DEPOSITIONAL ENVIRONMENTS

OF THE

SALT WASH MEMBER AND RECAPTURE CREEK MEMBER

OF THE MORRISON FORMATION IN SOUTHERN

MONTEZUMA CANYON, SAN JUAN COUNTY, UTAH

by
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ABSTRACT

The Salt Wash Member and Recapture Creek Member of the Jurassic Morrison Formation both occur as interbedded sandstones and mudstones in Montezuma Canyon. Thirteen stratigraphic sections were measured in the study area. Nineteen representative sandstone samples from the sections were analyzed by petrography and X-ray diffraction of the intergranular clays.

The southern half of the study area represents the northernmost extent of the Recapture Creek Member. The lithologies of the two members can be differentiated by the greater friability, lack of carbonaceous material, lighter color in outcrop, greater percentage of feldspars, and the occurrence of montmorillonite in the Recapture Creek Member.

Both members were deposited by low-sinuosity fluvial systems characterized by two or more anastomosing channels flowing over a low gradient. The channel systems ranged from 3 to 50 feet (1 to 15 m) deep and up to a mile (1.6 km) wide. During periods of greater than normal discharge, floodplain deposits of overbank silts and clays were deposited.

The Salt Wash Member sediments are interpreted from paleocurrent direction indicators as originating to the west of the study area near southern Nevada where sandstones and volcanic sediments were eroded. The incipient Comb Ridge

Monocline may have slightly restricted the movement of sediments from the west into the study area.

The Recapture Creek Member is interpreted as originating near Gallup, New Mexico, where sandstones and volcanic detritus were eroded. Active volcanism contributed volcanic ash to the sediments.

INTRODUCTION

Objectives of the Study

The purpose of this study is to interpret the depositional environments of the Salt Wash and Recapture Creek Members of the Upper Jurassic Morrison Formation in the Southern Montezuma Canyon/Monument Canyon area of southeastern Utah. The interpretations of depositional environments will be developed from the measurement of fourteen stratigraphic sections of the Salt Wash and Recapture Creek Members. Thirteen sections were measured within the study area; the remaining section was measured near the type locality of the Recapture Creek Member to the south of the study area. Sedimentary structures and paleocurrent direction indicators observed during the measurement of these sections are utilized to identify the conditions of deposition and to determine the paleo-transport directions. Further information as to the depositional environment and subsequent diagenesis of the sandstones is derived from petrographic and X-ray diffraction studies of samples collected during the measurement of the stratigraphic sections. This data as well as the sedimentary structures is compared to that in the literature of modern sedimentary environments to help interpret depositional environments.

The occurrence of the Recapture Creek Member within the study area is previously undocumented. Stokes (1954) and Gilluly and Reeside (1928) have documented its occurrence twelve miles (19.2 km) south of the study area, but it appears to be absent immediately to the north of the study area (LeBaron, 1980). A secondary aspect of this study is to compare, using sandstone petrologies, sedimentary structures and paleocurrent direction indicators of the Recapture Creek Member at its type locality with the suspected Recapture Creek Member units within the study area. This should determine whether the Recapture Creek Member occurs and, if so, its relationship to the Salt Wash Member within the study area.

LOCATION

The Montezuma Canyon/Monument Canyon area is in eastern San Juan County, Utah, approximately eleven miles (17.6 km) east of Blanding, Utah. Its northern boundary is approximately nineteen miles south of Monticello, Utah and is defined by the southernmost extent of LeBaron's (1980) study area (Fig. 1). The study area is limited to the south by a lack of Salt Wash Member outcrops. The study area covers approximately 84 square miles (approximately 218 square km), being twelve miles (19.2 km) in length and averaging seven miles (11.2 km) in width. It is completely contained within T36S-T37S, R24E-R25E, Utah base and meridian. Access to the study area from the south is from a

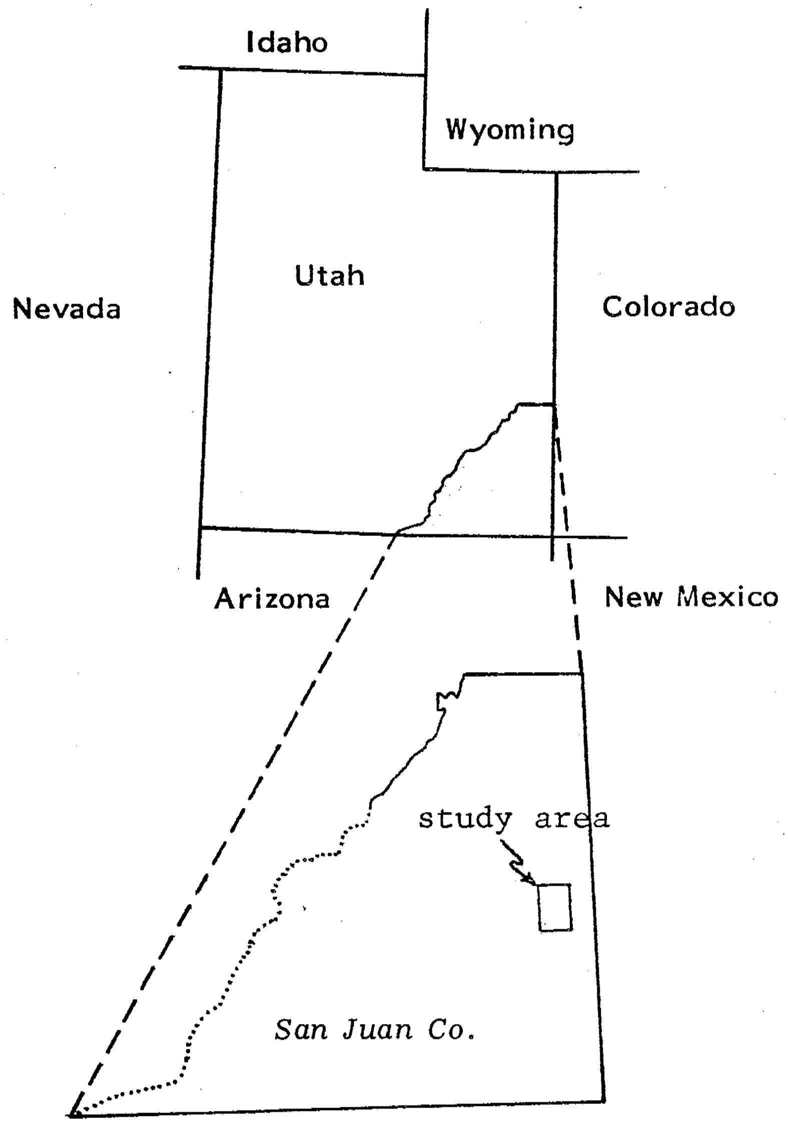


Figure 1. Location map of study area

point one mile (1.6 km) south of Blanding, Utah on U.S. Highway 163, where one turns east onto a graveled country road. This road is followed for 1.2 miles (1.9 km). At this point, another gravel road leads south and continues for eighteen miles (28.8 km) until it meets the gravel road in Montezuma Canyon. The southern boundary of the study area is 2.5 miles (4.0 km) north of this junction, just before the gravel road fords Montezuma Creek. Access from the south is limited to four-wheel-drive vehicles when the flow in Montezuma Creek is high or roads are wet; accessibility to the northern four miles (6.4 km) of the study area via Verdure Canyon road--which meets U.S. Highway 163 at a point five miles (8.0 km) south of Monticello--is generally good even in wet weather.

PHYSIOGRAPHIC AND TECTONIC SETTING

The Montezuma Canyon/Monument Canyon area is in the southern portion of the Canyon Lands section of the Colorado Plateau physiographic province (Fenneman, 1931). Two main geomorphic features are present in the area: the broad, nearly horizontal Great Sage Plain upland plateau and Montezuma Creek and its tributaries which have incised deeply into the Great Sage Plain. Montezuma Creek and its tributaries form a digitate series of steeply walled canyons (Fig. 2).

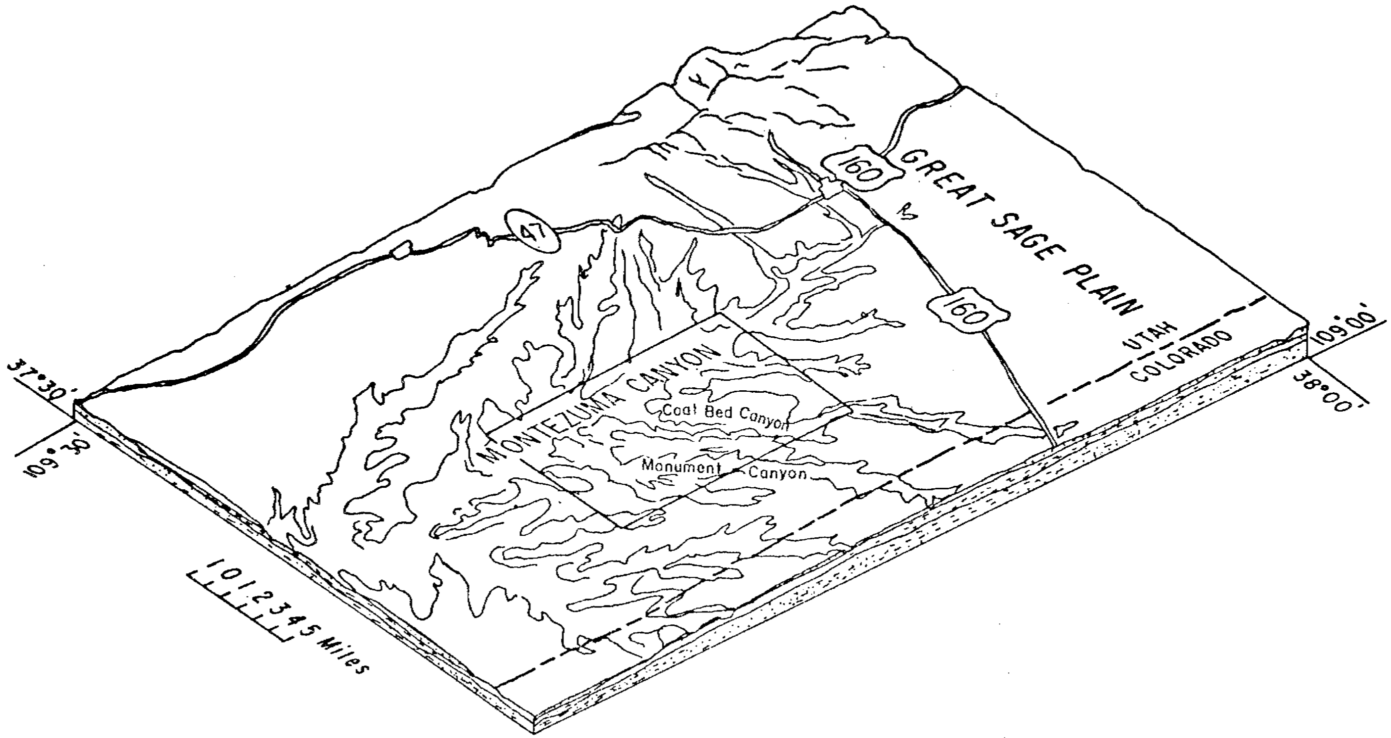


Figure 2. Geomorphic features of the study area (after Huff and Lesure, 1965)

The upland surface, which is at or near the top of the Dakota Sandstone, has an altitude of about 6,400 feet (1950.7 m) above sea level in the northern part of the study area, sloping gently to an altitude of about 5,600 feet (1706.9 m) in the southern part of the study area. Montezuma Creek has an average altitude in the study area of 5,170 feet (1575.8 m), providing a maximum relief of about 1,040 feet (316.9 m) near the mouth of Devil Canyon. The steep canyon walls of Montezuma Canyon are separated by broad slopes covered by colluvium and alluvial canyon floor deposits.

Two types of structural features are present on the Colorado Plateau; those structures, such as folded and faulted sedimentary rocks of the Monument Upwarp, San Rafael Swell, and Paradox fold and fault belt, which are due to tectonic activity, and those formed as a result of igneous intrusions. Hunt (1956) suggested that the two types of structural features formed independently and are not related. Kelley (1955) and Kelley and Clinton (1960) have shown a strong relation between the two types.

Three independent tectonic events have occurred in the Colorado Plateau. The first, in the Precambrian, produced features with a northeastward trend (Kelley, 1955). The second, during the Permian and Pennsylvanian Periods, produced structural features such as the Paradox Basin and Mogollon Uplift which trend northwest. Additionally, salt tectonics which produced anticlinal structures were active in the Colorado Plateau from the Permian Period probably until the Late Jurassic Epoch. The youngest structural features such as the Monument Upwarp occurred after the Jurassic Period, possibly in conjunction with the Laramide Orogeny (Witkind, 1964).

Kelley and Clinton (1960) suggest a slow, gentle subsidence northeast of the Mogollon Highland during the Medial and Late Jurassic Epochs. The Mogollon Slope produced by the subsidence is thought to be the dominant structural feature active during the Late Jurassic Epoch. A structural high, possibly the incipient Monument Uplift (LeBaron, 1980) acted as a barrier to the eastward transport of sediments during the time when the lowest portion of the Salt Wash Member of the Morrison Formation was deposited. Ragan (personal communication, 1980) has shown that this barrier was breached in the present-day Cottonwood Wash area; the full extent to which this barrier blocked transport to the east is not known, but may have been significantly less than thought by Peterson (1979).

The structure of the Montezuma Canyon area is relatively simple. The dips are low--generally less than 1°. This contrasts sharply with the pronounced structural features such as the Monument Upwarp to the west, and the laccolithic bodies to the north (Witkind, 1964). The dip is toward the Blanding Basin, which trends N50E over an area approximately thirteen miles (20.8 km) wide and 50 miles (80.0 km) long, centered near Blanding, Utah (Warner, 1978).

REGIONAL STRATIGRAPHY

The outcrops in the Colorado Plateau area consist of a fairly complete section of the Jurassic and Cretaceous Series, ranging from the Jurassic Navajo Sandstone of the Glen Canyon Group to the Upper Cretaceous Mancos Shale. Jurassic rocks of the Colorado Plateau are subdivided into three major Groups: The Glen Canyon Group (which does not occur within the study area), the San Rafael Group, and the Morrison Formation. The Groups represented in the study area occur throughout much of the Colorado Plateau, as described by Gregory (1938), Stokes and Phoenix (1948), Huff and Lesure (1965), and many other authors. The units present in the study area include the Entrada Sandstone, Summerville Formation, Morrison Formation (consisting of the informal Tidwell member, Salt Wash, Recapture Creek, Westwater Canyon, and Brushy Basin Members), Burro Canyon Formation, Dakota Sandstone, and Mancos Shale. Unconsolidated sediments of pediment gravel, loess, colluvial and landslide deposits, talus and Quaternary alluvial deposits occur in the canyon floors (Huff and Lesure, 1965), (Fig. 3).

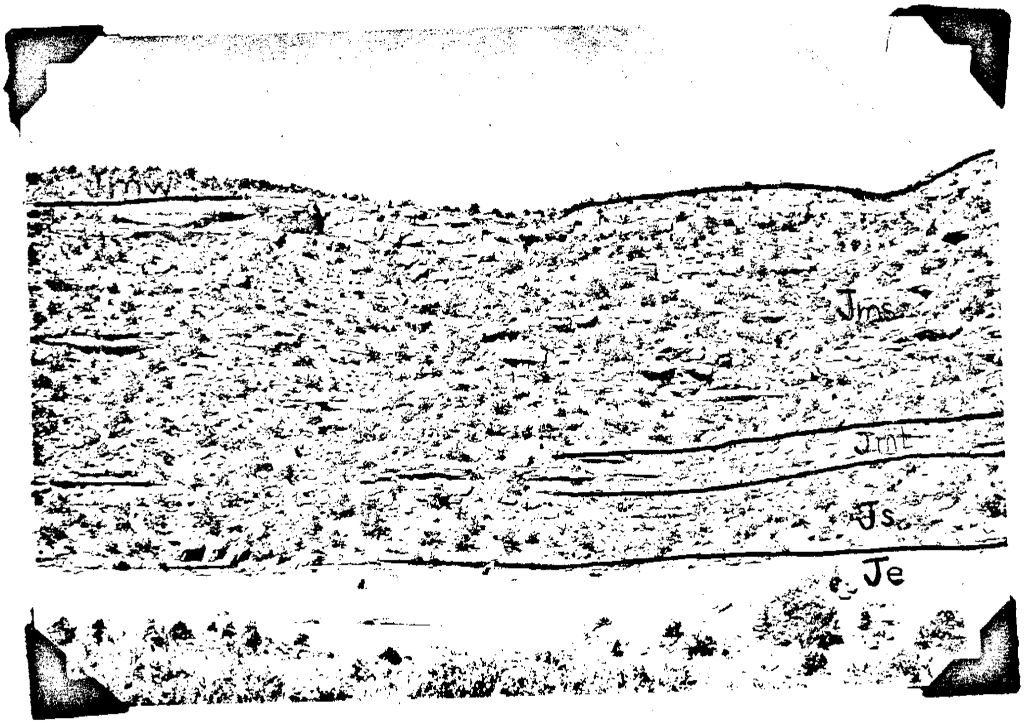


Figure 3. Units shown are Entrada Sandstone (Je), Summerville Formation (Js), Tidwell member (Jmt), Salt Wash Member (Jms), and Westwater Canyon Member (Jmw)

Nomenclature and regional correlation of stratigraphy is shown in Fig. 4. A form of Huff and Lesure's stratigraphic column will be used in this paper, with modifications of the Morrison Formation similar to those of Harshbarger and others, (1957) when discussing the Salt Wash and Recapture Creek Members and their enclosing lithologies. These modifications will be discussed in the section on the stratigraphy of the study area.

San Rafael Group

Entrada Sandstone

The Entrada Sandstone, although lacking age significant fossil remains, has been dated as early Late Jurassic due to its position elsewhere between the Carmel Formation and Curtis Formation which have diagnostic marine invertebrate fossils (Craig, 1955). First named by Gregory (1938) who erroneously correlated it to the Bluff Sandstone of the Morrison Formation, the Entrada Sandstone is widespread having been deposited throughout southern and eastern Utah, most of Colorado, all of northeastern Arizona and northwestern New Mexico (Harshbarger, and others, 1957). Craig (1955) has distinguished two distinct facies of the Entrada Sandstone--an earthy red facies of subaqueous origin which occurs in central and southwestern Utah, and a clean sandstone facies of alternating subaqueous and eolian origin which occurs in Colorado, eastern Utah, northeastern Arizona and northern New Mexico. Huff and Lesure (1965) suggest

Upper Cretaceous		Dakota Sandstone
		unconformity
Lower Cretaceous		Burro Canyon Formation
		unconformity
Jurassic	Morrison Formation	Brushy Basin Member
		Westwater Canyon Member
		Recapture Creek Member
		Salt Wash Member
		Tidwell member
	San Rafael Group	Summerville Formation
		Entrada Sandstone
		Carmel Formation
		unconformity
	Glen Canyon Group	Navajo Sandstone
Jurassic (?)		Kayenta Formation
Triassic		Wingate Sandstone

Fig. 4. Stratigraphic Nomenclature Used in the Montezuma Canyon/Monument Canyon Study Area

that the red sandstone facies may be what has been considered the underlying Carmel Formation.

The Entrada Sandstone generally forms a single cliff from 100 to 150 feet (30.5 to 45.7 m) thick of light colored, well-sorted, very fine- to medium-grained sandstone. Structures range from small-scale to subaqueous cross-bedding near the base to large and very large-scale sweeping eolian cross-bedding in the middle, back to alternating medium-scale eolian and small-scale subaqueous cross-bedding in the upper 20 to 30 feet (6.1 to 9.1 m) (Huff and Lesure, 1965).

Summerville Formation

The Summerville Formation, first named by Gregory (1938), conformably overlies the Entrada Sandstone in Montezuma Canyon. Although unfossiliferous, it is considered to be Late Jurassic because it overlies the fossiliferous Curtis Formation in central Utah (Baker and others, 1936). The Summerville Formation has been recognized throughout southcentral and southeastern Utah, southwestern Colorado, northeastern Arizona and northwestern New Mexico. It generally consists of even, regular and laterally continuous, thin-bedded to laminated red siltstone and red sandy siltstone. Sandy siltstone beds can be traced for several thousand feet (approximately 1 km) along canyon walls.

The Summerville Formation typically forms a step-like slope of a few feet to 130 feet (1 to 39.6 m) thick with more resistant sandy siltstones forming ledges separated by slopes formed by the weathering of the less resistant siltstone. Ripple marks, mud cracks, and salt-crystal impressions are abundant; only minor amounts of small-scale cross-bedding, scour and channel scale cut and fill structures occur. A shallow marine depositional environment has been suggested for the Summerville Formation (Gilluly and Reeside, 1928).

Morrison Formation

The Upper Jurassic non-marine Morrison Formation consists of four members in the Colorado Plateau--the Salt Wash, Recapture Creek, Westwater Canyon, and Brushy Basin Members.

The lowest formal member of the Morrison Formation was called the Salt Wash Member by Lupton (1914) to describe a coarse-grained sandstone which unconformably overlies the Summerville Formation in Salt Wash, Grand County, Utah. The base of the Salt Wash Member is an erosional unconformity between the fluvial deposits of the Salt Wash Member and the marine and marginal marine deposits of the Summerville Formation. The informal Tidwell member of the Morrison Formation is a transitional zone between the Summerville Formation and Salt Wash Member. First recognized in the

Henry Mountains and along the eastern flank of the San Rafael Swell, its basal contact is at the base of a thick gypsum bed (Herron, personal communication, 1980) or at a single layer of subangular to subrounded chert granules which occur slightly below the gypsum bed (Peterson, 1974).

The Salt Wash Member forms steep sandstone ledges and cliffs of variable thickness alternating with red and green mudstones which generally form talus covered slopes and benches. The sandstones can vary between three feet and 250 feet (1 to 76.2 m) thick and often have silty-sand or mudstone splits. The sandstones generally are fine- to medium-grained, light grey and quartzose but can range from very fine- to coarse-grained. Moderate limonite staining is common, often as either blebs or halos around a partially weathered pyrite core.

Sedimentary structures are generally well preserved. Scours, with large-scale, low angle trough-shaped sets of cross-stratification form sharp undulatory basal contacts with underlying mudstones.

The mudstone beds of the Salt Wash Member are usually covered; however, where exposed, load casts, convolute bedding and faint horizontal laminae are typical sedimentary structures. These mudstones are predominantly bright red; however, they often show secondary alteration to light grey-green, with the altered zones near the sandstone/mudstone contact.

The Salt Wash Member is distributed over a large fan-shaped area in eastern Utah, western Colorado, northeastern Arizona and northwestern New Mexico (Fig. 5). In north-easternmost Arizona basal parts of the Salt Wash Member intertongue with the Recapture Creek Member (Craig, 1955); in southeastern Utah at its type section the Recapture Creek Member conformably overlies the Salt Wash Member (Gregory, 1938; Stokes, 1944, 1947, 1954).

The Recapture Creek Member was named by Gregory (1938) to describe the interstratified pinkish-grey sandstones and mudstones approximately twelve miles (19.2 km) northeast of Bluff, Utah. It has been recognized in southern Utah, southwestern Colorado, much of northeastern Arizona and northwestern New Mexico (Harshbarger and others, 1951), (Fig. 6).

