STRATIGRAPHY AND PALEOENVIRONMENTS
OF THE
ENGLE COAL FIELD, SIERRA COUNTY, NEW MEXICO

by

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of the Requirements for the Degree of
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Abstract

The Engle coal field of south-central New Mexico contains approximately 3,000 feet of interbedded Upper Cretaceous pebble conglomerates, sandstones, siltstones, mudrocks and coals. These siliciclastic rocks represent a marine to fluvial facies transition deposited during the widespread late Turonian-early Coniacian regression of the Western Interior seaway. Infilling of the basin by progradation of fluvially-dominated depositional systems was interupted by a regionally significant transgression. Progradations recorded by the Tres Hermanos Formation and the Mesaverde Group are separated by the D-Cross Tongue of the Mancos Shale. These depositional systems contain rocks deposited in marine, marginal marine, and continental environments. Marine and marginal marine rocks represent offshore, distributary mouth bar, shoreface, beach, lagoonal, and washover fan subenvironments. Fluvial subenvironments are represented by channel, swamp, overbank, natural levee, crevasse splay, and point bar deposits. Sediment dispersal was predominantly toward the north-northeast. Guide fossils indicate that the base of the sequence is early Turonian in age, but the age of the top of the sequence is uncertain and may range from Coniacian to Maestrichtian.

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Acknowledgements

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Introduction: Purpose

The Upper Cretaceous Series of the San Juan Basin has been intensively studied throughout this century. Upper Cretaceous strata in south-central New Mexico have received comparatively little study until recently (McLafferty, 1979; Baker, 1981; Hook, Molenaar, and Cobban, in press; Jensen, in prep.; Arkell, in prep.; this study).

The overall objective of this study is a detailed stratigraphic analysis of the Engle coal field in south-central New Mexico. Specific objectives include:

1) interpretation of the spatial variability of facies and their paleoenvironments
2) incorporation of the Engle field siliciclastic sequence into the existing stratigraphic framework in New Mexico
3) determination of coal seam extent
4) proposal of depositional models

Most of the previous work done in the Engle field area has been general geologic mapping. Only vague suggestions have been made concerning the origin of facies in this area. Recent advances in clastic sedimentology allow detailed interpretation of paleoenvironments represented by these interbedded sandstones, siltstones, mudrocks, and coals, as well as refinement of the stratigraphic nomenclature.

Methods

Initial investigation involved examination of aerial photographs and reconaissance geologic mapping at a scale of 1:24000 to determine suitable locations for stratigraphic section measurement. A geologic map of lithostratigraphic units was constructed on an enlarged version of the U. S. Geological Survey Engle 15 minute quadrangle (Plate 1). Since the purpose of this investigation is stratigraphic and not structural, the map was constructed as a supplement to measured sections and other field observations. Many small faults and folds are not shown on Plate 1. Contacts shown for the southern portion of the area are slightly inaccurate, since faulting and igneous intrusions have significantly disturbed the stratigraphic succession. These localities include Sections 16, 17, 18, 20, 21, 28, and 29, T14S, R3W.

Three relatively complete sections were measured with a Jacob's staff and steel tape. Stratigraphic section measurement was concentrated near the northern portion of Mescal Creek, where relatively undeformed, steeply dipping strata provide good exposures. Selected lithologic samples were collected during section measurement for laboratory analyses. Field descriptions of component facies emphasize lithology, thickness, nature of contacts, grain size distribution trends, sedimentary structures and fossil content. Attitude of directional sedimentary structures and true bedding were recorded using a Brunton compass. A stereographic projection was used to restore paleocurrent measurements to their original orientations, thereby allowing paleocurrent analysis.

All recorded data are compiled on a N-S stratigraphic cross section with a vertical exaggeration of 13x (Plate 2). The cross section datum is the top of the Fite Ranch Sandstone Member of the Tres Hermanos Formation, which is considered to represent an approximately horizontal depositional surface based on its environmental interpretation. Hook, Molenaar, and Cobban (in press) mention that "the top of the Fite Ranch appears to be virtually synchronous" near Truth or Consequences, New Mexico. The relative confidence limits of different correlations is shown by means of a line code.

Petrographic study of representative sandstones involved examination of 18 thin sections. Relative abundances of clay mineral groups in selected samples was determined by semiquantitative analysis of diffractograms from x-ray diffraction. Paleontological analysis included identification of macrofossils and consideration of their biostratigraphic and paleoecologic significance.

Geographic Location

The Engle coal field is located on the eastern flanks of the Northern Caballo Mountains east of Truth or Consequences, Sierra County, New Mexico, as shown in Figure 1. The study area covers approximately 25 square miles (64

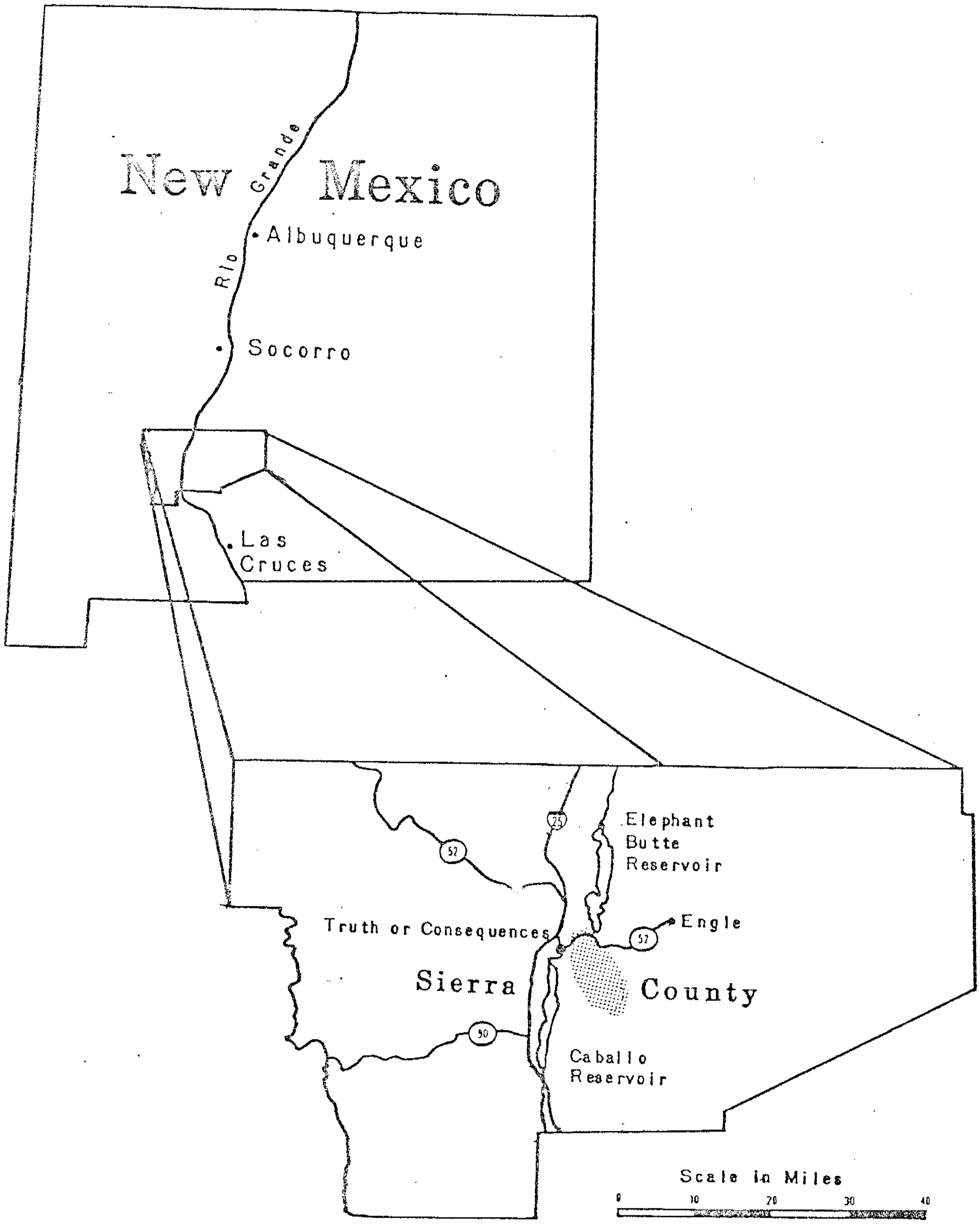


Figure 1 : Location map, study area shown by stippled pattern on Sierra County detail.

sq. km) , and lies within T13S, T14S, R3W, and R4W New Mexico Principal Meridian. Access to the southern portion of the study area may be gained by turning south off State Route 52 onto County Road 6, which connects with the Durham Ranch road system to the west. These roads are passable, but 4-wheel drive vehicles are recommended. Accessibility is otherwise limited to hiking from State Route 52.

Geologic and Tectonic Setting

The Engle coal field is situated on the eastern margin of the Rio Grande rift (Hawley, 1978) in south-central New Mexico. The study area lies in the Cutter Sag (Kelley, 1955) and along the eastern flank of the northern Caballo Mountains as shown in Figure 2. The Upper Cretaceous Series is underlain by rocks of the Permian, Pennsylvanian, Ordovician, and Cambrian Systems, which are in turn underlain by Precambrian basement rocks. Structural geology and Paleozoic stratigraphy of the Caballo Mountains are discussed in detail by Doyle (1951); Kelley and Silver (1952), and Mason (1976).

Upper Cretaceous strata crop out on the western limb of the Jornada del Muerto syncline. This study is concerned with siliciclastic rocks stratigraphically above the Mancos Shale and stratigraphically below volcaniclastic deposits of the McRae Formation. The study area is bounded to the north by the Hot Springs fault, and to the south and east by largely covered terrain. Outcrops of Mancos Shale form the

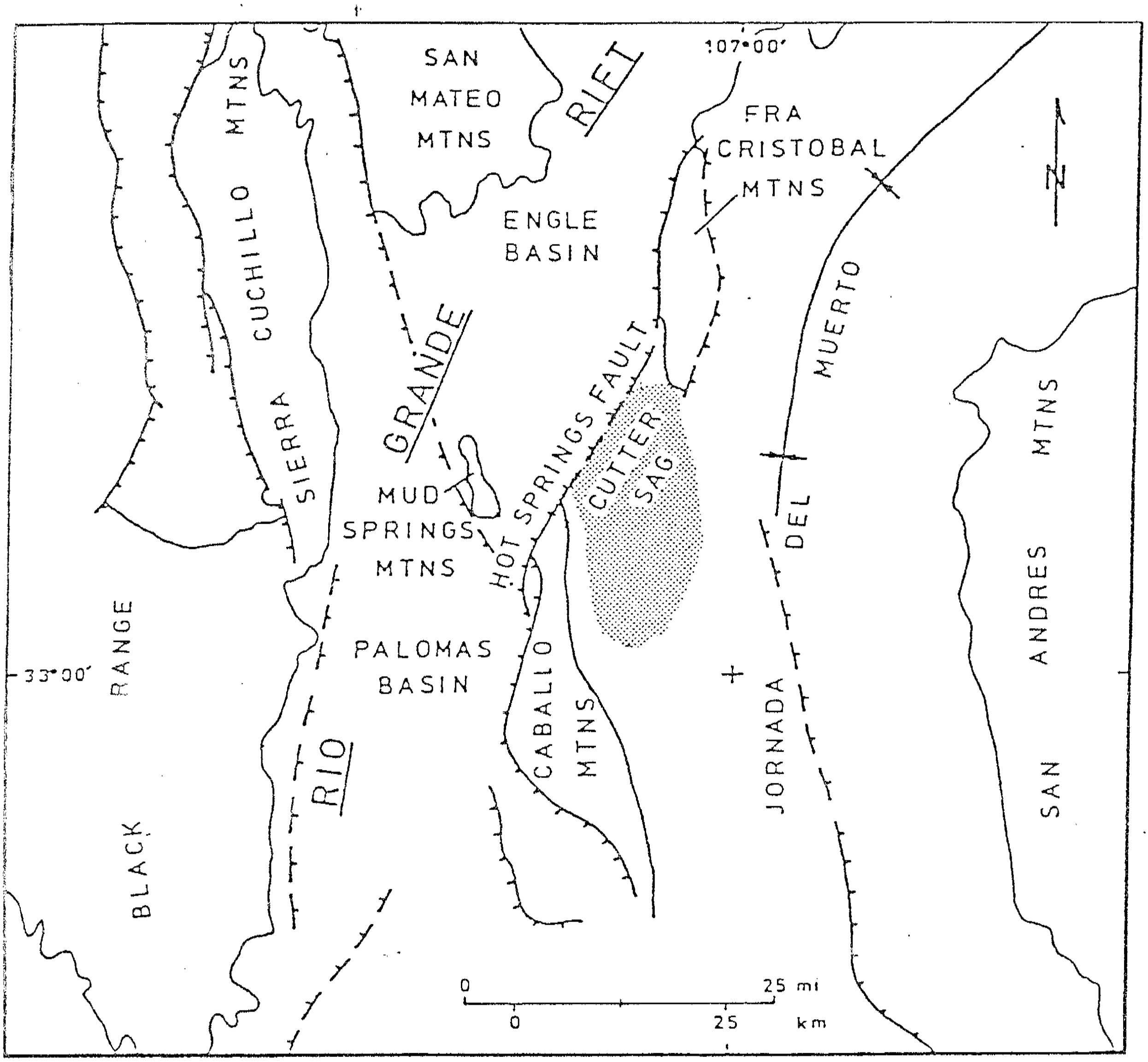


Figure 2 : Tectonic setting map, study area shown by stippled pattern (modified from Lozinsky, 1982)

western boundary.

This interval contains Upper Cretaceous terrigenous clastic deposits which have commonly been treated as a single unit by previous workers. These clastic deposits have a gradational contact with the underlying Mancos Shale, which in turn rests on the Dakota Sandstone. This interval is overlain by volcaniclastic deposits of the Upper Cretaceous-Lower Tertiary McRae Formation.

Cenozoic units consist of a variety of sedimentary and igneous rocks. Products of igneous activity include dikes, sills, and basalt flows, while sedimentary cover includes pediments, terraces, and alluvium. Dikes and faults commonly disturb or offset stratigraphic relationships, especially in the southern portion of the area (see Plate 1). The parallel character of igneous intrusions and the nature of stratigraphic offset associated with them indicate that they may be fault-controlled.

Previous Work

The Engle coal field was named by Lee (1905, p. 240) for the town of Engle, a railway station on the Atchison, Topeka, and Santa Fe Railway about 100 miles (138 km) north of El Paso, Texas. He reported coal-bearing strata near the base of a several thousand foot (metres) thick Cretaceous sandstone and shale sequence. Stratigraphic nomenclature applied to the Engle field area by previous workers is summarized in Figure 3.

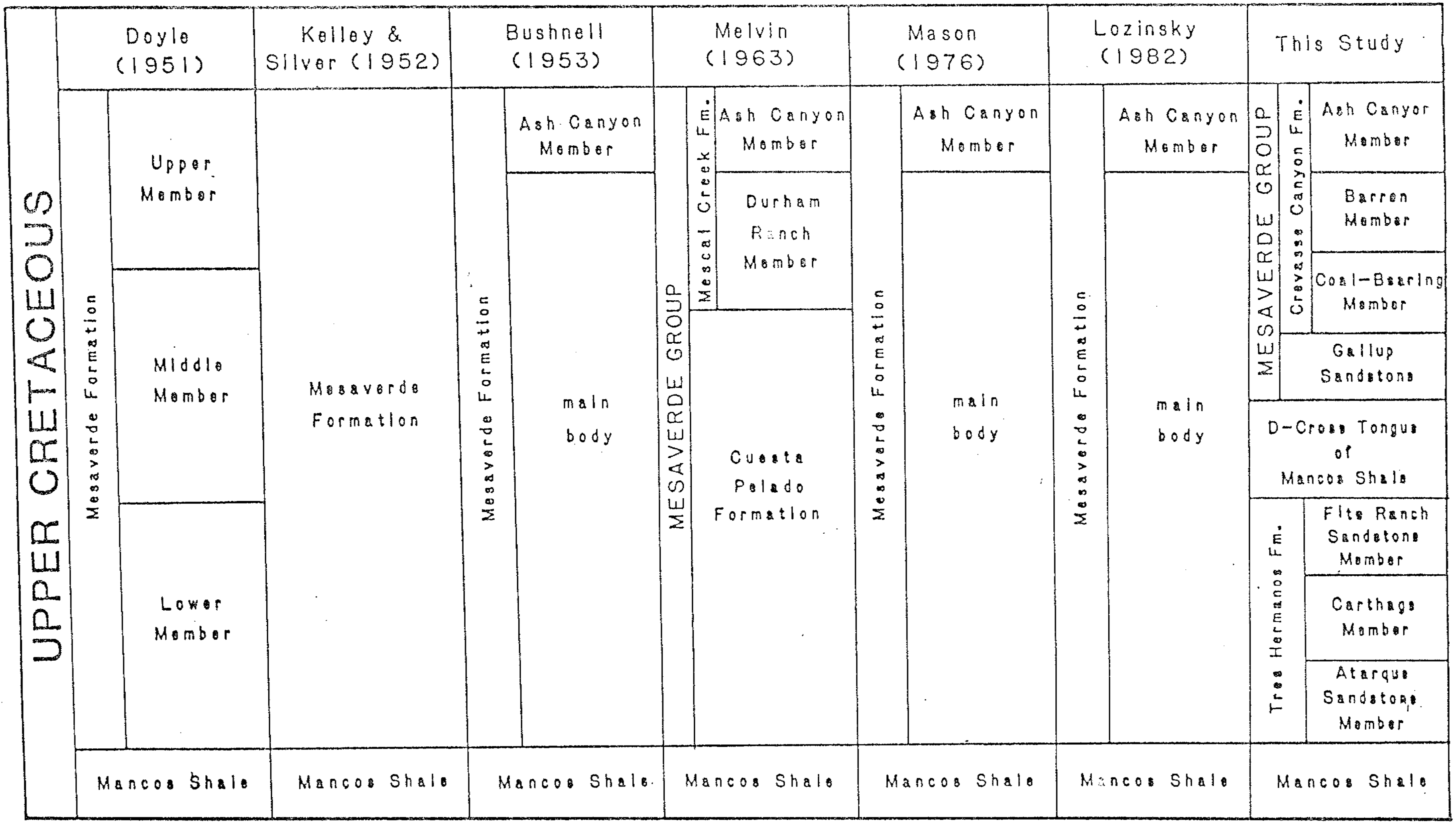


Figure 3 : Summary of stratigraphic nomenclature applied to the siliciclastic sequence of the Engle coal field (not to scale)

Doyle (1951, p. 25) mapped this sequence as the 3,375 foot (1029 m) thick Mesaverde Formation, and informally subdivided it into three members. Kelly and Silver (1952) estimated a thickness of 2,500 feet (762 m) for the Mesaverde Formation. Bushnell (1953) informally divided the Mesaverde Formation into two members, designating the pebble conglomerate at the top of the Mesaverde Formation as the Ash Canyon Member. He designated the thick lower portion of the Mesaverde as the main body member.

Allen and Balk (1954) elevated the Mesaverde to group status. Melvin (1963, p. 25) subdivided the Mesaverde Group into two formations, one of which was further subdivided into two members. Mason (1976, p. 58) and Lozinsky (1982, p. 17) followed the convention of Bushnell (1953). Tabet (1980) briefly summarized the geology of the Engle field.

Stratigraphy and Paleoenvironments: Introduction

The Engle coal field contains approximately 3,000 feet (914 m) of siliciclastic rocks consisting of pebble conglomerates, sandstones, siltstones, mudrocks, and coals. This sequence was deposited during the widespread Late Turonian-Early Coniacian regression of the western interior seaway (Figure 4). A generalized column of the stratigraphic momenclature used herein is shown in Figure 5.

The basal unit of the Upper Cretaceous Series is the Dakota Sandstone which consists of siliceous sandstones and shales (Melvin, 1963, p. 20). The Dakota is overlain by the

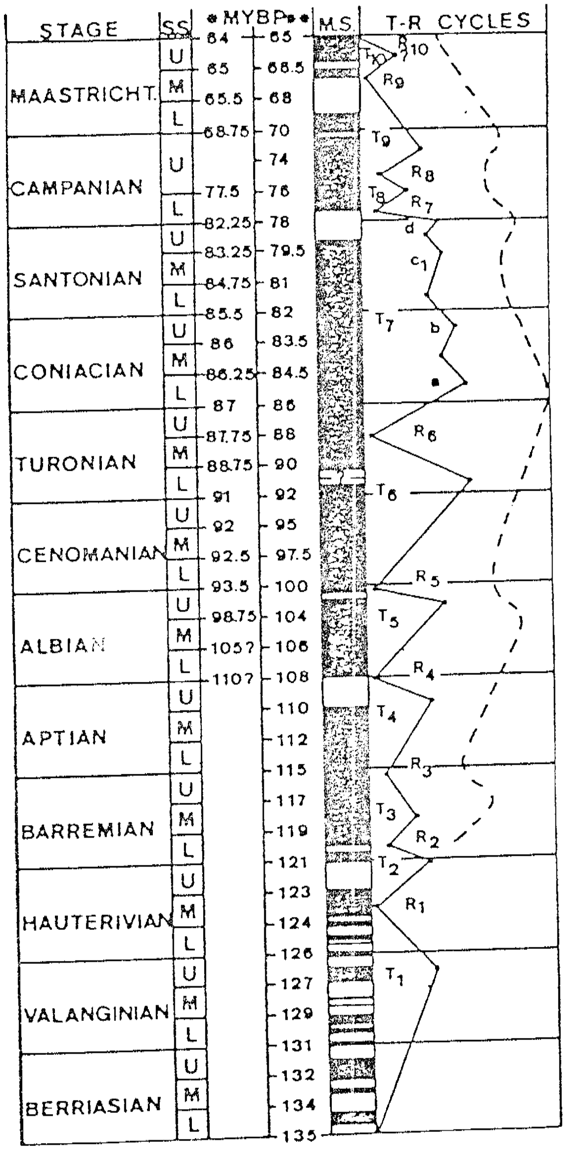


Figure 4 : Generalized radiometric time scale for the marine Cretaceous sequence in the Western Interior of North America. The Engle field sequence was deposited during the R6 regression (modified from Kauffman, 1977)

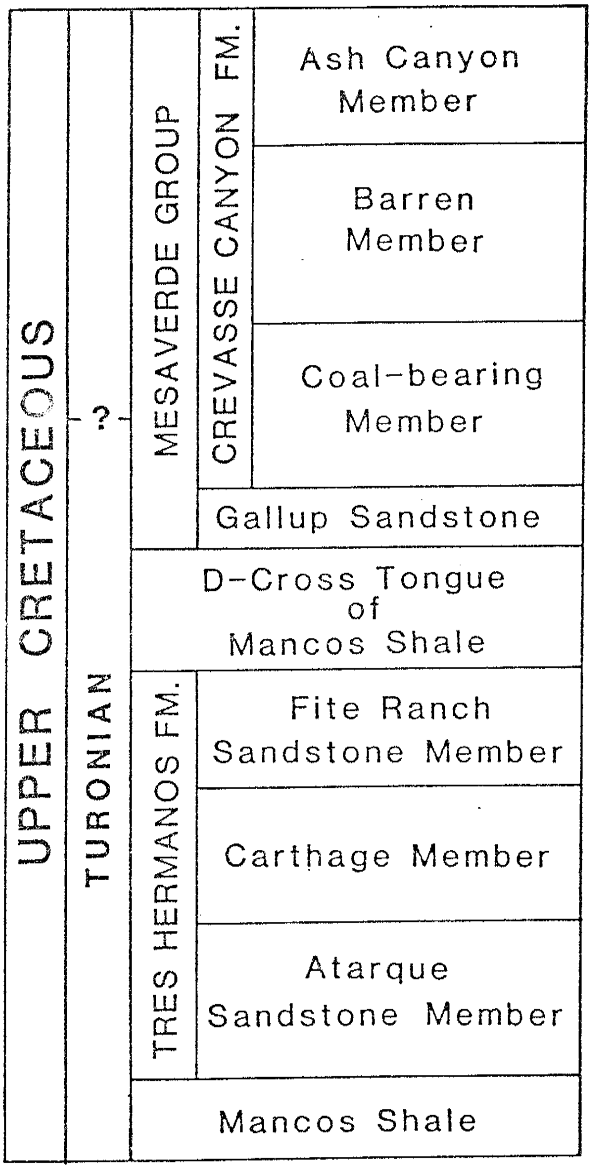


Figure 5 : Generalised column of stratigraphic nomenclature applied to the Engle field sequence in this study. Not to scale.

Mancos Shale which consists of silty shale, limestone, siltstones, and sandy shale with minor calcareous sandstone (Melvin, 1963, p. 22).

Melvin (1963, p. 21) interpreted the Dakota as marine and/or beach to lagoonal in origin. An open marine fauna has been collected from the Mancos Shale (Hook, 1983, unpub. data on file at New Mexico Bureau Mines and Mineral Resources). These fossils include ammonites, echinoids, corals, foraminifera, and oysters.

Figure 6 shows the orientation of the paleoshoreline during deposition of the D-Cross Tongue of the Mancos Shale, as well as the predominant directions of sediment dispersal during deposition of the Engle field sequence. The following sections of this paper describe siliciclastic rocks between the Mancos Shale and the McRae Formation.

Discussion of Stratigraphic Cross Section

Three measured sections shown in Plate 2 constitute the data base to which other field observations were compared. These sections were concentrated in the northern portion of the study area, where structural complexities are better understood.

Thicknesses for units stratigraphically below the Barren Member of the Crevasse Canyon Formation are taken from Section IV which was measured in lower Mescal Creek. In Sections I and III, this interval has been disturbed by faulting and dikes.

