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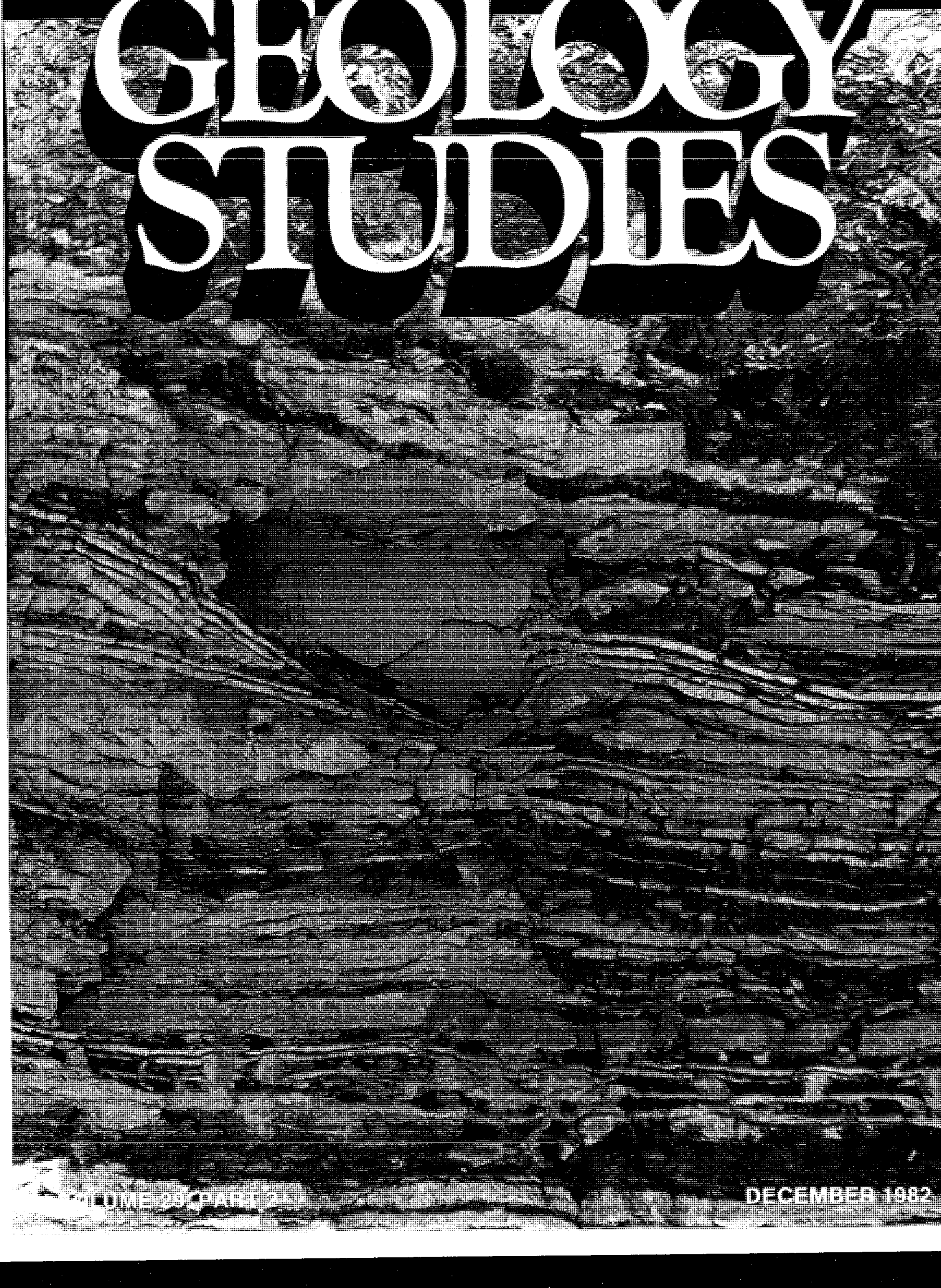

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CONTENTS

THE GLORY OF GOD IS INTELLIGENCE

Cover: Rafted or foreign cobble that settled into what were soft underlying sediments. From outcrop immediately east of the Sandy Creek Crossing on Blind Trail Wash Road, Garfield County, Utah. Photo courtesy Sidney M. Petersen and Robert T. Pack.

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Stratigraphy and Depositional Environments of the Upper Jurassic Morrison Formation near Capitol Reef National Park, Utah

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ABSTRACT.—Completely exposed Morrison Formation deposits along the east flank of the Teasdale Dome–Waterpocket Fold clearly show the vertical change from meandering stream channel-fill and overbank deposits in the Salt Wash Member, to lacustrine-deltaic deposits in the Brushy Basin Member. The shift of depositional pattern is documented in five stratigraphic sections.

Locally, Salt Wash Member beds range from 51.3 to 99.0 m of lenticular cross-bedded channel-fill sandstone and conglomeratic sandstone, with intervening siltstone, mudstone, and claystone, and some discontinuous dolomitic limestone. The Brushy Basin Member ranges from 28.6 to 86.1 m in thickness and consists of predominantly mudstone, claystone, and shale. The Brushy Basin Member contains some sheet and channel sandstones, and its beds are generally more continuous than Salt Wash Member beds.

Many exhumed paleochannel segments were identified in the area studied. Paleostreams flowed mostly ENE and had shallow gradients and variable rates of discharge according to calculations made using Schumm's formulae (1960, 1972; Derr 1974).

The change in depositional pattern was due to subsidence of a Jurassic miogeosyncline and aggradation of Morrison streams, which together effected a gradual change of the previously cyclic nature of Salt Wash Member deposition.

INTRODUCTION

The Morrison Formation is unusually well exposed along the Waterpocket Fold east of Capitol Reef National Park, Utah. Complete exposures there clearly show the vertical change from mostly meandering-stream and floodplain deposits in the Salt Wash Member to mostly deltaic lacustrine and lacustrine deposits in the Brushy Basin Member. Five detailed stratigraphic sections measured through these exposures east and south of Notom Junction, Utah (fig. 1), are the basis for a study of Morrison Formation paleoenvironments.

The Morrison Formation marks a dramatic change in Jurassic depositional patterns of the western United States. The Nevadan Orogeny raised highlands in central Nevada and produced sediments that forced Jurassic seas eastward and southward. As the sea later retreated northward, fluvial sediments from the orogenic belt were deposited on broad floodplains by mainly meandering but some braided streams, or in levees, backswamps, and fresh-water lakes. These sediments now comprise the Upper Jurassic Morrison Formation.

Previous Work

The Morrison Formation was first described by Cross (1894). Eldridge and Emmons (1896, p. 60) named the Morrison Formation from outcrops near Morrison, Jefferson County, Colorado, southwest of Denver. Mook (1916) described the Morrison Formation as a fluvial sequence on the Colorado Plateau, on the basis of lithology and sedimentary structures. Other publications on the Morrison Formation include but are not limited to Stokes (1944, 1954, 1958, 1961), Stokes and Sadlick (1953), Craig and others (1955), Mullens and Freeman (1957), and Derr (1974). Much attention has been given to uranium ore occurrences in the Salt Wash Member of the Morrison Formation by Stokes and others.

Acknowledgments

The authors thank J. Keith Rigby for guidance and direction during both fieldwork and preparation of the manuscript.

