DEPOSITIONAL ENVIRONMENT

OF THE

UPPER JURASSIC SALT WASH MEMBER OF THE MORRISON FORMATION

MONTEZUMA CANYON, SAN JUAN COUNTY, UTAH

By

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In Partial Fulfillment of Requirements

For the Degree of Master of Science

In Geology

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ABSTRACT

The Salt Wash Member of the Morrison Formation (Jurassic) in Montezuma Canyon is the result of deposition by a fluvial system which was moderately sinuous, flashy, carried abundant sand-size and finer sediments in both bed and suspended load and flowed in a channel system characterized by two or more anastomizing channels. The average direction of flow was approximately N 80^{o} E. Adjacent to the primary channels were floodplains upon which thick, laterally continuous sandy siltstones were deposited after transportation away from the primary channel in small distributary channels which flowed during periods of greater-than-bankfull discharge. Sediments which are now lithified in the exposures of the Salt Wash Member originated from highlands to the west of the study area in southern Nevada which contained abundant sandstone and sands, volcanic detritus, and may have been the site of active felsic volcanism. Tectonism which may have influenced sedimentation was a gentle sinking to the east to northeast away from the western source highland and north of the Mogollan Highlands to the southwest. Early movement of the Monument Upwarp may also have influenced sedimentation by creating a locally steeper gradient.

Data from which the environmental determination is made come from the measurement of ten stratigraphic sections through the Salt Wash Member, petrographic analysis of the sandstones, X-ray diffraction analysis of intergranular clays and descriptions of the regional geology of the Colorado Plateau.

INTRODUCTION

OBJECTIVES OF THE STUDY

The purpose of this study is to interpret the depositional environment of the Salt Wash Member of the (upper) Jurassic Morrison Formation in an approximately thirty-square-mile area in southeast Utah. The environmental analysis is developed from the measurement of stratigraphic sections of the Salt Wash Member and its enclosing lithologies. Emphasis is placed on the recognition of sedimentary structures for use in identifying probable conditions of emplacement and for determining paleotransport directions. The composition, fabric, and clay mineralogy of selected samples collected during the measurement of the ten stratigraphic sections is included in the analysis as is data derived from the literature regarding the geologic history of the study area and possible equivalent modern environments.

LOCATION AND GEOMORPHOLOGY

The study area (Fig. 1) is located in Montezuma Canyon, San Juan County, Utah. It is approximately 8 miles southeast of Monticello, Utah. The study area covers approximately 30 square miles, being 11 miles in length and varying from 2½ to 3 miles in width. It is more or less within T34S and T35S, R24E, Utah base and meridian. Major access to the study area is from a point approximately 5 miles south of Monticello, Utah on U. S. Highway 163. At this point turn east on a gravelled county road and descend into Verdure Canyon. The approximate northern boundary is marked by the junction of Montezuma Canyon and Verdure Canyon.

Montezuma Canyon is deeply incised into the Great Sage Plain of southeast Utah and southwest Colorado. Two steep cliffs seperated by a broad, talus covered slope are the prominent features of the canyon

LOCATION MAP

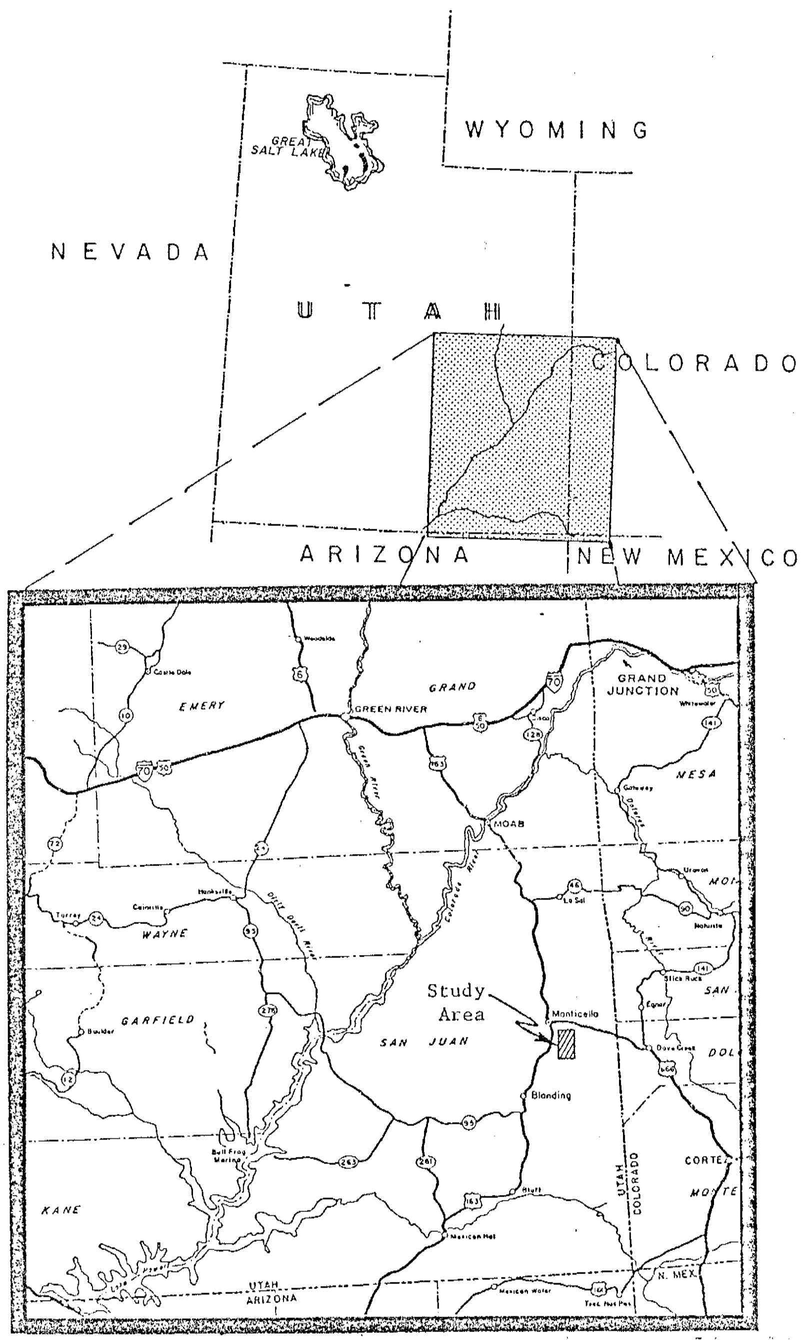


Figure 1.- Montezuma Canyon Study Area

walls. Numerous smaller canyons with similar features join Montezuma Canyon throughout the length of the study area. Total relief of Montezuma Canyon in the study area is approximately 1100 to 1200 feet from creek level to the top of the canyon and adjoining plains.

REGIONAL STRATIGRAPHY

Montezuma Canyon has a relatively complete section of Middle and Upper Jurassic rocks and Cretaceous rocks exposed along the canyon walls. The units exposed here are widespread and have been described over much of the Colorado Plateau by Gregory (1938), Stokes (1944), Craig (1955), Cater (1970) and many other authors. These units include the Navajo Sandstone, Carmel (?) Formation, Entrada Sandstone, Summerville Formation, Morrison Formation, Burro Canyon Formation, Dakota Sandstone, and Mancos Shale. Recent alluvial deposits are also present. (Huff and Lesure, 1965). Figure 2 shows some of these units and the general appearance of the outcrops in Montezuma Canyon.

A regional correlation of stratigraphy and nomenclature is shown in Figure 3. The right column from Huff and Lesure (1965) is modified from the work of several other authors and is the form that will be used in this paper when dealing with the Salt Wash Member and its enclosing lithologies. One modification of this interpretation is discussed with the specific stratigraphy of the study area.

Summerville Formation

The Summerville Formation is named by Gregory (1938) for a widespread, red, evenly to irregularly bedded siltstone which is the uppermost formation included in the San Rafael Group. It is present throughout southeast Utah, northwest New Mexico, northern Arizona, and southwest Colorado (Harshbarger, et al 1957). In eastern Utah and western Colorado

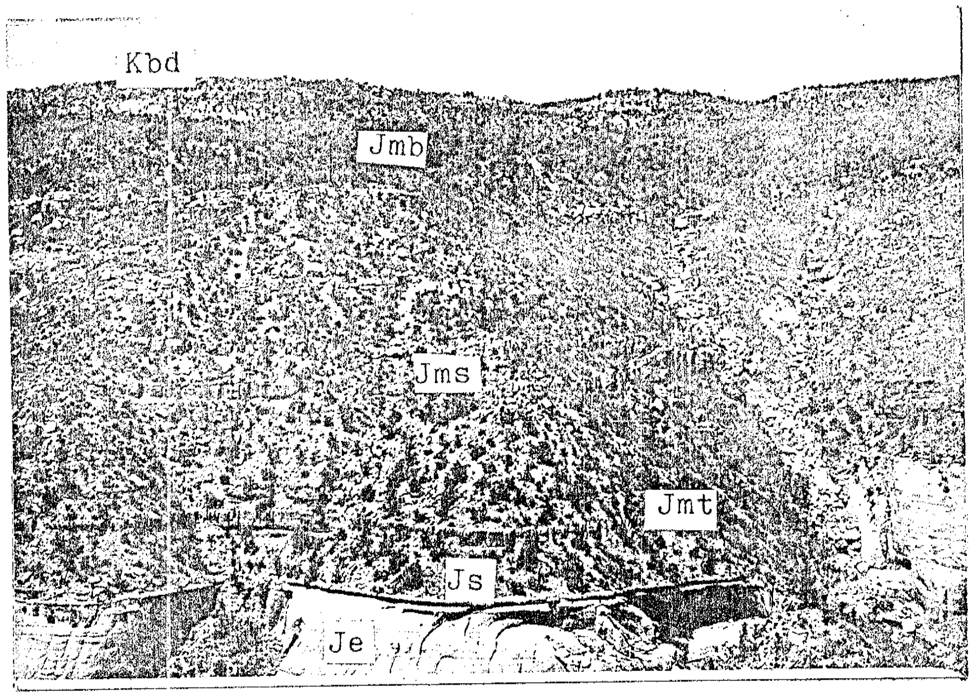
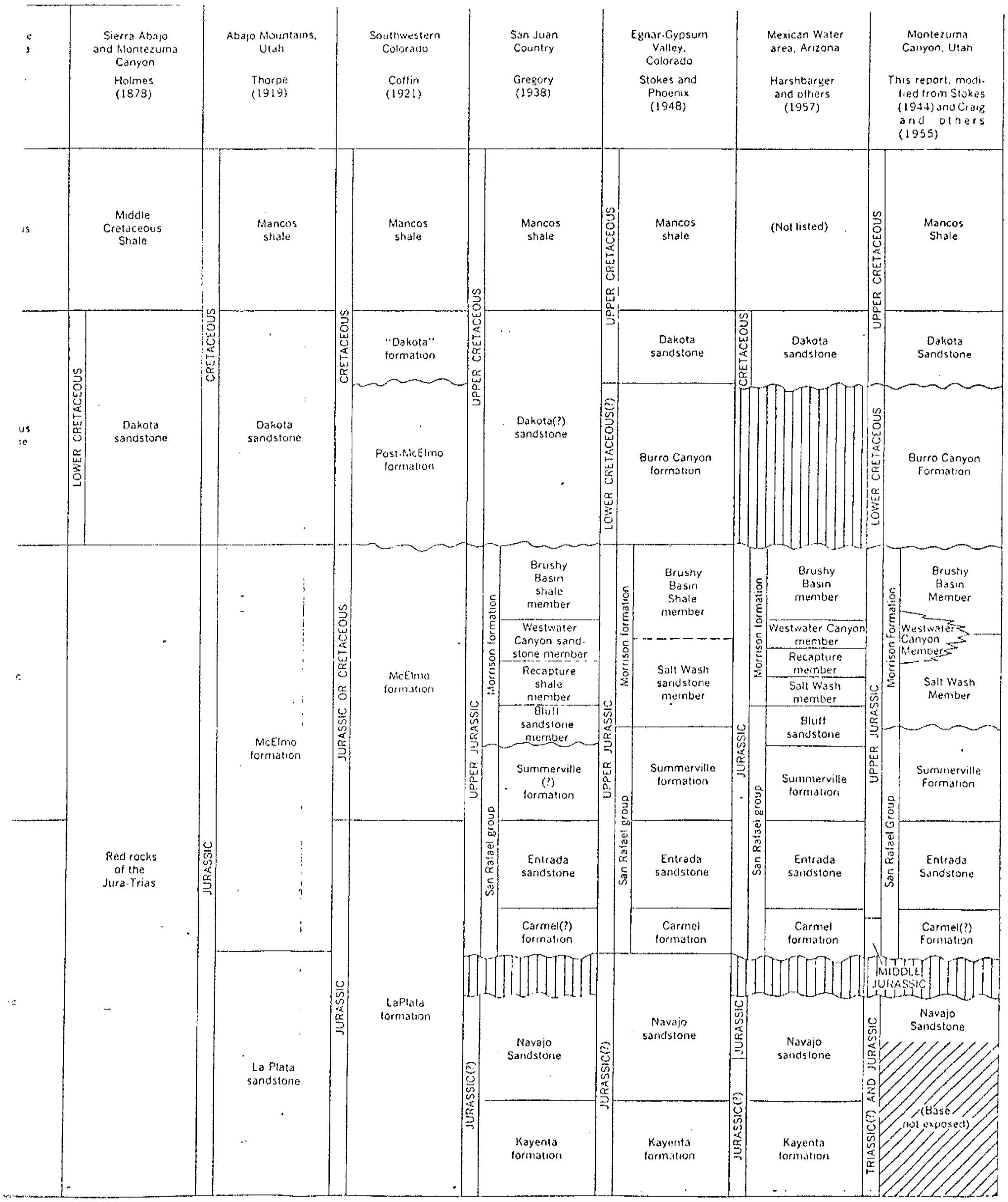


Figure 2- The west side of Montezuma Canyon across from section MC2. Units shown are the Entrada Sandstone (Je), the Summerville Formation (Js), Tidwell member (Jmt), Salt Wash Member (Jms), the Brushy Basin Member (Jmb), and undifferentiated Burro Canyon/Dakota Sandstone (Kbd). Several large channel scale cut and fill structures are visible in the Salt Wash Member and have been outlined.



STRATIGRAPHIC NOMENCLATURE USED IN THE MONTEZUMA CANYON AREA AND ADJACENT PARTS

(Huff and Lesure, 1965)

757-270 O - 65 (In pocket)

Figure 3

it forms a distinct slope and ledge-forming unit which immediately overlies the Entrada Sandstone.

Morrison Formation

The Morrison Formation on the Colorado Plateau is composed of four formal members; not all of which are present in the field area. The lowest of the four members is the Salt Wash Member, named by Lupton (1914) for a gray, coarse-grained sandstone which unconformably overlies the Summerville Formation in Salt Wash, southeast of Green River, Utah. The basal contact of the Salt Wash Member is defined by Craig (1955) as the base of fluvial deposits which overlie marine deposits of the San Rafael Group. Total thickness varies from 200 to 600 feet (Cater, 1970; Craig, 1955).

The Salt Wash Member is composed of interbedded sandstones and mudstones. Regionally the sandstone varies in fabric and composition, the average being a fine- to medium-grained, light gray, quartz sandstone (arenite). The sandstones are commonly cross-bedded and laminated and occur in lens-shaped bodies which form well defined cliffs. The mudstone is poorly sorted, locally contains abundant sand grains and is structureless to thinly flat-bedded and laminated (Craig, 1955).

Overlying the Salt Wash Member is the Recapture Member. The Recapture Member was named by Gregory (1938) for exposures of a strongly colored series of shales and sandstones which range in thickness from 100 to 300 feet. The Recapture Member intertongues with and grades into the Salt Wash Member in southeast Utah (Craig, 1955); farther south and east it becomes the basal member of the Morrison Formation.

Overlying the Recapture Member is the Westwater Canyon Member, named by Gregory (1938) for outcrops of white, medium- to coarse-grained quartz sandstones with local conglomerate bands and stringers composed of quartz aggregates, colored chert, clay concretions and some fossil debris. Interbedded with these are red mudstones, gray/green shaly mudstones and thin lenses of gray limestone-pebble conglomerate (Stokes, 1944). Two facies are recognized in the Westwater Canyon Member by Craig (1955). One is a conglomeratic sandstone facies which occurs in northwest New Mexico; the other is a sandstone facies which surrounds the conglomeratic facies and extends into northeast Arizona and a small portion of southeast Utah.

The uppermost member of the Morrison Formation is the Brushy Basin Member, named by Gregory (1938) for a variegated blue/green sandy mudstone exposed in Brushy Basin Wash near Blanding, Utah. Contained within the mudstones are lenses of conglomeratic sandstone with moderately abundant pebbles of red, green, white, and black chert (Craig, 1955). The basal contact of the Brushy Basin Member is placed at a change in lithology where the shaly and conglomeratic material described above begins. Frequently the contact is covered or poorly exposed (Craig, 1955; Cater, 1970).

Thickness of the Brushy Basin Member is variable, ranging from 150 to 750 feet, with a slight thinning over the salt anticlines of southwest Colorado (Huff and Lesure, 1965; Cater, 1970).

Post-Morrison Units

Overlying the Morrison Formation are units which are Cretaceous and younger in age. Craig (1955), Huff and Lesure (1965), Cater (1970) and many other authors have described these units in detail and the reader is referred to them for further information.

REGIONAL STRUCTURE AND TECTONICS

Dominant regional structures are the northwest trending anticlinal structures produced by salt tectonics and the extensive upwarps such as the San Rafael Swell and Monument Upwarp. In addition to these features there are several basin structures, the Blanding and Paradox Basin, which are less obvious (Kelley, 1958). The modern geomorphic expression of these structures is believed to be the result of uplift after the end of the Jurassic Period, possibly in conjunction with the Laramide Orogeny (Kelley, 1958; Kelley and Clinton, 1960). The salt anticlines experienced an earlier period of activity starting in the Permian and continuing until Triassic or Early Jurassic. Kelley (1958) postulates that the Middle and Late Jurassic Epochs were times of relative quiescence for these structures.

A slow, gentle subsidence northeast of the Mogollon Highlands (Kelley and Clinton, 1960) is postulated in Middle and Late Jurassic time. The slope into this basin, referred to as the Mogollon Slope by Kelley and Clinton (1960), is the major structural feature thought to be active during the Late Jurassic time. Petersen (personal communication, 1979) has evidence which indicates that a positive area centered on the present-day Monument Upwarp acted as a barrier to the eastward transport of sediments during the time when the lowest portion of the Salt Wash Member was deposited in the Henry Mountains Region. The relief of this positive area and the length of time or extent to which it blocked transport to the east is unknown.

Structures are known which are not as well understood or defined as those described previously. These are large-scale linear features which may be related to pre-Pennsylvanian structures and faults now covered or very poorly defined at the surface. These structures trend in a northeast direction and are used by Baars (1966) to help explain the evolution of the Paradox Basin. One of these, the Blanding structure, is centered on the town of Blanding, Utah and trends N 50° E in a zone approximately 20 km wide and 80 km long (Warner, 1978). A similar structure is west and northwest of the La Sal Mountains (Warner, 1978). For further information on these structures the reader is referred to Baars (1966), Hite (1975), and Warner (1978).

STRATIGRAPHY OF THE STUDY AREA

The measured sections used in this study include the interval from the base of the Summerville Formation (where exposed) into the Brushy Basin Member of the Morrison Formation. The units in this interval are the Summerville Formation, and part of the Morrison Formation including the Salt Wash Member, the lower part of the Brushy Basin Member, the Westwater Canyon Member, and a previously unrecognized member of the Morrison Formation referred to informally as the Tidwell member (Young personal communication, 1980). Appendix 1 gives the detailed measured section descriptions; Plate 1 shows the location of the measured sections.

SUMMERVILLE FORMATION

The Summerville Formation is the lowest unit included in the measured sections. It is the uppermost of the units in the San Rafael Group and is exposed in Montezuma Canyon for approximately 15 miles, starting at a point 2 miles north of Verdure Canyon.

The Summerville Formation in Montezuma Canyon is similar to that described by Gilluly and Reeside (1928) in the type area at the San Rafael Swell, except that the gypsum beds they noted are absent in Montezuma Canyon. The lower contact is sharp, planar, and conformable, and leads into the sandy, fine-grained, red siltstone which forms rough, step-like slopes which are frequently covered by debris from within the formation as well as from overlying units. Bedding is characteristically thin-bedded, with individual beds being continuous and sheet-like for distances of greater than 1 mile with little change in thickness.

TIDWELL MEMBER

A previously unrecognized unit is believed to be present in Montezuma Canyon. This unit is recognized along the eastern flank of the San Rafael

Swell and in the Henry Mountains but has not received a formal stratigraphic designation. It was mapped in the middle to late 1950's by a group of geologists working with the Atomic Energy Commission and the United States Geological Survey and named, informally, the Tidwell member of the Morrison Formation. The unit is considered a transitional unit between the marine Summerville Formation and the fluvial, cross-stratified Salt Wash Member and is recognized as an interval whose lower contact is at the base of a massive gypsum bed and whose upper contact is the base of the first extensive cross-stratified sandstone of the Salt Wash Member (Robert Young, Hunt Oil Company, Grand Junction, Colorado, personal communication, 1980). Petersen (1974) refers to this unit informally as the lower member of the Morrison Formation and more recently as the Tidwell member (Petersen, personal communication, 1979). Petersen (1974) identifies the lower contact of the Tidwell member by the occurrence of a single layer of subangular to subrounded chert grains which are coarse sand to granule size and occur slightly below the gypsum bed. This layer can be identified in numerous widespread locations throughout the Colorado Plateau (Petersen, personal communication, 1979).

In Montezuma Canyon the Tidwell member is present and is recognized by a change in character of the sandstone and siltstone originally included in the Summerville Formation by earlier workers. Neither the gypsum nor the bed of chert grains has been observed in Montezuma Canyon. The lower contact is defined as the base of a 10- to 15-foot-thick ledge of sandstone which is made up of three beds of approximately equal thickness which are seperated by siltstones less than 1 foot thick (Fig. 4). Structures in the sandstone are flat, slightly irregular laminations to thin beds. The sandstone marker ledge is a continuous unit throughout the study area and is prominent on the measured sections (Plate 2) and in outcrop.

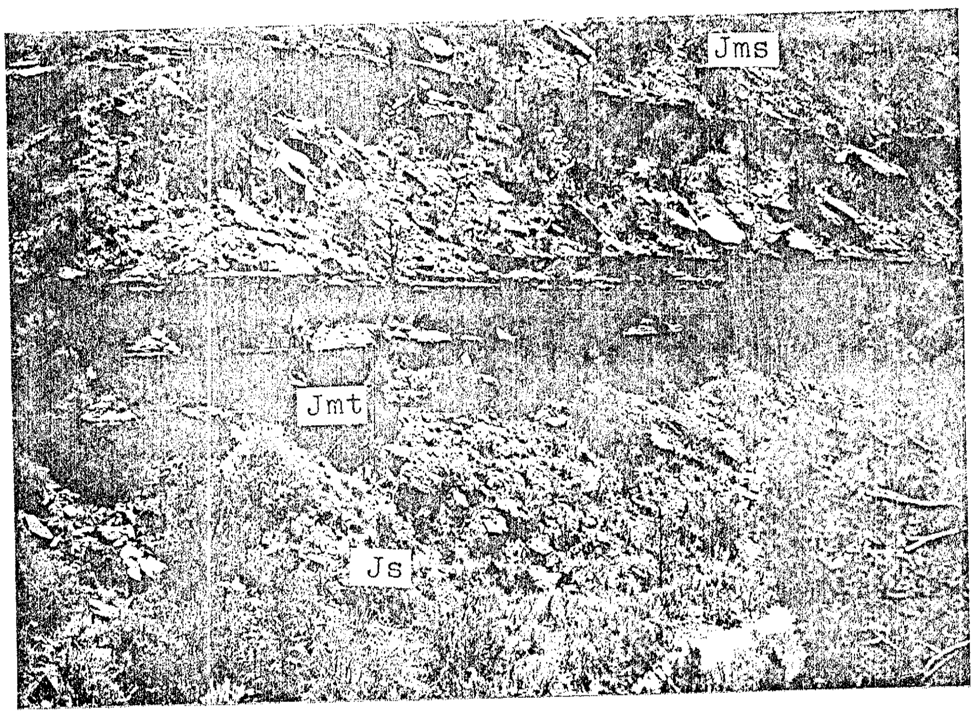


Figure 4- Three-part sandstone ledge which is the basal marker of the Tidwell member (Jmt). Underlain by the Summerville Formation (Js) and overlain by the Salt Wash Member (Jms).

Figure 5- Undulatory, thinly laminated, silty sandstone of the Tidwell member.

Above the basal marker ledge the Tidwell member is composed of thin to medium beds of structureless- to irregularly-bedded sheets of very fine- to fine-grained, red sandstone with thin to thick interlaminations of red, sandy siltstone (Fig. 5). Lithologically it is similar to the sandier units within the Summerville Formation and exposures are often better than those of the Summerville Formation because of the more abundant sandstone and the thicker, irregular bedding.

SALT WASH MEMBER

The Salt Wash Member is the lowest of the formally recognized units of the Morrison Formation which is present in Montezuma Canyon. It's lower contact with the Tidwell member is placed at the base of the lowest cross-stratified sandstone 3 feet or more in thickness with a lateral extent of at lease 300 feet. The lithology of the Salt Wash Member at the contact is similar to the lithology of the lower member, indicating that sediments from the lower member have been re-worked and incorporated into the basal Salt Wash Member. Above the basal ledge there is a slight coarsening of the sediments.

The upper contact is usually more difficult to determine, especially in the southern part of the study area where the Westwater Canyon Member interfingers with the Salt Wash and Brushy Basin Members (Plate 2). In all cases the upper contact is conformable and gradational and is placed at the base of a long covered interval which is covered with blocks of blue/green sandstone and siltstone. The covered slope often grades into outcrops of blue/green sandstone surrounded by blue/green siltstones which are characteristic of the Brushy Basin Member. These sandstones also have local conglomeratic pockets of granule- and pebble-size grains which are not common in the Salt Wash Member. Total thickness of the Salt Wash Member ranges from 255 feet to 360 feet.

The Salt Wash Member crops out in a series of discontinuous sandstone lenses and siltstones as illustrated in Plate 2 and Figure 2. In side canyons where exposures are adequate, the sandstone bodies can be identified as being pods and ribbons after the terminology of Potter (1967). The sandstone bodies are from less than 10 feet to greater than 60 feet in thickness, and extend laterally up to 1½ miles. The large sandstone bodies exposed in the cliff faces of Montezuma Canyon are the product of many smaller, single cycle, sandstone bodies combining to form multistory and multilateral sandstones as described by Potter (1967, p. 344). The multistory sandstones are slightly more common in the northern end of Montezuma Canyon and have a limited lateral extent, while the sheet-like or multi-lateral sandstones are slightly more common in the southern end of the study area (Fig. 2). Both multistory and multilateral sandstones are deposited in channel-scale cut and fill structures.

Bases of the sandstone bodies are slightly concave upward and have relatively flat, planar upper surfaces. Commonly the body pinch out in a symetrical lense away from the thicker central part of the body, but less common asymetric lenses also occur. The sandstone bodies contain an abundence of different sedimentary structures which give information on the stream pattern and processes during deposition.

The siltstone units which enclose the sandstone bodies are commonly covered, or very poorly exposed. The few outcrops are red, sandy siltstones which are structureless to indistinctly flat laminated. Ripple cross-laminations and irregular undulatory bedding are rare. Where siltstone units are in direct contact with the previously described sandstone bodies, the siltstone is commonly scoured out in a shallow trough shape which is filled by the sandstone.

In addition to thick red mudstones and siltstones are rare occurrences of gray/green carbonaceous mdustones which Petersen (1977) has attributed to a locally reducing environment within the fluvial system where long-term ponding can occur. The reducing environment produces a primary gray/green mudstone (Petersen, 1977) which, along with the occurrence of minute carbonaceous material and larger coaly fragments, is indicative of this particular lithology. The gray/green carbonaceous mudstones occur mainly in very thin beds within a sequence of sandstone or as small flakes and clasts which are incorporated into the sandstone during deposition.

Included with the siltstones are numerous very thin beds of very fine-grained sandstone. These are usually less than two inches thick and have a lateral extent of a few tens of feet. They are usually structureless or ripple cross-laminated and are intimately associated with the siltstones. Because of the close association between these thin sandstone occurrences and the siltstones, they are considered a single lithologic unit.

BRUSHY BASIN MEMBER

The lower portion of the Brushy Basin Member is included in most of the measured sections. The contact between the Salt Wash and Brushy Basin Members is difficult to place due to the amount of covered slope at the contact. That portion of the Brushy Basin Member included in the measurements is poorly exposed blue/green siltstone and small, discontinuous blue/green sandstone lenses. Locally there are small, pebbly or conglomeratic lenses which are characteristic of the Brushy Basin Member. Total thickness of the Brushy Basin Member has not been measured.

WESTWATER CANYON MEMBER

In measured sections MC7, MC8, and MC9 the Westwater Canyon Member interfingers with the Salt Wash Member and the Brushy Basin Member. Contacts as indicated on Plate 2 are only approximate and placed at the base of a thick and covered interval above the highest continuous cross-stratified unit identified as the Salt Wash Member and below the cherty, conglomeratic sandstone ledges identified as the Brushy Basin Member.

