BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES

Volume 21, Part 3 — October 1974

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Brigham Young University Geology Studies

Volume 21, Part 3 — October 1974

Contents

A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Brigham Young University Geology Studies is published semiannually by the department. *Geology Studies* consists of graduate-student and staff research in the department and occasional papers from other contributors. *Studies for Students* supplements the regular issues and is intended as a series of short papers of general interest which may serve as guides to the geology of Utah for beginning students and laymen.

Distributed October 31, 1974

Price $5.00

(Subject to change without notice)

Paleoenvironment of the Lower Triassic Thaynes Formation Near Cascade Springs, Wasatch County, Utah*

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ABSTRACT.—The Thaynes Formation, as exposed in northeastern Utah, is a cyclic sequence of sediments deposited on the eastern shelf of the Cordilleran miogeosyncline in Lower Triassic (Scythian) time. The section studied can be divided into three main lithologic units: (1) a lower member dominated by marine clastic and carbonate sediments, (2) a middle member dominated by nonmarine red beds, and (3) an upper member dominated by marine carbonate sediments.

Environments interpreted to have existed in the study area are: tidal flat and tidal channel, subtidal or nearshore marine, and open marine. Transgressive-regressive sequences shown by the cyclic appearance of these environments are present throughout the stratigraphic section.

Fluctuation in the rate of basin subsidence and the rate of sedimentation caused two major transgressive and one major regressive phase in the study section. The transgressive sequences are represented by the lower and upper members and contain green, fine-grained clastic units and marine carbonate units. The major regressive sequence is represented by the middle member and is composed of red siltstone and shale that are abundantly ripple marked and raindrop imprinted and that exhibit a bimodal direction of deposition.

The Thaynes Formation represents two of the last marine transgressive sequences in Lower Triassic time in the Cordilleran miogeosyncline before its destruction in the Lower Triassic.

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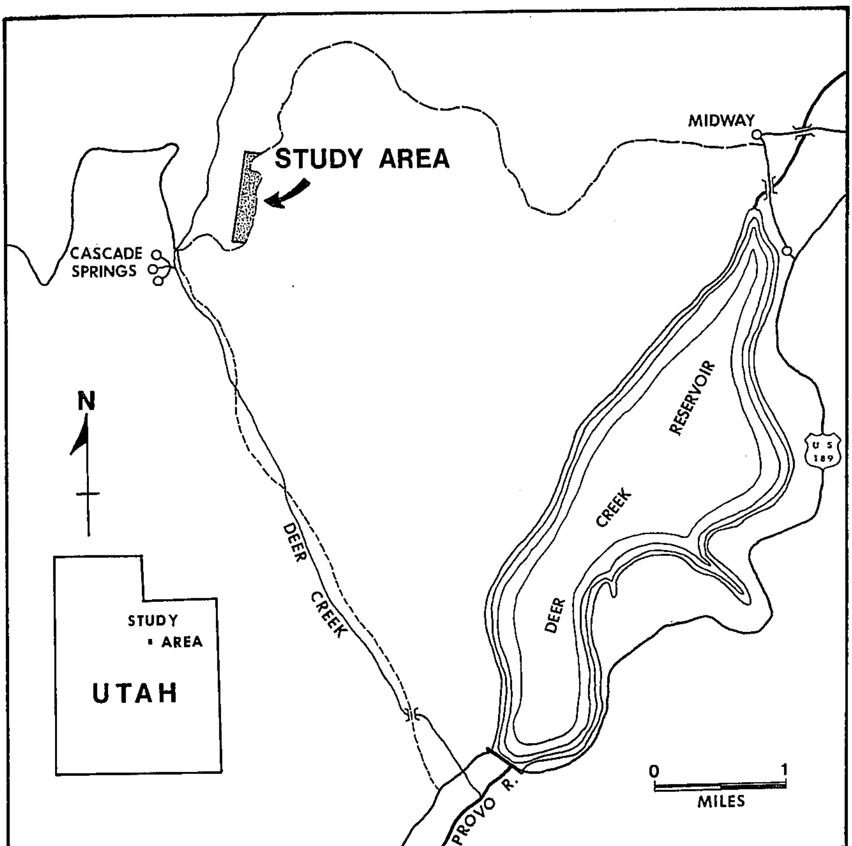
*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, April 17, 1974. Thesis chairman, J. Keith Rigby.

INTRODUCTION

The Lower Triassic Thaynes Formation, in central and northeastern Utah, is a cyclic series of sandstone, red beds, and carbonate rocks. Recent road cuts have exposed the section particularly well near Cascade Springs Recreation Area in the central Wasatch Mountains (Text-fig. 1). The formation is composed of a regressive-transgressive sequence of tidal flat and marginal marine shale and siltstone that grade upward to open marine and then into tidal flat and fluvial deposits of the overlying Triassic Ankareh Formation. Thickness of the Thaynes Formation in Utah ranges from a maximum of 1290 feet in the type section to 940 feet in the study area (Baker, 1948).

The Thaynes Formation is a shelf sequence, deposited on the eastern



TEXT-FIGURE 1. —Index map.

shelf of the Cordilleran miogeosyncline during Lower Triassic (Scythian) times (Kummel, 1953). The formation is present from southern Montana southward through eastern Idaho and western Wyoming into Utah, with the thickest sections found in east-central Idaho.

The purpose of this study is to develop a depositional and environmental model of a marine to nonmarine shelf sequence showing the transitional relationships of lithology, paleontology, sedimentary rock associations and structures, and paleocurrent directions.

Location

The study area is located in the central Wasatch Mountains, 1.5 miles northeast of Cascade Springs, in Secs. 18 and 19, T. 4 S., R. 4 E., on the road from Cascade Springs to Midway, Utah (Text-fig. 1). The area is accessible from both the east and the west by paved or dirt roads and was chosen for study because of the excellent exposures provided by the road cuts associated with these access roads. The road cut along the Midway-Cascade Springs road exposes the upper 710 feet of the Thaynes Formation without cover; the lower part of the formation was not studied because of poor exposure.

Geologic Setting

Paleogeographically, the study area lay on the eastern shelf of the Cordilleran miogeosyncline, with a positive area to the northeast; and the Uncompaghre Uplift to the southeast (Text-fig. 2) probably supplied most of the terrigenous sediments to the area (McKee, et al., 1959, p. 23).

Stratigraphically, the Thaynes Formation gradationally overlies the Lower Triassic Woodside Shale and also is gradational and partially equivalent to the overlying Ankareh Formation (Text-fig. 3).

