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Contents

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A Detailed Stratigraphic Study of Initial Deposition of Tertiary Lacustrine Sediments near Mills, Utah

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ABSTRACT.—Late Cretaceous and/or early Tertiary rocks west of U.S. Highway 91, near Levan, Utah, were studied for lithology, facies relationships, sedimentary structures, and fauna. Carbonate rock units show evidence of the transgressive phases of the Tertiary lake systems. Terrigenous clastic units show a regression of this system. They also show the dominant environment to be fluvial or near-shore lacustrine. This cycle of sediments occurs four times in six hundred feet (183 meters) of detailed measured stratigraphic sections.

Carbonate sediments were deposited in a shallow-water environment with periods of energy surges, due to either storms or tectonic activity.

A hypothetical sedimentary model infers that a migrating delta, located to the north, prograded from the Laramide orogenic events to the west.

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INTRODUCTION

Interfingering units of lacustrine and fluvial deposits are exposed at the West Hills of central Utah. This sequence of late Cretaceous (?) and early Tertiary sedimentary rocks provides evidence of the first appearance of

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, December 1975: Harold J. Bissell, thesis chairman.

lacustrine sediments at a time when tectonism influenced the main sedimentary environments of central Utah. These units are well exposed in a cuesta with beds dipping to the east. The area is paleogeographically situated near the western shoreline of a series of Tertiary lakes.

The area is excellent for the study of lacustrine and fluvial paleoenvironments because of numerous cycles occurring within the exposed strata. This investigation describes and documents lithologies, sedimentary structures, stratigraphic variations, and lateral and vertical facies relationships of approximately 600 feet (183 meters). From this data, interrelationships concerning sedimentary environments are interpreted.

Previous Work

Long Ridge was first mentioned by Howell (1875) as a "ridge west of Nebo." It later appeared in a cross section of Howell and Dutton (1880). The first work which deals specifically with the Long Ridge was by Eaton (1929), but it was a study of the northeast end. Eardley (1933) showed the Long Ridge on his published geologic map.

Muessig (1951) prepared a geologic map of the Long Ridge. Part of a doctoral dissertation, this map was never published, but information related to it appears on the geologic map of Utah (1963). Vogel's thesis included the southern portion of the West Hills in his mapping report (1957). Studies of the area by Muessig and Vogel were general mapping studies with short general statements pertaining to stratigraphy.

Location

The study area is located at the southern end of Long Ridge, known as the West Hills. The West Hills are located about five miles west and southwest of Levan, Utah (Text-fig. 1). The area of investigation deals with parts of T. 14 S, R. 1 W, specifically sections 19, 20, 29, 30, 31, and 32; T. 15 S, R. 1 W, sections 6, 7, and 18; and T. 15 S, R. 1-½ W, sections 1, 12, 13, and 24.

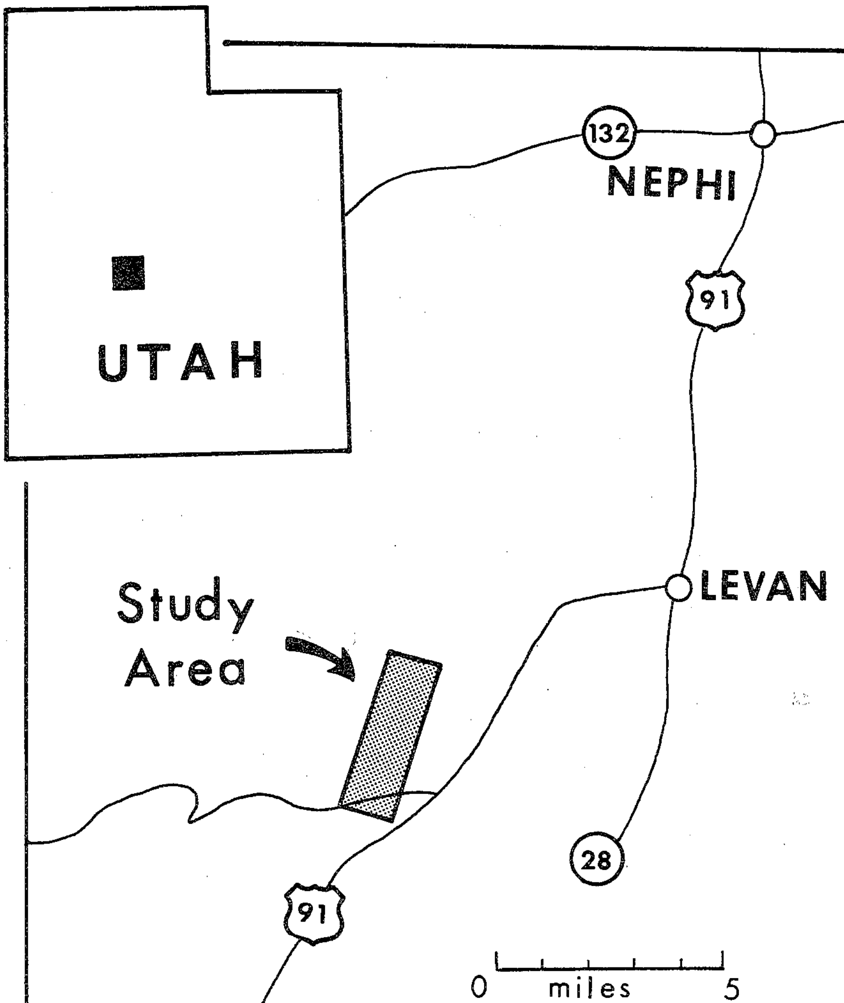
The area is readily accessible directly west of U.S. Highway 91. A paved road passes by the southern tip of the area and an unimproved road passes through the northern end. The area contains a cuesta with beds dipping to the east. Excellent exposures are found on the west side of the cuesta approximately two miles wide and six miles long.

Objective

The principal objective of this study is to construct a sedimentological model by making a detailed stratigraphic study of the lithologies and their relationships. With this information, the sedimentary conditions and changes of the Tertiary lake systems bordering the area are interpreted.

Methods of Study

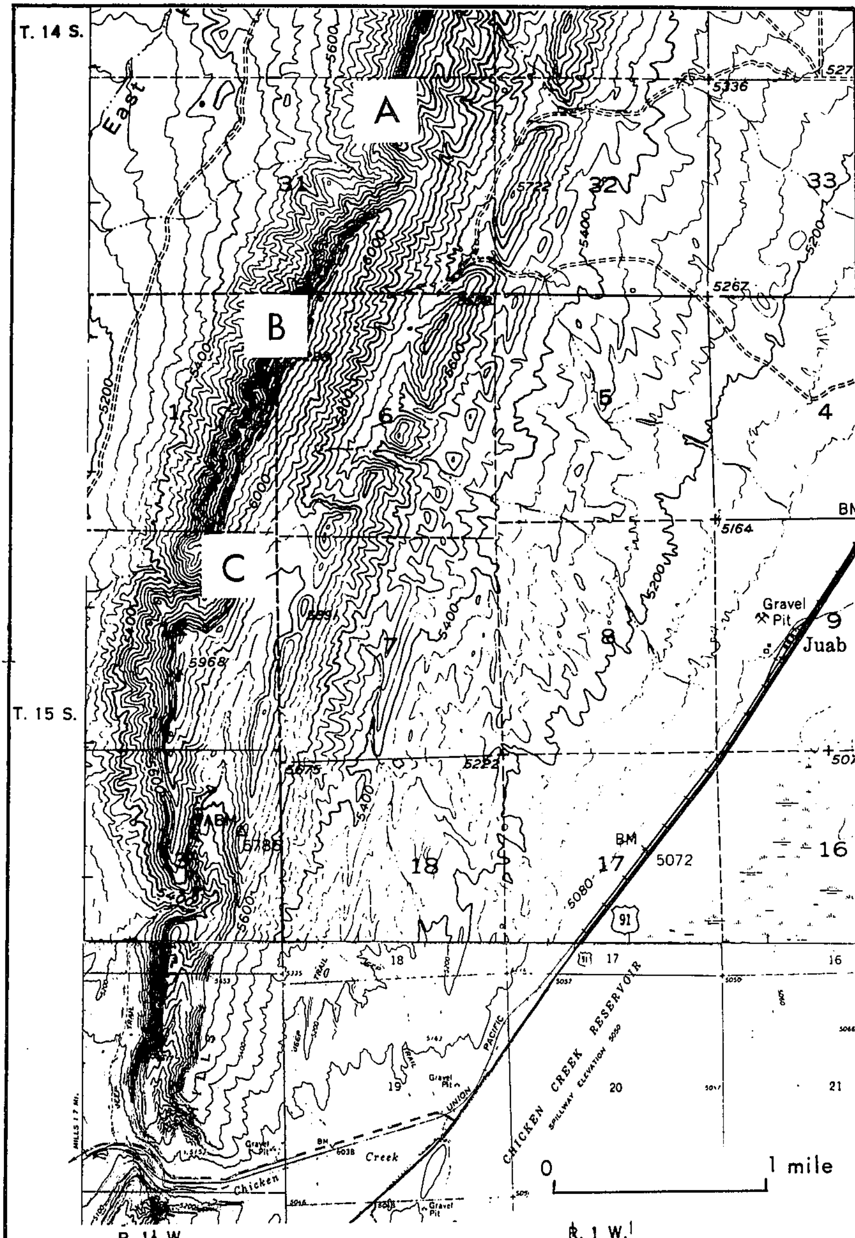
Field methods.—Three stratigraphic sections (Text-fig. 2) were measured in the fall of 1974 using a Brunton compass and a 100-foot steel tape. The strata marking the first prominent limestone unit was sampled, vertically, at five-foot intervals. Sampling of this type was done at five separate localities along a north-south traverse approximately five miles long. Thin-



TEXT-FIGURE 1.—Index map.

section analysis of these samples was used in the study of the initial occurrence of lacustrine environments. Description, identification, and documentation of these rock bodies were accomplished through photographs, samples, sketches, and notes. Correlation of depositional units was documented by photographic mosaics, aerial photographs, and field observation.

