GEOLOGY AND DEPOSITIONAL ENVIRONMENTS OF UPPER CRETACEOUS ROCKS, SEVILLETA GRANT, SOCORRO COUNTY, NEW MEXICO

by

Bruce W. Baker

Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science in Geology

New Mexico Institute of Mining and Technology

Socorro, New Mexico

June 1981

YOU CAN'T GO BACK

AND YOU CAN'T STAND STILL

IF THE THUNDER DON'T GET YOU

THE LIONMAN WILL

ANONYMOUS

ABSTRACT

More than 1300 feet of Upper Cretaceous strata unconformably overlie the Triassic Dockum Formation and are exposed on the Sevilleta Grant, near La Joya, Socorro County, New Mexico. The Upper Cretaceous strata are unconformably overlain by the Tertiary Baca Formation and Santa Fe Group. The Upper Cretaceous sequence extends from the Dakota Sandstone to the Crevasse Canyon Formation and consists largely of shales and sandstones. Coal deposits are present in the Carthage Member of the Tres Hermanos Formation and in the Crevasse Canyon Formation.

Based on lithology, paleontology, sedimentary structure, and paleocurrent direction of the stratigraphic units the following sequence of depositional environments are interpreted; 1) Dakota Sandstone- littoral environment, 2) lower tongue of Mancos Shale- transition zone from nearshore into open marine, 3) Twowells Tongue of the Dakota Sandstone- offshore shallow marine bar, 4) Rio Salado Tongue of the Mancos Shale- open marine to transition into nearshore, 5) Atarque Sandstone Member of the Tres Hermanos Formation- barrier-beach to lagoonal-estuarine, 6) Carthage Member of the Tres Hermanos Formation- lagoonal with coal swamps, 7) Fite Ranch Sandstone Member of the Tres Hermanos Formation- barrier-beach, 8) D-Cross Shale Tongue of the Mancos Shale- open marine that is transitional with the

under and overlying nearshore environments, and containing a fossiliferous sandstone marker bed interpreted as an offshore shallow marine bar, 9) Gallup Sandstone-Crevasse Canyon sequence- barrier-beach to lagoonal-swamp with coal deposits overlain by lagoonal facies.

Two thin sandstones in the basal part of the lower Mancos Shale tongue contain fossil ammonites (*Conlinoceras gilberti* Cobban and Scott and *Plesiacanthocerces wyomingense* Reagan). These beds are age equivalents of the Oak Canyon Member and the Paguate Tongue of the Dakota Sandstone respectively. The proximity of these beds probably indicates a disconformity or a period of slow deposition in the study area. The presence of the Twowells Tongue of the Dakota Sandstone in the study area is puzzling because it is absent to the northwest at Riley, New Mexico and to the southeast at the Carthage and Jornada del Muerto coal fields. The occurrence of the Twowells Tongue in the study area may be due to a change in orientation of the Late Cretaceous shoreline or a change in the orientation of the Twowells Tongue.

Coal, 1 ft (30 cm) thick, in the Crevasse Canyon Formation has been mined in the past. Chemical analysis of the coal indicates that it is fairly high in calorific value and low in sulfur. Being located on the Sevilleta Grant National Wildlife Refuge makes any extensive exploration or mining difficult.

ACKNOWLEDGMENTS

I gratefully acknowledge the many individuals who helped me during this study. The New Mexico Bureau Mines and Mineral Resources provided financial support. The National Wildlife Service allowed me access to the Sevilleta National Wildlife Refuge. Beth Baker was a great help throughout my graduate career. Dr. C. T. Smith served on my thesis committee providing helpful ideas in the field and critically read the manuscript. Dr. D. B. Johnson also served on my thesis committee and critically read the manuscript.

Special thanks to Dr. J. R. MacMillan for serving as my thesis advisor and for his generous advice in both the field and office. Many individuals in the New Mexico Bureau of Mines and Mineral Resources (especially Dr. S. C. Hook) provided useful ideas and equipment helpful to this study. Bogsy, my field assistant, was also a great help.

TABLE OF CONTENTS

PLATES

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Area of Study

The Sevilleta Grant is located southeast of La Joyita Hills approximately 20 miles northeast of Socorro, New Mexico. The study area encompasses approximately 18 square miles, including the area covered by adjacent corners of La Joya, Sierra de la Cruz, Mesa del Yeso, and Becker SW 7.5 minute topographic quadrangles. Figures 1 and 2 show the location of the study area in relation to other geographic features.

Objectives

The main objectives of this study include: 1) detailed geologic field mapping of the study area showing stratigraphy and structure; 2) measurement of stratigraphic sections showing vertical sequences of units characterized by lithology, sedimentary structures, and paleontology; 3) interpretation of the environment of deposition for each stratigraphic unit.

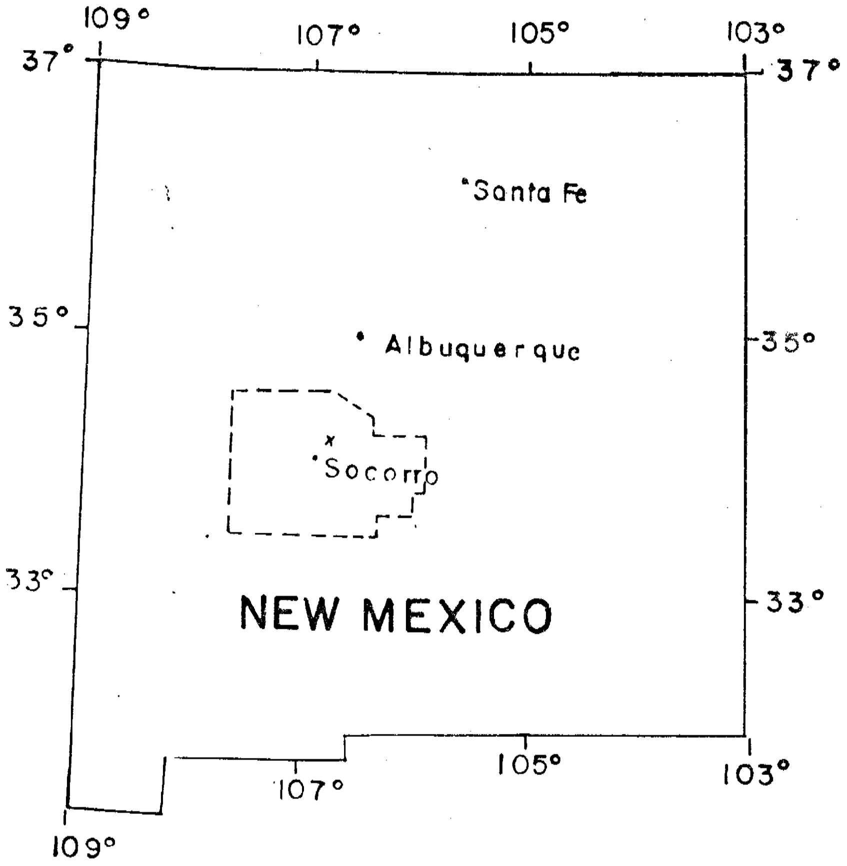


Figure 1. Geographic location of the study area, indicated by the x.

Scale
1 inch = 55 miles

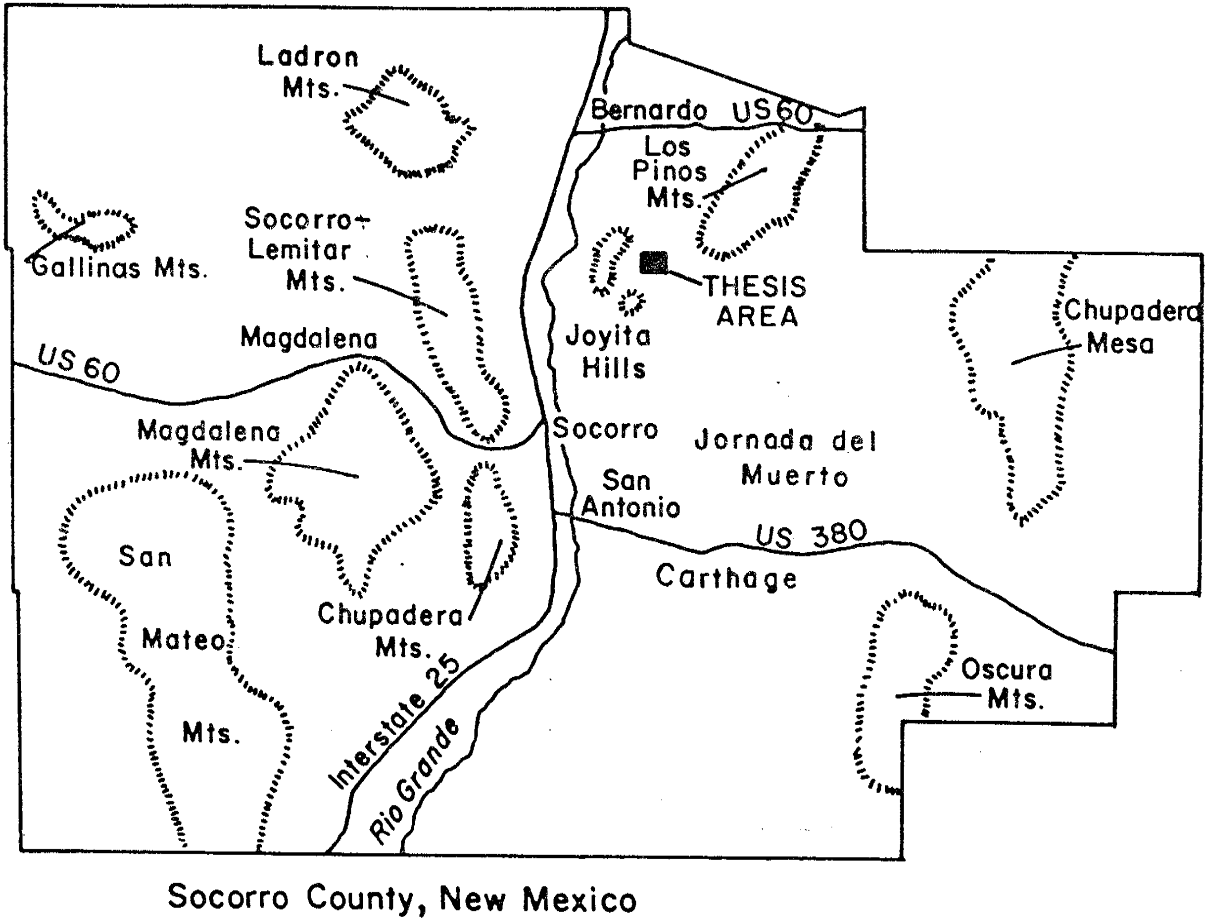


Figure 2. Location of the thesis area showing major topographic features.

Scale
1 inch = 9.5 miles

	Wilpolt & others (1946) Sevilleta Grant	Molenaar (1974) Carthage		Tabet (1979) Jornada del Muerto coal field		Hook, Molenaar, & Cobban (in press) Carthage		This Study (1981) Sevilleta Grant	
Lower Tertiary	Baca Formation	Crevasse Canyon Formation		Baca Formation		Crevasse Canyon Formation		Baca Formation	
Upper Cretaceous	Mesaverde Formation			Mesaverde Group				Crevasse Canyon Formation	
		Gallup Ss. "C" Sand				Gallup Sandstone		Gallup Sandstone	
	Mancos Shale	Mancos Shale	D-Cross Shale Tongue	Manco Shale	D-Cross Shale Tongue	Mancos Shale	D-Cross Shale Tongue	Mancos Shale	D-Cross Shale Tongue
		Lower Gallup (Atarque Member)			Tres Hermanos Sandstone Member	Tres Hermanos Formation	Fite Ranch Sandstone Member	Tres Hermanos Formation	Fite Ranch Sandstone Member
							Carthage Member		Carhtage Member
							Atarque Sandstone Member		Atarque Sandstone Member
		Mancos Shale	Lower Mancos Shale		lower tongue of Mancos Shale	lower tongue of Mancos Shale		Rio Salado Tongue of Mancos Shale	
								Twowells Tongue of Dakota Sandstone	
								lower tongue of Mancos Shale	
	Dakota Sandstone	Dakota Sandstone		Dakota Sandstone		Dakota Sandstone		Dakota Sandstone	
Upper Triassic	Dockum Formation							Dockum Formation	

Table 1. Stratigraphic nomenclature applied by selected references to Cretaceous rocks in the Carthage, Jornada del Muerto coal field and Sevilleta Grant areas, New Mexico.

Methods of Investigation

Methods of investigation include: 1) geologic field mapping at a scale of 1:12,000; 2) measurement of five stratigraphic sections; 3) lateral tracing of units and sedimentary structures within them; 4) measurement of paleocurrent directions where possible; 5) determination of composition and fabric of sandstones by petrographic analysis of representative samples; 6) x-ray diffraction for semi-quantitative analysis of clay mineral composition in the shales.

Previous Work

The stratigraphic nomenclature of Upper Cretaceous strata south of the San Juan Basin has been developing over the past several years. Table 1 lists the progression of stratigraphic terminology used by selected studies in the Carthage, Jornada del Muerto coal field, and Sevilleta Grant areas.

Studies of Upper Cretaceous exposures in the Socorro region include work to the northwest of the study area at Riley-Puertecito by Herrick (1900), Pike (1947), and Molenaar (1974). To the southeast studies have done at Carthage by Gardner (1910), Lee (1915), Pike (1947), Hook and others (in press), and at Jornada del Muerto coal field by Read and others (1950), Kottlowski and Beaumont (1965), and Tabet (1979). Work that includes the study area was done by Darton (1928), Wilpolt and others, (1946), and Wilpolt and Wanek (1951).

Darton (1928), in his discussion of Upper Cretaceous strata in Socorro County, mentions exposures in the Valle del Ojo de la Parida and in Palo Duro Canyon east of La Joya. He also mentions coal beds in the Valle del Ojo de la Parida and Arroyo Cibola. Darton (1928) noted in the basin south of La Joya that sandstones associated with coal deposits in the Mancos Shale were difficult to distinguish from the overlying Mesaverde Formation. Darton (1928) shows a partial measured section of the lower part of the Upper Cretaceous Series with 30 ft (9 m) of Dakota (?) Sandstone overlain by 410 ft (125 m) of alternating shales and sandstones capped by piedmont gravels. He reports a very limy shale suggesting that it might be the Greenhorn Limestone 160 ft (49 m) above the base.

Wilpolt and others (1946) and Wilpolt and Wanek (1951) made reconnaissance maps of the Socorro region including this study area using the stratigraphic nomenclature of the day (see Table 1). The following lithologic descriptions of the units in the La Joya area are taken from Wilpolt and others (1946). The Upper Cretaceous Dakota Sandstone, 112 ft (34 m) thick, yellowish-green, medium to coarse-grained sandstone, unconformably overlies approximately 500 ft (152.4 m) of the Triassic Dockum Formation. The Dockum Formation is characterized by maroon sandstones, siltstones, and shales. Overlying the Dakota Sandstone is the Mancos Shale consisting of buff and black shales and yellow, buff, and brown sandstones. Conformably overlying the Mancos Shale is the Mesaverde Formation, which ranges up to 200 ft (61 m) thick and consists of yellow and buff sandstones and shales with one thin coal bed. The upper contact of the formation is an erosional surface unconformably overlain by the Tertiary Baca Formation.

Figure 3. Photograph of shale, sandstone, and conglomerate in the Dockum Formation in the area south of Cibola Canyon.

TRIASSIC STRATA

Dockum Formation

The Triassic Dockum Formation was named by Cummins (1890) near Dockum, Texas. Wilpolt and Wanek (1951) extended the terminology into the area immediately north of Carthage, New Mexico where they recognized the Dockum Formation as the strata between the San Andres Formation and the Dakota Sandstone. The Dockum Formation is correlative with the Chinle Formation (Wilpolt and others, 1946) and the term Dockum is often used east of the Rio Grande. The Chinle Formation was named by Gregory (1916) after Chinle Valley, Arizona and is commonly applied to the west of the Rio Grande. The Dockum Formation unconformably underlies the Upper Cretaceous Dakota Sandstone in the study area and is composed of conglomerates, sandstones and shales (Figure 3).

The conglomerates contain pebbles and cobbles of quartzite, sandstone, and siltstone in a matrix of coarse-grained, bedded sandstones. The sandstones in the Dockum Formation are friable to moderately indurated, fine- to coarse-grained, and poorly sorted (see Appendix B for description of terms). Friable, fine-grained, well-sorted, grayish-orange-pink (10 R 8/2) sandstone lenses are present locally. The shales are medium light gray (N 6) to very dark red (5 R 2/6). Shale fragments and fossilized wood are present in the sandstones. Cross-bedding consists of medium-scale, tabular-shaped sets of low-angle tangential cross-beds with nonerosional lower contacts.

UPPER CRETACEOUS STRATA

The Upper Cretaceous Series in central New Mexico can be divided into the Dakota Sandstone, Mancos Shale, Tres Hermanos Formation, and Mesaverde Group. The definition of these units is not one of precise age limits or specific depositional environment, but rather one of general lithologic and depositional framework within the major transgressive-regressive sequences (Sears and others, 1941). Figure 4 shows the complete generalized stratigraphic section of the study area and the ages of the strata studied. Plate 2 shows the correlation of the measured stratigraphic sections in the study area.

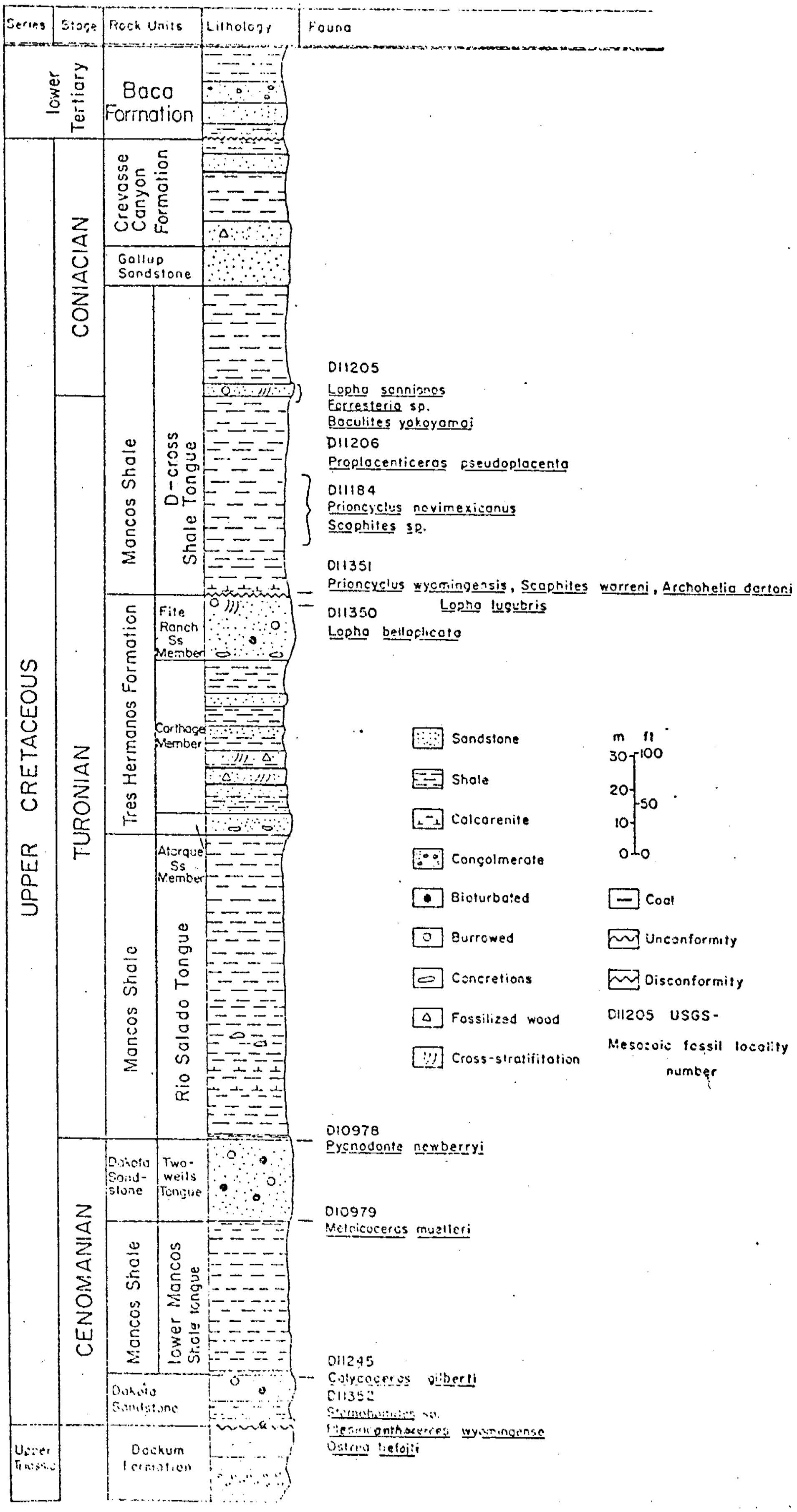


Figure 4. Generalized stratigraphic column of study area showing ages of strata studied.

General Discussion of Stratigraphic Units

Dakota Sandstone

The Dakota Sandstone is the oldest of the Upper Cretaceous strata exposed in the study area. The term Dakota was first used near Dakota, Nebraska to describe the basal sandstone of the Upper Cretaceous Series (Meek and Hayden, 1862). Dutton (1885) first recognized the great lateral continuity of the Dakota Sandstone. Gardner (1910) applied the term Dakota to the basal sandstone at Carthage, New Mexico. The Dakota Sandstone in the study area forms ridges and isolated hills trending northeast along the southwestern end of the Los Pinos Mountains. The Dakota Sandstone unconformably overlies the Triassic Dockum Formation.

The Dakota Sandstone in the study area is 51 ft (15.6 m) thick and consists of two sandstones separated by 17 ft (5.3 m) of silty medium gray (N 4) shale. The lower sandstone is 6 ft (1.8 m) thick, very fine to fine-grained, moderately to well-sorted, and light brown-gray (5 YR 6/1). This sandstone is bioturbated and contains local pebble conglomerate lenses. The lower sandstone contains abundant wood fragments and carbonaceous material. Due to bioturbation the sandstone is mostly structureless but does exhibit some ripple marks and small- and medium-scale, tabular- to wedge-shaped sets of low-angle tangential cross-beds.

The 17-ft (5.3 m)-thick shale is medium dark gray (N 4). The silty shale is thinly laminated and coarsens upward. The upper 28-ft (8.5 m)-thick sandstone has a similar lithology to the lower sandstone but is more extensively bioturbated (Figure 5). The upper sandstone forms a dip slope and contains *Thalassinoides*, carbonate apatite-bearing nodules, and goethite replacement nodules with pyrite centers.

Lower tongue of Mancos Shale

Cross (1899) was the first to apply the name Mancos to a dark shale exposed in the Mancos River Valley near Mancos, southwestern Colorado. Due to the intertonguing of the Mancos Shale with the sandstones of the Dakota Sandstone, Tres Hermanos Formation, and Mesaverde Group, the Mancos Shale has been divided into several tongues. In west-central New Mexico where these sandstones are not always present the informal term lower tongue of Mancos Shale has been used (Landis and others, 1973; Molenaar, 1974; and Hook and others, in press) and is used in this study.

The lower tongue of Mancos Shale is present north and south of Cibola Canyon. Only the upper 54 ft (16.5 m) of the lower Mancos Shale tongue is exposed in the area north of Cibola Canyon. The lower Mancos Shale tongue has a sharp contact with the conformably underlying Dakota Sandstone.

Figure 5. Photograph of upper sandstone in the Dakota Sandstone, south of Cibola Canyon. Distance between tick marks is 2 inches (5 cm).

The lower tongue of Mancos Shale in the study area is 203 ft (62 m) thick and consists of silty, medium gray (N 7) to light gray (N 5) shale. Interbedded siltstone layers 1-2 inches (3-6 cm) thick are present and contain Inoceramus sp. Five bentonite layers 1-4 inches (3-10 cm) thick occur throughout the lower Mancos Shale tongue. The very pale-orange (10 YR 8/2) bentonite layers are associated with selenite and can be detected by a slight color change in the weathered shales. The upper 16 ft (4.0 m) of the lower Mancos Shale tongue consists of light gray shale which coarsens upward with interbedded yellowish-gray (5 Y 8/1) friable, fine-grained sandstones.

Ten inches (25 cm) above the base of the lower tongue of Mancos Shale is the first of two 3-inch (8 cm)-thick, very fine-grained, moderately indurated sandstone (Figure 6). The sandstone contains pebbles and the ammonite Calycoceras (Conlinoceras) gilberti Cobban and Scott (all invertebrate fossil identifications by or confirmed by Hook, personal communication, 1980-81). Calycoceras gilberti Cobban and Scott is of Thatcher age and is probably age equivalent to the Oak Canyon Member of the Dakota Sandstone (Landis and others, 1973); however Calycoceras sp. has been reported in the Cubero Sandstone Tongue of the Dakota Sandstone (Landis and others, 1973). The Oak Canyon Member was described by Landis and others (1973) from its type locality near Laguna, New Mexico. Landis and others (1973) extended the intertonguing Dakota-Mancos terminology into

Figure 6. Photograph of lower tongue of Mancos Shale showing basal fossiliferous sandstones, south of Cibola Canyon.

west-central New Mexico. Also present in this bed are bone fragments, vertebrae, and the shark teeth *Ptychodus whipplei* Marcou and *Lamna semiplicata* Agassiz (all vertebrate fossil identifications by Wolberg, personal communication, 1981).

