UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

The Depositional Environment and Petrology of the White Rim Sandstone Member of the Permian Cutler Formation, Canyonlands National Park, Utah

by

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ABSTRACT

The White Rim Sandstone Member of the Cutler Formation of Permian age in Canyonlands National Park, Utah, was deposited in coastal eolian and associated interdune environments. This conclusion is based on stratigraphic relationships primary sedimentary structures, and petrologic features. The White Rim consists of two major genetic units. The first represents a coastal dune field and the second represents related interdune ponds. Distinctive sedimentary structures of the coastal dune unit include large- to medium-scale, unidirectional, tabular-planar cross-bedding; high-index ripples oriented parallel to dip direction of the foresets; coarse-grained lag layers; avalanche or slump marks; and raindrop impressions. Cross-bedding measurements suggest the dunes were deposited as transverse ridges by a dominantly northwest to southeast wind. Distinctive sedimentary structures of the interdune pond unit include wavy, horizontally laminated bedding, adhesion ripples, and desiccation polygons. These features may have been produced by alternate wetting and drying of sediment during water-table fluctuations. Evidence of bioturbation is also present in this unit.

Petrologic characteristics of the White Rim helped to define the depositional environment as coastal. A crinoid fragment was identified at one location; both units are enriched in heavy minerals, and small amounts of well rounded, reworked glauconite were found in the White Rim throughout the study area.

Earlier work indicates that the White Rim sandstone is late Wolfcampian to early Leonardian in age. During this time, the Canyonlands area was located in a depositional area alternately dominated by marine and nonmarine environments. Results of this study suggest the White Rim represents a coastal dune field that was deposited by predominantly on-shore winds during a period of marine transgression.

INTRODUCTION

The White Rim Sandstone Member of the Cutler Formation of Permian age was studied within the boundaries of Canyonlands National Park, Utah (fig. 1). Baker and Reeside (1929, p. 1444) named the White Rim Sandstone Member for exposures of a prominent, light-colored, cliff-forming sandstone bench located between the Green and Colorado Rivers. Early workers such as Baker (1946, p. 48), Heylmun (1958, p. 1810), and Hallgarth (1967a, p. 187) considered the White Rim to be largely of eolian origin. More recently, Baars and Seager (1970, p. 716) concluded that it was almost entirely of shallow marine origin. In order to resolve this conflict, a detailed study of the White Rim was completed in the area between the Green and Colorado Rivers. Stratigraphic relationships, sedimentary structures, and petrology were utilized in order to reconstruct the geologic history of the White Rim.

The study began in 1979 and extended through 1980 as a project for partial fulfillment of a master of science degree at the Colorado School of Mines, Golden, Colorado. Work was conducted in cooperation with and funded by the U.S. Geological Survey. The author wishes to acknowledge the encouragement and support extended by J. A. Campbell of the U.S. Geological Survey; Harry C. Kent and Richard H. DeVoto of the Colorado School of Mines; and Donald L. Baars, consultant. The author also wishes to acknowledge the field assistance of Karen J. Franczyk during the summer of 1979.

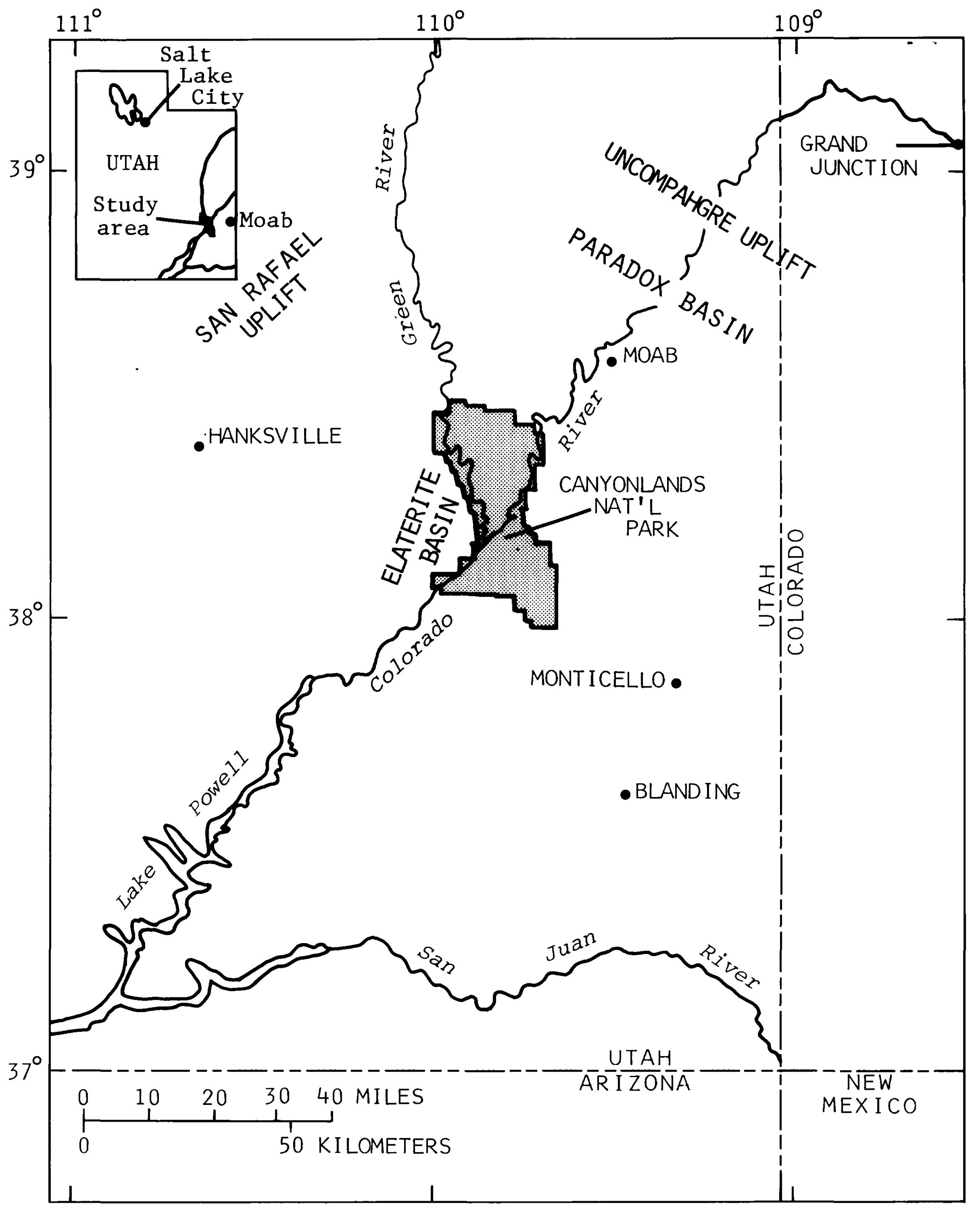

Figure 1. Index map of Canyonlands National Park and surrounding area.

METHODS OF STUDY

Excellent exposures of the White Rim Sandstone Member crop out in canyon walls of the Green and Colorado Rivers. Limited access to outcrops is via the White Rim trail, a primitive jeep trail, as shown on figure 2. Twelve complete and two partial stratigraphic sections were measured, described, and sampled. Stratigraphic sections were spaced in order to attain maximum coverage of the White Rim throughout the study area (fig. 2). Even though exposures of the White Rim in the park are excellent, working access to full sections of the member is limited because of its tendency to form steep cliffs.

In the course of measuring and describing stratigraphic sections, particular emphasis was placed on the examination and description of primary sedimentary structures in the White Rim Sandstone Member. The size, orientation and morphology of the structures were described in detail. Orientations of dip directions of cross-bed sets were plotted on equal-area rose diagrams and resultant vectors calculated. Local and regional geologic relationships of the White Rim to adjacent stratigraphic sequences were also noted. Appendix A contains written descriptions of the measured sections; Plate 1 is a stratigraphic section showing graphic representations of these sections; and Plate 2 shows the locations of cross bed measurement and their rose diagrams.

At each measured section the dune and interdune genetic units of the White Rim Sandstone Member and the stratigraphic sequences overlying and underlying the White Rim were sampled. A detailed petrographic examination was made of 107 thin sections from the rock samples collected. Special attention was paid to textures, mineralogy, and diagenetic features. Information obtained from these thin sections proved helpful in determining relationships within and between measured sections and in making environmental interpretations. Thin section data appear in Appendix B.

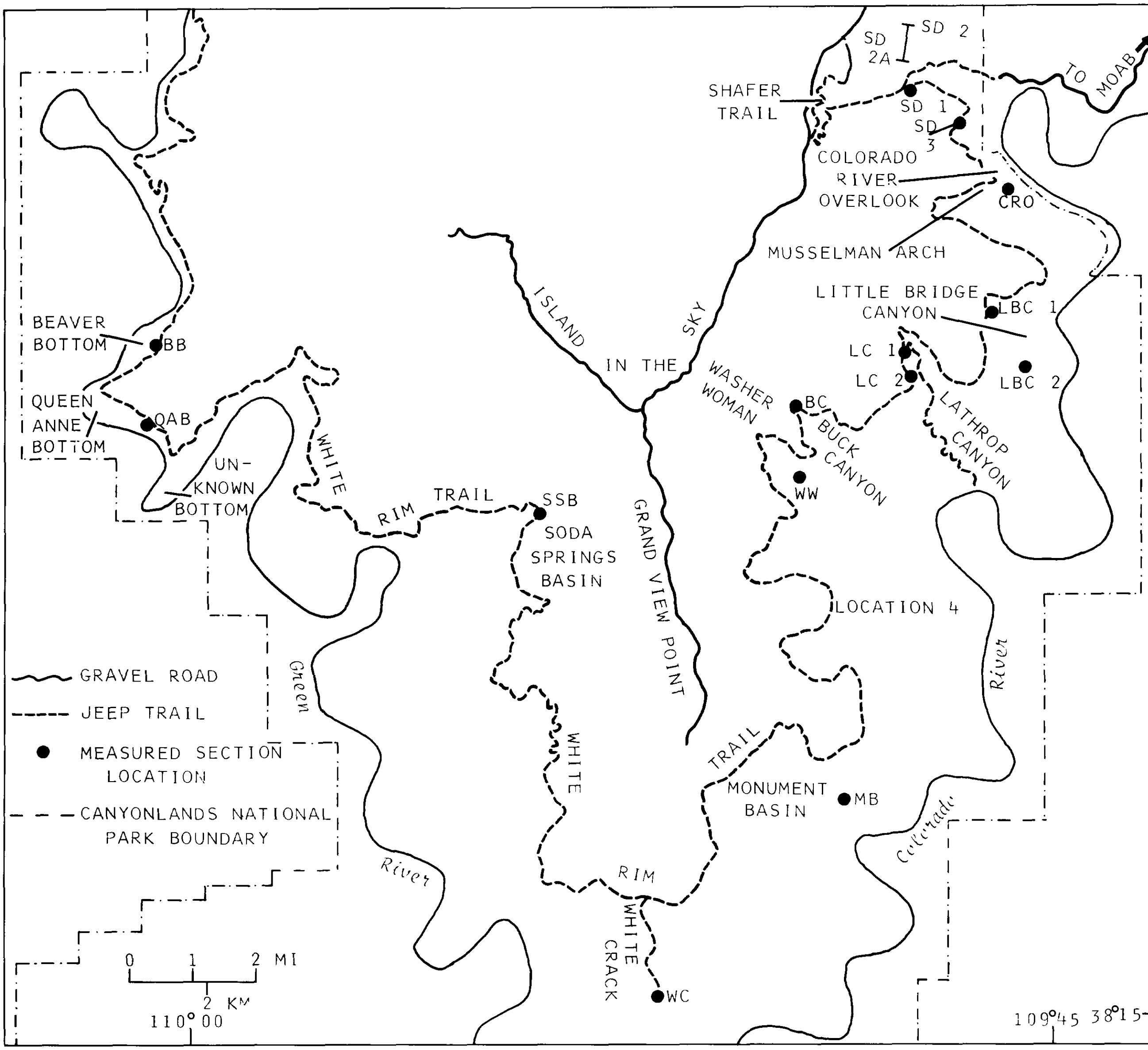

Figure 2. Detailed map at study area showing locations of measured sections.

GEOLOGIC SETTING

Rocks of Pennsylvanian to Jurassic age are exposed in Canyonlands (fig. 3). Permian rocks of the this area consist mainly of arkoses, sandstones, siltstones, and limestones deposited in both marine and nonmarine environments. Throughout much of the Early Permian the Uncompahgre uplift (fig. 1) contributed large amounts of detrital material to the area, resulting in a thick accumulation of clastic material adjacent to the uplift, the undifferentiated Cutler Formation. At the same time, marine sedimentation was prevalent further west. In the Canyonlands region, sediments deposited in both terrestrial and marine environments interfinger (Baars and Molenaar, 1971, p. 28). The Rico Formation, and the Organ Rock Shale, Cedar Mesa Sandstone and White Rim Sandstone Members of the Cutler Formation are units deposited in these alternating environments. Late Permian through Early Triassic time is represented by an unconformity.