Where exposed, the Westwater Canyon Member is a series of thin discontinuous blue/green sandstone ledges with interbedded blue/green siltstones. No conglomeratic sandstones have been observed within this sequence, and it is on this basis that the Westwater Canyon Member is differentiated from the Brushy Basin Member.

SEDIMENTARY STRUCTURES

Cross-stratification and small-scale bed forms are common throughout the sandstone units of the Salt Wash Member. The following descriptions are very general, and are intended to give the characteristics of the most common types of sedimentary structures observed. Appendix 1 and Plate 2 give more detailed descriptions and illustrate the sedimentary structures for each measured section. The terminology used to describe the cross-stratified units is after McKee and Weir (1953); that used for the ripple bed forms is after Allen (1968) (See Appendix 1).

Small-Scale Cross-Stratification

Small-scale structures include trough- and wedge-shaped sets of thin cross-laminations to very thin cross-beds. Cross-strata are mainly low-angle. Individual sets are 8 to 12 inches thick, and less than 1 foot in length. Approximately 60% of the small-scale cross-stratification is tangential trough-shaped.

Medium-Scale Cross-Stratification

Set shapes and types are similar to those described for small-scale types. Sets range from 1 to 5 feet thick and 1 to 20 feet in length (Fig. 6 and 7). They commonly have thin mud layers, (Fig. 8) rip-up and clay clasts (Fig. 6) at their bases. Inclination of cross-strata is variable but usually is slightly less than 20°.

Truncation due to downcutting by overlying cross-stratification sets is common, and probably accounts for the variation in size of this group of structures. The medium scale structures are the most common type observed.

Large-Scale Cross-Stratification

Trough- and wedge-shaped sets with very thin- to thin-bedded cross-strata are common in large scale structures. The wedge-shaped sets are slightly more common than trough-shaped sets. Individual wedge-shaped sets are one to seven feet thick and are greater than twenty feet in length. They contain low-angle, planar cross-strata (Fig. 9). Clay clasts and rip-ups are less common in the large-scale cross-strata than in the smaller scale types. Large-scale, trough-shaped sets are commonly a very low-angle, broad, sweeping type with tangential lower contacts. Other characteristics are similar to the previously described cross-stratification types.

Large-scale sets are less common than either small- or medium-scale cross-stratification, probably making up no more than 15 percent of the total cross-stratification.

Planar Tabular Sets

Tabular shaped sets of planar cross-stratification are rare and commonly grade laterally into low-angle, sweeping trough-shaped sets. Normally they are no more than one to two feet thick, although thicker sequences do occur. They extend laterally for distances of up to thirty feet, but are more commonly scoured by overlying sets of cross-stratification so that their average length is approximately ten feet.

Parting Lineations

Parting lineations are common, occurring on the more extensive flat and slightly inclined bedding surfaces. The lineations are elongate, parallel, very low ridges only a few grains in height. The length of individual lineations or groupings of lineations is from a few inches up to several feet.

Figure 6- In the left of the picture is a large scour which was cut into the silts and subsequently filled by sands. Several large rip-up strucures are visible near the base of the channel fill. Current direction is approximatley into the page and to the right.

Figure 7- Section MC6 - Medium scale wedge planar cross-stratification near the top of the section. Sandstone is uniform, fine to medium grained.

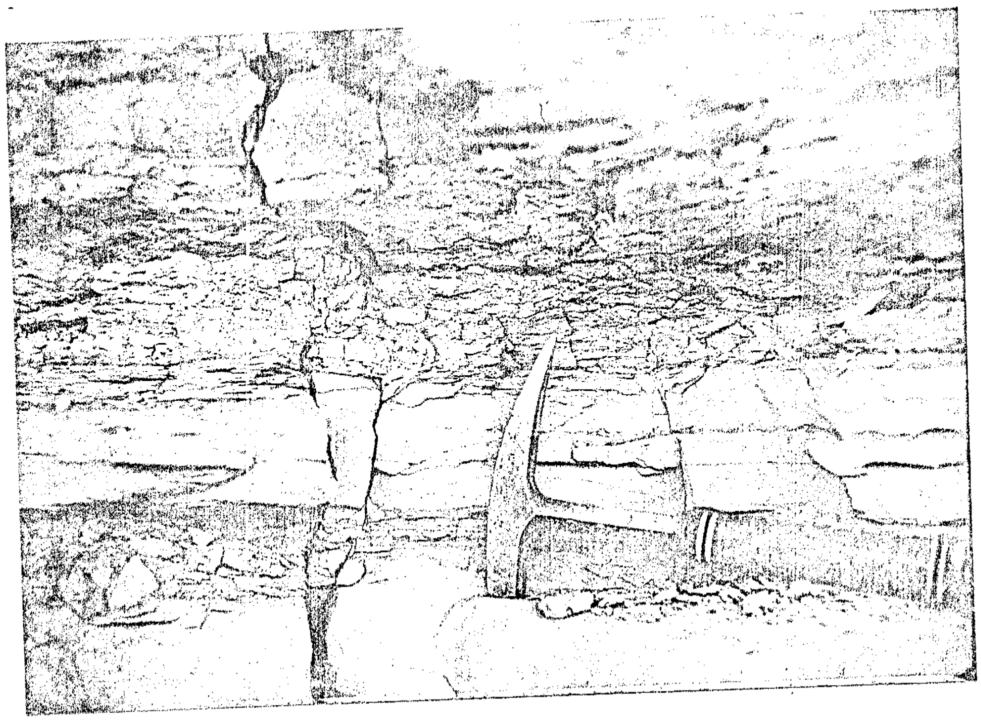


Figure 8- Siltstone in a scour base. Enclosing lithology is a sandstone. Structrues similar to this occur in the base of many of the cut and fill structures.

Ripple Marks

Ripple marks are straight to slightly sinuous and out of phase. The average distance from crest to crest is approximately 1½ inches, the average height approximately .15 inches. They are commonly asymmetrical, although symmetrical ripples also occur (Fig. 10 and 11).

Mud Cracks

Mud cracks occur in a very limited number of locations, mainly in silty sandstones as clasts. The average diameter of individual polygons is 1 to 4 inches.

Soft Sediment Deformation

Local occurrences of soft sediment deformation are present throughout the study area. Most of it is the result of differential setting between silts and sands while the sediments were still unconsolidated. Overturned small- and medium-scale cross-strata is also present in the study area (Fig. 12).

Trace Fossils

A limited number of burrows are present in the Salt Wash Member, mainly in the finer grained siltstones, although not entirely confined to that lithology. The burrows occur in a variety of orientations throughout the measured sections: Parallel, oblique, and perpendicular to bedding with approximately equal frequency.

The burrows occur as cylindrical to subcylindrical grooves, approximately ¼ inch (6.4 mm) or less in diameter, 1 to 10 inches (2.5 to 25.4 cm) in length. They often cross over one another, but branching has not been observed. The burrow walls are smooth with no ornamentation. The burrows retain a constant diameter throughout their length, and are straight to slightly sinuous (Fig. 13).

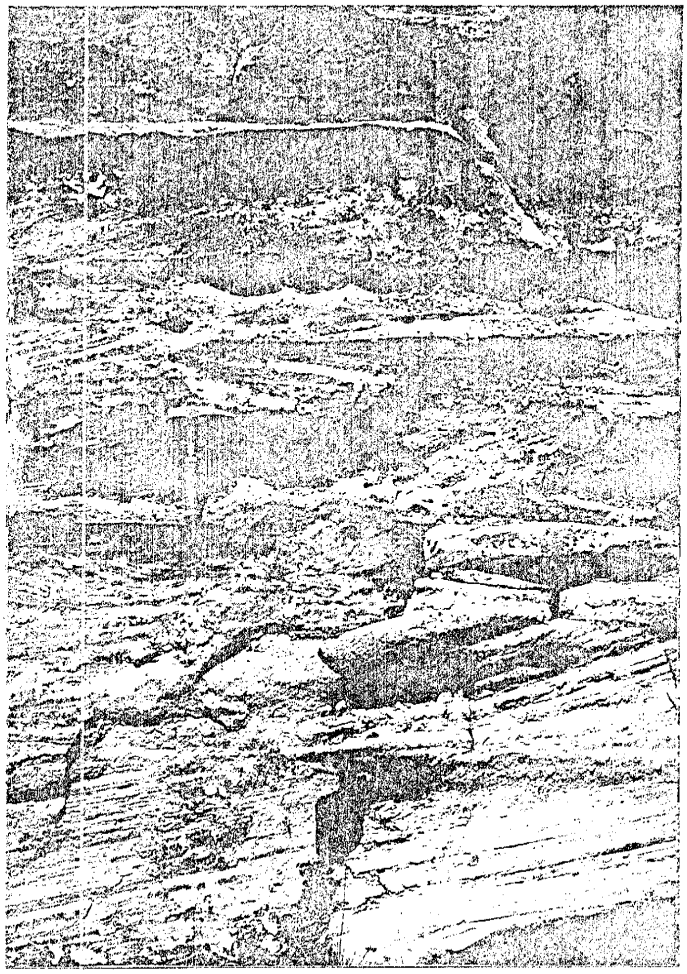


Figure 9- Both wedge planar and trough cross-stratification. Some fining upward of scale can be observed from the bottom of the picture up to the hammer. Just above the hammer is a scour surface separating the two sedimentation units.

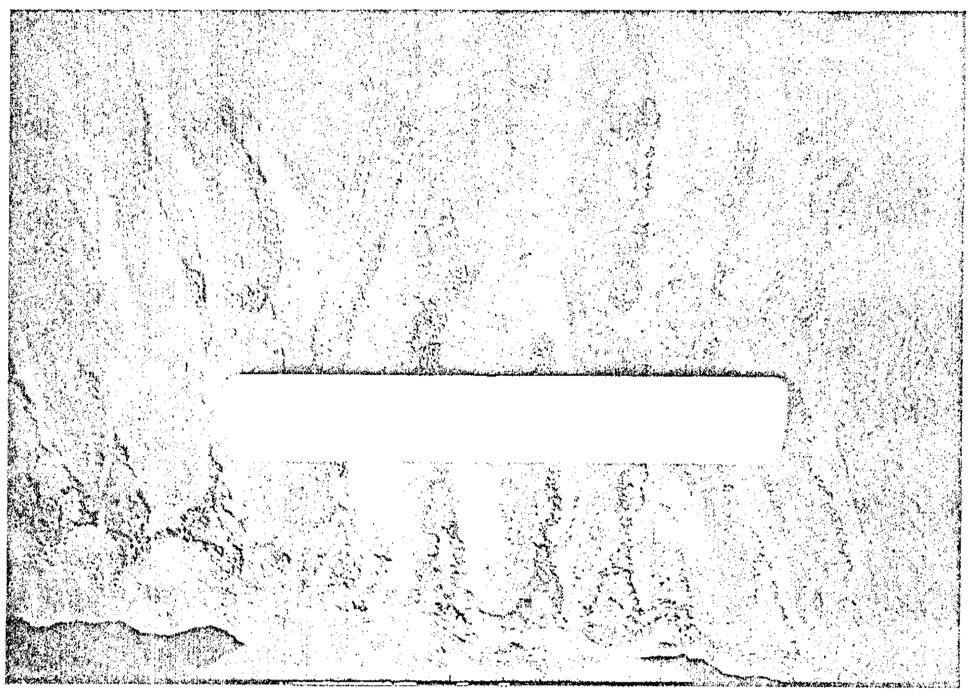


Figure 10- Ripple bed forms. Slightly sinuous, in phase, bifurcating ripples in a fine-grained silty sandstone. Scale is 6 inches (15 cm) long.

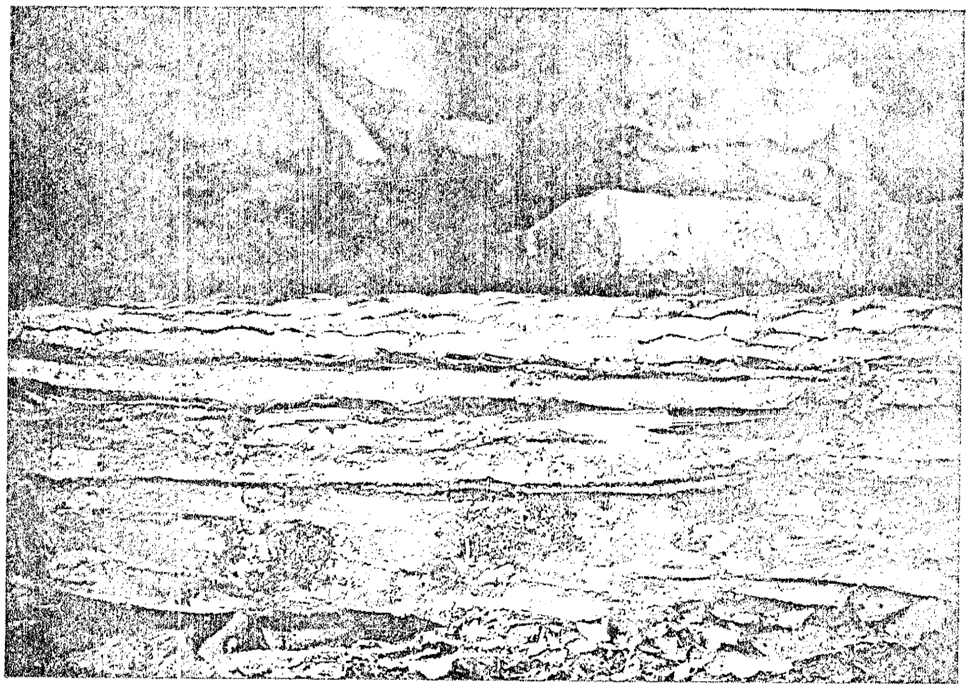


Figure 11- Cross-section of symmetrical ripples, thickly laminated to thinly bedded. This unit is overlain by thicker sandstones which have been scoured and filled by higher flow regime structures.

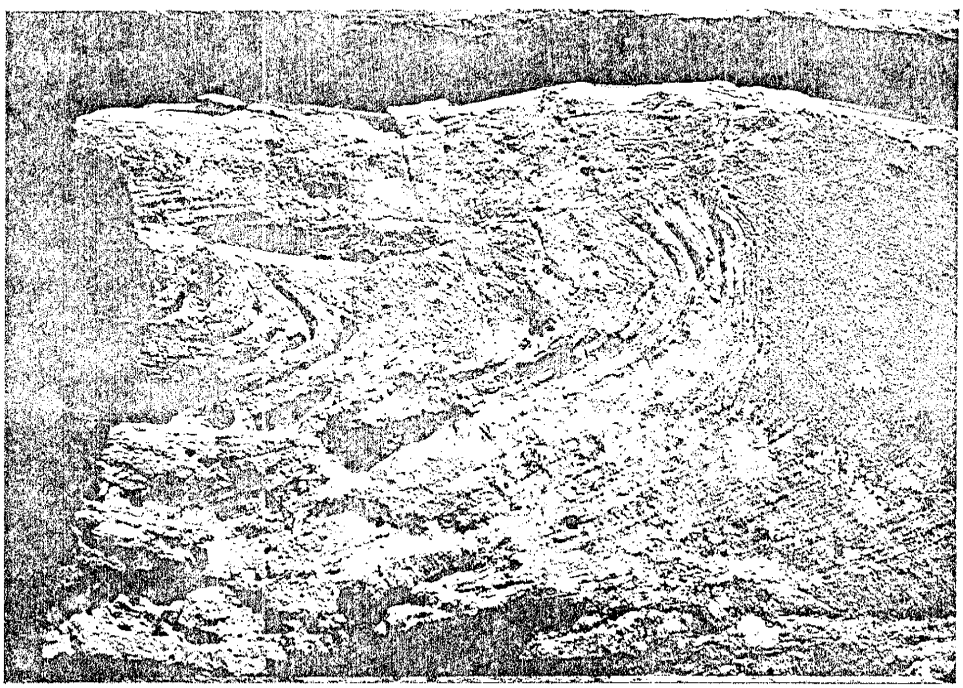


Figure 12- Section MC2- A soft sediment fold with subsequent truncation and erosion of the top and infilling by sands.

The burrows probably belong in the facies scoyenia (Seilacher, 1967), which is non-marine, usually occurring in red beds (Hantzchel, 1966). No definitive indentification is made here, but possible types include; Scoyenia, White, 1929, Palaeophycus, Hall, 1847, and Planolites, Nicholson, 1873. No specific organism is known to have produced any of the structures these classifications identify, although it is postulated that Scoyenia is made by a polychaete worm (Hantzchel, 1966).

Scoyenia is dated as being Permian, which makes it an unlikely possibility for the burrows in the Jurassic Salt Wash Member. Both Palaeophycus and Planolites have a range from Precambrian to Recent (Hantzchel, 1966).

Palaeophycus has a wide range of morphologies; it can be cylindrical or subcylindrical, usually sinuous, oriented obliquely to bedding, is commonly unbranched, though it may occasionally branch, has smooth walls, is 3 to 15 mm in diameter, up to 20 cm in length, and commonly intersects one another. Palaeophycus may have been incorrectly identified in sediments which have been identified as lacustrine. It is considered to be the pathways of various groups of erant organisms (Hantzchel, 1966).

Planolites is a cylindrical or subcylindrical infilled burrow up to 15 mm in diameter, straight to gently curved, nonbranching, more or less horizontal to oblique to bedding, and which may cross over one another. It is quite similar to Palaeophycus. No origin or specific environment is attributed to Planolites (Hantzchel, 1966).

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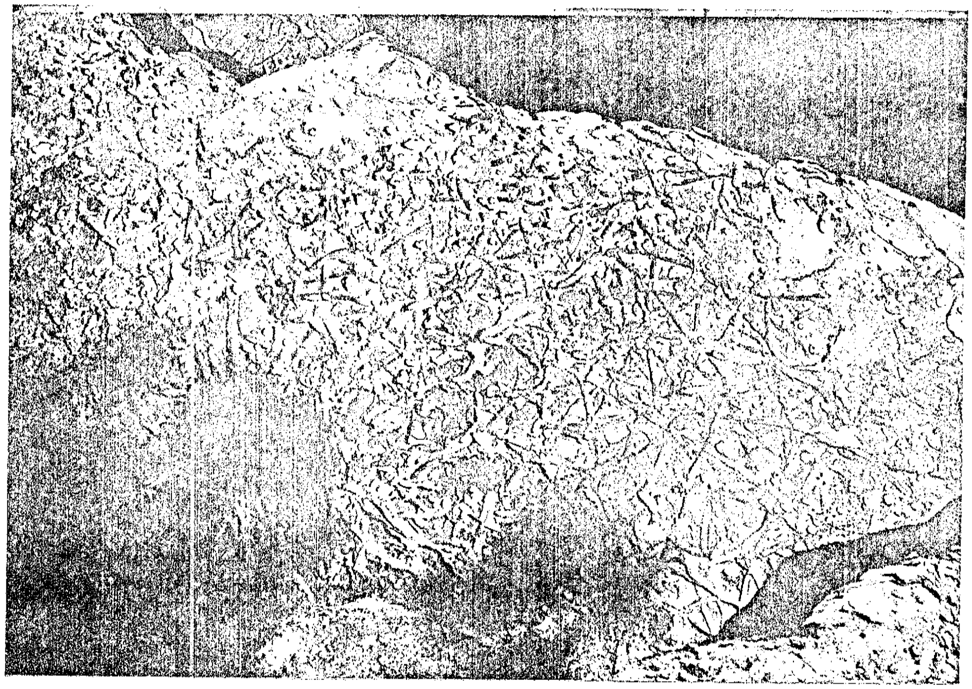


Figure 13- Burrows on a bedding plane. Average diameter is 3/8 inch (9.5mm).

LOCAL STRUCTURE AND TECTONICS

Local structures in Montezuma Canyon are simple. Bedding is essentially horizontal with a dip of 1° to the southeast which has been attributed to the intrusion of the Abajo Dome by Huff and Lesure (1965). Two grabens formed by a zone of east-west block faulting are present in the northern part of the study area in Verdure and Dodge Canyons. The Verdure Graben is approximately ½ mile wide and 25 miles long in an east-west direction with a measured throw of 182 feet in Montezuma Canyon. The fault dips 70° to 80° to the south, the south side being downthrown (Huff and Lesure, 1965). Jointing, oriented approximately parallel to the faults is common in Montezuma Canyon.

The age and origin of the previously described structures are not well known, but Huff and Lesure (1965) attribute them to the intrusion of the Abajo Dome in early Tertiary, while Craig (1955) believes that they may be due to collapse of subsurface salt structures, also post-Jurassic. In general, it appears that all present day structures were formed after deposition of the units presently exposed in Montezuma Canyon.

ANALYSIS OF STRATIGRAPHIC DATA

MARKOV ANALYSIS

To determine if a specific vertical sequence of sedimentary structures is characteristic of the Salt Wash Member, a Markov Chain transition matrix using five typical combinations of sedimentary structures and lithologies is constructed using a method outlined by Krumbein (1968), Potter and Blakely (1968), and Pettijohn, Potter, and Siever (1973). Krumbein (1968) gives an example of a process similar to the one used here, which is outlined in Appendix 3.

Figure 14 shows the preferred sequence of structures based on the matrix analysis, consisting of a trough-shaped set of cross-strata overlain by covered/siltstone overlain by a ripple cross-stratified unit. In general this is roughly analoguous to a fining upward of the scale of structures and possibly to a fining upward of grain size. Based on field observations it is expected that this sequence of structures would occur as the fill within a channel scale cut and fill structure and grade laterally into the overbank deposits.

PALEOCURRENT ANALYSIS

Paleocurrent measurements are taken to determine the direction of transport of sediments and to aid in the interpretation of the depositional environment of the Salt Wash Member. Many articles and books have been published dealing with the interpretation and use of paleocurrent data. Potter and Pettijohn (1977) discuss many aspects of paleocurrent analysis and its relationship to environments. The paleocurrent evaluations are done following techniques outlined in Potter and Pettijohn (1977) for both graphical evaluation using rose diagrams and mathemetical evaluations using vector addition to determine the vector mean current direction and

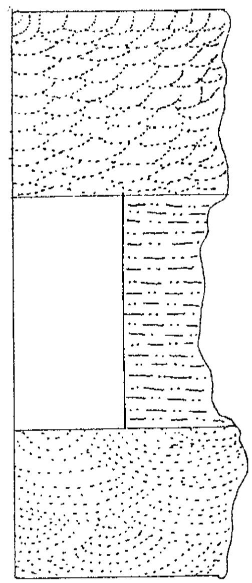


Figure 14- Vertical sequence of lithologies and structures resulting from Markov analysis.

a consistency ratio as an approximate measure of dispersion of the current readings. The equations used for the vector additions are from Potter and Pettijohn (1977, p. 392).

Approximately 200 unique, such as cross-stratification dip direction, and non-unique (polar), such as parting lineation, paleocurrent readings were taken during the measurement of the stratigraphic sections (Appendix 1). To determine if variations in mean current direction could be detected as a function of stratigraphic position, two interval thickensses with a basal reference of the lower contact of the Salt Wash Member are used to group the data. The smallest interval used is 60 feet, the largest 150 feet. The 60-foot intervals are selected to ensure that sufficient data are included in each interval for a statistically reliable result, and because this should show any significant change in mean current direction which may occur in that interval. The 150-foot interval is chosen to divide the Salt Wash Member into two approximately equal parts.

Data for both interval thicknesses are grouped so that each interval consists of the composite data from all ten measured sections. This ensures that sufficient data is used to compute a statistically reliable mean paleocurrent direction. Data for the 60-foot intervals are evaluated mathemetically, the data for the 150-foot intervals both mathematically and by constructing paleocurrent rose diagrams with 30^{o} intervals used for grouping data. Results of the 60-foot interval evaluation are tabulated in Figure 15. Rose diagrams for the 150-foot intervals are illustrated in Figures 16a and 16b with the mean current direction as determined by the criteria stated in Appendix 3 indicates. Figure 17 illustrates the results of evaluation of the 150-foot intervals by vector addition. In both the 60- and 150-foot interval evaluations the current parting lineations are treated as unique (non-polar) directions by plotting them within

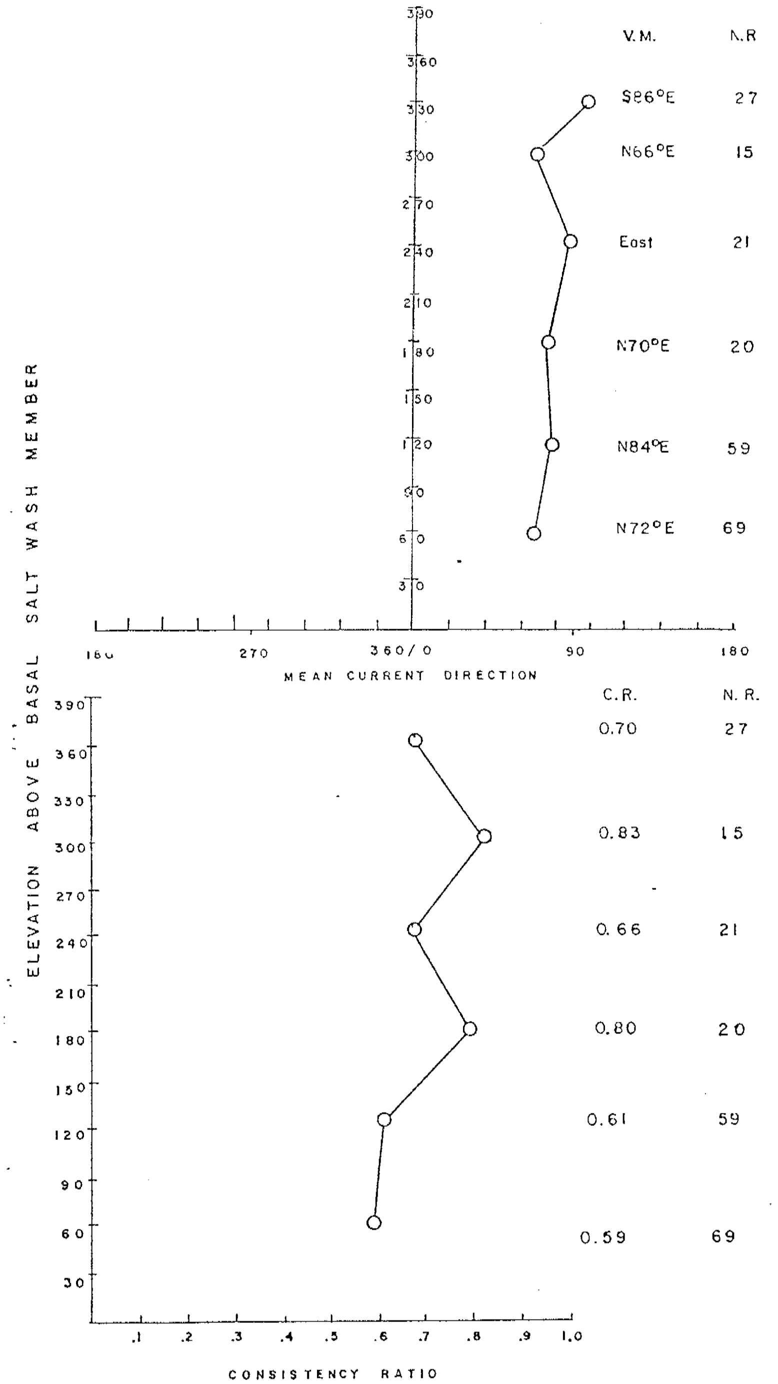


Figure 15.-Vertical Variation Graph

V.M.-Vector Mean

C.R.-Consistency Ratio

N.R.-Number Readings

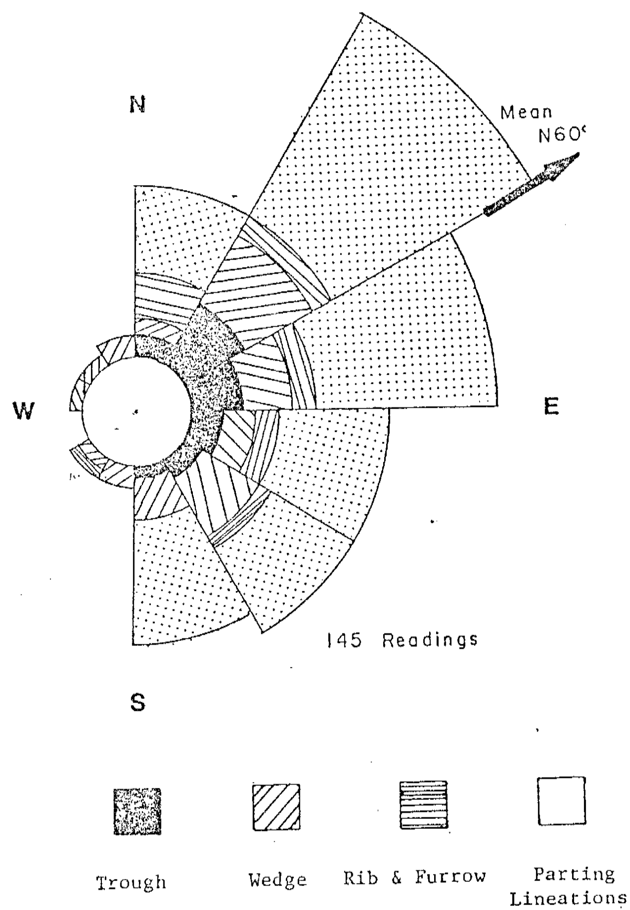
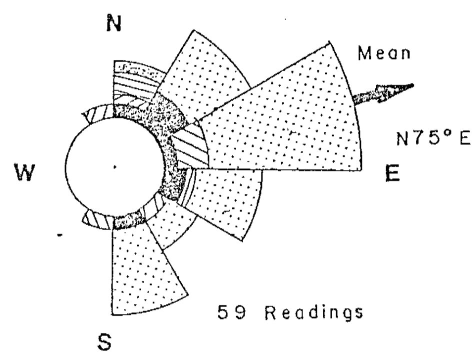


