N 4).	25.2	7.7
8	Sandstone: Weak bench-former, noncalcareous subarkose, poorly		

Unit	Description	Thickness Feet	Meters
	sorted, vaguely cross-stratified, cut base.	8.3	2.5
7	Shale: Poorly exposed.	10.3	3.1
6	Sandstone: Moderate-brown (5 YR 4/4) weathering, fine-grained, poorly sorted, weakly indurated, very calcareous, angular grains. Subarkose to lithicarenite, cut base with clay clast conglomerate .	6.9	2.1
5	Covered. Probably shale.	6.5	2.0
4	Sandstone: Fines upward. Upper fine- to lower medium-grained, subarkose, moderately sorted, crudely cross-stratified, wood impressions, sparce plecypods. Cut base with clay clast conglomerate.	5.8	1.8
3	Shale: Poorly exposed. Moderate olive (5 Y 4/4) noncalcareous, containing small concretions, very carbonaceous near top (N 4), minor thin greenish sandstones. . .	10.4	3.2
2	Sandstone: Cut base with clay clast conglomerate. Fining upward sequence, very coarse- to		

Unit	Description	Thickness Feet	Meters
	coarse-grained, moderately sorted. Upper surface dip-slope former. Trace fossils on bottoms of thin sandstones at top of unit. Unit is traceable over entire D Cross quadrangle. Concretionary, non-calcareous.	27.1	8.3
1	Composite. Sandstone and shale: Gradational to Gallup Sandstone. Sandstones are yellowish-white, fine-grained moderately to poorly sorted subarkoses, with small ripples and cross-laminae. Shales are poorly exposed, silty, carbonaceous, and have common feeding tracks. Laterally coal seams . . .	53.0	16.1
	TOTAL CREVASSE CANYON	793.6	241.9
	TOTAL SECTION MEASURED	793.6	241.9

MEASURED SECTION 10

Baca Formation

Measured along a southwest trending line starting in the NE 1/4, NW 1/4 Section 36, T. 3 N., R. 8 W. on October 3, 1978 with Jacob staff and Brunton compass.

Unit	Description	Thickness Feet	Meters
BACA FORMATION (Partial Section)			
46	Shale: Moderate-red (5 R 5/4), silty, slightly calcareous, with very minor, thin sandy zones	8.0	2.4
45	Sandstone: As unit 43.	7.1	2.2
44	Sandstone: Greyish-pink (5 R 8/2), moderately sorted, very slightly calcareous, friable, fine- to medium-grained arkose. Massive at base, horizontally laminated at top. Grades to unit 45.	3.5	1.1
43	Sandstone: Silty, greyish-pink (5 R 8/2), friable, slightly calcareous, fine-grained arkose . .	10.2	3.1
42	Sandstone: Sharp irregular cut base with clay clast conglomerate. Medium-grained,		

Unit	Description	Thickness Feet	Meters
	moderately sorted, slightly calcareous, arkose, greyish-pink (5 R 8/2), vaguely laminated or cross-bedded, minor contoured laminae. Fines upward to upper fine-grained cross-bedded sandstone. Grades to unit 43.	30.0	9.1
41	Sandstone: Sharp cut base with basal conglomerate, thick-bedded, massive, moderately sorted, slightly calcareous, medium coarse-grained arkose. . . .	12.9	3.9
40	Shale: Very sandy, rare light-red (5 R 6/6), 0.1-0.5 ft thick sandstone interbeds	4.0	1.2
39	Sandstone: As unit 17.	3.6	1.1
38	Shale: Light-red (5 R 6/6), silty, with interbeds of thin, 0.1 to 0.2 ft thick flaggy sandstone	15.1	4.6
37	Sandstone: Poor exposure, upper fine-grained, massive, friable, caliche nodules at top.	4.2	1.3