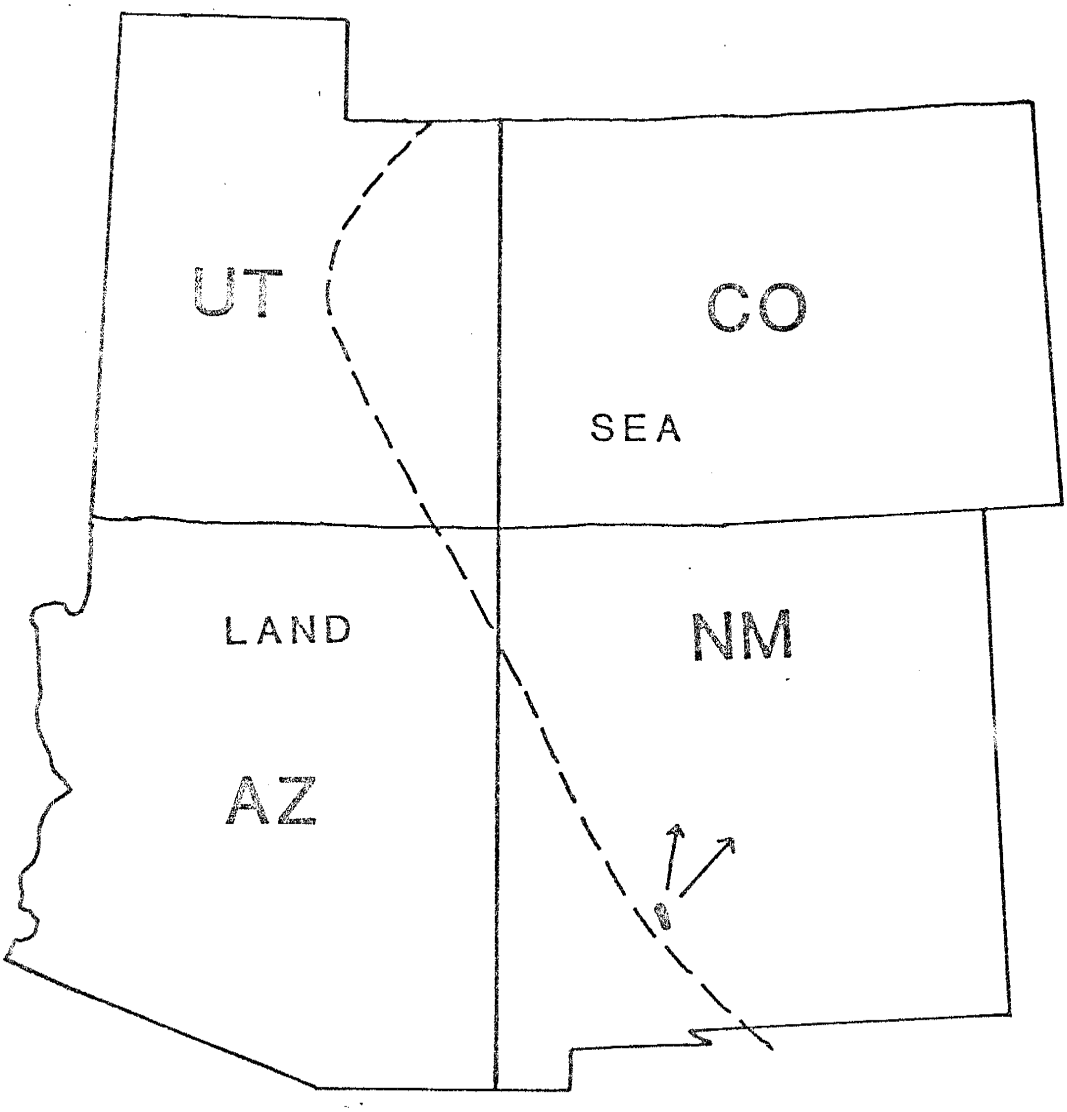


Figure 6 : Generalized paleoshoreline trend during the late Turonian. Study area shown in solid black. Arrows indicate predominant sediment dispersal directions (modified from Hook and Cobban, 1979)

Thicknesses for the Barren and Ash Canyon Members of the Crevasse Canyon Formation were taken from Section I. In Section IV, faulting has omitted part of the Barren Member, and erosion has removed part of the Ash Canyon Member. In Section III, faulting has apparently repeated part of the Barren Member, and the Ash Canyon Member is covered and eroded. Significant faults and the nature of their stratigraphic offset are indicated on Plate 2.

Tres Hermanos Formation: Introduction

The Mancos Shale is overlain by the tripartite Tres Hermanos Formation. The Tres Hermanos consists of the Atarque Sandstone Member at the base, the Carthage Member, and the Fite Ranch Sandstone Member at the top. The Tres Hermanos Formation has been referred to by other informal or obsolete names by previous workers. The nomenclature used herein follows that of Hook, Molenaar, and Cobban (in press). They designated a type section near Puertocito, New Mexico and a principal reference section near Carthage, New Mexico. Hook, Molenaar, and Cobban (in press) summarize the evolution of the nomenclature for these rocks. Correlation of units at Engle field with these sections is based on similarity in the succession of lithostratigraphic units.

Atarque Sandstone Member: Description

The Atarque Sandstone Member of the Tres Hermanos Formation overlies the Mancos Shale, and is a 75 foot (22 m) thick cliff-forming unit which crops out on the eastern side of the lowest reach of Mescal Creek. The Atarque is approximately tabular, although slight pinching and swelling occurs locally. The Atarque coarsens upward overall and consists of interbedded shales, siltstones, and very fine to fine-grained calcareous sandstones. A detailed stratigraphic section of the Atarque is shown in Figure 7.

The lower contact (Figure 8) is transitional with the underlying Mancos Shale, and is considered to be the base of several very thin to thin-bedded, very fine-grained sandstone beds. The lower 26 feet (8 m) of the Atarque consists of interbedded shales, siltstones, and structureless, very fine-grained sandstones. Bedding thickness of these sandstones increases upsection from several inches to about one foot and biogenic structures do not occur. These interbedded units are locally overlain by discontinuous lenses of light olive gray, very fine-grained sandstone which exhibit ball and pillow structures (Figure 9). These lenses average 5 feet (1.5 m) in thickness, and are laterally traceable for several hundred feet (metres). The overlying 9 foot (3 m) thick, yellowish gray, fine-grained sandstone (Figure 10) is very thinly ripple-bedded and locally contains very low angle cross-lamination. This facies grades laterally into 50 to

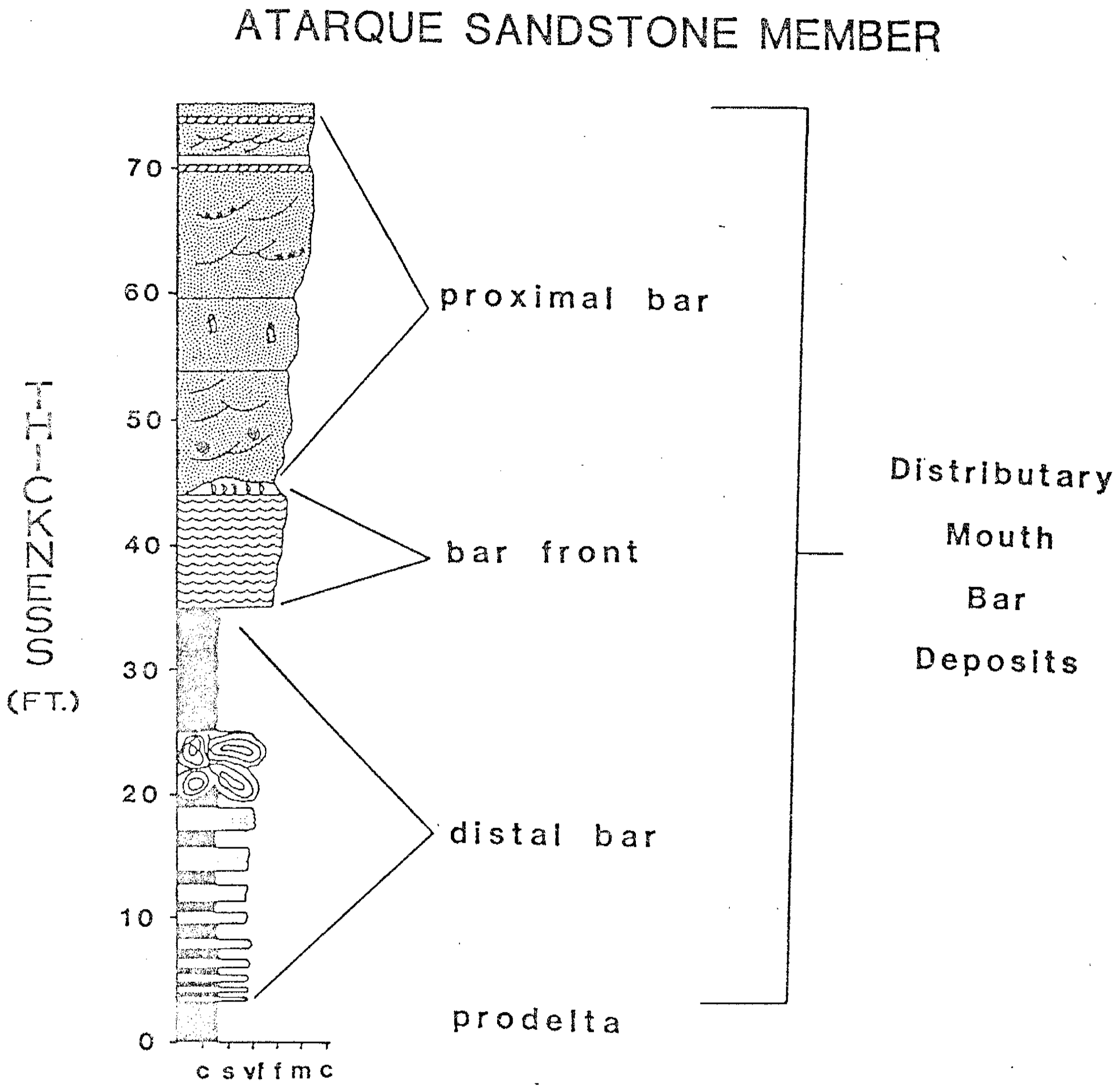


Figure 7 : Detailed section of the Atarque Sandstone Member measured in lower Mescal Creek.

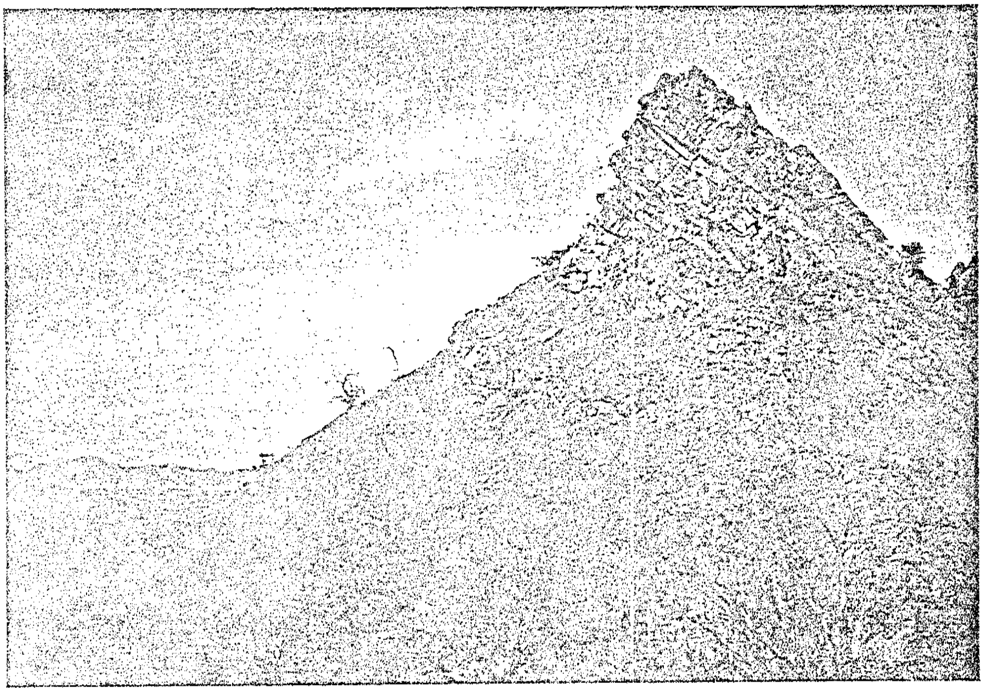


Figure 8 : Gradational contact between the Mancos Shale and the Atarque Sandstone Member (SW 1/4, Section 36, T13S, R4W)

Figure 9 : Ball and pillow structures occur locally near the top of the distal bar facies of the Atarque Sandstone Member (SW 1/4, Section 36, T13S, R4W)

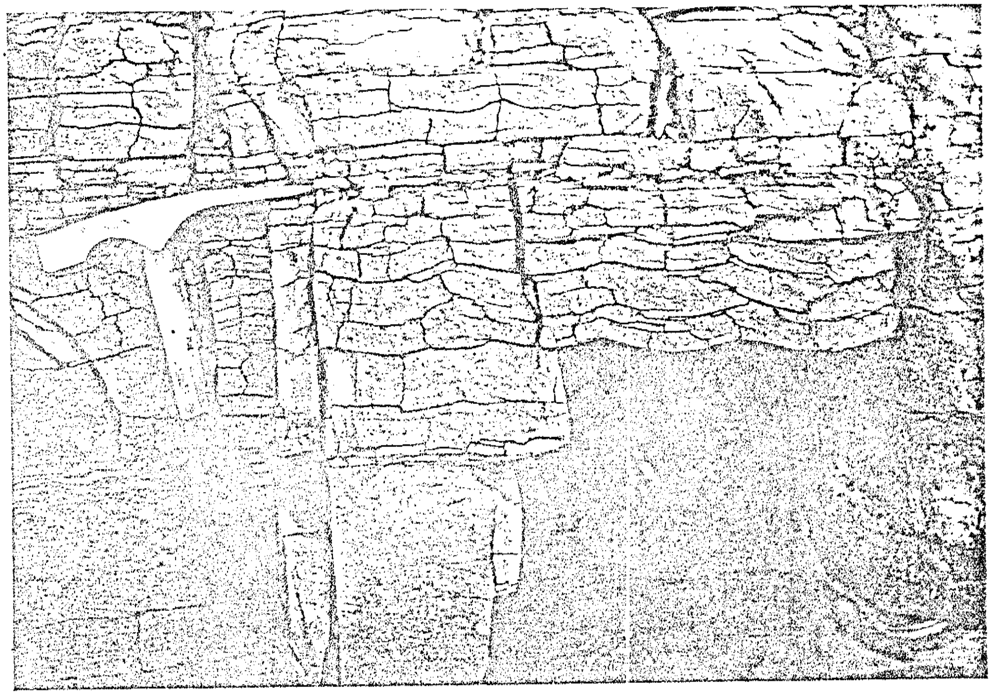


Figure 10 : Symmetrical ripple marks are common within fine-grained sandstone of the bar front facies of the Atarque Sandstone Member (SW 1/4, Section 36, T13S, R4W)

200 foot (15 to 61 m) wide lenses of silty fine-grained sandstone which contain thin beds of vertically-oriented, articulated oysters.

The upper 35 feet (11 m) of the Atarque Sandstone Member consists of slightly carbonaceous, yellowish gray, fine-grained sandstone with small to medium-scale, trough-shaped cosets of high to low angle tangential cross-beds with sharp, curved, erosional lower contacts. Locally, small-scale, tabular-shaped sets of high angle planar cross-laminae with sharp, planar, nonerosional lower contacts occur as well. A composite rose diagram of trough cross-bed axis orientations from this interval within the Atarque Member is shown in Figure 11.

Trough cross-strata contain 1/4 inch (0.6 cm) shale pebbles and abraded, randomly-oriented molluscan fragments (Figure 12). In structureless beds, most disarticulated bivalve valves are concave-down. Sparse smooth-walled, sand-filled, vertically-oriented Skolithos burrows occur in some structureless beds.

Concretionary to tabular zones of sandstone cemented by ferroan carbonate weather dark brown. These zones commonly contain abundant fossil accumulations. Fossils collected from this horizon include oysters, clams, and gastropods. Hook, Molenaar, and Cobban (in press) report the occurrence of a similar bed within the Atarque Sandstone Member throughout west-central New Mexico. Fragments of Inoceramus sp., Mytiloides sp., Ostrea sp., and Crassostrea sp., occur

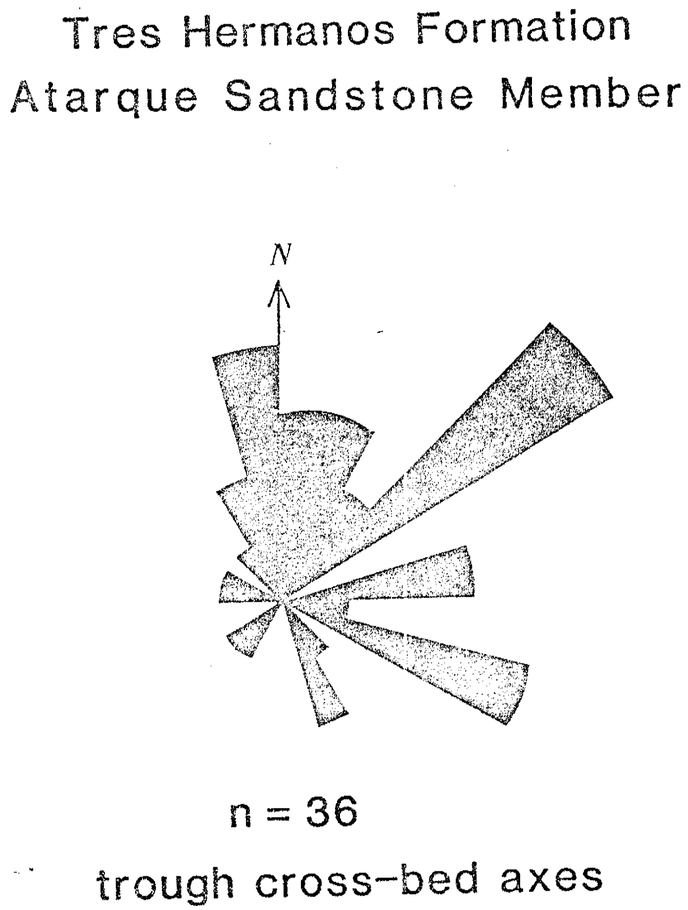


Figure 11 : Composite rose diagram of trough cross-bed axis orientations measured from the Atarque Sandstone Member. See Plate 2 for individual rose diagrams.

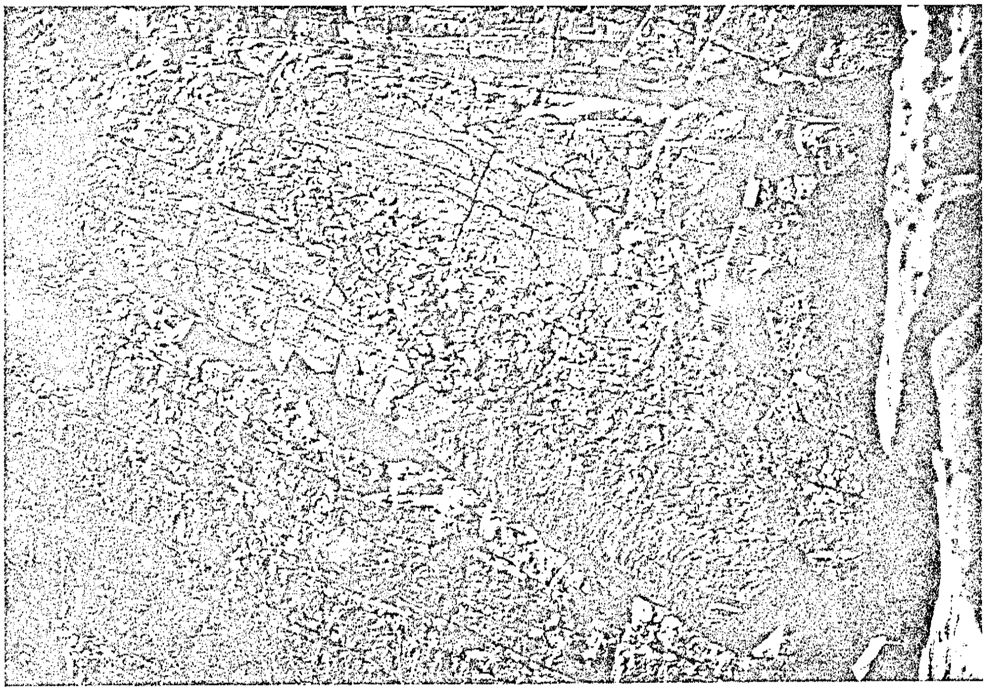


Figure 12 : Trough cross-beds of the proximal bar facies of the Atarque Sandstone Member commonly contain randomly oriented molluscan fragments (SW 1/4, Section 36, T13S, R4W)

Figure 13 : External molds of several species of clams occur near the top of the Atarque Sandstone Member (NW 1/4, Section 36, T13S, R4W)

in scour and fill structures. Well preserved external molds of Mytiloides mytiloides (Mantell) and other clams occur locally near the top of the Atarque (Figure 13). The top of the Atarque Sandstone Member is sharp and commonly exhibits symmetrical ripple marks. A composite rose diagram of symmetrical ripple crest orientations is shown in Figure 14.

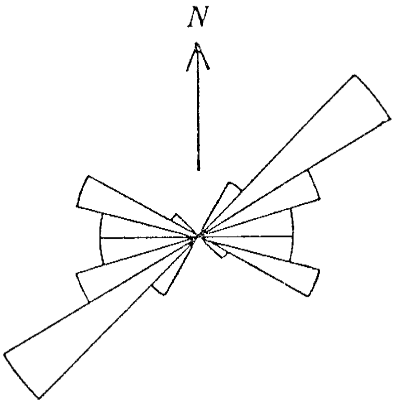
Atarque Sandstone Member: Interpretation

The Atarque Sandstone Member represents progradation of one or several distributary mouth bar(s) across a shallow epeiric sea. The Atarque was deposited in a low energy environment where tidal and wave energy were not great. No distinct tidal deposits were recognized.

Thin sandstones interbedded with shales at the base were deposited on the distal portion of the bar during storm events which moved sand downslope. The upsection increase in bedding thickness of these below-wave base storm deposits reflects increasing proximity to the shoreline through time. The paucity of biogenic structures and the occurrence of ball and pillow structures (Figure 9) indicate rapid sedimentation. These ball and pillow structures were produced by fluidized flow of sand onto highly porous, water-saturated mud. The 9 foot (3 m) thick unit of ripple-bedded sandstone (Figure 10) represents sand deposition along the bar front which was only slightly modified by basinal wave action.

The overlying 35 foot (11 m) thick, trough cross-bedded sandstone was deposited by a complex interaction of fluvial

Tres Hermanos Formation
Atarque Sandstone Member



n = 24

symmetrical ripple crests

Figure 14 : Composite rose diagram of symmetrical ripple mark crest orientations measured from the Atarque Sandstone Member. See Plate 2 for individual rose diagrams.

and wave energy. This interaction is reflected by the nature of the composite rose diagram of trough cross-bed axis orientation measurements (Figure 11). Although the rose diagram displays considerable orientational variability, most paleocurrent directions are oriented roughly basinward. This preferred orientation may be due to dominance of fluvial processes over basinal reworking processes. Small to medium-scale scour and fill structures and trough-shaped sets of cross-strata which contain molluscan fragments represent reactivation of inactive bar surfaces which had been colonized by infauna.

The sequence of subfacies within the Atarque Sandstone Member is remarkably similar to that described by Flores and Erpenbeck (1981) from the Pictured Cliffs Sandstone in the San Juan Basin, which they interpreted as distributary mouth bar deposits. Occurrences of the Atarque Sandstone Member on the Sevilleta Grant near La Joya, New Mexico were interpreted as "barrier-beach to lagoonal-estuarine" by Baker (1981). The occurrence of Mytiloides mytiloides (Mantell) near the top of the Atarque indicates that it is middle early Turonian in age (Kauffman, 1977, p. 235).

Carthage Member: Description

The Carthage Member is the middle member of the Tres Hermanos Formation, and is characterized by lithologic heterogeneity and lateral facies discontinuity. A typical outcrop of the Carthage Member is shown in Figure 15. The Carthage is 199 feet (61 m) thick in Mescal Creek, and

Figure 15 : Thin sandstones, siltstones, and carbonaceous mudrocks of the Carthage Member. Hammer in right center for scale (NW 1/4, Section 1, T14S, R4W)

consists primarily of discontinuous, thin and thick-bedded, very fine to fine-grained sandstones and carbonaceous mudrocks. The Carthage Member is a tabular unit despite the discontinuous nature of constituent beds. Biogenic structures and body fossils are rare. A detailed stratigraphic section of the Carthage Member is shown in Figure 16.

Interbedded sandy mudstones and muddy sandstones overlie the Atarque Sandstone Member. Fine hair-like rootlets less than one inch (2.5 cm) in depth occur in some sandy mudstones. Sandy mudstones are very light gray, dark yellowish orange, and moderate red to purplish gray. Locally, these sandstones contain poorly preserved, dense concentrations of Ophiomorpha and Thallasinoides burrows. These poorly exposed and poorly sorted units gradually fine upward into ripple cross-laminated, light olive gray siltstones, olive gray mudstone, and medium gray carbonaceous shale.

Several 5 to 10 foot (1.5 to 3 m) thick, slightly carbonaceous, well sorted, yellowish gray, fine-grained sandstones occur between thicker mudrock intervals. These laterally discontinuous sandstones have sharp, low relief, erosional lower contacts, and exhibit small to medium-scale cosets of trough cross-bedding. The thickness of individual sets decreases upward from over 1 foot (0.3 m) at the base to several inches (cm) near the top, where associated ripple cross-lamination is also common. Shale pebble rip-up

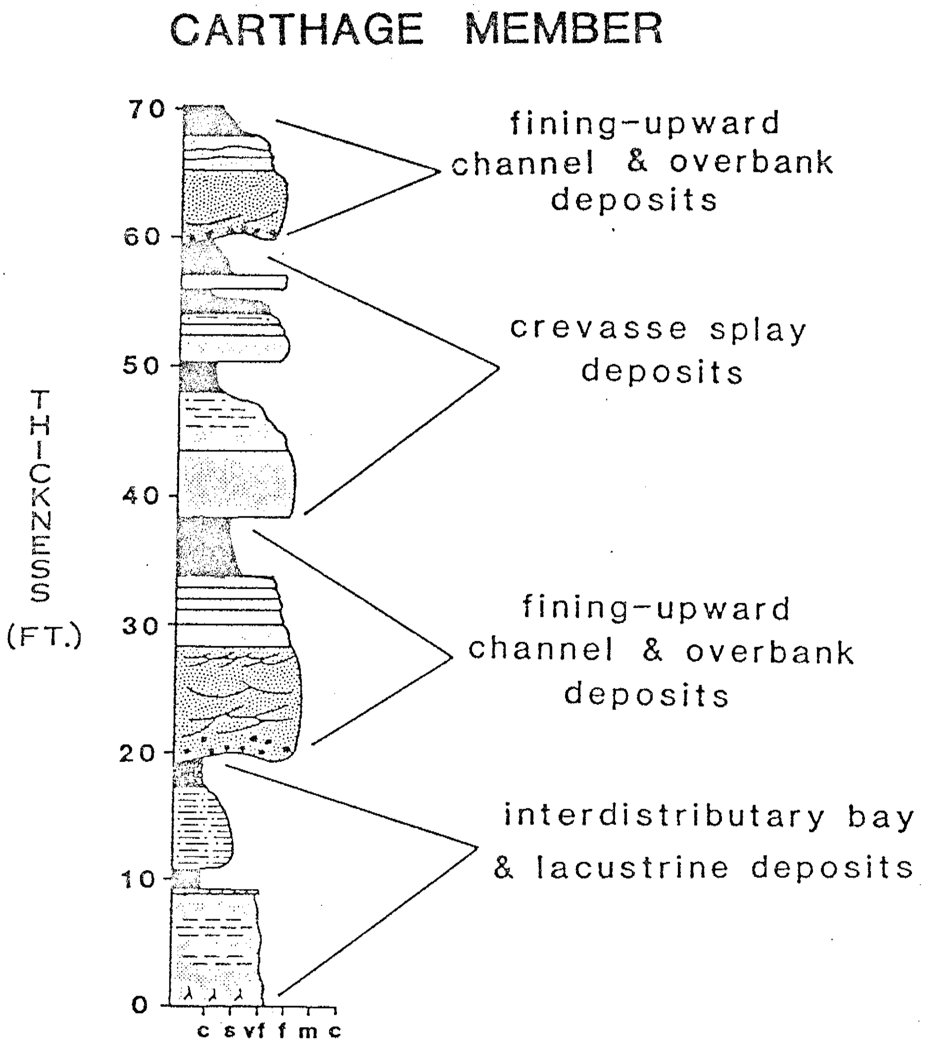


Figure 16 : Detailed stratigraphic section of the Carthage Member measured in lower Mescal Creek.

clasts (1/2 inch, 1.3 cm) and wood molds commonly occur at the base of these sandstones. These units are cemented by silica and/or carbonate cement, and are traceable in outcrop for several hundred feet (metres) at most.