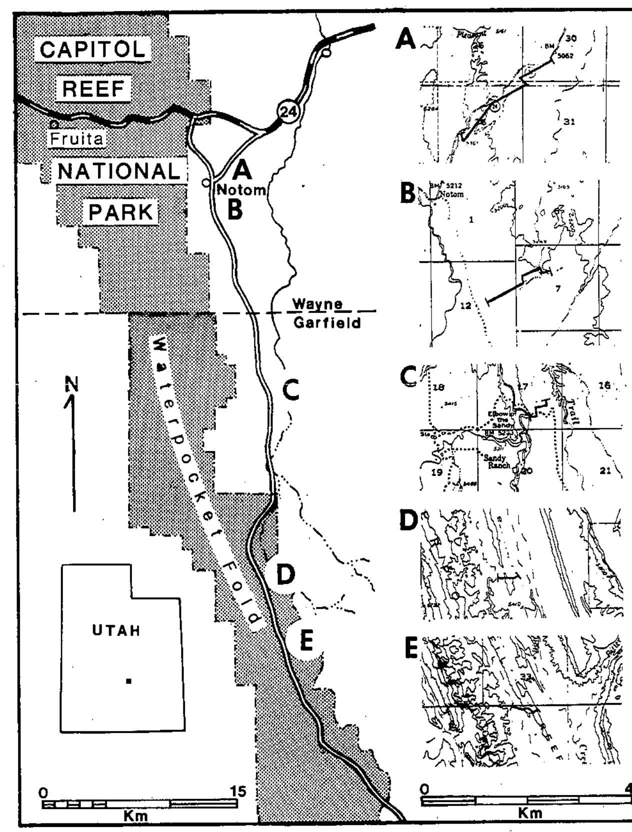


FIGURE 1.—Index map.

We also thank Verne P. Berry, Jess R. Bushman, Lehi F. Hintze, and J. Keith Rigby for critical reviews of the manuscript. Many students of the Brigham Young University geology summer field camp of 1980 helped to measure stratigraphic sections, including H. Gregory, C. Halcomb, J. Halverson, D. Hawkes, J. Kitzmiller, C. Lindh, S. Petersen, and C. Smith. Thanks are also extended to the Golden and McLean Durfey families of Bicknell and Salina, Utah, for their hospitality during the course of fieldwork. Finally, each of us expresses gratitude to his wife for patience and encouragement and help in typing the manuscript.

Location and Access

The area studied is east of Capitol Reef National Park, Utah. Access to and locations of the five measured sections are shown in figure 1.

Section A begins in section 36, T. 29 S, R. 7 E, and the top is in section 30, T. 29 S, R. 8 E.

The bottom of section B is in section 12, T. 30 S, R. 7 E, and its top is in section 7, T. 30 S, R. 8 E.

Measured section C is wholly contained in section 17, T. 31 S, R. 8 E.

Section D lies approximately 1.6 km west of section 16, T. 33 S, R. 8 E, in an area which was not surveyed into township and range sections before the 1953 Wagon Box Mesa Quadrangle topographic map.

Section E is likewise in an undivided portion of T. 34 S, R. 8 E, just west of section 3, T. 34 S, R. 8 E.

Methods

Stratigraphic sections were measured with a Jacob staff. Segments of exhumed paleochannels were measured by tape or by pacing.

Estimates of paleochannel gradient, mean annual and flood discharge, meander wavelength, and percent silt-clay particles in the channel perimeter were calculated using Schumm's formulae (1960, p. 20; 1972; Derr 1974, p. 28).

Statistical analyses of thin sections were made using Greensmith's formulae (1971, p. 67–68).

GEOLOGIC SETTING

The Morrison Formation is very extensive for a continental deposit, covering the area from Arizona, New Mexico, and Oklahoma northward across Kansas, Colorado, Utah, and Wyoming to Montana, North Dakota, and Alberta (McKee and others 1956). Its age is well established as Upper Jurassic Kimmeridgian through Portlandian (Imlay 1952, p. 953–60; Derr 1974, p. 4).

Structure

The area of our study is along the border between the High Plateaus and Canyonlands sections of the Colorado Plateau Province. Structurally, the Capitol Reef National Park area occupies a marginal belt between large basins and upwarps, on the east, and the normal fault-bounded blocks of the High Plateaus, on the west (Smith and others 1963, p. 57).

Exposures of the Morrison Formation in the Capitol Reef National Park area are almost entirely east of the park in cuestas east of Teasdale Dome or in steep small hogbacks along the Waterpocket Fold within the eastern parts of the park.

The Waterpocket Fold is one of the large monoclines of the Colorado Plateau and extends nearly 160 km from the Colorado River along the west side of the Henry Mountains Basin and the east side of the Circle Cliffs, to Thousand Lake Mountain on the north. Small flexures in the Waterpocket Fold are produced in the study area by arching of the Teasdale Dome. Generally, dips on the eastern limb of the monocline range from 6°, in the northernmost measured section, to 60°, in the southernmost measured section, toward N 45 E to N 85 E.

The Waterpocket Fold and other related folds of the area probably developed during the Paleocene (Smith and others 1963, p. 60). Baker (1935, p. 1501) postulated deep-seated faulting as a mechanism for the monoclines of the Colorado Plateau.

Variegated Brushy Basin Member beds are widely exposed in badlands-type topography in the northern part of the study area east of the Waterpocket Fold, where dips are very gentle.

STRATIGRAPHY

The Morrison Formation in the study area unconformably overlies the Upper Jurassic Summerville Formation, which is interpreted by Stanton (1976, p. 37) to be tidal flat deposits. The Morrison Formation is overlain by the Buckhorn Conglomerate Member of the Lower Cretaceous Cedar Mountain Formation. The Buckhorn Conglomerate was named by Stokes (1944) and consists of river floodplain deposits similar in nature to those in the Morrison Formation (Hintze 1973, p. 67). The Morrison Formation–Buckhorn Conglomerate contact is also unconformable.

Gregory (1938) recognized four members of the Morrison Formation in the Four Corners area, namely, the Brushy Basin Sandstone Member, the Westwater Canyon Sandstone Member, the Recapture Shale Member, and the Bluff Sandstone Member. Since then, the Bluff Sandstone Member has been dropped in favor of the Salt Wash Member, which Lupton (1914, p. 124) proposed and consequently used as a datum for mapping in the Green River Desert. Of the four members, only two are present in the area of study, the Salt Wash and Brushy Basin Members. Hunt and others (1953, p. 76) suggested that the Brushy Basin Member be subdivided into a lower variegated unit and an upper gray unit, although this subdivision has not at present been adopted.

As shown by the five measured sections (fig. 2), the general lithology, if not the stratigraphy, of the Morrison Formation is fairly consistent over the area of study. For ease of description, measured section A (figs. 1,2) has been taken to be typical and is reproduced in the appendix. Sections B through E are on file at Brigham Young University Department of Geology.

Salt Wash Member

The Salt Wash Member of the Morrison Formation consists of lenticular, cross-bedded channel-fill sandstone and conglomeratic sandstone, and alluvial-plain mudstone, siltstone, and claystone, with minor accumulations of dolomitic limestone and some concentrations of chert nodules. Total thickness of the Salt Wash Member in the study area ranges from 51.3 m to 99.0 m and averages 75.1 m (fig. 2).

Conglomeratic Sandstone

Conglomeratic sandstones throughout the Salt Wash Member have a number of features in common. Most are discontinuous and do not correlate laterally over even moderate distances. They crop out as ribbonlike or "shoestring" bodies, as described by Krynine (1948, p. 147) on dip slopes (fig. 3). They are resistant to weathering and tend to form blocky ledges. Most conglomeratic sandstone units are lenticular and have convex bottoms in cross section. Thickness of these individual lenses ranges from 1 m to as much as 12 m in some large channel-fill deposits. Conglomeratic sandstones are usually gray in overall appearance but may be a variety of colors, including brown, light brown, reddish brown, and gray-green. They are highly cross-bedded, and the pebbles are often arranged in stringers that show sedimentary structures very well (fig. 4). Conglomeratic sandstones are medium to thickly bedded, with blocky or massive parting. Lingoid ripple marks (fig. 5) are common on the top surfaces of conglomeratic sandstones, where they are exposed. Pebbles in the conglomerates are almost entirely chert and are usually brown and gray but sometimes green, yellow, black, and red. Pebbles are subrounded to rounded, with sizes ranging from coarse sand to 3.0 cm in diameter. Modal size is approximately 4–5 mm. Cementation in conglomerates is largely calcareous. Unit six, section A (appendix) is exemplary of this type of unit.

Dinosaur bones and, in other areas, silicified wood occur frequently in the conglomeratic sandstones of the area.