Three distinct facies have been recognized in the Recapture Creek Member. Near Gallup, New Mexico, it is composed of a conglomeratic sandstone with stringers of quartz, feldspar, granite, black and grey chert pebbles up to one inch (2.5 cm) in diameter. Surrounding the narrow lobate area of conglomeratic sandstone to the north, west and east is a sandstone facies which differs primarily by the lack of pebbles. The most extensive Recapture Creek Member facies is the interstratified sandstone and mudstone facies, which surrounds the sandstone facies to the north, west and east (Craig, 1955). It consists of variably impure

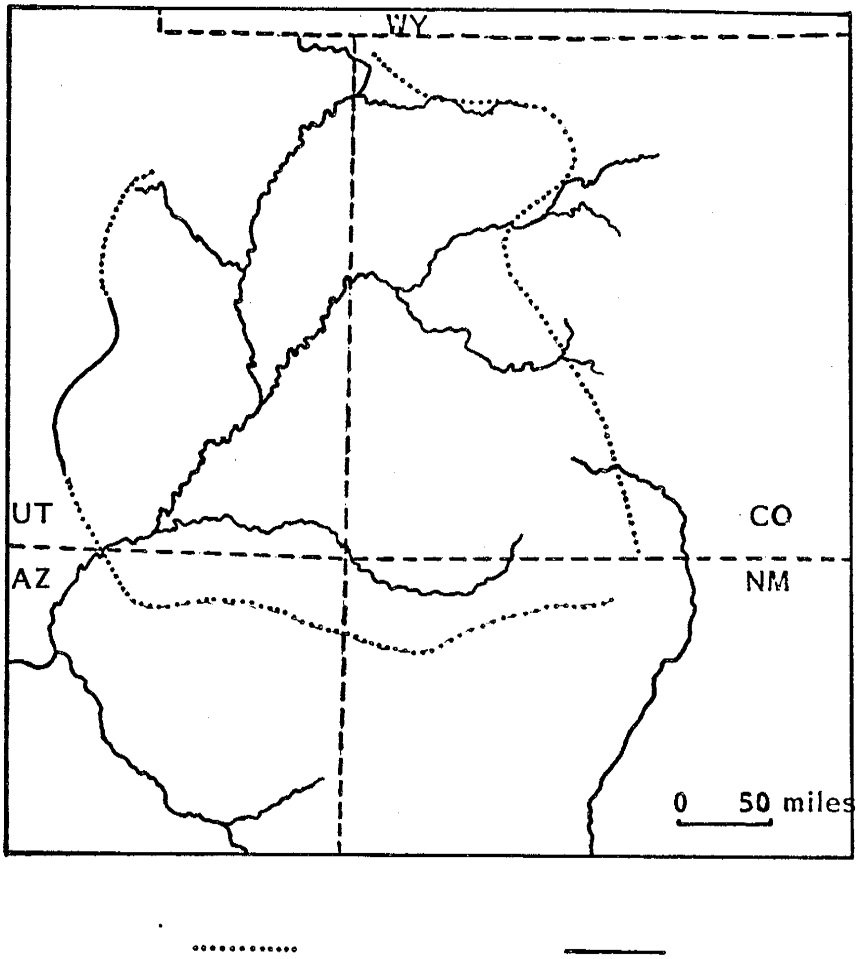
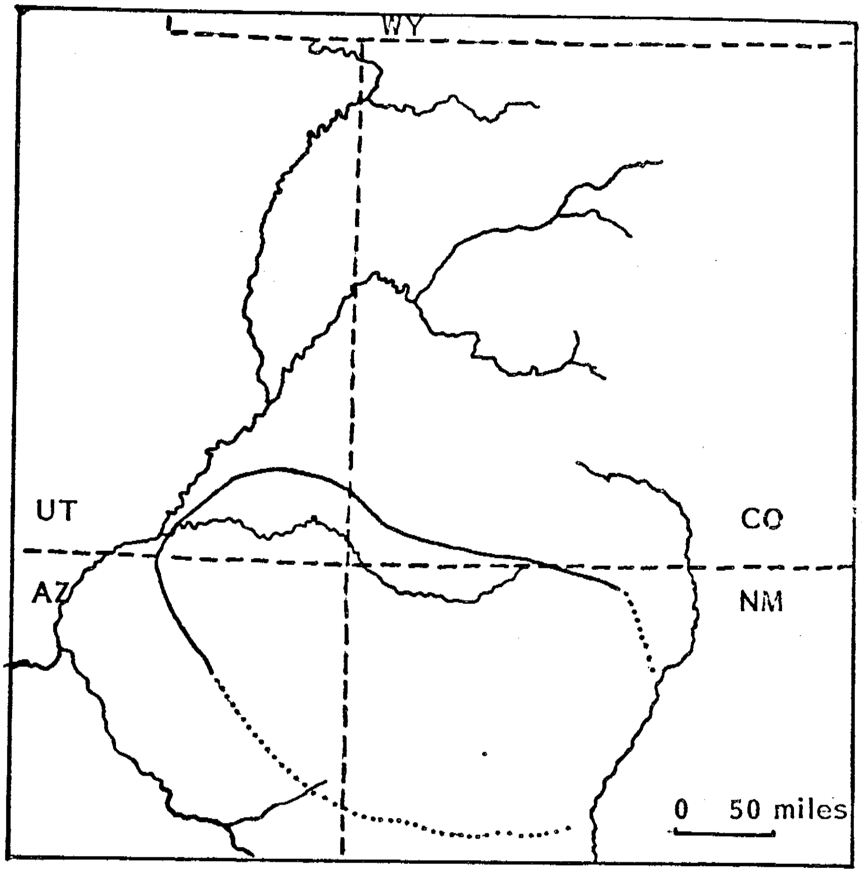


Fig. 5. Areal extent of the Salt Wash Member, Morrison Formation (after Craig and others, 1955)



Inferred Limit of Recapture Creek Member

Known Limit of Recapture Creek Member

Fig. 6. Areal extent of Recapture Creek Member, Morrison Formation (after Craig and others, 1955)

light brown to light grey-green mudstones and noncongiomeratic pinkish-grey to light brown, fine- to medium-grained sandstones. Sand grains in the interstratified sandstone and mudstone facies are generally poorly cemented, forming ledges and rounded cliffs of moderately to highly friable sandstone.

Due to the lack of good induration, the sedimentary structures of the sandstones are generally poorly preserved in outcrop. Where present, they range from medium-scale trough cross-stratification to flat lying, low angle beds and laminae of sandstone. Vertical joints, with calcium carbonate infilling of the smaller joints, and blocky weathering often occur in the sandstone units.

Overlying and intertonguing with the Salt Wash and Recapture Creek Members is the Westwater Canyon Member. Named by Gregory (1938) to describe a series of lenses of less resistant greenish, moderate to well-sorted, subangular to rounded very fine- to medium-grained quartz sandstone, which form a minor cliff set back from the Salt Wash Member ledges (Huff and Lesure, 1965). Interbedded with the sandstone ledges and cliffs are minor amounts of light greenish-grey to greyish-red mudstone and conglomerate bands and stringers. Craig (1955) has distinguished two facies based on textural differences. Near Gallup, a conglomeratic sandstone facies with pebbles of up to four inches (10 cm) diameter occurs. Pebbles in this facies are largely quartz, feldspars, granite and quartzite, with some black and grey chert pebbles. The size of these pebbles decreases to the north, east and west of Gallup. Both facies contain thin strata of claystone and mudstone. The second facies differs from the conglomeratic sandstone facies primarily by the absence of pebbles and a greater amount of claystone and mudstone. The Westwater Canyon Member occurs throughout northwestern New Mexico, and in southeastern Utah, southwestern Colorado and much of northeastern Arizona, reaching a maximum thickness of 330 feet (100.6 m) 30 miles (48.0 km) north of Gallup, New Mexico (Harshbarger and others, 1951).

The Brushy Basin Member (Gregory, 1938) occurs in western Colorado, eastern Utah, northern New Mexico and part of northeastern Arizona. It consists predominantly of variegated mudstones containing varying amounts of silt and sand. Thin, discontinuous limestone beds, lenses of conglomeratic sandstone and shale occur rarely; impure bentonite beds commonly form much of the Brushy Basin Member. The claystone and mudstone beds are thin and regular and range in color from pale-red and pale-red-purple to light greenish-grey (Huff and Lesure, 1965) where good exposures have been cut by gullies; generally the Brushy Basin Member is covered by rock slides, colluvium or its own debris. Generally the claystone or mudstone just above the uppermost sandstone ledge typical of the Salt Wash or Westwater Canyon Members is considered to be the base of the

Brushy Basin Member.

Post-Morrison Units

The post-Morrison units present throughout the Colorado Plateau are all of Cretaceous age or younger. Cater (1970) and many other authors have written extensively about these units and the reader is referred to them for further information.

STRATIGRAPHY OF THE STUDY AREA

Sections measured in the study area were started at the base of the Summerville Formation where possible. As the Summerville Formation, Tidwell member and Salt Wash Member are progressively covered to the south, all but the three northernmost sections were started in the Salt Wash Member and continued up to the Westwater Canyon Member. The Westwater Canyon Member is present in all but the northernmost section, where the Brushy Basin Member directly overlies the Salt Wash Member. Included in this interval are the Summerville Formation, the informal Tidwell ("Transition") member of the Morrison Formation (LeBaron, 1980), the Salt Wash Member, the Recapture Creek Member and the basal portions of the Westwater Canyon and Brushy Basin Members. The locations of the stratigraphic sections are shown in Fig. 7; detailed descriptions and correlations of measured sections appear in Appendix I.

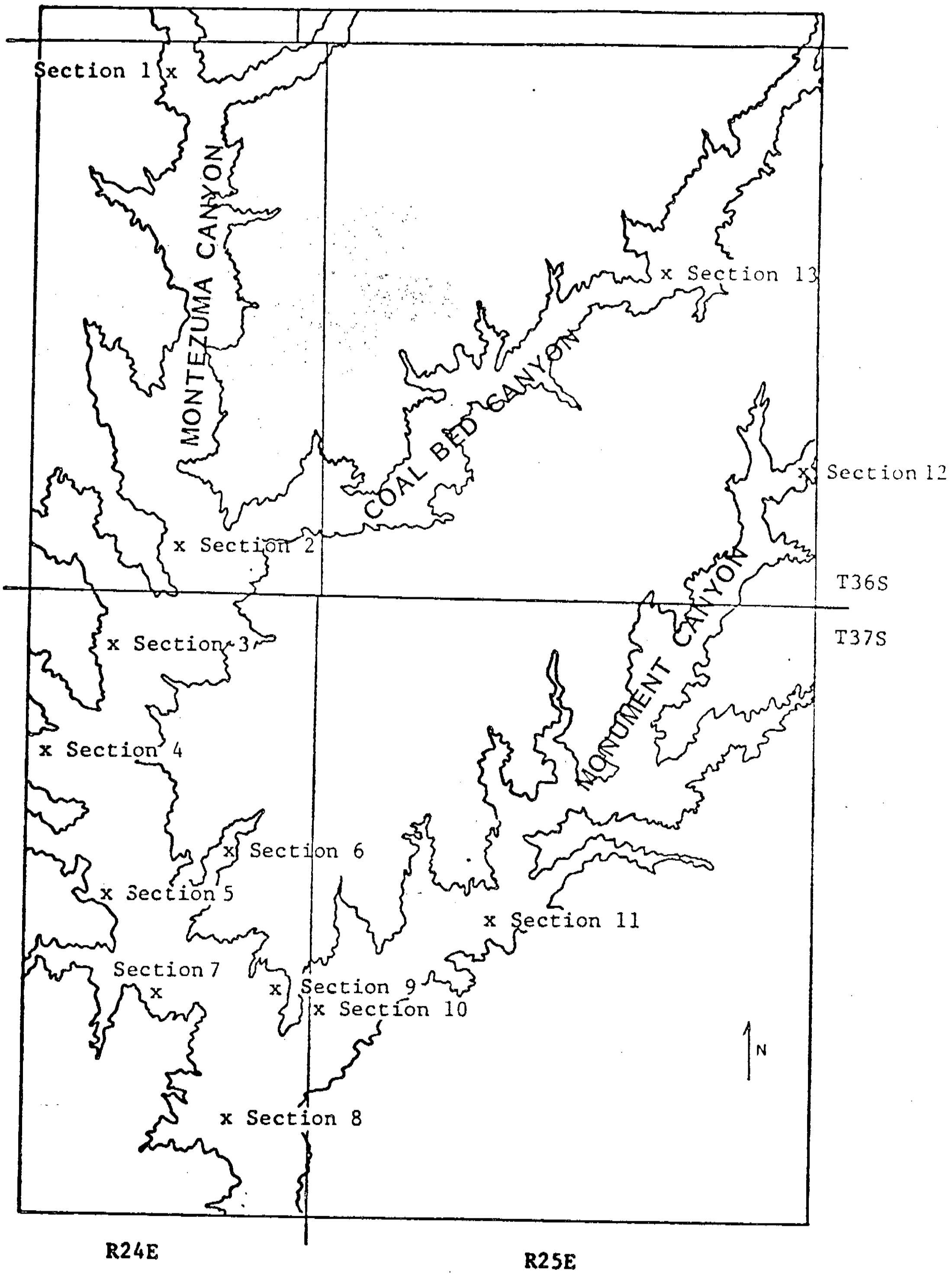


Figure 7. Locations of Measured Stratigraphic Sections within the study area

Summerville Formation

Overlying the Entrada Sandstone with a sharp, planar and conformable lower contact is the Summerville Formation. It is the uppermost member of the Upper Jurassic San Rafael Group and the lowest unit included in the measured sections. The Summerville Formation crops out for fifteen miles (24.0 km) north of the mouth of Coal Bed Canyon. To the south of this point it is covered by Quaternary colluvium and alluvium.

Consisting of regular, thinly interbedded fine-grained light colored sandstones, very fine-grained red siltstones and silty, fine-grained red sandstones, the Summerville Formation present in Montezuma Canyon differs from that described by Gilluly and Reeside (1928) in the type area of the San Rafael Swell only by the absence of gypsum beds in Montezuma Canyon. The sandstone beds generally lack visible structures, although some small-scale crossbedding and ripple marks occur. The sandstone beds, although thin, are laterally extensive for several thousand feet (approximately 1 km) with little variation in thickness. These beds form steep, step-like slopes in Montezuma Canyon which are often at least partially covered by colluvium.

Tidwell member

The Tidwell ("Transition") member appears to occur in Montezuma Canyon at the mouth of Coal Bed Canyon and to the north. Informally named in the late 1950's by a team of geologists working jointly for the Atomic Energy Commission and the United States Geologic Survey along the eastern flank of the San Rafael Swell and in the Henry Mountains (LeBaron, 1980), it is considered to be the lowest unit of the Morrison Formation. The Tidwell member is considered to be a transitional unit between the marine Summerville Formation and the continental fluvial, cross-stratified Salt Wash Member. The basal contact with the Summerville Formation, which it closely resembles, is marked by the occurrence of a very thin layer of subangular to subrounded chert granules which occur slightly below a gypsum bed (Peterson, 1974). In Montezuma Canyon, the chert granule layer and gypsum bed are absent, so the lower contact is defined as the base of a ten to fifteen foot (3.0 to 4.6 m) thick ledge of sandstone which is made up of three beds of approximately equal thickness. The beds are separated by siltstones less than a foot (30.5 cm) thick (LeBaron, personal communication, 1980). Its upper contact is the base of the lowest Salt Wash Member sandstone which is arbitrarily placed at the base of the lowest cross-stratified sandstone three feet (approximately 1 m) or more in thickness with a lateral extent of more than 300 feet (approximately 91 m).

Above the basal sandstone marker ledge, the Tidwell member consists of sandstones and siltstones similar in composition to those of the Summerville Formation. It differs primarily in the increased abundance of sandstones, and its thicker, more irregular bedding. Small-scale crossbedding occurs in the fine-grained sandstone beds. Due to the increased abundance of sandstones, the Tidwell member is often better exposed than the underlying Summerville Formation.

Salt Wash Member

The Salt Wash Member is the lowest formally recognized member of the Morrison Formation which is present in the Montezuma Canyon/Monument Canyon study area. It consists of steep sandstone ledges and cliffs of variable thickness alternating with mudstones, which are generally talus covered to form benches and slopes. The cliffs are produced by the buildup of several smaller sandstone bodies which combine to form multistory and multilateral sandstones (Potter, 1967). The multistory sandstones are generally limited to the northernmost and easternmost portions of the study area; in the south and central portion of the study area multilateral sandstones are in the form of ribbons and sheets (Pettijohn and others, 1973).

The contact of the Salt Wash Member with the Tidwell member has been described. Lithologic similarities between the Tidwell member and the Salt Wash Member indicate that the sediments of the Tidwell member have been reworked and incorporated into the basal portions of the Salt Wash Member.

The upper contacts of the Salt Wash Member with the Recapture Creek and Westwater Canyon Members are difficult to determine. In the northernmost portion of the study area, where the Salt Wash Member is conformably overlain by the Westwater Canyon Member, the contact is often gradational. For the purposes of this study, the contact between the Salt Wash Member and the Westwater Canyon Member is placed at the base of the lowest covered slope overlain by a series of greenish sandstone ledges which contain greenish-grey or greenish-yellow mudstone galls and conglomeratic pockets of granule- and pebble-size clasts. The sandstone ledges are generally less than fifteen feet (4.6 m) thick and have very dark and tightly cemented weathered surfaces. No intertonguing of the Westwater Canyon Member with the Salt Wash Member was observed in the study area.

The contact between the Salt Wash and Recapture Creek Members is more difficult to determine due to their similar lithologies and intertonguing relations. The Recapture Creek Member is less well cemented than the Salt Wash

Member; the contact is often marked by a broad covered slope or bench (40 to 200 feet (12.1 to 60.9 m) thick) overlain by a rounded cliff or ledge with a lighter colored fresh surface (white to light brown versus the light brown to brown of the Salt Wash Member). For the purposes of this study, the contact between the Salt Wash Member and Recapture Creek Member is placed at the base of this broad covered bench or slope. The light brown to brown colored (often with "freckles" of limonite staining) sandstone ledges and cliffs average fifteen feet (4.6 m) thick with only minor thin (less than eighteen inches (46 cm) thick) silty-sandstone or mudstone splits. The sandstone beds often extend laterally for 2 1/2 miles (4.0 km). Total thickness of the exposed Salt Wash Member in the study area ranges from seventeen feet (5.1 m) to 313 feet (95.4 m) because its basal contact dips below the canyon bottom.

The sandstone beds commonly have slightly concave upward bases with horizontal, relatively planar upper surfaces. These beds are thickest where they have been deposited in channel cut and fill structures and thin laterally from these structures. In thinner sandstone lenses, the beds commonly pinch out symmetrically away from the central part of the body. Primary sedimentary structures, such as cross-stratification, parting lineations and ripple marks, are abundant in this member and will be discussed in detail in a later chapter.

The siltstone and mudstone units of the Salt Wash Member are usually covered; where exposed they are predominantly bright red with local secondary alteration to light green. The best exposures occur near contacts between sandstone or siltstone with mudstone. Locally thin or small blebs of grey-green carbonaceous mudstones occur within the sandstones. Peterson (1974) has attributed these mudstones to a locally reducing environment within the fluvial system where long-term ponding can occur. Typical bed forms at exposures consist of load casts, convolute bedding, and horizontal laminae. At the contacts, siltstone and mudstone units are commonly scoured in a shallow trough shape which is filled by the overlying sandstone units.

Recapture Creek Member

Conformably overlying the Salt Wash Member in the southern and eastern portion of the study area is the Recapture Creek Member. This area represents the northernmost extent of this member.

The Recapture Creek Member is very similar in appearance to the Salt Wash Member, consisting of alternating beds of sandstones and mudstones. The thickness of the sandstone beds is highly variable, averaging 25 feet (7.6 m) but ranging up to 71 feet (21.6 m); they are generally thinner and less laterally extensive than sandstone beds in the underlying Salt Wash Member, often pinching or onlapping adjacent sandstone beds. Sandstones in the Recapture Creek Member are poorly cemented, forming moderately to highly friable rounded ledges and cliffs which are white to light brown in color due to a very minor amount of limonite staining. Sedimentary structures are generally poorly exposed due to the lack of a stable weathering surface, but, where visible, are predominantly medium-scale trough-shaped cross-stratified sets. Sandstone units commonly exhibit vertical joints with calcium carbonate infilling of the smaller joints. The smaller multilateral and multistory sandstones of the Recapture Creek Member often have minor thin (less than eight inches (20.3 cm) thick) yellow-green siltstone and mudstone splits. These sandstone beds typically lack the cut and fill structures common in the Salt Wash Member.

The mudstone beds consist of pale-red, greyish-red and very dusky red with widely varying amounts of silt and sand. Thin lenses of sandstone and siltstone, generally less than eighteen inches (45.7 cm) thick, are locally exposed; typically entire mudstone beds are completely covered with colluvium, forming slopes and benches. The best exposures of the mudstone beds occur near the base of sandstone beds. Where exposed, the mudstone beds exhibit convolute bedding, load structures or planar, very thin laminae. Alteration of the red mudstones to light green and white is common near the sandstone/mudstone interface. The grey-green coloration, which is due to early alteration associated with carbonaceous matter in the mudstones of the Salt Wash Member, is absent in the mudstones of the Recapture Creek Member. The Recapture Creek Member in the study area is notable for the dearth of carbonaceous matter in both the sandstones and mudstones. The overlying Westwater Canyon forms less resistant ledges than the Recapture Creek Member or Salt Wash Member sandstones and are set back on a bench from the uppermost sandstones of these members. The contact between the Recapture Creek or Salt Wash Members and the Westwater Canyon Member is difficult to place due to the covered slope at the contact. For the purposes of this study, it is placed at the base of the lowest covered slope overlain by a yellowish-brown to yellowish-green sandstone which exhibits well cemented, dark colored weathering surfaces. Unweathered surfaces exhibit abundant limonite blebs.

Westwater Canyon Member

Conformably overlying the Recapture Creek Member in the southern portion of the study area or the Salt Wash Member in the northern portion, is the Westwater Canyon Member of the Morrison Formation. The lower portion of the Westwater Canyon Member is included in all the measured sections.

The Westwater Canyon Member consists of interbedded sandstone ledges up to 25 feet (7.6 m) thick, and purplish-brown to light grey-green mudstones. The sandstones range from yellowish-brown to yellowish-green and typically have abundant pyrite crystals which have been altered to form limonite blebs or halos around a pyrite core. The sandstone is moderately to well-sorted and medium- to fine-grained with larger angular tuffaceous fragments up to 1/4 inch (.6 cm) along basal bedding planes. The sand grains are well cemented near weathering surfaces by silica minerals and/or carbonates; oxides of iron and manganese often produce a dark brown to black shiny desert varnish. Some sandstone ledges are locally conglomeratic, with rounded chert pebbles, coarse sand grains, and larger angular fragments of tuffaceous material. Mud clasts up to eight inches (20.3 cm) diameter, but averaging two to three inches (5.0 to 7.6 cm) diameter are common throughout sandstone units and often weather out to form pits which can obliterate bedding structures. Where visible, medium-scale trough-shaped sets of tangential cross-laminations are dominant with slightly less common medium-scale wedge-shaped sets of planar cross-laminations and medium-scale ripple cross-stratification. There appears to be none of the fining upwards in scale of bedding structures common in the Salt Wash Member. Carbonaceous matter has not been observed in the Westwater Canyon Member anywhere in the study area.

No intertonguing of the Westwater Canyon Member with either the Salt Wash or Recapture Creek Members has been observed within the study area.

SEDIMENTARY STRUCTURES

Primary sedimentary structures such as cross-stratification, ripple marks and parting lineations are common in sandstone beds of the Salt Wash Member. They doubtless occur to a similar extent in the Recapture Creek Member sandstones; however, due to the friable nature of these sandstones, the structures are often poorly preserved in outcrop. The following descriptions of the geometry, following McKee and Weir (1953) and Allen (1963, 1968), give the characteristics of the most common types of sedimentary structures which were observed. Generally, trough-shaped sets of cross-strata are analogous to Allen's Nu-cross-stratification (small-scale sets) and Pi-cross-stratification (large-scale sets). Wedge-shaped sets of cross-strata correspond to Allen's Mu-cross-stratification (small- and medium-scale sets) and Xi-cross-stratification (medium- and large-scale sets). More detailed descriptions of sedimentary structures observed in each measured section appear in Appendix I.

Exogenetic Structures:

Small-scale Cross-stratification

Small-scale structures include trough- and wedge-shaped sets of generally low angle (average inclination of less than 20°) very thin cross-beds to thin cross-laminations. Sets range from one to twelve inches (2.5 to 30.5 cm) thick and are less than twelve inches (30.5 cm) in length. The majority of the small-scale sets of cross-strata observed were trough-shaped sets of tangential cross-strata and occur in the uppermost portion of the sandstone beds. Wedge-shaped sets, bounded by planar, converging erosional surfaces, consist of low angle planar cross-strata (Fig. 8). Basal cross-strata often exhibit an increased amount of dark minerals and limonite staining. Small-scale structures commonly occur in the upper portions of sandstone beds in the Salt Wash Member; they are seldom observed in the Recapture Creek Member.

Medium-scale Cross-stratification

Medium-scale structures range from one to five feet (.3 to 1.5 m) thick and one to twenty feet (.3 to 6.1 m) in length and are similar to those described for small-scale types (Figs. 9 and 10). The cross-strata are generally low angle with thin mudstone or siltstone layers and clay clasts at their bases.

Downcutting by overlying cross-strata often results in truncation of the original cross-strata. This produces great variation in the size of the individual sets of these structures.