Two feet (60 cm) above the first sandstone is another 3-inch (8 cm)-thick sandstone (Figure 6) with characteristics similar to the first sandstone. This sandstone contains *Ostrea beloiti* Logan, *Stomohamites* sp., *Inoceramus rutherfordi* Warren, *Arrhoges modests* (Cragin)?, and *Plesiacanthocerces wyomingense* Reagan. The presence of these fossils indicate this bed is age equivalent to the Paguate Tongue of the Dakota Sandstone. The Paguate Tongue was described by Landis and others (1973) from its type locality near Laguna, New Mexico.

Twowells Tongue

Above the lower tongue of Mancos Shale in the study area up to 86 ft (26 m) of sandstone is present and is correlative with the Twowells Tongue of the Dakota Sandstone. The correlation is based on lithologic similarity, position in the lithostratigraphic column. The faunal content found in the study area is correlative with the Twowells Tongue also. The type section for the Twowells Tongue of the Dakota Sandstone is near Twowells, New Mexico (Pike, 1947). Pike (1947) considered the Twowells to be a lentil in the Mancos Shale. Owen (1966) considered it to be a member of the Dakota Sandstone. Landis and others (1973) redefined the Twowells as a tongue of the Dakota Sandstone and this is the terminology used today.

The Twowells Tongue north of Cibola Canyon is 86 ft (26 m) thick and forms a prominent ridge (Figure 7). The Twowells Tongue south of Cibola Canyon is approximately 63 ft (19 m) thick and is very friable, appearing mostly as a partly covered interval. The base of the Twowells Tongue is gradational with the underlying lower tongue of Mancos Shale.

North of Cibola Canyon, the base of the Twowells Tongue is a very friable, fine-grained, well-sorted, very pale orange (10 YR 8/2) to light brown (5 YR 5/6) sandstone. This medium bedded sandstone becomes less sorted upward. Metoicoceras muelleri Cobban (1977b) was found as float in the basal 20 ft (6.10 m).

The upper portion of the Twowells Tongue is composed of a very friable, medium-grained, well-sorted, white (N 9) sandstone. The lower one-third of the upper portion is medium-grained, well-sorted, extensively bioturbated sandstone, alternating with fine-grained, moderately sorted sandstone, 2 ft (60 cm) thick. Shale partings in the sandstones decrease upward. Fractures in the lower one-third are filled by secondary silica. The upper two-thirds of the upper portion is a very friable, medium-grained, very well-sorted sandstone with horizontal burrows. Bedding increases from medium- to very thick

Figure 7. Twowells Tongue north of Cibola Canyon, overlying the lower Mancos Shale which is faulted against the Triassic Dockum Formation.

bedded within the Twowells Tongue. The Twowells Tongue is overlain by the Rio Salado Tongue of the Mancos Shale.

Rio Salado Tongue

The Rio Salado Tongue of the Mancos Shale is named for exposures along the Rio Salado near Puertecito, New Mexico by Hook and others (in press); they define the Rio Salado Tongue as the shale between the Twowells Tongue of the Dakota Sandstone and the Tres Hermanos Formation. The type locality is north of the Rio Salado, approximately 2 miles northeast of Alamo Mission (Hook and others, in press). The Rio Salado Tongue is present north and south of Cibola Canyon.

The Rio Salado Tongue has a sharp lower contact with the conformably underlying Twowells Tongue of the Dakota Sandstone. The lower part of the Rio Salado Tongue in the study area is 317 ft (97 m) thick and consists of light olive-gray (5 Y 5/6), calcareous shales with interbedded calcarenites. The calcarenites are very fine-grained, thinnly laminated and form resistant layers. The calcarenites contain Inoceramus sp. The basal 5 ft (1.5 m) contains Pycnodonte aff. P. kellumi (Jones) and Pycnodonte newberryi (Stanton) (see Appendix C). The interbedded calcarenites and fauna indicate these beds are equivalent to the Bridge Creek Limestone Member of the Mancos Shale (Hook, personnel communication, 1981) and are late Greenhorn (very late Cenomanian to early Turonian) age. Hook and Cobban (1981a) extended the Bridge Creek Limestone Member terminology into the Mancos Shale in the Carthage and Jornada del Muerto coal field areas.

The 105-ft (32 m)-thick upper part of the Rio Salado Tongue is composed of medium light-gray (N 6) shale with calcareous septarian concretions. North of Cibola Canyon twenty feet (6.1 m) into the the upper part is an *en echelon* series of moderately indurated, fine-grained, moderately sorted sandstone dikes.

Tres Hermanos Formation

The name Tres Hermanos Sandstone was first used by Herrick (1900) for a concretion bearing sandstone east of Tres Hermanos Peak in the Rio Salado Valley, New Mexico. The name Tres Hermanos Sandstone in the past, has been applied to many different sandstone units low in the Mancos Shale (Hook and others, in press). These erroneous identifications of the Tres Hermanos Sandstone have led to much confusion in the literature.

Hook and others (in press) are in the process of raising the Tres Hermanos Sandstone Member of the Mancos Shale to formational rank and subdividing it into three members. The three members in ascending order are Atarque Sandstone, Carthage, and Fite Ranch Sandstone Members. The Atarque Sandstone Member is defined as the lower marine unit. The Carthage Member is named for the medial marginal marine and nonmarine shaley part. The Fite Ranch Sandstone Member is defined as the upper coastal marine sandstone. The principal reference section for the Tres Hermanos Formation is near Carthage, New Mexico.

Atarque Sandstone Member

The Atarque Sandstone Member of the Tres Hermanos Formation is named after a ranch 55 miles south of Gallup, New Mexico. The type section is near Horsehead Canyon in the SW 1/4 of section 32, T. 10 N., R. 17 W (Hook and others, in press).

The Atarque Sandstone Member is present north and south of Cibola Canyon. The Atarque Member has a gradational contact with the conformably underlying Rio Salado Tongue of the Mancos Shale. In the study area the thickness of the Atarque Sandstone Member varies from 11 ft (3.4 m) to 42 ft (13 m) (see Plate 2). The Atarque Member in the study area can be divided into basal, middle, and upper parts. The basal part consists of friable, very fine-grained, moderately sorted, calcareous sandstones. The white (N 9) to very light-gray (N 8) sandstones weather dark yellowish brown (10 YR 2/2). Small-scale, wedge- to tabular-shaped sets of low-angle tangential cross-beds with nonerosional lower contacts are present.

The middle part of the Atarque Member is composed of sandstones that are pale yellowish orange (10 YR 8/6) and weather grayish brown (5 Y 3/2). The sandstones are very friable to friable, very fine-grained to fine-grained, moderately sorted, calcareous, and thin bedded. Shale partings and wood fragments are present in these sandstones. The middle part of the Atarque Member varies laterally with locally very abundant fossiliferous beds or lenses (Figures 8 and 9). The fossiliferous beds are almost completely made of *Crassostrea soleniscus* (Meek). Elsewhere, *Crassostrea soleniscus* (Meek) is only sparsely present with very abundant shark teeth and skeletal fragments. *Crassostrea soleniscus* (Meek) shells compose almost all of the Atarque Member north of Cibola Canyon. North of Palo Duro Canyon and east of Arroyo los Alamos, the middle part of the Atarque Member contains abundant shark teeth, and other bone fragments in lenses. Forty-four species of shark teeth have been identified from these lenses (see Appendix C). The bone fragments include turtle carapace fragments, crocodilian teeth, fragments of dinosaur teeth and vertebrae, skate fragments, and freshwater gar-like teeth and vertebrae.

The cross-stratification is composed of small- and medium-scale, tabular-and wedge-shaped (Figure 10) sets of low-angle planar and tangential cross-beds with nonerosional lower contacts. Straight-crested, symmetrical and asymmetrical ripple marks are also present.

Figure 8. Photograph of Atarque Sandstone Member showing fossiliferous lense south of Cibola Canyon. Rock hammer is 11 inches (27.5 cm) long.

Figure 9. Photograph of Atarque Sandstone Member showing fossiliferous beds north of Cibola Canyon.

Figure 10. Photograph of medium-scale, trough-shaped set of low-angle tangential cross-beds in Atarque Sandstone Member, south of Cibola Canyon. Brunton Compass 2.5 inches (7 cm).

Figure 11. Photograph of medium-scale, wedge-shaped set of low-angle tangential cross-beds in Atarque Sandstone Member, south of Cibola Canyon. Brunton Compass 2.5 inches (7 cm).

The upper part in the area north of Cibola Canyon consists of very friable, very fine-gained, moderately sorted grayish-orange (10 YR 7/4) sandstone. Small- to medium-scale, trough- and tabular-shaped cosets of low- and high-angle tangential cross-beds with nonerosional lower contacts are present. South of Cibola Canyon the upper part consists of very friable, very fine- to fine-grained, moderately to well-sorted, thin- to thick-bedded, grayish-yellow (5 Y 8/4) sandstone. The cross-stratification is composed of medium-scale, wedge- and trough-shaped (Figure 11) sets and cosets of low-angle tangential cross-beds with nonerosional lower contacts.

Paleocurrent directions measured from the Atarque Member are shown in Figure 12 A-D as paleocurrent rose diagrams. For all paleocurrent measurements the effects of tectonic activity resulting in tilting of the strata is removed by using a steronet when the dip of the beds is greater than 10^{o}. Figure 12 D is a composite of all Atarque Member measurements.

Carthage Member

The Carthage Member of the Tres Hermanos Formation is named after the abandoned coal-mining community of Carthage about 16 miles (25 km) southeast of Socorro, New Mexico. The type section is located nearby in SE1/4 SE1/4 of section 8 and the NE1/4 NE1/4 of section 17 T. 5 S., R. 2 E (Hook

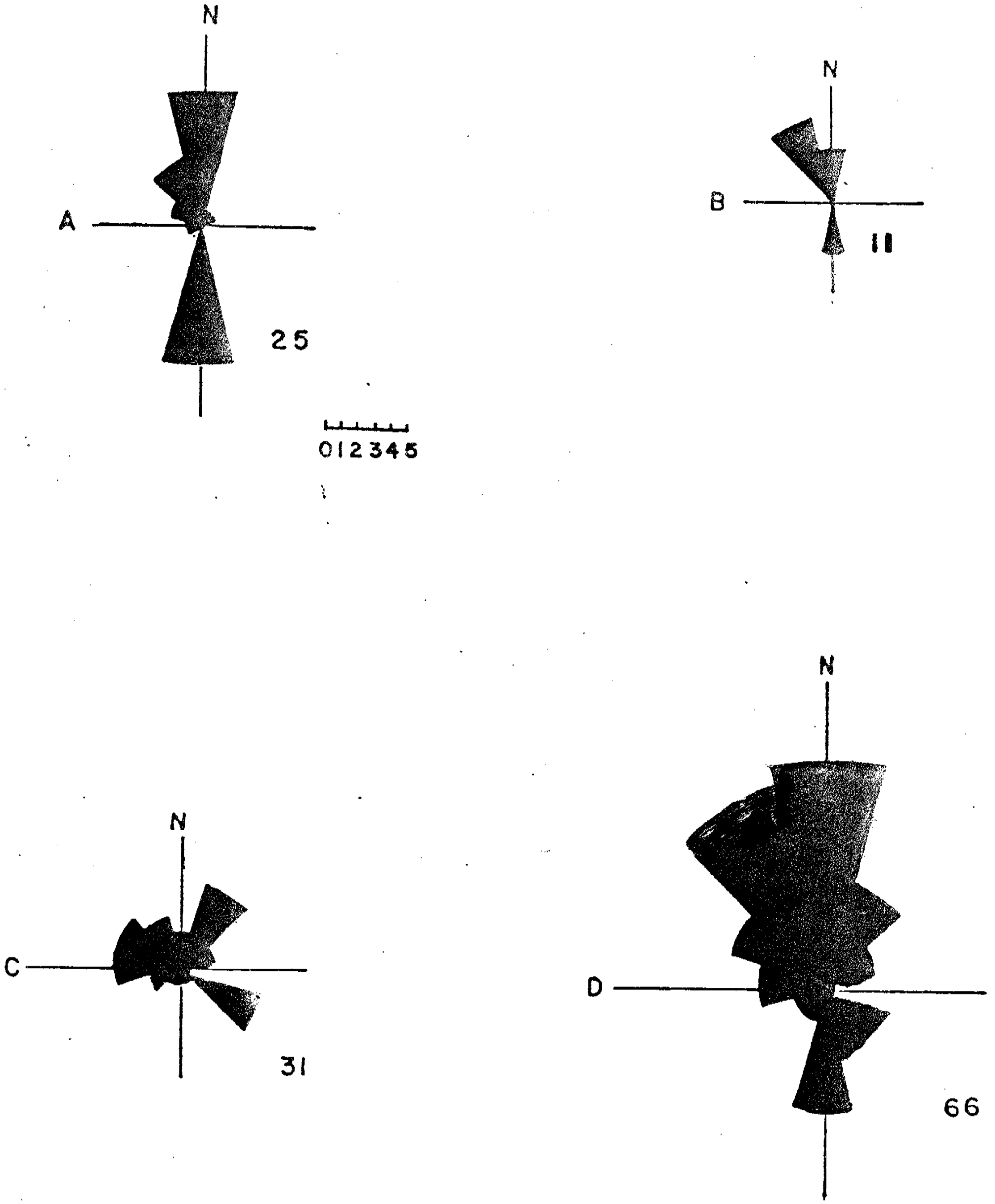


Figure 12. Paleocurrent Rose Diagrams From Atarque Member
A) From Section III, south of Cibola Canyon
B) From Section II, south of Cibola Canyon
C) From Section I, north of Cibola Canyon
D) Composite rose diagram
Number in low right quadrant indicates number of measurements.

and others, in press).

The entire Carthage Member is exposed north of Cibola Canyon and east of Arroyo los Alamos. The Carthage Member has a sharp contact with the underlying Atarque Sandstone Member of the Tres Hermanos Formation. The Carthage Member in the study area is up to 150 ft (46 m) thick and consists of sandstones interbedded with shale and coal (see Plate 2).

The portion below the coal is composed of very friable to moderately indurated, fine-grained, moderately sorted, pale yellowish-orange (10 Yr 8/6), medium bedded sandstones. Locally the sandstones are abundantly bioturbated and contain shale partings. The sandstones are interbedded with medium gray (N 5) shales. Local lenses of Crassostrea soleniscus (Meek) also occur. Several beds contain small-scale, tabular-shaped sets of low-angle planar cross-laminations with nonerosional lower contacts.

Coal is present as two thin, 4-inch (10 cm) seams (NE 1/4, SE 1/4, sec. 17, T. 1 N., R. 2 E.) in the area north of Cibola Canyon. The coal occurs 29 ft (8.84 m) above the base of the Carthage Member. Directly below the coal is a 6-inch (15 cm)-thick sandstone which contains abundant carbonaceous material. Between the coal seams are carbonaceous shales and grayish-yellow (5 Y 8/4) sandstones. The sandstone above the lower coal is medium to thick bedded with medium-scale, wedge-, tabular- and trough-shaped (Figure 13) cosets of low-angle planar cross-beds with erosional lower contacts. Paleocurrent directions measured

Figure 13. Photograph of medium-scale, trough-shaped set of low-angle tangential cross-beds in Carthage Member, south of Cibola Canyon. Rock hammer 27.5 cm (11 in) long.

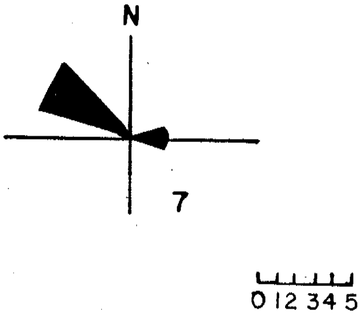


Figure 14. Composite paleocurrent rose diagram of Carthage Member. Number in lower right quadrant indicates number of measurements.

from this unit are shown as a paleocurrent rose diagram in Figure 14.

Directly above the coal is a very silty shale that contains rip-up clasts of carbonaceous material. Sandstones above the coal are friable, fine- to medium-grained, and poorly sorted. Fossilized wood is present throughout the sandstones. Above the coal is medium gray (N 5) to grayish yellow (5 Y 8/4), silty shale. Lenses of moderate yellow (5 Y 8/6) ferruginous material occur in the shale. The shale is interbedded with grayish-yellow (5 Y 8/4) sandstones, 3 to 6 ft (.90-1.8 m) thick. The sandstones are friable to moderately indurated, fine-grained and well-sorted, with carbonaceous material. The upper most portions above the coal consist of medium gray (N 5) shales. The shale coarsens upwards to silty shale.

Fite Ranch Sandstone Member

The Fite Ranch Sandstone Member of the Tres Hermanos Formation is named after Fite Ranch, which is about one mile west of Carthage, New Mexico. The type section is nearby in the NE 1/4 NE 1/4 of section 17, T. 5 S., R. 2 E (Hook and others, in press).

The Fite Ranch Sandstone Member is the most extensively exposed unit in the the study area, being repeated by faulting several times in the area east of Arroyo los Alamos. The contact of the Fite Ranch Member with the underlying Carthage Member of the Tres Hermanos Formation is gradational (Figure 15). The thickness of the Fite Ranch Member is up to 65 ft (19.8 m).

The lower units of the Fite Ranch Member are composed of very friable, very fine-grained, moderately sorted, light gray (N 7) sandstones. The calcareous sandstones locally contain carbonaceous material. Abundant calcareous fine-grained sandstone concretions whose diameter averages 28 inches (70 cm) are present. Some larger concretions have grown around smaller ones.

The remainder of the Fite Ranch Member except the highest unit consists of friable, very fine- to fine-grained, poorly sorted (with improving sorting upward), calcareous, dusky yellow (5 Y 6/4) to grayish-orange (10 YR 7/4) sandstones. White mica grains and red, purple and yellow staining occur locally. Goethite nodules occur as replacements of pyrite. The next to the highest unit is a well indurated, fine-grained sandstone and forms a distinctive and persistent stratigraphic marker bed. Bioturbation, wood fragments, and Thalassinoides (Figure 16) are abundant locally. The Thalassinoides is characterized by an oval cross section which ranges from 1/4 to 1/2 inch (.7-1.5 cm) in diameter. The outer surface of the burrows is smooth to irregular. The burrows are most apparent on stratification planes where they are randomly oriented. The burrows bifurcate at oblique to right angles and are enlarged at the point of bifurcation. Vertical burrows form

Figure 15. Photograph of Fite Ranch Sandstone Member south of Cibola Canyon.

Figure 16. *Thalassinoides*, rock hammer 11 inches (27.5 cm) long.

Figure 17. Vertical burrow, Brunton Compass 2.5 inches (7 cm).

resistant unit that protrude out of the rock similar to a stalagmite (Figure 17). Sparse fossil shark teeth and shell fragments are found in the upper units. In the exposures of the Fite Ranch Member north of Cibola Canyon, *Lopha bellaplicata* (Shumard) was found just below the highest unit. Large-scale, tabular-shaped sets of low-angle planar cross-beds with nonerosional lower contacts are present in the upper units.

The highest unit in all areas is a yellowish-gray (5 Y 8/4) sandstone that is very friable, fine-grained, moderately sorted, and calcareous. In most places the highest unit occurs only as a sandy, mostly covered interval. Fossils collected as float from this unit include *Lopha bellaplicata* (Shumard), *Ptychodus whipplei* Marcou, *Lamna semiplicata* Agassiz, skeletal fragments, and nodules as replacements of gastropods and pelecypods. The nodules contain carbonate apatite ($Ca_{10}(Po_4)_6(Co_3)\ H_2o$) (North, personal communication, 1981).

D-Cross Shale Tongue

The D-Cross Shale Tongue of the Mancos Shale was first described by Dane and others (1957) for exposures at D Cross Mountain, Socorro County, New Mexico. The D-Cross Shale Tongue is defined as the shale body between the Gallego Sandstone Member of the Gallup Sandstone and the lower part of the Gallup (Tres Hermanos Sandstone Member of the Mancos

Shale). The age of the D-Cross Shale Tongue in the study area based on fossil evidence is late Turonian to Coniacian (Hook, personal communication, 1981). The D-Cross Shale Tongue is present north and south of Cibola Canyon.

The D-Cross Shale Tongue in the study area is informally divided into a lower part of the D-Cross Shale Tongue below a fossiliferous sandstone marker bed, and the upper part of the D-Cross Shale Tongue (Figure 18) between the marker bed and the main Gallup Sandstone. The D-Cross Shale Tongue has a sharp contact with the underlying Fite Ranch Sandstone Member. The lower part of the D-Cross Shale Tongue is 210 ft (63 m) thick and above the marker bed the upper part of the D-Cross Shale Tongue is 150 ft (46 m) thick.

At the basal contact of the lower part of the D-Cross Shale Tongue are beds that are lithologically similar to and contain fossils typically found in the Juana Lopez Member of the Mancos Shale at its reference section near La Ventana, New Mexico (Dane and others, 1966). The Juana Lopez equivalent beds in the study area consist of two calcarenites separated by a silty, light gray (N 7) to medium gray (N 5) shale, 3 ft (90 cm) thick. The thickness of the calcarenites ranges from 6 inches (15 cm) to 1 ft (30 cm). The fine-grained calcarenites are pale yellowish brown (10 YR 6/2). The dark yellowish-brown (10 YR 2/2) weathering calcarenites form hard, brittle, thin bedded, resistant layers. Fossils in the Juana Lopez equivalent

Figure 18. Photograph of contact between the D-Cross Shale Tongue and the fossiliferous sandstone marker bed in the D-Cross Shale Tongue, south of Cibola Canyon.

beds include *Archohelia dartoni* Wells, *Scaphites warreni* Meek and Hayden, *Prionocyclus wyomingensis* Meek, *Inoceramus* sp., *Ptychodus whipplei* Marcou, and bone fragments.

The remainder of the lower part of the D-Cross Shale Tongue consists of medium gray (N 5) shale that lightens upward to pale yellowish-brown (10 YR 6/2) silty shale. The shale becomes interbedded with sandstone near the top of the lower part of the D-Cross Shale Tongue. Concretions form a stratigraphic horizon 40 ft (12.20 m) above the base of the D-Cross Shale Tongue. The concretions are 1 ft (30 cm) in diameter, calcareous, and septarian in nature. Ammonites or brown calcite often are incorporated in the concretions. The concretions contain *Prionocyclus novimexicanus* (Marcou) (see Appendix C), *Scaphites* sp., *Inoceramus* sp., and fossilized wood. Burrows in the lower part of the D-Cross Shale Tongue are characterized by long curved tubes with a diameter of 1/8 to 1/2 inch (.3-1.5 cm) (Figure 19). The outer surface of the burrow is smooth to irregular. In the field, the burrows often break into approximately 1 inch (2.5 cm) segments and are generally not related to stratification. This type of burrow is found only in the lower part of the D-Cross Shale Tongue of the Mancos Shale south of Cibola Canyon. A horizon of very fine-grained, calcareous, sandstone concretions with 3 ft (90 cm) diameters occurs 28 ft (8.5 m) below the base of the fossiliferous sandstone marker bed in the D-Cross Shale Tongue.

Figure 19. Curved burrows found in lower part of D-Cross Shale Tongue.

The fossiliferous sandstone marker bed in the D-Cross Tongue is up to 10 ft (3 m) thick in the study area and is composed mostly of large concretions, 6 ft (1.5 m) in diameter. Between the concretions are irregular laminated sandstones. The moderate yellowish-brown (10 YR 5/4) sandstones are friable to moderately indurated, very fine-grained, moderately sorted, calcareous, and coarsen upward. Nodules in the marker bed are dark reddish brown (10 R 3/4) and are more indurated than the surrounding sandstone. These nodules are spherical to ellipsoidal in shape and exhibit internal concentric banding. Local fossiliferous lenses contain Lopha sannionis (White), Forresteria sp., Baculites yokoyamai Tokunaga and Shimizu, gastropods, and pelecypods. Abundant Fucusopsis (Figure 20) is present on the upper contact of the marker bed.

The cross-bedding in the surrounding sandstones consists of medium-scale, wedge- and trough-shaped sets of high-angle tangential cross-beds with erosional and nonerosional lower contacts. The highest unit in the marker bed consists of small- to medium-scale, wedge-shaped sets of low-angle tangential cross-beds with erosional and nonerosional lower contacts. Figure 21 shows a paleocurrent rose diagram made from the paleocurrent directions collected from these cross-beds. Some symmetrical ripple marks are also present.

Figure 20. <u>Fucusopsis</u>, Brunton Compass 2.5 inches (7 cm).

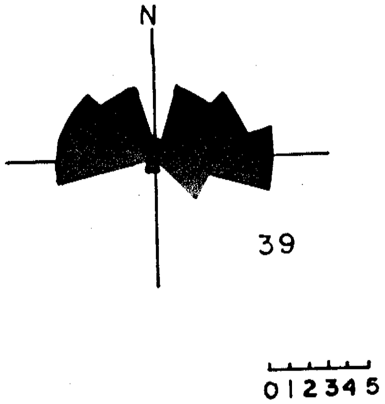


Figure 21. Composite paleocurrent rose diagram of fossiliferous marker bed. Number in lower right quadrant indicates number of measurements.