Thin-bedded, moderately sorted, light olive gray, very fine-grained sandstones are usually structureless, and have sharp, planar, nonerosional upper and lower contacts. These units occur repetitively in fining-upward sequences with siltstones, mudstones, and shales. These sequences are noncalcareous, slightly carbonaceous, contain sparse plant molds, and average 10 feet (3 m) in thickness. Silicified wood logs 1 foot (0.3 m) in diameter and 2 feet (0.6 m) in length occur in Section 29, T14S, R3W. Woody root molds up to 1 inch (2.5 cm) in diameter are also quite common at this locality.

A wide variety of mudrocks occur within the Carthage Member. Medium gray, carbonaceous mudstones and shales, and light olive gray mudstones occur in association with thin-bedded, tabular sandstones. Lenses of relatively pure olive gray claystone occur sporadically throughout the Carthage Member. These lenses are usually covered or poorly exposed, average 3 feet (1 m) in thickness, and are traceable in outcrop for several hundred feet (metres) at most.

Very thin beds of clayey, silty, sandy, carbonaceous calcarenite containing abundant molluscan debris are interbedded with mudstones and shales in Mescal Creek

(SW1/4, sec 1, T13S, R4W). These calcarenites contain small (<1/4 inch, 0.5 cm), well sorted, disarticulated clam valves, gastropods, and occasional coal spars. The majority of fossil fragments are unabraded and oriented parallel to bedding.

Carthage Member: Interpretation

Marginal marine and nonmarine deposits of the Carthage Member were deposited on a broad, low energy coastal or delta plain. Progradation of the underlying distributary mouth bar deposits created a near-sea level platform upon which fluvial channel, crevasse splay, swamp, and overbank sediments were deposited. Small rootlets immediately above the Atarque Member record the initial colonization of the bar surface by marsh vegetation.

Well sorted, fine-grained sandstones are interpreted as fluvial channel deposits. Fining-upward grain size distributions resulted from a decrease in depositional flow regime as indicated by the upward decrease in scale of sedimentary structures within these sandstones. In addition, these units display lateral discontinuity, erosional lower contacts, and basal lag deposits, all of which are common in ancient fluvial channel deposits.

Repetitive fining-upward sequences of sandstone, siltstone, mudstone, and shale represent episodic deposition of crevasse splay sands, and associated overbank sediments deposited during periods of waning flow. The presence of highly carbonaceous shales interbedded with these nonmarine deposits records incomplete or punctuated development of coal swamp environments. Coals have been reported from the Carthage Member in the Acoma and Zuni Basins (Hook, Molenaar, and Cobban, in press), and on the Sevilleta Grant near La Joya, New Mexico (Baker, 1981).

Discontinuous claystone lenses represent lacustrine sediments deposited in interfluvial areas. Other mudrock intervals contain very thin, impure calcarenites. Individual fossil grains have suffered little abrasion, and were probably transported only a short distance in a low energy environment. The small size of these fossils suggests that they may have lived in a schizohaline environment. These calcarenites could have been deposited in freshwater lakes or in brackish or saline interdistributary bays. The origin of these units has implications for the nature of the shoreline during Carthage time. If these calcarenites have a marine origin, then their occurrence within the Carthage Member implies an irregular digitate shoreline, which might be expected for the low energy, fluvially-dominated deltaic or interdeltaic depositional system represented by these deposits.

Fite Ranch Sandstone Member: Description

The Fite Ranch Sandstone Member is a thin, resistant, and laterally persistent sandstone unit which lies uncomformably upon the Carthage Member. A typical outcrop

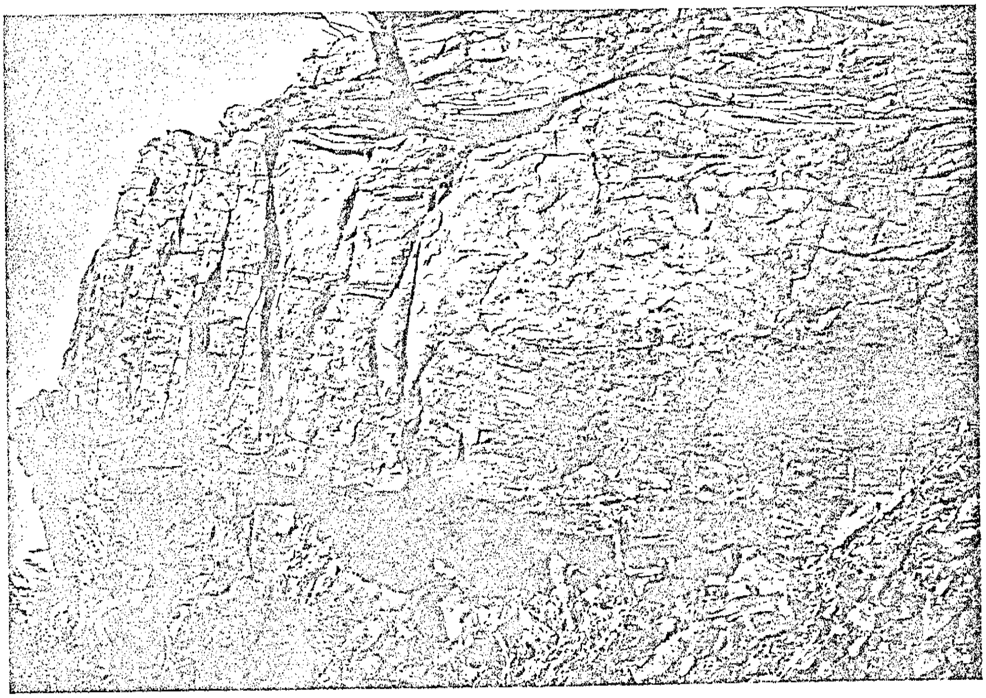


Figure 17 : Fite Ranch Sandstone Member. Hammer at erosional lower contact for scale (NW 1/4, Section 36, T13S, R4W)

of the Fite Ranch Member is shown in Figure 17. Thickness, color, grain size, sorting, and bedding style vary markedly along strike. The Fite Ranch averages about 9 feet (3 m) in thickness, but thickness varies from several inches (cm) to 32 feet (9.8 m) in Mescal Creek. A detailed stratigraphic section of the Fite Ranch Sandstone Member measured 1/8 mile (0.2 km) north of Mescal Creek is shown in Figure 18.

Fresh sandstone surfaces range from yellowish gray to dark yellowish brown in color, while weathered surfaces are commonly light olive gray. Average grain size is in the medium sand grade, but ranges from fine to coarse sand. Locally, the basal portion of the unit contains well sorted, yellowish gray, coarse-grained sandstone. In areas where the sandstone thins, average grain size decreases to the fine sand grade, and sorting decreases to moderate. The Fite Ranch contains very little carbonaceous material. Small-scale cosets of trough cross-bedding and very thin, planar horizontal bedding are the dominant stratification types, with less common, local sets of small-scale planar cross-lamination.

The occurrence of shale pebble rip-up clasts also shows considerable variation along strike. Shale pebbles commonly occur only near the base, but locally are evenly distributed throughout the entire unit. Thin, (1/8 to 1/4 inch, 0.3 to 0.5 cm), poorly preserved, smooth-walled, sand-filled, vertical tube burrows occur, but biogenic structures are rare. Sparse fragments of Inoceramus sp. occur rarely at

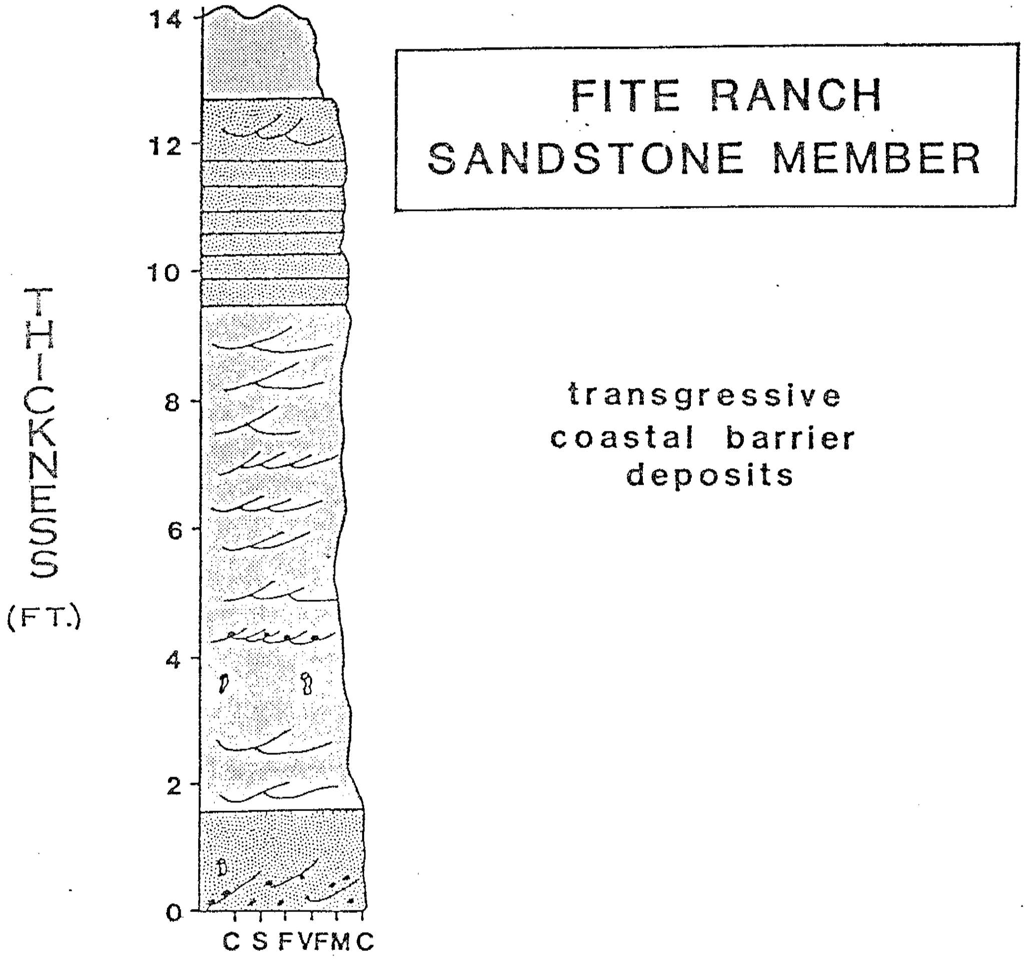


Figure 18 : Detailed stratigraphic section of the Fite Ranch Sandstone Member measured in lower Mescal Creek.

the base of the unit in Section 36, T13S, R4W.

The Fite Ranch Sandstone Member is generally cemented by both silica and carbonate. Dark yellowish brown, fine-grained intervals are usually noncalcareous. Recognition of the Fite Ranch in outcrop is commonly facilitated by quartz overgrowths, which tend to make the sandstone sparkle in sunlight.

The upper contact of the Fite Ranch Member is generally sharp and planar, although wavy bedding having an amplitude of 6 inches (15 cm) and a wavelength of 2 feet (0.6 m) occurs locally below this contact. In Mescal Creek, the lower 21 feet (6.4 m) of the Fite Ranch is overlain by a discontinuous 11 foot (3.4 m) thick sandstone which is different in appearance than the underlying sandstone. This unit is a friable, noncalcareous, orange and white, medium-grained sandstone exhibiting highly irregular, very thin wavy beds containing several large (4 inch, 10 cm) coal spars. This sandstone has a sharply gradational contact with overlying siltstones and shales, and appears to pinch out over several hundred feet (metres) along strike.

Fite Ranch Sandstone Member: Interpretation

The Fite Ranch records transgression of the seaway across low-lying coastal or delta plain deposits of the Carthage Member. The unit is a thin, tabular, transgressive shoreface/beach sandstone, whose variability in thickness suggests deposition on a very modest topography. Greater than average thicknesses of sand may have been deposited in paleochannels or in bay or lacustrine depressions, as wave-dominated processes effected transgression of a digitate shoreline. The absence of well-developed barrier island or mainland shoreface sequences suggests that considerable shoreface erosion accompanied this transgressive event (cf. Ryer, 1977). Consequently, it is not possible to determine if the Fite Ranch Member represents a barrier island complex or a mainland beach at this locality. The Fite Ranch Sandstone Member has been interpreted as a barrier island complex in areas to the north by Baker (1981) and Hook, Molenaar, and Cobban (in press).

D-Cross Tongue of the Mancos Shale: Description

The D-Cross Tongue of the Mancos Shale was named by Dane et al., (1957, p. 187) for a persistent marine shale unit exposed at D-Cross Mountain in Socorro County, New Mexico. The D-Cross at Engle field is a tabular, laterally persistent unit and is approximately 240 feet (73 m) thick in Mescal Creek. Minor flowage of these clay-rich rocks during the Laramide orogeny precludes a precise thickness determination. The D-Cross at Engle field is composed predominantly of laminated, light olive gray, noncalcareous siltstone, with lesser amounts of silty shale and laminated, calcareous, very fine-grained sandstone. The lower contact of the D-Cross is sharp, planar, and nonerosional. A detailed stratigraphic section of the D-Cross Tongue is shown in Figure 19.

The D-Cross contains three unnamed tongues of the Gallup sandstone, which range from 18 to 48 feet (5.5 to 14.6 m) in thickness. These calcareous, well sorted, yellowish gray, fine-grained sandstones are moderately to densely bioturbated, slightly carbonaceous, and generally lack physical sedimentary structures. The tops of the lower two sandstone tongues have a thin bed of olive gray, very fine-grained sandstone, which is noncalcareous, moderately sorted, and well-indurated. These thin beds are similar in appearance to discontinuity surfaces observed elsewhere by the writer. Two samples tested for phosphate-bearing minerals by x-ray diffraction produced negative results (R. M. North, 1983, pers. comm.).

The lowermost sandstone tongue displays a parallel laminated to burrowed bedding style, which was first described by Howard (1972) from the Book Cliffs of Utah (Figure 20). These units consist of thin-bedded, repetitive couplets of densely bioturbated sandstone and horizontally laminated sandstone. Individual Ophiomorpha burrows commonly extend upward into the basal few inches of laminated beds, while in other couplets, complete erosional truncation of biogenic structures occurs.

The abundance of biogenic structures within the D-Cross is directly proportional to sand content. Laminae in shales and siltstones are well-preserved, and evidence of

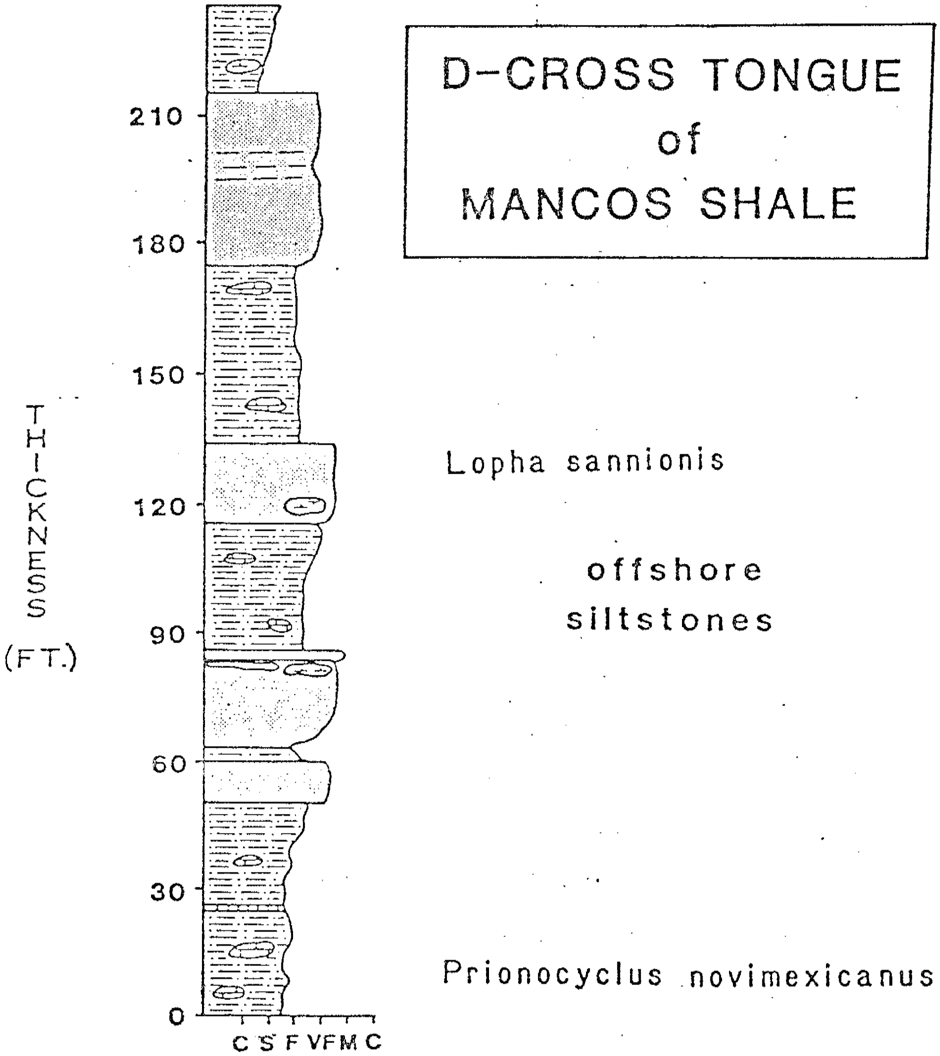


Figure 19 : Detailed stratigraphic section of the D-Cross Tongue of the Mancos Shale measured in lower Mescal Creek.

Figure 20 : Lowermost sandstone tongue within the D-Cross Tongue of the Mancos Shale. Densely bioturbated sandstone is interbedded with horizontally laminated sandstone (SE 1/4, Section 36, T13S, R4W)

biological activity is rare. Barely perceptible traces occur in clayey, silty, very fine-grained sandstones. Visibility of these traces is enhanced by the apparent biological concentration of clays along burrow walls. Well defined traces are readily apparent in the fine-grained sandstone tongues, where identification of distinct ichnogenera is possible in some instances.

Ophiomorpha and *Skolithos* occur as discrete biogenic structures. The morphology and size of *Ophiomorpha* vary considerably. Indistinct smooth-walled, *Ophiomorpha* are recognizable in clayey, silty, very fine-grained sandstones. Well sorted, fine-grained sandstones contain *Ophiomorpha* with knobby burrow linings, which are usually well exposed due to preferential erosion of friable burrow fill. *Ophiomorpha* burrows average 1/2 inch (1.3 cm) in diameter with a maximum length of 10 inches (25.4 cm). Commonly, only small oblique cross sections of burrows are exposed, making a reconstruction of burrow configuration impossible.

Skolithos occurs as thin, vertically-oriented, smooth-walled, sand-filled, burrow tubes 1/4 inch (0.5 cm) in diameter, with a maximum length of 6 inches (12.7 cm). No zonations in the relative abundance of ichnogenera were observed. Locally, trace fossil density is so great that induration is decreased, and the rock exhibits a bioturbate or 'churned' texture.

Two basic types of concretions occur within the D-Cross Tongue. One type is botryoidal carbonate mudstone or aggregates of acicular calcite, with septa of brown calcite. The second type is oblate-shaped carbonate mudstone which has a smooth outer surface. Both varieties may contain fossil ammonites, are roughly concentrated on stratigraphic horizons, and have their long axes parallel to bedding. Siltstone laminae are commonly draped around these concretions.

Hook and Cobban (1981, p. 54) report the occurrence of the ammonite *Prionocyclus novimexicanus* (Marcou) and the crenulate oyster *Lopha sannionis* (White) from the D-Cross in Mescal Creek. Specimens of *P. novimexicanus* were collected by the writer from limestone concretions within silty shale, four to six feet above the base of the unit. Disarticulated, abraded fragments of *L. sannionis* occur sparsely in the upper two sandstone tongues within the D-Cross Tongue.

D-Cross Tongue of Mancos Shale: Interpretation

The D-Cross Tongue of the Mancos Shale represents deposition of clay, silt, and very fine to fine sand seaward of the transgressing shoreline recorded by the Fite Ranch Sandstone Member. Fine-grained sandstone tongues record episodic progradation of the lower shoreface environment. The high silt and sand content of the D-Cross Tongue indicate that the shoreline was probably not more than several tens of miles (km) to the west during deposition of the D-Cross Tongue. The overlapping range zones of *P.*

novimexicanus and L. sannionis indicate that the D-Cross is late Turonian to possibly early Coniacian in age.

The distribution of biogenic structures within the D-Cross is probably related to substrate coherence, as discussed by Frey (1978, p. 63). Organisms responsible for the formation of Ophiomorpha and Skolithos were probably suspension feeders which were able to colonize only the relatively stable sands of the shoreface environment. Offshore silt and clay-rich sediments were probably highly water-saturated, and were unable to support burrow formation. In addition, these suspension feeders probably required a greater degree of water agitation than that normally occurring in the offshore environment. The high trace fossil density in these lower shoreface sandstones is probably related to low sedimentation rates rather than to actual organism density. The D-Cross Tongue represents a regionally significant transgression (Hook, Molenaar, and Cobban, in press), and separates the underlying Tres Hermanos Formation depositional system from that of the overlying Mesaverde Group.

Mesaverde Group: Introduction

Holmes (1877, p. 244) described Upper Cretaceous sandstones and shales in Mesa Verde National Park in southwestern Colorado, and named these strata the Mesaverde Group, which he divided into three unnamed formations. Since then, the nomenclature of Upper Cretaceous strata in the San Juan Basin area has undergone numerous revisions and reinterpretations. Various workers have alternately considered the Mesaverde as a formation (Sears, 1925; Hunt, 1936; Sears, Hunt, and Hendricks, 1941), and as a group (Pike, 1947; Allen and Balk, 1954; Dane, Wanek, and Reeside, 1957) depending on the date and geographic location of the investigation. Consequently, the term Mesaverde has been loosely applied to terrigenous clastic deposits of widely differing age and origin in localities as far away from the type section as central Wyoming and west-central New Mexico.

The Gallup Sandstone Member of the Mesaverde Formation was named by Sears (1925, p.17), for a mappable sequence of rocks near Gallup, New Mexico. Usage of the term Gallup Sandstone has also evolved through time (Molenaar, 1973; Hook, Molenaar, and Cobban, in press). Molenaar (1973) mentioned the occurrence of the Gallup Sandstone near Truth or Consequences, New Mexico. The writer follows the usage of Hook, Molenaar, and Cobban (in press).

Allen and Balk (1954) named the Crevasse Canyon Formation for sedimentary rocks lying between the top of the Gallup Sandstone and the base of the Point Lookout Sandstone. They divided the Crevasse Canyon into three members. Lithologic equivalents of the Gallup Sandstone and the Crevasse Canyon Formation occur at the Engle coal field, and are correlated with units to the northwest based on their position in the succession of lithostratigraphic units.

Gallup Sandstone: Description

The Gallup Sandstone in Mescal Creek (Sec. 36, T13S, R4W) is a 75 foot (22 m) thick, coarsening-upward sandstone sequence. The Gallup consists of calcareous, moderately sorted, yellowish gray, very fine-grained sandstone at the base and well sorted, medium-grained sandstone at the top. A detailed stratigraphic section of the Gallup measured in Mescal Creek is shown in Figure 21.

The abundances of physical and biogenic sedimentary structures are inversely related, with physical sedimentary structures dominant near the top of the Gallup. Five subfacies are recognized within the Gallup Sandstone in Mescal Creek. These are a lower bioturbated unit, a thin-bedded, ripple-modified unit, a ripple cross-laminated unit, a trough cross-laminated unit and an upper laminated unit.

The lower bioturbated subfacies lacks physical sedimentary structures and consists of clayey, silty, calcareous, light olive gray, very fine to fine grained sandstone which is densely bioturbated. The majority of biogenic structures are indistinct, however several ichnogenera are recognizable.

Randomly oriented *Ophiomorpha* average 1/2 inch (0.5 cm) in diameter and lack the characteristic knobby burrow lining observed in *Ophiomorpha* from fine to medium-grained sandstones. *Helminthoides* occurs sparsely as a cast of tightly looped fecal pellets. These traces occur in

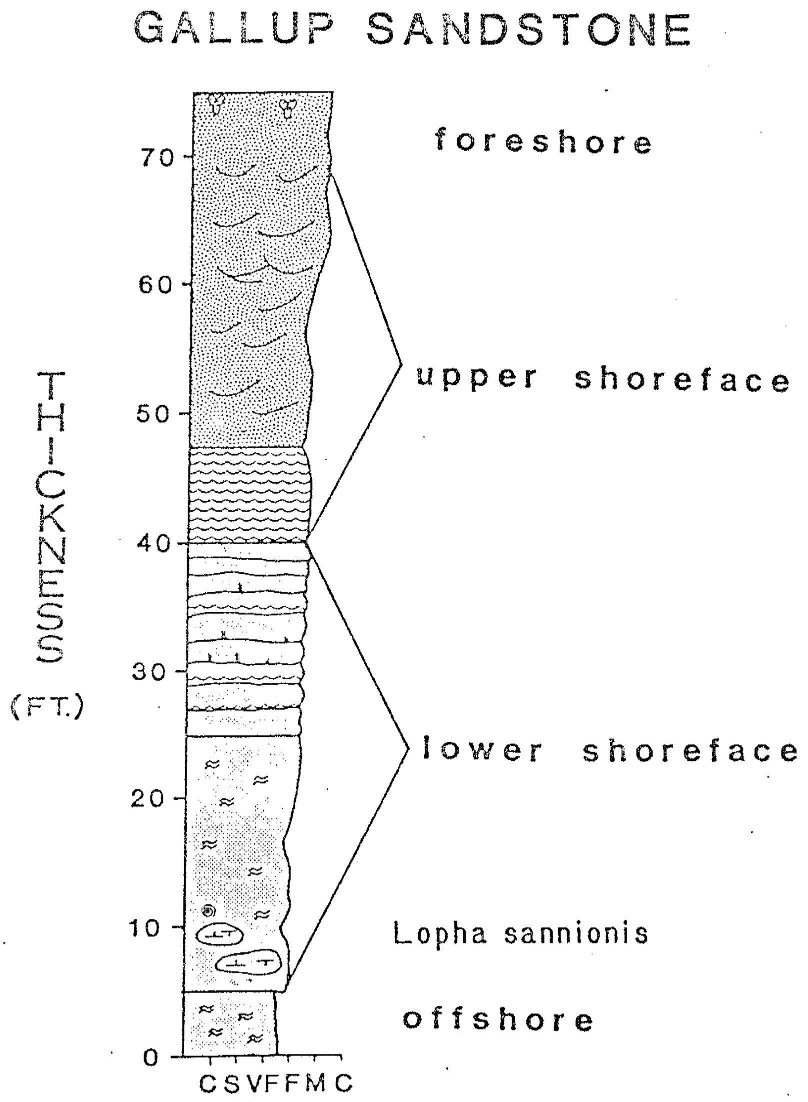


Figure 21 : Detailed stratigraphic section of the Gallup Sandstone measured in lower Mescal Creek.

epirelief on bedding surfaces, and average 5 inches (12.7 cm) in diameter. *Terebellina* occurs sparsely as slightly resistant, white calcareous, sand-filled tubes averaging 3/16 inch (0.5 cm) in diameter. Several tubes commonly occur in clusters. These traces are circular in transverse section, elliptical in oblique section, and are oriented obliquely with respect to bedding. *Terebellina* has been informally referred to as a 'soda straw' trace fossil, since it resembles plastic soda straws. The presence of other ichnogenera is inferred, but their recognition is hampered by the extremely high trace fossil density.