Figure 16a- Paleocurrent Rose Composite Interval
0-150 Feet



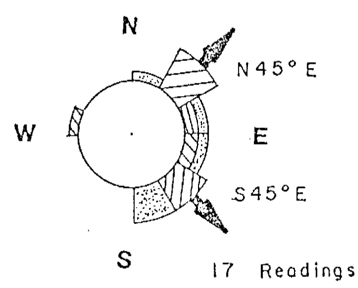


Figure 16b- Paleocurrent rose diagrams, composite intervals
150-300 feet (upper)
Greater than 300 feet (lower)

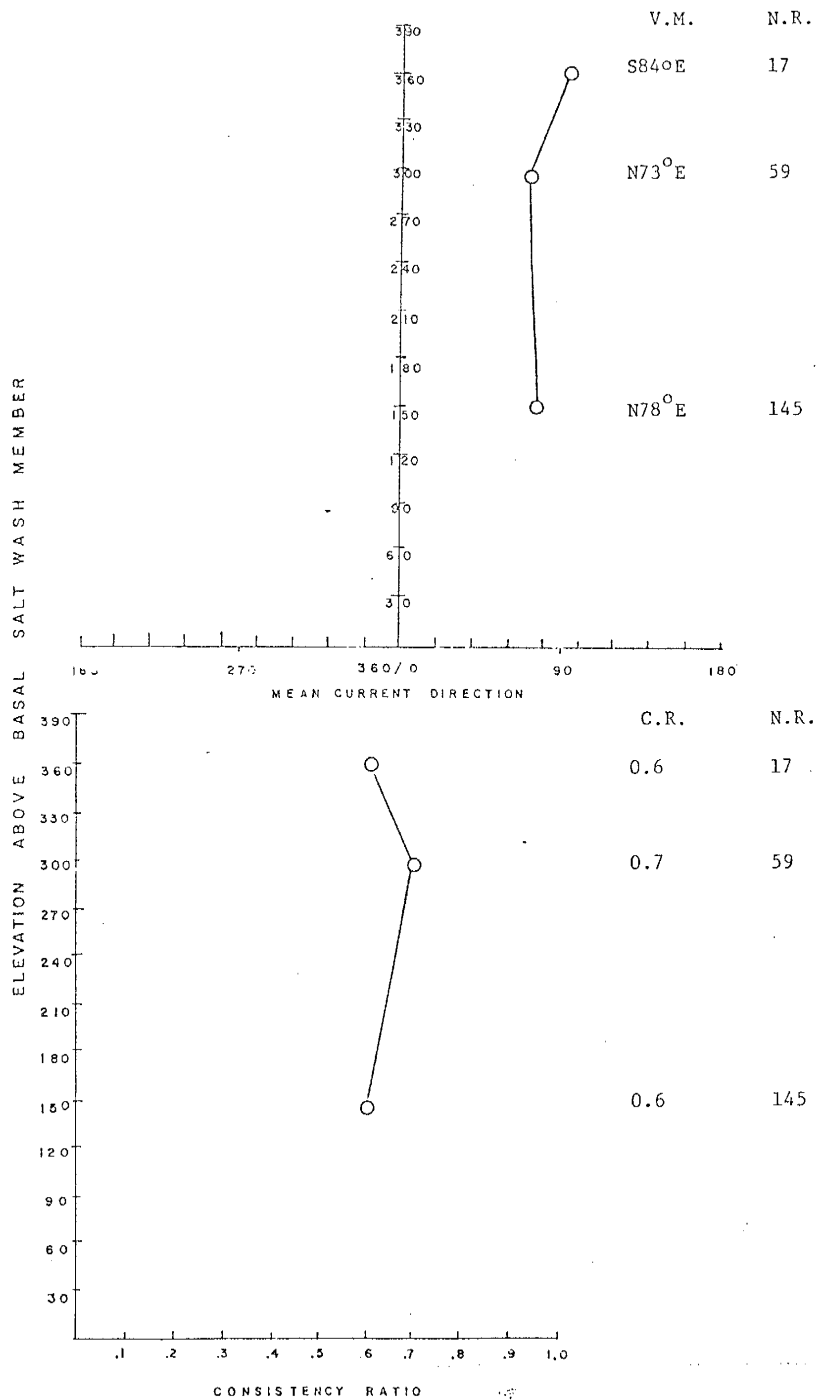


Figure 17.-Vertical Variation Graph

V.M.-Vector Mean
C.R.-Consistency Ratio
N.R.- NumberReadings

the 180^{o} portion of the compass which is coincident with the majority of the unique current indicators. There is close agreement between the transport direction of the re-interpreted current parting lineations and the trough axis readings, with trough axes being a statistically reliable indicator of paleocurrent direction and therefore channel orientation (Dott, 1973; High and Picard, 1974; and Smith, 1972).

In addition to the previously described methods of evaluation, 150-foot intervals for each individual measured section were computed, but are not presented here because the number of readings in each one is insufficient to be statistically reliable. Twenty readings are considered the minimum for obtaining reliable results (Potter and Pettijohn, 1977), and only three out of 18 intervals contained that number.

Results of the 60-foot intervals are shown in Figure 15. The average mean current direction is approximately N 80^{o} E and individual intervals do not vary a significant amount from this direction. Consistency ratios do show variations in a cyclic pattern which is significant for the depositional environment. Results from the 150-foot intervals are similar, with the average mean current direction being approximately N 70^{o} E in the lower 300 feet with a wide variation or low consistency ratio in the data. The interval of greater than 300 feet shows a direction of approximately due east, but does contain fewer readings than the lower two intervals (Fig. 17 and 18). In general, the composite paleocurrent readings from both the 60-foot and 150-foot intervals indicate that there appears to be no significant variation in mean current direction in the Salt Wash Member from the average mean current direction of N 70^{o} E to N 80^{o} E and that the data is spread over a wide range.

The conclusions reached from the comparison of the different methods of analysis is that, given sufficient data, the two methods of evaluation

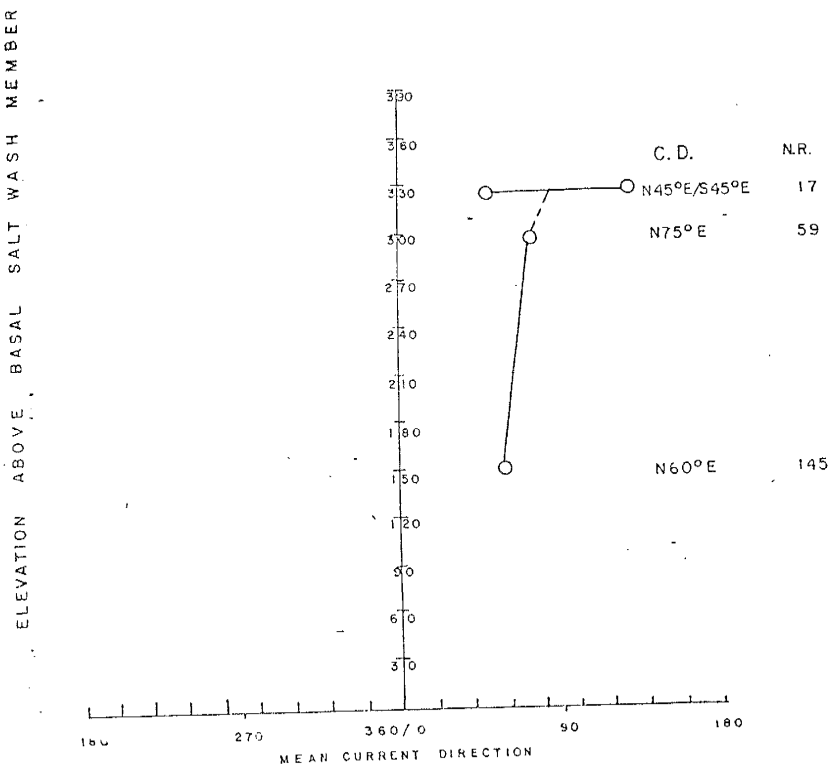


Figure 18.-Vertical Variation Graph

C.D.-Current Direction
N.R.-Number Readings

give a good correlation in mean current direction. The method of combining all readings for a given interval may increase the apparent variation in the mean current direction, but I feel that when the relatively small size of the study area is compared with the very wide areal extent of the total Salt Wash Member, that this method will not cause an appreciable reduction in the reliability of the resultant mean current direction for this study area.

STRATIGRAPHIC CORRELATIONS

Correlations within the Salt Wash Member are attempted based on the probable continuity of lithologic sequence, sedimentary structures, paleocurrent patterns, and visual tracing. Petersen (1977, 1978) has identified three sequences in the Salt Wash Member in the Henry Mountains Region, each the product of a slightly differing depositional environment, which may or may not extend eastward into the Montezuma Canyon area. The purpose of attempting these correlations within the study area is to see if any discrete sequences can be located in Montezuma Canyon using similar methods.

Individual sedimentary structures are generally limited in lateral extent to distances of less than 300 feet. Correlations between measured sections based on structure are not possible except for the structures used in conjunction with lithology which identify the lower contact of the Salt Wash Member. The lower contact of the Salt Wash Member is identified by a cross-bedded sandstone at least three feet thick and having a lateral extent of at least 300 feet. These structures are present throughout the study area and have been determined to be continuous by visual tracing.

Lithology, or sequences of lithologic types, do not correlate laterally for more than approximately 1 mile and a lack of marker horizons makes correlation of discrete lithologic units on this scale an imprecise exercise. Visual tracing of the thicker sandstone units shown on Plate 2 indicates that less than 50 percent of these units can actually be traced continuously to units which appear to be the lateral equivalents on Plate 2.

Correlation of stratigraphic intervals by paleocurrent direction is used by Petersen (personal communication, 1979) to distinguish the contact between two of his three sequences. The slight variations in mean current direction of the Salt Wash Member in Montezuma Canyon do not indicate a similar change in paleocurrent orientation with higher stratigraphic position.

The only method of correlation found during this study which can be reliably applied to the Salt Wash Member in Montezuma Canyon is visual tracing of the outcrop along the exposures. Using this method it is possible to trace individual sandstone bodies for distances of approximately one mile, and also to see that continuous sandstone bodies do not necessarily remain on one horizon for that entire distance. This may explain the difficulty in correlating adjacent sandstones on Plate 2.

In conclusion, it can be said that correlation of discrete stratigraphic intervals within the Salt Wash Member composed of either sandstone or siltstone is not reliable if the only basis for the correlation is the apparent lateral continuity of the intervals in adjacent measured stratigraphic sections. The exception to this is the basal Salt Wash Member of cross-bedded sandstones described previously. The three-part division of the Salt Wash Member used by Petersen (1977, 1978) could not be applied in the study area, nor could any other division.

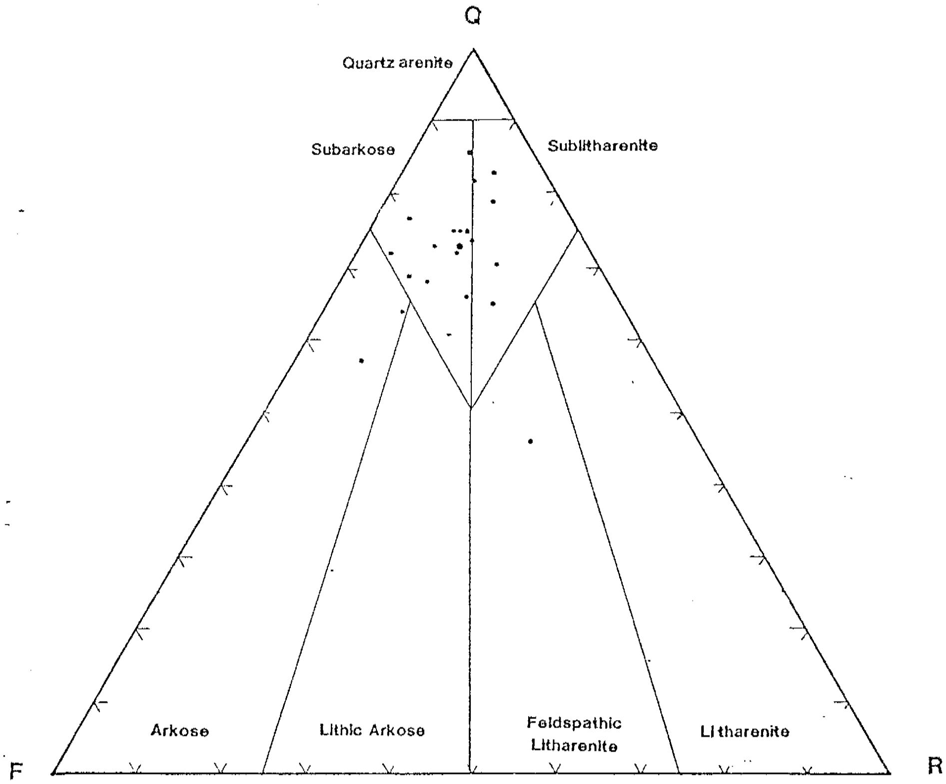


Figure 19- Plots of sandstone compositions of the Salt Wash Member, modified after McBride (1963) and Folk (1968).

PETROGRAPHY

INTRODUCTION

Twenty-one samples collected during the measurement of the stratigraphic sections are considered representative of the sandstones in the Salt Wash Member in the study area. These samples were analyzed by visual estimation to determine composition, fabric, and depositional and diagenetic history. A limited number of 500 point counts are included and compared to the data of Van der Plas and Tobi (1965) to determine the accuracy of both the point counts and visual estimation. Both methods are believed to result in an accuracy of approximately ± 5 percent. The samples are classified according to the system in Appendix 2 which is modified after Folk (1968) and McBride (1963). It is the purpose of the petrographic analysis to aid in an evaluation of source areas and terrains, to evaluate fabric, especially in terms of grain sizes and sorting, and to aid in the evaluation of the depositional environment.

Approximately 60 percent of the samples are classified as a calcareous Subarkose. The average composition of the detrital fraction is approximately 65 percent quartz, 14 percent feldspar, 4 percent chert, 7 percent lithic fragments, 4 percent clay, 2 percent opaques and trace amounts of other minerals. The remaining samples are mostly volcanic Sublitharenites (Fig. 19).

DETRITAL COMPONENTS

The major detrital components of the smaples are quartz, feldspar, chert, lithic fragments, varying amounts of clays, and opaque minerals. Other minerals are present in amounts of less than two to three percent. Appendix 2 is the detailed thin section descriptions, tables 1a, 1b, and 2 give percentages of the various detrital components, and Figure 19 is a plot of the points on the ternary classification diagram used in this study.

Table la. - Detrital Components, 500 Point Counts; Percentages rounded to nearest whole percent, precision from the data of van der Plas and Tobi, (1965). No entry indicates no observation.

	MC1-2	MC3-1	MC3-2	MC3-3	MC3-4	MC4-1
Quartz	93 ± 3	85 ± 3	51 ± 4	46 ± 4	56 ± 4	85 ± 3
Feldspar	3 ± 1	7 ± 2	23 ± 3	7 ± 2	33 ± 4	6 ± 2
Chert			1 ± .5	29 ± 4	Tr	6 ± 2
Lithic Fragments	3 ± 1	3 ± 1	4 ± 2	16 ± 3	8 ± 2	1 ± .5
Clay		1 ± .5	18 ± 3		1 ± .5	1 ± .5
Opaques		3 ± 1	2 ± 1	1 ± .5	Tr	Tr
Other			Tr	Tr	1± .5	Tr

Table 1b. - Detrital Components from Visual Estimation Percentages are rounded to the nearest whole percent, no entry indicates no observation.
Sample MC3-3 was not visually estimated, only point counted due to alteration of lithic fragments.

	MC1-1	MC1-2	MC1-3	MC1-5	MC3-1	MC3-2
Quartz	65	90	60	65	80	50
Feldspar	22	5	15	14	10	20
Chert				4		3
Lithic Fragments	12	3	15	7	5	5
Clay		1	7	4	1	20
Opaques			2	2	3	Tr
Other	Tr	Tr	Tr		Tr	Tr

	MC3-3	MC3-4	MC4-1	MC4-3	MC4-4	MC4-5
Quartz		65	85	70	60	78
Feldspar		20	5	13	10	5
Chert		2	5	3	4	3
Lithic Fragments		5	2	7	4	7
Clay		3	1	6	20	4
Opaques		2	Tr	Tr	Tr	2
Other	1	Tr	Tr			

	MC5-1	MC5-3	MC5-4	MC6-1	MC7-1	MC8-1
Quartz	75	70	75	60	60	70
Feldspar	8	12	7	15	15	12
Chert	5	5	4	10	2	3
Lithic Fragments	7	8	8	9	5	8
Clay	2	1	3	5	12	4
Opaques	1	2	2	Tr	3	2
Other	1	1	Tr	Tr	2	Tr

	MC8-1
Quartz	80
Feldspar	8
Chert	4
Lithic Fragments	5
Clay	1
Opaques	Tr
Other	Tr

Table 2. - Values are recomputed to 100% for determination of rock type on the ternary classification diagram.

Q = monocrystalline plus polycrystalline quartz
F = all feldspars
R = all types of lithic fragments plus chert

SAMPLE	Q	F	R
MC1-1	66%	22%	12%
MC1-2	94%	3%	3%
MC1-3	66%	17%	17%
MC1-5	72%	16%	12%
MC3-1	90%	7%	3%
MC3-2	65%	29%	6%
MC3-3	47%	7%	46%
MC3-4	58%	34%	8%
MC4-1	87%	6%	7%
MC4-3	75%	14%	11%
MC4-4	77%	13%	10%
MC4-5	84%	5%	11%
MC5-1	79%	8%	13%
MC5-3	73%	13%	14%
MC5-4	80%	7%	13%
MC6-1	64%	16%	20%
MC7-1	73%	18%	9%
MC8-1	75%	13%	12%
MC10-1	83%	8%	9%

Quartz

Quartz is the most abundant component in all 21 samples, ranging from 46 to 93 percent of the detrital components. Both monocrystalline and polycrystalline quartz are present in a ratio of approximately 9:1, monocrystalline quartz being the most abundant. Monocrystalline quartz grains are subangular, subequant, moderately undulose, have very few inclusions and 10 to 15 percent have rounded overgrowths marked by an indistinct band of oxides or other inclusions beneath the overgrowth (Fig. 20). Approximately 10 percent or less of the monocrystalline quartz is euhedral with a hexagonal outline, and has a fractured, mottled appearance.

The polycrystalline quartz has an average of five crystals per grain; the crystal-to-crystal contact being very finely sutured. The shape of the polycrystalline quartz grains is similar to that of the monocrystalline grains, but is slightly more elongate. No significant alteration is noted for either variety of quartz.

Feldspars

Both potassic and sodic feldspars are present in the samples in a ratio of approximately 9:1, potassium feldspar to plagioclase. Total feldspar content ranges from 3 percent to 33 percent, most samples containing approximately 15 percent feldspar. Both feldspar varieties are subhedral, subrounded, and subequant and display some degree of alteration, mainly to clays.

The potassic feldspars are mostly orthoclase, although a rare occurrence of sanidine is noted in sample MC3-2 and variable amounts of microcline are also present (Fig. 21). Alteration is similar for all the varieties of potassium feldspar, the common occurrence being very small blebs of clay or very thin rims of clay on the grain. Approximately 10 percent of the orthoclase has rounded rims of orthoclase overgrowths.

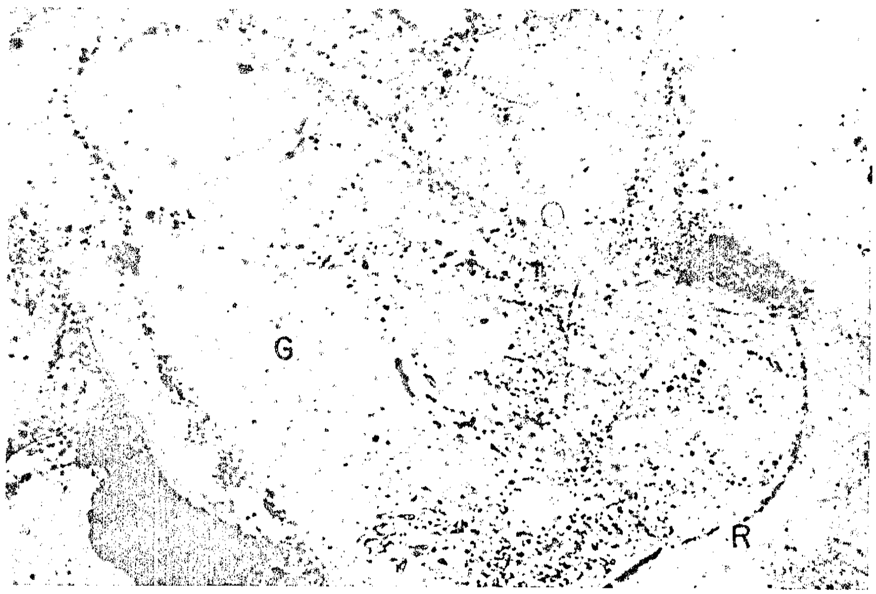


Figure 20- Rounded quartz grain with an overgrowth of syntaxial rim cement. Core grain (G) boundary is outlined by a rim of dark inclusions (R), probably oxide stains.

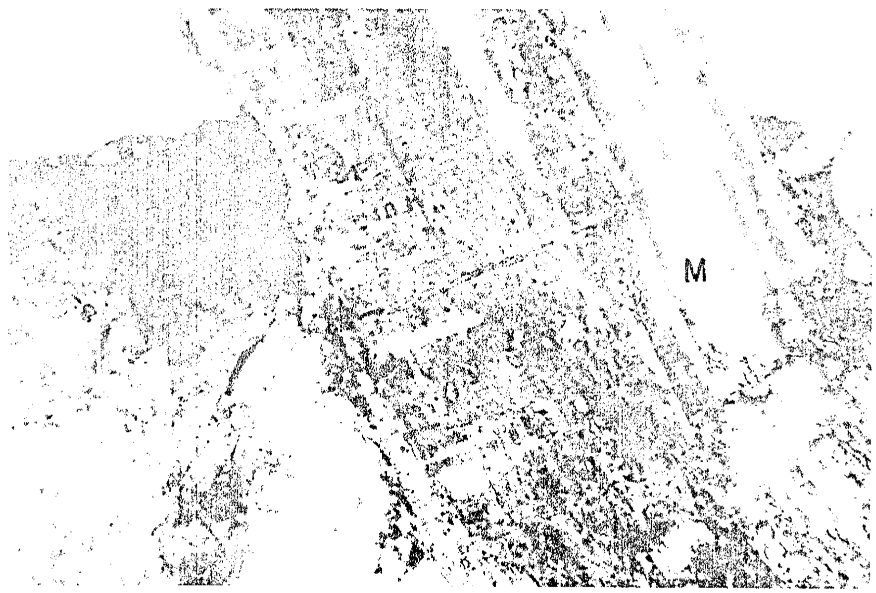


Figure 21- Microcline crystal (M) on right side of the photo shows some minor alteration to clay. Clay appears as small white blebs within the partially extinct side of the grain.

The plagioclase is slightly more elongate than the orthoclase and usually alteration is more advanced. Alteration to clays is common along twin planes and as a rim around the grain, and commonly is advanced to the point where only relict twinning is visible. Twinning is Albite and combined Carlsbad-Albite and is used to determine the composition by the Michel-Levy method. The range of compositions in the plagioclase is narrow, from An_{33} or Andesine. In addition to the previously described plagioclase, one grain is present which is euhedral and progressively zoned.

Chert

Chert is very finely polycrystalline, anhedral, subrounded, and contains 10 to 20 percent inclusions. Coatings of a red/brown oxide are present on approximately 50 percent of the chert and 5 to 10 percent of the grains are recrystallizing to a more coarsely crystalline variety (Fig. 22). The greatest variation in the chert fraction is in degree of crystallinity, and type of inclusions when present. Most common of the inclusions are small, dark spots believed to be oxides, and fluid-filled vacuoles.

Lithic Fragments

Lithic fragments are from two sources: volcanic and sedimentary. The volcanic lithic fragments are believed to be of felsic, possibly rhyolitic, origin and vary greatly in the degree of alteration they exhibit. Volcanic lithic fragments are very fine-grained, crystal rich and have a glassy, isotropic, brown matrix. The common intragranular mineralogies are quartz, orthoclase, and plagioclase, with minor amounts of phyllosilicates (biotite?) and opaque minerals. The volcanic lithic fragments are subrounded and subelongate.

Figure 22- Possible recrystallization of very fine poly-crystalline silica or chert to a more coarsely crystalline variety of silica.

Alteration of the volcanic lithic fragments is progressive and is subdivided according to the degree of preservation of primary mineralogy and texture. The initial stage is virtually unaltered fragments. Primary mineralogies and igneous textures are still very clear. Advanced alteration is characterized by the replacement of intragranular mineralogies, especially the feldspars, by cherty, very finely crystalline silica. Primary igneous textures and the groundmass are still well defined (Fig. 23). Alteration proceeds with a loss of primary igneous textures and devitrification of the glassy matrix material (Fig. 24a and 24b). The boundaries of the lithic fragments are still well defined at this point. The most advanced stage of alteration is characterized by the complete loss of all primary mineralogy and igneous textures and a loss of definition of the lithic fragment boundary. The grains are replaced by or altered to finely crystalline silica which is distinguished from chert by its slight brown coloration, abundant inclusions, and the poorly defined grain boundary. These grains may be partly replaced by the cement as well. Alteration to this degree is rare, occurring in 5 percent or less of the grains. Approximately 50 percent or slightly more of the grains are at the stage where initial loss of primary mineralogy and texture is occurring.

Sedimentary lighic fragments are argillaceous fragments in which neither structures nor mineralogies could be recognized. The source of many of these may be intraformational based on their larger size and greater angularity relative to the volcanic lithic fragments. No alteration of these fragments is recognized.

Clays

Detrital clays occur as finely disseminated intergranular material and in thin, deformed veins and clasts. They are very finely granular if

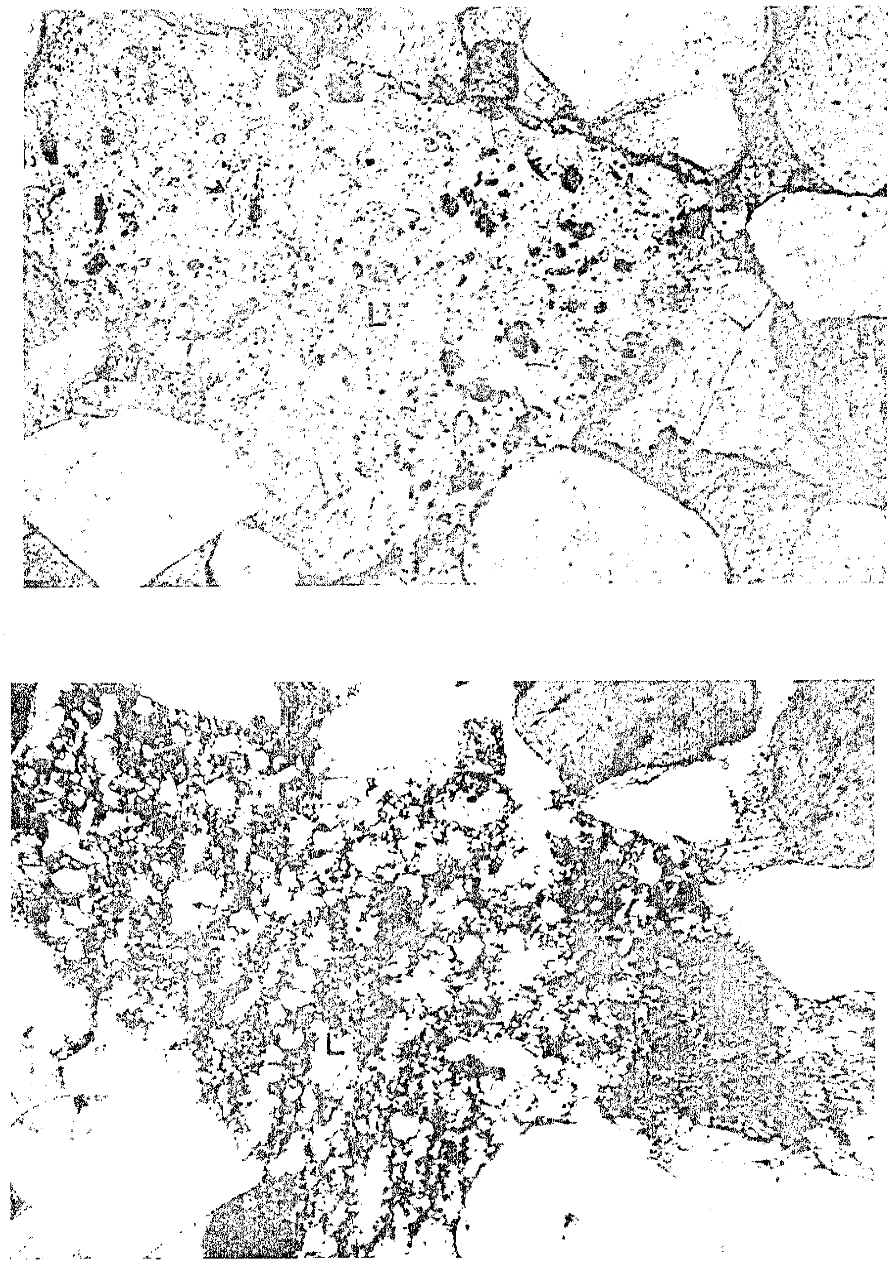


Figure 23- The upper photo shows what was determined to be a volcanic lithic fragment (L) in plain light, the lower photo under crossed nicols. Relict strucutes and intragranular mineralogies can still be observed. Fragment is identified as a tuffaceous and crystal rich, volcanic fragment.