Unit	Description	Thickness Feet	Meters
36	Covered. Red shales laterally.		
*	Note: Common rounded resistate pebbles litter slope from unit 35 through 40. Source not determined.		
35	Sandstone: Medium-bedded, massive at base contact not exposed. Upper part is horizontally laminated to low angle cross-laminated. Moderately sorted, calcareous, medium- to coarse-grained subarkose. Upper few feet are interbedded sandstone and shale similar to unit 34	10.0	3.0
34	Composite. Sandstone and shale: Section poorly exposed. Sandstones are white (N 9), lenticular, 0.3-5.0 ft thick and more numerous toward top of unit, shales are silty	34.1	10.4
33	Covered. Laterally red shales. . .	16.9	5.1
32	Sandstone: Cut base with clay clast conglomerate. Base is thick- to thin-bedded, massive		

Unit	Description	Thickness Feet	Meters
	to low angle cross-laminated, moderately sorted medium-grained arkose, slightly calcareous. Fines upward, grades to unit above by interbedding	22.0	6.7
31	Shale: Moderate-to-light red (5 R 5/4 to 5 R 6/6), silty, structureless	9.1	2.8
30	Sandstone: Three beds as unit 29 separated by 0.5-1.0 ft shale breaks.	15.9	4.8
29	Sandstone: Sharp flat basal contact. Thinly laminated, low angle cross-laminated, fine-grained, clayey arkose with shale parting. Grades to unit above	4.8	1.5
28	Shale: Clean, light-red (5 R 6/6), slightly calcareous	8.9	2.7
27	Covered. Laterally shale as unit above.	28.8	8.9
26	Sandstone: Fine-grained arkose, greyish-pink (5 R 8/2), moderately calcareous, tabular cross-stratified in sets that are		

Unit	Description	Thickness Feet	Meters
	eight inches thick. Grades to unit above.	7.5	2.3
25	Shale: As unit 17.	1.2	0.4
24	Sandstone: Sharp cut base, tabular and horizontally laminated, slightly calcareous, moderately sorted, fine- to medium-grained greyish-pink (5 R 8/2), arkose with minor shale breaks.	6.3	1.7
23	Shale: Dominately light-red, silty (5 R 6/6) flaggy fine-grained sandstones and siltstones common	19.1	5.8
22	Sandstone: White (N 9), resistant, calcareous, medium-grained, sorted arkose. Tabular cross-laminated in sets 0.3 ft thick, grades to unit above by interbedding	4.0	1.2
21	Shale: As unit 17.	5.8	1.8
*	Crossed small fault, displacement unknown.		

Unit	Description	Thickness Feet	Meters
20	Sandstone: Poorly exposed, cut base, structureless, arkose, fines upward.	5.2	1.6
19	Shale: As unit 17, grades laterally to siltstone and sandstone	5.5	1.7
18	Sandstone: As unit 16.	12.9	3.9
17	Shale: Light-red (5 R 6/6), slightly calcareous, silty, slope-former, structureless	4.9	1.5
16	Sandstone: Fines upward, cut base with clay clast conglomerate. Base is white (N 9), massive to horizontally laminated, moderately sorted arkose. Upper part is thinly laminated with rare rippled zones. Parting lineations common. Grades to unit above	30.1	9.2
15	Composite. Sandstone and shale: Sandstones are thinly bedded, light-red (5 R 6/6), moderately sorted, calcareous. Shales are as unit 17. Grades to unit 14.	20.0	6.1

Unit	Description	Thickness Feet	Meters
14	Sandstone: Moderately to poorly sorted, medium-grained, light pink, arkose. Low angle cross-stratified, grades to unit 15 . . .	21.5	6.5
13	Shale: As unit 17: numerous thin sandstone interbeds, thickest is 2.0 ft, sandstones increase in number vertically, grades to 14.	15.9	11.4
12	Sandstone: Medium- to fine-grained arkose. Grades above and below to bounding units, middle part is medium-bedded and horizontally laminated, top and bottom are structureless, and thin-bedded	15.8	4.8
11	Shale: As unit 15 with caliche concretions in some horizons.	20.2	6.2
10	Sandstone: Cut base with clay clast conglomerate, very calcareous, coarse-grained arkose. Fines upward into interbedded sandstones and shales. Base is low angle cross-stratified . . .	12.0	3.7

