INTERPRETED DEPOSITIONAL ENVIRONMENTS

OF THE SALT WASH AND LOWER MEMBERS

OF THE MORRISON FORMATION,

GRAND COUNTY, UTAH

by

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ABSTRACT

The Morrison Formation (Upper Jurassic) in the area between the Green and Colorado Rivers, Grand County, southeast Utah, is divided into the Salt Wash Sandstone Member and the Brushy Basin Shale Member in ascending order. The Salt Wash Sandstone Member consists of lensoid and tabular sandstones interlayered with siltstone and mudstone, with a basal sequence of limestone, mudstone, and some gypsum. The Brushy Basin Shale Member consists of a series of mudstones, siltstones, limestones, and sandstones locally with conglomeratic lenses. Information from 16 measured stratigraphic sections in this area indicates that the Salt Wash Sandstone Member represents deposition in two types of environments: a lower environment dominated by lacustrine sedimentation, and an upper environment dominated by fluvial sedimentation. Within the upper fluvial environment, a transition occurs between the deposits of streams of low sinuosity and low braiding at the base to deposits of streams of low sinuosity and higher braiding at the top. These streams resulted as a lobe of the aggrading Salt Wash Sandstone Member alluvial-fan system spread over the study area. The oldest (lowest) streams choked and filled the lakes of the lower lacustrine environment, establishing low-sinuosity nonbraided channels and associated floodplains. As the lobe grew in size, increased gradient and competence of the streams caused establishment of

low-sinuosity braided channels and minor floodplains. Abandonment of the lobe of the Salt Wash Sandstone Member alluvial fan in the study area may have occurred some time before establishment of the dominantly lacustrine environment of the Brushy Basin Shale Member. The environments of deposition of the Salt Wash Sandstone Member interpreted for the study area are sufficiently distinctive to serve as a basis for division of the Salt Wash Sandstone Member into two subunits.

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INTRODUCTION

The Upper Jurassic Series of the Colorado Plateau has been studied in detail by numerous workers; most previous reports have dealt with the occurrence of uranium ores in thick, tabular bodies of sandstone in the Morrison Formation. Many reports include an interpretation of the depositional environment of the Morrison Formation or its members. Of these members, the Salt Wash Sandstone Member and the Westwater Canyon Sandstone Member are most extensively mineralized and hence most extensively studied.

Purpose

The purpose of this study was to interprete the environment of deposition of the Salt Wash Sandstone Member of the Morrison Formation in the area between the Green and Colorado Rivers, Grand County, in southeast Utah (figure 1). It was undertaken to add to the general knowledge of the Salt Wash Sandstone Member and to study local depositional environments within the major depositional system of the member.

Methods

A combination of field and laboratory work was undertaken for this study. Field methods include measurement and drafting of stratigraphic sections,

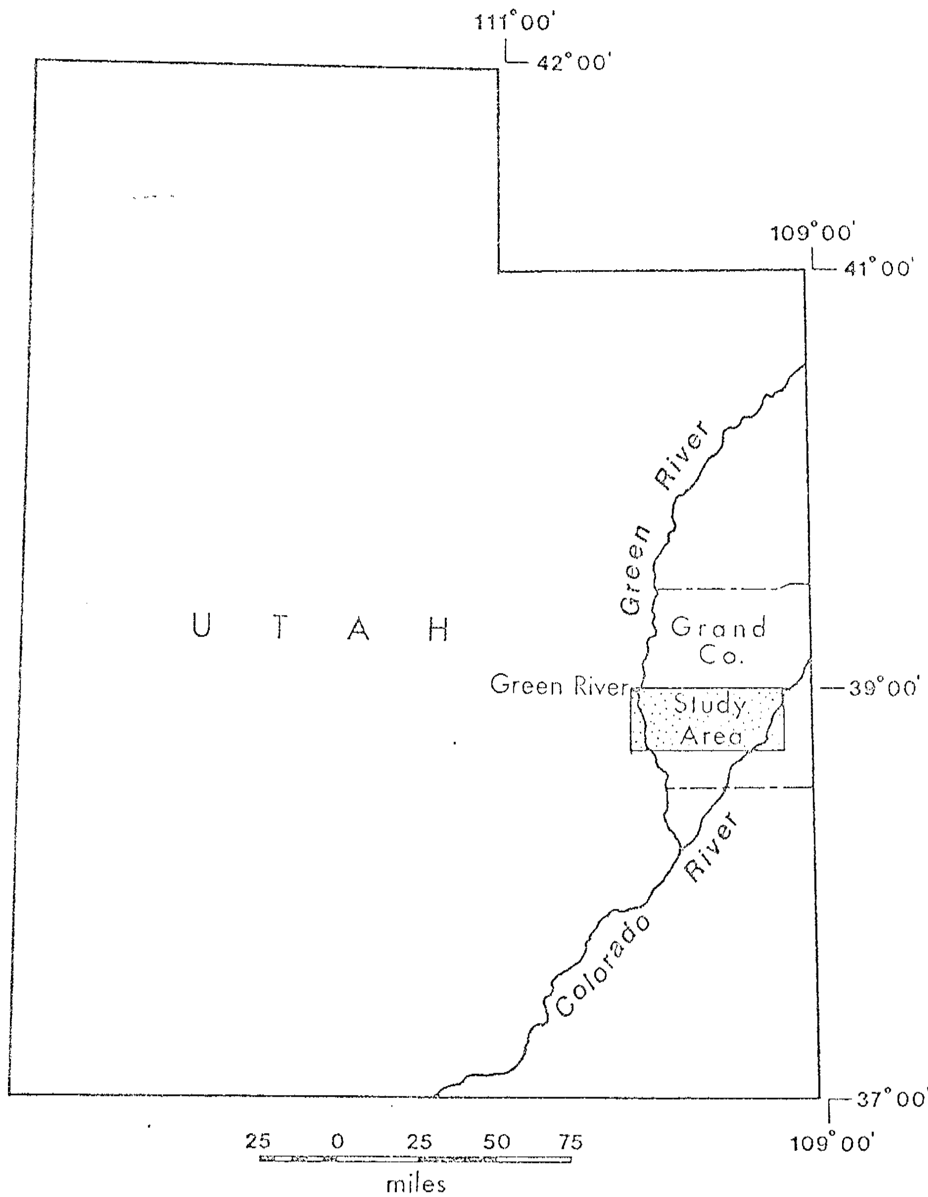


Figure 1-Index map of Utah showing location of study area.

collection and description of samples of rocks and fossils, and field trips guided by experienced geologists both in and outside of the study area. The field season was from May 21 to August 26, 1979, centered in the town of Green River, Utah. Laboratory methods included analysis of sandstone samples for grain texture, analysis of thin sections of selected samples, identification of fossil plants and animals, and interpretation of observed structural and lithologic characteristics. Laboratory work was done at the New Mexico Institute of Mining and Technology, Socorro, New Mexico. Where appropriate, specific methods are described in more detail.

Location of the study area

The study area is located in Grand County, southeast Utah (figure 2). This area encompasses the outcrop of the Morrison Formation between the Green River on the west and the Colorado River on the east. The town of Green River is located in the northwestern portion of the study area; the towns of Crescent Junction, Thompson, Cisco, and Dewey are also in the area. The city of Moab, Utah is about 2 km south of the central part of the study area.

Field work on this area and the area immediately adjacent to the west was done jointly with Suzanne Sexsmith (1982); data from the area along the east bank of the Green River are used in both studies.

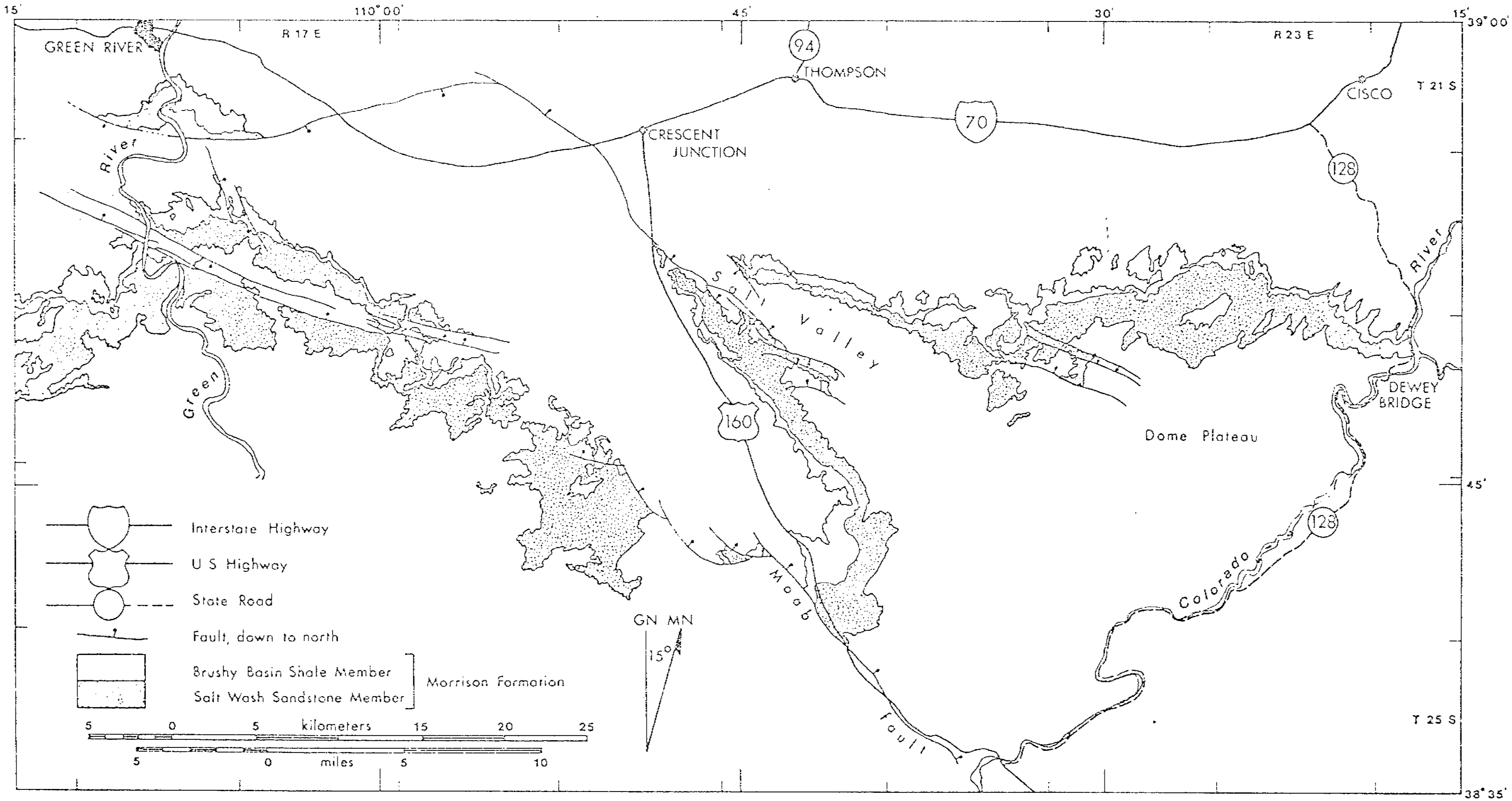


Figure 2—Map of study area showing outcrop of Morrison Formation, associated faults, major roads, and cultural features.

Major access to the study area is provided by I-70, which crosses the study area east-west, and US-160, which connects I-70 with Moab and southern Utah. Utah-128 gives access to the eastern part of the area and the southwest bank of the Colorado River below Dewey Bridge. Numerous unpaved but graded roads open the area to travel by two-wheel-drive vehicles, and abundant poorer quality and unmaintained prospecting, mining, and drilling roads requiring four-wheel-drive vehicles, penetrate the rougher terrain.

Stratigraphy of the study area

The stratigraphy of the Colorado Plateau, including the study area, was described by Dane (1935), Gregory (1938), Stokes (1944, 1952), Craig and others (1955), Mullens and Freeman (1957), Williams (1964), Tanner (1965), Peterson and Hite (1969), Williams and Hackman (1971), Butler and Fisher (1978), and Young (1978).

Morrison Formation

The Morrison Formation is exposed over most of the Colorado Plateau. In the study area, the Morrison Formation consists of two members; in ascending order they are the Salt Wash Sandstone Member (Lupton, 1914) and the Brushy Basin Shale Member (Gregory, 1938). The Salt Wash Sandstone Member is a series of lensoid to tabular sandstones from a few centimeters to 10 m thick, generally medium- to coarse-grained and locally conglomeratic (granules to cobbles), interlayered with and laterally grading into siltstone and mudstone. The basal contacts of the sandstones are typically scour surfaces. Siltstone and mudstone basal contacts are gradational with the sandstones and with each other. Thin, discontinuous limestones, locally cherty, occur near the base of the Salt Wash Sandstone Member; gypsum occurs at this horizon in the western part of the study area. Thick, locally conglomeratic sandstones in the upper part of the member host uranium mineralization.

The Brushy Basin Shale Member consists of thinly bedded purple, red, green, and white mudstones; siltstones; limestones; and sandstones which are locally conglomeratic (cobbles). Dinosaur bones are fairly common in the member. The Salt Wash-Brushy Basin contact is apparently conformable except where sandstones and conglomerates in the Brushy Basin scour into the underlying Salt Wash Sandstone Member. The top of the Brushy Basin is the top of the Morrison Formation and marks the upper boundary of the Jurassic System in the study area.

Laterally equivalent to the Salt Wash Sandstone Member to the southeast and east of the study area is the Recapture Member (Gregory, 1938) of the Morrison Formation. The Recapture Member consists of interlayered sandstone and sandy and silty mudstone. The Westwater Canyon Sandstone Member of the Morrison Formation (Gregory, 1938) is the general east-southeast lateral equivalent of the Brushy Basin Shale Member. The Westwater Canyon Sandstone Member is made up of carbonaceous, locally conglomeratic sandstones interlayered with mudstones. The sandstones of this member host uranium mineralization.

Informal division of the Morrison Formation

Peterson (1978), working in the Henry Mountains about 100 km south of the study area, suggested informal subdivision of the Morrison Formation into a lower member, Salt Wash member, and Brushy Basin Shale Member. The lower member in the Henry Mountains area consists of mudstones with thin limestone and sandstone; the Salt Wash member consists of subequal proportions of sandstones and mudstones. Associations of lithologies, similar to those noted by Peterson (1978), occur in the formal Salt Wash Sandstone Member in the study area. A lower sequence at the base of the Morrison Formation consists of thin, discontinuous limestones, thin lensoid and tabular sandstones, local occurrences of gypsum, and calcareous mudstones. Above this sequence is a series of thin to thick lensoid and tabular sandstones truncating, laterally grading into, and overlain by siltstones and mudstones. These two lithologic associations are similar to those noted by Peterson (1978), and his informal subdivision of the Morrison Formation is used in this report. The informal subunits of the Morrison Formation in the study area are referred to as the lower member and the Salt Wash member; the formal subunits are the Salt Wash Sandstone Member and the Brushy Basin Shale Member.

Table 1 illustrates the relationships of the formal and informal divisions of the Morrison Formation as described above.

The lower member consists of a sequence of mudstone containing thin sandstones and limestones, and local gypsum occurrences. This member encompasses the lowermost part of the Morrison Formation, as well as the uppermost gypsum layer included in the Summerville Formation by Trimble and Doelling (1978) and other workers. The base of the lower member of the Morrison Formation is placed at the occurrence of an angular unconformity truncating the red-brown siltstone and mudstone of the Summerville Formation, the lowest occurrence of a layer of detrital granule-sized chert grains, and a distinctive color change from red-brown Summerville strata to gray-green lower member strata.

The Salt Wash member consists of the sequence of sandstones, siltstones, and mudstones included in the formal Salt Wash Sandstone Member. The top of the informal Salt Wash member is coincident with the top of the formal Salt Wash Sandstone Member; the base of the Salt Wash member is placed at the base of the lowest sandstone in the sequence which has an erosional base, is 1 m or more in thickness, and extends at least 10 m laterally.

Table 1

Stratigraphy of Upper Jurassic and Lower Cretaceous rocks in the study area.

<table>
<tr><td>Lower Cretaceous</td><td colspan="3">Burro Canyon Formation</td></tr>
<tr><td rowspan="5">Upper Jurassic</td><td rowspan="2">Morrison Formation</td><td colspan="2">Brushy Basin Shale Member</td></tr>
<tr><td>(formal stratigraphy)
Salt Wash Sandstone Member</td><td>(informal stratigraphy)
Salt Wash member</td></tr>
<tr><td colspan="2">gypsum layer
Summerville Formation</td><td>lower member</td></tr>
<tr><td colspan="3">Curtis Formation
(present in extreme western part of study area only)</td></tr>
<tr><td colspan="3">Entrada Sandstone</td></tr>
</table>

Structure

The study area lies almost entirely within the limits of the Paradox Basin, a late Paleozoic structural trough trending approximately N 60°W.. This basin terminates against the Uncompahgre uplift to the northeast, a subsurface elongate structure not expressed as a topographic high in Jurassic time. To the west is the San Rafael swell, a north-trending anticline of Cretaceous age approximately 160 km long and 80 km wide. Several salt-cored anticlines lie within the Paradox Basin; one such structure is exposed in the study area. Structural elements within the study area are shown in figure 3.

Several northwest-trending anticlines and synclines cross the study area. The major structures are the Salt Valley anticline and the adjacent Courthouse syncline, both of which lie in the central part of the study area. These structures are relatively simple to the north but become more complex and contorted to the southeast, breaking into smaller, parallel tight folds (King's Bottom, Moab, Castle Valley, and Fisher Valley anticlines, Yellow Cat dome, and the Elephant Butte folds). In the northeast corner of the study area, the Singer's Wash syncline and Cisco anticline trend N 40°-60° W.

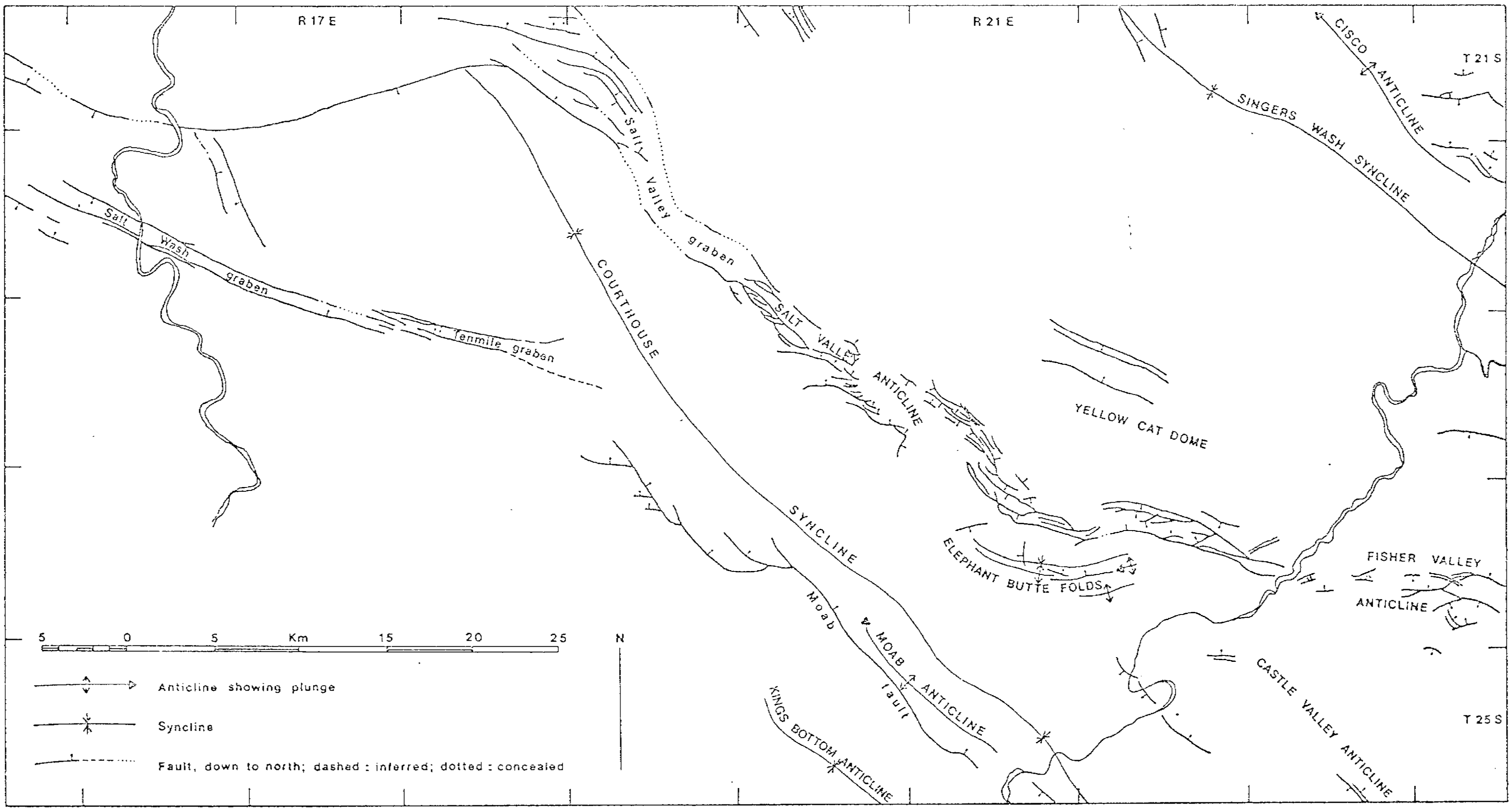


Figure 3—Map of study area showing structural elements.

The axial trends of all folds in the study area are parallel to the main axis of the Uncompahgre uplift. The Salt Valley anticline is unique in the study area; its crest is downfaulted into a complex sinuous graben over most of its length. The floor of this graben is covered with alluvium; Rocks from Pennsylvanian to Cretaceous in age are exposed in scattered areas.

The major faults in the study area occur in a zone of intense normal faulting bounding the central graben of the Salt Valley anticline (figure 3). The Salt Valley graben located south of Crescent Junction is the best developed of these. The bounding and internal faults of this graben are northwest-trending, parallel the structural axis of the anticline, and are complexly interconnected with arcuate offshoots trending generally to the west. Throw is generally less than 50 m on any single fault (Baker, 1935).

In the south-central part of the study area, the Moab fault trends N 40 W, parallel to the axis of the Moab anticline. This normal fault, downthrown to the east, becomes a system of branching arcuate faults, always arcing west and north while the parent fault dies out northward. Near the termination of this fault system, the long, narrow Salt Wash-Tenmile graben begins and continues west-northwest to the western edge of the study area. Several saline springs occurring along this graben give Salt Wash its name. North of the Salt Wash-Tenmile graben, an east-west trending normal fault, and downthrown to the south, extends from the northern terminus of the Salt Valley anticline to the western limit of the study area. Throw on this fault is 100-200 m at its exposure south of the town of Green River.

FIELD RELATIONSHIPS

This chapter consists of field descriptions of the rock units, their contacts and possible origins based on these data. It is supplemented by appendix A (descriptions of measured stratigraphic sections) and plates I and II (graphic stratigraphic sections).

Location and numbering of measured stratigraphic sections

Locations of the 16 measured stratigraphic sections used in this study are shown in figure 4. Sections are numbered chronologically; Section 1 is the first section measured, Section 29 the last. There is no preferred areal distribution to the section locations. Numbers missing from the sequence 1-29 lie in the field area assigned to Suzanne Sexsmith (1980), who did a related study west of the Green River. Sections are referred to in the text by number. Table 2 lists locations of the sections by township and range.

The locations of the measured sections were chosen to satisfy the requirements of: 1) existence of a complete, unfaulted section of the Salt Wash Sandstone Member; 2) lateral spacing of 5-10 km between locations; and 3) accessibility by 4-wheel drive vehicles.

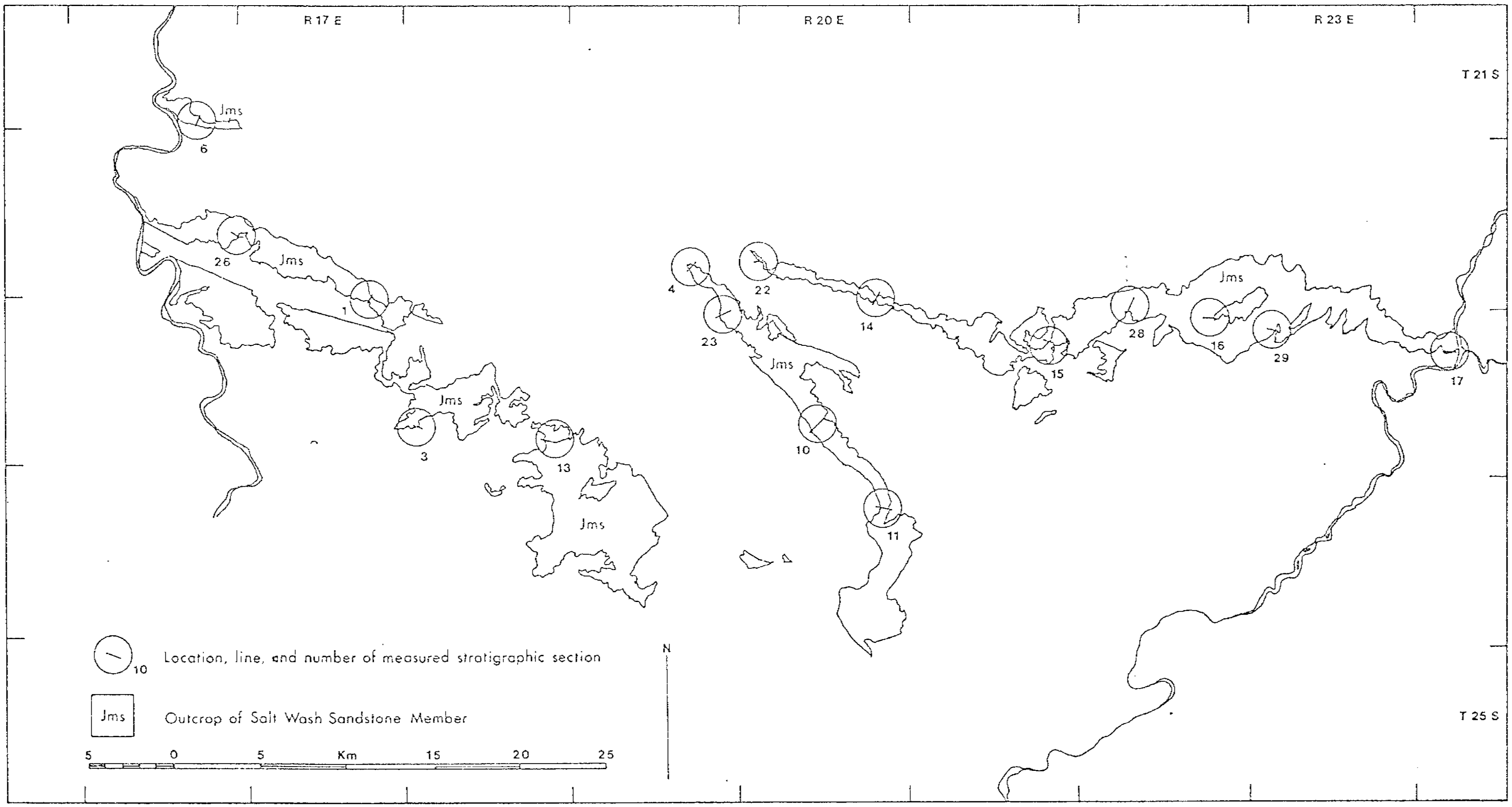


Figure 4—Map of study area showing location, horizontal traverse line, and number of measured stratigraphic sections.