Figure 24a- Devitrification of probable volcanic fragment. Note the lack of any relict structures or minerologies (crossed nicols).

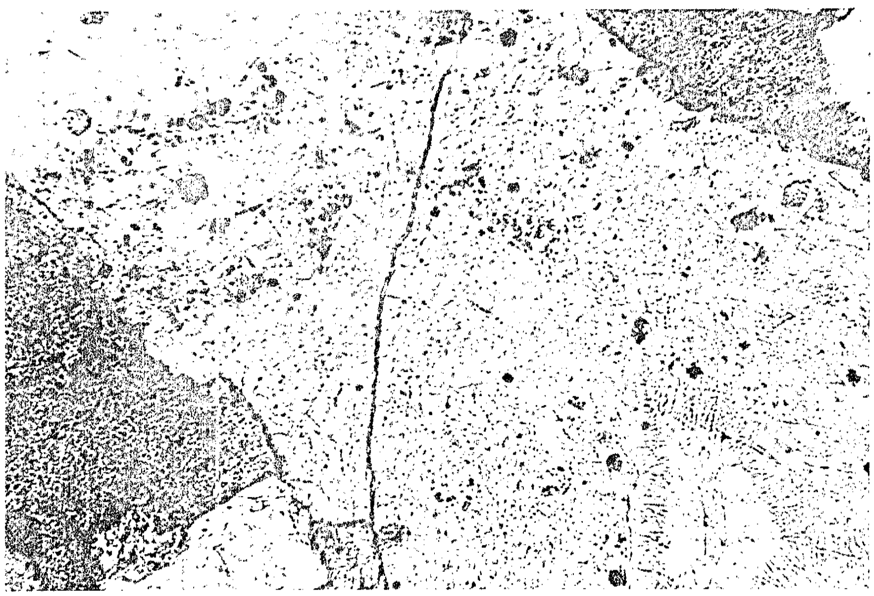


Figure 24b- Same fragment as 24a, in plain light.

any texture can be observed and frequently the larger masses are penetrated by the harder detrital grains.

Opaque Minerals

Opaque minerals are very fine-grained, usually less than .05 mm in diameter and occur in linear bands, one to two grains thick, parallel to bedding planes. They are subhedral, equant, reddish brown in reflected light and make up only 1 to 2 percent of the detrital grains. The most common mineral is probably magnetite, with rare occurrences of pyrite. One pseudomorph of hematite after pyrite is present in sample MC7-1 (Appendix 6).

Other Minerals

Other minerals are present in amounts which range from a trace to 2 or 3 percent. These include micas, probably biotite, hornblende, and zircon. Of these only zircon is present in an appreciable quantity in a number of the samples. The zircon is very fine-grained, well rounded, may have slight overgrowths, and is very widely disseminated (Fig. 25). The various other minerals present are for the most part very fine-grained and well rounded.

CEMENTS

Two major cements are present in the samples: calcium carbonate and silica. The carbonate cement is the most abundant and averages approximately 60 percent or more of the total cement. The carbonate is identified as calcite and commonly occurs as large poikiolotopic masses enclosing three to five detrital grains. The other common occurrence of calcite cement which is slightly less than 50 percent of that cement is as finely crystalline intergranular cement. During cementation many of

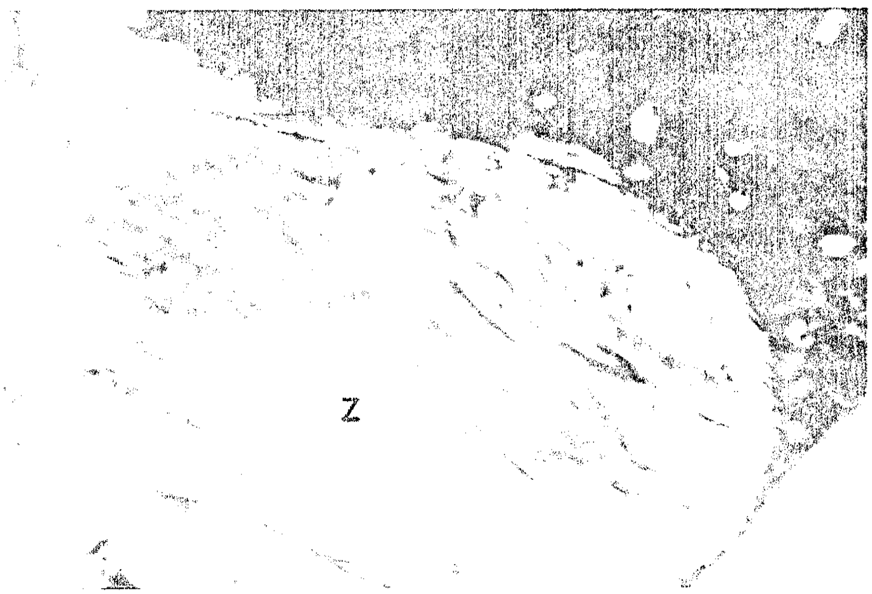


Figure 25- Detrital Zircon (Z), magnification 50x.

the detritial grains and much of the silica cement has been simultaneously dissolved and embayed by the calcite cement, resulting in irregular, serrate grain boundaries. Based on cement-to-cement contacts it appears that the calcite cement developed after the silica (Fig. 26).

Silica cement is a finely crystallized opaline variety. It occurs later than any overgrowths based on the smooth, regular contacts between detrital grains, both with and without overgrowths, and the silica cement. As noted previously, it is the first cement to form and is being replaced by the later carbonate cements.

Other cements which may be present are iron oxide coatings. These account for 1 percent or less of the total cement.

FABRIC

The fabric of all the samples is similar. Average grain size is approximately 0.25 mm, sorting is moderate, grains are subangular to subrounded. Matrix material, the very fine-grained intergranular material which is petrographically irresolvable, varies in abundance but is rarely more than 3 or 4 percent. Pseudomatrix occurs in a few sections and is derived from the compacted, deformed clay clasts which are squeezed between and around other detrital grains. Pore space is limited, only trace amounts could be positively identified, although some of that may be due to plucking of grains during the sample preparation. Textural maturity (Folk, 1968) is submature on all but a very few samples. Line contacts are the most abundant grain-to-grain contact followed by approximately equivalent abundances of point contacts and concave-convex contracts.

CLAY MINERALOGY

Five clay samples were analyzed by semi-quantitative X-ray diffraction methods to determine types and relative abundances of clay minerals. The

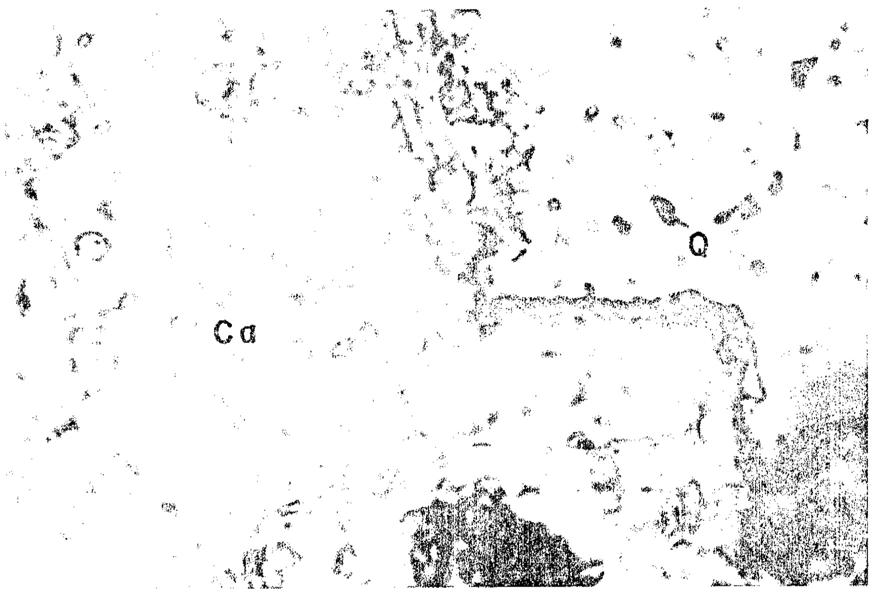


Figure 26-Carbonate cement (Ca) embaying Quartz (Q).

objective of the clay mineral analysis was to determine if this is an useful aid in the environmental analysis.

The samples used for the studies are obtained by crushing whole rock samples to release the fine silt and clay size fraction contained as intergranular material and to get the fine-grained material which is present in clasts and veinlets. This allows not only X-ray analysis of the samples, but also visual observation of structures and occurrences in the thin sections. Table 3 gives the sample number and primary mode of occurrence of the clay size fraction used in the analysis. Appendix 3 contains a detailed description of the sample preparation technique.

Interpretation of the X-ray diffraction patterns shows that all the samples contain significant amounts of Kaolinite, Illite, and mixed layer clays (Table 3). Montmorillonite, if present, is in such insignificant quantities that it is indistinguishable from the illite peak. In addition to the clays, quartz is also present in all samples.

The origin of the major clays is both authigenic and allogenic, based on abundances, petrographic observations, and sampling methods. Samples MC4-3, MC6-1, and MC7-1 have significantly greater amounts of Illite than do the other samples (Table 3). The samples contain clasts and thin veins of mudstone from which the samples are taken. Both occurrences are from detrital clays emplaced with the surrounding sand grains and are thought to have come from a pre-existing sediment source rather than being authigenic. They are therefore not believed to be indicative of an unique environment of deposition.

Samples MC4-1 and MC1-4 both contain abundant Kaolinite (Table 3). During examination of the thin sections of these samples, interstitial clays were noted which were sampled. Based on the petrographic relations and X-ray diffraction results, the Kaolinite is thought to be authigenic, Relative Percentages of Clay Minerals In Parts In Ten

	MC1-4	MC4-1	MC4-3	MC6-1	MC7-1
Kaolinite	9	9	5	7	4
Illite	0	1	5	3	5
Mixed Layer	0	0	0	0	1

Mode of Occurrence of Clay Samples

MC1-4 -- Clays present as intergranular matrix

MC4-1 -- Clays present as intergranular matrix

MC4-3 -- Clays present as a small vein

MC6-1 -- Clays present in a large mudstone clast and small veins

MC7-1 -- Clays present in a large mudstone clast

Table 3

forming during weathering and breakdown of the K-feldspars. Time of formation of the interstitial clays is not known, but it may be a relatively recent occurrence which began after lithification, and after erosion had exposed the rock to weathering processes. If this is the case, then the Kaolinite is not a good indicator of depositional environment. The alternative, formation of the Kaolinite soon after deposition of the sediments, would indicate an environment which is somewhat acidic (Krauskopf, 1967).

Based on petrographic observations which show authigenic clay rims on many of the feldspar grains which are presently enclosed in both the earlier silica and later carbonate cement, I believe that a majority of the Kaolinite formed soon after primary deposition of the sediments.

The information obtained from the five samples indicates that further sampling and clay mineral analysis is probably of minimal use in the evaluation of the depositional environment. The technique of Brown et al. (1977) is not applicable to the non-marine sequence being studied due to the absence of the indicative clay minerals which they used to compute relative position of marine, marginal marine, and continental deposits, and because the Salt Wash Member was not the product of a transitional environment.

PROVENANCE

Two major sources of sediments in the Salt Wash Member sandstones are pre-existing sedimentary rocks and felsic, volcanic deposits. Other sources which contributed sediments may include intrusive igneous and metamorphic terrrains.

Evidence for multi-cycle sands comes from the occurrence of rounded overgrowths on subrounded to rounded core grains (Fig. 20). Grains which do not have overgrowths may be either multicycle or first cycle. One type of quartz grain believed to be first cycle is angular and has a fractured, mottled appearance similar to that described for semicomposite or composite grains of volcanic origin (Folk, 1968).

The shape and number of crystals is used by Basu et al. (1975) and Blatt et al. (1972) as an indication of source for polycrystalline quartz. Polycrystalline quartz from the Montezuma Canyon samples averages five crystals per grain and detrital grains are slightly elongate. These characteristics are used by Basu et al. (1975) to indicate that a schist is the source rock rather than gneisses or plutonic rocks which have only two to three crystals per grain and a slightly larger grain size.

A volcanic source is interpreted from the presence of volcanic lithic fragments, the rare occurrence of sanidine, the progressively zoned plagioclase, and the composite quartz crystals (Folk, 1968). The range in degree of alteration of the volcanic lithic fragments indicates a possibility that two ages or episodes of volcanism were responsible for the volcanic detritus rather than a single source. Possible explanations are contemporaneous air-fall deposits being incorporated into the sediments during deposition to account for the fresh lithic fragments, and erosion of older bedded flow or air-fall deposits up-slope in the source area for the altered lithic fragments.

The sandstones of the Salt Wash Member are probably not the result of a single point source. A petrologic study by Cadigan (1967) indicates several source areas in the uplands which contributed sediments to the Salt Wash Member, each identified with a unique mineralogy or assemblage of mineralogies. Paleocurrent data from the present study indicates that a major source area for Montezuma Canyon was in a direction which averages approximately ten degrees south of due west. The variability of the paleocurrent readings indicates that a good deal of the sediment may have come from sources both to the south and north of that westerly source.

The most abundant of the sediments which is used to indicate a source are those of volcanic origin. A probable source area for these sediments is southwest Utah or southern Nevada. Both are known to have had Jurassic volcanism (Cadigan, 1967). No one formation or episode is known which can be used as a source of volcanic detritus, but Longwell et al. (1965), Wilden and Speed (1974) and Tschanz and Pampeyan (1970) all note moderately abundant felsic to intermediate volcanics in the upper Triassic and middle Jurassic rocks of southern and central to west-central Nevada which are a possible source. Albers and Stewart (1972) make note of the fact that during the medial and late Jurassic Epochs highs existed in parts of west-central Nevada which were undergoing extensive erosion. These highs may also have contributed volcanic and other detrital sediments to the Salt Wash Member.

The provenance of the sparse zircon noted in the thin sections is indicated to be south to southwest of the present day limits of the Salt Wash Member by Cadigan (1967). The grains are frequently well rounded and may be from reworked sedimentary deposits or from igneous intrusives in the area of southern Nevada (Longwell, et al., 1965).

DIAGENESIS AND DEPOSITIONAL HISTORY

The depositional history and a simplified sequence of diagenetic events for the samples studied begins with the deposition of sediments having an initial porosity of 30 percent or greater based on pre-cement void space. Shortly after or concurrent with deposition some compaction occurred, deforming the still plastic clay clasts and rip-ups and causing penetration of them by the harder detrital grains. Porosity at this point is probably 10 to 30 percent, or approximately equal to the present amount of space occupied by the cements.

A probable sequence of diagenetic events which leads to the observed characteristics of the samples begins with initial alteration of the volcanic detrital grains and feldspars. During diagenesis both components can be expected to take water into their structure and lose potassium, sodium and calcium ions, and silica to the pore fluid. The product of diagenesis at this stage is clay, Kaolinite from the feldspars and montmorillonite from the volcanic detritus (Pettijohn, Potter, and Siever, 1973). Continued diagenesis can further alter these initial products to Illite by incorporating the K^+ ions into the structure. Illite is relatively stable and will probably not undergo further significant alteration (Helgeson, Brown, and Leeper, 1978). The excess silica from alteration of the volcanics can be incorporated partially with the Kaolinite to form the illite and can be deposited as an initial cement and as overgrowths on detrital quartz grains. Dissolution of the silica cement and detrital grains and subsequent precipitation of carbonate cement follows the previous events.

The sequence described here is supported by evidence drawn from the clay mineral analysis, petrographic observations, and cement relationships. Not supported though is the formation of the montmorillonite from the volcanic detritus due to its absence in the clay mineralogy analyses. This may be due to older diagenetic events having caused alteration of the volcanics to montmorillonite and then to illite before the sediments were incorporated into the Salt Wash Member. The montmorillonite that formed during diagenesis in the Salt Wash Member either was insignificant or very quickly incorporated K^+ to become illite.

DEPOSITIONAL MODELS

The majority of authors who have worked on the Salt Wash Member of the Morrison Formation have defined it as a braided, fluvial system (Stokes, 1944; Craig, 1955; Huff and Lesure, 1965; Cater, 1970). To determine if the Montezuma Canyon study area resulted from a braided stream depositional environment, research into modern and ancient fluvial braided systems has been undertaken and a comparison between the observed characteristics of the deposits and models has been done.

Fluvial systems are classified according to the channel pattern and the degree of sinuosity of the channel. Braided streams are regarded as being relatively straight and composed of two or more anastomosing channels, while meandering streams are more sinuous and usually confined to one channel on a well defined floodplain. An infinite number of gradations exist between the two end members (Leopold and Wolman, 1957; Reineck and Singh, 1975).

Vertical sequences of sedimentary structures and lithologies in fluvial systems are well known. Relative abundance of many characteristic structures are dependent on the type of pattern the particular stream has developed. As an example, lateral accretion features, interpreted as point-bar deposits, are typically associated with meandering stream systems (Fig. 27). These deposits result from deposition under spatially differing, but synchronous flow conditions (Reineck and Singh, 1975). Braid-bar deposits, making multilateral and multistory deposits with a wide range of types and styles of sedimentary structures, are typical of deposits in a braided stream system (Fig. 28). Both braided and meandering stream systems show considerable overlap of characteristic deposits.

Studies of the depositional environment of braided stream systems have been conducted by Leopold and Wolman (1957), Coleman (1969), Smith

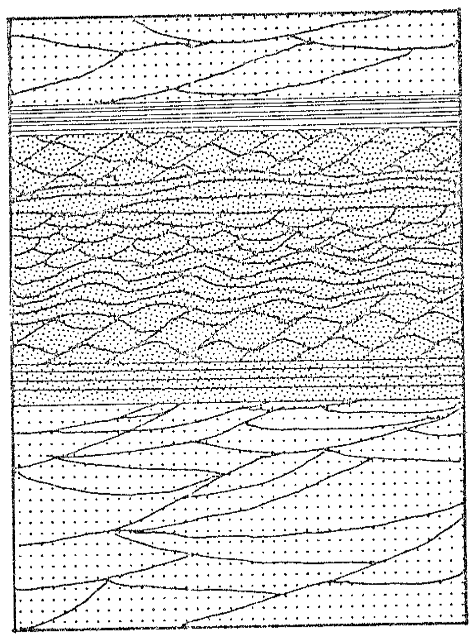


Figure 27- Idealized fining upqard sequence of a point bar deposit (Reineck and Singh, 1975).

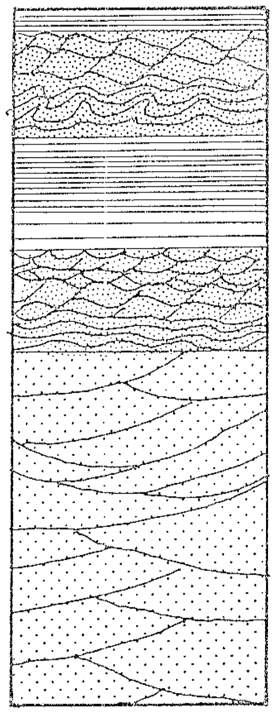


Figure 28- Idealized veritical sequence of a braid bar deposit (Reineck and Singh, 1975)

(1970, 1972, 1974), Blodgett (1974), Blodgett and Stanley (in press) and many other authors. The physical environment in which these studies have been conducted has varied from sub-artic glacial outwash plains with coarse pebble- and cobble-sized sediments and stream gradients up to 60 feet per mile to coastal plains with predominantly sand-size or smaller sediments and gradients of less than 1 foot per mile. Despite the wide range of stream morphologies, many common features can be selected which will allow characterization of ancient fluvial deposits as being braided.

Braided stream patterns result from a relationship between gradient, discharge and sediment load. In areas with a low stream gradient, a higher discharge and greater bed load are necessary for development of a braided stream pattern, while in higher gradient areas less discharge and sediment load is necessary to produce a braided pattern (Coleman, 1969; Smith, 1970). Discharge in braided streams can be highly variable over periods of a few days to several weeks, producing a wide range of sedimentary structures and depositing interbedded sand and silt which are confined to small areas and are not laterally continuous as would be point-bar deposits in meandering stream systems. In addition, muds are frequently deposited in cut-off stream anabranches and are later re-worked and deposited as clasts within a sandstone (Coleman, 1969; Smith, 1970; Blodgett, 1974).

Coleman (1969) and Smith (1970) in their studies of modern braided streams make many observations concerning the development of a braided stream pattern and the characteristic deposits of these streams. During his study of the braided Platte River, Smith (1970) identified two major forms of bars. These are longitudinal bars, whose long axis is oriented approximately parallel to the stream channel, and transverse bars, whose long axis is oriented approximately normal to the stream channel. Superimposed on the bars are abundant dunes and ripples. The braided pattern results from the dissection of transverse bars and accretion on the margins of the longitudinal bars (Smith, 1970). Coleman (1969) noted similar processes and deposits in the Brahmaputra River but of a larger scale due to the greater size of the river system.

Internal structures and surface features of the two primary types of bars vary and are dependent on stream energy, sediment size, and location within the system relative to the head of the stream. On the Platte River longitudinal bars made up of coarse pebble- and cobble-size sediments nearer the head of the stream have crude flat bedding which changes to trough shaped sets of cross-stratification downstream where sand-size, not pebble-size, sediments are more abundant. Transverse bars, which are more abundant downstream relative to longitudinal bars, have well developed tabular shaped sets of planar cross-stratification which can grade into trough shaped sets of cross-stratification on the upstream margin of the bar. Since the type of bar, and therefore the sedimentary structure, is dependent on the energy and sediment size of a stream, it should be possible to predict the variety of bar which contained the sedimentary structures preserved in ancient deposits, and to locate its position in an upstream-downstream sense relative to the total paleostream system. Bedding ratios are used by Smith (1970) and Travena (1977) to determine relative position in paleostream systems based on the relative abundance of certain bedding types and their probable location within the stream system. Smith's (1970) ratio (Fig. 29) uses an abundance of flat bedding (as related to coarse sediments deposited in longitudinal bars) as an indicator of a relatively more upstream location, and abundant planar bedding (tabular-shaped sets of planar cross-stratification) as an indicator

$$\frac{P}{P + H}$$

P = total thickness of planar (tabular-planar) cross-stratification.

H = total thickness of horizontally (flat) stratified units.

A (Smith, 1970)

$$\frac{H + P}{T}$$

H = total thickness of horizontally (flat) stratified units and structureless conglomerate units.

P = total thickness of tabular-planar cross-stratified unit.

T = total thickness of trough cross-stratified units.

B (Travena, 1977)

Figure 29. EQUATIONS FOR STRATIFICATION RATIOS

of a relatively more downstream location. Trough-shaped sets of cross-stratification maintain an approximately constant abundance throughout the stream. Travena (1977) found a similar relationship between types of cross-stratification and relative position in a paleostream system with the exception of an apparent increase in trough-shaped sets of cross-stratification in a downstream direction, a factor reflected in the equation used to arrive at his bedding ratio (Fig. 29b). Travena (1977) further states that streams with intermediate to meandering channel patterns frequently have preserved large quantities of medium- to large-scale tabular- and trough-shaped sets of cross-stratification. Petersen (personal communication, 1979) uses both Smith's (1970) and Travena's (1977) bedding ratios to determine relative upstream-downstream position in the Salt Wash Member on the Kaiparowits Plateau and in the Henry Basin. These ratios, in conjunction with other indicators such as paleo-transport directions, appear to be reliable indicators within that area. A simpler and apparently equally reliable indicator used by Petersen (personal communication, 1979) is the percentage of flat beds, with higher percentages indicating a location relatively upstream to lower percentages of flat beds.

Sedimentary structures are used to determine an approximate measure of stream energy and the range over which it varied. Harms and Fahnestock (1965) describe certain structures which are used as indicators of flow regime, and Blodgett (1974), describes associations of structures and grain size distribution which he feels are good indicators of flow energy and the variation which occurs in non-steady flow in natural systems.

Paleocurrent data is used to determine the direction of transport of sediment and as an indicator of the type of pattern a stream develops. Information from Potter and Pettijohn (1977) indicates that fluvial systems should have unimodal distributions and that on the average, variability of current readings will cover from 120° to 180° depending on the stream pattern. Braided streams normally show the least variability of current direction, usually 90° to 120°, while meandering streams will cover 180° or more. An infinite number of patterns and degrees of variation exist between the two end members. Evaluations by use of vector addition have the greatest consistency ratio for braided streams, the lowest for meandering streams. No precise ranges for consistency ratio values are known (Coleman, 1969; Potter and Pettijohn, 1977). Variations can be caused by local stream conditions and the type of structure from which a reading is taken, but for a fluvial system in general which is not confined the mean current direction at several localities over a limited area should be similar. In addition, if sufficient readings are available, the mean current direction should be approximately the same from all types of sedimentary structures with the greatest amount of variation being in measures of variability or consistency ratio.

DEPOSITIONAL ENVIRONMENTS

The Salt Wash Member is considered as two discrete lithofacies which, when combined and evaluated with known regional events, gives an overall picture of the depositional environment in the study area. The two lithofacies are the interchannel mudstones and siltstones, and the channel sandstones.

INTERCHANNEL SILTSTONES

The thick siltstones and covered intervals which occur between the major channel sandstones are interpreted as overbank deposits deposited on a flood plain during periods of greater-than-bank-full discharge. "Floodplain" as used here identifies the area immediately adjacent to the main flow-carrying channel which can be inudated and cut by small second-order distributary channels during periods of greater-than-bank-full discharge.

The second-order distributary channels are preserved as very thin beds and small lens-shaped sandstones which are intimately associated with the siltstones and are frequently gradational with the thicker, more extensive channel-scale sandstones. The sedimentary structures associated with the siltstone lithofacies are all indicators of lower flow regime (Harms and Fahnestock, 1965) to non-flow, and the increase in abundance of trace fossils in this lithology is not unusual since most of these organisms prefer less turbid environments. The rare mud-crack impressions noted indicate that occasionally the floodplains were dry for extended periods due to either low discharge or a shifting of the primary channel away from the area.

Related to the siltstone lithofacies, but the result of a different chemical sub-environment, are rare occurrences of gray/green carbonaceous mudstone. Primary deposition and reduction of the gray/green carbonaceous muds probably occurred in low areas adjacent to the stream at or below the low-flow stage where ponding can occur, but where subaerial exposure cannot occur. This would produce an area which is wet, out of the oxidized region and stable for periods of time sufficient for the reduction of muds, production of the carbonaceous material, and dependent on the chemistry, production of pyrite as described in sample MC7-1 (Appendix 6). Petersen (1974) has postulated that similar muds in the Salt Wash Member in the Henry Mountains region are produced in this sort of environment adjacent to the primary channels.

CHANNEL SANDSTONE

The channel sandstones are recognized by their size and sedimentary structures. They have a minimum thickness of 3 feet and contain abundant sets of cross-stratification. They make up the large multi-lateral and multistory sandstone cliffs which are the dominant feature in outcrop and are characteristic of deposits produced by a braided stream system. Figure 30 from Williams and Rust (1969) illustrates an ideally developed sandstone body of a braided stream which is quite similar to what can be observed in outcrops in Montezuma Canyon (Fig. 31). Both figures illustrate sandstones composed of abundant trough-shaped, channel-scale sandstone beds which form the thick multi-lateral and multistory sandstones.