Unit	Description	Thickness Feet	Meters
9	Sandstone: Light-red (5 R 6/6), fine-grained, poorly sorted, moderately calcareous, dirty, thin-bedded, cross-stratified micaeous arkose. Fines upward. . .	19.0	5.8
8	Covered. Laterally interbedded sandstone and shale	45.0	13.7
7	Sandstone: Moderately sorted, calcareous, friable, fine-grained, cross-stratified arkose. Cut base, weak bench-former. (10 R 8/2)	5.0	1.5
6	Shale: Poorly exposed, vague bedding	15.4	4.7
*	Crossed small fault-displacement unknown.		
5	Conglomerate: Slightly erosional base. Dip-slope former, brown (5 YR 3/4), with rounded, compact, or elongate, clast up to 0.5 ft diameter. Vaguely laminated and cross-stratified. Moderately calcareous, clasts are randomly oriented quartz, chert, limestone, granite, arkose, schist, quartzite.		

Unit	Description	Thickness Feet	Meters
	Minor interbedded cross-stratified arkoses. Unit is probably the base of Givens measured section for Baca Formation.	15.8	4.8
4	Sandstone: Greyish-yellow (5 Y 8/4), friable, moderately calcareous, massive to crudely cross-stratified, at base. Top is moderately sorted, calcareous, indurated. Tabular cross-stratified greenish-yellow, moderately indurated subarkose. . .	13.9	4.2
3	Covered. Grassy flat. May be similar to unit 2	15.2	4.6
2	Sandstone: Yellowish-grey (5 Y 8/1), medium-grained, moderately sorted, slightly calcareous subarkose. Sharp cut base with clay clast conglomerate. Both tabular and horizontal laminations present. Fines upward, underlying shale are bleached white. Upper contact covered.	7.6	2.3
1	Composite. Sandstone and shale: Sandstones are very fine-grained,		

Unit	Description	Thickness Feet	Meters
	slightly calcareous, silty, hematite stained. Bottoms are erosional, irregular and have ironstone layers in underlying shales. Thin-bedded. Shales are dominate lithology and are; variegated, vaguely laminated, slightly to noncalcareous, and sandy in areas. Colors include hues of yellow, red, lavender, green grey, olive. 0.1-0.2 ft diameter hematite nodules and layers and 1.0 ft diameter carbonate concretions are abundant . .	45.0	13.7
	TOTAL BACA FORMATION	638.9	194.8
	TOTAL MEASURED SECTION	638.9	194.8

MEASURED SECTION 11

Conglomerate of Rock Tank Canyon

Measured along a west to east trending line starting in the creek bed in the SE 1/4, NW 1/4 Section 34, T. 3 N., R. 8 W., on July 18, 1978 with Jacob staff and Brunton compass.

Unit	Description	Thickness Feet	Meters
CONGLOMERATE OF ROCK TANK CANYON			
3	Composite. Conglomerate and sandstone: Basal part of unit is pebble conglomerates as unit 1. Fines upward to interbedded pinkish-grey (5 YR 8/1), cross-stratified, coarse-grained, moderately to poorly sorted, volani-carenites. Moderately indurated with calcite. Interbedded conglomerates are in beds 0.5-3.0 ft in diameter and cross-stratified: tabular. Clast are exclusively of volcanic origin. Thin		

Unit	Description	Thickness Feet	Meters
	caliche zones and mud-cracked shale occur throughout the unit	225.3	68.7
2	Sandstone: Very pebbly coarse-grained volcarenite. Crudely medium- to thick-bedded. Dominately horizontally laminated.	22.0	6.7
3	Conglomerate: Grey (N 6 to N 8), abundant, cut-and-fill structures, wavy-lenticular beds, well stratified, both tabular and horizontal laminations present. Minor sandstones that are cross-stratified and grade vertically and laterally to conglomerates. Medium-bedded. Maximum clast size 2.5 ft, average is less than 0.1 ft, imbricated, subrounded to subangular, rhyolitic to latite tuffs, very minor basalts. Trace limestone and sandstone as clasts.		