Laboratory methods.—Thin sections were made of major lithologic types to aid in the investigation. These were studied under the petrographic microscope for composition, texture, grain orientation, and classification. Friable samples were impregnated with epoxy and set in a vacuum oven prior to



TEXT-FIGURE 2.—Index map of stratigraphic column field locations.

mounting them on glass slides. These sections were stained to aid in the identification of calcite and dolomite.

Samples were submitted to Gulf Oil Company for palynology studies.

Nomenclature

Descriptive grain-size terminology used is the modified Wentworth grade-scale proposed by Dunbar and Rogers (1957, p. 161). Carbonate classification is modified from Leighton and Pendexter (1962), and Dunham (1962).

Acknowledgments

Special thanks go to Dr. H. J. Bissell, who served as committee chairman and gave of his time freely in consultation and guidance of this work. Thanks are due also to Dr. Baer and Dr. Bushman, committee members, who aided me. Recognition must be given to my wife, Gayle, who aided in many ways. Financial aid for palynology studies was provided by Gulf Oil Company.

STRATIGRAPHY

General Statement

This study focuses chiefly on nonmarine sedimentary rocks of late Cretaceous (?) and/or early Tertiary and Tertiary ages. Muessig (1951) mapped three formations in this area, namely: North Horn Formation (Late Cretaceous and Paleocene), Flagstaff Formation (Paleocene), and Green River Formation (Eocene) (Spieker, 1949). As a result of detailed stratigraphic investigations by the present writer, no definitive evidence was found proving that the North Horn Formation is present, but since palynology studies did not provide any further information about a relative age of the sediments, this writer accepts the divisions of the formational units of the previous writer.

Cretaceous (?) and Tertiary Systems

North Horn Formation.—North Horn Formation, at the type locality, consists of a series of lacustrine and fluviatile deposits which are divided into four units by Spieker (1946). Muessig stated (1951, p. 71), "Common practice has been to map the top of the North Horn at the top of the last major red bed, or where the North Horn consists of sandstone, at the top of the sandstone." The North Horn Formation has been described as having a variety of lithologies and also displays temporal transgression in that it becomes progressively younger to the west.

Upper units of the North Horn Formation (?) crop out in the northern portion of the study area, and a southeastern dip of the beds causes the North Horn Formation to disappear to the south under the valley floor.

The North Horn Formation (?) mapped in the study area is dissimilar to the type section. Here it consists of interbedded red siltstone, sandstone, and conglomerate. Sandstones are medium- to coarse-grained and are interbedded with siltstones and conglomerates; conglomerates receive the red coloration from a red, sandy matrix. Both dark- and light-colored quartzite cobbles, which are up to 2-3 feet (0.6-0.9 m), are found in lenses within the formation. Red, sandy oncolites up to one inch (25 mm) in diameter are also a distinguishing feature of this formation. Gastropods, which have weathered out of the matrix, include *Bulimulus?* sp. and *Helix? riparia* White (Muessig, 1951).

Flagstaff Formation.—The type section of the Flagstaff Formation is found at Flagstaff Mountain, Utah. It was defined by Spieker and Reeside (1925). Lithologies present in the type section are gray shales, sandstones, crystalline limestones, and limestone beds filled with fossils of fresh-water gastropods and pelecypods. The formation is approximately 250 feet thick at the type section and is characterized by the upper unit forming a "cap" to its lower units.

The Flagstaff Formation, in the study area, is made up of a series of carbonate rocks as follows: micrite, intraclastic limestone, and wackestone. Also present are red, green, and brown sandstones; red and green conglomerates; and red and green mudstones.

Four carbonate units form distinct ledges throughout the area. Conglomerate facies are lenticular in nature and vary in thickness, tending to thicken to the south. Sandstone grains also become larger to the north, changing some units to a gritstone and conglomerate.

Sedimentary structures are rare within the formation. Channeling is noted in the conglomerate sequences and cross-bedding occurs in one sandstone unit.

LITHOLOGIES OF THE LOWER FLAGSTAFF FORMATION

Conglomerate

Red conglomerate.—Red conglomerate occurs in section A, unit 13 (pl. 2, fig. 5), and unit 20 of section B (Text-fig. 3). These units are very similar to the underlying North Horn Formation (?), which occurs with sandstone and mudstone. The cyclic occurrence displays gradational features in contrast with subjacent and superjacent beds. It grades from poor sorting to bimodal sorting, and from a predominantly sandy matrix with some cobbles to a 50-50 distribution of matrix to pebbles and cobbles. The cobbles are well rounded, but the terrigenous grains within the matrix are angular to well rounded; in some areas the cobbles are as much as eight inches (0.2 m) in diameter.

Green conglomerate.—Green conglomerate occurs in section B, units 11, 18, 22, and 24. It occurs associated with gritstone and wackestone. Its sandy, gritty matrix displays a green cast which commonly stains the outer layer of the cobbles green. Sorting ranges from poor to good and the grains are angular to very well rounded. Plate 1, figure 6 shows almost no matrix with dark brown and green rock fragments. Cementation varies from friable to resistant and ledge forming. Pebbles range up to four inches (0.1 m) in diameter (Pl. 2, fig. 6; Pl. 4, figs. 1 and 3).

Sandstone

Although sandstone units comprise only 15 percent of the measured section (Text-fig. 3), they range from red and brown to green. The grain sizes increase toward the north where gritstones and fine-textured conglomerates are characteristic.

Red sandstone.—Red sandstone occurs in units 11 and 17 of section B. Interbedded with mudstone, sandy limestone, and conglomerate, it commonly