Sections were measured using a Brunton compass and tape according to the methods of Kottlowski (1965).

Entrada Sandstone

Several stratigraphic sections in the central and eastern parts of the study area are based on the top of the Entrada Sandstone, which forms a broad white bench in outcrop. West of the Salt Valley anticline, the Entrada dips below the surface, beneath the Summerville Formation. Sections based on the Entrada Sandstone are Sections 4, 10, 11, 14, 16, 17, 22, and 29 (figure 4).

Summerville Formation

The Summerville Formation varies in thickness in the study area. In the western third, it consists of a sequence of thin to medium interbeds of mudstone, siltstone, and fine-grained sandstone, red brown to chocolate brown, 40-50 m thick, hosting gypsum in its upper part. It weathers as cliffs of relatively even resistance; gypsum plates and veins up to 6 cm wide stand out from the cliff in a boxwork pattern. The upper contact of the Summerville in this area is an angular unconformity of 2-4 degrees, overlain by either gypsum with interbedded siltstone, limestone, and red chert (welded chert of Peterson, 1978), or the limy sands and muds of the lower member of the Morrison Formation. Over the Salt Valley anticline and in the eastern third of the study area, the appearance of the Summerville is different. The unit is dark red brown, composed of thinly bedded mudstone, siltstone, and fine-grained sandstone, varying from 4 to 50 m thick. Locally the Summerville scours into the underlying Entrada Sandstone and contains clean white sandstones. No gypsum occurs in the Summerville in this area. The upper contact appears conformable but is probably a paraconformity. Measured sections based on the Entrada include the Summerville; sections based in the Summerville are Sections 1, 3, 6, 13, 15, and 26.

Lower member of the Morrison Formation

Lithology

The lower member consists dominantly of mudstones with thin sandstones, siltstones, limestones, and gypsum. One to several layers of detrital chert granules occur at and above the Summerville-Morrison contact. These layers are herein referred to as the chert-granule facies and are extensive over several thousand square kilometers (Peterson, 1977) including the study area. Each layer is one to several granules thick; grains are 3-10 mm apart and consist of subrounded to rounded green, gray, red, and pink chert. In the western part of the study area the granules occur in a matrix of silt and fine sand at the base of a thick gypsum layer just above the anguar unconformity between the Summerville Formation and the Morrison Formation. In the

Table 2

Location of measured stratigraphic sections by township, range, and map.

Section number	Location: Township and Range	Location: USGS quadrangle
1	NE1/4 S2 T23S R17E	Green River
3	S1/2 S36 T23S R17E	Crescent Junction
4	E1/2 S27 T22S R19E	Crescent Junction
6	SW1/4S34 T21S R16E	Green River
10	E1/2 S28 T23S R20E	Thompson
11	C S12 T23S R21E	Moab
13	SE1/4S26 T23S R18E	Crescent Junction
14	S1/2 S35 T22S R20E	Thompson
15	C S12 T23S R21E	Thompson
16	NE1/4 S2 T23S R22E	Cisco
17	S1/2 S5 T23S R24E	Cisco
22	E1/2 S30 T22S R20E	Crescent Junction
23	N1/2 S1 T23S R19E	Crescent Junction
26	SW1/4S19 T22S R17E	Green River
28	NE1/4 S5 T23S R22E	Thompson
29	W1/2 S5 T23S R23E	Cisco

Table 3

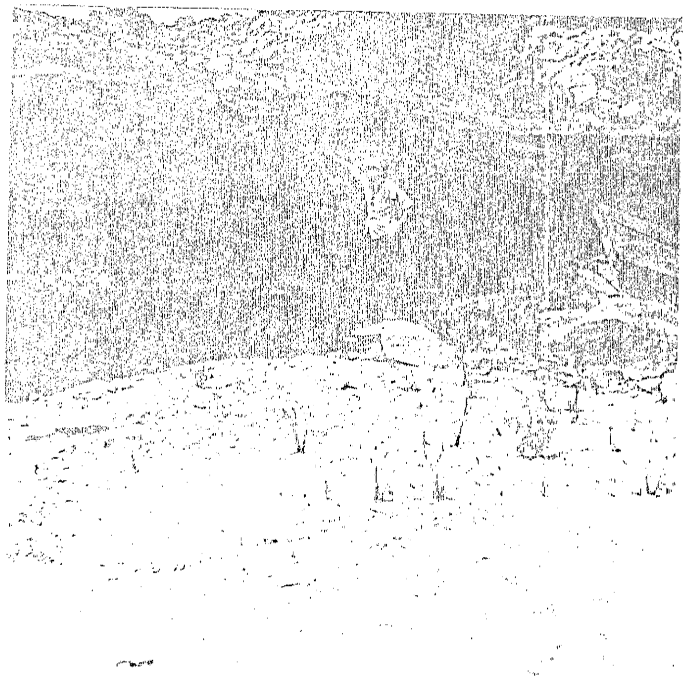
Thickness and percentage of sandstone in Salt Wash and lower members of the Morrison Formation in each measured stratigraphic section.

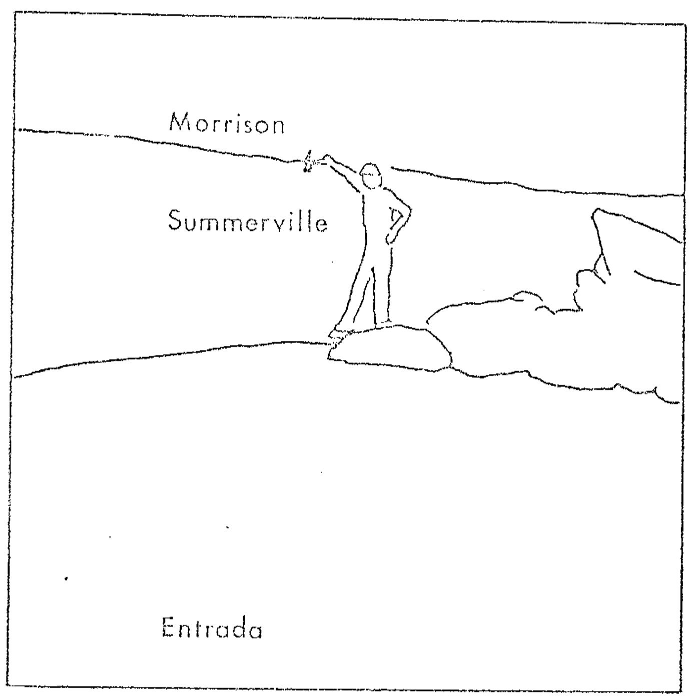
Section	Thickness in meters					Sandstone percentage				
number	1	2	3	4	5	1	2	3	4	5
1	59.5	40.8	33.3	7.5	18.7	50	68	72	48	6
3	92.1	71.8	44.1	27.7	20.3	54	69	70	68	10
4	84.6	68.7	27.0	41.7	15.9	50	60	60	59	5
6	62.9	58.4	30.3	28.1	4.5	59	76	99	50	1
10	90.5	65.5	35.2	30.3	25.0	46	63	77	47	2
11	70.5	50.2	27.8	22.4	20.3	45	60	76	40	9
13	97.0	79.4	45.1	34.3	17.6	52	64	78	46	6
14	78.0	64.3	25.4	38.9	13.7	34	37	44	32	22
15	74.7	46.0	26.6	19.4	28.6	36	54	71	31	8
16	63.4	47.3	31.3	16.0	16.1	49	62	50	84	7
17	66.5	48.4	23.1	25.3	18.1	50	58	90	26	26
22	58.4	36.0	27.3	8.7	22.4	40	60	72	24	7
23	-	59.7	26.1	29.5	-	-	50	69	33	-
26	44.2	26.7	12.1	14.6	17.5	25	36	41	29	1
28	64.2	45.9	34.2	11.7	17.3	38	46	49	38	15
29	64.0	51.4	35.3	16.1	12.6	38	44	48	35	13
Average	71.6	53.8	30.3	23.3	17.9	44	57	67	43	9

1=total undivided Salt Wash Sandstone Member; 2=total Salt Wash member; 3=upper portion of Salt Wash member; 4=lower portion of Salt Wash member; 5=lower member of Morrison Formation. Section 23 is incomplete.

eastern part of the study area, the granules occur in fine sand above the red-brown strata of the Summerville Formation. Wherever the granules occur with other established criteria, the base of the lowest granule layer marks the contact between the Summerville and the Morrison Formations (Peterson, 1978). South of the study area, in the Henry Mountains, the granule layer with its sandy matrix fills possible mud cracks in uppermost Summerville strata (Peterson, 1978).

The sandstones of the lower member are typically less than 60 cm thick. The most common sandstone shape is tabular, laterally extensive up to 500 m, with exceptional units traceable for hundreds of meters. The sands are fine grained and are well indurated with carbonate cement. Commonly the basal surface is erosional and is overlain by a zone of rip-up clasts of underlying mudstones. These sandstones host the chert-granule facies. Photograph 1 illustrates the relationships of the Entrada Sandstone, Summerville Formation, and Morrison Formation at Section 10; the Summerville here is approximately 2.3 m thick. The rock hammer is being held along the chert granule-bearing sandstone which marks the Summerville-Morrison contact, an angular unconformity with very low angle discordance at the base of the sandstone.





Photograph 1

Base of Stratigraphic Section 10, showing in ascending order the Entrada Sandstone, Summerville Formation, and lowermost Morrison Formation. Point of hammer is at the Morrison-Summerville contact.

Less commonly, sandstones in the lower member are lensoid, 20-80 cm thick, extending laterally up to 20 m but usually less than 10 m. The sandstones are typically fine-grained but with erosional lower contacts and mudstone rip-up clasts in coarse-grained granule-bearing sandstones near their lower contact. Siltstones occur gradationally above most sandstones.

Micritic and often sandy limestones are present in the lower member; these occur as thin, discontinuous bodies of tabular shape. Their thickness ranges from 10 to 70 cm thick; they extend laterally up to 30 m and exhibit a bumpy or nodular weathering surface and sharp, irregular upper and lower contacts. Occasional nodules and rare layers of chert and agate occur in the limestones.

Mudstone as used herein is a general term for a terrigenous sedimentary rock composed dominantly of material finer than silt but containing silt and fine sand in subordinate amounts. Weathering surfaces are usually slopes broken by thin ledges or more resistant material. Weathered material is usually short and bladed in shape and forms a loose rubbly talus slope; silt- and sand-rich mudstones sometimes weather as rounded or knobby surfaces, but this is more common in the stratigraphically higher Salt Wash member. Mudstones are very calcareous and may contain minute black specks which may be carbonaceous material. Mudstone dominates the lower member, making up 70-99 percent of the lithology.

In the western part of the study area (Sections 6 and 26), a layer of gypsum up to 7 m thick occurs. This material consists of structureless, granular gypsum with thin, irregular, interlayered limestone and siltstone.

The thickness of the lower member varies from 14 to 30 m. The average thickness (table 3) is approximately 19 m. The percentage of sandstone in the lower member ranges from 1 to 26 and averages 9 percent. Figure 5 is an isopachous and sandstone-percentage map of the lower member. Sections 23 and 28 are based in the lower member. Section 23 is incomplete; the base of the lower member is faulted out along the boundary fault of the Salt Valley graben. This section was not used in compiling the data for the lower member listed in table 3 and shown in figure 5. Section 28 is based at or slightly above the base of the lower member and includes virtually all of that unit.

In the western third of the study area, the isopachous contours are parallel to the sandstone-percentage contours such that the lower member thickens and is composed of more sand to the south and west. This area overlies a north-trending basin which contains a layer of unevenly stratified granular gypsum. This layer occurs in Section 6 and is up to 7 m thick. The distribution of gypsum shown in figure 5 was determined by field work west of the study area.

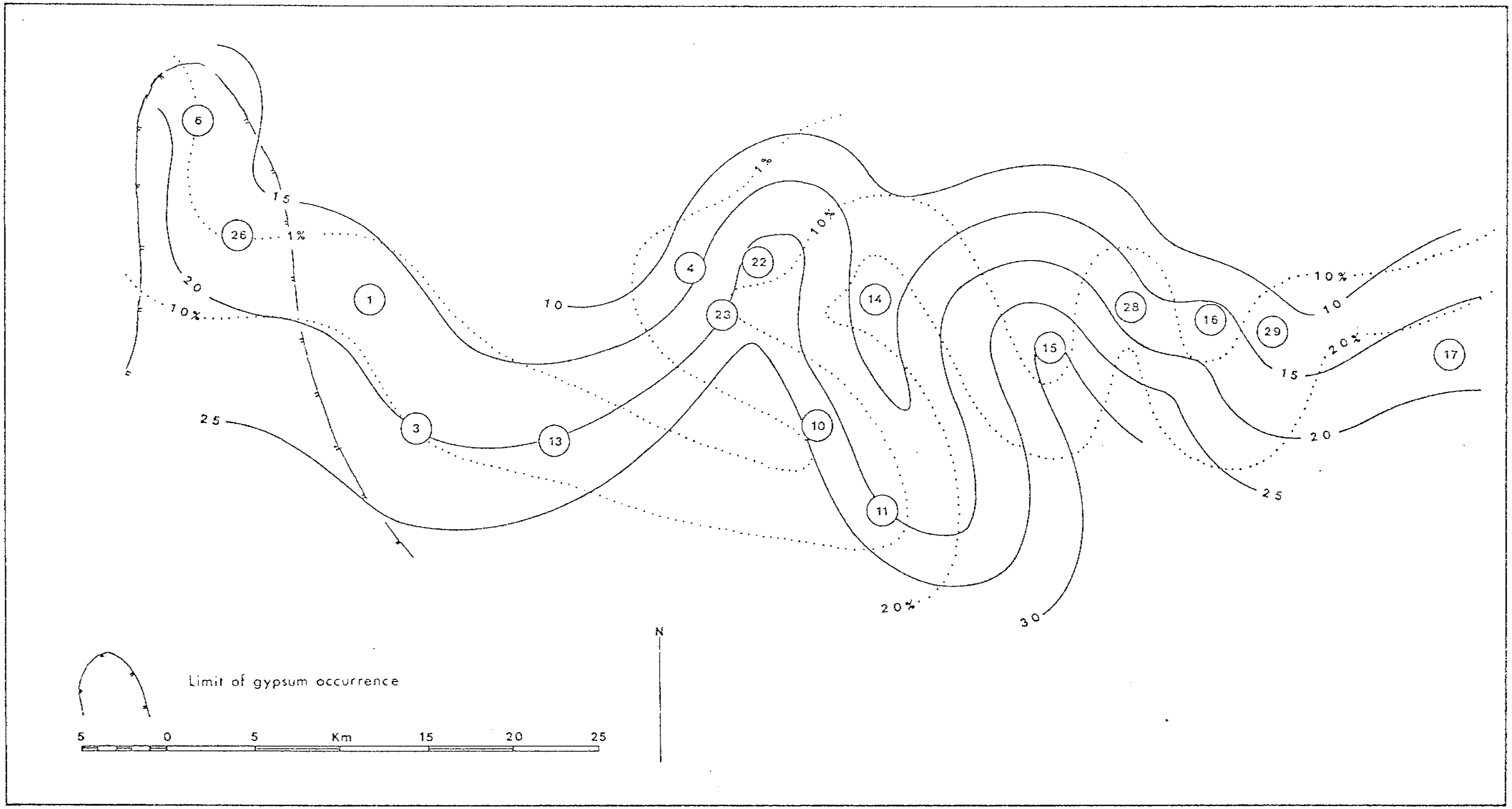


Figure 5—Map of study area showing isopach lines and percentage of sandstone in the lower member of the Morrison Formation. Isopach contour (————) interval is 5 meters; sandstone-percentage contour (·······) is drawn at 1, 10, and 20 percent. Numbered circles identify measured stratigraphic sections.

The central and eastern thirds of the study area are marked by a discordance of the thickness of the member and the abundance of sand within it. In the vicinity of the Salt Valley anticline and further to the east near the Yellow Cat dome, this discordance is most pronounced; thickness of the lower member is inversely related to percentage of sandstone.

Sedimentary structures of the lower member

Sedimentary structures were described in the field using the classification of McKee and Weir (1953), modified by Jacob (1970). Terminology of other authors is cited where used.

Sedimentary structures observed in sandstones of the lower member are:

1.) Small- to medium-scale trough-shaped sets of cross-laminations;

2.) Small- to medium-scale wedge-shaped sets of planar cross-laminations;

3.) Small- to medium-scale tabular-shaped sets of planar cross-laminations;

4.) Horizontal laminations;

5.) Undulatory laminations;

6.) Ripple marks;

7.) Structureless appearance;

8.) Casts of dissolved crystals.

Small-scale trough-shaped sets of cross-laminations occur at the tops and edges of thick sandstone units, within thin tabular sandstone bodies, and in lensoid and tabular silty sandstones. In some thick (greater than 1 m) sandstones, small-scale cross- laminations occur at irregular intervals averaging about 1.5 m in the vertical sequence, gradational with structures below and truncated by structures above. Laterally, these small-scale cross-laminations vanish into erosional surfaces or grade into structureless sandstone or sandy siltstone.

Component grains are fine sand to silt. Sets are low angle; individual laminations are normally graded. Thickness of laminations within sets ranges up to 3 mm.

Medium-scale trough-shaped sets of planar cross-laminations are less common in the sandstones of the lower member than small-scale sets. The width of individual sets ranges from 1 m to 3 m, and the sets are typically 20-70 cm thick. Individual laminations are usually several mm to 1 cm thick and exhibit normal grading internally, from medium-grained sand upward to fine-grained sand. The sets have gently curved lower surfaces. Laminations are low angle within the sets and tangential to the lower surface in axial section.

Small- to medium-scale wedge-shaped and tabular-shaped sets of planar cross-laminations occur in the study area but are uncommon; wedge-shaped sets are more abundant than tabular-shaped sets. Some sets of planar cross-laminations occur with trough cross-laminations in thick sandstones. These sets are 5-40 cm thick and are composed of normally graded laminations. Other sets, tabular in shape, occur in thinner sandstones. Some sandstones consist of a single set; laminations in these sets are usually inclined 15-25 degrees to the lower bounding surface.

Horizontal laminations occur in some thin sandstones of the lower member but are uncommon. Sets are typically poorly developed and may merge laterally and vertically into undulatory laminations or structureless sandstone. Component grains are fine sand to silt; laminations are normally graded.

Undulatory laminations less than 5 mm thick occur throughout the sandstones of the lower memver, typically in sandstones less than 50 cm thick. Undulatory lamination may be associated with small-scale cross-lamination but most commonly occurs in otherwise structureless sandstones. Discontinuous undulatory lamination occurs as low amplitude sinusoidal layers, generally less than 30 cm in lateral extent. Continuous undulatory lamination extends laterally within sets which locally are tabular in shape.

Preserved ripple bedforms are uncommon in the study area but do occur in the Summerville Formation and in the lower member of the Morrison Formation. Crestlines of these ripple marks are straight to slightly sinuous. Calculation of the ripple index (ripple length/ripple height) and ripple symmetry index (horizontal projection of stoss side/horizontal projection of lee side; Reineck and Singh, 1975) for ripples in a sandy silt unit hosting crystal casts (Section 17, unit 4) indicates that these are asymmetrical wave ripples.

Sandstones with a structureless appearance are common throughout the lower member. These units occur as thin, irregular bodies of fine sand and silt which alternately pinch and swell within a mudstone layer. Basal contacts are generally erosional. Undulatory stratification appears locally in some units.

Casts of fine sand in molds of dissolved crystals occur in the lower member of the Morrison Formation in unit 4 of Section 17. Two separate types of crystal casts are preserved.

One type consists of parts of cubes, 2-5 mm on a side, in a layer of fine-grained sandstone 1 cm thick. These are probably casts of halite.

The second type of cast occurs on the base of a layer, 4-5 cm thick, of structureless fine sand with a 50 mm layer of rippled silty sand at the top. The casts are ovoid, 1-2 cm long and 40-50 cm wide, with a granular surface, and an uneven crack or split along the long dimension. There is no preferred linear orientation within the plane of the sand layer of the long axes of the casts.

These casts are tentatively interpreted to be casts of gypsum crystals (Peterson, 1979, personal communication). The gypsum-cast layer occurs below the salt-cast layer in unit 4 of Section 17. This unit is the basal sand of the lower member in this part of the study area.

Mudstones in the lower member generally show no definite structure. Poorly preserved horizontal laminations occur uncommonly; laminations are less than 1 mm in thickness.

Limestones exhibit no primary structures in the lower member. Stylolites occur in some limestone units.

Gypsum in the western part of the study area occurs as a granular, structureless layer containing interlayered fine sandstone, siltstone, mudstone, and limestone.

Analysis of paleocurrents

Paleocurrent directions were measured with a Brunton compass by the four-gradient method. A standard of 25 measurements was set for each rock unit exhibiting directional structures; however, due to poor exposure and inadequate structural development in some units, this goal was not always achieved. Detailed descriptions of the method and measured structures are included in Appendix D. Paleocurrent distributions for individual rock units are displayed in Plates 1 and 2.

Very few suitable exposures and structures occur in the lower member from which paleocurrents can be measured. Sections 1 and 14 exhibit current distributions of nearly 360 degrees; dominant directions are N, N 60 E, and S 30 W, compiled from very few observations. Based on this limited data, the paleocurrents are assumed to reflect deposition in minor or intermittant streams. Source areas and direction of overall flow cannot be determined.

Lower portion, Salt Wash Member of the Morrison Formation

The Salt Wash member in the study area consists of three major and two minor rock types: lensoid sandstones, tabular sandstones, mudstones, siltstones, and limestones.

The field relationships of these rock types suggest two general styles of deposition which more or less correspond to the lower and upper portions of the member. These styles are recognized by: paleocurrent directions, morphology of sandstone bodies, and relative abundance of sandstone. The criteria for distinguishing the upper and lower portions of the member are changes in the dominant character of the three factors rather than a quantitative formula. However, following subdivision of the Salt Wash member into the lower and upper portions based on changes in dominant characteristics, it is clear that the sandstone percentage in the two portions is quantitatively different (table 3). The lower portion of the Salt Wash member averages 43 percent sand, while the upper portion averages 67 percent. Both portions, however, contain both high and low percentages. The average difference is 24 percent and ranges from 1 to 64 percent.

Percentages and morphology of sandstones reflect local conditions and it must be stressed that even short lateral distances will considerably alter these factors. However, enough consistency exists between sections that general trends can be used for this study.

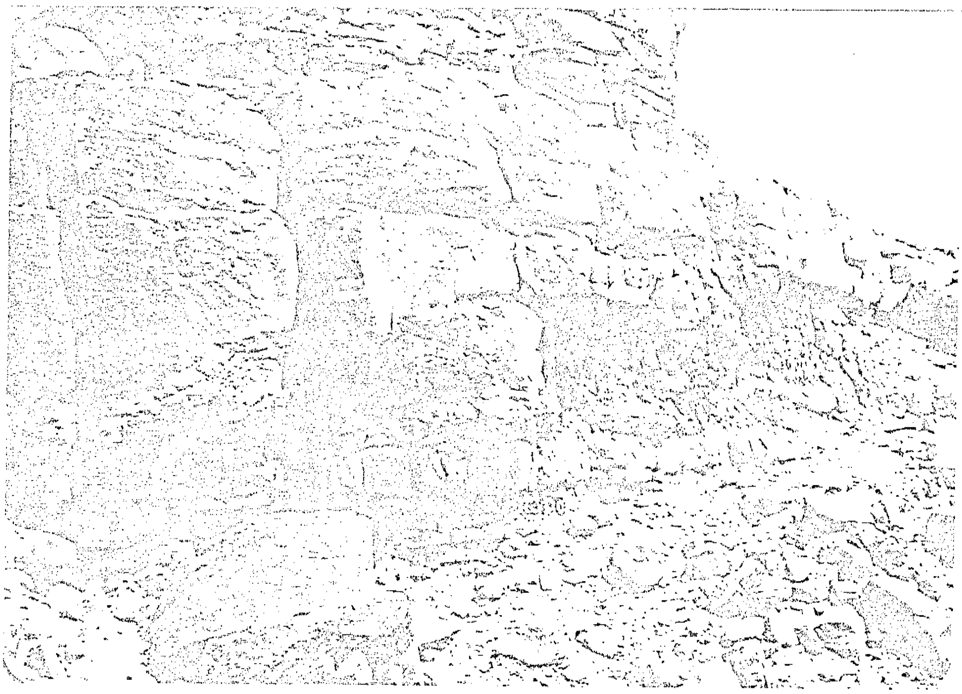
The division of the Salt Wash member into upper and lower portions is shown in plates 1 and 2.

Lithology

The lower portion of the Salt Wash member contains (with some exceptions) more mudstone than sandstone. The base of the Salt Wash member is placed at the base of the lowest sandstone which has an erosional base, is 1 m or more thick, exhibits medium-scale sets of cross-laminations, and extends more than 20 m laterally. This arbitrary delineation controls the thickness of the rocks of both the lower member and the Salt Wash member, but is considered valid in separating differing environments of deposition while allowing transitional environments to be grouped together.

The sandstones in the lower portion of the Salt Wash member are lensoid and tabular. Lensoid sandstones dominate in some sections; tabular sandstones are more common in others. Overall, lensoid sandstones are more abundant. Transitional forms are less common than either lensoid or tabular.

Lensoid sandstones are 50 cm to 15 m thick and average about 3 m. Lateral extent of the sandstones may be greater than 60 m in cross section and hundreds of meters along depositional strike. Perpendicular to strike, these sandstones pinch out and grade into siltstones and mudstones laterally and vertically (photograph 2). On the average, sandstones are medium grained but range from fine grained to



Photograph 2

Rock unit 28 of Stratigraphic Section 3, showing typical relationship of sandstone, siltstone, and mudstone in lower portion of the Salt Wash member.

coarse grained. Basal surfaces are erosional and are commonly overlain by a conglomeratic interval of rip-up clasts and granules.

Tabular and transitional sandstones are fine- to medium-grained and maintain a relatively constant thickness (10-80 cm) over their lateral extent. Tops of these sands are gradational into siltstone and mudstone; basal surfaces are typically erosional and commonly are overlain by a conglomeratic interval.

Mudstone with thinly interbedded siltstone and fine-grained sandstone averages 57 percent of the lithology in the lower portion of the Salt Wash member. Mudstones are typically maroon to red gray and weather gray green to pale brown. Green rinds and border zones along sandstone contacts occur throughout the study area.

Weathering surfaces are usually slopes. Knobby or nodular surfaces occur where the mudstone is exposed to weathering beneath overhanging sandstones. Layers or zones of lime concretions and hematite nodules occur.