During the Permian-Pennsylvanian the Canyonlands region underwent a period of orogenic activity. Major structural features formed include the northwest-southeast trending Uncompahgre uplift and the adjacent, parallel-trending Paradox basin (fig. 1). The eastern pinchout of the White Rim closely parallels the western flank and northern plunge of the Monument upwarp (fig. 4) indicating that this structural feature may have been active (Baars, 1979, p. 6).

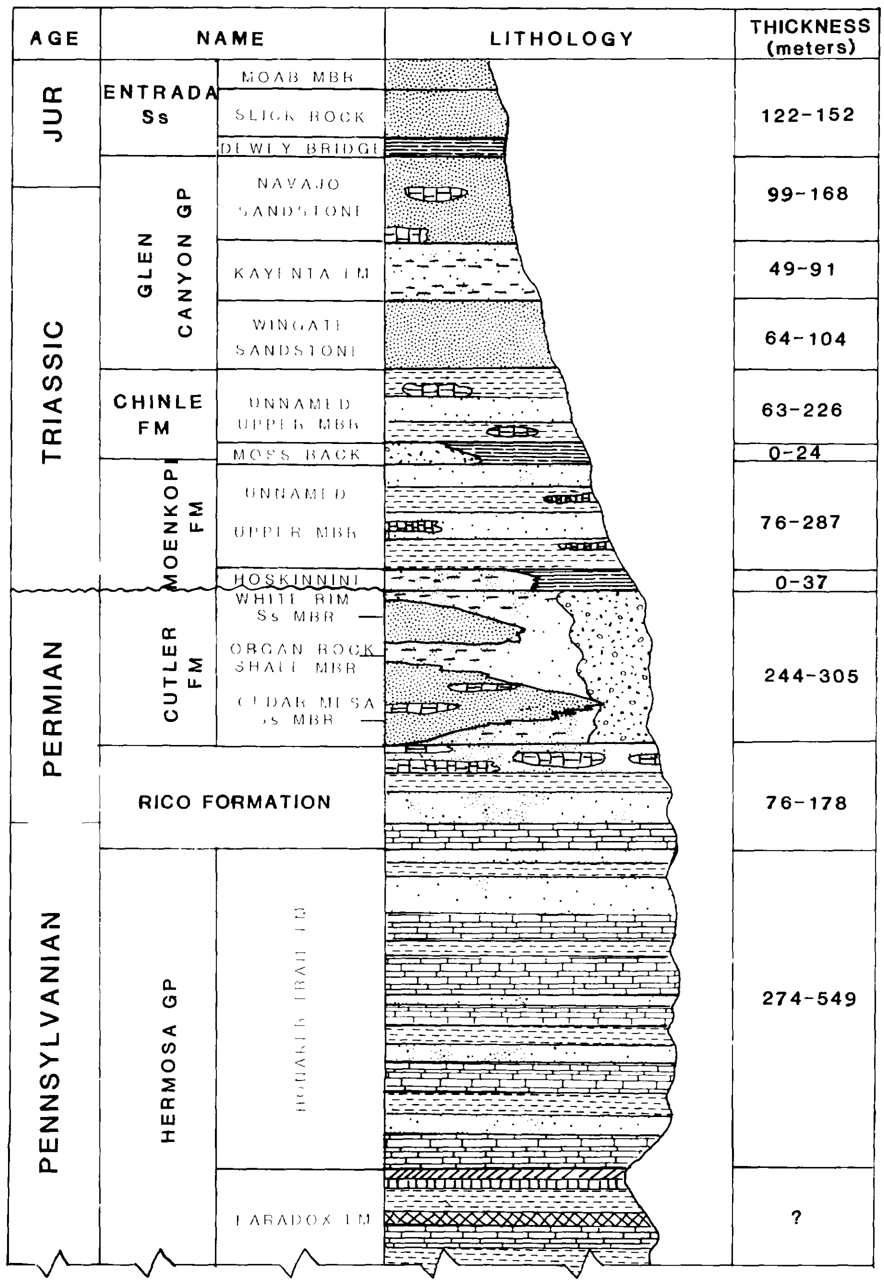

Figure 3. Generalized stratigraphic column of Canyonlands National Park. (Modified from Lohman, 1974)

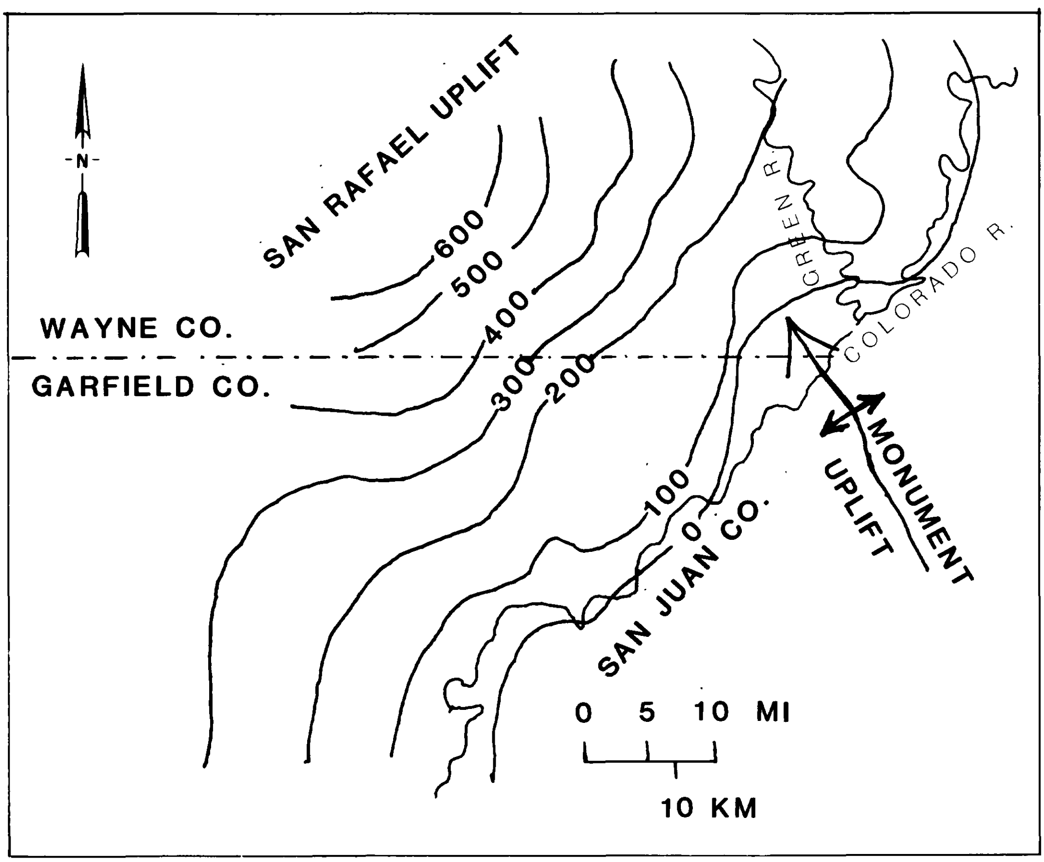

Figure 4. Isopach map of White Rim Sandstone Member (modified from Baars and Seager, 1970).

STRATIGRAPHIC RELATIONSHIPS

The White Rim Sandstone Member forms an elongate northeast-southwest-trending sandstone body (fig. 4) which abruptly pinches out eastward into the Organ Rock Shale Member (fig. 5) and gradually dips to the northwest where it thickens to an estimated 725 feet (Baars and Seager, 1970, p. 711). The White Rim is underlain west of the study area by the Cedar Mesa Sandstone Member (fig. 5) and south of the study area by the De Chelly Sandstone Members of the Cutler Formation (Irwin, 1971, p. 1989). The White Rim, Cedar Mesa, and De Chelly are all light-colored, massive sandstone bodies making the contacts between them difficult to distinguish in both lithologic logs and cores.

Where the White Rim is underlain by the Organ Rock Shale Member the contact between the two is sharp and distinct. The Organ Rock consists mostly of interbedded silty sandstones and shales. Baars and Molenaar (1971, p. 41) consider the depositional environment of the Organ Rock to be fluvial and flood plain. In the southern and western part of the study area the White Rim may be underlain by the Cedar Mesa Sandstone Member of the Cutler Formation. The rock units below sections MB, WC and WW (fig. 2 and Plate 1) are more massively bedded and contain less shale than the Organ Rock Shale Member and distinct burrows were observed at section WW (fig. 2 and Plate 1). A near-shore marine to coastal eolian depositional environment for the Cedar Mesa is proposed by Baars (1962, p. 178). The top portion of both units is often intensely altered and bleached, possibly due to a short period of subaerial exposure before the deposition of the White Rim.

The upper boundary of the White Rim is typically sharp and distinct but irregular. This irregularity is largely depositional and is related to the eolian nature of the White Rim. Also, the top portion of the White Rim near sections SD1 and SD3 (fig. 2) contains thin deposits of very coarse-grained to granule-sized material that is parallel laminated and graded.

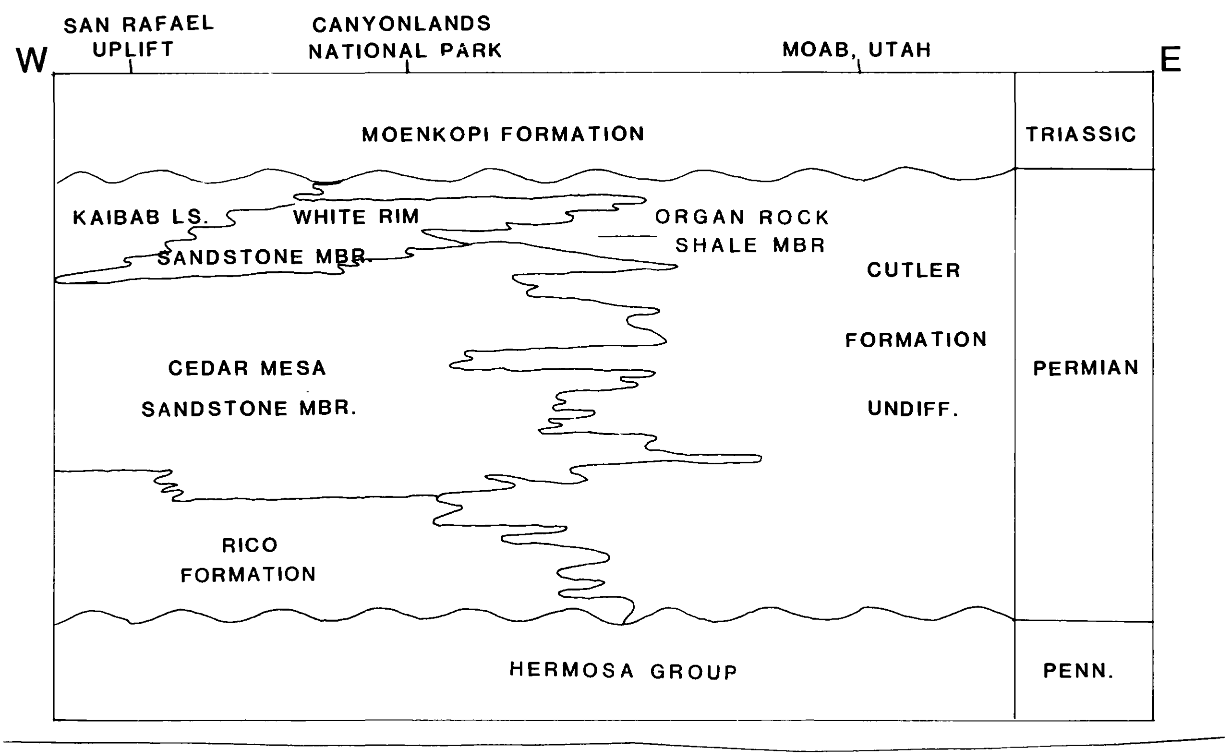

Figure 5. Generalized east-west stratigraphic section, Canyonlands National Park and surrounding area. (Modified from Baars and Seagar, 1970)

In the Canyonlands area the White Rim is overlain by an unnamed sandstone unit of the Cutler Formation. This unnamed unit is a massively bedded, poorly sorted, arkosic sandstone that appears to be bioturbated. Little has been written on this unit, however, Kunkel (1958, p. 167) suggests an origin similar to the Organ Rock Shale Member. The unnamed unit is not laterally persistant. Southwest of Elaterite Basin (fig. 1) the Triassic Moenkopi Formation contains a basal conglomerate and is unconformably underlain by the White Rim (Baars and Seager, 1970, p. 710), suggesting the Permian-Triassic boundary is at the top of the White Rim in some areas.