Sandstone

Conglomeratic sandstone grades both laterally and vertically into sandstone. Sandstone units of the Salt Wash Member also share some features that make it convenient to group them together.

Sandstones occur as part of conglomerate sequences or in lenses and stringers in conglomerate and mudstone or claystone. Like conglomeratic sandstone, sandstone is usually laterally discontinuous and may crop out on dip slopes as serpentine ridges. Sandstones are medium to thick bedded and commonly have slabby or blocky parting. They form rounded or irregular cliffs and ledges, except where exposed as exhumed paleochannel segments on dip slopes. Meander and point-bar sequences are exposed in some of these exhumed channel-fill sandstones. The color of these units ranges from pale yellow gray to light brown. Sand grains in these beds are generally medium to well sorted, medium to very fine grained, and subrounded to rounded, with as much as 30 percent calcareous cement in some units. Sandstones are predominantly cross-bedded (fig. 6) and show good lingoid ripple marks where the tops of the units are exposed. Paleocurrent flow directions range from due north to S 40 E, and average approximately ENE (fig. 2). Unit 14 (appendix) is an excellent example of these types of rocks.

Stream-channel-fill sandstones in the study area have localized uranium and vanadium ore deposits, chiefly carnotite. Active claims are situated near measured sections B and E (fig. 1).

Siltstone, Mudstone, and Claystone

Siltstone, mudstone, and claystone occur in the Salt Wash Member between sequences of sandstone or conglomeratic sandstone (fig. 7) and exhibit features which make it convenient to group them together. These fine-grained clastic rocks surround sandstone and conglomeratic sandstone units both vertically and laterally. Beds range from 0.1 to 5.8 m thick, and are generally reddish brown to brown or light greenish gray to green. These beds commonly consist of both brown and green units together. All of these units form slopes or recesses and have obscure bedding and parting. Where fine clastic rocks are overlain by sandstone or conglomeratic sandstone, load structures, scour marks, and erosional surfaces are evident. Some of these units have ripple marks on their top surfaces, where exposed. Unit 18, section A (appendix) is a typical example of this sequence of beds.

Dolomite and Dolomitic Limestone

Carbonate rocks are minor units of the Salt Wash Member in the study area. As is the case with many other units, carbonate rocks are very discontinuous. Unit 15, section A (appendix) includes a 0.1-m-thick lenticular layer of dolomitic limestone, and unit 26, section B (fig. 2) is 4.5 m of dolomite and dolomitic limestone. These rocks are pale yellow green to greenish gray and thinly bedded, and they exhibit slabby or blocky parting. Dolomitic limestone in section A occurs in thin lenticular pods, while the carbonates in section B form ledgy slopes.

Brushy Basin Member

The Brushy Basin Member of the Morrison Formation includes most of the lithologic types found in the Salt Wash Member, but the finer-grained clastic rocks such as mudstone, claystone, and shale predominate. Brushy Basin Member beds are more laterally extensive than Salt Wash Member beds, and some Brushy Basin beds can be traced at least 1 or 2 km. The contact between these two members is gradational in the study area, and is generally drawn where the variegated siltstone, mudstone, and claystone begin to predominate. Total thickness of the Brushy Basin Member in the study area ranges from 28.6 m to 86.1 m and averages 53.1 m.

Siltstone, Mudstone, Claystone, and Shale

Units in the variegated siltstone, mudstone, claystone, and shale beds range from 0.2 to 8.8 m thick, and their colors range from light red to dark reddish brown and from dark green to light greenish gray. These units form barren badlands-type slopes in the upper part of the Morrison Formation. Bedding is difficult to determine because the weathered layer is deep.

Most of these units are bentonitic to some degree, and some of them are mostly bentonite. Beds with a high proportion of bentonite display characteristic "popcorn" weathering.

Secondary gypsum (bladed selenite) has weathered out of some fine-grained clastic beds.

Units 32 and 33 of section A (appendix) are typical of this lithology.

Sandstone

Sandstone units in the Brushy Basin Member are subdividable into two categories. One is a rounded ledge-former, and the other is an unconsolidated sand that forms a slope. The ledge-forming sandstones are generally thin bedded and lenticular. They comprise only a minor portion of the Brushy Basin Member in this area and are less frequent toward the top of the member. Color of these units ranges from yellowish gray to brown. Sand grains in them are mostly quartz and are generally fine to very fine grained, well sorted, and subrounded. Cross-bed sets are present in some units and range in height from 3 to 10 cm. Cross-bed sets also provide vectors of paleocurrent flow direction. Unit 27, section A (appendix) may be regarded as typical of this lithology.

The unconsolidated sandstone beds range in thickness from 0.3 to nearly 4.0 m, and are relatively continuous when compared with most Salt Wash Member sandstones. They are composed of noncemented grains and form slopes. Color of these sandstones varies from pinkish gray to yellowish brown. Sand grains in them are medium to very fine grained, medium to poorly sorted, rounded to subrounded, and approximately 95 percent quartz, the remainder being chert and feldspar. Unit 38, section A (appendix) is a good example of unconsolidated sandstone.

Conglomeratic Sandstone

Conglomeratic sandstones occur in the Brushy Basin Member in three of the five measured sections (fig. 2). Unit 50, section A, and unit 52, section B, are related beds and represent one of the most laterally continuous beds in the study area. This bed forms a prominent rounded ledge. Pebbles are green, gray, red, and brown chert, are subrounded, and are packed in an open framework. Cement is noncalcareous, and cross-bedding is evident. This unit has a lag gravel at its base, and the contact with underlying rocks is erosional.

Correlation

Correlation of beds of one measured section with those of another is difficult because of the discontinuous nature of Morrison Formation deposits. Thickness varies by several tens of meters between sections (fig. 2). Some general symmetry is, however, maintained between sections in the study area. Lenticular sandstone and conglomeratic sandstone dominate the Salt Wash Member in all five sections, with similar relationships of siltstone, mudstone, and claystone. Fine-grained clastic rocks are typical in all five Brushy Basin Member sections.