Rare, thin discontinuous limestones occur in the lower portion of the Salt Wash member. They are less than 20 cm thick and are composed of sandy and silty micrite. Upper and lower surfaces are very irregular, and weathering produces a bumpy appearance. Laterally these limestones pinch out in mudstone.

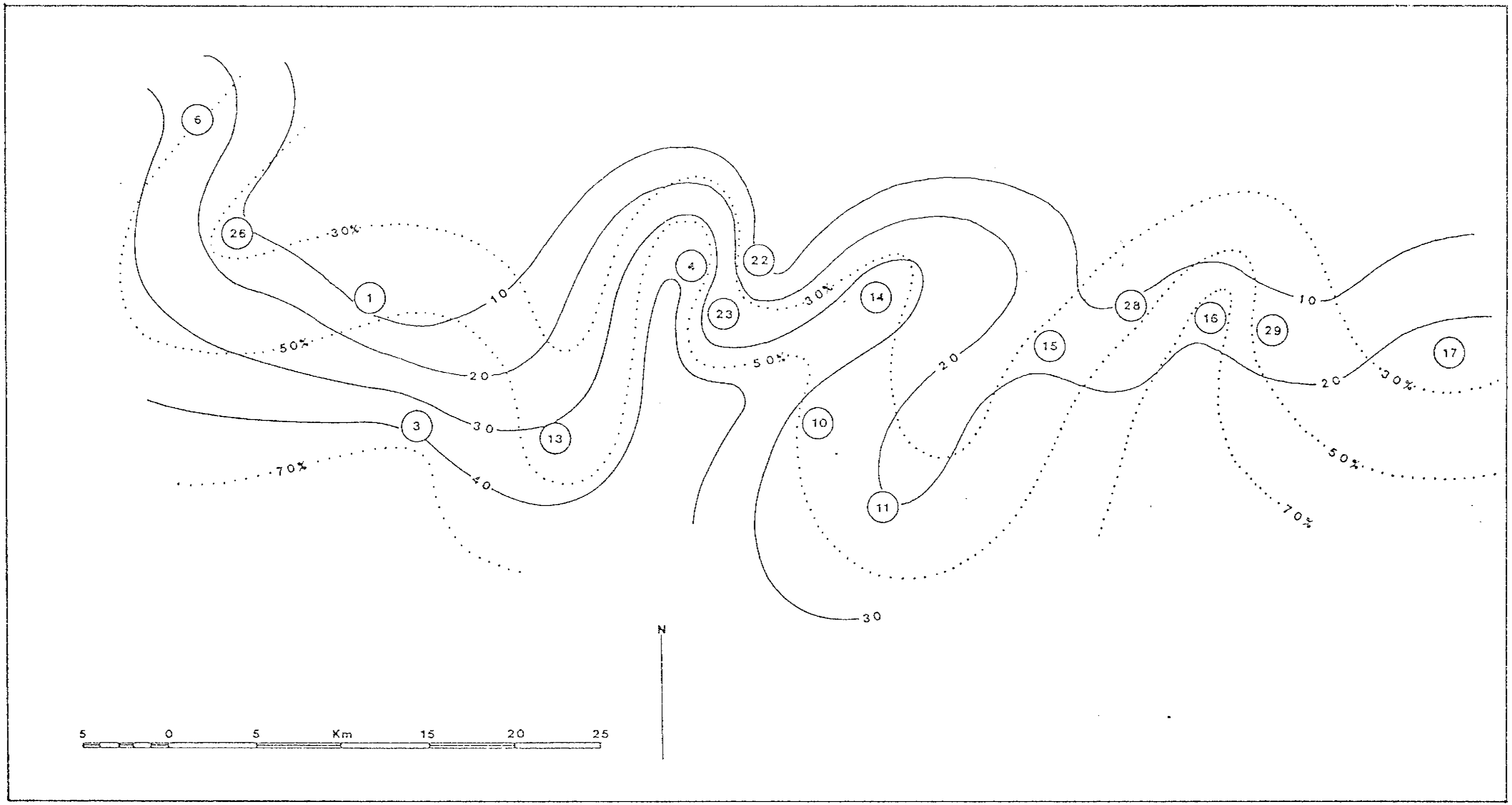


Figure 6—Map of study area showing isopach lines and percentage of sandstone in the lower portion of the Salt Wash member of the Morrison Formation. Isopach contour (————) interval is 10 meters; sandstone-percentage contour (·······) is drawn at 30, 50, and 70 percent. Numbered circles identify measured stratigraphic sections.

Discontinuous zones of lime nodules and concretions occur within mudstones and weather out as gray to purple irregular masses.

Figure 6 is an isopachous and sandstone-percentage map of the lower portion of the Salt Wash member. Percentage of sandstone increases in the western and eastern thirds of the study area, indicating a local dominance of sand deposition. Over the Salt Valley anticline, the sandstone percentage follows the isopach contours. However, the strong variation in thickness and percentage of sandstone in this area indicates some disturbance in the paleotopography. A high area is indicated at Sections 22 and 23, and at the area bounded by Sections 10, 11, 14, and 15. The Salt Wash deposits show anomalous thinning in both areas.

Sedimentary structures

Sedimentary structures observed in sandstones of the lower portion of the Salt Wash member are:

1.) Small- to medium-scale trough-shaped sets of cross-laminations;

2.) Small- to medium-scale wedge-shaped sets of planar cross-laminations;

3.) Small- to medium-scale tabular-shaped sets of planar cross-laminations;

4.) Horizontal laminations;

5.) Parting lineations;

6.) Sand rills;

7.) Undulatory laminations;

8.) Climbing ripples;

9.) Structureless appearance;

10.) Soft-sediment deformation.

Trough-shaped sets of cross-laminations occur in the sandstones of the lower portion of the Salt Wash member generally in the same manner as in the lower member. Medium-scale sets are most common. These structures occur in the thicker (1 m +) sandstones and are typically composed of fine to coarse sand with local conglomeratic phases of granules, pebbles, and cobbles. Cosets occur in multistory sandstones in which the basal sets are composed of coarser material than the upper sets (photograph 3), both within the cosets and on a larger scale within the entire sandstone body. Basal conglomerates of silt and mud rip-up clasts and occasional lime clasts exhibit medium-scale trough cross-lamination and stratification which is generally broader and shallower than that developed higher in the unit.

Photograph 3

Rock unit 31 of Stratigraphic Section 3, showing structure of multistory sandstone unit.

Wedge-shaped and tabular-shaped sets of planar cross-lamination are more common in the lower portion of the Salt Wash member than in the lower member; medium-scale sets occur in greater abundance than small-scale sets. Planar cross-lamination occurs in close association with trough-shaped sets of cross-lamination.

Horizontal laminations, 3 mm to 1 cm thick and laterally extensive up to 5 m, occur in sandstones of the lower portion of the Salt Wash member. Sets vary in thickness up to 2 m and have erosional lower surfaces. Laminations are horizontal to slightly dipping and are parallel to the lower bounding surface. Individual laminations are normally graded from medium to fine sand.

Horizontal laminations occur at the base, within the body, and at the top (photograph 4) of some sandstones. In thick sandstones, horizontally stratified sets occur as intervals of 1-3 m thickness. Laterally, horizontally stratified sets merge with sets of medium-scale trough cross-laminations; laminations curve, concave upward, and are truncated by adjacent overlying sets of trough cross-laminations. Vertically, they are bounded by small- to medium-scale trough sets when they occur within the sandstone body, or grade into structureless sandstone or small-scale sets of cross-laminations where they occur at the top of a sandstone unit.

Photograph 4

Rock unit 20 of Stratigraphic Section 16, showing horizontal laminations at top of sandstone.

Parting lineations are parallel ridges of sand, only several grains high which occur on surface of horizontal laminations. These structures are termed current lineations by some workers (Barns and others, 1975; Reineck and Singh, 1975), and are considered to be primary sedimentary structures.

Sand rills--As termed here, sand rills are linear accumulations of sand several cm in height and width, which occur on surfaces of horizontal stratification. Sand rills of Reineck and Singh (1975) are erosional structures and are not related to the structures under discussion.

Sand rills are extremely rare in the study area. Their origin is not clearly understood, but may be similar to that which produces primary current lineation--a streamlining effect parallel to the stream flow (Harms and others, 1975; Reineck and Singh, 1975). Supporting this hypothesis is the concordance between current directions measured from trough cross-laminations and current lineations with the elongation of sand rills in the same strata. These structures may be analogous to sand strips and seif dunes, found in desert environments; in these areas, alternating, subparallel wind currents sweep sand grains into narrow, elongated ridges separated by broad flat zones. These structures are much larger than sand rills, but the difference in scale may reflect the differing transporting capacities of the media involved.

Undulatory laminations in sandstones of the lower portion of the Salt Wash member share the same form and occurrence as in sandstones of the lower member.

Climbing ripples are uncommon in the Salt Wash member. They generally occur at the lateral extremes of lensoid sandstone units or within a thin sandstone unit with an erosional base. Individual ripples are not more than 5 cm in amplitude and have wavelengths up to 8 cm. The sequence of climbing ripples is less than 30 cm thick and grades upward from fine sandstone to siltstone. Less commonly, climbing-ripple units are overlain gradationally by small-scale trough cross-strata.

Two types of sandstones with structureless appearance occur in the lower portion of the Salt Wash member. One type occurs below thick, multistory sandstone units, as a series of thin sands interlayered with mudstone and silty mudstone. The structureless sands are generally coextensive with overlying thick sandstones; this occurrence is shown in photograph 5.

The second type of structureless sandstone occurs at the tops of thick sandstone units and sometimes occupies the entire thickness of thinner sands. It is characterized by a pockmarked and extremely irregular weathering surface. Apparent remnants of primary sedimentary structures occur in scattered patches.

Photograph 5

Rock unit 17 of Stratigraphic Section 17, showing relationship of sandstone units.

This second type of structureless sandstone is herein interpreted to be due to bioturbation of previously deposited sands; burrowing and reworking of the sand by insect and/or invertebrate faunas as well as possible disturbance by plant roots has destroyed most of any pre-existing primary structure. This feature is most abundant in horizontally laminated fine- and medium-grained sandstones.

Deformation of primary sedimentary structures occurs in many of the sandstones of the Salt Wash member. These deformation structures are related to two depositional styles. The most common style consists of overturned trough cross-lamination in sandstones overlain by other cross-laminated sandstones. These structures are interpreted to result from a combination of drag (shear stress) on already deposited sediments, produced by friction of the current flow above them, and liquefaction of the sediments, produced by release or escape of water trapped when the sediment was deposited. The laminations thus deformed are twisted, forced up into recumbent U-shaped segments, or oversteepened into high-angle or overturned stratification. The direction of oversteepening or overturning is assumed to be the direction of current flow, and while this was not used as a paleocurrent indicator, a good degree of agreement was noted between these directions and the paleocurrent directions measured from trough cross-strata and current lineations in units directly overlying the deformed strata.

The other, less common type of deformational structure occurs in sandstones, thicker than approximately 1 m, overlying mudstones. These structures are load casts, sand protuberances into the underlying mud, up to about 15 cm deep, and ball-and-pillow structures, somewhat larger masses of sand up to about 75 cm across, which detached from the overlying sand and slumped into the underlying mud. These structures are interpreted to result from gravitational instability produced by rapid sedimentation of sand on a substrate of soft mud.

Flute casts are the most common sole markings preserved on the basal surfaces of the sandstones. Two very general types occur. The most prevalent type is deep and narrow with a bulbous appearance, up to 20 cm long and 4 cm deep and wide; less common is a type with a triangular shape, wide and rather shallow, up to 10 cm long and 8 cm wide.

Larger scour structures are elongate drumlin-shaped features, tapering at both ends, up to 1 m long and 20 cm deep.

These features occur on the base of sandstones which were deposited over mudstones, and indicate partial erosional removal of the underlying fine material. The majority of the thick (greater than 1 m) sandstones do not exhibit sole markings; the basal surfaces overlain by a thin zone of sand are scour surfaces pocked by rip-up clasts.

Rarely, the base of a sandstone will exhibit small tubular casts that resemble meandering horizontal burrows; This may indicate deposition of the sand with no erosion of the substrate in that particular area.

Mudstones show poorly preserved structure in some outcrops, and appear structureless in others. Horizontal laminations range in thickness from less than 1 mm to approximately 2 mm. Areas directly beneath thick sandstone units exhibit laminations which are distorted, convoluted, and truncated by the overlying sandstones. Mudstones above and between sandstones typically appear structureless or exhibit undisturbed horizontal laminations.

Analysis of paleocurrents

The lower portion of the Salt Wash member contains the lowermost occurrence of thick, laterally extensive sandstones with erosional bases. Paleocurrents from these units are unimodal with few exceptions (figure 7). The dominant trend is N 5°E to N 85°E. From west to east across the study area, currents tend to shift from northerly to easterly. Paleocurrents of thin sand units do not conform universally to this trend.

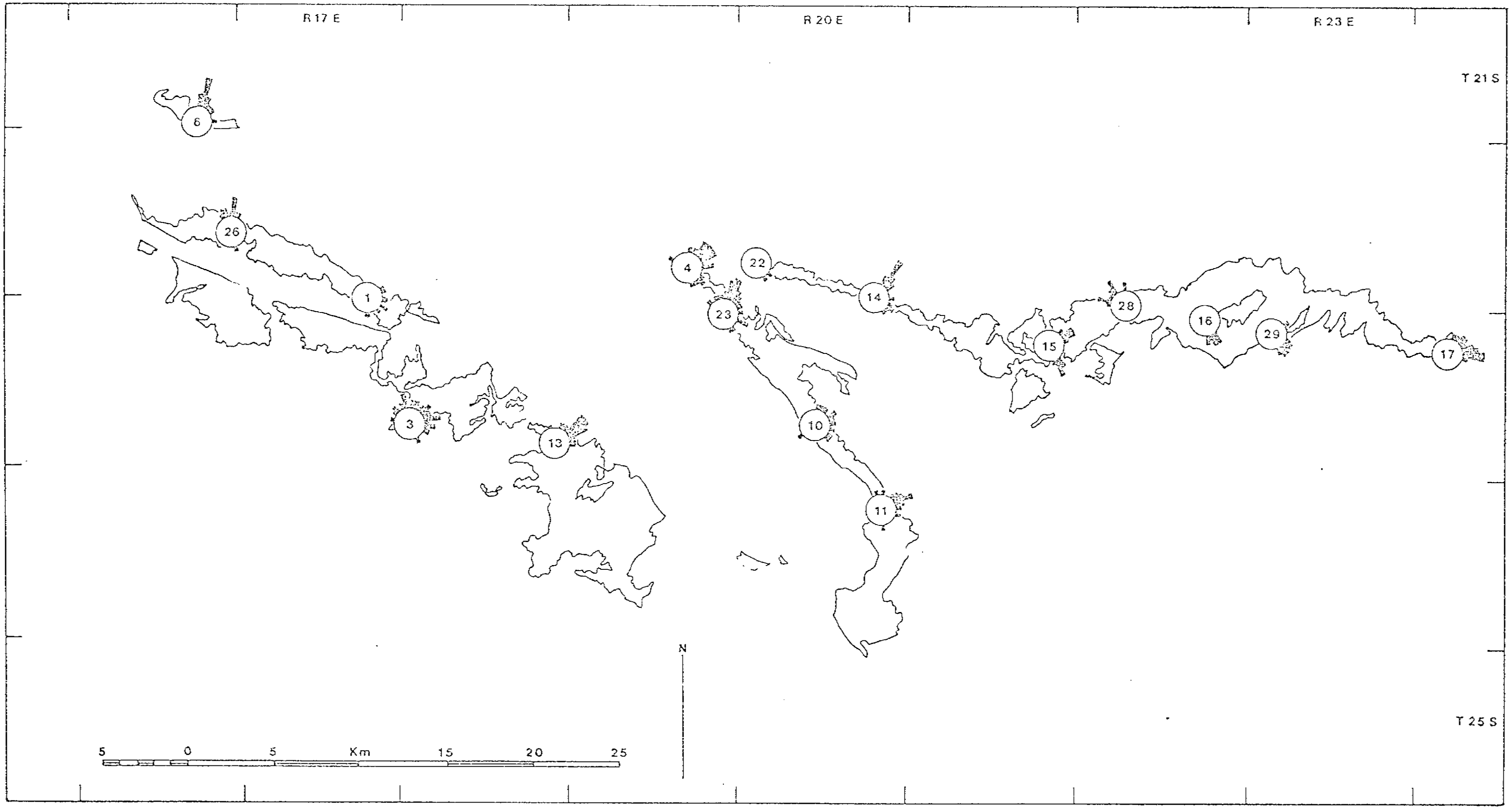


Figure 7—Map of study area showing distribution of paleocurrent directions for the lower portion of the Salt Wash member of the Morrison Formation. Rose diagrams are composites for the lower portion of the member for each measured stratigraphic section (numbered circles). Outcrop of the Salt Wash Member is shown for reference.

Section 16, in the eastern part of the study area, contains a laterally extensive stacked-channel sandstone, 5.5 m thick, which overlies and locally scours the top of a similar unit 9 m thick. Paleocurrents obtained from small-scale trough sets in sandy siltstone at the top of the upper sandstone exhibit a strong S 50°E trend. No paleocurrent measurements were taken from the body of the sandstones exposed only as a formidable cliff; current lineations exposed on shallow trough surfaces at the base of the combined sequence also trend S 50°E. These basal lineations appear to be at a considerable angle to the observed elongation of the sand units, as are the directions of the troughs at the top of the upper unit. Section 29, about 5 km east of Section 16, exhibits this same southeast trend in thin sandstones. Similar units in Section 28, 7 km west of Section 16, show an exactly opposite trend. These sandstones, and the uppermost sandy siltstone at Section 16, may be high-water overbank deposits radiating away from a major channel which flowed to the northeast at Section 16. The orientation of the current lineations at the base of the unit is probably a reflection of lateral flow during the scouring and filling of the initial channel-formation phase.

In the western part of the study area, the major sand body in the lower portion of the Salt Wash member is 11 m thick. A series of lenses 1-2 m thick and 3-5 m wide with erosional bases forms a stacked-channel body which exhibits a polymodal current distribution ranging through 310 degrees. Maxima are at N 70° W, N 30° W, N 20° E, and N 70° E.

This wide variation in paleocurrent distribution is unique in the lower part of the Salt Wash member in the study area; polymodal distributions occur in the upper part of the member, but are infrequent and show less variance.

The variability of the paleocurrent distribution may be deceptive. There are two sets of maxima, each at approximate right angles, and one such set is dominant in the distribution. The positions of the maxima may be the result of fluctuations of current in a stream of low sinuosity undergoing some lateral accretion or avulsion, rather than deposition in a high-sinuosity stream of highly variable current direction (Allen, 1967).

In the central third of the study area containing the Salt Valley anticline, paleocurrents shift from north to east. Sections 10 and 11, along the southwest flank, trend to the east, while Sections 4 and 23 at the nose of the structure and Section 14 along the north flank trend north. The pattern is one of divergence or deflection of the streams around a topographic high in the area of the anticline.

The pattern of paleocurrent distribution matches Selley's (1968) radiating piedmont-fan model in the eastern part of the study area; in the western part, the pattern is very locally similar to his centripedal basin-fill model, indicating convergent streams flowing into a local depression.

In general, the paleocurrents of the lower part of the Salt Wash member indicate a system of major channels of low sinuosity and limited lateral migration, alternating with and surrounded by small channels and floodplain deposits. Dominant major-channel flow was to the north in the western third of the study area, north to east in the central part over the Salt Valley anticline, and east in the eastern third.

Upper portion of the Salt Wash member of the Morrison Formation

Lithology

The upper portion of the Salt Wash member is characterized by a greater percentage of sandstone than mudstone, with some exceptions. The range of sandstone percentage is 41 to 99, averaging 67 (table 3).

The sandstones in the upper portion of the Salt Wash member are similar to those of the lower portion in form, but differ in abundance. Lensoid sandstones are dominant, and multistory sandstones are the most common form of lensoid sandstones. These units range up to 21 m thick and tend to coalesce locally in the uppermost part of the upper portion of the Salt Wash member to form laterally extensive, thick sandstone units that stand out as very prominent cliffs and broad benches. Thinner lensoid and tabular sands are dominant in some sections. Conglomerates of granules to pebbles occur near the top of the Salt Wash member and commonly form the top sandstone of the measured section.

Thin tabular sandstones occur locally and are similar in form to those in the lower portion of the Salt Wash member.

Mudstones average 33 percent of the sediment in the upper part of the Salt Wash member, and in most sections occur in one to several layers between thick multistory sandstones. The mudstones contain thin tabular and lensoid sandstones and infrequent zones of lime concretions. They tend to be carbonaceous, containing local accumulations of plant debris up to 10 percent of the volume of the mudstone. Most mudstones are red brown; carbonaceous mudstones are usually gray green. Both types weather gray to pale brown.

One limestone layer, 20 cm thick and discontinuous, occurs in the mudstone of the upper part of the Salt Wash member in Section 29 (unit 20).

Figure 8 is an isopachous and sandstone-percentage map of the upper portion of the Salt Wash member. The sandstone-percentage contours very roughly parallel the isopachous contours but diverge strongly at Section 6 in the western third of the study area and Sections 16, 28, and 29 in the eastern third. The upper portion of the Salt Wash

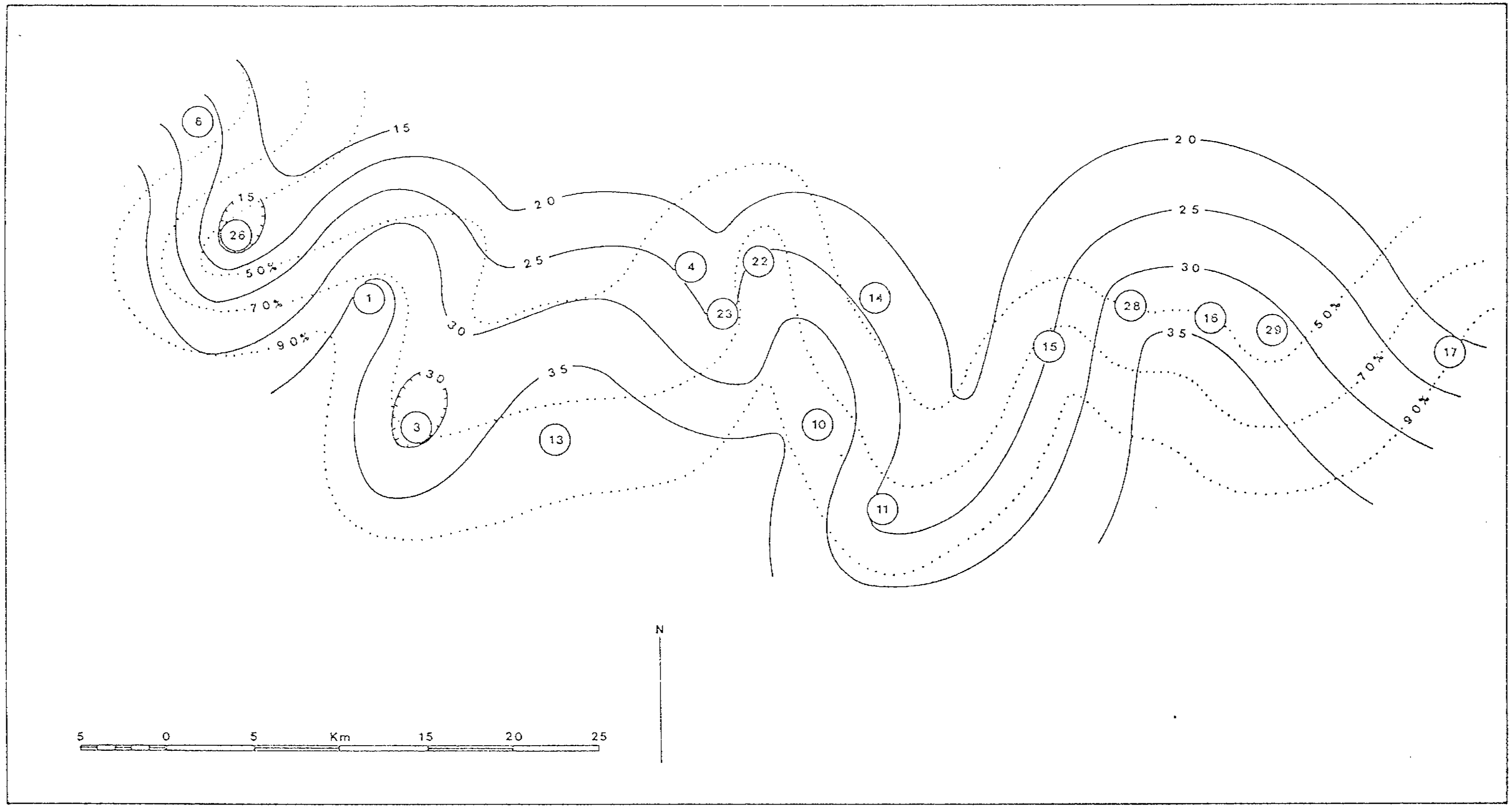


Figure 8—Map of study area showing isopach lines and percentage of sandstone in the upper portion of the Salt Wash member of the Morrison Formation. Isopach contour (————) interval is 5 meters; sandstone-percentage contour (······) is drawn at 50, 70, and 90 percent. Numbered circles identify measured stratigraphic sections.

member also thins over the Salt Valley anticline, but this pattern is not as strongly developed as in the lower portion of the member. Only a vague pattern remains of the small topographic high at Sections 22 and 23 which is evident in figure 6. The abrupt decrease in sandstone percentage in the east indicates a higher area to the north which caused deflection of the streams to the east.

Sedimentary structures

Sedimentary structures observed in sandstones of the upper portion of the Salt Wash member are:

1.) Small- to large-scale trough-shaped sets of cross-laminations;

2.) Small- to medium-scale wedge-shaped sets of planar cross-laminations;

3.) Small- to medium-scale tabular-shaped sets of planar cross-laminations;

4.) Horizontal laminations;

5.) Parting lineations;

6.) Sand rills;

7.) Undulatory laminations;

8.) Structureless appearance;

9.) Soft-sediment deformation.

Sedimentary strucutres observed in the upper portion of the Salt Wash member are generally the same as those of the lower portion of the member. Differences are in relative abundance rather than in form. Medium-scale trough-shaped sets of cross-laminations are the most common sedimentary structure; horizontal laminations are next in abundance, followed by wedge-shaped and tabular-shaped sets of planar cross-laminations. Other structures occur as described for the lower portion of the member.

Mudstones exhibit horizontal laminations in some exposures; convoluted laminations occur beneath thick sandstones as in the lower portion of the member.