The most widely accepted facies equivalents of the White Rim are the gamma member of the Kaibab Limestone and the upper part of the Toroweap Formation (Kunkel, 1958, p. 167; Heylmun, 1958, p. 1795; Hallgarth, 1967a, p. 187; Baars and Seager, 1970, p. 718; and Irwin, 1971, p. 2005). The Toroweap consists of sandstones, carbonates and evaporites, all lithologies that suggest a restricted marine depositional environment (Hallgarth, 1967a, p. 189). The overlying gamma member of the Toroweap contains invertebrate marine fauna and has a high magnesium content. McKee (1954, p. 21) suggests that depositional environment for this unit is also restricted marine.

ECONOMIC GEOLOGY

The White Rim Sandstone Member has major petroleum reserves and contains the largest tar sand deposit in the United States (Ritzma, 1980, p. 774). Campbell and Ritzma (1979, Table 2) have estimated the tar sands may contain up to 16,000 million barrels of oil in place. These deposits are found west of the study area in the Elaterite basin region (fig. 1) and are either part of national park land or proposed wilderness areas. The oil is trapped by the updip pinchout of the White Rim on the northwest plunge of the Monument upwarp (Campbell and Ritzma, 1979, p. 15). According to Baars and Seager (1970, p. 717), the most likely source for the petroleum is the Permian Kaibab Limestone because of its stratigraphic position adjacent to the White Rim.

The White Rim also has been studied for uranium potential in the San Rafael Uplift area (fig. 1) by Mickle and others (1977, p. 1). A few anomalies were found related to asphaltite-impregnated sandstone along faults and fractures. They consider the White Rim generally unfavorable for economic uranium deposits due to lithologic characteristics, distance from a possible source of uranium, and lack of any apparent mineralization.

FIELD OBSERVATIONS

The White Rim Sandstone Member can be divided into two genetic units; a dune unit and a related interdune unit. Weimer (1975, p. 9) defines a genetic unit as "...a deposit resulting primarily from the physical and biological processes operating within the environment at the time of sedimentation." The dune genetic unit was deposited by eolian processes while the interdune genetic unit was deposited by a combination of both wind and water action.

The contacts between the dune and the interdune genetic units are sharp. Each of these units has a number of distinctive sedimentary structures and petrologic features which permit easy recognition in the field.

Sedimentary Structures

Dune genetic unit

Distinctive sedimentary structures in the eolian dune unit include the following: (1) large- to medium-scale, unidirectional, tabular planar cross bedding, (2) high-index ripples oriented parallel to dip direction of the foresets, (3) coarse-grained lag layers, (4) slump structures, and (5) raindrop impressions.

One of the most prominent features of the dune genetic unit is its conspicuous crossbedding which is almost entirely planar tabular with a few troughs. Thickness of the crossbed sets range from less than 1/2 m to 6 m with and average about 1.5 m. Laminations within each set are commonly concave upward; forming long, sweeping, tangential bases and the sets are separated by bounding surfaces that are nearly horizontal (fig. 6). The crossbedding is strongly unidirectional (Plate 2) having an average dip direction of S47E and an average dip angle of 22^{0}.

High-index ripples (R.I. >15) oriented parallel to dip direction of the foreset were found throughout the study area (fig. 7). Locally, the ripples extend for several meters, but more commonly extend for less than 10 cm. Because of the low amplitude of the ripples, they are best observed either during the early morning or late afternoon when the angle of the sun is low.

Coarse-grained layers occur at the base of the crossbed sets, especially in the western part of the study area. Each individual layer is about 1 mm thick and decreases in grain size upward. These layers reach thicknesses of 15.5 cm and extend for almost the entire length of the dune set. A particulary coarse example was found at Monument Basin (fig. 2) where the lower 10 to 15 cm of one crossbed set consists entirely of coarse-grained sand- to granule-size material.

Figure 6. Tablular planar crossbed sets from the dune genetic unit showing concave upward laminations forming tangential bases and a nearly horizontal bounding surface between sets, top of Beaver Bottom section. (Black line indicates bounding surface)

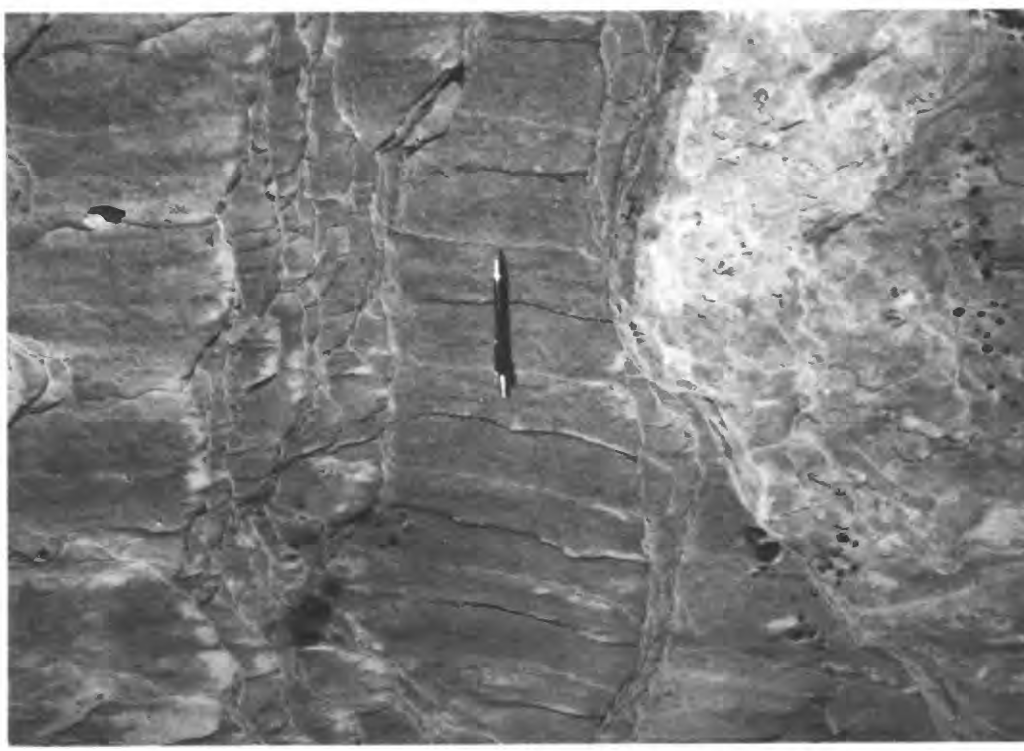

Figure 7. High-index ripples from dune genetic unit, base Queen Anne Bottom section. Ripple wavelength is approximately 5 inches (13 cm) and ripple height is approximately 1/8 inch (3 mm). (Scale: Pencil = 6 inches)

Both slump or avalanche structures and raindrop impressions were found but are much less common than other structures. Nevertheless they are important in helping determine the depositional environment of the dune genetic unit.

Interdune unit

There are four distinctive sedimentary structures in the interdune unit: (1) wavy, horizontally laminated bedding, (2) adhesion ripples, (3) desiccation polygons, and (4) bioturbation.

The most common feature of the interdune units is irregular wavy, horizontally laminated bedding (fig. 8) which typically occurs throughout the entire thickness of the unit. This type of lamination is interpreted to be the result of superimposed layers of adhesion ripples. Adhesion ripples are formed by dry sand being blown over a smooth moist surface and consist of irregular parallel running crests of sand arranged at right angles to the direction of the wind (Reineck and Singh, 1975, p. 56). Figure 9 shows an example of adhesion ripples exposed on a bedding surface.

Often, bedding surfaces show desiccation polygons (fig. 10). Polygons are 5-sided, have widths up to 1 m, and occur in sand sized material. They sometimes have raised rims but also may appear only as a bleached pattern on the bedding surface.

One example of bioturbation was observed. At Location 4 (fig. 2) the top portion of one of the interdune units has a mottled, homogeneous appearance which is considered characteristic of bioturbation (Friedman and Sanders, 1978, p. 129).

Figure 8. Wavy, horizontally laminated bedding from interdune genetic unit, slump block at base of Shafer Dome 1 section.

Figure 9. Plan view of adhesion ripples from interdune genetic unit, near Washer Woman section.

Figure 10. Desiccation polygons on upper surface of interdune genetic unit (1) overlain by dune unit (D), Musselman Arch.

Miscellaneous primary and secondary sedimentary structures

Other sedimentary structures found in the White Rim that are not necessarily useful environmental indicators include the following: (1) liesegang banding, (2) intraformational folds, and (3) sandstone dikes.

Liesegang banding is fairly common in the White Rim Sandstone Member and is found in both the dune and interdune units. These bands generally appear as rhythmic red and yellow limonitic bands subparallel to the bedding surfaces. This secondary sedimentary structure has affected the cementation of the White Rim. The liesegang banded portions of it are more resistant and occasionally form small, pillar-like features (fig. 11).

Intraformational deformation of the White Rim occurs at several localities, including section LBC2 and near section WW (fig. 2). At section LBC2 (fig. 2) the upper portion of the White Rim is locally deformed into large-scale, gentle folds. Near section WW (fig. 2) the upper portion of the White Rim has been eroded and only the lower 2-3 m remain. At this location the beds have been broken and folded upward resulting in features resembling diapirs (fig. 12).

Figure 11. Pillar-like structure due to differential cementation as the result of liesegang banding from dune genetic unit, near Washer Woman section.

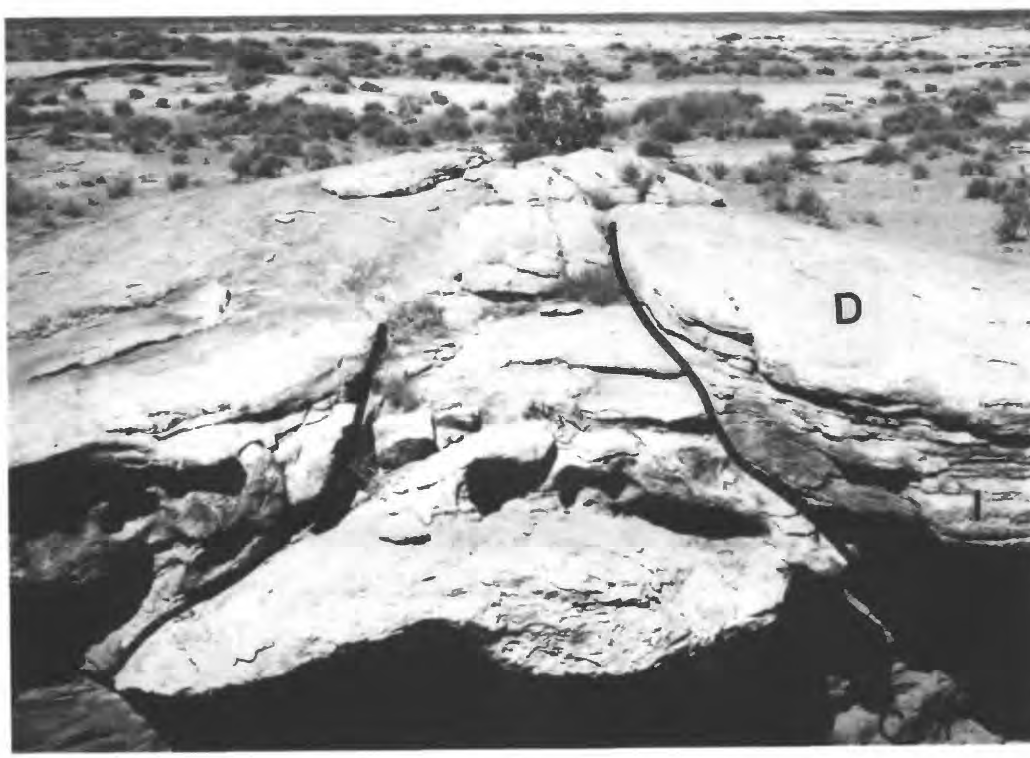

Figure 12. Diapir-like structure in the White Rim, near Washer Woman. (CM-Cedar Mesa Sandstone Member, D-dune genetic unit and I-interdune genetic unit).

Sandstone dikes are not common but were observed in the dune genetic unit at locations SD1 and WC (fig. 2). They cut the bedding but do not deform the laminations, are always sand injected into sand, and appear to have been injected from below.

Petrology

The lithology of the White Rim is fairly uniform in both genetic units. It is a fine-grained, moderately well-sorted, carbonate-cemented, quartz-rich sandstone. Most of the grains are subrounded to rounded but the original roundness of many of the grains has been masked by secondary quartz overgrowths. Frosted grains are also found in the coarser fraction.

The White Rim Sandstone Member is typically light-colored, ranging from white, yellowish-brown, and pale-green to pale-red. The dune unit and interdune unit commonly are slightly different in color. The interdune unit has a more mottled appearance and is yellower than the dune unit. Generally, the basal one foot of the White Rim is pale green. Hematite staining of the unit is uncommon but is present at several localities, especially LBC1 and LBC2 (fig. 2).

The White Rim stands out compared to the surrounding units and is one of the few light-colored units in the entire exposed stratigrahic section of Canyonlands. The underlying Organ Rock Shale Member is dark purple to maroon. The overlying unnamed upper Permian sandstone is orange-red but at several locations (BC, QAB, and BB) (fig. 2), it is bleached pale yellow to white.