Highly calcareous sandstone concretions contain a sparse, diverse, molluscan fauna. These fossils include disarticulated valves of *Lopha sannionis*, at least two species of small turretellid gastropods averaging 3/4 inch (1.9 cm) in length, and at least two species of *Corbula* (?). Coalified wood fragments up to 10 inches (25.4 cm) in length also occur sparsely within these concretions.

The thin-bedded, ripple-modified subfacies consists of well sorted, light olive gray to yellowish gray, fine-grained sandstone. Beds vary from 2 to 14 inches (5 to 36 cm) in thickness, and upper surfaces display symmetrical ripple marks. These beds are separated by thin shale partings approximately 1/16 inch (0.2 cm) thick. Trace fossil density is lower than in the subjacent bioturbated facies, and biogenic structures are predominately vertically-oriented. *Ophiomorpha* and *Skolithos* are the only positively identifiable ichnogenera occurring in this unit.

The ripple-bedded subfacies consists of thick-bedded, well sorted, yellowish gray, fine-grained sandstone which exhibits internal ripple cross-lamination throughout. These ripple structures are not immediately apparent, and are only visible locally, where oxidation of organic material within ripple troughs reveals their presence. Biogenic structures are significantly less abundant than in subjacent subfacies. Skolithos is the dominant ichnogenera, along with rare, knobby-walled, Ophiomorpha.

The ripple cross-laminated subfacies grades abruptly into a trough cross-laminated subfacies, which consists of yellowish gray, well sorted, fine-grained sandstone. Shallow, small to medium-scale, trough-shaped sets and cosets of high to low angle tangential cross-laminae with sharp, curved, erosional lower contacts are encased in apparently structureless sandstone. Rare, isolated occurrences of Skolithos are the only biogenic structures which occur.

The top of the Gallup consists of thick-bedded, yellowish gray, well sorted, fine to medium-grained sandstone which exhibits planar horizontal lamination. Isolated, small to medium-scale, trough-shaped sets of low angle tangential cross-lamination with sharp, curved, erosional lower contacts are encased within laminated sandstone. Rare Skolithos burrows occur throughout the unit. The upper surface of the Gallup displays densely concentrated Ophiomorpha burrows which exhibit complex burrow configurations.

Elsewhere in Engle field, this well-developed sequence does not occur and the Gallup displays a greater degree of stratigraphic and sedimentologic variability. These localities are discussed in the section on interpretation of the Gallup Sandstone.

Gallup Sandstone: Interpretation

The Gallup Sandstone records the most extensive progradation of shoreface environments represented by sandstone tongues within the D-Cross Tongue of the Mancos Shale. Progradational shoreline sequences generally have high preservation potential, and the Gallup Sandstone at Engle field is no exception. The deposits of many subenvironments of deposition have been preserved, providing the stratigrapher with an excellent example of Walther's Law. The lowermost bioturbated sandstone was deposited on the lower shoreface, presumably below average wave base. This environment offered suspension feeders maximum circulation of nutrients coupled with minimal disturbance from energy input. Any physical sedimentary structures present at the time of deposition have been obliterated by subsequent bioturbation.

The thin-bedded, ripple-modified sandstone represents sand which was episodically transported to the lower shoreface, and subsequently modified by gentle oscillatory wave action. Vertically-oriented biogenic structures in this subfacies and in superjacent subfacies are probably escape burrows, formed as suspension feeding organisms attempted to avoid sudden depositional and erosional episodes. The morphological diversity of these escape structures reflects varying degrees of success experienced during these 'escapes.'

The thick-bedded, ripple cross-laminated sandstone represents sand deposited at the toe of the upper shoreface under the persistent influence of oscillatory wave energy. The overlying trough cross-laminated sandstone represents the 'surf zone' where energy expended by breaking waves continually reworked sediment. The paucity of biogenic structures in these units is probably due to their initially low preservation potential, although the relatively high energy regime of this environment may have been hostile to many organisms.

The uppermost horizontally laminated sandstone represents sand deposition by 'swash zone' processes at the strandline. Preservation of dense concentrations of well developed Ophiomorpha burrow structures at the top of the subfacies is related to progradation of relatively quiet water, lagoonal deposits over barrier island sands of the Gallup. The upsection increase in abundance of physical sedimentary structures reflects the increasing energy regime which resulted from progressive shoaling of shoreline sands as progradation occurred.

The corresponding upsection decrease in the abundance and diversity of biogenic structures constitutes a rather diagnostic trace fossil gradient which occurs due to the aforementioned environmental and preservational considerations. Preservation of this complete nearshore sandstone sequence indicates that sediment supply and progradation were uninterrupted during deposition of the Gallup at this locality. The occurrence of *Lopha sannionis* within the lower portion of the Gallup indicates that it is late Turonian to early Coniacian in age.

Exposures to the south of Mescal Creek indicate that the Gallup Sandstone is not everywhere a tabular sandstone body. Field sketches by the writer show that the Gallup bifurcates and thins locally along strike. It should be noted that data shown in these sketches are approximate, especially with regard to thicknesses. Stacked shoreface/lagoonal sequences are shown in Figure 22. Locally, one of the lagoonal units is missing from the sequence (Figure 23). At another locality, the stratigraphic position of the lagoonal deposits is occupied by densely bioturbated, light gray, well sorted, fine-grained sandstone (Figure 24). Locally, this fine-grained sandstone contains densely packed, discrete *Skolithos* burrows which are vertically-oriented. These burrows extend up to 1 1/2 feet (0.45 m) in length, and are erosionally terminated by overlying structureless sandstone. Figure 25 shows a distributary channel sandstone incised

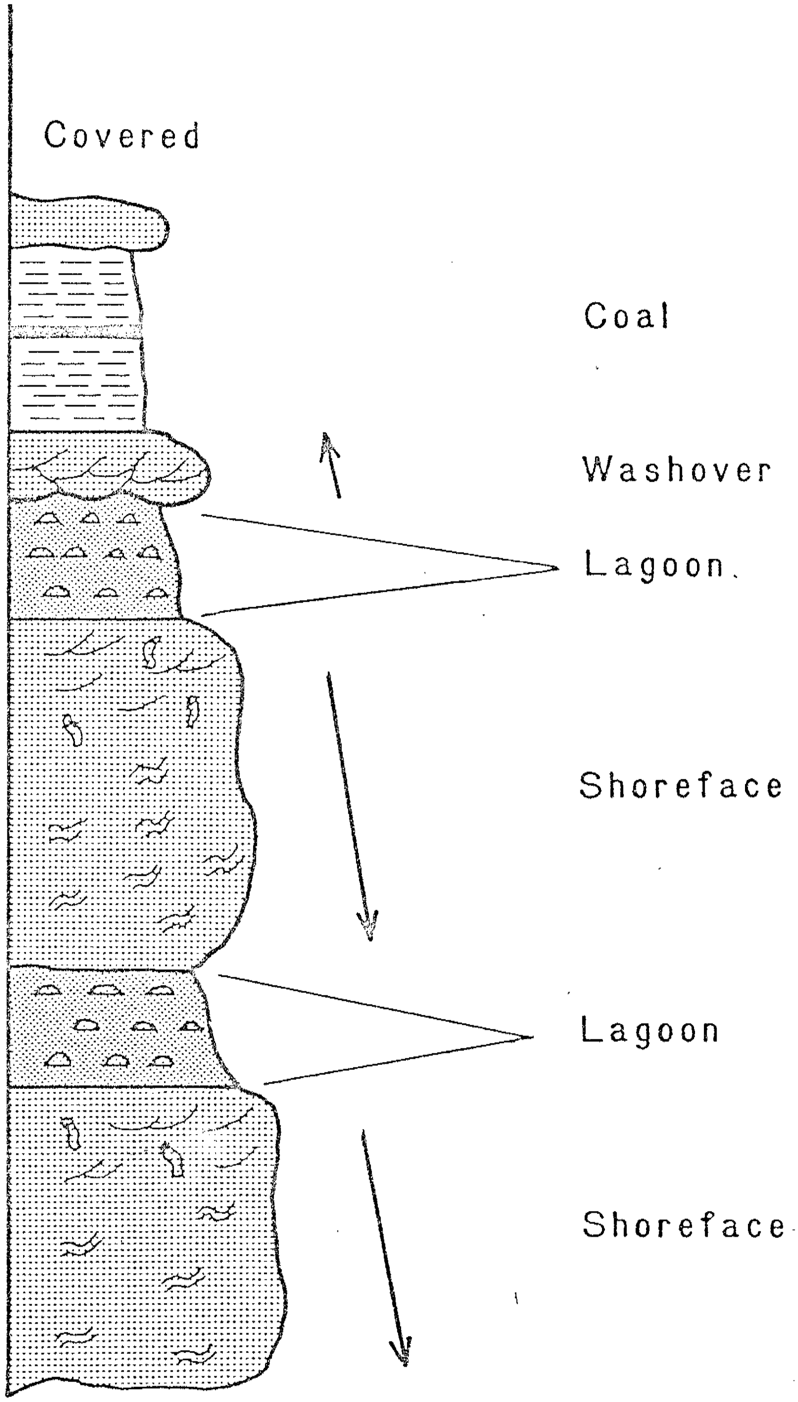


Figure 22 : Field sketch of the Gallup Sandstone in SW 1/4, Section 18, T14S, R3W. One inch equals approximately 25 feet. Arrows indicate direction of fining.

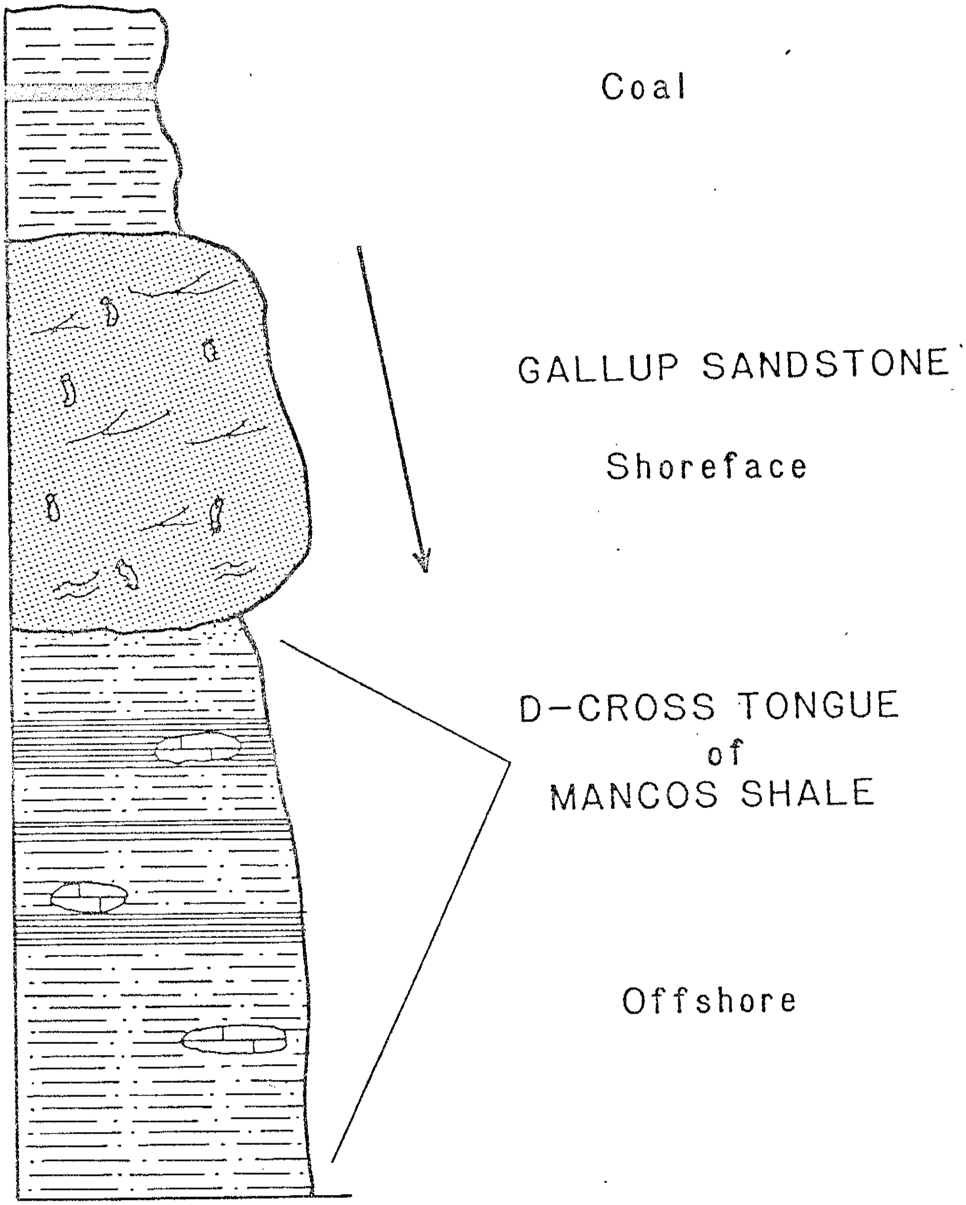


Figure 23 : Field sketch of the Gallup Sandstone in SW 1/4, Section 20, T14S, R3W. One inch equals approximately 15 feet. Arrow indicates direction of fining.

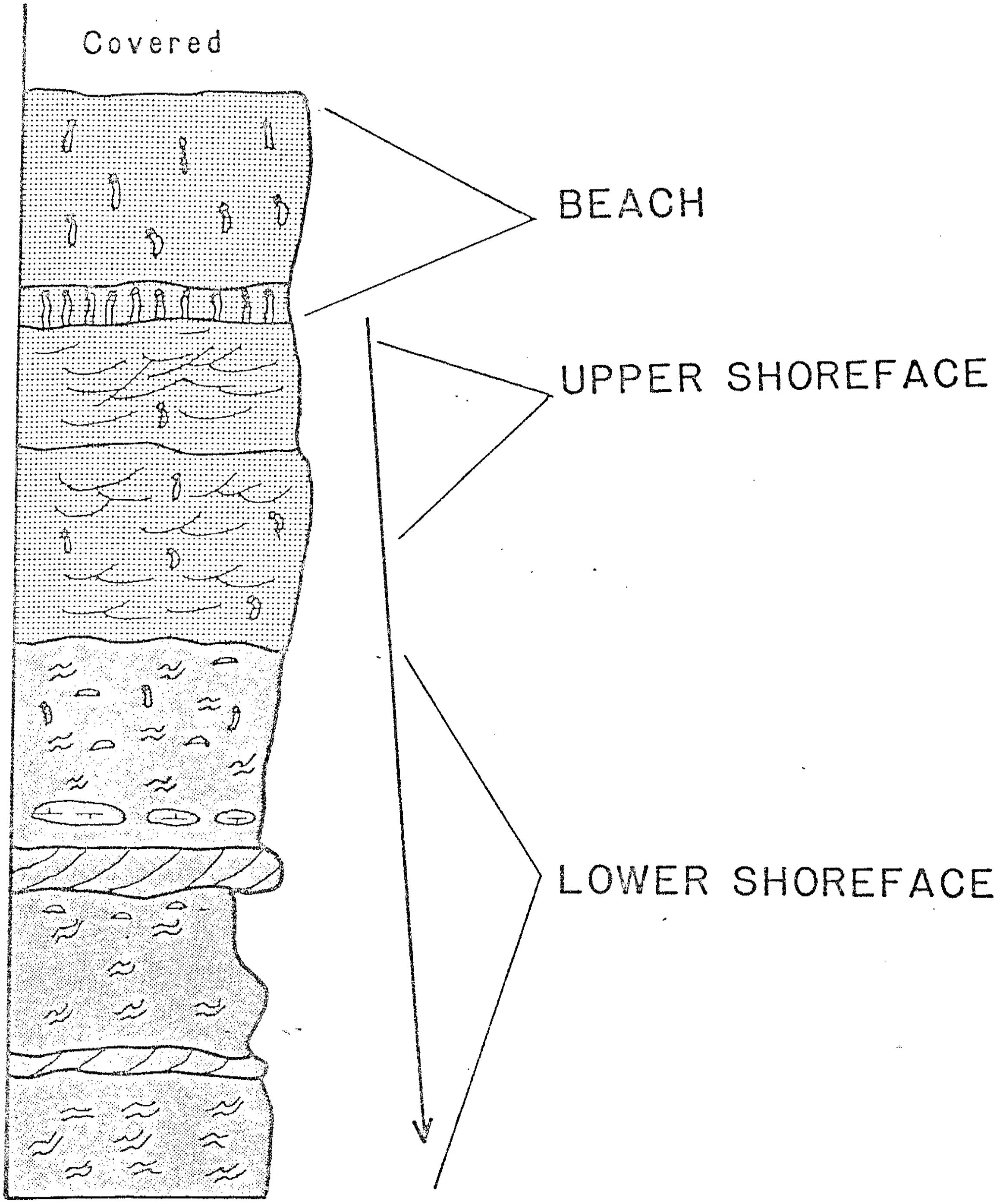


Figure 24 : Field sketch of the Gallup Sandstone in NW 1/4, Section 17, T14S, R3W. One inch equals approximately 15 feet. Arrow indicates direction of fining.

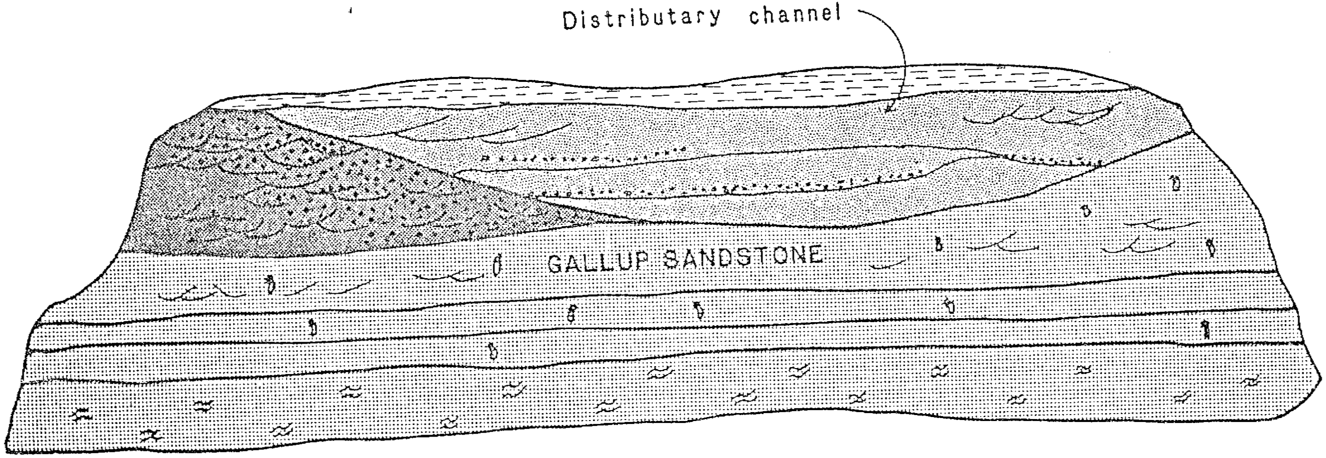


Figure 25 : Distributary channel incised into the Gallup Sandstone in NW 1/4, Section 20, T14S, R3W. Channel thalweg has migrated from left to right. One inch equals approximately 20 feet.

into the Gallup Sandstone. This channel deposit is similar to those described from the Coal-bearing Member.

These observations indicate that considerable variability in thickness, geometry, and sedimentology occur parallel to strike within the Gallup Sandstone. Since structural strike is approximately coincident with the orientation of the paleoshoreline as inferred from paleocurrent data, these lateral facies changes reflect environmental variability along depositional strike. This variability supports the interpretation that the Gallup Sandstone represents fluvially-dominated progradation of a barrier strandline. The apparent absence of tidal inlet deposits and the relatively small scale of trough cross-laminated strata indicate that wave and tidal energy were not great. Longshore sand transport probably created localized barrier islands downcurrent from fluvial axes, and development of restricted marine lagoons or interdeltaic areas occurred in low energy environments landward of these deposits.

Crevasse Canyon Formation: Introduction

The Crevasse Canyon Formation at Engle field consists of at least 2,300 feet of marginal marine and fluvial conglomerates, sandstones, siltstones, mudrocks, and coals. These deposits are herein subdivided into a lower Coal-bearing Member, a Barren Member, and the Ash Canyon Member. Minor faulting and erosion preclude a precise thickness determination.

Coal-bearing Member: Description

The Coal-bearing Member of the Crevasse Canyon contains very fine, fine, and medium-grained sandstones, siltstones, carbonaceous mudrocks, and coals. A thickness of 450 feet (137 m) was measured from the top of the Gallup Sandstone to the top of the uppermost, highly carbonaceous mudrock (humate) exposed in Mescal Creek. A detailed stratigraphic section of the lower portion of the Coal-bearing Member is shown in Figure 26.

The basal unit (Figure 27) consists predominantly of thin to thick-bedded, clayey, silty, friable, light olive gray, very fine and fine-grained sandstones, with minor siltstone and thin, medium gray limestone beds. Thickness varies from 0 to 45 feet (0 to 15.7 m) along strike, but averages approximately 40 feet (12 m). The lower contact is everywhere sharp, planar, and nonerosional.

An abundant molluscan fauna occurs within this unit. The oysters _Inoceramus_ sp. and _Crassostrea_ sp. predominate, with less abundant _Ostrea_ sp. and _Corbula_ sp. Many exhibit extensive borings similar to those made by the boring demosponge _Cliona_. Body fossils can be placed into 3 taphonomic assemblages based on articulation, abrasion, and orientation. Disarticulated, highly abraded, randomly-oriented, molluscan valves generally occur in beds separate from those containing articulated, unabraded valves having a well-developed horizontal preferred alignment. These assemblages are not mutually exclusive however, as

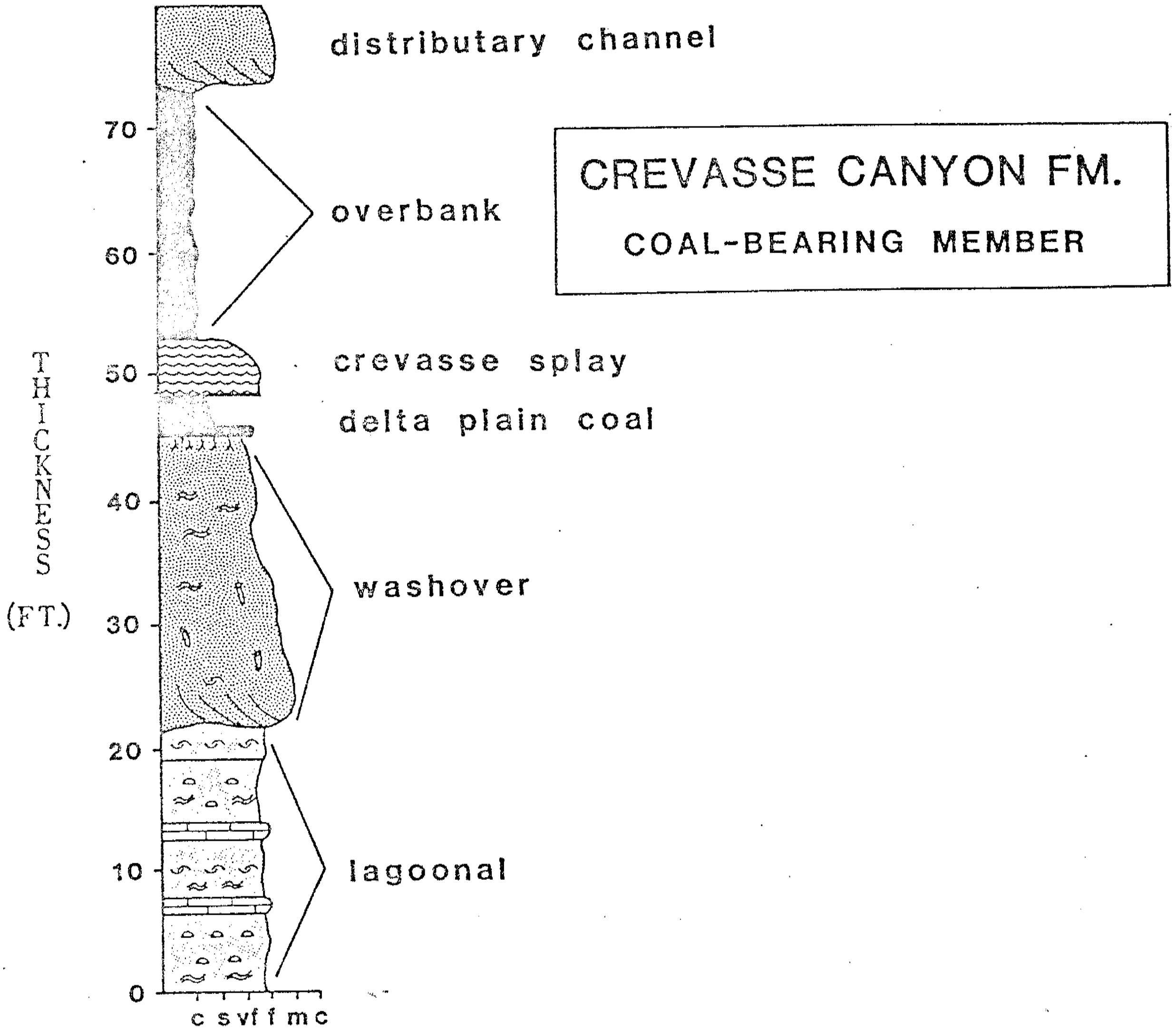


Figure 26 : Detailed stratigraphic section of the lower portion of the Coal-bearing Member, which contains marginal marine and fluvial deposits. Measured in lower Mescal Creek.

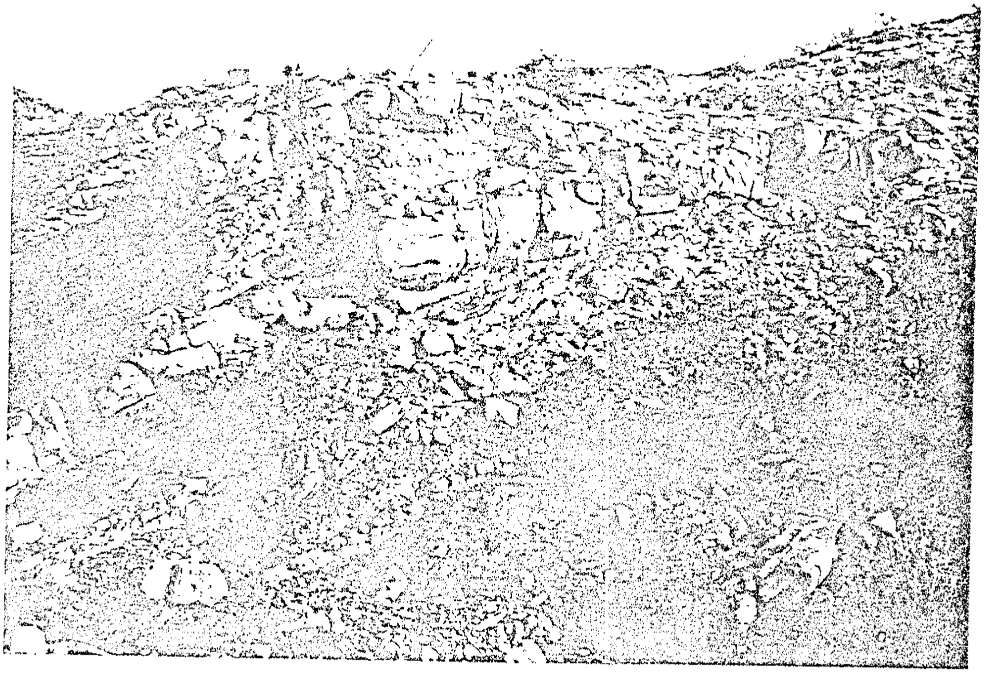


Figure 27 : The lower portion of the Coal-bearing Member contains marginal marine lagoonal deposits overlain by washover deposits (SW 1/4, Section 36, T13S, R4W)

evidenced by the occurrence of a mixed assemblage containing both modes of preservation.