Medium-scale tabular-shaped sets of planar cross-strata often occur in the uppermost portion of sandstone beds in the Salt Wash Member; they occur less often in the upper portion of the Recapture Creek Member. They consist of very low angle beds and laminae of sandstones commonly with

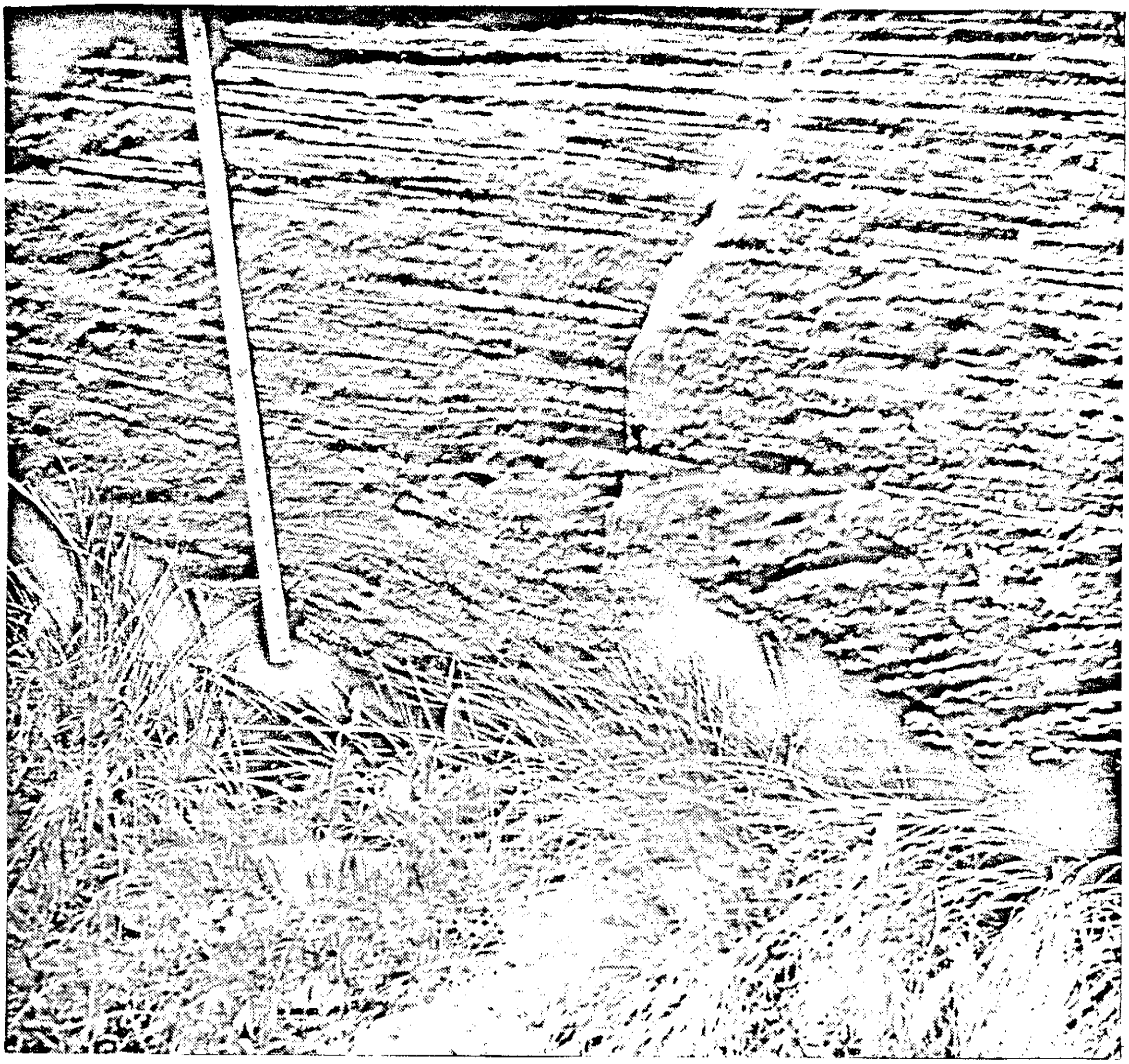


Figure 8. Low angle wedge-shaped sets of cross-strata

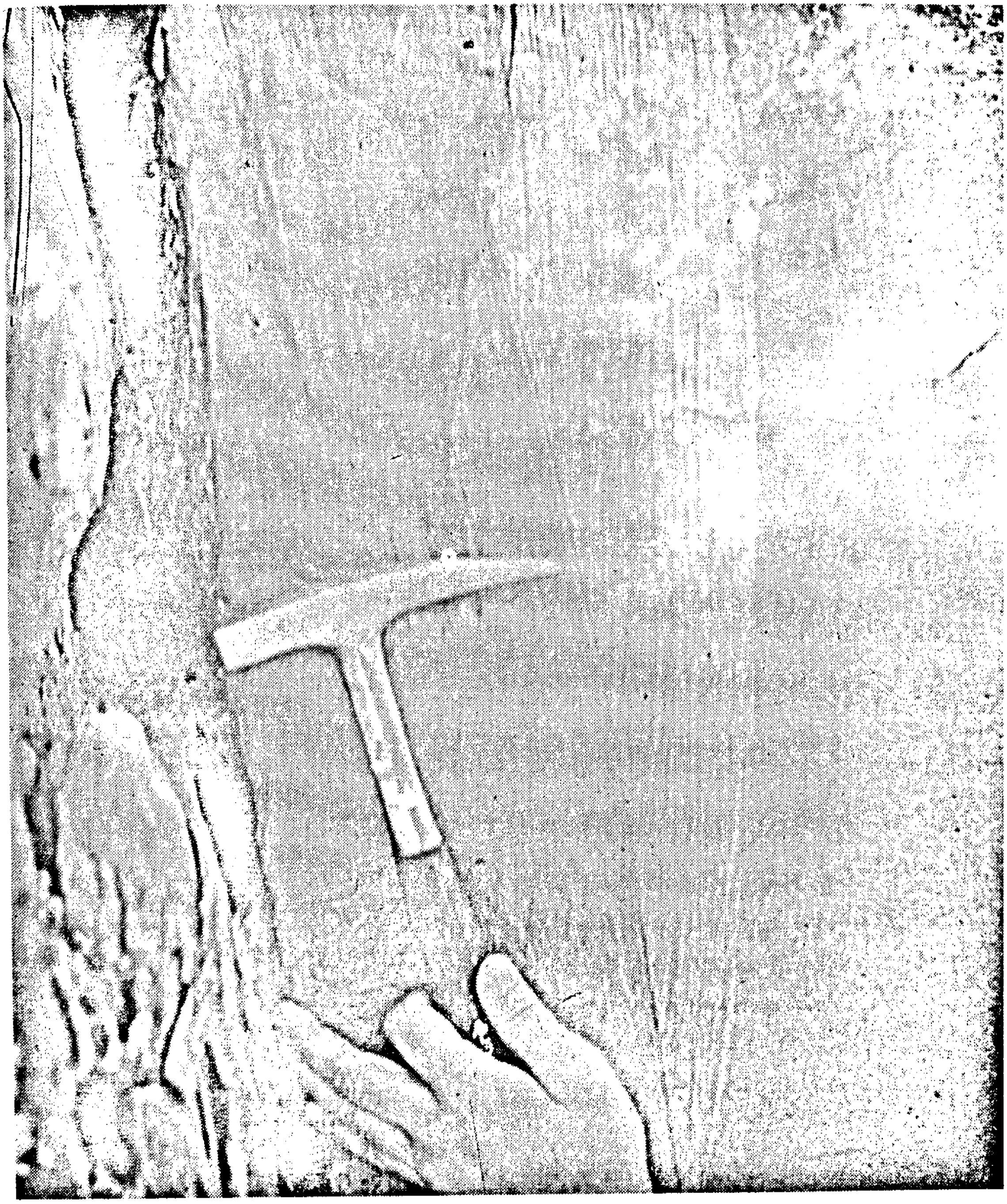


Figure 9. Fresh surface exhibiting low angle medium-scale trough-shaped sets of cross-stratification

Figure 10. Weathered surface exhibiting low angle medium-scale trough-shaped sets of cross-stratification

weathered out laminae of mudstones and siltstones. They are seldom more than two to three feet (.6 to .9 m) thick and extend laterally for distances of up to twenty feet (6.1 m).

Large-scale Cross-stratification

Large-scale structures include trough- and wedge-shaped sets of cross-strata. These commonly occur in the basal portion of sandstone beds, often exhibiting very low angle, broad erosional lower contacts with underlying mudstone beds. Individual sets of cross-strata, while showing great variability due to truncation resulting from downcutting by overlying cross-stratification sets, range from one to seven feet (.3 to 2.1 m) thick and are greater than twenty feet (6.1 m) in length. Wedge-shaped sets, bounded by planar, converging erosional surfaces, consist of low angle, planar cross-strata (Fig. 11). Trough-shaped sets, bounded by curved converging erosional surfaces, consist of very low angle, broad sweeping cross-strata, often with clay clasts and organic debris along the lower bounding surfaces of the sets.

Large-scale cross-stratification, while less common than the medium-scale and small-scale cross-stratification, comprises about twenty percent of the cross-stratified structures in the Salt Wash Member; in the Recapture Creek Member, large-scale cross-stratification is essentially absent.

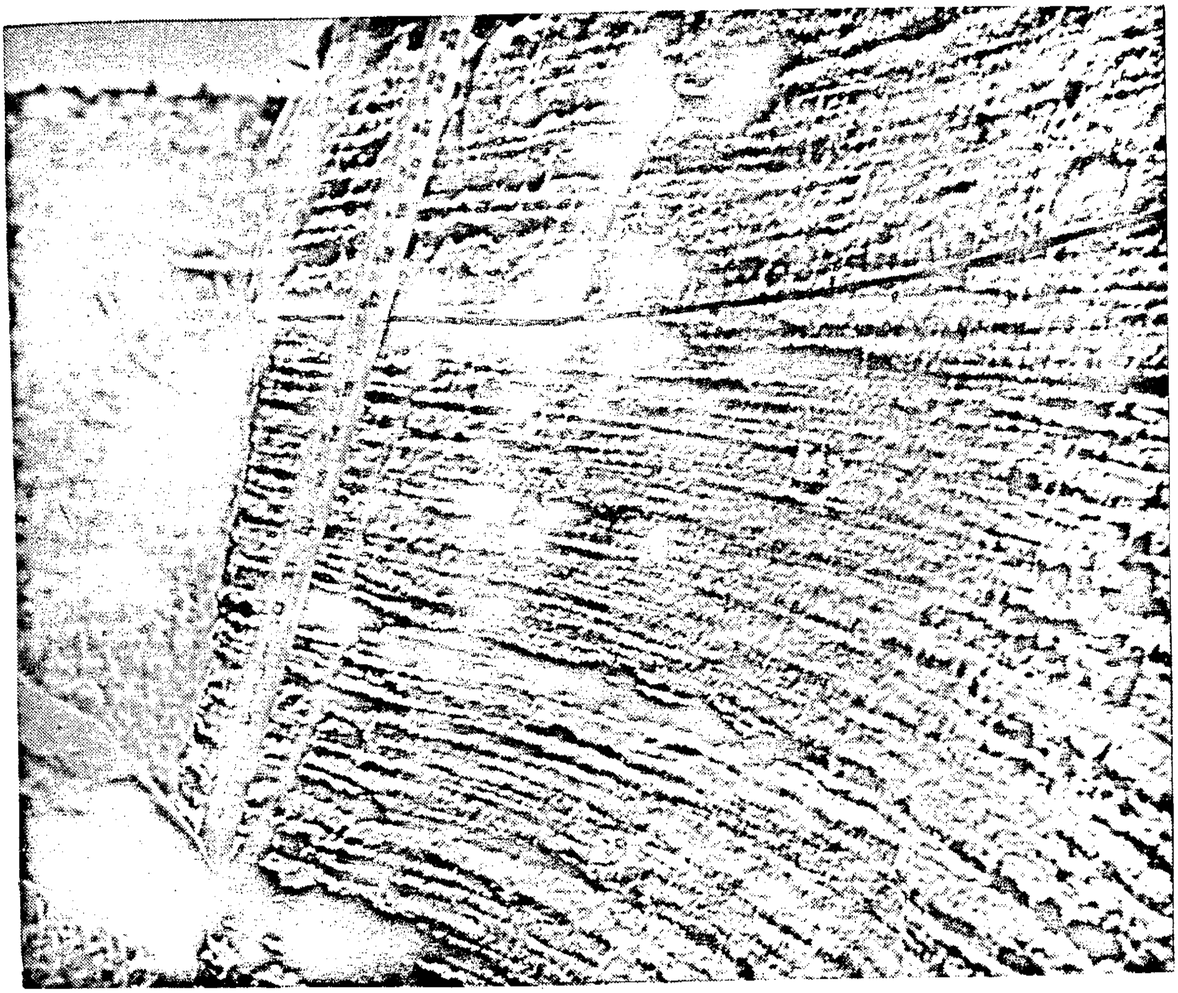


Figure 11. Large scale low angle wedge-shaped sets of cross-stratification

Ripple Marks

Ripple marks are less common in the Salt Wash Member than cross-stratified sets. Typically the ripple marks have straight to slightly sinuous crestlines which are out of phase; commonly they are asymmetrical in cross section. The average ripple-mark wavelength is approximately two inches (5 cm) and average ripple-mark amplitude is .2 inches (.5 cm). Carbonaceous debris and chert granules commonly are deposited in the troughs (Figs. 12 and 13).

Rib and furrow structures, while rare, occur at several locations. They consist of long, parallel grooves three to five inches (7.6 to 12.7 cm) wide which are separated by narrow, discontinuous ridges which are less than an inch (2.5 cm) wide. Rib and furrow structures are produced by the intersection of a weathering surface with sets of cross-laminations produced by the downstream migration of small linguoid (cuspate) ripples arranged in phase.

Parting Lineations

Consisting of groups of en echelon ridges from a few inches to a few feet (.05 to 1 m) in length, parting lineations are often extensively exhibited on flat lying or slightly inclined bedding surfaces of sandstone in the Salt Wash and Recapture Creek Members. The ridges are only a few sand grains in height and are composed of slightly coarser sand grains than those of the surrounding hollows (Fig. 14).

Figure 12. Asymmetrical ripple laminations

Figure 13. Carbonaceous debris in ripple troughs

Figure 14. Parting lineations. Current direction parallel to head of rock hammer

Endogenetic Structures:

Mud Cracks

Mud cracks occur at several locations in the Salt Wash Member. They consist of irregular polygons or as clasts in silty sandstones. The size of the polygons is highly variable, but average between three and eight inches (7.6 to 20.3 cm) diameter (Fig. 15).

Soft Sediment Deformation

At the contacts between overlying sandstone beds and mudstone beds, load structures often occur. Differential settling between the silts and sands while the sediments were still unconsolidated results in convolute laminations, "ball and pillow" structures and overturned small-scale cross-strata. These load structures occur primarily in the Salt Wash Member and only rarely in the Recapture Creek Member (Fig. 16).

Biogenetic Structures:

Trace Fossils

The Recapture Creek Member, possibly due to its friable nature, generally lacks structures such as burrows which are usually seen in relief. In the finer grained sandstones and siltstones of the Salt Wash Member a limited number of burrows occur. The burrows are oriented parallel, oblique and perpendicular to bedding (Fig. 17).

Figure 15. Mud cracks

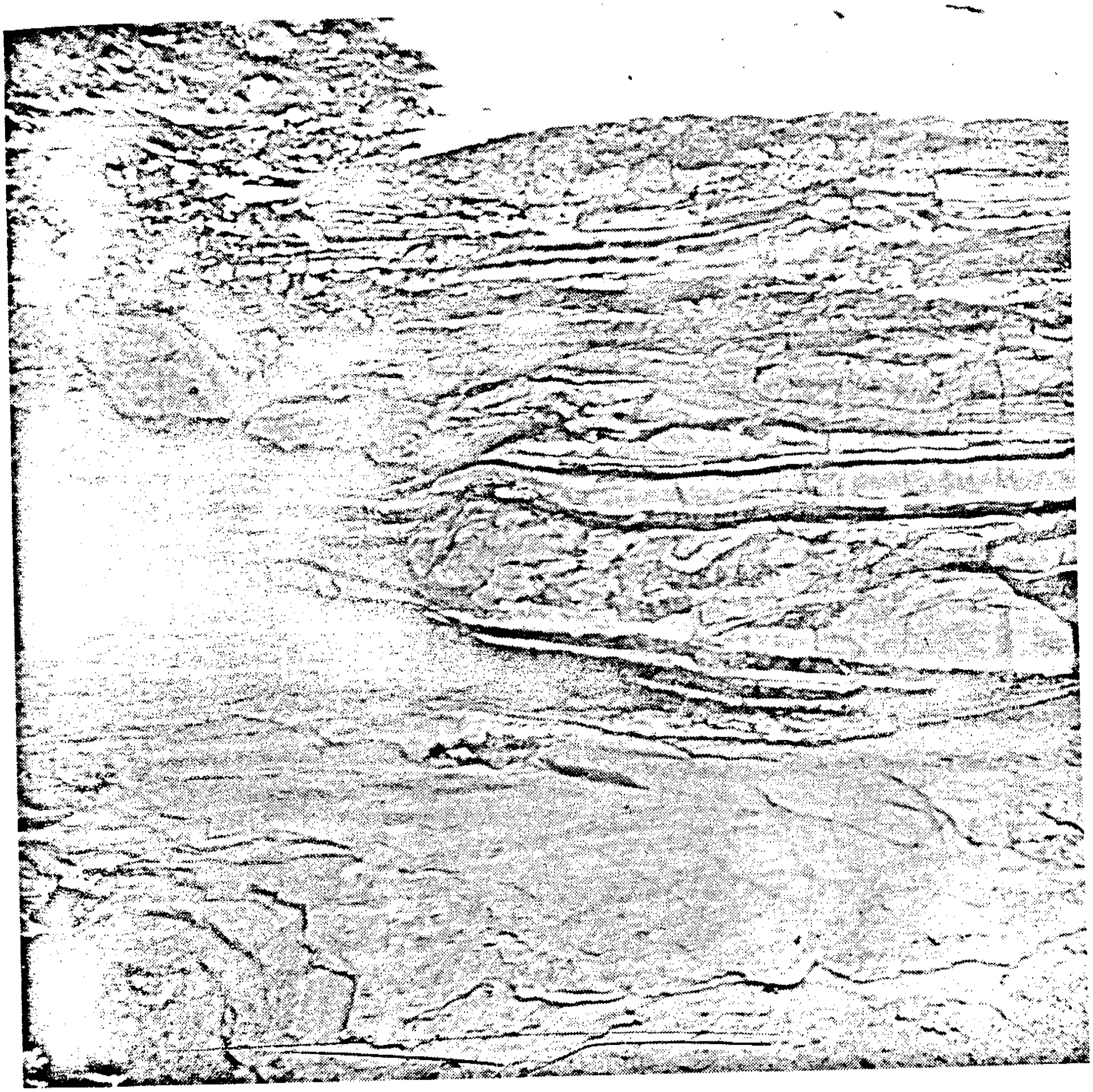


Figure 16. Convolute bedding (center) and "ball and pillow" structures (left)

Figure 17. Burrows parallel and perpendicular to bedding

The burrows are smooth walled without ornamentation and maintain a fairly constant diameter throughout their length. Averaging 1/4 inch (.6 cm) or less in diameter, from three to twelve inches (7.5 to 30.0 cm) in length, the burrows parallel to stratification often cross over each other, but have not been observed to branch. The individual burrows, are straight to slightly sinuous. The burrows perpendicular to bedding have a slightly greater average diameter (about 3/8 inches) (1 cm).

The burrows probably represent the Scoyenia assemblage which is typical of non-marine clastic sediments, especially continental "red beds" and floodplain deposits (Frey, 1975).

LeBaron (1980) tentatively identified the burrow types present as: Palaeophycus, Hall, 1847 and Planolites, Nicholson, 1873, and Scoyenia, White, 1929. Additionally, Scalarituba, Weller, 1899, and Scolicia, de Quatrefauges, 1849, appear to be present in the study area. While the specific organisms which created these burrows are not known, Hantzschel (1966) proposed that Scoyenia was produced by a polychaete worm or an organism similar to that which made the marine ichogenus Tambia, Muller, 1969.

Planolites, Palaeophycus and Scalarituba have a range from Precambrian to recent. Scoyenia and Scolicia are dated as Permian and Upper Permian, respectively, and whether they could be represented in the Jurassic Salt Wash Member is highly speculative (Hantzschel, 1966).

Palaeophycus is an ichnogenus which shows a wide range of morphologies; it is commonly unbranched with smooth walled cylindrical to subcylindrical sinuous burrows. The burrows are generally 1/8 to 2/3 inches (.3 to 1.7 cm) in diameter and up to eight inches (20.3 cm) in length. The burrows often intersect each other and are commonly oriented obliquely to bedding. *Palaeophycus* may have been incorrectly identified as *Spongillipsis*, Geinitz, 1862 in lacustrine sediments. *Palaeophycus* is considered to be the pathways of unknown groups of errant organisms (Hantzschel, 1966).

Planolites are commonly unbranched, smooth walled with straight to slightly sinuous cylindrical to subcylindrical burrows and are very similar to *Palaeophycus*. The burrows range from 1/4 to 2/3 inches (.3 to 1.7 cm) in diameter and are oriented from parallel to oblique to bedding. No specific organism has been attributed to *Planolites* (Hantzschel, 1966).

Scalarituba, Weller, 1899 are cylindrical to subcylindrical, sinuous burrows which are nonbranching and range from 1/8 to 1/2 inches (.3 to 1.3 cm) in diameter. The burrows may be perpendicular, parallel or oblique to bedding and show no ornamentation. They commonly cross over one another, and are commonly interpreted as being the internal trail of sediment-eating worms or worm-like organisms (Hantzschel, 1966).

ANALYSIS OF STRATIGRAPHIC DATA

Markov Chain Analysis

To determine if a preferred vertical succession of lithologies and sedimentary structures is characteristic of the Salt Wash and Recapture Creek Members, an embedded Markov chain analysis was applied to seven lithologies and sedimentary structures typical of both members. These seven lithologies and sedimentary structures are covered/mudstones, large-scale trough-shaped sets of cross-stratification, medium-scale trough-shaped sets of cross-stratification, small-scale trough-shaped sets of cross-stratification and ripple marks, medum-scale wedge-shaped sets of planar cross-strata, flat-lying planar beds, and structureless beds. Krumbein (1968), Potter and Blakely (1968), Pettijohn and others (1973), and Miall (1978) provide statistical treatments of the raw stratigraphic data similar to that which is employed here.

To determine whether the sedimentary structures were deposited under control of Markov processes a transition count matrix is made. The matrix thus obtained consists of a table in which all possible vertical transitions among the seven types are arrayed such that an entry represents the number of transitions from the row structures to the column structure (Table 1). A probability matrix is then derived from this transition count matrix such that each row sums to one, which yields the probability of a row structure under-

a. Transition Count Matrix, Salt Wash Member

Sedimentary Structures		1	2	3	4	5	6	7	Row Sum
covered/mudstone	1	X	29	32	0	3	6	5	75
large-scale trough	2	3	X	26	1	1	1	0	32
medium-scale trough	3	21	0	X	14	7	24	3	69
small-scale trough & ripple cross-strata	4	13	1	3	X	0	1	1	19
medium-scale wedge planar	5	1	0	4	1	X	7	0	13
flat lying	6	31	3	3	3	2	X	0	42
structureless	7	6	0	0	0	0	3	X	9
Total		75	33	68	19	13	42	9	259

b. Transition Count Matrix, Recapture Creek Member

Sedimentary Structures		1	2	3	4	5	6	7	Row Sum
covered/mudstone	1	X	1	0	0	1	4	4	10
large-scale trough	2	0	X	2	0	0	0	0	2
medium-scale trough	3	8	1	X	0	1	4	4	18
small-scale trough & ripple cross-strata	4	0	1	1	X	0	1	0	3
medium-scale wedge planar	5	1	0	1	0	X	1	0	3
flat lying	6	5	0	0	1	1	X	2	9
structureless	7	7	0	3	0	0	0	X	10
Total		21	3	6	2	3	10	10	55

Table 1. Transition Count Matrices of a) Salt Wash Member and b) Recapture Creek Member

lying a column structure (Table 2). An equal likelihood matrix, which shows the expected probability of a given transition occurring in the section is then constructed (Table 3). Using the difference between the expected probability of a given transition and the observed probability of the same transition, a difference matrix is then constructed (Table 4). Comparatively larger positive entries in the difference matrix help emphasize the Markov property by suggesting which transitions have occurred with a greater than random frequency. The probability and equal likelihood matrices for both the Salt Wash and Recapture Creek Member transitions are then subjected to a chi-square test to accept or reject the null hypothesis that the transitions are statistically random.

A chi-square test result of zero would indicate that the transitions are randomly produced and the null hypothesis would be accepted. Using a 99 percent confidence limit for the chi-square test of the Salt Wash Member and Recapture Creek Member yielded results of 5.729 and 11.972 respectively. Therefore, the null hypothesis is rejected for both the Salt Wash Member and the Recapture Creek Member; the transitions appear to have been produced by non-random processes. To determine the preferred vertical succession, the highest values in the difference matrices are followed. Transitions not thus encountered may be attributed to the occurrence of non-cyclic, "random" changes in the depositinal sequences.

a. Probability Matrix, Salt Wash Member

Sedimentary Structures		1	2	3	4	5	6	7
covered/mudstone	1		.38	.43	0	.04	.08	.07
large-scale trough	2	.10		.81	.03	.03	.03	0
medium-scale trough	3	.30	0		.20	.10	.36	.04
small-scale trough & ripple cross-strata	4	.68	.05	.16		0	.05	.05
medium-scale wedge planar	5	.08	0	.31	.08		.53	0
flat lying	6	.74	.07	.07	.07	.05		0
structureless	7	.67	0	0	0	0	.33	

b. Probability Matrix, Recapture Creek Member

Sedimentary Structures		1	2	3	4	5	6	7
covered/mudstone	1		.10	0	0	.10	.40	.40
large-scale trough	2	0		1.00	0	0	0	0
medium-scale trough	3	.44	.06		0	.06	.22	.22
small-scale trough & ripple cross-strata	4	0	.33	.33		0	.33	0
medium-scale wedge planar	5	.33	0	.33	0		.33	0
flat lying	6	.56	0	0	.11	.11		.22
structureless	7	.70	0	.30	0	0	0	

Table 2. Probability Matrices of a) Salt Wash Member and b) Recapture Creek Member

a. Equal Likelihood Matrix, Salt Wash Member

Sedimentary Structures		1	2	3	4	5	6	7
covered/mudstone	1	X	.18	.37	.10	.07	.23	.05
large scale trough	2	.33	X	.30	.08	.06	.19	.04
medium scale-trough	3	.39	.17	X	.10	.07	.22	.05
small-scale trough & ripple cross-strata	4	.31	.14	.28	X	.05	.18	.04
medium-scale wedge planar	5	.30	.13	.28	.08	X	.17	.04
flat lying	6	.35	.15	.31	.09	.06	X	.04
structureless	7	.30	.13	.27	.08	.05	.17	X

b. Equal Likelihood Matrix, Recapture Creek Member

Sedimentary Structures		1	2	3	4	5	6	7
covered/mudstone	1	X	.09	.18	.06	.09	.29	.29
large-scale trough	2	.40	X	.12	.04	.06	.19	.19
medium-scale trough	3	.43	.06	X	.04	.06	.20	.20
small-scale trough & ripple cross-strata	4	.39	.06	.11	X	.06	.19	.19
medium-scale wedge planar	5	.40	.06	.12	.04	X	.19	.19
flat lying	6	.47	.07	.13	.04	.07	X	.22
structureless	7	.47	.07	.13	.04	.07	.22	X

Table 3. Equal Likelihood Matrices of a) Salt Wash Member and b) Recapture Creek Member

a. Difference Matrix, Salt Wash Member

Sedimentary Structures		1	2	3	4	5	6	7
covered/mudstone	1	X	+.20	+.06	-.10	-.03	-.15	+.02
large-scale trough	2	-.23	X	+.51	-.05	-.03	-.16	-.04
medium-scale trough	3	-.09	-.17	X	+.10	+.03	+.14	-.01
small-scale trough & ripple cross-strata	4	+.37	-.09	-.12	X	-.05	-.13	+.01
medium-scale wedge planar	5	-.22	-.13	+.03	0	X	+.36	-.04
flat lying	6	+.39	-.08	-.24	-.02	-.01	X	-.04
structureless	7	+.37	-.13	-.27	-.08	-.05	+.16	X

b. Difference Matrix, Recapture Creek Member

Sedimentary Structures		1	2	3	4	5	6	7
covered/mudstone	1	X	+.01	-.18	-.06	+.01	+.11	+.11
large-scale trough	2	-.40	X	+.88	-.04	-.06	-.19	-.19
medium-scale trough	3	+.01	+0.0	X	-.04	0.0	+.02	+.02
small-scale trough & ripple cross-strata	4	-.39	+.27	+.22	X	-.06	+.14	-.19
medium-scale wedge planar	5	-.07	-.06	+.21	-.04	X	+.14	-.19
flat lying	6	+.09	-.07	-.13	+.07	+.04	X	0.0
structureless	7	+.23	-.07	+.17	-.04	-.07	-.22	X

Table 4. Difference Matrices of a) Salt Wash Member and b) Recapture Creek Member

Figure 18 shows the preferred vertical sequence of lithologies and sedimentary structures in the Salt Wash Member as determined by the Markov chain analysis, which consists of large-scale trough sets of cross-stratification overlain by medium-scale trough sets of cross-stratification overlain by flat-lying laminae and thin beds of sandstone which are, in turn, overlain by covered or mudstone units. This is the typical upward-fining of the scale of sedimentary structures and of grain size of fluvial deposits. These structures have been observed in the field to occur as fill within channel-scale cut and fill structures. They often grade laterally into the mudstone unit.

