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CONTENTS

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Contents

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The Paleoenvironment of the Summerville Formation on the West Side of the San Rafael Swell, Emery County, Utah*

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ABSTRACT.—The Upper Jurassic (Oxfordian) Summerville Formation along Interstate 70 is one of the best exposed tidal flat sequences in North America. The base of the Summerville Formation is gradational with the underlying marine Curtis Formation, but the top is disconformable with the overlying Morrison Formation. The Summerville Formation is cyclic with two main patterns: 1) a dark red siltstone and red sandstone alternation, and 2) a dark red siltstone and gray green channel fill sandstone alternation. Sandstone fillings in tidal channels are common throughout the Summerville Formation. The Summerville Formation, capped by a massive gypsum unit, becomes evaporitic near the top.

Sedimentary structures are most evident in medium red sandstone beds, but are masked by deep weathering in dark red siltstone units. Flattened clay pebbles are characteristic of the gray green sandstone channel fills. Evidence indicates currents were strongly bimodal, with average azimuths on currents of 70° (dominant) and 250° (subordinate). The entire formation is ripple marked, with many varieties of structures related to soft sediment deformation present. Mud cracks are present, but not abundant. Trace fossils are found only in the channel fillings of gray green sandstone. The remainder of the Summerville Formation in the study area is unfossiliferous. Facies relationships, cyclicity, and types of sedimentary structures indicate that the Summerville Formation was deposited on a broad, low-relief, tidal flat on a quiet, arid coast.

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*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Sciences, August 1975. J. Keith Rigby, thesis chairman.

INTRODUCTION

The Upper Jurassic (Oxfordian) Summerville Formation is one of the best exposed tidal flat sequences in North America. The spectacular assemblage of sedimentary structures and facies relationships, and the cyclic nature of the Summerville Formation make it possible to determine the paleoenvironment, and develop a sedimentary model for deposition in this part of the Sundance Sea. The best and most readily available exposures of the Summerville Formation are in road cuts along Interstate Highway 70 on the west flank of the San Rafael Swell. A broad, low-relief tidal flat on a quiet, arid coast is envisioned as the environment of deposition of the studied section.

Previous Work

The Summerville Formation was named by Gilluly and Reeside (1928, p. 80) for the excellent exposures on Summerville Point in the San Rafael Swell in east central Utah.

Gilluly and Reeside (1928) described the Summerville Formation at its type locality, as well as at other areas in the San Rafael Swell. Gilluly (1929), discussing the oil and gas prospects in the San Rafael Swell, described some of the lateral extent of the Summerville Formation, and also discussed general stratigraphy of the Formation. Baker, Dane, and Reeside (1936) described the relationship of the Summerville Formation with the underlying Entrada Sandstone, near Moab, where the Curtis Sandstone is not present. Gregory (1938), Stokes (1952), and Hunt et al. (1953) described the relationship of the Summerville Formation with the overlying Morrison Formation and with the underlying Curtis Sandstone or Entrada Sandstone. Peterson (1972) correlated the Summerville Formation with parts of the Todilto Formation and said that it was, in part, a facies equivalent of the Curtis Formation. Most discussions on the Summerville Formation have been based on the work by Gilluly and Reeside. Harshbarger and others (1957) correlated the Summerville Formation with rocks in southwestern Colorado, northwestern New Mexico, and northwestern Arizona. They also refined some of the work done by earlier studies on stratigraphy of the Summerville Formation. Imlay (1957) published conclusions on the paleoenvironment of the Summerville Formation which were based on the general work of Gilluly, Reeside and others.

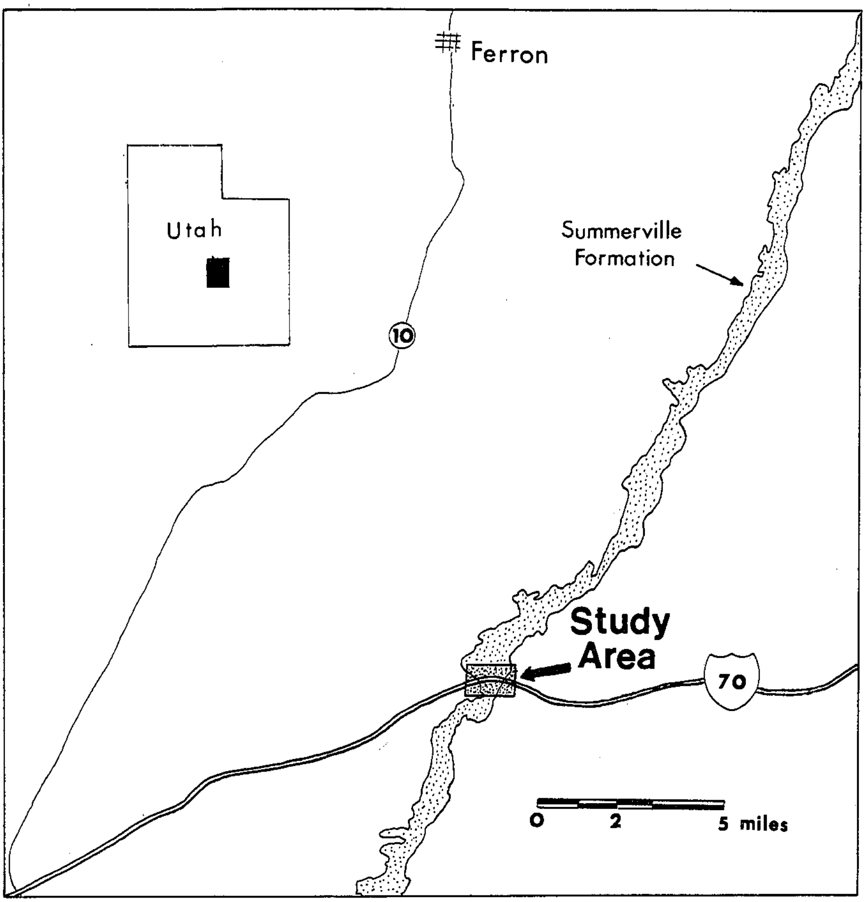
The Summerville Formation, from which only trace fossils have been recovered, is considered to be Upper Jurassic because of its gradational contact with the underlying fossiliferous Curtis Sandstone and because of its position below the younger Morrison Formation.

Location

The study area is in road cuts on Interstate Highway 70, approximately 10 miles east of Fremont Junction, 54 miles west of Green River, Utah, in Section 9 and 10, T. 23 S, R. 6 E, in Mesa Butte Quadrangle, Emery County, Utah. Bulk of the field work was done in the interstate road cuts, but additional observations were made for approximately 1 mile on either side of the freeway.

Geologic Setting

The studied exposures of the Summerville Formation are on the west flank of the San Rafael Swell in the northeastern part of the relatively stable Colo-



TEXT-FIGURE 1.—Index map.

rado Plateau. The San Rafael Swell is an asymmetrical Laramide Uplift, with the steeper limb on the east side.

Rocks studied were deposited in the southwesternmost part of the Sundance Sea, a narrow arm of the sea that transgressed into Utah from Canada in Oxfordian times (Peterson, 1972, p. 186). Sources of Summerville sediments were probably early uplifts of the Sevier Orogeny to the west, and possibly the last remnant of the Umcompahgre Uplift to the east and northeast.

Interbedded siltstone and sandstone of the Summerville Formation intertongue with the uppermost underlying Curtis Formation, and are topped by a disconformity at the base of the Morrison Formation.

Methods of Study

Field Methods.—A detailed stratigraphic section was measured of exposures in road cuts and in natural outcrops in order to compile a complete section of the formation. A meter stick was used for measuring, and units were differentiated and described according to natural lithologic breaks. Rock type, sedimentary structures, trace fossils, current directions, and color of the units were noted, as well as facies relationships. The cuesta face on both sides of the road cuts was examined for channel occurrence, continuity of units, and facies relationships. Oriented samples were collected of each lithology in the section, and extra samples were taken of trace fossils and sedimentary structures.

Laboratory Methods.—Laboratory work involved thin section study and trace fossil identification. Thin sections of every lithology were made from samples collected from various points in the section, and were used for comparison and for study of grain size and rock type. The thin sections were stained to determine percentages of calcite and dolomite cement. Rock slices were impregnated with epoxy resin in a vacuum oven and allowed to cure overnight before thin sectioning. This impregnation was necessary because of the friable nature of the rocks.

Colors used in the descriptions are as the rocks appeared in natural light at the outcrop. Descriptive grain size terms are those of the Modified Wentworth Grade Scale proposed by Dunbar and Rogers (1966).

Acknowledgments

The author would like to acknowledge the guidance and assistance, in the field, laboratory, and with the writing, of Dr. J. K. Rigby, committee chairman, who gave freely of his time and even resources when needed. Also appreciated are the advice and constructive criticism of Dr. W. K. Hamblin.

Field assistance was given by fellow graduate students, Larry Bagshaw, Larry Smith, and Ron Lowrey.

Special appreciation is given to my wife Marlene for her help as laboratory technician and typist, and for her unceasing support and encouragement.