Unit	Description	Thickness Feet	Meters
	Platy to compact shape.		
	Sharp erosional contact with		
	Baca Formation.	47.1	14.4
	TOTAL CONGLOMERATE OF ROCK TANK CANYON	294.4	89.8
	TOTAL MEASURED SECTION	294.4	89.8

MEASURED SECTION 12

Mesaverde Undivided--Tres Hermanos Sandstone

Jornada del Muerto area. Bustos Well 7-1/2' quadrangle, Section 5, T. 3 S., R. 3 E. Measured on September 15, 1978 with Jacob staff and Abney level by B. Robinson, D. Tabet, G. Massingill and S. Hook.

Unit	Description	Thickness Feet	Meters
MESAVERDE UNDIVIDED (Partial Section)			
37	Sandstone: Fine-grained, moderately sorted, very calcareous, subangular quartz grains, minor chert and opaques. (10 R 8/2 to 10 YR 7/4). Medium-bedded with parallel planar cross-laminations. Basal contact sharp and undulatory.	19.5	5.9
	TOTAL MESAVERDE	19.5	5.9
D CROSS TONGUE			
36	Shale: Noncalcareous, fissile, (5 Y 6/2)	15.0	4.6

Unit	Description	Thickness Feet	Meters
35	Limestone: Micrite concretions, (5 Y 8/4) containing Lopha sannionis	1.0	0.3
34	Shale: Noncalcareous, fissile, (N 6)	20.5	6.3
33	Sandstone: Calcarenite, silty, thinly laminated, burrowed, with gradational top and bottom, (5 Y 7/2)	0.5	0.1
32	Shale: Silty, fissile, (5 YR 6/1).	15.0	4.6
31	Shale: Noncalcareous, fissile, (5 Y 5/1)	18.0	5.5
30	Shale: Fissile, contains numerous limestone concretions elongate to bedding plane, 2.0 ft by 5.0 ft, (5 Y 5/1)	47.0	14.3
29	Shale: Noncalcareous, fissile, contains thin siltstone beds at 20.0 ft, 30.0 ft and 34.0 ft above base of unit. Siltstones are laminated and calcareous. . . .	44.9	13.7
28	Limestone: Micrite, (10 YR 7/4). .	0.1	0.1
27	Shale: As unit 29, thin calcarenite beds at 128.0 ft, 130.0		

Unit	Description	Thickness Feet	Meters
	ft and 132.0 ft above base of unit.	137.0	41.8
26	Limestone: Concretionary micrite nodules form almost complete bed. _Baculites yokoyami_ and _Prionocyclus sp_. . . .	0.5	0.1
25	Shale: Noncalcareous, fissile, (5 Y 5/1), containing six inch micrite concretions at 23.0 ft, 26.0 ft and 32.0 ft above base. Concretions are similar to unit 26	42.5	13.0
18	Sandstone: Silty calcarenite, fossiliferous, (10 YR 7/2) contains: _Scaphites ferronensis_, _Prionocyclus wyomingensis_	0.2	0.1
17	Shale: Noncalcareous, fissile, clean, (5 Y 6/1).	9.7	3.0
16	Sandstone: Calcarenite as 33 . . . contains: _Scaphities warreni_ and _Prionocyclus wyomingensis_	0.3	0.1
15	Shale: Very poorly exposed	8.5	2.6
	TOTAL D CROSS TONGUE	360.7	110.0

Unit	Description	Thickness Feet	Meters
TRES HERMANOS SANDSTONE			
14	Sandstone: Coarsening upward sequence. Very fine-grained at base, fine-grained at top. Moderately sorted subarkose (5 Y 8/1), 10 YR 8/4, 7 YR 8/2, 10 YR 7/6). Upper surface rippled and bioturbated. Massively bedded.	41.0	12.5
13	Shale: Silty, fissile, abundant gypsum crystals, (N 5 to N 7). Septarian concretions containing fossils throughout unit. Grades to unit above. _Lopha bellaplicata_ and _Ostrea sp_.	35.0	10.7
12	Composite. Sandstone and shale; sandstones are fine-grained, moderately calcareous, 0.3-1.0 ft thick and comprise 50% of the unit. Shales are poorly exposed	15.0	4.6
11	Sandstone: Base is thick-bedded and cross-laminated;		