Appendix B contains detailed petrographic descriptions.

Texture

The dune genetic unit consists of well to moderately-well sorted, fine- to coarse-grained sandstone with an average mean grain size of 2.26 phi (fine sand). Some of the samples taken from the coarse-grained sandstone are bimodal and show textural inversion (fig. 13). Folk (1968, p. 9) describes textural

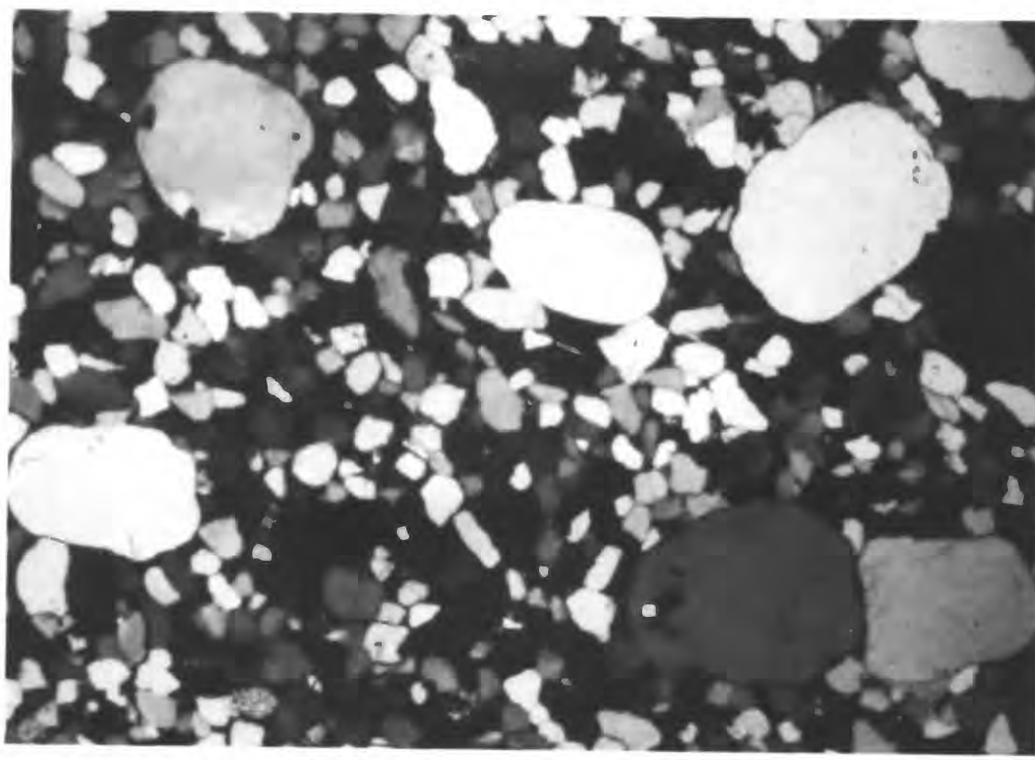

Figure 13. Textural inversion in the dune genetic unit, BB-1, Beaver Bottom section. (Field of view approx. 5.5 mm)

inversion as the occurrence of large, rounded quartz grains "floating" within finer quartz grains and considers this to be a product of deflationary eolian processes.

The interdune unit has the same textural characteristics as the dune unit except coarse-grained material is not as common. There is no significant differece between the grain size and sorting of the two genetic units.

These textural features are common to most ancient eolian sandstones and resemble those of modern dune sands although as McKee (1979, p. 191) points out, texture alone is not a valid indicator for an eolian environment. He further states that such characteristics as sorting and rounding represent inherited features and have little to do with length or manner of transport in the final depositional regime. Composition solely reflects the source of the sediment.

The units overlying and underlying the White Rim are texturally different. The underlying Organ Rock Shale and Cedar Mesa Sandstone Members are finer grained and more poorly sorted. The overlying unnamed upper Permian unit is distinct from the White Rim in that it is poorly to very poorly sorted.

Mineralogy

Both genetic units of the White Rim have similar mineralogy (Appendix B). The dominant mineral constituent is monocrystalline quartz. The other major grain constituents include: potassium feldspar (mostly microcline); polycrystalline quartz (igneous or metamorphic rock fragments); well rounded chert; and mica. Green, chloritized mica makes up enough of the basal White Rim in the eastern part of the study area to give the rock a pale green color.

Accessory minerals in the White Rim include, in order of decreasing abundance; zircon, tourmaline, apatite, glauconite, magnetite-ilmenite, garnet and possible altered pyrite. Most of the accessory minerals are very well rounded and unaltered. Both genetic units are also relatively enriched in heavy minerals. In the interdune unit, these heavies are frequently concentrated in distinct layers.

Both the underlying and overlying units are also quartz-rich and have a similar mineralogy to the White Rim. The underlying Organ Rock Shale and Cedar Mesa Sandstone Members, however, contain more mica.

Biologic constituents

Fecal pellets and one crinoid fragment were observed. The fecal pellets are confined to the interdune unit. Their preservation is poor and they are usually encased in secondary dolomite rhombohedrons. A crinoid fragment was found at the base of the WC section (fig. 3) in a conglomeratic lens (Plate 1).

Unstructured organic material (dead oil?) occurs in some of the White Rim samples; however, no identifiable biologic constituents were found in either the overlying or underlying units.

Chemical constituents

The sandstones of the White Rim are dominantly carbonate cemented with some of the carbonate recrystallized to dolomite. A very small amount of gypsum cement is present in a few of the thin sections (Appendix B). Silica cement in the form of secondary quartz overgrowths is also common in many of the samples.

Individual dolomite rhombohedra are prevalent in the interdune unit. Some of these rhombs may be of detrital origin. They occur between grains and sometimes appear to be abraded. Dolomite rhombs often are in distinct layers within the wavy, horizontally laminated unit.

The overlying unnamed Permian unit is carbonate cemented with few quartz overgrowths. The underlying units are also carbonate cemented but heavy iron staining often obscures the intergranular areas of samples.

Diagenetic features

Diagenesis has destroyed much of the original porosity of the White Rim

Sandstone Member. Quartz overgrowths are common and can make up as much as 15 percent of the total content, such as in BC-4 (Appendix B). Compaction has caused pressure solution and stylolitization, especially in sections SD1, SD2 and LC1 (fig. 2).

Clay matrix is found in many of the samples. Most of the clay appears to have formed from the alteration of feldspars and rock fragments. A small amount of authigenic clay is also present and occurs as small crystalline patches or books between grains.

The uppermost part of the underlying Organ Rock Shale and Cedar Mesa Sandstone Members is typically altered. Most feldspars have been completely destroyed, authigenic clay books are abundant, and most micas are bleached. Locally, these units are heavily iron stained.

The unnamed Permian unit overlying the White Rim is not as intensely altered as the underlying units although commonly it is iron-stained and does contain clay matrix. At two locations BC and BB (fig. 2) the unit is bleached to pale yellow and is difficult to distinguish from the overlying White Rim. Bleaching is most likely related to petroleum migration in the White Rim.

DISCUSSION

Interpretation of Depositional Environments

Unlike many other depositional environments, no single facies model exists for eolian systems. This is due to the tendency for an irregular and unpredictable distribution of dune types in the eolian evironment, resulting in no preferred vertical sequences of sedimentary structures or any consistent lateral changes (Walker, 1979, p. 40). According to McKee and Bigarella (1979b, p. 191), there are two criteria by which ancient eolian deposits may be determined. One is the presence of features that are distinctive of modern eolian environments. The other is the presence of features that are compatible with an eolian environment but are not definite proof of wind deposition.

Glennie (1970, p. 12), Bigarella (1972, p. 12) and McKee and Bigarella (1979a, p. 89) list a number of different features of wind-deposited sediment. These are the more important ones:

1. Sets of medium- to large-scale tabular planar or wedge planar foresets that dip downwind at angles from 29^{o} to 34^{o}. In ancient eolian sandstones this angle tends to be less due to compaction and/or removal of uppermost part of the dune. Trough cross beds may also occur but are less common.

2. Cross-bed sets are separated by bounding surfaces that are either horizontal or inclined at low angles.

3. High-index ripples, R. I. >15, oriented parallel or subparallel to the dip direction of the foresets.

4. Boundaries of eolian deposits are usually abrupt and they normally interfinger rather than grade into adjacent facies.

5. The occurence of various forms of deformation such as avalanche tongues, slump marks or contorted bedding may be present.

6. Within cross-bed sets individual laminae tend to be well sorted, especially in the finer grain sizes.

7. Grain size may range from silt to coarse sand with fine sand being the most common. Wind may transport grains up to 1 cm but grains over 5 mm are rare.

8. The larger sand grains (0.15 to 1.00 mm) tend to be well rounded.

9. Quartz is the dominant constituent and some larger quartz grains may exhibit frosted or pitted surfaces.

10. Clay drapes are rare and the sands are generally free of clay.

11. Micas are generally absent except in coastal dunes adjoining micaceous beach sand, in dunes derived directly from mica-rich waterlaid sediments or in dunes formed very near micaceous outcrops.

12. The presence of coarse-grained lag layers in either dunes or interdune areas formed by deflation.

13. Adhesion ripples are common on interdune surfaces.

14. Signs of exposure to subaerial conditions such as the presence of raindrop impressions, root structures or animal tracks and trails. Interdune areas may also show desiccation cracks.

The White Rim Sandstone Member in the Canyonlands area exhibits many of these characteristics and is here interpreted to have been deposited by eolian processes. The two genetic units described represent dune and related interdune deposits that formed along a coastline during a time of marine transgression.

The geometry of dune sandstones is probably closely related to their depositional environment (McKee and Bigarella, 1979b, p. 191). An inland dune field would tend to form an extensive tabular or wedge-shaped sand sheet. A coastal dune field would occur as a more narrow, elongate sand sheet. The White Rim forms an elongate, northeast-southwest sand body and is more characteristic of a coastal dune field.

The strong, unidirectional, northwest to southeast trend of the cross-bed sets (Plate 2) indicates that the dune form was either barchanoid or transverse ridges. These two dune forms are always oriented at approximately right angles to the dominant effective wind direction (fig. 14), and are the result of moderate winds with fairly abundant sand supply (McKee, 1979, p. 9). According to Goldsmith (1978, p. 196), barchanoid and transverse ridges are common dune forms along coastlines today, especially where there is a lack of anchoring vegetation.

Sedimentary structures related to dunes include high-index ripples, coarse-grained lags, slumps and raindrop impressions. The high-index ripples are found on the lee side (fig. 7) of the dune and are formed either by the deflection of wind over the dune surface or by temporary change in the wind direction

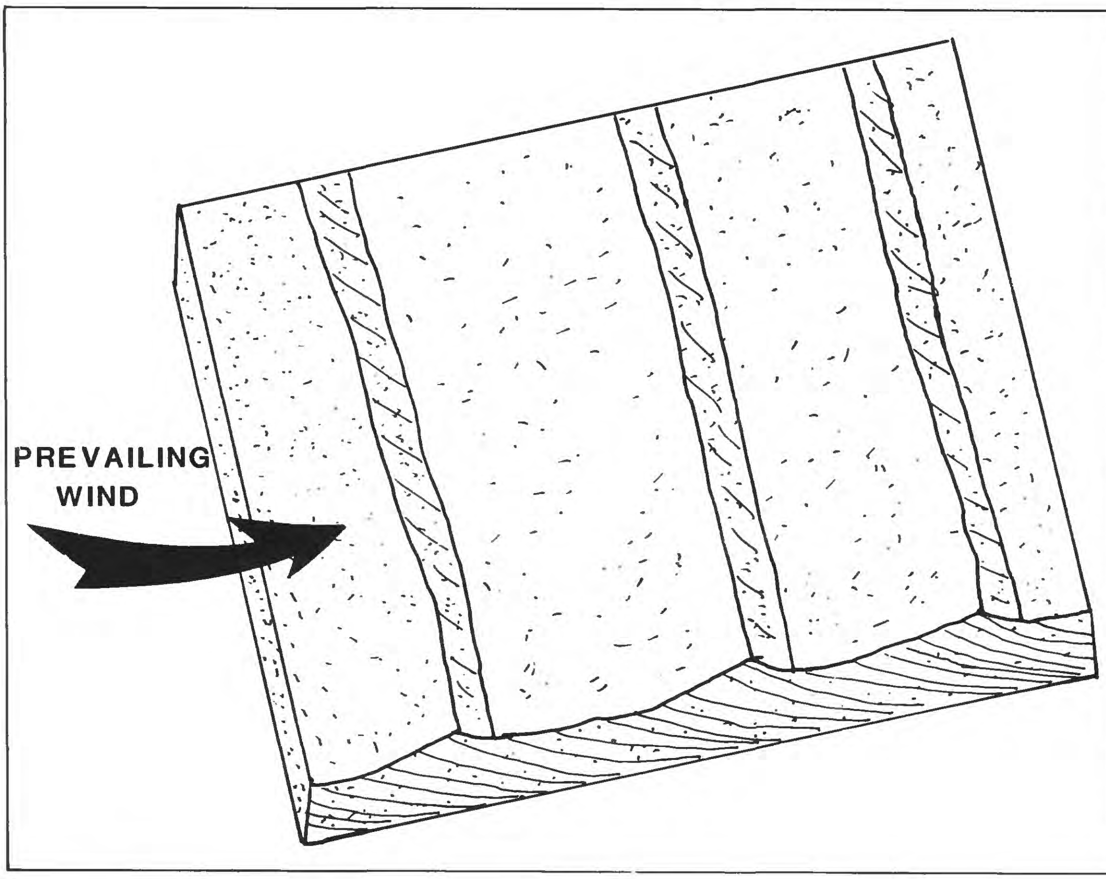

Figure 14. Schematic diagram of transverse dune ridges. (Modified from McKee, 1979)

(Bigarella, 1972, p. 27). Coarse-grained material, usually found at the base of the dune sets probably represents a deflation lag. This lag material is not moved by the wind and is eventually buried by the next advancing dune. The slump or avalanche structure found near the base of section QAB (fig. 2) probably formed as a failure of part of the dune. Raindrop impressions found on the dune surfaces indicate exposure to subaerial processes.