Analysis of paleocurrents

Paleocurrent directions measured in rocks of the upper part of the Salt Wash member exhibit both unimodal and bimodal distributions (figure 9). Bimodal distributions are limited to thick sandstone units composed of multistory deposits, while unimodal distributions occur both in these deposits and in thinner sands. Directions of maxima range from N 10°W to S 70°E with a dominant trend of N 60°E to N 80°E. No well-defined shift in direction occurs in relation to section location. The central part of the study area,

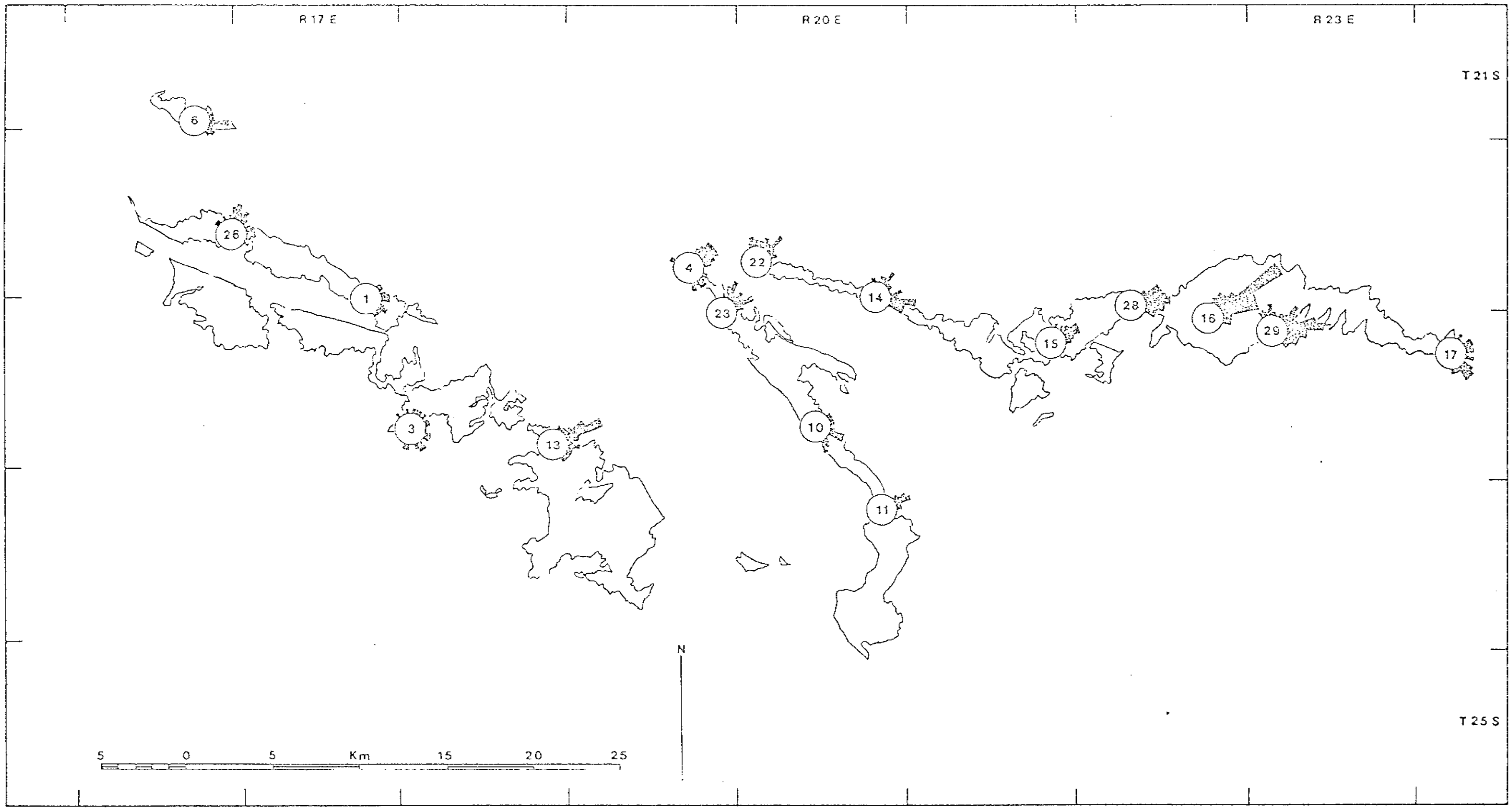


Figure 9—Map of study area showing distribution of paleocurrent direction for the upper portion of the Salt Wash member of the Morrison Formation. Rose diagrams are composites for the upper portion of the member for each measured stratigraphic section (numbered circles). Outcrop of the Salt Wash Sandstone Member is shown for reference.

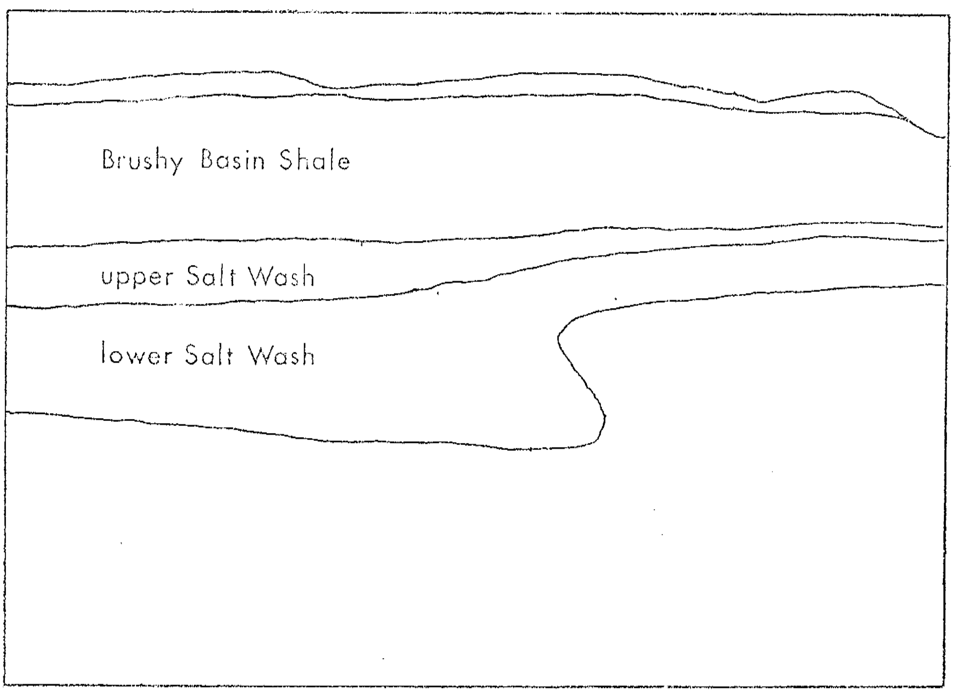
however, exhibits a localized deviation from the northeast and east trends of the paleocurrents in the adjacent deposits. Sections 4, 22, and 23 show a northerly paleocurrent trend over the present nose of the anticline. Section 10, on the southwest flank of the structure, shows a strong southeast direction which is not shared by Section 11, 7 km further to the southeast.

Bimodal distributions have modes which average 80 degrees apart. At Sections 4, 10, and 14, the bimodality results fron lateral changes in the dominant paleocurrents along depositional strike. The bimodal distribution at Section 29 results from discordance between rib- and-furrow structures and current lineations on horizontal laminations in the same general area. Ribs-and-furrows trend east while current lineations trend north. This may indicate a divergence between current flow and lateral-accretion strata (Allen, 1970).

In general, the paleocurrents of the upper part of the Salt Wash member indicate deposition in well-established channels of low local sinuosity. Patterns match Selley's (1968) radiating piedmont-fan model; deviations are due to a high spot in the area of the Salt Valley anticline. Vertical variation of currents in major-channel deposits is less than 80 degrees. This indicates strong control of the streams by gradient; depositional slope was to the northeast and was steep enough to prevent development of meandering streams.

Morphology of paleostreams of the Salt Wash member

The nature of the streams can be inferred from the combined evidence of lithology and sedimentary structures discussed above. The depositional system of the Salt Wash member in the study area was classified by Craig and others (1955) as the sandstone and mudstone facies, near the transition to the claystone and lenticular-sandstone facies. Young (1978) placed the boundary between the humid-region alluvial-fan system, which encompasses the apical area of the fan, and the more distal braided-channel system across the northern edge of the study area; the meanderbelt system was placed 20-80 km farther north. These classifications of the streams of the Salt Wash member are based on large-scale and regional studies. Within the local systems of the study area, the streams do not fit the models of either meandering or braided streams (Leopold and Wolman, 1957) but share features of both. A closer fit is possible using the models proposed by Moody-Stuart (1966). His low-sinuosity/ low-braid-index stream model fits the sedimentary structures and lithologic characteristics of the lower portion of the Salt Wash member; the upward changes in the deposits of the Salt Wash member match the changes expected with an increase in the braid index of the streams (though this quantity cannot be measured in vertical sections, it can be inferred from the nature of the deposits). This results in a



Photograph 6

Morrison Formation viewed from top of Stratigraphic Section 17, at confluence of Dolores and Colorado Rivers, showing typical morphology and relative proportions of sandstones within the Salt Wash member; view to east.

predominance of channel deposits over floodplain deposits, noted by Doeglas (1962) and Smith (1970, 1974) in studies of braided streams. The streams of the lower part of the Salt Wash member are interpreted to be Moody-Stuart's (1966) low-sinuosity/low-braid- index streams. The sandstones of the top of the Salt Wash member may locally be the result of true braided-stream deposition (Leopold and Wolman, 1957). Photograph 6 shows the two general types of stream deposits in the Salt Wash member; the lower is characterized by a concave-up lower surface and pinches laterally into surrounding floodplain deposits. This is the low-sinuosity/low-braid stream of Moody-Stuart. The upper stream deposits are tabular and thick; floodplain deposits are minor or absent. This is the low-sinuosity/high-braid stream.

Brushy Basin Shale Member of the Morrison Formation

The Brushy Basin Shale Member is a sequence of multicolored shales and siltstones with local limestones and lenses of conglomeratic sandstone and sandy pebble conglomerate. The Brushy Basin conformably overlies the Salt Wash Sandstone Member, typically with a thin gradational interval between a bench of sandstones of the uppermost Salt Wash Sandstone Member and silty shales of the Brushy Basin Shale Member (photograph 7). The Brushy Basin weathers as soft rounded slopes strewn with blocks of conglomeratic sandstone from the lenses within the Brushy

Photograph 7

Top of Stratigraphic Section 22, showing typical contact between Salt Wash member (bench) and Brushy Basin Shale Member (slope).

Basin and from the overlying Cedar Mountain Formation. In many areas the Brushy Basin has been entirely removed by erosion, leaving a broad bench of uppermost Salt Wash sandstone strewn with a lag of resistant debris. Sands in the Brushy Basin Shale Member are frequently cemented with both carbonate and silica and are more resistant than the sands of the Salt Wash Sandstone Member. Conglomeratic phases are often of brightly colored chert and aid in distinguishing these Brushy Basin sands from their more drab counterparts in the Salt Wash Sandstone Member.

Most measured stratigraphic sections terminate in the Brushy Basin Shale Member where it is present. In areas where it has been stripped off and a laterally extensive bench of conglomeratic sandstone is exposed, this has been taken as the top of the Salt Wash Sandstone Member. Erosion may have removed up to several meters of Salt Wash sandstone in these areas; this uncertainty is unavoidable but is not considered a source of serious error.

PETROLOGY

Textural, hand-specimen, and thin-section analysis of samples from the study area are discussed separately below.

Textural analysis

Eight samples of sandstones from the lower member and Salt Wash member were analysed for grain texture. Methods and tabulated results are given in appendix B. Figure 10 illustrates the traction, saltation, and suspension grain-size populations, according to Visher (1969), of all samples.

Sample 11-3-1 is the only sandstone from the lower member that was analysed. This sample is from a tabular sandstone 50 cm thick, with undulatory to poorly developed planar-tabular lamination.

The log-normal distribution of grain sizes matches the fluvial model of Visher (1969). The traction population accounts for only 0.15 percent of the sediment (material coarser than 1.25 phi) while the suspension population (finer than 3.50 phi) makes up 13 percent. The sands are fine grained, moderately sorted, strongly fine skewed, and leptokurtic (terminology of Folk, 1974). Sample 11-3-1 has a greater traction load than all other samples (except sample 24-10-1), which coupled with the fluvial shape of the curve, suggests deposition of this sand as a flood, a single

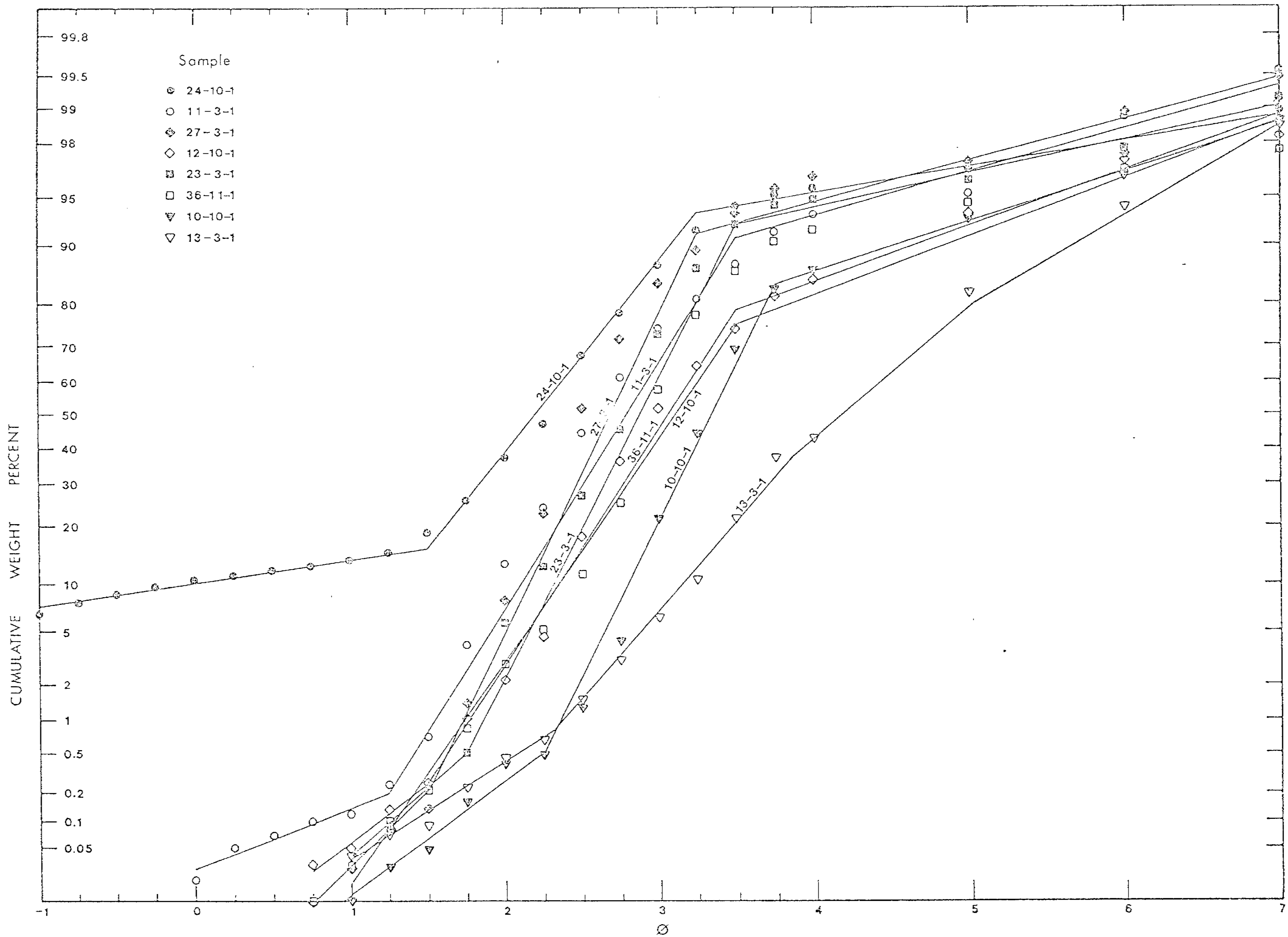


Figure 10—Chart showing distribution of particle sizes of disaggregated sandstones from the study area (after Visher, 1969).

depositional event under rapid erosional and depositional conditions.

Three of the seven samples of the Salt Wash member have grain-size distributions which differ from the others. Two occur in the lower part of the member; one is from the top sandstone of the member.

Sample 13-3-1 is from the basal unit of the Salt Wash member at Section 3 in the western part of the study area (figure 4). This unit is approximately 1 m thick with both medium- and small- scale cross-lamination. The distribution curve of grain sizes matches that of Visher's (1969) fluvial current-rippled sand. There are no definite populations indicated by the distribution. The grains are coarse silt, moderately sorted, finely skewed and mesokurtic. This unit was probably deposited in rapidly slowing currents. The mesokurtic distribution indicates rapid dumping of sediment without much differentiation into load populations. This could occur during overbank flooding when sediment-laden waters course over the natural levee of a channel and suddenly slow and disperse.

Sample 10-10-1 is from the lower part of a lensoid multistory sandstone, 4.0 m thick, in the lower part of the Salt Wash member. Structures are medium-scale cross-laminations. The grain-size distribution matches the fluvial distributions of Visher (1969). The sands are very fine grained, moderately well sorted, strongly fine skewed and very leptokurtic. The suspension population makes up 17 percent of the sample.

Steep saltation slopes and leptokurtic distribution indicate deposition in a fluvial channel. The traction population is very minor; deposition from the saltation population was dominant. The very fine sand size indicates deposition in the upper part of a bar.

The remaining sandstones from the Salt Wash member below the top sandstone all have a very similar grain-size distribution which corresponds well to Visher's fluvial model for point bar and trough cross-stratified channel deposits.

Suspension populations are 5 to 25 percent and saltation-suspension breaks occur at 3.25 phi-3.50 phi. Sands are fine to medium grained, moderate to moderately well sorted, nearly symmetrical to strongly fine skewed, and leptokurtic to very leptokurtic. These sands were deposited in a fluvial environment; there is no apparent correlation between thickness of the sandstone, position in the stratigraphic sequence (between the lower member and the top sandstone of the Salt Wash), and the shape of the grain-size distribution.

The top unit of the Salt Wash member at Section 10 is a conglomeratic sandstone. Sample 24-10-1 is from this unit. Structures are medium-scale cross-laminations. This sample has a grain-size distribution which most closely matches Visher's distribution curve for a tidal-influenced channel deposit. The traction population of sample 24-10-1 makes up 15 percent of the sediment, less than the model, and is less well sorted than the model. The suspension population (7 percent of the sample) matches the upper range of the fluvial distributions. The sand is fine grained, poorly sorted, strongly coarse skewed and very leptokurtic. This sand was deposited as bedload of a fluvial channel. Friedmann (1961) concluded that dune and river sands should have a fine-skewed distribution while beach deposits should be coarse-skewed. The structures in the sandstone, as well as its morphology, however, are of a fluvial nature. The difference in distribution of grain sizes results from the increased competency of the stream to transport coarse material.

Petrology of hand specimens

Hand specimens of most sandstone units measured in the field were examined with a 10X hand lens, and estimates of major-mineral composition were used to classify the rock according to Folk's (1974) system. Sandstones of the Entrada, Summerville, and lower member of the Morrison are dominantly classed as subarkoses, feldspathic litharenites, and lithic arkoses, with lesser numbers of specimens classed as sublitharenites, litharenites, and arkoses. A pattern of composition is not evident within this group of specimens.

The quartz content of all specimens ranges from 61 percent to 92 percent with the average at approximately 77 percent. Dominant grain size for all specimens is fine sand. Grains in most specimens are subrounded to rounded. Sandstones of the lower and upper portions of the Salt Wash member and the lowest sandstones of the Brushy Basin Shale Member are mostly classed as subarkoses and sublitharenites, with quartz content averaging approximately 81 percent. Some specimens of the topmost sandstone of the Salt Wash member and the lowest sandstone of the Brushy Basin Shale Member are enriched in chert and are therefore classed as litharenites with quartz content ranging down to 59 percent. Grain sizes range from dominantly fine sand for Salt Wash member sandstones to coarse sand and some granule and pebble conglomerates in the topmost Salt Wash member and lowermost Brushy Basin Shale Member sandstones. Grains in sandstones of the lower and most of the upper portions of the Salt Wash member are subangular to rounded, with most being subrounded. Grains in sandstones of the topmost Salt Wash member and lowest Brushy Basin Shale Member are almost equally subrounded and subangular; a minor amount are rounded. Granules and pebbles in conglomerates tend to be rounded to well rounded.

Analysis of thin sections of clastic rocks

Methods and results of thin-section analysis of 24 samples of clastic and carbonate rocks from the study area are given in appendix C. Results are shown in Figure 11.

Summerville Formation

One thin section of Summerville sandstone was studied. This rock is classified as a subarkose and is very poor in lithics and richer in quartz than most of the other sandstones studied. The sample (thin section 1-17-1) is from the base of Section 17, which directly overlies the Entrada Sandstone.

Grains are cemented by syntaxial silica cement; no carbonate cement is present. About 20 percent of the grains are elongate and their long dimensions display subparallel orientations within the plane of the thin section.

This sample probably represents reworking of Entrada sands during early Summerville deposition.

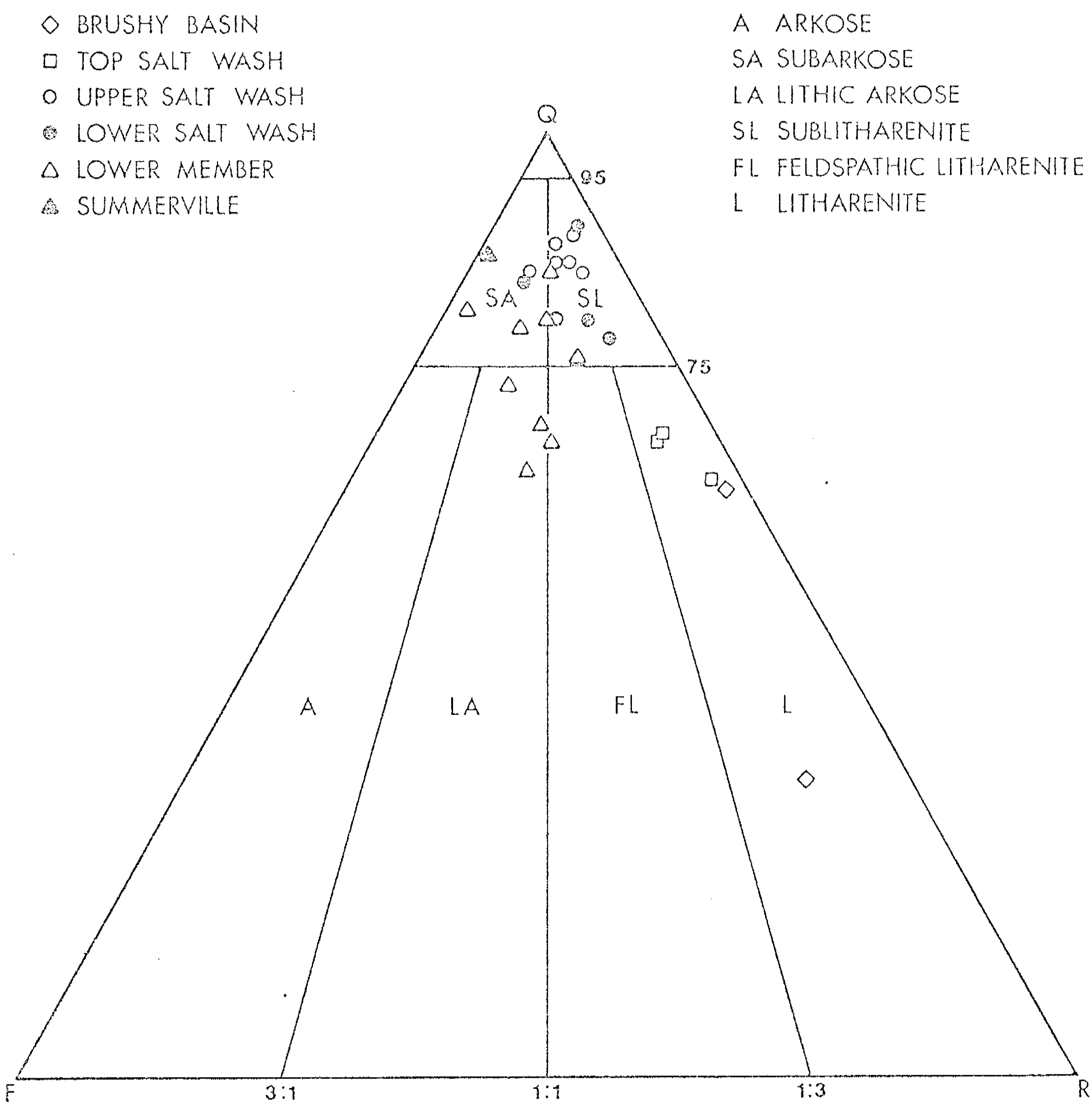


Figure 11--Sandstone classification of Folk (1974) showing compositions of specimens from study area analyzed in thin section. Q = all quartz excluding chert; F = all feldspars + granite, and gneiss fragments; R = all other rock fragments + chert.

Lower member of the Morrison Formation

Sands from the lower member fall in a field included in the subarkose, lithic arkose, sublitharenite, and feldspathic sublitharenite divisions (figure 11). Detrital grains make up about 70 percent of the rocks, and carbonate cement makes up 30 percent. All lower member sands are from units less than approximately 1 m thick. Structures are undulatory and small- to medium-scale cross- laminations. There is no evident correlation between structure of the sands and composition, but the lower member sands as a group are somewhat different from the sands higher in the section.

Quartz is fine grained and is monocrystalline in most sections; polycrystalline grains occur in trace amounts. Quartz grains exhibit dominantly straight extinction. Rutilated quartz occurs in thin section 4-17-2.

Feldspar is mostly potassium feldspar, 20 percent of which exhibits microcline twinning; most of the rest is orthoclase. Plagioclase feldspar is present in trace amounts to 1 percent. Feldspar grains average 0.2 mm (fine sand) in size and are altered irregularly.

Chert is the major lithic fragment and occurs most commonly as silicified volcanic (?) rock fragments. Sedimentary chert grains frequently include angular quartz grains. Both types of chert vary in size much more than other detrital grains. Thin section 3-29-1 contains detrital sedimentary chert grains up to 1.2 mm (very coarse sand), in a matrix of fine sand, and may be part of the chert-granule facies. Chalcedony occurs as a very rare replacement of volcanic (?) rock fragments.

Accessory minerals are zircon, pyroboles, and opaque iron oxides.

The cementing agent in the lower member sands is carbonate. The carbonate is present as a micritic mass surrounding detrital grains, giving the rock a matrix-supported appearance. No crystalline carbonate was observed in the thin sections. Carbonate frequently etches grain edges. No silica cement was observed.

Detrital grains of the lower member sandstones were apparently deposited in a lime mud which crystallized to micrite. The lack of initial porosity and permeability prevented the growth of syntaxial silica cement which requires free circulation of pore fluids (Heald and Renton, 1966). Devitrification of probable volcanic debris released silica which replaced these lithic fragments with chert and rare chalcedony. Chalcedony forms at a much slower rate than chert and grows from fewer crystallization centers (Heald and Renton, 1966; Folk and Weaver, 1952), and its development in the lower member sandstones was impeded by the growth of chert which used up most of the available silica. Etching of the replacement chert took place later.

The sediments in the lower member of the Morrison Formation are probably a mixture of locally derived sands and detrital sedimentary chert of uncertain origin. Volcanic (?) debris was contributed from a nearby source, indicated by the larger size and angularity of this softer material.