The upper part of the D-Cross Shale Tongue consists of medium gray (N 5) shale. The shale coarsens into silty shale and interbedded sandstones near the top of the tongue. Concretions in the upper part of the D-Cross Shale Tongue are calcareous and weather dark yellowish orange (10 YR 6/6). Fossils contained in the upper part include *Lopha sannionis* (White), *Inoceramus* sp., gastropods, and pelecypods.

Mesaverde Group

The Mesaverde was described first by Holmes (1877) for exposures in the valley of Rio San Juan of western Colorado and northwestern New Mexico. Cross and Spencer (1854) later redefined it as a formation. After consulting the U.S. Geological Survey Allen and Balk (1954) raised the Mesaverde Formation to the rank of a group. The Mesaverde Group consists of from oldest to youngest Gallup Sandstone, Crevasse Canyon Formation, Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone.

Gallup Sandstone

The Gallup Sandstone of the Mesaverde Group was named by Sears (1925) for exposures in the vicinity of Gallup, New Mexico of three massive sandstones. Because of the intertonguing nature of the Gallup Sandstone with the Mancos

Shale, regional correlations have been difficult and in the past these units have been miscorrelated. Molenaar (1973) correlated the Gallup Sandstone and its tongues by putting informal letter names on the sandstone tongues. Hook and others (in press) are now updating these correlations using the same terminology. The term Gallup Sandstone is used for the highest marine sandstone below the nonmarine deposits in the Mesaverde Group. The Gallup Sandstone in the study area is difficult to distinguish from the overlying Crevasse Canyon Formation. The lithology of the two units is similar, with only isolated fossiliferous lenses occurring within the Gallup Sandstone. The Gallup Sandstone is present north and south of Cibola Canyon.

The Gallup Sandstone has a gradational lower contact with the underlying D-Cross Shale Tongue of the Mancos Shale. The thickness of the Gallup Sandstone in the study area ranges from 14 ft (4.27 m) to 27 ft (8.23 m). The Gallup Sandstone (Figure 22) in the study area consists of light gray (N 7) to yellowish-gray (5 Y 8/1), friable to moderately indurated, very fine- to fine-grained, poorly sorted sandstones. The sandstones contain sparse shale partings and wood fragments. Local fossiliferous lenses contain Lopha sannionis (White), gastropods and pelecypods.

Cross-stratification consists of small- and medium-scale, wedge- and tabular-shaped sets of low-angle tangential cross-beds with erosional and nonerosional lower contacts. Paleocurrent directions collected from these

Figure 22 Photograph of gradational contact between the upper part of the D-Cross Shale Tongue and the Gallup Sandstone, overlain by piedmont gravel, south of Cibola Canyon

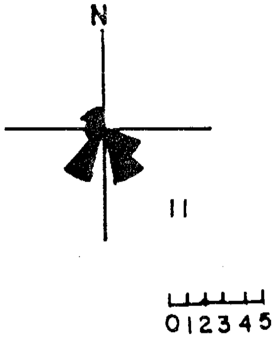


Figure 23 Composite paleocurrent rose diagram of Gallup Sandstone. Number in lower right quadrant indicates number of measurements.

cross-beds are shown in Figure 23 as a paleocurrent rose diagram.

Crevasse Canyon Formation

Allen and Balk (1954) defined the Crevasse Canyon Formation of the Mesaverde Group, for exposures in a north fork of Catron Creek about 3 miles southwest of the mouth of Crevasse Canyon near Gallup, New Mexico. Beds in the study area correlative with the Crevasse Canyon Formation and are probably equivalent to the basal Dilco Coal Member of the Crevasse Canyon Formation. The Dilco Coal Member was named by Sears (1925) at the Dilco Mine near Dilco, New Mexico. The Crevasse Canyon Formation is present north and south of Cibola Canyon.

The Crevasse Canyon Formation in the study area is unconformably overlain by the Tertiary Baca Formation (Figure 24). It has a gradational lower contact with the underlying Gallup Sandstone. The Crevasse Canyon Formation in the study area is up to 108 ft (33 m) thick.

The basal units of the Crevasse Canyon Formation in the study area are very friable, very fine-grained, poorly sorted, dark reddish-brown (10 R 3/4) to pinkish-gray (5 YR 8/1) sandstones. The sorting improves and the grain size coarsens upward. Small- to medium-scale, wedge-shaped sets of low-angle tangential cross-beds are present. The middle unit below the coal seams consists of shales with

Figure 24. Photograph of Crevasse Canyon Formation consisting of sandstone and carbonaceous shale, overlain by Tertiary Baca Formation, north of Cibola Canyon.

interbedded very fine-grained thin laminated sandstones, 4 inches (10 cm) thick. The shales are brownish gray (5 YR 4/1) with abundant carbonaceous material and some fossilized wood. Abundant lenses of moderate yellow (5 Y 8/6) ferruginous material occur in the shales. Fractures in the shales are filled by secondary gypsum forming boxwork structures. The interbedded sandstones are moderately indurated, very fine- to fine-grained, moderately sorted, and calcareous.

Two coal seams, 6 inches (15 cm) and 1 foot 2 inches (35 cm) thick, occur 56 ft 7 inches (17.25 m) above the base of the Crevasse Canyon Formation. The units above the coal seams are composed of sandstones with two interbedded carbonaceous, light gray (5 YR 6/1) to medium gray (N 5) shales. The sandstones are grayish orange (10 YR 7/4), moderately to well indurated and very fine-grained with moderate sorting. The interbedded shales are 10 ft (3 m) and 8 ft (2.40 m) thick. A medium gray (N 5) limestone bed occurs 12 ft (3.70 m) above the coal. The blackish red (5 R 4/2) limestone is 6 inches (16 cm) thick. The highest two sandstones (Figure 25) both contain Flemingostrea aff. prudencia and with Crassostrea soleniscus (Meek) (see Appendix C) in the highest sandstone. The lower sandstone has irregular laminations. South of Cibola Canyon straight-crested asymmetrical ripple marks are present.

Figure 25. Photograph of fossil-bearing sandstone in the upper part of the Crevasse Canyon Formation, north of Cibola Canyon. Distance between tick marks 4 inches (10 cm).

Figure 26. Photograph of twenty-five foot long fossilized log in Crevasse Canyon Formation, south of Cibola Canyon. Rock hammer 11 inches (27.5 cm) long.

Fossilized wood is present throughout the Crevasse Canyon Formation. One log found in the Crevasse Canyon Formation is 25 ft (7.65 m) (Figure 26) long with its long axis oriented northeast-southwest. A fossilized stump south of Cibola Canyon contains fossilized roots that grow in the stump. Fossilized wood in the carbonaceous shale below the coal seams contains carbonaceous material with a black (N 1) color that weathers very pale orange (10 YR 8/2).

TERTIARY AND QUATERNARY UNITS

Baca Formation

Wilpolt and others (1946) designated the basal 648 ft (208.50 m) of Winchster´s (1920) Datil Formation as the type section for the Baca Formation. The type section was measured in Baca Canyon near Bear Mountain, Socorro County, New Mexico. Elston (1976) abandoned the use of the Datil Formation and separated it into several formations including the basal Baca Formation. Gardner (1910) and Wolberg (personal communication, 1981) have found several fossil teeth that date part of the Baca Formation at Carthage, New Mexico to be Bridgerian (middle Eocene) age. The Baca Formation is exposed along the western edge of the study area.

The Baca Formation in the study area consists of coarse unsorted conglomerates, red and gray sandstones, and red to gray shales (Figure 27). The conglomerates contain abundant pebbles, cobbles, and boulders of Carboniferous (?) limestone, Permian (?) sandstones, and quartzites (Wilpolt and Wanek, 1946). The dark yellowish-brown (10 YR 5/4) to moderate brown (5 YR 3/4) sandstones are very friable to moderately indurated, very fine- to fine-grained and moderately sorted. Two-feet (61 cm)-diameter sandstone concretions occur in these sandstones. Ironstone concretions and iron oxide staining is abundant throughout

Figure 27. Photograph of Tertiary Baca Formation consisting of shale, sandstone, and conglomerate, south of Cibola Canyon.

the sandstones. Fossilized wood is present and is preserved by iron oxide minerals. The shales range in color from pale pink (5 RP 8/2) to medium light gray (N 6). Cross-stratification consists of medium scale, tabular-shaped sets of low angle planar cross-beds with nonerosional lower contacts.

Spears Formation

The Spears Ranch Member of the Datil Formation was initially named by Tonking (1957). Tonking's type section was measured near Puertecito, Socorro County, New Mexico. Chapin (1971) raised the Spears Ranch Member to formation status. The Spears Formation is exposed only north of Palo Duro Canyon in the study area.

The Spears Formation in the study area consists of a sandstone that is composed almost entirely of very angular volcanic debris. The sandstone is moderately indurated, fine- to coarse-grained, very angular, very poorly sorted, and is very light gray (N 8). The individual grains consist of quartz, biotite, hornblende, and lithoclasts of tuff. Concretions occurring in the Spears Formation have clasts of highly altered tuff in their centers. The clasts are pale pink (5 RP 8/2) with phenocrysts of hornblende, feldspar, biotite, and quartz.

Figure 28. Intrusive basaltic andesite dikes along fault in area south of Cibola Canyon. Basaltic andesite dikes also in the background.

Igneous Intrusions

Basaltic andesites occur locally as dikes. In the area south of Cibola Canyon along the southeastern end of the study area basaltic dikes (Figure 28) are intruded along a northeastern trending fault. The Atarque Sandstone and Carthage Members of the Tres Hermanos Formation are cut out of the section at this point by the faulting. This is the largest exposure of basaltic andesite in the study area.

The aphanitic basaltic andesite is extensively weathered and altered to yellow brown minerals. Feldspar laths and calcite occur in gas cavities. The shale and sandstone along the dikes are also altered.

Santa Fe Group

Hayden (1869) described the Santa Fe Formation as marls and conglomerates in the Rio Grande Trough around Santa Fe, New Mexico. Spiegel and Baldwin (1963) formally raised the Santa Fe to group status. The Santa Fe Group is mapped undifferentiated in this study and crops out north of Cibola Canyon. The Santa Fe Group consists of conglomerates cemented by calcareous cement and light red (5 R 6/6) shales with sand- to cobble-size clasts. The overall color of the conglomerates are pale pink (5 RP 8/2). Clasts in the conglomerate range from sand- to boulder-sized, and are predominantly limestones and sandstones with some quartzites and schists. The Santa Fe Group in the study area unconformbly overlies Upper Cretaceous strata with 3 ft 6 inches (1.1 m) of shale, overlain by the conglomerate that coarsens upward.

Piedmont Gravel

In the area south of Cibola Canyon piedmont gravel caps the top of the mesa. The piedmont gravel unconformably overlies Upper Cretaceous strata and is 30 ft (9.14 m) thick. The bottom 10 ft consists of pale red (10 R 6/2) loosely consolidated clay. The piedmont gravel consists of limestone, red sandstone, and Upper Cretaceous sandstone clasts of pebble- to cobble-size that coarsen upward. The top of the piedmont gravel is cemented by caliche.

Alluvium

Quaternary alluvium consists of flat-lying deposits of red and yellow sand, gravel and mud which are loosely consolidated. The alluvium occurs as basin fill in the Valle del Ojo de la Parida. These deposits are derived from the surrounding Santa Fe Group, Baca Formation, Dockum Formation, and Upper Cretaceous strata. Recent channels contain alluvium composed of reworked sediments.

Colluvium

Active talus slopes and stabilized colluvium are widespread in the study area. The colluvium is related to areas capped by the Santa Fe Group and piedmont gravel. In general, these deposits were only mapped where they obscured geologic contacts or structure.

STRUCTURE

Regional Setting

The study area is located along the eastern margin of the Rio Grande Rift, bounded by the Albuquerque basin on the north, the Los Pinos uplift on the east, and the Joyita Hills on the west. The structure is complex, reflecting Pennsylvanian faulting trends as well as Laramide trends and Rio Grande Rift related tectonic activity.

The Joyita Hills are a complex tilted horst, bordered by the west and east Joyita faults along the Rio Grande graben. The Wolfcamp Joyita uplift was a major uplift centered in the Joyita Hills area and was flanked by depositional basins to the east and west (Kottlowski and Stewart, 1970). The Joyita Hills was also a high during the deposition of the Abo and Yeso Formations (Kottlowski and Stewart, 1970).

Regional extension and development of the Rio Grande Rift occurred from 32 m.y. ago to present (Chapin and others, 1978). The rift began with extension along major north trending zones of weakness (Chapin, 1976). In the Socorro-Magdalena area the rift broadens into a series of parallel basins and intrarift horsts, bounded by normal faulting. Post-Baca erosion removed Upper Cretaceous strata from the surrounding area except in the Valle Del Ojo De La Parida where it is present today (Wilpolt and others, 1946).

Faulting

All faults in the study area offset Triassic, Cretaceous and Tertiary strata, and are largely covered by the Santa Fe Group and Quaternary deposits. Faults in the study area generally trend northwest or northeast. The northwest trending faults may be rejuvenated Pennsylvanian structural breaks (Chamberlin, personal communication, 1981). The faults trending northeast are normal faults related to tectonic activity along the Rio Grande Rift. The northeast trending faults are nearly vertical and the northwest trending faults dip at relatively low angles.

In the area northwest of the Los Pinos Mountains, there is a fault trending N45°E a throw of approximately 370 ft (112.78 m). Most of the Rio Salado Tongue of the Mancos Shale, and the Atarque Sandstone and Carthage Members of the Tres Hermanos Formation are faulted out. A low angle fault trends N30°W (probably dipping southwest) and offsets beds across strike giving a right-lateral sense of displacement. The N80 W trending faults are offset by the N45°E trending fault.

In the northwestern end of the area south of Cibola Canyon a fault trending N10°W displaces beds of the lower part of the D-Cross Shale Tongue of the Mancos Shale against beds below the coal in the Crevasse Canyon Formation. Further southeast the Fite Ranch Sandstone Member and part of the Carthage Member of the Tres Hermanos Formation are repeated by northeast trending normal faults. North of Arroyo los Alamos and Palo Duro Canyon the Twowells Tongue of the Dakota Sandstone is faulted against the Triassic Dockum Formation.

Folding

The principal fold in the study area is a broad southerly plunging syncline in the Valle Del Ojo De La Parida. The folding is probably Laramide (late Cretaceous to Eocene) in age. In the area south of Cibola Canyon a syncline and a flat-crested anticline are present. The axial trace of the syncline trends N50°E through the Crevasse Canyon Formation. The northwestern flank is composed of repeated fault slices of the Fite Ranch Sandstone Member of the Tres Hermanos Formation. The axial trace of the anticline is N45°E through the Atarque Sandstone Member of the Tres Hermanos Formation.

PETROLOGY

Petrographic Analysis

Petrographic analysis was done using the following aids; 1) Heinrich (1965) for mineral identifications, 2) sorting images from Folk (1968), 3) a chart for visual estimation of roundness from Powers (1953), 4) the thin sections were stained for potassium with sodium cobaltinitrite after etching with hydrofluoric acid vapor, 5) a semiautomatic point-counter was used for percentage of composition using 500 counts per thin section. Five hundred counts per thin section were done to get approximately 400 detrital grain counts. Four hundred grain counts according to Pettijohn and others, (1973) as shown in Figure A-3 (modified from van der Plas and Tobi, 1965) will give a 95% confidence level with a precision varying from 1%+ to 4%+ of the estimations. Results of the point-counting analysis are shown in Tables 2 and 3 which form the basis for the following descriptions of the typical marine and nonmarine sandstones in the study area and their classification according to Folk (1974) (Figure 29). The typical marine and nonmarine sandstone were chosen as represeentive of the most abundant sandstone lithologies in the study area.

TABLE 2

DETRITAL GRAIN COMPOSITION OF SANDSTONE THIN SECTIONS

Percentage of Detrital Grains

			Quartz	K-Feldspar	Plagioclase	Chert	Lithic Fragments	Micas	Opaque Heavy Minerals	Nonopaque Heavy Minerals
	1-3	m	88	3	6	1	tr	tr	tr	tr
	1-7	m	90	2	6	tr	tr	tr	tr	tr
*	1-22	m	74	4	4	15	tr	tr	tr	tr
	1-46	nm	68	3	5	22	tr	tr	tr	tr
	1-66	m	78	7	5	5	tr	tr	tr	tr
	1-94	m	63	7	6	16	2	tr	tr	3
**	1-117	nm	82	1	3	12	tr	tr	tr	tr
	II-18	m	60	4	6	25	1	tr	tr	tr
	III-17	m	88	3	3	4	tr	tr	tr	tr
	III-18	m	83	3	3	9	tr	tr	tr	tr
	III-24	m	88	4	2	tr	tr	tr	tr	tr
	III-25	m	79	5	8	5	tr	tr	tr	tr
	III-28	m	85	3	5	7	tr	tr	tr	tr
	IV-7	nm	70	tr	4	25	tr	tr	tr	tr
	V-1	m	91	4	tr	4	tr	tr	tr	tr
	V-5	m	95	3	tr	3	tr	tr	tr	tr
	V-45	m	81	4	4	9	tr	tr	tr	tr
	V-72	nm	63	5	2	28	tr	tr	tr	tr

tr - less than 1%
n/o - not observed
m - marine sandstone
nm - nonmarine sandstone
* - 28% fossil material
** - 9% organic material

First number of sample is the measured stratigraphic section number and and the second number is the field unit number.

TABLE 3

GRAIN SIZE AND TEXTURE OF SANDSTONE THIN SECTIONS

		Carbonate Cement	Silica Cement	Matrix	Pore Space	% Detrital Grains	Average Grain Diameter (mm)	Sorting	Overall Roundness
1-3	m	n/o	4	13	3	80	.15	moderately	subangular
1-7	m	n/o	tr	9	7	84	.2	well	subrounded
1-22	m	20	1	tr	6	75	.15	moderately	subrounded
1-46	nm	n/o	tr	21	6	73	.08	poor	subangular
1-66	m	tr	tr	25	1	74	.15	well	subangular
1-94	m	tr	1	13	5	82	.15	moderately	subrounded
1-117	nm	tr	tr	14	3	74	.05	moderately	subangular
II-18	m	20	2	7	9	67	.2	moderately	subrounded
III-17	m	n/o	2	17	3	78	.1	poor	subangular
III-18	m	8	n/o	9	3	80	.1	moderately	subangular
III-24	m	29	tr	1	1	68	.25	poor	subangular
III-25	m	tr	tr	11	7	85	.1	moderately	subangular
III-28	m	n/o	3	7	13	77	.2	well	subrounded
IV-7	nm	tr	10	12	20	58	.1	poor	subangular
V-1	m	tr	tr	8	2	89	.2	well	subrounded
V-5	m	3	tr	1	4	90	.3	very well	rounded
V-45	m	29	tr	tr	1	69	.1	well	subrounded
V-72	nm	tr	12	6	2	80	.1	poor	subangular

tr - less than 1%
n/o - not observed
m - marine sandstone
nm - nonmarine sandstone
First number of sample is the measured stratigraphic section number and the second number is the field unit number.

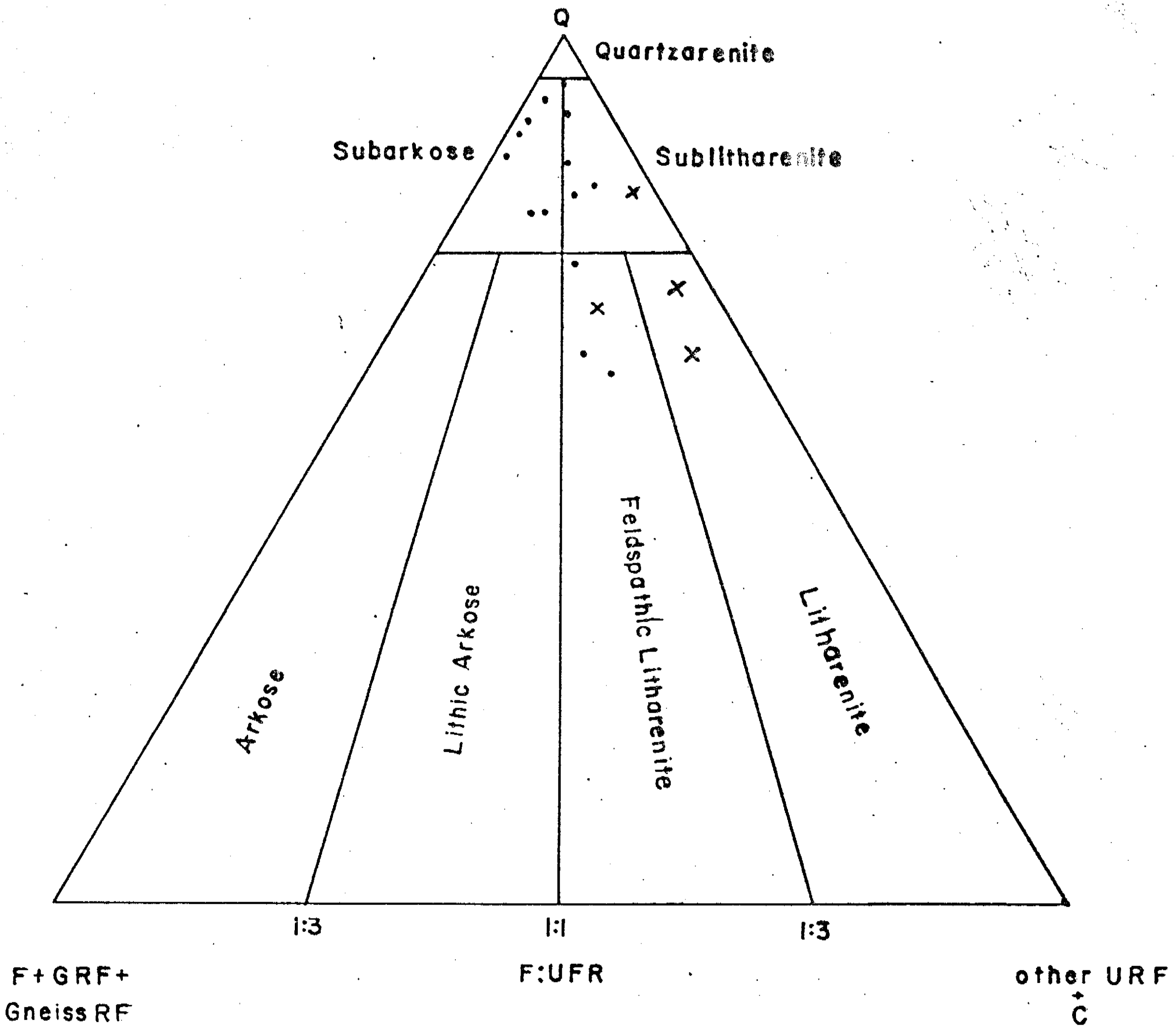


Figure 29. Sandstone classification (Folk, 1974).
• Marine
× Nonmarine

Description of Marine Sandstones

Chosen as typical marine sandstones are samples II-18,III-17, and III-18. Composition and characteristics of sample III-18 are very close to the average of all fourteen thin sections of marine sandstones except for the lack of any silica cement and a finer average grain size. The following description of marine sandstone is based only on these three samples.

Detrital grains average 75% of the rock and range from 67% to 80%. Quartz averages 77% of the detrital grains and ranges from 60 to 88%. The quartz occurs as both monocrystalline and polycrystalline, very fine- to fine-grained sand grains. The quartz grains are in some cases embayed by calcite cement. Inclusions of zircon and tourmaline occur in some quartz grains. Feldspars average 7.3% of the detrital grains and range from 6 to 10%. Potassium feldspars are mostly microcline and average 3.3% and range from 3 to 4% of the detrital grains. Plagioclase feldspars average 4% and range from 3 to 6% of the detrital grains. Alteration of the feldspars is moderate and is mostly to clay minerals. Lithic fragments occur mostly as chert with trace amounts of volcanic clasts. Chert averages 12.7% and ranges from 4 to 25% of the detrital grains. Accessory minerals are zircon, white micas, tourmaline, hematite and magnetite.

3% and range from trace to 5% of the detrital grains. Plagioclase feldspars average 3.7% and range from 2 to 5% of the detrital grains. Alteration of feldspars is abundant, mostly to calcite and clay minerals. Lithic fragments occur mostly as chert. Chert averages 25% and ranges from 22 to 28% of the detrital grains. Accessory minerals are zircon, white and dark micas, magnetite, hematite, and glauconite occurring in trace amounts.

Cement averages about 6% and ranges from 0.0 to 12% of the rock. The cement is typically silica cement (averaging 5.5% and ranging from a trace to 12%. Most of the silica cement occurs as syntaxial rims on quartz grains. Some cherty silica occurs as a precipitate in previously open pores. Pore space averages 13% and ranges from 6 to 21% of the rock. The lack of argillaceous lithic fragments here again is probably related to the formation of pseudomatrix. Matrix averages 13% and ranges from 6 to 21% of the rock. On the average sorting is poor and grains are subangular.

Summary

The marine sandstones contain more abundant polycrystalline quartz grains. Alteration of feldspars is greater in the nonmarine sandstones. The typical nonmarine sandstones contain twice as many chert grains. Cement in the nonmarine sandstones is siliceous but is calcareous in the marine sandstones. The typical marine sandstones are better sorted than the typical nonmarine sandstones.