The wavy, horizontally laminated interdune deposits formed by alternating wet and dry conditions related to capillary action and seasonal water table fluctuations (Glennie, 1970, p. 73). This type of constantly changing environment facilitated the formation of the adhesion ripple lamination. The sandstone dikes and intraformational folds observed in the White Rim may also be related to these alternating conditions. They may have formed as the result of sediment loading due to the migration of the dunes over less mobile interdune material.

The surface of many of these interdune deposits are covered with desiccation polygons (fig. 10). The polygons usually have raised ridges and are found in a medium that is almost totally sand with very little clay-sized material. According to Pettijohn (1975, p. 123), it is not likely that desiccation polygons will form in deposits consisting entirely of sand-sized material. They frequently form in material which changes volume upon dehydration such as clay or mud. Polygons in the White Rim may have formed as salt polygons, similar to those described by Glennie (1970, p. 61), which are presently forming on the surface of a large inland sebkha in Oman. Salt polygons are formed as the result of alternating periods of deposition and desiccation. Ericksen and Stoertz (1978, p. 637) have suggested that an initial salt crust forms as the result of capillary evaporation of saline ground water. The polygons, outlined by surface tensional cracks, form as the salt crust desiccates and volume is lost by evaporation of the water content in the sediment under the desiccating salt crust, capillary evaporation results in the deposition of new material causing the polygons to expand forming raised ridges. Sand is mixed with the salt as the polygons form. Later the salt is dissolved leaving only a raised ridge of sand-sized material.

An alternative explanation is that polygons initially formed as mud cracks. Small amounts of clay-sized material could have been brought into the area during storm events creating a very thin layer of mud in the interdune areas. After the layer desiccated and cracked the cracks were infilled with sand-sized material. Subsequent wind action removed the clay chips, leaving only a raised ridge of sand.

Plate 3 is a schematic fence diagram compiled from the measured sections showing the regional stratigraphic relationship between the dune and interdune genetic units. In the eastern part of the study area the entire basal portion of the White Rim is composed of the wavy, horizontally laminated interdune unit. It reaches a thickness of up to 19 meters (5.8 feet). Upward within each measured section and westward throughout the study area the dune and interdune units are interbedded, with the interdune unit occurring as a number of distinct discontinuous lenticular deposits within the dune unit. To the northwest, in sections QAB and BB (fig. 2) the interdune unit is absent and the White Rim is composed entirely of the dune unit.

This pattern of deposition may be the result of a combination of factors such as the position of or changes in the water table level, the influence of small structural features, the sand supply to the area, wind strength and the coastal nature of the White Rim dune field. Data presented here suggests that the thick interdune deposit at the base of the White Rim in the eastern portion of the study area represents an extensive coastal pond or sebkha that formed in a low area behind the main coastal dune field. The smaller, discontinuous, lenticular interdune deposits represent deposition in small, scattered interdune ponds.

Coastal dune sands are essentially beach sediments that have been reworked and piled up by the wind. Several petrologic features of the White Rim Sandstone Member indicate the close proximity of a beach. The most important is the presence of glauconite. Well rounded, unaltered pellets of glauconite (fig. 15) were observed in thin sections from samples collected from all sections measured (Appendix B) and was found in both dune and interdune units. Glauconite is a dull-green, amorphous mineral of the mica group that forms under local reducing conditions in shallow marine water. The presence of glauconite in a rock unit usually indicates a marine depositional environment for it rarely survives erosion and re-deporition in nonmarine environments (Triplehorn, 1966, p. 95). The occurrence of these well rounded, unaltered glauconite pellets suggests the sea was relatively close. Along with the glauconite, the crinoid fragment and the relative enrichment of heavy minerals in the White Rim may also indicate a nearby beach. According to Potter (1967, p, 354), skeletal debris, heavy mineral concentrates and small amounts of glauconite are common constitutents of many beaches.

Stratigraphic relationships of the White Rim Sandstone Member also imply a coastal environment. It abruptly pinches out into the continental Organ Rock Shale Member eastward. Westward it apparently grades into the largely marine upper member of the Toroweap Formation and the gamma member of the Kaibab Limestone. These relationships further suggest the possibility of the White Rim being a coastal dune field.

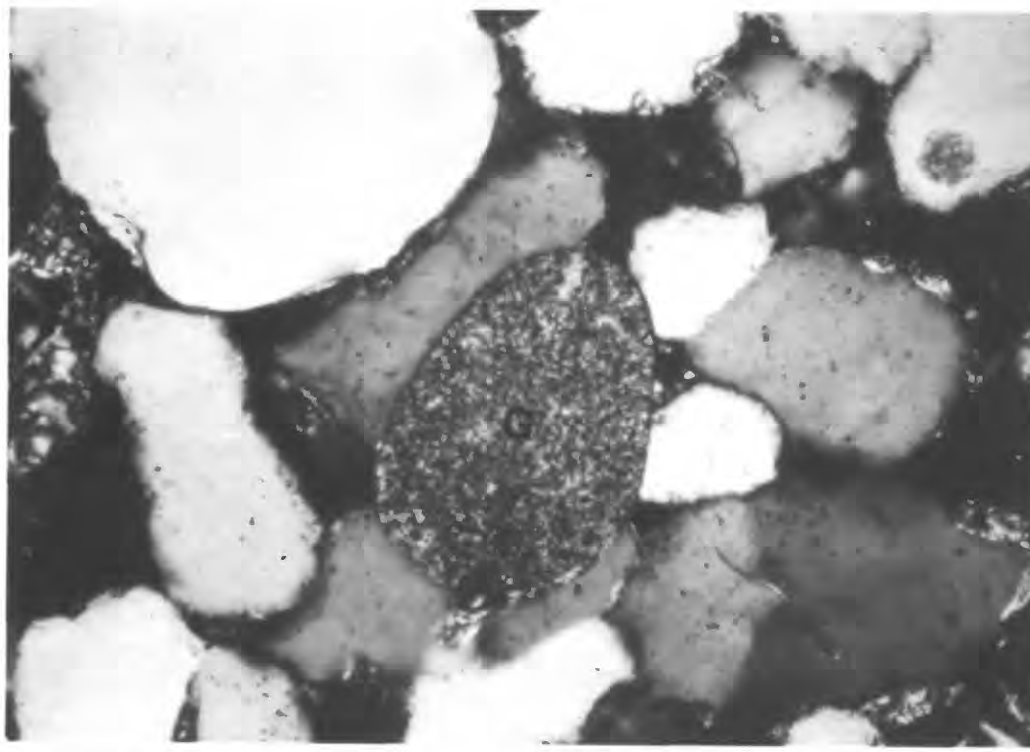

Figure 15. Glauconite pellet (G) in the dune genetic unit, BB-1, Beaver Bottom section. (Field of view approx. 0.7 mm)

Paleogeography

The White Rim Sandstone Member was deposited during the Early Permian or late Wolfcampian to early Leonardian time (Baars and Seager, 1970, p. 711). Figure 16 shows the proposed paleogeography of the Canyonlands area for this time. To the west of Canyonlands was a broad stable, shelf and to the east the positive Uncompahgre highlands and the Monument upwarp. The proposed paleomagnetic equator was to the north and Canyonlands was at approximately 5^{o}S latitude (Opdyke and Runcorn, 1960, p. 969, and Dott and Batten, 1976, p. 292).

Much of North America was in the Southeast Trade Winds Belt and was dominated by tropical climates during the late Paleozoic (Dott and Batten, 1976, p. 292). A southerly wind pattern was common during the Permian and is evident in a number of Permian eolian units including the White Rim and De Chelly Members of the Cutler Formation and the Coconino Sandstone (Poole, 1962, p. 148). Although the presence of eolian deposits has been used in the past to indicate an arid climate dune sands alone are not valid proof of an arid climate because coastal dunes do form today in both humid and arid climates (Bigarella, 1972, p. 12). Vaughn (1964, p. 567) found plant fossils in the Cutler Formation that are indicators of at least a semi-arid climate.

CONCLUSIONS

From the data and observations gathered in this study as well as previously published information, the following depositional history is proposed for the White Rim Sandstone.

During Late Pennsylvanian to Early Permian (Wolfcampian) time, normal marine conditions were prevalent in southcentral Utah but restricted marine conditions were more dominate directly west of Canyonlands. During this time tectonic activity resulted in the formation of the Uncompahgre highlands and Monument upwarp, east and southeast of the Canyonlands area. Large amounts of

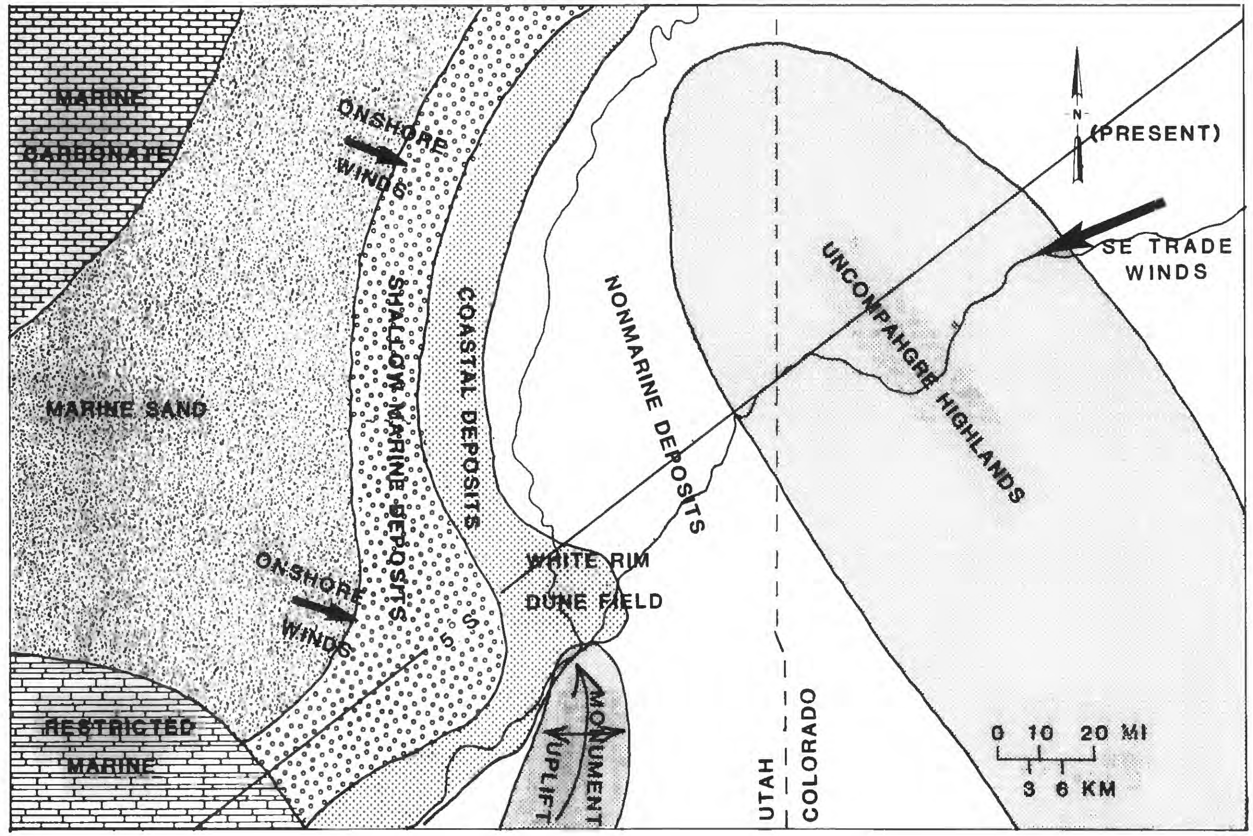

Figure 16. Paleogeographic map of Canyonlands National Park and surrounding area: late Wolfcampian--early Leonardian time. (Modified from Hallgarth, 1967b.)

clastic material were eroded from the newly formed Uncompahgre highlands and nonmarine sedimentation was dominant adjacent to the uplift. Canyonlands was situated in an environmentally mixed coastal plain area where there was a fluctuation between marine and nonmarine depositional environments. Deposits of these two environments interfinger in the Canyonlands area.