1

2

3

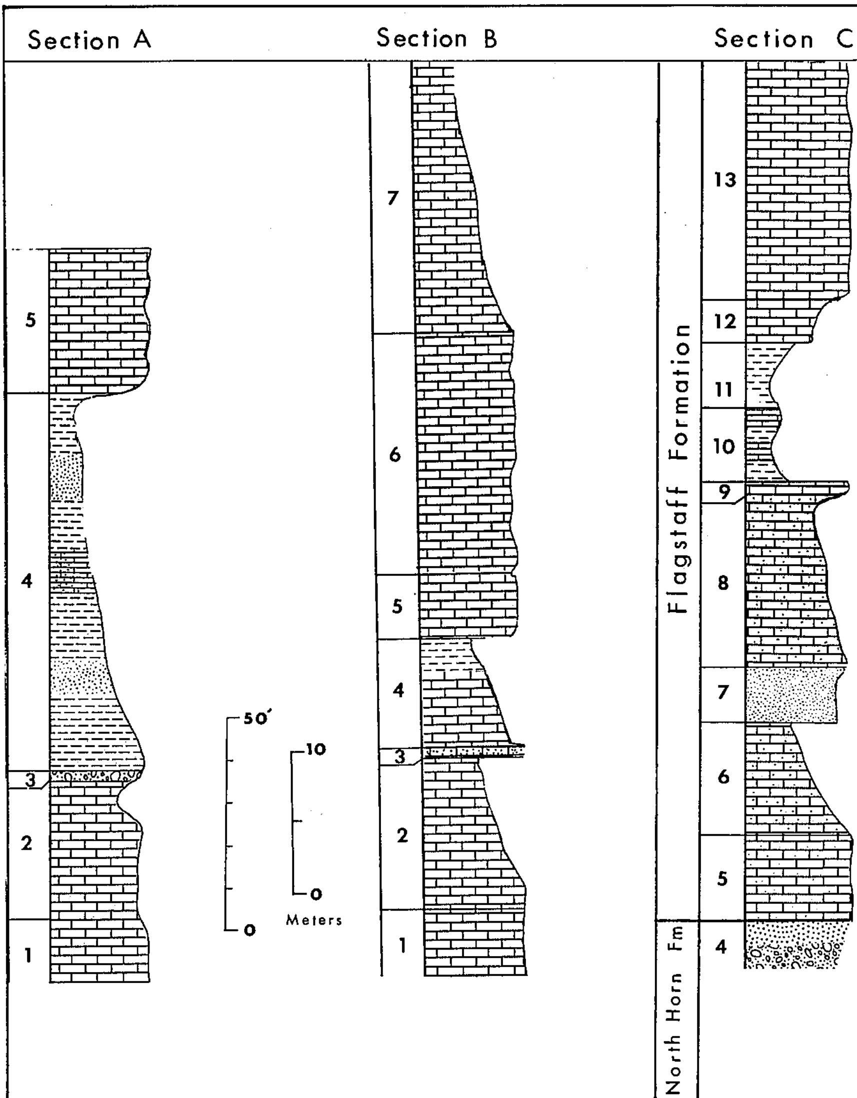
4

5

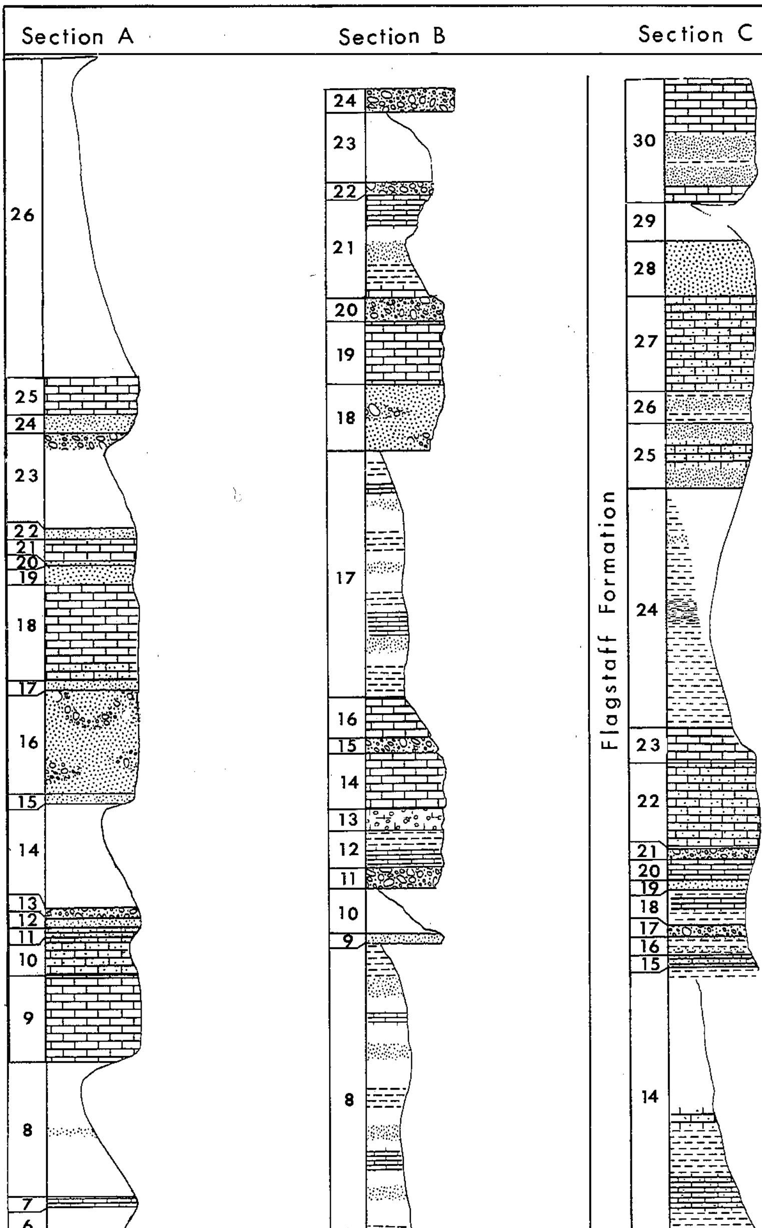
6

EXPLANATION OF PLATE 1
Field Views

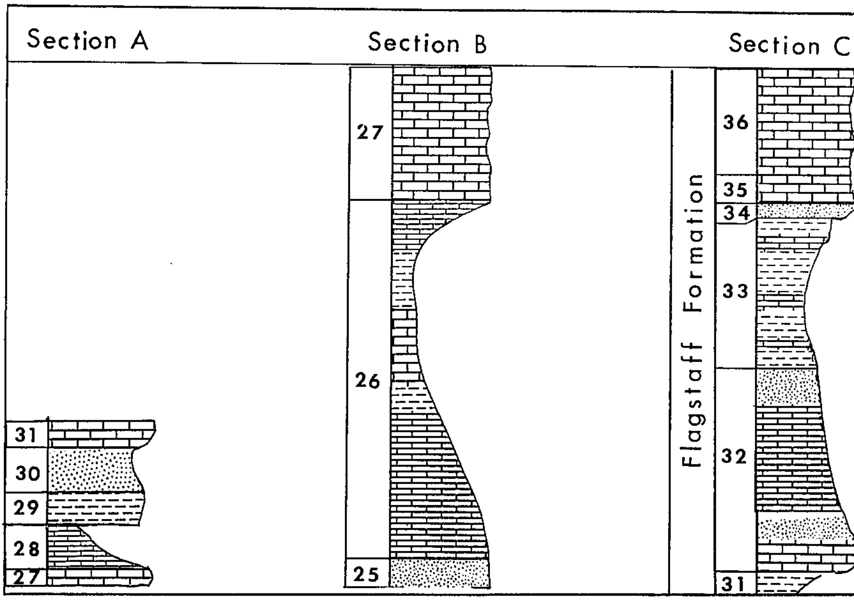
FIG. 1.—View of units 1 and 2, section B, showing the first change occurrence of lacustrine facies. Outcrops are approximately 35 feet (10.0 m) high.
FIG. 2.—Unit 7 of section B forming a prominent 50-foot (15.0 m) ledge.
FIG. 3.—Channeling of conglomerate; unit 20 of section B.
FIG. 4.—Erosional surface of conglomerate unit 24 overlain by interbedded layers of coarse and fine sandstone of unit 25, section B.
FIG. 5.—Interfingered conglomerate and wackestone.
FIG. 6.—Conglomerate unit 18, section B, showing very little matrix due to sorting.



Section A
Section B
Section C
5
4
3
2
1
50'
0
10
0
Meters
7
6
5
4
3
2
1
Flagstaff Formation
North Horn Fm
13
12
11
10
9
8
7
6
5
4



TEXT-FIGURE 3.—Stratigraphic columns of three measured sections showing lithology (see Text-fig. 2 for locations).



occurs as a middle member in a gradational cycle. Quartz is the dominant mineral, but rock fragments here and there make up as much as 10 percent of the rock by volume. A red calcareous matrix surrounds the quartz grains and rock fragments. The sorting ranges from fair to good, and the grains are subangular to subrounded. These red beds, interbedded with wackestone, mudstone, and conglomerate, grade into each other vertically and laterally.

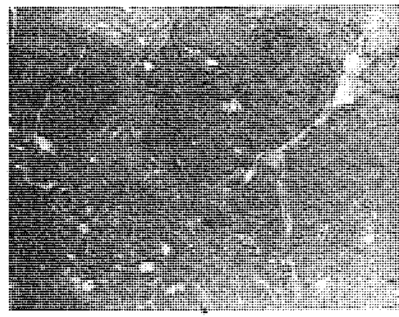
Green sandstone.—Green sandstone occurs in units 9, 15, and 18, commonly associated with conglomerate lenses. It is normally the lower unit of a gradational cycle that grades to conglomerate. The green tint is given by the green quartzite grains and also the green matrix. Grains range from highly angular to subangular shapes with a fair degree of sorting. Unit 20, section A, is only one inch (25 mm) thick and is distinctly separated from the underlying and overlying units.

Brown sandstone.—Brown sandstone occurs in section B, units 9 and 25; section A, unit 24. These sandstone units are the only sandstone units that contain sedimentary structures. The sandstone is thin bedded with well-defined cross-bedding and ripple marks. It is characterized by good sorting, and the grains are subrounded to rounded. The unit is very resistant to weathering (Pl. 4, fig. 4).

Mudstone

Mudstone, a clastic, nonfissile rock of clay- and silt-size particles, occurs in section B, units 8 and 17, and is interbedded within the red sandstones and maroon and pink carbonate units. They are the slope-forming units, and consequently thickness of beds is difficult to measure accurately because of float cover. Highly calcareous, they grade into both the carbonate units and sandstone units. Terrigenous quartz grains and rock fragments are also found.