Two scales of sedimentary structures are present in the channel sandstones; the large channel-scale cut and fill structures and the sedimentary structures which fill them in. The channel-scale cut and fill structures have relatively flat bases which frequently do not cut deeply into the underlying deposits. Much of the channeling or channel-like features which are present may be the result of deposition of two or more bars with

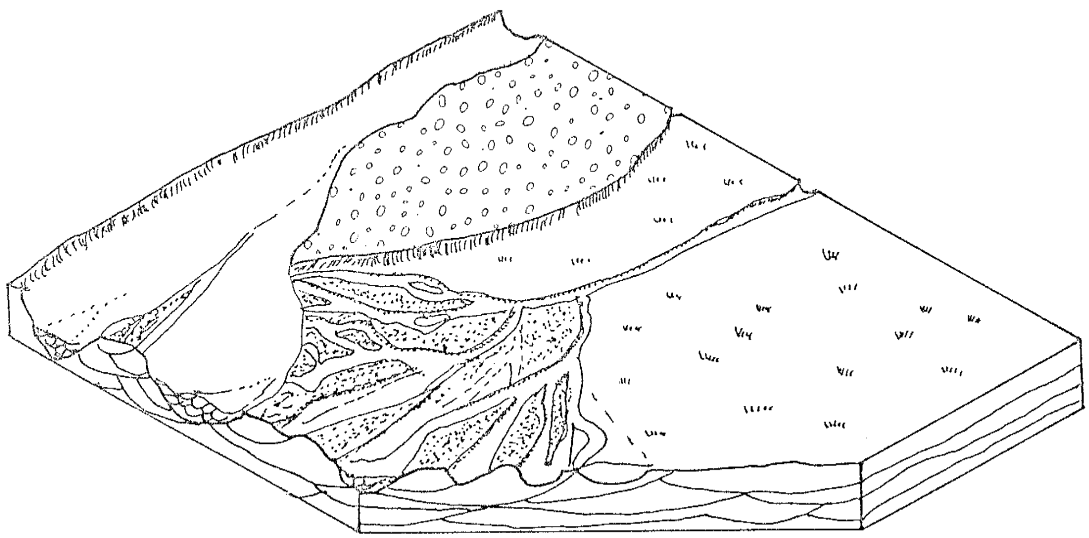


Figure 30- Idealized braided stream deposits
(Williams and Rust, 1969)

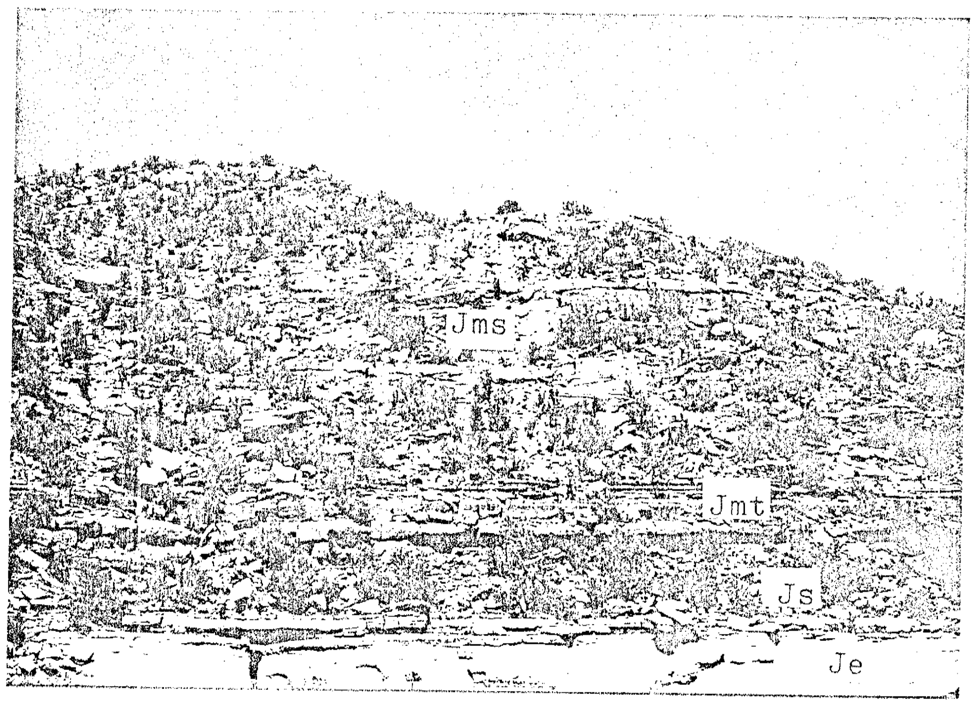


Figure 31- Outcrop of sandstone units in Montezuma Canyon, Salt Wash Member, which are multilateral and multistory sandstones similar in appearance to the of Figure 30.

the resultant trough between them acting as the channel. The trough then becomes a site of deposition for the abundant cross-stratified sand-size sediments, or, if the trough becomes cut-off from the main channel, the site of deposition of intrachannel siltstone and mudstone. If a channel does become cut-off and is re-entered at a later time, reworking of the intrachannel mudstones could occur resulting in abundant basal rip-ups and clay clasts similar to those described at the base of many of the channels.

Medium-scale, trough-shaped sets of cross-stratification are the most abundant type of structure in sediments filling the channel-scale cuts. The average flow regime (Harms and Fahnestock, 1965) identified by these structures is the lower flow regime, but, based on the variety of sedimentary structures and the abrupt, non-gradational nature of many of the contacts between sedimentary structures as illustrated by the Markov Analysis, it is apparent that flow varied a great deal about the average and that these variations were frequently very abrupt.

The average sediment load of the Salt Wash fluvial system is unknown, but based on the predominance of depositional rather than erosional features, the nature of lower contacts of cross-stratified sets, and the limited amount of intergranular clay and mud it is assumed to have been quite high. Lower contacts of the trough-shaped sets of cross-stratification are dominantly tangential and are used as an indication that abundant sediment was available and that avalanching down the lee face of dunes and other bedforms was the method by which much of the sand-size sediment was transported and deposited. The silt-size and finer sediments probably settled in cut-off channels to form the thin drapes at the base of some sets of cross-stratification, and on the flood plains.

The channel sandstones are the units from which a majority of the paleocurrent readings are taken. The mean paleocurrent direction and variability should be good indicators of channel trend on a local scale, and if extended should indicate regional trnasport directions. Locally the paleocurrent trends should be able to detect larger scale tectonic movements through changes in mean paleocurrent direction with increased stratigraphic height which are not otherwise detectable because of the small size of the study area. As noted previously, the mean current orientation does not change a significant amount with increased stratigraphic height, but consistency ratios and variability do change in a cyclic pattern. Inspection of the measured sections does not show any changes in dominant lithology to accompany these variations, so it is possible that regional tectonism may have caused the variations. During periods when tectonic activity was greatest and regional tilting along the Mogollon Highland (Kelley, 1958; Kelley and Clinton, 1960), the ancestral Monument Upwarp (Petersen, 1979), or other highlands, such as those to the west in Nevada (Albers and Steward, 1972), were proceeding most rapidly, the stream gradients were greatest and a less sinuous stream pattern resulted. With a lessening of tilt or other slow-down in tectonic activity, a decrease in stream gradient would occur and the stream could become more sinuous. The very slight change in mean paleocurrent direction to the north in association with the less sinuous stream pattern may be a response to the direction of tilting during increased tectonic activity, while the slight change back to the south in association with more sinuous intervals may be a regional response to the lower stream gradients or a local variation due to the greater range in current directions of the more sinuous stream pattern. In other words, the current direction associated with the less sinuous intervals is more nearly a direct response to a regional tectonic slope, while the current direction associated with the more sinuous intervals does not respond to a regional tectonic slope as closely and may simply reflect local variations in stream pattern. If this is true, the regional tectonics of the area were consistent, with very little change in orientation during deposition of the Salt Wash Member. It also indicates that smaller local structures either were not active or were incapable of producing a detectable change in paleocurrent orientation.

An alternative explanation for the variations in consistency ratios is arrived at by inspecting the lithologies which enclose the Salt Wash Member. Both the Tidwell member and the Brushy Basin Member are lower-energy deposits relative to the Salt Wash Member. If these enclosing lower-energy deposits can be assumed to have been deposited in areas with relatively low average gradients, then their close association with the most sinuous of the fluvial deposits of the Salt Wash Member, which I believe were also deposited in low-gradient areas, is indicative of a regional change to a greater stream gradient during deposition of the Salt Wash Member. The interval of more sinuous deposits at 240 feet above the base of the Salt Wash Member (Fig. 15) may be the result of a local or regional decrease in slope which was relatively short lived.

Both these concepts of regional tectonism are inadequately supported by the data collected in the study area, but recent work by Petersen (1974, 1979) indicates that structures which had previously been assumed to have been inactive may have played a very subtle role in controlling deposition of the Salt Wash Member in the Henry Mountains. The possibility therefore exists that the Monument Upwarp may have caused a local steepening of the gradient as the fluvial system crested the upwarp and continued its eastward flow. The salt structures to the northeast of the study area may also have influenced deposition on a regional scale, but this cannot be detected with certainty within the study area because of its limited size.

Determination of the relative upstream/downstream location of the study area can only be approximated based on the abundance of trough cross-stratification and lack of lat bedding. The ratios of Smith (1970) and Travena (1977) cannot be used because of the small size of the area under consideration in relation to the Salt Wash Member as a whole. A very general location would be in the distal portion of the system based in part on the relative abundance of trough cross-stratification versus flat stratification and Travena's (1977) ratio (Fig. 29b), from the size and degree of sorting of the sediments in the sandstone, and based on the distance from the probable source areas to the west.

CONCLUSIONS

The depositional environment of the Salt Wash Member as interpreted from the observed characteristics and from data compiled from the literature is a braided to intermediate fluvial system. It is not, in my opinion, a strictly braided deposit as papers by Craig (1955), Huff and Lesure (1965), Cater (1970), and other authors indicate, but rather a medial to distal, moderately sinuous, aggrading, flashy stream system composed of two or more anstomosing channels separated by longitudinal bars. The deposits are similar to the south Saskatchewan facies assemblage of Miall (1978) and Cant (1978): sandy, braided, aggradational river deposits of a distal facies which are transitional between braided and meandering streams. No regular order of sedimentary structures is known in this facies.

Individual channel systems of the Salt Wash fluvial system were rarely more than approximately 1 mile in width, and 10-30 feet in depth. The flood plain adjacent to the channels was the site of deposition of overbank sandy siltstones and mudstones and was cut by numerous small distributary channels. During periods of low discharge the flood plains were subaerially exposed except for small areas where ponding and locally reducing environments occurred in depressions adjacent to the main channels.

During deposition of the sediments there was concurrent uplift and erosion of highlands to the west and southwest and in addition, possible felsic volcanism. The stream system carried the sediments derived from these sources eastward over a relatively flat, low-gradient plain. A very slight positive area may have retained the material coarser than sand-size west of Monument Upwarp and created a slightly greater stream gradient to the east and into the area of Montezuma Canyon. The surface upon which the sediment was deposited had little, if any, topographic relief and maintained a consistent orientation throughout the time interval during which the Salt Wash Member was deposited, although some cyclic movement of the surface with resulting variations in gradient may have occurred.

SUGGESTIONS FOR FUTURE WORK

Additional evaluations similar to this study should be carried out on a regional basis to further define the depositional environment of the Salt Wash Member. The following items are of particular interest:

1. Evaluation of subtle structural controls on deposition as caused by salt tectonics and the large upwarp features.
2. Evaluation of major paleochannel trends to define a primary, regional channel system, if one is present.
3. Subdivision of the Salt Wash Member into lithologic and environmental facies as done by Petersen (1974, 1979) to see if similar subdivisions can be done in areas outside the Henry Mountains.
4. Continue investigations into the extent and characteristics of the Tidwell member.

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APPENDIX 1

DESCRIPTION OF NOMENCLATURE USED IN IDENTIFICATION OF SANDSTONE AND SEDIMENTARY STRUCTURES AND DESCRIPTION OF MEASURED STRATIGRAPHIC SECTIONS

NOMENCLATURE USED FOR THE FIELD CLASSIFICATION OF SANDSTONES AND SEDIMENTARY STRUCTURES

SANDSTONE

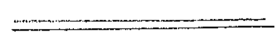
Grain size - determined from the Udden-Wentworth (1922) size classification.

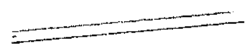
Sorting - determined visually from the sorting images of Folk (1968).

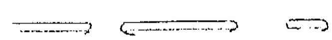
STRATIFICATION

Thickness - terminology and thickness of strata from McKee and Weir (1953)

Bed Shapes -

Flat, continuous 

Inclined 

Discontinuous 

Undulatory, regular 

Undulatory, irregular 

CROSS-STRATIFICATION

Terms describing set, set shape, dip of cross-strata, and scale are from McKee and Weir (1953).

Terminology describing ripple cross-lamination and ripple patterns and types is from Allen (1968).

MEASURED SECTIONS

The following descriptions are taken from the field notes made during the measurement of the stratigraphic sections. Included are the units measured, lithologies, sedimentary structure and unit and cumulative footages. The paleocurrent data follows the measured section descriptions and is listed in tabular form.

MC1 N/S ½ Sec. line of sections 35, T34S, R24E, and Sec. 2, T35S, R24E.

	Unit Feet	Cum. Feet
I. Summerville Formation		
1. Contact, Summerville Fm. with Entrada Sandstone -- at contact the Entrada is fine-grained, well sorted quartzose sandstone conformably overlain by red siltstone of the Summerville Formation -- contact poorly exposed, most of unit is covered.	38.0	38.0
II. Tidwell Member, Morrison Formation, Contact Erosional		
2. Fine-grained, subangular, moderately sorted red/gray sandstone -- composition 99+% quartz, trace fine-grained red chert, magnetite.		
a. structureless to very slightly undulatory bedding;	3.0	
b. undulatory bedding;	3.0	
c. small-scale, wedge planar to trough cross-stratification, average set thickness 5 in. to 1 ft.;	6.0	
d. ripple laminations (?)	1.5	
e. covered slope; probably thinly bedded to laminated siltstone and sandstone;	5.0	
f. ripple laminated sandstone	1.5	58.0
3. Covered slope; probably thinly bedded to laminated interbedded red siltstone and sandstone.	9.0	67.0
4. Sandstone, fine-grained, moderately sorted, well indurated, red/gray, calcareous -- bed thickness 1-3 inches.		
a. ripple laminated, ripples, symetrical, straight to sinuous crested.	5.5	72.5
5. Covered slope; probably interbedded red siltstone, thinly bedded sandstone.	10.0	82.5
III. Salt Wash Member, Morrison Formatio -- Contact erosional		
6. Sandstone, very fine-grained, subangular to subrounded, moderate sorting, well indurated. Composition is of 99+% quartz, trace accessory minerals; chert, magnetite.		
a. small-scale troughs, grade upward into ripple laminations;	3.0	

		Unit Feet	Cum. Feet
b.	thinly laminated siltstone and very fine sandstone;	0.75	
c.	small-scale trough cross-stratification, grading upward into small-scale wedge planar cross-stratification;	2.5	
d.	basal scour with clay galls overlain by irregular interlaminated red siltstone and sandstone in thin beds;	0.5	
e.	basal scour with red mud and clay clasts -- wedge planar cross-stratification, small-to medium-scale -- sandstone slightly coarser than unit 6c;	4.75	
f.	flat bedded to very low-angle tabular planar -- tabular planar beds pinch out laterally over varying distances;	8.75	
g.	sandstone contains 2% orange/yellow chert up to 1% magnetite -- thin-bedded green/gray sandstone and red siltstone;	1.5	
h.	sandstone contains 5% feldspar (orthoclase?) and 3% orange chert -- structures glat, thin bedding;	4.0	
i.	small-scale trough cross-bedding with clay galls and scour base -- burrows at 3.0 ft.;	4.0	
j.	large basal scour, approximately 4 ft.-- deep into underlying sandstone -- medium to large-scale trough cross-bedding -- very little interbedded siltstone.	19.0	131.25
7.	Covered slope; local outcrops of green siltstones and mudstones.	12.0	143.25
8.	Sandstone, fine-grained, subangular, poorly sorted, green/white -- composition is 99+% quartz, trace green and orange chert, trace magnetite -- local clay galls and acicular carbonaceous trash.		
a.	small-scale trough cross-bedding overlying larger scale trough and low angle planar cross-bedding	10.0	153.25
9.	Covered slope; probably interbedded siltstone and sandstone.	12.0	165.25
10.	Sandstone, medium-grained, subangular, very poorly sorted, light brown/green -- basal section has coarse-grained lags of green, red, and orange chert oriented roughly		

	Unit Feet	Cum. Feet
parallel to bedding plane -- basal section contains carbonaceous particles as previously described -- composition 3% feldspar, trace to 3% chert, 95+% quartz.		
a. trough cross-bedding, small-scale, many basal scours;	21.0	
b. flat, thin-bedded;	4.0	
c. trough cross-bedding, small-scale.	13.0	203.25
11. Covered slope; probably interbedded siltstone and sandstone.	8.0	211.25
12. Sandstone, fine- to medium-grained, subangular, poorly sorted -- composition 5-6% feldspar, 1-2% chert, 90% quartz -- gray/green in color.		
a. trough cross-stratification, small-scale.	3.5	214.75
13. Interbedded siltstone and thin-bedded, sandstone -- fine-grained, subrounded, poorly sorted -- composition 2% chert, trace magnetite, local, random clay clasts, 95+% quartz.		
a. thin-bedded to ripple laminated.	2.5	217.25
14. Covered slope; local outcrops of flat, thin-bedded, fine-grained sandstone with thin-interbedded siltstones.	36.0	253.25
15. Sandstone, fine-grained, subrounded, poorly sorted -- composition 1-2% red and orange chert, 3-4% feldspar, trace magnetite, 25% quartz -- local pockets of coarse-grained to granule size lag, mainly chert fragments.		
a. flat bedded to low-angle wedge planar cross-bedding -- local small-scale trough cross-beds with clay galls and lag deposits in base.	21.0	274.25
16. Covered slope, float is a silty gray mudstone.	29.0	303.25
17. Sandstone, fine-grained, moderately sorted -- composition 99+% quartz, local clay clasts and traces of chert.		

		Unit Feet	Cum. Feet
	a. ripple laminated (?) over basal scour;	1.5	
	b. trough cross-stratification, small-scale with local lags of coarse-grained chert and interbedded silts;	8.0	
	c. flat thin-bedded.	1.5	314.25
18.	Covered slope, local outcrops of thin-bedded ripple laminated sandstone and siltstone.	37.0	351.25
19.	Sandstone, fine-grained, subangular, moderately sorting -- composition 2% feldspar, 2-3% chert, 95% quartz.	2.0	353.25
20.	Covered slope, local thin beds of siltstone and fine-grained sandstone.	20.0	373.25
21.	Sandstone, fine-grained, subangular, poorly sorted, yellow -- composition 4-5% feldspar, 2-3% red/orange chert, 92% quartz.		
	a. flat, thin-bedded;	2.0	
	b. ripple laminated, thickly laminated;	2.5	
	c. covered, probably similar to 21a and 21b;	5.0	
	d. scour, with clay gals up to 1 in. in diameter and numerous rip-up structures filled by coarse-grained sandstone;	1.5	
	e. trough cross-stratification, small- to medium-scale -- basal scour with sparse chert pebbles up to ¼ in. diameter;	22.0	
	f. trough to wedge planar cross-stratification, small- to medium-scale;	7.0	
	g. flat bedded to wedge planar cross-stratification, small- to medium-scale	10.0	423.25
IV.	Conformable Contact Probably Base of Brushy Basin Member, Morrison Formation		
22.	Covered slope.	30.0	453.25
23.	Sandstone, fine-grained, subangular, poorly sorted, gray -- composition is 3-4% red, green chert, 1% magnetite, 95% quartz -- structures poorly defined -- this sandstone outcrop is more of a slope former than a distinct cliff.	14.0	467.25
24.	Covered slope.	44.0	511.25

		Unit Feet	Cum. Feet
25.	Sandstone, similar to that in unit 23.		
	a. small-scale trough cross-beds.	4.0	515.25

Total thickness:	Section MC1	515.25
	Summerville Fm.	38.0
	Tidwell Member	44.5
	Salt Wash Member	340.75

MC2 N½, S½, NE¼, Sec. 11, T35S, R24E.

Section starts just south of a fault which has displaced the units to the south approximately 50 feet, but with little disturbance of the units otherwise.

	Unit feet	Cum. feet
I. Summerville Formation		
1. Entrada/Summerville contact covered or poorly exposed, but appears to be similar to that described in section MC1.		
a. covered slope	35.0	35.0
II. Tidwell member, Morrison Formation, contact erosional		
2. Sandstone, fine-grained, subangular, moderate to poor sorting -- composition, trace chert, 3% magnetite, or other dark minerals, 95+% quartz -- lowest exposure of this outcrop is a red siltstone of unknown thickness -- color of sandstone is gray to white.		
a. structureless, except some probable soft sediment deformation, very silty sandstone which weathers to a rounded "BB shot" surface;	9.0	
b. undulatory flat, thinly bedded sandstone	7.0	51.0
3. Poorly exposed except for one section of sandstone, very fine-grained, poorly sorted, red with 1% orange to red chert, and 1% magnetite, 95+% quartz.		
a. poorly exposed, but appears to have thinly bedded, ripple (?) laminated siltstone;	16.0	
b. interbedded silt and sand, flat to ripple laminated, thickly bedded	6.0	73.0
4. Covered slope, probably similar to #3	10.0	83.0
III. Salt Wash Member, Morrison Formation, contact Erosional		
5. Sandstone, fine-grained, subrounded to subangular, poorly sorted -- composition 3-4% red to orange chert, 2% black opqaue (magnetite), 95% quartz -- this starts the channeled sands and scoured basal intervals.		
a. lateral gradation over 25 feet from rippled to small scale trough cross-stratification to flat bedded sandstones;	2.0	
b. ripple laminated;	6.0	
c. scour with red siltstone in base;	2.3	
d. tabular planar to wedge planar cross-stratification, small-scale;	5.0	

		Unit Feet	Cum. Feet
	e. thin-laminated sandstone with red mud clasts along laminations;	2.0	
	f. trough cross-stratification, small-scale over scour bases in channel deposits that are approximately 3 feet thick;	12.0	
	g. ripple laminated;	2.0	
	h. variable structures from small-scale troughs to small- to medium-scale wedge planar cross-stratification.	11.0	125.3
6.	Covered slope.	11.0	136.3
7.	Sandstone, fine-grained, subangular, poorly sorted, brown -- composition 99+% quartz, trace chert and magnetite.		
	a. small-scale trough to wedge planar cross-stratification.	14.0	150.3
8.	Covered slope.	18.0	168.3
9.	Sandstone, fine-grained, subangular, poorly sorted, brown -- trace chert and magnetite, 99+% quartz -- channel deposit approximately 50 feet wide, 12-15 feet deep at thickest section -- base of channel deposit is scoured, contains clay galls and rip-ups.		
	a. medium-scale trough cross-stratification.	25.0	193.3
10.	Very poorly exposed, local outcrops of very fine-grained sandstone, moderately sorted, green/gray in color -- 1% each of chert and magnetite, 98+% quartz.		
	a. covered;	6.0	
	b. thin-bedded flat to ripple laminated;	4.0	
	c. covered;	20.0	
	d. ripple laminated;	2.5	
	e. covered.	10.0	235.8
11.	Sandstone, medium-grained, subrounded, moderate sorting, green/white in color -- composition is 1% red chert, 2% magnetite, 97+% quartz -- also contains interbedded gray mudstone with carbonaceous material in layers up to 4 in. thick.		

		Unit Feet	Cum. Feet
	a. flat to small-scale very low angle wedge planar thin-bedded cross-stratification;	10.0	
	b. low angle, small-scale, trough cross-stratification.	6.0	251.8
12.	Covered slope.	19.0	270.8
13.	Sandstone, similar to unit 11, very slight increase in chert -- very steep faced cliff with numerous channel deposits -- channeled areas are deeply scoured with numerous rip-ups and clay clasts.		
	a. Horizontal, thickly bedded changing to medium-scale trough cross-stratification	23.5	294.3
14.	Covered	44.0	
15.	Sandstone, fine-grained, subangualr, poorly sorted -- composition, 99+% quartz, trace of chert and magnetite, possible weathered tuffaceous fragments or feldspars		
	a. trough cross-stratification, small-scale;	6.0	
	b. structureless, silty green sandstone;	1.5	
	c. wedge planar cross-stratification, small-scale;	38.0	
	d. same structures as c, but burrowed;	3.0	
	e. trough cross-stratificatio-, small-scale;	5.0	
	f. horizontal to low angle wedge planar, small-to medium-scale	8.0	399.8
IV.	Brushy Basin Member, Morrison Formation, contact Conformable		
16.	Poorly exposed, local outcrops of sandstone -- beginning of a long slope leading to the next outcrop of probable Brushy Basin Member.		
	a. covered;	11.0	
	b. small ledge, no apparent structure;	1.0	
	c. covered	21.0	432.8
17.	Covered slope, float is blue/green siltstone and mudstone	17.0	449.8

Total Thickness:		
	Section MC2	449.8
	Summerville Formation	35.0
	Tidwell Member	48.0
	Salt Wash Member	366.8

MC3 N/S ½ line of Sec. 14, T35S, R24E

	Unit feet	Cum. feet
I. Summerville Formation		
1. Entrada/Summerville contact, similar to that described in previous sections		
a. covered slope, local outcrops of sandstone, fine-grained, subrounded, moderate sorting, pink/white -- composition 99+% quartz, trace red chert and magnetite. Sandstone structureless	34.0	34.0
II. Tidwell Member, Morrison Formation, contact Erosional		
2. Sandstone, fine-grained, angular, poorly sorted, red in color -- composition 99+% quartz, trace chert, feldspar, and magnetite -- large fraction of fine clay sizes		
a. structureless to faintly flat;	7.0	
b. small-scale trough cross-stratification;	2.0	
c. flat to undulatory thin-bedded;	6.0	
d. rippled, thinly laminated	2.0	51.0
3. Covered slope, float of red siltstone and very fine-grained sandstone	12.0	63.0
4. Sandstone, very fine-grained, subrounded, poorly sorted, pale red -- composition, 1% orange chert, trace magnetite, 98+% quartz		
a. rippled, thinly bedded	2.0	65.0
5. Covered slope, sparse exposures of red siltstone and mudstone	25.0	90.0
III. Salt Wash Member, Morrison Formation, Erosional Contact		
6. Sandstone, fine-grained, subangular, poorly sorted, pale brown -- composition is 99+% quartz, trace of red and orange chert, magnetite or other opaque minerals		
a. flat thin-bedded;	5.5	
b. small-scale wedge planar cross-stratification;	3.0	

	Unit feet	Cum. feet
c. small-scale tabular planar cross-stratification;	1.5	
d. burrowed, thinly bedded flat bedded;	2.5	
e. trough cross-stratification, medium-scale, with scour bases, locally burrowed;	2.5	
f. medium-scale trough cross-stratification	17.5	122.5
7. Covered slope	19.0	141.5
8. Sandstone, similar to unit 6, above.		
a. wedge planar, medium-scale, very low angle cross-stratification;	5.6	
b. interbedded red siltstone and mudstone, lensoid bodies with red clay clasts;	2.0	
c. trough cross-stratification, medium-scale -- chert 1-2%;	10.5	
d. deep scour surface with red clay clasts, overlain by medium-scale trough cross-stratification.	26.0	185.6
Note: outcrops within this area are all discontinuous with abrupt zones within which they thicken and thin or split into several thinner ledges.		
9. Covered slope, minor exposures of red and green siltstone and mudstone.	53.0	238.6
10. Sandstone, fine-grained, poorly sorted, gray/white -- composition, 4% chert, 95% quartz, local clay clasts.		
a. wedge planar, medium-scale cross-stratification;	5.0	
b. trough cross-stratification, medium-scale set size decreases upward.	5.5	249.1
11. Covered slope.	29.0	278.1
12. Sandstone, fine-grained, subangular, poorly sorted, light brown/white -- composition, 4% orange chert, 4-5% black, opaque material as thin laminations, 90% quartz.		
a. wedge planar, medium-scale cross-stratification with very thin interbeds of green/white very fine sand;	15.5	

	Unit feet	Cum. feet
b. wedge planar cross-stratification, medium-scale, grading laterally into ripple laminated sands;	7.0	
c. medium bedded sandstone lenses with thin interbedded gray mudstones -- mudstones occur as continuous layers and as clasts;	2.0	
d. trough cross-stratification, medium- to large-scale with scour bases and mud clasts;	13.0	
e. flat to low angle trough cross-stratification, medium-scale;	20.0	
f. flat, thinly bedded;	4.0	
g. trough cross-stratification, low angle, large-scale;	13.0	
h. trough and wedge planar cross-stratification, medium- to large scale;	6.0	
i. trough cross-stratification, medium-scale -- numerous lag deposits of pebble and granule size orange and red chert;	6.0	
j. trough cross-stratification, small- to medium-scale;	18.0	
k. interlaminated very fine sandstone and gray mudstone;	1.0	
l. trough cross-stratification, low angle, medium-scale -- trace chert, 99+% quartz - scour bases with red siltstone;	22.0	
m. trough cross-stratification, large-scale, low angle to flat -- scour bases with red siltstone and mudstone.	23.0	428.6

IV. Brushy Basin Member, Morrison Formation, Contact Conformable

13. Poorly exposed, probable start of the Brushy Basin Member -- long slope leads up to the next significant outcrop -- exposures are blue/green siltstones and sandstones -- lag and coarse fraction also make a radical increase within the next units -- composition, 5-6% red, oragne, gray chert, coarse-grained, poorly sorted.	66.0	494.6

Total Thickness:		
	Section MC3	494.6
	Summerville Fm.	34.0
	Tidwell Member	56.0
	Salt Wash Member	404.6

MC4 E½, SE¼, Sec. 35, T35S, R24E	Unit feet	Cum. feet
I. Summerville Formation		
1. Entrada/Summerville contact, similar to that in previous sections -- Summerville Fm. is interbedded red siltstone and fine-grained sandstone -- sandstone is moderately sorted, contains 1-3% orange chert.		
a. poorly exposed, local thin sandstone ledges;	33.0	
b. undulatory bedding with thin inter-bedded silts;	4.0	
c. "knobby" weathering red siltstone. Structureless;	3.0	40.0
II. Tidwell Member, Morrison Formation, contact erosional		
2. Interbedded red siltstone and thin-bedded fine-grained sandstone -- poor exposures in some locations.		
a. Structureless sandstone	27.0	
b. ripple laminated and structureless sand-stones;	18.5	
c. covered or poorly exposed	26.0	111.5
III. Salt Wash Member, Morrison Formation - Erosional Contact		
3. Channel sands, cross-stratified -- sandstone fine-grained, subangular, poorly sorted, pink in color -- composition 2% magnetite or other black opaque mineral, trace chert, 95+% quartz -- local interbeds of red siltstone in the sandstone.		
a. ripple laminated siltstone;	2.0	
b. trough cross-stratification, small-scale;	1.5	
c. tabular planar to very low angle planar cross-stratification, medium-scale;	1.0	
d. flat cross-stratification similar to b, but not as highly truncated;	6.0	
e. poor exposure of thin-bedded and ripple laminated sandstone;	6.0	
f. trough cross-stratification, but basal section is poorly defined -- small- to medium-scale structures -- this unit grades upward into tabular planar and wedge planar sets of about the same size scale;	9.5	

		Unit feet	Cum. feet
	g. small scour base overlain by ripple laminated very fine sandstone -- scour area is filled by red siltstone	12.5	150.0
4.	Covered slope with a few sparse exposures		
	a. covered;	16.0	
	b. strucutureless, "BB shot" weathering;	4.0	
	c. covered	33.0	203.0
5.	Sandstone, fine-grained, subangular, moderate sorting -- 3% orange chert, 3-4% black opaque mineral.		
	a. wedge planar cross-stratification to flat bedded, medium- to large scale -- some scour bases with mud clasts which contain small gray accicular carbonaceous flecks -- muds are gray/green. Channel systems are 3-4 feet thick, extend laterally 30-50 feet -- general outline of the channels is symmetrical;	11.5	
	b. trough cross-stratification with basal scours and rip-ups containing red muds. small to medium scale;	5.0	
	c. wedge planar to flat, thinly bedded;	10.0	
	d. planar tabular grading upward into small-scale trough cross-stratification;	6.5	
	e. covered;	5.0	
	f. rippled, thinly laminated.	2.0	243.0

Note: all sandstones in this unit are extremely friable, have calcareous cement.