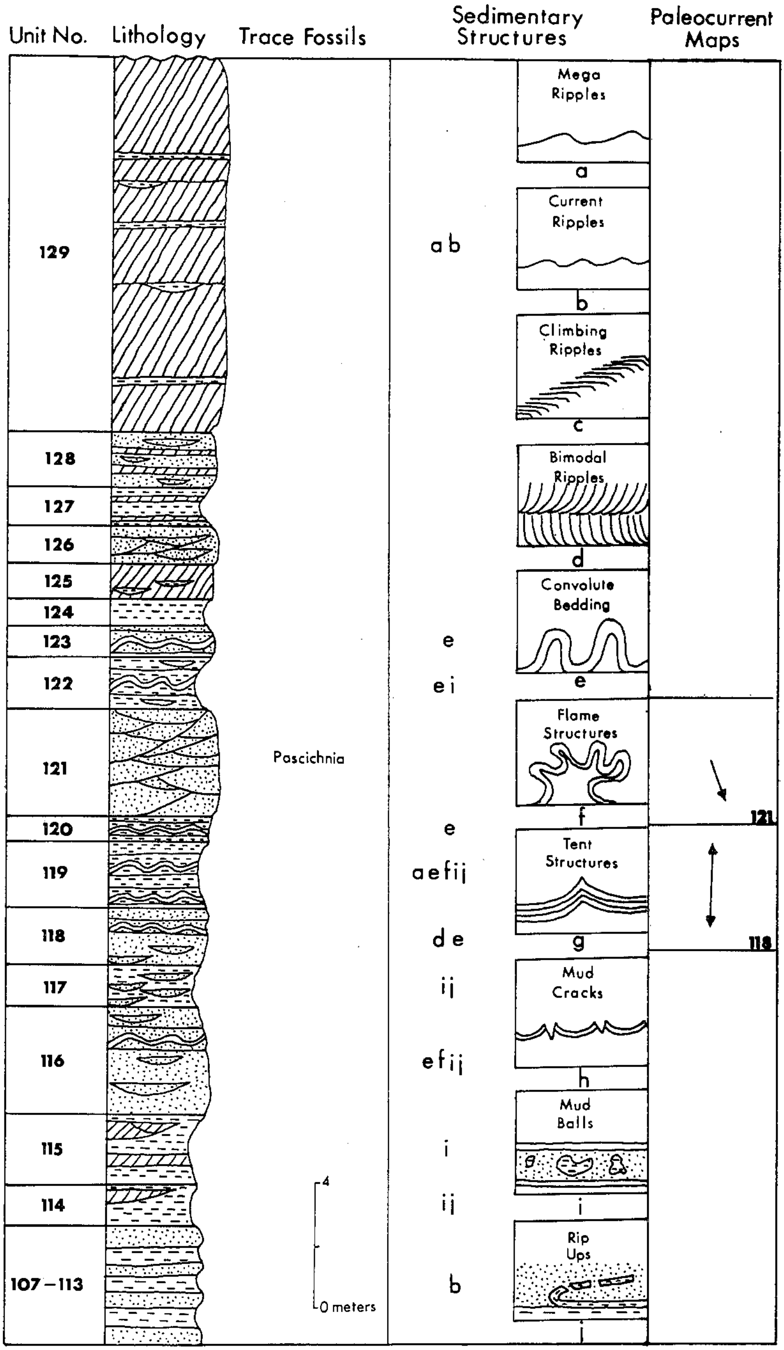
LITHOLOGIES

Siltstone Facies

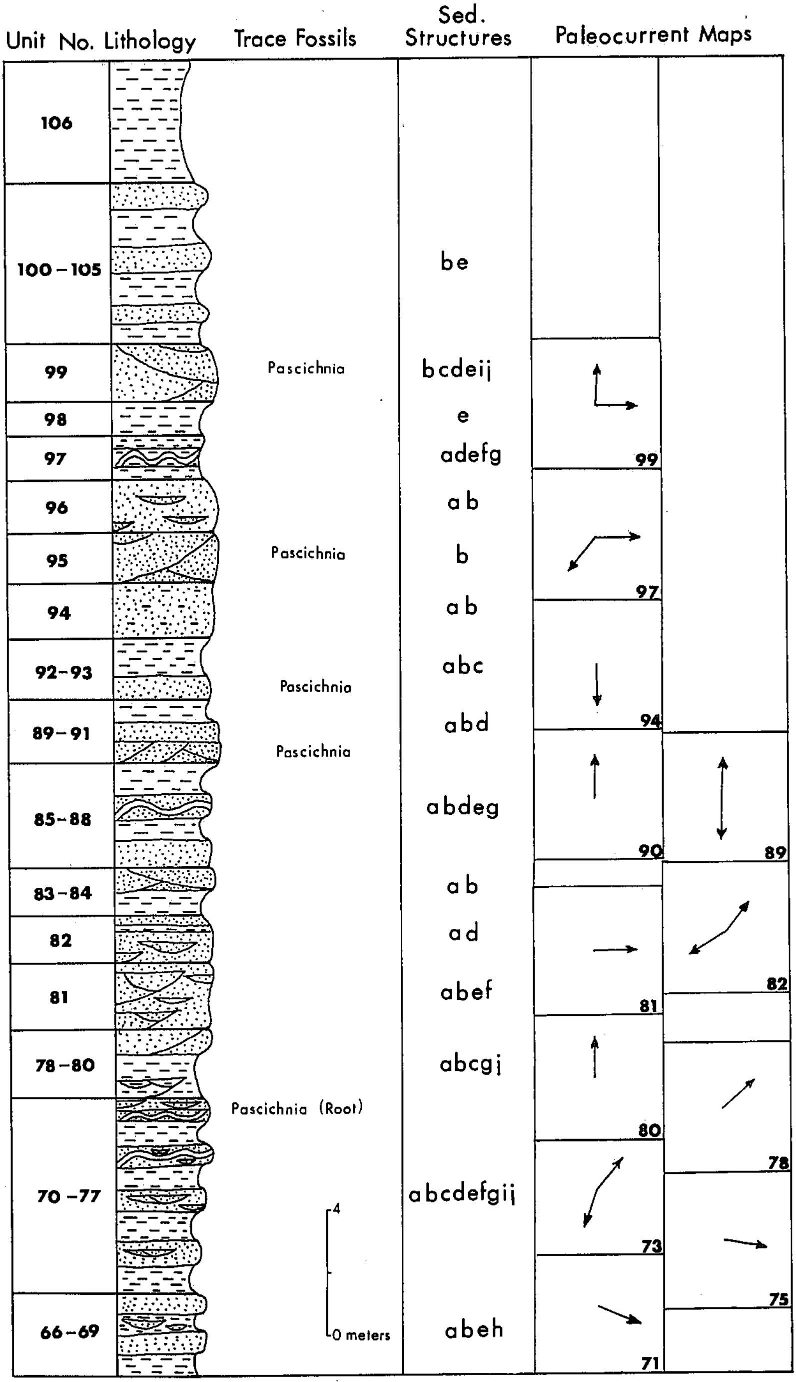
Siltstone is the most abundant rock type in the Summerville Formation. It is composed mostly of silt with abundant clay and some sand-size particles. The siltstone facies shows nearly all the kinds of sedimentary structures present in the formation, but these structures are often masked by the deep and soft weathering habit of that facies.

Siltstone recurs throughout the section and is interbedded with every other lithology present, but even when the dominant rock type is another lithology, lenses of siltstone are present. Siltstone of the Summerville Formation is generally medium dark red, with some individual beds darker or lighter. Color of the siltstone varies slightly from pale green to a purple red, with greener units found near the base of the formation and darker purple units near the top.

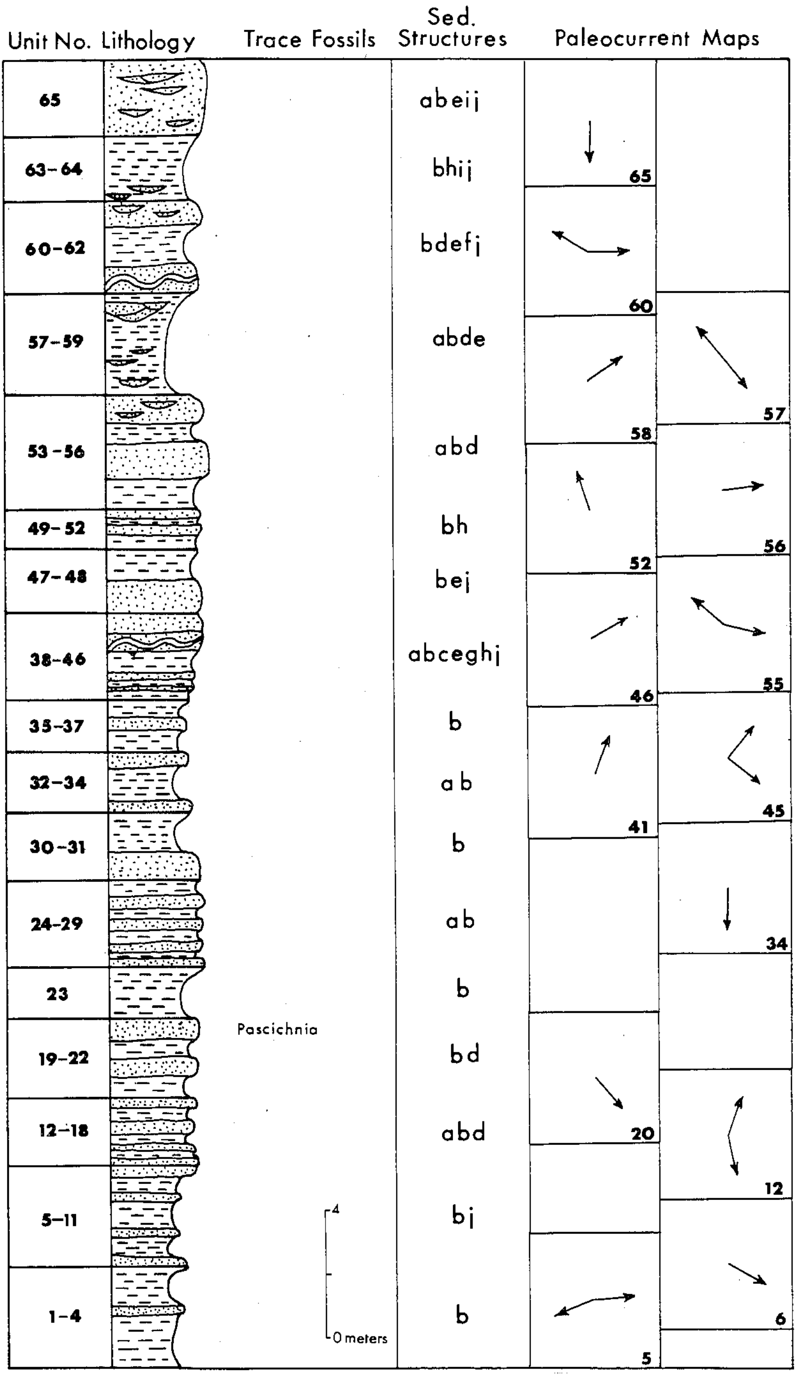
The siltstone is commonly mottled, with these variations ghosting the sedimentary structures present. Channels are the most common structure and are filled with a variety of rock types. Many of the structures, such as ripple marks, convolute bedding, flame structures, and tent structures are visible only because of mottling. Mud balls and sand balls are also present. Many indi-



TEXT-FIGURE 2a.—Upper 40 meters of the studied stratigraphic section of the Summerville Formation, showing sedimentary structures, paleocurrent directions, and trace fossils.



TEXT-FIGURE 2b.—Middle 40 meters of the studied stratigraphic section of the Summerville Formation, showing sedimentary structure, paleocurrent directions, and trace fossils.



TEXT-FIGURE 2c.—Lower 40 meters of studied stratigraphic section of the Summerville Formation, showing sedimentary structures, paleocurrent directions, and trace fossils.

vidual siltstone beds show loss of bedding, with no primary sedimentary structures preserved.

Details of the siltstone facies are mostly seen in the unweathered road cuts; in natural outcrop all siltstone units form slopes and weather to a mud in which structural details have been obliterated.

Only one thin section was successfully made of the siltstone. In that section the cement which comprises 5 to 10 percent of the rock is approximately 50 percent calcite and 50 percent dolomite, with both disseminated throughout the sample.

Sandstone Facies

Red Sandstone.—Red sandstone is the most abundant sandstone type in the Summerville Formation, and is fine grained and most prevalent near the middle of the formation. Red sandstone beds are fewer in the upper part, and thinner in the lower part of the formation.

The red sandstone facies has by far the most preserved sedimentary structures. Red sandstone is highly channeled, has megaripples, unidirectional current ripple marks, bimodal current ripple marks, climbing ripple marks, convolute bedding, flame structures, tent structures, mud balls, and ripped up clay flakes. These structures are discussed in a later part of the paper. Sandstone beds are resistant units, and sedimentary structures in them are well exposed. The red sandstone facies also contains some pascichnia trace fossils and root (?) impressions.

Red sandstone beds commonly interfinger with the siltstone beds. In traverses from the southwest to the northeast, sandstone beds were seen to change into siltstone beds in a horizontal distance of 10 to 15 meters.

The ratio of calcite to dolomite in the cement varies from unit to unit, but generally calcite is dominant although in some beds the calcite-dolomite ratio is near 1:1. Dolomite and calcite are disseminated throughout the samples.

Red sandstone units commonly have green mottles, which sometimes ghost trace fossils or sedimentary structures and other times follow bedding. Red sandstone units with green mottles are closely associated with units of the green sandstone facies.

Green Sandstone.—Green sandstone of the formation is similar to the red sandstone facies in most respects except color. Green sandstone beds are not nearly as common as red sandstone ones, and have fewer sedimentary structures, but those present are of the same general types in both kinds of sandstone.

The green sandstone facies is mottled with red, and the color variation ghosts sedimentary structures. Single beds may be green at the bottom and red at the top, with a gradational mottled transition in between.

Types and percentages of cement are about the same as found in the red sandstone.

Gray Green Sandstone.—Gray green sandstone occurs only as channel fillings or in some rare cases as lenses which lead to channels filled with gray green sandstone. Gray green sandstone beds are commonly medium grained and are the coarsest sandstones of the formation.

Sedimentary structures present in this facies are channels, mud cracks which are preserved in the bottom of channels filled by the sandstone, and ripped up clay flakes. Some of the clay flakes are red near the bottom of the channel but are more and more green up in the green sandstone.

The most conspicuous aspect common to most gray green sandstone units is the presence of trace fossils. Pascichnia are present at the base of many of these channel fillings, and except for three observed occurrences all of the trace fossils found during the present study in the Summerville Formation are in these gray green sandstone beds.