Other vertical successions are possible in the Salt Wash Member, but are less common.

Figure 19 shows the preferred vertical sequence of sedimentary structures and lithologies for the Recapture Creek Member as determined by the Markov chain analysis. It consists of large-scale trough-shaped sets of cross-stratification overlain by medium-scale trough-shaped sets of cross-stratification overlain by a covered or mudstone unit. This forms the typical upward-fining sequence of both scale and grain size of fluvial deposits. These structures, like those of the Salt Wash Member, have been observed in the field to occur as fill within channel-scale cut and fill structures, and often grade laterally into mudstone units.

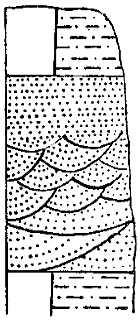


Figure 18. Preferred vertical sequence of structures and lithologies in the Salt Wash Member indicated by Markov analysis.

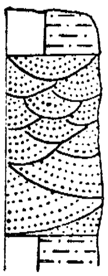


Figure 19. Preferred vertical sequence of structures and lithologies in the Recapture Creek Member indicated by Markov analysis.

Notable is the greater probability of a randomly occurring structureless unit and the lesser probabilities of small-scale structures or flat-lying laminae and beds in the Recapture Creek Member than in the Salt Wash Member.

PALEOCURRENT ANALYSES

Paleocurrent Indicators

Trough-shaped sets of cross-strata, which are typical of almost all traction transported sands (Pettijohn and others, 1973) provide a widespread, easily measureable directional indicator of local current flow at the time of deposition of the Salt Wash and Recapture Creek Members. They provide a unidirectional indicator of current flow, with the current flowing parallel to the trough axis and towards the maximum dip direction of the foresets in the trough.

The sinuous crestlines of ripple marks are generally oriented perpendicular to current flow; however, rib and furrow structures can be used to indicate the direction of current flow. The grooves of the rib and furrow structures are oriented parallel to current flow and the cusps which form the furrows are oriented convex upcurrent. Both trough-shaped sets and rib and furrow structures provide unique paleocurrent readings.

Parting lineations were formed parallel to the current flow on essentially planar surfaces. While they provide non-unique (polar) paleocurrent indicators, they are numerous, widespread and easily measureable in both the Salt Wash and Recapture Creek Members. Measurements of parting lineations, due to the polar nature of the structure, were consistantly measured such that they were oriented towards the northern hemisphere.

Paleocurrent directional structures were measured at each sandstone bed in a stratigraphic section where they could be determined. Beds were walked out laterally for distances up to 1/4 mile (400 m) in each direction; at least twenty readings per outcrop were taken on the average.

Analysis of Paleocurrent Data

Approximately 400 readings of paleocurrent directions occurring in the Salt Wash Member were taken during the measurement of stratigraphic sections and approximately 150 paleocurrent readings were measured in the Recapture Creek Member; they are tabulated according to the measured section and lithologic unit numbers in Appendix II. The fewer measurements taken in the Recapture Creek Member can be attributed to several factors--the greater abundance of structureless beds and the greater friability of the Recapture Creek Member--which greatly reduced the number of acceptable directional structures which could be measured.

compensation for angular error due to structural dip was unnecessary; throughout the study area, the dip of strata was generally less than 1°.

As shown on Plate 1 the paleocurrent directions recorded in any single sandstone unit within a half mile of the measured stratigraphic section in both the Salt Wash and Recapture Creek Members have a range typically of 90° or less and always less than 200°. In addition the rose diagrams are typically unimodal which combined with the limited range is characteristic of braided fluvial systems according to Selley (1968), Potter and Pettijohn (1963), and Reineck and Singh (1973).

All paleocurrent directions recorded in the lowest portion of the Salt Wash Member within the study area form a bimodal rose diagram with a range of about 200°; the dominant mode is E and the secondary mode is NW. Paleocurrent directions recorded in the stratigraphically middle portion of the Salt Wash Member in the study area form a polymodal rose diagram with a range of 360°; the dominant mode is SE with two subequal secondary modes NE and N. Paleocurrent directions recorded in the highest portion of the Salt Wash Member in the study area form a bimodal rose diagram with a range of 270°; the dominant mode is E with a very minor secondary mode N. All paleocurrent directions recorded in the Recapture Creek Member in the study area form a unimodal rose diagram with a vector mean transport direction toward N55°E and a vector strength of .91.

Two regional paleocurrent classifications for fluvial systems have been proposed by Selley (1968). The first model is that of a radiating alluvial piedmont fan which is typified by fan-shaped, radiating divergent current patterns. The second is the centripetal basin fill model, typified by convergent current patterns. While in local areas of the Salt Wash Member paleocurrent directions appear to converge, the majority of paleocurrents measured in this study conform fairly well with the radiating alluvial fan model, with current directions radiating from an apex to the south-southwest of the study area. This is consistent with Craig and others (1955) and Selley's (1968) interpretation of the Salt Wash Member as accumulating on a broad, nearly horizontal, fan-shaped alluvial plain. Local areas of convergent paleocurrent vectors probably serve as small-scale centripetal basin fill where currents flowed around topographic highs into local basins; however, the size of the study area may be too small to determine whether the Salt Wash Member was deposited as an alluvial fan or as centripetal basin fill.

The Recapture Creek Member is similar to the Salt Wash Member although it lacks the localized convergent paleocurrent flows. The Recapture Creek Member paleocurrent direction indicators encountered in the study area are indicative of fluvial deposition on a broad, nearly horizontal fan-shaped alluvial plain as described by Craig and others (1955), however Craig and others (1955) determined a source area to the south-southeast of the study area; this is inconsistent with current directions radiating from an apex to the west-southwest of the study area as indicated by the paleocurrents observed in this study area. This difference between the source area which was expected and that which was determined could result either from the influence of the slope following deposition of the Salt Wash Member upon this distal portion of the Recapture Creek Member, or from the occurrence of multiple sources for the Recapture Creek Member rather than the expected single point source.

PETROGRAPHIC ANALYSIS

Nineteen samples considered to be representative of the sandstones of the Salt Wash and Recapture Creek Members were collected during the measurement of stratigraphic sections. These samples were made into thin sections which were analysed by visual estimation to determine the fabric and composition. From this data, the depositional and diagenetic history of these units may be interpreted. Ten of the thin sections were point-counted, with 500 points per slide. The data from these point count analyses was compared to van der Plas and Tobi's (1965) chart to determine the precision of the point count results and compare them with the visual estimations.

Samples were classified according to the system proposed by Folk (1968). The end members of the ternary diagram are Q + C = quartz, including monocrystalline and polycrystalline quartz, and chert; F + GRF = feldspar, including potassium and plagioclase feldspars and rock fragments of granite and gneiss, and other LRF = all other rock fragments. This system of classification was chosen due to the allocation of specific types of rock fragments to end member groups which closely follow the order of fragmental stability (quartz and chert > feldspars > labile rock fragments) (Blatt and others, 1972).

Approximately 55 percent of the Salt Wash Member samples are classified as calcareous arkoses, 27 percent fall just into the calcareous lithic arkose field, and eighteen percent are classified as subarkoses (Fig. 20). The average composition of the detrital fraction is approximately 67 percent quartz, 22 percent feldspars, five percent lithic fragments, three percent detrital clays, two percent chert, one percent opaques with trace amounts of other minerals. This average falls well into the calcareous arkose field.

The Recapture Creek Member samples fall into the calcareous lithic arkose field. The average composition of the detrital fraction is approximately 50 percent quartz, 35 percent feldspars, six percent lithic fragments, five

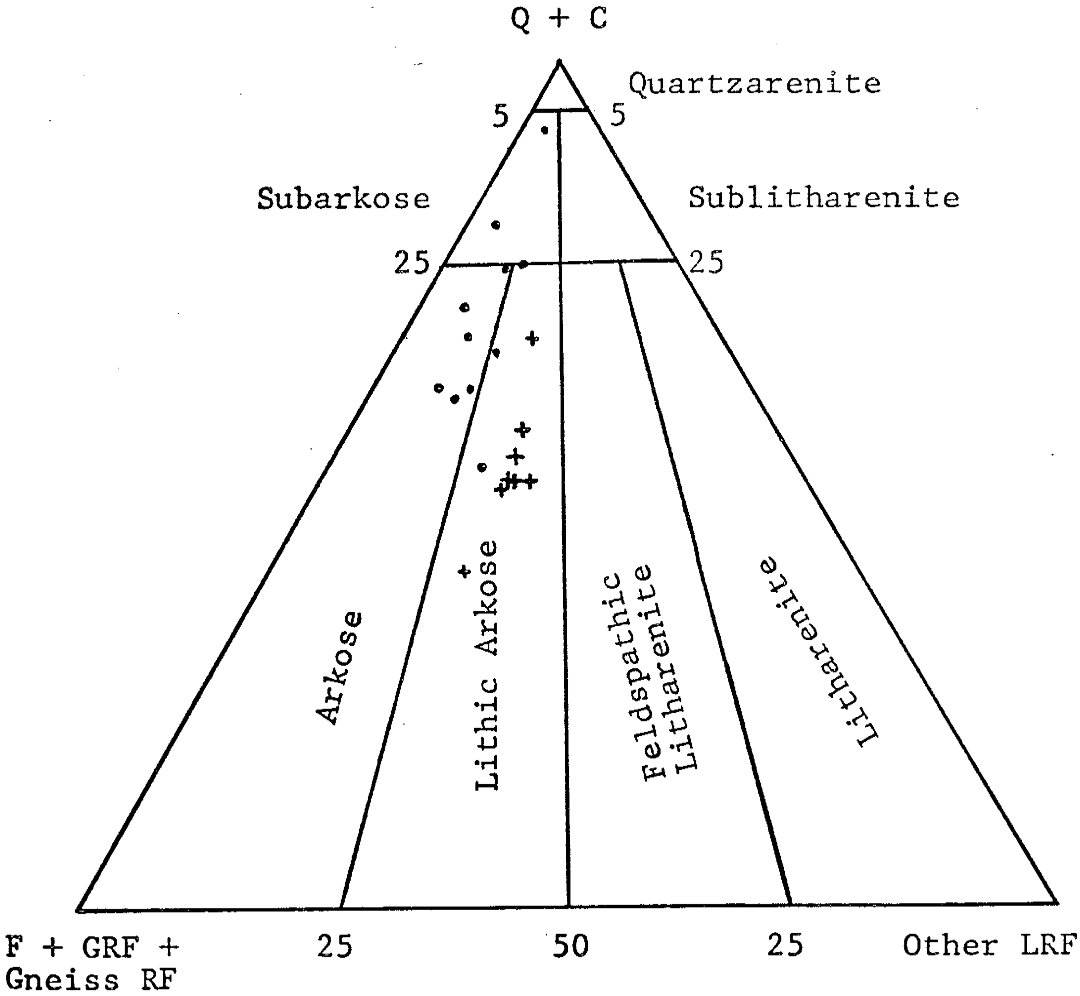


Figure 20 - Plots of sandstone compositions of Salt Wash Member (•) and Recapture Creek Member (+) sandstone units, after Folk (1968).

percent detrital clays, four percent chert and only trace amounts of opaques and other minerals.

Detrital Components

The major detrital components of the Salt Wash Member samples consist of quartz, feldspars, lithic fragments, detrital clays, chert and opaque minerals. The major detrital components of the Salt Wash Member and the Recapture Creek Member samples will be discussed in detail. Detailed thin section analyses are presented in Appendix III; Tables 5, 6, and 7 and give percentages of the rock components.

Quartz

Quartz is the most abundant mineral in all the thin sections of both the Salt Wash Member and the Recapture Creek Member. In the Salt Wash Member samples, it comprises from 53 up to 82 percent of the detrital components. Both monocrystalline and polycrystalline quartz are present, however the monocrystalline quartz is by far the most abundant.

Monocrystalline quartz grains are generally subrounded and subelongate, exhibit moderately undulose extinction and have many very small vacuoles and few inclusions. They average approximately 0.4 mm in diameter without siliceous cements precipitated since deposition. Syntaxial overgrowths can be distinguished on many grains due to the

Sample	(%) Quartz	K-feldspar	Plagioclase Feldspars	Chert	Matrix and Detrital Clay	Lithic Fragments	Cement	Pore Space
*SWMC 10-2	51 ± 5	10 ± 3	3 ± 2	2 ± 1	14 ± 4	5 ± 2	10 ± 3	4 ± 2
*SWMC 11-3	55 ± 5	14 ± 4	3 ± 2	3 ± 2	8 ± 3	3 ± 2	12 ± 3	3 ± 2
*SWMC 11-9a	58 ± 5	10 ± 3	1 ± 1	1 ± 1	10 ± 3	1 ± 1	17 ± 4	2 ± 1
*SWMC 12-6	46 ± 5	12 ± 3	1 ± 1	1 ± 1	17 ± 4	7 ± 3	13 ± 4	3 ± 2
*SWMC 13-10a	54 ± 5	10 ± 3	3 ± 2	2 ± 1	7 ± 3	2 ± 1	16 ± 4	4 ± 2
+SWMC 10-6	38 ± 5	22 ± 4	4 ± 2	2 ± 1	18 ± 4	8 ± 3	4 ± 2	4 ± 2
+SWMC 10-8	36 ± 5	22 ± 4	3 ± 2	2 ± 1	20 ± 4	5 ± 2	8 ± 3	3 ± 2
+SWMC 11-13	33 ± 5	20 ± 4	4 ± 2	3 ± 2	21 ± 4	5 ± 2	9 ± 3	5 ± 2
+SWMC 12-12	40 ± 5	21 ± 4	4 ± 2	4 ± 2	6 ± 3	7 ± 3	15 ± 4	3 ± 2
+SWMC 14-6	32 ± 5	24 ± 4	0	3 ± 2	5 ± 2	4 ± 2	4 ± 2	28 ± 4

* Salt Wash Member

\+ Recapture Creek Member

Table 5. Point count analyses of Salt Wash Member and Recapture Creek Member sandstones (500 counts). Precision after van der Plas and Tobi (1965)

Sample	(%) Quartz	Feldspar	Orthomatrix and others		Chert	Lithic Fragments		Micas	Others	Cement	Pore Space
			ortho	other		VRF	ARF				
SWMC 10-2	52	14	4	8	3	6	0	tr	3*	7	3
SWMC 10-4	47	15	8	4	1	4	4	tr	1+	14	2
SWMC 11-3	52	20	4	1	tr	tr	4	tr	tr	8	11
SWMC 11-5b	52	19	5	3	1	2	5	tr	1*	11	1
SWMC 11-9a	60	11	1	5	tr	1	1	tr	tr+	17	4
SWMC 11-11a	59	15	3	6	1	3	3	tr	tr	8	2
SWMC 12-6	45	13	5	7	tr	8	6	0	3*	12	1
SWMC 13-2c	45	16	5	5	1	5	5	0	1*	15	2
SWMC 13-10a	54	18	3	4	2	1	tr	tr	tr	14	4
SWMC 13-12e	41	21	4	4	3	8	4	0	tr*	11	4
SWMC 13-14	48	18	7	5	1	4	4	0	tr*	11	2

* chlorite and pyrite

+ zircon and pyrite

Table 6. Petrographic analyses of Salt Wash Member sandstones

Sample	(%) Quartz	Feldspar	Orthomatrix and others		Chert	Lithic Fragments		Micas	Others	Cement	Pore Space
			ortho	other		VRF	ARF				
SWMC 10-6	37	26	5	9	2	8	4	tr	tr*	4	5
SWMC 10-8	37	25	7	6	2	3	6	0	tr*	12	2
SWMC 11-13	30	26	11	6	3	6	6	0	2*	8	2
SWMC 11-15	37	25	9	2	6	5	9	0	tr*	6	1
SWMC 12-12	39	25	3	1	6	6	3	tr	2+	14	1
SWMC 14-4	26	21	3	1	6	5	1	2	tr*	5	30**
SWMC 14-6	34	24	4	3	3	tr	3	tr	1*	3	25**
SWMC 14-8	37	29	2	4	4	6	2	tr	tr*	4	12

* chlorite and pyrite

+ pyrite

** high due to plucking

Table 7. Petrographic analyses of Recapture Creek sandstones

occurrence of fine inclusions of oxides or other minerals about the original crystal. Hackly fracturing is common in the grains, usually occurring through both the syntaxial overgrowths and the original grains.

Approximately seventeen percent of the quartz grains are polycrystalline with an average of four crystals per grain. The crystals are generally of equal size and shape with sutured crystal-to-crystal contacts. The polycrystalline grains are slightly larger than the monocrystalline grains. There is essentially no alteration of either the monocrystalline or polycrystalline grains.

In the Recapture Creek Member samples, quartz grains comprise from 41 up to 52 percent of the detrital components. Monocrystalline quartz grains are finer grained than those of the Salt Wash Member, averaging 0.2 mm in diameter and are generally subangular, subelongate, with straight extinction, many small vacuoles and few inclusions of (possibly) tourmaline. Syntaxial overgrowths can be distinguished on many grains due to the occurrence of fine inclusions of opaques about the original grain and by fracturing in the original grain which does not continue into the syntaxial overgrowth.

Polycrystaline quartz, while present, is even less abundant than in the Salt Wash Member samples, accounting for only approximately seven percent of the quartz. There are an average of four crystals per grain. The crystals are generally equal in size, however a bimodal distribution of sizes occurs in about 35 percent of the polycrystalline quartz grains. The polycrystalline grains are slightly more elongate than the monocrystalline grains; otherwise they are very similar in shape to the monocrystalline grains.

Feldspars

Both plagioclase and potassium feldspars occur in the Salt Wash Member and Recapture Creek Member samples. In the Salt Wash Member samples, feldspars account for from fifteen to 27 percent of the detrital components, with approximately 89 percent of the feldspars (or approximately seventeen percent of the detrital components) as potassium feldspars. Both feldspars are generally subrounded, subequant and have been at least partially altered to phyllosilicates.

The potassium feldspars in the Salt Wash Member samples are primarily orthoclase, which accounts for between 50 and 88 percent of the feldspars. Microcline, perthite and sanidine also occur commonly, although they are less abundant than orthoclase. Alteration of all the potassium feldspars is similar with rims of clay on the grain and blebs of clay within the grain. Syntaxial orthoclase overgrowths on orthoclase grains occur rarely.

The plagioclase feldspars commonly display albite or carlsbad plus albite twinning, which was used to determine the composition by the Michel-Levy method. Andesine was the most common plagioclase, accounting for almost 95 percent of the plagioclase crystals analyzed. Alteration along the grain boundaries and twinning planes is quite abundant and often more advanced than in the potassium feldspars.

In the Recapture Creek Member, feldspars range from 30 to 37 percent of the detrital components, with approximately 77 percent of the feldspars (or approximately 27 percent of the detrital components) as potassium feldspars. Both plagioclase and potassic feldspars are generally subrounded, subequant and have undergone less alteration to phyllosilicates than those of the Salt Wash Member.

The potassium feldspars in the Recapture Creek Member samples are primarily orthoclase, which accounts for approximately 40 percent of the feldspars. Perthite accounts for approximately 30 percent of the feldspars, and microcline and sanidine are more common than in the Salt Wash samples. Alteration, while less abundant than in the Salt Wash samples, occurs along the rims of the grains and as blebs within the grain. Syntaxial orthoclase overgrowths on orthoclase grains were slightly more common than in the Salt Wash Member.

The plagioclase feldspars were determined to be primarily andesine, with a very narrow range of compositions similar to plagioclases in the Salt Wash Member. Alteration along grain boundaries and along the twinning planes was less abundant than in the Salt Wash Member.

Chert Grains

The chert present is subrounded and accounts for approximately two percent of the detrital components. Reddish-brown coatings of oxides occur on many of the grains in both the Salt Wash Member and the Recapture Creek Member.

Lithic Fragments

The lithic fragments in both the Salt Wash Member and Recapture Creek Members consist of two types: volcanic and sedimentary. The volcanic lithic fragments are very similar in both members, consisting of very fine-grained phenocrysts in an isotropic brown groundmass. The phenocrysts are commonly quartz, orthoclase, plagioclase, biotite and opaque minerals. The volcanic lithic fragments occur in about equal abundances in the Recapture Creek and the Salt Wash Members, accounting for approximately seven percent of the detrital components in the former and approximately nine percent in the latter. Alteration of some of the felsic phenocrysts to phyllosilicates has been observed such that the phenocryst boundaries are fuzzy or partially obscured.

Sedimentary lithic fragments are angular, structureless argillaceous fragments in which the mineralogies could not be determined. They are generally larger than the volcanic lithic fragments in both the Salt Wash and Recapture Creek Members. An origin from within the formation has been interpreted for these sedimentary lithic fragments due to their large size and greater angularity. During compaction many of the sedimentary lithic fragments are deformed producing pseudomatrix (Dickinson, 1970); the percentage of the rock composed of pseudomatrix is added into the percentage of lithic fragments.

Detrital Clays

Detrital clays (Dickinson's (1970) orthomatrix) occur as weakly recrystallized, disseminated interstitial material. The interstitial material is very finely granular to amorphous. The Salt Wash Member samples generally appear to have slightly less detrital clays than the Recapture Creek Member samples (four percent versus five percent), but this difference is within the precision limits.

Opaque Minerals

Opaque minerals are more common in the Salt Wash Member than in the Recapture Creek Member (two percent versus trace amounts). They are equant, often apparently cubic and reddish-brown in reflected light. The most common minerals are probably pyrite and magnetite. Occasional halos of hematite about the opaque minerals occur.

Trace Minerals

Zircons, tourmaline, micas (primarily biotite) and chlorite (possibly altered hornblende) occur in trace amounts in thin sections of the Salt Wash Member. Chlorite, tourmaline and micas have been observed in trace amounts in thin sections of the Recapture Creek Member. None of these minerals are present in appreciable abundances in any of the thin sections.

Fabric

The fabrics of the Salt Wash and Recapture Creek Members differ slightly in many aspects. The Salt Wash Member has an average grain size of approximately 0.4 mm, sorting is moderate, grains are subelongate and subrounded. Matrix, defined as the fine-grained, petrographically irresolvable fine silt and clay (Blatt and others, 1972), comprises approximately twelve percent of the thin section, ranging from seven to eighteen percent. Pore space averages about two percent, which is doubtless at least slightly high due to plucking during preparation of the thin section. Textural maturity of the sandstones now is immature on all but one sample due to extensive diagenetic production of matrix. Originally the textural maturity of the sands was immature to submature.

The Recapture Creek Member has an average grain size of 0.25 mm, sorting is moderate, grains are intermediate in elongation and subangular. Matrix averages approximately fourteen percent, ranging from five to 25 percent, and pore space averages about four percent, excluding the plucking of 30 percent of one slide. Textural maturity of these sandstones ranges from immature to submature, but originally the sands were texturally submature.

Cements

Calcium carbonate cement is present in both the Salt Wash Member and the Recapture Creek Member samples, and is the most abundant cement mineralogy in both. It occurs primarily as poikilotopic masses enclosing from four to six grains in the Salt Wash Member samples and enclosing from two to five grains in the Recapture Creek Member samples, and appears to be the last cement developed during diagenesis. Drusy calcite overgrowths plus finely crystalline, blocky texture, intergranular calcite, which account for less than 30 percent of the remaining calcite cement, appear to have developed prior to the poikilotopic calcite.

Silica cement occurs primarily in the Salt Wash Member, although it has been observed in several samples of the Recapture Creek Member. The silica cement occurs as a finely crystalline, almost opaline, variety which has developed later than syntaxial overgrowths of quartz but prior to the development of calcite cements. Some replacement of the silica cement by calcite has been interpreted due to embayment of the silica with calcite inclusions.

Phyllosilicate cements occur in the Recapture Creek Member samples and can be observed either as a radial arrangement of finely granular crystals rimming a detrital grain reflecting its growth in open pore space or as a finely granular coating on quartz grains. This was developed prior to the poikilotopic calcite cement.

Clay Mineralogy

Nineteen sandstone samples were analysed by semi-quantitative X-ray diffraction methods to determine the specific clay mineral species and their relative abundances in the sandstones of both the Salt Wash Member and Recapture Creek Members. The aim of these analyses is twofold: to determine if the clay fraction of the sandstone would be a useful means of differentiating between the Salt Wash Member and the Recapture Creek Members, and to aid in the environmental analyses.