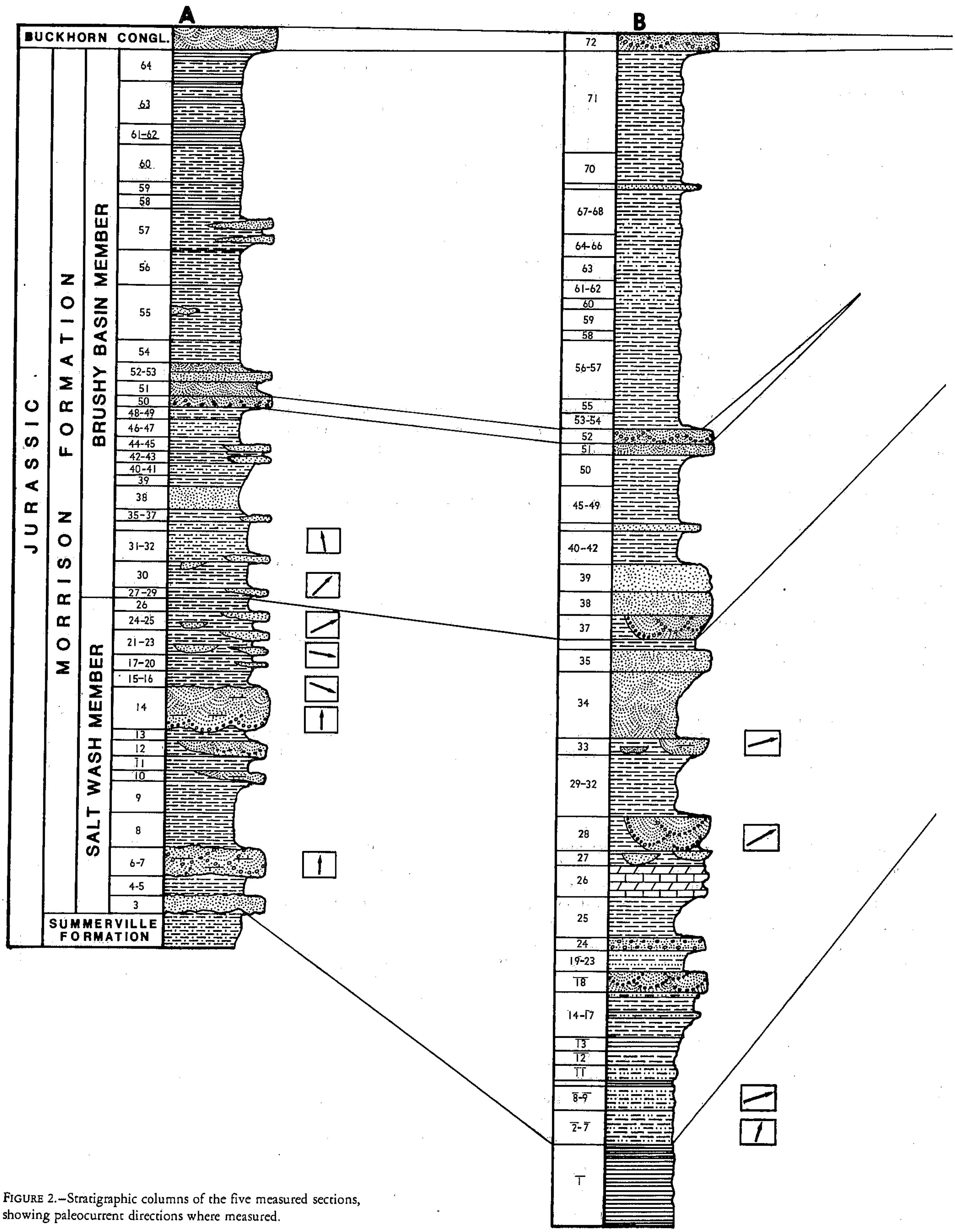
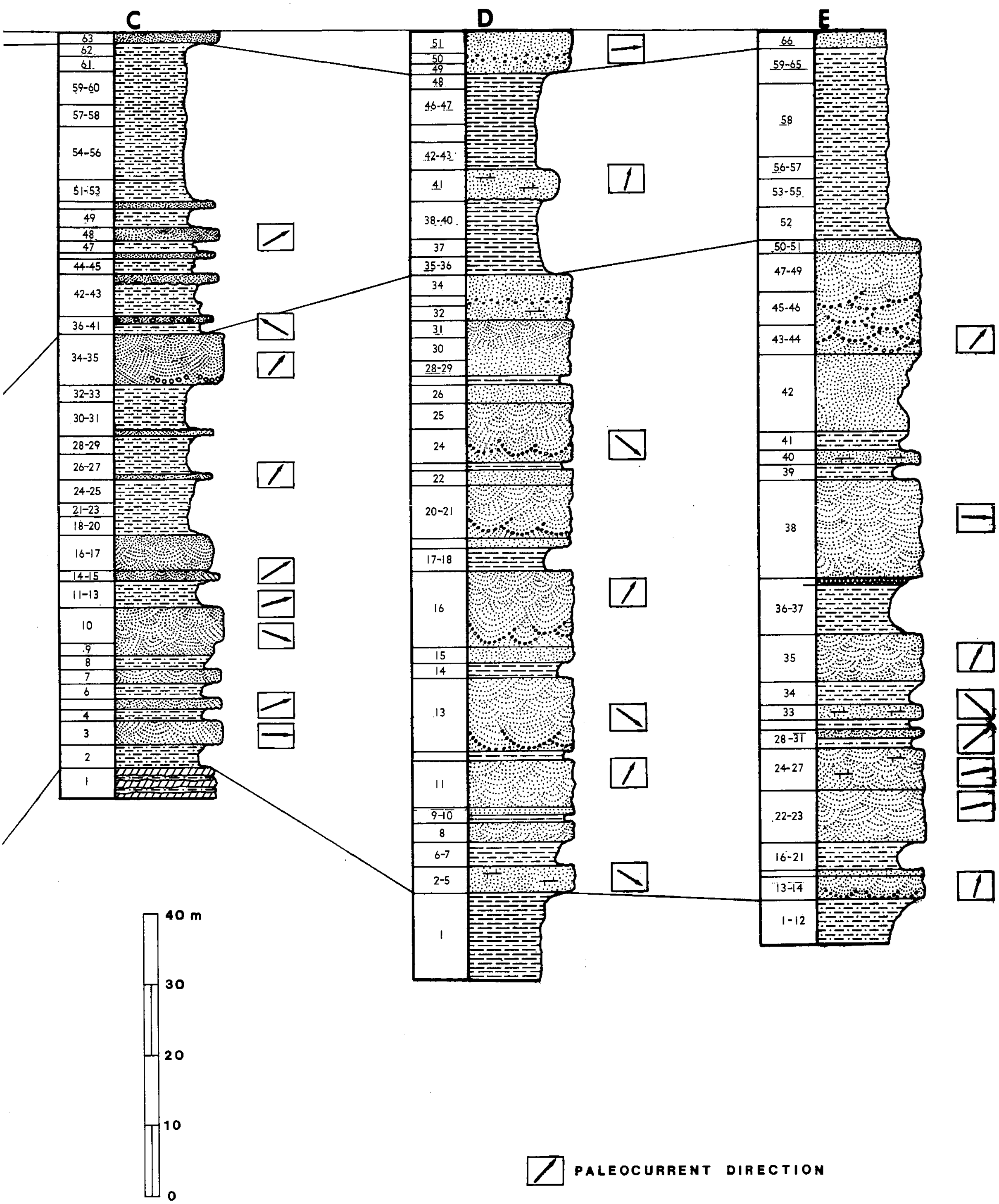


FIGURE 2.–Stratigraphic columns of the five measured sections, showing paleocurrent directions where measured.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PALEOCURRENT DIRECTION

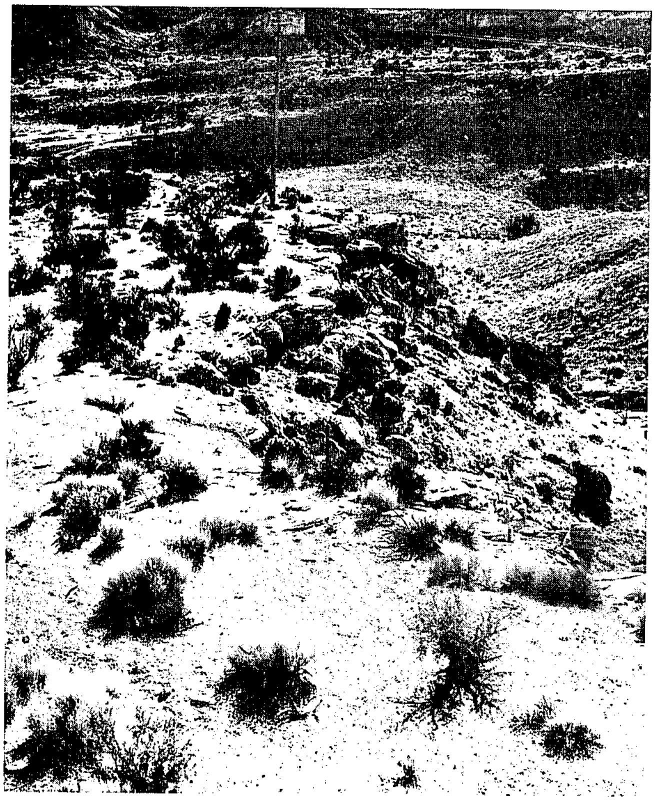

FIGURE 3.–Outcrop of unit 14, section A, conglomeratic channel-fill sandstone as exposed on a dip slope.

FIGURE 4.–Pebble stringers in conglomeratic sandstone of the Salt Wash Member.