1



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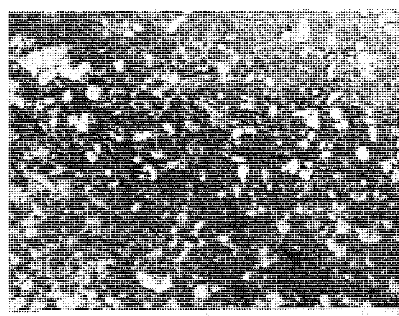

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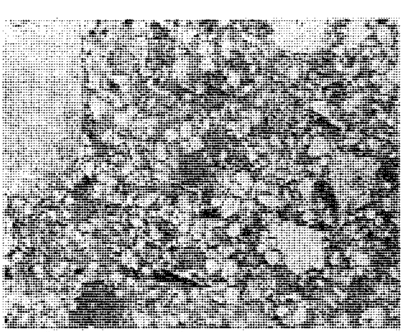

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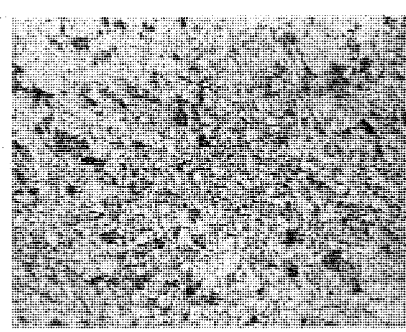

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EXPLANATION OF PLATE 2
Photomicrographs

FIG. 1.—Thin section of algal micrite at the top part of unit 1, section B.
FIG. 2.—Thin section of intraclastic limestone; unit 7 of section B.
FIG. 3.—Thin section of wackestone at the basal part of unit 1, section B.
FIG. 4.—Thin section of pelletal limestone, unit 13, section B.
FIG. 5.—Thin section of conglomerate; unit 13, section A.
FIG. 6.—Thin section of conglomerate; unit 9 of section B.

They are common within the red bed sequences but also occur within the green sandstones, wackestones, and conglomerates (Pl. 2, fig. 5).

Carbonate Rocks

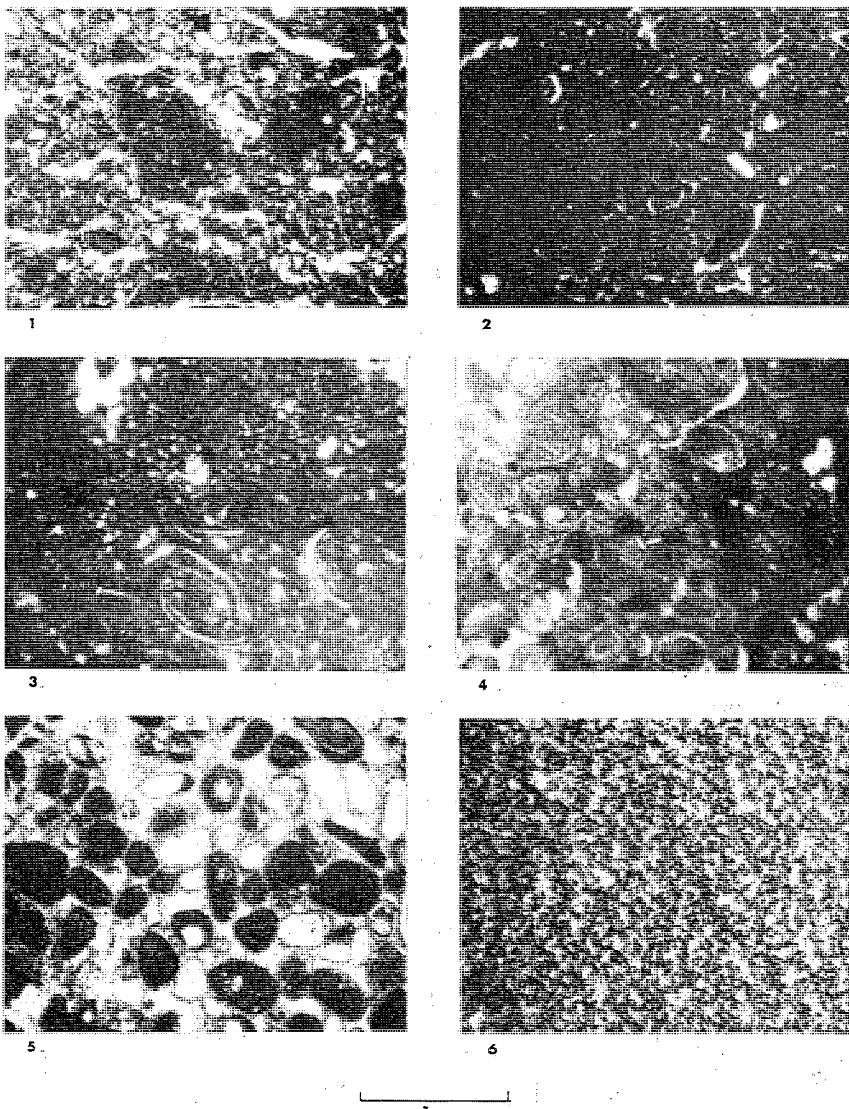
Carbonate rocks make up about 50 percent of the lower 600 feet (183 meters) of the Flagstaff Formation of the study area. They range from wackestone, a muddy, carbonate matrix with up to 50 percent detrital quartz grains and rock fragments, to micrite. Even though the lithologies are commonly gradational, the carbonate rocks of the study area have been classified into four categories: (1) micrite, (2) intraclastic limestone, (3) wackestone, and (4) pelletal limestone.

Micrite.—Micrite occurs in units 2, 4, 6, and 27 in the measured section B (Text-fig. 3). These carbonate units are the most distinct units within the area because they are highly resistant to weathering, and therefore produce the prominent ledges of the cuesta (Pl. 1, fig. 2). They are uniform in color ranging from buff to cream; conchoidal fracturing occurs when the rock is broken. The fine-grained matrix is thought to be a result of lime-secreting algae. Mud lumps and pellets scattered through the matrix are also inferred to be of algal origin. *Chlorellopsis* (Muessig, 1951) beds, stromatolitic algal and oolitic features, found higher in the Flagstaff Formation, also support the abundance of algae within the sedimentary basin. Because of these observations, a classification of algal mudstone might also be considered for these lithologies. Microscopic observation shows lumps up to 1.0 mm (Pl. 2, fig. 1, and Pl. 3, figs. 2 and 4).

Intraclastic limestone.—Intraclastic limestone occurs in units 1, 5, 19, and 26 of section B. This group has a variety of rock types. The color ranges from cream to buff, yellow, green, and red, and the rocks commonly have a mottled appearance due to different sedimentary intraclasts (Pl. 2, fig. 2). The limestone varies in density with some of the spore spaces filled with sparry calcite. The different types of sedimentary material present are algal spheres (Leighton and Pendexter, 1962), mud lumps, micritic ooze, and terrigenous detrital material (Pl. 3, fig. 2).

Wackestone.—Rock types that can be classified as wackestone occur in units 3, 7, 14, and 21 of section B. This group has a lime mud matrix, which makes up at least 50 percent of the rock by volume. The remaining 10-50 percent of the wackestone consists of rock fragments, quartzite grains, crystalline limestone fragments and intraclasts of lime mud. The size of the terrigenous detrital material ranges from microscopic size to 1.0 mm. The sorting ranges from very poor to fair, with rock fragment shapes ranging from round to angular. Colors of the hand samples are normally pink and maroon; however, green and buff wackestones are also present in some units (Pl. 2, fig. 3).

Pelletal and oolitic limestone.—Unit 13 of section B contains pellets, small rounded aggregates of clay mineral ranging from 0.1 to 0.3 mm in diameter (Pettijohn). During thin-section analysis some of these structures had a quartz nucleus, indicating that they were accretionary structures. Coated grains in unit approach the size needed for classifying them as oolites (Pl. 2, fig. 4 and Pl. 3, fig. 5). Unit 2 also contains coated grains. During thin-



EXPLANATION OF PLATE 3

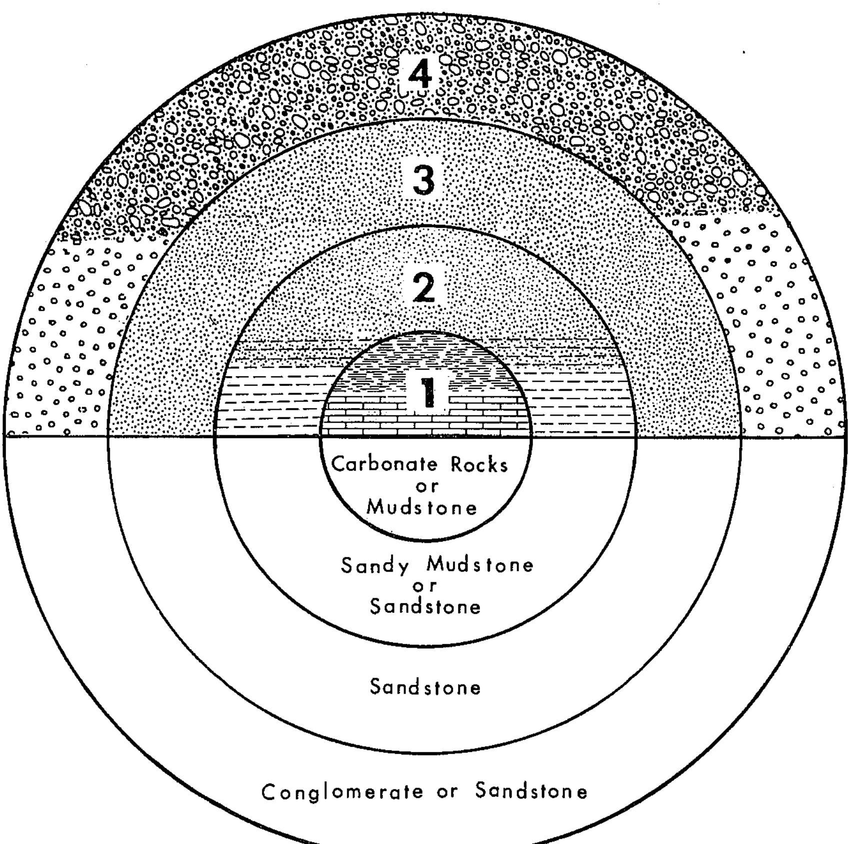
Photomicrographs

FIG. 1.—Thin section of unit 1, section B.
FIG. 2.—Thin section of unit 1, section B.
FIG. 3.—Thin section of unit 1, section B.
FIG. 4.—Thin section of algal micrite of unit 6, section B.
FIG. 5.—Thin section of pelletal limestone of unit 13, section B.
FIG. 6.—Thin section of pelletal limestone of unit 2, section B.