The samples were prepared according to standard techniques, starting with the crushing of sandstone samples and grinding them in a mortar and pestle until they passed through a 200 mesh (75u) sieve. The samples were then boiled in EDTA solution for eight hours to remove the carbonates. The samples were then sonically disaggregated, thoroughly stirred, then allowed to settle for 45 minutes. The 2u and finer fraction was then removed. Four sedimented slides were prepared for each sample and allowed to air dry before either being glycolated at 60°C for at least one hour (to expand the swelling clays), heated at 375°C for at least one hour (to dehydrate the montmorillonite), heated at 550°C for at least three hours (to check for the occurrence of chlorite) or left untreated.

The samples were scanned from 2° to 35° two Theta at a scan speed of 2° per minute, with a chart speed of 20 mm per minute using a 1-4-1 slit, CuK radiation/filter at 40 kilovolts and 20 millamper.

Using a method modified from Johns and others (1954) and Austin and Leininger (1976), the relative proportions of the clay species are determined by using peak heights rather than peak areas (Table 8).

The dominant clay species is kaolinite in all samples. Illite and illite/montmorillonite mixed layer clays are common constituents of the Salt Wash Member sandstones; the Recapture Creek Member sandstones have significant amounts of montmorillonite and chlorite in addition to the illite and mixed layer clays. Quartz is present in all samples.

Kaolinite occurs primarily as poorly crystallized kaolinite which varies somewhat in its degree of disorganization. Along with the pseudomorphs of clays after feldspar grains, this strongly suggests alteration of kaolinite in place rather than transportation of kaolinite material into the basin of deposition. Further alteration

	SWMC 10-2@	SWMC 10-4@	SWMC 10-6*	SWMC 10-8*	SWMC 11-13@	SWMC 11-5b@	SWMC 11-9a@	SWMC 11-11a@	SWMC 11-13*	SWMC 11-15*
kaolinite	9	8	3	5	8	7	6	6	4	4
illite/mont-morillonite mixed layer clays	-	1	3	2	1	2	3	1	2	1
illite	1	1	2	2	1	1	1	2	2	2
chlorite	-	-	1	1	-	-	-	1	2	2
mont-morillonite	-	-	1	-	-	-	-	-	-	1

	SWMC 12-6@	SWMC 12-12*	SWMC 13-2@	SWMC 13-10a@	SWMC 13-12e@	SWMC 13-14@	SWMC 14-4*	SWMC 14-6*	SWMC 14-8*
kaolinite	7	4	5	7	9	4	4	5	6
illite/mont-morillonite mixed layer clays	1	1	2	-	-	1	2	1	1
illite	2	1	3	2	1	5	2	2	1
chlorite	-	3	-	1	-	-	1	1	1
mont-morillonite	-	1	-	-	-	-	1	1	1

@Salt Wash Member
*Recapture Creek Member

Table 8. Relative Percentages of Clay (in parts per ten)

of illite to kaolinite in the Salt Wash Member is suggested by not only the poorly crystalline nature of the kaolinite but also by the elevated kaolinite/illite ratios compared to those of the Recapture Creek Member (Hosterman and others, 1970). As many of the altered feldspar grains were observed in thin section to be enclosed by siliceous and carbonate cements, it is suggeted that much of the formation of kaolinite in the Salt Wash Member occurred soon after deposition. This would be indicative of low pH solutions circulating soon after the deposition of the Salt Wash Member sediments.

The presence of montmorillonite in the Recapture Creek Member implies a geochemically "younger" sediment (Baird and others, 1980), with less alteration of montmorillonite to kaolinite. Further, as montmorillonite is a product of alteration of volcanic ash, its occurrence implies volcanic activity taking place at the time of deposition of the Recapture Creek Member sediments. The increased relative proportions of illite and montmorillonite suggest that the solutions circulating through the Recapture Creek Member sediments were less acidic than those of the Salt Wash Member sediments.

DIAGENETIC HISTORY

Salt Wash Member

Based on pre-cementation void space, the Salt Wash Member sediments were deposited with an initial porosity of greater than 25 percent. Compaction, with subsequent reduction of pore space to less than sixteen percent, deformation of the still plastic clay clasts and galls, and some fracturing of feldspars probably occurred shortly after deposition. Alteration of feldspars and volcanic detritus probably began during or shortly after compaction. Silica, calcium, sodium, iron and potassium ions were liberated from the feldspars and volcanic detritus, and water was doubtless absorbed. Due to the presence of carbonaceous detrital material (visible in outcrop) which yields a low pH solution, the calcium, sodium and much of the potassium ions were leached away by circulation of the pore fluids. Due to the presence of illite, which incorporates potassium ions into its structure, a pore fluid with a pH greater than 4.0 and less than 5.0 would be expected, as potassium ions form soluble complexes at lower pHs (Huddle and Patterson, 1961) and there is little kaolinite enrichment at a pH greater than 5.0 (Staub and Cohen, 1978). The excess silica from the alteration of the feldspars and volcanics could have been deposited to form the initial silica cement. After the deposition of this initial silica cement, compaction occurred, which fractured quartz grains, the unaltered feldspars and doubtless the initial silica cements and reduced the intergranular pore spaces further. Some further alteration of feldspars and the possible formation of sutured contacts took place at this point. Dissolution of the initial silica cement and precipitation of the carbonate cements--initially as a drusy rim cement, followed by pore filling blocky cement--then occurred. The poikilotopic calcite cement occurred last.

Recapture Creek Member

The Recapture Creek Member sediments were deposited with an initial porosity of at least 30 percent, based on pre-cementation void and estimated compaction. Compaction with subsequent reduction of pore space to about ten percent, deformation of the still plastic clay clasts and galls and fracturing of quartz and feldspar grains probably occurred shortly after deposition. Alteration of feldspars and volcanic detritus (including volcanic ash) probably began shortly after compaction. While the alteration of the volcanic ash to montmorillonite proceeded completely (there is no visible ash material in any of the thin sectins), the pore fluid was either of a pH greater than 5.0 or did not circulate very extensively, as the montmorillonite was not completely altered to illite or kaolinite. Similarly, the alteration of feldspars was not as extensive in sediments of the Recapture Creek Member as in sediments of the Salt Wash Member, as can be seen by lack of completely altered feldspars, distinguishable solely by relict grain boundaries.

Following alteration of the feldspars and volcanic detritus, cementation by carbonates occurred. As in the Salt Wash Member, drusy rim cements on detrital grains were initially precipitated, followed by pore filling blocky cements.

PROVENANCE

The two primary sources of sediments in both the Salt Wash Member and Recapture Creek Member sandstones were sedimentary and felsic volcanic rocks. While metamorphic and igneous intrusives may have contributed some sediments, they comprise only minor fractions of sandstones of both members.

Angular quartz grains appear in both the Salt Wash Member and Recapture Creek Member sandstones. Exhibiting a fractured, mottled appearance, they are similar to those described by Folk (1968) as having a volcanic origin.

Both the Salt Wash Member and Recapture Creek Member sandstones exhibit rounded syntaxial overgrowths on rounded to subrounded quartz grains. This is indicative of multicycle sands. Rounded to subrounded quartz grains which do not exhibit overgrowths may be either multicycle or first cycle grains.

Basu and others (1975) suggest that the shape and number of crystals in the polycrystalline quartz grains is indicative of the source of the polycrystalline quartz. Both the Salt Wash Member and Recapture Creek Member sandstones average four crystals per grain, which is intermediate between the five or more crystals which are indicative of a schist source rock and the two to three crystals which are indicative of gneissic or plutonic rocks. The presence of sanidine, progressively zoned plagioclase and angular quartz crystals support a plutonic (granitic), possibly local, source for these polycrystalline quartz grains (Craig, 1955).

The feldspars in the Salt Wash Member sandstones were probably derived from up-slope volcanic deposits. Cadigan (1967) mentions volcanic activity during the Jurassic Period in southwest Utah and southern Nevada, and Tschanz and Pampeyan (1970) describe moderately abundant felsic to intermediate volcanics in the upper Triassic and middle Jurassic Series of southern to central Nevada, any or all of which could be sources. This would be in general agreement with the northeastern paleocurrent direction although the great variability of the paleocurrent readings suggest that sediments may have been derived from other areas as well.

The presence of montmorillonite and the greater abundance of the feldspars and angular quartz grains in the Recapture Creek Member sandstones suggests the occurrence of volcanic activity at the time of deposition and a local source area. Two sources of these materials is suggested: air-fall deposits of volcanic ash, which later became montmorillonite, and erosion of older, up-slope volcanic deposits. The source for the volcanic ash does not have to be local; due to the ease with which volcanic ash can be transported by the wind, it could be quite distant (Keller, 1956). The feldspars may have been contributed from a high located south of Gallup, New Mexico (Craig, 1955). While this source direction is not in agreement with the paleocurrent direction observed in the study area, it must be remembered that this area constitutes the northernmost extent of the Recapture Creek Member where it intertongues and grades into the Salt Wash Member. The factors controlling deposition of the Salt Wash Member doubtless contributed significantly to controls over the Recapture Creek Member.

The sandstones of both the Salt Wash and Recapture Creek Members were probably not the result of a single point source. Cadigan (1967) suggests that several source areas for both members occur, based on mineral assemblages found throughout the Colorado Plateau.

DEPOSITIONAL ENVIRONMENTS

The Salt Wash and Recapture Creek Members of the Morrison Formation both consist of fine- to medium-grained sandstones interstratified with mudstone and siltstone units. The majority of the sandstones have large- and medium-scale trough-shaped sets of cross-strata and are multistory and multilateral tabular and lensoid deposits. The lower contacts of the sandstones are erosional and the sandstones grade laterally and upward into mudstone and siltstone units. These characteristics are diagnostic of deposition in a fluvial environment (Potter, 1967).

Moody-Stuart (1966) distinguished two major types of fluvial systems: high-sinuosity and low-sinuosity rivers. Both the Salt Wash Member and the Recapture Creek Member show a "fining upwards" of sediments, approximately horizontal upper surfaces with trough-shaped erosional lower surfaces and lack levee deposits (wedge-shaped ridges of fine-grained sediments bordering stream channels). The Recapture Creek Member further shows a unimodal paleocurrent pattern. All of these characteristics are diagnostic of a low-sinuosity fluvial system.

Low-sinuosity streams vary from braided to meandering according to Moody-Stuart (1966). Braided streams are characterized by two or more anastomosing channels which form a relatively straight, wide main channel (Reineck and Singh, 1975). Meandering streams are more sinuous than braided streams, and usually are confined to one channel on a low gradient. A continuum exists between the braided and meandering stream end members (Leopold and Wolman, 1957; Reineck and Singh, 1975), yielding significant overlaps between the characteristics of braided and meandering stream deposits.

Braided and meandering stream patterns result from a relationship between sediment load, gradient and discharge. Given two rivers of similar gradient, a braided stream will develop where higher discharge and greater sediment load are present, while a lower discharge and smaller sediment load favors meandering streams (Smith, 1970; Reineck and Singh, 1975).

Meandering streams are in a stage of depositional equilibrium. Deposits consist almost entirely of floodplain, natural levee, point bar and other lateral accretion deposits (Selley, 1965). Natural levee and point bar deposits are largely absent from both the Salt Wash Member and the Recapture Creek Member.

Braided streams are in a stage of depositional dis-equilibrium, where deposition is dominant (Selley, 1965). Typical braided stream deposits include floodplain and channel deposits, such as braid bars (which make multilateral and multistory deposits with a broad range of sedimentary structures) and other channel bar deposits (Fig. 21). These deposits occur through both the Salt Wash Member

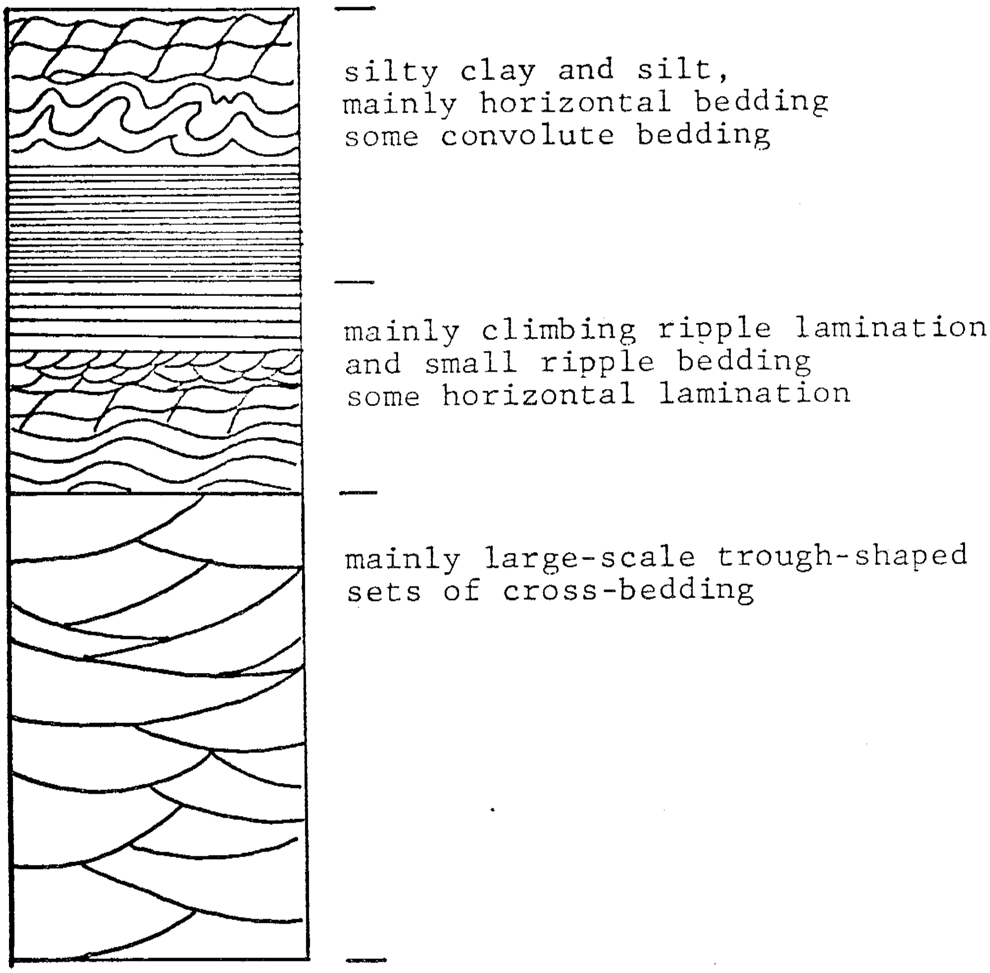


Figure 21. Idealized vertical sequence of sedimentary structures of a channel (braid) bar deposit (after Reineck and Singh, 1972)

and Recapture Creek Member.

The mudstones, siltstones and covered intervals which occur between the channel deposits are interpreted as overbank deposits. During times when the discharge is greater than the channel's carrying capacities, these sediments were deposited adjacent to the main channels. These floodplains can be inundated and cut by secondary channels which yield small, discontinuous lensoid sandstones which are often associated with mudstones and siltstones. The sedimentary structures occurring in the mudstones and siltstones are typical of low flow regimes (Harms and Fahnestock, 1965). The presence of mudcracks, although relatively rare, suggests that the floodplain deposits were alternately exposed and subjected to desiccation. This could be due to periods of low discharge or due to the shifting of the main channels.

In the Salt Wash Member, rare occurrences of grey-green carbonaceous mudstones have been interpreted by Peterson (1974) as being deposited in low areas near the main channels where subaerial exposure does not occur. These ponded areas last for sufficient periods of time for the reduction of muds and, dependent upon the chemistry, the production of pyrite. The presence of a high water table in the Salt Wash Member is supported by the presence of soft sediment deformation. Williams (1971) states that the presence of a locally or regionally high water table is a necessary condition for the production of soft sediment deformation. This and the presence of plants, which contributed carbonaceous detrital material to the mudstones and sandstones, is suggestive of a moist or subhumid climate at the time of deposition.

In the Recapture Creek Member, carbonaceous grey-green mudstones are entirely absent and soft sediment deformation occurs rarely. This suggests that the water table was significantly lower shortly after deposition than during deposition of the Salt Wash Member. The lack of carbonaceous detrital material and the lower water table suggests a less humid, possibly subarid, climate during deposition.

The channel sandstones can be recognized by their size, areal extent and sedimentary structures. The sandstones range from three feet (1 m) thick to over 50 feet (15 m) thick. The thick, multistory and multilateral sandstones, which produce prominent cliffs in outcrop, are characteristic of deposits produced by braided stream systems (Williams and Rust, 1969) (Fig. 22). Trough-shaped, channel-scale erosional surfaces filled with sandstone beds are apparent in both Williams and Rust's model and outcrops in Montezuma Canyon (Fig. 23).

Modern braided streams actively migrate laterally, yielding wide channels. Holmes (1965) noted that the Kosi River of India, a modern braided river, has shifted 107

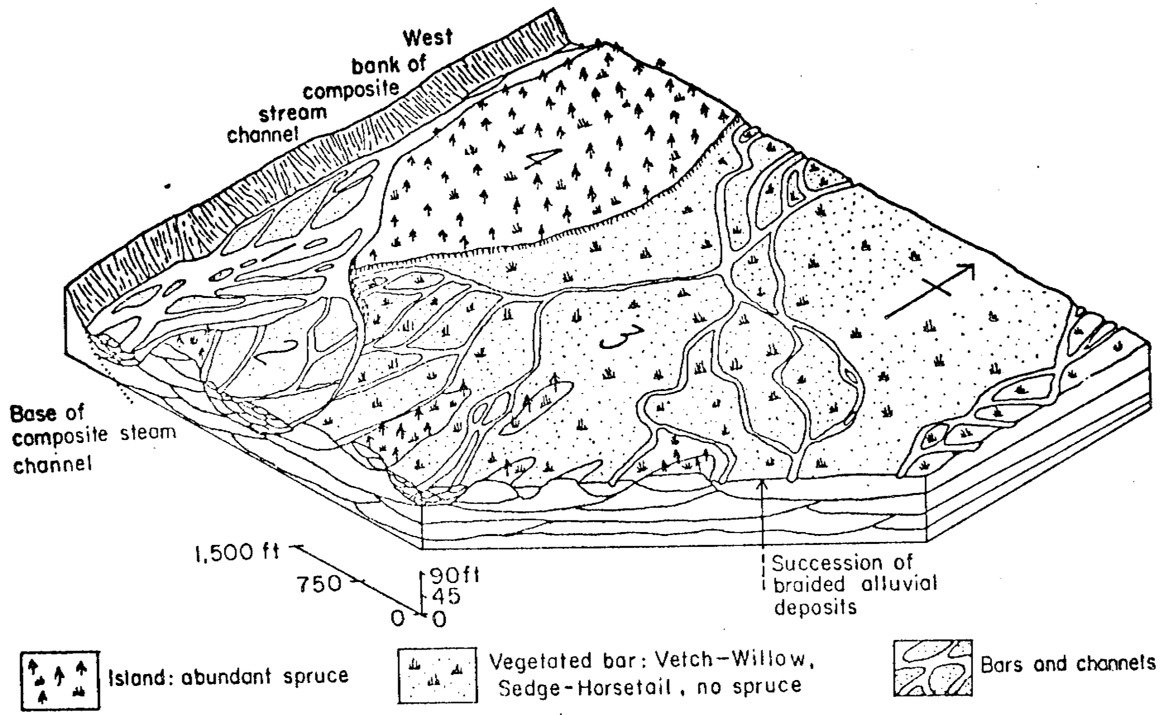


Figure 22. Model of braided stream deposit (after Williams and Rust, 1969)

Figure 23. Overlapping large-scale trough-shaped sets of cross-stratification forming multistory and multilateral sandstones.

miles (170 km) over the last two hundred years. The channels have been observed to shift more than 328 feet (100 m) in eight days. The channel sandstones in both the Salt Wash and Recapture Creek Members are continuous for distances up to one mile (1.6 km), which strongly suggets a braided stream deposit.

The structures of the channel sandstones are present in two scales: the larger channel-scale cut and fill structures, and the sedimentary structures which occur in the sandstone within them. The large channel-scale cut and fill structures have erosional, undulating lower surfaces, with the lowest portions (which correspond to the thickest portions of the overlying sandstones) marking the location of main channels. The troughs formed by the channels are commonly filled with cross-stratified sands. If a channel becomes temporarily abandoned, it can become the site for deposition of silts and muds. These are later either removed by erosion or represented by basal rip-ups and clay clasts at the base of many of the channel-scale cut and fill structures.

The sedimentary structures filling the channel-scale cuts are dominantly medium-scale trough-shaped sets of cross-stratified sandstone. The Markov Analyses of both the Salt Wash Member and Recapture Creek Member show depositional processes of diminishing energy upward within the channel sandstones with upper flow regime structures near the base of cut and fill structures and a progression to lower flow regime structures near the upper surface. The Recapture Creek Member exhibits fewer upper flow regime structures than the Salt Wash Member, which is not entirely consistent with the intermittent, flashy streams expected of a subarid climate at the time of deposition. It can be explained by a smaller rate of discharge than that of the Salt Wash Member. Also this would be consistent with the paleocurrent directions which indicate the direction of transport at this distal end of the Recapture Creek Member was controlled by the topographic surface in existance during and remaining after deposition of the Salt Wash Member.

CONCLUSIONS

The Recapture Creek Member, previously undocumented in the study area, occurs in the southern portion. It is distinguishable from the Salt Wash Member in outcrop by its greater friability, rounded cliffs, lack of carbonaceous detrital material, general lack of large-scale trough-shaped sets of cross-stratification, greater number of apparently structureless sandstones, lighter colored fresh surface (due to lack of limonite staining), and lack of the carbonaceous grey-green mudstones. The sandstones of the Recapture Creek Member contain a larger proportion of feldspars which exhibit less alteration than those of the Salt Wash Member, and larger proportions of montmorillonite and chlorite, which are absent in the Salt Wash Member, in the interstitial clay fraction of sandstones in the Recapture Creek Member.

Both the Salt Wash Member and the Recapture Creek Member of the Morrison Formation are interpreted as having been deposited in low-sinuosity, aggrading, braiding to slightly meandering stream systems consisting of several anastomosing channels. Due to avulsion and overbank flooding, fine-grained sediments were deposited over and between the channel sands. The deposits of both members are similar to Cant's (1978) southern Saskatchewan facies assemblage, which consists of sandy, braided, aggradational stream deposits transitional between braided and meandering streams which represent the distal end of the fluvial system.

The Salt Wash Member is interpreted as having been deposited in a subhumid climate, with channel systems ranging from three to 50 feet (1 to 15 m) in depth and up to a mile (1.6 km) in width. The stream system flowed northeasterly over a relatively flat, low-gradient plain. Floodplains adjacent to the channels were periodically flooded during times of high discharge causing deposition of overbank silts and muds or due to the high water table, ponding in local depressions. Reducing environments occurred in the local ponds, elsewhere the silts and muds which were subaerially exposed were desiccated.

The Recapture Creek Member is interpreted as having been deposited in a more arid environment with a lower water table than that which was present during the deposition of the Salt Wash Member. The channel systems ranged from three to 70 feet (1 to 21 m) deep and up to about three-fourths of a mile (1.2 km) wide. The stream system appears to have flowed east-northeast in the study area. As this is the furthest extent to the north of the Recapture Creek Member and it intertongues and grades into the Salt Wash Member in the central and northern portion of the study area, it is suggested that the Salt Wash Member fluvial system strongly influenced and possibly diverted the Recapture Creek Member fluvial system or that the Recapture Creek Member was a product of several source areas, as opposed to the single source implied by Craig (1955). The presence of a large proportion of feldspars, montmorillonite and chlorite supports a more local source area than that of the Salt Wash Member.