These fluctuating environments continued in the Canyonlands area throughout Wolfcampian to Leonardian time. The White Rim represents a coastal dune field that formed along a shoreline that was situated roughly north-south during a period of marine transgression. The White Rim dune field is generally thickest to the northwest and thins eastward, pinching out into the nonmarine Organ Rock.

There were probably several sediment sources for the White Rim, including material eroded from the nearby Uncompahgre highlands to the east and material from the Kaibab and Toroweap seas to the west. The material was reworked by both wind and water in the coastal environment.

Northwest to southeast, onshore winds formed the White Rim dune field even though the Canyonlands area lay in the Southeast Trade Winds Belt, which has a dominant southeast to northwest wind pattern. According to Goldsmith (1978, p. 171) however, differential cooling and warming between land and sea assures an onshore wind pattern regardless of the general wind circulation pattern.

During this same time period the largely marine upper part of the Toroweap Formation and the lower, gamma member of the Kaibab Limestone were deposited west of Canyonlands in southcentral Utah and northeastern Arizona. These two marine units are considered to be facies equivalents of the nonmarine White Rim. Unfortunately much of the westernmost White Rim occurs in the subsurface and little information is available. A transition between these two environments may begin just west of Canyonlands, in the Elaterite Basin area (fig. 1) where the uppermost part of the White Rim contains well developed oscillation ripples (Baars and Seager, 1970, p. 716). Also northwest of the study area, near the San Rafael uplift (fig. 1) the top of a unit identified as White Rim is bioturbated and contains marine fossils (Orgill, 1971, p. 141).

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APPENDIX A

MEASURED SECTIONS

Shafers Dome 1 (SD1)

Location: Section measured at base of Shafer Trail between the junction of the White Rim Trail and the road to Potash, NE, NE 1/4 sec. 14, T27S, R19E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
42.8 (13.0)	18.0 (5.5)	D	Sandstone; light gray to white; fine-grained; moderately sorted; subrounded to subangular; moderately well cemented; calcareous; dominantly quartz, dominantly quartz, trace feldspar and mica; tabular planar cross-bed sets with long tangential bases, high-index ripples parallel to dip of foresets.
24.8 (7.6)	5.6 (1.7)	C	Sandstone; pale yellow to white; fine-grained; moderately sorted; subrounded to subangular; moderately well cemented; dominantly quartz, trace feldspar and mica; wavy horizontally laminated bedding, interbedded with several thin beds same as unit D.
19.2 (5.9)	18.2 (5.5)	B	Sandstone; pale yellow to white; fine-grained; moderately sorted; subrounded to subangular; well cemented; calcareous; dominantly quartz; trace feldspar and mica; wavy horizontally laminated bedding.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
1.0 (0.3)	1.0 (0.3)	A	Sandstone, pale green, very fine-grained, well sorted, subrounded to subangular, moderately friable, dominantly quartz, trace feldspar (some altering to clay) and mica, massive.

Total White Rim 42.8 feet (13.0)

Organ Rock Shale Member
(not measured)

Shafers Dome 2 (SD2)

Location: Section measured along the road to Potash, bottom of section NE, NE 1/4 sec. 11, T27S, R19E; top of section NE, SE 1/4 sec. 11, T27S, R19E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
40.0 (12.2)	15.5 (4.7)	D	Sandstone; pale yellow; fine- to medium-grained; moderately sorted; subangular to subrounded; variable cementation becomes more friable upward; calcareous; dominantly quartz, trace feldspar and mica; tabular planar cross-bed sets with long tangential bases, high-index ripples parallel to dip of foresets.
	--lateral shift in section--		
24.5 (7.5)	5.5 (1.7)	C	Sandstone; pale yellow; fine- to medium-grained; moderately sorted; subangular to subrounded; moderately well cemented; calcareous; dominantly quartz, trace feldspar and mica; wavy horizontally laminated bedding, interbedded with several thin beds same as unit D.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
19.0 (5.8)	18.0 (5.5)	B	Sandstone; pale yellow; fine- to medium-grained; moderately sorted; subangular to subrounded; moderately well cemented; calcareous; dominantly quartz, trace feldspar and mica; wavy horizontally laminated bedding.
1.0 (0.3)	1.0 (0.3)	A	Sandstone to siltstone, greenish gray, very fine- to fine-grained; moderately sorted; subangular to subrounded; moderately friable; calcareous; dominantly quartz, trace feldspar and mica; massive.

Total White Rim 40.0 feet (12.2)

Organ Rock Shale Member
(not measured)

Shafer Dome 3 (SD3)

Location: Section measured along the White Rim Trail approximately 1 1/2 miles from the base of Shafer Trail, NW, SE 1/4 sec. 11, T27S, R19E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
32.0 (9.8)	11.0 (3.4)	D	Section partially covered; sandstone; pale yellow to white; fine- to medium-grained; moderately sorted; subangular to subrounded; moderately well cemented; calcareous; dominantly quartz, trace feldspar and mica; tabular planar cross-bed sets with long tangential bases.
21.0 (6.4)	6.3 (1.9)	C	Sandstone; white to pale yellow, fine- to medium-grained; moderately sorted; subangular to subrounded; moderately well cemented; calcareous; dominantly quartz, trace feldspar and mica, wavy horizontally laminated bedding; interbedded with several thin beds same as unit D.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
16.7 (5.1)	14.7 (4.5)	B	Sandstone; white to light gray; fine- to coarse-grained, moderately sorted; subangular to subrounded; moderately well cemented; calcareous; dominantly quartz, trace feldspar and mica, wavy horizontally laminated bedding, several coarse grained layers lower 2 feet.
2.0 (0.6)	2.0 (0.6)	A	Sandstone to siltstone; pale green; very fine- to fine-grained; moderately sorted; subangular to subrounded; moderately friable; calcareous; dominantly quartz, trace feldspar and mica, massive.

Total White Rim 32.0 feet (9.8)

Organ Rock Shale Member
(not measured)

Colorado River Overlook (CRO)

Location: Section measured along White Rim Trail at Colorado River Overlook turnout, NE, SE 1/4 sec. 13, T27S, R20E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
11.0 (3.4)	2.0 (0.6)	C	Sandstone; pale yellow to white, fine-grained; moderately sorted; subangular to subrounded; moderately friable; calcareous; dominantly quartz, trace feldspar and mica; tabular planar cross-bed sets with long tangential bases; high index ripples parallel to dip of foresets, raindrop impressions(?).
9.0 (2.7)	8.0 (2.4)	B	Sandstone; pale yellow to white; fine- to coarse-grained; moderately sorted; subangular to subrounded; moderately well cemented; calcareous; dominantly quartz, trace feldspar and mica; wavy horizontally laminated bedding, coarse-grained layers toward base, desiccation(?) polygons on the upper surface where exposed.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
1.0 (0.3)	1.0 (0.3)	A	Sandstone to siltstone; pale purple; very fine- to fine-grained; moderately sorted; subangular to subrounded; moderately friable; calcareous; dominantly quartz, trace feldspar (some altering to clay) and mica, massive.

Total White Rim 11.0 feet (3.4)

Organ Rock Shale Member
(not measured)

Little Bridge Canyon 1 (LBC1)

Location: Section measured along White Rim Trail approximately 6 1/2 miles from base of Shafer Trail, north of re-entrant that forms Little Bridge Canyon, NW, SW 1/4 sec. 31, T27S, R20E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
31.0 (9.5)	13.5 (4.1)	C	Sandstone; pinkish tan; fine-grained; well sorted; subangular to subrounded; variable cementation becomes more friable upward; clacareous; dominantly quartz, trace feldspar; dominantly tabular planar cross-bed sets with long tangential bases; a few thin lenses of wavy, horizontally laminated material; similar lithology; desiccation(?) polygons where upper surface of horizontally laminated material exposed.
18.5 (5.6)	2.5 (0.8)	B	Sandstone; reddish brown; fine-grained; well sorted; subangular to subrounded; moderately friable; dominantly quartz; trace feldspar and mica, subequal amounts of tabular planar cross bed sets with long tangential bases and wavy horizontally laminated lenses.
16.0 (4.9)	16.0 (4.9)	A	Sandstone, no description available, wavy horizontally laminated bedding.

Total White Rim 31.0 feet (9.5)

Organ Rock Shale Member
(not measured)

Little Bridge Canyon 2 (LBC2)

Location: Section measured 1/2 mile off White Rim Trail, approximately 7 miles from the base of Shafer Trail, south of re-entrant that forms Little Bridge Canyon; SW, NE 1/4 sec. 6, T28S, R20E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
7.5 (2.3)	1.5 (0.5)	C	Sandstone; pale yellow; fine- to medium-grained; well sorted, sub-angular to subrounded; calcareous; variable cementation becomes more friable upwards; calcareous; dominantly quartz, trace feldspar, iron stained; tabular planar cross-bed sets with long tangential bases interbedded with thin lenses of wavy horizontally laminated material, lithology same as unit B, desiccation(?) polygons where upper surface exposed.
6.0 (1.8)	4.5 (1.4)	B	Sandstone; yellow brown; fine- to medium grained, moderately sorted; subanggular to subrounded; well cemented; dominantly quartz, trace feldspar, wavy horizontally laminated bedding.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
1.5 (0.5)	1.5 (0.5)	A	Sandstone to siltstone; pale green; very fine- to fine-grained; moderately sorted; subangular to subrounded; moderately friable; calcareous; dominantly quartz, trace feldspar (some altering to clay) and mica; wavy horizontally laminated bedding.

Total White Rim 7.5 feet (2.3)

Organ Rock Shale Member
(not measured)

Lathrop Canyon 1 (LC1)

Location: Section measured along the White Rim Trail at the top of the road down Lathrop Canyon, NE, NE 1/4 sec. 2, T28S, R19E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
30.2 (9.2)	9.5 (2.9)	D	Sandstone; pale yellow; fine- to medium-grained; moderately sorted; subangular to subrounded; variable cementation becomes more friable upward; calcareous; dominantly quartz trace feldspar; tabular planar cross-bed sets with long tangential bases; high-index ripples parallel to dip of fore-sets.
20.7 (6.3)	4.3 (1.3)	C	Sandstone; pale yellow; fine- to medium-grained; moderately sorted; subrounded to subangular; moderately well cemented; calcareous; dominantly quartz, trace feldspar; wavy horizontally laminated bedding; interbedded with subequal amount of unit D.
16.4 (5.0)	15.4 (4.7)	B	Sandstone; pale yellow; fine-grained; moderately well sorted; subangular to subrounded; well cemented; calcareous; dominantly quartz; trace feldspar; wavy horizontally laminated bedding.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
1.0 (0.3)	1.0 (0.3)	A	Sandstone; pale green; very fine- to fine-grained, moderately sorted; subangular to subrounded; moderately friable; calcareous; dominantly quartz, trace feldspar and mica, massive.

Total White Rim 30.2 feet (9.2)

Organ Rock Shale Member
(not measured)

Lathrop Canyon 2 (LC2)

Location: Section measured along the White Rim Trail, approximately 13.5 miles from the base of Shafer Trail and 0.5 mile from the Lathrop Canyon road turn-off; NE, SE 1/4, sec. 2, T28S, R19E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
25.0 (7.6)	16.2 (4.9)	C	Sandstone; white; fine- to medium-grained; moderately sorted; subangular to subrounded; variable cementation becomes more friable upwards; calcareous; dominantly quartz; trace feldspar; tabular planar cross-bed sets with long tangential bases; high-index ripples parallel to dip of foresets interbedded with thin lenses of material same as unit B.
8.8 (2.7)	8.3 (2.5)	B	Sandstone; yellow-white-black mottled; very fine- to fine-grained; moderately sorted; sub-angular to subrounded; moderately well cemented; calcareous; dominantly quartz; trace feldspar and mica; wavy horizontally laminated bedding.
0.5 (0.2)	0.5 (0.2)	A	Sandstone; pale green; very fine- to fine-grained; moderately sorted; subangular to subrounded; moderately friable; calcareous; dominantly quartz; trace feldspar (some altering to clay) and mica; massive.