Clay Mineral Analysis

Clay mineral analysis of shales was done to; 1) identify the clay minerals of the samples by X-ray diffraction, 2) determine the relative proportion of the clay mineral components in each sample, 3) plot variations in types and relative proportions of clay minerals with respect to stratigraphic position, 4) determine if variations found can be used to aid in interpreting depositional environments. Carroll's (1970) paper on X-ray identification of clay minerals is used as the basic reference for the clay mineral analysis of this study.

Twelve representative shale samples were collected from the Upper Cretaceous shales in the study area. Samples as fresh as possible were collected and put in plastic sample bags and sealed. Samples in the lab were crushed to 1/16 inch diameter grain size and disaggregated in a beaker of distilled water. Whole rock slides were made by grinding the sample with a mortar and pestle and sieving with a 200 mesh sieve. All samples flocculated and were boiled in EDTA to remove any carbonates present in the samples. Oriented clay slides were prepared from gravity settled clay fractions less than 8u and 2u. The 8u slides were made to check for detrital feldspars and the removal of carbonates. Three slides of each sample were made of the less than 2u fraction and run on the X-ray diffractometer under the following conditions; 1) air-dried, 2) glycolated for two hours at 60°C, 3) after heating for two hours at 350°C and 550°C.

The slides were scanned from 2° to 40° 2θ. The following instrumental settings were used to obtain the diffraction patterns:

Radiation/Filter	Cu/Ni
Kilovolt/Milliampere	40/20
Counts per second	2500 or 5000
Standard deviation	3%
Time constant	0.1 or 0.2 seconds
Slits	1 -4 -1
Scan rate	2°/minute
Chart drive	1"/minute

Interpretation of the x-ray diffraction patterns show that the samples contain significant amounts of kaolinite, mixed layer clays, illite, and discrete montmorillonite; chlorites are absent. Quartz is also present in significant amount but will not be discussed further.

The method used to calculate the relative proportions of clay mineral components has been modified from Johns and others (1954) by Austin (personal communication, 1981). The method is based on the peak height rather than the peak area and compares the relative proportions of each clay mineral with the total amount of clay minerals present. Calculations are performed following the formulas below.

$T = Ih + Kl$
$I = Ig/T$
$K = Kl/T$
$M = Mg/4/T$
$Mx = Ih/T - I - M$

T = total clay minerals present
Ih = heated illite, peak height at 10 A

Kl = kaolinite, peak height at 7.15 A
Ig = glycolated illite, peak height at 10 A
Mg = glycolated montmorillonite, peak height at 17 A
I = calculated proportion of illite
M = calculated proportion of montmorillonite
Mx = calculated proportion of mixed-layer clays
K = calculated proportion of kaolinite

The calculated proportions are in percentage but are reported as parts per ten. Following the recommendations of Austin and Leininger (1976), results are reported to only one significant figure. Heated samples after removal from the furnace rapidily absorb moisture and this can lead to approximately a 10% loss in peak height and concentration. This however was not considered in this analysis.

Table 4 shows the variations of the proportions of clay mineral components as a function of sample number and stratigraphic position. Samples 1-2 are from the lower tongue of Mancos Shale (Kml) and samples 3-4 are from the Rio Salado Tongue of the Mancos Shale (Kmr). Sample 5 is from directly above the first coal seam in the Carthage Member of the Tres Hermanos Formation (Ktc). Sample 6 was collected above the second coal seam in the Carthage Member. Samples 7-10 are from the D-Cross Shale Tongue of the Mancos Shale (Kmd). The remaining samples were collected from the Crevasse Canyon Formation (Kc); sample 11 from directly below the coal seams, and sample 12 from above the coal seams.

Lateral variations of clay mineral assemblages have been used to aid in interpretation of depositional environments, particularly in the transition from marine to

TABLE 4

Open Marine

Sample Number	K	Mx	I	Mo	Strata
10	7	3	-	-	Kmd
9	6	2	2	1	Kmd
8	3	1	6	-	Kmd
7	4	4	2	-	Kmd
4	4	2	2	2	Kmr
3	2	5	2	2	Kmr
2	4	2	2	2	Kml
1	3	-	2	5	Kml
ave.	4.13	2.38	2.25	1.50	

Marginal Marine - Nonmarine

Sample Number	K	Mx	I	Mo	Strata
12	1	3	1	-	Kc
11	4	2	1	1	Kc
6	4	3	1	2	Ktc
5	4	2	1	1	Ktc
ave.	3.25	2.50	1.00	1.00	

K- Kaolinite
Mx- Mixed-layer Clays
I- Illite
Mo- Discrete montmorillonite

Clay mineral components vs. Environment of Deposition, in parts per ten.

nonmarine depositional environments. Parham (1966) discusses the general trend of clay mineral assemblages with respect to depositional environments compiled from the results of various workers. However direct comparison of the results of this study with the trends found by Parham (1966) is difficult due to the difference in clay mineral species which were studied.

Pryor and Glass (1961) did a study on the Cretaceous-Tertiary clay mineralogy of the Upper Mississippi Embayment. They determined that clays deposited in the fluviatile environment are dominantly kaolinite, those deposited in the inner neritic environment are composed of nearly equal amounts of kaolinite, illite, and montmorillonite, and those in the outer neritic environment are dominantly montmorillonite. The clay minerals in the neritic environment are similar to the mineralogy of the shales in this study.

In a study of modern river sediments, Brown and Ingram (1954) found a decrease of kaolinite and an increase of mixed-layered clays downstream especially at the mouth of the river and the head of the estuary. Brown and others (1977) in a study of Middle Pennsylvanian deltaic deposits found that the transition from marine to nonmarine depositional environments corresponds with a decrease in illite and an increase in kaolinite and mixed-layered clays. The trend of increasing kaolinite inland, indicated by these two studies is also supported by the same trend observed by

Parham (1966).

The trend of increasing kaolinite and mixed-layer clays inland is not seen in this study. The lack of this trend may be due to the lack of continental and fluvial deposits in the study area. Montmorillonite is generally more abundant in shales below the Tres Hermanos Formation in the study area. Illite is less abundant in the marginal marine to nonmarine shales of the Carthage Member of the Tres Hermanos Formation and the Crevasse Canyon Formation than in marine shales of the study area.

Coal

Coal Exposures

The thickest exposure of coal in the study area is in the Crevasse Canyon Formation, north of Cibola Canyon. The coal in the Crevasse Canyon Formation is laterally continuous in the study area. The coal thins south of Cibola Canyon to one seam 6 inches (15 cm) thick. Two thin coal seams are exposed in the Carthage Member of the Tres Hermanos Formation north of Cibola Canyon. The coal in the Crevasse Canyon Formation is exposed in an open slope mine in S 1/2 section 17, T. 1 N., R 2 E. Darton (1928) shows a coal mine on his cross-section of Cibola Canyon and a list of fossils collected by T. W. Stanton as being from above the Garcia y Goebel mine northeast of Socorro. But no positive correlation can be made with this mine and the one found in the study area. The mine in the study area was catalogued by the Abandoned Mine Land Program of the New Mexico Bureau of Mines and Mineral Resources.

In the mine the coal seams are 6 in (15 cm) and 1 ft 2 in (30 cm) thick and are separated by 1 ft (30 cm) of sandy carbonaceous shale (Figure 30 A). The mine is 15 ft (4.5 m) wide, 60 ft (18.30 m) deep with a $20_o - 25_o$ slope. A 13,000 cubic-ft waste pile (65 ft x 40 ft x 5 ft) is present and consists of coal and shale (Figure 30 B). Two hundred yards (182.88 m) southwest of the mine is a trench prospect 15 ft (4.16 m) wide and 25 ft (7.62 m) long and with a 6 ft (1.85

Figure 30. Photograph of Crevasse Canyon Formation coal beds in area north of Cibola Canyon; A) Adit, coal beds dipping at 16 , B) Tailings pile.

m) headwall. Two small pit prospects were also found in the Crevasse Canyon Formation south of Cibola Canyon.

Chemical Analysis

Chemical analyses of the coal were done by Hazen Research Inc. for the New Mexico Bureau of Mines and Mineral Resource´s Coal Group. Coal from the Crevasse Canyon Formation and the two coals in the Carthage Member of the Tres Hermanos Formation were analyzed and are listed in Table 5. The coals are fairly high in ash but show good calorific value.

Economic Potential

The exposures of coal on the Sevilleta National Wildlife Refuge are thin and show no great thickening to the south in the Jornada del Muerto coal field (Tabet, 1979). Exploration drilling, especially to the west of the Upper Cretaceous exposures north of Cibola Canyon, might be carried out to determine if the coal thickens in the subsurface; however faulting in the area may pose a problem.

The Sevilleta Grant now being a national wildlife refuge, is maintained in a totally natural state with no improvements of any kind allowed. This would make any mining or exploration activity difficult, and with the thinness of the coal probably would not be worth undertaking.

TABLE 4

ANALYSES OF COAL SAMPLES FROM SEVILLETA GRANT

	Crevasse Canyon Formation		Carthage Member 1		Carthage Member	
PROXIMATE ANALYSIS (%)	As Received	Dry Basis	As Received	Dry Basis	As Received	Dry Basis
Moisture	12.96	-	14.14	-	6.21	-
Ash	12.72	14.61	47.05	54.80	56.96	60.73
Volatile Matter	36.70	42.17	21.80	25.38	24.83	26.48
Fixed Carbon	37.62	43.22	17.01	19.82	12.00	12.79
	100.00	100.00	100.00	100.00	100.00	100.00
Calorific Value (Btu/lb)	7,651	8,791	3,522	4,101	3,495	3,727
Sulfur (%)	1.10	1.26	0.59	0.69	0.63	0.67
Mineral Matter Free (Btu/lb)	-	10,449	-	10,057	-	10,848
ULTIMATE ANALYSIS (%)						
Moisture	12.96	-	14.14	-	6.21	-
Carbon	48.46	55.68	24.77	28.85	23.54	25.10
Hydrogen	3.04	3.49	0.96	1.12	1.47	1.56
Nitrogen	0.95	1.09	0.48	0.56	0.50	0.53
Chlorine	-	-	-	-	-	-
Sulfur	1.10	1.26	0.59	0.69	0.63	0.67
Ash	12.72	14.61	47.05	54.80	56.96	60.73
Oxygen (difference)	20.77	23.87	12.01	13.98	10.69	11.41
	100.00	100.00	100.00	100.00	100.00	100.00

INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS

Depositional environments are interpreted based on; 1) lithology 2) paleonotogy, 3) sedimentary structures, 4) paleocurrent directions, 5) stratigraphic relationships. The approach of this study is to compare these characteristics with established criteria for recognizing marine and nonmarine depositional environments. Because of the limited exposures in the study area most lateral variations of the strata cannot be determined. However, variations where found in the study area are considered. The interpreted depositional environments are based only on the evidence present in the study area.

Deposition during the Upper Cretaceous in New Mexico occurred in transgressive-regressive cycles with minor cycles within them producing intertonguing of stratigraphic units (Massingill, 1979 and Molenaar, 1973). Figure 31 shows the major transgressive-regressive cycles found in the Upper Cretaceous Series in New Mexico and is compared to the generalized stratigraphic section.

Dakota Sandstone

The lower sandstone in the Dakota is characterized by moderately to well-sorted sandstone that fines upward. The sandstone is extensively bioturbated and contains abundant shale partings, wood fragments, carbonaceous material, and

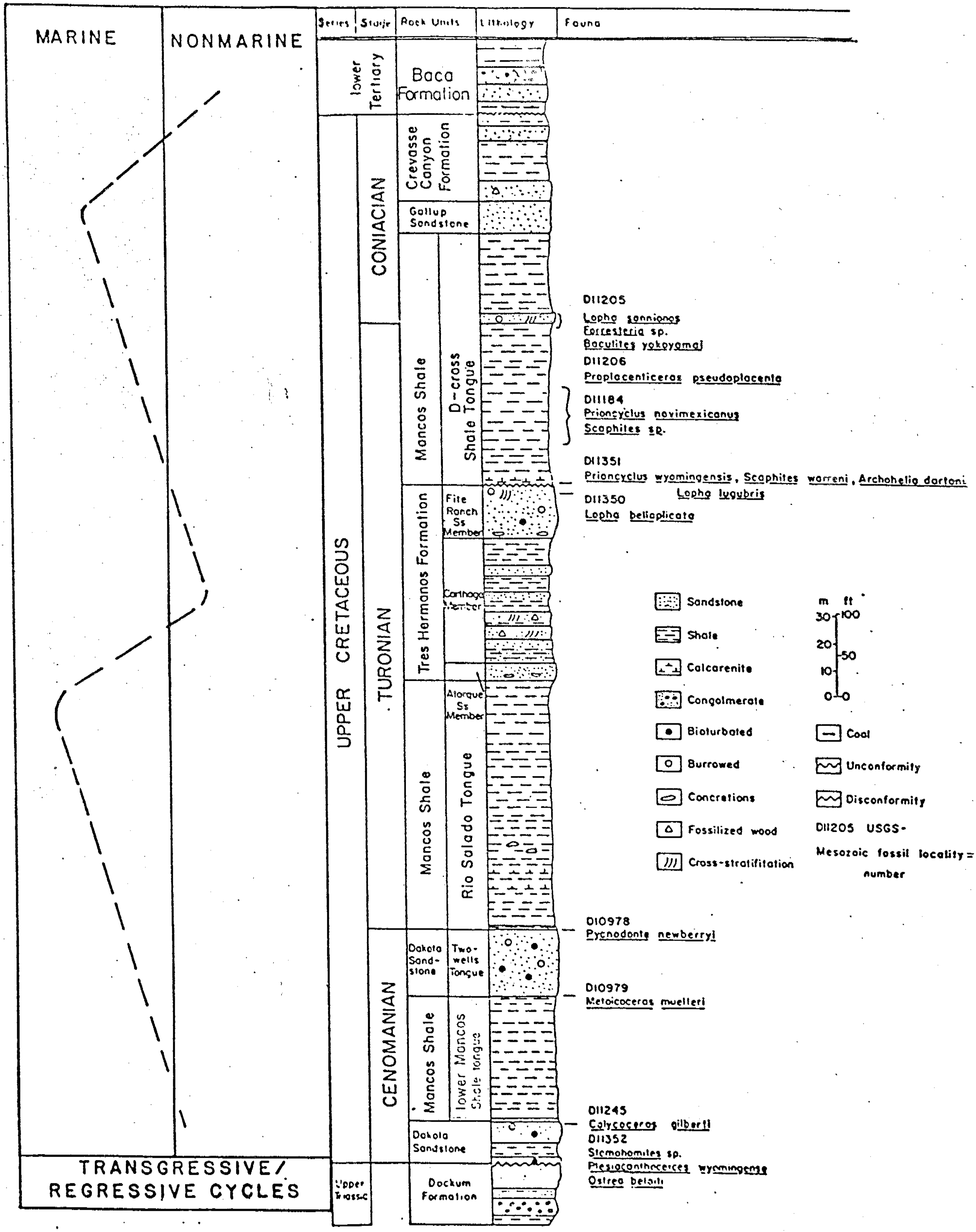


Figure 31. Transgressive-regressive cycles in Upper Cretaceous compared to generalized stratigraphic column of study area.

local pebble conglomerate. The sharp upper contact is overlain by silty shale that separates the lower and upper sandstones. The upper sandstone has a similar lithology to the lower sandstone but is more extensively bioturbated and coarsens upward.

The Dakota Sandstone in the study area has features similar to those displayed by the low energy shelf-beach profile at Gulf of Graeta, Italy (Reineck and Singh, 1975). The sequence at the Gulf of Graeta is divided into seven facies proceeding landward. The shelf-mud contains extensive bioturbation with intercalations of storm-silt layers, laminated and weakly graded. The transition-zone contains extensively bioturbated, very fine-grained sands with almost no primary sedimentation structures. The lower shoreface contains very fine- to fine-grained extensively bioturbated sands with some laminations. The middle shoreface contains burrowed sands with some laminations and ripple cross-bedding. The upper shoreface contains fine- to medium-grained cross-bedded sands with minor bioturbation and laminations. The foreshore contains laminated sands with heavy mineral concentrations. The most shoreward facies is the eolian sand dunes containing cross-bedded sands with plant roots. Overall, the grain size and wave induced structures increase upward (landward), and bioturbation decreases upward (landward). These facies after Reineck and Singh (1975) will be used for comparison throughout the discussion of depositional environments.

The Dakota Sandstone in the study area can be interpreted as being deposited in a nearshore environment during a period of transgression. The lower sandstone is interpreted to have been deposited in a middle shoreface environment with the overlying shale representing an interval of a minor transgressive-regressive cycle. The middle shoreface deposits are indicated by the burrowed sandstone with some ripple cross-bedding. The lower sandstone was probably deposited in a low energy environment as indicated by abundant wood fragments, shale partings, and carbonaceous material. The presence of Thalassinoides is an indicator of a nearshore environment (Frey and Howard, 1970 and Hantzschel, 1962). The completeness of bioturbation is a common characteristic of the most seaward of modern low energy shorezone facies (Moore and Scruton, 1957). The upper sandstone demonstrates aspects of both the lower shoreface and transition-zone of Reineck and Singh (1975), and is here regarded as intermediate to the transition-zone developed in the overlying lower tongue of Mancos Shale. The lower shoreface deposits are indicated by the extensively bioturbated very fine- to fine-grained sandstone. Molenaar (1973) describes lithologically similar units of lower shoreface deposits in the Gallup Sandstone. Molenaar´s (1973) sequence consists of generally flat bedded, very fine- to fine-grained sands with increasing grain size upward. Burrows are common to abundant. Owen (1973) described the Dakota Sandstone of the San Juan Basin

Area, New Mexico as coastal-sandstone units.

Lower tongue of Mancos Shale

The basal part of the lower tongue of Mancos Shale fines upward and consists of thin interbedded shales and sandstones. The sandstones contain fossils, goethite nodules with pyrite centers, and wood fragments. The middle part is characterized by gray shales with interbedded thinly laminated siltstones containing Inoceramus sp. The shale becomes more silty upward. The upper part of the lower tongue of Mancos Shale is composed of interbedded sandstones and shales. The fossiliferous thin bedded nodular sandstones coarsen upward.

The presence of Calycoceras sp. is an indicator of a shallow-water open marine environment (Landis and others, 1973) and Ostrea beloiti Logan indicates shallow-water of normal or near normal salinity (Cobban and Hook, 1981). The presence of Inoceramus sp. is also an indicator of an open water normal marine environment (Sabins, 1963). The lower part is transitional from the underlying lower shoreface sands of the Dakota Sandstone. The lower tongue of Mancos Shale can be interpreted as deposits of a normal transgressive progression from marine transitional-zone muds and silts to offshore marine shelf-muds, and back again to transitional-zone deposits. The transitional-zone is indicated at the base and top of the lower tongue of Mancos

Shale by the gradational change from interbedded very fine-grained structureless sandstones and silty shales to open marine shales. Pyrite is known as a diagenetic mineral in sandstones and implies reducing conditions, presumably reflecting a deoxygenated environment (Berner, 1964). The presence of pyrite nodules in the sandstones probably represents local reduced pockets.

The basal part of the lower tongue of Mancos Shale was deposited in Seboyeta Bay as indicated by the presence of Thatcher age fauna (Hook and others, 1980) and represents an extension of the bay further south and east. Three faunal zones should be found between the ammonites in these beds according to Cobban's (1977a) faunal zones. Hook and others (1980) report Thatcher age fauna 10 ft (3 m) above the base of Dakota Sandstone at D Cross Mountain, Socorro County, New Mexico. At D Cross Mountain there is approximately 70 ft (21 m) of section representing the lower part of the Mancos Shale that occurs between the Thatcher age fauna and the Paguate Tongue (Hook and others, 1980). The proximity of the Oak Canyon Member and the Paguate Tongue age equivalent beds in the study area could be caused in several ways. Faulting could have placed these beds in their current position. However, there is no evidence of omitted beds or fault scarps in this section of the study area. Another possibility, though unlikely, is that the proximity of the index fossils in these beds is because of an extension in the range of one or more of the ammonites involved. The proximity of the Oak Canyon Member and the Paguate Tongue age equivalent beds in the study area probably indicates a disconformity or a period of slow deposition.

Twowells Tongue

The Twowells Tongue consists of fine- to medium-grained sandstones that coarsen and improve sorting upward. The shale content in the sandstones decreases upward. Bioturbation occurs in the lower part. The upper part is characterized by extensively bioturbated sandstone alternating with "clean" non-bioturbated sandstone. The top 29 ft (8.85 m) is a very well-sorted, medium-grained sandstone. The sandstones are very thick bedded with alternating beds of bioturbated sands at the base of the upper part. Marine shales underlie and overlie the Twowells Tongue.

La Fon (1981) describes the Semilla Sandstone Member of the Mancos Shale from the San Juan Basin, New Mexico as an offshore shallow-marine bar. The bar facies is described by La Fon (1981) as a silty-sandstone lower bar facies with extensive burrowing, and a cross-bedded sandstone upper bar facies. The lower facies contains abundant shale partings but very few are present in the upper facies.

The Twowells Tongue is transitional from the underlying open marine lower tongue of Mancos Shale. It has characteristics similar to other barrier sandstones as described by Molenaar (1974), Cotter (1975), and Campbell (1971), but is conformably overlain by marine shale instead of lagoonal deposits as seen in prograding barrier island sequences. The Twowells Tongue can be interpreted as a offshore shallow marine bar. The Twowells Tongue has a lithologically similar sequence to La Fon´s (1981) interpretation of the Semilla Sandstone Member except that the cross-bedding is missing in the upper part and is probably due to uniform composition and diagensis. The lower part of the Twowells Tongue can be interpreted as lower shoreface deposits as indicated by the extensively bioturbated, fine-grained sandstones. The upper part can be interpreted as middle shoreface deposits as indicated by burrowed and bioturbated sandstones that coarsen upward and the decrease in shale partings upward. The lack of sedimentary structures in the Twowells Tongue is compatible with the massive portion of a marine bar (Conybeare and Crook, 1968). The "clean" non-bioturbated sandstones may represent upper shoreface deposits that have been reworked by wave action but show no cross-bedding due to the homogeneity of the sandstones. The coarsening near the top of the bar is consistent with shallower-water deposition caused by building-up of the bar. Dane and others (1971) and Landis and others (1973) interpret the Twowells Tongue regionally to be an extensive, offshore, shallow-water bar sandstone.

This occurrence of the Twowells Tongue raises a question as to its presence in the study area. The Twowells Tongue is present at Puertecito, New Mexico and pinches out at Riley, New Mexico (Massingill, 1979). The Twowells Tongue is not present at Carthage or the Jornada del Muerto coal field (Hook and others, in press, and Tabet, 1979). Three possible explanations are offered here for its occurrence in the study area. The first is that the unit is actually just a lentil in the Mancos Shale and has very similar lithologic characteristics to the Twowells Tongue.

The second explanation is that the shoreline locally changes orientation. In the study area a change in the orientation of the shoreline is indicated in the lower Mancos Shale Tongue by the occurrence of Thatcher age fauna extending Hook and others' (1980) Seboyeta Bay. A change in the orientation of the shoreline is also indicated by the change in lithology and thickness of the Atarque Sandstone Member of the Tres Hermanos Formation within the study area. The extension of Hook and others' (1980) Seboyeta Bay into the study area may have influenced the Late Cretaceous shoreline during the deposition of the Twowells Tongue. The third explanation is that the interpreted offshore bar was oriented so that it passed through the study area and not through the Upper Cretaceous exposures mentioned above. A north-south orientation of the offshore bar may be indicated by the change in thickness and lithology of he Twowells Tongue south of Cibola Canyon. The lack of Upper Cretaceous outcrops surrounding the study area makes it difficult to resolve this question.

Rio Salado Tongue

The basal part of the Rio Salado Tongue consists of gray shales with interbedded fossiliferous siltstones and calcarenites. The remainder of the Rio Salado Tongue is composed of silty shale with local calcareous concretions. Rio Salado calcarenites, similar to those found in the Juana Lopez Tongue of the Mancos Shale in the San Juan Basin, may have been deposited during a period of widespread shoaling in which there was little clastic influx (Hook and others, in press). The presence of <u>Inoceramus</u> sp. is an indicator of open water normal marine environment (Sabins, 1963). The Rio Salado Tongue of the Mancos Shale can be interpreted as having been deposited in the transitional-zone and marine shelf-mud environments as indicated by the transition from interbedded calcarenites and siltstones to marine shales. The Rio Salado Tongue is overlain by regressive sandstones and nonmarine deposits. This represents a change from transgression to regression of the sea in the study area.

The source of the sandstone dike in the Rio Salado Tongue north of Cibola Canyon is probably related to the surrounding shale or the overlying Atarque Sandstone Member of the Tres Hermanos Formation. The underlying Twowells Tongue of the Dakota Sandstone consists of medium-grained, very well-sorted sandstones making it an unlikely source for the fine-grained dike; however, the sandstone dike is not seen to be connected to the Atarque Sandstone Member.