		Unit feet	Cum. feet
6.	Covered, with some exposures of sandstone -- sandstone is fine- to medium-grained, subangular, moderately sorted, has limonite stains and is composed predominantly of quartz.		
	a. flat, thickly laminated;	2.5	
	b. small-scale trough cross-stratification;	2.5	
	c. rippled, thinly bedded with short covered intervals.	10.5	258.5
7.	Sandstone, base covered -- sandstone fine-grained, subangular, moderately sorted, has numerous limonite spots, is composed almost entirely of quartz.		

	Unit feet	Cum. feet
Note: In the area of this unit was an old Uranium prospect which exposed the rock quite well. In the exposures was a conglomeratic material with a large quantity of gray/green mud clasts. Also in this area were some chalky limestone nodumes which were within the lags. The stratification is extremely irregular, basically as though it was part of one quite large scour.		
a. flat, thin-bedded;	5.0	
b. small-scale trough cross-stratification;	5.0	
c. low angle, to flat cross-stratification, small-to medium-scale;	12.0	
d. covered.	23.0	303.5
8. Sandstone and short covered intervals -- sandstone is fine to very fine-grained, subangular, moderately sorted, contains 3-4% orange chert, 506% black opaque minerals, 90% quartz.		
a. rippled, thickly laminated, middle section is burrowed;	8.0	
b. covered;	11.0	
c. interbedded gray/green siltstone and fine gray/green sandstone	5.0	327.5
9. Sandstone, fine-grained, subangular, moderately sorted, green in color -- composition is 99+% quartz -- also contains clay clasts, rip-ups, and a conglomerate lag		
a. trough cross-stratification, medium-scale;	5.0	
b. flat to low angle planar cross-stratification, thin to thick beds;	7.0	
c. wedge planar cross-stratification, medium-scale;	2.0	
d. trough cross-stratification, small-scale;	10.5	
e. wedge planar cross-stratification, medium-scale	13.0	365.0

IV. Probably Base of the Brushy Basins Member, Morrison Formation -- Change in Character of Deposits, but Contact Appears Conformable

Measurement ended at the top of the hill on a long slope leading up to a distant outcrop of the Dakota Sandstone -- Brushy Basin Member/Salt Wash contact not definitely located.

		Unit feet	Cum. feet
Total Thickness:	Section MC4		365.0
	Summerville Formation		40.0
	Tidwell Member		71.5
	Salt Wash Member		253.5

		Unit feet	Cum. feet
MC5	SW¼, Sec. 12, T35S, R24E		
I.	Summerville Formation -- Conformable Contact with Entrada Sandstone		
	1. Contact similar to that in previous sections -- covered or poorly exposed unit, exposures are of red siltstone and very fine-grained red sandstone -- structures poorly defined or structureless.		
II.	Tidwell Member, Morrison Formation, contact erosional	33.0	33.0
	2. Sandstone, very fine-grained, poorly sorted, light red -- 95% quartz, 3-4% magnetite or other black opaque mineral.		
	a. structureless to very poorly defined flat, thin bedding;	6.5	
	b. red siltstone, structureless;	1.0	
	c. flat, crude bedding;	7.5	
	d. red siltstone;	1.5	
	e. crude flat bedding;	8.0	
	f. red siltstone	1.0	58.5
	3. Sandstone, very fine-grained, similar to unit 2.		
	a. thinly bedded, splits along bedding planes	19.0	77.5
	4. Covered -- local exposures of siltstone and sandstone -- very fine-grained, red, 2-3% orange chert in sandstone -- exposures show local ripple laminations.	23.0	100.5
III.	Salt Wash Member, Morrison Formation -- Contact Unconformable		
	5. Sandstone, fine-grained, subangular, poorly sorted, pale red -- composition is 2-3% red and orange chert, 1% magnetite or other black opaque mineral, 95% quartz -- this is the lowest occurrence of well defined bedding structures.		
	a. flat, thickly laminated;	2.5	
	b. brown/red siltstone;	5.0	
	c. flat, thickly laminated, contains vertical burrows -- color is green/gray;	3.5	

	Unit feet	Cum. feet
d. small-scale trough cross-stratification with a few vertical burrows	2.5	114.0
6. Interbedded siltstone and sandstone -- sandstone is very fine-grained, subrounded, poorly sorted pale red -- contains 4-5% orange chert, and 95% quartz.		
a. red siltstone with small lenses of green, fine-grained sandstone;	1.5	
b. ripple laminated or thin laminations of sandstone;	2.0	
c. covered, float consists mainly of red siltstone with minor amounts of fine-grained sandstone.	8.0	125.5
7. Sandstone, fine-grained, moderate sorting, subrounded, white -- 98+% quartz, trace chert and black opaque minerals -- lowest well defined channel deposits with scour bases.		
a. small-scale wedge planar cross-stratification;	1.5	
b. small-scale trough cross-stratification, underlain by scours;	1.5	
c. thin-bedded, local burrows;	1.5	
d. small-scale trough cross-stratification, clay clasts at base and scattered throughout;	0.5	
e. scour base, filled with red siltstone;	1.0	
f. poorly defined ripple laminations, increase in chert to 2%;	4.5	
g. interbedded red siltstone and very fine-grained sandstone as lensoid bodies;	4.0	
h. medium-scale trough cross-stratification. underlain by scours which contain clay clasts and small rip-up structures;	5.0	
i. trough shaped sets, with internal ripple laminations, thinly laminated;	4.5	
j. interbedded red siltstone and sandstone lenses. Sandstone lenses are 0.5 to 1.5 feet thick. Some of the sandstones are ripple laminated.	7.0	156.5
8. Sandstone, fine-grained, subangular, moderately sorted, gray/green to white -- 2% orange chert, trace black opaque mineral.		

	Unit feet	Cum. feet
a. scour base, filled by rippled thinly laminated sands, clay clasts toward top;	5.5	
b. red siltstone, structureless;	2.0	
c. trough cross-stratification, medium-scale;	3.0	
d. flat, very thinly bedded;	2.0	
e. tabular planar, medium-scale grading upqard into rippled, thinly laminated sandstone;	6.0	
f. flat, very thinly bedded;	3.5	
g. rippled, thinly laminated.	1.5	180.0
9. Covered slope with thin intervals of exposed sandstone -- sandstone is similar in composition to that in unit 8.		
a. covered;	14.0	
b. rippled, thinly laminated beds. Individual beds are up to 8 inches thick. Underlain by a red siltstone;	2.0	
c. covered;	6.0	
d. interbedded sandstone and red siltstone -- rippled, thinly laminated with local areas which are burrowed -- siltstone predominates.	13.0	215.0
10. Sandstone, fine-grained, subangular, poorly sorted, pale green/white -- composition is 3% orange chert, trace magnetite or other black opaque mineral, 95% quartz.		
a. trough shaped boundaries filled in with thinly ripple laminated sandstone. Scour bases contain numerous red and green clay clasts, with green clasts becoming more abundant upward. The upper one-half of this sub-unit is wedge planar, small-scale, cross-stratification;	7.6	
b. trough cross-stratification, small-scale, in what appears to be a series of overlapping scours and channels. Upper 5 inches of this sub-unit consists of red and green mudstone lying conformably over the cross-stratified sandstone;	5.5	
c. trough cross-stratification, low angle, medium scale grading upward into wedge planar, also medium-scale;	8.6	
d. rippled, thinly laminated interlaminated very fine sandstone and siltstone, both red in color;	3.0	

		Unit feet	Cum. feet
e.	trough cross-stratified, small-scale, sandstone -- sandstone is spotted with limonite, gray in color;	3.0	
f.	wedge shaped sets of rippled, thinly laminated sandstone.	9.0	251.7
11.	Covered or poorly exposed.		
a.	covered;	12.0	
b.	interbedded silty sandstone and red siltstone, medium bedded -- siltstone layers contain burrows and carbonized plant fragments;	14.0	
c.	covered.	34.0	311.7
12.	Sandstone, fine-grained, subangular, moderate sorting -- composition is 99+% quartz, trace chert -- base covered.		
a.	low angle tabular planar to flat, medium bedded;	8.5	
b.	bedding similar to sub-unit a, but there is a distinct scour base and large quantities of carbonaceous trash and dark gray mudclasts;	4.6	
c.	trough cross-stratification, medium-scale;	4.0	
d.	tabular planar cross-stratification, small-scale;	2.0	
e.	flat to tabular planar cross-stratification, small- to medium-scale;	7.0	
f.	trough cross stratification, medium-scale, underlain by scour surfaces and clay clasts.	23.0	360.8
IV.	Brushy Basin Member, Morrison Formation, Change in Color and Character of Sandstone		
13.	Covered, float suggests red and blue shales and siltstones.	23.0	383.8
14.	Sandstone, very fine-grained, moderate sorting pale gray/green in color -- composition is 1% black opaque minerals, trace chert, 98% quartz.		
a.	bedding indistinct;	2.0	
b.	wedge planar cross-stratification, medium-scale. Scour bases with green sandstone and gray mud clasts, carbonaceous trash--		

	Unit feet	Cum. feet
c. flat, thinly bedded;	9.0	
d. wedge planar cross-stratification, small-scale;	25.0	
e. flat, thinly bedded	10.0	436.8

Note: The base of the Brushy Basin Member at this point is not certain, it may be at the base of unit 14, or it may occur at some point within unit 14.

Total Thickness:	Section MC5	436.8
	Summerville Formation	33.0
	Tidwell Member	67.5
	Salt Wash Member	336.3

	Unit feet	Cum. feet
MC6 Middle 1/3 of $W\frac{1}{2}$ of Sec. 13, T36S, R24E		
I. Summerville Formation		
1. Entrada/Summerville contact, similar to that described in previous sections -- Summerville Fm. is poorly exposed or covered, float is red siltstone and very fine sandstone.		
a. covered;	31.0	31.0
b. indistinct, undulatory bedding;	5.0	
c. covered;	3.0	
d. sandstone, structureless;	6.0	
e. covered;	5.5	
II. Tidwell Member, Morrison Formtion, contact erosional.		
2. Sandstone, fine-grained, poorly sorted, trace red/orange chert, red in color.		
a. sandstone, more shaly with some soft sediment deformation;	10.5	
b. rippled, thinly laminated, silty, structureless often difficult to determine;	8.0	
c. covered, with very minor exposures of structureless sandstone	57.5	126.5
III. Probable base of the Salt Wash Member, Morrison Formation -- Summerville below here seems to be somewhat thicker than normal, true contact may be covered.		
3. Sandstone, very fine-grained, poorly sorted, green/gray in color -- composition is 2-3% orange chert, 1% opaque black minerals, 95% quartz.		
a. structureless to slightly rippled, thinly laminated;	3.5	
b. sandstone, similar to that in sub-unit a, but color is pale red to brown;	14.5	
c. scour, 3-4 inches of red siltstone in base. Overlain by low angle wedge planar to flat bedded sands, thinly bedded. Widely spaced burrows throughout. Well indurated;	9.0	

		Unit feet	Cum. feet
d.	trough cross-stratification, medium-scale with clay clasts in basal sections near scours -- troughs usually grade into low angle wedge planar cross-stratification, medium-scale, in upper parts of the section -- an apparent single channel in this sandstone is approximately 15 feet thick, up to 250 feet wide;	11.0	
e.	wedge planar cross-stratification, medium- to large-scale, with basal scour surfaces -- this sub-unit appears to be a single channel deposit;	18.0	
f.	wedge planar cross-stratification, small- to medium-scale, overlain by rippled, thinly laminated sandstone.	8.0	190.5

4. Sandstone, with local covered intervals -- sandstone is fine-grained, subangular, poorly sorted, gray/white in color -- composition is 1-2% orange chert, 3% opaque black minerals, 95+% quartz -- sandstone also contains some thin interlaminations of red siltstone.

		Unit feet	Cum. feet
a.	covered;	11.0	
b.	wedge planar cross-stratification, medium-scale, last 1 foot is rippled, thinly laminated;	11.0	
c.	wedge planar cross-stratification, small-scale;	1.0	
d.	flat to very low angle planar cross-stratification, thinly bedded;	6.0	
e.	flat to very slightly inclined tabular planar cross-stratification, thin to medium bedding, medium-scale cross stratification -- contains less than 5% interlaminated red and gray siltstone -- burrows 5 feet above base, and at the top of the sub-unit;	11.5	
f.	covered;	3.0	
g.	sandstone, 1% magnetite (?), 1% chert, flat to rippled, thinly laminated to thinly bedded.	2.0	236.0

5. Sandstone, cliff exposure -- sandstone is fine-grained, moderately sorted, gray/white in color -- composition is 1-2% black opaque mineral, trace chert, 98% quartz -- zones of lag deposits composed of coarse-grained to granule size chert and feldspar or tuffaceous fragments and mud clasts through cliff, within

	Unit feet	Cum. feet
the lowest 10 feet is a possible mineralized zone which occurs in a scour containing highly deformed, overturned cross-stratification -- interbedded with the sandstone are thin laminations and galls of gray mudstone -- the mineralized structures are in all cases relatively small-scale, being no more than 4-5 inches thick and extending 10 feet or less.		
a. trough cross-stratification, small-scale, scour bases;	4.0	
b. flat, thinly bedded or thickly laminated;	6.0	
c. trough cross-stratification, medium-scale, decreasing to small-scale in the upper 4-6 feet -- also within this sub-unit are isolated occurrences of tabular planar-stratification, usually 8-12 inches thick and of limited lateral extend.	23.5	269.5
6. Covered section, overlain by a sandstone cliff. Sandstone, fine grained, subangular, moderately sorted, white to green/gray in color -- composition is 2% orange chert, 1% black opaque mineral, 95% quartz.		
a. covered;	39.0	
b. flat to low angle wedge planar cross-stratification, with local isolated trough cross-stratification. All types are medium-scale;	7.5	
c. interbedded very fine-grained sandstone and red siltstone with a scour base. Thickly laminated to thinly bedded;	1.0	
d. trough cross-stratification, small- to medium-scale;	4.0	
e. poorly defined tabular planar to flat, probably thinly bedded;	4.5	
f. trough cross-stratification, medium-scale;	5.0	
g. covered, but base is very fine-grained material, rippled, thinly laminated, which is probably the end of the previous depositional sequence.		
7. Sandstone, fine-grained, subangular, poorly sorted, white to gray/green -- composition is 1% orange chert, 1% opaque black mineral, 96% quartz.		

		Unit feet	Cum. feet
a.	trough cross-stratification grading upward into flat or very low angle wedge planar, medium-scale, on scour bases which contain red clay clasts;	8.0	
b.	wedge planar cross-stratification, medium-scale decreasing to small-scale at top of measurement. Fewer scours and clay clasts;	18.0	
c.	same as sub-unit b, but upper 4 feet is flat, thinly bedded, locally burrowed.	5.0	383.5

IV. Probable Base of the Brushy Basin Member, Morrison Formation - Contact Conformable

8. Poorly exposed except for local sandstone ledges. Sandstone is mainly fine-grained, subangular, moderately sorted, blue/green -- covered sections have a float that is composed of red, blue, and green siltstones and mudstones.

		Unit feet	Cum. feet
a.	covered;	20.0	
b.	structureless sandstone;	6.0	
c.	covered;	20.0	
d.	rippled, thinly laminated sandstone;	10.0	
e.	covered;	3.5	
f.	structureless sandstone;	2.0	
g.	covered, very small exposure of blue shale at top.	16.0	461.0

Above the top of the measured Section MC6 to the top of the overlying slope is mainly covered with outcrops of sandstone.

Total Thickness:	Section MC6	468.0
	Summerville Fm.	31.0
	Tidwell Member	95.5
	Salt Wash Member	341.5

	Unit feet	Cum. feet
MC7 NW¼, NW¼, Sec. 25, T36S, R34E		
Entrada/Summerville contact is covered at the base of this section. The section starts at an undetermined height above this contact in the Summerville Formation.		
I. Summerville Formation		
1. Sandstone and siltstone, interbedded -- sandstone is typical of the Summerville as described in previous sections.		
a. structureless to very crude, irregular flat bedding. Upper 3 feet has what appears to be soft sediment deformation;	12.5	12.5
II. Tidwell Member, Morrison Formation, contact erosional.		
2. Sandstone with local short covered sections, sandstone is very fine-grained, subangular, poorly sorted, white to gray in color. Composition is 3% orange and red chert, 95% quartz.		
a. undulatory to crude, irregular flat bedding, thickly laminated to thinly bedded;	12.0	
b. red siltstone, structureless;	4.5	
c. thinly laminated to medium bedded sandstone and siltstone;	6.0	
d. rippled, thinly bedded siltstone and very thickly bedded sandstone;	9.0	
e. covered;	30.0	
f. wedge shaped sets of rippled, thinly laminated cross strata -- small- to medium-scale;	4.5	
g. covered;	6.0	
h. rippled, thinly laminated, burrowed;	2.5	
i. covered.	11.0	98.0
III. Salt Wash Member, Morrison Formation, contact unconformable		
3. Sandstone, fine-grained, subangular, moderately sorted, white. Composition is 1-2% orange and green chert, 98% quartz.		
a. flat, thinly bedded;	3.0	
b. wedge planar cross-stratification, medium-scale;	1.0	

	Unit feet	Cum. feet
c. flat underlain by a scour surface. Scour cuts approximately 1 foot into lower bed, thinly bedded;	2.0	
d. wedge planar cross-stratification, medium to small-scale, channel-scale-cut-and-fill structures up to 2.5 feet deep observed laterally;	1.0	
e. scour, filled with rippled, thinly laminated, very fine-grained sandstone;	1.0	
f. trough cross-stratification, small-scale;	2.5	
g. covered;	2.0	
h. wedge planar cross-stratification, medium- to large-scale, becoming more trough shaped toward top of sub-unit;	17.0	
i. tabular planar, cross-stratification, medium-scale;	8.0	
j. covered.	18.0	153.5
4. Sandstone, fine-grained, subrounded, poorly sorted, 3% black opaque minerals, 2% orange chert, 95% quartz.		
a. trough to wedge planar cross-stratification. Small-scale, grading upward to medium-scale;	8.5	
b. low angle wedge planar cross-stratification, medium-scale;	5.0	
c. wedge planar cross-stratification, small- to medium-scale, underlain by a scour with red siltstone clasts -- sandstone contains 3-4% orange and red chert, 5% weathered feldspar or tuffaceous fragments;	5.0	
d. trough cross-stratification, small-scale, scour base with 2 inch thick siltstone below cross-stratification;	5.0	
e. red siltstone, structureless;	1.0	
f. trough cross-stratification, small-scale;	14.0	
g. covered, or poorly exposed except for very small outcrops of trough cross-stratified sandstone. Scale could not be determined from the small outcrops.	10.0	202.0
5. Sandstone, fine-grained, moderately sorted, pink to pale gray -- composition is 2% orange chert, 2% black opaque minerals, 95% quartz.		
a. wedge planar cross-stratification, medium-scale;	18.0	

	Unit feet	Cum. feet
b. low angle wedge planar, large-scale, at the base of some sets are deposits of coarse sand and granule size lag composed mainly of chert and weathered feldspar or tuff;	14.0	
c. trough cross-stratification, medium-scale;	19.0	
d. rippled, thinly laminated, burrowed in upper 1.5 feet;	5.5	
e. covered.	17.0	275.5
6. Sandstone, fine-grained, poorly sorted, white to gray in color -- composition is 2% orange chert, 2% black opaque minerals, 4% weathered feldspar or tuffaceous material, 90% quartz. Local short covered intervals.		
a. trough cross-stratification, medium-scale, local burrows;	4.0	
b. wedge planar cross-stratification, medium-scale, becoming rippled, thinly laminated and burrowed toward the top of this sub-unit;	4.0	
c. poorly exposed, no structures identified;	6.0	
d. covered;	5.0	
e. thickly interlaminated very fine sandstone and siltstone;	2.0	
f. trough cross-stratification, small-scale, over a scour base. Sandstone is very fine-grained, green/gray in color;	2.0	
g. siltstone with thick laminations of sandstone;	2.5	
h. trough cross-stratification, medium-scale, with deep scour bases filled by red siltstone with abundant mud clasts, also red. Upward the troughs become flatter and grade into wedge planar cross-stratification;	16.0	
i. rippled, thinly laminated;	2.0	
j. trough cross-stratification, small-scale;	1.5	
k. covered.	2.0	322.5
7. Sandstone, fine-grained, subangular, poorly sorted, green/gray in color -- composition is 4% orange and green chert, 95% quartz.		
a. wedge planar cross-stratification, medium-scale;	3.0	

	Unit feet	Cum. feet
b. scour surface, filled with very fine-grained green sandstone with red siltstone clasts and clay galls;	1.0	
c. trough cross-stratification, medium-scale, with numerous scour surfaces. Distance between scours vertically is approximately 3 feet, with the spacing decreasing upward. May represent a fining upward sequence.	15.0	341.5
8. Sandstone, in the start of another channel sequence -- sandstone is similar to that described in unit 7, contains local accumulations of green mudstone and carbonaceous material as accicular fragments.		
a. scour surface, filled by thinly interlaminated very fine sandstone and siltstone. Color is a light green;	1.0	
b. trough cross-stratification, small-scale with numerous red clay galls;	1.5	
c. trough cross-stratification, medium-scale with minor scours marked by accumulations of green/gray clay galls;	7.0	
d. scour surface filled by interlaminated sandstone and gray/green mudstone as both thin laminations and clasts -- carbonaceous trash present in the mudstone;	1.0	
e. flat to low angle wedge planar cross-stratification, thinly bedded -- possible mineralization within scours that extend laterally beyond the stratified sandstones;	2.0	
f. trough cross-stratification, medium- to large-scale -- six feet up in this measurement is a two foot thick burrowed interval;	26.0	
g. wedge planar cross-stratification, medium-scale, underlain by a 3 inch thick green mudstone;	3.5	
h. trough to wedge planar cross-stratification, medium-scale with local thin laminations of red siltstone.	12.5	396.0
9. Sandstone, similar to that in unit 8, slightly coarser-grained. Several thick covered intervals.		
a. covered;	10.0	
b. wedge planar cross-stratification, sandstone is bluish/green, fine-grained;	3.0	

	Unit feet	Cum. feet
c. flat, thinly bedded;	2.0	
d. trough cross-stratification, medium-scale. Scour surfaces at intervals of 4-5 feet vertically.	12.0	423.0

IV. Probable base of the Westwater Canyon Member, Morrison Formation, contact conformable

	Unit feet	Cum. feet
10. Covered, float is blue/green sandstone and blue, and red siltstones. Much of the sandstone contains coarse sand to graunule size lags of chert and tuffaceous material.		
a. covered;	65.0	
11. Sandstone, medium-grained; subangular, poorly sorted, gray in color -- contains 2-3% green and orange chert, 95% quartz. Structures are wedge planar cross-stratification, large-scale, with lag deposits as described above.	16.0	504.0

Total Thickness:		
	Section MC7	504.0
	Summerville Fm.	12.5
	Tidwell Member	85.5
	Salt Wash Member	325.0
	Westwater Canyon Mbr	65.0

	Unit feet	Cum. feet
MC8 SW¼, SE¼, Sec. 22, T36S, R24E		
I. Tidwell Member, Morrison Formation, base covered		
1. Covered, with local outcrops of sandstone. Sandstone is fine-grained, red, typical of the Summerville Formation. At this location it seems to have a greater content of silt than at other locations.		
a. sandstone, structureless;	1.0	
b. covered;	17.0	
c. sandstone, with thin interlaminations of red siltstone -- flat, medium to thick bedded.	16.0	34.0
II. Salt Wash Member, Morrison Formation - Contact Unconformable		
2. Sandstone, fine-grained, subangular, poorly sorted, red/gray in color -- 99+% quartz, trace of black chert.		
a. trough cross-stratification, small-scale;	4.0	
b. wedge planar to tabular planar cross-stratification, medium scale;	9.0	
c. rippled, thinly laminated;	7.0	
d. thinly interbedded siltstone and mudstone;	1.0	
e. trough cross-stratification, size of sets changes upward from small-scale to medium-scale within the first 16 feet. Numerous scour bases.	20.5	75.5
3. Sandstone, fine-grained, subangular, poor sorting, light brown in color -- 5% feldspar, 3% black opaque minerals, trace orange chert, 90% quartz.		
a. covered, one very small outcrop of rippled, thinly laminated sandstone;	23.5	
b. flat to low angle, medium-scale, wedge planar cross-stratification;	12.5	
c. covered;	6.0	
d. poorly exposed, sandstone;	2.5	
e. poorly exposed, mainly siltstone with a few thin beds of sandstone;	19.0	
f. rippled, thinly laminated, probably burrows;	1.5	
g. poorly exposed;	4.0	

		Unit feet	Cum. feet
	h. rippled or small-scale trough cross-stratification;	3.0	
	i. red siltstone, structureless	1.5	149.0
4.	Sandstone, fine- to medium-grained, subangular, poorly sorted, gray to white in color -- composition is 3% orange chert, 2% black opaque minerals.		
	a. trough cross-stratification, medium-scale;	16.0	
	b. covered;	27.0	
	c. trough cross-stratification, small-scale, for lower five feet -- scour surface overlain by planar parallel cross-stratification, which changes vertically to trough, both are medium-scale;	18.0	
	d. covered;	9.0	
	e. flat to low angle wedge planar cross-stratification, thinly bedded, medium-scale.	8.5	227.5
5.	Sandstone and covered intervals -- sandstone similar to that described in unit 4.		
	a. highly variable structures, changes from large-scale trough cross-stratification to wedge planar and tabular planar, all low angle;	11.0	
	b. covered;	15.0	
	c. wedge planar cross-stratification, medium-scale;	8.0	
	d. flat, thickly laminated to thinly bedded. Lower surface truncates very slightly the structures in sub-unit c. Burrowed throughout;	5.0	
	e. covered;	16.0	
	f. trough cross-stratification, medium-scale, with clay galls in basal section. Some sets are overlain by thin red siltstones;	9.0	
	g. wedge planar cross-stratification, medium-scale.	7.0	298.5
6.	Sandstone, with local covered intervals -- sandstone is medium-grained, subangular, moderately sorted, white in color -- composition is 6% feldspar or tuffaceous fragments, trace black opaque minerals, 93% quartz.		

		Unit feet	Cum. feet
a.	covered;	20.0	
b.	low angle tabular planar to trough cross-stratification, small-scale;	11.0	
c.	trough cross-stratification, medium-scale. Channel scale cut-and-fill dimensions of approximately 40 feet wide by 8-10 feet deep;	10.0	
d.	covered;	27.0	
e.	trough, low angle, cross-stratification, large-scale. Scours with green mud clasts;	11.0	
f.	flat, thickly laminated to thinly bedded;	3.0	
g.	similar to sub-unit f, contains some burrows;	3.0	
h.	trough cross-stratification, medium-scale	14.0	397.5

III. Probable base of Westwater Canyon Member, Morrison Formation, Contact conformable

7. Sandstone, with numerous covered intervals -- fine-grained, subangular, poorly sorted, very light greenish white. Composition is 2-3% feldspar or tuffaceous material, trace orange chert, 96% quartz.

		Unit feet	Cum. feet
a.	covered;	22.0	
b.	sandstone, structureless;	10.0	
c.	poorly exposed, local outcrops of thinly laminated blue/gray and red shale;	50.0	

IV. Probable base of the Brushy Basin Member, Morrison Formation, Contact conformable

		Unit feet	Cum. feet
8.	Wedge planar cross-stratification, large-scale	30.0	509.5

NOTE: At top of this section is a very long slope leading to the next cliff exposure of Dakota Sandstone. In this section there is probable intertonguing of the Brushy Basin and Westwater Canyon Members of the Morrison Formation.