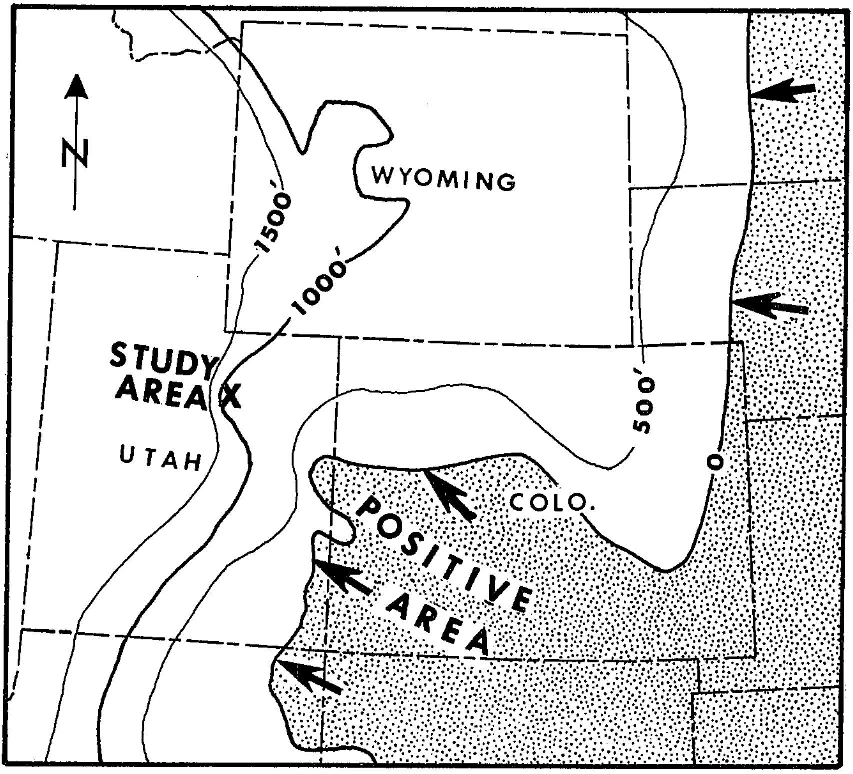
Physical Characteristics

The Thaynes Formation in the study area is divided into three main members: (1) a lower member composed of a basal limestone and interbedded limestone and clastic beds, (2) a middle, dominantly red bed, member called the middle red (Boutwell, 1907) or the Lanes Tongue of the Ankareh (Kummel, 1953), and (3) an upper interbedded limestone and terrigenous clastic member. The first appearance of *Meekoceras* has been utilized to locally define the base of the Thaynes Formation, and the formation has been divided into five main ammonoid zones (Kummel, 1954), from the bottom up: (1) *Meekoceras,* (2) *Anasibirites,* (3) *Tirolites,* (4) *Columbites,* and (5) *Prohungarites.* These ammonoid zones have been used to correlate the shelf-sequence material and marine units with formations to the west. The study section includes the ammonoid zones from *Anasibirites* to *Prohungarites;* however, no ammonoids were encountered in the section. In more eastern exposures of the formation, where red beds dominate the lithology, these fossils are not present (Kummel, 1954).

The middle member of the section is a thick sequence of interbedded red shale and siltstone and is a tongue of the Ankareh Formation that represents a major regressive sequence.

Previous Work

The Thaynes Formation was named by Boutwell (1907) in the Park City Mining District approximately 25 miles north of the study area. The type



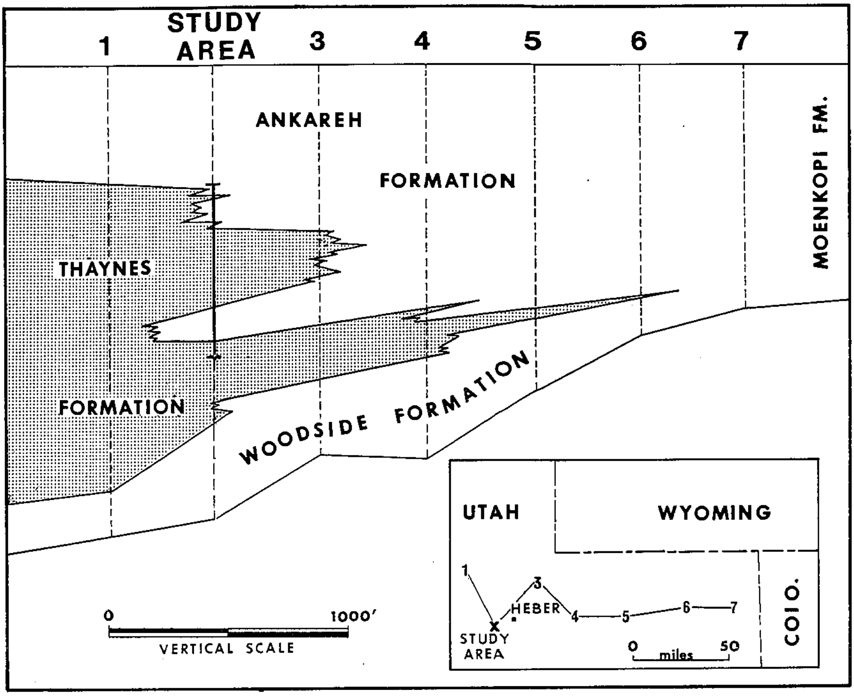
TEXT-FIGURE 2.—Paleogeographic setting of the study area (after McKee et al., 1959).

section in Thaynes Canyon consists of 1290 feet of interbedded clastic and marine material, with a thick medial red-bed unit and was first assigned a late Permian age. Boutwell (1912) reassigned it to the Early Triassic after further work was done with the fauna.

The present study area was mapped by Baker (1948), and Kummel (1953, 1954) considered the stratigraphic and faunal variations of the Thaynes Formation from southern Montana to central Utah. The Thaynes Formation has been described in nearby areas by Bissell (1959), Bromfield (1968), Clark (1957), Mansfield (1916), and Scott (1950, 1954, 1959). The most complete work on the paleoenvironment of the Thaynes Formation is a Ph.D. dissertation from the University of Utah by Smith (1969); however, this study was a general combination of stratigraphy and paleoecology similar to Kummel's (1953) paper and does not provide a unit-by-unit interpretation of paleoenvironments.

Methods of Study

Field Methods.—A detailed stratigraphic section was measured using a Brunton compass and a 10-foot steel tape. During stratigraphic measurement, samples were taken from each of the 104 lithologic units (refer to



TEXT-FIGURE 3.—Facies relationship of the Thaynes Formation with the Ankareh and Woodside formations (after Kummel, 1953). Heavy bar in the study area indicates the measured section.

Appendix 1) or at every 5 feet within thicker units. Special attention was paid to relationships of various sedimentary rock types and the sedimentary structures found in them. These sedimentary structures were used to determine paleocurrent directions and sedimentary environments. Trends of directional features on dipping beds were rotated back to the horizontal position by stereographic projection methods, and field-reference photographs were taken.

Laboratory Methods.—Samples of the principal carbonate units were etched with dilute acetic acid to recover phosphatic microfossils. Oriented thin sections were made of all major lithologic types to aid in investigation of composition, microstructures, grain orientation, textures, and classification. Carbonate classification is modified from that of Grabau (1913), and grain-size terms are those of the modified Wentworth grade scale as proposed by Dunbar and Rogers (1966).

Acknowledgments

The author gratefully acknowledges the time and help given by Dr. J. Keith Rigby, thesis committee chairman, in the completion of this study. Also appreciated is the help of Dr. W. Kenneth Hamblin, who served as a thesis committee member, and of Dr. Harold J. Bissell for his criticism of ideas developed during the project.