Atarque Sandstone Member

The lower contact of the Atarque Sandstone Member is transitional with the underlying Rio Salado Tongue of the Mancos Shale. The Atarque Member consists of cross-bedded sandstones that coarsen upward. Shale partings and wood fragments are present in the upper part. The thickness of the Atarque Member varies laterally between 11 ft (3.4 m) and 42 ft (12.2 m). The area south of Cibola Canyon contains fossil-rich lenses. The oyster *Crassostrea soleniscus* (Meek) is the dominant invertebrate fossil and is most abundant in the lower lenses. The upper lenses contain dominantly vertebrate fossils, shark teeth being the most abundant.

Davies and others (1971) at Galveston Island, Texas found a distinctive vertical sequence of sedimentary features. They subdivided the sequence from bottom to top into four distinctive units. The lower shoreface sediments were deposited seaward of the break in slope and consist of interbedded, bioturbated, very fine-grained sands, silts, and clayey silts which reach a thickness of 6 ft (1.8 m). The middle shoreface sediments were deposited overlying and shoreward of the lower shoreface sediments. They consist of

10 ft (3 m) to 30 ft (9 m) thick, very fine-grained sands which are extensively bioturbated and have rare sedimentary structures and shale partings. The beach-upper shoreface sediments accumulated gradationally above the middle shoreface and consist of very fine- to fine-grained, well laminated sands with planar cross-lamination. The 3-10 ft (1-3 m) thick sand contains sparse burrows with locally abundant shells. Eolian sediments cap the Galveston barrier and consist generally of cross-laminated sands.

The environments of deposition can be interpreted as barrier-beach to lagoonal-estuarine. The lower part is interpreted as being deposited in a barrier-beach environment. Evidence to support this includes 1) transition from underlying open marine shale, 2) cross-bedding in the basal part, 3) coarsening of grain size upward, and 4) the presence of overlying nonmarine sediments. The cross-bedded eolian facies of Davies and others (1971) is absent in the Atarque Member, and the upper shoreface is poorly developed if it is present at all. The shoreline was probably very digitate and embayed as indicated by the ranges in the thickness and variation of the shoreline sandstone units (Hook and others, in press).

The upper unit represents a lagoonal-estuarine environment. A lagoonal environment is indicated by deposits of very fine-grained, cross-bedded sandstones. The cross-bedded sandstones suggest tidal influence in the lagoon. Pritchard (1967) defined an estuary as "a semi-enclosed coastal body of water which has a free connection with open sea and within which sea water is measurably diluted with fresh water derived from land drainage." The presence of Crassostrea soleniscus (Meek) indicates a brackish water environment when found as the sole fauna (Hook, personal communication, 1981). A warm shallow-water environment is indicated by the abundance and varieties of fauna. The teeth of Ptychodus are well adapted for feeding on benthic mollusks (Wolberg, personal communication, 1981). The presence of the abundant broken shells may be caused by shark feeding. Many of the shark species reported from the study area are related to species found in warm shallow-water environments today (Wolberg, personal communication, 1981). The presence of freshwater fish bones, turtle carapace fragments, reptilian vertebrae, and crocodile teeth suggests an estuarine environment with a nearby freshwater source. The fossil-rich lenses were probably deposited as lag deposits in scours. Rose diagrams of the Atarque Member show a bimodal pattern with bipolar modes oriented approximately north and south (see page 28) suggesting tidal influences. Reineck and Singh (1975) report that small-scale cross-bedding is commonly produced by current ripples on tidal sand flats. The origin of the cross-beds in the upper part of the Atarque Member is probably due to tidal influences and indicates an east-west shoreline in the study area. Regionally Hook and others (in press) interpreted the Atarque Member to have been deposited along a relatively low energy shore with tidal currents being an important depositional process.

Carthage Member

The lower part of the Carthage Member consists of shales with interbedded sandstones. The middle part forms a cyclic sequence. The base of the cyclic sequence consists of cross-laminated sandstone with local lenses of the oyster Crassostrea soleniscus (Meek). The next unit is composed of sandstone that contains fossilized wood and below, a thin coal seam, abundant carbonaceous material. The coal is overlain by carbonaceous shales that contain rip-up clasts and plant fragments. The cyclic sequence is capped by cross-bedded sandstones. This cyclic sequence is then repeated and overlain by carbonaceous shales and interbedded carbonaceous sandstones. The upper part of the Carthage Member is composed of gray shales that are transitional with the overlying marine sandstones of the Fite Ranch Sandstone Member of the Tres Hermanos Formation.

Lagoonal deposits are characterized by the interlayering of lagoon muds, sand derived from the barrier island, and sediments derived from the land. The sand layers of a lagoon may exhibit wave ripples on bedding surfaces and internally are either horizontally laminated or wave-ripple cross-laminated. Lagoonal deposits may be extensively bioturbated, and may contain peat, oyster reefs, abundant shells, or evaporites (Dickinson and others, 1972 and Reineck and Singh, 1975). Berryhill and others (1969) report that lagoonal sediments generally occur as organic and calcareous muds which interfinger with barrier-island sands; the fauna is less diverse than that of the open sea and unbroken shells are abundant. Subaqueous shale and siltstone deposits are commonly characterized by brackish water macroinvertebrate shells (Berryhill and others, 1969).

Lagoonal environments are composed of many interrelated subenvironments such as lagoonal pond, tidal flats along the margins of the lagoon, washover fans, and distal splays. Various workers recognize these subenvironments based on their geometry, vertical succession, and other criteria listed below. Lagoonal ponds accumulate gray to brown shales and siltstones with some burrows and brackish water oysters. Tidal flat deposits are silty shales and sands with some small-scale ripple cross-bedding. Thin, lenticular, ripple-bedded to structureless sands are characteristic of both distal splays and washover fans. Distal splay deposits are poorly sorted, fine- to medium-grained sands. Washover fan deposits are well-sorted, medium-grained, weakly laminated sands. Gaffke (1979) describes washover deposits from the Upper Cretaceous Williams Fork Formation as a layer of abundant broken oyster shells (Crassostrea) in sandy mudstone. The mudstone grades upward into fine-grained, planar laminated sandstone. Disseminated carbonaceous material and imprints of plant remains are common in some shale beds, indicating the interfingering of proximal marsh and subaqueous lagoonal environments (Reinson, 1980).

Reinson (1980) describes characteristics similar to those described above in the Carthage Member as occurring in a lagoonal environment including 1) thin coals usually accumulating on sands along the lagoonal margins, 2) washover sheet sand deposits, 3) sheet sands of flood-tidal origin and 4) fine-grained facies that include those of subaqueous lagoon and tidal flats. Stabilization by marsh vegetation on washover flats can lead to the development of very thin coal lenses overlying organic-rich sandstones (Reinson, 1980).

The Carthage Member can be interpreted as having been deposited in a shallow lagoonal-swamp environment. The cyclic part of the Carthage Member can be interpreted as marsh-tidal flats deposits associated with a lagoonal environment. Evidence to support this includes 1) transition from the underlying barrier-beach deposits of the Atarque Member of the Tres Hermanos Formation, 2) interbedded silty shales and sandstone with some small-scale cross-bedding, 3) organic-rich shales, 4) abundant fossilized wood, and 5) lenses of broken brackish water oyster shells. The fossiliferous sandstone that occurs below the first coal seam has a vertical sequence similar to the washover deposit described by Gaffke (1979) as indicated by shales grading upward into very fine- to fine-grained, laminated sandstones and capped by a layer of abundant broken Crassostrea. Coal was probably developed on stabilized washover flats as indicated by the underlying organic-rich sandstone. The cross-bedded, fine- to medium-grained sandstone above the coal seams may represent a tidal delta but cannot be fully recognized because of lack of exposures. Masters (1967) describes a tidal delta with similar characteristics as cross-bedded sandstone with bipolar orientation implying tidal current movement. A tidal delta is indicated by the abrupt change from carbonaceous shales to cross-bedded sandstone. The abundant fossil wood in this sandstone suggests quick burial. Lower sulfur content in the coals (see Table 5 page 77) suggests a greater influence of fresh versus marine water (Stach and others, 1975). Paleocurrent data from the cross-bedded sandstone is bimodal with bipolar modes and may represent tidal influences. The above described environments could also be found in a tidal dominated delta complex similar to the Niger Delta as described by Oomkens (1974).

The upper part of the Carthage Member is usually deposited as a marine shale (Hook, personal communication, 1980), but the change from nonmarine to marine shales in the study area cannot be determined. Regionally Hook and others (in press) interpreted the Carthage Member as having been deposited on a broad, very low-relief coastal delta plain.

Fite Ranch Sandstone Member

The Fite Ranch Sandstone Member can be divided into two lithologic parts. The lower thick to very thick bedded bioturbated part and the upper cross-bedded, fossiliferous part. Sandstones in the lower part locally contain carbonaceous material and shale partings. The upper part is composed of fossiliferous fine-grained, moderately sorted sandstones with wood fragments, skeletal fragments, and carbonate apatite-bearing replacement nodules of pelecypods and gastropods.

Sequences of sediments which accumulate during transgressions are generally thin and consist primarily of deposits of the shoreface, nearshore, and offshore marine environments (Blatt and others, 1972). Bridges (1976) describes a barrier island in a transgressive sequence from the Silurian as consisting of 1) lagoonal deposits at the base, 2) barrier island sand deposits and 3) open marine deposits, with the barrier sands being thinner than in regressive sequences. This general sequence is found in the Fite Ranch Member except for an interval of possible marine shales in the upper part of the Carthage Member.

The Fite Ranch Sandstone Member of the Tres Hermanos Formation is dominantly composed of prograding coastal sandstones that were deposited during a period of transgression. The Fite Ranch Member accumulated during a transgression as seen by the underlying lagoonal deposits of the Carthage Member and the overlying open marine deposits of the D-Cross Shale Tongue of the Mancos Shale. The presence of *Thalassinoides* indicates a nearshore environment. The lower part is interpreted as lower shoreface deposits as indicated by thick to very thick bedded, extensively bioturbated sandstones. The completeness of bioturbation is a common characteristic of the most seaward of modern low energy shorezone facies (Moore and Scruton, 1957). The upper part is interpreted as middle to upper shoreface deposits as indicated by 1) wedge- and tabular-shaped sets of crossbeds, 2) fossil material and 3) the overlying open marine shales. The Fite Ranch Member has a vertical sequence and characteristics similar to those described by Davies and others (1971) (see page 88) except the capping cross-bedded eolian facies is absent and the upper shoreface is poorly developed if it is present at all.

Lopha bellaplicata (Shumard) is thought to be an open marine oyster (Hook and others, in press). Its presence in the top of the Fite Ranch Member is indicative of the transition into the open marine environment of the D-Cross Shale Tongue of the Mancos Shale. Regionally Hook and others (in press) interpreted the Fite Ranch Member to be a coastal barrier sandstone associated with the overlying transgressive D-Cross Shale Tongue of the Mancos Shale.

D-Cross Shale Tongue

The lower part of the D-Cross Shale Tongue is composed of gray shales with fossiliferous septarian concretions. The basal part consists of fossiliferous calcarenites and calcareous shales. Calcarenites in the Juana Lopez Tongue of the Mancos Shale in the San Juan Basin may have been deposited during a period of widespread shoaling in which there was little clastic influx (Hook and others, in press) and may be the origin of the Juana Lopez equivalent beds in the study area. The lower part of the D-Cross Shale Tongue was deposited during a transgression into an open marine environment as indicated by the transition from the barrier-beach deposits in the underlying Fite Ranch Sandstone Member of the Tres Hermanos Formation to open marine shales.

Scaphites warreni Meek and Hayden and *Prionocyclus wyomingensis* Meek suggest Juana Lopez equivalent beds in the study area are correlative to the upper part of the Juana Lopez Member (Dane and others, 1966). Dane and others (1966) reported that the thickest beds normally occur near the top of the member as massive calcarenite beds and are most common in areas where the member is abnormally thin. The upper unit of the Fite Ranch Sandstone Member of the Tres Hermanos Formation contains *Lopha bellaplicata* (Shumard) which indicates an age older than the Juana Lopez Member (Hook, personal communication, 1981). Nodules as replacements of gastropods and pelecypods also occur in this unit and contain carbonate apatite.

Phosphatized internal molds of bivalves and ammonite chambers have been associated by Hook and Cobban (1981a) with an erosional surface at Carthage and in the Bridge Creek Limestone of the Colorado Formation in the Cooke´s Range of southwest New Mexico. Between the lower contact and the base of the upper part of the Juana Lopez Member there is approximately 100 ft (30.48 m) of section at its reference section. The proximity of the top of the Tres Hermanos Formation and upper Juana Lopez age equivalent beds in the study area indicates a disconformity or a period of slow deposition in the study area. There is no evidence of faulting in this section and extension of the faunal ranges used seems unlikely.

The fossiliferous sandstone marker bed in the D-Cross Shale Tongue can be interpreted as a shallow-water offshore bar deposit. This origin is indicated by 1) the transition from the underlying open marine shale, 2) cross-bedding in the lower part, 3) an upward increase in grain size and sorting, and 4) open marine shale above the bar. The sequence being underlain and overlain by open marine shales is important in distinguishing it as an offshore bar sequence. The presence of Lopha sannionis (White) indicates a shallow-water or nearshore environment (Hook and Cobban, 1981b). The lower part represents lower shoreface deposits as indicated by the gradational change from the underlying transitional-zone deposits up into the cross-bedded sandstones. The upper part represents middle shoreface deposits as indicated by burrowed, cross-bedded sandstone. Paleocurrent data from this unit is bimodal with two modes that are roughly bipolar (see page 42). The east-west bipolar modes probably represent longshore current influences.

The upper part of the D-Cross Shale Tongue is composed of silty shales and coarsens upward into interbedded sandstones near the top of the tongue. The upper part is overlain by coastal sandstone and nonmarine beds. The upper part is interpreted as having been deposited in a shelf-mud to transitional-zone during a period of regression as indicated by open marine shales that are gradational into interbedded sandstones and siltstones.

Gallup Sandstone-Crevasse Canyon Formation

The Gallup Sandstone is gradational into the Crevasse Canyon Formation. Because of difficulty in distinguishing them from each other, they will be considered together when interpreting their depositional environment. The lower part of the Gallup Sandstone-Crevasse Canyon sequence consists of very fine- to fine-grained sandstones gradational with the upper part of the D-Cross Shale Tongue of the Mancos Shale. Sorting increases and the grain size coarsens upward. Locally cross-bedding, concretions and fossiliferous lenses occur.

The middle and upper parts of the Gallup Sandstone-Crevasse Canyon sequence consist of carbonaceous shales, coal seams, and interbedded fine- to medium-grained, very poorly sorted to well-sorted carbonaceous sandstones. Locally ripple marks occur. Individual sandstone beds contain rip-up clasts and shale partings. Thin ironstone beds and ironstone concretions with cone-in-cone structures are present below the coal seams. Fossil wood is present both in the sandstones and the shales. A 4-ft (1.20 m)-thick sandstone occurs above the coal seams, and contains the brackish water oysters _Crassostrea_ _soleniscus_ (Meek) and _Flemingostrea_ _aff._ _prudencia_.

The Gallup Sandstone-Crevasse Canyon sequence can be interpreted as a barrier-beach to lagoonal-swamp sequence. The lower part can be interpreted as having been deposited in a barrier-beach environment. Evidence to support this includes 1) transition from the underlying open marine shale, 2) wedge and tabular cross-bedding, 3) coarsening of grain size and improvement of sorting upward and 4) the presence of overlying nonmarine sediments. This sequence is similar to the one described by Davies and others (1971) at Galveston Island except for the absence of the cross-bedded eolian facies.

The middle and upper part of the Gallup Sandstone-Crevasse Canyon sequence can be interpreted to have been deposited in a lagoon to coastal-swamp environment. Evidence to support this includes 1) transition from underlying barrier-beach deposits, 2) local variations in thickness and lithology, 3) poorly-sorted, very fine-grained sandstones in the basal part, 4) organic-rich shales with coal deposits, and 5) brackish water oyster beds. A swamp environment is also indicated by the presence of ironstone concretion beds with cone-in-cone structures. Ironstone concretions imply a paludal origin (Pettijohn, 1975). The presence of cone-in-cone structures and hematitic beds implies a carbonate association, as cone-in-cone structures normally develop only on muddy carbonates which are, in part, ankeritic or sideritic (Pettijohn, 1975).

Coal deposits in the Crevasse Canyon Formation occur in a coastal-swamp environment at the top of a bayfill sequence. Bayfill sequences have been described by Horne and others (1980), Roehler (1977), and Gaffke (1979). Gaffke (1979) describes a cyclic bayfill sequence from the Williams Fork Formation as 1) shale representing lagoonal bay deposits, 2) thin beds of wavy-laminated siltstones and sandstones representing distal splays, 3) deposits of coal representing a swamp environment, formed on the partially filled lagoonal bay and 4) the coal is overlain abruptly by sandstone representing distal splays. This sequence is very similar to the one found in the study area. In the Crevasse Canyon Formation the abundant carbonaceous shale below the coal represents the transition from the lagoonal bay to coastal-swamp environment. The presence of brackish water oysters in the sandstones above the coal represents a resurgence of the lagoonal pond (bay).

SUMMARY AND CONCLUSIONS

Detailed geologic mapping of Upper Cretaceous strata in the Sevilleta Grant shows more than 1300 ft (400 m) of Cretaceous strata from the Dakota Sandstone to the Crevasse Canyon Formation. The Upper Cretaceous strata rest unconformably on the Triassic Dockum Formation and are overlain unconformably by the Tertiary Baca, Spears, and Santa Fe Formations. Structurally the study area is a southerly plunging syncline and anticline along the eastern edge of the Rio Grande Graben between the Joyita Hills and the southern end of the Los Pinos Mountains.

Depositional environments of the Upper Cretaceous strata were interpreted using lithology, paleontology, sedimentary structures, and paleocurrent directions. The Dakota Sandstone consists of two fine-grained, moderately sorted, bioturbated sandstones separated by 17 feet (5.3 m) of silty shale. The Dakota Sandstone is interpreted as having been deposited in a littoral environment during a period of transgression.

The lower tongue of Mancos Shale is composed of silty, gray shale with interbedded calcareous sandstones. A sandstone in the basal part contains the ammonite *Conlinoceras gilberti* Cobban and Scott (Thatcher age) and is the age equivalent of the Oak Canyon Member of the Dakota Sandstone. Two feet above this sandstone is another lithologically similar sandstone that contains *Ostrea* beloiti Logan, Plesiacanthocerces wyomingense Reagan and is the age equivalent of the Paguate Tongue of the Dakota Sandstone. The proximity of these beds compared to their reference section indicates a possible disconformity or a period of slow deposition in the study area. The lower Mancos Shale was deposited in a transitional zone from nearshore and into an open marine environment. The presence of Thatcher age fauna extends the southeastern edge of Seboyeta Bay into the study area.

The Twowells Tongue of the Dakota Sandstone consists of fine- to medium-grained, well-sorted, bioturbated sandstone. The Twowells Tongue is interpreted as having been deposited as a shallow offshore marine bar. The occurrence of the Twowells Tongue in the study area is not fully understood. The occurrence of the Twowells Tongue in the study area can be explained in three ways, 1) the Twowells Tongue is actually just a lentil in the Mancos Shale with very similar lithologic characteristics to the Twowells Tongue or, 2) it occurs because of a local change in the orientation of the Late Cretaceous shoreline, or 3) the offshore bar itself is oriented so that it passes through the study area. The lack of exposures of Upper Cretaceous strata surrounding the study area makes it difficult to resolve this question.

The Rio Salado Tongue of the Mancos Shale is composed of silty shale with interbedded calcarenites and calcareous sandstones. The basal part of the Rio Salado Tongue is age equivalent to the Bridge Creek Limestone Member of the

Mancos Shale and the presence of *Pycnodonte newberryi* (Stanton) indicates an age of late Cenomanian to early Turonian. The Rio Salado Tongue was deposited in an open marine to transitional zone into nearshore environment.

The Atarque Sandstone Member of the Tres Hermanos Formation consists of very fine-grained, moderately sorted, calcareous, cross-bedded sandstones. The Atarque Member varies laterally and is interpreted as having been deposited in a barrier-beach to lagoonal-estuarine environment.

The Carthage Member of the Tres Hermanos Formation consists of nonmarine sandstones, shales and two thin coal seams. The Carthage Member is interpreted as having been deposited in a lagoonal environment.

The Fite Ranch Sandstone Member of the Tres Hermanos Formation is composed of fine-grained, bioturbated sandstones. The highest unit contains *Lopha bellaplicata* (Shumard) and carbonate apatite-bearing replacement nodules of gastropods and pelecypods. The Fite Ranch Member is interpreted as having been deposited as a barrier-beach sequence during a period of transgression.

The D-Cross Shale Tongue of the Mancos Shale consists of silty shales divided by a fossiliferous sandstone marker bed. The basal part of the D-Cross Shale Tongue contains upper Juana Lopez equivalent beds indicated by *Scaphites warreni* Meek and Hayden and *Prionocyclus wyomingensis* Meek. A disconformity at the top of the Fite Ranch Sandstone Member in the study area is suggested by the age difference between these beds and the top of the Fite Ranch Sandstone Member, and by the presence of carbonate apatite-bearing replacement nodules. The marker bed contains Coniacian age fossils (Lopha sannionis (White), Forresteria sp., and Baculites yokoyamai Tokunaga and Shimizu). This marker bed is interpreted as an offshore marine bar underlain and overlain by open marine shales.

The Gallup Sandstone-Crevasse Canyon sequence is composed of fossiliferous sandstones overlain by nonmarine shales and sandstones with a 1 foot (30 cm) thick coal seam. The Gallup Sandstone-Crevasse Canyon sequence is interpreted as having been deposited in a barrier-beach to lagoonal environment.

Petrographic analysis indicates that the nonmarine sandstones contain more chert, and the marine sandstones contain more polycrystalline quartz grains and are better sorted. Clay mineral analysis yields an assemblage of kaolinite, illite, montmorillonite, and mixed-layer clays. When compared with the interpreted depositional environments kaolinite is most abundant in open marine environments. Montmorillonite is more abundant in shales below the Tres Hermanos Formation and illite is less abundant in marginal to nonmarine shales.

The coal in the study area is thin, though fairly high in calorific value and low in sulfur. Being located on a national wildlife refuge makes any drilling or mining highly improbable.

Suggestions for Further Work

Further work in the study area may prove useful in specifically defining the depositional environments, particularly of the Atarque Member of the Tres Hermanos Formation and Crevasse Canyon Formation. A detailed study of the Atarque Sandstone Member is needed to determine the exact extent of the depositional environments related to the shark teeth-rich lenses and shell-rich beds. A paleobotanical study might provide additional information on depositional environments. South of the study area and the Sevilleta Grant, Upper Cretaceous strata are exposed and are probably in the Crevasse Canyon Formation. A more detailed study of the Crevasse Canyon Formation in the study area might prove useful in determining if there is any coal present in the subsurface to the south and if it thickens to any extent.

REFERENCES

Agassiz, C. J., 1838, Sur les ossements fossiles de Stonesfield qui avaient ete rapportes a des didelphes: C. R. Acad. Sci. Paris, v. 7, 537 p.

-----1839, Fossil from Lausanne: Verh. schweiz. Ges. Naturwiss., v. 24, 49 p

-----1843, Recherches sur les poissons fossiles: Neuchatel and Soleure, 5 vols

-----1844, Synoptical table of British fossil fishes, arranged in the order of the geological formations: Rep. Brit. Assoc. Adv. Sci., Cork XIII, 194-207 (1843)

Allen, J. R. L., 1963, The classification of cross-stratified units with notes on their origin: Sedimentology, v. 2, p. 93-114

Allen, J. E., and Balk, R., 1954, Mineral resources of Fort Defiance and Tohatchi quadrangles, Arizona and New Mexico: New Mexico Bureau of Mines and Mineral Resources Bull. 36, p. 1-192

Arambourg, C., 1935 Poissons fossils du Bassir sedimentaire du Gabon (avec la collaboration de D. Schneegans): Ann. Paleont., Paris, v. 24, p. 139-160

Austin, G. S., 1981, personal communication, Deputy Director, New Mexico Bureau of Mines and Mineral Resources

Austin, G. S., and Leininger, R. K., 1976, The effects of heat-treating sedimented mix-layer illite-smectite as related to quantitative clay mineral determinations: Journal of Sedimentary Petrology, v. 46, p. 206-215

Berner, R. A., 1964, Iron sulfides formed from aqueous solutions at low tempature and atmospheric pressure: Jour. of Geology, v. 72, p. 273-306

Berryhill, H. L. Jr., Dickinson, K. A., and Holmes, C. W., 1969, Criteria for recognizing ancient barrier coastlines: Am. Assoc. Petroleum Geologists Bull. v. 53, p. 706-707

Blatt, H., Middleton, G. and Murray, R., 1972, Origin of sedimentary rocks: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 634 p.

Bonaparte, C. L., 1838, Synapis vertebratorum systematis: Nvovi. Ann. Sci. nat. (Bologna), II, p. 105-133. from the San Juan Basin in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources, Memoir 25, p. 15-30

Bridges, P. H., 1976, Lower Silurian transgressive barrier island, southwest Wales: Sedimentology, v. 23, p. 347-362

Brown, C. Q., and Ingram, R. L., 1954, The clay minerals of the Neuse River sediments: Jour. Sed. Petrology, v. 24, p. 196-199

Brown, L. F., Bailey, S. W., Cline, L. M., and Lister, J. S., 1977, Clay mineralogy in relation to deltaic sedimentation patterns of Desmoinesian cyclothems in Iowa-Missouri: Clay and Clay Minerals, v. 25. no. 3, p. 171-186

Campbell, C. V., 1971, Depositional model - Upper Cretaceous beach shoreline, Ship Rock area, northwestern New Mexico: Jour. Sed. Petrology, v. 41, p. 395-409

Cappetta, Henri, Selachians from the Carlile Shale (Turonian) of South Dakota: Jour. Paleontology, v. 47 no. 3, p. 504-514

Carroll, D., 1970, Clay minerals: a guide to their X-ray identification: Geol. Soc. America Spec. Paper 126, 80 p.