Total Thickness:	Section MC8	509.5
	Tidwell Member	34.0
	Salt Wash Member	363.5
	Westwater Canyon Member	82.0

	Unit feet	Cum. feet
MC9 SW and NE ¼'s of NE¼, Sec. 35, T36S. R24E		
I. Tidwell Member, Morrison Formation, base covered.		
1. Sandstone, very fine-grained, some silt, very poorly sorted, red in color -- composition is 98+% quartz, trace of chert.		
a. no apparent structures.	3.5	3.5
II. Salt Wash Member, Morrison Formation. Contact sharp, unconformable.		
2. Sandstone, very fine-grained, subangular, poorly sorted, red to pink in color -- composition is 98+% quartz, trace red chert.		
a. trough cross-stratification, medium-scale. Possible ripple laminations in the last 2 feet of this measurement;	10.0	
b. covered, probably red siltstone;	0.5	
c. flat to crudely undulatory bedding. Very thin to thin bedding -- upper two feet is very small-scale trough cross-stratification;	22.0	
d. sandstone and red siltstone, thickly laminated to very thinly bedded, siltstone dominates;	6.0	
e. covered -- local outcrops of ripple laminated sandstone and siltstone.	54.0	96.0
3. Sandstone and siltstone -- sandstone is very fine-grained, poorly sorted, pink in color -- composition similar to that in unit 2.		
a. red siltstone;	2.0	
b. rippled, thinly laminated sandstone. Underlain by a thin scour surface;	1.5	
c. red siltstone;	1.5	
d. wedge planar cross-stratification, medium-scale, overlies a 6 inch scour with numerous clay galls and red clay clasts;	11.5	
e. wedge planar cross-stratification, small-scale -- local burrows, chert content has increased to 3%;	7.0	
f. covered.	12.0	131.5
4. Sandstone, fine-grained, subrounded, moderately sorted, light brown in color -- composition is 99% quartz, trace chert and black opaque minerals.		

		Unit feet	Cum. feet
a.	trough cross-stratification, small- to medium-scale atbase, decreasing to small-scale at top of sub-unit a;	5.5	
b.	red siltstone;	0.5	
c.	trough cross-stratification, small-scale. Burrowed toward top of sub-unit c;	6.5	
d.	trough cross-stratification, small-scale, burrowed;	6.0	
e.	covered.	17.0	167.0
5.	Sandstone, fine-grained, subangular, moderately sorted, pink in color -- composition is 3% orange and green chert, 95% quartz.		
a.	flat to probable low angle trough cross-stratification;	4.0	
b.	trough cross-stratification, small-scale;	2.0	
c.	wedge planar cross-stratification, medium-scale;	11.0	
d.	flat, very thinly bedded. Contains up to 3% carbonaceous particles which are oriented parallel to bedding planes;	4.0	
e.	trough cross-stratification, small-scale, some low angle wedge planar sets also occur within this sub-unit;	5.0	
f.	flat to rippled, thickly laminated;	1.0	
g.	covered;	6.0	
h.	scour zone, filled with interbedded siltstone and sandstone, some siltstones as lenses and clasts. Within the upper 6 inches are red and green mud clasts. Thickly laminated;	2.5	
i.	trough to low angle wedge planar cross-stratification, medium-scale. Numerous scour surfaces marked by accumulations of mud clasts;	19.0	
j.	covered.	29.0	250.5
6.	Sandstone, fine-grained, subangular, poorly sorted, pale green to white -- composition is 99% quartz, trace of pink and orange chert.		
a.	wedge planar, low angle, cross-stratification, medium-scale;	8.0	
b.	trough cross-stratification, medium-scale bases marked by numerous scours which contain clay galls;	22.0	
c.	red siltstone;	0.5	
d.	wedge planar cross-stratification, large-scale. Numerous scour surfaces;	5.5	

		Unit feet	Cum. feet
e.	flat thinly bedded;	2.0	
f.	wedge planar, very low angle, medium-scale, cross-stratification;	5.0	
g.	flat, thinly bedded;	2.0	
h.	trough cross-stratification, low angle, large scale;	8.0	
i.	rippled, thinly laminated;	4.0	
j.	flat, thinly bedded;	2.0	
k.	rippled, thinly laminated;	2.5	312.0

Note: There has been a gradual increase in the chert content of the unit, up to 4% in 6 k.

III. Probable Contact, Westwater Canyon Member, Morrison Formation, Contact Conformable.

7. Slope, float indicates blue/green shales beneath this interval. Sandstone, fine grained, moderate sorting, pale gray to bluish -- 3-4% orange chert, 4-5% feldspar, 90% quartz.

		Unit feet	Cum. feet
a.	covered;	105.0	
b.	flat medium bedding;	10.0	427.0

IV. Probable Contact, Brushy Basin Member, Morrison Formation, Contact Conformable.

8. Mainly covered; sandstones similar to unit 7.

		Unit feet	Cum. feet
a.	Covered, float contains blue sandstone and red and blue siltstone and shale;	25.0	
b.	Rippled, thinly laminated	3.0	455.0

Total Thickness:	Section MC9	455.0
	Tidwell Member	3.5
	Salt Wash Member	308.5
	Westwater Canyon Member	115.0

	Unit feet	Cum. feet
MC10 (Horsehead Canyon) SE¼, NW¼, Sec. 31, T35S, R25E		
I. Summerville Formation, a short distance above the Entrada/Summerville contact, which is covered.		
1. Alternating sandstone and covered intervals -- very fine-grained sand to silt size, subangular, moderately sorted, pink to white -- composition is 3% feldspar or tuffaceous material, 3% opaque minerals, 92% quartz.		
a. covered;	22.0	
b. structureless, very fine sand to silt;	14.0	36.0
II. Tidwell Member, Morrison Formation, Contact Unconformable.		
2. Sandstone similar to unit 1		
a. flat, thinly bedded;	8.0	
b. rippled, thinly laminated;	8.0	
c. poorly defined cross-stratification, appear to be trough or wedge planar, medium-scale;	8.0	
d. undulatory to rippled; thinly bedded sandstone and siltstone;	14.0	
e. covered.	34.0	108.0
III. Salt Wash Member, Morrison Formation, Contact Unconformable.		
3. Sandstone, very fine-grained, subangular, moderately sorted, pink -- composition is 2% orange chert, 1-2% feldspar or tuffaceous fragments, trace black opaque minerals -- the first outcrop can be correlated across the canyon and appears to be a continuous bed of sandstone on both sides for at least ¼ mile.		
a. flat cross-stratification which grades upward into trough -- numerous small channels, 6-20 inches thick;	8.5	
b. structureless, extensively burrowed;	7.5	
c. covered;	18.0	
d. structureless to very slightly undulatory;	2.0	
e. low angle, planar parallel to wedge, thickly laminated sandstone -- contains sparse, thin laminations of siltstone;	5.0	

		Unit feet	Cum. feet
f.	covered;	4.0	
g.	trough cross-stratification, small-scale;	8.0	
h.	covered.	2.0	163.0

4. Interbedded sandstone and siltstone -- sandstone is similar to that in unit 3, chert content is approximately 4% -- contains lenses of gray/green sandstone within red and gray siltstone.

		Unit feet	Cum. feet
a.	flat, thickly bedded sandstone and siltstone;	7.0	
b.	trough cross-stratification, medium-scale, with basal lags of granule size material. Set size decreases upward from 8-12 feet wide to 3-4 feet wide;	18.0	
c.	covered;	18.0	
d.	trough to low angle wedge planar cross-stratification, medium-scale. Probable mineralization, with gray/green muds in small lenses. No carbonaceous material;	2.0	
e.	trough cross-stratification, medium- to large-scale;	14.0	
f.	flat, thickly laminated. This sandstone is less resistant than adjacent sandstones and is a gray/green color. Contains what looks like bleached concentric rounded zones or solution fronts. Within the sand are abundant carbonaceous flecks and tiny mud clasts;	5.0	
g.	trough cross-stratification, medium-scale;	14.0	
h.	trough cross-stratification, large-scale, clay clasts mark bases of individual scours and channel sequences;	12.0	
i.	red siltstone;	7.0	
j.	flat, thinly laminated, very fine sand, with numerous vertical and horizontal burrows;	3.0	
k.	flat, interbedded sandstone and siltstone;	2.5	
l.	trough cross-stratification, medium-scale;	10.5	
m.	trough cross-stratification, small- to medium-scale, conformably overlain by flat medium bedded sandstones.	2.0	278.0

5. Sandstone, similar to that in unit 4.

		Unit feet	Cum. feet
a.	covered;	38.0	
b.	trough cross-stratification, medium-scale, scour only at base of sub-unit;	7.0	

	Unit feet	Cum. feet
c. trough cross-stratification, medium-scale, burrowed, very few scours;	8.0	
d. similar to sub-unit c, but separated by very thin beds of red siltstone and fine sandstone;	8.5	
e. flat, planar, thinly bedded;	6.5	
f. very poorly exposed, may belong in the Brushy Basin or Westwater Canyon Member.	42.0	388.0

6. Sandstone, medium-grained, subangular, moderately sorted, pink in color -- composition is 2% feldspar, 98% quartz -- change in composition with increased height above base of unit 6 is an increase in feldspar by 1-2%.

a. wedge planar, low angle to slightly trough shaped cross-stratification, medium-scale;	45.0	433.0

III. Brushy Basin Member, Morrison Formation. Good break in slope occurs above this point. Throughout this section, it is possible to correlate almost unit for unit across the canyon, probably due to the narrowness of the canyon. Because of this it is possible to determine that the individual units are continuous for distances of up to 300 or 400 feet, and in some cases even further.

Total Thickness:		
	Section MC10	433.0
	Summerville Fm.	36.0
	Tidwell Member	72.0
	Salt Wash Member	325.0

SECTION MC1

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
5	N85°W		N75°E	North
	N55°E		S75°E	S25°W
			N80°E	
			N70°E	
10a	N50°E	N70°E	N15°E	N80°E
	N45°E	N20°E	N60°E	S45°E
	N5°W		N45°E	S39°E
			N55°E	S60°E
			N55°E	
			N30°E	
21g		S75°E		N36°E
		N80°E		S64°E
				N62°W

SECTION MC2

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
5h	North	S50°W		S59°E
				S55°W
				S6°E
				N45°W
				N55°E
7				S20°E
1a				S45°E
5c	N15°W			S45°E
	N30°W			S45°E
	N10°W			

SECTION MC3

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
6b	N65°W			N82°W
	N45°W			S51°E
	N60°E			
8c	N35°E			
	N40°E			
	N30°E			
	N30°E			
	N35°E			
	N25°E			
	N17°W			
	N17°W			
	N23°W			

SECTION MC3 (cont.)

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
9	N55°W			S5°W
12b	N65°E N67°E N20°E	N75°E N15°E		North N60°E S51°E N60°E N55°E

SECTION MC4

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
3f	N60°E N65°E East N73°E		N25°W N68°E	N31°E S25°E
4b		S80°E	N30°E	
5a	N65°E N65°E N60°E N45°E	S40°E		S75°E
8a	N30°W N60°E N65°E			East

SECTION MC5

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
3	N5°W N25°E N55°W	N60°E S80°E	N80°E	South
4	N15°W N50°W N40°E N50°E			S20°E N63°E
5d	N63°W N60°W N5°W	N80°E		N10°W
7h			S64°E N25°E S28°E	N63°E

SECTION MC6

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
3d	N35°W			S25°W
	N15°W			South
4b	N15°E			N80°E
	N80°E			N64°E
5c	N40°E			N35°E
	N75°W			S80°E
6b	East	S85°E		
	N80°W			
	East			
	East			
	N15°W			
	N15°W			
7b	N50°E			
	N75°E			
	N70°E			
	N85°W			
	N55°E			
8d	N85°W		S75°E	N70°E
	N60°W			
	East			

SECTION MC7

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
3h	N30°W		S70°E	
	N40°W		N54°E	
	N70°W		S40°E	
	N75°W		S55°E	
	N45°W			
	N85°W			
	N15°W	N65°E		
	N25°E			
	N15°E			
	N40°W			
	N10°W			
	N80°W			
4a	N35°E			
	N20°W			
	N25°E			
	N45°E			

SECTION MC7 (cont.)

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
5a	N45°E			S54°E
	N50°E			N46°E
	N40°E			
	N30°E			
	N47°E			
	N47°E			
6b	N37°E			N52°E

SECTION MC8

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
3a	East			
	N70°W			
	N85°E			
	N80°E			
	N85°E			
4e	N60°E			
	N60°E			
5a	N20°E			
	N65°E			
	East			
	N70°W			
	N40°W			
6f	East			

SECTION MC9

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
2c	N40°E	N15°E	N40°E	
	N25°E	N20°E		
	N30°W	N15°E		
	N30°W	N70°E		
	N50°W	S55°E		
3b	N50°W	N60°E	N57°E	
	N10°W			
	N70°E			
	East			
	N80°W			
	N65°W			
	North			

SECTION MC9 (cont.)

Unit Number	Lineation	Rib & Furrow	Trough Axis	Wedge-Planar
5e	N55°E		N40°E	N10°W
	N55°E		N43°E	
	N60°E		N40°E	
	N15°W		East	
	N10°W			
	N10°W			
	N20°W			
	N20°W			
6h	N80°E	N25°E		
	N85°W			
	N75°W			
	N85°E			
	N70°E			

SECTION MC10

No Data

APPENDIX 2

EXPLANATION OF SANDSTONE CLASSIFICATION

AND

DESCRIPTIONS OF THIN SECTIONS

EXPLANATION OF PETROGRAPHIC CLASSIFICATION SYSTEM

The sedimentary rock classification system I have used is a combination of Folk (1968) and McBride (1963) (Figure 19). The end members on the ternary diagram are the same as those used by Folk (1968). They are:

Q: all types of quartz including polycrystalline quartz, but not chert

F: all single feldspar (K or Na/Ca) plus granite and gneiss fragments.

R: all other rock fragments; chert, slate, schist, volcanics, etc.

The divisions along the feldspar-lithic fragment side of the ternary diagram are placed at 25% increments, similar to the system used by Folk (1968). The boundary between Subarkose and Arkose/Lithic Arkose and Sublitharenite and Feldspathic Litharenite/Litharenite is selected so that a rock which contains less than 25% feldspar or lithic fragments and less than 90% quartz will be classified as either a Subarkose or a Sublitharenite. This division at 25% is similar to McBride's (1963) system. The quartzarenite field has been enlarged to 90% quartz, as opposed to Folk's (1968) and McBride's (1963) 95%.

If a composition falls into the Litharentite/Sublitharenite fields, a prefix of the dominant rock fragment type may be used to further describe it.

This chart is developed mainly to simplify the classification and nomenclature of the sandstones from the study area. Using this system the dominant rock type is a Subarkose. Volcanic (rhyolitic?) Sublitharenite is also common.

The classification which have been published by Folk (1968), McBride (1963), Pettijohn (1975), and others were not used because after plotting the compositions according to their classifications it created a scatter of points which did not appreciably limit the rock types to a workable number even though the actual range of compositions was within a relatively tight grouping. Figure 19 shows the plotted compositions on the modified ternary classification diagram.

SAMPLE MC1-1

Field Relations -- Taken at 89 feet above the base of section MC1. Sandstone is tan, structures are small scale trough shaped sets of cross-stratification which grade laterally into tabular planar, medium cross-beds. Within the sandstones are green clay galls.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

65% Total Quartz

61.75% monocrystalline -- anhedral, subangular to subrounded, moderately to strongly undulose extinction -- overgrowths believed to be on the more highly rounded grains, but not positively observed -- approximately 80% of the monocrystalline grains are coated by an oxide, all grains are slightly embayed by carbonate cement.

3.25% polycrystalline -- 2 to 7 crystals per grain, otherwise similar to monocrystalline grains.

22% Total Feldspar

Tr Plagioclase -- composition not determined.

5% Microcline -- subhedral to euhedral, very fine, littler alteration.

17% Orthoclase -- subhedral grains, similar in size to quartz, very minor alteration to clays (?) along cleavage traces and grain boundaries -- some orthoclase overgrowths noted.

12% Lithic Fragments

Dominantly volcanic fragments, possibly tuffaceous fragments -- very finely polycrystalline silicate, coated by iron oxide -- approximately 20% appear to be devitrified.

Tr - Other Minerals

Probably hornblende.

Fabric

Diameter - .2mm

Sorting - moderate

Roundness - subrounded

85% Detrital grains (as percentage of rock)

14% Cement

13.3% carbonate, poikiotitic enclosing 1 to 2 grains. Carbonate has embayed and corroded the quartz grains.

0.7% silicate - polycrystalline which appears to be replacing carbonate within small areas.

Tr Matrix - very minor clays

Tr Pore space - not positively identified, possibly due to plucking during thin section preparation.

Textural Maturity - submature

Grain contact - line contact most common

Rock Name - Calcareous Subarkose

SAMPLE MC1-2

Field Relations -- Taken at a point 103 feet above the base of the measured section, within the lower part of the Salt Wash Member. The rock is tan to gray, has flat thin bedding, but occurs within an interval which has highly variable cross-stratification types.

THIN SECTION DESCRIPTION

Detrial Components (as percentage of detrital grains)

93% Total Quartz

91.1% monocrystalline -- anhedral, subangular to moderately rounded, subequant, with moderately to slightly undulose extinction -- quartz overgrowths on less than 10% of the grains, core grains appear to be more highly rounded than on grains which lack overgrowths so that the angular grains appear to be first cycle grains -- embayments by carbonate noted on all grains in contact with the carbonate cement.

1.9% polycrystalline -- well rounded, equant grains with greater than 10 crystals per grain.

3% Total Feldspar

2% Plagioclase -- euhedral, angular, slightly smaller than quartz grains -- composition on grains is An_{34}, Andesine.

1% microcline -- similar characteristics to plagioclase

Tr orthoclase -- probably more abundant, but not a major constituent because abundance of other feldspar is low.

3% Lithic Fragments

Volcanic fragments, size similar to other detrital components, angular grains are the most common -- color brown to gray in plain light, often coated with iron oxides -- many have very small feldspar laths within glassy material -- small areas are partially devitrified but no other alteration noted.

Fabric

Average diameter -- .2 mm

Sorting -- moderate

Roundness -- .4

85% Detrital grains (as percentage of rock)

14% Cement

14% Calcite - has coroded and embayed the detrital grains, minor areas of poikilotopic cement enclosing 1 or 2 grains

Tr other cements - mainly silica

Tr Matrix

Tr Pore space -- none observed

Textural Maturity - submature

Grain Contacts -- line more common than point

Rock Name -- Calcareous Quartzavenite

SAMPLE MC1-3

Field Relations -- From 153.5 feet above the base of section MC1. The sandstone is greenish white, contains green clay clasts and a very thin layer of carbonaceous layer. Structures are small scale, trough-spaced sets of thinly cross-stratified sandstone which change laterally into large scale, low angle tabular-olaned and wedge-shaped sets of thinly cross-stratified sandstone.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

60% Total Quartz

54% monocrystalline -- subhedral, subangular, with moderately undulose extinction -- no overgrowths identified.

6% polycrystalline -- grain size is slightly finer than the monocrystalline quartz -- grains are moderately rounded and have 2 to 7 crystals per grain, with less than 5% of the polycrystalline grains having greater than 10 crystals per grain.

15% Total Feldspar

.75% microcline -- euhedral to subhedral, fine grained -- traces of alteration to clays (?)

14.25% orthoclase - subhedral, similar in size to monocrystalline quartz grains, very little alteration noted.

15% Total Lithic Fragments

13.0% volcanic-very fine grained, coated with oxides -- within fragments are feldspar laths in glassy material -- most of the volcanic fragments are well rounded, appear to be tuffaceous.

2.0% argillaceous -- very fine grained, well rounded, somewhat elongate, slightly larger than monocrystalline quartz grains.

7% Total Clays

Very fine grained, translucent green/brown -- occurs as thin bands along bedding planes and as intergranular masses -- some areas may be clay clasts which have deformed plastically around sand-size grains during compaction.

2% Total Opaques

Probably magnetite -- occurs as very fine grains concentrated along two linear zones -- in reflected light it is a metallic gray/black.

In Other Minerals

1 grain of well rounded hornblende

Fabric

Average diameter -- .22 mm

Sorting -- poor

Roundness -- subangular

90% Detrital grains (as percentage of rock)

10% Cememt plus matrix - combined because they are indistinguishable -- only 1-2% of the cement is carbonate -- primary cement is an intergranular argillaceous hash in combination with either calcite or silica.

Tr pore space -- probably due to plucking of grains during thin section preparation.

Textural matruity -- Inmature

Grain contacts -- line approximately equal to concave-convex

Rock Name -- Subarkose/Sublitharenito

SAMPLE MC1-5

Field Relations -- Taken at a point 516 feet above the base of section 1, near the contact with the overlying Brushy Basin Member. The rock is tan to gray in color (fresh), has small-scale, trough shaped sets of thin cross-beds.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

65.0% Total Quartz

61.8% monocrystalline -- subhedral to anhedral, subangular, subequant, with moderately undulose extinction -- few inclusions, small areas with visible overgrowths -- less than 2% of the monocrystalline quartz grains are rimmed by an opaline or cherty polycrystalline cement -- embayments by calcite are common on most grain boundaries in contact with carbonate cement -- overall appearance of grains is mottled, fractured.

3.2% polycrystalline -- greater than 10 crystals per grain, cockscomb crystal-to-crystal contacts -- anhedral, subrounded, subelongate grains with moderately undulose extinction -- no significant alteration noted.

14.0% Total Feldspar

1.4% Plagioclase -- subhedral to euhedral, subrounded, equant -- composition of 3 individuals ranged from An_{30} to An_{36}, averaging An_{33} (Andesine) -- Twins appear to be slightly strained -- alteration is variable, from relatively fresh to highly altered -- dominant alteration is a clay rim and small clay embayments along twin planes.

3.5% Microcline -- subhedral to anhedral, subrounded, subequant -- overgrowths noted on 1 or 2 grains, but dominant alteration is to clays, similar to plagioclase.

9.1% Orthoclase -- shape and alteration similar to microcline -- alteration less advanced, only minor clay rim alteration -- overgrowths more common than on the other feldspar varieties, but could be identified on only ten of the feldspar grains.

4% Total Chert

Anhedra, subrounded, subequant -- very finely polycrystalline with short line contacts -- few inclusions -- alteration variable, approximately 50% have oxide staining of red/brown iron (?) -- possible recrystallization of rim area to a coarser polycrystalline silicate in 5%-10% of the grains which appear to have been rimmed by an opaline cement -- embayments by calcite cement common along grain boundaries.

7% Total Lithic Fragments

One variety in this sample. Very fine-grained, aphanitic, brown, with small areas which are isitropic and others which appear to be devitrified due to radial crystalline structure -- size and shape of fragments similar to that reported for quartz -- individual phenocrysts within the fragment could not be identified -- alteration mainly a devitrification of what was probably originally a glassy vitric fragment -- a brown, cloudy oxide coating is common to all grains -- other alterations are replacement by calcite cement, removal of relic textures, and replacement or alteration to a finely polycrystalline silicate -- lithic fragment is probably volcanic.

4% Clays

Dominant occurrence is in large originally, well-rounded clasts which have deformed plastically within the clasts are angular fragments of quarts, generally less than .01 mm in diameter -- no internal structures occur in the clasts -- general color is a translucent green/brown.

Alteration is mainly a very slight replacement by calcite cement in 1%-2% of the clays, and alteration to an undetermined phyllosilicate in 2% of the clays.

2% Total Opaques

Primary detrital opaque minerals are probably magnetite as very fine, euhedral, rec/black grains.

Tr micas -- very few, extremely small flecks, possibly biotite.

Other Minerals

None observed.

Fabric

Average diameter -- .25 mm

Sorting -- Moderate

Roundness -- .4 (subangular)

55% Detrital grains (as percentage of the rock)

30% Cement

19.8% Carbonate, probably calcite -- dominant occurrence is in poiliotopic masses enclosing 3-5 detrital grains.

7.2% Opaline or cherty, very finely polycrystalline, silicate, partially replaced by calcite cement.

3.0% Quartz syntaxial rim cement -- limited to spots where quartz grains were in close proximity.

4% Pseudomatrix -- as described under clays.

10% pore space -- in a vein-like pattern rather than as discrete intergranular pores -- this is a relatively high percentage of pore space as compared to the other samples.

Textural maturity -- submature

Grain to grain contacts -- point contact - line contact, approximately 10% of grains are floating.

Rock Name -- Calcareous Subarkose

SAMPLE MC3-1

<u>Field Relations</u> -- Taken 90 feet above the base of section MC3-1, in the base of unit 6. The rock is pale tan to buff, has flat or slightly inclined medium bedding. Laterally the bedding changes to medium scale, trough-shaped sets of cross-stratification.

THIN SECTION DESCRIPTION

<u>Detrital Components</u> (as percentage of detrital grains)

<u>85% Total Quartz</u>

84% Monocrystalline -- anhedral, approximately 50% well rounded, the other 50% are subangular -- approximately 20% of the grains appear to have been highly fractured. 50% of the grains have overgrowths on subrounded or better grains -- alteration mainly embayments of grain boundaries by carbonate cement. A very small member of grains had tiny acicular tourmaline inclusions.

1% polycrystalline -- rounded, equant grains with greater than 10 crystals per grain.

<u>7% Total Feldspar</u>

1.4% Plagioclase -- very fine (.1-.15mm) subhedral grains quite fresh, little alteration -- composition is An_{36}, Andesine.

Tr Microcline

5.6% Orthoclase -- little alteration, similar in size and shape to Quartz.

<u>3% Total Lithic Fragments</u>

2.25% volcanic -- very fine grained, well rounded, size and shape are similar to the quartz grains -- grains strained, possibly by iron oxide

.75% argillaceous fragments -- very fine grained, brown to green, elongate grains. No identifiable mineralogy.

1% Total Clays

Concentrated along cleavage of carbonate cement, unable to determine whether detrital or diagenetic.

3% Total Opaques

Predominantly magnetite, possibly ilmenite -- red to orange, occurs as discrete flecks and grains, widely disseminated.

Other Minerals

None observed.

Fabric

Average miameter -- .2 mm

Sorting -- moderate

Roundness -- averages .5 - .6

80% Detrital grains

20% Cement

Very finely crystalline intergranular calcite.

Tr - 1% Matrix - clays as described above.

Tr Pore Space - possibly due to plucking of grains during the thin section preparation.

Textured maturity - submature

Grain contacts - line approximately equal to point

Tock Name - Calcareous Subarkose

SAMPLE MC3-2

Field Relations -- Taken at 160 feet from the base of the measured section. The sandstone is reddish-tan with large-scale, trough-shaped sets of cross-stratification. The sample comes from the base of a trough set within the scour zone.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

51% Total Quartz

45.9% monocrystalline -- anhedral, angular, serrate grain boundaries due to corrosion by cement, moderately undulose extinction -- no overgrowths or inclusions.

5.1% polycrystalline -- 3 to 5 crystals per grain with sutured crystal contacts -- grains are subsequent to slightly elongate.

23% Total Feldspar

2.3% Plagioclase -- subhedral, subsequent, slight fracturing -- little alteration.

Tr Sanadine -- 1 grain identified

1% Microcline -- similar to other feldspars

1% Chert -- very finely polycrystalline, subrounded -- often difficult to distinguish from lithic (volcanic) fragments.

3.3% Lithic Fragments

2.5% volcanic -- very finely crystalline, isotopic -- no distinct intragranular mineralogies.

.8% argillaceous -- very fine grained, well rounded, opaque to translucent, dark green to brown fragments.

18% Clays

Probably origin from clay clasts which became deformed during lithifications are now thin, semi-continuous layers of clay.

2% Opaques

Occur both in distinct layers and as widely disseminated grains -- similar to the opaques in other samples -- probably magnetite.

Tr Other Minerals -- Hornblende

Fabric

Average diameter -- .2mm

Sorting -- Moderate

Roundness - subrounded (.5)

85% Detrital grains

14% Cement

13.0% carbonate - very coarsely crystalline, poikiolotic, embays the quartz grains.

10% opaline or cherty cement - appears to be replacing the calcite

1% Matrix - clays as previously described

Pore Space -- none observed

Textural Maturity -- submature

Grain Contact -- line most common

Rock Name -- Arkose

SAMPLE MC3-3

Field Relations -- Taken at 238.5 feet above the base of the measured section, near the base of unit 10. The sandstone is light gray in color and the sample is from a basal scour below medium scale, trough-shaped sets of cross-stratification.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

46% Total Quartz

43.7% monocrystalline -- anhedral, well rounded, subequant, with moderately to strongly undulose extinction -- minor inclusions (tourmaline?) present along fractures -- no overgrowths.

2.3% polycrystalline -- subangular to subrounded, greater than 5 crystals per grain -- contacts are sututed or cockscomb -- few inclusions, little alteration.

7% Total Feldspar

Tr Plagioclase -- subhedral, subangular, very fine grained -- composition ranges from An_{34} to An_{40}, averages An_{38} or Andesine -- alteration variable from minor clays in small intragranular blebs to complete replacement by calcite with relict twinning preserved.

0.7% microcline -- subhedral, subrounded, fine grains -- variable degrees of alteration, all to clays.

6.3% orthoclase -- subhedral, subrounded, fine grains. Possibly some orthoclase overgrowths - very little other alteration.

29% Chert

Primary chert is difficult to distinguish from possible secondary silicification of lithic fragments. Very finely crystalline, greater than 10 crystals per grain -- crystals are much less than 0.1 mm in diameter -- no alteration observed.

16% Lithic Fragments

15.2% volcanic -- similar to those in other samples -- alteration is in the four stages as described in text.

0.3% argillaceous -- very fine, dark green grain -- partially replaced by calcite.

1% Opaques

Probably magnetite, similar to previously described opaques.

Tr Other Minerals

Probably zircon and hornblende.

Fabric

Average diameter - 1.2 mm

Sorting - poor

Roundness - subangular to subrounded

70% Detrital grains (as percent of rock)

30% Cement

29.4% Carbonate - very coarsely crystalline, poikilotopic

0.6% Silica - probably opaline silicate cement, partially replaced by calcite.

Textural Maturity - submature

Grain Contacts - line greater than point, indicating that unrecognized quartz overgrowhts may occur.