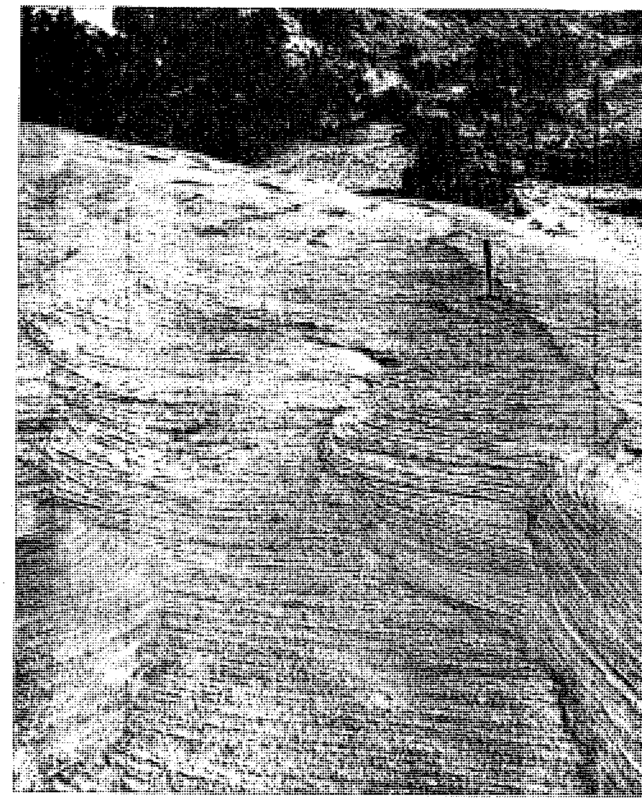

FIGURE 5.–Lingoid ripple marks on the top surface of unit 28, section B, toward paleocurrent direction.

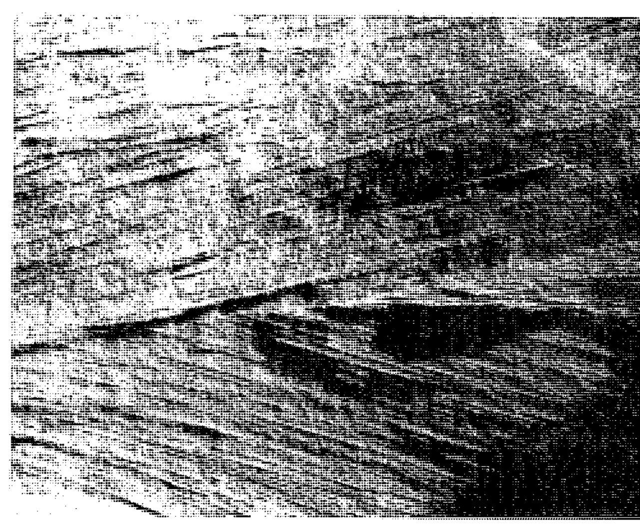

FIGURE 6.–Cross-bedding in Salt Wash Member sandstone.

One notable exception is unit 50, section A, a conglomeratic unit which correlates well with unit 52, section B (fig. 2).

PALEOCHANNELS

The northern part of the study area, where dips are more gentle, provides many good exposures of exhumed paleochannels. These paleochannels are preserved as channel-fill sandstone and conglomeratic sandstone. Four well-exposed channels were measured for statistical analysis (table 1). Channels 1 and 2 are located in unit 14, section A, and channels 3 and 4 are found in units 33 and 28, respectively, of section B. Three of the paleochannels, numbers 1, 2, and 3, are exposed as exhumed point-bar sequences on dip slopes (fig. 3). Channels 1 and 2 are individual channels, while channel 3 is actually two superimposed channels (fig. 8). Channel 4 is itself a broad dip slope that is covered at its widest point on the edges, and eroded away in other places. Erosion has exposed sedimentary structures in all of the exhumed fluvial channels, and channel 4 is well exposed in cross section on a knoll near section B (fig. 9).

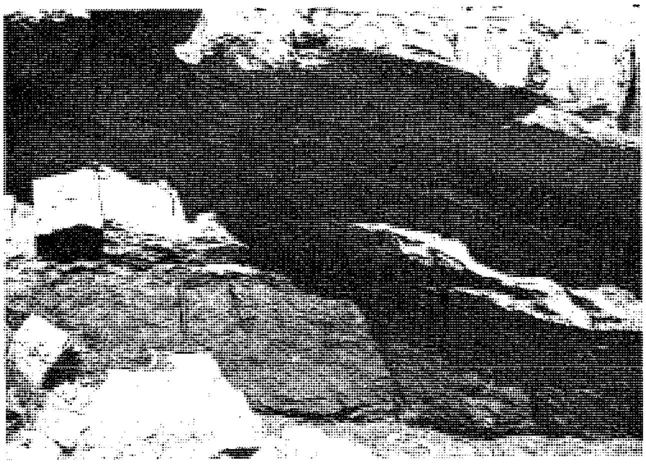

FIGURE 7.–Fine clastic rocks between exhumed channel-fill sandstones, units 31 and 32 of section B. Compare with figure 8.

FIGURE 8.–Exhumed and superimposed point-bar depositional complexes, units 28–33 of section B. Compare with figure 7.

Morphology

Channels 1, 2, and 3 are shoestring bodies of sandstone that are sinuous in plan view. Measured width and depth of these channel segments is summarized in table 1. Sequences of point-bars are defined on the exhumed channels by cross-bed sets that dip toward the point-bars, and by current indicators such as lingoid ripple marks on the surface of the channel. Viewed from the side (fig. 8), these channel-fill deposits thicken and thin laterally. Thicker portions also mark point-bars, where sheets of sediment have shingled off the edge of the growing point-bar into deeper cuts at the apex of the meander as the paleostream widened its meanders. These three paleochannels have convex bases and appear to have been completely surrounded by fine clastic rocks (siltstone, mudstone, and claystone) before erosion. Their lithology has been described previously (Stratigraphy).

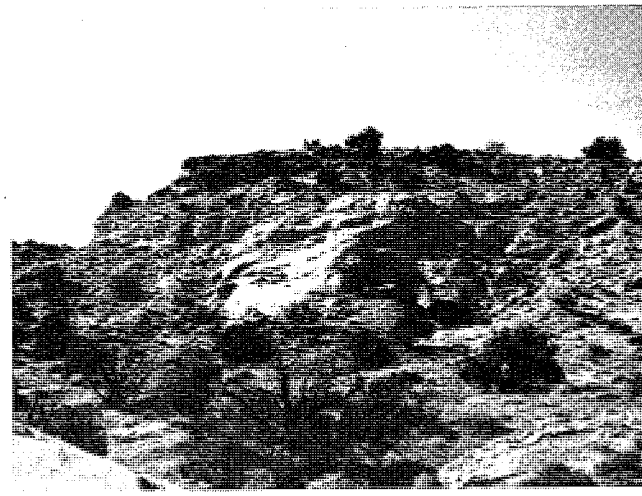

FIGURE 9.–Cross sectional view of channel 4 (table 1) as exposed in a knoll near measured section B, in SE¼, NW¼, SW¼, section 7, T. 30 S, R. 8 E.

Channel 4 (table 1) as exposed in cross section is much deeper than the others. This paleochannel is lenticular and has a very convex base. Its outcrop pattern (fig. 9) resembles a cross section of a modern stream meander. If the vegetation and debris were removed from the knoll in figure 9, a view similar to figure 10 would result. This channel is approximately 12 m deep and 35 m wide at the top. Current direction appears to have been toward the viewer, as determined from lingoid ripple marks on other exposures of unit 28, section 2. This paleochannel is surrounded by fine clastic rocks, and another channel, represented by the conglomerate cap of the knoll, has been superimposed over channel 4.