Lower portion of the Salt Wash member of the Morrison Formation

Sands from the lower portion of the Salt Wash member are subarkoses and sublitharenites (figure 11). Detrital grains make up approximately 80 percent of the rocks; cement is carbonate with minor silica. Cement content decreases upward in the section from 30 to 12 percent.

Quartz is abundant and is monocrystalline with a trace of polycrystalline grains. Quartz of both types exhibits straight extinction. Quartz grains range from 0.25 to 0.70 mm (medium to coarse sand) in size.

Feldspar ranges from 2 to 10 percent of the detrital grains. Plagioclase makes up a trace to 5 percent of the detrital grains; the majority is potassium feldspar, 10 percent of which is microcline. Feldspars are 0.25-0.30 mm (medium sand) in size. Alteration is moderate and is mostly to clay minerals. Grain edges are embayed by carbonate.

Lithic fragments are chert and appear to be mostly altered volcanic debris. Grains are 0.20 to 1.2 mm (fine to very coarse sand) in size. Lithic fragments in thin section 8-4-1 are partially to completely replaced by carbonate; this affects 10 percent of the lithics. These grains have been partially dissolved. Minor chalcedony occurs in some lithic fragments in the three thin sections.

Accessory minerals are pyroboles and zircon.

Cement is dominantly carbonate, ranging from 30 to 12 percent upward in the section. In thin sections 8-4-1 and 22-11-1 the carbonate resembles that of the lower member sands. Thin sections 12-4-1 and 6-17-1 contain both types of cement. Carbonate cement is microcrystalline with rare crystals up to 0.1 mm. Silica cement occurs as overgrowths which bond clusters of grains together. Approximately 40 percent of the grains of these thin sections are aggregated. Carbonate has partially replaced the edges of the grains.

Diagenesis of the samples with no observable silica cement was similar to that of the sands of the lower member. Diagenesis of samples 6-17-1 and 12-4-1 was dominated by the formation of aggregates of detrital grains, cemented by syntaxial silica overgrowths.

This indicates a good degree of permeability in the early diagenetic environment. Both samples are moderately sorted and were deposited with little primary matrix.

Silica overgrowths cemented detrital grains together before the formation of carbonate cement isolated the grains and reduced the permeability of the rock. Carbonate cement began embaying the grains after the cessation of silica cement formation. Feldspars were probably altered prior to deposition in the sands. These grains are most likely of multicycle nature. Carbonate embayment occurred after the silica-cement phase.

The abundance of monocrystalline quartz with straight extinction and the low feldspar content indicate a mineralogically mature source (Blatt and Christie, 1963; Pittman, 1969). This source was most likely composed of sedimentary rocks. A volcanic source contributed fresh material to the depositional system, probably from fairly close to the study area.

Upper portion of the Salt Wash member of the Morrison Formation

Sands from the upper portion of the Salt Wash member plot as two very distinct groups (figure 11): subarkose-sublitharenites, and litharenites. These groups are directly related to stratigraphic position.

The subarkose-sublitharenite group consists of sands up to but not including the topmost sand of the Salt Wash. Detrital grains make up 80 percent of the rock; cement comprises 20 percent, mostly carbonate with minor syntaxial silica overgrowths. Within this group are 7 thin sections of diverse sandstones. There is no correlation between rock type or structure and the composition or cement of the samples.

Mineralogic composition of the sands of this part of the Salt Wash member is very similar to that of the lower part of the Salt Wash (appendix C).

Cement is present in the same types and amounts as in samples 6-17-1 and 12-4-1, and the abundance of aggregates is the same. Diagenesis and inferred source rocks are as given for these samples.

The sands of the top of the Salt Wash member plot in the litharenite group. These units are conglomeratic sandstones with local finer material from which the samples were taken. Detrital grains make up 78 percent of the rock. Carbonate cement fills interstices; 50-80 percent of the grains are cemented by silica overgrowths.

Quartz, monocrystalline with straight extinction, is the most abundant detrital material, and ranges from 0.2 to 0.4 mm (fine to medium sand). Approximately 60 percent of the quartz contains inclusions of bubbles and other minerals.

Feldspar is mostly potassium feldspar; plagioclase is present in trace amounts. Feldspar grains average 0.2 mm (fine sand).

Lithic fragments are present in greatest abundance of all the thin sections studied. These grains average 0.4 mm (medium sand) and are composed of about 70 percent volcanic rock fragments altered to chert and minor chalcedony; 30 percent are sedimentary chert. One chert grain in thin section 22-4-1 is made up of silicified oolites 0.15 mm in diameter. Together the lithic fragments make up 30 percent of the rock.

Accessory minerals are pyrobole and zircon but are rare.

Silica cement as syntaxial overgrowths on quartz grains formed first after deposition of the sediment. The coarseness of the grains and the overall poor sorting indicate that silica cementation occurred fairly rapidly (Heald and Renton, 1966). Alteration of the lithic fragments probably occurred during this stage and released silica to the pore fluids. Silica was also supplied by the volcanic-ash-rich Brushy Basin strata above. Carbonate cement precipitated and probably caused the termination of silica cement growth; carbonate attacked and etched the detrital grains. A later period of chalcedonic silica fills fissures in the rock but this too is etched by carbonate.

Sedimentary rocks were eroded to yield the sediment for sands of the uppermost Salt Wash. Volcanic rock fragments were supplied by a close source independent of the sedimentary rocks.

Brushy Basin Shale Member of the Morrison Formation

Two thin sections from samples of the Brushy Basin Shale Member were studied. These samples are from Section 4 and are from thick conglomeratic sandstones with medium-scale cross- strata. They plot as litharenites (figure 11).

Quartz is the major detrital component in thin section 32-4-1, and is subordinate in thin section 26-4-1. Quartz grains are monocrystalline with straight extinction and are 0.3-0.4 mm (medium sand) in size.

Feldspar makes up 8 percent of thin section 26-4-1 but is present in only trace amounts in thin section 32-4-1. Feldspar in 26-4-1 is mostly potassium feldspar, 0.3 mm (medium sand) in size; a trace of plagioclase occurs, 0.2 mm (fine sand) in size.

Lithic fragments make up 59 percent of thin section 26-4-1 and are mostly of sedimentary origin. One chert grain is a replacement of coralline algea. Chert replacement of volcanic debris also occurs. Lithic fragments range up to 0.8 mm (coarse sand). Thin section 32-4-1 contains 36 percent lithic fragments, dominantly sedimentary in origin. These grains range up to 0.4 mm (medium sand) in size.

Thin section 26-4-1 contains 23 percent carbonate cement ranging from microcrystalline to crystals of 0.2 mm. Rare aggregates of grains are cemented by silica overgrowths. Thin section 32-4-1 is almost totally cemented by syntaxial silica overgrowths, imparting an angular appearance to the detrital grains. Less than 1 percent carbonate cement occurs as patches of corrosion between grains and along sutured cement contacts.

Both samples of the Brushy Basin sandstones were deposited as relatively porous, permeable material. The poorly sorted sediment of sample 26-4-1 was cemented with carbonate of uncertain origin. The lacustrine environment of the Brushy Basin may have operated as suggested for the sands of the lower member and contributed carbonate in the form of lime mud, but more likely the carbonate was precipitated from solution. Sample 32-4-1 is moderately sorted, less originally permeable than sample 26-4-1 (unless lime mud was deposited with that sample) but is completely cemented by silica. It is however higher in the Brushy Basin and hence is likely to have been saturated with waters richer in dissolved silica than lower rocks. Later attacks of carbonate cement of the silica cement resulted when the diagenetic environment was altered.

The sands of the Brushy Basin Shale Member were derived from a source similar to that of sands of the Salt Wash member. This source shed fossiliferous cherts and multicycle sands which were mixed with minor volcanic material from a (probably) nearer source area.

Summary

A pattern of shifting composition is evident in figure 11. Lower member sands occupy a wide, scattered field; in the Salt Wash member, the sands are more quartz-rich while the relative proportions of feldspar and lithic fragments remain the same. A strong shift to a lithic-rich, quartz-poor composition occurs abruptly at the top of the Salt Wash member and continues into the Brushy Basin sands. This compositional trend does not reflect a change in the source area of the respective members, but is a function of the increased competency of the streams and perhaps a variability in the mineralogic ratios in the source area toward a greater percentage of chert.

A change is indicated, however, in the source areas for the lower member versus the Salt Wash and Brushy Basin Members. The following conclusions are drawn from the data:

1) The source area for the sands in the lower member of the Morrison Formation was probably local and was most likely reworked Summerville material.

2) The sands of the Salt Wash member were derived from a different source than the sands of the lower member. This source area was composed of sedimentary rocks of relatively

high mineralogic maturity. A variable volcanic source operated near to the study area.

3) The sands of the Brushy Basin Shale Member were derived from the same source area as the sands of the Salt Wash member. A change in the relative proportion of the mineral components of the source area may have occurred at this time.

4) Very minor contributions to the sands of the Salt Wash and Brushy Basin Shale Members may have come from metamorphic and plutonic sources (see also Craig and others, 1955).

Analysis of thin sections of carbonate rocks

Eight thin sections of carbonate rocks were examined for this study. The thin sections are from samples of limestones collected from the lower member of the Morrison Formation. Hand specimens are dark gray to purple gray with rounded weathering surfaces and conchoidal fracture. Grains of fine sand weather out on the surface. The carbonate rocks are mudstones (less than 10 percent grains) or wackestones (greater than 10 percent grains) according to Dunham (1962).

Results of thin-section analysis of these samples are listed in appendix C.

The matrix of each section is micrite to neomorphic spar (Folk, 1974). Several thin sections contain up to 25 percent sparry calcite that was precipitated in pores in skeletal material and other open spaces. Crystals are up to 0.2 mm and are bounded by straight line faces. Terrigenous material makes up from 7 to 20 percent of the rock and consists of angular quartz and rare feldspar grains 0.05-0.20 mm (coarse silt to fine sand) in size.

Most skeletal material in the carbonate samples consists of algal material, remains of charophyte green algae (Scholle, 1978). The algal material consists of pores (tubes) up to 0.1mm in diameter surrounded by thin walls of micritic material. Pore spaces are filled with precipitated sparry calcite crystals up to 0.02 mm in size. Algal material composes up to 40 percent of the rock volume in local accumulations. It occurs in five of the eight sections; thin sections 6-14-1, 27-15-1, and 31-15-1 contain no observed algal material.

Fragments and whole specimens of ostracode shells occur in the same thin sections as the algae and make up 1-2 percent of the rocks. Intact articulated shells form shelter pores filled with precipitated sparry calcite.

Oval masses of micrite and neomorphic spar (intraclasts) make up 2-80 percent of some thin sections. Thin sections 10-11-1, 2-14-1, 1-15-1, and 13-15-1 contain no observed intraclasts. Intraclasts in thin section 6-1-1 contain up to 15 percent terrigenous material.

Deposition occurred as lime mud containing varying amounts of skeletal debris and up to 40 percent silt and fine sand. Disturbance of this soft material by flooding currents caused clasts of lime mud to be torn from the bottom and redeposited as intraclasts. Thin section 6-14-1 consists entirely of intraclasts with precipitated spar between. Cementation of the lime mud by crystallization occurred during or prior to precipitation of pore-filling sparry calcite. Crystallization of skeletal material to micrite occurred at an unknown time in the diagenetic history but is complete; staining of thin sections reveals no aragonite. Formation of fissures and filling with a second generation of sparry calcite, and growth of neomorphic spar in the matrix, occurred before the final stage of vug and fissure formation.

Summary

The depositional environment of the carbonate rocks was dominantly quiet water with limited influx of silt and fine sand in almost all cases. The environment was fresh water; though charophyte algae can tolerate alkaline water, thin-shelled ostracodes require fresh water (Peck, 1961). Periodic strong currents disturbed the bottom of most of the lakes.

PALEONTOLOGY

Remains of plants and animals are not abundant in the study area. Occurrences are discussed with respect to the rock units in which they occur.

Lower member of the Morrison Formation

Fossils in the lower member are of both plants and animals. Plant remains consist of algal material in limestones. Charophytes occur throughout the study area and adjacent areas (Sexsmith, 1980). Charophytes are green algae which live in fresh to highly saline water and can survive dry periods (Peck, 1957; Burne and others, 1980).

Animal remains are of invertebrates. Shells of ostracodes, small planktonic and benthonic crustaceans, are preserved both intact and in broken condition in limestones throughout the area. These creatures had thin, unornamented valves and are interpreted to be fresh-water dwellers (Benson, 1961). Molluscs occur in the lower member west (Sexsmith, 1980) and southwest (Yen, 1952) of the study area. These were filter-feeding clams of the order Unionoida and lived in a moving-water environment.

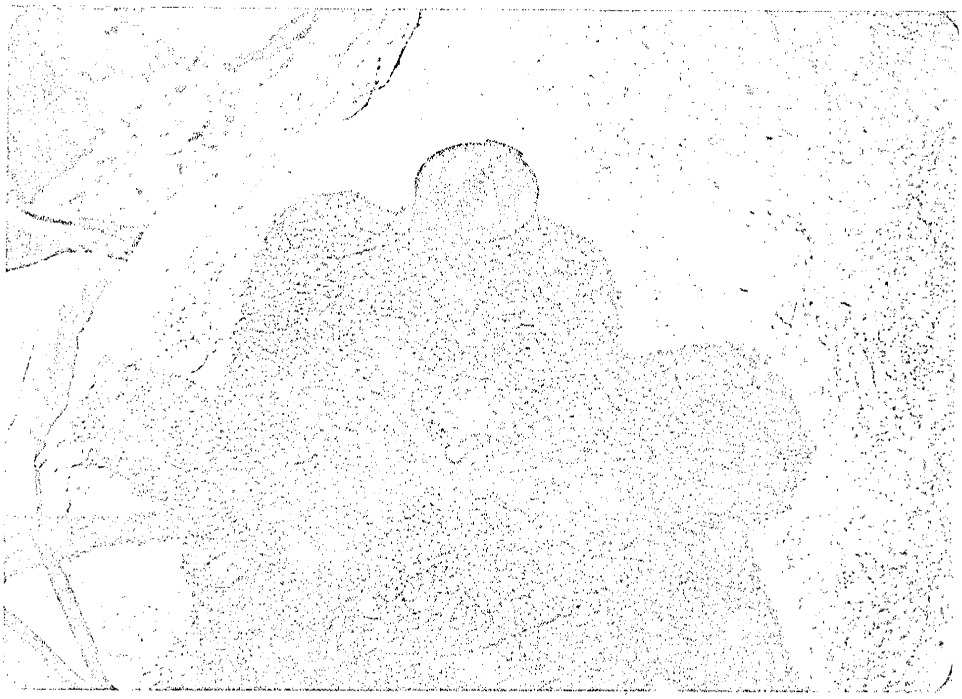
Salt Wash member of the Morrison Formation

Fossils in the Salt Wash member are dominantly of plants; animal remains are very rare. In the basal sand of the Salt Wash member at Section 17, imprints of fern fronds are preserved between layers of fine sand (photograph 8). These fronds have highly branching frondules and small leafy areas. Other plant remains occur in the form of petrified logs and chips of wood, coalified layers of plant debris, and small fragments of leaves and twigs in locally abundant accumulations. In general, the abundance and size of the preserved plant material increases upward in the Salt Wash member.

Animal remains consist of very rare fragments of dinosaur bones. Dinosaurs of the genera Brontosaurus and Allosaurus flourished in the environments of the upper Salt Wash member and of the Brushy Basin Shale Member (Gregory, 1938). The bone fragments are much more abundant in the Brushy Basin than in the Salt Wash member.

Trace fossils

Trace fossils occur throughout the lower member and the Salt Wash member. The most prevalent form is that of vertical burrows, commonly 1 cm in diameter, and up to 1 m in length. These structures occur in sandstones of all thicknesses and structures but are most often seen in the



Photograph 8

Rock unit 6 of Stratigraphic Section 17, showing preserved imprints of fossil fern fronds on upper surface of fine-grained sandstone.

upper parts of thick channel-sand deposits. When the internal structure is preserved, a series of ringlike ridges occurs, several mm to 2 cm apart on the burrow wall.

Much less common are horizontal to slightly inclined burrows up to 1 cm in diameter. No internal structure was observed. The scarcity of these structures may be partly due to lack of exposure.

Identification of the burrowing organisms is not possible from the burrow alone. Many types of creatures burrow in sandy substrates (Frey, 1974; Seilacher, 1964). Intensity of burrowing in a unit may be a general indication of the relative length of time that the environment of the burrowing organisms persisted.

DEPOSITIONAL ENVIRONMENTS OF THE MORRISON FORMATION

The following interpretations are based on the data analysed in this study and the conclusions of other authors as cited.

Origin of the chert-granule facies

The Summerville Formation-Morrison Formation transition represents a change in several factors. During the deposition of the upper part of the Summerville, tectonic activity in the vicinity of the study area was renewed, and folding began along pre-existing structural axes. Withdrawal of the sea along the margin of which the Summerville was deposited coincided with this period and may have been initiated by the renewed tectonic activity. Shallow basins of periodic evaporite deposition were deepened, and the areas of Summerville strata which were uplifted were exposed subaerially. An arid climate prevailed and erosion was slow. Wind and minor streams were the active erosional agents. Erosion probably kept pace with slow uplift, and eroded material was deposited in the deepening basins, offlapping the older Summerville strata at the basin margins, which were gentle slopes. Chert nodules and concretions liberated from the Summerville remained essentially in place as a lag deposit. This period of uplift and erosion persisted for some time; Trimble and Doelling (1978) estimate that up to 60 m of Summerville strata were removed in uplifted areas. The uplifts were areally small in comparison to the basins and the offlap resulting from the erosion-deposition was subtle. By the end of Summerville deposition, the study area consisted of relatively higher ground in the eastern two thirds undergoing arid erosion, and a deeper, restricted basin stretching west and southwest, one arm of which trended north-northwest in the western third of the study area (Sections 6 and 26). Tectonic activity ended at this time. The chert grains remaining in the higher areas were considerably broken and rounded by desert erosional processes by this time, and the older strata of the basin margin were truncated at 2-4 degrees to the west. The climate became more humid and small short streams of local drainage formed. These streams carried small amounts of chert, along with fine sand, silt, and mud into the basin and other depressions; the clastic material was distributed across the basin floor. In some areas, gypsum deposition occurred simultaneously and the chert fragments and associated fine material were deposited as thin layers in the basal part of the gypsum. In others, the detritus was spread as a thin veneer over the erosional surface truncating the Summerville. Deposition of the chert-granule facies was a slow, penecontemporaneous process across the study area and continued in the basin as more material was washed in from the higher ground to the east during the gypsum-depositional phase of lower member deposition.

Deposition of the lower member

Deposition of lower member sediments occurred in two general stages during and after deposition of the chert-granule facies. The first was the deposition of the thick gypsum sequence in the western basin (figure 12). There was no free circulation of the basin water. Beginning with the initial deposition of the chert-granule facies, gypsum formed subaqueously and precipitated on the basin floor of truncated Summerville strata.

The basin received very little clastic sediment throughout its early history. Thin layers of limestone formed during gypsum deposition; gradually, up to 7 m of gypsum with minor limestones and clastic sediment layers were accumulated.

The transitional zone between the western basin and the flank of the Salt Valley high ground east of Sections 10, 11, and 23 was a gentle slope and formed the shoreline of the basin. Minor wave action and storm surges generated a gradually increasing amount of clay and silt which were distributed throughout the basin. During this period, the Salt Valley anticline was rising as a salt diapir intruded the overlying strata. The climate was arid and transportation of clastic material was minimal. A topographic high existed in the area of Sections 10, 11, and 14 (figure 12) and a smaller high formed at Section 4.

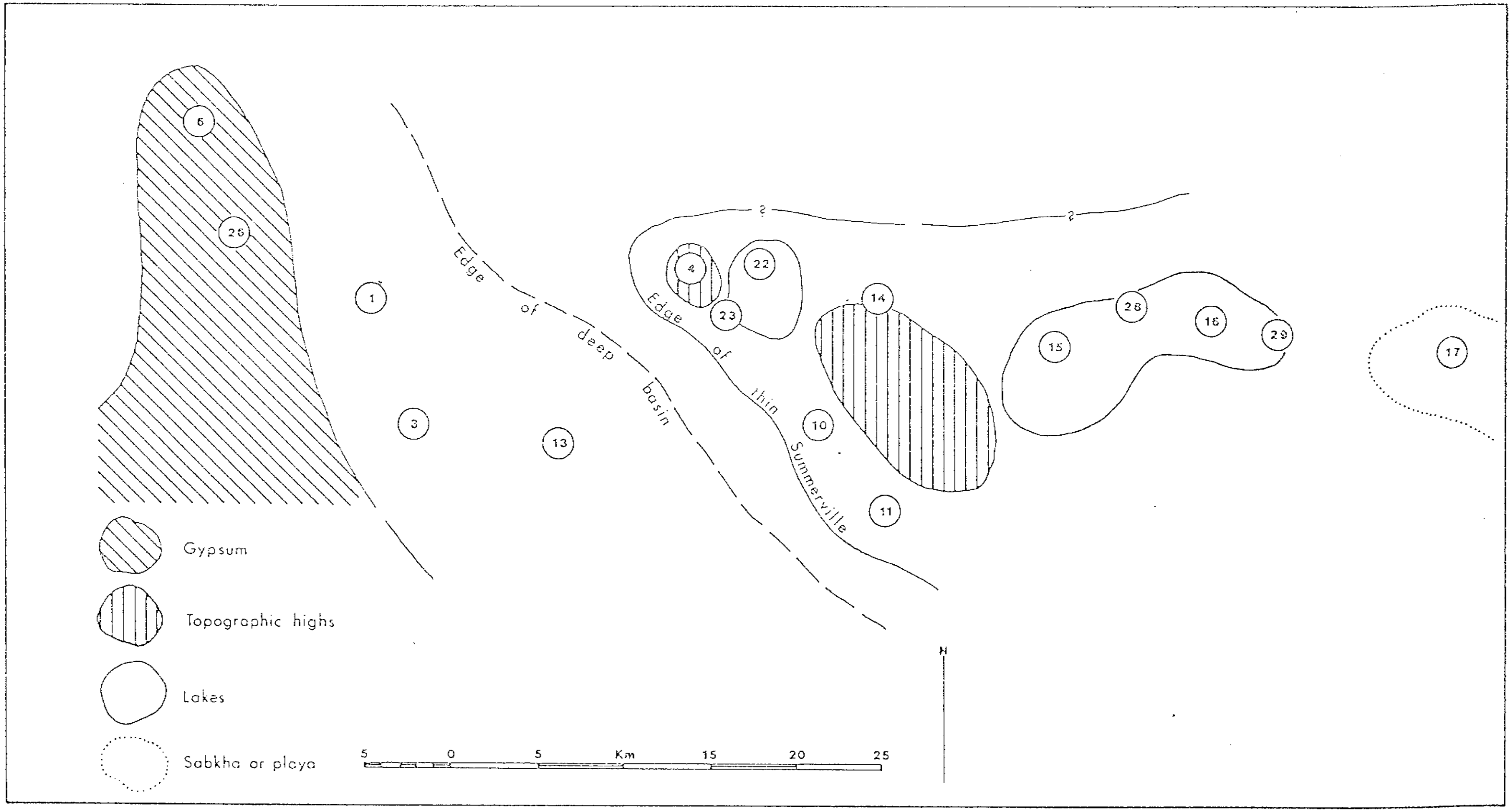


Figure 12—Paleoenvironmental map of study area during early deposition of the lower member of the Morrison Formation. Numbered circles locate measured stratigraphic sections for reference.

Shallow depressions in the Summerville strata were floored with chert granule layers and fine sand. Relief throughout the area was no more than several tens of meters.

A change in the climate initiated the second stage of lower member deposition. The climate became more humid, coincident with the rise of the source area of the Salt Wash. The study area received increasing precipitation. The depth and size of the western basin increased; the influx of fresh water and the decreased evaporation terminated the gypsum-deposition phase. Lacustrine sedimentation became dominant. Local depressions in the higher ground were filled by water carried in by short streams; exposed Summerville strata were locally reworked and deposited as both granule-bearing and granule-free sands. The topographic high of the Salt Valley anticline was partly eroded and sand was deposited along the flanks. The lakes grew larger, eventually drowning the small streams. In the eastern extremes of the study area, stream deposition alternated with periods of evaporation in a shallow playa lake or inland sabkha (figure 12).

During this period, the alluvial fan of the Salt Wash member was prograding to the north and east. Its distal edge contributed water and fine sediment to the study area during late lower member deposition (figure 13). Areas of dominantly lacustrine nature alternated with areas of mixed lake and stream sediments. Charophytes and ostracodes

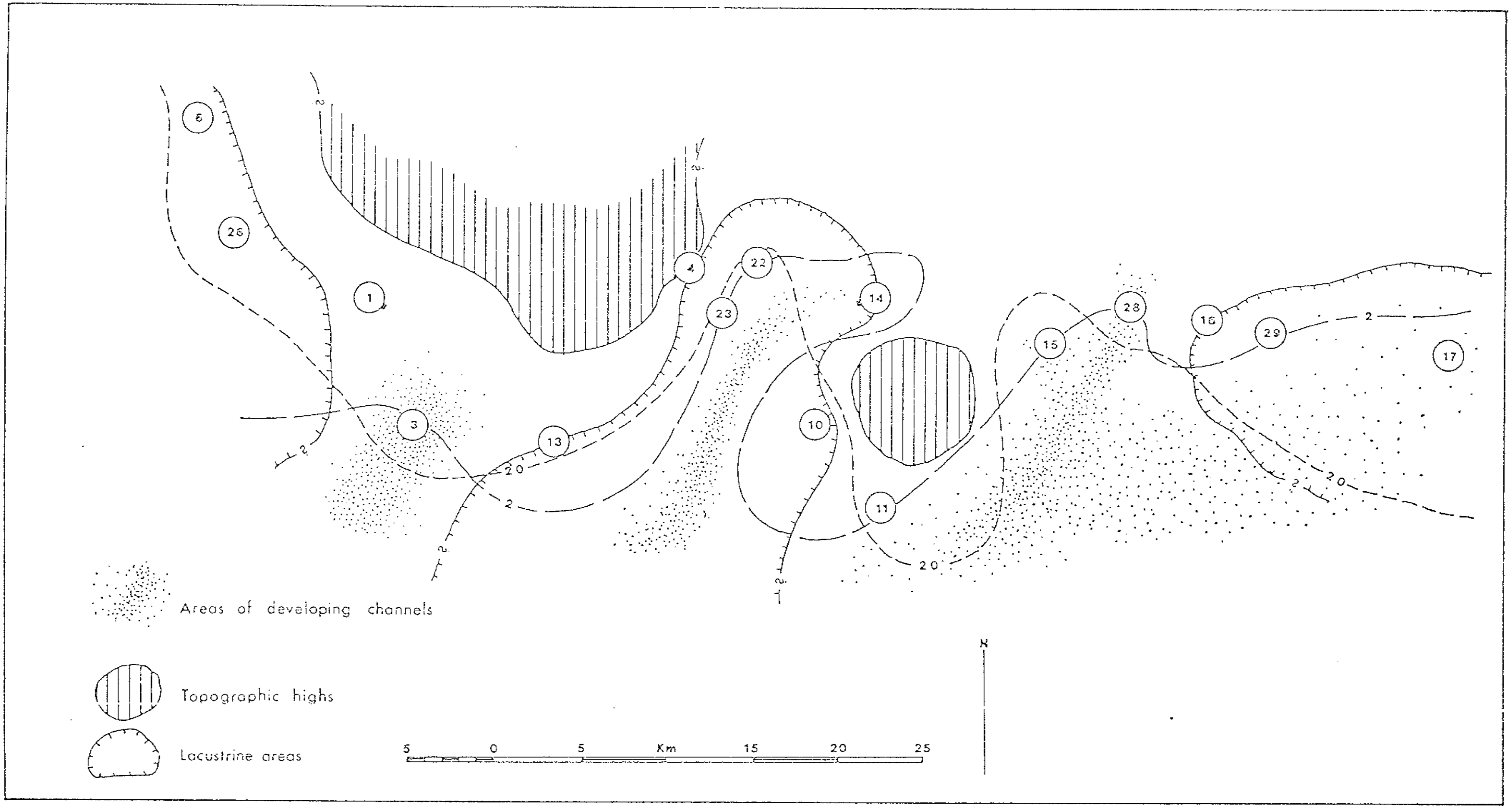


Figure 13—Paleoenvironmental map of study area during late deposition of the lower member of the Morrison Formation. Sandstone isopach contour (— —) and siltstone + mudstone isopach contour (-----) in meters; numbered circles locate measured stratigraphic sections for reference.

flourished in the lakes while areas of moving water supported scattered pelecypod populations. Clastic deposition concentrated in areas of developing channels as Salt Wash streams neared the area. The average thickness of the lower member at this time was 20-25 m (figure 13).