Total White Rim 25.0 feet (7.6)

Organ Rock Shale Member
(not measured)

Buck Canyon (BC)

Location: Section measured along White Rim Trail, approximately 15 miles from the base of Shafer Trail, one of the few canyons that one can walk down to the base of the White Rim Sandstone; NW, NW 1/4 sec. 10, T28S, R19E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
52.4 (16.0)	43.6 (13.3)	C	Sandstone; pale yellow to white; fine- to medium-grained; moderately sorted; subangular to subrounded; moderately well cemented; calcareous; dominantly quartz; trace feldspar; tabular planar cross-bed sets with long tangential bases; high-index ripples parallel to dip of foresets; interbedded with subequal amounts of sandstone; orange-yellow-black mottled; very fine- to fine-grained; moderately well sorted; subangular to subrounded; moderately well cemented; calcareous; dominantly quartz; trace feldspar; wavy horizontally laminated bedding.
8.8 (2.7)	7.8 (2.4)	B	Same lithologies as unit C but more wavy horizontally laminated material than tabular planar cross bedded material.
1.0 (0.3)	1.0 (0.3)	A	Sandstone; pinkish yellow; very fine-grained; moderately sorted; subangular to subrounded; moderately friable; very calcareous; dominantly quartz; trace feldspar (some altered to clay) and mica; massive.

Total White Rim 52.4 feet (16.0)

Organ Rock Shale Member
(not measured)

Washer Woman (WW)

Location: Section measured approximately 1/2 mile off White Rim Trail, 16 1/2 miles from base of Shafer Trail; NW, NW 1/4 sec. 15, T28S, R19E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
40.0 (12.2)	28.0 (8.5)	B	Sandstone; pale yellow to white; fine-grained, moderately sorted; subangular to subrounded; variable cementation becomes more friable upward; calcareous; dominantly quartz, trace feldspar; tabular planar cross-bed sets with long tangential bases; high-index ripples parallel to dip of foresets; interbedded with thin lenses of unit A; desiccation(?) polygons where upper surface exposed.
12.0 (3.6)	12.0 (3.6)	A	Sandstone; yellow-white-black mottled; fine- to very fine-grained; moderately sorted; subangular to subrounded; moderately well cemented; dominantly quartz; trace feldspar and mica; wavy horizontally laminated bedding.

Total White Rim Member 40 feet (12.2)

Cedar Mesa(?) Sandstone Member (not measured)

Monument Basin (MB)

Location: Section measured along the White Rim Trail, approximately 29.0 miles from base of Shafer Trail, at NE re-entrant of Monument basin, approximately 1.0 mile along the rim; NW, NE 1/4 sec. 10, T29S, R19E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
42.0 (12.8)	26.2 (8.0)	C	Sandstone; white to gray; granule to fine-grained; moderately sorted; subangular to subrounded; variable cementation becomes more friable upward; calcareous; dominantly quartz, trace feldspar and mica; tabular planar cross-bed sets with long tangential bases; high index ripples parallel down foreset beds; avalanche tongues(?), granule to coarse-grained layers concentrated at base of some cross-bed sets; interbedded with thin lenses of sandstone; pale yellow to white; very fine- to fine-grained moderately sorted; subangular subrounded; moderately friable; calcareous; dominantly quartz, trace feldspar and mica; wavy horizontally laminated bedding.
15.8 (4.8)	10.3 (3.1)	B	Poor exposure, sandstone; white; fine- to coarse-grained; poorly sorted; subangular to subrounded; moderately friable; calcareous; dominantly quartz, trace feldspar and mica; contains several coarse

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			grained layers; plus several thin, noncontinuous tabular planar cross-bedded units, lighology same as unit C.
5.5 (1.7)	5.5 (1.7)	A	Poor exposure, sandstone; white; fine- to medium-grained; moderately sorted; subangular to subrounded; moderately well cemented; slightly calcareous; dominantly quartz, trace feldspar and mica; wavy horizontally laminated bedding.

Total White Rim 42 feet (12.8)

Cedar Mesa(?) Sandstone Member
(not measured)

White Crack (WC)

Location: Section measured along White Rim Trail, approximately 35 miles from base of Shafer Trail at White Crack campground, section measured just below point where road blocked, White Rim face exposed due to blasting; T29S, R19S.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
48.0 (14.6)	15.5 (4.7)	F	Sandstone; pale yellow to white; fine-grained; moderately sorted, subangular to subrounded; moderately well cemented, calcareous, dominantly quartz, trace feldspar, tabular planar cross-bed sets with long tangential bases, high-index ripples parallel to dip of foresets; possibly interbedded with thin lenses of wavy horizontally laminated material, lithology same as unit E.
32.5 (9.9)	28.5 (8.7)	E	Sandstone; pale yellow; fine- to very fine-grained; moderately sorted; subangular to subrounded; well cemented; calcareous; dominantly quartz, trace feldspar and mica; wavy horizontally laminated bedding, interbedded with occasional tabular planar cross bedded material, lithology same as unit F.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
4.0 (1.2)	1.0 (0.3)	D	Poor exposure; sandstone; pale yellow; fine-grained; moderately sorted; subangular to sub-rounded; well cemented; calcareous; dominantly quartz, trace feldspar and mica; appears to be partially ripple laminated, R.I. of 17.0, ripples symmetrical.
3.0 (0.9)	1.5 (0.5)	C	Poor exposure; sandstone to conglomerate; pale yellow; granule to fine-grained; poorly sorted; subangular to subrounded; well cemented; calcareous, dominantly quartz, trace feldspar and mica; unable to tell bedding forms.
1.5 (0.5)	1.0 (0.3)	B	Sandstone; pale yellow; lithology same as unit E; wavy horizontally laminated bedding.
0.5 (0.2)	0.5 (0.2)	A	Sandstone to conglomerate; pale yellow; coarse- to fine-grained; poorly sorted; subangular to subrounded, moderately well cemented; calcareous; dominantly quartz, clay clasts(?); trace mica; massive.

Total White Rim 48.0 feet (14.6)

Cedar Mesa(?) Sandstone Member
(not measured)

Queen Anne Bottom (QAB)

Location: Section measured off western limb of White Rim Trail along Green River at the end of the marked trail down to Queen Anne Bottom; SW, NE 1/4 sec. 11, T28S, R17 1/2E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			NOTE: QAB only partial section, section started at river level but estimated to be approximately 10 feet above White Rim-Cedar Mesa(?) contact.
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
150 (45.7)	150 (45.7)	A	Sandstone; pale yellow to white; fine- to coarse-grained; moderately sorted; subangular to subrounded; variable cementation becomes more friable upward; calcareous; dominantly quartz; trace feldspar, iron stained, tabular planar cross-bed sets with long tangential bases, coarse-grained material concentrated at base of sets; high-index ripples parallel to dip of foresets, slump structures(?), raindrop impressions(?).

Beaver Bottom (BB)

Location: Section measured off western limb of White Rim Trail along Green River Beaver Bottom approximately 1 1/2 miles south of last Potato Bottom camp site; NE, NE 1/4 sec. 2, T28S, R17 1/2E.

Total Thickness ft. (m)	Interval Thickness ft. (m)	Unit	Description
			NOTE: BB only partial section, section started at river level; no estimate of total thickness.
			Cutler Formation
			Unnamed Permian Unit (not measured)
			White Rim Sandstone Member
66+ 20.1+	66+ (20.1+)	A	Sandstone; pale yellow to white; fine- to coarse-grained; moderately sorted; subangular to subrounded; variable cementration becomes more friable upward; calcareous; dominantly quartz, trace feldspar and mica; tabular planar cross-bed sets with long tangential bases; coarse-grained material concentrated at base of sets; high-index ripples parallel to dip of foresets; slump structures(?), raindrop impressions(?).

APPENDIX B

PETROGRAPHIC DATA

Appendix B

Appendix B contains the results of the petrographic examination of 107 thin sections made from rock samples collected from each measured section. Sample locations in the table are all referenced from the base of the White Rim Sandstone Member. See Plate 2 for specific locations. All textural information is based on 100 grain counts and sorting values are based on Folk (1974, p. 105). All compositional information is in percent and is based on 300 grain counts. The following symbols are used:

N -- not observed
* -- trace
A -- apatite
G -- glauconite
Ga -- garnet
Gy -- gypsum
M -- magnetite
T -- tourmaline
Z -- zircon

VWS -- very well sorted
WS -- well sorted
MS -- moderately sorted
PS -- poorly sorted
VPS -- very poorly sorted

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over-growths	Acc. Min.	
SD1-1	-2.5 (-0.8)	Organ Rock	3.43	PS 1.14	39	7	N	2	6	N	*	44	N	1 M,T	highly altered, iron stained, carbonate cement and matrix mixed
SD1-3	0.5 (0.2)	White Rim	3.37	MS 0.59	63	2	N	12	2	N	2	18	N	1 A,G,M,T,Z	
SD1-5	15.0 (4.6)	White Rim	1.83	VWS 0.27	73	*	*	4	N	3	6	*	9	N	
SD1-6	24.8 (7.6)	White Rim	2.55	MS 0.51	75	2	N	6	N	4	6	8	*	* A,G,M,T,Z	stylolites
SD1-7	35.0 (10.7)	White Rim	2.45	WS 0.38	85	2	N	3	N	*	5	5	*	* A,T,Z	stylolites
SD1-8	42.0 (12.8)	White Rim	2.59	VWS 0.23	87	2	*	4	N	4	N	3	*	* Gy,T	
SD1-9	42.8 (13.1)	Unnamed Permian	2.04	PS 1.28	75	1	N	3	N	N	19	2	*	* T	iron stained
SD1-10	42.0 (12.8)	White Rim	0.28	PS 1.55	67	*	1	11	N	*	19	1	*	N	coarse-grained material, lateral to the top of of section
SD2-1	-6.0 (-1.8)	Organ Rock	2.49	PS 1.50	37	3	2	4	1	N	32	21	N	1 M,T	highly altered, iron stained
SD2-2	0.5 (0.2)	White Rim	3.22	WS 0.42	80	1	*	*	1	N	5	12	N	* A,G,M,T,Z	
SD2-3	1.0 (0.3)	White Rim	2.41	WS 0.49	72	*	N	5	N	1	9	2	10	* G,T,Z	stylolites

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over-growths	Acc. Min.	
SD2-4	14.0 (4.3)	White Rim	2.19	WS 0.44	76	*	*	3	N	6	6	1	7	* Gy,T,Z	graded layers
SD2a-1	1.0 (0.3)	White Rim	2.14	WS 0.43	82	1	N	2	*	1	7	6	1	* A,G,Gy, T,Z	lateral shift in section, stylolites
SD2a-2	25.0 (7.6)	White Rim	2.92	MS 0.59	84	1	N	6	*	N	7	3	*	* A,G,Gy, M,T,Z	stylolites
SD2a-3	26.0 (7.9)	White Rim	1.96	VWS 0.26	83	*	*	3	N	6	*	*	8	N	
SD2a-4	40.0 (12.2)	White Rim	2.34	WS 0.43	78	*	*	1	N	N	19	*	1	* T	
SD2a-5	40.5 (12.3)	Unnamed Permian	2.37	PS 1.10	78	1	1	2	*	1	7	5	5	* Gy,Z	dolomite rhombs
SD3-1	-1.0 (-0.3)	Organ Rock	3.02	PS 1.30	57	7	N	1	7	N	1	27	N	* A,T,Z	highly altered, iron stained
SD3-2	0.5 (0.2)	White Rim	3.50	MS 0.52	70	2	*	1	2	*	15	10	*	* A,G,M, T,Z	
SD3-3	6.0 (1.8)	White Rim	2.50	WS 0.47	91	1	*	1	N	N	7	*	*	* G,Gy,T,Z	
SD3-4	20.4 (6.2)	White Rim	2.19	WS 0.41	88	1	*	3	N	*	4	2	1	N	
SD3-5	30.8 (9.4)	White Rim	2.16	VWS 0.32	82	1	*	1	*	7	N	1	8	N	

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over-growths	Acc. Min.	
SD3-6	31.0 (9.5)	Unnamed Permian	2.72	PS 1.41	78	1	N	2	*	N	9	9	1	* G,Gy,T,Z	iron stained, dolomite rhombs
SD3-7	30.5 (9.3)	White Rim	2.23	VPS 2.42	86	*	3	1	1	N	7	2	N	* A,Ga, Gy,T,Z	coarse grained material, lateral to the top of section
CRO-1	-2.0 (-0.6)	Organ Rock	4.21	MS 0.77	7	N	N	N	1	N	92	N	N	N	iron stained
CRO-2	-0.5 (-0.2)	Organ Rock	0.88	MS 0.52	19	19	N	3	*	N	54	4	N	N	feldspar highly altered, dolo-mitized
CRO-3	0.5 (0.2)	White Rim	3.35	WS 0.47	66	2	*	1	1	N	23	6	N	1 A,M,T,Z	dolomite rhombs, carbonate cement and matrix mixed
CRO-4	9.0 (2.7)	White Rim	2.35	WS 0.41	89	2	*	1	N	4	N	1	2	* A,G,Ga, Gy,M,T,Z	
CRO-5	11.0 (3.4)	White Rim	2.05	WS 0.50	88	1	*	1	*	5	3	*	3	* G,Gy	
CRO-6	11.5 (3.5)	Unnamed Permian	2.39	WS 0.34	77	1	N	1	*	1	10	*	10	* G,Ga,Z	contact covered, sample may be White Rim
LBC1-1	16.0 (4.9)	White Rim	2.95	WS 0.44	81	1	*	1	1	*	15	*	*	* A,G,M, T,Z	pellets(?), dolomite rhombs