I would especially like to thank my wife, Ruth Ann, for her help in the field and in laboratory work during the project and for her encouragement and understanding during this time.

Considerable financial support for this project came from summer work, and the financial support received from my family is greatly appreciated.

LITHOLOGIES

Sandstone

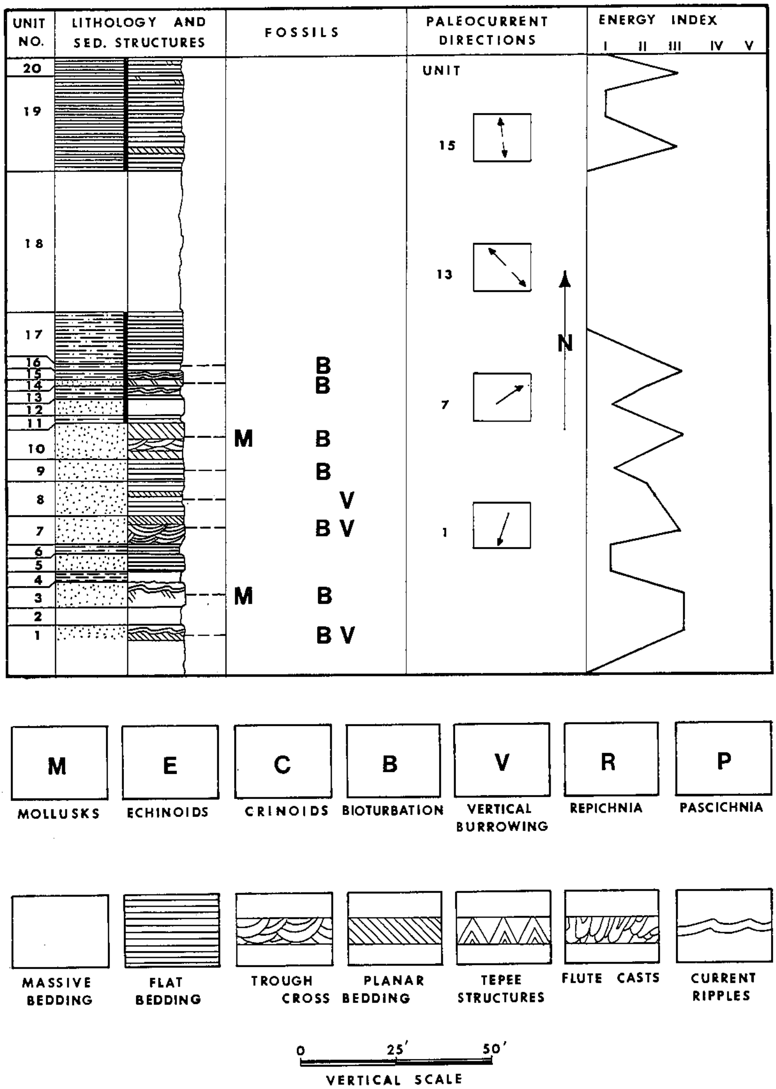
Sandstone, one of the major lithologies in the measured section, includes four main colors that indicate different environmental processes. These are: (1) red, (2) brown to orange brown, (3) green, and (4) gray. All the sandstone units present in the section are fine grained and fairly uniform in composition, sedimentary structures, and fossil content.

Red sandstone.—Red to dark red sandstone occurs in units 12, 14, 87, 88, and 104 in the measured section (Text-fig. 4). These units range in thickness from 6 inches to 52 feet, with an average thickness of 1 to 4 feet. Grain size of characteristic samples from these units ranges from approximately 0.06 mm in diameter to approximately 0.125 mm in diameter, although some siltstone lenses occur in units 87 and 104. Sandstones are composed mainly of detrital quartz grains and have minor amounts of feldspar, dolomite (some of which appears to be detrital), calcite, mica, and clay-sized material. Most grains are angular to subangular, although a few are rounded.

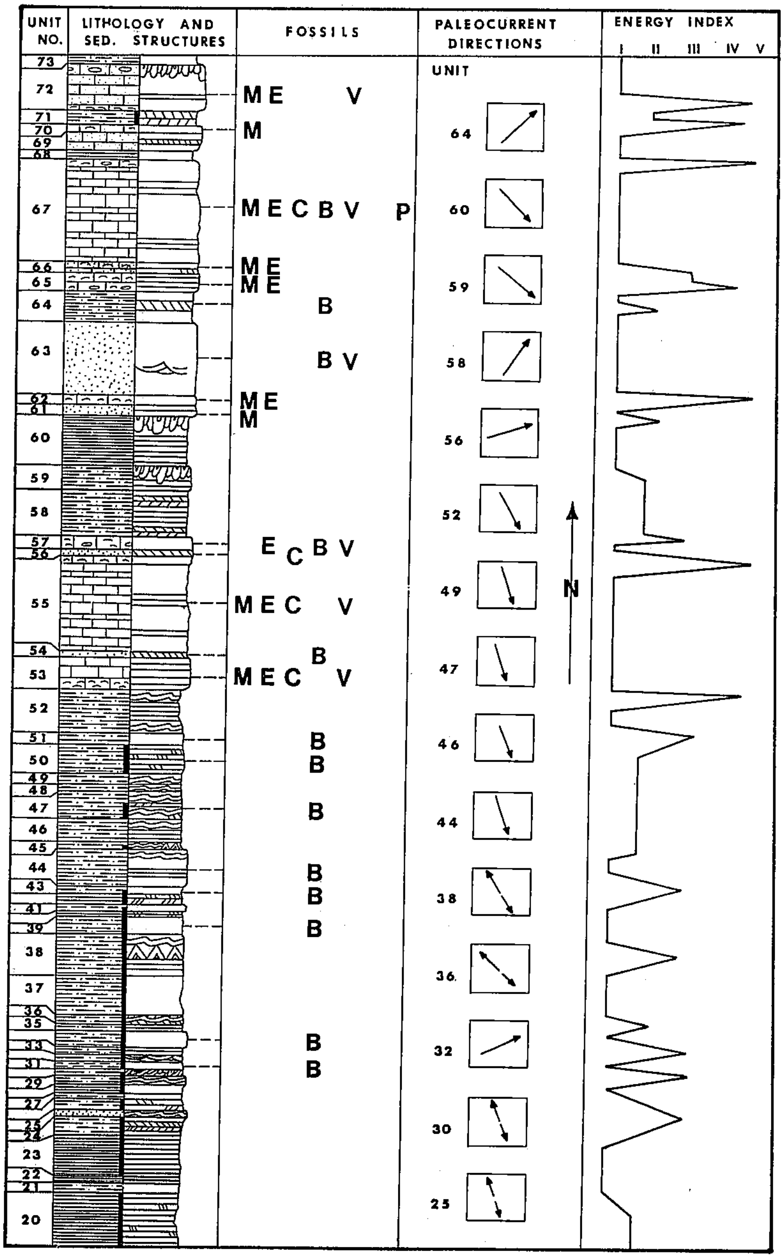
The red sandstones are dense, moderately to poorly sorted, and usually calcareous, and they contain vugs filled with sparry calcite. Individual laminae show graded bedding in thin sections. Both trough and foreset cross-bedding occur in units 14 and 104, but bedding has been destroyed in most units by considerable bioturbation. Bedding is usually irregular, and contacts tend to be gradational. These sandstones are usually interbedded with red siltstone. The red coloring of these units, their sedimentary structures, and their association with red siltstones indicate a dominantly subaerial, oxidizing environment such as a tidal flat.