Cement in these sandstone channel fillings is about 10 to 15 percent of the rock, and varies from about 80 percent dolomite and 20 percent calcite to about 30 percent dolomite and 70 percent calcite. In general the cement is dolmitic and disseminated throughout.

Red Brown Sandstone.—Red brown sandstone usually occurs as a channel filling, but is also present as thin sandstone lenses extending over a large area. The sandstone is very fine grained and breaks with a concoidal fracture (Plate 2, fig. 1).

The sedimentary structures present in this lithology are megaripples, current ripple marks, and climbing ripple marks. Some channel fillings are composed of intensely climbing ripple-marked sandstone.

This facies is not prevalent in the formation. When more than one red brown channel is found, lenses of dark red siltstone occur between the channels.

Red brown sandstone units are well cemented with the cement comprising about 20 percent of the rock, and the cement ratios vary from about 80 percent dolomite and 20 percent calcite to about 70 percent calcite and 30 percent dolomite. Both calcite and dolomite are disseminated throughout the units.

Gypsum Facies

Gypsum is present in the Summerville Formation as secondary veins and stringers, as channel fills, and as beds. Gypsum is present only in the upper 50 meters of the formation and is prevalent only in the upper 35 meters.

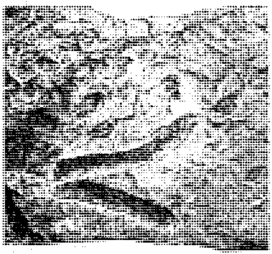
Gypsum fills channels but also has been channeled, and megaripple and current ripple marks are present in the clastic units in the gypsum. The gypsum contains a high percentage of siltstone, many places approaching 50 percent. Most channels in the gypsiferous part of the formation are filled either with siltstone or very silty gypsum.

Calcite cement associated with siltstone lenses in the gypsum causes many of the gypsum samples to effervesce with dilute HCl.

TRACE FOSSILS

Trace fossils are the only evidence of life found in the Summerville Formation. Such fossils are most prevalent in the gray green sandstone channel fillings. All of the trace fossils observed are pascichnia which range from 3 to 7 mm in diameter. One trace fossil, possibly not a pascichnia, may be a root impression (Plate 1, fig. 6). It is 3 cm in diameter. Most of the burrows are parallel to bedding. Only one clearly defined, nearly vertical burrow was discovered (Plate 1, fig. 3) but less conclusive evidence of others was found. Burrowing organisms apparently stopped their vertical burrows at the base of the unit in which they were feeding. These or other organisms burrowed along the base of suitable units at a texture contact of sandstone on siltstone (Plate 1, fig. 5).

PLATE 1



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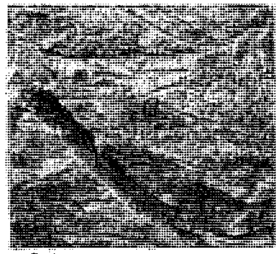

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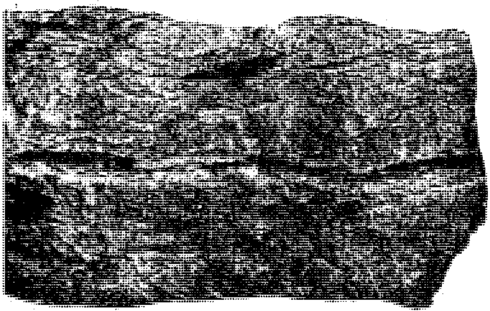

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EXPLANATION OF PLATE 1
TRACE FOSSILS

FIG. 1.—U-shaped horizontal burrow from Unit 121.
FIG. 2.—Horizontal burrows along textural contact from Unit 121.
FIG. 3.—Nearly vertical burrow in red sandstone from Unit 92.
FIG. 4.—Horizontal burrow in red sandstone from Unit 22.
FIG. 5.—Winding burrows along textural contact and vertical burrows that stop at textural contact from Unit 99.
FIG. 6.—Horizontal burrow or root (?) from Unit 77.
FIG. 7.—Horizontal burrows and tool marks from Unit 121.

SEDIMENTARY STRUCTURES

Ripple Marks

Ripple marks are the most common sedimentary structure present in the Summerville Formation. The ripple marks found include (1) unidirectional current ripple marks, (2) bimodal current ripple marks, (3) climbing ripple marks, and (4) megaripple marks.

Almost every unit in the Summerville Formation in the study section contains current ripple marks. These are best preserved in sandstone beds such as units 82, 60, and 45 or sandstone lenses in siltstone units, like units 41, 37, and 33.

A majority of the units in the Summerville Formation have bidirectional ripple mark series, like those found in units 97, 82, and 60, an indication of bimodal transport (Plate 2, fig. 4). Dark red siltstone, medium red sandstone, and green sandstone are the rock types in which bimodal ripple marks have been found. Sandstone lenses in siltstone units, such as units 57 and 55, contain bimodal ripple marks.

The dominant current producing the ripple marks appears to have been towards the northeast. The subordinate component of ripple mark direction been towards the northeast. The subordinate component of ripple mark direction was from the northeast towards the southwest and these currents appear to have been more erosive than depositional. The deposition which did take place by currents from the northeast was mainly in the form of reworked sand and channel fills.

Megaripple marks are found on or in every rock type, such as units 96, 93, 90, and 87, and have wavelengths which vary from approximately 60 cm up to nearly 8 m. Megaripple amplitudes in the Summerville Formation are usually less than 10 cm. Megaripple marks in the Summerville Formation are unimodal towards the northeast, and usually occur as single beds, rarely over 10 cm thick, or as tops of units that have been megarippled. Sandstone is the most dominant rock type showing megaripple marks in the Summerville Formation. When siltstone units have megaripple marks, they are preserved in the sandstone lenses in the siltstone.

Crests of all megaripples observed in the Summerville Formation are smooth with no superimposed small ripples. The lack of small ripple marks superimposed on the backs of megaripples indicates formation by high velocity currents according to Bagnold (1956, p. 258).

Climbing ripple marks are found in red brown sandstone units, such as unit 80, and medium red sandstone units like unit 92 (Plate 2, fig. 5). These climbing ripple sets document single events. Ripple wave lengths within these beds are usually 2 to 4 cm and the ripple sets are up to 20 cm high. Climbing ripple marks are the least common of the ripple mark types found in the Summerville Formation.

Units that show climbing ripple lamination are either channel fills or units with a great number of channels in them. When the climbing ripple lamination is found in rock units, climbing ripples are not continuous throughout the entire unit. Individual units show a change from unidirectional ripple lamination to climbing ripple lamination near the tops of the units. The change from unidirectional current ripple marks to climbing ripple marks is shown well in units 45 and 46 (Appendix). Unit 46 is distinct from unit 45 because of the change in appearance created by climbing ripple lamination at the top of this red brown sandstone unit.

The change in ripple lamination as seen from unit 45 to 46 is similar to changes in climbing ripple lamination described by Jopling and Walker (1968, p. 982) from their study on ripple-drift cross lamination. Jopling and Walker's interpretation of their observed change in ripple lamination was a decrease in the ratio of suspended load to bedload. Climbing ripple laminations, in general, are formed when abundant sediment is available to a current, so that the ripples are built upward in an overlapping series (Reinick and Singh, 1974, p. 95).

Structures Produced by Soft Sediment Deformation

There is a great variety of structures produced by soft sediment deformation in the Summerville Formation. These structures are found mostly in medium red sandstone beds, but they also occur in dark red siltstone beds. Soft sediment deformation structures observed include convolute bedding, flame structures, tent structures, rippled upclasts, mud balls, and load casts.

Convolute bedding is present in many units, such as units 97 and 75. The deformed interval ranges in height from a few centimeters to 20 or 30 cm. The convolute overturn is usually in the same direction as the dominant current (Plate 3, fig. 3). Convolute bedding is most commonly found in the Summerville Formation in units where thin lenses of siltstone are interbedded with thin lenses of sandstone. Deformation is not continuous laterally but commonly occurs only in areas a few meters across. In some cases such as in unit 68, convolutelike structures were observed on channel sides. The deformation on the sides of channels appears to be the result of slumping.

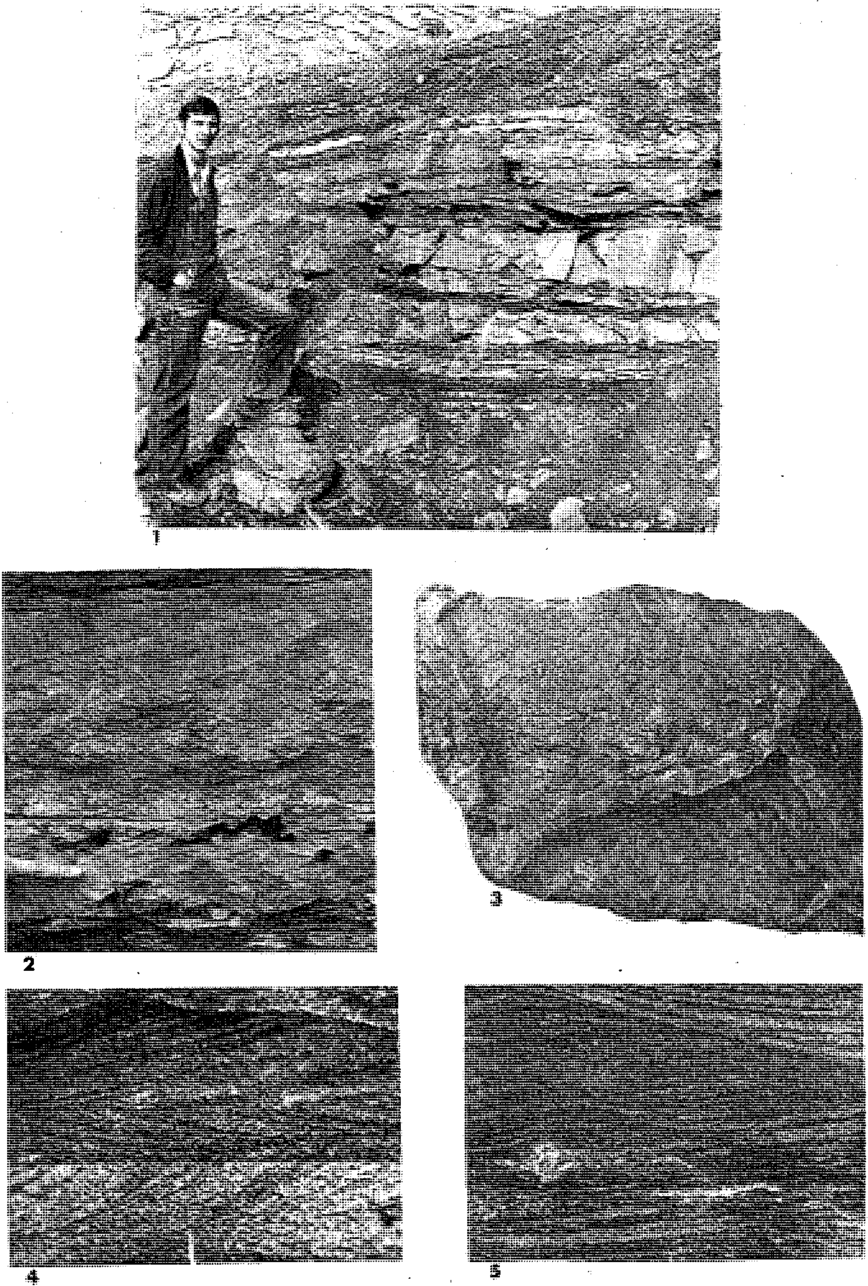
In general, convolute bedding in recent sediments is considered to be the result of strong currents flowing over sediments in a state of liquefaction (Williams, 1960, p. 211). Slumping and flowage of thin sheets of mud down slopes of channel banks produces convolutelike structures in modern sediments (Evans, 1965, p. 226).