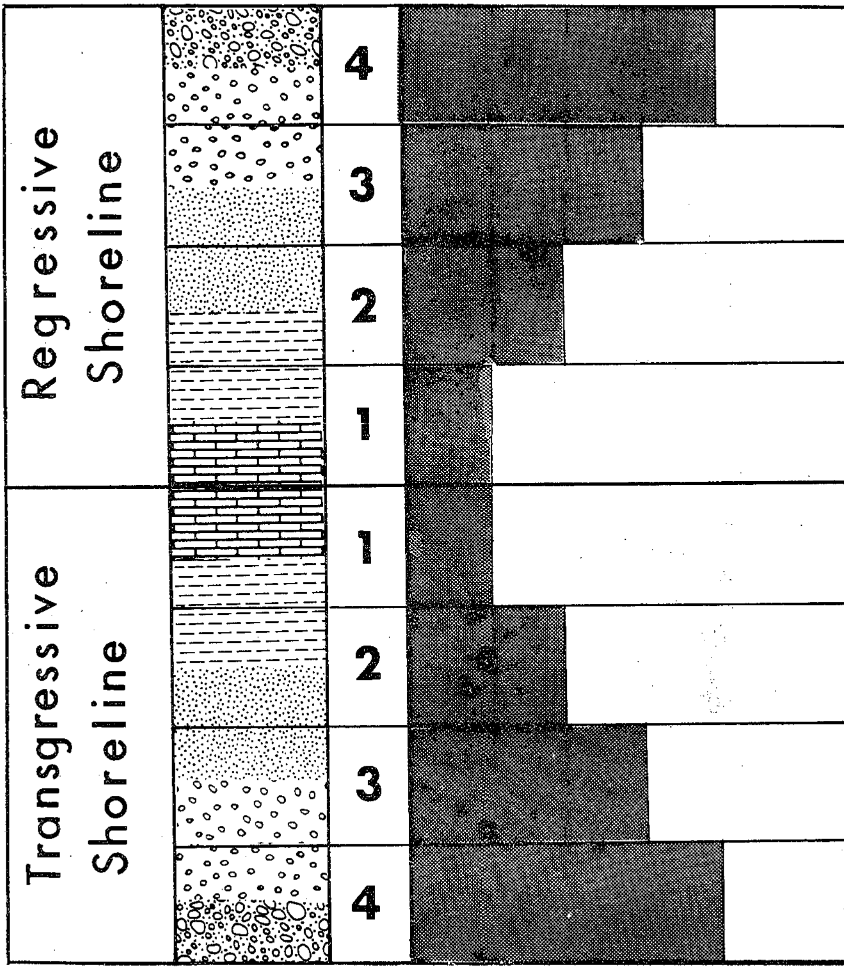
section analysis, an intraclast of coated grains less than 0.1 mm (Pl. 3, fig. 6) was found in matrix of pelletal material 0.3 mm in size.

FACIES RELATIONSHIPS

The ideal facies pattern of lacustrine deposits is represented by Text-figure 4. Without indicating relative scales of facies, the model shows that fine-grained sediments are located at the center of the basin, and coarse deposits located on its periphery. If this facies pattern is workable, then a cyclicity of facies could be explained by Text-figure 5. A transgressive shoreline cycle would be evidenced by coarse sediments of the outer belt of shore gravels, overlain by sands of the intermediate belt, finally topped by mudstone and carbonate lithologies. This cycle is reproduced four times within the 600-foot (183 m) section. The first occurrence is on the contact of the North Horn and Flagstaff Formations. This gradation from conglomerate to algal micrite is the first appearance of predominantly lacustrine sediments



TEXT-FIGURE 4.—Ideal lacustrine facies pattern (modified from Picard and High, 1972).



TEXT-FIGURE 5.—Idealized cycle of lacustrine deposits.

in the study area. This major lithology change is noted at the base of unit 1, section B, as it grades from red wackestone to cliff-forming, cream-colored micrite (Pl. 1, fig. 1). This transgressive cycle also occurs as unit 11 changes to unit 12, section B (Text-fig. 3). A quick change from conglomerate to carbonate facies occurs as unit 24 is overlain by a two-foot (0.61 m) layer of sandstone which is overlain by carbonate rocks (Pl. 1, fig. 4).

The reverse order of this cycle occurs as the shoreline recedes or as the lake ultimately is filled with terrigenous clastic sediments. The regressive pattern (Text-fig. 4) is seen in the section as units 7 through 11 and unit 16 grades into unit 18, section B. This gradational change is not always the rule, inasmuch as the fine-grained carbonate unit 19 of section B is directly overlain by the coarse conglomerates of unit 20 (Pl. 1, fig. 3).

SEDIMENTARY FEATURES

Sedimentary features occurring commonly throughout the section are: (1) intraclasts, (2) channeling, (3) interlayered bedding, (4) ripple marks, and (5) stylolites.

Intraclasts

Intraclasts within the carbonate facies can be categorized into two main types:

1. Carbonate fragments that have been ripped from their initial place of deposition and redeposited with other intraclasts or into a sedimentary basin that has not been disturbed (Pl. 2, fig. 2). Intraclasts of this nature occur in units 2, 5, 19, and 26 of section B.
2. Mud lumps appear as intraclasts as they are washed into and settle down into an existing sedimentary basin. These mud lumps could be of organic origin (Pl. 3, figs. 2 and 4). Small mud intraclasts are common in units 5, 6, 7, and 21 of section B.

Channeling

Channeling occurs in the conglomerate facies of units 11, 18, 20, and 22 of section B (Pl. 1, fig. 3). Channeling is present in both the red and green beds; however, channeling with high-angle dips of strata occurs in the green conglomerate in unit 18. Due to the exposure of these conglomerate units, an east-west direction was the only paleocurrent direction that could be documented, but it is assumed that the direction of these channels varied from the downstream direction. The different features seen in the different conglomerate units suggest that these channels could have been made by either meandering streams or braided streams (Derr, 1974). The current direction of unit 18 was measured by the use of imbricate orientation of flat, disc-shaped pebbles. The direction of paleocurrents in this channel gravel was S 60° E.

Thinly Interlayered Bedding

This bedding shows alternating layers of fine-grained and coarse-grained sediments of the sandstone, particularly in unit 24, section A (Pl. 1, fig. 4).

Ripple Marks

Ripple marks in the section are generally asymmetrical current ripples. They are common in unit 25 of section B. This brown sandstone unit produces well-formed ripples observable from a vertical view. Wavy features assumed to be ripple marks could be recognized from a horizontal view. The rounded crests and asymmetrical shape suggest a unidirectional current.

Paleocurrents of ripple marks found within the sandstone range from S 7° W to S 16° E. These and paleocurrents of channels support the overall current direction of north to south. The main supporting evidence of this hypothesis is the gradation of facies units from coarse to finer grain in a north to south direction. Unit 3, which is a conglomerate at section A, grades to the south: a sandstone with some pebbles (section C).

Stylolites

During thin-section analysis, microscopic stylolites were noted within the intraclastic limestone—unit 6 of section B. The amplitude oscillation of these features is less than 1.0 mm high. Some of these features are filled with red stain, most likely iron oxide.

PALEONTOLOGY

Fossils

Bulimulus? sp. and *Helix? riparia* White, both land snails, were found and described by Muessig in his description of the red beds of the underlying North Horn Formation (1951). These two gastropods are relatively abundant but are not helpful in age determination, because of long range. They were not helpful in the study of the environment; their appearance is most likely a death assemblage. The lacustrine carbonate unit of the Flagstaff produces fish jaws, some of which are recognized as more characteristic of a Green River fish fauna. Two other mollusks collected by Muessig were identified by LaRoque (1956); they are *Physa bridgerensis* Meek and *Oreohelix* sp.