Brown to orange brown sandstone.—Brown or buff to light orange brown sandstone occurs in units 1, 3, 5, 7, 8, 56, 61, and 75. Thicknesses of the units range from 6 inches to 7 feet, with an average thickness of 2 to 3 feet. Grain size in characteristic samples varies from 0.06 mm to 0.125 mm in diameter, with some of the units grading upward into coarse silt-sized material. These sandstone units are composed of detrital quartz grains, with minor amounts of feldspar (usually less than 10 percent), dolomite, calcite, mica, and clay-sized material. Detrital grains are mostly angular to subangular, although a few are rounded. Color of the beds is due to hematite and significant amounts (10 to 15 percent) of calcite and dolomite.

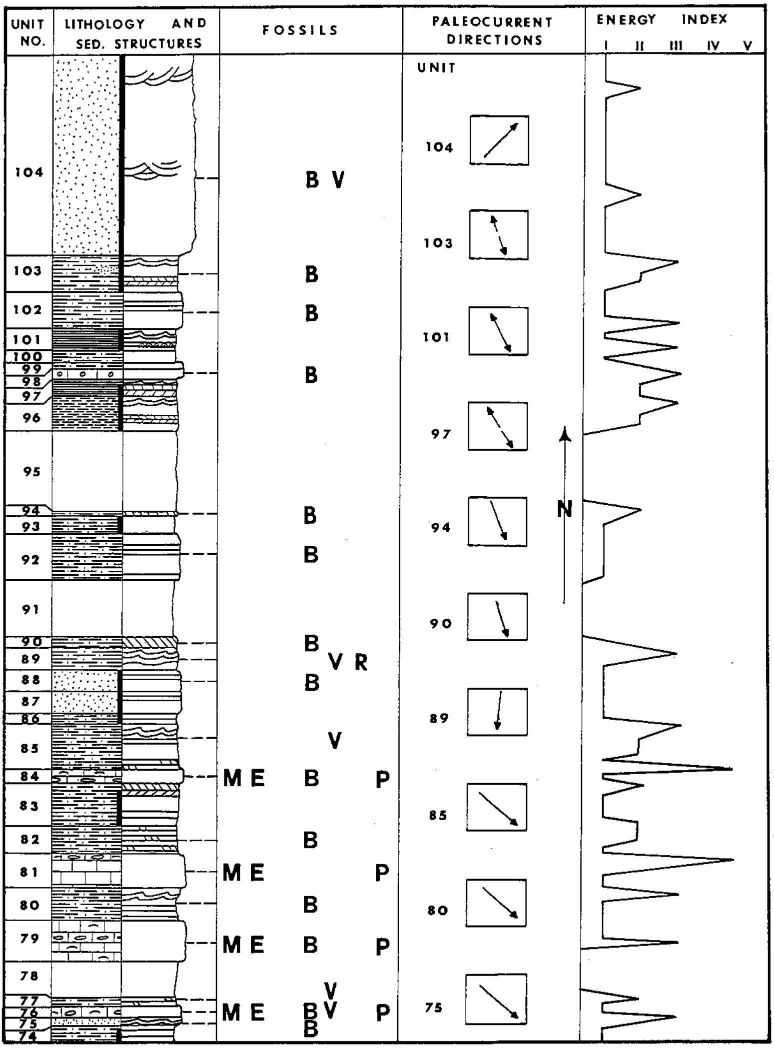
These beds are generally dense and well cemented, with fair to poor sorting, depending on the amount of clay-sized material present. With the exception of units 61 and 75, all beds are calcareous. Stratification in these beds is thin and regular, but contacts are usually irregular though sharp, with little gradation into adjacent beds. Burrowing occurs in units 3, 7, 8, and 75 where bedding is partially destroyed. Some trough and foreset cross-bedding occurs, usually on a microscopic scale, except in unit 7 where cross-bedding sets are up to 2 feet high. Pelecypod, echinoid, and crinoid debris are abundant in



TEXT-FIGURE 4.—Total studied stratigraphic section, showing lithology and sedimentary structures. Fossils and paleocurrent directions are keyed to the stratigraphic units. The energy index is modified from Plumley et al. (1962). I: quiet water, II: intermittently moderately agitated water, III: slightly agitated water, IV: moderately agitated water, and V: highly agitated water. Blacked in part of lithology column indicates red beds.



Text-figure 4 (Continued)



units 3, 56, and 61. These three units are associated with marine clastic and carbonate units. Environmentally, these units are subtidal—as shown by the burrows, fossil material, and sedimentary structures present.

Green to light green sandstone.—Units 25, 54, and 63 are composed of a green to light green, fine-grained sandstone. Thicknesses of these units range from 1 to 19 feet, with an average of approximately 5 feet. The grain size in characteristic samples from these units varies from 0.06 mm to 0.125 mm in diameter, with the average grain size approximately 0.08 mm (Pl. 3, fig. 1). Some of the units grade upward into coarse siltstone. The units are composed of angular to subangular quartz grains, with minor amounts of feldspar, dolomite, calcite, and mica. Color of the units is due to the reduction of iron and possibly some illite (Keller, 1953).

The rocks are calcareous, dense, moderately to well cemented, and moderately to poorly sorted because of the amount of clay-sized material present. Stratification in these units is thin to blocky and somewhat irregular with sharp contacts. Some foreset cross-bedding occurs but only on small scale. Other structures present include asymmetrical ripple marks in unit 63. The units rarely have body fossils, but burrowing and bioturbation are common in all units and have destroyed most bedding in the units. These sandstone units are found in association with marine limestone and clastic units. The color of these units indicates a reducing, subaqueous environment as shown by the burrows and fossil material in the units.

Gray sandstone.—Gray, quartzose sandstone occurs in units 9 and 66. Thicknesses range from 6 inches to 5 feet, with an average of approximately 2 feet. Grain size in the gray sandstone units is 0.10 mm in diameter as an average, but unit 66 grades into coarse, silt-sized material in places. Grains are mostly angular to subangular quartz, but both dolomite and calcite also form a high percentage of the units. Dolomite in unit 9 is iron stained and appears to be detrital rather than diagenetic in origin. Color of these rocks is caused by the association of iron sulfide with the fossil material.

The sandstone is dense, well cemented, calcareous, and with fair to poor sorting due to mixed clay-sized material and large fossil fragments. Stratification is thin and irregular, with sharp contacts at both surfaces. Unit 66 has several layers of coarse bioclastic material, mostly pelecypod, echinoderm, and gastropod debris, deposited in the upper part of the unit where it grades into a calcisiltite. Stylolites are also present in unit 66, and some material has been pyritized. Associated with marine material, these units grade into carbonate rocks in unit 66 and often have burrowing and fossil material indicative of a marine environment.