Flame structures in the Summerville Formation are closely associated with areas of convolute bedding, as for example in unit 77, but are less common than convoluted areas. Flame structures in the Summerville Formation vary in height from a few centimeters up to 20 or 30 cm. These flame structures occur as curved pointed tongues of siltstone projecting up into overlying sandstone layers.

EXPLANATION OF PLATE 2
LITHOLOGIES AND SEDIMENTARY STRUCTURES

FIG. 1.—Two channels of red brown sandstone with lens of dark red siltstone between channels, Unit 80.
FIG. 2.—Clay flakes ripped up and incorporated in sandstone. Climbing ripple laminations are present in upper part of bed, Unit 44.
FIG. 3.—Mud cracks from Unit 63, 1/3x.
FIG. 4.—Bimodal current ripple marks from Unit 47, 1x.
FIG. 5.—Climbing ripple marks from Unit 44, 1x.

PLATE 2



Flame structures in the Summerville Formation are limited almost entirely to medium red sandstone beds, which overlie siltstone units, and appear to be the result of sand loading on the easily deformed silt. In modern sediments flame structures occur as the result of the deposition of sand over a hydroplastic mud layer (Kuenen and Prentice, 1957, p. 174).

Tent structures are associated with convolute bedding, and are most common in medium red sandstone units, such as unit 87, but are also present in siltstone units. The tent structures range in height from a few millimeters to 20 or 30 cm, and are less common than convolute bedding (Plate 3, fig. 2). Some units, such as unit 43, have tent structures throughout the full thickness of the unit. Unit 43 is a series of interbedded siltstone and sandstone lenses, and in this case the tent structures appear to be the result of loading of the sandstone lenses on the siltstone. Tent structures present in other units, as for example in unit 77, appear not only to be the result of loading, but sediment flowage also appears to have played a part in their development.

Tentlike structures in modern sediments have been noted to be produced by both loading of sand lenses on mud, and flowage associated with loading when sand is deposited on mud (Dzulynski and Walton, 1965, p. 153).

Rip-up clasts are common in the Summerville Formation. They occur at the base or in the lower part of most sandstone units (Plate 2, fig. 2), which are deposited over siltstone, as, for example, unit 44. Ripped up clasts in the Summerville Formation vary in size from a few millimeters up to 20 to 30 cm long. In many cases mud-cracked fragments have been ripped up during deposition of the sand and incorporated into the units, as in unit 63. In some cases mud flakes ripped up and incorporated in gray green channel fill are red at the base of the unit but are green up in the gray green sandstone.

Ripped up clasts are most common in channel fills. In some channel fills, such as in channels in unit 99, the rip-up clasts are present in large enough numbers to produce a flat pebble conglomerate.

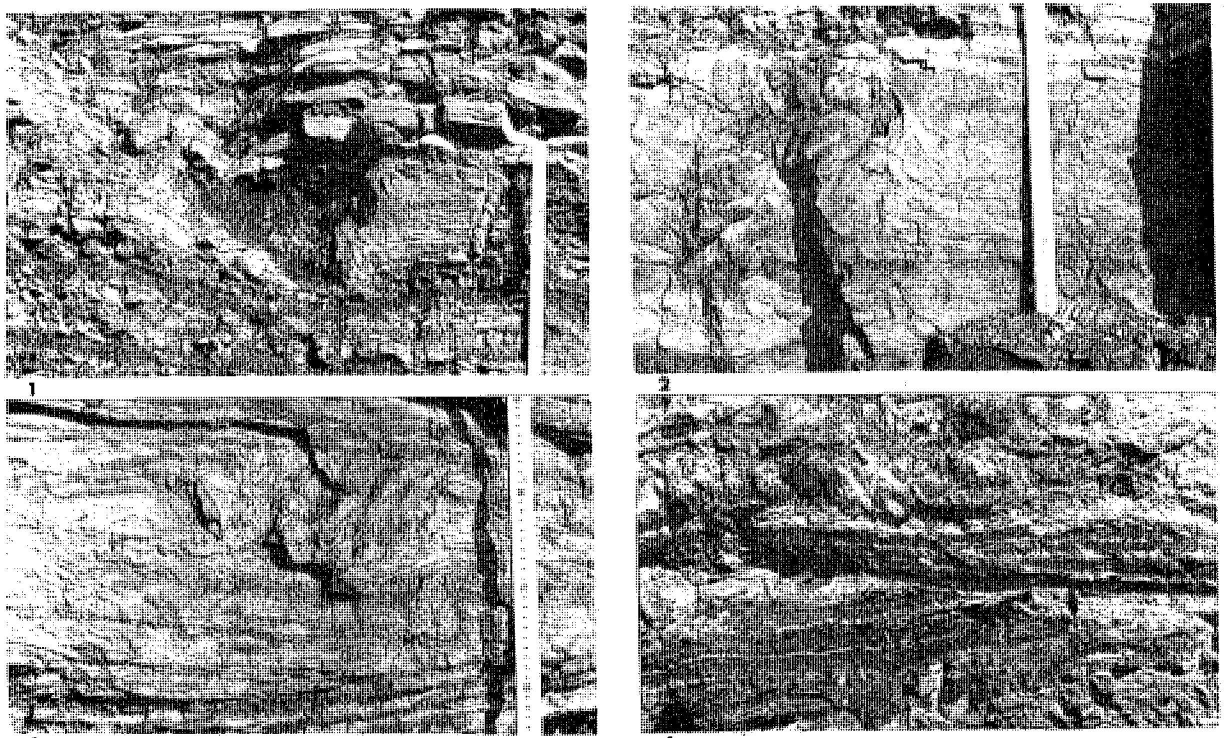
In many cases the rip-up clasts can be traced back to the siltstone lens from which they were detached. In other units all evidence of the siltstone unit from which the rip-up clasts came is gone. Gypsum and sandstone rip-up clasts are also present in the Summerville Formation, but are not common.

Ripped up clasts and clay pebbles are common in areas where sand is deposited on clay-rich beds by high velocity currents (Van Straaten, 1961, p. 206). Evans (1965, p. 221) notes that mud flakes produced by tidal waters stripping surface mud laminae are incorporated in the Wash tidal flat on the east coast of England. The mud flakes and ripped up clasts are usually quite small, but some rip-up clasts a foot square were found (Evans, 1965, p. 221).

Mud balls are common in sand units, like units 77 and 75, in the Summerville Formation and appear to result from large rip-up clasts being rolled by high velocity currents, during deposition. In some cases the Summerville mud balls appear to have been rolled with much force (Plate 3, fig. 1). Most mud balls in the study section are 2 to 5 cm in diameter, but some as large as 30 cm in diameter are present.

In general the large mud balls found in the Summerville Formation are red. The smaller mud balls and mud pebbles found in the Summerville Formation are either red or green. Color of the small mud balls appears to be a result of the environment into which they were deposited and not of the

PLATE 3



SEDIMENTARY STRUCTURES

FIG. 1.—Mud ball in sandstone from Unit 77.
FIG. 2.—Tent structure in sandstone from Unit 77.
FIG. 3.—Convolute bedding in sandstone from Unit 77.
FIG. 4.—Channel cut-and-fill, Units 123 and 124.

original deposition environment of the siltstone from which the mud balls were formed.

Sand balls and gypsum balls are also present in the Summerville Formation, as for example in units 122 and 117, but are not common. Sand balls appear to be the result of ripping up and rolling of muddy sandstone lenses and incorporation of them in other sediments, in about the same way the mud balls were formed. Gypsum balls occur only in the upper part of the Summerville Formation, where gypsum lenses were ripped up during sand deposition, rolled, and incorporated in detrital sediments. Gypsum balls may be more common than observed in the upper part of the Summerville Formation, but gypsum heaving in this portion of the section made some determinations impossible.

Mud balls are common in channel bottoms of the Wadden tidal flat, and are caused by high velocity currents ripping up and rolling mud laminae that were deposited during moments of slack water (Van Straaten, 1961, p. 206). Mud balls up to a foot across are ripped up, rolled, and incorporated into the sediments by tidal waters on the Wash tidal flat in England (Evans, 1965, p. 221).

Load casts, such as those found in unit 56, are present at the base of most sandstone units deposited on siltstone in the Summerville Formation. The underlying siltstone units, like unit 98, in many cases show a loss of bedding. The siltstone in unit 98 appears to have been deposited in a state of liquefaction, which would allow movement from unequal loading by overlying sandstone units, and would result in the formation of load casts.

In modern sediments load casts are considered to be caused by sand deposited on a hydroplastic mud layer (Reinick and Singh, 1974, p. 76). Overloading or unequal loading of these mud layers results in the sinking of sand into the mud as lobes (Kuenen and Prentice, 1957, p. 173).

Mud Cracks

Mud cracks in the Summerville Formation (Plate 2, fig. 3), are found only in channels filled with sandstone like unit 63. Evidence of ripped up mud-cracked polygons is common, but actual filled mud cracks are not. Most of the mud cracks which may have been present appear to have been destroyed by later deposition.

There are a great number of ripped up mud flakes that appear to be the result of a thin layer of mud drying out and cracking. If these mud flakes are the result of mud cracks, the mud cracks which produced the flakes were not deep nor were the polygon flakes very large. The fact that these flakes have been incorporated in the overlying sediments, and that the apparent size of the mud crack polygons which produced the flakes was small indicates that the period of exposure which produced the mud cracks was not long. The small mud-cracked polygons, shortly after their formation, must have been covered again by water and incorporated into new layers.

Two distinct sizes of mud-crack polygons are present in the Summerville Formation. The first group averages about 4 cm across and the second group averages about 10 cm across. The only well-preserved, mud-cracked polygons preserved in the Summerville Formation are those of the large group, and these are rare.

The large mud cracks in the Summerville Formation apparently formed during periods of long exposure, and were resistant enough to be preserved when again covered with water. The resistance of the large mud cracks to erosion allowed them to be filled with sand and preserved. The small mud cracks were probably formed during shorter exposures to the air, and were not resistant enough to be preserved when they were covered with water again.

Mud cracks in general result from desiccation of clay-rich sediments in areas that alternate between wet and dry conditions (Van Straaten, 1961, p. 214). Evans (1965, p. 221) in his work on the Wash tidal flat reports that the only mud cracks preserved in cores are large ones, some to 6 inches deep. The smaller mud-crack polygons are represented in his material only as mud flakes in the sediments.

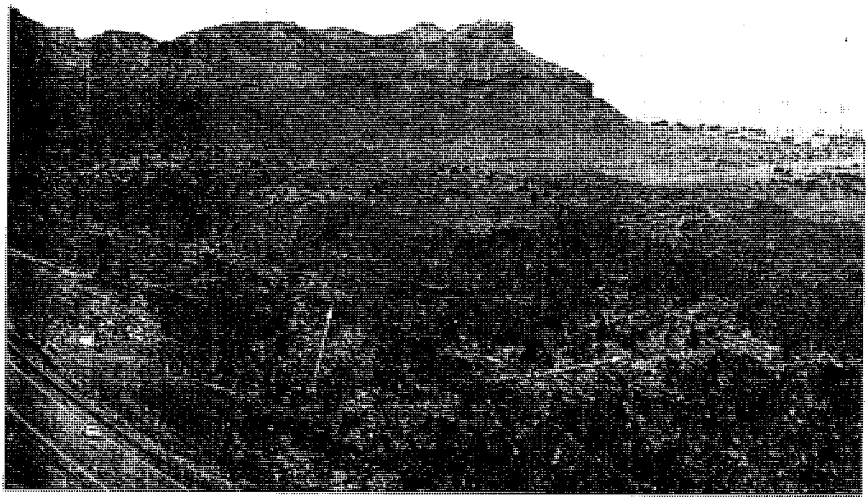
Channels

Filled channels are common throughout the Summerville Formation. Channels are cut into every lithology and are filled at one level or another with every lithology found in the Summerville Formation. There are single channels, channels that show channel cut-and-fill, such as those in unit 71 (Plate 3, fig. 4), and channels that show some degree of meandering and point bar migration. Summerville channels range in depth from a few centimeters, like those in unit 83, to about a meter, like those in unit 116. Average channel depth throughout the studied exposures is approximately 40 to 50 cm. Some units that contain channels are thicker than one meter, but the individual channels usually are not that deep.