Casier, E., 1947, Constitutuion et evolution de la racine dentaire des Euselachii II, Etude comparative des types: Inst. Roy. Sci. Nat. Belgique, Bull. 23 , p. 1-32

Chamberlin, R. C., 1981, personal communication, Geologist, New Mexico Bureau of Mines and Mineral Resources

Chapin, C. E., 1971, K-Ar age of the Lara Peak Andesite and its possible significance to mineral exploration in the Magdalena Mining District, New Mexico: Isochron/west, v. 2, p. 43-44

-----,1976, Evolution of the Rio Grande Rift: Geol. Soc. of America Abstracts with Programs, v. 8, p. 808

Chapin, C. E., Chamberlin, R. M., Osburn, G. R., White, D. L., and Sanford, A. P., 1978, Exploration framework of the Socorro geothermal area, New Mexico: New Mexico Geol. Soc. Spec. Pub. 7, p. 115-129

Cobban, W. A., 1977a, Characteristic marine molluscan fossils from the Dakota Sandstone and intertongued Mancos Shale, west-central New Mexico: U. S. Geol. Survey, Pro. Paper 1009, 30 p.

------1977b, Cenomanian Ammonite fauna from the Moby Sandstone of Central Montana: U. S. Geol. Survey Prof. Paper 243-D, 55 p.

Cobban, W. A., and Hook, S. C., 1981, Occurrence of <u>Ostrea beloiti</u> Logan in Cenomanian rocks of Trans-Pecos Texas: <u>IN Dickerson</u>, P. W. and Hoffer, J. M. eds. New Mexico Geol. Soc. 31st Field Conference, Tran-Pecos region, p. 169-172

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.

Conrad, T. A., 1857, Descriptions of Cretaceous and Tertiary fossils: IN Emory, W. H., Report on the United States and Mexican boundary survey: U. S. 34th Congress, 1st session, Senate Executive Document 108 and House Executive Document 52, p. 169

Conybeare, C. B., and Crook, K. W., 1968, Manual of sedimentary structures: Bureau of Mineral Resources, Geology, and Geophysics, Canberra, A. C. T., Bull. no. 102, 372 p.

Cotter, E. 1975, Late Cretaceous sedimentation in a low-energy coastal zone: the Ferron Sandstone in Utah: Jour Sed. Petrology, v. 45, p. 669-685

Cragin, F. W., 1893, A Contribution to the invertebrate paleontology of the Texas Cretaceous: Texas Geol. Survey, Ann. Rept. 4, p. 139-246

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

Cross, C. W., and Spencer, A. C., 1854, La Plata folio, Colorado: U. S. Geol. Survey, Geologic Atlas of the U. S., no. 60, 14 p.

Cummins, 1890, Texas Geological Survey, First Annual Report, 189 p.

Cuvier, G., 1817, Tome 1., 1st ed., Paris, v. 4

Dane, C H., Wanek, 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 Geologists Bull., v. 41, 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. p. 1-15

Dane, C. H., Landis, E. R., and Cobban, W. A., 1971, The Twowells Sandstone Tongue of the Dakota and Tres Hermanos Sandstone as used by Herrick 1900, western New Mexico: U. S. Geol. Survey Prof. Paper 750-B, p. 1317-132v3

Darton, N. H., 1928, "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, 74 p.

Davies, D. K., Ethride, F. G., and Berg, R. R., 1971, Recognition of barrier bars: Am. Assoc. Petroleum Geologists Bull., v. 55, p.. 550-565

Denny, C. S., 1941, Quaternary geology of the San Acacia area, New Mexico: Journal of Geology, v. 49, p. 225-260

Dickinson, W. R., 1970, Interpreting detrital modes of graywacke and arkose: Jour. Sed. Petrology, v. 40, p. 695-707

Dickinson, K. A., Berryhill, H. L., Jr., and Holmes, C. W., 1972 Criteria for recognizing ancient barrier coastlines, IN Rigby, J. K., and Hamblin, W. K., eds. Recognition of ancient sedimentary environments: Society of Economic Paleontologists and Mineralogists Spec. Pub. No. 16, p. 192-214

Dutton, C. E., 1885, Mount Taylor and the Zuni plateau: U. S. Geol. Survey, 6th Ann. Rept., p. 105-198

Elston, W. E., 1976, Glossary of stratigraphic terms of the Mogollan-Datil volcanic field, New Mexico: New Mexico Geological Society Spec. Pub. no. 5, p. 131-147

Estes, R., 1964, Fossil vertebrates from the Late Cretaceous Lance Formation, eastern Wyoming: Unv. Calif. Pub., Geol. Sci., v. 49, 180 p.

Folk, R. L., 1968, Petrology of sedimentary rocks: Austin, Texas, Hemphill´s Book Store, 170 p.

Frey, R. W., and Howard, J. D., 1970, Comparison of Upper Cretaceous ichnofaunas from siliceous sandstone and chalk, IN Crimes, T. P., and Harper, J. C., eds., Trace Fossils: Liverpool, Seal House Press p. 141-160

Gaffke, T. M., 1979,Depositional environments of a coal-bearing section in the Upper Cretaceous Mesaverde Group, Routt County, Colorado: Open file report, U. S. Geological Survey, 79-1669, p. 1-15

Gardner, J. H., 1910, The Carthage coal field, New Mexico: U. S. Geol. Survey Bull. 381-C, p. 452-460

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

Hantzschel. W., 1962, Treatise on invertebrate paleonotogy, Part W supplement, Trace Fossils: Boulder, Colorado and Lawrence Kansas. Geol. Society of America Inc. and University of Kansas Press, 269 p.

Hayden, F. V., 1869, U. S. Geog. and Geol. Survey Terr., 3rd Annual Report, 90 p.

Heinrich, E. W., 1965, Microscopic identification of minerals: New York, McGraw - Hill Book Company, 414 p.

Herrick, E. L. 1900, Report of a geological reconnaissance in western Socorro and Valencia Counties, New Mexico: American Geologist, v. 25, no. 6, p. 331-346

Holmes, W. H., 1877, Geological report on the San Juan District, Colorado: U. S. Geol. and Geog. Survey Terr. 9th Ann. Rept, 1875

Hook, S. C., 1980-81, personal communication, Paleontologist, New Mexico Bureau of Mines and Mineral Resources

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

----- 1979, Prionocyclus novimexicanus (Marcou) -- common Upper Cretaceous guide fossil in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Annual Report 1977-78, p. 34-42

-----1980, Reinterpretation of type section of Juana Lopez Member of Mancos Shale: New Mexico Geology, v. 2 no. 2

-----1981a, Late Greenhorn (Mid-Cretaceous) discontinuity surface ,southwest New Mexico, IN Contributions to mid-Cretaceous paleontology and stratigraphy of New Mexico, compiled S. C. Hook: New Mexico Bureau of Mines and Mineral Resources, Circular 180, p. 5-16

-----, 1981b, Lopha sannionis (White) -- common Upper Cretaceous guide fossil in New Mexico: New Mexico

Bureau of Mines and Mineral Resources, Annual Report, p. 52-56

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

Hook, S.C., Molenaar, C. M., and Cobban, W. A. in press, Redefinition of the Cretaceous Tres Hermanos Sandstone of Herrick (1900), west-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Circ. 185

Horne, J. C., McKenna, L. C., Levey. R. A., and Petranoff, T. V., 1980, Wave-dominated deltas: an important economic depositional model for Upper Cretaceous of southwestern Wyoming, Lorman, C. ed., IN Procedings of the Fourth Symposium on the geology of Rocky Mountain coal--1980: Colorado Geological Survey, p. 7-12

Hyatt, Alpheus, 1903, Pseudoceratites of the Cretaceous, T. W. Stanton ed.: U. S. Geol. Survey, Mon. 44, 351 p.

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

Jaekel, O. 1894, Die eocanen Selachier vom Monte Bolca: Springer, Berlin 176 p.

Johns, W. D., Grim, R. F., and Bradley, W. F., 1954, Quantitative estimations of clay minerals by diffraction methods: Jour. Sed. Petrology, v. 24, p. 242-251

Jones, T. S., 1938, Geology of Sierra de la Pena and paleontology of the Indidura Formation, Coahuila, Mexico: Geol. Soc. America, Bull., v. 49. no.1, p. 69-149

Klein, G. deV., 1967, Paleocurrent analysis in relation to modern marine sediment dispersal patterns: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 366-382

Kottlowski, F. E., and Beaumont, E. C., 1965, Coal: New Mexico Bureau of Mines and Mineral Resources, Bull. 87, p. 100-116

Kottlowski, F. E., and Stewart, W. J., 1970, Part 1- the Wolfcampian Joyita uplift in central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Mem. 23, 82 p.

La Fon, N. A., 1981, Offshore bar deposits of Semilla Sandstone Member of Mancos Shale (Upper Cretaceous), San Juan Basin, New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 65, p. 706-721

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, 44 p.

Lee, W. T., 1915, Relation of the Cretaceous Formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, p. 27-58

Leidy, J., 1856, Remarks on certain extinct species of fishes: Proc. Acad. Nat. Sci., Philadelphia. v. 8, p. 301-302

Logan, W. N., 1899, Contribution to the paleontology of the Upper Cretaceous Series: Field Columbian Museum Pub. 36, Geological Survey, v. 1, no. 6, p. 207-214

Marcou, Jules, 1858, Geology of North America; with two reports on the prairies of Arkansas and Texas, The Rocky Mountains of New Mexico and the Sierra Nevada of California: Zurich, 144 p.

Massingill, G. L., 1979, Geology of Riley-Puertecito area, southeastern margin of Colorado Plateau, Socorro County, New Mexico: University of Texas at El Paso, unpub. P.H.D. dissertation 301 p.

Masters, C. D., 1967, Use of sedimentary structures in determination of depositional environments, Mesaverde Formation, Williams Fort Mountains, Colorado: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 2033-2043

Meek, F. B., and Hayden, F. V., 1862, Description of new Cretaceous fossils from Nebraska Territory: Acad. Nat. Science Phla. Proc. 1862, p. 21-28

------1876, Invertebrate Cretaceous and Tertiary fossils: U. S. Geol. Survey of the Territories , v. 9, 629 p.

MeKee, E. D., and Weir, G. W., 1953, Terminology for stratification and cross-stratification in sedimentary rocks: Geol Soc. America Bull., v. 64, p. 381-390

Molenaar, C. M., 1973, Sedimentary facies and correlation of the Gallup Sandstone and associated formations, northwestern New Mexico: IN Fassett, J. E., ed., Cretaceous and Tertiary rocks of the southern Colorado Plateau: A Memoir of the Four Corners Geol. Soc., p. 85-110

------1974, Correlation of the Gallup Sandstone and associated formations, Upper Cretaceous, Eastern San Juan and Acoma Basins, New Mexico: IN Siemers C. T., ed., New Mexico Geol. Soc. 25th Ann. Field Conf., Ghost Ranch, Central-Northern New Mexico, p. 251-258

Moore, D. G., and Scruton, P. C., 1957, Minor internal structure of some recent unconsolidated sediments: Am. Assoc. Petroleum Geologists Bull. v. 41, p. 2723-2751

North, R. M., 1981, personal communication, Mineralogist, New Mexico Bureau of Mines and Mineral Resources

Oomkens E., 1974, Lithofacies relations in the Late Quaternary Niger delta complex: Sedimentology, v. 21, p. 195-222

Owen, D., 1849, On the structure of the teeth of some fossil fish of the Carboniferous period: Ann Mag. Nat. Hist., v. 3, p. 41-42

Owen, D. E., 1966, Nomenclature of Dakota Sandstone (Cretaceous) in San Juan Basin, New Mexico and Colorado: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 1023-1028

----- 1973, Depositional history of the Dakota Sandstone, San Juan Basin Area, New Mexico: IN Fassett, J. E., ed., Cretaceous and Tertiary rocks of the southern Colorado Plateau: A Memoir of the Four Corners Geol. Soc., p. 37-51

Parham, W. F., 1966, Lateral variations of clay mineral assemblages in modern and ancient sediments: Proceedings of the International Clay Conference, 1966, v. I, p. 135-145

Perkins, B. F., and Stewart, C. L., 1971, Wallace Ranch, IN Trace Fossils: School of Geoscience Miscellaneous Pub. 71-1, Louisiana State University, P. 66-70

Pettijohn, F. J., 1975, Sedimentary Rocks: New York, Harper and Row, 628 p.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1973, Sand and sandstone: New York, Spring-Verlag, 618 p.

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

Potter, P. E., and Pettijohn, F. J., 1963, Paleocurrents and basin analysis: New York, Academic Press Inc., 296 p.

Powers, M. C., 1953, A new roundness scale for sedimentary particles: Jour. Sed. Petrology, v. 23, p. 117-119

Pritchard, D. W., 1967, What is an estuary: physical viewpoint: IN Estuaries, Lauff, G. D. ed., American Assos. Adv. Sci., p. 3-5

Pryor, W. A., and Glass, H. D., 1961, Cretaceous-Tertiary clay mineralogy of the Upper Mississippi Embayment: Jour. Sed. Petrology, v. 31, p. 38-51

Rankin, C. H., 1944, Stratigraphy of the Colorado Group; Upper Cretaceous, in northern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 20, 27 p.

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

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

Reinson, G. E., 1980, Barrier island systems, IN Facies models, Walker, R. E., ed.: Geological Assoc. of Canada, p. 57-75

Roehler, H. W., 1977, Lagoonal origin of coal in the Almond Formation in the Rock Spring Uplift, Wyoming, IN Murray, D. K. ed., Geology of Rocky Mountain coal, a symposium 1976: Colorado Geological Survey, p. 65-90

Romer, A. S., 1942, Notes on certain American Paleozoic fishes: American Jour. Sci., v. 240, p. 216-228

------1953, Museum of Comparitive Zoology, Ann. Rept. Din. Mus. Comp. Zool., Harvard, 1952-1953, p. 1-24

Sabins, F. F. Jr., 1963, Anatomy of stratigraphic trap, Bisti Field, New Mexico: Am. Assoc. Petroleum Geologist Bull. 47, p. 193-230

Schaeffer, B., 1963, Cretaceous fishes from Bolivila, with comments on pristid evolution: Amer. Mus. Novit., v. 2159, p.1-20

Sears, J. D., 1925, Geology and coal resources of the Gallup-Zuni Basin, New Mexico: U. S. Geol. Survey Bull. 767

Sear, 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

Selley, R. C., 1968, A classification of paleocurrent models: Jour. Geology, v. 76, p. 99-110

Shelton, J. W., 1967, Stratigraphic models and general criteria for recognition of alluvial, barrier-bar, and turbidity current sand deposition: Am. Assoc. Petroleum Geologist Bull., v. 51, p. 2441-2461

Shumard, B. F., 1860, Descriptions of new Cretaceous fossils from Texas: Acd. Sci. St. Louis Trans., v. 1, p. 590-610

Spiegel, Z., and Baldwin, B., 1963, Geology and water resources of the Santa Fe area, New Mexico: U. S. Geol. Survey, Water Supply Paper 1525, 258 p.

Stach, E.; Mackowsky, M.; Teichmuller, M.; Taylor, G.; Chandra, P.; and Teichmuller, R., 1975, Coal Petrology: Gebruder Borntraeger Berlin-Stuttart, 428 p.

Stanton, T. W., 1893, The Colorado Formation and its invertebrate fauna: U. S. Geol. Survey, Bull. 106, 288 p.

Tabet, D. E., 1979, Geology of Jornada del Muerto coal field, Socorro County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 168, 20 p.

Tokunaga, Shigeyasu, and Shimizu, Saburo, 1926, The Cretaceous formation of Futaba in Iwaki and its fossils: Tokyo. Imp. Univ. Fac. Sci. Jour., Sec. 2, v. 1, p. 181-212

Tonking, W. H., 1957, Geology of Puertecito quadrangle, Socorro County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bull. 41, 68 p.

Van der Plas, L., and Tobi, A. C., 1965, A chart judging the reliability of point counting results: Am. Jour. Sci., v. 263, p. 87-90

Warren, P. S., 1930, New species of fossils from Smoky River and Dunvegan Formations, Alberta: Alberta Research Council, Geol. Sur. Rept. 2, p. 57-68

Wells, J. N., 1933, Corals of the Atlantic and Gulf Coastal Plains and Western Interior of the United States: U. S. Bull. American Paleontology, v. 18, no. 67, p. 83-292

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, p. 377-392 1074-1106

White, C. A., 1876, Invertebrate paleontology of the Plateau Province, IN Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto: U. S. Geol. and Geog. Survey of the Territories, p. 74-137

Whitley, G. P., 1939, Taxonomic note on shark and rays: Australian Zoologist, v. 9, p. 227-262

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L., and Vorbe, Georges, 1946, Geologic map and stratigraphic section 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 Inv. Map 61

Wilpolt, R. H., and Wanek, A. A., 1951, Geology of the region from Socorro and San Antonio, east to Chupadera Mesa, Socorro County, New Mexico: U. S. Geol. Survey, Oil and Gas Inv. Map om 121

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. Geological Survey Bull. 716, p. 1-15

Wolberg, D., 1980-81, personal communication, Paleontologist, New Mexico Bureau of Mines And Mineral Resources

Woodard, A. S., 1889, Remarks on Sclerorhynchus atavus: Proc. zool. Soc. London, 1889, p. 449-451

-----, 1912, The fishes of the English Chalk, Palaeontog. Soc. Mon. XLVII-LIV: Hull Mus. Pub. 137 p.

APPENDIX A

Description of measured sections

All shale units due to their ease of weathering are partly covered in flat topographic areas. Areas where the shale exposures are very poor are described as mostly covered in the measured sections. Meters are in parenthesises.

Abbreviations Used

Symbol	Meaning
Rock	
ss	sandstone
sh	shale
sls	siltstone
cong	conglomerate
ls	limestone
Color	
wh.	white
v. pale or.	very pale orange
gr. or.	grayish orange
dr. yel. or.	dark yellowish orange
pale yel. or.	pale yellowish orange
pale pink	pale pink
mod. or. pink	moderate orange pink
gr. or. pink	grayish orange pink
gr. red	grayish red
bl. red	blackish red
mod. red	moderate red
dusky red	dusky red
lt. br.	light brown
pale br.	pale brown
pale yel. br.	pale yellowish brown
lt. ol. br.	light olive brown
mod. yel. br.	moderate yellowish brown
mod. br.	moderate brown
mod. red br.	moderate reddish brown
dr. red br.	dark red brownish
dr. yel. br.	dark yellowish brown
gr. br.	grayish brown
pale ol.	pale olive
mod. yel.	moderate yellow
dusky yel.	dusky yellow

gr. yel.	grayish yellow
yel gr.	yellowish gray
lt. ol. gr.	light olive gray
ol. gr.	olive gray
lt. br. gr.	light brownish gray
pinkish gr.	pinkish gray
br. gr.	brownish gray
v. lt. gr.	very light gray
lt. gr.	light gray
med. lt. gr.	medium light gray
med. gr.	medium gray
med. dr. gr.	medium dark gray
gr. bl.	grayish black

Induration

wlind.	well indurated
mod.ind.	moderately indurated
fri.	friable
vfri.	very friable

Mean Grain Size of Sandstones

vcgrn.	very coarse-grained
cgrn.	coarse-grained
mgrn.	medium-grained
fgrn.	fine-grained
vfgrn.	very fine-grained

Abundance of Carbonate Minerals

vcal.	very calcareous
cal.	calcareous
slcal.	slightly calcareous

Abundance of Carbonaceous Material

abncarb.	abundant carbonaceous material
carb.	moderate carbonaceous material
spcarb.	sparse carbonaceous material

Sedimentary Structures

crbd.	cross-bedded
tab.	tabular
pl.	planar
tang.	tangential
sol.	solitary
cr-bd.	cross-beds
cr-lam.	cross-lamination
l.	lower
eros.	erosional
noneros.	nonerosional

Abundance of Fossil Material

vfos.	very fossiliferous
fos.	fossiliferous
slfos.	slightly fossiliferous

Miscellaneous

abn.	abundant
bd.	bed, bedded
crns.	coarsens
frag.	fragment
interbd.	interbedded
lam.	lamination
med.	medium
mod.	moderate, moderately
nod.	nodular
2ndy.	secondary
sl.	slighlty
sm.	small
sp.	sparsely
tk.	thick
tn.	thin
v.	very

Section I

Becker SW 7 1/2 minute quadrangle, S 1/2, sec. 17, T. 1 N., R. 2 E., Socorro County, New Mexico; measured June 23-26, 1980, by B. Baker using a Brunton compass and a Jacob staff. Section covers interval from lower tongue of Mancos Shale to the top of Crevasse Canyon Formation.

Unit	Description	Thickness Ft.	 In.
1-112	sh, med. gr.	13 (4.00)	1
1-111	ss, med. br., wlind., vfgrn. to fgrn., mod. sorted, vfos.; <u>Flemingostrea aff. prudencia</u>, <u>Crassostrea soleniscus</u> (Meek)	2 (.60)	-
1-110	ss, gr. or., mod. ind., vfgrn., mod-sorted, fos.; <u>Flemingostrea aff. prudencia</u>	2 (.80)	8
1-109	sh, med. gr., crns. upward	7 (2.30)	7
1-108	ss, gr. or., vfri., mod. sorted, nodules, fos; <u>Fleminfostrea aff. prundencia</u>	2 (.80)	8
1-107	sh, med. gr., top 10 cm. carb.	10 (3.10)	2
1-106	ss, gr. or., mod. ind., mod. sorted	- (.20)	8
1-105	ls, med. gr., wea. bl. red	- (.16)	6
1-104	ss, gr. or., mod. ind., vfgrn., mod-sorted	- (.25)	10
1-103	sh, lt. br. gr., interbd. ss 1 in. (2 cm) tk., carb.	7 (2.30)	7
1-102	ss, pale br., wea. pinkish gr., vfri., vfgrn. to fgrn., poorly sorted, carb., rip-up clasts, sh partings	3 (1.00)	3
1-101	coal, 2ndy gypsum	1 (.35)	2

1-100	sh, lt. br. gr., abncarb., 2ndy gypsum	1	-	(.30)
1-99	coal, 2ndy gypsum	-	6	(.15)
1-98	sh, lt. br. gr., abncarb., pt. wood, yel. stained	1	10	(.55)
1-97	sh, med. gr., iron nodules	3	5	(1.05)
1-96	ss, yel. gr., mod. ind., vfgrn.	1	-	(.30)
1-95	sh, lt. br. gr., carb.	-	10	(.25)
1-94	sh, med. gr., silty	1	-	(.30)
1-93	ss, pinkish gr., fri., fgrn., mod-sorted, vcal.	3	5	(1.05)
1-92	ironstone, dusky red, cone-in-cone	-	1	(.03)
1-91	ss, pale yel. or., mod. ind., vfgrn., mod. sorted, cal.	-	6	(.15)
1-90	sh, br. gr., silty to sandy, local ss lenses	5	4	(1.60)
1-89	sh, lt. br. gr., silty to sandy, pt. wood, yel. stained	-	8	(.19)
1-88	sh, br. gr., silty	-	8	(.19)
1-87	sh, lt. br. gr., abncarb., pt. wood, yel. stained	-	8	(.20)
1-86	sh, lt. gr., silty, fines upward	10	6	(3.20)
1-85	ss, pale pink, vfri., fgrn., mod. sorted	1	11	(.58)
1-84	ss, v. lt. or., vfri., fgrn., well-sorted	4	5	(1.50)
1-83	ss, wh., vfri., fgrn., mod. sorted	4	3	(1.30)
1-82	ss, pinkish gr., vfri., fgrn., mod. sorted	5	7	

				(1.70)
1-81	ss, gr. red, vfri., fgrn., mod. sorted	-	8	(.20)
1-80	ss, pinkish gr., vfri., fgrn., mod. sorted	3	8	(1.10)
1-79	ss, dr. red br., vfri., vfgrn. to fgrn., poorly sorted	-	8	(.21)
1-78	ss, gr. yel., vfri., vfgrn., poorly sorted	-	4	(.10)
1-77	ss, dr. red br., vfri., vfgrn. to fgrn., poorly sorted	2	4	(.70)

Base of formation

Total thickness of Crevasse Canyon Formation
107 ft 6 in. (32.76 m)

1-76	ss, yel. gr., vfri., vfgrn. to fgrn., poorly sorted	13	1	(4.00)
1-75	ss, gr. or., mod. ind., vfgrn. to fgrn., poorly sorted	5	9	(1.75)
1-74	ss, v. lt. gr., mod. ind., vfgrn. to fgrn., poorly sorted	8	10	(2.70)

Base of formation

Total measured thickness of Gallup Sandstone
27 ft. 8 in. (8.45 m)