Siltstone

Siltstone makes up most of the clastic rocks in the measured section and is of two main types: (1) red to purple, and (2) green; other types include brown and gray but are of minor amounts.

Red to purple siltstone.—Red to purple siltstone occurs in 26 of the 104 units in the measured section, and these units range in thickness from 6 inches to 13 feet, the average being 4 to 6 feet thick. Grain size in these units averages 0.06 mm, the smallest grains being approximately 1/64 mm in diameter. Most of the material is coarse to medium sized, the smaller material comprizing approximately 30 percent of the units. Sand-sized material, up to 0.10 mm in diameter, also occurs, with some units containing up to 25 percent of this size material. Grains are angular to subangular quartz, feldspar, and some clay-sized material, with minor amounts of calcite and mica. Color is due to hematite in the matrix.

Most of these siltstones are dense, with little to no cement, and sorting is fair to poor because of admixed sand and clay. Stratification is irregular, and contacts between units are often gradational. Small-scale foreset cross-bedding occurs in almost all of these units, usually showing directly opposed current directions. The beds are thin and finely laminated, and asymmetrical ripple marks, raindrop imprints, and "teepee" structures (Smith, 1974) also occur. Organic activity during deposition is evidenced by burrowing and other forms of bioturbation that have destroyed bedding. The red color of the units and the presence of sedimentary structures indicate an alternating subaqueous-subaerial environment such as a tidal flat.

Green siltstone.—Green siltstone forms 23 of the 104 units in the section and is one of the most abundant rock types encountered. Thicknesses of these units range from 6 inches to 12 feet, with an average of 6 to 7 feet. Grain size is like that of the red to purple units (Pl. 3, fig. 2), but the sorting in the green units is somewhat better.

Green units tend to be well cemented with calcite. Ripple marks, burrows. and trails are often present and some foreset cross-bedding also occurs. Stratification is thin and irregular but somewhat better than in the red to purple siltstones. Green units are often interbedded and gradational with other siltstone units. Color of the units, burrowing, and sedimentary structures associated with this material indicate a low-energy marine (subtidal) environment.

Brown and gray siltstone units are minor and are similar to the green and red siltstone units. None of the brown or gray beds produced well-preserved, distinctive fossils, but fragments and some casts were observed.

Shale and Claystone

These fine-grained units are found principally in the medial red-bed member of the section. Shale is one of the dominant lithologies in this member, and color ranges from red to purple, but green shale units are present in the upper part of the section. Little fossil evidence (other than some wandering ridges and depressions that could be trails) was found in these units. Green shales of units 4, 60, 68, and 78 were processed for fossils, but the samples were barren. Several green units also show lamination and flute casts in the upper part of the member. Some minor foreset cross-bedding occurs in the red shale.

"Claystone," as used here, refers to fine-grained rocks made of clay and very fine silt which lack fissility. Such rocks possibly were deposited in a higher-energy environment. Claystone units are most common in the medial red-bed member and appear to have been bioturbated. No fossils were found in these units, and sedimentary structures are obscured.

Carbonate Rocks

Carbonate rocks make up most of the upper part of the measured section (Text-fig. 4) and are important in determining paleoenvironments of that part of the section. Seven main carbonate lithologies occur, including (1) calcilutite, (2) biocalcilutite, (3) calcisiltite, (4) biocalcisiltite, (5) pelletal calcisiltite, (6) biocalcarenite, and (7) algal calcarenite.

Calcilutite.—Sandy calcilutite occurs in units 55 and 66 and ranges from 3 feet to 32 feet thick. Both units are dark gray to medium gray, massive, dense limestones that form ridges in the section and weather to a brown, sandy-appearing surface. Each unit contains up to 20 percent detrital quartz grains and exhibits fair sorting. Unit 55 has several layers of coarse-grained bioclastic material, representative of higher-energy surges in the depositional environment. These coarse layers grade upward into the normal calcilutite of the unit.

Unit 66 grades from a sandstone into a calcilutite and then into a coarser calcarenite at the top. Both units 55 and 66 have secondary sparry calcite in vugs; pyritization also has occurred in both units, and burrows are also common.

Biocalcilutite.—Light bluish gray to dark gray biocalcilutite occurs in units 53, 62, 65, and 79, which range in thickness from 3 to 24 feet. All these units are massive and hold up ridges in the section. Detrital quartz grains form 10 to 20 percent of these rocks, and the units look quite sandy when weathered. All the units are abundantly fossiliferous, containing pelecypod, gastropod, echinoid, and crinoid debris, and algal and fecal pellets are also present in most of these units. Units 53 and 79, in particular, contain abundant algal material. Secondary sparry calcite has replaced or recrystallized most pelecypod material. Echinoid spines in unit 65 have been replaced with glauconite. Chert nodules occur in units 65 and 79, and burrowing occurs in all units, some of the burrows being filled with chert.

Calcisiltite.—A gray to dark gray calcisiltite occurs in unit 67 and is 27 feet thick. It is massive to thick bedded, is ridge forming, and contains approximately 10 to 15 percent detrital quartz grains. When weathered, it has a brown, vuggy, sandy surface. Burrowing is present throughout the unit, especially at the top, and the unit has some chert in the form of nodules.

Biocalcisiltite.—Gray to dark gray biocalcisiltite occurs in units 67 and 72. Unit 67 grades from a calcisiltite at the base to a biocalcisiltite at the top. These units are extremely fossiliferous at the bottom and top with several thin layers of coarse bioclastic material composed of pelecypod, gastropod, and echinoderm debris. Most of this bioclastic debris has been replaced with sparry calcite, and some, with pyrite. The upper part of each unit is intensely bioturbated, and lenses of chert are common.

Pelletal calcisiltite.—Unit 81 is a ledge-forming, gray to dark gray pelletal calcisiltite 8 feet thick. It contains less than 10 percent detrital quartz and weathers to a vuggy, pitted surface. Most of the unit appears to be composed of algal and fecal pellets of varying size, and some layers show well-defined current stratification. Several layers of coarse pelecypod debris are interbedded in the pelletal material, and chert occurs in lenses in the upper part of the unit.

Biocalcarenite.—Biocalcarenite occurs in units 55 and 76 and has thicknesses of 3 to 8 feet. Unit 55 grades upward from a calcilutite at the base to a biocalcarenite in the upper part. The rocks are gray to dark gray and contain less than 10 percent detrital quartz grains and minor algal pellets. Pelecypod, gastropod, and echinoderm debris is abundant in both units; and both are burrowed, particularly in the upper part. Some bioclastic material has been pyritized. Chert nodules occur in unit 76.

Algal biocalcarenite.—An algal biocalcarenite, similar to the biocalcarenite of units 55 and 76, occurs in unit 84. The algae form matlike structures and are particularly abundant in the upper part of the unit. Algal plates are associated with pelecypod and echinoderm debris.