Ostracod carpaces were noted in the thin section of carbonate unit 2 (Pl. 3, figs. 1 and 3). Ostracod zones within the Flagstaff Formation as established by Swain (1965) did not include any specimens collected from the Flagstaff in the study area. No identification was possible in thin section. Ichnofossils and bioturbation were not noticeable in any of the lithologic units studied.

Palynology

Ten rock samples were sent to the palynology laboratory of Gulf Oil Corporation in Houston, Texas. Samples were collected along the traverse of section B (Text-fig. 2). One sample was collected approximately 200 feet below the contact of the North Horn (?) and Flagstaff formations. Samples sent from the lower Flagstaff Formation were collected from units 7, 8, and 17 of section B.

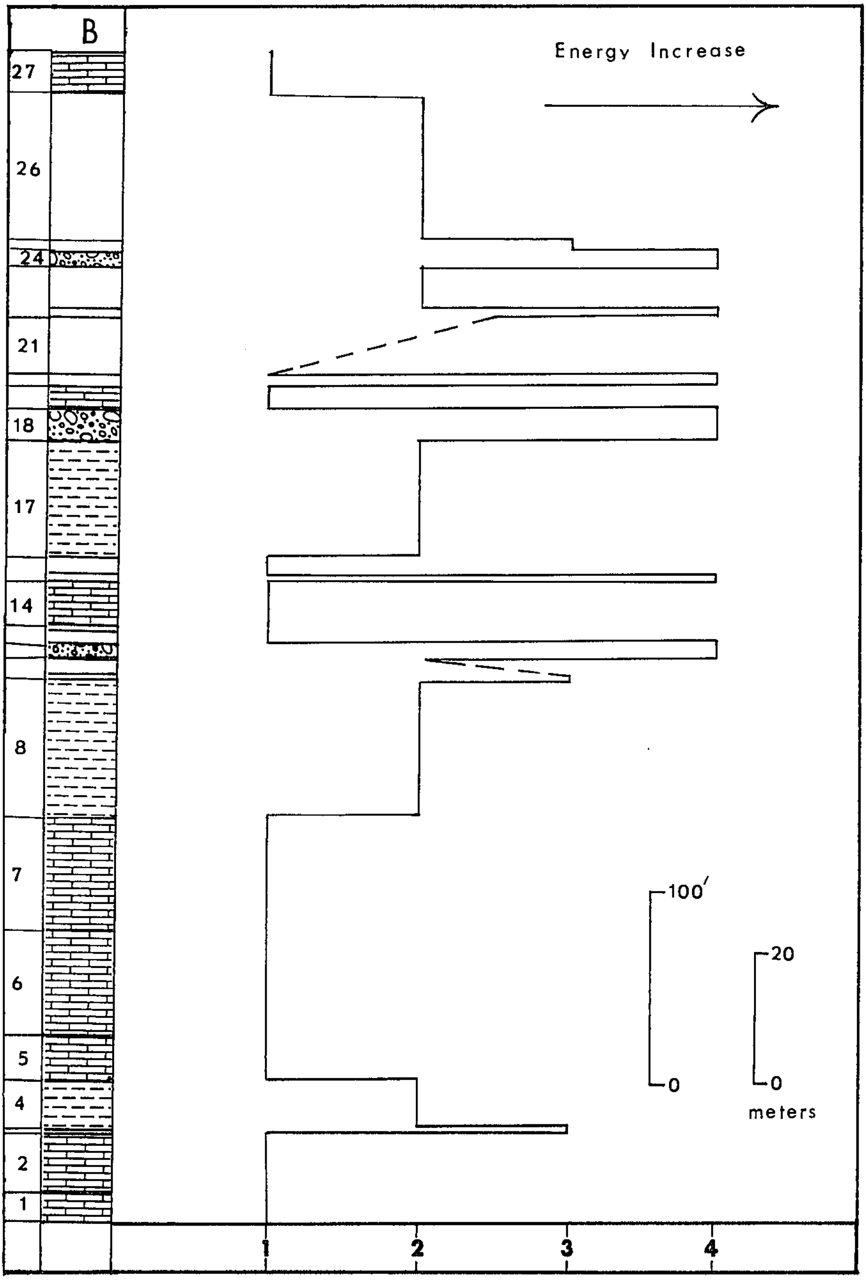
Three other samples were obtained from higher in the Flagstaff Formation. One sample was sent from unit 37 and one from unit 51 of Muessig's Section 1, East Sage Valley. The third was collected from unit 53, formed from Chlorellopsis (1951).

Three samples were collected from the Green River Formation. These samples were located at units 58, 74, and 84 of Section 1, East Sage Valley (Muessig, 1951). Two came from green mudstones and one from a dark gray, fossiliferous limestone.

INTERPRETATION OF SEDIMENTARY ENVIRONMENTS

The change of lithologies from the red mudstone, sandstone, and conglomerate units of the North Horn Formation (?) to the interbedded limestones and sandstones, mudstones, and conglomerates of the Flagstaff Formation is documented in unit 1, section B (Pl. 5). This unit grades from a red, calcareous, poorly sorted wackestone to a cream-colored, algal mudstone or micrite. This gradational unit marks the first sediments of the Tertiary lake sequence.

The energy index of the lake varied a great deal at this locality (Text-fig. 6). The majority of the lithologies represent a near shore lacustrine environment. Clastic terrigenous material could be accounted for at least in part by a nearby migrating delta system, interpreted to be located to the north, prograded from the Laramide orogeny (Armstrong, 1968). The shifting



TEXT-FIGURE 6.—Lacustrine energy index within section B as related to lithologies and grain sizes (see Text-figs. 4 and 5).

of the stream channels could be the source for the influx of terrigenous clastic material into this locality of the sedimentary basin.

Conglomerate Facies

The conglomerate units are interpreted to represent several different environments. The first is fluvial channel gravels as evidenced by unit 20 of section B (Pl. 1, fig. 3). The unit is six feet (1.8 m) thick at the measured section. The conglomerate facies changes entirely to a sandstone facies which is unit 28 of section C.

Unit 18 of section B is a green conglomerate 18 feet (5.5 m) thick (Pl. 1, fig. 6). This unit contains channels having a smaller radius than those observed in the red conglomerate units. It also shows more prominent cut and fill features than the red beds. Characteristic features of these channel gravels are (1) a convex-downward channeled configuration of the lenses, (2) the truncation of underlying beds, (3) the occurrence of rounded pebbles and cobbles. The other environments represented by conglomerate units would be piedmont deposits related to tectonic activity, storms, or the regression of the lake waters. These environments are evidenced by (1) gradational lithologies, (2) poorly sorted material, (3) highly angular immature sediments, and (4) the absence of channeling.

Lateral gradation of conglomerates could be due to longshore currents. Unit 3, section A (Pl. 4, fig. 2), appears as a pink conglomerate with pebbles up to four inches (10.2 cm) in diameter. The unit is three feet (0.9 m) thick at section A; one mile (1600 m) to the south this unit has graded to a calcareous sandstone with rock fragments; another mile (1600 m) to the south the unit is a calcareous sandstone containing some small pebbles. This type of gradational unit could be due to longitudinal currents reworking terrigenous clastic material from their immediate implacement into the sedimentary basin. North to south current directions would explain the occurrence of coarser material to the north grading to finer material to the south.

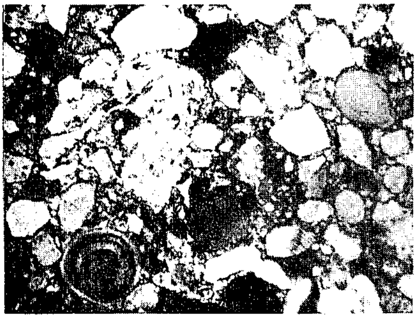
Sandstone Facies

The red and green sandstones found interbedded with conglomerates in unit 8, section B, are interpreted to be of piedmont and fluvial origin. Characteristic of these red bed deposits which support this environmental classification are (1) lenselike structure, (2) high textural range, (3) well to poorly sorted (usually gradational), (4) angular to well rounded grains, (5) lack of fossils, and (6) distribution in irregular areas.

Brown sandstones shown in unit 25 of section B are thought to be from near-shore lacustrine environments due to the cross-bedding present and ripple marks. The grains are very well sorted and are subrounded to rounded.