The small channels which are less than about 30 cm in depth are generally filled with siltstone, as, for example, in unit 78. These siltstone channel fills have almost no internal structure preserved in the channels. This apparent lack of internal structure is due to a large degree to the deep mudstone weathering that characterizes the siltstones in the Summerville Formation. Small siltstone-filled channels are usually symmetrical, and show several periods of filling in most cases. Different periods of filling in the small channels, as in unit 33, are marked by sandstone lenses that are commonly green or red and green mottled. Mud cracks are preserved in the Summerville Formation in only one of these small channels that has been filled with sand.

Medium-sized channels, like those in unit 68, average about 45 cm deep and are usually filled with fine-grained sandstone, but are also commonly filled with siltstone and medium grained sandstone. Medium-sized channels, such as those in unit 84, commonly show channel cut-and-fill as well as a variety of ripple marks and crossbeds. The medium depth channels also contain abundant rip-up clasts and mud balls, as for example in unit 65.

Medium depth channels are the most common channels in the Summerville Formation. The sandstone that commonly fills these channels makes them resistant to erosion. On some benches and small plateaus in the Summerville Formation the preserved channel fills can be traced out and their form observed. In map plan these channels have sinuous braided patterns (Text-fig. 3). In the middle part of the studied Summerville Formation section units have been extensively reworked by channels, which are now filled with sandstone. These well-cemented sandstone channeled units now stand out as resistant ledges, like the ledge formed by unit 38.



TEXT-FIGURE 3.—Sinuous channels in the middle third of the Summerville Formation. The entire Summerville Formation is seen in the background.

Some larger channels also occur in the Summerville Formation. Some of these channels are over a meter deep, as for example those in unit 121, but the large channels average about 90 cm deep. These large channels are almost always filled with medium-grained sandstone, and the coarsest grained material in the studied section of the Summerville Formation is found in these channels.

Most of the trace fossils in the Summerville Formation are found in fillings of large channels, as for example in unit 99. The presence of trace fossils in these large channels, and the general lack of fossils of any kind in other parts of the Summerville Formation, make it appear that the deeper channels were the most hospitable environment for such organisms during deposition of the formation.

Rip-up clasts, mud-balls, a variety of ripple marks, and channel cut-and-fill are all common to the large channels. Slumpage also occurred along the channel banks.

Channels in modern sediments are generally caused by water flowing over soft sediments (Reinick and Singh, 1974, p. 62). Channels in the recent sediments of the Dutch Wadden show characteristics similar to the channels in the Summerville Formation, in that the Wadden channels have coarse sand fill in the large channels, sand and mud fill in the intermediate-sized channels, and mud fill in the small channels (Van Straaten, 1961, p. 205). The Wadden channels also show a variety of ripple marks, cross-bedding, mud balls, clay pebbles, and cut-and-fill structures (Van Straaten, 1961, p. 206).

INTERPRETATION OF SEDIMENTARY ENVIRONMENT

Siltstone Facies

Relatively thick beds of siltstone with sandstone lenses are the dominant sedimentary element of the Summerville Formation. Sedimentary structures in siltstone units of the Summerville Formation are generally found in the sandstone lenses, as in the case of ripple marks, or are outlined by sandstone lenses, as in the case of channels. Megaripples and bimodal current ripple marks are common in the sandstone lenses in the siltstone units.

Mud cracks and structures produced by soft sediment deformation are present in the siltstone units of the Summerville Formation. The siltstone units also have sections which show loss of bedding, and other sections that show laminated bedding.

Mottling in the siltstone units is due to partial reduction of the iron present. The reduction of the iron in the Summerville Formation to produce green sediments is probably not more extensive throughout the formation because of the low amount of organic matter present in the sediments. Presence of more green siltstone in the lower part of the study section and less green siltstone in the upper part of the section indicate a gradual decrease in reduction of the iron in the sediments, which could be caused by a decrease in contact with the sea, perhaps related to northward withdrawal of the Sundance Sea (Peterson, 1972, p. 186).

Important deposits of tidal flats on low energy coasts are laminated mud, with interbedded sand lenses (Reinick and Singh, 1974, p. 359). Megaripples and current ripple marks, common on modern tidal flats, are found in the sand lenses, and not in the muddy deposits (Evans, 1965, p. 223). Bimodal transport in areas of tidal flat deposition is commonly shown in sandy sediments (Reinick and Singh, 1974, p. 356).

Channels are important in a tidal flat environment. Van Straaten (1961, p. 215) concluded that if no channel deposits were found in a sedimentary sequence it was likely not the product of a true tidal flat environment.

Mud cracks are common in recent tidal flat environments (Evans, 1965, p. 221), and so are structures produced by soft sediment deformation in tidal muds (Evans, 1965, p. 226).

Partial reduction of iron in tidal flat sediments is commonly due to restriction of the movement of oxygen through the sediments by mud lenses deposited periodically by the sea during slack water (Van Straaten, 1950, p. 364).

Red and Green Sandstone Facies

Red and green sandstone facies in the Summerville Formation, for the most part, are lithologically the same except for the difference in the oxidation state of the iron in the rocks. The environment of deposition of these two rock types is also essentially the same, and will be treated as one basic environment in this discussion. Stratigraphic and geographic relationships of the red sandstone facies to the siltstone facies indicate that red sandstone was deposited landward from the siltstone. The Summerville Formation is interpreted to be a tidal flat sequence; as a result, the red sandstone in the Summerville is thought to represent upper sand flat deposits.

The red sandstone facies is thought to be the result of sand being deposited on the upper tidal flat by wind and intermittent streams. This sand was reworked by the periodic tides and then covered by the dominant muddy sediments of the tidal flat.

Red sandstone of the Summerville Formation contains most of the different types of sedimentary structures found in the formation. In modern tidal flats, more sedimentary structures are preserved in sandy deposits than in muddy deposits (Van Straaten, 1961, p. 207). The extent of the tidal flat also has a bearing on the development and preservation of sedimentary structures. The broader the tidal flat is, the greater the distance the tide has to travel, and the higher the velocity of currents in the tide. Lateral extent and thickness of the Summerville Formation indicate that it represents deposits of a broad extensive tidal flat, which may have been tens of kilometers across. Strong tidal currents on that flat could have created a great number and variety of sedimentary structures in the sand of the upper sand flat.

Tidal flat deposits along a desert coast would have some properties essentially different from tidal flat deposits along a temperate coast line. Different properties could be related to direct supply of material from the land by sand storms and streams (Van Straaten, 1961, p. 213). Sand supplied from a land source can extend a tongue of sand out on a dominantly mud flat, like that shown on the upper edge of the estuarine clay flats of the Bay of Funday (Klein, 1963, p. 849). This sand on the estuarine clay flats was derived from the land behind the clay flats and deposited on the clay flats by wind and streams.

The great variety of sedimentary structures in the Summerville Formation, including channels, which are caused by soft sediment deformation, and the variety of ripple marks, are like those discussed by many authors as being common in modern tidal flat deposits (Evans, 1965; Van Straaten, 1961; Reinick and Singh, 1974; and Klein, 1963).

Gray Green Sandstone Facies

Gray green sandstone is limited almost entirely to channel fillings in the Summerville Formation. Channels that are filled with gray green sandstone in the Summerville Formation are the channels deeper than 45 cm.

Gray green sandstone appears to have filled channels in the Summerville Formation either as lag or as sand brought in by the flooding tide. Most channels in the Summerville Formation appear to have been filled as the result of lag from the ebb tide, with a dominant depositing current direction towards the northeast. Gray green sandstone deposited as a lag is commonly interbedded with clayey siltstone that must have been deposited during periods of slack water.

Channels which appear to have been filled with sand brought in with the flood tide are characterized by filled mud cracks at their base. The presence of mud cracks indicates that the area was dry before the sand was deposited, so the deposition of the sand in these channels must have been during the flood tide or strong storms. The flood tide-filled channels are smaller and generally appear to have been nearer the high tide line.

The larger gray green sandstone-filled channels commonly have trace fossils present at their base while fossils of any kind are absent in other parts of the Summerville Formation. These deeper channels are interpreted as the most consistently moist environment in the Summerville Formation.

There are a great variety of sedimentary structures found in the channels in the Summerville Formation including mud cracks, rip-up clasts, mud balls, crossbeds, and a variety of ripple marks.

Work done by Evans (1965, p. 229) indicates that sandy channel fill can accumulate both as lag deposit associated with the ebb tide, and as sand brought in with the flood tide. Lag tide deposits are generally near the low tide line, and the flood tide deposits are generally nearer the high tide line.

In a tidal flat the larger channels generally have their maximum depth below low tide level, which makes these channel floors more nearly normal marine, for they are always covered with water (Van Straaten, 1961, p. 205).

The types of sedimentary structures present in the gray green channel fills of the Summerville Formation are common in the channel fills in modern tidal flat environments (Van Straaten, 1961, p. 206).

Red Brown Sandstone Facies

Units of red brown sandstone in the Summerville Formation seem to have been deposited as a single event or series of discrete events. Red brown sandstone is found in the Summerville Formation as both channel fills and as thin sheets of sandstone. Red brown sandstone units in the Summerville Formation are usually found within a relatively thick unit of siltstone, and sometimes the red brown sandstone channel fills have siltstone lenses between individual channel fill elements (Plate 2, fig. 1).

Dominant sedimentary structures in the red brown sandstones are ripple marks, but channel cut-and-fill is also present. Climbing ripple marks and megaripple marks are the most prevalent types of ripple marks in the red brown sandstone.

The association in the Summerville Formation of the red brown sandstone with dark red siltstone indicates deposition of the sandstone on the lower mud flat. The red brown sandstones appear to have resulted from high velocity current flow on the lower mud flat during maximum ebb tide flow.

Megaripple marks are most common in channel fill deposits on recent tidal flat (Evans, 1965, p. 226). In most recent tidal flats, climbing ripple marks occur only near the mouth of channels (Reinick and Singh, 1974, p. 358).

Gypsum Facies

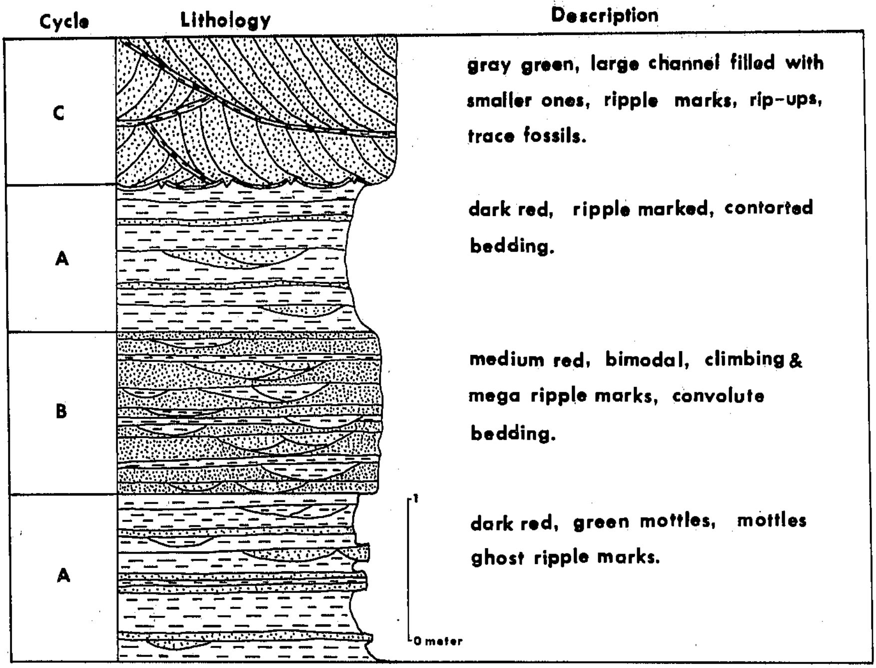
The gypsum facies in the Summerville Formation represents the last depositional phase in the Summerville Formation. Much of the gypsum is a complex mixture of siltstone and gypsum. Gypsum in the Summerville Formation is interpreted as accumulating on evaporating pans that were only refreshed during maximum high tides. Siltstone and sandstone of the normal tidal flat decreased in abundance until only gypsum was deposited, as terrigenous sediment influx was barred from the pans by the withdrawal of the Sundance Sea.