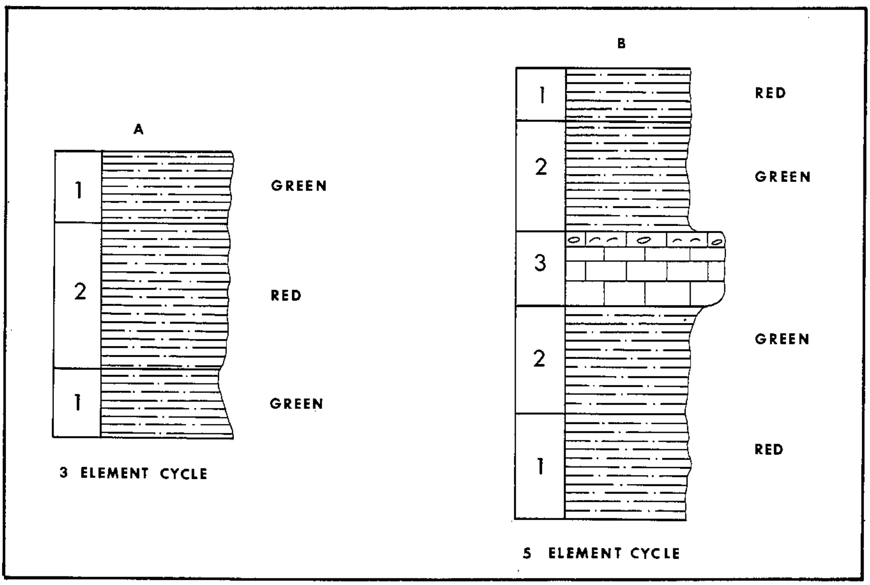
LITHOLOGIC RELATIONS

Cyclic repetition of various rock types is characteristic of this section of the Thaynes Formation. The most repetitive units in the measured section are siltstone, and the clastic-carbonate cycles encountered give good environmental parameters for the formation.

Most of the lithologic repetition occurs in the middle and upper members of the section. The normal cycle in the middle member is (1) red siltstone or shale, (2) green siltstone or sandstone, and (3) red siltstone. This three-element cycle is repeated eight times in the middle member. In the upper member, the normal cycle is five-element and consists of (1) red siltstone, (2) green siltstone or sandstone, (3) a carbonate unit with minor coarse bioclastic layers, (4) green siltstone, and (5) red siltstone (Text-fig. 5). Several variations of this five-element cycle occur in the upper member, with red siltstone being deposited directly on carbonate units or only a green siltstone separating carbonate units. Both variations indicate either rapid or partial regression and interruption of the normal pattern.

In the upper part of the measured section, where carbonates dominate, there are three main cycles of these carbonate units: (1) units 53 to 57, (2) units 65 to 76, and (3) units 79 to 84 (Text-fig. 4). These three cycles start on top of a thin regressive red siltstone, and the carbonate units commence with the deposition of a fine-grained biocalcilutite or calcilutite and grade upward to end in coarser calcarenites and biocalcarenites. The cycle then repeats, starting with the deposition of siltstone.

Thin layers of coarse bioclastic material occur in all the carbonate units, either at the base or at the top of the unit, with none of the coarse accumulations occurring in the middle of these units. Such a distribution is probably related to single high-energy events, such as storms, in a normally low-energy environment, the material being transported in by the storm surges and deposited. Water depth was probably shallow because this material had been deposited at the beginning or end of a transgressive sequence. Most of the carbonate units



TEXT-FIGURE 5.—Typical cycles in the stratigraphic section: Column A—a typical three-element cycle; column B—a typical five-element cycle.

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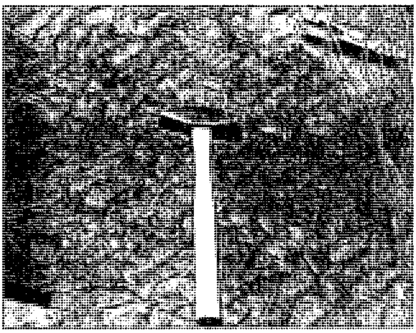

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EXPLANATION OF PLATE 1
FIELD VIEWS

FIG. 1.—View of unit 7, showing massive sandstone and large-scale cross-beds.

FIG. 2.—Trough cross-beds in lower part of unit 7.

FIG. 3.—Asymmetrical ripple marks in unit 13, showing the major southeast direction of deposition. Raindrop imprints and foreset cross-beds are also associated with these ripple marks.

FIG. 4.—Uppermost sandstone unit (probably a tidal channel) in the lower member and the gradation into red siltstone and shale of the middle member. Sandstone seen here is bioturbated and has some foreset cross-beds.

FIG. 5.—"Teepee" structure in unit 38 formed by the expansion of beds as salts formed in the interstitial spaces of the sediment or between the beds.

FIG 6.—View of the upper, weathered, cherty surface of a carbonate unit.

have chert associated with the coarse bioclastic material, usually as nodules or burrow infillings. Chert was not encountered in the fine-grained rocks above or below the coarse bioclastic material. Because the chert is associated with the carbonate units as nodules or as burrow fillings, the chert is considered secondary (Pettijohn, 1957, p. 439).

SEDIMENTARY STRUCTURES

Sedimentary structures are common throughout the section and are grouped into four main types: (1) ripple marks, (2) cross-bedding, both planar and trough, (3) "teepee" structures, and (4) flute casts.. These sedimentary structures are most common in the lower and middle members and in the top of the upper member where terrigenous clastic material is abundant.

Ripple Marks

Ripple marks in the section are generally asymmetrical current ripples. They are most common in the middle member, where they are well formed and are associated with raindrop imprints and larger-scale planar cross-bedding. Some of the ripple marks in the lower member have a superficial symmetrical appearance but show imbricate bedding on close examination of polished surfaces.

Most ripple-marked beds in the middle member are red siltstone. Ripple beds in these units are close together vertically (usually less than 1 inch), and this packing tends to destroy some of the lower ripples. Generally in this member and in other red siltstone beds a distinctly ripple-marked layer (Pl. 1, fig. 3) overlies other layers where ripple-marked surfaces have been destroyed, but their imbricate cross-bedding is still visible beneath the eroded surface. Using all current indications it was found that most of the middle member was deposited in an environment of bimodal current direction. This is particularly true of most red siltstone and shale in the measured section.

Ripple marks are fewer and lack a bimodal pattern in the lower and upper members of the section, but where they are preserved they are generally more distinct and show good planar cross-bedding. Many of the ripple-marked horizons in these members are also burrowed.

Cross-bedding

Cross-bedding in the formation is mainly of two types: (1) planar, usually associated with ripple marks, and (2) trough, usually found in the more massive sandstone.

Planar cross-bedding is common and is particularly well developed in the middle member and upper part of the upper member. Planar cross-bed sets are generally small, usually only 1 to 2 inches high. Larger-scale sets, 2 to 3 feet high, do occur in unit 7 (Pl. 1, fig. 1).

Trough cross-bedding is encountered in several of the more massive sandstone units, particularly in units 7 (Pl. 1, fig. 2), 10, and 104. These cross-beds are usually 1 to 2 feet across and 6 inches to 1 foot in height.