1-73	sh, med. gr., cal.	46	9	(14.26)
1-72	ss, v. lt. gr., vfri., vfrgn., well-sorted, concretions, 6 in. (50 cm) dia.	10	6	(3.20)
1-71	sh, med. gr., silty to sandy	15	7	(4.80)
1-70	sh, med. gr., cal., wood frag.	30	3	(9.21)

1-69	ss, yel. or., mod. ind., fgrn., mod-sorted, tn. lam.	–	8	(.20)
1-68	ss, yel. br., fri. to mod. ind., vfgrn., mod. sorted, crbd; med.-scale wedge- and trough-shapevd sets of hi.-angle tang. cr-bd. wih eros. l. contact, nodules, ripple marks, horz. burrows, unit made of v. large 5 ft. 4 in. (1.6 m) dia. concretions, marker bed, fos; *Lopha sannionis* (White) gastropods, pelecypods	9	6	(2.90)
1-67	sh, lt. ol. gr., crns. upward, fos; *Lopha sannionis* (White), pelecypods	26	3	(8.00)
1-66	sh, med gr.	139	–	(42.31)
1-65	partly covered, probably sh.	35	–	(10.64)
1-64	calcarenite, med. gr., wea. dusky yel., fos; shark teeth, *Inoceramus* frag., *Prionocyclus wyomingensis* Meek *Lopha lugubris* (Conrad)	–	6	(.15)
1-63	sh, lt. ol. gr., silty, cal.	1	–	(.30)
1-62	calcarenite, med. gr., wea dusky yel., fos; shark teeth, *Inoceramus* frag., *Scaphite warreni* Meek and Hayden, *Prioncyclus wyomingensis* Meek *Lopha lugubris* (Conrad)	–	4	(.10)
1-61	sh, lt. gr., silty, cal.	1	2	(.35)

Base of tongue

Total measured thickness of D-Cross Shale Tongue of Mancos Shale
316 ft 4 inches (96.44 m)

1-60	ss, yel. gr., vfri., fgrn., well-sorted, cal., carbonate apatite nodules	–	8	(.20)
1-59	ss, pale yel. br., wea. dr. yel. br., wlind., fgrn., well-sorted, biotur., inclined burrows, spfos; *Lopha bellaplicata* (Shumard)	1	4	(.40)

1-58	ss, v. lt. gr., vfri., fgrn., mod-sorted, red stained	18	3	(5.55)
1-57	ss, gr. or., fri., frgn. to cgrn., poorly-sorted, abn. wood frag., horz. burrows spfos; shark teeth, shell frag.	1	6	(.45)
1-56	ss, pale ol., fri., vfgrn. to fgrn., poorly sorted, cal., med. bd.	1	3	(.40)
1-55	ss, dusky yel., fri., vfgrn. to fgrn., poorly sorted, cal., med. bd.	5	11	(1.80)
1-54	ss, dr. yel. or., fri., vfgrn. to fgrn., poorly sorted, sh partings, biotur., wood frag., horz. burrows	26	4	(8.00)
1-53	ss, lt. gr., vfri., vfgrn., mod. sorted, abn. concretions; med. lt. gr., 2 ft. 4 in., (70 cm) dia., cal.	10	10	(3.30)

Base of member

Total measured thickness of Fite Ranch Sandstone Member
of Tres Hermanos Formation
66 ft (2o m)

1-52	partly covered, probably sh to silty sh	13	-	(3.95)
1-51	sh, med. gr., interbd. ss, 1-9 in. (2-15 cm) tk.	15	9	(4.80)
1-50	sh, br. gr., carb., yel. stained, prosecpt	1	8	(.50)
1-49	sh, med. gr.	7	7	(2.30)
1-48	partly covered, probably sh	30	6	(9.30)
1-47	ss, dusky yel., vfri. to fri., vfgrn., mod. sorted, med. to tn. bd., carb.	5	5	(1.05)
1-46	sh, gr. yel.	7	3	(2.20)
1-45	ss, gr. yel., fri., fgrn., well-sorted, carb., spcal.	3	1	(.95)
1-44	sh, med. gr., carb.	1	6	(.45)

1-43	sh, gr. yel., silty to sandy	1	10	(.55)
1-42	ss, gr. or., mod. ind., vfgrn., well-sorted	2	11	(.90)
1-41	sh, interbd ss, gr. or., mod. ind., well-sorted, wood frag., med. bd.,	3	9	(1.15)
1-40	sh, med. gr., silty	1	8	(1.64)
1-39	ss, pale yel. or., fri., fgrn. to mgrn., mod. sorted, crbd; med.-scale, tab.-shaped sets of low-angle pl. cr-bd. with eros. l. contact	6	2	(1.90)
1-38	sh, lt. gr., silty to sandy	3	3	(1.00)
1-37	ss, lt. gr., fri., vfgrn., mod. sorted, carb.	-	7	(.16)
1-36	coal	-	3	(.09)
1-35	ss, gr. bl., abncarb.	-	6	(.15)
1-34	partly covered, probably sh to vfri. ss	3	8	(1.12)
1-33	partly covered, probaly vfri. ss	3	3	(1.00)
1-32	ss, gr. yel., fri., fgrn. to mgrn., poorly-sorted, pt. wood, med. to tk. bd., crbd; med.-scale, tab.- and wedge-shaped cosets of low-angle pl. cr-bd. with eros. l. contact	5	9	(1.75)
1-31	sh, lt.gr., silty, carb., rip-up clasts	2	7	(.80)
1-30	coal	-	4	(.10)
1-29	ss, gr. bl., fri., fgrn., poorly sorted, adncarb.	-	4	(.10)
1-28	ss, pale yel. gr., vfri., fgrn., mod - sorted, pt. wood, carb. top 1 in. (2 cm)	5	11	(1.80)
1-27	ss, pale yel. or., vfri., fgrn., mod. sorted, sh partings, v. tn. bd., abn. Crassostrea	3	5	(1.05)

	soleniscus (Meek) float			
1-26	ss, gr. yel., wea. dr. yel. br., mod. ind., vfgrn., mod. sorted, crbd; sm.-scale, tab. shaped sets of low-angle pl. cr-lam. with eros. l. contact	-	10	(.25)
1-25	sh, med. gr.	2	6	(.75)
1-24	calcarenite, lt. gr., wea. gr. br., spcal.	-	1	(.02)
1-23	sh, med. gr.	4	5	(1.35)
1-22	ss, mod. red, fri., fgrn., mod. sorted, tk. lam., crbd; med.-scale, tab.-shaped sets of low-angle pl. cr-lam. with noneros. l. contact	1	2	(1.15)
1-21	sh, med. lt. gr., silty	7	7	(2.30)

Base of member

Total measured thickness of Carthage Member
of Tres Hermanos Formation
152 ft. 10 in. (45.96 m)

1-20	ss, gr. or., fri., vfgrn., mod. sorted, tn. bd., crbd; sm.- to med.-scale, trough- to tab.-shaped cosets of low- to hi.-angle tang. cr-bd. with eros. l. contact	2	11	(.90)
1-19	ss, pale yel. or., wea. gr. br., fri., fgrn., mod. sorted, tn. bd., vfos; *Crassostrea soleniscus* (Meek), crbd; med.-scale wedge-shaped sets of low-angle tang. cr-bd. with eros. l. contact	5	1	(1.55)
1-18	ss, gr. or., vfri., fgrn., mod. sorted, v. tn. bd., fos; *Crassostrea soleniscus* (Meek)	2	6	(.75)

Base of member

Total measured thickness of Atarque Sandstone Member
of Tres Hermanos Formation
10 ft. 6 in. (3.20 m)

1-17	sh, med. lt. gr., concretion zone 45 ft. 8 in. (13.90 m) above base, cal., 1 ft. 4 in. (40 cm) dia., ss dike, 1 ft. (30 cm) tk.	172	6	(52.80)
1-16	bentonite, wea. v. pale or.,	-	3	(.08)
1-15	sh, lt. ol. gr., silty, interbd. calcarenite, fos; *Inoceramus* sp.	20	3	(6.16)
1-14	sh, lt. ol. gr., interbd sls, lt. br.	9	6	(2.90)
1-13	sh, pale br., interbd calcarenite, gr. or.	19	9	(6.00)
1-12	partly covered, probably sh	26	3	(8.00)
1-11	calcarenite, gr. or., vfos; *Inoceramus* sp.	-	4	(.10)
1-10	sh, gr. or., interbd calcarenite, spfos; *Inoceramus* sp.	21	-	(6.40)
1-9	partly covered, probably sh	26	3	(8.00)
1-8	ss, dusky yel., vfri., vfgrn., fines to silty sh, ol. gr., interbd calcarenite, tn. lam., fos; USGS Mesozoic fossil locality D 10291 *Pycnodonte newberryi* (Stanton)	21	-	(6.40)

Base of tongue

Total measured thickness of Rio Salado Tongue of Mancos Shale
317 ft. (96.64 m)

1-7	ss, wh., wea. v. lt. gr., vfri., mgrn., v. well-sorted, horz. burrowed, v. tk. bd. 2ndy silica veins	28	10	(8.80)
1-6	ss, wh., wea. lt. gr., vfri., mgrn., well-sorted, abn. biotur., burrowed at base, 2 ft. (60 cm) tk., alternating with ss, wh., wea. gr. or., vfri., fgrn, mod-sorted	19	3	(5.85)
1-5	ss, lt. br., vfri., fgrn., tk. bd.	4	7	(1.40)

1-4	ss, gr. or., vfri., vfgrn. to fgrn., mod. sorted, med. bd.	12	6 (3.80)
1-3	ss, v pale or., vfri., fgrn., well-sorted, med. bd.	19	4 (5.90)

Base of tongue

Total measured thickness of Twowells Tongue of Dakota Sandstone
84 ft. 6 in. (25.75 m)

1-2	sh, lt. gr., interbd. ss, yel. gr., fri., fgrn., crns. upward, tn. bd., nod.	13	8 (4.15)
1-1	sh, br. gr., silty	40	6 (12.35)

Total measured thickness of lower tongue of Mancos Shale
54 ft. 2 in. (16.50 m)

Faulted agianst Triassic Dockum Formation

Section II

La Joya 7 1/2 minute quadrangle, SE 1/2, sec. 30, T. 1 N., R. 2 E., Socorro County, New Mexico; measured July 16, 1980, by B. Baker using a Brunton compass and a Jacob staff. Section covers interval from Rio Salado Tongue of the Mancos Shale to Fite Ranch Sandstone Member of the Tres Hermanos Formation.

Top of section covered

Unit	Description	Thickness	
		Ft.	In.
2-21	ss, v. lt. gr., fri., vfgrn., well-sorted, biotur., horz. burrows, tk. bd., yel. stained	5	11 (1.80)
2-20	ss, lt. gr., vfri., vfgrn., mod. sorted, carb., yel. stained	5	4 (1.60)
2-19	ss, lt. gr., vfri., vfgrn., well-sorted, carb., yel. stained, tn. bd.	6	7 (2.00)

Base of member

Total measured thickness of Fite Ranch Sandstone Member
of Tres Hermanos Formation.
15 ft 9 inches (5.40 m)

2-18	sh, br. gr., silty to sandy, concretions 1 ft. (30 cm) dia., wea. gr. br.	10	6 (3.20)
2-17	sh, br. gr., silty, interbd., ss, v. lt. gr., mod. ind., vfgrn., well-sorted, tk. lam., 1 ft. (30 cm) tk.	6	6 (1.98)
2-16	ss, v. lt. gr., vfri. fgrn., well-sorted	5	4 (1.60)
2-15	partly covered, probably ss, pt. wood	7	10 (2.40)
2-14	ss, v. pale or., fri., fgrn., poorly-sorted, sh partings, biotur.	1	3 (.40)
2-13	sls, pinkish gr., mod. sorted, tk. lam.	2	7

				(.80)
2-12	ss, gr. or., vfri., vfgrn., well-sorted, abn. biotur.	1	11	(.60)
2-11	partly covered, probably ss	4	11	(1.50)
2-10	ss, yel. gr., fri., vfgrn. to fgrn.,	1	10	(.55)
2-9	partly covered, probably sh	2	11	(.90)
2-8	ss, gr. or., fri., fgrn., poorly sorted, tn. bd., cal.	-	6	(.15)
2-7	sh, lt. ol. gr., carb. top 1 ft. 8 in. (50 cm)	10	6	(3.20)

Base of member

Total measured thickness of Carthage Member
of Tres Hermanos Formation
50 ft 2 inches (15.30 m)

2-6	ss, yel. gr., vfri., vfgrn. to fgrn., mod. sorted, tn. bd., alternating with ss, yel. gr., mod. ind., fgrn., well-sorted, 4 in. (10 cm) tk., shell frag.	5	11	(1.80)
2-5	ss, gr. yel., vfri., fgrn., v. well-sorted, tn. to tk. bd., crbd; med.-scale, wedge- and trough-shaped cosets of low-angle tang. cr-bd. with eros. and noneros. l. contact, ripple marks	16	3	(4.95)
2-4	ss, yel. gr., vfri., vfgrn. to fgrn., mod. sorted, spcal., crbd; sm.-scale, wedge- and tab.-shaped sets of low-angle pl. cr-bd. with eros. l. contact with local lenses of ss, v. lt. gr., wea.gr. br., mod. ind., fgrn., poorly sorted, fos; Crassostrea soleniscus (Meek)	10	6	(3.20)
2-3	sh, med. gr., silty, crns. upward	6	7	(2.00)
2-2	ss, wh., fri., vfgrn., mod. sorted, cal, shell frag., crbd; sm.-scale, wedge- and tab.-shaped sets of low-angle tang. cr-bd.	2	4	(.72)

with eros. l. contact, alternating
with ss, v. lt. gr., wea. dr. yel. br.,
mod. ind., fgrn., well-sorted, tn. bd.

Base of member

Total measured thickness of Atarque Sandstone Member
of Tres Hermanos Formation.
41 ft 7 inches (12.67 m)

2-1	sh, lt. ol. gr., silty, local ss lenses	21 (6.68)	11

Total measured thickness of Rio Salado Tongue of Mancos Shale
21 ft 11 inches (6.68 m)

Section III

La Joya quadrangle 7 1/2 minute, E 1/2, sec. 31, T. 1 N., R. 2 E., and NW 1/4, sec 5, T. 1 S. R. 2 E., Socorro County, New Mexcio; measured July 17-19, 1980, by B. Baker using a Burnton compass and a Jacob staff. Section covers interval from Rio Salado Tongue of the Mancos Shale to the Gallup Snadstone.

Unit	Description	Thickness Ft.	 In.
3-45	ss, v. pale. or., vfri. to fri., fgrn., v. poorly sorted, tn. lam., crbd; sm.- to med.-scale, wedge- and tab.-shaped sets of low-angle tang. cr-bd., with eros. and noneros. l. contact	11 (3.40)	2
3-44	ss, or. pink, vfri., vfgrn., v. poorly-sorted, tn. lam.	7 (2.40)	10
3-43	ss, v. pale or., fri., vfgrn., mod-sorted, concretions (.40 t0 1.00 m) dia., fos; gastropods	3 (1.00)	3
3-42	ss, gr. or., vfri., fgrn., v. poorly-sorted, sh partings, pt. wood, local abnfos. lenses Lopha sannionos (White), gastropods, pelecypods	9 (3.00)	10

Base of formation

Total measured thickness of Gallup Sandstone
32 ft 2 inches (9.8 m)

Unit	Description	Ft.	In.
3-41	sh, ol. gr., cal., spetarin concretions, 1 ft. (30 cm) dia., crns. upward, fos; USGS Mesozoic fossil locality D 11206 Proplacenticeras pseudoplacenta (Hyatt) Lopha sannionos (White)	120 (36.73)	6
3-40	ss, yel. gr., mod. ind., vfgrn., well-sorted, tk. lam., crbd; sm.- to med.-scale, wedge- and tab.-shaped cosets of low-angle tang. cr-bd. with noeros, l. contact, local fos. lenses;	4 (1.30)	3

	Inoceramus sp., Lopha sannionos, (White) gastropods, concretions 3 ft. 3 in. (1 m), dia., cal. ss, br. gr., wea., yel br., mod. ind., vfgrn., well-sorted, fos., some lenses red stained centers vfos., marker bed			
3-39	ss, gr. or., wea. pale yel. or., vfri., fgrn., poorly sorted, crbd; med.-scale, wedge- and tab.-shaped cosets of low-angle tang. and pl. cr-bd. with eros. and noneros. l. contact	2	6	(.75)
3-38	sh, pale br., wea. lt. br. gr., silty, fos. nod., pectin, gastropod, alternating ss, lt. br. gr., fri., vfgrn., well-sorted, 6 in. (.15 cm) tk.	18	7	(5.65)
3-37	sh, ol. gr., spetarin concretions, 15 ft. 8 in. (4.80 m) above base of unit, pt. wood,fos; USGS Mesozoic fossil locality D 11184 Prioncyclus novimexicanus (Marcou) Scaphites sp.	195	4	(59.54)
3-36	calcarenite, med. gr., wea. dusky yel., tn. bd.	-	4	(.10)
3-35	partly covered, probably silty sh	-	8	(.20)
3-34	calcarenite, mod. yel. br., wea. med. gr., tn. bd., fos; USGS Mesozoic fossil locality D 11349 Prioncyclus wyomingensis Meek Scaphites warreni Meek and Hayen Lopha lugubris (Conrad) Inocermaus sp.	-	6	(.15)
3-33	partly covered, probably silty sh	1	6	(.35)
3-32	calcarentite, mod. yel. br., wea. med. gr., tn. bd., fos; USGS Mesozoic fossil locality D 11350 Prioncyclus wyomingensis Meek Lopha lugubris (Conrad) Inocermaus sp.	1	3	(.30)
3-31	sh, lt. gr., silty, interbd. ss, lt. ol. gr., vfri., vfgrn., mod. sorted, cal., sh partings, shell frag.	3	3	(1.00)

Base of tongue

Total measured thickness of D-Cross Shale Tongue of Mancos Shale
351 ft 3 inches (104.07 m)

3-30	ss, dr. yel. or., vfri.,vfgrn., mod-sorted, cal., vfos; USGS Mesozoic fossil locality D 11351 *Lopha bellaplicata* (Shumard) skeletal frag., replacement nod. of gastropods and pelecypods, shark teeth	-	4	(.09)
3-29	ss, mod. or. pink, wlind., fgrn., mod. sorted, vert. and horz. burrowed, spfos; shark teeth	1	4	(.40)
3-28	ss, lt. gr. or., vfri. vfgrn. to fgrn., poorly sorted, spfos; shark teeth	5	4	(1.60)
3-27	ss, gr. or., fri. vfgrn to fgrn., mod-sorted,	4	1	(1.25)
3-26	ss, v. lt. gr., fri. fgrn., well-sorted	2	7	(.80)
3-25	ss, dr. yel. or., vfri., fgrn., mod-sorted, locally crbd., med.-scale, tab.- and wedge-shaped sets of low-angle tang. cr-bd. with noeros. l. contact	4	11	(1.50)
3-24	ss, lt. ol. br., wea. dr. yel. br., mod. ind., fgrn. to cgrn., mod. sorted, goethite replacement nod. of pyrite locally fos; shark teeth, skeltal frag., wood frag., shell frag.,	1	5	(.35)
3-23	ss, lt. ol. gr., wea. pale yel. br., wlind., fgrn., mod. sorted, burrowed top., cal.	1	4	(.30)
3-22	ss, pale yel br., vfri., vfgrn. to fgrn., mod. sorted, abn. horz. burrows, crbd; large-scale, tab.-shaped sets of low-angle pl cr-bd. with noneros. l. contact	14	9	(4.50)
3-21	ss, dr. yel. br., vfri., fgrn. to mgrn., v. poorly sorted	-	6	(.15)
3-20	ss, mod. yel., vfri., vfgrn., mod-sorted	2	10	(.85)
3-19	ss, gr. yel., vfri., vfgrn., mod. sorted, abn. biotur.	7	7	(2.30)
3-18	ss, gr. yel., vfri., vfgrn., mod-	-	5	

	sorted, biotur., carb.			(.12)
3-17	ss, lt. gr., vfri., vfgrn., poorly-sorted, carb.	7	10	(2.40)
3-16	ss, lt. gr., vfri., vfgrn. to fgrn., poorly sorted, carb.	11	2	(3.40)

Base of member

Total measured thickness of Fite Ranch Sandstone Member
of Tres Hermanos Formation
61 ft (18.60 m)

3-15	partly covered, probably sh	13	2	(4.00)
3-14	ss, mod. yel. br., fri., fgrn., poorly-sorted	-	10	(.25)
3-13	partly covered, probably sh	1	6	(.35)
3-12	ss, yel. gr., fri., fgrn., mod. sorted	2	-	(.60)
3-11	partly covered, probably sh	5	4	(1.60)
3-10	ss, pale yel. or., vfri., fgrn., mod-sorted, tn. bd., crbd; med-scale, wedge- and tab.-shaped sets of low-angle cr-bd. with eros. l. contact	4	3	(1.30)
3-9	partly covered, probably sh	3	7	(1.10)
3-8	ss, gr. or., mod. ind., fgrn., mod-sorted	1	6	(.35)
3-7	partly covered, probaly sh and ss	3	3	(1.00)
3-6	sls., v. lt. gr., well-sorted, biotur.	-	8	(.20)
3-5	parly covered, probably ss, pt. wood	7	9	(2.35)
3-4	[illegible] gr., silty	-	4	(.10)

3-3 bentonite - 2 (.05)

Base of member

Total measured thickness of Cathage Member
of Tres Hermanos Formation
43 ft 6 inches (13.25 m)

3-2 ss, yel. gr., vfri. to fri., vfgrn. to fgrn., crns. upward, mod. sorted, crbd; sm.- and med.-scale, wedge- and tab.-shaped sets of low-angle pl. cr-bd. with eros. l. contact local lenses of ss, v. lt. gr., wea. dusky yel. br.,fri. to mod. ind., mgrn., v. poorly sorted, sh partings, wood frag., vfos; 11 2 (3.40)

<u>Crassostera</u> <u>soleniscus</u> (Meek)

Base of member

Total measured thickness of Atarque Sandstone Member
of Tres Hermanos Formation
11 ft 2 inches (3.40 m)

3-1 partly covered, probably silty sh 10 6 (3.20)

Total measured thickness of Rio Salado Tongue of Mancos Shale
10 ft 6 inches (3.20 m)

Section IV

La Joya quadrangle 7 1/2 minute, NW 1/4, sec. 5, T. 1 S., R. 2 E., Socorro County, New Mexico; measured July 21, 1980, by B. Baker using a Brunton Compass and a Jacob staff. Section covers interval in the Crevasse Canyon Formation.

Unit	Description	Thickness FT.	 In.
4-13	sh, med. gr., crns. upward	11 (3.60)	10
4-12	ss, yel. gr., mod. ind., vfgrn., mod-sorted, ripple marks	1 (.40)	3
4-11	sh, med. gr., crns. upward	1 (.30)	-
4-10	ss, v. lt. gr., vfri., vfgrn., mod-sorted, carb.	2 (.60)	-
4-9	sh, yel. br., silty, abncarb.	- (.23)	4
4-8	ss, pinkish gr., vfri., vfgrn., mod-sorted, carb.	9 (2.95)	8
4-7	sh, br. gr., abncarb.	- (.23)	4
4-6	coal	- (.15)	6
4-5	sh, mod. br., silty, abncarb.	1 (.45)	6
4-4	ss, yel. br., vfri., vfgrn., poorly-sorted, carb., tn. lam.	2 (.65)	1
4-3	sh, br. gr.	2 (.75)	5
4-2	ss, mod. br., vfri., fgrn., yel. stained	- (.15)	6

4-1	ss, v. pale or., vfri., vfgrn., mod-sorted, concretions	3	3 (1.00)

Total measured thickness of Crevasse Canyon Formation
37 ft 1 inch (11.31 m)

Section V

Mesa del Yeso 7 1/2 minute quadrangle, SE 1/4, sec. 5, T. 1 S., R. 2 E., Socorro County, New Mexico; measured July, 26-31, by B. Baker using a Brunton compass and a Jacob staff. Section covers interval from base of Dakota Sandstone to the Crevasse Canyon Formation.