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APPENDIX I

NOMENCLATURE USED FOR FIELD CLASSIFICATIONS

SANDSTONES AND SEDIMENTARY STRUCTURES

AND

MEASURED STRATIGRAPHIC SECTIONS

NOMENCLATURE USED IN MEASURED STRATIGRAPHIC SECTIONS

Grain size: based on Wentworth (1922) size classification

Sorting: based on sorting images of Folk (1968)

Roundness: based on images from Powers (1953) in Pettijohn and others, (1973)

MEASURED STRATIGRAPHIC SECTIONS

SWMC 1

T36S R24E SEC. 2 SE 1/4 OF SW 1/4

	Unit Feet	Cum. Feet
I. Summerville Formation		
1. most of unit covered; ledges up to 2.5 feet thick of very fine-grained, poorly sorted, subangular red sandstone; contact between sandstones and underlying mudstones: irregular, with differential compaction of siltstones at base	30.4	30.4
2. contact covered; unit covered inferred lithology red and green siltstones	4.5	34.9
II. Tidwell member, Morrison Formation		
3. contact sharp, irregular with mud gall impressions at base; unit consists of a fine-grained, subangular moderately sorted, light pink to light brown sandstone--composition 97% quartz, 2% chert, and less than 1% dark minerals; mudsplit 2 1/2" above base; structures: small-scale, low angle trough-shaped sets of cross-stratification and thin platy lamiations; unit continuous more than 500′ in each direction	4.3	39.2
4. unit covered; inferred lithology interbedded red siltstone and thinly bedded sandstone	3.0	42.2
5. contact sharp, undulatory; unit consists of fine-grained, subrounded, moderately sorted light brown sandstone--composition 96% quartz, 3% chert, and less than 1% dark minerals		
a. flat lying beds with irregular bedding planes	5.5	
b. flat lying beds with horizontal bedding planes	2.2	49.9
6. unit covered; inferred lithology interbedded red siltstone and thinly bedded sandstone	2.0	51.9

7.	contact covered; light brown sandstone similar to Unit 5 with slight coarsening of grain size; continuous sets of small-scale ripple cross-strata, sets from 1′ thick at base to 4" thick near top; small-scale trough-shaped sets of cross-stratification found towards south; sandstone thickens towards south.	7.7	59.6
8.	unit covered; inferred lithology interbedded red siltstone and thinly bedded sandstone	2.5	62.1
9.	contact sharp, undulatory; fine-grained, subrounded moderately sorted light brown sandstone--composition 94% quartz, 5% chert, 1% dark minerals with interstitial calcite; thin lenticular beds of ripple cross-stratification; mudstone stringers 3/4" to 1" long	3.8	65.9
10.	unit covered; inferred lithology interbedded red siltstone and thinly bedded sandstone	.8	66.7
11.	contact sharp; irregular; very fine-grained subangular, poorly sorted light brown sandstone--composition 96% quartz, 3% chert, and less than 1% dark minerals; red oxide staining of quartz grains; thinly laminated beds, low angle to flat lying, beds thin towards top of unit	1.3	68.0
12.	unit covered; inferred lithology red to light brown siltstones and thinly bedded sandstones		
13.	contact gradational over 6" from silty sandstone to very fine-grained, subangular, poorly sorted light brown sandstone; low angle, platy, discontinuous lenses of ripple-like sets of cross-strata, grading upwards to structureless sandstones	13.6	81.6
14.	unit covered; inferred lithology light brown silty sandstone	32.4	114.0
15.	contact covered; fine-grained, subangular, poorly sorted light grey sandstone; middle section burrowed 1′ above base, burrows	6.3	120.3

1/2" diameter, 2" long horizontal non-branching and straight		
16. unit covered; inferred lithology light brown siltstone interbedded with thinly bedded sandstones	38.5	158.8
III. Salt Wash Member, Morrison Formation		
17. contact covered; medium-grained subangular, moderately sorted, light grey, moderately friable sandstone--composition 95% quartz, 2% chert, 2% tuffaceous material and 1% dark minerals		
a. broad, low angle large-scale trough-shaped sets of cross-stratification	2.7	
b. contact planar, flat lying thinly laminated beds, replaced by medium-scale trough-shaped sets to north	2.6	
c. medium-scale trough-shaped sets of cross-stratification with vertical burrows which cut across bedding planes restricted to top 4′	10.6	174.7
18. unit covered; steep slope former, inferred lithology interbedded red siltstone and thinly bedded sandstone	50.0	224.7
19. contact sharp, undulatory; medium grained, subrounded moderately sorted, friable, light grey sandstone		
a. medium-scale, low angle trough-shaped cross-stratification with small mud clasts throughout	3.7	
b. contact sharp, undulatory; lower 7.4′ structureless with layer of mud galls 1′ thick, 3′ from base, upper .6′ medium-scale, platy low angle trough-shaped sets of cross-stratification	8.1	
c. flat lying to low angle thin laminations with upper .5-1′ small-scale trough-shaped sets of cross-stratification	3.0	
d. medium-scale trough-shaped sets of cross-stratification	6.0	245.5
20. unit covered; inferred lithology light brown siltstone interbedded with thin sandstone beds	6.8	252.3

21. contact covered; fine-grained moderately sorted, subrounded light brown, moderately friable sandstone--composition 94%, 1% chert, 2% dark minerals and 3% tuffaceous material; calcium carbonate cement — 5.5 — 257.8

22. contact planar, flat lying; medium-grained, subrounded, moderately sorted, well indurated, light brown sandstone--composition 96% quartz, 1% chert, 2% tuffaceous material, and 1% dark minerals; low-angle medium-scale trough shaped sets of cross-stratification throughout unit — 7.7 — 265.5

23. unit covered; inferred lithology interbedded red siltstone and thinly bedded sandstone — 56.0 — 321.5

24. contact covered; medium-grained, subrounded, poorly sorted moderately friable yellow sandstone--composition 93% quartz, 1% chert, 3% tuffaceous material, 1% dark minerals, less than 1% pyrite; calcium carbonate cement; large-scale trough-shaped sets of cross-stratification grading upwards to medium-scale trough-shaped sets of cross-stratification; angular tuffaceous pebbles up to 1" diameter along basal planes — 32.5 — 354.0

25. unit covered; inferred lithology interbedded red siltstones and thinly bedded sandstones — 11.0 — 365.0

IV. Westwater Canyon Member, Morrison Formation

26. contact covered; medium-grained, poorly sorted, subangular, well indurated light greenish-grey sandstone with abundant vertical horizontal burrows--composition 96% quartz, 2% chert, 2% tuffaceous material, less than 1% dark material; blocky, irregular, structureless beds — 34.0 — 399.0

SWMC 2

T36S R24E SEC. 35 NE 1/4 of SW 1/4

I. Tidwell member, Morrison Formation

1. contact covered; interbedded red, very thinly laminated silts and very fine-grained, subangular, well-sorted, well indurated light brown sandstone--composition 97% quartz, 2% chert, 1% dark minerals; cemented with calcium carbonate; sandstone beds maximum thickness 2" with ripple cross-laminae	8.0	8.0
II. Salt Wash Member, Morrison Formation		
2. a. contact sharp, undultory	0.3	
b. fine-grained, subangular, well sorted red sandstone--composition 94% quartz, 3% tuffaceous material, 2% dark minerals, 1% chert; flat to undulatory thin beds grading up to medium-scale trough-shaped sets of cross-stratification	33.3	41.6
3. a. unit covered, inferred lithology interbedded red siltstone and thinly bedded sandstone	4.6	
b. contact gradational over .3′; fine-grained, subrounded, well rounded light brown sandstone--composition 96% quartz, 2% chert, 1% tuffaceous material, 1% dark minerals; structureless	2.5	
c. unit covered; inferred lithology interbedded red siltstone and thinly bedded sandstone	10.0	
d. contact gradational over .5′; interbedded very thin laminae of siltstone and very thin beds of sandstone; red and green mottling in the mudstone	4.8	
e. contact sharp, planar; mud crack casts and burrows on lower surface; fine-grained, subangular moderately sorted, light brown sandstone--composition 97% quartz, 2% chert, 1% dark minerals; calcium carbonate cement; medium-scale trough-shaped sets of cross-stratification	2.3	
f. unit covered; inferred lithology interbedded red siltstones and thinly bedded sandstone	11.0	
g. mudstone, red and green mottled with thin undulatory, irregular sandstone and siltstone beds	5.8	82.6
4. contact undulatory; abundant red mud clasts approximately .7′ diameter in base of sandstone; medium-grained,		

moderately sorted, subrounded light brown sandstone--composition 95% quartz, 3% dark minerals, 1% chert, trace amounts of tuffaceous material; calcium carbonate cement		
a. low angle, large-scale trough-shaped sets of cross-stratification	6.7	
b. medium-scale, platy, higher angle trough-shaped sets of cross-stratification	13.4	
c. low angle, sweeping medium-scale trough-shaped sets of cross-stratification	4.5	
d. large ripple-wave length 2′, 5" amplitude	1.7	
d. continuous width, medium-scale, wedge planar cross-stratification	5.3	
f. flat to low angle thinly laminated sandstone grades to wedge-shaped sets of cross-stratification	9.1	
g. small-scale trough-shaped cross-stratification	6.2	
h. low angle, small-scale trough-shaped sets of cross-stratification	2.0	131.2
5. unit covered; inferred lithology interbedded red siltstone and very thinly bedded sandstone	16.0	147.2
6. contact gradational over .5′; medium-grained, subrounded, moderately sorted, white sandstone--composition 96% quartz, 2% chert, 1% tuffaceous material, 1% dark minerals, abundant limonite blebs; low angle, medium-scale trough-shaped sets of cross-stratification with mud galls up to 1/2" diameter along bedding planes, grade upward to small-scale trough-shaped sets of cross-stratification	10.0	157.2
7. unit covered; occasional thin outcrops of sandstone flat to low angle laminated beds	25.3	182.5
8. contact covered; medium-grained, subrounded, moderately sorted light brown sandstone--composition 97% quartz, 1% tuffaceous material, 1% chert, 1% dark minerals, abundant limonite staining; calcium carbonate cement		
a. medium-scale trough-shaped sets	3.3	

	of cross-stratification		
	b. low angle, medium-scale trough-shaped sets of cross-stratification grading vertically to wedge planar and very low angle platy laminae at top	7.0	
	c. covered; inferred lithology interbedded red siltstone and thinly bedded sandstone	6.5	
9.	contact covered; medium-grained, subrounded, poorly sorted, light brown sandstone--94% quartz, 2% tuffaceous material, 2% chert, 1% pyrite, 1% dark minerals; calcium carbonate cement		
	a. high angle medium-scale trough-shaped sets of cross-stratification	3.0	
	b. silty sandstone with clasts of grey-green mudstone, medium thick laminations with carbonaceous material along bedding planes	2.8	
	c. contains grey-green mudstone as clasts up to 4" in length--abundant carbon as small flakes and thin laminae in flat beds and at base of medium-scale trough-shaped sets of cross-stratification	15.6	
	d. low angle, large-scale trough-shaped sets of cross-stratification	2.5	
	e. low angle, small-scale trough-shaped sets of cross-stratification grading up to flat lying thin platy beds; carbon abundant in laminae near base and 4′ from top	15.0	
	f. covered; inferred lithology light brown siltstone	4.5	
	g. contact covered; sandstone, large-scale, low angle trough-shaped sets of cross-stratification grading vertically to low angle medium-scale wedge planar sets of cross-stratification to low angle platy beds	13.5	
	h. very low angle, large-scale trough-shaped sets of cross-stratification in basal 8′, 1/4" silt splits between roughs; grades upward into very low angle, very thin platy beds	24.5	280.7
10.	unit covered; inferred lithology interbedded light brown siltstone and thinly bedded sandstone	51.4	332.1

11. contact gradational over 1.5′ with load casts and mud galls; medium grained, moderately sorted, subrounded light brown sandstone with abundant limonite staining in bottom 2′; medium-scale low angle trough-shaped sets of cross-stratification fining to small-scale, high angle trough-shaped sets of cross-stratification 50′ to north; highly burrowed, burrows horizontal, non-branching 1/2" diameter	16.7	348.8
12. unit covered; inferred lithology interbedded siltstone and thinly bedded sandstone	31.7	380.5
13. contact covered; fine-grained, subangular, well-sorted light grey sandstone--composition 94% quartz, 3% tuffaceous material, 2% chert, 1% dark minerals; structureless	11.0	391.5
14. unit covered; inferred lithology interbedded light brown siltstone and thinly bedded sandstone	12.9	404.4
15. contact covered; medium-grained, moderately sorted, subrounded light brown sandstone with abundant limonite blebs--composition 92% quartz, 5% tuffaceous material, 1% chert, 2% dark minerals; medium-scale low angle trough-shaped sets of cross-stratification in lower 8′, low angle parallel bedding in middle 3′, small-scale, high angle trough-shaped sets of cross-stratification in upper 1.5′	12.5	416.9
16. contact covered; medium-grained, moderately sorted subangular light brown sandstone with abundant limonite blebs throughout--composition 97% quartz, 2% tuffaceous material, 1% dark minerals; medium-scale low angle trough-shaped sets of cross-stratification with 1/4" siltstone partings along bedding planes	5.3	422.2
17. unit covered; inferred lithology light brown interbedded siltstone and thinly bedded sandstone	13.3	435.5
18. contact sharp, undulatory; medium grained, moderately sorted, subrounded		

light brown sandstone--composition 94% quartz, 4% dark minerals, 2% tuffaceous material, very fine carbon flecks along bedding planes 4.7′ from base near grey-green mud clasts; large-scale low angle trough-shaped sets of cross-stratification at base, fines upwards to medium-scale, low angle trough-shaped sets of cross-stratification at top

19. unit covered; inferred lithology light brown interbedded siltstone and thinly bedded sandstone	28.5	464.0

III. Westwater Canyon Member, Morrison Formation

20. contact covered; medium-grained, moderately sorted, subrounded, yellow-brown sandstone with abundant limonite staining; siliceous cement; composition 94% quartz, 4% tuffaceous material, 1% dark minerals, 1% chert; medium-scale, low angle trough-shaped sets of cross-stratifiction; highly burrowed; grades upward to medium-scale, high angle trough- and wedge-shaped sets of cross-stratification	29.7	423.7

<u>SWMC 3</u>

T37S R24E SEC. 3 NE 1/4 of SE 1/4

I. Tidwell member, Morrison Formation

1. contact covered; medium-grained, moderately sorted subrounded, well indurated, red sandstone--composition 94% quartz, 3% dark minerals, 2% chert, 1% tuffaceous material, carbonate cement, abundant limonite staining; low angle planar laminae	3.3	3.3
2. unit covered; slope former; inferred lithology light-brown siltstone	0.3	3.6

II. Salt Wash Member, Morrison Formation

3. contact sharp, undulatory; medium-grained, moderately sorted light brown sandstone--composition 96% quartz, 2% red chert, 2% dark minerals; medium-scale low angle trough-shaped sets of cross-	8.9	12.5

stratification

4.	interbedded red and green mottled siltstone and mudstone	3.6	16.1
5.	a. contact sharp, undulatory; medium-grained moderately sorted sub-rounded light brown sandstone--large-scale low angle trough-shaped sets of cross-stratification infilling large cut and fill structure	8.2	
	b. contact sharp, undulatory; red mudstone split	0.3	
	c. contact sharp, undulatory; composition same as 5a; medium-scale, low angle trough-shaped cross-strata grading upward to low angle platy beds	20.2	44.8
6.	unit covered; inferred lithology red mudstone	2.6	47.4
7.	contact sharp, undulatory; medium-grained, moderately sorted, subrounded light brown sandstone--composition 91% quartz, 5% chert, 3% tuffaceous material, 1% dark minerals, abundant limonite blebs with up to 2% interstitial green clay clasts; medium-scale, low angle trough-shaped sets of cross-stratification with .2′ mud splits along bedding planes	8.3	55.7
8.	unit covered, except sandstone ledges with composition of Unit 7 at 11′, 28′, and 52′; ledges less than 1.5′ thick; remainder of unit inferred red and green mottled siltstone	66.7	122.4
9.	contact covered; medium-grained, moderately sorted subrounded light brown sandstone--composition 97% quartz, 2% chert, 1% dark minerals		
	a. low angle, large-scale trough-shaped sets of cross-stratification grades upward to planar laminae	11.2	
	b. high angle, medium-scale trough-shaped sets of cross-stratification	14.2	
	c. low angle, platy beds up to 1" thick	5.7	
	d. red mudstone	0.7	
	e. medium-scale, wedge-shaped sets of cross-stratification	9.0	
	f. very thin platy beds (.5")	2.3	

g. low angle, medium-scale trough-shaped sets of cross-stratification	4.8	170.3
10. unit covered; inferred lithology red and green mudstone	11.0	181.3
11. contact sharp, irregular; medium-grained, moderately sorted, sub-angular light brown sandstone--composition 96% quartz, 1% tuffaceous material, 2% chert, 1% dark minerals; large-scale low angle trough-shaped sets of cross-stratification fines upwards to medium-scale low angle trough-shaped sets	45.2	226.5
12. unit covered; inferred lithology red mudstone	49.5	276.0
13. contact covered; medium-grained, moderately sorted, subrounded yellow sandstone--composition 97% quartz, 2% dark minerals, 1% tuffaceous material, less than 1% chert		
a. large-scale, low angle trough-shaped sets of cross-stratification	22.0	
b. medium-scale trough-shaped sets of cross-stratification	24.0	
c. structureless	4.3	326.3
14. unit covered; inferred lithology red and green mudstone	0.9	327.2
III. Westwater Canyon Member, Morrison Formation		
15. contact covered; medium-grained, poorly sorted, subangular light green-grey sandstone--composition 96% quartz, 4% tuffaceous material, 1% chert, 1% dark minerals, abundant limonite staining; siliceous cement; low angle medium-scale trough-shaped sets of cross-stratification	16.5	343.7
16. unit covered; inferred lithology red mudstone	25.1	368.8
17. contact sharp, irregularly undulatory; composition and structures same as Unit 15	10.3	379.1
18. unit covered; inferred lithology light brown siltstone	60.5	439.6

19. contact covered; composition same as Unit 15		
a. structureless	8.0	
b. medium-scale, low angle trough-shaped sets of cross-stratification	7.9	455.5
20. unit covered; inferred lithology red and green mottled siltstone	11.0	466.5
21. contact covered; composition same as Unit 15; large-scale, low angle trough-shaped sets of cross-stratification	15.7	482.2

SWMC 4

T37S R24E SEC. 10 SE 1/4 of NW 1/4

I. Salt Wash Member, Morrison Formation

1. contact covered; medium-grained, moderately sorted subrounded, light brown sandstone--composition 95% quartz, 1% tuffaceous material, 2% dark minerals, 2% chert		
a. medium-scale wedge- and trough-shaped sets of cross-stratification	3.6	
b. contact sharp, irregularly wavey; flat lying thick laminae	2.0	
c. red and green mottled mudstone; beds 2" thick, flat lying	0.7	
d. contact sharp, irregular; large-scale low angle trough-shaped sets of cross-stratification grading to medium-scale, low angle trough-shaped sets of cross-stratification in upper 4′	12.3	
e. red and green mottled siltstone	1.0	
f. medium-scale, high angle trough-shaped sets of cross-stratification with mud splits up to 3" thick along bedding planes	13.8	
g. small-scale, low angle trough-shaped sets with occasional ripples	9.5	42.9
2. red and green siltstone grading upward to mudstone over 3′	3.0	45.9
3. contact sharp, undulatory; medium-grained, poorly sorted at base, moderately sorted above basal 1′; subrounded light brown sandstone--	16.0	61.9

	composition 77% quartz, 10% chert, 3% dark minerals, 5% tuffaceous material in basal 1′; 96% quartz, 2% chert, 1% tuffaceous material, 1% dark minerals in upper 15′; large-scale trough-shaped sets of cross-stratification, grades into medium-scale trough-shaped sets over basal 6′		
4.	contact sharp, undulatory; composition same as upper 15′ of Unit 3; medium-scale, low angle trough-shaped sets of cross-stratification	11.8	73.7
5.	a. contact sharp, undulatory; red and green mottled mudstone	1.2	
	b. conformable; light brown siltstone	0.7	
	c. contact gradational over 4"; red and green mottled mudstone	0.3	75.9
6.	contact sharp, undulatory; composition same as Unit 3; medium-scale trough-shaped sets of cross-stratification	12.7	88.6
7.	red and green mottled mudstone; pinches out 100′ to south	0.7	89.3
8.	contact sharp, undulatory; medium-grained, moderately sorted, subrounded, light brown sandstone--composition 96% quartz, 3% tuffaceous material, 1% chert, less than 1% dark minerals; large-scale, low angle trough-shaped sets of cross-stratification in basal 15′, grades vertically and laterally into medium-scale trough-shaped sets with mud galls and carbon flakes along bedding planes	28.3	117.6
9.	covered unit; inferred lithology red and green mottled siltstone	20.7	138.3
10.	contact sharp, undulatory; medium-grained, moderately sorted subrounded highly indurated, light brown sandstone--composition 95% quartz, 2% tuffaceous material, 2% dark minerals, 1% chert; medium-scale trough-sets up to 2′ thick, 8′ long forming multistory and	16.7	155.0

multilateral beds; burrows 4" long 6′ from base

11.	unit covered; inferred lithology red and green siltstone	8.5	163.5
12.	contact covered; moderately sorted, medium-grained, subrounded, highly friable light brown sandstone--composition 94% quartz, 3% dark minerals, 2% chert, 1% tuffaceous material, carbonate cement; medium-scale trough-shaped sets of cross-stratification in basal 2′, small-scale trough-shaped sets in upper 12.5′	14.5	178.0
13.	unit covered; inferred lithology red and brown siltstone	38.7	216.7
14.	contact covered; fine-grained, moderately sorted, subangular, highly indurated, light brown sandstone--composition 97% quartz, 2% red chert, 1% dark minerals, less than 1% tuffaceous material		
	a. medium-scale wedge-shaped sets of cross-stratification	4.7	
	b. medium-scale trough-shaped sets of cross-stratification	5.5	
	c. unit covered; inferred lithology red siltstone	3.5	
	d. medium-scale sets of wedge planar cross-stratification	16.7	247.1
15.	unit covered; inferred lithology red siltstone	16.8	263.9
16.	contact covered; medium-grained, poorly sorted, subrounded, light brown sandstone--composition 96% quartz, 1% chert, 2% tuffaceous material, 1% dark minerals, up to 5% interstitial green clay galls 1/8" or less; unit forms prominent ledge		
	a. large-scale trough-shaped sets of cross-stratification with green mud galls up to 1/2" diameter in basal 1.5′	5.3	
	b. medium-scale trough-shaped sets of cross-stratification	7.7	
	c. greenish-yellow siltstone inter-bedded with dark purple mudstone	0.7	

	d. large-scale trough-shaped sets of cross-stratification	7.8	
	e. medium-scale trough-shaped sets of cross-stratification	13.3	
	f. structureless	16.7	315.4

II. Recapture Creek Member, Morrison Formation

17.	unit covered; inferred lithology light brown siltstone; forms large bench	53.7	369.1
18.	contact covered; medium-grained, poorly sorted, subangular, very friable, light grey sandstone--composition 92% quartz, 2% tuffaceous material, 2% chert; structureless	2.7	371.8
19.	unit covered; inferred lithology light grey siltstone interbedded with brown mudstone	56.0	427.8
20.	contact covered; medium-grained, poorly sorted, subangular, friable light grey sandstone--composition 91% quartz, 6% tuffaceous material, 2% chert, 1% dark minerals, some interstitial green muds; medium-scale trough-shaped sets of cross-stratification	6.9	434.7
21.	unit covered; inferred lithology light grey siltstone	24.3	459.0

SWMC 5

T37S R24E SEC. 15 SE 1/4 of SE 1/4

I. Salt Wash Member, Morrison Formation

1.	contact covered; medium-grained moderately sorted, subrounded, light brown sandstone--composition 92% quartz, 3% chert, 3% dark minerals, 2% tuffaceous minerals, abundant limonite blebs; medium-scale trough-shaped sets of cross-stratification	7.8	7.8
2.	unit covered; inferred lithology red and green mottled siltstone; forms large bench	39.3	47.1
3.	contact covered; medium-grained, moderately sorted, subrounded, light	19.3	66.4

brown sandstone--composition 94% quartz, 3% red chert, 2% dark minerals, 1% tuffaceous material; medium-scale trough cross-stratification

4.	unit covered except for numerous thin sandstone ledges less than 1.5′ thick, composition same as Unit 3	36.8	103.2
5.	contact covered; medium-scale, well sorted, subrounded, moderately friable, light brown sandstone--composition 92% quartz, 4% chert, 3% tuffaceous material, 1% dark minerals; large-scale trough-shaped sets of cross-stratification in lower 8′, medium-scale trough-shaped sets in upper 14.8′	22.8	126.0
6.	unit covered; inferred lithology red and green mudstones	53.2	179.2
7.	a. contact covered; fine-grained, moderately sorted, subangular, light grey sandstone--composition 98% quartz, 1% chert, 1% tuffaceous material; medium-scale trough-shaped sets of cross-stratification	1.2	
	b. flat lying laminae of light grey siltstone	0.3	
	c. composition same as Unit 7a; large-scale, low angle trough-shaped sets of cross-stratification	15.3	195.0
8.	unit covered; inferred lithology red and green mudstone	6.8	201.8
9.	contact sharp, undulatory; fine-grained, well-sorted, subrounded, well indurated, light brown sandstone--composition 98% quartz, 1% tuffaceous material; 1% dark minerals, abundant limonite blebs; large-scale, low angle trough- and wedge-shaped sets of cross-stratification, fining upwards to medium-scale trough-shaped sets; forms prominent ledge; carbon flakes along bedding planes in lowest 15′, tree trunks and branches 700′ south	44.9	246.7

II. Recapture Creek Member, Morrison Formation

10.	unit covered; inferred lithology red siltstone	23.3	270.0
11.	contact covered; medium-grained, moderately sorted, subrounded, friable, light brown sandstone--composition 88% quartz, 2% chert, 8% dark minerals, 2% tuffaceous material; large-scale trough-shaped sets of cross-stratification in lowest 4′, grades to medium-scale, low angle, platy trough-shaped sets vertically	21.7	291.7

III. Westwater Canyon Member, Morrison Formation

12.	unit covered; inferred lithology light brown siltstone	135.9	427.6
13.	contact covered; medium-grained, moderately sorted, subrounded, greenish-yellow sandstone--composition 91% quartz, 8% dark minerals, 1% chert, interstitial green clay clasts up to 1/4" diameter; basal 8.5′ structureless, upper 13.8′ medium-scale, low angle, platy wedge-shaped sets of planar cross-stratification; highly burrowed, burrows vertical and horizontal, 1/8" diameter, non-branching, cross each other	22.3	449.9