The entire unit is densely bioturbated, but discrete biogenic structures are rare. Locally, horizontally oriented, sand-filled, Thallassinoides and smooth-walled Ophiomorpha exhibit boxwork burrow configurations. Numerous, well indurated, calcareous sandstone concretions occur throughout the unit, varying in size from 1 to 10 inches (2.5 to 25 cm) in diameter. These concretions range from spherical to oblate in shape, and commonly contain fossil fragments. Thin limestone beds are sandy, fossiliferous packstones averaging 6 inches (15 cm) in thickness. They contain abundant, randomly-oriented, disarticulated mollusk valves and upper fine to medium sand grains. No trace fossils occur within these beds. In the southern portion of the study area, this unit is either absent or stacked repetitively with sandstone sequences. Variability in the nature and occurrence of this unit is discussed in the section on interpretation of the Gallup Sandstone.

This highly fossiliferous basal unit is overlain by a thick-bedded, bioturbated, calcareous sandstone sequence, whose lithology and geometry vary considerably along strike. This sequence consists of well-sorted, light olive gray, fine to medium-grained sandstone at the base, with moderately sorted, fine-grained sandstone above. This unit has a sharp, slightly irregular, erosional lower contact.

Thickness varies considerably along strike, ranging from 1 foot (30 cm) to 25 feet (8 m) in Mescal Creek, with an average of about 15 feet (5 m). The basal 5 feet exhibit medium-scale, tabular-shaped cosets of high to low angle tangential cross-beds with sharp, curved, erosional lower contacts. A composite rose diagram of trough cross-bed axis orientations from this interval is shown in Figure 28.

Discrete Skolithos and vertically-oriented, knobby-walled Ophiomorpha burrows occur sparsely in the basal portion, while overlying beds exhibit a bioturbate texture. The overlying 10 feet (3 m) are densely bioturbated, and contain numerous well indurated, ovoid, calcareous, fine-grained sandstone concretions averaging 1 inch (2.5 cm) in length.

The uppermost 10 feet (3 m) are structureless with minor laminated intervals. Poorly preserved, internal molds of disarticulated Corbula sp. valves occur along these laminae. All molds display a convex-upward orientation, and occur only locally in dense concentrations.

The two dimensional geometry of this sand body exposed in outcrop is highly variable along strike. In some localities, it is apparently tabular, with a slightly irregular lower contact. In Mescal Creek, it is lenticular in shape, and pinches out into muddy sandstone to the north. To the south, it pinches out into fossiliferous, calcareous, poorly sorted, light gray, fine-grained sandstone, which contains very coarse sand and granules. Thick beds of

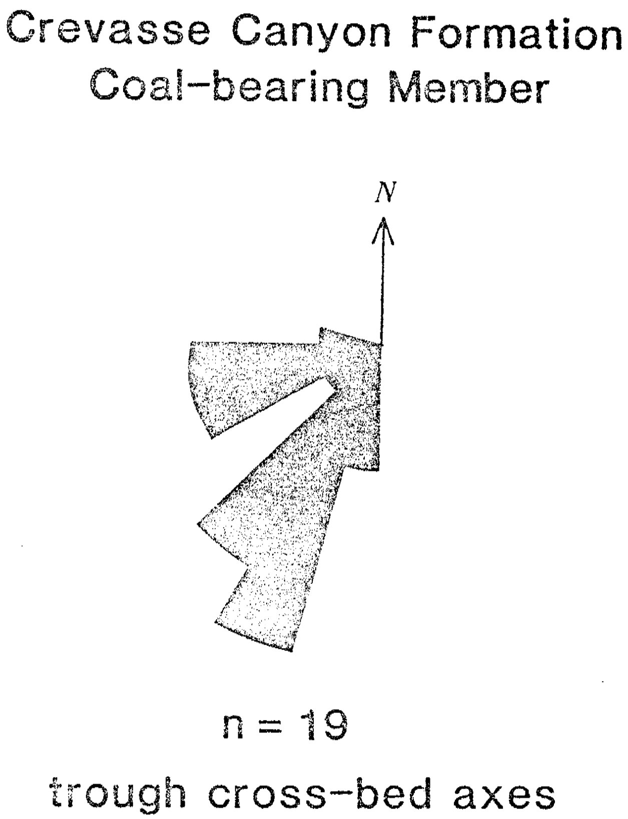


Figure 28 : Composite rose diagram of trough cross-bed axis orientations measured from sandstones immediately overlying lagoonal deposits in lower Mescal Creek. See Plate 2 for individual rose diagrams.

similar calcareous sandstones occur locally within this sand body along strike.

Two coal seams crop out within the Coal-bearing Member. A laterally persistent, coal-bearing interval occurs at the top of this enigmatic sand body. This interval consists of clayey and silty carbonaceous mudrocks, poorly sorted sandstones, and coals. This lowermost seam is closely associated with the top of the Gallup Sandstone, and averages about 5 inches (12.7 cm) in thickness (Figure 29). Locally, well developed woody root traces extend as much as 15 inches (38 cm) into the underlying sandstone. A maximum thickness of 10 inches (25.4 cm) occurs 1/4 mile (0.4 km) north of Mescal Creek and at the Southwestern mine (see Tabet and Frost, 1978). Humates and extremely localized thin pods of coal occur sparsely throughout the remainder of the Coal-bearing Member. The top of the Coal-bearing Member is considered to be the uppermost humate/coal bed in Mescal Creek. This horizon apparently displays lateral continuity, but its correlation to other stratigraphic sections is based solely on stratigraphic position, and physical continuity is not demonstrable.

The lowermost coal is overlain by approximately 45 feet (13.7 m) of thinly ripple-bedded, very fine-grained sandstones, and olive gray, silty mudstones. The overlying 440 feet (134 m) consist of lenticular, slightly carbonaceous, moderately to well sorted, noncalcareous, fine-grained sandstones, silty mudstones and carbonaceous

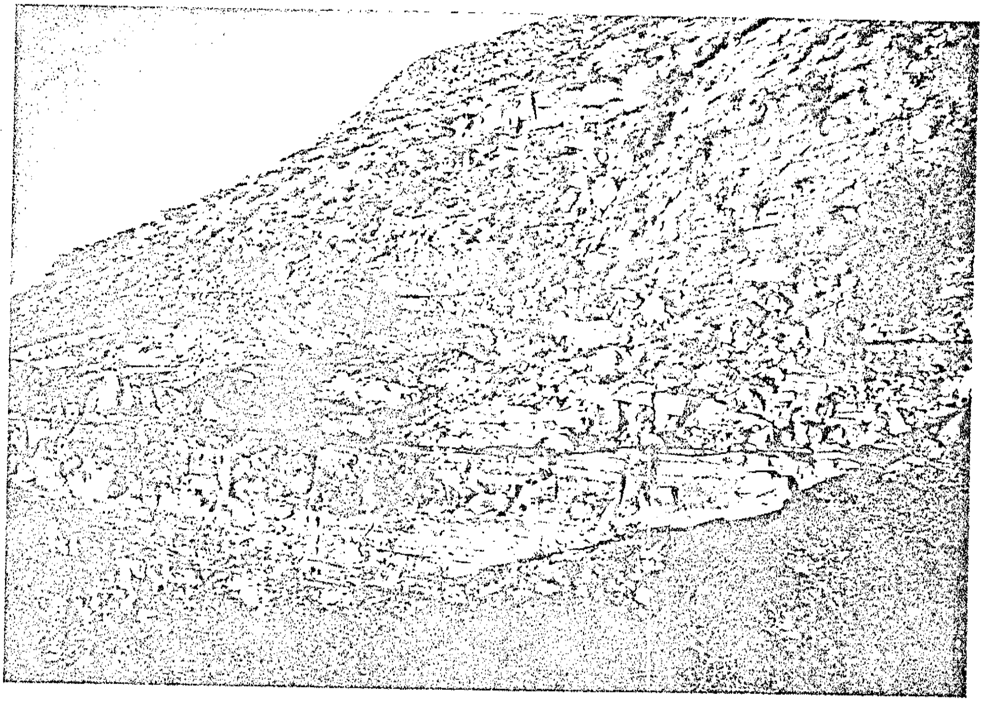


Figure 29 : Lowermost coal seam within the Coal-bearing Member rooted in washover sandstone in lower Mescal Creek. Coal bed is overlain by fluvial deposits. (SW 1/4, Section 36, T13S, R4W).

shales. These sandstone bodies differ sedimentologically from those occurring within the Barren Member, and will be examined in detail first. A detailed stratigraphic section of unit IV-25 is shown in Figure 30. This unit is typical of many lenticular, discontinuous sandstones within the Coal-bearing Member, and displays a fining-upward grain size distribution. The sequence has a sharp, curved, erosional lower contact, and is 28 feet (8.5 m) thick. The base of the sequence is structureless, thick-bedded, well sorted, light olive gray, fine-grained sandstone with local medium-scale, wedge and tabular-shaped, cosets of high to low angle tangential cross-beds with sharp, curved, erosional lower contacts. Clay chips averaging 1/2 inch (1.3 cm) in length and wood molds occur locally near the base within trough cross-beds. The scale of trough cross-beds decreases upward and asymmetrical ripple marks occur locally. These structures are overlain by thinly interbedded, horizontally laminated and planar cross-laminated sandstone, which forms the top of the well sorted portion of the sequence.

The remainder of the fining-upward sequence consists of thin, poorly sorted, light olive gray, very fine-grained sandstones containing abundant clay drapes and sparse clay chips 1/4 inch (0.5 cm) in length. These sandstones are overlain by silty, light olive gray mudstones and medium gray carbonaceous shale. Many other sandstones within the Coal-bearing ember exhibit similar sequences.

Another type of sandstone body commonly occurring

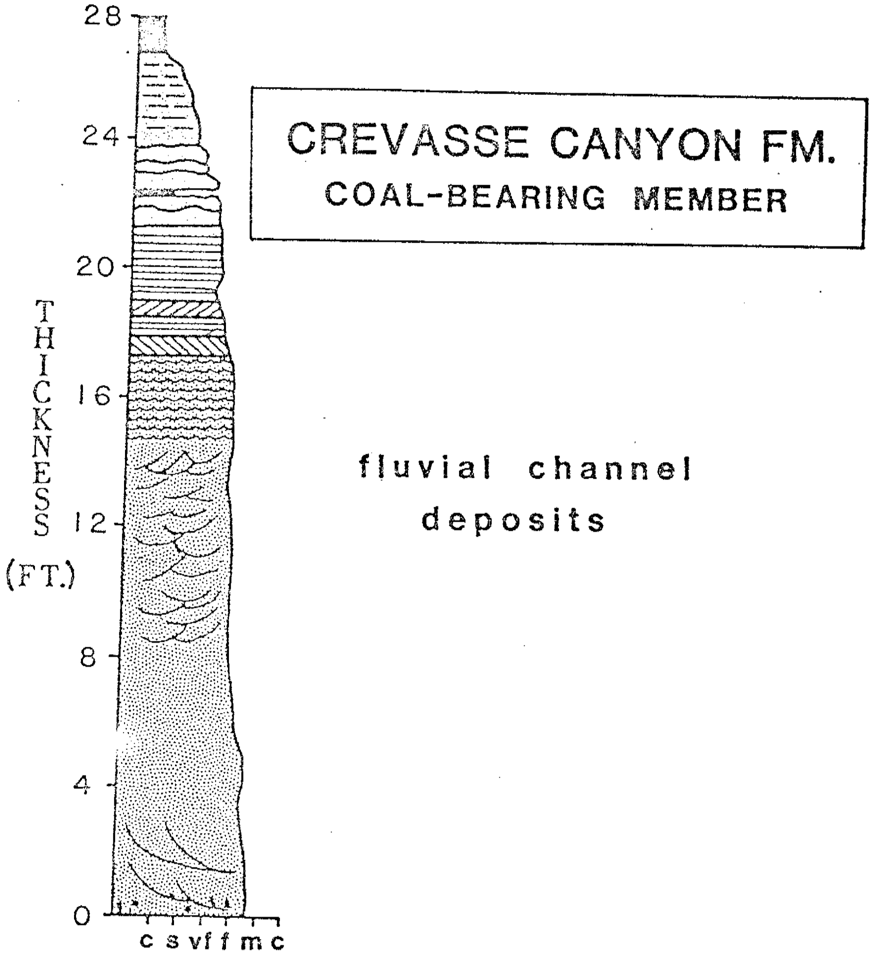


Figure 30 : Fining-upward fluvial channel deposits characteristic of many sandstones within the Coal-bearing Member (unit IV-25 on Plate 2).

within the Coal-bearing Member is herein referred to as tabular, discontinuous sandstone, which contains a less diverse assemblage of sedimentary structures. Such sandstones commonly have sharp, planar, nonerosional or gradational lower contacts, and are lithologically similar to previously described lenticular sandstones. These beds consist of slightly carbonaceous, moderately sorted, light olive gray, very fine and fine-grained sandstones, which are less well sorted than lenticular sandstones. Dominant bedding styles are structureless, trough cross-stratified, and ripple-bedded. Structureless and trough cross-bedded intervals commonly contain shale pebbles and clay chips which average approximately 1/2 inch (1.3 cm) in length and reach a maximum length of 6 inches (15 cm) (Figure 31). Trough cross-stratified intervals display small to medium scale, trough-shaped sets and cosets of high to low angle tangential cross-beds with sharp, curved, erosional lower contacts. Small-scale, trough-shaped sets of high to low angle tangential cross-laminae with sharp, curved, erosional lower contacts and climbing ripple cross-lamination commonly occur as well. The lower surfaces of some of these sandstones display flute casts. A composite rose diagram of flute cast orientations from the Coal-bearing Member is shown in Figure 32. Wood and plant molds (Figure 33) are common, and many trough cross-bedded sandstones contain abundant coal spars up to 1 inch (2.5 cm) in diameter.

Figure 31 : Shale pebbles and clay chips are common within channel and crevasse splay deposits throughout the Crevasse Canyon Formation (NW 1/4, Section 18, T14S, R3W)

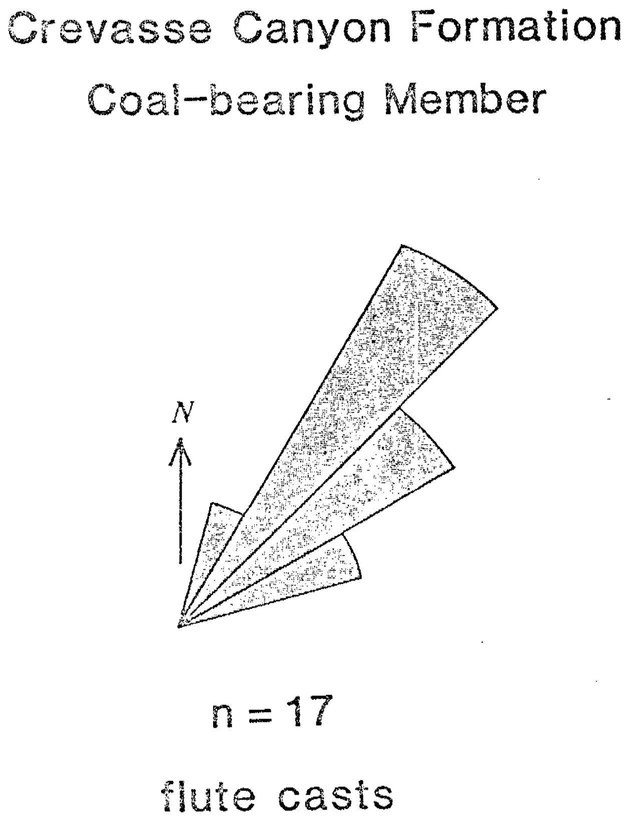


Figure 32 : Composite rose diagram of flute cast orientations measured from the Coal-bearing Member.

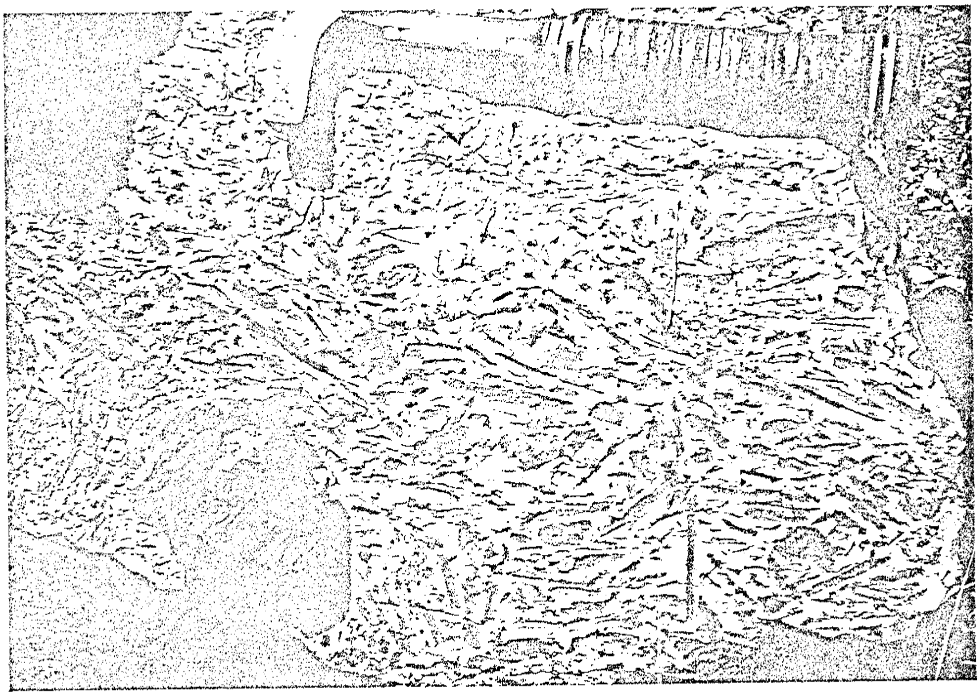


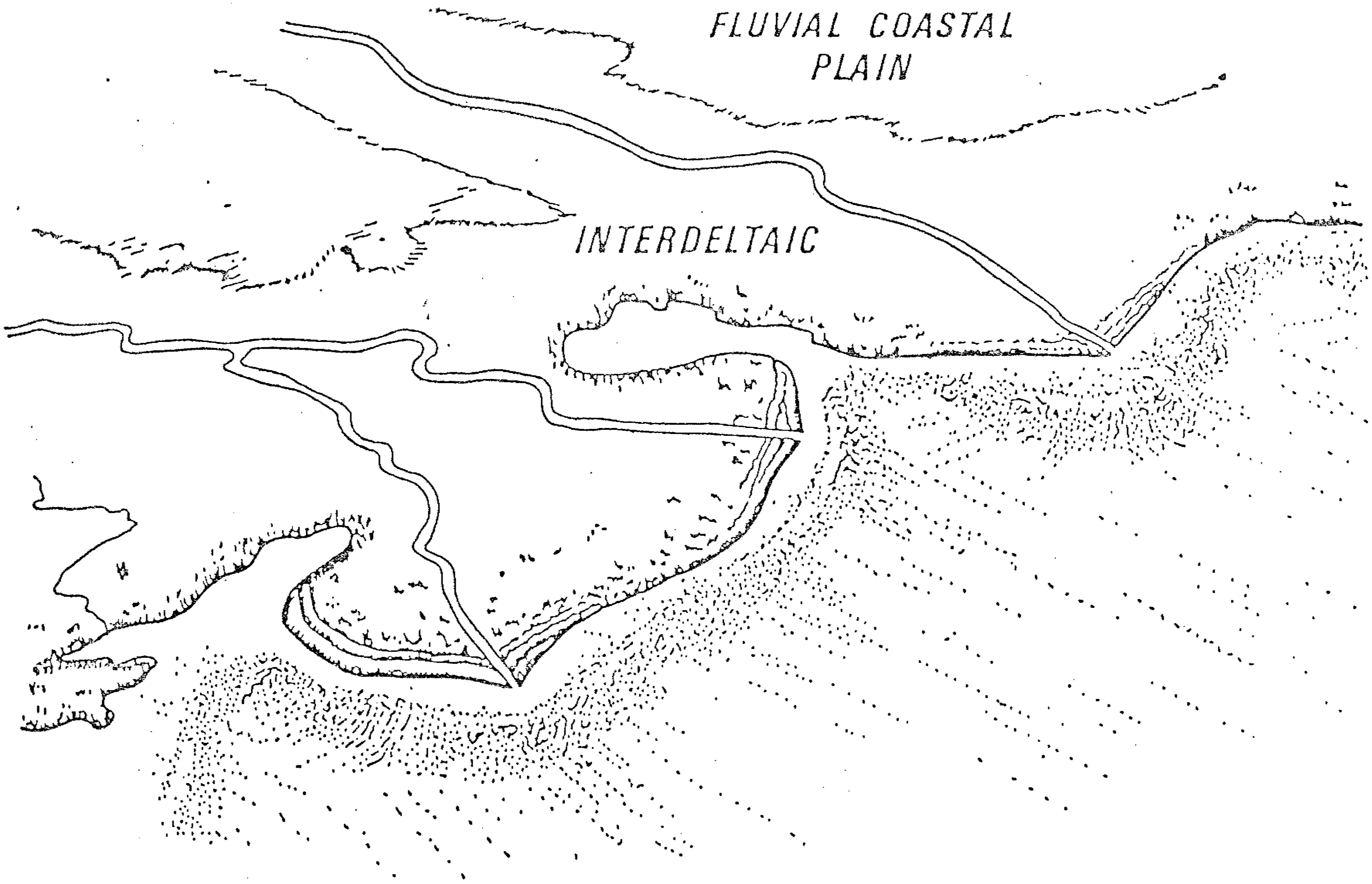
Figure 33 : Wood and plant impressions are common throughout the Crevasse Canyon Formation (NW 1/4, Section 18, T14S, R3W)

Coal-bearing Member: Interpretation

Marginal marine and fluvial deposits of the Coal-bearing Member represent several environments of deposition. Seaward shoaling of nearshore sands formed a barrier, allowing proliferation of a high abundance, low diversity molluscan fauna in a lagoonal environment. The horizontal attitude of burrow configurations, as well as the bioturbate texture of the entire basal unit, suggest that deposition or at least subsequent bioturbation, occurred in relatively low energy waters. The 3 taphonomic assemblages probably represent a transportational continuum whereby beds representing transportation of shell material into and within the lagoon are interbedded with beds containing fossils buried in situ. The occurrence of the mixed assemblage indicates simultaneous operation of both processes.

These 'lagoonal' deposits are quite sandy compared to lagoonal shales reported from other localities in the Western Interior Basin (see Masters, 1966; Balsley, 1982). An alternate interpretation is that they were deposited in interdeltaic areas between axes of deltaic sedimentation as shown in Figure 34. However, the lateral continuity and lithologic homogeneity of these deposits support the former interpretation.

Interpretation of the two dimensional exposure of the overlying sand body is somewhat problematic. The rose diagram shown in Figure 28 indicates that paleoflow was



(modified after Balsley, 1982)

Figure 34 : Marginal marine units may have been deposited in irregularly shaped interdeltaic areas rather than in long linear lagoons.

directed toward the southwest. Since paleocurrent indicators from underlying and overlying rocks indicate sediment transport was directed largely toward the northeast, this interval records a minor but significant deviation in paleoflow. It can be said with certainty that this stratigraphically dynamic sand body represents a complex assemblage of lagoon-filling deposits that varied in time and space, along an irregularly shaped back barrier environment. Assignment of specific depositional subenvironments to individual deposits is difficult because they contain no uniquely diagnostic features. This sand package probably represents washover fan deposition during lagoonal infilling, which may have resulted from a local decrease in sediment supply. Discontinuous, fossiliferous, calcareous sandstones represent local development of sandy, bioclastic lime shoals in back-barrier environments.

The occurrence of laterally extensive coal beds indicates widespread development of coal-forming environments occurred on a coastal platform formed by progradation of the barrier coastline. These coals are encased in mud-dominated fluvial deposits. Coal-forming environments were commonly terminated by an influx of mud, silt, and sand represented by crevasse splay and overbank deposits. The virtual absence of lateral accretion deposits in these channel sandstones indicates that sedimentation occurred primarily by vertical accretion. Fining-upward channel sequences enjoyed high preservation potential as a result of near-base level deposition.

Tabular, fine-grained sandstones with sharp, nonerosional or gradational lower contacts are interpreted as crevasse splay deposits. The external geometry and internal structure of these sandstones vary according to channel proximity, event magnitude and multiplicity, and depositional substrate. Abundant coal spars indicate that low-lying peat swamps were being eroded by streams. Crevasse splay deposits within the Coal-bearing Member are less abundant, but thicker than those of the overlying Barren Member. Insufficient regional information precludes determination of whether this coal-forming platform was an abandoned delta lobe or simply a mainland coastal plain.

Barren Member: Description

The Barren Member of the Crevasse Canyon Formation is so named for its lack of exposed coal beds. A thickness of 1075 feet (328 m) is estimated from the top of the Coal-bearing Member to the base of the Ash Canyon Member. An exact thickness is not obtainable due to minor faulting which introduces repetition and omission errors into measured sections. This relatively thick sequence is most complete 1/4 mile (0.4 km) south of NM 52 in the Coyote Canyon area, and is apparently not significantly repeated by faulting. A detailed stratigraphic section of the Barren Member is shown in Figure 35.