Unit	Description	Thickness Feet	Meters
	top is horizontally laminated. Fines upward from medium-grained to fine-grained. Moderately calcareous, wood impressions and concretionary (large), also wood (petrified). (10 YR 8/2). . .	7.5	2.3
10	Shale: Fissile, noncalcareous, silty, grades to unit 9, sharp contact with unit 10. (N 6)	4.0	1.2
9	Sandstone: Light-grey (N 4), poorly sorted, angular subarkose. Thick-bedded, tabular cross-stratified with sparce petrified wood and dark-brown (5 YR 2/4) carbonate concretions that are up to 4.0 ft thick and 20.0 ft long near base. Sharp irregular basal contact	20.0	6.1
8	Sandstone: Very fine-grained, locally siltstone and mudstone. . .	5.0	1.5
7	Sandstone: Noncalcareous, fine-grained, medium-bedded, subarkose, (10 YR 7/4), low angle planar		

Unit	Description	Thickness Feet	Meters
	cross-laminated and mottled or structureless. Minor knobby *Ophiomorpha* burrows	5.0	1.5
6	Shale: Silty, micaceous, fissile, slightly to non-calcareous.	5.0	1.5
5	Sandstone: Very fine-grained, silty, slightly calcareous, moderately bioturbated, (10 YR 7/4)	0.9	0.3
4	Shale: Poorly exposed.	12.0	3.7
3	Sandstone: Slightly calcareous, fine- to medium-grained, moderately sorted, medium-bedded, tabular cross-stratified subarkose, (10 YR 7/4)	4.0	1.2
2	Shale: Fissile, (N 6) with a few thin fine-grained sandstone interbeds	5.0	1.5
1	Sandstone: Medium- to thick-bedded, structureless, mottled or cross-laminated. Locally cuspate ripples, moderately sorted, fine- to medium-grained, subarkose. Horizontal laminations at base,		

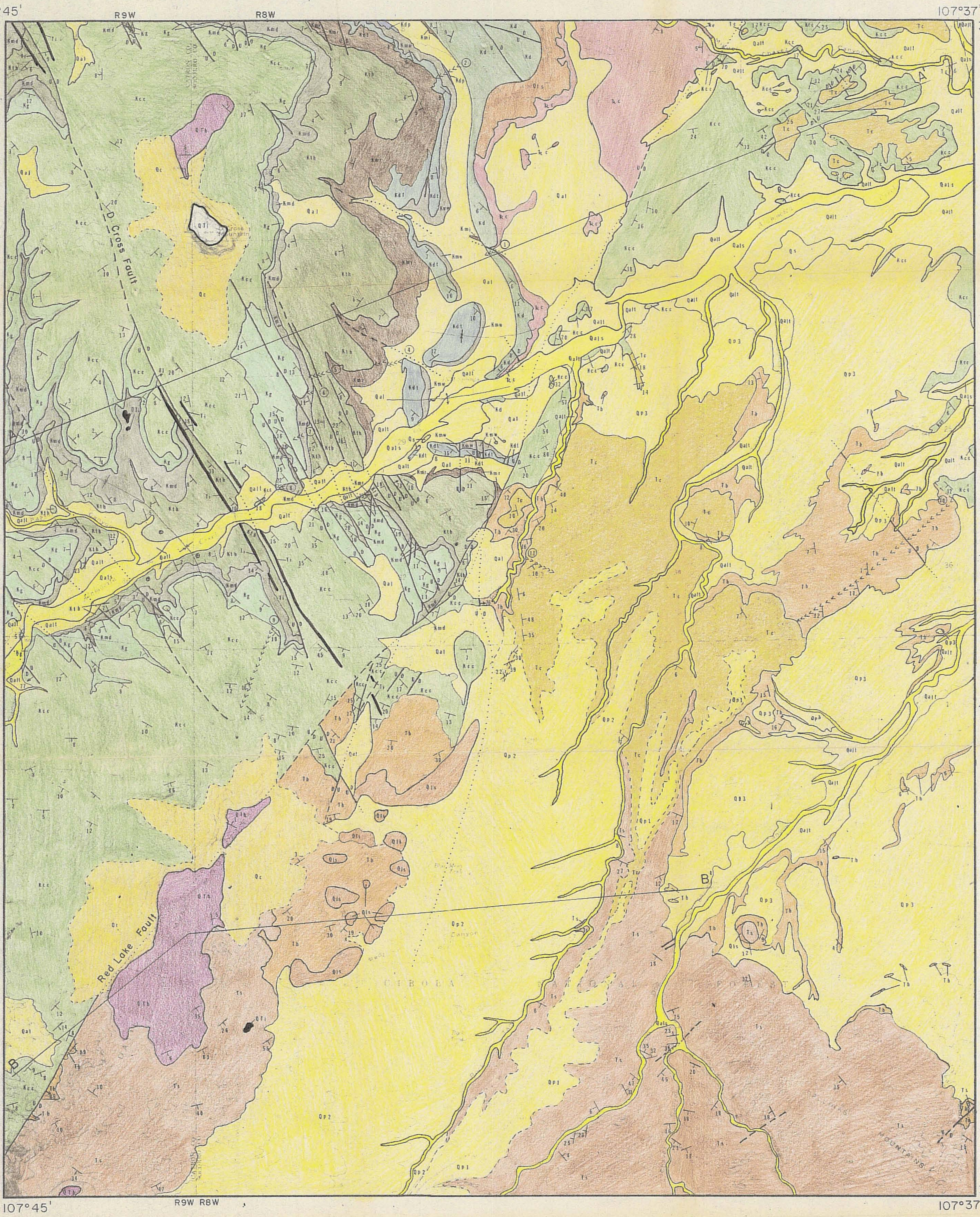
Unit	Description	Thickness Feet	Meters
	tabular cross-laminations near top. Minor clay clast conglomerates and concretions throughout unit. Fossiliferous; Collignoniceras woollari woollgari.	79.0	24.1
	TOTAL TRES HERMANOS	238.4	72.7
	TOTAL MEASURED SECTION	618.6	188.6