Mudstone Facies

Mudstone in the study area is generally found above and below by both high and low energy sediments and is completely free from fossils. The stratigraphic position of the mudstone units, between wackestones and sandstones, indicates an unstable energy level. The mudstones were deposited in an environment subject to rapid changes of energy and clastic source material. This type of environment could be a mud plain or mud flat. Other characteristics of the mudstone that also support this conclusion are (1)



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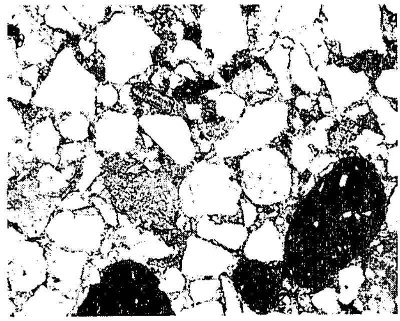

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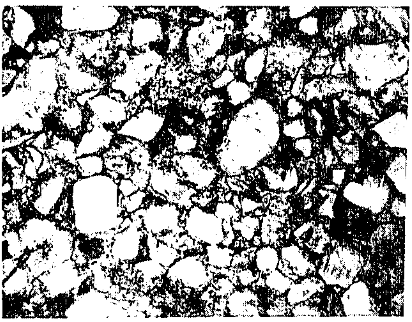

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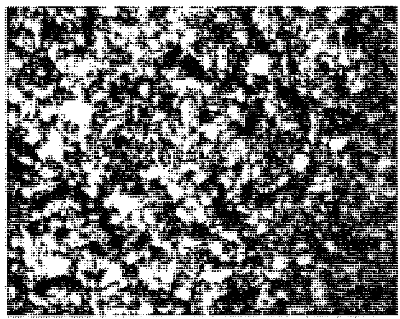

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1mm

EXPLANATION OF PLATE 4

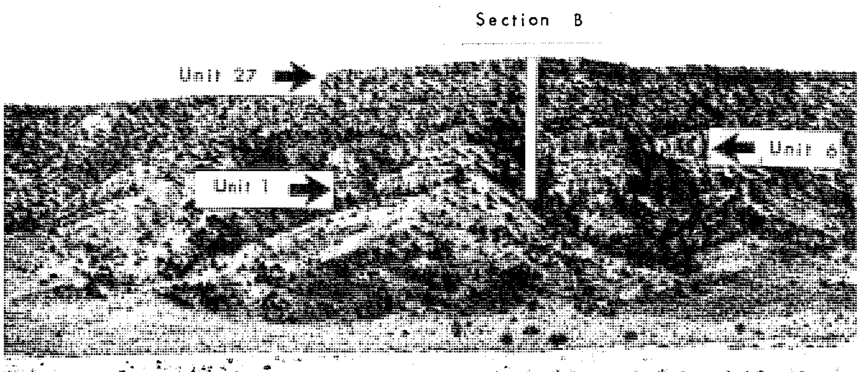
Photomicrographs

FIG. 1.—Thin section of green conglomerate in unit 18, section B, showing rock fragments and coated grains (lower left corner).

FIG. 2.—Thin section of green conglomerate in unit 3, section A.

FIG. 3.—Thin section of matrix material of conglomerate unit 9, section B.

FIG. 4.—Thin section of fine-grained sandstone in unit 25, section B.



EXPLANATION OF PLATE 5

Field View

FIG. 1.—View of measured section B; unit 1 marks contact of North Horn Formation (red conglomerates and sandstones of piedmont and fluvial environments) and Flagstaff Formation (interbedded limestones, mudstones, sandstones, and conglomerates of lacustrine, near-shore, and fluvial environments).

red or green color, (2) friability, (3) rock fragments, (4) calcite cement, and (5) poor sorting.

Unit 8, which is 77 feet (23.5 m) thick at section B, is interbedded mudstone, sandstone, and sandy mudstone. Thicknesses are difficult to measure due to the slope-forming nature of this unit.

Carbonate Facies

Micrite.—The micrite or algal mudstone units are interpreted to be still-water lacustrine deposits. They are (1) very fine grained, (2) uniform in thickness, (3) distributed continuously over a large area, (4) surrounded by near shore lacustrine deposits, (5) of a low textural range, and (6) vertically but not laterally graded into other lithologies. These continuous mapable units form the dominant ledges and cap rocks of the study area. Units 2, 4, 6, and 27 of section B are uniform in nature and thickness throughout the study area.

As previously mentioned, algae flourished in this quiet-water environment. Although the micritic ooze could have been precipitated out of the lake waters, the occurrence of algal spheres and coated grains also supports the hypothesis that this ooze is a result of lime-secreting organisms.

Intraclastic limestone.—The intraclastic limestone units are interpreted to represent an interrupted still-water lacustrine deposit. These are evidenced by (1) fine textured material, (2) units that are distributed continuously over a large area (in relation to the lake), (3) grading into micrite and/or wackestone vertically but not laterally, and (4) intraclastic material of a still-water environment. These intraclasts indicate a tearing up of the bottom by an increase in current velocity, such as storms, lowering of the wave base by partial emergence, or possible tectonic instability of the basin of deposition.

Units 1, 5, 19, and 26 of section B are lithologies with these parameters. These units vary in thickness and grade upward into algal micrite.

Wackestone.—These terrigenous carbonate units are the middle members of an energy cycle. The abundance of terrigenous material can be explained by at least two hypotheses. One, that uplift or proximity of the source area caused a more rapid influx of detritus, or two, that a change of conditions in the depositional basin suppressed chemical activity, as the terrigenous minerals accumulated by default (Folk, 1959). The wackestones found related to the fine-grained limestone units are interpreted to represent a transitional phase from near-shore lacustrine to open lacustrine deposits. This environment is evidenced by (1) gradational contact with intraclastic limestone units and algal limestone, (2) angular terrigenous grains, (3) medium to high textural range, and (4) textural divisions grading out in all directions.

The change of environments producing lithology changes is found as the underlying North Horn Formation (?) grades into unit 1. This gradation occurs in a thickness of 25-75 feet (7.6 m-22.9 m). Unit 26, which is 88 feet (26.8 m) thick, also has the same gradational characteristics. Unit 3, which grades from wackestone 2 feet (0.6 m) thick at section B to a conglomerate 3 feet (0.9 m) thick one mile (1600 m) to the north at section B (Text-fig. 2), shows gradation laterally as well as vertically, illustrating an application of Wather's Law.

Pelletal limestone.—This very well-sorted grainstone, found in unit 13 of section B, shows a period of very shallow lake waters. Oscillating currents washed fine material out of the area leaving the coated grains as the only sedimentary material. The study of thin sections showed that some of the grains had a quartzite grain as the nucleus, thus indicating that these were accretionary structures.

In unit 2 of section B, an intraclast of pelletal limestone with grain sizes averaging 0.3 mm, was found in a matrix of pelletal material less than 0.1 mm. A disruption of this mild oscillating current by a surge of energy, due to either storm activity or sedimentary basin alteration, must have occurred. Coated grains could also be an indication of the source rock since many residual clays (Pettijohn, 1957) show this concretionary or pisolitic structure.

SEDIMENTARY MODEL

Although the Tertiary lake systems completely blanketed the underlying piedmont sediments with open lacustrine carbonates, coarse-grained terrigenous clastic material is interbedded throughout the Flagstaff Formation. The change from coarse-grained terrigenous clastic sediments to fine-grained algal micrite occurs four times in 600 feet (183 meters). The clastic-carbonate ratio is 2-1 to the north, 1-1 at the central part, and 1-2 at the south. This ratio does not indicate that the duration of lacustrine and fluvial environments was also equal to this ratio.

The sedimentary model is based on two events: (1) the orogenic events of the Sevier and Laramide orogenies, and (2) the transgression of the Tertiary lake systems. Although orogenic and epeirogenic activity was to the west of the study area (Text-fig. 7), the source material appears to have come from the north. This source material may have been supplied from a migrating delta located to the north. The migration of the channels could also explain the rapid change of energy along with the increase of coarse-grain sediments. Paleocurrents also suggest that clastic material was moving in a north to south direction during deposition; however, material may have been derived from a westerly provenance, but the basin was filled as southerly directed currents transported detritus.

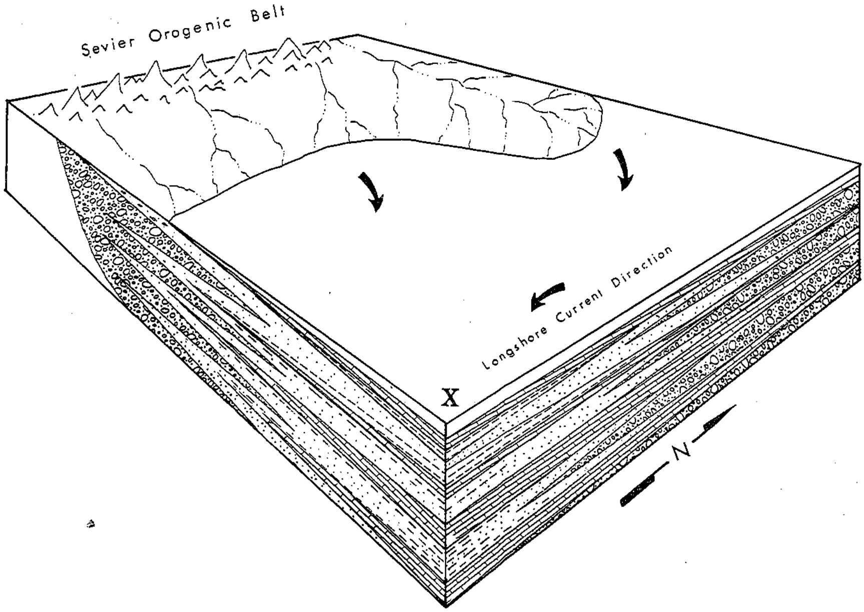
Coated grains and oolites and the presence of algae are thought to represent shallow water depths. These lacustrine waterways were also influenced by agitated currents. Lack of organic material could be a result of these shallow environments and clean, oxygenated waters, along with the reworking of sediments destroying those remains.