Rock Name - Calcareous Tuffaceous Litharenite

SAMPLE MC3-4

Field Relations - Taken at 334.5 feet above the base of the section. The sandstone is green, has medium scale wedge shaped sets of planar cross-stratification which grades laterally into ripples. There is a very small amount of carbonaceous trash associated with it.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

57% Total Quartz

45.6% monocrystalline -- anhedral, subangular, with straight to moderately undulose extinction, minor inclusions and vacuoles evenly distributed within the grains.

11.4% polycrystalline -- 5 to 1 crystals per grain, with sutured crystal to crystal contacts -- grains are subrounded.

34% Total Feldspar

1.7% plagioclase -- subhedral angular -- composition range is An_{28} to An_{38}, average composition being near An_{38}, or Andesine -- major alteration is replacement by calcite, with relict plagioclase twinning preserved.

1% microcline -- subhedral, subangular, very fine grains -- slight clay rim alteration.

31.3% orthoclase -- subhedral, subrounded, similar in size to quartz -- orthoclase overgrowths -- very little alteration to clays.

8% Lithic Fragments

Volcanic - isotopic, glassy, originally tuffaceous material -- recrystalization to polycrystalline silica has occurred in approximately 40% of the grains - no other lithic fragments.

Tr% Chert

Greater than 10 crystals per grain -- subrounded, similar in size to quartz.

2% Clays

Occur as a very thin band parallel to bedding -- green/brown in color, deformed around coarser detrital grains.

Tr% Opaques

Widely disseminated black grains, similar to those described in other sections -- probably magnetite.

1% Other Minerals

Predominant minerals are hornblende, zircon or sphene -- all are subrounded.

Fabric

Average Diameter - .1 mm

Sorting - moderate

Roundness - subrounded

75% detrital grains

24% cement -- all carbonate cement. Very finely crystallized, but small areas are coarsely crystalline and poikiolotopic.

Tr matrix - finely disseminated clays, near the clay band described above.

Textural maturity - submature

Grain contacts - point greater than line

Rock name - Calcareous Arkose

SAMPLE MC4-1

Field Relations - Taken 227.5 feet above the base of section MC4. Sandstone is light tan, has medium scale trough shaped sets of cross-stratification with numerous red clay rip-ups at the base of the stratification.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

85% Total Quartz

72.2% Monocrystalline -- anhedral, subrounded, with moderately undulose extinction and slight discontinuous fracturing -- Quartz overgrowths on 5% of these grains, but are probably more common.

12.8% polycrystalline - shape similar to monocrystalline -- 5 to 7 crystals with sutured contacts, per grain -- possible recrystallization from a more finely crystalline silicate material is occurring.

6% Total Feldspar

Tr Microcline -- 2 very small euhedral grains.

6% Orthoclase -- subhedral, subrounded, similar in size to quartz -- possible orthoclase overgrowths with core grains defined by a rim of inclusions -- very little other alteration except very small clay blebs.

1% Lithic Fragments

Volcanic -- very widely distributed -- subangular, very fine-grained, isotropic -- alteration variable.

6% Chert

Subrounded, similar in size to quartz -- very finely polycrystalline with much greater than ten crystals per grain -- crystal to crystal contacts are cockscomb.

Clays

Very finely crystalline, green/brown, occurs between coarser detrital grains.

Tr Opaques

Widely disseminated, very fine, probably magnetite -- similar to previously described opaques.

Tr Other Minerals

One very fine grain of fresh, unaltered biotite.

Fabric

Average diameter -- .5 mm

Sorting -- moderate

Roundness - subrounded

87% Detrital grains

12% Cement

11.75% Carbonate -- very finely crystalline, embays detrial quartz grains.

0.25% Silicate -- small areas of opaline silicate cement, partially replaced by carbonate cements where the two are in contact.

Tr - 1% Matrix -- as described in clays

Textural Maturity -- Submature

Grain Contact -- lin approximately equals concave-convex

Rock Name - Calcareous Sublitharenite

SAMPLE MC4-3

Field Relations -- Taken 284.5 feet above the base of section MC4. The sandstone is white, has glat, thick laminations and abundant gray-green mud clasts.

THIN SECTION DESCRIPTION

Detrital Components (as percent of detrital grains)

70% Total Quartz

66.5% monocrystalline -- anhedral, subangular, subequant to elongate -- moderately undulose extinction -- grain boundaries are corroded by calcite cement -- 40% of the monocrystalline grains have quartz overgrowths. 5% polycrystalline -- less than 5 crystals per grain with sututed crystal contacts -- similar in form to monocrystalline quartz.

13% Total Feldspar

Tr Plagioclase -- subhedral, angular, -- composition could not be reliably determined, but is approximately An_{34} or Andesine.

0.7% Microcline -- subhedral, subrounded, and subangular, very fine grained, alteration to clay has occurred along cleavage traces and grain boundaries -- microcline overgrowths occur on a very few grains.

12.3% Orthoclase -- subhedral, subrounded, slightly elongate -- alteration to clays has occurred along cleavage traces -- orthoclase overgrowths are present on approximately 50% of the grains.

7% Lithic Fragments

6.6% Volcanic -- very fine grained, subrounded, subelongate -- alteration has obliterated all but some very faint relict textures, those visible are vesicular with euhedral phenocrysts -- all lithic fragments have coatings of iron oxide.

0.4% argillaceous -- very fine grained, rounded, suequant, gray/green color.

6% Clays

Occur as thin, continuous, .3mm thick, layers across the sample, yellow/brown in color -- clays have a fibrous texture, oriented parallel to bedding.

3% Chert

Greater than 10 crystals per grain with sutured crystal to crystal contacts -- slight corrosion by carbonate cement.

Tr Opaques

Similar to previously described opaques, widely disseminated -- probably magnetite.

Tr Other Minerals

Biotite, subhedral, very few grains.

Fabric

Diameter -- .3mm

Sorting -- poor

Roundness -- subangular

85% Detrital grains

13% Cement

12.3% Calcite -- finely crystalline, intergranular -- has employed and corroded the detrital quartz grains.

0.7% silicate -- as rim cement between quartz grains.

2% matrix -- intergranular clays, not including the previously described clay layers.

Textural Maturity -- immature

Grain Contacts - line greater than concave-convex

Rock Name -- Calcareous Subarkose

SAMPLE MC4-4

Field Relations -- Taken at the same location as Sample MC4-3, but sandstone is dark gray and contains carbonaceous flecks.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

60% Total Quartz

57% monocrystalline -- anhedral, subrounded to well rounded, slightly elongate, moderately undulose extinction, many grains have been fractured. 3% polycrystalline -- average of 5 crystals per grain, crystal to crystal contacts are sutured - similar in size to monocrystalline quartz.

9% Feldspar

Tr Plagioclase -- euhedral, subangular, slightly elongate -- composition ranges from An_{28} to An_{47}, averages An_{36} (Andesine) -- alteration to clays along cleavage traces and grain boundaries.

Tr Microcline -- subhedral, subrounded to subangular, slightly elongate -- alteration to clays on grain boundaries.

8.9% Orthoclase -- subhedral, subrounded, slightly elongate -- very little alteration.

4% Lithic Fragments

Volcanic -- subrounded, slightly elongate, very fine grained -- 90% or more of the volcanic fragments are being replaced by opaline silica or some very finely polycrystalline silicate -- degree of replacement varies throughout the sample -- very little relict texture remains.

20% Clays

Red/brown in color, occurs in bands approximately 4.0 mm thick across the slide -- these bands are parallel to bedding and separated by zones of greater apparent porosity.

4% Chert

Subrounded grains with greater than 10 crystals per grain -- clear with very few inclusions -- approximately one-half of the grains are recrystallizing to a coarser phase.

Tr Opaques

Widely disseminated, black grains -- probably magnetite with very minor amounts of carbonaceous material.

Fabric

Diameter -- 0.3 mm

Sorting -- Poorly sorted

Roundness -- rounded

60% Detrital Grains (as percentage of rock)

20% Carbonate cement -- calcite as both finely crystalline intergranualr and poikiolitopic cements.

19% matrix - clays as described previously

1% pore space

Textural Maturity - immature

Grain Contact - line greater or equal to point greater than floating

Rock Name - Calcareous Subarkose

SAMPLE MC4-5

Field Relations -- Same location as sample MC4-4, but taken 100 feet north. Sandstone is flat, thin bedded, gray in color.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

78% Total Quartz

70% monocrystalline -- anhedral, subrounded, slightly elongate, slight to moderately undulose extinction -- grains are fractured and contain sparse cacuoles -- quartz overgrowths on approximately 50% of the monocrystalline grains.

8.0% polycrystalline -- average 5 crystals per grain with sutured crystal to crystal boundaries -- similar in size and shape to monocrystalline grains.

5% Total Feldspar

0.3% microcline -- very fine grained, anhedral, subangular -- alteration to clays along grain boundaries, serrate grain boundaries due to corrosion by calcite cement.

4.7% Orthoclase -- subhedral, subrounded, subelongate -- very little alteration -- orthoclase overgrowths on at least 5% of the total orthoclase grains.

7% Lithic Fragments

7% Volcanic - very fine grained, subhedral and euhedral phenocrysts in a galssy matrix -- 2 types of alteration, 75% of the grains have devitrified with a slight oxide staining -- the remaining 25% are undergoing replacement by a very finely polycrystalline silicate which in turn is partly replaced by calcite.

4% Clays

Occur as clasts which are deformed around other detrital grains -- color is green/brown.

3% Chert

Much greater than 10 crystals per grain with sutured crystal contacts -- a small number of grains are being partially replaced by calcite.

2% Opaques

Black, euhedral, metallic luster -- probably magnetite.

Fabric

Diameter - .4 mm

Sorting -- moderate

Roundenss - subrounded

85% Detrital grains (as percentage of rock)

10% Cement -- calcite as a finely crystalline intergranular material

3% Matrix -- very fine clay coating on grains

2% pore space

Textural maturity -- submature

Grain Contacts -- line equalt concave-convex is greater than point

Rock Name -- Calcareous sublitharenite

SAMPLE MC5-1

Field Relations -- Taken 133 feet above the base of the measured section from a pale gray, ripple cross-laminated sandstone. This is near the base of the Salt Wash Member.

THIN SECTION DESCRIPTION

Detrital Components (as percent of detrital grains)

74% Quartz

67.5% monocrystalline -- andehral, subangular, elongate -- moderately undulose extinction -- quartz overgrowths with boundaries corroded by calcite cement.

7.5% polycrystalline -- number of crystals per grain ranges from less than 5 to 9 -- sutured crystal contacts -- shape similar to monocrystalline.

8% Feldspar

0.8% microcline -- subhedral to anhedral, subangular -- very little alteration of grains -- grain boundaries are corroded by calcite cement.

7.2% orthoclase - subhedral, subrounded -- very little alteration -- size similar to quartz grains.

7% Lithic Fragments

Volcanic -- very fine grains subangular, elongate, brown, glassy with relict phenocryst outlines -- alteration to clay rim and oxides with slight corrosion by calcite cement on rims.

Tr argillaceous fragments -- very fine grains, clay-like fragments.

2% Clays

Very fine, widely disseminated flecks.

5% Chert

Finely polycrystalline, subangular to subrounded -- grain boundaries slightly corroded by calcite cement -- no alteration or recrystallization.

1% Opaques

Subhedral, very fine intergranular black, metallic flakes -- probably magnetite.

1% Other Minerals

Tr -- .5% eugedral biotite -- very fine

Tr hornblende -- very small, identification uncertain.

Fabric

Average diameter -- 0.25 mm

Sorting -- moderate

Roundness -- subangular

75% detrital grains

25% Cement -- all calcite, very finely crystalline intergranular material.

Tr Matrix

Textural maturity -- submature

Grain contacts -- point equals line contact

Rock Name -- Calcareous sublitharenite

SAMPLE MC5-3

Field Relations -- Taken 277.5 feet above the base of the measured section from a series of thinly interbedded red siltstones and brown sandstones. This interval contains burrows and carbonaceous plant fragments. The siltstone is more abundant than sandstone.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

70% Quartz

66.5% monocrystalline -- anhedral, angular, moderately to strongly undulose -- approximately one-half of the monocrystalline grains are mottled or fractured -- grain boundaries corroded by calcite cement.

3.5% polycrystalline -- 508 crystals per grain -- cockscomb crystal to crystal contacts -- grains are anhedral, rounded with corroded boundaries due to calcite cement.

12% Feldspar

Tr Plagioclase -- subhedral, angular -- composition of one observed grain is An_{28} (oligoclase) -- relatively fresh, unaltered.

2.5% Microcline -- subhedral, subangular -- minor alteration to clays along grain boundaries -- small areas of grains replaced by calcite.

9.5% Orthoclase -- similar to microcline -- very little alteration.

8% Lithic Fragments

7.2% Argilaceous -- calcareous, well rounded, light brown, very finely granular fragments occur in elongate masses.

0.8% volcanic -- glassy, no structures or mineralogies could be observed -- subangular.

1% Clays -- widely disseminated, very minor quantities -- light brown green, finely crystalline.

5% Chert -- very finely crystalline, subrounded to subangular -- little alteration -- corrosion of grain boundaries by calcite cement.

2% Opaques -- subhedral, subrounded -- occurs in linear zones 1 or 2 grains in thickness extending the length of the slide -- black, metallic -- probably magnetite.

1% Other Minerals -- trace of mica, variety not determined due to small size, trace hornblende.

Fabric

Average diameter -- .25 mm

Sorting -- moderate

Roundness -- subrounded

70% Detrital grain

25% Cement -- calcite, finely to coarsely crystalline intergranular cement.

5% Matrix -- mainly a pseudomatrix derived from the argillaceous fragments.

Textural maturity -- mature

Grain Contacts -- Point greater than line

Rock Name -- Calcareous Sublitharenite.

SAMPLE MC5-4

Field Relations -- Taken 392 feet above the base of section MC5-4 from wedge shaped sets of planar cross-stratification. The sandstone is green in color and contains clasts of gray mud which contains carbonaceous material.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

75% Quartz

71.25% Monocrystalline -- anhedral, subrounded, moderately undulose extinction -- numerous vacuoles and inclusic oriented parallel to fractures in grains -- well defined quartz overgrowths on most grains.

3.75% Polycrystalline -- 5-7 crystals per grain, sutured crystal to crystal contacts -- very clear, few inclusions -- subrounded, elongate to subequant.

7% Feldspar

0.7% microcline -- euhedral to subhedral, subrounded -- clay alteration rims grains, and along cleavage traces.

6.3% Orthoclase -- euhedral to subhedral, subrounded -- alteration to clays along cleavage traces.

Tr Sanadine -- very low 2V of approximately 20° -- similar to orthoclase

8% Lithic Fragments

Volcanics -- subrounded, isotropic, brown, crystal rich -- main phenocrysts within the fragments are euhedral, elongate feldspars oriented parallel to one another -- lithic fragments are coarser than other common detrital components - alteration is mainly oxides coating grains, probably replacement by polycrystalline silicate in a few instances.

3% Clays

1 major occurrence as a veinlet, partially removed during sample preparation -- very finely granular, green with yellow (limonite?) spots distributed throughout -- other occurrences as widely disseminated patches.

4% Chert

Subrounded, subequant, very finely polycrystalline -- crystal to crystal contacts are sutured -- grains contain dark inclusions, probably of iron oxide -- slight corrosion by calcite cement along grain boundaries.

3% Opaques

Probably magnetite, similar to that described in previous sections.

Tr Other Minerals

Mica, as discrete, widely disseminated flakes -- subjedral, very fine grains.

Fabric

Average diameter -- .25 mm

Sorting -- moderate

Roundness -- subrounded

60% detrital grains

37% Cement

7% Calcite -- intergranular, finely crystalline - embays detrial grains.

30% Syntaxial Rim Cement -- cement due to joining of quartz overgrowths as described in detrital grains.

Tr Matrix -- pseudomatrix, mainly clay clasts

2% Pore space

Textural maturity -- mature

Grain contact -- line equals concave-convex

Rock Name -- Sublitharenite

SAMPLE MC6-1

Field Relations -- Taken 237 feet above the base of the measured section from low angle wedge planar to flat bedded, light gray sandstone. In the sandstone are gray/green clay clasts up to ½ inch in diameter.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

65% Quartz

63.7% monocrystalline -- anhedral, subequant to elongate, subrounded to subangular, moderately undulose extinction to strongly undulose extinction -- grains appear fractured -- overgrowths on 8% of the total monocrystalline grains -- grain boundaries corroded by calcite cement.

1.3% polycrystalline -- 3-4 crystals per grain, similar in shape to monocrystalline quartz.

15% Feldspar

Tr Plagioclase -- subhedral, subangular, very fine grain -- composition is An_{32}, andesine -- slight alteration to clay on grain boundary.

2% microcline -- very fine grains, subhedral -- fresh, very little alteration -- embayments and saw tooth terminations caused by calcite cement.

12.5% orthoclase -- subhedral, subrounded to subangular -- no alteration, some minor orthoclase overgrowths.

0.5% Sanadine -- very low 2v, 10^{o} or less -- some very faint twinning -- similar in appearance to orthoclase.

10% Lithic Fragments

Volcanic -- subangular, isotropic groundmass with poorly defined phenocrysts, thick oxide coating on grains -- many appear to be devitritied glassy fragments -- alteration in some grains is recrystallization to an opaline cement.

15% Clay -- occurs in two forms

1. A single large clasts, light brown, well rounded which contains abundant very fine angular quartz grains -- 2-3 mm in diameter.
2. In discontinuous, bifurcating layers, parallel to bedding -- clay similar to that described above.

10% Chert -- subrounded, subequant, very finely polycrystalline, up to 0.5 mm in diameter -- no alteration -- crystal contacts are sutured.

Tr Opaques -- magnetite as described previously

1% Other Minerals

Very fine, very well rounded grains identified as Zircon.

Fabric

Average diameter -- .25 mm

Sorting -- poor

Roundness -- subrounded

70% Detrital grains

25% Cement -- all calcite, poikilotopic, embays detrital grains

5% Matrix -- pseudomatrix as described under clays of the second type of occurrence.

Textural maturity -- immature

Grain Contacts -- point far more abundant than line contacts.

Rock Name -- Calcaveous Sublitharenite

SAMPLE MC7-1

Field Relations -- Taken 377 feet above the base of the measured section from flat to very slightly inclined thin bedding in a dark gray sandstone. Green mudstone clasts occur in the sandstones.

THIN SECTION DESCRIPTION

Detrital Components (as percentage of detrital grains)

60% Quartz

57% monocrystalline -- anhedral, subrounded, slightly elongate, moderately undulose extinction -- quartz overgrowths present, but ore grain boundaries are very indistinct.

3% polycrystalline -- 3-4 crystals per grain with sutured crystal contacts -- size and shape similar to monocrystalline quartz.

15% Feldspar

Th plagioclase -- 2 grains observed -- euhedral, elongate, subangular -- composition An_{36} andesine$_2$ -- grains are being replaced by calcite with preservation of plagioclase twins.

3% microcline -- subhedral, subangular, subequant -- ragged, saw tooth embayments by calcite cement appears very fresh, unaltered.

12% orthoclase -- subhedral, subangular to subrounded -- very slight clay rim, otherwise fresh and unaltered -- a few grains have orthoclase overgrowths.

5% Lithic Fragments

Volcanic -- subrounded, elongate -- relict feldspar laths are present in a glassy matrix -- grains are heavily coated with iron oxides -- alteration similar to that described in other samples.

12% Clays

Occurs in one major "pod" as a green/brown matrix around some very fine, angular detrital quartz grains -- alteration and replacement by both calcite and silicates is occurring.

2% Chert

Subrounded, highly polycrystalline with sutured crystal contacts -- grain boundaries corroded by calcite cement.

3% Opaques

One example of a pseudomorph after pyrite within the clay described above -- is now red/brown, dull, earthy, probably hematite -- other opaques are magnetite as described previously.

2% Other Minerals

Zircon as very small, subhedral, well rounded, subequant grains -- trace amounts of hornblende and biotite.

Fabric

Average diameter -- .3 mm

Sorting -- moderate to poor

Roundness - subrounded

55% Detrital grains

33% Cement -- all calcite, poikilotopic, embays detrital grains

12% matrix as described under clays - is probably pseudomatrix

Textural maturity -- submature

Grain contacts -- point more abundant than floating which is more abundant than line contacts.

Rock Name -- Calcareous Subarkose

SAMPLE MC8-1

Field Relations -- Taken 38 feet above the base of the measured section from a gray, trough shaped set of thirty cross-bedded sandstone. This sample is taken at the Lower Member/Salt Wash contact.

THIN SECTION DESCRIPTION

Detrital Components (as percent of detrital grains)

70% Quartz

68% Monocrystalline -- anhedral, subrounded, elongate, moderately undulose extinction -- quartz overgrowths on most grains -- light coating of red/brown oxide on many grains.

2% Polycrystalline -- 4-5 crystals per grain, subrounded, straight crystal contacts -- very few grains have quartz overgrowths.

12% Feldspar

Tr Plagioclase -- extremely small, rounded grain with poorly developed twinning -- composition could not be determined.

3.5% Microcline -- subhedral, subangular -- rimmed by microcline overgrowths with very minor clay alteration on grain boundaries.

8.5% Orthoclase -- subhedral, subangular, orthoclase overgrowths are common to most grains -- very little alteration to clay.

8% Lithic Fragments

Volcanic-size similar to quartz and feldspar -- fragments are similar to volcanic described previously -- alteration is of two types -- one a slight devitritication, but still very glassy with numerous opaque brown/red (iron oxide) blebs -- the other alteration is where feldspar phenocrysts within the fragment have altered to clay but retained a lath-shaped outline within a glassy matrix.

Tr argillaceous fragments -- one dark red, very fine grained, subangular fragment -- contains numerous very small euhedral grains of a dark red/brown transluscent material -- probably iron oxide as a pseudomorph after pyrite.

4% Clays -- occurs as small, rounded, deformed red/brown clasts with intergranular very fine angular quartz -- other detrital grains penetrate the clasts.

3% Chert -- subrounded, elongate, very finely polycrystalline -- no alteration.

2% Opaques -- magnetite in well rounded, intergranular anhedral masses.

Tr Other Minerals -- probably well rounded, elongate zircon.

Fabric

Average diameter -- 0.2 mm

Sorting -- poor

Roundness -- rounded

65% Detrital grains

30% Cement

15% Finely crystalline, intergranular simicate cement.

10% Rim cement from overgrowths

5% Calcite -- finely crystalline intergranular cement with corrodes grain boundaries.

4% Matrix -- pseudomatrix has described under clays

Tr Pore Space

Textural Maturity -- submature

Grain contacts -- concavoconvex approximately equals line contact

Rock Name -- Subarkose

SAMPLE MC10-1

Field Relations -- Taken 60 feet above the base of the measured section from light pink to white, flat to very low angle tabular shaped sets of tabular thinly cross-bedded sandstone. This is just below the lower member/Salt Wash contact.

THIN SECTION DESCRIPTION

Detrital Components (as percent of detrital grains)

80% Quartz

72% Monocrystalline -- anhedral (subrounded, moderately undulose extinction -- most grains rimmed by a dark brown (oxide) coating -- grains in contact with calcite cement are corroded by the calcite.

8% polycrystalline -- 8-10 crystals per grain with sutured crystal contacts -- size and shape similar to that of monocrystalline quartz.

8% Feldspar

Tr Plagioclase -- 1 grain, subhedral, subrounded, much finer than the quartz (less than 0.1 mm) -- composition is An_{43}, Andesine.

1% microcline -- subhedral, subrounded -- fresh, light oxide coating on grain boundaries.

7% orthoclase -- subhedral, subrounded -- similar to microcline.

5% Lithic Fragments

Volcanic -- subrounded, slightly glassy with very few relict structures -- fragments are being replaced by a crystalline silica -- abundant oxides (iron) as grain coating and intergranular blebs.

1% Clay

Very small amounts as disseminated intergranular material.

4% Chert

Subrounded, finely polycrystalline -- green under plain light -- no alteration.

Tr Opaques

Magnetite, similar to previous descriptions.

Tr Other Minerals

1 probably zircon grain -- very well rounded, elongate.

Fabric

Average diameter -- 0.15 mm

Sorting -- well sorted

Roundness -- rounded

60% Detrital grains

20% Cement

10% Calcite -- poikilotopic, coarsely crystalline

5% Hematite -- widely disseminated

5% Silicate -- small patches which are being replaced by the calcite cement.

20% Pore Space -- a few percent of the pore space may be due to plucking of detrital grains and cement during sample preparation.

Textural Maturity -- mature

Grain contacts -- point contact is the most common

Rock Name -- sublitharenite

APPENDIX 3

ANALYTICAL METHODS

EXPLANATION OF MARKOV CHAIN MATRICES

The premise on which the Markov chain operates is that the probability of one type of sedimentary structure being overlain by the same or a different type of structure can be determined by inspection of a matrix which records the number of times each possible transition occurs. Figure 32 A is the tally matrix with the numer of occurrences of transitions plotted directly. Included is the total number of occurrences of each individual row. Figure 32 B shows the same matrix recomputed to give the probability (as a decimal fraction of the row sum).

As an example, the probability that flat stratification overlies trough cross-stratification is .35, while the probability that siltstone/covered overlies trough cross-stratification is .46. This indicates that it will be more common to have a siltstone/covered interval overlying the trough cross-stratification than it will be to have flat intervals.

By selecting a starting point either randomly or by inspection to determine the most common initial structural type and then using the matrix to find the structures which appear to overlie the initial structure most often, it is possible to get a sequence of structural types which may give the most probable vertical succession.

To test the "typical" sequence against the other possible sequences a tree diagram (figure 33) is constructed and the probability computed for each possible sequence, provided that each sequence has the same number of transitions in it as do the others.

From figure 33 it can be seen that the sequence trough, covered, rippled has a higher probability (.18) than does trough, covered, trough (.14). Other possible sequences are illustrated, all of which show a lower probability of occuring than does the initial sequence above. It appears that for the data and arrangement of sedimentary structures in Montezuma Canyon that the most common, or preferred, sequence of structures and lithologies should be trough cross stratified sandstone overlain by a covered interval/siltstone, overlain by a ripple cross-stratified sequence as illustrated in figure 14.

	Rippled	Planar	Trough	Wedge	Siltstone/ covered	Total/Row
Rippled	0	8	8	4	14	34
Planar	5	17	28	7	22	79
Trough	11	30	30	17	39	127
Wedge	0	9	18	4	12	43
Siltstone/ covered	17	20	43	7	6	93

Table A is the transitions Matrix as compiled from the sum of the total of Sections MC1, through MC10.

Rippled	0	.24	.24	.12	.41
Planar	.06	.22	.35	.09	.28
Trough	.09	.24	.24	.13	.31
Wedge	.00	.21	.42	.09	.28
Siltstone/ covered	.18	.22	.46	.08	.06

Table B is a recomputation of Table A so each row sums to one, thereby giving the probability of the row structure following a column structure.

Figure 32

TREE DIAGRAM

	.46	Covered	.41	Rippled	=	.18
			.31	Trough	=	.14
Trough	.42	Wedge	.13	Trough	=	.05
			.12	Rippled	=	.05
	.35	Planar	.24	Rippled	=	.08
			.24	Trough	=	.08

Figure 33

CRITERIA FOR EVALUATION OF PALEOCURRENT ROSE DIAGRAMS

The following criteria are used to enhance the modal class of the paleocurrent rose diagrams and determine a unique paleocurrent direction.

I. To reinterpret lineations to a unique current direction;

   A. the dominant direction of the unique current indicators is determined and the current lineations are plotted to enhance the unique current indicators.

II. To determine a paleocurrent direction from the paleocurrent rose diagram;

   A. plot a line segment which is oriented approximately perpendicular to the primary mode and which;

   B. eliminates the fewest (apparently significant) large scale current measurements

   C. determine the current direction which is normal to the line segment in II. A., above.

PROCEDURE USED IN CLAY PREPARATION AND ANALYSIS

The samples, after being coarsely crushed with a hammer, are ground in a mortar and pestle, sieved in a 200 mesh (75 u) sieve, boiled in a solution of EDTA to remove carbonate, sonically disaggregated, and allowed to settle. After setting for the appropriate time, a sample of the 2u or smaller fraction is removed and sedimented slides are prepared for each sample and allowed to air dry.

Four runs of each sample are analyzed; air dried, glycolated for one hour at 60°C, heated to 375°C for at least one hour, and heated to 550° - 600°C for several hours to verify the occurrence of chlorite. The following settings are used on the instrument.

Radiation/Filter	CuK
Kilovolt/millampere	40/20
Slit	1-4-1
Counts per second	1×10^4
Standard deviation	3%
Time constant	.1 or .2 seconds
Scan rate	2°/min.
Chart rate	1 inch/min.

Scans covered from 2° to 35° 2 Theta

The method by which the samples are analyzed to calculate relative percentages is from McLafferty (1979) as modified from Hohns, Gime, and Bradley (1954). The method uses peak heights rather than peak area and is arrived at through the following calculations.

$T = Ih + K_1$

$I = Ig/T$

$M = Mg/4T$

$Mx = Ih/T - I - M$

$K = K_1/T$

Ih = heated Illite peak height at 10 Å at 375°

K_1 = kaolinite peak height at 7.15 Å

Ig = glycolated peak height at 10 Å of Illite

Mg = glycolated peak height at 17 Å of Montmorillonite

I = calculated proportion of Illite

M = calculated proportion of Montmorillonite

M_x = calculated proportion of mixed layer clays

K = calculated proportion of kaolinite

Calculated proportions are in parts per one and are multiplied by ten to produce proportions in parts per ten. Results are reported to the nearest whole percent.

This dissertation is accepted on behalf of the faculty of the

Institute by the following committee:

Adviser

May 16, 1980

Date