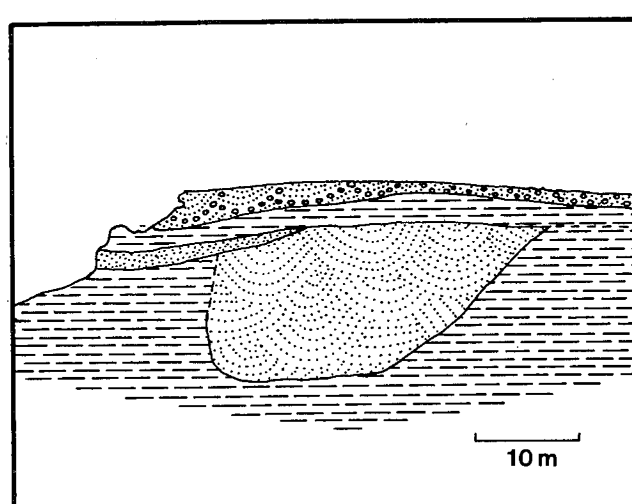

FIGURE 10.–Simplified view of channel 4 (table 1). Compare with figure 9.

TABLE 1
Stream Character Relationships

Channel	F (w/d)	w (m)	d (m)	l (m)	s (m/km)	Qma (cms)	Qm (cms)	M (%)
1	3.1	10	3.2	111	.5	500	21	52.8
2	8.9	40	4.5	506	.38	2160	190	4.9
3	10	30	3	441	0.56	128	8.1	17.9
4	3	35	12	260	0.15	359	46.1	54.5

$l = 18(F^{.53} W^{.69})$ where l = meander wavelength in feet, F = width to depth ratio of channel, w = channel bank-full width in feet

$s = 30 \frac{F^{.95}}{w^{.98}}$ where s = channel gradient in feet per mile

$Qma = 16 \frac{w^{1.56}}{F^{.66}}$ where Qma = flow during mean annual flood in cubic feet per second

$Qm = \frac{w^{2.43}}{18 F^{1.13}}$ where Qm = mean annual discharge in cubic feet per second

Schumm 1972

$F = 225 M^{-1.08}$ where M = percent silt-clay (particles less than 0.074 mm) in the channel perimeter

Schumm 1960

Note: All calculations were made using feet. Answers were converted to metric units for consistency.

Geometry and Stream Characteristics

Measured widths and depths of the four fluvial channels can be used to estimate gross channel geometry and other useful statistics. Application of Schumm's formulae (1960, 1972), derived from observations of modern streams, yields estimates of meander wavelength, channel gradient, mean annual discharge, flood discharge, and the percent of silt-clay (particles less than 0.074 mm) in the channel perimeter. These calculations are summarized in table 1 and show that all of the channels had low gradients and variable rates of discharge. Many factors of uncertainty are likely to influence the use of these formulae, such as climate and rates of erosion, so that Schumm's formulae should be seen as general guides to aid in the interpretation of fluvial environments and not necessarily as accurate statistics for the study area.

DEPOSITIONAL ENVIRONMENTS

Mook (1916) early concluded that the Morrison Formation is composed of deposits from a number of large streams that issued from a mountainous area and crossed a broad, flat plain. Many writers since also have concluded that the Morrison Formation is of continental fluvial origin (Stokes 1944, Smith and others 1963, Derr 1974).

Measured stratigraphic sections in the Capitol Reef area (fig. 2) show a vertical progression from mostly fluvial deposits to mostly lacustrine deposits, as earlier noted by Smith and others (1963). This change in depositional environments is largely due to interaction of tectonism and deposition. Early Morrison streams that deposited the Salt Wash Member had low gradients (table 1) as they flowed over a nearly flat floor of marginal marine and tidal flat sediments left by the northward-retreating Late Jurassic Sundance-Twin Creek-Carmel Sea. Aggradation was the result of thick sediment accumulation and slow subsidence in the headwater and trunk parts of the drainage. This accumulation combined with deposition downstream, where the rate of increase of the drainage area per mile of channel length was low, and hence tributary contribution was small. In the semiarid Late Jurassic climate (Derr 1974, p. 33), water could be lost to evaporation and seepage into the alluvium according to the general model proposed by Schumm (1961, p. 67). Streams transporting Salt Wash Member sediments had no outlet into the sea south of Wyoming (Mullens and Freeman 1957, p. 519) although it seems probable from Kimmeridgian-Portlandian lithofacies maps by McKee and others (1956, plate 7) that they drained into the Arctic Ocean, possibly near the area of Hudson Bay.

Salt Wash Member

Sedimentary rocks of the Salt Wash Member represent the dominantly fluvial end of the continuum. Isopach maps by Mullens and Freeman (1957, p. 517–18) show that rocks of the Salt Wash Member near Capitol Reef National Park are about evenly distributed between stream deposits and floodplain deposits. The Salt Wash Member in the study area represents accumulation of a system of mainly meandering and less commonly braided streams with nearly parallel drainages across a broad alluvial plain. Direction of flow, or transport, was nearly constantly to the northeast, implying a probable source area to the southwest of the study area.

Rocks in all five measured stratigraphic sections (fig. 2) show a cyclic pattern within the Salt Wash Member. That pattern is typified by (1) establishment of a stream channel, (2) avulsion and infilling of the stream channel with bedload and suspended load sediments, (3) local reestablishment of a roughly parallel stream channel across a topographically lower occasionally lacustrine or marshy part of the floodplain, (4) deposition of fine overbank sediments on top of and surrounding the abandoned and infilled channel, and (5) differential compaction of sediments to produce topographic lows that would help position later streams as the cycle repeated. Figures 7 and 8 show the relationship of abandoned infilled channels to overbank mudstones and siltstones exposed in an exhumed channel complex in measured section 2.

Paleochannels in the Salt Wash Member are of particular interest for documentation of fluvial processes. Many sandstone bodies in the study area show some or all of the following characteristics. (1) Available cross sections show that sandstone units are lenticular and generally have convex bottoms. (2) In plan view they are shoestring or prismatic bodies like those pro-

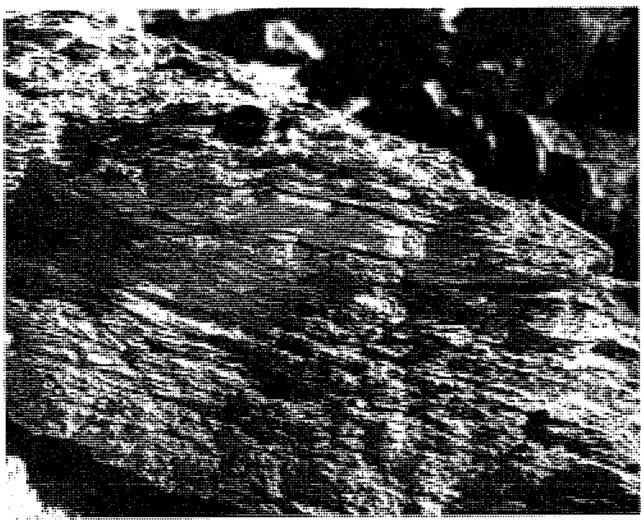

FIGURE 11.–Levee accretion sandstone deposit on a Salt Wash Member paleochannel.

posed by Krynine (1948, p. 146). (3) Sandstone units are generally channeled into underlying units, although some flat-bottomed splay deposits continue great distances away from the parent source channel. (4) Pebbles in the common and widespread conglomerates are fairly well sorted and rounded to subrounded. (5) Sandstone and conglomerate are often cross-bedded. (6) Top surfaces of sandstone and conglomerate (where exposed) often show lingoidal ripple marks and trough cross-bed sets (fig. 5) that indicate a general current direction for the paleochannel. (7) Many sandstone bodies have basal conglomerates and are upward-fining depositional complexes.

In addition, levee and point-bar sequences are observable in some Salt Wash Member paleochannels. Levees in the study area are characterized by relatively thin units of thinly bedded, fine-grained sandstone (fig. 11). Point-bars, similar to models proposed by Bernard and Major (1963), exhibit shingling toward the cut bank of the paleochannel and are fining upward lenses. Rosiwal analyses of thin sections were made from point-bar lenses in unit 28, section B, and Greensmith's formulae (1971, p. 67–68) were applied to the data. The lenses show a sorting coefficient of greater than 1.2 and a skewness coefficient of less than 1.0, which Reineck and Singh (1973, p. 119) cite as characteristics of the point-bar environment.