APPENDIX

MEASURED STRATIGRAPHIC SECTION OF THE LOWER FLAGSTAFF FORMATION, FOUR MILES TO THE NORTH OF MILLS ROAD (SECTION B)

Beginning at the outcrop of red beds where the first non-red beds appear, and ending at the top of the first major ridge.

Unit	*Description*	*Unit Feet (Meters)*	*Total Feet (Meters)*
27	Limestone; cliff forming, buff to gray, fine-grained micrite, fractures filled with calcite, black lichen on weathered surface, blotchy.	30 (9.1)	619 (188.6)



TEXT-FIGURE 7.—Diagrammatic interpretation of the interrelationship of source area, current directions, and sedimentary basin. *X* marks the interpreted location of the study area.

26	Covered.	86 (26.2)	589 (179.5)
25	Sandstone; brown, tan to yellow, thin bedded, coarse and fine grained, very resistant.	3 (0.9)	503 (153.3)
24	Conglomerate; well-rounded pebbles, brown tan pebbles, quartzite and limestone pebbles.	4 (1.2)	500 (152.4)
23	Covered.	21 (6.5)	496 (151.2)
22	Conglomerate; green quartz pebbles up to 4 inches in diameter, green and purple, blotchy.	3 (0.9)	475 (144.7)
21	Limestone; gray to buff with green and pink blotches, terrigenous clastic material up to 0.3 inches, quartzite and rock fragments, very porous, iron stains around pores, pores filled with crystalline calcite, algal mud lumps.	28 (8.5)	472 (143.8)
20	Conglomerate; red matrix, dark and light quartzite pebbles dominant, some limestone pebbles.	6 (1.8)	444 (135.3)
19	Limestone, gray, sandy, ledge forming.	16 (4.9)	438 (133.5)
18	Gritstone; sandy matrix, green quartz pebbles up to 0.7 inches, subrounded-subangular, matrix very calcareous.	18 (5.5)	422 (128.6)

17	Sandstone and siltstone; red, interbedded, calcareous covered, interbedded mudstone inferred.	65 (19.8)	404 (123.1)
16	Limestone; light gray, sandy, medium grained.	10 (3.0)	339 (103.3)
15	Sandstone and conglomerate; green quartzite fragments.	2 (0.6)	329 (100.3)
14	Wackestone; light gray, green blotches.	15 (4.6)	327 (99.7)
13	Limestone; coated grains.	2 (0.6)	312 (95.1)
12	Shale and limestone; interbedded, maroon.	10 (3.1)	310 (94.5)
11	Conglomerate, gritstone; mud matrix with green cast, angular grains in matrix, green and dark brown rock fragments, poorly sorted, slightly calcareous, very friable, mudstone pebbles present.	3 (0.9)	300 (91.4)
10	Covered.	13 (4.0)	297 (90.5)
9	Sandstone; purple to light gray, fine grained, green blotches, highly angular-subangular, highly calcareous, bottom side of ledge, fair sorting.	2 (0.6)	284 (86.5)
8	Mudstone; very calcareous, fractures, stringers filled with calcite, interbedded with red sandstone and siltstone, gray to maroon veinlets run horizontal, mottled and lumpy, grains up to 0.1 mm, slope forming.	77 (23.5)	282 (85.9)
7	Limestone; light gray, slightly sandy, mottled, slope forming.	58 (17.7)	205 (62.4)
6	Limestone; light gray, cherty, ledge forming, black lichen on weathered surface, continuous laterally throughout area.	55 (16.7)	147 (34.7)
5	Limestone; gray, purple and maroon blotches, highly calcareous, pores filled with crystalline calcite, fine grained, lumpy intraclasts dominant feature, light colored intraclasts of algal mud.	20 (6.1)	92 (28.0)
4	Limestone; micrite, cream colored, brittle, conchoidal fracturing, cliff forming.	25 (7.6)	72 (21.9)
3	Limestone; fine-grained, rock fragments abundant, light gray to buff, grades into unit 4.	2 (0.6)	47 (14.3)
2	Limestone; micrite, fine grained, light gray to buff, highly resistant, conchoidal fracturing, gastropod mold found, ostracods present in thin section, calcite stringers with no orientation.	35 (10.7)	45 (13.7)
1	Limestone; grades from wackestone at the bottom 10 feet to fine-grained algal limestone, pores filled with calcite, terrigenous quartz grains.	10 (3.0)	10 (3.0)

MEASURED STRATIGRAPHIC SECTION OF THE LOWER FLAGSTAFF FORMATION, FIVE MILES TO THE NORTH OF MILLS ROAD (SECTION A)

Unit	*Description*	*Unit Feet (Meters)*	*Total Feet (Meters)*
31	Limestone; buff to cream, very resistant, vugs filled with calcite, forms ledge.	8 (2.5)	522 (158.8)
30	Sandstone; pale red, well sorted, current bedding present, highly calcareous, slope forming.	10 (3.0)	514 (156.3)
29	Mudstone; calcareous, red, lumpy, grades into unit 29, poorly exposed.	6 (1.8)	504 (153.3)
28	Limestone; maroon to pink, mostly covered float.	10 (3.0)	498 (151.5)
27	Limestone; very resistant, meringue weathering, tan to buff.	3 (0.9)	488 (148.5)
26	Covered with limestone float on eastern dipping slope.	87 (26.5)	485 (147.6)
25	Limestone; fractured red, yellow, green, and buff, mottled, very fine grained, laminated stringers filled with calcite.	10 (3.0)	398 (121.1)
24	Sandstone, gritstone; green to cream colored, some ripple marks and cross bedding, paleocurrents S 16° E, banded layers to fine and coarse grained, angular-subrounded.	5 (1.5)	388 (118.1)
23	Covered upper 2 feet contains green conglomerate.	25 (7.7)	383 (116.6)
22	Sandstone; thin bedded, interbedded coarse and fine grained, green to brown, calcareous.	3 (0.9)	358 (108.9)
21	Limestone; cream to gray, sandy, grades into sandstone unit 22.	6 (1.8)	355 (108.0)
20	Sandstone; green, 1-inch thick, continuous capping unit of unit 19.		349 (106.2)
19	Sandstone; coarse grained, brown, well sorted, calcareous.	6 (1.8)	349 (106.2)
18	Limestone; massive, gray with pink and brown blotches, fine grained, lumpy.	25 (7.7)	343 (104.4)
17	Sandstone; pink to tan, grades into unit 18.	2 (0.6)	318 (96.7)
16	Sandstone and gritstone with conglomerate channels; quartzite cobbles up to 8.0 inches in diameter, green to gray brown.	22 (6.7)	316 (96.1)
15	Sandstone, gritstone; maroon to pink, small pebbles up to 0.2 inches, pebbles are angular to subrounded, calcareous.	2 (0.6)	294 (89.4)
14	Covered.	33 (10.0)	292 (88.8)
13	Conglomerate; red, pink, maroon, fair sorting, angular to well rounded, sandy matrix, pebbles up to 3 inches in diameter.	2 (0.6)	259 (78.8)
12	Sandstone; red to maroon, grades into conglomerate.	2 (0.6)	257 (78.2)

11	Limestone; red, abundant rock fragments, grades into unit 12.	2 (0.6)	255 (77.6)
10	Limestone; gray, fine grained, mottled, vugs filled with calcite, mud lumps, slightly sandy.	10 (3.0)	253 (77.0)
9	Limestone; gray to cream, fine to medium grained, mud lumps abundant, rock fragments, and quartz grains rare, ledge forming.	22 (6.7)	243 (74.0)
8	Covered; float material suggests interbedded red mudstone and sandstone.	35 (10.7)	221 (67.3)
7	Limestone; gray pink, fine-grained micrite, conchoidal fracturing, vugs filled with calcite, intraclasts abundant mud lumps range from 1-4 mm, ledge forming.	3 (0.9)	186 (56.6)
6	Covered.	10 (3.0)	183 (55.7)
5	Limestone; maroon to pink, lumpy and blotchy, stringers filled with calcite, small stylolites filled with iron oxide stain, forms prominent ledge.	35 (10.7)	173 (52.7)
4	Mudstone and sandstone; red, calcareous, poorly exposed, interbedding inferred from float material.	87 (26.5)	138 (42.0)
3	Conglomerate; pink to buff, calcareous, pebbles, poorly sorted, angular to well rounded, oncolites and mudstone pebbles also found.	3 (0.9)	51 (15.5)
2	Limestone; fine grained, gray to buff, lumpy, ledge forming.	33 (10.0)	48 (14.6)
1	Limestone; micrite, algal mud lumps present, light gray to buff, well exposed ledge.	15 (4.6)	15 (4.6)

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