Unit	Description	Thickness Ft.	In.	
5-79	sh, lt. br. gr., silty	3	3	(3.28)
5-78	ss, gr. or., fri., vfgrn.to fgrn., poorly sorted, sh partings	-	6	(.15)
5-77	sh, br. gr., silty	-	10	(.25)
5-76	ss, pale yel. br., vfri., vfgrn., poorly sorted, yel. stained	-	4	(.10)
5-75	coal	-	10	(.25)
5-74	sh, pale br., abncarb., yel. stained, plant frag.	-	4	(.33)
5-73	ss, v. lt. gr., vfri. to fri., vfgrn., well-sorted, v. tn. bd., carb. top 8 in. (20 cm)	4	-	(1.20)
5-72	sh, pale br., anbcarb., yel. stained	-	4	(.33)
5-71	ss, lt. br. gr., vfri., vfgrn., interbd carb.	2	1	(.65)
5-70	sh, br. gr., silty	-	6	(.15)
5-69	ss, pinkish gr., fri., vfgrn., mod-sorted, carb., tk. lam.	2	-	(.60)
5-68	partly covered, probably sandy sh	7	4	(2.20)
5-67	ironstone, gr. bl., wea. dr. yel. or. to med. red br., cone-in-cone	-	4	(.10)

5-66	sh, med. dr. gr.	2	10	(.80)
5-65	sh, pale yel. br., silty, interbd., ss, vfgrn., 4 in. (10 cm) tk.	3	3	(1.00)
5-64	partly covered, probably sh and vfri. ss	19	-	(5.80)
5-63	ss, gr. or., wea. dr. yel. br., mod. ind., fgrn., poorly sorted, tn. bd., cal. v. poorly sorted	-	10	(.25)
5-62	ss, gr. or., vfri., fgrn. to mgrn.,	5	6	(1.70)
5-61	sh, mod. br., silty, carb.	-	4	(.10)

Base of formation

Total measured thickness of Crevasse Canyon Formation
61 ft. (18.59 m)

5-58	covered interval, probably vfri. ss	3	8	(1.10)
5-57	ss, lt. gr., vfri., vfgrn., mod. sorted	13	9	(4.20)

Base of formation

Total measured thickness of Gallup Sandstone
17ft. 5 in. (5.30 m)

5-56	sh, med. gr., silty, concrections, 1 ft. (30 cm) dia.	140	-	(42.67)
5-55	ss, yel. br., wea. pale yel. br., wind., mod. sorted, fgrn., tn. bd., abn. horz. burrows and trails, local fos. lenses; *Lohpa sannionis* (White)	-	6	(.15)
5-54	ss, dusky yel., wea. mod. yel. br., vfri., vfgrn., well-sorted, cal., abn. concretions, 5 ft. 4 in., (1.60 m) dia., wea. yel. gr., mod. ind., vfgrn., cal., marker bed, fos; USGS Mesozoic fossil locality D 10288 *Lohpa sannionis* (White)	3	3	(1.00)

Forresrteria sp.
Baculites yokoyamai
Tokugmaga and Shimizu

5-53	ss, gr. or., mod. ind., vfgrn., well-sorted, abn. horz. and inclined burrows, cal.	1	-	(.30)
5-52	ss, v. pale or., vfri. to fri., vfgrn., well-sorted, slcal., shell frag. crbd; sm.- to med.-scale, wedge-shaped sets of low-angle tang.. cr-lam. with noneros. l. contact	2	10	(.85)
5-51	ss, gr, or., mod. ind., vfgrn., well-sorted, nodular	1	-	(.30)
5-50	sh, pale yel. br., crns. upward, interbd. ss, 2 in. (5 cm) tk., carb.	10	6	(3.20)
5-49	ss, gr, yel., mod. ind., vfgrn., mod. sorted, tn. lam.	1	4	(.40)
5-48	sh, pale yel. br., crns. upward	8	6	(2.60)
5-47	ss, lt. gr., fri., vfgrn., mod. sorted, shell frag.	7	6	(2.30)
5-46	sh, lt. or. br., silty, septarian concretions, 40 ft. (12.20 m) above base fos; *Prioncyclus novimexicanus* (Marcou) concrection 28 ft. (8.5 m) below fossilierous sandstone, in vfri ss	172	2	(52.48)
5-45	calcareinte, pale yel. br., wea. dr. yel. br., fgrn., tk. lam., abnfos; *Prionocyclus wyomingensis* Meek, *Lopha lugubris* (Conrad), *Inoceramus* sp.	1	1	(.33)
5-44	sh, med. gr.	-	8	(.20)
5-43	calcarenite, pale yel. br., wea. dr. yel. br., fgrn., tn. lam., abnfos; *Prionocyclus wyomingensis* Meek, *Scaphites warreni* Meek and Hayden, *Lopha lugubris* (Conrad), *Inoceramus* sp.	-	6	(.15)

Base of tongue

Total measured thickness of D-Cross Shale Tongue of Mancos Shale
350 ft 7 inches (108.27 m)

5-42	partly covered, ss, carbonate apatite replacement nodules of pelecypods and gastorpods, <u>Lopha bellaplicata</u> (Shumard)	1	7 (.50)
5-41	ss, gr. or., wea. mod. yel. br., wlind., fgrn., mod. sorted	-	6 (.15)
5-40	ss, yel gr., fri., fgrn., mod. sorted, tn. bd.	7	5 (2.25)
5-39	ss, gr. or. pink, wea mod. br., fri., fgrn., mod. sorted	1	7 (.50)
5-38	ss, dusky yel., fri., fgrn., mod. sorted, biotur. top, horz. burrows, goethite replacement of pyrite	7	7 (2.30)
5-37	ss, or. gr., fri., fgrn., poorly sorted	3	- (.90)
5-36	ss, v. lt. gr., vfri., vfgrn., well-sorted, purple stained, horz. burrows	6	11 (2.10)
5-35	ss, gr. or., vfri., vfgrn., poorly sorted, vert. burrows	1	10 (.55)

Total measured thickness of Fite Ranch Sandstone Member
of Tres Hermanos Formation
30 ft. 4 in. (9.25 m)

Faulted, Carthage and Atarque Sandstone Members missing, top of Rio Salado Tongue and bottom of Fite Ranch Sandstone Member also missing.

5-34	sh, med. dr. gr., silty	30	- (7.00)

Base of tongue

Total measured thickness of Rio Salado Tongue

5-33	ss, med. lt. gr., vfri., top 3 ft. (90 cm) vfos; <u>Pycnodonte newberryi</u> (Stanton)	63 (19)	-

Base of tongue

Total measured thickness of Twowells Tongue of the Dakota Sandstone 63 ft (19 m)

5-32	sh, lt. ol. gr., silty	4	6	(15.70)
5-31	bentonite	-	3	(.07)
5-30	sh, med. gr., silty	1	8	(.50)
5-29	sls, v. lt. gr.	-	3	(.07)
5-28	sh, ol. gr., silty	42	-	(12.80)
5-27	bentonite	-	4	(.11)
5-26	sh, med. gr., silty	10	6	(3.20)
5-25	bentonite	-	2	(.05)
5-24	sh, med. gr., silty	1	-	(.35)
5-23	bentonite	-	4	(.10)
5-22	sh, med. gr., silty	-	8	(.20)
5-21	bentonite	-	1	(.07)
5-20	sh, med. dr. gr., silty, interbd. sls., fos; Incoreamus sp.	15	9	(4.80)
5-19	covered interval probably silty sh	9	2	(2.80)
5-18	sls, lt. med. gr.	1	-	(.30)
5-17	sh, v. lt. gr., silty, interbd. sls, 1-2 in. (1 cm) tk., fos; Inoceramus sp.	7	11	(2.40)
5-16	ss, lt. gr., mod. ind., fgrn., mod-sorted, burrowed top, fos; Ostrea beloiti Logan	-	4	(.10)

5-15	sh, med. gr., silty	-	9	(.24)
5-14	bentonite	-	2	(.06)
5-13	sh, lt. ol. gr., silty, interbd. sls, slcal, tn. lam., fos; Inoceramus sp	16	8	(5.10)
5-12	covered interval, probably silty sh	3	3	(1.00)
5-11	ss, v. pale or., fri., vfgrn. to fgrn., poorly sorted, fos; USGS Mesozoic fossil locality D 11352 Plesiacanthocerces wyominginse Reagan, Ostrea beloiti Logan	-	2	(.06)
5-10	partly covered, probably sh	-	9	(.23)
5-9	ss, yel. gr., mod. ind., vfgrn., mod. sorted, fos; Ostrea beloiti Logan	-	2	(.05)
5-8	ss, gr. or. pink, fri., fgrn., mod. sorted, fos; Ostrea beloiti Logan	-	7	(.18)
5-7	ss, yel. gr., mod. ind., fgrn., mod. sorted, wood frag., fos; shark teeth, skeletal frag., USGS Mesosoic fossil locality D 11245 Calycoceras (Conlinoceras) gilberti Cobban and Scott Ostrea beloiti Logan	-	3	(.08)
5-6	partly covered, probably vfri. ss, goethite and goethite replacing pyrite nodules	-	10	(.25)

Base of tongue
Total measured thickness of lower tongue of Mancos Shale
202 ft. 6 in. (61.72 m)

5-5	ss, v. pale or., mod. ind., fgrn., crns. upwards, mod. sorted, abn. biotur., abn. horz. burrows, wh. nodules, forms dip slope	3	3	(1.00)
5-4	ss, dr. yel. or., vfri., fgrn., mod-sotred	2	4	(.70)
5-3	ss, lt. br. gr., vfri., vfgrn. to fgrn., poorly sorted, interbd. carb.	22	-	(6.70)
5-2	sh, med. dr. gr., silty	17	5	(5.30)

5-1	ss, pale br., mod. ind., vfgrn. to fgrn., fines upwards, mod- to well-sorted, abn. biotur., local pebble cong lenses, abn. wood frag., carb., ripple marks	5 11 (1.80)

Base of formation

Total measured thickness of Dakota Sandstone
53 ft. 8 in. (16.35 m)

APPENDIX B

Terminology used for description of lithology and stratification

Color

Rock colors are taken from GSA Rock Color Chart (1979) and desribes both fresh and weathered surfaces unless otherwise noted:

Abbreviation	Color	Munsell System
wh.	white	N 9
v. pale or.	very pale orange	10 YR 8/2
gr. or.	grayish orange	10 YR 7/4
dr. yel. or.	dark yellowish orange	10 YR 6/6
pale yel. or.	pale yellowish orange	10 YR 8/6
pale pink	pale pink	5 RP 8/2
mod. or. pink	moderate orange pink	5 YR 8/4
gr. or. pink	grayish orange pink	10 R 8/2
gr. red	grayish red	5 R 4/2
bl. red	blackish red	5 R 2/2
mod. red	moderate red	5 R 4/6
dusky red	dusky red	5 R 3/4
lt. br.	light brown	5 YR 5/6
pale br.	pale brown	5 YR 5/2
pale yel. br.	pale yellowish brown	10 YR 6/2
lt. ol. br.	light olive brown	5 Y 5/6
mod. yel. br.	moderate yellowish brown	10 YR 5/4
mod. br.	moderate brown	5 YR 3/4
mod. red br.	moderate reddish brown	10 R 4/6
dr. red br.	dark red brownish	10 R 3/4
dr. yel. br.	dark yellowish brown	10 YR 2/2
gr. br.	grayish brown	5 Y 3/2
pale ol.	pale olive	10 Y 6/2
mod. yel.	moderate yellow	5 Y 7/6
dusky yel.	dusky yellow	5 Y 6/4
gr. yel.	grayish yellow	5 Y 8/4
yel gr.	yellowish gray	5 Y 8/1
lt. ol. gr.	light olive gray	5 Y 5/7
ol. gr.	olive gray	5 Y 3/2
lt. br. gr.	light brownish gray	5 YR 6/1
br. gr.	brownish gray	5 YR 4/1
pinkish gr.	pinkish gray	5 YR 8/1
v. lt. gr.	very light gray	N 8
lt. gr.	light gray	N 7
med. lt. gr.	medium light gray	N 6

med. gr.	medium gray	N 5
med. dr. gr.	medium dark gray	N 4
gr. bl.	grayish black	N 2

Grain size

Grain size of the sandstones using the Udden-Wentworth Scale (1922) were determined visually by the use of a grain size chart containing actual grains of each size.

Sorting

Sorting of the sandstones were determined visually with the use of sorting chart from Folk (1968).

Abundances

abundant, very	> 30%
moderate*	30% - 5%
sparse, slightly	< 5%

* Percentage for terms used in Appendix A that have no prefix.

Stratification

Terminology for the strata thickness is from Ingram (1954):

Very thickly bedded	>1 m.
Thickly bedded	30 - 100 cm.
Medium bedded	10 - 30 cm.
Thinly bedded	3 - 10 cm.
Very thinly bedded	1 - 3 cm.
Thickly laminated	.3 - 1 cm.
Thinly laminated	<.3 cm.

Classification of cross-stratified units is modified from McKee and Weir (1953) and Allen (1963). The scale of the cross-beds is based on the length of cross-stratum. The scale is divided into three parts, small scale less than 30 cm, medium scale .3-6 m, and large scale greater than 6 m. The shape of a set or coset of cross-beds is described as tabular-, wedge-, or trough-shaped. The cross-beds are grouped as either sets or cosets. The shape and angle of the cross-stratum is described as planar or tangential with a dip angle of high (greater than 20°) or low (less than

20^{o}). The thickness of the cross-stratum is described as bedding (greater than 1 cm), or lamination (less than 1 cm). The lower surface of the cross-bed is described as either erosional or nonerosinal.

APPENDIX C

Paleontology

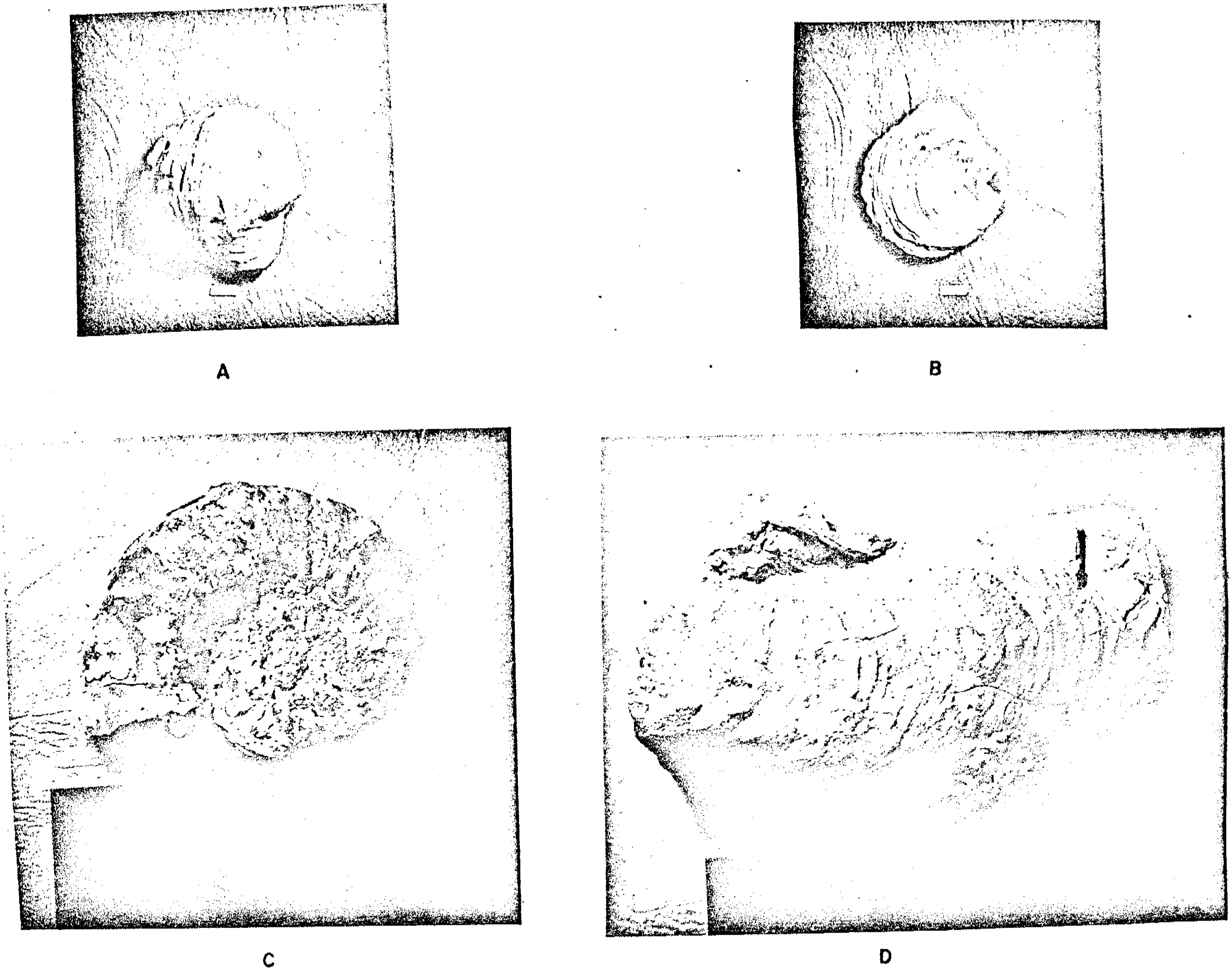


Figure C-1. *Pycnodonte newberryi* (Stanton) A-B (scale in mm), *Prionocyclus novimexicanus* (Marcou) C (scale 4 inches (10 cm)), and *Crassostrea soleniscus* (Meek) D.

Table C-1. Shark teeth faunal list.

- Class Chondrichthyes
  - Clade Hybodontiformes
    - Order Selachii
      - Suborder Ctenacanthoidei
        - Family Hybobontidei Owen, 1846
          - *Hybodus*
          - *Lonchidion* Estes, 1964
      - Suborder Anacoracoidei
        - Family Anacoracidae Casier, 1947
          - *Squalicorax* Whitley, 1939
          - *Squalicorax falcatus* (Agassiz), 1843
          - *Squalicorax* sp.
    - Order Lamniformes
      - Suborder Lamnoidei
        - Family Isuridae
          - *Lamna* Cuvier, 1817
          - *Lamna appendiculata*
          - *Lamna semiplicata* Agassiz, 1844
    - Order Heterodontiformes
        - Family Ptychodontidae Woodward, 1912
          - *Ptychodus* Agassiz, 1839
          - *Ptychodus whipplei* Marcou, 1858
  - Calde Euselachiformes
    - Order Euselachii
      - Suborder Squatinoidei
        - Family Squatinidae Bonaparte, 1838
          - *Squatina* sp.

- Family Orectolobidae
  - *Brachaelurus*
  - *Brachaelurus greeni* Cappetta, 1973
  - *Brachaelurus* sp.
  - *Cantioscyllium* Woodward, 1889
  - *Cantioscyllium decipiens* Woodward, 1889
- Family Mitsukurinidae Jordan, 1898
  - *Scapanorhynchus* Woodward, 1889
  - *Scapanorhynchus texanus* (Roemer), 1852
  - *Scapanorhynchus rhaphiodon* (Agassiz)
- Family Odontaspidae
  - *Odontaspis* Agassiz, 1838
  - *Odontaspis parvidens* Cappetta, 1973
- Family Cretoxyrhinidae Glyckman, 1958
  - *Cretoxyrhina* Glyckman, 1958
  - *Cretoxyrhina* sp.
  - *Cretolamna* Glyckman, 1958
  - *Cretolamna* sp.
  - *Plicatolamna*
  - *Plicatolamna arcutata* (Woodward)
  - *Plicatolamna* sp.
- Family Alopiidae Bonaparte, 1838
  - *Paranomotodon*
  - *Paranomotodon* sp.

Order Rajiformes

Suborder Rhinobatoidei

Family Rhinobatidae

Rhinobatos

Rhinobatos sp.

Family Sclerorhynchidae

Pucapristis Schaeffer, 1963

Pucapristis n.sp.

Suborder Pristoidei

Family Pristidae

Subfamily Granopristinae Arambourg, 1935

Ischyriza Leidy, 1856

Ischyriza mira Leidy, 1856

Ischyriza aconicola Estes (1968)

insertae sedis

Ptychotrygon Jaekel, 1894

Ptychotrygon sp.

Suborder Dasyatoidei

Family Myliobatidae Bonaparte, 1838

Subfamily Myliobatinae

Brachyrhizodus Romer, 1942

Brachyrhizodus sp.

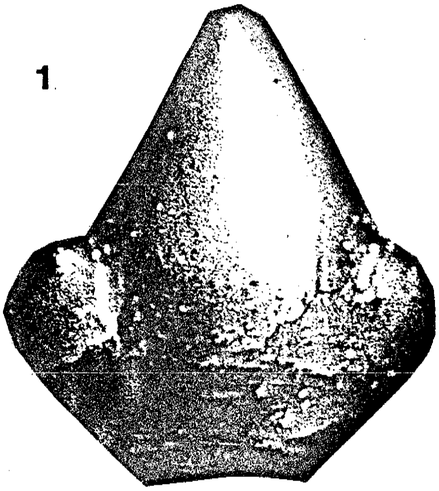
Rhombodus

Rhombodus sp.

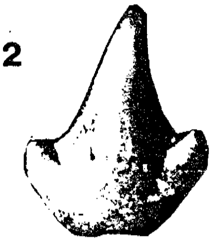
Dayatoides sp.

Figure C-2. Shark teeth found in Atarque Sandstone Member; 1 *Brachaelurus* sp. (x 30), 2 *Brachaelurus greeni* (x 15), 3 *Paranomotodon* sp. (x 5), 4 *Plicatolamna* sp. (x 10), 5 *Odontaspis parvidens* (x 15), 6 *Ptychotrygon* sp. (x 10), 7 *Cretolamna* sp. (x 7), 8 *Squalicorax* sp. (x 5), 9-10 *Scapanorhynchus texanus* (x 5), 11 *Hybodus* sp. (x 15), 12 *Ischirhiza mira* (x 10), 13 *Ischirhiza avonicola* (x 15), 14 c.f. *Squatina* (x 13).

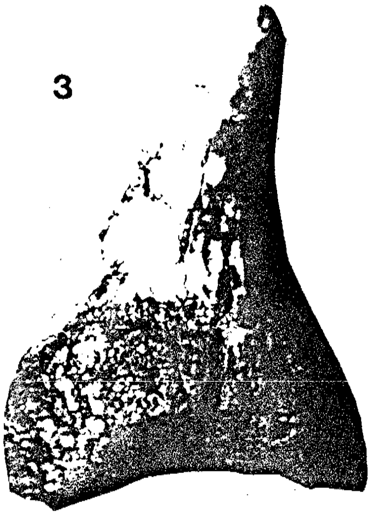
1



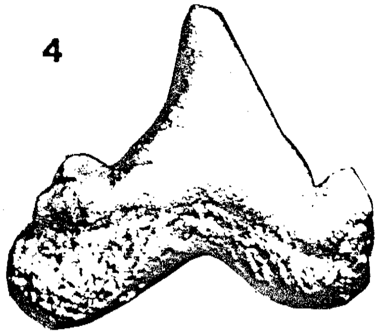
2



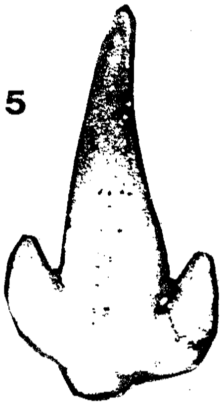
3



4

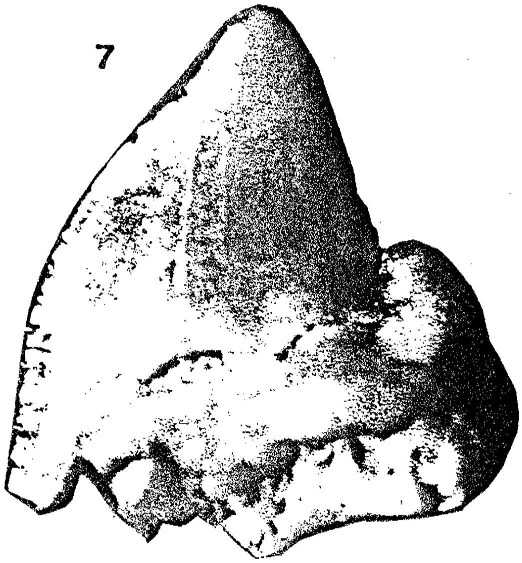


5

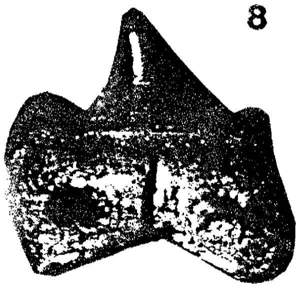


6

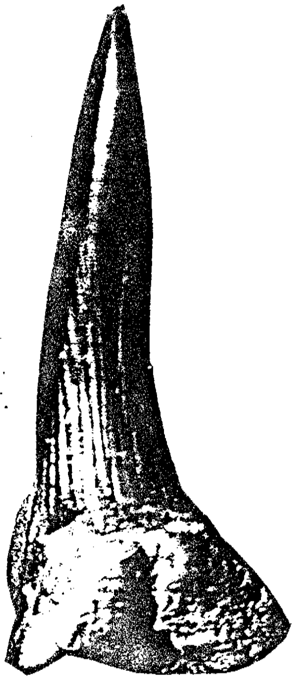
7



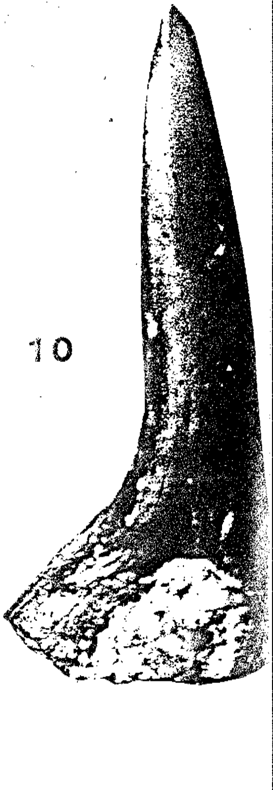
8



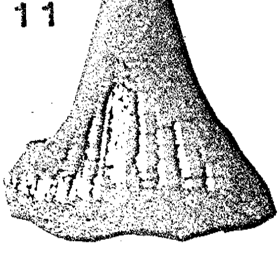
9



10

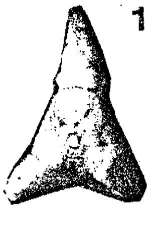


11



12

13



14