Some beds of the Salt Wash Member in the study area are definitely lacustrine deposits, and many represent marginal lakes and backswamps behind meanders on the floodplain. Unit 26 of measured section B (fig. 2) is the best example of a lacustrine unit in the Salt Wash Member. These deposits are not laterally extensive in the studied sections and appear to represent quiet water stranded in local topographic low points dammed by accretion of levees on the stream banks or by depressions resulting from combined differential compaction and deposition. The lakes these sediments were deposited in were probably much like the lakes in the modern Lower Mississippi River valley.

Bones of herbivorous dinosaurs are common in many Salt Wash channel deposits, especially in the northern part of the study area. These bones are fragmented and were probably transported some distance. There is a dearth of fossil plant material, except for a few pieces of silicified wood, even in undeformed mudstones and claystones. That lack and the generally transported nature of the fossils might indicate a rather barren Late Jurassic landscape in the area of study. No dinosaur bones or other fossil material were found in the Brushy Basin Member in the studied sections although elsewhere Brushy Basin beds are sites of famous dinosaur bone quarries in the western United States.

Brushy Basin Member

Rocks of the Brushy Basin Member record a gradual change in depositional pattern toward a dominantly lacustrine environment. Throughout this change, the regional slope to the northeast in the study area was sufficient to maintain drainage patterns established during deposition of the Salt Wash Member.

Continued aggradation of streams on a plain of low topographic relief established by Salt Wash Member deposition suggests that those streams were easily dammed by local topographic high points, resulting in broad, shallow lakes. This process was greatly assisted by regional subsidence during Jurassic time that affected Wyoming, southeastern Idaho, and parts of Utah including the Capitol Reef area, which McKee and others (1956, p. 3) describe as a possible miogeosyncline. The geosyncline apparently subsided faster than deposition could fill the basin, and large lakes developed which have left thick deposits of laterally extensive mudstone, claystone, and shale. Many Brushy Basin lakes were shallow, as is shown by the variegated beds depicting subaqueous and subaerial exposure.

Occasional surges of coarser sediment are recorded by tongues, lenses, and sheets of sandstone and conglomerate. Thin lenticular sandstones, such as unit 57 of section A and unit 50 of section E (fig. 2), were probably stream or splay deposits, which are not laterally extensive. Some sandstone sheets are laterally continuous for several kilometers and were not characteristic deposits of meandering streams. Unit 50 of section A is continuous with unit 52 of section B (fig. 2). Possibly they are the result of braided streams or of major splays. Smith (1970, p. 2993) proposed three major factors favorable for development of braided streams, namely: (1) high regional slopes, (2) variable discharge, and (3) abundant sediment supply. Morrison Formation drainage appears to have had an abundant sediment supply, as is seen by the areal extent and continuity of the formation, and variable discharge would be consistent with a semiarid climate and the stream geometry (table 1); but regional gradient, as reflected by exhumed channels in the study area, was as low as 0.15 m/km (table 1). However, Gole and Chitale (1966) have described braided portions of the Kosi River in India that have gradients of 0.06 m/km or less. The origin of these sheet sandstones and conglomerates is possibly similar to that of the Westwater Canyon Member of the Morrison Formation in northwestern New Mexico, described by Campbell (1976) as a fluvial sandstone formed by a number of aggrading and coalescing braided stream systems.

The bentonitic nature of many lacustrine claystones in the Brushy Basin Member documents possible multiple sources and results from volcanic ash transported and hence reworked by Brushy Basin drainage. Chert formed from silica dissolved from the reworked volcanic ash is also abundant in the study area.

ECONOMIC GEOLOGY

Uranium was mined from the Colorado Plateau as early as 1896 for use as a coloring agent in the ceramics industry (Jensen and Bateman 1942, p. 174). The Salt Wash Member of the Morrison Formation on the Colorado Plateau has been the site of concentrated exploration and production of uranium oxides since 1948, when price incentives first increased dramatically.

Although the origin of uranium ores is uncertain, some environmental conditions are known to be conducive to the localization and concentration of uranium oxides in sandstone bodies. Primary among these is the area(s) in the paleostream where deposition and hence accumulation of organic debris occurs. Associated with this accumulation, in many cases, are zones of oxidation and reduction within the sedimentary body. Uranium oxides are likely to be near the margin of the reduction zone contact with the oxidation zone, especially if calcite cement is also present.

Fluvial paleochannels of the Salt Wash Member often have these combined conditions present in point-bar deposits in the inside of stream meanders, and the carnotite deposit in measured section 2 is such a deposit.

Exploration for uranium oxides near the study area would be most profitable where paleochannels are highly sinuous, have short meander wavelengths, and are easily mappable or traceable in the subsurface. Such conditions commonly exist from the northern part of the study area northeastward to the eastern edge of the San Rafael Swell near Green River, Utah.

APPENDIX

Stratigraphic section of the Morrison Formation measured northeast of Notom Junction, Wayne County, Utah. The bottom of the section is in the NE¼, SW¼, section 36, T. 29 S., R. 7 E. Basal beds of the section are exposed in a high bluff approximately 500 m east of the junction between the new Capitol Reef National Park road and old Utah 24. This section was measured up the western face of the bluff to the base of the blocky ledge at the top of the bluff. From there the traverse was offset 650 m eastward along the old road. From that point, the section closely parallels the road for 1.5 km, to the top of the section at the base of the Buckhorn Conglomerate Member of the Cedar Mountain Formation, in the SE¼, SW¼, section 30, T. 29 S., R. 8 E.

Unit		*Thickness meters*	*Total meters*
65	Sandstone: light gray, weathers reddish brown; thick bedded; blocky parting; resistant ledge former; some pebbles 5–10 mm; sand grains rounded, average sorting, siliceous cement, fine to medium grained; noncalcareous; very indurated; ripple marks in float; slickensides in float.	1.5	132.3
	Base of the Buckhorn Conglomerate Member of the Cedar Mountain Formation and top of Brushy Basin Member of the Morrison Formation.		
64	Shale: same as unit 58 except more bentonitic.	2.8	130.8
63	Interbedded shale and mudstone: same as units 58 and 59; shale units approximately 0.3 m thick; last mudstone unit weathered dark brown at the top.	6.0	128.0
62	Shale: same as unit 58.	1.8	122.0
61	Mudstone: same as unit 59.	1.3	120.2
60	Claystone: weathers dark green; slope former; interbedded with a 0.3-m-thick unit composed of gypsum and bentonite plus a grayish black shale.	6.1	118.9
59	Mudstone: weathers reddish brown; slope former; some bentonite.	1.5	112.9
58	Claystone or shale: weathers dark green; slope former; bentonitic; some gypsum.	1.9	111.3
57	Mudstone: same as unit 55 except two interbedded sandstone units and one shale unit; sandstone light gray, very thinly bedded, flaggy parting, forms rounded ledge, fine grained, poor to good sorting, noncalcareous, low porosity, 99% quartz, 1% chert; shale is same color, obscurely bedded.	5.3	109.4
56	Claystone: same as unit 54 except less bentonite and no limonite.	6.0	104.1
55	Mudstone: brownish red; slope former; gypsiferous; bentonitic; 30 m to the west there is a 0.5-m-thick sandstone, light gray, laminated bedding, rounded ledge former, very fine grained, noncalcareous, medium sorting.	8.8	98.1
54	Claystone: dark green, grading to brown towards the top; slope former; gypsiferous.	2.7	89.3
53	Sandstone: yellowish brown; obscurely bedded; slope former; rounded grains, well sorted, very fine grained, 98% quartz, 1–2% chert; some limonite staining and bentonite.	2.4	86.6
52	Sandstone: grayish brown; very thinly bedded; flaggy parting; forms rounded ledge; grains rounded to well rounded, medium sorted, fine to medium grained; noncalcareous; 95% quartz, 5% chert.	0.4	84.2
51	Sandstone: grayish brown, weathers dark grayish brown; slope former; unconsolidated; grains rounded to subangular, poorly sorted, 90% quartz, 10% chert.	2.5	83.8
50	Conglomerate with sandstone lenses: color varies from pinkish brown to light brown; very thick bedding; massive parting; forms rounded ledge; pebbles mostly green, gray, red, brown, and light brown chert; pebbles packed in open framework; matrix poorly sorted, subrounded, noncalcareous, medium porosity sand; cross-bedded with lag gravel at bottom of unit; contact with lower unit shows channeling.	1.5	81.3
49	Claystone: same as unit 33.	1.3	79.8
48	Siltstone: same as unit 32.	0.4	78.5
47	Claystone: same as unit 33 except less bentonitic.	1.1	78.1
46	Siltstone: same as unit 32 except more bentonitic.	1.2	77.0
45	Claystone: same as unit 43.	0.7	75.8
44	Sandstone: same as unit 36 except only 2% chert.	1.2	75.1
43	Claystone: same as unit 33 except more bentonitic.	1.9	73.9
42	Sandstone: same as unit 38 except brownish gray; fine to very fine grained.	0.3	72.0
41	Claystone: same as unit 33.	0.5	71.7
40	Siltstone: same as unit 32 except fewer grains, more clay; gypsiferous.	1.2	71.2
39	Claystone: same as unit 33.	1.5	70.0
38	Sandstone: pinkish gray; slope former; grains rounded to subrounded, medium grained, medium sorting, 95% quartz, 5% chert.	3.9	68.5
37	Claystone: same as unit 33.	0.9	64.6
36	Sandstone: greenish brown, weathers light brown; laminated; shaly parting; forms rounded ledge; calcareous; grains subrounded, well sorted, fine grained, 90% quartz, 10% chert fragments.	0.2	63.7
35	Claystone: same as unit 33.	0.4	63.5
34	Siltstone: same as unit 32.	0.8	63.1
33	Claystone: medium green; slope former; very bentonitic.	0.8	62.3
32	Siltstone: dark reddish brown; slope former; bentonitic.	3.4	61.5