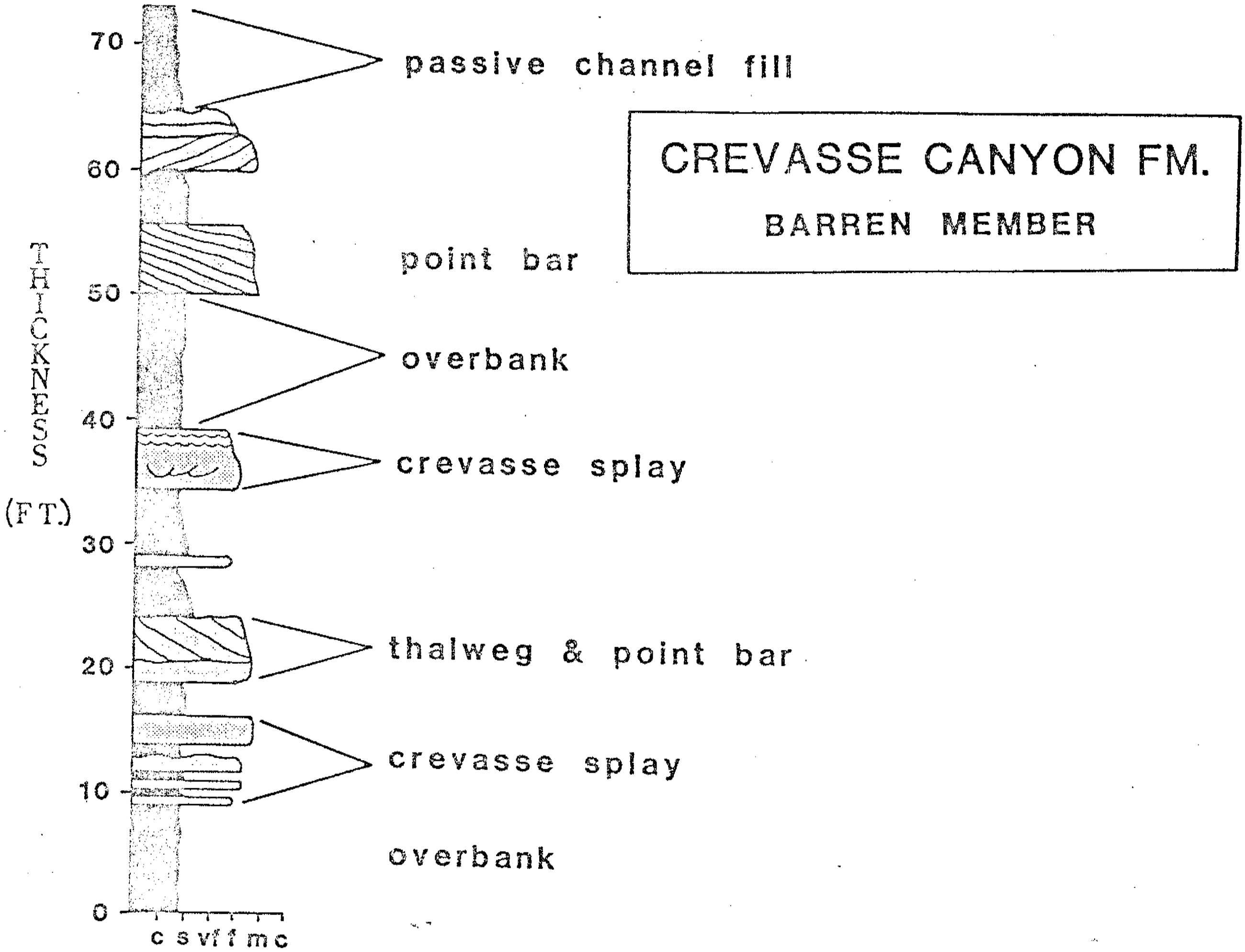


Figure 35 : Detailed stratigraphic section of the Barren Member measured in upper Mescal Creek.

The overall geometry of the Barren Member is probably approximately tabular, although this cannot be determined with certainty. Erosion has removed most of the overlying Ash Canyon Member and part of the Barren Member, consequently, recognition of fluvial axes and/or variability in geometry is not possible.

The Barren Member consists of fine to medium-grained sandstones, siltstones, mudstones, and shales. Individual sandstone bodies have lenticular geometries, but differ sedimentologically from those of the Coal-bearing Member. Essentially two types of sandstones occur within the Barren Member. The first is thick-bedded, moderately to well sorted, light olive gray to yellowish gray, fine to medium-grained sandstone. Thickness ranges from 5 to 20 feet (1.5 to 6 m). These units have lenticular geometries, sharp, curved, and irregular, erosional lower contacts, and often contain clay chips and shale pebbles. Internally, these sandstones contain structureless, laminated, and cross-stratified beds.

The most abundant varieties of cross-stratification are small to medium-scale, trough-shaped sets and cosets of high to low angle tangential cross-beds with sharp, curved, erosional lower contacts, as well as small to medium-scale, tabular-shaped sets and cosets of high to low angle tangential cross-beds with sharp, planar, nonerosional lower contacts. Small-scale, tabular-shaped sets of high angle, planar cross-laminae with sharp, planar, erosional lower contacts occur locally, but are generally less abundant than trough cross-bedded intervals. Clay chips and shale pebbles commonly occur as lags at the base of structureless and trough cross-bedded units.

Another medium to large scale variety of cross-stratification commonly occurs within these sandstones. This bedding style is herein referred to as lateral accretion bedding, and consists of individual very thin to thin sandstone beds which slope downward at varying angles through the sand body. Beds may be nearly planar, but most are slightly concave up, and intersect a flat base as shown in Figure 36. The slope of these beds ranges from 6 to 18 degrees, and averages about 14 degrees. Set thicknesses vary from approximately 2.5 to 6 feet (0.75 to 1.8 m), and average approximately 3 feet (1 m). These individual beds and bedding surfaces are characterized by internally heterogeneous assemblages of sedimentary structures and erosional surfaces. In some instances, asymmetrical ripple marks occur more or less normal to depositional dip, but more commonly deposition of these sets by lateral accretion processes must be inferred.

The second type of sandstone body within the Barren Member consists of thin-bedded, poorly to moderately sorted, light olive gray, very fine to fine-grained sandstone. These sandstone beds are tabular, and have both sharp and gradational, nonerosional lower contacts. Thickness ranges from 1 foot (0.3 m) to 5 feet (1.5 m). These sandstones are

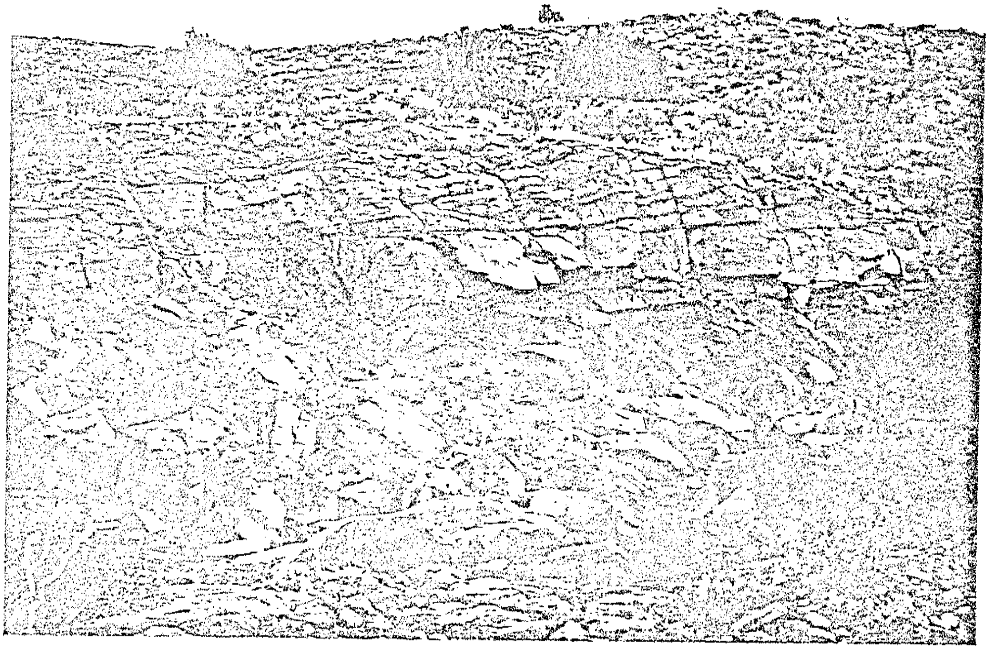


Figure 36 : Lateral accretion deposits overlying structureless thalweg sandstone. Point bar migrated from right to left (NE 1/4, Section 18, T14S, R3W)

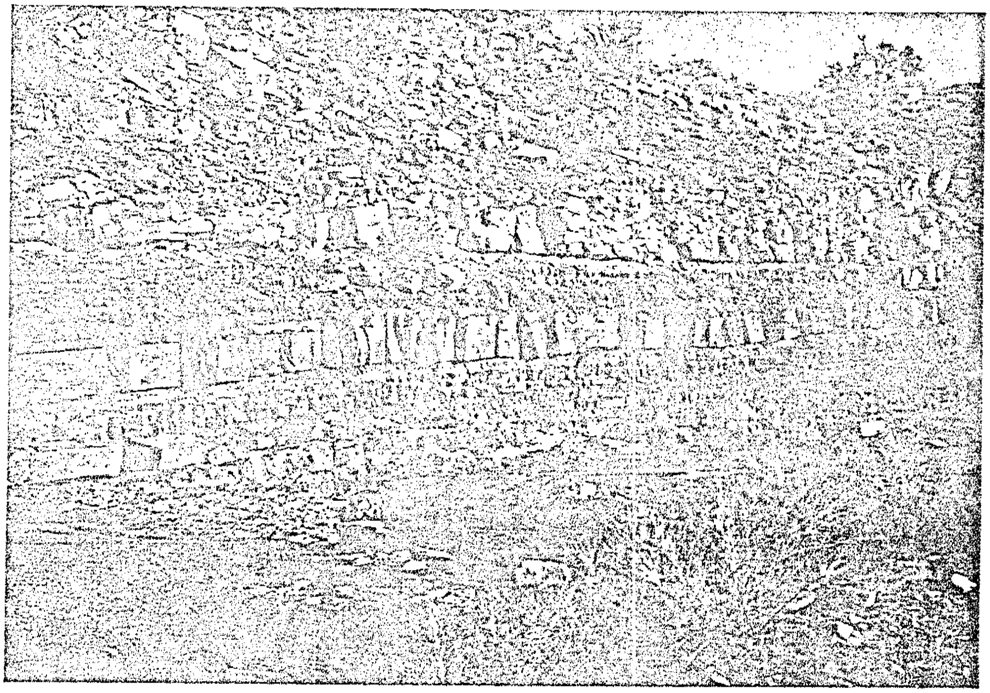


Figure 37 : Interbedded crevasse splay and overbank deposits of the Barren Member overlain by lateral accretion deposits which have migrated from right to left (NE 1/4, Section 18, T14S, R3W)

commonly interbedded repetitively with mudrocks and siltstones (Figure 37). In SW1/4, Section 17, T14S, R3W, a complex of these sandstones grades laterally into a 40 foot (12 m) thick, well sorted, medium-grained channel sequence. Medium-scale, trough-shaped cosets of high to low angle tangential cross-beds with sharp, curved, erosional lower contacts occur in association with thin-bedded, tabular sandstones. Medium-scale scour and fill structures also occur within this 'nested' sandstone complex.

Raindrop impressions occur on the upper surfaces of some of these sandstones. Plant molds are common, and well preserved leaf fossils occur in several sandstone beds. These leaf fossils include Sequoia montana, Ficus planicostata, cf. Dryophyllum sp., cf. Laurophyllum wardiana, cf. Dillenites cleburni, Cercidiphyllum sp., and cf. Quercus viburnifolia (identified by C. Robison, Bureau of Land Management, 1982, pers. comm.).

Composite rose diagrams of trough cross-bed axis, planar cross-bed dip, and parting lineation orientations are shown in Figures 38, 39, and 40 respectively. Parting lineations are treated as unidirectional paleocurrent indicators based on associated occurrences of trough cross-stratification.

Barren Member: Interpretation

Deposition of the Barren Member by mixed and suspended load streams of moderate sinuosity occurred on an upper

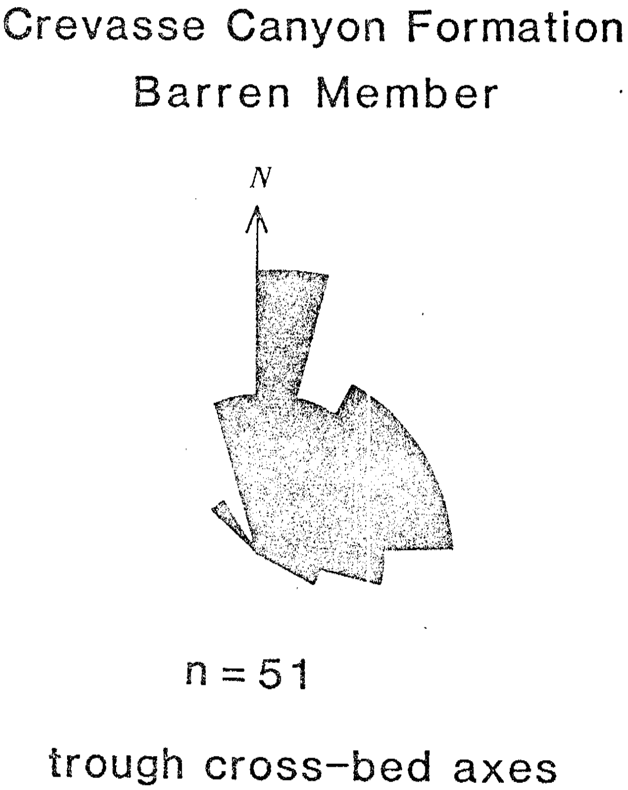
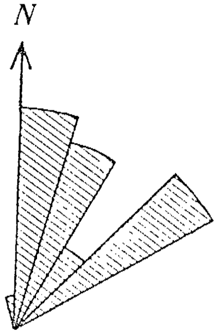


Figure 38 : Composite rose diagram of trough cross-bed axis orientations measured from the Barren Member. See Plate 2 for individual rose diagrams.

Crevasse Canyon Formation
Barren Member



n = 24

planar cross-beds

Figure 39 : Composite rose diagram of planar cross-bed dip directions measured from the Barren Member. See Plate 2 for individual rose diagrams.

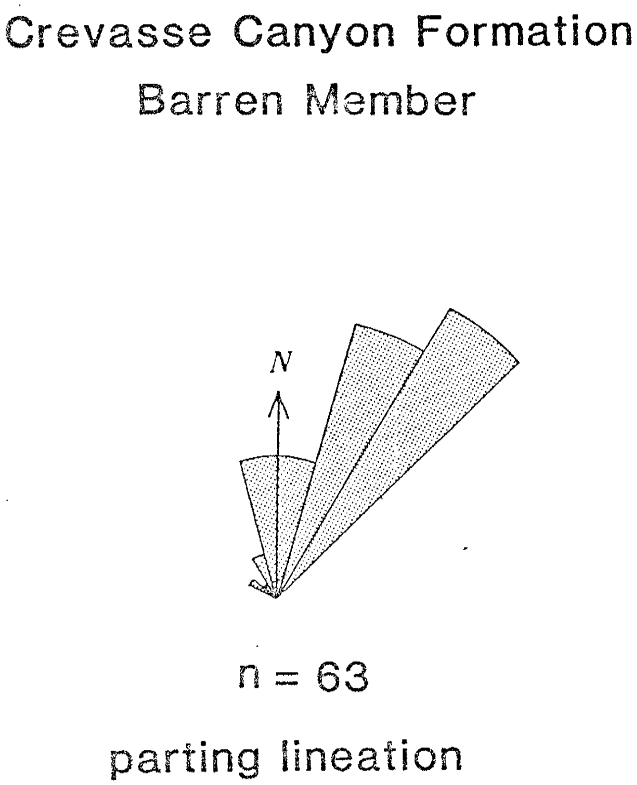


Figure 40 : Composite rose diagram of parting lineation orientations measured from the Barren Member. Measurements treated as unidirectional paleocurrent indicators based on associated trough cross-stratification. See Plate 2 for individual rose diagrams.

coastal or delta plain. Most thick-bedded, well sorted, sandstones are interpreted as channel sandstones, while the majority of thick-bedded, moderately sorted sandstones represent relatively thick crevasse splay deposits. Very thin to thin-bedded, poorly to moderately sorted sandstones interbedded with thin-bedded mudstones and siltstones represent more frequent minor crevasse splay events.

Variability in the nature of lateral accretion bedding is a result of flow time-velocity characteristics which influence the magnitude and type of deposition, erosion, and hence preservation. For instance, structureless thalweg sandstones commonly underlie lateral accretion bedding as shown in Figure 36. In other units, deposition and/or preservation of a thalweg sandstone did not occur, and lateral accretion bedding lies directly upon overbank deposits. The extent of lateral accretion bedding depended on migration distance and the type of sediment available for channel fill. Channel sandstones represent active channel fill deposits, whereas channels filled with very thin to thin-bedded mudrocks, siltstones, and very fine-grained sandstones are passive channel fill deposits.

Lateral transitions from lateral accretion bedding to an adjacent sandy channel fill rarely occur. Central portions of channels are commonly filled by mudstones, shales, very thin-bedded siltstones, and very fine-grained sandstones of overbank origin. Such channel fills are commonly referred to as 'clay plugs', whose geometry, size, and lithology are related to the nature of abandonment.

Wedge-shaped sandstone bodies whose beds slope away from a muddy channel fill may be natural levee deposits. Such units are grossly similar to lateral accretion bedding in that they consist of individual sloping beds which exhibit a variety of sedimentary structures, and evidence of a genetic relationship with a channel is necessary for their recognition. An example of this type of deposit is exposed on the eastern side of Mescal Creek in SE 1/4, Section 7, T14S, R3W.

Although statistically significant width/depth ratios were not calculated for channels within the Crevasse Canyon Formation, they appear to decrease slightly from the Coal-bearing Member to the Barren Member. In addition, several asymmetrical channel cross sections occur within the Barren Member. These observations may reflect an increasing degree of channel confinement and suspended sediment load.

Ash Canyon Member: Description

The Ash Canyon Member of the Mesaverde Formation was informally proposed by Bushnell (1953), who mapped coarse-grained sandstones, pebbly sandstones, and pebble conglomerates at Engle field as the Ash Canyon Member of the Mesaverde Formation. Following elevation of the Mesaverde to group status by Allen and Balk (1954), Melvin (1963) informally subdivided the Mesaverde into two formations. He included the Ash Canyon Member in his Mescal Creek Formation. Subsequent advances in clastic sedimentology and refinement of regional Upper Cretaceous stratigraphy indicate that usage of Melvin's proposed nomenclature is inappropriate.

Bushnell's (1953) definition of the Ash Canyon Member is confusing. He states on page 15, "the upper conglomeratic beds of the (Mesaverde) formation are mapped separately and called the Ash Canyon Member of the Mesaverde Formation." However, on page 19 he states, "the Ash Canyon Member consists of conglomerate and coarse-grained sandstone," and that, "the Ash Canyon Member intertongues with the underlying main body of the Mesaverde Formation." It is clear from the preceding statements that Bushnell's principle criterion for definition of the Ash Canyon Member is the occurrence of pebble size grains. As such, this definition is vague and difficult to apply in the field (Mason, 1976, p. 58; Lozinsky, 1982, pers. comm.; this study). In addition, one of his definitive criteria is that "no volcanic material was observed in beds of the Ash Canyon Member." The writer has commonly observed felsic volcanic pebbles in pebble conglomerates mapped by Bushnell and others (Melvin (1963); Mason (1976); Lozinsky (1982)) as Ash Canyon Member.

Despite the ambiguity surrounding Bushnell's definition of the Ash Canyon Member, the concept of a coarser-grained facies overlying relatively fine-grained rocks is a valid one. This study indicates that beds mapped as Ash Canyon Member by Bushnell (1953) are actually part of a thicker lithosome. The type section proposed by Bushnell (1953) is inadequate since it is in fault contact with the McRae Formation, and its lower contact is not exposed. The lower contact of the Ash Canyon Member is herein considered to be the transition between the mud-dominated Barren Member and the sand-dominated Ash Canyon Member. Melvin (1963) recognized this transition as well. This transition occurs through changes in sandstone geometry and abundance, bedding style, grain size, and color. The contact is locally distinct, but may be difficult to recognize in some areas. A detailed stratigraphic section of the Ash Canyon Member is shown in Figure 41.

The Ash Canyon Member consists predominately of medium, coarse, and very coarse-grained sandstones, pebbly sandstones, and pebble conglomerates. Sandy mudstones, muddy sandstones, shales, siltstones, and very fine to fine-grained sandstones are significantly less abundant. Sandstones range from yellowish gray to grayish yellow in color on fresh surfaces, and weather to very pale orange and grayish orange pink. Most sandstones are well sorted, and the degree of sorting is directly proportional to grain size. Pebbly sandstones and pebble conglomerates are moderately to poorly sorted, and are yellowish gray, light gray, and moderate red in color. The occurrence of red conglomerate is related to local hematite cementation.

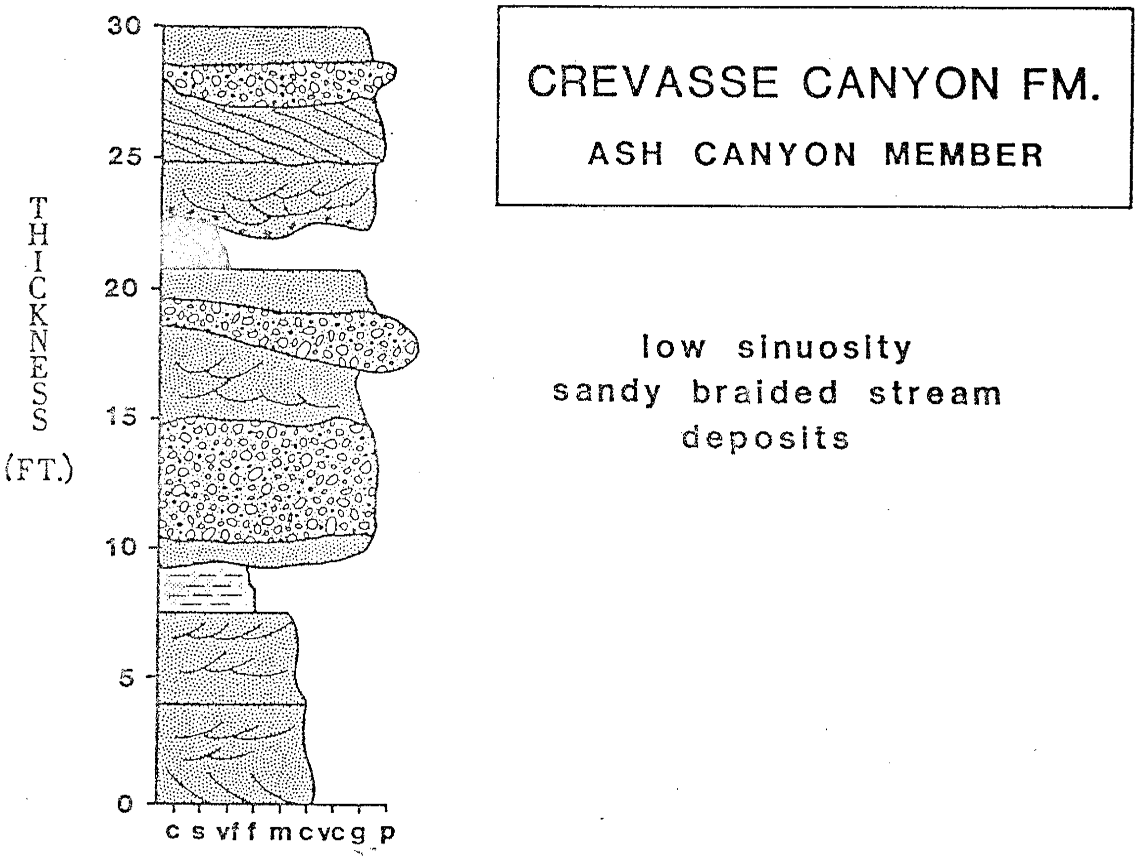


Figure 41 : Detailed stratigraphic section of the Ash Canyon Member measured immediately south of the Elephant Butte dam.

These rocks are indurated, cemented by silica, and contain very little carbonaceous material. Pebble lithologies within the Ash Canyon Member include chert, quartz, quartzite, fine and medium-grained sandstone, silicified dolomite and limestone, finely crystalline granite, and felsic and intermediate volcanic varieties.

A minimum thickness of approximately 790 ft (240 m) was measured 1/4 mile (0.4 km) south of NM 52 in the Coyote Canyon area. In many areas, the Ash Canyon Member is thinner or absent. Some thickness variability may be due to post-Ash Canyon, pre-McRae Formation erosion, but the majority is probably due to the fact that the top of the Ash Canyon has largely been removed by Tertiary and Quaternary erosion. There is no evidence indicating that this interval represents the total thickness of the Ash Canyon Member deposited in this area.

Ash Canyon sandstones have a sheet geometry, and recognition of individual, confined channel-fill sequences is usually not possible. The geometry of Ash Canyon sandstones contrasts markedly with that of lenticular sandstones within the Barren Member. Sandstones of the Ash Canyon Member are thin to thick-bedded, and have irregular erosional lower contacts. The dominant bedding styles consist of medium-scale, trough-shaped cosets of high to low angle tangential cross-beds with sharp, curved, erosional lower contacts (Figure 42), and medium-scale, tabular-shaped cosets of high to low angle tangential cross-beds with sharp

Figure 42 : Trough cross-bedded sandstones of the Ash Canyon Member. Hammer in center for scale (NW 1/4, Section 31, T13S, R3W)

Figure 43 : Scour and fill structure filled with pebble conglomerate within the Ash Canyon Member. Hammer at top center for scale (NE 1/4, Section 31, T13S, R3W)

planar, erosional lower contacts. Planar cross-bedding is considerably less abundant although small-scale, tabular and wedge-shaped cosets of high angle planar cross-laminae with sharp, planar, nonerosional and erosional lower contacts occur in association with trough cross-beds. Smooth-crested asymmetrical ripple marks occur rarely.

Lateral accretion bedding occurs sparsely throughout the Ash Canyon Member, and constitutes an insignificant percentage of the total rock volume. These lateral accretion deposits are similar to those described from the Barren Member.

Scour and fill structures are common throughout the Ash Canyon Member. Scours range in size up to 30 feet (9 m) in width, 4 feet (1.3 m) in height, and 40 feet (12 m) in length. Scour fills generally consist of coarser-grained material than that of the underlying substrate, and are most conspicuous when filled with pebbly sandstone and pebble conglomerate (Figure 43).

Locally, crude fining-upward sequences are recognizable within the Ash Canyon Member. These fining-upward sequences differ markedly from those of the Coal-bearing Member. The basal portion consists of thick-bedded, trough cross-stratified, coarse-grained sandstone which fines upward to medium-grained sandstone, capped by either sandy mudstone, siltstone, or poorly sorted, very fine to fine-grained sandstone. These finer intervals are generally quite thin, ranging from several inches (cm) to several feet (metre) in thickness. Some of the thicker fine intervals are laterally traceable for distances of up to 1200 feet (418 m), before they pinch out. Sand-free mudstones and shales are rare, and most fine intervals contain an appreciable percentage of sand size grains.

Silicified wood fragments and logs are common. Bushnell (1953, p. 20) reports a log of silicified wood 30 feet in length and 3 feet in diameter. Silicified wood and abundant wood molds were the only fossils observed within the Ash Canyon during this study. A composite rose diagram of trough cross-bed axis orientations within the Ash Canyon Member is shown in Figure 44.

Ash Canyon Member: Interpretation

The Ash Canyon Member of the Crevasse Canyon Formation, as redefined herein, records an influx of relatively coarse-grained sediment into a stable, low energy depositional system. This influx probably records the initial sedimentary response to source area tectonism responsible for overlying volcaniclastic deposits of the McRae Formation, and may mark the beginning of the Laramide orogeny.