SWMC 6

T37S R24E SEC. 13 SW 1/4 of NW 1/4

I. Salt Wash Member, Morrison Formation

1. a.	contact covered; medium-grained, moderately sorted, subrounded light brown sandstone--composition 95% quartz, 3% dark minerals, 1% chert, 1% tuffaceous material, abundant limonite blebs and staining; flat lying beds .3′ thick	2.8	
b.	unit covered; inferred lithology same as Unit 1a	0.3	
c.	contact covered; composition same as Unit 1a	11.0	14.1
2.	unit covered; inferred lithology	57.0	71.1

	red mudstone		
3.	contact covered; medium-grained, moderately sorted, subrounded, highly indurated, light brown sandstone--composition 96% quartz, 2% tuffaceous material, 1% chert, 1% dark minerals, slight limonite staining; medium-scale trough-shaped sets of cross-stratification with mud splits up to .3′ thickness in basal 1′	19.1	90.2
4.	unit covered; inferred lithology red mudstone	24.0	114.2
5.	a. contact covered; fine-grained, well-sorted, subrounded, highly indurated, light brown sandstone--composition 94% quartz, 2% feldspars, 2% tuffaceous material, 1% chert, 1% dark minerals; medium-scale trough-shaped sets of cross-stratification	6.9	
	b. unit covered; discontinuous 100′ to north and south; inferred lithology red mudstone	5.9	
	c. contact covered; composition and structures same as Unit 5a	5.2	
	d. contact sharp; composition same as Unit 5a; tangential tabular planar sets of cross-stratification	2.3	
	e. contact covered; composition same as Unit 5a; large-scale trough-shaped sets of cross-stratification grades upward to medium-scale trough-shaped sets	16.9	151.4
6.	unit covered; inferred lithology interbedded red siltstones and thinly bedded sandstones	55.0	206.4
7.	a. contact sharp, undultory; fine-grained, poorly sorted, subrounded light brown sandstone--composition 87% quartz, 7% clay galls, 3% carbon as coaly chunks and flakes, 2% chert, 1% dark minerals; medium-scale trough-shaped sets of cross-stratification in basal 9′, upper 9.7′ large-scale trough-shaped sets	18.7	
	b. contact sharp, undultory; composition same as Unit 7a;	7.6	

	medium-scale trough-shaped sets of cross-stratification		
c.	pink and green silty mudstone; structureless	4.0	
d.	contact sharp, undulatory; composition same as Unit 7a; medium-scale trough-shaped sets of cross-stratification	17.5	254.2

II. Recapture Creek Member, Morrison Formation

8. a.	unit covered; inferred lithology very friable sandstone	10.0	
b.	contact covered; fine-grained, well-sorted, subangular white sandstone--composition 98% quartz, 1% tuffaceous material, 1% red chert; structureless	11.3	
c.	unit covered; inferred lithology red and green mudtone	11.9	287.4
9. a.	contact sharp, undulatory with abundant green and red mudstone clasts; fine-grained, well sorted, subrounded white sandstone--composition 96% quartz, 2% chert, 2% tuffaceous material; flat lying laminae	2.7	
b.	composition same as Unit 9a; medium-scale trough-shaped sets of cross-stratification	23.5	313.6

III. Westwater Canyon Member, Morrison Formation

10. a.	unit covered; inferred lithology red mudstones	33.0	
b.	contact covered; medium-grained, moderately sorted, subangular, highly indurated light grey-green sandstone--composition 91% quartz, 3% tuffaceous material, 3% interstitial green clay, 1% chert, 1% dark minerals; poorly defined medium-scale trough-shaped sets of cross-stratification; abundant desert varnish	5.7	
c.	unit covered; inferred lithology green-grey mudstone	29.5	
d.	contact sharp, undulatory; composition and structures same as Unit 10b	6.7	
e.	conformable with Unit 10d; very friable	8.2	
f.	unit covered; inferred lithology green mudstone	33.0	429.7

SWMC 7

T37S R23E SEC. 23 SE 1/4 of SE 1/4

I. Salt Wash Member, Morrison Formation

1. contact covered; medium-grained, moderately sorted, subrounded, well indurated, light brown sandstone--composition 91% quartz, 6% chert, 2% dark minerals, 1% tuffaceous material; medium-scale trough-shaped sets of cross-stratification with mud splits up to .3′ thick at base of sets	11.0	11.0
2. unit covered; inferred lithology red and green mudstones	16.7	27.7
3. contact sharp, undulatory; medium-grained, subrounded, moderately sorted, light brown sandstone--composition 96% quartz, 2% red chert, 1% dark minerals, 1% angular tuffaceous material, sparse limonite; medium-scale trough-shaped sets of cross-stratification	50.0	77.7

II. Recapture Creek Member, Morrison Formation

4. unit covered; inferred lithology red mudstone; forms large bench	36.5	114.2
5. contact covered; fine-grained, well sorted, subrounded, friable, white sandstone--composition 96% quartz, 2% chert, 1% dark minerals, 1% tuffaceous material; medium-scale trough-shaped sets of cross-stratification	54.5	168.7
6. unit covered; inferred lithology red mudstones	16.5	185.2
7. a. contact covered; fine-grained, well-sorted, subrounded, very friable, light green sandstone--composition 95% quartz, 3% tuffaceous material, 1% dark minerals, 1% chert; ripple cross-laminae	7.3	
b. conformable; composition same as Unit 7a; medium-scale wedge-	5.0	

shaped sets of planar cross-
stratification

APPENDIX II

PALEOCURRENT DATA FROM STRATIGRAPHIC SECTIONS

Appendix II

Paleocurrent Data from Stratigraphic Sections
(Data in degrees)

SECTION SWMC1

Member	Unit	Parting Lineation	Trough Axis	Rib & Furrow
Salt Wash	19	N35W	S50E	
		N50W	S15E	
		N10W		
		N37E		
		N41E		
		N37E		
		N35E		
		N36E		
	22	N65W	S43E	
		N45W	S40E	
		N48W	S33E	
			S70E	
			S55E	

SECTION SWMC 2

Member	Unit	Parting Lineation	Trough Axis	Rib & Furrow
Salt Wash	4f	N38E	N60E	
		N34E	N35E	
		N45W	N70E	
		N60E	N70E	
		N55E		
		N59E		
	9c	N52W	N78W	S60W
		N56W	N60W	S60W
		N50W	N65W	N65W
			N78W	West
	9h	N11W		
		N14W		
		N12W		
		N15W		
		N18W		
		N17W		
		N14W		
		N12W		
		N22W		

SECTION SWMC 3

Member	Unit	Parting Lineation	Trough Axis	Rib & Furrow
Salt Wash	1	N36W		
		N33W		

		N38W
		N36W
	11	N45E
		N43E
		N62E
		N50E
		N49E
		N46E
		N44E
		N51E
		N47E
		N47E
		N45E
		N44E
		N49E

SECTION SWMC 4

Salt Wash	1d	East	
		N80E	
		N84E	
		N86E	
	4	N28E	N32E
		N32E	N36E
		N31E	
		N33E	
		N26E	
		N27E	
		N22E	
		N24E	
		N14E	
		N34E	
		N28E	
		N29E	
		North	
		N31E	
		N34E	
		N29E	
		N30E	
		N31E	
	8	N44E	
		N46E	
		N44E	
		N46E	
		N44E	
		N55E	
		N57E	
		N42E	
		N44E	
		N52E	
		N61E	
		N60E	
		N62E	
		N64E	

		N71E		

SECTION SWMC 5

Salt Wash	1	N40W	N24W	
		N38W	N36W	
		N41W	N29W	
		N41W	N32W	
		N44W		
		N48W		
		N46W		
		N43W		
		N36W		
		N40W		
		N39W		
		N40W		
		N47W		
		N37W		
	9	N78W	N79W	
		N80W		
Recapture Creek	11	East	N80E	
		East	N79E	
		N76E	N89E	
		N70E		
		N79E		
		N78E		
		N84E		
		N80E		
		N78E		
		N86E		
		N79E		
		N88E		
		N85E		

SECTION SWMC 6

Salt Wash	3	N5E	East	
		North	S80E	
		North		
		North		
	5a	N40W		S40E
		N40W		
		N44W		
		N38W		
		N36W		
		N38W		
		N34W		
		N20W		
	5d	N8E		
		N10E		
		N8E		
		N4E		
		N5E		

		North	
		N3E	
		N6E	

SECTION SWMC 7

Salt Wash	3	N30E	S20E
		N48E	North
		N36E	
		N41E	
		N37E	
		N40E	
		N43E	
		N45W	
		N45W	
		N45W	
		N41W	
		N55W	
		N60W	
		N48W	
		N62W	
		N62W	
		N58W	
		N65W	
		N59W	
		N50E	

SECTION SWMC 8

Salt Wash	1a	N80E	N70E
		N79E	
		N83E	
		N65E	
	1b	N74W	S35E
		N69W	
		N74W	
		N82W	
		N85W	
		N81W	
Recapture Creek	2	N85W	
		N80W	
		N81W	
		N82W	
		N85W	
		N65W	
		N80W	
		N85W	
		N85W	
		N78W	
		N80W	
		N85W	
		N89W	
		N87W	

		N83W	
		N86W	
		N83W	
		N88W	
		N83W	
		N81W	
	4a	N65W	
		N60W	
		N84W	
		N89W	
		N76W	
		N79W	
		N89W	
		West	
		West	
		N85W	
		N87W	
		N87E	
		N89W	
		N87E	
		N89E	
		N80E	
		N89W	
		N87E	
		N87W	
		N87E	

<u>SECTION SWMC 9</u>

Salt Wash	2a	N65W	N70W
		N65W	
		N67W	
		N54W	
		N58W	
	2b	N50W	
		N85E	
		N80E	
		N89E	
		N34W	
		N40W	
		N34W	
		N36W	
		N40W	
		N30W	
		N31W	
		N35W	
		N26W	
		N24W	
		N28W	
		N25W	
		N38W	
		N27W	
		N25W	
		N18W	

		N26W
	2c	North
		N2E
		North
		North
		North
		N4E
		N1E
		N2E
		N3E
		N5E
		N8E
		N7E
		N10E
		N4E
		N5E
		N4E
		North
		N4W
		N2W
Recapture Creek	4a	N87E
		East
		N45E
		N54E
		N57E
		N58E
		N50E
		N42E
		N82E
		East
		N77E
		N79E
	5b	N70W
		N70W
		N75W
		N68W
		N69W
		N69W
		N62W
		N65W
		N64W
		N72W
		N72W
		N50W
		N50W
		N57W
		N53W
		N52W
		N45W
		N47W
		N56W
		N52W
		N30W
		N50W
	7	N80E

		N78E	
		N68E	
		N84E	
		N86E	
		East	
		N80E	
		N83E	
		N76E	

SECTION SWMC 10

Salt Wash	4b	N60E	N79W
		N65E	
		N70E	
		N68E	
		N69E	
		N61E	
		N71E	
		N69E	
		N68E	
		N70E	
		N68E	
		N71E	
		N73E	
		N68E	
		N71E	
		N75W	
		N80W	
		N79W	
		N82W	
		N84W	
		N88W	
		N84W	
		N86W	
		N82W	
Recapture Creek	8b	N80E	
		N20E	
		N55E	
		N62E	
		N64E	
		N68E	
		N65E	
		N65E	
		N61E	
		N63E	
		N61E	
		N61E	
		N18E	
		N20E	
		N22E	

SECTION SWMC 11

Salt Wash	1	N40E	N10E
		N35E	N12E
		N37W	
		N14W	
		N15W	
		N2W	
		N1W	
		N3W	
	3	N70W	
		N67W	
		N71W	
		N68W	
		N65W	
		N80W	
		N81W	
		N78W	
		N73W	
		N74W	
		N72W	
		N71W	
		N87W	
		N85W	
		N86W	
		N84W	
		N85W	
		N85W	
		N81W	
		N82W	
		N81W	
	9c	N40E	S20E
		N38E	
		N42E	
		N39E	
		N36E	
		N32E	
		N28E	
		N29E	
		N31E	
		N26E	
		N25E	
		N27E	
		N38E	
		N40E	
		N42E	
		N41E	
		N45E	
		N89W	
		N88W	
		N85W	
		West	
		N80W	
		N79W	
	11b		S43E
Recapture Creek	15	West	N30W
		N79W	

		N89W	
		N86W	
		N87W	
		N83W	
		N76W	
		N78W	
		N67W	
		N79W	
		N81W	
		N81W	
		N82W	
		N86W	
		N88W	
		West	
		N88W	
		N78W	
		N77W	
		N76W	

SECTION SWMC 12

Salt Wash	2	N15E	
		N10E	
		N12E	
		N18E	
		N17E	
		N13E	
		N15E	
		N27E	
		N28E	
		N30E	
		N31E	
		N35E	
		N34E	
		N34E	
		N32E	
		N31E	
		N35E	
	4		N18E
	8c	N80E	N70W
		N82E	
		N84E	
		N89E	
		East	
		N88W	
		N87W	
		N88W	
		N89W	
		East	
		N89W	
		N87W	
		N86W	
		N84W	
		N83W	

		N84W	
		N80W	
		N79W	
		N81W	
		N84W	
Recapture Creek	12d	N10E	N40W
		N8E	
		N11E	
		N12E	
		N17E	
		N18E	
		N15E	

SECTION SWMC 13

Salt Wash	4	N50E	N40E
		N48E	
		N48E	
		N51E	
		N52E	
	6	N79W	S72E
		N80W	
		N78W	
		N72W	
		N73W	
		N74W	
		N72W	
		N78W	
		N77W	
		N75W	
	10c	N20W	S82E
			N40W
Recapture Creek	12d		N55E
			N60E
			N80E
			N76E
	12f		N62E
			N70E

SECTION SWMC 14

Salt Wash	3a	N63W	
		N59W	
		N52W	
		N67W	
		N61W	
		N58W	
		N35W	
		N38W	
		N39W	
		N54W	
		N52W	
	3c	N85E	N63E

N88E	N70E
N80E	N78E
N89E	
N87E	
N89E	
East	
N68E	
N72E	
N84E	
N73E	
N78E	
N81E	
N69E	
N81E	
N86E	
N78E	
East	
N79E	
N89E	
N76E	
N83E	

APPENDIX III

DESCRIPTION OF NOMENCLATURE USED IN THE THIN SECTION ANALYSES

AND

THIN SECTION ANALYSES

NOMENCLATURE USED IN THIN SECTION ANALYSES

Grain size:

Wentworth Grades: based on the Wentworth (1922) size classification

Phi Scale: where ∅ = -log (diameter in mm) in Pettijohn and others (1973)

Sorting: based on sorting images of Folk (1968)

Elongation Index: based on Folk (1968)

Roundness: based on Krumbein and Sloss (1963)

Grain to Grain Contacts: based on Pettijohn and others (1973)

Matrix: defined in Blatt and others (1972) but subdivided according to Dickinson (1970) into orthomatrix (recrystallized detrital clays), epimatrix (clays produced as chemical alteration products of detrital grains) and pseudomatrix (physically deformed argillaceous lithic fragments)

Textural Maturity: based on Folk (1968) and using percentage of orthomatrix as "percentage of clay"

Lithic Fragments: VRF = volcanic lithic fragment
ARF = argillaceous (sedimentary) lithic fragments including those deformed into pseudomatrix

Salt Wash Member

Thin Section SWMC 10-2

Total Rock:
Ave. Gn. Size: .20 mm 2.28 ϕ fine sand
Sorting: 1.1 poorly sorted
Ave. Elongation Index: .66 subelongate/intermediate boundary
Ave. Roundness: .37 subangular
Textural Maturity now: immature
Gn. to Gn. Contacts: concavo-convex decreasing abn.
line contacts
sutured
point to point contact

% of rock composed of:

a) detrital gns.: 77
b) cement: 7 cement (poikilotopic 6% and veins of carbonate cross-cutting gns.)
c) matrix: phyllosilicate 12
types of matrix (w/%): orthomatrix 4
epimatrix 8
d) pore space: 3

Textural maturity @ time of deposition: submature

Detrital Components (%):

a) qtz. (varieties later): 52
b) feldspars: 14
c) chert: 3 red staining
d) lithic fragments: 6 altered VRF
e) micas: light - trace
dark - 0
f) non-opaque heavy minerals: 1
Types: chlorite
g) opaques: 2 pyrite blebs (partially altered; limonite blebs

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	95	.2	2.28	fine sand

roundness: 37
elong. index: .66 subelongate/intermediate boundary
diagenetic changes: syntaxial rim growth followed by fracturing

	% or qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	5	.25	2.0	fine to med. sand

roundness: .45 subrounded
Ave. # xstals/gn: 3

elong. index: .69 intermediate
contacts: sutured
size dist. of xstals w/in gn: subequal
diagenetic changes: fracturing through all crystals

Mono and Poly:
vacuoles: many very fine vacuoles
extinction: undulatory
inclusions: unknown red mineral with tetrahedral form - no extinction

Feldspars: % of Feld.: Ave. Gn. Size: ϕ
K-spars:
microcline: trace
roundness: .41 subrounded
elong. index: .70 subequant
orthoclase/sanidine: 50
perthite: 35
Plagioclase: 10

Salt Wash Member

Thin Section SWMC 10-4

Total Rock:
Ave. Gn. Size: .62 mm .7 ϕ coarse sand
Sorting: 1.2 poorly sorted
Ave. Elongation Index: .73 equant
Ave. Roundness: .65 subrounded
Textural Maturity now: immature
Gn. to Gn. Contacts: line contacts decreasing abn.
concavo-convex
point to point
sutured

% of rock composed of:

a) detrital gns.: 72
b) cement: 14 poikilotopic 12; carbonate drusy rim cement 1; silica syntaxial rim cement 1
c) matrix: 12
types of matrix (w/%): orthomatrix 8
epimatrix 2
pseudomatrix 2
d) pore space: 2

Textural maturity @ time of deposition: immature

Detrital Components (%):

a) qtz. (varieties later): 47
b) feldspars: 15
c) chert: 1
d) lithic fragments: 4 altered VRF, 5 ARF

e) micas: light - 0
dark - trace
f) non-opaque heavy minerals: trace
Types: zircon
g) opaques: 1 pyrite crystals (often altered to limonite)

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	79	60 mm	.72	coarse sand

roundness: .65 subrounded
elong. index: .73 equant
diagenetic changes: fracturing due to compression

	% or qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	21	.65	.68	coarse sand

roundness: .60 subrounded
Ave. # xstals/gn: 6
elong. index: .71 subequant
contacts: sutured
size dist. of xstals w/in gn: equal
diagenetic changes:

Mono and Poly:
vacuoles: many very small
extinction: 80% undulatory, 20% complete
inclusions: rutile

Feldspars:	% of Feld.:	Ave. Gn. Size:	ϕ	
K-spars:	98	.60	.72	coarse sand

orthoclase/sanidine: 88
perthite: 8
microcline: 2
roundness: .75 rounded
elong. index: .76 very equant
diagenetic changes: much alteration/sericitization

Plagioclase: 2%
Rock type: subarkose

Salt Wash Member

Thin Section SWMC 11-3

Total Rock:
Ave. Gn. Size: .3 mm 1.75 ϕ med. sand
Sorting: 1.5 poorly sorted
Ave. Elongation Index: .61 elongate
Ave. Roundness: .7 subrounded
Textural Maturity now: immature
Gn. to Gn. Contacts: line — decreasing abn.
concavo-convex
point to point
sutured

% of rock composed of:

a) detrital gns.: 76
b) cement: 8 poikilotopic carbonate 5; drusy carbonate 1; silica cement 2
c) matrix: phyllosilicates 5
   types of matrix (w/%): orthomatrix 4
   pseudomatrix 1
d) pore space: 11 (doubtless high due to plucking)

Textural maturity @ time of deposition: submature

Detrital Components (%): (77% total)

a) qtz. (varieties later): 52
b) feldspars: 20
c) chert: trace
d) lithic fragments: 4 ARF + minor; some VRF
e) micas: light - trace
   dark - trace
f) non-opaque heavy minerals: trace
   Types:
g) opaques: trace

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	70	.25	2	med/fine sand

roundness: .3 subangular
elong. index: .61 elongate
diagenetic changes: all qtz. grains highly fractured, much syntaxial rim (11-12 obvious ones)

	% or qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	30	.4 mm	1.3	med. sand

roundness: .3 subangular
Ave. # xstals/gn: 3.1 (out of 20)
elong. index: .70 subequant
contacts: sutured/concavo-convex with some phyllosilicates altered
size dist. of xstals w/in gn: much variation (.1 mm-.3 mm)
diagenetic changes: formation of syntaxial rim cements, fracturing, formation of phyllosilicates at some gn.-gn. boundaries

Mono and Poly:
vacuoles: minor (numerous but very small)
extinction:
inclusions: tourmaline (blue), rutile

Feldspars:	% of Feld.:	Ave. Gn. Size:	ϕ	
K-spars:	85	.2 mm	2.25	fine sand

orthoclase/sanidine: 65
perthite: 5
microcline: 15
roundness: .7 rounded
elong. index: .74 equant
diagenetic changes: sericitization of microcline and orthoclase, fracturing with subsequent sericitization evident

Plagioclase: 5%
Rock type: Lithic Arkose

Salt Wash Member

Thin Section SWMC 11-5b

Total Rock:
Ave. Gn. Size: .3 mm 1.75 ϕ med. sand
Sorting: .67 moderate
Ave. Elongation Index: .68 intermediate
Ave. Roundness: .55 subrounded
Textural Maturity now: immature
Gn. to Gn. Contacts: concavo-convex decreasing abn.
line
point to point
sutured

% of rock composed of:

a) detrital gns.: 80
b) cement: 11
c) matrix: 8
types of matrix (w/%): orthomatrix 5
pseudomatrix 3
d) pore space: 1

Textural maturity @ time of deposition: immature

Detrital Components (%):

a) qtz. (varieties later): 52
b) feldspars: 19
c) chert: 1 red staining (hematite?)
d) lithic fragments: 2 VRF, 5 ARF
e) micas: light - trace
dark - 0
f) non-opaque heavy minerals: trace
Types: chlorite
g) opaques: 1 limonite after pyrite

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	85	.3	1.75	med. sand

roundness: .55 subrounded
elong. index: .68 intermediate

diagenetic changes: fracturing through syntaxial rim cements

	% of qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	15	.35	1.5	med. sand

roundness: .50 subrounded
Ave. # xstals/gn: 4
elong. index: .68
contacts: sutured
size dist. of xstals w/in gn: equal
diagenetic changes:

Mono and Poly:
vacuoles: many very small
extinction: undulatory and regular
inclusions: opaques and (tourmaline?)

Feldspars:	% of Feld.:	Ave. Gn. Size:	ϕ
K-spars:	90		

orthoclase/sanidine: 60
perthite: 20
microcline: 10
roundness: .65 rounded
elong. index: .70 subequant
diagenetic changes:

Plagioclase:
Rock type: Lithic Arkose

Salt Wash Member

Thin Section SWMC 11-9a

Total Rock:
Ave. Gn. Size: .35 mm 2 ϕ med/fine sand
Sorting: .7 moderately sorted
Ave. Elongation Index: .64 subelongate
Ave. Roundness: .7 rounded
Textural Maturity now: Folk - immature
Gn. to Gn. Contacts: concavo-convex 60% of contacts — decreasing abn.
line
sutured (minor--mainly in polycrystalline quartz)
pt. contacts (minor)

% or rock composed of:

a) detrital gns.: 73
b) cement: carbonate (alteration to clays) 17
Poikilotopic with very minor drusy texture*
c) matrix: phyllosilicates 6
types of matrix (w/%): orthomatrix 1
epimatrix 4

pseudomatrix 1
d) pore space: 4 (appears higher due to plucking)
Textural maturity @ time of deposition: submature

Detrital Components (%): (Total 73%)

a) qtz. (varieties later): 60
b) feldspars: 11
c) chert: less than 1
d) lithic fragments: less than 1 VRF, 1 ARF
e) micas: light - trace
dark - 0
f) non-opaque heavy minerals: trace
Types: zircon (1 grain, well rounded) trourmaline and rutile as inclusions
g) opaques: trace
*altered to phyllosilicate

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	φ	
Monocrystalline:	85	.25 mm	2	med/fine sand (bound)

roundness: .7 rounded
elong. index: .63
diagenetic changes: much fracturing of grains (some doubtless prior to deposition, but is some); "leafing"; 3 syntaxial rims observed

	% of qtz:	Ave. Gn. Size:	φ	
Polycrystalline:	15	.20	2.25	fine sand

roundness: .7 rounded
Ave. # xstals/gn: 2.3 (20 gns.)
elong. index: .57
contacts: line contacts and sutured
size dist. of xstals w/in gn: approx. equal (.1 mm)
diagenetic changes: much fracturing, some phyllosilicate growth at grain boundaries

Mono and Poly:
vacuoles:
extinction:
inclusions: tourmaline; rutile (in 1 qtz. gn.)