31	Sandstone: same as unit 17 except very fine grained; not as much cement; well sorted; small cross-bed sets 3–5 cm high; rooting evident toward levee sequence; current direction toward 350°.	0.9	58.1
30	Mudstone: same as unit 18 except red unit's color is darker red; very bentonitic.	4.1	57.2
29	Sandstone: greenish gray, weathers light brown; thin to very thin bedding; flaggy to slabby parting; forms resistant ledge; grains subrounded, well sorted, very fine grained; very calcareous; medium porosity.	0.2	53.1
28	Mudstone: same as unit 18.	1.0	52.9
27	Sandstone: yellowish brown; medium bedded; slabby to blocky parting; forms resistant ledge; grains subangular, poorly sorted, coarse to fine grained; noncalcareous; pebble lenses; cross-bed sets 10 cm high; slumping in unit which has deformed sand layers; paleocurrent direction toward 25–40°.	0.6	51.9

Base of the Brushy Basin Member of the Morrison Formation and top of the Salt Wash Member of the Morrison Formation.

26	Mudstone: same as unit 18 except green unit weathered light brown.	2.0	51.3
25	Sandstone: same as unit 17 except very fine grained.	1.3	49.3
24	Mudstone: same as unit 18 except there is a limonite layer in the red unit, and the red and green units are bentonitic; load structures in the top of the unit.	1.5	48.0
23	Sandstone: same as unit 17 except very fine grained; well sorted; paleocurrent direction toward 90° but varies to 50°.	1.6	46.5
22	Mudstone: same as unit 18.	0.7	44.9
21	Sandstone with pebble lenses: same as unit 17 except for pebble lenses; grayish pink color due to 7% chert fragments, weathers brownish pink; pebbles mostly chert; sand is 20% same pink chert; paleocurrent direction toward 100°.	1.0	44.2
20	Mudstone: same as unit 18 except green part is only 0.1 m thick.	0.6	43.2
19	Sandstone: same as unit 17 except chert pebbles 1–3 mm.	0.8	42.6
18	Mudstone: from bottom to top, pale greenish gray, reddish brown; forms slopes and recesses; contains some poorly sorted sand.	0.4	41.8
17	Sandstone: pale yellow gray, weathers dark yellow gray; medium bedding; slabby to blocky parting; forms rounded ledge; grains subrounded, medium sorting, fine grained, 90% quartz; calcareous cement.	0.8	41.4
16	Mudstone: bottom to top, pale brown, medium grayish purple, pale green gray, reddish brown, medium grayish purple; very thick bedding; massive parting; forms recessed slope; splits into flakes or lumps.	2.1	40.6
15	Siltstone, mudstone, and dolomitic limestone: mudstone, lower part is greenish gray, middle part is mottled brown, upper part is brownish red; siltstone is greenish gray; limestone is pale yellow green; siltstone forms slope, obscure bedding; limestone is lenticular, thinly bedded, slabby parting, forms re sistant ledge, indurated.	0.3	38.5
14	Sandstone: pale yellow to greenish gray, weathers slightly darker; medium to thick bedded; flaggy to blocky parting, thinner towards top of unit; forms rounded cliff; lenticular; some pebbles as large as 20–30 mm, 1–2 mm modal size, mostly chert; grains subrounded; brown and gray grains comprise 70%, remainder are green, white, black and pink; sand grains subrounded, poorly sorted at bottom of unit and better sorted toward top, fine grained; calcareous cement comprises about 30% of sandstone; porosity is intergranular and very good; 90% quartz; two sets of lenticular cross-beds, one 1.5 m thick and another 0.3 m thick, both superimposed on point-bar shingles that are 6.0 m thick, equalling the channel depth; some honeycomb weathering; paleocurrent direction on top of unit is toward 100–120°, but near the bottom of the unit is toward 0°; dinosaur bones 500 m to the east in this unit. Note: this unit was measured across lenses formed by paleochannel meanders, and fines upward.	6.7	38.2

Offset 650 m eastward on top of unit 14 where it crops out by the road.

13	Mudstone: medium brown; slope former; covered.	1.5	31.5
12	Sandstone with conglomerate lenses: light gray, weathers light brown; very thick bedded; ledge former; cross-bedded; pebbles 10–20 mm; dinosaur bones at bottom of unit.	2.4	30.0
11	Mudstone: greenish gray; slope former; covered.	1.4	27.6
10	Sandstone: medium brown, weathers light brown; thinly bedded; slabby parting; calcareous; medium porosity; forms resistant ledge; cross-bedded.	1.7	26.2
9	Mudstone: greenish gray; slope former; covered.	4.5	24.5
8	Mudstone: reddish brown; slope former; chert nodules 2–4 cm; covered.	5.8	20.0
7	Conglomerate: medium gray; thickly bedded; blocky parting; ledge former; sandstone matrix; very calcareous; very porous; pebbles are green, light brown, brown, white, 90% chert; some chert nodules.	1.3	14.2
6	Conglomerate: light brown, weathers light red; very thick bedded; massive parting; ledge former; cross-bedding with pebbles on slip face; lenses of sandstone, fine grained, light green, weathers reddish brown; calcareous; porous; pebbles green, gray, brown, and yellow, subrounded to rounded, 90% chert.	3.0	12.9
5	Claystone: greenish gray; forms recessed slope; bentonitic.	0.1	9.9
4	Mudstone: brownish red; laminated; shaly parting; calcareous; gypsiferous; ripple marks, paleocurrent direction toward 03°	2.6	9.8
3	Sandstone: light brown, weathers medium gray; lower part thinly bedded; small channels 0.3–1.0 m deep; upper part thick bedded; blocky parting; ledge former; friable; grains subrounded, fine grained.	2.5	7.2

Base of the Salt Wash Member of the Morrison Formation and top of the Summerville Formation.

2	Siltstone: green; very thinly bedded; forms recessed slope; some gypsum.	0.7	4.7
1	Siltstone: light red, weathers dark red; very thinly bedded; papery; slope former.	4.0	4.0

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