VITA

Bob Russell Robinson was born in Laurel, Mississippi, November 21, 1949, the son of Doris and James Robinson. After graduation from Vidor High School in Vidor, Texas, he entered college at Lamar University in Beaumont, Texas where he received a Bachelor of Science degree in 1972. He was employed for nine months in 1973 with Exploration Logging U.S.A. as a well-site geologist before entering the Graduate School at the University of Houston, Houston, Texas. Upon receiving his Master of Science degree in May, 1976, he began work on his Doctorate of Geological Sciences at the University of Texas at El Paso. While working on his degree he has held faculty positions in the Department of Geology at New Mexico State University (Spring, 1979); Eastern New Mexico University (1979-80); and New Mexico Institute of Mining and Technology (Summer, 1980).

Permanent address: Box 233
Vidor, Texas 77662

GEOLOGIC MAP OF THE D CROSS MOUNTAIN QUADRANGLE, NEW MEXICO



Contour Interval 20 feet

Datum is Mean Sea Level

SCALE 1:24000

1 1/2 0 1 mile

0 .5 0 1 km

N 13° 231 mils

1964 Magnetic Declination

New Mexico

Map Location

EXPLANATION

CENOZOIC: Holocene; Plio - Pleistocene; Miocene; Oligocene; Paleocene? Eocene

MESOZOIC: Upper Cretaceous; Triassic

SEDIMENTARY ROCKS

Qc — COLLUVIUM

Qls — LANDSLIDE

Qs — EOLIAN

Qals, Qalt, Qal — ALLUVIUM

Qals - recent stream channel deposits

Qalt - flood plain muds, sands and gravels

Qal - undifferentiated sands and gravels

Qp3, Qp2, Qp1 — PEDIMENT GRAVELS

Qp3 - youngest gravel covered surface

Qp2 - intermediate age surface

Qp1 - oldest gravel covered surface

QTb — BASALT OF BLUE MESA