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over-growths	Acc. Min.	
LBC1-2	20.0 (6.1)	White Rim	2.75	MS 0.58	34	*	N	2	*	N	13	*	*	* A,G,M, T,Z	pellets(?), dolomite rhombs
LBC1-3	31.0 (9.5)	White Rim	2.71	WS 0.46	87	1	*	2	*	N	5	*	N	* G,M,T,Z	pellets(?), dolomite rhombs
LBC2-1	-2.0 (-0.6)	Organ Rock	4.59	WS 0.50	53	1	N	*	1	N	N	44	N	* G(?)	iron stained, carbonate cement mixed with matrix
LBC2-3	0.5 (0.2)	White Rim	3.36	WS 0.45	34	1	N	N	*	N	4	9	*	1 A,G,Ga, T,Z	pellets(?), dolomite rhombs
LBC2-4	2.0 (0.6)	White Rim	2.53	WS 0.40	90	*	*	*	*	1	2	2	5	* A,T,Z	pellets(?) dolomite rhombs
LBC2-5	7.5 (2.3)	White Rim	2.09	VWS 0.35	87	1	*	3	N	2	*	*	6	* T	
LBC2-5a	7.5 (2.3)	White Rim	2.19	VWS 0.31	90	1	1	1	*	4	N	1	2	* T	lateral to top of section
LBC2-6	8.0 (2.4)	Unnamed Permian	2.60	PS 1.90	65	1	N	2	1	*	10	21	1	* T,Z	iron stained, dolomite rhombs
LC1-1	-2.0 (-0.6)	Organ Rock	4.23	WS 0.38	64	1	N	*	*	N	5	30	N	* A,T,Z	iron stained

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over-growths	Acc. Min.	
LC1-3	0.5 (0.2)	White Rim	3.07	WS 0.47	80	3	N	2	2	1	N	12	*	* A,G,T,Z	
LC1-4	3.0 (0.9)	White Rim	2.47	WS 0.47	87	2	*	3	*	3	*	2	2	* A,G,M,T,Z	
LC1-5	19.0 (5.8)	White Rim	2.09	MS 0.52	91	*	2	*	*	5	N	N	1	* G,T,Z	
LC1-6	20.7 (6.0)	White Rim	2.99	MS 0.51	90	1	1	*	*	*	4	3	*	* A,G,M, T,Z	pellets(?) dolomite rhombs, stylolites
LC1-7	29.0 (8.9)	White Rim	2.15	VWS 0.35	91	*	N	N	N	3	5	*	*	N	
LC1-8	30.2 (9.3)	Unnamed Permian	3.29	PS 1.47	71	1	N	*	*	N	8	20	N	* M,T,Z	iron stained
LC2-1	-1.5 (-0.2)	Organ Rock	4.41	WS 0.38	74	*	N	1	1	N	1	23	N	* T	iron stained, carbonate cement mixed with matrix
LC2-2	0.5 (0.2)	White Rim	3.39	WS 0.48	72	2	N	3	2	N	9	12	N	* A,G,M, T,Z	pellets(?) dolomite rhombs
LC2-3	1.0 (0.3)	White Rim	2.48	MS 0.88	67	2	N	3	*	2	22	2	3	* G,T,Z	dolomite rhombs
LC2-4	9.8 (3.0)	White Rim	2.83	MS 0.62	85	2	*	1	*	6	*	5	*	* A,G,T,Z	
LC2-5	10.8 (3.3)	White Rim	1.88	VWS 0.32	75	2	*	1	*	6	13	1	1	* T,Z	

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over-growths	Acc. Min.	
LC2-6	17.0 (5.2)	White Rim	2.37	VWS 0.25	80	3	*	1	N	9	N	*	6	* T	
LC2-7	18.8 (5.7)	White Rim	2.71	MS 0.52	83	*	N	2	*	1	13	*	*	* G,T	dolomite rhombs
LC2-8	25.0 (7.6)	Unnamed Permian	2.61	PS 1.36	75	2	N	1	*	N	12	10	N	* T	iron stained, dolomite rhombs
BC-1	-1.0 (-0.3)	Organ Rock	4.32	MS 0.67	61	1	N	N	7	N	1	28	N	N	iron stained, carbonate cement mixed with matrix
BC-3	0.5 (0.2)	White Rim	4.30	MS 0.62	23	N	N	N	1	N	75	1	N	N	dolomitized
BC-4	3.0 (0.9)	White Rim	2.15	VWS 0.29	72	1	*	2	N	9	N	1	15	* G	
BC-5	10.0 (3.1)	White Rim	1.94	MS 0.77	84	2	1	3	N	7	N	1	2	* G,T,Z	
BC-6	11.0 (3.4)	White Rim	2.70	WS 0.50	90	1	N	N	1	N	4	3	N	* A,G,T,Z	dolomite rhombs, graded layers
BC-7	39.0 (11.9)	White Rim	2.71	MS 0.53	83	1	N	N	*	1	11	4	*	* G,M,T,Z	pellets(?) dolomite rhombs
BC-8	45.0 (13.7)	White Rim	2.50	VWS 0.26	87	2	*	3	N	4	N	1	4	* G,M,T,Z	
BC-9	50.0 (15.2)	White Rim	2.71	MS 0.57	80	1	*	4	N	2	10	3	1	* G,T,Z	

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over-growths	Acc. Min.	
BC-10	55.0 (16.8)	Unnamed Permian	2.60	MS 0.97	78	2	*	3	*	*	10	4	3	* A,T,Z	bleached
BC-10a	53.4 (16.3)	Unnamed Permian	2.34	MS 0.91	79	2	1	2	*	N	9	7	N	* Gy,T	bleached
BC-11	60.4 (18.4)	Unnamed Permian	2.79	PS 1.87	57	2	N	1	N	N	3	36	N	* T	bleached
WW-1	-1.5 (-0.5)	Cedar Mesa(?)	2.02	MS 0.67	15	11	*	1	1	N	57	16	N	N	
WW-2	0.5 (0.2)	White Rim	3.43	MS 0.59	68	3	N	1	*	N	1	26	*	1 G,M,T,Z	
WW-3	2.0 (0.6)	White Rim	2.59	VWS 0.24	79	3	*	2	N	7	1	2	7	* G,M,T,Z	
WW-4	19.0 (5.8)	White Rim	2.79	MS 0.57	86	1	*	3	*	*	7	2	*	* A,G,M,T,Z	
WW-5	21.0 (6.4)	White Rim	2.34	WS 0.33	91	2	*	2	N	3	N	1	*	* G,T,Z	
WW-6	33.2 (10.1)	White Rim	2.33	VWS 0.23	86	1	N	2	N	8	N	N	2	N	
WW-7	35.0 (10.7)	White Rim	2.45	WS 0.45	85	2	*	2	N	N	9	3	1	* G,M,T,Z	
WW-8	40.0 (12.2)	Unnamed Permian	2.63	PS 1.35	73	1	*	*	1	N	8	16	*	* T	iron stained

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over-growths	Acc. Min.	
MB-1	-10.0 (-3.1)	Cedar Mesa(?)	3.59	WS 0.43	50	*	N	N	1	N	48	1	N	* G,M,T,Z	dolomite rhombs
MB-2	-0.5 (-0.2)	Cedar Mesa(?)	1.35	PS 1.33	46	8	*	5	N	N	37	3	N	* A,M,Z	
MB-3	0.5 (0.2)	White Rim	2.85	MS 0.61	85	4	*	1	1	3	N	4	1	* A,G,M, T,Z	laminations
MB-4	6.0 (1.8)	White Rim	2.13	PS 1.25	82	7	*	5	N	3	1	*	1	* G,T,Z	
MB-5	7.0 (2.1)	White Rim	2.70	VWS 0.30	89	2	*	*	*	5	N	2	2	* G,T,Z	
MB-6	20.8 (6.1)	White Rim	2.16	MS 0.52	92	1	*	1	N	3	1	*	3	N	
MB-7	23.8 (7.3)	White Rim	2.63	VWS 0.29	92	1	*	1	*	3	2	*	*	* A,G,M,T,Z	
MB-8	28.8 (8.8)	White Rim	0.35	WS 0.41	44	6	N	11	N	N	39	*	N	N	grains very well rounded
MB-9	31.1 (9.5)	White Rim	2.38	MS 0.55	95	2	*	1	*	1	1	*	N	* A,T,Z	
MB-10	42.0 (12.8)	Unnamed Permian	2.47	MS 0.87	77	1	*	2	1	N	16	3	1	* G,Gy,M, T,Z	iron stained
WC-1	-3.0 (-0.9)	Cedar Mesa	3.41	PS 1.15	47	6	N	*	*	N	N	47	N	* T	iron stained

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over- growths	Acc. Min.	
WC-2	0.5 (0.2)	White Rim	3.44	WS 0.46	48	1	N	1	N	N	48	2	N	* G,Z	echinoderm frag-, ment, dolomitized
WC-3	1.5 (0.5)	White Rim	3.09	VWS 0.28	82	1	N	1	N	N	12	1	2	* A,G,T	pellets(?) dolomite rhombs
WC-4	3.0 (0.9)	White Rim	0.65	MS 0.55	51	7	*	12	*	N	23	5	1	N	dolomite rhombs
WC-5	4.8 (1.5)	White Rim	3.01	WS 0.43	82	3	*	1	N	1	9	5	*	* G,T,Z	pellets(?) dolomite rhombs
WC-6	19.0 (5.8)	White Rim	2.53	VWS 0.29	82	1	*	3	N	4	4	2	3	* G,T,Z	
WC-7	22.0 (6.7)	White Rim	2.05	WS 0.39	85	1	N	1	*	12	N	*	1	N	
WC-8	31.0 (9.5)	White Rim	2.73	MS 0.62	87	2	N	1	N	*	4	4	1	* G,T,Z	
WC-9	40.0 (12.2)	White Rim	2.48	WS 0.50	89	1	*	*	N	1	7	1	*	* T,Z	
WC-10	50.0 (15.2)	Unnamed Permian	2.94	PS 1.69	72	*	N	N	N	N	15	12	1	* Z	iron stained
QAB-D1	136.0 (41.5) above river level	White Rim	2.00	WS 0.39	91	1	1	1	N	5	*	N	1	* Z	poor slide
QAB-D2	141.0 (42.9) above river level	White Rim	2.69	WS 0.37	71	1	*	N	N	N	27	N	N	* T,Z	

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over-growths	Acc. Min.	
QAB-D3	143.0 (43.5) above river level	White Rim	2.51	VWS 0.29	91	*	*	1	N	3	4	*	*	* G,T	
QAB-1	4.0 (1.2) above river level	White Rim	2.31	VWS 0.27	94	N	*	1	N	2	2	1	*	* G,Z	possilbe altered pyrite
QAB-7	157.0 (47.9) above river level	Unnamed Permian	2.09	MS 0.76	81	1	N	1	N	*	1	*	1	* T,Z	silicified oolite bleached
BB-1	4.0 1.2 above river level	White Rim	1.96	PS 1.01	89	3	*	1	N	4	2	*	*	* G,T,Z	possible altered pyrite
BB-2	5.0 (1.5) above river level	White Rim	2.24	VWS 0.29	92	*	N	1	N	2	2	1	1	* T,Z	
BB-3	40.0 (12.2) above river level	White Rim	2.44	WS 0.30	93	1	*	1	N	3	N	1	1	* T,Z	
BB-4	40.0 (12.2) above river level	White Rim	2.60	MS 0.89	89	1	N	3	N	N	5	2	N	* G,T,Z	laminations

Sample Information			Texture		Composition										Remarks
Thin section number	Location in section ft (m) above base	Member	Mean grain size phi	Sorting phi std. deviation	Monoxln. quartz	Feldspar	Chert	Rock frags. + polyxln. quartz	Mica	Voids	Carbonate cement	Matrix plus clay	Quartz over-growths	Acc. Min.	
BB-5	45.0 (13.75) above river level	White Rim	2.11	PS 1.30	91	1	N	5	N	N	1	3	N	* Z	
BB-6	50.0 (15.2) above river level	White Rim	2.70	VWS 0.22	93	1	*	1	N	1	1	1	1	* T,Z	
BB-7	60.0 (18.3) above river level	White Rim	1.98	VWS 0.29	92	*	*	1	N	3	*	*	4	* T	
BB-8	66.0 (20.1) above river level	Unnamed Permian	2.13	MS 0.81	81	*	*	1	N	N	14	1	3	* G,T,Z	bleached
BB-9	76.0 (23.2) above river level	Unnamed Permian	2.88	PS 1.22	63	3	*	N	N	N	22	12	N	* G	iron stained