"Teepee" Structures

Teepee structures similar to those described in the Permian of Texas (Newell, 1953) and the Triassic of Italy (Bosellini, 1974) are encountered in units

38, 45, and 101, all of which are red siltstone and shale. These structures are generally small, ranging from 2 to 6 inches high (Pl. 1, fig. 5). Research on the origin of the structures is limited, but one of the most recent papers on them relates the formation of these structures to the expansion of the sediment and wedging apart of the beds due to the deposition or formation of salts or caliche in interstitial spaces during lithification (Smith, 1974). Expansion of beds due to crystallization of salts within them causes these beds to flex upward and become rounded at the top of the wedge. Kendall (1969) proposed that these structures were the result of dessication and mudcracking, but the features in the section show no splitting of beds in the middle of the structure that would indicate dessication and mudcracking, so the author feels that the formation of the structures was due to expansion.

Flute Casts

Flute casts are encountered in units 30, 59, 60, and 72 and are associated with a variety of lithologies, including red siltstone, green siltstone and shale, and sandy limestone. These structures are quite pronounced, ranging from 1 to 1.5 feet long and six inches wide (Pl. 2, figs., 2, 3).

Other sedimentary structures found in the section are graded bedding, usually on a microscopic scale, and raindrop imprints associated with the red siltstone and shale. These structures occur throughout the section in favorable beds.

PALEONTOLOGY

Occurrence and Preservation

Fossil material in the section is of two types: (1) body fossils, and (2) ichnofossils (trace fossils). Most body fossils are preserved in the carbonate units, but ichnofossils occur throughout the section.

Preservation of the body fossils is generally poor, most of this skeletal material being badly broken and concentrated in the coarse-grained bioclastic layers in the carbonate units of the upper member. Samples from all of the carbonate units were prepared with dilute acetic acid to recover silicified elements. Some of the fossils found in this residue are identifiable, but most forms occur as steinkerns or are broken or worn so that, generally, identification is possible only to class or family level.

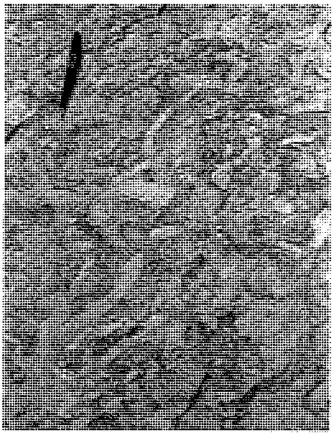
Ichnofossils, however, are generally well preserved because these trace impressions may be chert fillings of burrows or because they occur in sandstone or siltstone. Bioturbation of clastic units is common.

Fossils found in each of the stratigraphic units are given in Text-fig. 4.

Body Fossils

Pelecypods, gastropods, echinoid debris (spines and interambulacral plates), and crinoid debris occur as body fossils in the section. These fossils are generally restricted to the coarse-grained bioclastic layers in the carbonate units, only a few small pectins being found outside of these layers.

Pelecypods.—Pelecypods occur almost exclusively in the upper member, except for some encountered in the clastic units of the lower member. Pelecypod valve fragments comprise the major part (70 percent) of the bioclastic layers in the upper member, and the material is broken and generally unidentifiable (Pl. 4, figs. 3, 5). Some small pectinoid forms of the genus *Aviculipectin,*



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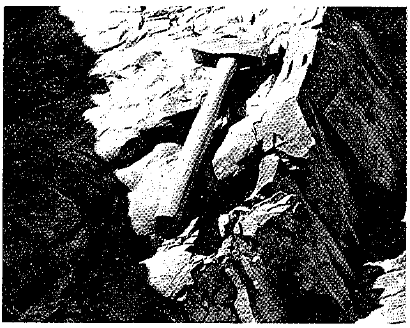

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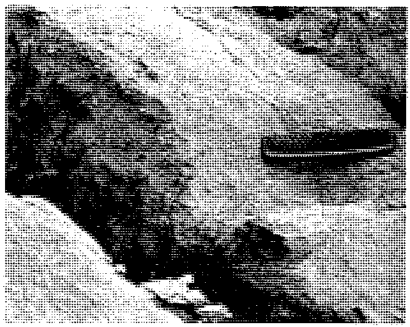

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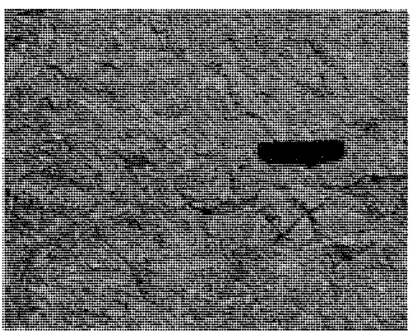

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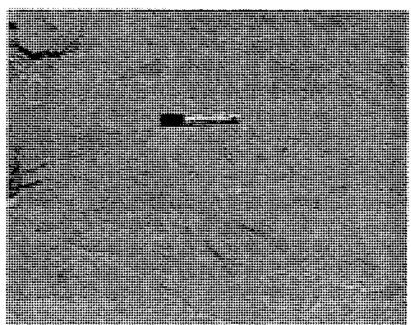

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EXPLANATION OF PLATE 2

FIELD VIEWS

FIG. 1.—Pascichnia burrows in upper part of unit 67.
FIG. 2.—Flute casts on upper surface of unit 72.
FIG. 3.—Flute casts on upper surface of unit 60.
FIG. 4.—Bioclastic layer in lower part of unit 81.
FIG. 5.—Pascichnia burrows in unit 81.
FIG. 6.—Dominichnia burrows in ripple-marked surface of unit 89.

a free-swimming pectinoid bivalve, occur on bedding planes of carbonate units. Shell fragments of the pelecypods are generally replaced with sparry calcite, but some have also been pyritized (Pl. 4, fig. 3).

Gastropods.—Gastropods are restricted to the upper member of the section and are seen only in thin section (Pl. 4, fig. 3) or picked from the residue of prepared samples. Most of the specimens appear to be immature, for they are only 1 to 2 mm long, marine forms. Maturity is difficult to determine, however, due to the preservation as steinkerns. Differential sorting could explain the grouping of such small specimens as transportation concentrated a certain size material. No large forms of gastropods were found in the section. Because of the preservation even generic identification is impossible. Most of the specimens found are either high-spired, turritellid-like forms, planispiral, or low-trophospiral forms and probably were transported from a beach or near-beach environment by storm surges. Gastropods occur in units 53, 56, 62, 65, 66, 67, 73, and 79 and form between 5 and 10 percent of the fossil material.

Echinoid debris.—Echinoid material consists of spines (Pl. 3, fig. 3) and interambulacral plates. Identification of the echinoid material is difficult, owing to poor preservation and breakage. Identifying some material according to family is possible, and that identified belongs to either *Archaeocidaridae* or *Miocidaridae*. These families are characterized by long, slender, porous spines that have a slender collar, a milled ring, and a cupped base. The interambulacral plates of the specimens found are characterized by an accentuated, pore-bearing mamelon, a small areole area, and a ring of scrobicular tubercles. Outside of the scrobicular tubercles numerous miliary tubercles are present.