When the Sundance Sea withdrew to the north, areas in the south were left as evaporating pans. In the west this retreat is evidenced by the evaporites of the Summerville Formation; in the east the retreat is evidenced by evaporites of the upper Todilto Formation (Peterson, 1972, p. 186).

A chaotic mixture of siltstone and gypsum is produced on modern pans when gypsum crystals grow contemporaneously with mud cracks, in a mud flat undergoing excessive evaporation (Thompson, 1968, p. 26).

CYCLICITY

The Summerville Formation is cyclic, with two main kinds of cycles, one of alternating siltstone and red sandstone, and the other of alternating siltstone



TEXT-FIGURE 4.—Stratigraphic column of the two main types of cycles in the Summerville Formation, showing the general lithologies, structures, and associations.

and gray green channeled sandstone (Plate 4 and Text-fig. 4). The dominant unit in both cycles is the dark red siltstone. The dark red siltstone is designated as unit A in Plate 4 and Text-figure 4. In Plate 4 siltstone is seen to interbed cyclicly with medium red sandstone labelled *B*, in the lower and middle part of the road cut. Near the top of the road cut (Plate 4) siltstone interbeds with channeled gray green sandstone, labelled *C*.

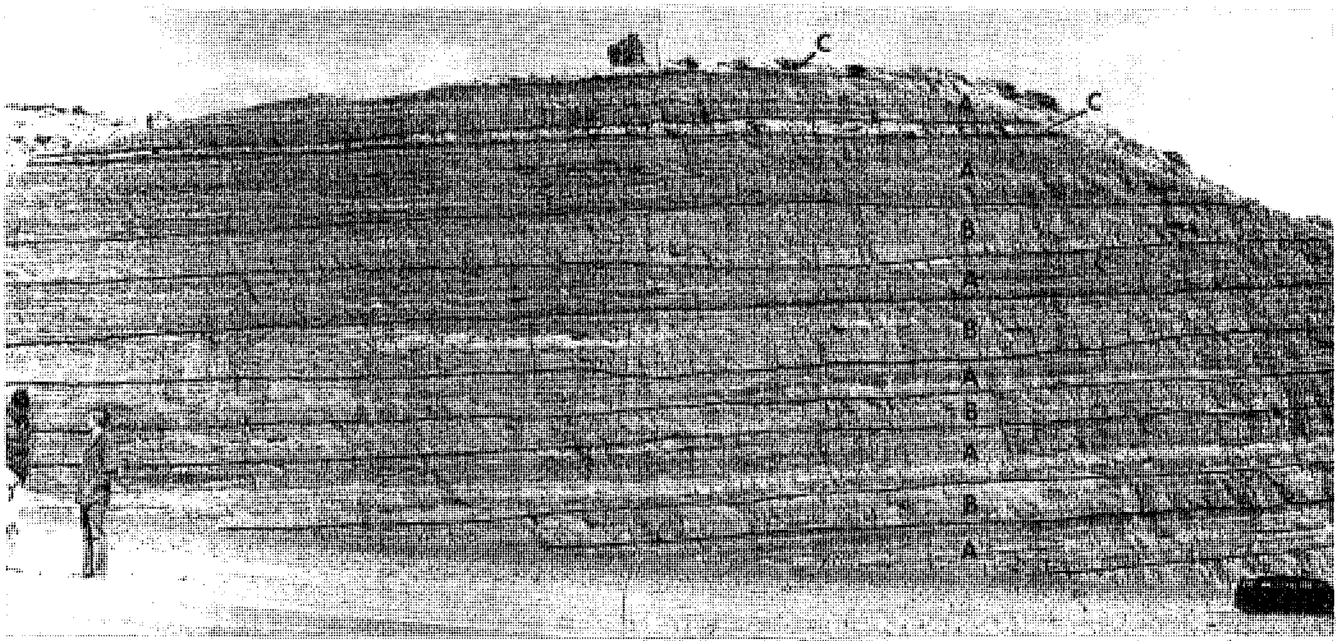
The general characteristics of the cyclic patterns are illustrated in Text-figure 4, which shows the relationships of the cycles to lithologies and structures present in the two types of cycles.

Siltstone in the Summerville Formation represents the dominantly muddy sediments on a mud flat, with these siltstone deposits characterized by sandstone lenses throughout the unit.

Sedimentary structures are not commonly preserved in these siltstone units, but when they do occur they are usually observed in, or outlined by sandstone lenses. This is true of the channels and other sedimentary structures present in siltstone units of the Summerville Formation.

Siltstone deposits in the Summerville Formation are commonly covered by sandy tidal flat material. This sand could have been brought onto the tidal flat from surrounding areas by wind or streams.

The sandstone element of the cyclic Summerville Formation is characterized by a great variety of sedimentary structures. These structures include



EXPLANATION OF PLATE 4
CYCLIC UNITS

Lower road cut used in study, showing two dominant types of cycles. Unit A, dark red siltstone; Unit B, medium red sandstone; Unit C, gray green sandstone. A-B cycle is dominant in lower and middle part of road cut, and A-C cycle is dominant in upper part of road cut.

channels, a great variety of ripple marks, and structures produced by soft sediment deformation.

Lenses of dark red siltstone are common in the medium red sandstone beds. Two generalizations can be made about these siltstone lenses: first, they increase in number towards the top of the beds; and second, they increase in number as the bed is traced towards the northeast. This relationship between the red sandstone and siltstone is a good example of Walther's Law (Walther, 1893-1894).

Siltstone, the dominant rock type in the mud flat deposits of Summerville Formation, commonly covers the red sandstone units. The red siltstones are at times interbedded with gray green channel fills which represent the third main element of the cyclic Summerville Formation.

The gray green sandstone appears to represent the sandy channel floor sediments. The thickness of these units depends to a large degree on the depth of the individual channels. These channel sandstones overlie the lower tidal flat siltstones, and clay pebbles derived from these siltstones are common in the channel fills, and occur near the base of the individual channels. Siltstone lenses are also consistently found between channels.

The upper part of the channel fill contains crossbeds showing the direction of movement of the current that filled the channel, and the channel fills are usually flat topped.

The relationship of the red sandstone to the siltstone is predictable in regards to associated rock types and sedimentary structures present. The gray green sandstone-siltstone cycle is less common than the siltstone-red sandstone cycle, but when it occurs it is just as predictable, as far as types of sedimentary structures present and associated rock types are concerned.

The vertical sequence in stratified rocks is important in determining the environment of deposition. The following sequence is considered typical for tidal deposits: comparatively sandy channel floor sediments, with their thickness depending on the depth of the channels, covered by muddy deposits, in turn covered by sandy material, and more clayey, silty sediments (Van Straaten, 1961, p. 209).

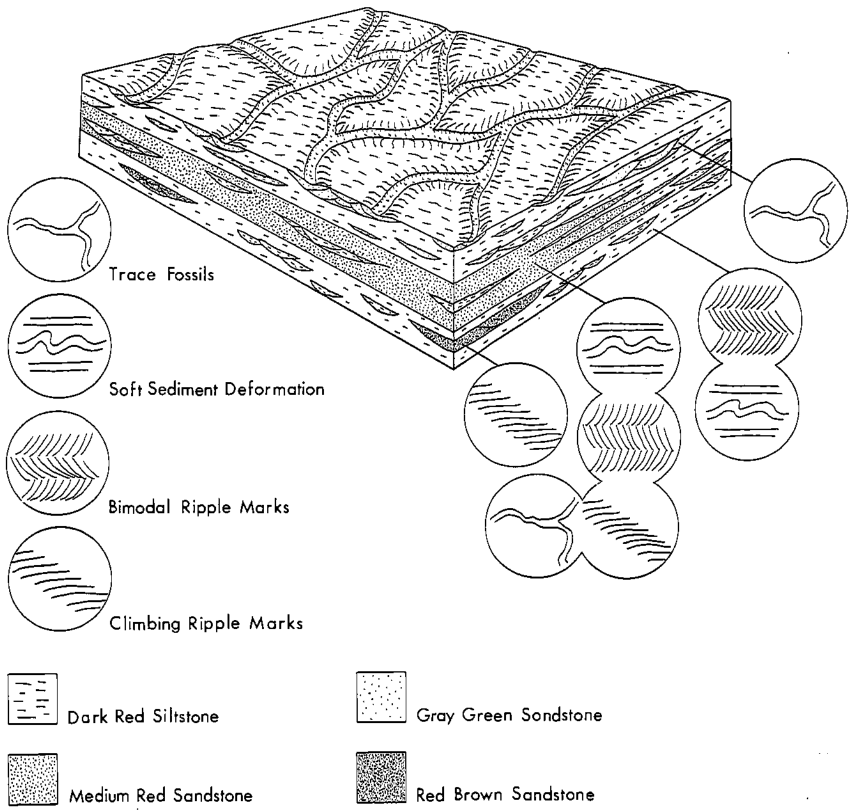
MODEL

The Summerville Formation on the west side of the San Rafael Swell represents a very broad low-relief tidal flat on the southwest end of the Sundance Sea (Text-fig. 5). The tidal flat was perhaps 30 to 40 kilometers wide, with a tidal range as indicated by the channels of about a meter. The broadness of the tidal flat created high velocities in the currents of the periodic flood and ebb tides.

The area around the sea was low, dry, and arid. Sand storms were probably common; these, along with intermittent and possibly year-round streams, kept a supply of clastic sediments coming into the area. Seasonal storms advanced tongues of sand out on the dominantly mud tidal flat. This sand was worked by the periodic tides, and finally covered with mud.

Life in the tidal flat was limited almost entirely to the deeper channels, and then only when these channels were filled with water. The little organic matter found in the area was concentrated in these deeper channels.

Tidal flat deposition ended with the withdrawal to the north of the



TEXT-FIGURE 5.—Sedimentary model showing hypothetical tidal flat of very low relief. Surface is highly channeled, and the profiles of old channels are seen on the sides of the block. Relationships of the four basic rock types present in the Summerville Formation are represented, with a major advance of light red sandstone. Types and occurrences of sedimentary structures are also indicated.

Sundance Sea, and the deposition of the evaporites on the once-tidal-dominated plain.