Sheet sandstones of the Ash Canyon Member were deposited by low sinuosity, sandy, braided streams. The unimodal paleocurrent distribution shown by Figure 44 indicates that sediment dispersal was directed to the northeast. Although sedimentation occurred primarily by

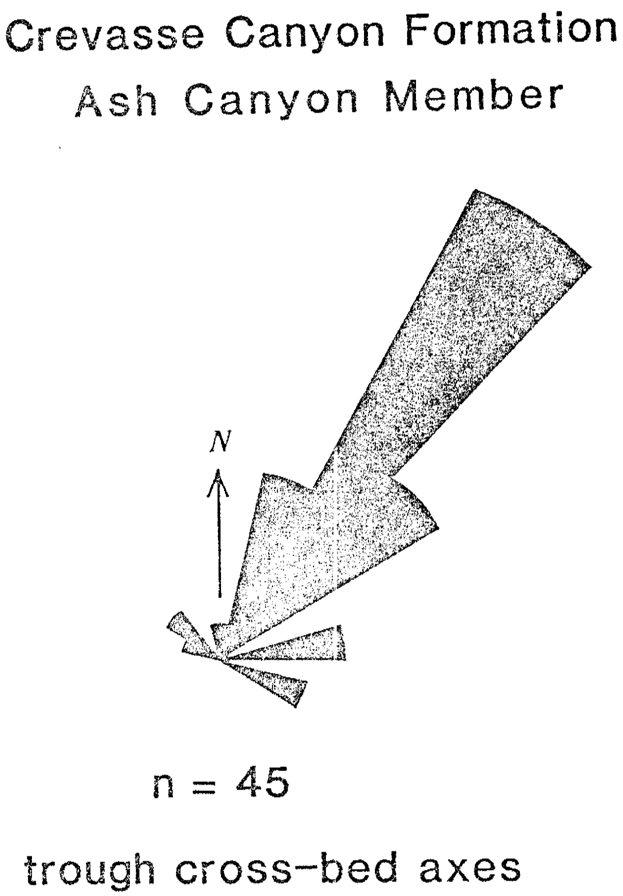


Figure 44 : Composite rose diagram of trough cross-bed axis orientations measured from the Ash Canyon Member. See Plate 2 for individual rose diagrams.

vertical accretion, these relatively unconfined streams migrated across the floodplain forming multilateral and multistory sand bodies.

Widespread coalescence and stacking of active channel fill deposits have resulted in the sheet geometry of the Ash Canyon Member. In contrast, sandstones of the underlying Barren Member are discrete, lenticular, active channel-fill and crevasse splay deposits which are encased in a matrix of muddy floodplain deposits. Consequently, finer-grained floodplain deposits of the Ash Canyon Member had a low preservation potential, and were often reworked and destroyed during stream migration.

The Ash Canyon Member represents the coarsest detritus deposited and/or preserved within the Mesaverde Group in New Mexico. One significant unsolved problem is the age of the Ash Canyon Member. No age-diagnostic fossils were found in fluvial deposits of the Mesaverde Group. The overlying McRae Formation is generally considered to be Late Cretaceous in age based on the occurrence of ceratopsian dinosaur bones near Elephant Butte Reservoir (Kelley and Silver, 1952, p. 117). According to the paleogeographic reconstructions shown by Molenaar (1983), post-Turonian transgressions did not reach the Truth or Consequences area. Consequently, fluvial deposits of the Mesaverde Group at Engle field may range from Coniacian to Maestrichtian in age, or may represent a smaller time span. Solution of this problem would allow calculation of sedimentation rates for strata of the Mesaverde Group, and would also shed light on the paleotectonic significance of the Ash Canyon Member.

Petrography

Petrographic analysis was performed primarily to describe local lithologic character and variability , as well as to aid interpretation of provenance and depositional environments. Eighteen samples collected during section measurement were examined petrographically. Mineralogical data for twelve representative coarse-member samples are tabulated in Table 1. Point counting involved recording a minimum of 350 'whole rock' points including cements, matrix, porosity, and unknowns. Observation was restricted to upper fine to medium sand grades to eliminate effects of grain size on relative grain abundances, except in the two very coarse grained samples. Sample classification is modified from McBride (1963) and Folk (1980). Subequal abundances of lithic arkose, feldspathic litharenite, and litharenite occur, with a poorly developed trend toward litharenites in younger strata.

Detrital Components: Quartz

Quartz is classified into five varieties. Monocrystalline quartz (Mx) is subdivided by extinction behavior (Folk, 1980, p.72) into straight (<1), slightly undulose (1 to 5), and undulose (>5) varieties. Polycrystalline quartz (Px) is subdivided on the basis of

Table 1 Lithologic Components of Twelve Sandstone Thin Sections (350 points each slide expressed as percentages)

Sample Number		IV-2T	IV-7	IV-10	I-18	IV-20T	IV-22B	IV-23	IV-42	I-68	I-111	I-130A	I-130B
Quartz:		34	35	42	32	30	42	38	23	22	35	46	46
	Mx(straight)	11	8	12	9	10	12	9	7	6	9	10	15
	Mx(sl. und.)	5	6	9	4	5	8	11	3	5	9	11	13
	Mx(undulose)	7	11	14	5	6	9	8	7	5	13	18	12
	Px (composite)	5	4	5	5	4	6	4	4	3	2	4	3
	Px (multixline)	6	6	2	9	5	7	6	2	3	2	3	3
K-spar:		12	8	8	8	13	8	6	7	9	12	5	4
	Orthoclase	10	6	6	6	7	6	5	5	7	9	5	3
	Microcline	0	tr	0	tr	2	tr	tr	0	0	1	0	0
	Perthite	2	2	2	2	3	2	tr	2	2	2	0	1
Plagioclase:		10	10	9	8	14	13	8	10	7	9	2	3
	Untwinned	4	5	5	4	8	7	5	5	5	7	2	2
	A-twin	4	4	2	3	4	5	2	4	1	2	0	1
	C-twin	2	1	2	1	1	1	tr	1	1	tr	0	0
	A+C-twin	0	tr	tr	tr	1	tr	tr	tr	0	0	0	0
Micas:	Biotite	tr	tr	tr	1	tr	tr	tr	tr	0	0	0	0
	Muscovite	tr	tr	tr	3	0	tr	tr	tr	0	0	0	0
Lithic Fragments:		16	20	11	21	28	19	22	38	43	26	33	24
SRF	SS	0	0	0	0	0	0	0	0	1	0	0	3
	sltst	tr	tr	0	0	tr	tr	0	1	tr	0	1	tr
	sh	3	tr	tr	tr	tr	tr	1	tr	1	1	0	0
	mdst	2	3	2	2	2	3	tr	5	9	3	1	2
	carbonate	0	0	0	0	tr	0	0	0	0	0	0	0
	chert	2	4	2	4	4	3	4	6	8	4	13	5
MRF	phyllite+slate	0	0	0	0	0	tr	0	tr	0	0	0	0
	schist	1	tr	0	1	2	1	0	tr	0	0	0	tr
VRF	felsic	5	8	4	9	14	8	11	16	15	10	12	7
	mafic	0	0	0	0	0	0	0	0	0	0	0	0
GRF	granitic	3	4	3	5	5	4	6	9	8	8	6	7
Matrix:		17	17	15	24	3	2	14	4	12	6	1	6
	orthomatrix	4	8	6	14	tr	0	1	0	1	1	tr	3
	epimatrix	6	6	7	7	2	2	12	3	6	5	1	3
	pseudomatrix	7	3	2	3	1	tr	1	1	5	1	0	tr
	organic matrix	0	0	0	tr	0	0	0	tr	tr	0	0	0
Porosity:		2	3	6	tr	7	3	6	9	4	4	5	2
Cement:		11	6	8	2	4	10	6	8	2	3	10	15
	quartz	2	5	4	2	tr	2	2	3	1	3	10	15
	calcite	6	0	3	0	3	7	0	0	0	0	0	0
	clay	0	0	0	0	0	0	3	4	0	0	0	0
Unknown:		3	1	1	tr	1	1	1	1	1	tr	tr	tr

number of crystals per grain, into composite (<3) and multicrystalline (>3) varities. The overall polycrystalline to monocrystalline quartz ratio is 0.29.

Monocrystalline quartz (straight) occasionally contains small irregular muscovite and biotite inclusions, vacuoles, acicular rutile needles, subhedral tourmaline and zircon inclusions. Most Mx grains are anhedral, subangular, and subelongate to subequant, although grains in a particular thin section often display the entire spectrum of roundness and elongation values.

Polycrystalline composite and multicrystalline quartz are present in subequal amounts. Virtually all individual crystals in composite quartz have undulatory extinction, and would be equivalent to the composite metamorphic quartz of Folk (1980, p.72). Multicrystalline quartz generally has many nonuniformly distibuted crystals (>10) per grain. Crystal shape is anhedral to subhedral, and crystal contacts are planar. Occurrences of preferred alignment of crystal elongation and sutured crystal contacts are rare.

Feldspar

Potassium and plagioclase feldspars are present in subequal amounts. Both varieties of feldspar are generally subhedral, subangular, and subelongate to subequant. Orthoclase is the dominant potassium feldspar, with lesser amounts of microcline and perthitic feldspar. Orthoclase rarely exhibits Carlsbad twinning. Sanidine does not occur as discrete grains. The degree of diagenetic alteration of orthoclase is variable, ranging from fresh to extensively altered. Alteration of orthoclase occurs as randomly distributed patches of reddish brown secondary limonite or clays. Preferential replacement along composition planes also occurs.

Plagioclase twin varieties occur, in decreasing order of abundance, as untwinned, albite-twinned, Carlsbad-twinned, and combined albite plus Carlsbad-twinned. Antiperthite is not observed. Plagioclase compositions were not measured quantitatively, but perusal of several grains using the Michel-Levy method yielded compositions ranging from albite to andesine. Partial sericitization is the most common diagenetic alteration of plagioclase feldspars. Zoned plagioclase is not observed.

Formation of secondary feldspar dissolution porosity is a late diagenetic event in all samples, and apparently occurs independently of composition. Recording these pores as porosity during point counting decreases the relative abundance of feldspar. Consequently, points plotted on the classification diagram (Figure 45) could be shifted slightly toward the F pole. However, this effect is regarded as negligible since porosity averages only 4%, a considerable portion of which is primary intergranular porosity.

Lithic Fragments

Lithic fragments from sedimentary, plutonic, volcanic and metamorphic rocks were observed. Sedimentary

Figure 45: Sandstone Classification Diagram (modified from McBride (1963) and Folk (1980))

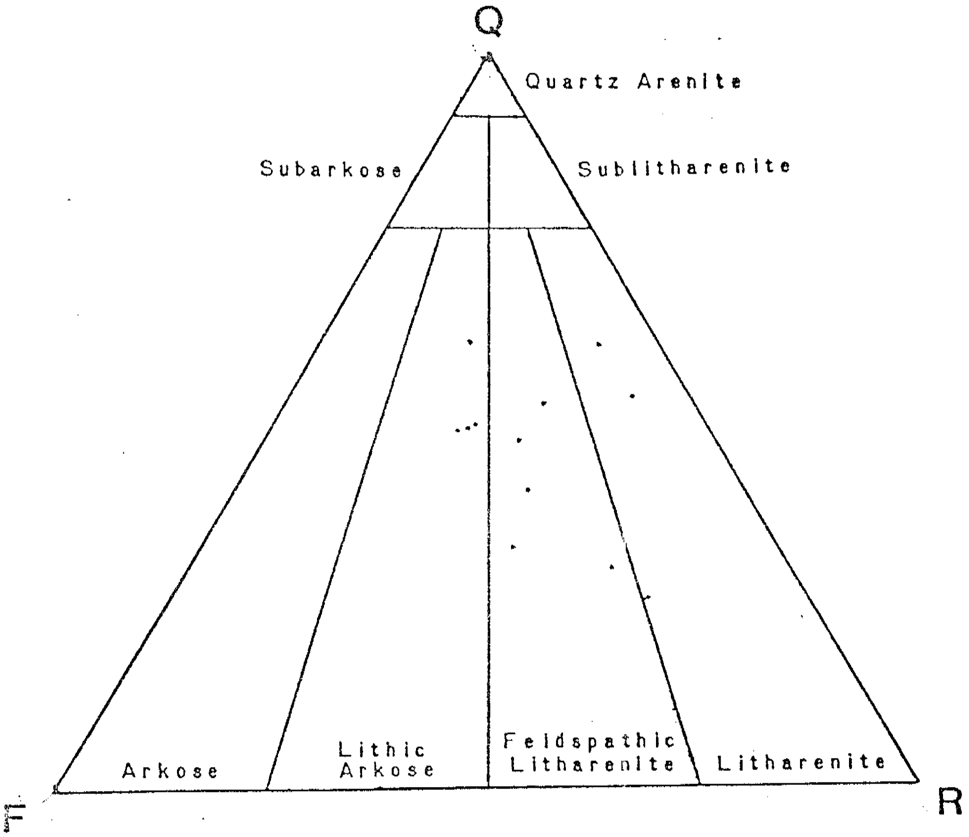


Table 2 : Pole Percentages for Classification Diagram

Sample Number		Q	F	R
I130B	(Ash Canyon Mbr.)	60	8	32
I130A	"	54	8	38
I111	(Barren Mbr.)	42	26	32
I68	(Coal-bearing Mbr.)	27	20	53
IV42	"	30	22	48
IV23	"	51	19	30
IV22B	"	49	26	25
IV20T	(Gallup Sandstone)	35	32	33
I18	(Carthage Mbr.)	46	24	30
IV10	(Fite Ranch Mbr.)	59	24	17
IV7	(Carthage Mbr.)	48	25	27
IV2T	(Atarque Mbr.)	48	30	22

Q = monocrystalline and polycrystalline quartz
F = all feldspars
R = all rock fragments including chert

lithic fragments occur, in decreasing order of abundance, as chert, mudstone, shale, siltstone, sandstone, and carbonate.

Chert occurs as microquartz (<20um) and megaquartz (>20um). Some grains contain both varieties distributed as irregular patches, while others contain veins of megaquartz within microquartz. Some megaquartz chert grains contain relict gastropods, bryozoans, sponges, fusulinids, and rhombohedrons, whose outlines remain recognizable by the preservation of micron-scale inclusions. Other megaquartz chert grains contain regions of radial, botryoidal chalcedony, which occur as cavity fillings, or as replacement of original cavity fillings. Sandstone lithic fragments are moderately sorted, fine-grained quartz arenites. Mudstone lithic fragments are the most abundant sedimentary lithic fragment besides chert, followed by siltstones, shales, and carbonate mudstones.

Plutonic igneous lithic fragments consist of finely crystalline granite containing quartz, feldspar, muscovite and biotite. Most are strongly altered, difficult to recognize, and may include gneissic lithic fragments. Grains of quartzofeldspathic mica schist and slate/phyllite occur rarely in most samples.

Felsic volcanic lithic fragments (VRF) occur in all samples. Precise identification of VRF varieties is commonly difficult due to alteration of groundmass and/or microphenocrysts. Many VRF grains lack microphenocrysts and resemble chert. Upon close examination these are usually cloudy, vacuole-rich, polymineralic, aphanitic microcrystalline grains which possess considerable intragranular microporosity resulting from dissolution of feldspathic groundmass. The effect of complete dissolution of feldspar microphenocrysts is often observed as relatively large intragranular pores. Most grains have subhedral to euhedral microphenocrysts of twinned plagioclase and untwinned potassium feldspar (sanidine ?), as well as subhedral quartz and mica microphenocrysts. It is likely that some grains reported as epimatrix or as unknowns may be altered felsic volcanic lithic fragments.

Other Minerals

Muscovite, biotite, zircon, and tourmaline occur in most samples. Micas are generally absent or present in trace amounts, although they rarely constitute 4-5% of the rock. Discrete zircon occurs as very fine-grained anhedral to euhedral crystals. Euhedral crystals display a prismatic habit. Tourmaline is slightly less abundant than zircon, and crystals are anhedral, well rounded, and equant. Opaque heavy mineral grains were not observed.

Cements

Quartz, calcite, and clay cements were observed. Early growth of quartz syntaxial rim cement is generally the initial diagenetic event. Only in instances where detrital quartz grains are thoroughly surrounded by matrix are overgrowths absent. Beds deposited under marine conditions often have partial to extensive intergranular drusy calcite cementation. In some instances, intergranular calcite cement has begun to replace plagioclase feldspars. Clay rim cements occur on grains in some fluvial channel sandstones, and this early cementation has apparently inhibited precipitation of quartz overgrowths and resulted in preservation of remaining primary intergranular porosity.

Matrix and Porosity

Matrix classification used herein is that of Dickinson (1970), with one exception. Epimatrix is redefined to describe framework grains whose original identity is obscured by chemical alteration. The presence of orthomatrix is inversely related to the energy regime of the depositional subenvironment for a particular sandstone body. Organic matrix consists of carbonaceous flakes or amorphous organic material of unknown composition.

Most porosity is a combination of primary intergranular porosity and secondary feldspar dissolution porosity. Porosity averages approximately 4%, and ranges from 2% to 9%.

Clay Mineralogy

Nine representative mudrock samples collected during section measurement were analyzed by x-ray diffraction to determine relative abundances of clay mineral groups. Sample preparation and semiquantitative analysis techniques are those used by Krukowski (1983).

Mixed layer clays and illite predominate with lesser amounts of chlorite and kaolinite. Discrete smectites were not detected. Relative abundances of clay mineral groups are shown in Table 3. Sample numbers correspond to sedimentation units in measured section I on Plate 2.

Provenance

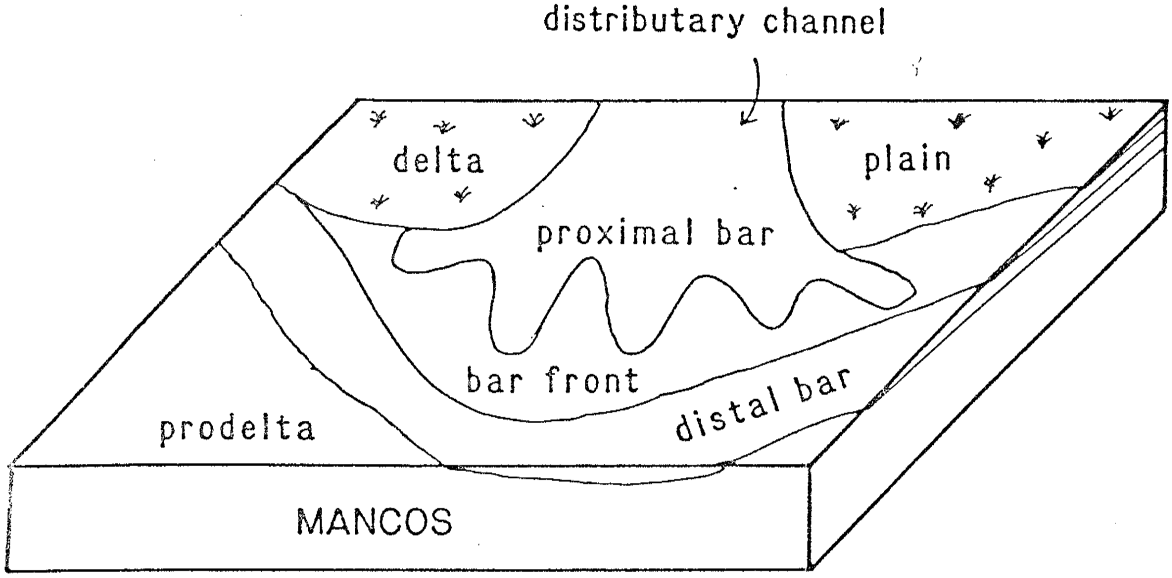
Grains derived from plutonic, volcanic, metamorphic, and sedimentary sources are present in most samples. This high degree of grain diversity indicates that sandstones of the Engle field were derived from lithologically heterogeneous source rocks. The occurrence of silicified, partially dolomitized, fusulinid wackestone grains requires exposure of Upper Paleozoic strata at least as early as deposition of the Ash Canyon Member of the Crevasse Canyon Formation. The non-statistical sampling procedures used do not permit a more detailed provenance interpretation. Although no significant stratigraphic trends in grain type occurrence are observed in this study, detailed petrographic study underway may reveal possible structural control of provenance within these strata (S. Johansen, 1983, pers. comm.).

	Mancos	I-19	I-26	I-46	I-66	I-81	I-91	I-122	I-126
Kaolinite	tr	tr	1	tr	–	5	1	tr	–
Chlorite	2	1	1	–	–	–	–	1	–
Mixed Layer	1	7	7	8	8	3	6	7	7
Illite	6	2	2	2	2	1	3	3	3
Montmorillonite	–	–	–	–	–	–	–	–	–

Table 3 : Clay mineral group abundances determined by x-ray diffraction expressed in parts per ten. Sample numbers correspond to sedimentation units in section I on Plate 2.

Depositional Models and Geologic History

The Tres Hermanos Formation represents deposition of nearshore sands and coastal plain deposits within a low energy, fluvially-dominated depositional system. A schematic representation of depositional paleoenvironments during deposition of the Atarque Sandstone Member is shown in Figure 46. The Atarque represents deposition of a distributary mouth bar in a shallow epeiric sea. Mouth bar progradation created a near-sealevel platform upon which coastal or delta plain and marginal marine sediments of the Carthage Member accumulated as shown in Figure 47. Transgression of the seaway across these fluvial and marginal marine deposits is recorded by the Fite Ranch Sandstone Member. The Fite Ranch represents deposition of a beach/shoreface complex which was accompanied by shoreface erosion (Figure 48). The D-Cross Tongue of the Mancos Shale represents shallow, open marine conditions. A schematic representation of paleoenvironments during the last transgression of the seaway is shown in Figure 49. Thin tongues of the Gallup Sandstone within the D-Cross Tongue of the Mancos Shale record several minor incomplete progradational episodes. Progradation and/or regression of the seaway resulted in deposition of the Gallup Sandstone. The Gallup represents a well developed barrier island complex, and is overlain by back-barrier lagoonal and washover deposits (Figure 50) of the Coal-bearing Member of the Crevasse Canyon Formation. Progradation created a



Atarque Sandstone Member

Figure 46 : Local paleoenvironments during progradation of the Atarque Sandstone Member. The Atarque may actually represent several coalescing distributary mouth bars.

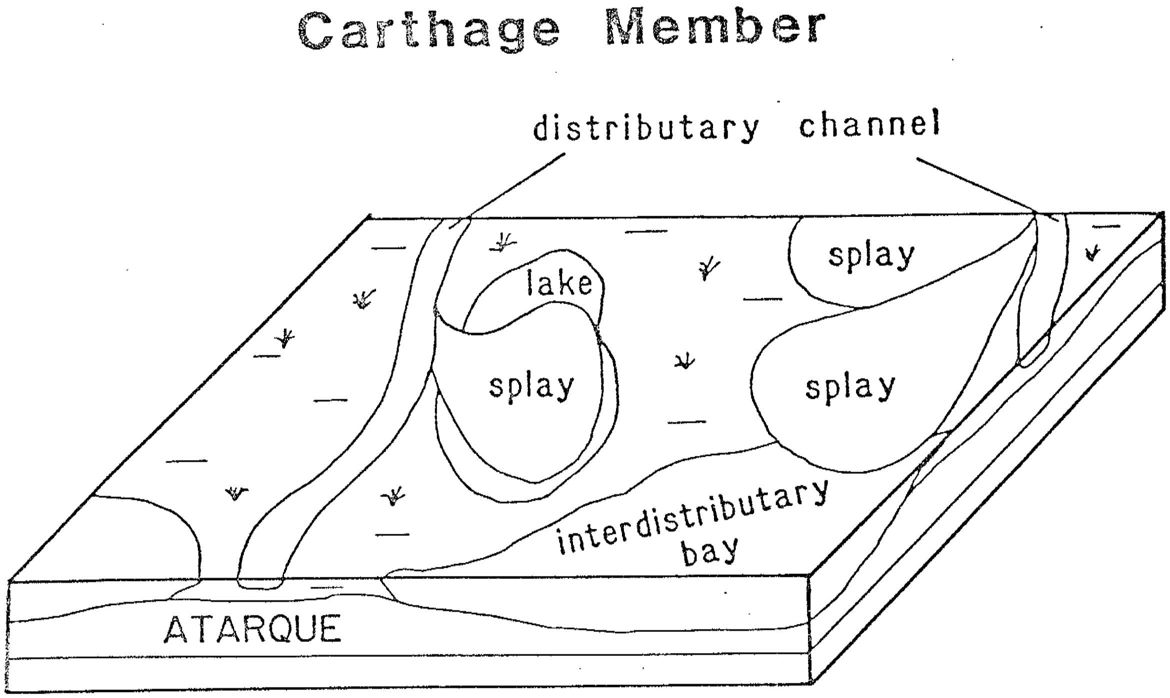
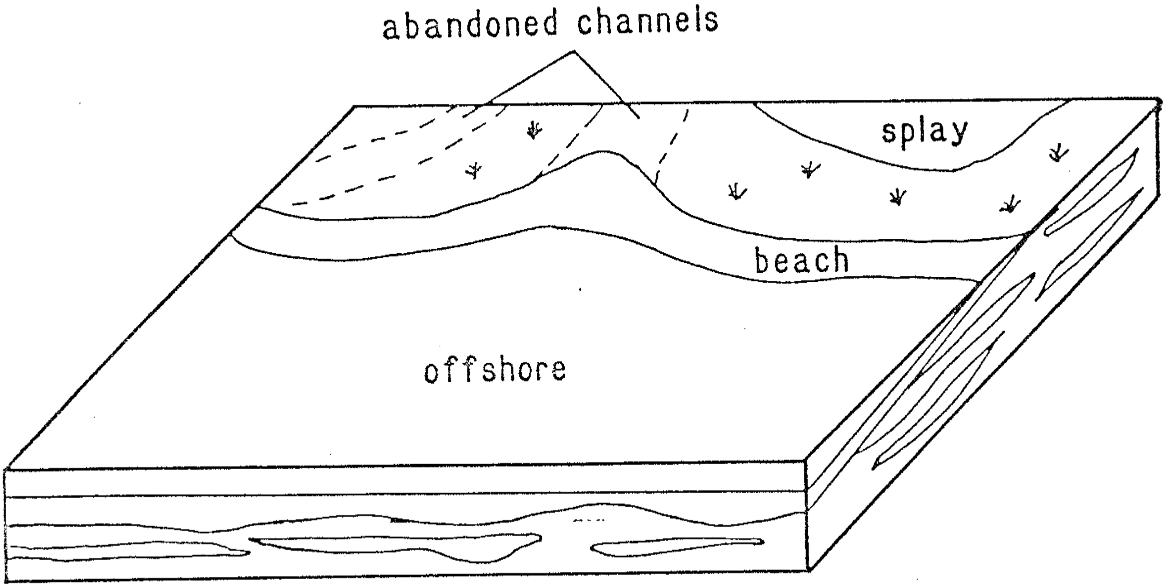


Figure 47 : Local paleoenvironments during deposition of the Carthage Member.



Fite Ranch Sandstone Member

Figure 48 : Local paleoenvironments during the transgression recorded by the Fite Ranch Sandstone Member. The Fite Ranch Member displays variability in thickness which may be the result of deposition on a modest topography.