Feldspars:	% of Feld.:	Ave. Gn. Size:	φ	
K-spars:	(90%)			
orthoclase/sanidine:	70			
perthite:	trace			
microcline:	20	.2 mm	2.25	fine sand

roundness: .3 sub
elong. index: .70 subequant
diagenetic changes: some feldspars altering to phyllosilicates (brown/orange brown)

Plagioclase: 10 average grain size
roundness: .3 .2 mm 2.25 fine sand
Rock type: Subarkose

Salt Wash Member

Thin Section SWMC 11-11a

Total Rock:
Ave. Gn. Size: .45 mm 1.10 ϕ med. sand
Sorting: .7 moderately
Ave. Elongation Index: .65 subelongate
Ave. Roundness: .5 subrounded
Textural Maturity now: immature
Gn. to Gn. Contacts: concavo-convex decreasing abn.
line
point to point
sutured

% of rock composed of:

a) detrital gns.: 84
b) cement: 8 carbonate Poikilotopic carbonate
syntaxial rim cement (silica);
drusy carbonate rim cements
c) matrix: phyllosilicate and silts 9
types of matrix (w/%): epimatrix 3
pseudomatrix 3
orthomatrix 3
d) pore space: 2
Textural maturity @ time of deposition: submature

Detrital Components (%):

a) qtz. (varieties later): 59
b) feldspars: 15
c) chert: 1
d) lithic fragments: 3 VRF, 3 ARF
e) micas: light - 0
dark - 0
f) non-opaque heavy minerals: 1
Types:
g) opaques: 2 limonie/pyrite

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ
Monocrystalline:	86	.5	1.0 med/coarse sand

roundness: .5 subrounded (.7 w/out syntaxial rim cement) rounded
elong. index: .65 subelongate
diagenetic changes: silica syntaxial rim cement followed by fracturing

followed by carbonaceous
rim cement

% of qtz: Ave. Gn. Size: ϕ

Polycrystalline: 14
roundness: .7 rounded
Ave. # xstals/gn: 4
elong. index: .63 subelongate
contacts: sutured and line
size dist. of xstals w/in gn: equal
diagenetic changes:

Mono and Poly:
vacuoles: very small
extinction: undulatory and totally at once
inclusions: dark (opaques) along original grain boundaries

Feldspars: % of Feld.: Ave. Gn. Size: ϕ

K-spars: 90
orthoclase/sanidine: 65
perthite: 5
microcline: 20
roundness: .8 rounded to well rounded boundary
elong. index: .71 subequant
diagenetic changes: sericitization of grain boundaries; carbonate in-filling of fractures

Plagioclase: 10%

Rock type: Arkose

Salt Wash Member

Thin Section SWMC 12-6

Total Rock:
Ave. Gn. Size: .25 mm 2.0 ϕ med/fine sand
Sorting: .85 moderately
Ave. Elongation Index: .71 subequant
Ave. Roundness: .42 subrounded
Textural Maturity now: immature
Gn. to Gn. Contacts: sutured decreasing abn.
concavo-convex
line
point

% of rock composed of:

a) detrital gns.: 75
b) cement: 12 poikilotopic calcite, carbonate rim cement, silicacious syntaxial rim cement
c) matrix: 12
types of matrix (w/%): phyllosilicates: orthomatrix 5

pseudomatrix 6
epimatrix 1

d) pore space: 1
Textural maturity @ time of deposition: submature

Detrital Components (%):

a) qtz. (varieties later): 45
b) feldspars: 13
c) chert: trace
d) lithic fragments: 8 VRF - quartz, feldspars, biotite -- feldspars altered, 6 ARF
e) micas: light - 0
dark - 0
f) non-opaque heavy minerals: trace
Types: zircon, chlorite
g) opaques: 3 pyrite, edges altering to limonite

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	80	.25	2.0	med/fine sand

roundness: .42 subrounded
elong. index: .71 subequant
diagenetic changes: fracturing through syntaxial rim cement

	% of qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	20	.25	2.0	med/fine sand

roundness: .42 subrounded
Ave. # xstals/gn: 6
elong. index: .68 subequant
contacts: sutured
size dist. of xstals w/in gn: equal
diagenetic changes:

Mono and Poly:
vacuoles: many very small
extinction: undulatory (60%) complete
inclusions: pyrite? ie. dark opaque

Feldspars:	% of Feld.:	Ave. Gn. Size:	ϕ
K-spars:	95		

orthoclase/sanidine: 65
perthite: 20
microcline: 15
roundness: .5 subrounded
elong. index: .73 equant
diagenetic changes:
Plagioclase:
Rock type: Arkose

<u>Salt Wash Member</u>

Thin Section SWMC 13-2c

Total Rock:
Ave. Gn. Size: .35 mm 1.5 ϕ med. sand
Sorting: .75 moderately sorted
Ave. Elongation Index: .65 subelongate
Ave. Roundness: .35 subangular
Textural Maturity now: immature
Gn. to Gn. Contacts: concavo-convex decreasing abn.
sutured
line
point to point

% of rock composed of:

a) detrital gns.: 73
b) cement: 15 poikilotopic 12; syntaxial rim 1; carbonate drusy rim 2
c) matrix: 9
types of matrix (w/%): orthomatrix 5
pseudomatrix 4
epimatrix 1
d) pore space: 2

Textural maturity @ time of deposition: submature

Detrital Components (%):

a) qtz. (varieties later): 45
b) feldspars: 16
c) chert: 1
d) lithic fragments: 5 VRF, 5 ARF
e) micas: light -
dark -
f) non-opaque heavy minerals: trace
Types: chlorite
g) opaques: 2 pyrite/limonite

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	85	.35	1.5	med. sand

roundness: .35 subangular (.65 w/out syntaxial rim cement) rounded
elong. index: .65 subelongate
diagenetic changes: fracturing - syntaxial rim growths - suturing

	% of qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	15	.25	1.95	med. sand

roundness: .25 subangular
Ave. # xstals/gn: 4
elong. index: .68 intermediate
contacts: sutured

size dist. of xstals w/in gn: bimodal
diagenetic changes:

Mono and Poly:
vacuoles: many very small
extinction: undulatory
inclusions: small opaques

Feldspars:	% of Feld.:	Ave. Gn. Size:	ø
K-spars:	72	.25	2.0 med/fine boundary

orthoclase/sanidine: 51
perthite: 10
microcline: 1
roundness: .55 subrounded
elong. index: .71 subequant
diagenetic changes:

Plagioclase: 28
Rock type: Arkose

Salt Wash Member

Thin Section SWMC 13-10a

Total Rock:
Ave. Gn. Size: .35 mm 1.5 ø med. sand
Sorting: .79 moderately sorted
Ave. Elongation Index: .65 subelongate
Ave. Roundness: .63 rounded
Textural Maturity now: immature
Gn. to Gn. Contacts: concavo-convex decreasing abn.
line
sutured
point contacts

% of rock composed of:

a) detrital gns.: 74
b) cement: 14 carbonate cement (rim) and poikilotopic 11; silica syntaxial rims 4
c) matrix: 7
types of matrix (w/%): orthomatrix 3
epimatrix 4
d) pore space: 4

Textural maturity @ time of deposition: mature

Detrital Components (%): (Total % of 74%)

a) qtz. (varieties later): 53
b) feldspars: 18
c) chert: 2 red staining
d) lithic fragments: 1 some altered VRF, trace ARF
e) micas: light - trace

dark - 0
f) non-opaque heavy minerals: trace
Types:
g) opaques: trace pyrite (cubic crystals)

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	90	.31	1.7	med. sand

roundness: .55 subrounded .7 rounded
elong. index: .65 subelongate
diagenetic changes: syntaxial rim cementations w/fracturing running through rim cements; concoidal fracturing (stress)

	% of qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	10	.31	1.7	med. sand

roundness: .45 subrounded
Ave. # xstals/gn: 4
elong. index:
contacts:
size dist. of xstals w/in gn: approx. equal
diagenetic changes: alteration

Mono and Poly:
vacuoles: numerous very small
extinction: undulatory
inclusions: small opaque inclusions along original grain boundaries; one qtz. grain with high relief (tourmaline)

Feldspars: % of Feld.: Ave. Gn. Size: ϕ
K-spars:
orthoclase/sanidine: 50 alteration along cleavage planes to phyllosilicates
perthite: 35
microcline: trace
roundness: .45 subrounded
elong. index: .71 subequant
diagenetic changes:
Plagioclase: 15
Rock type: Arkose

Salt Wash Member

Thin Section SWMC 13-12e

Total Rock:
Ave. Gn. Size: .63 mm .7 ϕ med. sand
Sorting: 1.5 poorly sorted
Ave. Elongation Index: .61 subelongate
Ave. Roundness: .37 subangular
Textural Maturity now: immature

Gn. to Gn. Contacts: sutured / concavo-convex / line / point to point — decreasing abn.

% of rock composed of:

a) detrital gns.: 77
b) cement: 11
c) matrix: 8
   types of matrix (w/%): orthomatrix 4
                          pseudomatrix 4
d) pore space: 4 - high due to plucking

Textural maturity @ time of deposition:

Detrital Components (%): 77

a) qtz. (varieties later): 41
b) feldspars: 21
c) chert: 3 red staining
d) lithic fragments: 8 VRF, 4 ARF
e) micas: light -
          dark -
f) non-opaque heavy minerals: trace
   Types: chlorite
g) opaques: trace - pyrite? w/limonite alteration

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	75	.63 mm	.7	med. sand

roundness: .37 subangular
elong. index: .61 subelongate
diagenetic changes: extensive fracturing through sutured contacts

	% of qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	25	.55	.9	coarse sand

roundness: .45 subrounded
Ave. # xstals/gn: 8
elong. index: .67 intermediate
contacts: line
size dist. of xstals w/in gn: equal
diagenetic changes: fracturing of crystals w/in grain

Mono and Poly:
vacuoles: many very small
extinction: undulatory (90%)
inclusions: opaques

Feldspars:	% of Feld.:	Ave. Gn. Size:	ϕ
K-spars:	90		

orthoclase/sanidine: 55/10
perthite: 20

microcline: 15
roundness: .50 subrounded
elong. index: .71 subequant
diagenetic changes:
Plagioclase: 10
Rock type: Lithic Arkose

Salt Wash Member

Thin Section SWMC 13-14

Total Rock:
Ave. Gn. Size: .8 mm .20 ϕ coarse sand
Sorting: 1.0 poorly sorted
Ave. Elongation Index: .68 intermediate
Ave. Roundness: .55 subrounded
Textural Maturity now: immature
Gn. to Gn. Contacts: line decreasing abn.
concavo-convex
sutured
point to point

% of rock composed of:

a) detrital gns.: 75
b) cement: 11 poikilotopic calcite 8; syntaxial rim cements 3
c) matrix: 12
types of matrix (w/%): orthomatrix 7
pseudomatrix 5
d) pore space: 2
Textural maturity @ time of deposition: submature

Detrital Components (%):

a) qtz. (varieties later): 48
b) feldspars: 18
c) chert: 1
d) lithic fragments: 4 VRF, 4 ARF
e) micas: light - 0
dark - 0
f) non-opaque heavy minerals: trace
Types: chlorite
g) opaques: trace - pyrite

Qtz:

varieties: % of qtz: Ave. Gn. Size: ϕ
Monocrystalline: 85 .8 mm .2 coarse sand
roundness: .55 subrounded (.7 w/out syntaxial rim cement) rounded
elong. index: .67 intermediate
diagenetic changes: syntaxial rim cement - rounding - fracturing

	% of qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	15	.55 mm	.85	coarse sand

roundness: .65 rounded
Ave. # xstals/gn: 3
elong. index: .70 subequant
contacts: sutured
size dist. of xstals w/in gn: equal
diagenetic changes: fracturing

Mono and Poly:
vacuoles: many very small
extinction: undulatory predominately
inclusions: tourmaline

Feldspars:	% of Feld.:	Ave. Gn. Size:	ϕ	
K-spars:	75	.45	1.3	med. sand

orthoclase/sanidine: 50/5
perthite: 15
microcline: 5
roundness: .5 subrounded
elong. index: .68 subequant
diagenetic changes: much alteration to phyllosilicates, fracturing (1st)

Plagioclase: 25
Rock type: Arkose

Recapture Creek Member

Thin Section SWMC 10-6

Total Rock:
Ave. Gn. Size: .20 mm 2.3 ϕ fine sand
Sorting: .5 moderately sorted
Ave. Elongation Index: .66 intermediate/subelongate boundary
Ave. Roundness: .35 subangular
Textural Maturity now: immature
Gn. to Gn. Contacts: concavo-convex decreasing abn.
line
sutured
point to point

% of rock composed of:

a) detrital gns.: 77
b) cement: 4 carbonate drusy rims over silica syntaxial rims
c) matrix: 14
types of matrix (w/%): orthomatrix 5
pseudomatrix 4
epimatrix 5
d) pore space: 5

Textural maturity @ time of deposition: submature or mature

Detrital Components (%): 76

a) qtz. (varieties later): 37
b) feldspars: 26
c) chert: 2
d) lithic fragments: 8 VRF, 4 ARF
e) micas: light - trace
dark - 0
f) non-opaque heavy minerals: trace
Types: chlorite
g) opaques: trace - limonite

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	φ	
Monocrystalline:	99	.19	2.31	fine sand

roundness: .35 subangular
elong. index: .66 intermediate
diagenetic changes: silicaceous rim cement (noticeable due to dark inclusions); fracturing (stress); carbonate rim cement later; suturing of grains (no fractures through these contacts)

	% of qtz:	Ave. Gn. Size:	φ	
Polycrystalline:	1	.22	2.29	fine sand

roundness: .45 subrounded
Ave. # xstals/gn: 6
elong. index: .63 subelongate
contacts: sutured
size dist. of xstals w/in gn: equal
diagenetic changes:

Mono and Poly:
vacuoles: very small
extinction: complete
inclusions: tourmaline

Feldspars:	% of Feld.:	Ave. Gn. Size:	φ
K-spars:	80		

orthoclase/sanidine: 45
perthite: 20
microcline: 15
roundness: .50 subrounded
elong. index: .71 subequant
diagenetic changes: sericitization of edges

Plagioclase: 20
Rock type: Lithic Arkose

Thin Section SWMC 10-8

Total Rock:
Ave. Gn. Size: .25 mm 2.0 ϕ fine/med. sand
Sorting: .75 moderately sorted
Ave. Elongation Index: elongate .60
Ave. Roundness: .3 subangular
Textural Maturity now: immature
Gn. to Gn. Contacts: line contact decreasing abn.
point to point
concavo-convex

% of rock composed of:

a) detrital gns.: 73
b) cement: 12 poikilotopic carbonate 11; carbonate drusy rim cement 1; some alteration/ mixing w/phyllosilicates
c) matrix: 13
types of matrix (w/%): orthomatrix 7
pseudomatrix 4
epimatrix 2
d) pore space: 2

Textural maturity @ time of deposition: submature

Detrital Components (%): 73

a) qtz. (varieties later): 37
b) feldspars: 25
c) chert: 2
d) lithic fragments: 3 VRF, 6 ARF
e) micas: light - 0
dark - 0
f) non-opaque heavy minerals: trace
Types: chlorite
g) opaques: trace - pyrite (some alteration to limonite)

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	95	.25	2.0	fine/med. sand boundary

roundness: .3 subangular (.3 w/out syntaxial rim cement)
elong. index: .60 elongate
diagenetic changes: fracturing, carbonate rim cementation

	% of qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	5	.2	2.3	fine sand

roundness: .35 subangular

Ave. # xstals/gn: 3
elong. index: .63 elongate
contacts: sutured
size dist. of xstals w/in gn: equal
diagenetic changes:

Mono and Poly:
vacuoles: many very small
extinction: complete, 5% undulatory
inclusions: dark and opaques (very fine), tourmaline

Feldspars: % of Feld.: Ave. Gn. Size: ϕ
K-spars: 85
orthoclase/sanidine: 35
perthite: 45
microcline: 10
roundness: .50 subrounded
elong. index: .70 subequant
diagenetic changes:
Plagioclase: 15
Rock type: Lithic Arkose

Recapture Creek Member

Thin Section SWMC 11-13

Total Rock:
Ave. Gn. Size: .35 mm 1.5 ϕ med. sand
Sorting: .72 moderate
Ave. Elongation Index: .68 intermediate
Ave. Roundness: .35 subangular
Textural Maturity now: immature
Gn. to Gn. Contacts: sutured decreasing abn.
concavo-convex
line
point

% of rock composed of:

a) detrital gns.: 73
b) cement: 8 poikilotopic 4; syntaxial rim 3; drusy carbonate 1
c) matrix: 17
types of matrix (w/%): orthomatrix 11
pseudomatrix 6
d) pore space: 2

Textural maturity @ time of deposition:

Detrital Components (%):

a) qtz. (varieties later): 30
b) feldspars: 26
c) chert: 3

d) lithic fragments: 6 VRF, 6 ARF
e) micas: light -
dark -
f) non-opaque heavy minerals: trace
Types: chlorite
g) opaques: 2 - pyrite/limonite

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	90	.35	1.5	med. sand

roundness: .35 subangular (.65 w/out syntaxial rim cement) rounded
elong. index: .68 intermediate
diagenetic changes: fracturing

	% of qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	10	.20	2.15	fine sand

roundness: .30 subangular
Ave. # xstals/gn: 4
elong. index: .65 intermediate
contacts: sutured
size dist. of xstals w/in gn: bimodal
diagenetic changes:

Mono and Poly:
vacuoles: many
extinction: undulatory
inclusions: very small opaques, tourmaline

Feldspars:	% of Feld.:	Ave. Gn. Size:	ϕ
K-spars:	89	.20	

orthoclase/sanidine: 50
perthite: 27
microcline: 12
roundness: .45 subrounded
elong. index: .70 subequant
diagenetic changes:
Plagioclase: 11
Rock type: Lithic Arkose

Recapture Creek Member

Thin Section SWMC 11-15

Total Rock:
Ave. Gn. Size: .35 mm 1.5 ϕ med. sand
Sorting: 1.1 poorly sorted
Ave. Elongation Index: .65 subelongate
Ave. Roundness: .35 subangular
Textural Maturity now: immature
Gn. to Gn. Contacts: line — decreasing abn.
concavo-convex
sutured

point to point

% of rock composed of:

a) detrital gns.: 82
b) cement: 6 poikilotopic 4; syntaxial rim cement 2
c) matrix: 11
types of matrix (w/%): orthomatrix 9
pseudomatrix 2
d) pore space: 1

Textural maturity @ time of deposition: immature

Detrital Components (%):

a) qtz. (varieties later): 37
b) feldspars: 25
c) chert: 6 red staining
d) lithic fragments: 5 VRF, 9 ARF
e) micas: light -
dark -
f) non-opaque heavy minerals: trace
Types: chlorite - rounded
g) opaques: trace - limonite/pyrite cubes

Qtz:

varieties:	% of qtz:	Ave. Gn. Size	ϕ	
Monocrystalline:	80	.32	1.6	med. sand

roundness: .35 subangular
elong. index: .65 subelongate
diagenetic changes: fracturing

	% of qtz:	Ave. Gn. Size:	ϕ
Polycrystalline:	20	.45	

roundness: .35 subangular
Ave. # xstals/gn: 6
elong. index: .65 subelongate
contacts: sutured
size dist. of xstals w/in gn: bimodal
diagenetic changes: fracturing

Mono and Poly:
vacuoles: many very small
extinction: complete
inclusions: many very small opaques, a few tourmalines

Feldspars:	% of Feld.:	Ave. Gn. Size:	ϕ
K-spars:	85		

orthoclase/sanidine: 40
perthite: 25
microcline: 20
roundness: .50 subrounded
elong. index: .72 subequant
diagenetic changes:

Plagioclase: 15
Rock type: Lithic Arkose

Recapture Creek Member

Thin Section SWMC 12-12

Total Rock:
Ave. Gn. Size: .25 mm 2.0 ϕ med./fine sand
Sorting: .55 moderately
Ave. Elongation Index: .65 subelongate
Ave. Roundness: .35 subangular
Textural Maturity now: submature
Gn. to Gn. Contacts: decreasing abn.

% of rock composed of:

a) detrital gns.: 81
b) cement: 14 poikilotopic 11; syntaxial rim 2; carbonate rim 1
c) matrix: 4
types of matrix (w/%): orthomatrix 3
pseudomatrix 1
d) pore space: 1

Textural maturity @ time of deposition: immature

Detrital Components (%):

a) qtz. (varieties later): 39
b) feldspars: 25
c) chert: 6 red staining
d) lithic fragments: 6 VRF, 3 ARF
e) micas: light -
dark - trace biotite
f) non-opaque heavy minerals:
Types:
g) opaques: 2 - pyrite 2%

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	80	.25 mm	2.0	med./fine sand

roundness: .35 subangular (.65 w/out syntaxial rim cement) rounded
elong. index: .65 subelongate
diagenetic changes: extensive fracturing - syntaxial rim/suturing

	% of qtz:	Ave. Gn. Size:	ϕ
Polycrystalline:	20		

roundness: .25 subangular
Ave. # xstals/gn: 4
elong. index: .65 subelongate

contacts: sutured
size dist. of xstals w/in gn: bimodal
diagenetic changes:

Mono and Poly:
vacuoles: many very small
extinction: undulatory
inclusions: many very small opaque

Feldspars:	% of Feld.:	Ave. Gn. Size:	ϕ	
K-spars:	85	.7	.5	coarse sand

orthoclase/sanidine: 30
perthite: 20
microcline: 35
roundness: .59 subrounded
elong. index: .71 subequant
diagenetic changes: sericitization

Plagioclase: 15
Rock type: Lithic Arkose

Recapture Creek Member

Thin Section SWMC 14-4

Total Rock:
Ave. Gn. Size: .25 mm 2.0 ϕ med./fine sand
Sorting: .45 well-sorted
Ave. Elongation Index: .71 subequant
Ave. Roundness: .35 subangular
Textural Maturity now: submature
Gn. to Gn. Contacts: concavo-convex decreasing abn.
line contacts
point contacts
sutured

% of rock composed of:

a) detrital gns.: 61
b) cement: 5 carbonate rim cement 3; poikilotopic 1; (over qtz. syntaxial rim)
c) matrix: 4
types of matrix (w/%): orthomatrix 3
pseudomatrix 1
d) pore space: 30 (definately very much plucking)

Textural maturity @ time of deposition: submature

Detrital Components (%):

a) qtz. (varieties later): 26
b) feldspars: 21
c) chert: 6 hematite (?) staining
d) lithic fragments: 5 VRF, 1 ARF
e) micas: light - trace
dark - 2

f) non-opaque heavy minerals: trace possible chlorite
Types:
g) opaques: trace

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ	
Monocrystalline:	99	.25	2.0	med/fine sand

roundness: .9 rounded
elong. index: .75 very equant
diagenetic changes: fracturing due to pressure at contacts, carbonate rim cement with micro drusy texture and some carbonate infilling of fractures in grains

	% of qtz:	Ave. Gn. Size:	ϕ	
Polycrystalline:	1	.25	2.0	med/fine sand

roundness: .9 rounded
Ave. # xstals/gn: 2
elong. index: .75 very equant
contacts: sutured
size dist. of xstals w/in gn: equal
diagenetic changes:

Mono and Poly:
vacuoles: many very fine
extinction: complete
inclusions: none observed

Feldspars: % of Feld.: Ave. Gn. Size: ϕ
K-spars:
orthoclase/sanidine: 20
perthite: 5
microcline: 10
roundness: .59 subrounded
elong. index: .71 subequant
diagenetic changes:
Plagioclase: 65
Rock type: Lithic Arkose
Note: very much plucking, despite epoxying sample; suggestive of poor cementation; also, may skew sample to rounded and equant by removal of finer fraction

Recapture Creek Member

Thin Section SWMC 14-6

Total Rock:
Ave. Gn. Size: .25 mm 2.0 ϕ med./fine sand
Sorting: .4 well-sorted

Ave. Elongation Index: .69 subequant
Ave. Roundness: .39 subangular
Textural Maturity now: immature
Gn. to Gn. Contacts: concavo-convex decreasing abn.
line
point to point
sutured

% of rock composed of:

a) detrital gns.: 65
b) cement: 3 syntaxial rim cement (silicates), carbonate rim cement w/fine drusy texture
c) matrix: 7
types of matrix (w/%): orthomatrix 4
pseudomatrix 3
d) pore space: 25 (plucking?)

Textural maturity @ time of deposition: mature

Detrital Components (%): 65%
a) qtz. (varieties later): 34
b) feldspars: 24
c) chert: 3
d) lithic feldspars: trace VRF, 3 ARF
e) micas: light - trace
dark - trace
f) non-opaque heavy minerals: 1
Types: chlorite
g) opaques: trace - limonite

Qtz:

varieties:	% of qtz:	Ave. Gn. Size:	ϕ
Monocrystalline:	99	.25	

roundness: .5 subrounded
elong. index: .39 subangular
diagenetic changes: growth of syntaxial (silica) rim cement followed fracturing then by carbonate rim cement

	% of qtz:	Ave. Gn. Size:	ϕ
Polycrystalline:	1	.25	

roundness: .5 subrounded
Ave. # xstals/gn: 6
elong. index:
contacts:
size dist. of xstals w/in gn: equal
diagenetic changes:

Mono and Poly:
vacuoles: very small
extinction: completely at once no undulatory
inclusions: tourmaline

Feldspars: % of Feld.: Ave. Gn. Size: ϕ
K-spars: 76
orthoclase/sanidine: 11
perthite: 60
microcline: 5
roundness: .56 subrounded
elong. index: .71 subequant
diagenetic changes: sericitization of feldspars minimal (sericitization of feldspars in lithic fragments considerable)
Plagioclase: 24
Rock type: Lithic Arkose

Recapture Creek Member

Thin Section SWMC 14-8

Total Rock:
Ave. Gn. Size: .20 mm 2.3 ϕ fine sand
Sorting: .5 moderately sorted
Ave. Elongation Index: .65 subelongate
Ave. Roundness: .4 subangular/subrounded boundary
Textural Maturity now: immature
Gn. to Gn. Contacts: concavo-convex decreasing abn.
line
point to point
very little suturing

% of rock composed of:

a) detrital gns.: 78
b) cement: 4 carbonate drusy rim cement; minor poikilotopic
c) matrix: 6
types of matrix (w/%): orthomatrix 2
epimatrix 4
d) pore space: 12

Textural maturity @ time of deposition: submature

Detrital Components (%): 78

a) qtz. (varieties later): 37
b) feldspars: 29
c) chert: 4 red staining
d) lithic fragments: 6 VRF, 2 ARF
e) micas: light - trace
dark - trace
f) non-opaque heavy minerals: trace
Types: chlorite (less than .1 mm)
g) opaques: trace - limonite

Qtz:

varieties: % of qtz: Ave. Gn. Size: ø
Monocrystalline: 99 .2 mm 2.5 fine sand
roundness: .4 subangular
elong. index: .65 subequant
diagenetic changes: fracturing, growth of carbonate rim cement

% of qtz: Ave. Gn. Size: ø
Polycrystalline: 1
roundness: .45 subrounded
Ave. # xstals/gn: 4
elong. index: .65 subequant
contacts:
size dist. of xstals w/in gn: equal
diagenetic changes:

Mono and Poly:
vacuoles: many very small
extinction: complete
inclusions: tourmaline, possible rutile

Feldspars: % of Feld.: Ave. Gn. Size: ø
K-spars: 85
orthoclase/sanidine: 50
perthite: 25
microcline: 10
roundness: .50 subrounded
elong. index: .71 subequant
diagenetic changes:
Plagioclase: 15
Rock type: Lithic Arkose

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