APPENDIX

Stratigraphic Section
Top of Summerville Formation

Unit	*Description*	*Thickness* *Unit* *(cm)*	*Cumulative* *(meters)*
129	Gypsum: white to pink; lenses of light green siltstone and sandstone, and medium dark red to light red siltstone and sandstone; siltstone more common than sandstone; massive bedded; channeled, some channels to 80 cm deep; channels show high percentage of red siltstone; bedding very distorted;	1157	119.25

	large number of secondary gypsum dikes; unconformity at top.		
128	Sandstone: medium light green, heavy red mottles; fine grained; silty; interbeds of gypsum up to 40 cm thick; interbeds of medium dark red clayey siltstone, mostly in small channels; bedding contorted; red siltstone increases towards top.	172	107.68
127	Siltstone: medium dark brown red, with green mottles; gypsum lenses throughout; mudstone weathering; some mottles blue green.	116	105.96
126	Sandstone: medium light green, with red mottles; fine grained; lenses of dark green siltstone throughout, similar to unit 114, but more green and different structures; megaripple marked; wavelength 120 cm; small channels; channel cut-and-fill; small ripple marks.	120	104.80
125	Gypsum: white to pink; lenses of medium light green sandstone, with red mottles; gypsum heaving; small scale channels.	110	103.60
124	Siltstone: medium dark brown red, grading to light green at top; mottled; mudstone weathering.	82	102.50
123	Sandstone: light green, with slight red mottles; fine grained, white to pink gypsum throughout lenses and nodules; lenses of clayey siltstone, medium red and light green; soft sediment deformation.	103	100.65
122	Siltstone: medium dark red; lenses of light green sandstone; mudstone weathering; channeled with channels up to 50 cm deep; convolute bedding below sandstone lenses; mud balls; sand balls.	161	100.65
121	Sandstone: medium light green; medium grained; massive channels; channel direction 160°; individual channels to 180 cm; a 6 cm lens in upper third of unit has lots of burrows on base of bed; many large channels at this horizon in the formation.	330	99.04
120	Siltstone: medium dark red purple to medium dark red; gypsum throughout up to 50% of unit; light green sandstone lenses throughout; mudstone weathering; soft sediment deformation.	86	95.74
119	Siltstone: medium dark red, with green mottles; slightly gypsiferous; medium red, and light green sandstone lenses throughout, increasing towards top; megaripples, flame structures, rip-ups, mud balls, convolute bedding; channels to 65 cm deep; channels near top filled with medium green sandstone.	205	94.88
118	Sandstone: medium light green, with red mottles; fine grained; lenses of medium red siltstone throughout, increasing towards top; sandstone decreases towards top, ripple marked; bimodal at 360° and 180°; soft sediment deformation.	177	92.83

117	Siltstone: medium dark red; gypsiferous; highly channeled; contains several large channels to 70 cm deep, filled with medium light green sandstone and gypsum; lenses of light green sandstone throughout; these lenses lead to channels and appear as channel fill overflow; green and red mottling present in unit; channels near top of unit contain mud balls, gypsum balls, and rip-ups.	130	91.06
116	Sandstone: medium light red, and medium light green, interbedded, with red and green mottles; fine grained; extensive soft sediment deformation; convolute bedding, flame structures, some gypsum nodules and lenses; channeled, channels up to 1 m deep; top one third has mud lumps, mud balls, clayey siltstone rip-ups; gypsum increases towards top; unit topped by flat-topped gypsum; filling channels.	318	89.76
115	Siltstone: medium dark red, green mottles; sandy and clayey; gypsum present throughout in nodules and lenses; bedding highly contorted; top of unit channeled, with channels to 80 cm deep; channels filled with flat-topped gypsum; gypsum thickens to the west; channels contain green and red mud balls.	218	86.58
114	Siltstone: medium dark red, green mottles; sandy; grades up into silty sandstone; gypsum in lenses and nodules; channeled; channels to 50 cm deep; channels near top of unit filled with white to pink gypsum; gypsum varies from 30 to 70 cm thick and is flat topped; lumps of clayey siltstone and gypsum ripped up and rolled in channels.	131	84.40
113	Sandstone: medium light red, with green mottles; fine grained; gypsum throughout, increasing towards top; secondary gypsum filling fractures; ripple marked.	52	83.09
112	Siltstone: medium dark red brown, gypsiferous, increasing towards top; gypsum dominates top; slight green mottling.	34	82.57
111	Sandstone: medium light green; fine grained; gypsiferous; thin medium dark red siltstone lenses, ripple marked.	18	82.23
110	Siltstone: medium dark red with slight green mottles; medium light green sandstone lenses; mudstone weathering.	28	82.05
109	Sandstone: medium light red; fine grained; lenses of clayey siltstone; ripple marked; 4 cm thick bed of primary gypsum near top.	74	81.77
108	Siltstone: medium dark red, some slight green mottles; clayey siltstone lenses throughout; lenses medium light green and light red.	86	81.03

107	Sandstone: medium light red; lenses; fine grained; interbedded with lenses of medium dark red siltstone; ripple marked; slight green mottling towards top.	73	80.17
106	Siltstone: medium dark red; slight green mottles; fine grained sandstone lenses throughout; lenses changing from medium light green in lower half to medium red in upper half; mudstone weathering.	367	79.44
105	Sandstone: medium light green; fine grained; interbedded with medium dark red siltstone with mudstone weathering; red and green mottling present.	14	75.77
104	Siltstone. medium dark red, weathers medium red; slope former; some lenses of light green sandstone 2 cm thick.	96	75.63
103	Sandstone: medium light green; fine grained; interbedded with medium dark red clayey siltstone; siltstone shows mudstone weathering.	30	74.67
102	Siltstone: medium dark red, with green mottles; slope former; green sandstone lenses near bottom structure masked by mudstone weathering.	114	74.37
101	Sandstone: medium light red, with green mottles; fine grained; interbeds of medium red siltstone; highly ripple marked; green mottles more prevalent in upper and lower fourths; lower fourth shows convolute bedding.	151	73.23
100	Siltstone: medium dark red; light green mottles near bottom; clayey siltstone; thin lenses of fine grained sandstone; medium light green with slight red mottles.	87	71.72
99	Sandstone: medium green gray; medium grained; large channel filled by several smaller ones, ripple marked; bimodal trending 90° and 360°; rip-up clasts, clay pebbles, climbing ripple marks, trace fossils; secondary gypsum pinches out to the east into a medium light gray green sandstone which weathers red; with siltstone interbeds, channels, rip-ups, convolute bedding.	180	70.85
98	Siltstone: dark red; slight green mottles in lower third and near top; upper two-thirds show loss of bedding; stone-baby weathering; soft sediment deformation; convolute bedding.	105	69.05
97	Siltstone: medium dark red; sandy, medium red and medium green sandstone lenses; ripple marked; bimodal trending 90° and 220°, dominant 90°; small channels; rip-ups; convolute bedding; tent structures, flame structures, megaripple marks; structures show mainly in sandstone lenses; bottom third and top third shows stone-baby weathering.	140	68.00
96	Sandstone: medium dark red; fine grained; interbeds of clayey siltstone increasing towards top, and east;	162	66.60

	some green mottling; small channels, up to 40 cm deep; ripple marked; trending 90°; megaripple marks; some small channels filled with medium green sandstone; slight stone-baby weathering near top.		
95	Sandstone: medium light green gray; medium grained; large channel, filled by several smaller ones; channel exposure approximately 70 meters in length; interbeds of green clayey siltstone; load casts, trace fossils, channel cut-and-fill; small crossbeds and ripple marks in channels; rounded green clay pebbles near bottom; thins in both directions.	163	64.98
94	Sandstone: medium dark red, with green mottles lower 20 cm; upper unit shows loss of bedding; looks quicksandy; stone-baby weathering; ripple marked; megaripple marked; trending 180°.	174	63.35
93	Siltstone: medium dark red, with slight green mottles near bottom; clayey; has 5 cm deep red purple bed in upper third; fine grained sandstone lenses near top show ripple marks and megaripple marks.	77	61.61
92	Sandstone: medium red with green mottles; fine grained; base shows loss of bedding, looks almost rooted; ripple marked; climbing ripple marks; megaripple marks; grades into medium dark red siltstone, with mudstone weathering to the east.	105	60.84
91	Siltstone: medium dark red with slight green mottles; clayey; ripple marked; grades to the west into a medium red sandstone with green mottles.	73	59.79
90	Sandstone: green gray, weathers medium light red; clayey siltstone lenses throughout; thin bedded at bottom grading to thick bedded at top; ripple marked; trending 360°; megarippled.	68	59.06
89	Sandstone: light green gray; medium to fine grained; channel, filled by several smaller ones; ripple marks; bimodal; trending 360° and 180°; trace fossils.	52	58.38
88	Siltstone: medium dark red; clayey, interbedded sandstone lenses; lenses light green near base grading to medium red near top; soft sediment deformation; megaripple marked wave length 3 m; channeled, channels up to 50 cm deep; grades into medium light red sandstone to the west.	79	57.86
87	Sandstone: medium light red, lower half; medium light green with red mottles, upper half; fine grained; siltstone lenses throughout; tent structures, convolute bedding, ripple marked, megaripple marked; current bimodal trending 40° and 180°	66	57.07
86	Siltstone: medium dark red with slight green mottles; clayey; medium light green sandstone lenses near center of unit; highly soft sediment deformed, slight stone-baby weathering.	104	56.41

85	Sandstone: medium dark red with green mottles; fine grained; silty, interbeds of dark red clayey siltstone lenses.	75	55.37
84	Sandstone: medium red brown, with slight green mottles; medium grained; channel; siltstone lenses near top; ripple marked trending 90°; climbing and megaripple marked; channel cut-and-fill.	43	54.62
83	Siltstone: medium dark red with green mottles; sandy; highly channeled; medium light green sandstone bed, with red mottles near top; mottles ghost ripple marks; channels to 5 cm deep.	108	54.19
82	Sandstone: medium light green with red mottles; fine grained; interbedded with medium dark red siltstone lenses, with green mottles; siltstones increase towards top; channeled, channels to 10 cm deep; ripple marked; bimodal trending 40° and 240°; megaripple marked; dominant current direction 40°, slight stone-baby weathering.	140	53.11
81	Sandstone: medium red; fine grained; interbeds of medium dark red siltstone; siltstone increases towards top, and red sandstone with light green mottles; highly channeled; ripple marked trending 90°; megaripple marked; troughs running north-south; convolute bedding; flame structures.	200	51.71
80	Sandstone: medium red brown, slight green mottles; medium grained; ledge former; channels trend 360°; interfingers with medium dark red siltstone lenses, with green mottles; channel cut-and-fill, climbing ripple marks.	60	49.71
79	Siltstone: medium dark red with green mottles; clayey; sandy; mudstone weathering middle third; interbeds of light green silty sandstone with red mottles; megaripple marks; crests trend north-south.	68	49.11
78	Siltstone: medium dark red, with slight green mottles; fills channels up to 33 cm deep; highly channeled; thin lenses of green sandstone throughout, with some lenses of red sandstone; grades up into a sandstone, medium light red; ripple marked; trending 50°; tent structures, laminated inpart, slight green mottles, rip-ups, channel cut-and-fill, climbing ripple marks.	84	48.43
77	Sandstone: medium red; fine grained; highly channeled; some channels fill with medium dark red siltstone; red and green mottled sandstone lenses throughout; some channels medium light green sandstone, and gray green sandstone; highly rippled marked; trending 90°; megaripple marked; soft sediment deformation; convolute bedding; flame structures, large mud balls, clay pebbles, tent struc-	90	47.59

	tures, climbing ripple marks; large channels generally sandstone; small channels generally siltstone.		
76	Siltstone: medium dark red; basal 5 cm; dark red sandy silt, with green mottles; mudstone weathering.	17	46.49
75	Sandstone: medium light red; fine grained; highly channeled; channel cut-and-fill; highly ripple marked; trending 100°; flame structures, convolute bedding, megaripples; flattened mud balls, up to 4 cm by 7 cm; unit thickens to the north.	117	46.52
74	Siltstone: medium dark red; thin medium red sandstone lenses throughout; highly channeled.	15	45.35
73	Sandstone: medium light red; highly channeled; channel cut-and-fill; lenses of medium dark red silt throughout; ripple marked; bimodal; trending 200° and 40°; dominant direction 40°.	77	45.20
72	Siltstone: medium dark red; slight green mottles; interbeds up to 5 cm thick of medium light red sandstone; sandstone highly ripple marked trending 180°.	26	44.43
71	Sandstone: medium light red; interbeds of medium dark red siltstone, up to 4 cm thick; ripple marked; trending 110°; climbing ripples; megaripple marked; highly channeled; channel cut-and-fill.	47	44.17
70	Siltstone: medium dark red, slight green mottles; thin medium light red sandstone lenses throughout.	11	43.70
69	Sandstone: medium red gray; fine grained; concoidal fracture; ripple marks can be seen only on weathered surface, medium dark red, slightly green mottled; siltstone lenses throughout; surface of unit megaripple marked; wave length 160 cm.	22	43.59
68	Siltstone: medium dark red, light green mottles; large channels; sides of channels show soft sediment deformation; large convolutes 40 cm high; channels to 45 cm deep; some channels filled with siltstone, some filled with light green gray sandstone with slight red mottles, some with red gray brown sandstone; cross bedding evident in siltstone channels.	180	43.47
67	Sandstone: medium red gray; fine grained; concoidal fracture; calcarious cement; ripple marks evident only on weathered surface; lenses of medium dark red siltstone throughout; grades upward into a light green gray sandstone, with red mottles; load casts present.	37	41.57
66	Siltstone: medium dark red, slight green mottles; mudstone weathering; masked ripple marks; mud cracks; 3 cm bed of medium light gray sandstone, with green mottles near center of unit.	15	41.20
65	Sandstone: medium light red; fine grained; interbeds of medium dark red siltstone, with lenses of light green sandstone; highly channeled; chan-	237	41.05