D-Cross Tongue of Mancos Shale

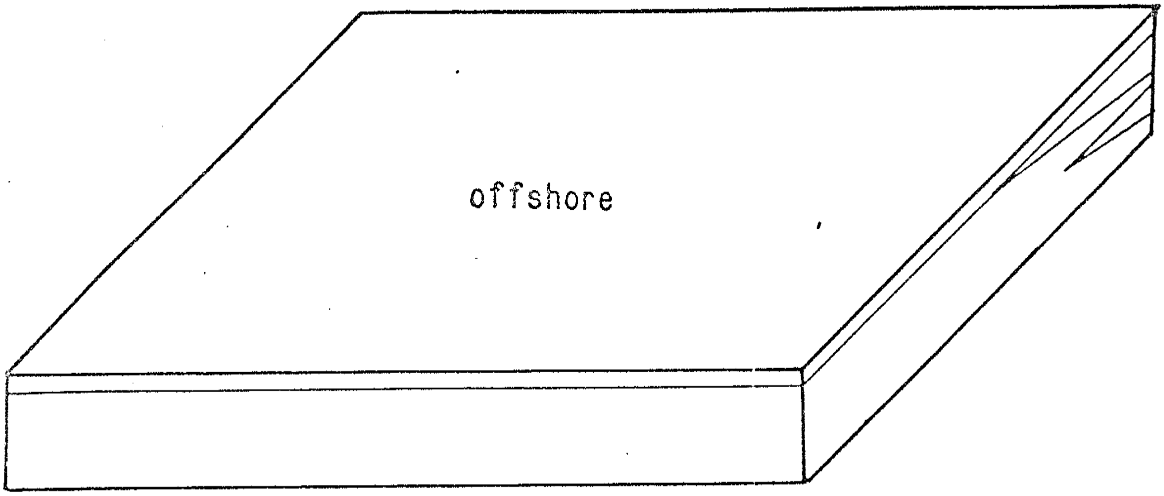


Figure 49 : Open marine conditions prevailed during deposition of the D-Cross Tongue. Thin sandstone tongues represent minor progradations of the lower shoreface environment.

Gallup Sandstone

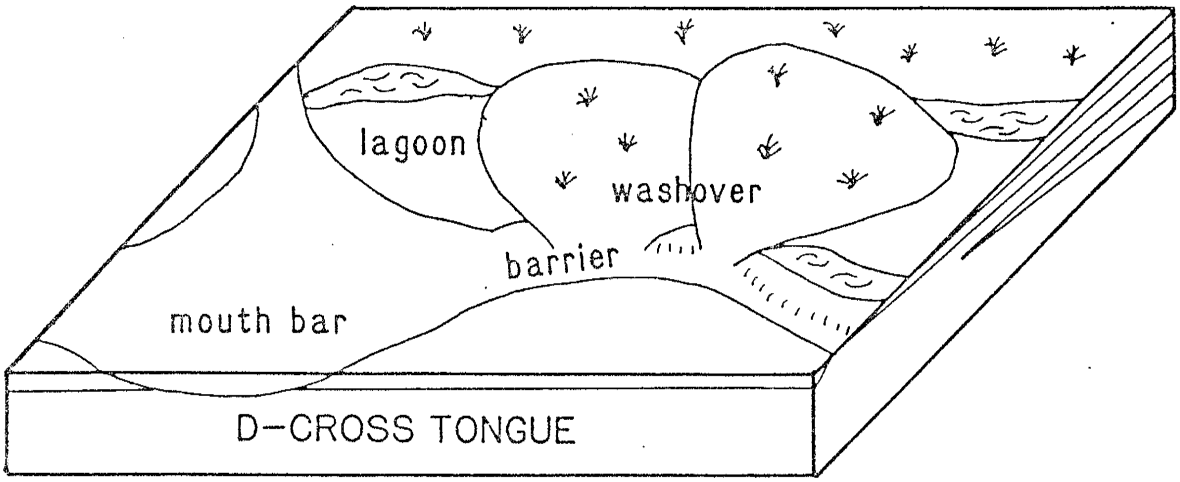


Figure 50 : Local paleoenvironments during progradation of the Gallup Sandstone. The Gallup represents fluvially-dominated nearshore sand deposits and localised barrier islands.

coastal or delta plain upon which vegetation and coal-forming environments developed (Figure 51).

Low sinuosity, mixed load streams carried sediment across a lower coastal or delta plain, and punctuated development of these coal-forming environments as shown in Figure 52. The top of the Coal-bearing Member is marked by a laterally continuous carbonaceous shale and/or coal. A gradual transition in the style of sedimentation occurred upsection, where moderate sinuosity, mixed load and suspended load streams transported sediment on an upper coastal or delta plain as shown in Figure 53. This low energy, meandering stream environment gradually gave way to low sinuosity, mixed load and bedload braided streams of the Ash Canyon Member as shown in Figure 54. The Ash Canyon Member is unconformably overlain by volcaniclastic deposits of the McRae Formation.

Coal Occurrence and Potential

Several thin coal seams occur within the Coal-bearing Member of the Crevasse Canyon Formation. Coal-forming environments developed immediately landward of the prograding shoreline represented by the Gallup Sandstone. Although the Coal-bearing Member is laterally persistent, individual coal seams may not be. The lowermost coal seam shown on stratigraphic sections I and IV occurs in close association with the top of the Gallup Sandstone throughout Engle field. Consequently, its downdip geometry is probably

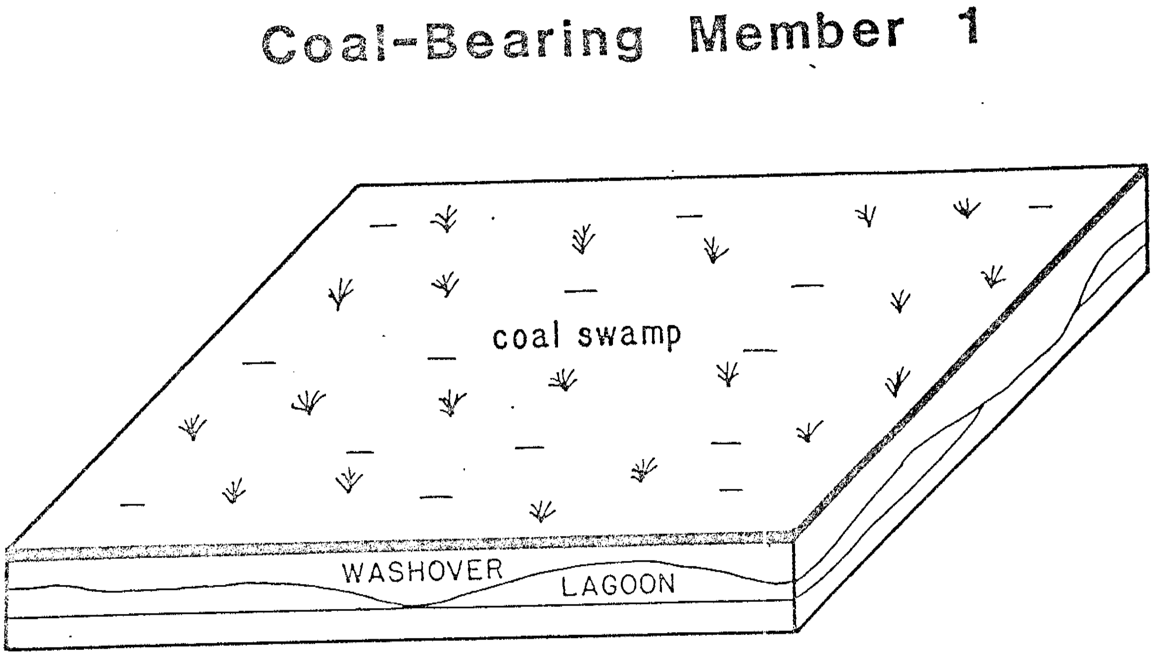


Figure 51 : Laterally extensive coal-forming environments developed upon retrograded barrier deposits of the Coal-bearing Member.

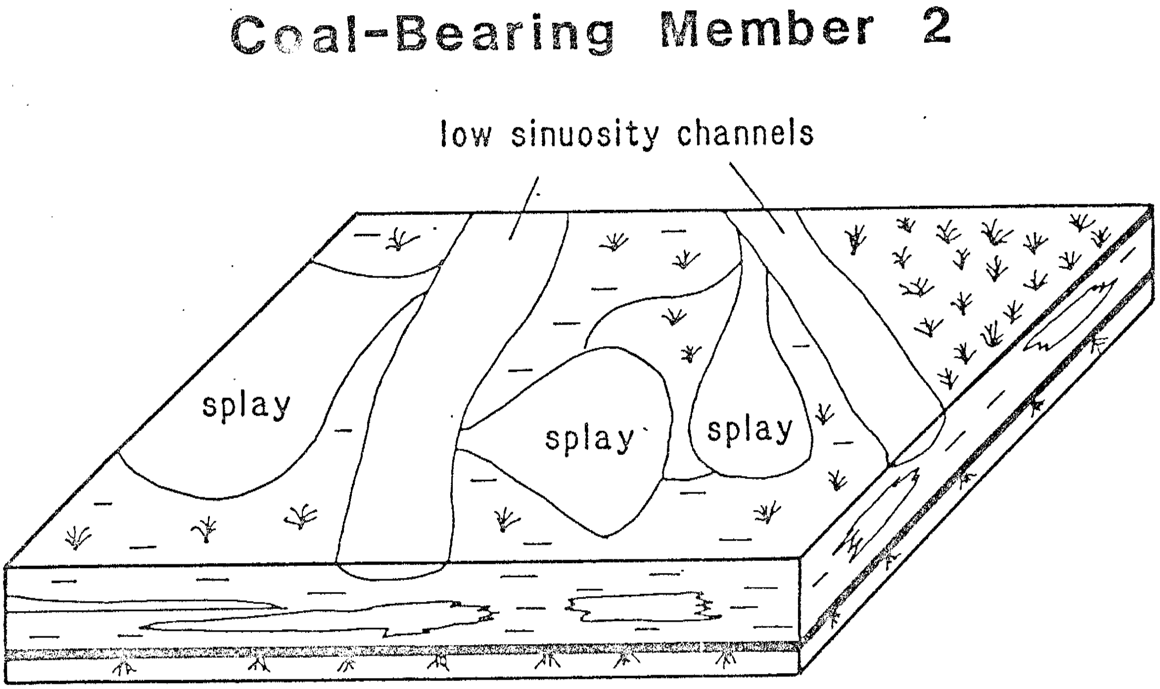


Figure 52 : Coal-forming environments were often short-lived due to input of mud-dominated fluvial deposits. Humates and small coal lenses occur locally.

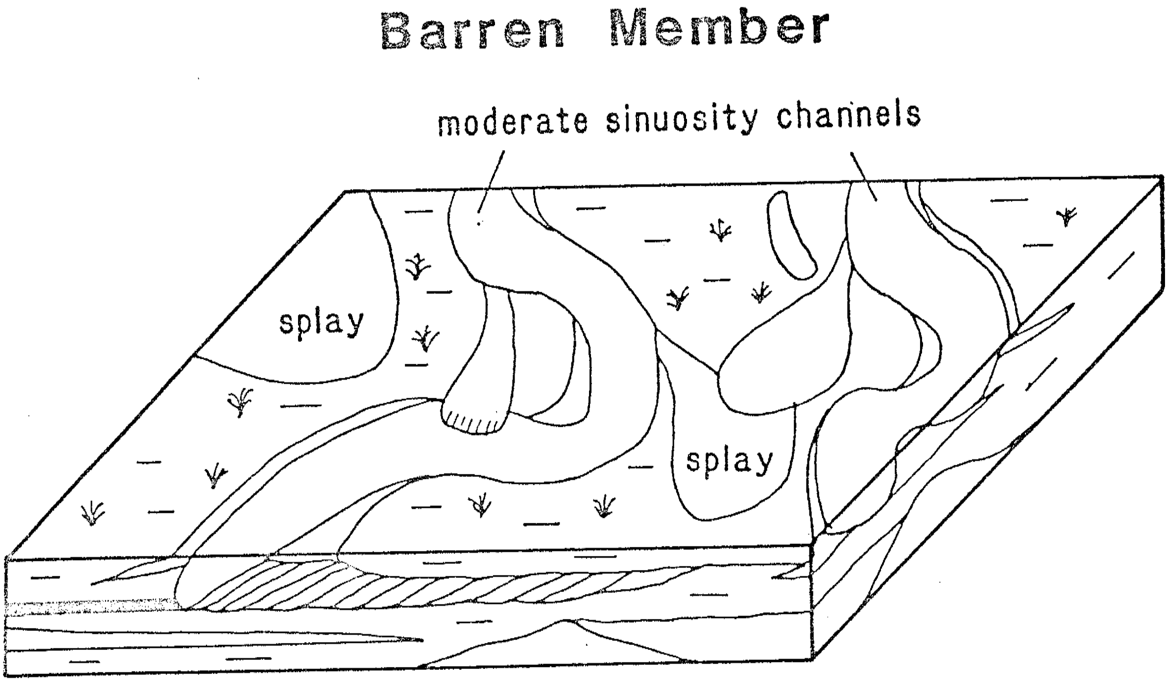


Figure 53 : Local paleoenvironments during deposition of the Barren Member. The Barren Member represents a low energy, meandering stream system.

Ash Canyon Member

low sinuosity sandy braided streams

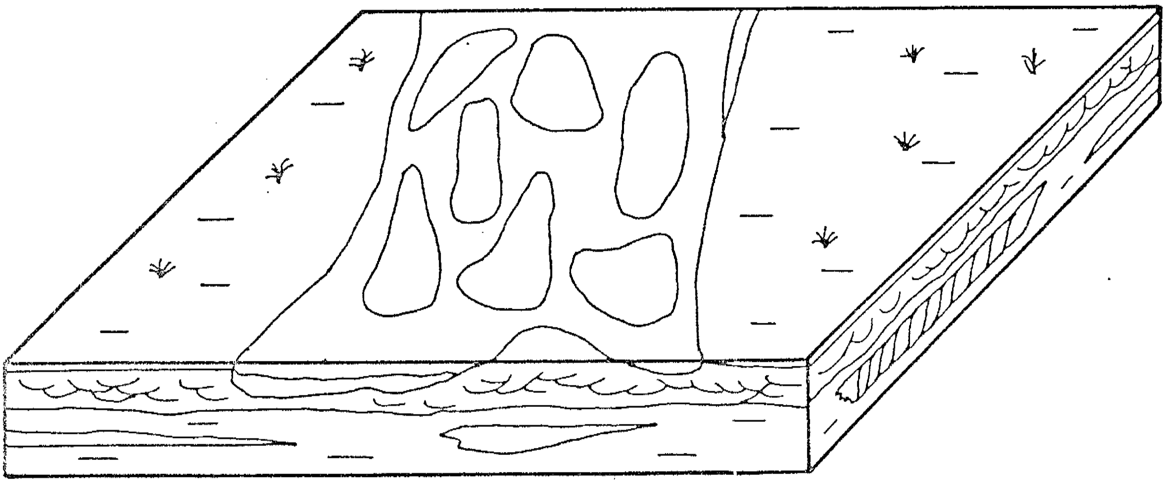


Figure 54 : Sheet sandstone and local pebble conglomerate of the Ash Canyon Member represent a relatively high energy, braided stream system.

controlled by the stratigraphic behavior of the Gallup Sandstone.

Thin impure coal and/or carbonaceous shale defines the upper contact of the Coal-bearing Member. Carbonaceous shales commonly grade laterally into small lenses of coal. These carbonaceous shales are best classified as humates (Siemers, 1978) rather than coal horizons since coal lenses are extremely localized and highly impure. Tabet and Frost (1978) report 3 surface workings at the Engle field. All of these mines produced coal from the lowermost coal seam within the Coal-bearing Member of the Crevasse Canyon Formation.

The Southwestern mine consisted of a 172 foot (52 m) shaft in a coal seam dipping approximately 80 degrees, and a 145 foot (44 m) drift which exposed 18 inches of coal (Tabet, 1980). Tailings and well preserved remnants of this shaft occur on the surface at this locality.

The Nogal coal seam occupies the same stratigraphic position as that of the Southwestern mine, but folding, faulting, and igneous intrusions have uplifted this horizon to the surface. No evidence of mining activity was observed by the writer at this locality. Several timbers exposed along a largely covered coal seam are all that remain of the Durham Ranch mine.

In the northern portion of the study area, steep dips rapidly place the Coal-bearing Member into the subsurface. In the southern portion of the area, several folds repeat parts of the Crevasse Canyon Formation, and coals lie closer to the surface. Although coals in the southern portion of the area may be at strippable depths, coal seam continuity is disrupted by numerous faults and dikes.

Despite problems associated with potential coal development at the Engle field, several positive points should be mentioned. The Santa Fe railway and Elephant Butte Reservoir are less than 10 miles from any potential coal mine. In addition, numerous igneous intrusions throughout Engle field indicate that coal bed methane potential may be high. The reported occurrence of coals up to 4 feet (1.3 m) in thickness in the subsurface (Tabet, 1980) may allow an in situ exploitation technique to be employed.

In light of these considerations, the writer recommends that coal resources of the Engle field be classified as economically submarginal reserves whose development must wait for advances in exploitation/extraction technology.

Oil and Gas Potential

Limited hydrocarbon exploration in the Jornada del Muerto Basin has been unsuccessful to date. More than 11 wells have been drilled to various depths, resulting in dry holes and insignificant hydrocarbon shows. Petrographic study of surface sandstone samples indicates that several units may have reservoir potential. Some fluvial channel sandstones exhibit thin clay rim cements which have apparently inhibited subsequent cementation. Porosities of up to 9% occur in channel sandstones of the Coal-bearing and Barren Members of the Crevasse Canyon Formation (Figure 55). Secondary feldspar dissolution porosity occurs to varying degrees in all samples (Figure 56). Samples from the top of the Gallup Sandstone have secondary porosities of up to 7%. In addition, organic-rich marine and continental deposits are interbedded with potential reservoir rocks.

Conclusions

The Engle field siliciclastic sequence was deposited during two separate major progradational episodes, which were part of the widespread late Turonian-early Coniacian regression of he western interior seaway. Depositional systems of the Tres Hermanos Formation and the Mesaverde Group represent fluvially-dominated deltaic or interdeltaic progradation of relatively low energy shorelines. Economically unattractive coals occur within the Coal-bearing Member of the Crevasse Canyon Formation, and their development in the near future is not likely. The Ash Canyon Member of the Crevasse Canyon Formation records an influx of coarse detritus into the low energy Mesaverde depositional system, and as such constitutes a significant paleogeographic data point.

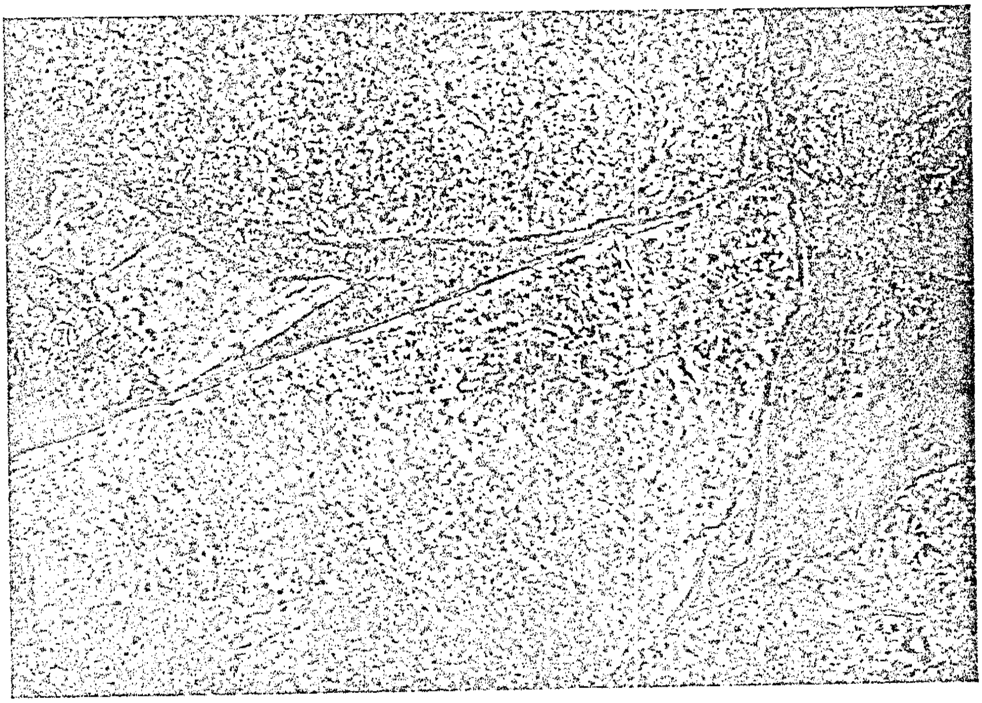


Figure 55 : Clay rim cements in medium-grained, channel sandstone of the Barren Member. Early clay cementation has inhibited subsequent precipitation of quartz overgrowths. One inch equals 0.06 mm.

Figure 56 : Secondary feldspar dissolution porosity in medium-grained Gallup Sandstone. One inch equals 0.15 mm.

Suggestions for Further Work

The McRae Formation overlies the Mesaverde Group wherever it has been spared from Tertiary and Quaternary erosion. The McRae is a stratigraphically dynamic unit whose origin, age, and tectonic significance are not well understood. A petrologic and geochronologic investigation of the McRae coupled with detailed stratigraphic control might shed light on these problems.

As mentioned earlier, determination of the age of the Ash Canyon Member would constitute a significant paleotectonic and paleogeographic data point for the Cretaceous System in southern New Mexico. Finally, although no vertebrate fossils were observed in this study, it seems highly probable that significant dinosaur remains would occur within coastal plain deposits of the Engle field siliciclastic sequence.

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Appendix 1: Raw Paleocurrent Data

Atarque Sandstone Member

Symmetrical ripple crests

Station I	Location	Strike and Dip
N46E	NW1/4 Sec 25 T13S R4W	N1E 49SE
N60E		
N79E		
N67E		
N57E		

Station II	Location	Strike and Dip
N99E	NW1/4 Sec 25 T13S R4W	N39W 26SE
N124E		
N88E		
N120E		
N119E		
N110E		
N103E		
N96E		
N111E		

Station III	Location	Strike and Dip
N51E	SW1/4 Sec 25 T13S R4W	N2E 33SE
N40E		
N38E		
N61E		
N55E		
N47E		
N43E		
N40E		
N49E		
N36E		

Trough Cross-beds

Station I	Location	Strike and Dip
N30W	NW1/4 Sec 25 T13S R4W	N39W 26NE
N18E		
N49E		
N47E		
N6E		
N39E		
N10W		
N8E		
N46E		
N7W		
N8E		
N80E		

Station II	Location	Strike and Dip
N152E	NW1/4 Sec 25	N1E 49SE
N89E	T13S R4W	
N150E		
N140W		
N27E		
N97E		
N9W		
N18E		

Station III	Location	Strike and Dip
N89E	SW1/4 Sec 25	N4E 28SE
N47E	T13S R4W	
N10W		
N49E		
N36W		
N70W		
N81W		
N19W		
N37E		
N52E		
N108E		
N115E		
N121E		
N121E		

Coal-bearing Member

Trough cross-beds

Station I	Location	Strike and Dip
N144W	SE1/4 Sec 36	N4E 32SE
N161W	T13S R4W	
N152W		
N158W		
N165W		
N153W		
N175W		
N166W		
N143W		
N177W		
N165W		

Station II	Location	Strike and Dip
N110W	SW1/4 Sec 18	N52W 19NE
N114W	T14S R3W	
N93W		
N89W		
N129W		
N111W		
N98W		
N96W		

Flute Casts

Station I	Location	Strike and Dip
N43E	SE1/4 Sec 36	N7W 32N
N41E	T13S R4W	
N37E		
N37E		

Station II	Location	Strike and Dip
N63E	SE1/4 Sec 25	N2E 27S
N58E	T13S R4W	
N59E		
N61E		
N65E		
N59E		
N56E		
N57E		

Station III	Location	Strike and Dip
N33E	NW1/4 Sec 18	N30W 20N
N27E	T14S R3W	
N29E		
N37E		
N35E		

Barren Member

Trough Cross-beds

Station I	Location	Strike and Dip
N30W	NW1/4 Sec 7	N10W 30NE
N3E	T14S R3W	
N34E		
N68E		
N14W		
N72E		
N18E		
N53E		
N5W		
N8W		
N22E		
N29E		

Station II	Location	Strike and Dip
N98E	NW1/4 Sec 7	N23W 32NE
N86E	T14S R3W	
N76E		
N79E		
N92E		
N96E		
N114E		
N102E		
N103E		
N79E		
N82E		

Station III	Location	Strike and Dip
N10W	SE1/4 Sec25	N30W 5NE
N46E	T13S R4W	
N30E		
N72E		
N68E		
N34E		
N27E		
N50E		
N115E		
N30E		
N1W		
N24E		
N34W		

Station IV	Location	Strike and Dip
N94E	NW1/4 Sec 30	N36W 20NE
N60E	T13S R3W	
N27E		
N45E		
N1E		
N64E		
N7E		
N37E		
N10E		
N44E		
N14E		
N57E		
N8E		
N17E		

Parting Lineation

Station I	Location	Strike and Dip
N32E	NE1/4 Sec 18	Horizontal
N36E	T14S R3W	
N32E		
N30E		
N32E		
N32E		
N33E		
N42E		
N20E		
N29E		
N36E		
N25E		
N30E		
N22E		
N26E		
N33E		
N30E		
N34E		
N34E		

Station II	Location	Strike and Dip
N49W	NW1/4 Sec 20	N40W 26NE
N44W	T14S R3W	
N51W		
N10W		
N17W		
N13W		
N20W		
N19W		
N30W		
N6W		
N12W		
N4W		
N8W		

Station III	Location	Strike and Dip
N21E	SW1/4 Sec 30	N35W 33NE
N6E	T13S R4W	
N15E		
N17E		
N4E		
N10E		
N1E		
N12E		
N14E		
N6W		
N19E		
N2E		

Station IV	Location	Strike and Dip
N30E	SW1/2 Sec 6	N30W 27NE
N14E	T14S R3W	
N29E		
N9E		
N12E		
N11E		
N17E		
N26E		
N30E		
N30E		
N19E		

Station V	Location	Strike and Dip
N34E	SW1/4 Sec 25	N24W 32NE
N30E	T13S R3W	
N32E		
N27E		
N27E		
N25E		
N29E		
N28E		

Planar Cross-beds

Station I	Location	Strike and Dip
N3E	center Sec 7 T14S R3W	N20W 24NE
N5E		
N3E		
N3E		
N12E		

Station II	Location	Strike and Dip
N23E	East center Sec 17 T14S R3W	Horizontal
N20E		
N20E		
N17E		
N23E		
N23E		

Station III	Location	Strike and Dip
N1W	SE1/4 Sec 36 T14S R3W	N10E 19SE
N5E		
N5E		

Station IV	Location	Strike and Dip
N59E	NE1/4 Sec 7 T14S R3W	N50W 21NE
N46E		
N55E		
N55E		
N50E		

Station V	Location	Strike and Dip
N39E	NE1/4 Sec 36 T13S R4W	N9E 30SE
N39E		
N45E		
N45E		
N45E		

Ash Canyon Member

Trough Cross-beds

Station I	Location	Strike and Dip
N81E	SW1/4 Sec 30 T13S R3W	N9W 15NE
N79E		
N32E		
N17E		
N24E		
N119E		
N36W		
N14W		
N106E		
N50W		
N39W		
N46E		
N16E		

Station II	Location	Strike and Dip
N45E	Sw 1/4 Sec 30 T13S R3W	N14E 12SE
N50E		
N42E		
N35E		
N40E		
N36E		
N51E		
N60E		
N43E		
N41E		
N40E		
N20E		
N30E		
N50E		
N117E		
N39E		

Station III	Location	Strike and Dip
N15E	NW 1/4 Sec 31 T13S R3W	N14E 12SE
N30E		
N35E		
N62E		
N50E		
N140E		
N50E		
N46E		
N90E		
N100E		
N38E		
N33E		
N48E		
N25E		
N35E		
N76E		
N38E		
N32E		

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