dense, black, porphyritic

UNCONFORMITY

Tc — CONGLOMERATE OF ROCK TANK CANYON

volcanic pebble conglomerates and sandstones

UNCONFORMITY

Ts — SPEARS FORMATION

quartz latite tuffs, mudflow breccias and megabreccias

UNCONFORMITY

Tb — BACA FORMATION

interbedded cross-stratified arkoses and red shale

UNCONFORMITY

Kcc — CREVASSE CANYON FORMATION

interbedded yellow lithic arkoses, grey shales and coal

Kg — GALLUP SANDSTONE

white, cross-stratified subarkose

Kmd, Kmr, Kmw, Kmi — MANCOS SHALE

Kmd - D Cross tongue: dark concretionary shale

Kmr - Rio Salado tongue: dark fossiliferous shale

Kmw - Whitewater Arroyo tongue: dark silty shale

Kmi - INM Springs tongue: dark fossiliferous shale

Kth — TRES HERMANOS SANDSTONE

subarkose and olive-green shales

Kdt, Kdp, Kd — DAKOTA SANDSTONE

Kdt - Twowells tongue: cross-stratifed subarkose

Kdp - Paguate tongue: cross-stratified quartzarenite

Kd - Main body: chert pebble conglomerate and sublitharenites

UNCONFORMITY

℞c — CHINLE FORMATION

interbedded feldspathic sedarenites and red shale

INTRUSIVE ROCKS

QTi — NECKS AND PLUGS

black basalts containing xenoliths

Ti — DIKES

basaltic andesite

SYMBOLS

CONTACT
dashed where approximate

FAULT
U - upthrown side
D - downthrown side
dashed where inferred
dotted where concealed

SYNCLINE AXIS

ANTICLINE AXIS

STRIKE AND DIP OF BED

DIP OF FAULT PLANE

MEASURED SECTION

PROSPECT

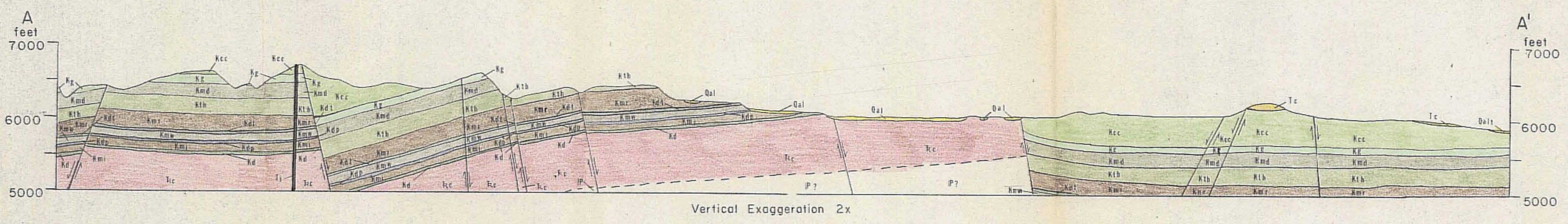
INTERMITTENT STREAM

GRADED ROAD

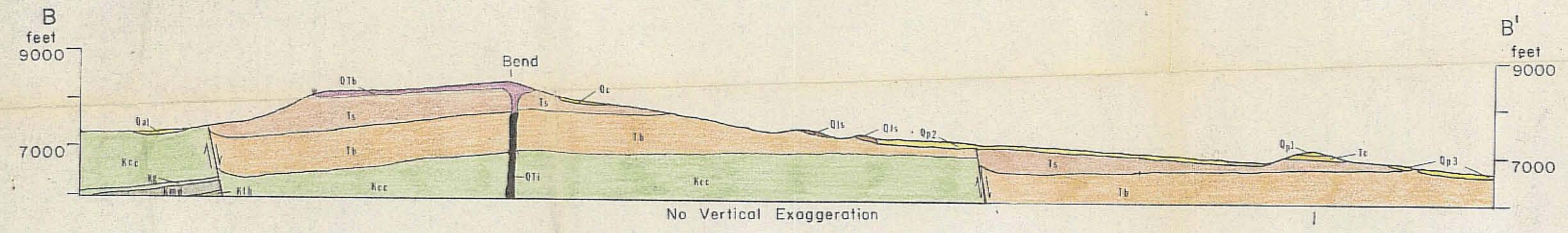
x 7768
POINT OF ELEVATION

BM X6654
BENCHMARK

BUILDING



Vertical Exaggeration 2x



No Vertical Exaggeration

PLATE I

B. ROBINSON, U.T.E.P., 1980