	nels to 43 cm deep; some channels contain siltstone, some contain light gray green sandstone; ripple marked trending 180°, mud balls, rip-ups, mega-ripple marks, convolute bedding.		
64	Siltstone: medium dark red; mudstone weathering; two interbeds of medium to light green gray sandstone 7 to 10 cm thick, with ripple marks; trending 110°; slight red mottles.	87	38.68
63	Siltstone: medium dark red; highly channeled, channels to 30 cm deep; channel fill of medium grained medium light green sandstone; mud cracks, rip-ups, clay balls, lenses of light green gray and red sandstone throughout unit; red and green mottles; ripple marked; trending 280°.	115	37.81
62	Sandstone: medium dark red with light gray green mottles, grading up to medium light red sandstone with light gray green mottles, into a light gray green sandstone with red mottles; fine grained; channeled; local lenses of medium dark red siltstone, with mudstone weathering.	97	36.66
61	Siltstone: medium dark red; interbeds of light green gray sandstone with red mottles; mottles ghost ripple marks; highly channeled; sandstones locally thicken into 15 cm channels; load casts, convolute bedding, rip-ups, flame structures.	92	35.69
60	Sandstone: medium light red, slight green mottles; fine grained; interbeds of medium dark red siltstone; with mudstone weathering; ledge former; ripple marks obvious on weathered surface; bimodal; trending 90° and 300°, 90° dominant; convolute bedding; locally channeled by unit 61.	95	34.77
59	Siltstone: medium dark red, slight green mottles; highly channeled; channels outlined by light green sandstone lenses; channels to 70 cm deep; some channels filled with siltstone, some with medium light red sandstone; sandstones ripple marked; trending 90°; crossbeds in channels; megaripple marks in upper half; wavelength of 65 cm; convolute bedding present above megaripple marks.	146	33.82
58	Siltstone: medium dark red, slight green mottles; fine grained; interbeds of green gray sandstone, with red mottles; mottles ghost ripple marks; ripple marks trend 55°; sandstone fills local channels up to 20 cm deep.	100	32.36
57	Siltstone: medium dark red, light green mottles near base; local channels of medium red to light gray green sandstone; channels to 24 cm deep; ripple marked; bimodal; trending 140° and 320°, 140° dominant direction.	71	31.36

56	Sandstone: medium light red, slight green mottles; fine-grained interbeds of medium dark red siltstone; channels of siltstone to 12 cm deep; grades laterally into a 38 cm channel of light pinkish brown sandstone; ripple marked; trending 85°; load casts.	54	30.65
55	Siltstone: medium dark red, slight green mottles near base; interbeds of medium red sandstone with slight green gray mottles; three 2 cm beds of light green sandstone near top; ripple marked; bimodal; trending 105° and 310°.	57	30.11
54	Sandstone: medium light green with red mottles; grading up into a medium light red sandstone, with green mottles, to medium light red sandstone; medium dark red siltstone lenses throughout; highly ripple marked; trending 100°.	114	29.54
53	Siltstone: medium dark red with slight green mottles; interbeds of medium light green sandstone with red mottles, varying in thickness from 4 to 8 cm; megaripple marked, wavelength 70 cm; mottling ghosts ripple marks.	130	28.40
52	Sandstone: medium light green with red mottles, grading up into a medium light red sandstone with green mottles; fine grained; interbedded with lenses of medium dark red siltstone; upper half of unit ripple marked; trending 345°.	51	27.10
51	Siltstone: medium dark red; interbeds of medium light red sandstone; mudstone weathering, thin bedded to laminate.	18	26.59
50	Sandstone: medium red, slight green gray mottles; fine grained; medium bedded; slight mudstone weathering near top; thickens to the east into a bar.	40	26.41
49	Siltstone: medium dark red, slight green mottles near bottom; ripple marked, but ripple marks masked by mudstone weathering; mud cracks on some surfaces; thin bedded to laminate.	10	26.01
48	Siltstone: medium red with light green gray mottles; interbedded with medium light green and medium light red brown sandstone; sandstone dominates towards top; channeled; channels to 18 cm deep; grades laterally into greenish gray sandstone with red mottles.	95	25.91
47	Sandstone: medium red brown; fine grained lenses of clayey siltstone throughout; flattened clay pebbles; ripple marked; upper half shows loss of bedding; mudstone weathering; soft sediment deformation.	100	24.96
46	Sandstone: medium light red brown; fine grained; single bed; climbing ripple marks; ripple sets 2-4 cm thick; current 60°; shingles out to the east.	13	23.96

45	Sandstone: medium red brown; fine grained; interbeds of medium dark red sandy siltstone; unit highly ripple marked; current trend 40° lower half, 130° upper half; convolute overturn direction 40°.	43	23.83
44	Sandstone: light medium red; fine grained; ledge former; thick bedded; intensely climbing ripple marked; horizons of rip-up clay clasts; current trend 65°; clay pebble conglomerate lower part of unit.	65	23.40
43	Siltstone: medium red; light green lenses of sandstone throughout, mudstone weathering, tent structures, full thickness, ripple marked, ripple marks trend 60°.	30	22.75
42	Sandstone: light green gray, slight red mottles; fine grained; resembles base of unit 38; top megaripple marked; wave length 2.5 to 3 m; crest trend 20°; medium bedded.	25	22.45
41	Siltstone: medium dark red; lenses of light green sandstone throughout, megaripple marked, wave length 6 to 8 meters, crest trend 20°.	80	22.20
40	Sandstone: light gray green, slight red mottles; fine grained; pinches out in either direction; marks major change above and below; resembles base of unit 38.	8	21.40
39	Siltstone: medium dark red brown; shaley parting; small-scale soft sediment loading.	14	21.32
38	Sandstone: upper and lower third light gray green, middle third medium red; fine grained; medium to fine bedded; low ledge former; ripple marked; ripple marks trend 40° near the base, 70° middle third, 30° upper third; small channels near top; channels 40 cm deep, 4 to 5 meters wide; channels filled with well-cemented, light green, sandy siltstone.	58	21.18
37	Siltstone: medium dark red; lenses of light green and medium light red sandstone lenses throughout; sandstones mottled, showing evidence of ripple marks.	40	20.60
31	Siltstone: medium dark red; lenses of medium light red sandstone throughout, with slight green mottles; similar to unit 7, but more sandstone lenses; sandstone lenses slightly ripple marked.	110	17.14
30	Sandstone: medium light red, with light green mottles throughout; fine grained; interbeds of medium dark red siltstones up to 10 cm thick; unit ripple marked, but not distinct enough to measure trend; mottles ghost ripple marks.	100	16.04
29	Siltstone: medium dark red, slight green mottles; mudstone weathering; some very small lenses of medium red sandstone.	20	15.04

28	Sandstone: medium light gray green, with red mottles; fine grained; interbedded with red siltstone lenses; channeled; channels to 30 cm deep; ripple marked.	40	14.84
27	Siltstone: medium dark red; interbeds of medium light red sandstone, locally to 50% of unit; sandstone lenses show some indication of ripple marks.	70	14.44
26	Sandstone: medium gray green, with red mottles; fine grained; megaripple marked; wavelength 65 cm; trend 170°.	18	13.74
25	Siltstone: medium dark red, slight green mottles; lenses of medium light green, and medium light red sandstone throughout; sandstones mottled.	57	13.56
24	Sandstone: upper and lower thirds medium light gray green; middle third red gray; weathers red; fine grained; lenses of medium dark red clayey siltstone throughout; unit highly ripple marked; trending 150°; megaripple marked.	56	12.99
23	Siltstone: medium dark red; lenses of medium light red sandstone, with slight green mottles throughout; sandstone lenses show ripple marks.	164	12.43
22	Sandstone: red gray, weathers medium red, grades up to gray green with red mottles; fine grained; thin lenses of clayey siltstone throughout, increasing towards top; ripple marked; trend 140°; wave length 25 cm.	78	10.79
21	Siltstone: medium dark red; lenses of medium red sandstone throughout; unit shows small-scale stone-baby weathering.	23	10.01
20	Sandstone: medium light gray green, with red mottles; fine grained; interbedded lenses of medium dark red clayey siltstone; unit ripple marked; ripple trends 140°; indication of bimodal transport.	32	9.78
19	Siltstone: medium dark red; lenses of medium light green throughout; sandstones show indication of ripple marks.	110	9.46
18	Sandstone: medium light red; slight evidence of ripple marks; weathers into rounded pebbles.	7	8.36
17	Siltstone: medium dark red; lenses of light green sandstone throughout; sandstones show slight ripple marks.	40	8.29
16	Sandstone: medium light red; fine grained; silty; slightly ripple marked.	10	7.89
15	Siltstone: medium dark red; lenses of medium light green sandstone; slight evidence of channels or megaripple marks.	65	7.79
14	Sandstone: medium light red, with light green mottles at base; slightly ripple marked.	7	7.14
13	Siltstone: medium dark red, slight green mottles; lenses of light green sandstone throughout.	56	7.07

12	Sandstone: light gray green, red mottles in middle of unit; fine to medium grained; channeled; highly ripple marked in part, laminated in part; ripple marks bimodal; trends 170° and 20°.	20	6.51
11	Siltstone: medium dark red; interbeds of light gray silty sandstone to 5 cm thick; sandstone ripple marked; trend 60°.	120	6.31
10	Sandstone: medium light red, slight green mottles; fine grained; ripple marked; trending 90°.	20	5.11
9	Siltstone: medium dark red, slight green mottles; interbedded with 2 cm thick lenses of medium light green sandstone.	56	4.91
8	Sandstone: medium light red, slight green mottles; slight interbeds of medium dark red siltstone; ripple marked.	15	4.36
7	Siltstone: medium dark red; interbeds of medium light green sandstone, with red mottles; signs of ripple marks.	40	4.20
6	Sandstone: light green; medium grained; good marker; ledge former; upper half highly ripple marked; trending 120°; lower half has ripped-up mud flakes, load casts.	19	3.80
5	Sandstone: medium green gray, weathers medium light red, more gray toward top; fine grained; interbeds of medium red siltstone; medium light green sandy siltstone near top; highly ripple marked; bimodal; trending 86° and 250°.	44	3.61
4	Siltstone: medium dark red, weathers medium light red; clayey, similar to unit 1; interbeds of 2 cm thick medium red sandstone and medium light green sandstone; sandstone lenses mottled; some sign of ripple marks.	141	3.17
3	Sandstone: medium light red, light green gray mottles; fine grained; silty; lenses of medium dark red siltstone throughout; ripple marked.	10	1.76
2	Siltstone: similar to unit 1 medium dark red; clayey; 20° of unit medium green sandstone lenses; weather as green sandy lines on red background.	100	1.66
1	Siltstone: medium dark red; clayey, 40% of unit medium light gray green clayey siltstone lenses; entire unit laminated; indication of ripple marks, badland weathering.	66	.66

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