Deposition of the Salt Wash member

Lower portion

The influx of the depositional system of the Salt Wash member occurred in the form of streams of low sinuosity. These streams filled and overran most of the lakes of the lower member and scoured deeply into their sediments, stripping several meters of material in places from the paleosurface. Several major channels formed (figure 14); the advance of the Salt Wash system was rapid and thick channel deposits formed in major streams. The western basin was filled and did not influence the system except very locally (Sections 1 and 3). The northern edge of the advancing system was generally along the northern limit of the study area during early deposition of the Salt Wash member.

Channel scouring created the irregular contact between the lower member and the Salt Wash member. In relatively higher areas where streams were minor or did not develop, a transitional environment (lacustrine-floodplain) occupied this stratigraphic horizon.

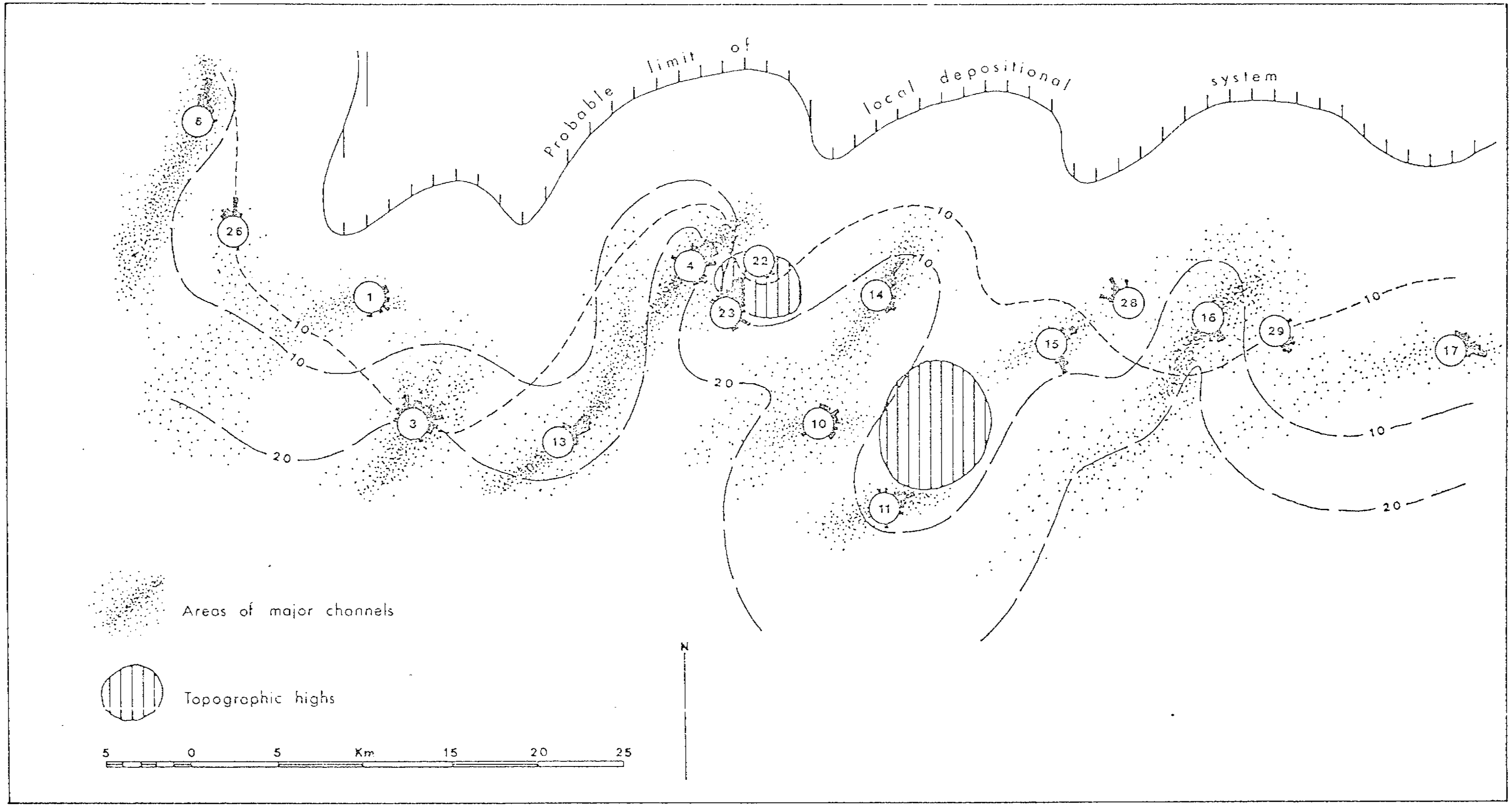


Figure 14—Paleoenvironmental map of study area during deposition of the lower portion of the Salt Wash member of the Morrison Formation. Sandstone isopach contours (— —) and siltstone + mudstone isopach contour (-----) in meters; paleocurrent diagrams are composites for the lower portion of the member for each measured stratigraphic section (numbered circles).

Between the channels, areas of floodplain deposition dominated over lacustrine environments. Seasonal flooding and filling of abandoned channels rapidly built up the floodplain with fine silt, sand, and mud, while channel scouring and deposition built channel sand deposits at a slower rate, probably near equilibrium. Channel choking and avulsion were infrequent. The channels diverged around the Salt Valley anticlinal high, which continued to rise as it was eroded. A local high at the site of Sections 22 and 23 developed; streams washed against its flanks and flowed around it. The rate of rise of this structure was rapid but sporadic, and was caused by the local doming of salt beneath the structure.

The climate was temperate to semiarid. Local abundances of vegetation existed. Discharge in the streams was seasonally variable.

Burrowing organisms bioturbated the channel sands during periods of relative quiescence, and smaller channels underwent subaerial exposure. Cyclic erosion-deposition within channels scoured clay and silt clasts from the underlying deposits; these events were seasonal but occurred over a period of several days (Campbell, 1967).

Upper portion

During deposition of the upper portion of the Salt Wash member, the Salt Valley anticline continued to be a positive topographic element in the study area. Relief was several tens of meters. The small dome at the nose of the structure was not a high; its surface expression was eroded and buried. Deposits of major streams dominated over floodplain deposits. Virtually all lacustrine deposition ceased. Well established streams coursed uninterrupted over the western basin site and over the eastern part of the study area (figure 15), flowing east and deviating to the northeast and southeast around the anticlinal high. As the energy of the streams increased, braided channels replaced the low-sinuosity nonbraided streams of the lower part of the Salt Wash member. Vegetation in the area increased in abundance between the streams and in the local transport-system area. Trees of considerable size grew along the trunk stream which supplied sediment to the study area. Thick accumulations of plant debris were washed into the study area during floods and buried in channel deposits and occasional abandoned channels. Dinosaurs roamed the study area as the upper sands were deposited. The climate was temperate; yearly variations in temperature were low, while seasonal monsoons occurred.

Figure 15—Paleoenvironmental map of study area during deposition of the upper portion of the Salt Wash member of the Morrison Formation. Sandstone isopach contours (—— —) and siltstone + mudstone isopach contour (-----) in meters; paleocurrent diagrams are composites for the upper portion of the member for each measured stratigraphic section (numbered circles).

The increased seasonal runoff caused an increase in the competence of the streams and brought coarser material in higher energy stream systems. The change to an easterly flow was caused by a shift in the local trunk-stream system, but the sediment source did not change; it remained a terrain of sedimentary rocks with a local contribution of volcanic debris. The northern boundary of higher ground (figure 14) was partly buried but still exerted limited control over the system, deflecting stream flow to the east in some areas (figure 15).

Deposition of the Brushy Basin Shale Member

The transition from the low-sinuosity/high-braid-index streams of the upper part of the Salt Wash member to the meandering streams and floodplain-lacustrine environments of the Brushy Basin Shale Member was caused by an extreme increase in the humidity of the region. The Colorado Plateau was covered with meandering streams, swamps, lakes, and dinosaurs. The sediment source was the same in both systems, but the gravels in the Brushy Basin streams are generally coarser and less mineralogically mature.

Regional depositional relationships

The relationship of the depositional systems of the local study area to the regional Salt Wash fan system (Mullens and Freeman, 1957) is shown in figure 16. Fans of

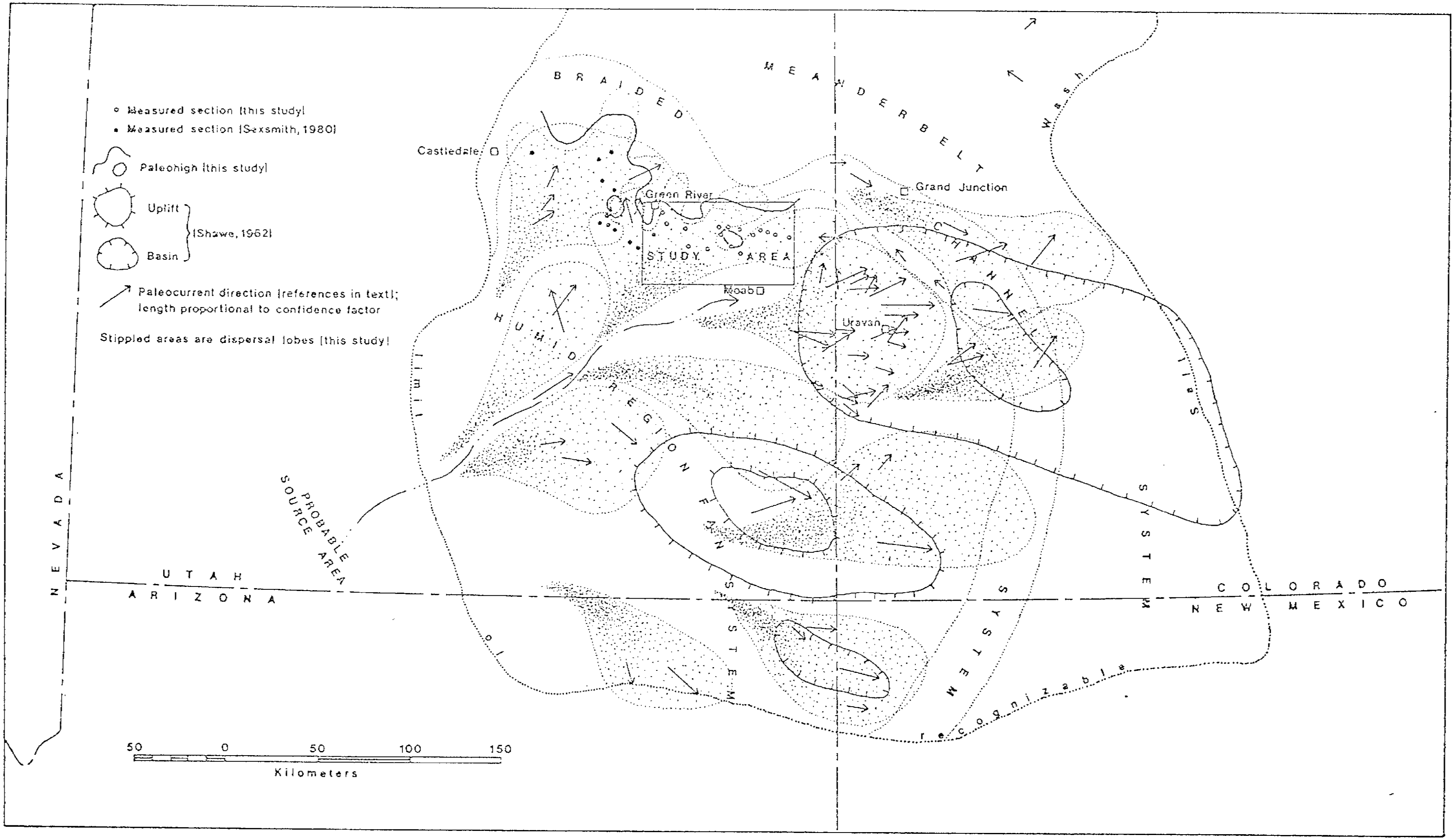


Figure 16—Map showing relationship between local depositional system of the study area and regional depositional system of the Salt Wash Sandstone Member as described by several authors.

the Salt Wash are made up of a number of dispersal lobes comprising the humid-region fan system of Craig and others (1955). These lobes conform to the local paleocurrent directions indicated in figures 14 and 15 compiled by Fischer and Hilpert (1952), Stokes (1954), and Craig and others (1955). The northern lobes radiate from a major trunk stream (Shawe, 1962) which may be considered the primary sediment transport system of the fan complex. This primary stream terminates near Moab at the apex of the Uravan dispersal lobe (Fischer and Hilpert, 1952).

In an effort to define the paleotopography of the Salt Wash depositional surface, Shawe (1962) compared the thickness of the Salt Wash Sandstone Member with that of an idealized alluvial fan of equal lateral dimensions and orientation. He suggested the presence of a large basin up to 60 m deep, beginning near the southwest corner of the study area and extending east to the limit of the Salt Wash Sandstone Member (figure 16). A dome and a smaller basin were suggested in the Four Corners area. As noted by Shawe (1962), the apparent uplift in the Four Corners area is probably the result of thinning and intertonguing of the Salt Wash with the Westwater Canyon Member of the Morrison Formation rather than a true uplift. Since the depositional systems of both the Salt Wash and the Westwater Canyon flowed into this area, a basin is more likely. The small basin suggested by Shawe (1962) was probably larger. In general, the depositional trends of both systems were largely influenced by the pre-Morrison Lake Todilto basin (Tanner, 1965), the western edge of which coincides with both basins of Shawe (1962).

The study area lies at the edge of the major fan system (figure 16), near the termination of the primary or trunk stream. The eastern part of the area is dominated by the east-northeast flow of a dispersal lobe which divides around the Salt Valley anticlinal high. In the western part of the area, the lobe fans to the north and northwest and coalesces with a separate dispersal lobe over the area of the San Rafael swell (Sexsmith, 1982). These lobes (the San Rafael and Salt Valley lobes) interfinger and create a chaotic paleocurrent distribution in the area of the western basin south and west of the town of Green River. Streams of both lobes flowed into the basin early in the depositional history of the Salt Wash member; paleocurrents indicate that the San Rafael lobe was the dominant agent during the basin-filling stage. The San Rafael lobe was also dominant over the extreme western edge of the study area (Section 6) during deposition of the upper sands of the Salt Wash. The primary stream fed both lobes and distributed sediment from the same source area; Craig and others (1955) noted no change in mineral composition across the entire fan complex, which indicates a common source and transport system. The trunk stream fed all lobes of the region through secondary distributary streams which shifted across the fan by avulsion when their channels became choked. Rapid deposition of the dispersal lobes occurred following such shifting to a steeper gradient; the San Rafael and Salt Valley lobes resulted from such tertiary distributary systems.

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APPENDIX A

Descriptions of measured stratigraphic sections

The following abbreviations and terms are used in the descriptions of the measured stratigraphic sections. Rock units are those shown in Plates 1 and 2.

Cont. horiz. lam.- continuous horizontal laminations

Cov.- covered; lithology inferred from weathered material or minor outcrops

Discont. horiz. lam.- discontinuous horizontal laminations

Discont. und. lam.- discontinuous undulatory laminations

Eros. base- erosional base; base of a sandstone unit which contains material scoured from underlying unit, generally clay or silt, in a matrix usually coarser grained than the upper part of the sandstone

Med.- medium or medium-scale

M.- meters

Mudstone- term for deposits composed mostly of clay-size particles with lesser amounts of silt- and sand-size grains

Multistory sandstone- sandstone unit composed of deposits of several scour-and-fill cycles; each deposit has an erosional lower surface, lens shape, and is truncated by adjacent and overlying deposits

Plan. tab. x-lam.- tabular-shaped sets of planar cross-laminations

Plan. wedge x-lam.- wedge-shaped sets of planar cross-laminations

Trough x-lam.- trough-shaped sets of cross-laminations

W.- weathering to

Measured stratigraphic sections

Stratigraphic Section 1, NE1/4, sec.2, T23S, R17E, Green River Quad.

Morrison Formation-Brushy Basin Shale Member

Unit	Description	Thickness
31	Sandstone, white w. brown-buff, fine sand, structureless to discont. und. lam., eros. base, tabular shape, cliff	0.6 m.
30	Mudstone, red-green, cov., slope	9.0
	Salt Wash member, upper portion	
29	Sandstone: top, white w. buff, fine sand, cont. horiz. lam., top burrowed, gradational base, tabular shape; middle, white w. buff, fine sand, med. plan. tab. x-lam., eros. base, top grades into silty sandatone, tabular shape; bottom, white w. buff, fine sand, med. plan. tab. x-lam. grading up to med. trough. x-lam., eros. base, tabular shape, ledge	4.7
28	Mudstone, red-green, and sandstone, gray-green, structureless, cov., slope with ledge	4.2
27	Sandstone, white w. brown, fine sand, structureless, burrowed, ledge	1.1
26	Mudstone, red-green, cov., slope	2.0
25	Sandstone, white w. buff, fine sand, multistory unit: base, eros., med. trough. x-lam., truncated above by cont. horiz. lam., grading up to med. trough. x-lam., top burrowed, cut-and-fill series, lens shape, bench	8.0
24	Mudstone, red-green, cov., slope	1.5
23	Sandstone, white w. buff, fine-med sand, multistory unit, med. trough. x-lam., cut-and-fill series, eros. base, top of each unit burrowed and truncated by unit above, lens shape, cliff, bench	11.8
	total:	33.3
	Salt Wash member, lower portion	
22	Sandstone, white w. buff, fine sand, small plan. tab. x-lam., eros. base, lens shape, ledge	0.2
21	Mudstone, red-green, cov., slope	0.3
20	Sandstone, white w. buff, fine sand to silt, structureless, eros. base, lens shape	0.3
19	Mudstone, red-green, cov., slope	0.4
18	Sandstone, white w. buff, fine sand, small trough. x-lam., lens shape	0.6
17	Sandstone, gray w. buff, fine sand, med. trough. x-lam., eros. base, lens shape	0.4
16	Sandstone, gray w. buff, fine sand; bottom: eros. base, small trough. x-lam., grading up to cont. horiz. lam., into structureless siltstone, truncated by upper sandstone: same as lower; tabular shape, bench	1.3
15	Mudstone, green, cov., slope	0.3
14	Sandstone, gray w. brown-buff, fine sand, med. trough. x-lam., eros. base, lens shape	0.4

13	Mudstone, green-purple, cov., slope	2.7
12	Sandstone, gray w. white-buff, fine sand, med. trough. x-lam., eros. base, burrowed, lens shape	0.6
	total:	7.5
	lower member	
11	Mudstone, gray w. white, cov., slope	3.0
10	Sandstone, gray-green w. red-brown, fine sand, ripples, tabular shape, ledge	0.3
9	Mudstone, green-white, cov., slope	2.0
8	Sandstone, green w. buff, fine-med. sand, structureless, tabular shape	0.2
7	Mudstone, green-white, mostly cov., thin limestone ledge, slope	3.0
6	Limestone, gray, contains fine sand, structureless, ledge	0.3
5	Mudstone, red-green w. red-green, cont. horiz. lam., cliff and slope	5.0
4	Sandstone, red-gray w. green-gray, fine-med. sand, discont. und. lam., lens shape	0.6
3	Mudstone, red-green, cov., slope	4.0
2	Sandstone, white w. green, fine sand, ripples, lens shape	0.3
	total:	18.7
	Summerville Formation	
1	Siltstone, red w. red-brown, silt to fine sand, cont. horiz. lam., cliff	1.0
	total section:	70.1

Stratigraphic Section 3, S1/2, T23S, R17E,
Crescent Junction Quad.
Morrison Formation-Brushy Basin Shale Member

Unit	Description	Thickness
33	Sandstone, lt. gray w. dk. buff, fine sand, med. plan. wedge x-strat., laterally structureless, bench	1.2 m.
32	Mudstone, red w. red, green, cov., slope	2.0
	Salt Wash member, upper portion	
31	Sandstone, lt. gray w. dk. buff, fine-med. sand, local granule-pebble conglom., med. plan. wedge x-strat., top 1 m. cont. horiz. strat., top burrowed, tabular shape, cliff-bench	7.4
30	Mudstone, red w. red, green, mostly cov., top 1 m. cont. und. lam., slope	2.7
29	Sandstone, white w. buff, fine sand, small-med. plan. wedge x-lam., top structureless, eros. base, cliff	5.3
28	Mudstone, red w. red, green, cov., slope	1.7
27	Sandstone, white-green w. buff, fine-med sand, structureless, tabular shape, ledge	0.8
26	Mudstone, red w. red, green, cov., slope	4.5
25	Sandstone, white-green w. dk. buff, fine sand, structurless, tabular shape, ledge	0.7
24	Mudstone, red w. red, green, cov., slope	2.8
23	Sandstone, white-green w. dk. buff, fine-med. sand, med. plan. wedge x-lam., top structurless,	

	burrowed?, eros. base, tabular shape, extensive bench, cliff	3.4
22	Mudstone, red w. red, green, and thin sandstone, structureless to small trough. x-lam., some discont. und. lam., cov. slope with thin ledges	10.4
21	Sandstone, lt. red-brown w. brown-buff, fine sand, med. plan. wedge x-lam., top structureless to discont. und. lam., eros. base, tabular shape, cliff	0.9
20	Mudstone, red w. red, green, cov., slope	3.4
	total:	44.1
	Salt Wash member, lower portion	
19	Sandstone, lt. buff w. buff-brown, fine-med. trough. x-lam., upper middle unit cont. horiz. lam., top burrowed, eros. base, cut-and-fill series, bench-cliff	12.7
18	Mudstone, red w. red, green, cov., slope	1.4
17	Sandstone, white w. red-brown, fine sand, med. trough. x-lam., eros. base, cliff	0.6
16	Mudstone, red w. red, green, cov., slope	3.3
15	Sandstone, lt. gray w. brown-buff, fine sand, med. plan. wedge and plan. tab. x-lam. to cont. horiz. lam., eros. base, cut-and-fill series, cliff	5.7
14	Mudstone, red w. red, green, top 0.2 m. cont. horiz. lam., mostly cov., slope	2.9
13	Sandstone, white w. brown, fine sand, small	1.1
	total:	27.7
	lower member	
12	Mudstone, red, green w. red, green, with very thin lenses of sandstone and siltstone, mostly cov., slope with ledges	14.3
11	Sandstone, white w. purple-brown, fine-med. sand, discont. und. lam., tabular shape	0.5
10	Mudstone, gray-green w. gray-red, cov., slope	3.8
9	Sandstone, white w. red-brown, fine-med. sand, cont. und. and horiz. lam., pinches and swells laterally, eros. base, lense shape, cliff	1.7
	total:	20.3
Summerville Formation		
8	Mudstone, red-gray w. red, top 2 m. cont. und. lam., some thin structureless sandstones exposed, mostly cov., slope	2.0
7	Sandstone, red w. red, very fine sand, structureless	0.4
6	Siltstone, red w. orange-red, cov., slope	1.6
5	Sandstone, red w. orange-brown, structureless	0.5
4	Siltstone, red w. orange-red, cov., slope	1.8
3	Sandstone, red w. red, fine sand, cont. horiz. lam. to small plan. tab. x-lam., base cov.	0.4
2	Siltstone, red w. orange-red, cov., slope	4.2
1	Sandstone, red-brown w. red-brown, fine sand, cont. horiz. lam. to small plan. tab. x-lam., base cov.	0.5

total section: 105.1

Stratigraphic Section, 4 E1/2 sec. 27, T22S, R19E,
Crescent Junction Quad.
Morrison Formation-Brushy Basin Shale Member

Unit	Description	Thickness
33	Mudstone, purple w. red, green, authigenic chert layer 5 cm. thick near top, cov., slope	10.5 m.
32	Sandstone, white w. white, med.-coarse sand, med. trough. x-lam., eros. base, bench	6.8
31	Mudstone, red w. red, green, mostly cov., slope	1.7
30	Sandstone, white-green w. brown-buff, fine-med. sand, med. plan. tab. x-lam., eros. base, lense shape, bench	0.9
29	Siltstone, green, red w. red, silt to very fine sand, cont. horiz. lam., thins and thickens laterally between sandstones	0.3
28	Sandstone, buff white w. brown, coarse sand, local granule-pebble conglom. at base of unit, med. trough. x-lam., eros. base, tabular shape, cliff	1.8
27	Siltstone, red, green, with green sandstone lenses, mostly cov., slope with thin ledges	3.5
26	Sandstone, gray-green w. brown-buff, med. sand, some granules at base, cont. und. to cont. horiz. lam., eros. base, lense shape, burrowed, ledge	0.9
25	Mudstone, green, cov., slope	3.3
24	Sandstone, green-gray w. gray, fine sand, structureless, tabular shape, ledge	0.4
23	Mudstone, green w. red, cov., slope	9.0
	Salt Wash member, upper portion	
22	Sandstone, white w. buff-gray, coarse sand, granules at base, med.-fine sand upward, med. trough. x-lam., eros. base, lense shape, cliff	6.4
21	Mudstone, red w. green, cov., slope	2.3
20	Sandstone, lt. gray w. brown, fine sand, med. plan. wedge x-lam., eros. base, lense shape, ledge	0.5
19	Mudstone, red w. green, some cont. horiz. to und. lam., mostly cov., slope	6.6
18	Sandstone, lt. gray w. brown-buff, fine sand, med. trough. x-lam., eros. base, ledge	0.6
17	Mudstone, red, cov., slope	1.6
16	Sandstone, white w. buff, fine sand, med. trough. x-lam., eros. base, tabular shape, top 1 m. burrowed, cliff	9.0
	total:	27.0
	Salt Wash member, lower portion	
15	Mudstone, red w. green, red, thin sandstone, forming ledge in cov. slope	11.6
14	Sandstone, white w. brown-buff, med. sand, granules ar base and within unit, med. trough. x-lam., cut-and-fill series, eros. base, lense shape, cliff	12.1
13	Siltstone, white w. green, silt to fine sand,	

Unit	Description	Thickness
	small trough. x-lam., gradational base, lense shape, poor outcrop	0.5
12	Sandstone, lt. buff w. brown, fine-med. sand, med. trough. x-lam., eros. base, lense shape, cliff	4.3
11	Mudstone, green-red w. red, mostly cov., slope	3.3
10	Sandstone, white w. buff, fine sand, discot. und. lam., eros. base, tabular shape, ledge	0.2
9	Mudstone, buff w. pink, cov., slope	1.9
8	Sandstone, white w. brown-buff, med. sand, med. trough. x-lam., eros. base, lense shape, cliff-bench	7.8
	total:	41.7
	lower member	
7	Siltstone, gray w. green, cov., slope	1.6
6	Siltstone, red w. gray-red, cov., slope	12.0
5	Sandstone, white w. buff, fine-med. sand, discont. und. lam., tabular shape, ledge	0.4
4	Siltstone, red-green w. red-green, silt to very fine sand, discont. to cont. und. and horiz. lam., cliff	1.6
3	Sandstone, buff w. buff, fine sand, cont. horiz. lam., eros. base, tabular shape ledge	0.3
	total:	15.9
Summerville Formation		
2	Mudstone, red w. red, cov., slope	3.0
1	Siltstone, red w. red, silt to fine sand, cont. horiz. to und. lam., ledge	0.3
	total section:	127.0

Stratigraphic Section 6, SW1/4 sec. 35, T21S, R16E, Green River Quad.

Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
20	Sandstone, gray-buff w. gray, fine-med. snd, top 6 m. granule-pebble conglom. med. trough. x-lam., small trough. x-lam., locally at base, top erodedd, lense shape, conglom. cuts into lower sandstone, cut-and-fill series, cliff	30.3 m.
	total:	30.3
	Salt Wash member, lower portion	
19	Mudstone, red-green, cov., slope	2.1
18	Sandstone, upper, gray w. buff, fine sand, structureless, eros. base, tabular shape, ledge; lower, gray w. buff, fine sand, discont. und. lam., cov. base, ledge	1.4
17	Mudstone, red-green, cov., slope	4.2
16	Sandstone, lt. gray w. brown-buff, fine sand, clay clasts in middle of unit, structureless, eros. base, lense shape, burrowed, ledge	0.8
15	Sandstone, lower, gray w. buff, fine sand, discont. und. lam., base cov., grades up to siltstone, ledge Sandstone, upper, gray w. buff, fine sand, discont. und. lam., eros. base, ledge, grades up to cov. mudstone slope	3.9

Unit	Description	Thickness
14	Mudstone, red-green, cov., slope	1.3
13	Sandstone, gray w. buff-brown, fine sand, discont. und. lam., eros. base, lense shape, ledge	0.7
12	Mudstone, red w. red, green, cont. horiz. lam., slope	1.7
11	Sandstone, gray-green w. brown-buff, fine sand, small trough. x-lam., cov. base, ledge	0.3
10	Mudstone, red, green, cov., slope	0.4
9	Sandstone, same as unit 11	0.2
8	Siltstone, red w. brown, discont. und. lam., poor outcrop	0.3
7	Sandstone, gray w. gray-brown, fine snd, cont. horiz. lam., eros. base, tabular shape, ledge	0.4
6	Siltstone, same as unit 8	0.1
5	Sandstone, white w. brown, fine sand, local granule conglom., med. trough. x-lam., cont. horiz. lam., grading up to small trough. x-lam. at top., eros. base, lense shape, cliff	6.0
4	Siltstone, red green w. red, green, cont. horiz. lam., slope	0.7
3	Sandstone, white w. brown-buff, fine sand, med. trough. x-lam., top 1 m. structureless, burrowed, eros. base, top gradational to siltstone, lense shape, cliff	2.6
	total:	28.1
	lower member	
2	Mudstone, green, calcareous nodules locally, cov., slope	4.5
	total:	4.5
	Summerville Formation	
1	Siltstone, yellow-red w. red-brown, silt to very fine sand, cont. horiz. lam. and strat., thin veins of gypsum cut lam., cliff	13.5
	total section:	71.9

Stratigraphic Section 10, E1/2 sec. 28, T23S, R20E, Thompson Quad.
Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
24	Sandsone, gray w. brown, med. sand, locally some granules near base, med. trough. x-lam., eros. base, top eroded, tabular shape, cliff, extensive bench	3.5m
23	Siltstone, red, green, cont. horiz. lam., poor exposure	0.4
22	Sandstone, gray w. brown, med. sand, structureless grading up to cont. horiz. lam., eros. base, tabular shape, cliff	1.6
21	Mudstone, red, green, cov., slope	3.3
20	Sandstone, w. black-brown, fine sand, small trough. x-lam., eros. base, lens shape, ledge	0.5
19	Mudstone, red, green, cov., slope	1.1
18	Sandstone, w. buff-brown, fine sand, med. trough. x-lam., eros. base, tabular shape, bench	1.5

17	Mudstone, red, cov., slope	3.3
16	Sandstone, w. buff-orange, med. sand, med. trough. x-lam., top 1 m. cont. horiz. lam., burrowed; base of most trough sets contains rip-up clasts; eros. base, tabular shape, cliff, bench	20.0
	Salt Wash member, lower portion total:	35.2
15	Mudstone, red, green w. red, green, discont. und. lam. in top 1.5 m., mostly cov., slope with thin sandstone ledges	4.9
14	Sandstone, w. gray, fine sand, structureless, lens shape, poor exposure	1.3
13	Mudstone, red, green, cov., slope	1.7
12	Sandstone, w. buff-brown, fine sand, tabular shape, series of sandstones separated by gradational siltstone layers: from base: small trough. x-lam.; same, burrowed; structureless, burrowed; small plan. tab. x-lam., burrowed; same; same; top 3 sandstones thinner than lower 3; ledges	3.9
11	Mudstone, red, green, mostly cov., top 1 m. contains thin sandstone lenses, slope	4.5
10	Sandstone, gray w. buff-brown, fine-med. sand, granules above eros. surfaces; lower sandstone: eros base, med. trough. x-lam., grading up to small trough. x-lam., to thin horiz. lam. siltstone; upper sandstone: same; lens shape, cliff, bench	4.0
9	Mudstone, cov., slope	2.5
8	Sandstone, w. buff-gray, fine sand, cont. und. lam., eros. base, lens shape, ledge	1.6
7	Mudstone, green, red, cov., slope	2.6
6	Sandstone, w. buff-gray, fine sand, med. trough. x-lam., base of most trough sets contains rip-up clasts, eros. base, lens shape, cliff	3.3
	lower member total:	30.3
5	Mudstone, gray, cov., slope	0.3
4	Limestone, gray, contains fine sand, poor exposure	0.3
3	Mudstone, red, cov., slope	8.0
2	Limestone, gray, finely crystalline, poor exposure	0.8
1	Mudstone, red, gray, cov., slope; basal sandstone: cont. und. lam., ledge	15.6
Summerville Formation	total:	25.0
	total section:	

Stratigraphic Section 11, Center Sec. 12, T24S, R20E
Moab Quad.
Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
38	Sandstone, white w. buff-whie, fine sand, local med. to coarse sand, multistory unit, med. trough. x-lam., locally structureless; each unit: eros. base, top burrowed, truncated	

	by unit above; entire unit: eros. base, top burrowed, tabular shape, bench	8.3m
37	Mudstone, red, green, cov., slope	1.5
36	Sandstone, buff-white w. buff, fine sand, structureless, eros. base, tabular shape, bench	2.3
35	Mudstone, red, green w. red, green, cont. horiz. lam., bottom half cov., top half cliff	5.0
34	Sandstone, pink-white w. brown-buff, fine sand, multistory unit, med. grading up to small trough. x-lam.; each unit: eros. base, top truncated by unit above, some x-lam. sets contain rip-up clasts; entire unit: eros. base, top burrowed, tabular shape, cliff, bench	10.7
	total:	27.8
	Salt Wash member, lower portion	
33	Mudstone, red, green, cov., slope	0.4
32	Sandstone, w. gray, fine sand, structureless, poor outcrop	0.3
31	Mudstone, red, green, cov., slope	0.6
30	Sandstone, gray-white w. brown-buff, fine sand, med. trough. x-lam., eros. base, top burrowed, lens shaped, cliff	2.2
29	Mudstone, red, green w. red, green, cont. horiz. lam., mostly cov., slope	1.5
28	Sandstone, w. gray-white, fine sand, structureless, lens shape, poor outcrop	0.3
27	Mudstone, red, cov., slope	3.6
26	Sandstone, gray-white w. gray-brown, fine sand, cont. und. lam., lens shape, ledge	0.5
25	Mudstone, cov., slope	1.9
24	Sandstone, buff-pink w. brown-buff, fine sand, discont. und. lam. grading up to med. trough. x-lam., tabular shape, ledge	0.9
23	Mudstone, red, green, cov., slope	3.2
22	Sandstone, white w. buff-brown, very find sand, small plan. tab. x-lam., grading up to med. trough. x-lam., to small trough. x-lam., eros. base, tabular shape, ledge	1.1
21	Mudstone, red, green, cov., slope	2.1
20	Sandstone, w. buff-black, fine sand, med. trough. x-lam., most trough sets contain rip-up clasts; eros. base, top burrowed, tabular shape, cliff, bench	3.8
	total:	22.4
	lower member	
19	Mudstone, red, green, mostly cov., slope	1.1
18	Sandstone, w. gray, fine sand, calcareous, discont. und. lam., poor exposure	0.2
17	Mudstone, gray, purple, cov., slope	2.2
16	Sandstone, w. buff-gray, fine sand, structureless, eros. base, tabular shape, ledge	0.6
15	Mudstone, red, green, cov., slope	0.8
14	Sandstone, w. buff-gray, fine sand, poor outcrop	0.2
13	Mudstone, red, gray, cov., slope	0.9

Unit	Description	Thickness
12	Sandstone, white w. red, fine sand, small plan. tab. x-lam., poor outcrop	0.3
11	Mudstone, red, cov., slope	2.8
10	Limestone, gray, contains fine sand, poor outcrop	0.3
9	Mudstone, gray, cov., slope	6.9
8	Sandstone, w. red, fine sand, structureless, calcareous, ledge	0.3
7	Mudstone, red, cov., slope	3.3
6	Sandstone, w. red, fine sand, structureless, chert nodules, poor exposure	0.4
	total:	20.3
Summerville Formation		
5	Mudstone, red, cov., slope	1.4
4	Sandstone, white w. red, fine sand, cont. und. to horiz. lam., tabular shape, ledge	0.5
3	Mudstone, red, cov., slope	4.0
2	Sandstone, red-gray w. red, fine sand, calcareous, cont. horiz. lam., tabular shape, ledge	0.4
1	Mudstone, red, cov., slope	3.1
	total:	9.4
Entrada Sandstone	total section:	79.9

Stratigraphic Section 13, SE1/4, sec. 26, T23S, R18E
Crescent Junction Quad.
Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
29	Sandstone, gray w. buff-white, med. sand, bottom 2 m. granule conglom., med. trough x-lam., eros. base, tabular shape, cliff, bench	6.0m
28	Mudstone, red-green, cov., slope	3.0
27	Mudstone, red-green, cov., and sandstone, gray, fine sand, small trough. x-lam., lens shape, ledge	0.6
26	Sandstone, lt. gray w. buff, fine-med. sand, small-med. trough. x-lam., locally granule conglom., eros. base, tabular shape, cliff, bench	3.2
25	Mudstone, green, red, cov., slope	1.5
24	Sandstone, white w. buff, fine sand, small trough. x-lam., eros. base, tabular shape, burrowed, ledge	0.3
23	Mudstone, green, red, cov., slope	0.9
22	Sandstone, pink-buff w. buff-brown, med. sand, locally granule-pebble conglom., siltstone and limestone clasts, med. trough. x-lam., bottom 1.2 m cont. horiz. lam., eros. base, tabular shape, bench, cliff	11.2
21	Mudstone, red, green, cov., slope	3.2
20	Sandstone, lt. buff w. orange-brown, med. sand, multistory unit, med. trough. x-lam., bases of units eros., tabular shape, cliff	14.5
	Salt Wash member, lower portion total:	45.1
19	Siltstone, red-green w. red-green, cont. horiz.	

	lam., cliff	1.9
18	Sandstone, white w. buff., find sand, med. to small trough. x-lam., eros. base, lens shape, burrowed, cliff	1.2
17	Mudstone, red, green, cov., slope	8.7
16	Sandstone, white w. gray, fine sand, structureless, poor outcrop	0.3
15	Mudstone, red, green, cov., slope	1.7
14	Sandstone, pink-buff w. buff, fine sand, med. plan. tab. x-lam., tabular shape, poor outcrop	0.8
13	Mudstone, red, green, with thin sandstone ledges, cov., slope	6.3
12	Sandstone, white w. buff-brown, med.-coarse sand, locally granule conglom., med. to local small trough. x:lam., eros. base, lens shape, cliff	5.7
11	Sandstone: top: white w. buff, fine sand, med. trough. x-lam., eros. base; middle: white w. buff, fine sand, small trough. x-lam., eros. base; bottom: white w. brown, fine-med. sand, structureless, eros. base; each unit grades up to siltstone, ledge-slope	1.3
10	Sandstone, white w. brown-buff, med. sands locally coarse sand, med. trough x-lam., eros. base, lens shape, bench, cliff	6.4
	lower member total:	34.3
9	Mudstone, red-green w. red-green, cont. horiz. lam., cliff	0.9
8	Sandstone, buff w. buff-brown, fine sand, discont. und. lam., eros. base, lens shape	0.6
7	Mudstone, red, green, cov., slope	4.3
6	Limestone, gray, micritic with local coarse crystalline pockets, poor outcrop, ledge	0.3
5	Mudstone, gray w. green cov., slope	0.3
4	Limestone, red-brown, contains silt and fine sand, ledge	0.4
3	Mudstone, red w. gray, cov., slope	1.7
2	Limestone, purple-gray, micritic with crystalline patches, ledge	0.8
1	Mudstone, red w. gray, with sandstone: white w. white, fine sand, discont. und. lam.; cov., slope with ledges	8.3
Summerville Formation	total:	17.6
	total section:	

Stratigraphic Section 14, S1/2, sec. 35, T22S, R20E
Thompson Quad.
Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
30	Conglomerate, gray w. gray, granules supported by matrix of med. sand, med. trough. x-lam., top eroded, eros. base, tabular shape, cliff, bench	5.3m
29	Mudstone, red w. gray, mostly cov., slope	3.3
28	Sandstone, gray w. gray-buff, fine sand, cont.	

	horiz. lam., grading laterally to med. trough. x-lam., eros. base, lens shape, cliff	0.4
27	Mudstone, red, cov., slope	0.9
26	Sandstone, pink-gray w. red-green, fine sand, disc. und. lam., eros. base, lens shape, ledge	0.5
25	Mudstone, red, green, cov., slope	1.8
24	Sandstone, buff w. brown, med. sand, med. trough. x-lam., eros. base, tabular shape, bench	0.7
23	Mudstone, red, green, cov., slope	8.2
22	Sandstone, buff-gray w. buff, med. sand, med. trough. x-lam., grading up to small trough. x-lam., base eros., locally small trough. x-lam., tabular shape, bench	4.3
	Salt Wash member, lower portion total:	25.4
21	Mudstone, red, green, cov., slope	4.8
20	Sandstone, gray w. gray, fine sand, structureless, poor outcrop	0.3
19	Mudstone, red, green, cov., slope	3.6
18	Sandstone, gray w. brown, small trough. x-lam., poor outcrop	0.5
17	Mudstone, green, red, cov., slope	3.2
16	Sandstone, gray, fine sand, srtructureless, poor outcrop	0.5
15	Mudstone, gray, green, cov., slope	0.6
14	Sandstone, white w. buff, fine sand, small trough. x-lam., eros. base, tabular shape, bench	1.2
13	Siltstone, gray-green, silt to fine sand, structureless, slope	0.7
12	Sandstone, same as 14	0.6
11	Mudstone, green, red, cov., slope	1.0
10	Sandstone, same as 14	0.6
9	Mudstone, red, cov., slope	1.6
8	Sandstone, buff-brown, fine sand, med. trough. x-lam., top 1.2 m. cnt. horiz. lam., eros. base, top burrowed, tabular shape, cliff, bench	8.0
7	Mudstone, red-green w. red, green, with thin structureless sandstones, mostly cov., slope with ledges	3.2
6	Limestone, gray, with fin sand and crystalline patches, poor exposure	0.3
5	Mudstone, red, gray-green, cov., slope	7.2
4	Sandstone, green-gray w. buff-gray, fine sand, med. to small trough. x-lam., eros. base, tabular shape, bench	0.9
	lower member total:	38.9
3	Mudstone, red-irange, cov., slope	4.3
2	Limestone, gray-purple, contains silt and fine sand, ledge	0.4
1	Mudstone, red, cov., broken by sandstones, from base: cont. horiz. lam.; structureless; cont. und. lam.; small trough. x-lam.; slope with ledges	9.0
	total:	13.7
	Summerville Formation	
	total section:	

Stratigraphic Section 15, center sec. 12, T23S, R21E, Thompson Quad.
Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
49	Sandstone, white-gray w. buff-brown, fine sand, med. trough. x-lam. grading vert. and lateral. to cont. horiz. lam., eros. base, top burrowed, locally structureless, tabular shape, cliff, extensive bench	6.6m
48	Mudstone, dk. red, cov., slope	0.5
47	Sandstone, white w. buff-red, med. sand, med. trough. x-lam., local horiz. lam., eros. base, tabular shape, bench	1.6
46	Mudstone, purple-red, cov., slope	1.5
45	Sandstone, white-green w. red-buff, fine-med. sand, multistory unit; base: cont. horiz. lam.; grading up to med. trough. x-lam.; most sets contain rip-up clasts; entire unit; eros. base, lens shape, bench	4.7
44	Mudstone, red-green w. red, green, cont. horiz. lam., with thin sandstones and thin siltstones, cliff with resistant ledges	5.5
43	Sandstone, same as 45	6.3
	total:	26.7
	Salt Wash member, lower portion	
42	Mudstone, gray-green, cov., slope	6.4
41	Sandstone, w. white-gray, fin sand, structureless to med. trough. x-lam., eros. base, poor outcrop, ledge	1.6
40	Mudstone, red, cov., slope	1.2
39	Sandstone, w. brown, fine sand, med. trough. x-lam. truncated by cont. horiz. lam., grading up to small trough. x-lam., eros. base, top burrowed, tabular shape, bench	1.3
38	Mudstone, gray, red, cov., slope	1.6
37	Sandstone, white-green w. brown, fine sand, med. trough. x-lam., eros. base, tabular shape, ledge	1.1
36	Mudstone, gray, red, cov., slope	1.7
35	Sandstone, white w. brown, fine sand, discont. und. lam. grading up to small trough. x-lam., eros. base, top burrowed, tabular shape, ledge	0.4
34	Mudstone, red, gray, cov., slope	1.9
33	Sandstone, pink-gray w. buff-brown, fine sand, med. trough. x-lam., top 1 m. cont. horiz. lam., burrowed, eros. base, lens shape, bench	2.2
	total:	19.4
	lower member	
32	Mudstone, red, green, cov., slope	1.0
31-27	Series of thin sandstones and siltstones, calcareous, structureless, poor exposure	0.6
26	Mudstone, red, green, cov., slope	1.1
25	Sandstone, w. gray-green, fine sand, structureless, ledge	0.2

24	Mudstone, red, green, cov., slope	1.2
23-18	Series of sandstones, gray-purple, fine sand, calcareous, structureless, ledges, separated by cov. red-gray slopes	2.6
17	Sandstone, white w. brown, fine sand. med. trough. x-lam., some rippled trough surfaces at top, eros. base, lens shape, ledge	0.8
16	Mudstone, red, gray, cov., slope	1.1
15-5	Series of thin sadstones, gray, fine sand, calcareous, med. trough. x-lam. to structureless, separated by thin sandy siltstones, ledges	2.1
4	Mudstone, gray, red, cov., slope	1.7
3	Sandstone, purple, fine sand, calcareous, poor exposure	0.2
2	Mudstone, red, cov., slope	1.4
1	Mudstone, red, gray, cov., slope, broken by limestone, purple-gray, some red chert nodules, and basal sandstone, w. red, fine sand, granule layer at base, discont. und. lam. to small trough. x-lam. at top, eros base	14.6
	total:	28.6
Summerville Formation	total section:	74.7

Stratigraphic Section 16, NE1/4, sec. 2, T23S, R22E, Cisco Quad.

Morrison Formation-Brushy Basin Shale Member

Unit	Description	Thickness
26	Conglomerate, w. yellow-buff, granules supported in matrix of med.-coarse sand, med. trough. x.-lam., eros. base, top eroded, tabular shape, bench	2.0m
25	Mudstone, red, cov., slope	6.0
	Salt Wash member, upper portion	
24	Sandstone, w. buff-gray, med. sand, local granules, cont. horiz. lam. grading up to med. trough. x-lam., tabular shape, bench	2.4
23	Mudstone, red, horiz. lam., slope	1.4
22	Sandstone, gray w. brown-black, fine sand, structureless, poor outcrop	0.6
21	Mudstone, red, cov., slope	1.5
20	Sandstone, w. buff-gray, fine-med. sand, med. trough. x-lam., grading up to cont. horiz. lam., eros. base, tabular shape, extensive bench	4.4
19	Mudstone, red w. red, green, siltstone, green, horiz. lam., cliff	3.4
18	Sandstone, pink-gray w. buff-brown, fine sand, mostly structureless, some discont. und. lam., lens shape, bench	0.9
17	Mudstone, red, gray, cov., slope	0.6
16	Sandstone, pink w. red-brown, fine sand, med. plan. tab., eros. base, lens shape, ledge	0.2
15	Mudstone, red, cov., slope	3.3
14	Sandstone, w. gray, med. sand, cont. horiz. lam. grading up to med. trough. x-lam., top	

	burrowed, lens shape, ledge	1.1
13	Mudstone, gray, red, cov., slope	0.5
12	Sandstone, gray w. gray, fine sand, med. trough. x-lam. grading up to cont. horiz. x-lam., top burrowed, eros. base, tabular shape, bench	2.0
11	Mudstone, red, cov., slope	1.8
10	Sandstone, w. buff-gray, med. sand, med. trough. x-lam. at top, eros. base, tabular shape, bench	3.3
9	Mudstone, gray, cov., slope	1.8
8	Sandstone, white w. gay, fine sand, mostly structureless, some discont. und. lam., eros. base, lens shape, ledge	0.6
7	Mudstone, gray, cov., slope	1.5
	total:	31.3
	Salt Wash member, lower portion	
6	Sandstone, gray w. gray buff, fine sand, multistory unit; lower unit: eros. base, cont. horiz. lam. grading up to med. trough. x-lam. up to cont. horiz. lam.; middle unit: eros. base, med. trough. x-lam.; top unit: eros. base, med. trough. x-lam.; entire unit: top burrowed, lens-tabular shape, bench	16.0
	total:	16.0
	lower member	
5	Mudstone, siltstone, sandstone series, red, purple, buff, cont. horiz. lam., lower 2/3 cov., slope, upper 1/3 cliff	13.5
4	Limestone, gray, micrite, tabular shape, ledge	0.2
3	Mudstone, gray, red, cov., slope	2.1
2	Sandstone, white-green w. gray, fine sand, cont. und. lam., poor outcrop	0.3
	total:	16.1
Summerville Formation		
1	Mudstone, red, cont. horiz. lam., cliff-slope	0.7
	total section:	72.1

Stratigraphic Section 17, S1/2, sec. 5, T23S, R24E, Cisco Quad.

Morrison Formation-Brushy Basin Shale Member

Unit	Description	Thickness
23	Sandstone, lt. buff w. white, med. sand, med. trough. x-lam., eros. base, top eroded, tabular shape, bench	0.9m
22	Mudstone, red, cov., slope	6.4
	Salt Wash member, upper portion	
21	Sandstone, lt. buff w. buff, med. trough. x-lam., eros. base, top eroded, extensive bench	8.0
20	Mudstone, red, with thin sandstone, w. gray, structureless, slope with ledges	2.3
19	Sandstone, gray w. buff, med. sand, multistory unit; each unit: eros. base, cont. horiz. lam., grading up to med. trough. x-lam., truncated by unit aboe, most trough sets contain rip-up	

	clasts; entire unit: eros. base, top burrowed, tabular shape, extensive bench	11.4
18	Sandstone, w. buff, fine sand, silt, discont. und. lam., lens shape, ledge	1.4
	total:	23.1
	Salt Wash member, lower portion	
17	Mudstone, siltstone, sandstone, green, gray, purple, horiz. lam. to thinly strat., cliff with thin ledges	6.2
16	Mudstone, red, gray, cov., slope	1.4
15	Sandstone, white-gray w. buff, fine sand, structureless, eros. base, top borrowed, ledge	0.7
14	Mudstone, red, gray, cov., slope	1.3
13	Sandstone, lt. gray w. brown, fine sand, med. trough. x-lam., eros. base, top burrowed, lens shape, cliff	1.5
12	Sandstone, gray-green w. gray-buff, fine sand, small trough. x:lam. interlayered with gradational siltstone layers, poor exposure, ledges	1.3
11	Mudstone, red, gray, cov., with thin sandstone w. gray, fine sand, structureless to small trough. x-lam., ledge, slope	3.5
10	Mudstone, red, gray, cov., with thin sandstone w. gray-green, poor exposure, slope	1.2
9	Sandstone, w. gray, fine sand, structureless, top burrowed, lens shape, ledge	0.4
8	Mudstone, red, cov., slope	3.5
7	Mudstone, red, cov., with thin sandstone, green w. red-brown, fine sand, discont. und. lam., lens shape, ledge, slope	2.8
6	Sandstone, white w. buff, fine sand, med. to small trough. x-lam., eros. base, fossil fern imprints in top 50 cm, lens shape, cliff	1.6
	total:	25.3
	lower member	
5	Mudstone, red, cov., with thin sandstone, white w. gray, fine sand, calcareous, some red chert nodules, slope, ledges	9.4
4	Sandstone-siltstone series; fro, top: pink w. red, fine sand, discont. und. lam. to small trough x-lam., tabular shape; white w. buff-red, fine sand, structureless, grades up to siltstone, tabular shape; gray w. red-buff, fine sand, cont. und. lam., thin concordant gypsum vein, grades up to horiz. lam. siltstone, tabular shape; white w. gray-buff, fine sand, cont. und. lam., top rippled, crystal casts, grades up to red horiz. lam. sltstone, tabular shape; white w. red, fine sand, small plan. tab. x-lam., grades up to silt-stone, tabular shape; white w. red, fine sand, cont. to discont. und. lam., grades up to silt-stone, tabular shape; white w. red, fine sand, cont. und. lam., locally small plan. tab. x-lam., grades up to red, green siltstone, tabular shape;	

entire unit, ledges 8.7

total: 18.1

Summerville Formation

3 Mudstone, red, green, mostly cov., horiz. lam., cliff, slope 6.3

2 Sandstone, white w. red, fine sand, discont. und. lam., lens shape, ledge 0.4

1 Mudstone, red, cov., with thin sandstone at base, white w. red, fine sand, structureless, lens shape, poor exposure 1.6

total: 18.1

Entrada Sandstone total section: 82.1

Stratigraphic Section 22, E1/2 sec. 30, T22S, R20E, Crescent Junction Quad.

Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
16	Sandstone, lt. gray w. gray-brown, med.-coarse sand, locally granule conglom. in upper part of unit, med. trough. x-lam. with some cont. horiz. lam., eros. base, top eroded, tabular shape, cliff, bench	11.3m
15	Mudstone, red, cov., with thin sandstone ledges, slope	7.7
14	Sandstone, lt. gray w. gray-brown, fine sand, cont. horiz. lam. grading up to med. trough. x-lam., eros. base, tabular shape, cliff, bench	8.3
	Salt Wash member, lower portion total:	27.3
13	Mudstone, red, cov., slope	6.6
12	Sandstone, lt. gray w. buff, med. sand, med. trough. x-lam., eros bae, top burrowed, tabular shape, cliff, bench	2.1
	lower member total:	8.7
11	Mudstone, red, cov., slope	9.1
10	Sandstone, gray-green w. gray-brown, fine sand, structureless, ledge	0.3
9	Mudstone, red, cov., slope	8.0
8	Limestone, gray-reds contains silt, crystalline patches, thin tabular ledge	0.3
7	Mudstone, red, cov., slope	1.4
6	Sandstone, gray-red w. gray-buff, silt to fine sand, discont. horiz. lam. to small trough. x-lam., eros. base, tabular shape, ledge	0.8
5	Mudstone, red, cov., slope	1.8
4	Sandstone, red-gray w. gray-buff, fine sand, cont. horiz. lam., eros. base, tabular shape, ledge	0.7
	Summerville Formation total:	22.4
3	Mudstone, red, cov., slope	0.6
2	Sandstone, red w. red-brown, fine med. sand, med. plan. tab. x-lam., tabular shape, ledge	0.5
1	Mudstone, red, cov., slope	1.4
	Entrada Sandstone total:	2.5
	total section:	

Stratigraphic Section 23, N1/2, sec. 1, T23S, R19E, Crescent Junction Quad.

Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
27	Conglomerate, yellow-buff w. brown, granules sup. by matrix of med. sand, med. trough. x-lam., eros. base, tabular shape, top eroded, cliff, bench	4.5m
26	Siltstone, red-purple, silt with very fine sand, cont. horiz. lam., slope	2.7
25	Sandstone, buff-orange w. buff, fine sand, multistory unit, base: cont. horiz. lam., med. plan. tab. x-lam., truncated above by med. trough. x-lam., grading up to structureless sand, top of some units burrowed, eros. base, tabular shape, cliff, bench	7.8
24	Mudstone, red, cov., slope, broken by thin sandstone ledge	5.9
23	Sandstone, white w. buff, fine-med. sand, multistory unit, base: med. trough. x-lam., truncated by med. plan. wedge. x-lam., grading up to small trough. x-lam., truncated by cont. horiz. lam., truncated by med. trough. x-lam., truncated by discont. horiz. x-lam., eros. base, tabular shape, cliff, bench	5.2
	Salt Wash member, lower portion total:	26.1
22	Mudstone, red, cov., slope	3.4
21	Sandstone, lt. gray w. gray-buff, fine sand, structureless, burrowed, tabular, ledge	0.4
20	Mudstone, red, cov., slope	0.7
19	Sandstone, white w. buff, fine sand structureless, upper and lower unit with eros. bases, top burrowed, lens shape, ledge	2.3
18	Mudstone, red-brown, cov., slope	5.2
17	Sandstone, buff w. brown, fine sand, small trough. x-lam., lens shape, ledge	0.5
16	Siltstone, red, horiz. lam., slope	0.2
15	Sandstone, gray w. brown, silt to fine sand, structureless to horiz. lam., top burrowed, eros. base, lens shape, poor outcrop	0.8
14	Siltstone, red, horiz. lam., slope	0.4
13	Sandstone, gray w. brown, fine sand, series of thin sandstones: bottom: discont. horiz. lam., burrowed; grading up to small plan. wedge. x-lam., grading up to structureless, grading up to cont. horiz. lam., all separated by thin siltstones; eros. base, tabular shape, ledges	2.5
12	Mudstone, red, cov., with sandstone, gray, structureless, slope with ledge	3.7
11	Sandstone, buff w. brown, find sand, discont. und. lam., burrowed, lens shape, ledge	0.6
10	Mudstone, red, cov., with thin sandstone at top 1 m., slope with ledge	4.0

9	Sandstone, gray w. brown, fine sand, small trough. x-lam., tabular shape, ledge	0.2
8	Sandstones, same as 9, separated by thin siltstones, ledges	2.0
7	Sandstone, same as 9	0.2
6	Mudstone, red, cov., slope	1.0
5	Sandstone, buff w. brown, med. sand, med. plan. wedge. x-lam., grading up to med. trough. x-lam., eros. base, tabular shape, bench	1.4
	total:	29.5
	lower member (incomplete)	
4	Mudstone, red, cov., slope	0.8
3	Sandstone, buff w. red-brown, very fine sand, structureless with some discont. und. lam., eros. base, lens shape, ledge	0.6
2	Mudstone, red, cov., slope	2.0
1	Limestone, gray-pink, contains silt to fine sand, structureless	0.7
	total (incomplete):	4.1
	total section:	

Stratigraphic Section 26, SW1/4, sec. 19, T22S, R17E, Green River Quad.
Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
25	Sandstone, buff w. white, fine sand, cont. horiz. lam., some med. trough. x-lam., eros. base, top eroded, tabular shape, extensive bench	4.9m
24	Mudstone, gray, cov., slope	1.9
23	Sandstone, gray w. buff, fine sand, cont. horiz. lam., thin siltstone in middle, gradational contacts, lens shape	0.8
22	Mudstone, gray, cov., slope	0.4
21	Sandstone, in descending order: gray w. buff, fine sand, structureless, some discont. und. lam., eros. base, lens shape; gray w. buff, fine sand, small trough. x-lam. at base, grading up to horiz. lam. siltstone, tabular shape; gray w. buff, fine sand, med. trough. x-lam., eros. base, lens shape	4.1
	Salt Wash member, lower portion total:	12.1
20	Mudstone, gray w. green, cov., slope	1.6
19	Sandstone, gray w. buff, fine sand, discont. und. lam., eros. base, ledge	0.4
18	Siltstone, gray w. brown, structureless, slope	0.2
17	Sandstone, brown w. buff, fine sand, small plan. wedge. x-lam., eros. base, ledge	0.3
16	Mudstone, red, green, cov., slope	5.1
15	Sandstone, lt. green w. buff, fine sand, discont. und. lam., eros. base, ledge	0.4
14	Siltstone, dk. gray w. brown, cov., slope	0.6
13	Sandstone, buff w. gray-buff, fine sand, small trough. x-lam. grading up to siltstone, structureless, series of 3 sandstones, ledge	1.1

12	Mudstone, gray, cov., slope	0.3
11	Limestone, gray, contains fine sand and silt, mostly cov., ledge	0.2
10	Mudstone, gray, and sandstone, gray, fine sand, mostly cov., slope with resistant ledge	1.7
9	Sandstone, gray w. buff., fine sand, base: eros., structureless to discont. und. lam.; middle: small trough. x:lam., top: climbing ripples grading into mudstone; tabular shape, bench	0.9
8	Mudstone, gray, cov., slope	0.7
7	Sandstone, buff w. gray-buff, fine sand, small trough. x-lam., eros. base, lens shape	1.1
	lower member total:	14.6
6	Mudstone, gray, cov., slope	1.5
5	Limestone, gray, contains red chert, tabular shape, ledge	0.3
4	Mudstone, red-green w. gray-green, cov., slope	5.1
3	Gypsum, gray, with red and green siltstone, structureless, cliff-slope	7.9
2	Siltstone, green w. gray-green, silt to fine sand, cont. horiz. lam., eros. base with granules, unconformity at base, slope	2.7
Summerville Formation	total:	17.5
1	Siltstone, red w. red, cont. horiz. lam., gypsum veins, slope	1.0
	total section:	45.2

Stratigraphic Section 28, NE1/4, sec. 5, T23S, R22E, Thompson Quad.

Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
38	Sandstone, w. brown-buff, fine sand, locally granules, med. trough. x-lam., upper 1/3 cont. horiz. lam., most trough sets contain granules along lower bounding surface, eros. base, top eroded, tabular shape, extensive bench	7.6m
37	Mudstone, red, green, cov., slope	7.9
36	Sandstone, w. brown-buff, structureless, burrowed, poor exposure	0.5
35	Mudstone, red, cov., slope	6.9
34	Sandstone, lt. gray w. white, fine sand, med. trough. x-lam., locally cont. horiz. lam., eros. base, tabular shape, bench	1.9
33	Mudstone, gray, green, cov., slope	1.7
32-31	Sandstone, yellow w. white-buff, fine sand, multistory unit: from base; small plan. tab. x-lam., truncated by med. trough. x-lam., truncated by cont. horiz. lam. grading up to med. trough. x-lam.; horiz. lam. to trough. x-lam. series repeated upward; entire unit: eros. base, top burrowed, tabular shape, bench, cliff	6.9
30	Mudstone, gray, cov., slope	1.4

29	Sandstone, w. gray, fine sand, small trough. x-lam., eros. base, lens shape, ledge	0.4
	total:	35.2
	Salt Wash member, lower portion	
28	Mudstone, red, gray, cov., slope	4.2
27	Sandstone, pink w. red, fine sand, small trough. x-lam., poor outcrop	0.2
26	Mudstone, red, horiz. lam., slope	0.2
25	Mudstone, red, cov., with thin structureless sandstone, slope, ledge	1.1
24	Sandstone, w. gray, fine sand, cont. horiz. lam. grading up to med. trough. x-lam., eros. base, top burrowed, tabular shape, cliff, bench	1.5
23	Mudstone, red, cov., slope	0.8
22	Sandstone, gray w. buff, fine sand, small trough. x-lam., lens shape, ledge	1.0
21	Mudstone, gray-red, cov., slope	1.0
20	Sandstone, w. gray, fine sand, structureless, poor outcrop	0.2
19	Mudstone, red-gray, cov., slope	0.2
18	Sandstone, gray w. brown, fine sand, cont. horiz. lam., grading up to med. trough. x-lam., up to horiz. lam. siltstone, grading up to med. trough. x-lam., top burrowed, base eros., tabular-lens shape, bench	1.3
	total:	11.7
	lower member	
17-13	Mudstone, red-gray, green, cov., with thin sandstones, structureless, fine sand, slope with ledges	4.3
12	Sandstone, w. brown, fine sand, structureless grading up to siltstone up to small trough. x-lam., structureless sandstone burrowed, lens shape, ledge	1.0
11-3	Mudstone, red, gray, cov., with thin sandstones, gray w. brown, fine sand, structureless to discont. und. lam., slope, ledges	8.2
2	Limestone, red-purple, contains silt, poor outcrop	0.2
1	Mudstone, red, horiz. lam., thin siltstones and limy sandstones interstratified, slope, ledges	3.6
	total:	17.3
Summerville Formation	total section:	64.2

Stratigraphic Section 29, W1/2, sec. 5, T23S, R23E, Cisco Quad.

Morrison Formation-Salt Wash member, upper portion

Unit	Description	Thickness
27	Sandstone, gray w. buff, med. sand, granules, med. trough. x-lam., local cont. horiz. lam., most trough sets contain granules along lower bounding surface, eros. base, top eroded, tabular shape, extensive branch	3.1m

26	Mudstone, red, cov., and siltstone-sandstone, thinly strat., red, purple, gray, mostly cov., slope, ledges	3.8
25	Sandstone, w. red-brown, fine sand, structureless, eros. base, tabular shape, top burrowed, bench	0.5
24	Mudstone, red, purple, cov., slope	3.9
23	Sandstone, gray w. red, fine sand, small trough. x-lam., eros. base, top burrowed, lens shape, ledge	0.4
22	Mudstone, red, purple, cov., slope	4.0
21	Sandstone, buff w. brown, fine-med. sand, multistory unit, med. trough. x-lam., locally grading into cont. horiz. lam., eros. base, tabular shape, extensive bench	8.7
20	Mudstone, green, gray, mostly cov., with thin limestone outcrop, poorly exposed, slope	6.3
19	Sandstone, buff w. yellow-brown, fine sand, multistory unit, med. trough. x-lam. grading up to small trough. x-lam., locally small plan. wedge x-lam., most trough sets contain rip-up clasts along lower surfaces; eros. base, tabular shape, bench	4.6
	total:	35.3
	Salt Wash member, lower portion	
18	Mudstone, siltstone, red-green, silt with very fine sand interstratified with horiz. lam. mudstone, cliff	1.9
17	Mudstone, gray, cov., slope	1.6
16	Sandstone, white w. buff-gray, fine sand, structureless, local discont. und. lam., lens shape, ledge	1.5
15	Sandstone, gray w. buff-brown, fine sand, structureless grading up to small trough. x-lam., truncated by cont. horiz. lam., top burrowed, grading up to mudstone, gray, cov., ledge, slope	2.4
14	Mudstone, red, cov., slope	3.2
13	Sandstone, buff w. brown, fine sand, small trough. x-lam., eros. base, top burrowed, lens shape, bench	1.0
12	Mudstone, red, cov., with thin sandstone, structureless, burrowed, slope	2.3
11	Sandstone, buff w. brown, fine sand, med. trough. x-lam., local horiz. lam., eros. base, top burrowed, tabular shape, bench	2.2
	total:	16.1
	lower member	
10	Mudstone, red, cov., slope	1.5
9	Limestone, gray-purple, silty, poor outcrop	0.2
8	Mudstone, red, cov., slope	0.3
7	Sandstone, white w. gray, fine sand, small plan. tab. x:lam., eros. base, lens shape, ledge	0.4
6	Mudstone, red, horiz. lam., mostly cov., slope	1.9
5	Limestone, gray, blocky outcrop, with gray mudstone slope; chert, red, gray, blue, nodules	

	in limestone, ledges	1.7
4	Mudstone, red, cov., slope	1.4
3	Sandstone, gray w. buff-brown, fine sand, granules at base, structureless, local discont. und. lam., eros. base, lens shape, ledge	0.7
2	Mudstone, red, cov., slope, with sandstone, same as 3, base of lower member, ledge	4.5
	total:	12.6
Summerville Formation		
1	Mudstone, red, cov., slope	3.4
	total:	3.4
Entrada Sandstone	total section:	67.4

APPENDIX B

Textural analysis

Sample selection--Samples were selected from hand specimens collected during the field season. Selection was based on achieving a representative vertical and horizontal distribution of samples from the study area.

Sample preparation--Samples of 80-200 grams were used. Dry weight was recorded to 0.005 g. Samples were disaggregated in 20 percent HCl solution; disaggregation was complete when addition of fresh acid to the sample failed to produce a reaction when stirred. The disaggregated individual samples were centrifuged to remove the acid solution without loss of fine material. The washed disaggregate was then mixed with 300 ml distilled water and 20 ml of 50 g/l Calgon dispersant solution, stirred for 5 minutes, and allowed to stand for 24 hours. If flocculation occurred, the washing procedure was repeated.

Hydrometer analysis--The Calgon solution-sample mixture was flushed into a 1000 ml settling tube. Distilled water was added to bring the contents to 1000 ml exactly. The mixture was stirred for 1 minute. Hydrometer readings were taken following this at time intervals derived by solution of Stokes' Law. These readings reflect the density of material remaining in suspension which is equal to and finer than whole-phi increments:

4 phi--35 seconds after settling begins
5 phi--2 minutes 36 seconds
6 phi--12 minutes
7 phi--40 minutes
8 phi--3 hours

A correction factor for the Calgon solution was determined by allowing the hydrometer to come to equilibrium in 1000 ml of distilled water-Calgon solution equivalent to the solution mixed with the sample. Corrected hydrometer readings yielded values in grams/liter which were equivalent to the weight in grams of sediment of each size range in the total sample.

Pipette analysis--The sample was again stirred for 1 minute and allowed to settle. After 30 minutes, 20 ml of the solution was withdrawn by pipette from 2 cm depth in the settling tube (time and depth based on solution of Stokes' Law). This portion of solution plus suspended sediment was placed in a drying dish previously weighed to 0.00005 g. and dried in a 100 degrees Celsius oven. Correction for the weight of Calgon was made by drying and weighing 20 ml of equivalent Calgon-distilled water solution. The dry weight of sediment in the drying dish minus the Calgon correction yielded a weight for the amount of material 8 phi and finer in size in 1/50th of the sample; 50 times this value equalled the weight in grams of material 8 phi and finer (clay size) in the total sample.

Sieve analysis--The total sample was wet-sieved through a 230-mesh (4 phi) screen to remove clay and silt, which were found to absorb water from the air and gum up the sieve set. The sand portion remaining on the screen was dried and weighed to 0.005 g. The sand was then sieved through a set of US Standard testing sieves at quarter-phi intervals from -1.00 phi to +4.00 phi. Each sample was sieved on a Ro-Tap for 15 minuted. Each quarter- phi fraction was weighed, and the total sample was weighed again to detect loss or gain during the sieving process.

Inclusive size analysis--The data from the sieve, hydrometer, and pipette analyses was analysed by a Fortran IV computer program entitled SIVQRT.FOR modified by Robert Brod and Scott Anderholm of New Mexico Institute of Mining and Technology in 1979. Results are weight percent and cumulative weight percent for each quarter-phi fraction (sand size) and whole-phi fraction (silt and clay size); histogram and cumulative arithmetic curve; and the statistical parameters of Folk (1974). Of these parameters, the graphic mean, inclusive graphic standard deviation (sorting), inclusive graphic skewness, and graphic kurtosis are used in this study,as recommended by Folk (1974).

Reliability--Several factors influence the reliability of the data presented.

1) Aggregates of grains cemented with silica occur in many of the Salt Wash sandstones. These rocks do not totally disaggregate in HCl. This was a major problem; of 23 samples tested, only the 8 used in this analysis disaggregated to a useable degree. These 8 samples also contain aggregates of grains, but examination under the binocular microscope showed that aggregates make up a maximum of 4 percent and an average of 1 percent of any size class.

2) Much of the clay and silt in the sandstones is probably due to the presence of clay and silt clasts in the rock. This material only partially dissolved or dispersed in some samples, completely in others, but its origin was not as original matrix. The suspension population of the samples is not a true reflection of that particular transport class.

3) Flocculation and initial lack of disaggregation of clay and silt contributes to the larger size classes rather than the clay and silt sizes. While this offsets factor 2, it does not make the results more accurate.

4) Precision of hydrometer and pipette and accuracy of measurements introduce error into the results. These influences are difficult to assess.

For these reasons, interpretation of the size analysis is purposely only general and is limited to the major populations. Subpopulations are not considered.

Results are summarized and shown graphically below.

Sample Number	Graphic Mean (phi)	Inclusive Graphic Standard Deviation		Inclusive Graphic Skewness		Graphic Kurtosis	
11-3-1	2.68	0.75	M	0.32	SF	1.52	VL
13-3-1	4.24	0.95	M	0.17	F	1.07	M
10-10-1	3.37	0.66	MW	0.40	SF	2.02	VL
12-10-1	3.12	0.85	M	0.42	SF	1.41	L
23-3-1	2.77	0.56	MW	0.09	NS	1.58	VL
27-3-1	2.55	0.50	M	0.27	F	1.33	L
36-11-1	2.99	0.67	MW	0.35	SF	2.55	VL
24-10-1	2.18	1.16	P	-0.31	SC	2.15	VL

M = moderately sorted; MW = moderately well sorted; P = poorly sorted; SF = strongly fine skewed; F = fine skewed; NS = nearly symmetrical; SC = strongly coarse skewed; VL = very leptokurtic; L = leptokurtic; M = mesokurtic; terminology of Folk, 1974.

Sample Number	Population breaks (phi) and percentages					Saltation Slope
	Traction		Saltation		Suspension	
11-3-1	0.15%	1.25	86.85%	3.50	13%	60 degrees
13-3-1		40%		~4.0	60%	35 - 45
10-10-1	0.40%	2.25	82.60%	3.75	17%	75
12-10-1	0.20%	1.50	74.80%	3.50	25%	60
23-3-1	0.20%	1.75	88.80%	3.50	18%	70
27-3-1	0.20%	1.50	88.80%	3.25	11%	70
36-11-1		75%		3.50	25%	65
24-10-1	15%	1.50	79%	3.25	7%	44
Fluvial (Visher, 1969)	0-5%	1-2	75-85%	~3.50	15-25%	55-70 degrees

APPENDIX C

Thin section analysis

A total of 32 thin sections of hand specimens from the study area were examined, 26 of clastic rocks and 6 of carbonates. The clastic rocks represent all parts of the lower member, Salt Wash Member, and the lower part of the Brushy Basin Shale Member. The carbonates are all from the lower member.

Clastic rocks--Modal composition of major components was determined by counting points using a Zeiss petrographic microscope and a Swift automatic point counter; 500 points per thin section were counted. Counts for quartz, total feldspar, and total lithic fragments were calculated to 100 percent and the resulting compositional distribution plotted on a ternary diagram after Folk (1974).

Identification of potassium feldspar was enhanced by staining with sodium cobaltinitrite. Staining for plagioclase feldspar was not done; plagioclase is not a major constituent of the sandstones studied.

Thin Section Number	Formation or member	Major Detrital Minerals (recalculated to 100%) Quartz	Feldspar	Lithics	Cement % and type	Porosity % and type
1-17-1	Summerville	87	12	1	1 S	1 P
9-3-1	lower member	80	10	10	20 C	2 P
4-17-1	(salt casts)	81	17	1	36 C	6 P
4-17-2		69	16	15	25 C	3 P
3-29-1		85	7	8	35 C	3 P
5-17-1		64	20	16	27 C	6 P
17-15-1		76	8	16	25 C	4 P
1-15-1		67	16	17	30 C	5 P
27-15-1		79	13	8	28 C	4 P
31-15-1		73	17	10	33 C	4 P
8-4-1	lower Salt Wash	78	5	17	30 C	3 P
6-17-1	(ferns)	84	5	11	18 C, 1 S	2 P
22-11-1		80	6	14	21 C	2 P
12-4-1		90	2	8	12 C	1 P
18-17-1	upper Salt Wash	80	9	11	20 C	2 P
14-4-1		89	3	8	15 C	2 P
14-4-2		86	6	8	18 C	2 P
16-4-2		85	9	6	21 C	1 P
29-3-1		86	4	10	20 C	2 P
29-3-3		86	5	9	25 C	1 P
20-4-1		88	5	7	20 C	3 P
22-4-1	top Salt Wash	63	3	34	24 C, 2 S	2 P, I
38-11-1		68	5	27	23 C	2 P
30-14-1		67	6	27	13 C, 1 S	1 P
26-4-1	Brushy Basin	31	10	59	23 C	3 P, I
32-4-1		63	1	36	5 S	1 P

C = carbonate cement; S = silica cement in syntaxial overgrowths and rare chert and chalcedony; P = plucked grains; I = intergranular pores.

Carbonate rocks--Component percentages of carbonate constituents were estimated using the charts of Wentworth (1922). Two sections were stained for aragonite, but none was detected.

APPENDIX D

Determination of Paleocurrent Directions

Paleocurrents are displayed in rose diagrams on Plates 1 and 2, beside the rock unit from which the data were collected. Diagrams were constructed on radial grid paper; each directional measurement within a 10-degree segment added an increment to that section of the rose. No distinction between the features measured was made on the rose diagrams. Each feature is identified below and its relative contribution to the data set is given.

Paleocurrents from strata dipping at 12 degrees in the Salt Valley anticline were rotated to correct for dip (Ramsay, 1961). This correction amounted to a maximum of 1 degree; paleocurrents in this area are generally parallel to the dip direction of the strata as indicated by elongation of sand bodies and trough axes, and were relatively unaffected by the tilt of the strata.

Rib-and-furrow structures--These features occur when trough (festoon) cross-strata are exposed on erosion surfaces generally parallel to the upper depositional surface of the sand unit. They consist of a series of C-shaped laminations, horizontally stacked and bounded by relatively straight, parallel edges. The laminations are the sedimentary fill of elongate troughs. The edges are parallel to the axis of the trough; both the edges and the axis are parallel to the direction of the current which scooped and filled the trough (Harms and others, 1975; Reineck and Singh, 1975; Dott, 1973). Rib-and-furrows reflect the scale of the troughs; both medium-scale and small-scale structures were measured. Rib-and-furrow structures account for approximately 90 percent of paleocurrent data. Of these, about 80 percent were medium scale.

Trough axes--Estimated axial directions of trough-shaped cross-strata were collected where vertical exposure of the sedimentary structure was dominant. These measures are less accurate than rib-and-furrows, and account for only about 2 percent of the data.

Current lineations--These structures are parallel ridges, a few grains high, which occur on planar-parallel cross-strata and planar-tabular foreset laminations. They are exposed as parting lineations on the laminations, oriented parallel to the depositional current (Reineck and Singh, 1975). These structures yield a linear bearing but not a directional sense. Their common association with trough-shaped cross strata indicates deposition in the same flow regime, however. Current lineations account for approximately 7 percent of the data used in the study, and in most instances a directionality was assumed to be parallel with intimately associated rib-and-furrows.

Sand rills--These structures are elongate, straight to slightly sinuous ridgelike sand accumulations, up to 3 cm high and 6 cm wide, of coarser sand than the surface (usually planar-parallel or planar-tabular; rarely very broad shallow troughs) on which they occur. Elongation of the rill is parallel to the depositional current. These features are rare and account for less than 1 percent of the measured directions. Where they occur together with more reliable indicators, agreement is good.

Ripple marks--Ripples occur mostly in finer sand and silt units and are not abundant in the study area. Both symmetrical and asymmetrical varieties were measured for current trend. Symmetrical ripples give a linear trend; asymmetrical ripples give direction. Ripple measurements account for less than 1 percent of the data.

Sole marks--Several types of sole markings were measured for paleocurrent directions; these account for less than 1 percent of the total measurements. Most common are flute molds of flute casts preserved on the underside of sandstone units. Two general types occur: narrow, deep marks with irregular, bulbous appearance, and smoother shallow marks which are shorter and wider. Both types taper and deepen upstream (Reineck and Singh, 1975). Less common are molds of larger, elongate scours up to 1 m long and 10 cm deep. Other linear molds may represent tool markings, although this is uncertain.

Fossil trees--Several trunk segments up to 0.6 m in diameter were seen in thick sandstone units. Long-axis orientation was measured as an indicator of flow direction, and was usually concordant within 30 degrees of other paleocurrents in the unit.

This dissertation is accepted on behalf of the faculty of the Institute by the following committee:

Advisor

Date