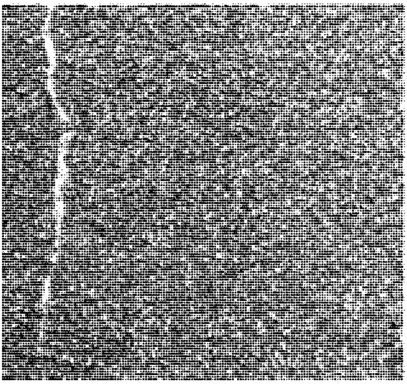
Pyritization has affected much of the echinoid debris, especially in units 53 and 66 where the spines are encrusted. Glauconite has partially replaced some of the echinoid spines in unit 65.

Crinoid debris.—Crinoid stem fragments are restricted to the upper member, usually occurring in carbonate units but with some occurrences in calcareous sandstone. All of the crinoid material appears to be *Pentacrinus* fragments, and most appears to be *Pentacrinus californicus* (Clark), a species characterized by abundant crenelli and an accentuated star-shaped columnal with a small circular lumen. Crinoidal fragments are generally moderately to poorly preserved, so that specific identification is possible only in the acid-etched residues. Only the initial starlike shape of the columnals is preserved in most specimens.

Other echinoderm material includes ophiroid vertebrae that occur in 5 of the carbonate units, but even their generic identification is made impossible by fragmentation and poor preservation.

EXPLANATION OF PLATE 3
PHOTOMICROGRAPHS

FIG. 1.—Thin section of characteristic fine-grained sandstone in unit 10, x10.
FIG. 2.—Thin section of characteristic siltstone, unit 89, x10.
FIG. 3.—Echinoid and pelecypod debris in unit 65, x10.
FIG. 4.—Coarse bioclastic debris in unit 67, showing replacement by sparry calcite, x10.
FIG. 5.—Interfingering of bioclastic material and the normal calcisiltite in unit 67, x5.
FIG. 6.—Pelletal calcisiltite in unit 81.



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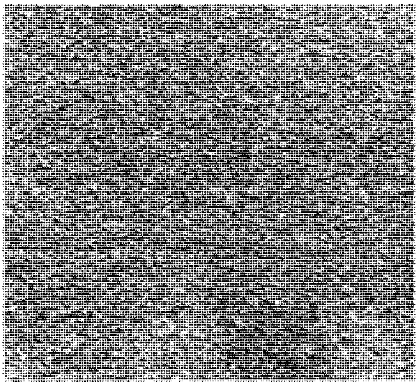

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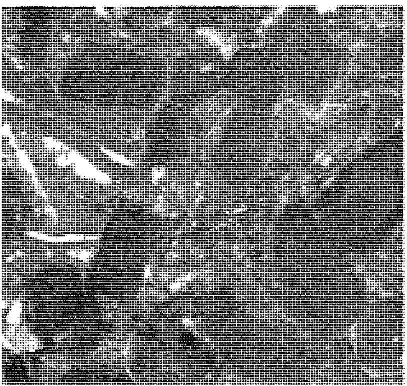

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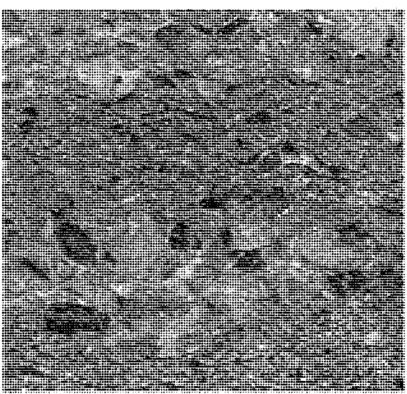

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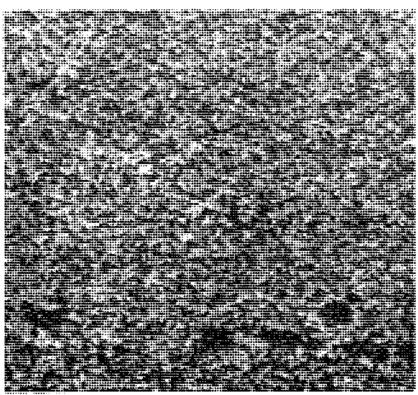

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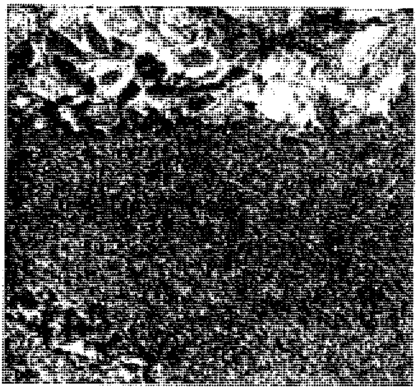
PLATE 3



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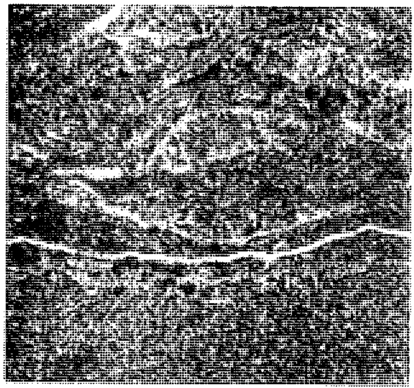

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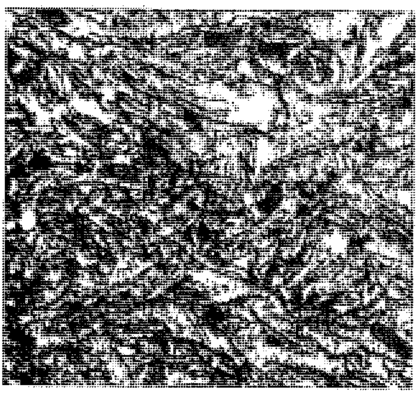

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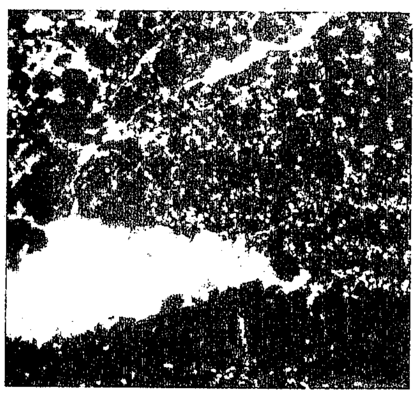

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PLATE 4

Ichnofossils

Ichnofossils and bioturbation are common in the formation, and they are usually the only evidence of organic activity in the clastic units, often having destroyed the bedding characteristics of those units. Feeding burrows (pascichnia and repichnia) (Pl. 2, figs. 1, 5) (Seilacher, 1964) are present throughout the section but are most common in the upper, more dominantly marine member. Dominichnia or dwelling burrows are also present but are restricted to the green siltstone and sandstone (Pl. 2, fig. 6). The lower member of the section is commonly bioturbated, but individual burrow types are not preserved. Burrows are commonly preserved in the coarse bioclastic layers (Pl. 4, figs. 1, 4). Some silicified burrows 1 to 2 mm in diameter were observed in residues etched from carbonate samples but were otherwise unidentifiable.

FOSSIL ASSOCIATIONS

Most of the fossil associations that occur in the section are death assemblages and therefore are not useful from an environmental standpoint (Boucot, 1953). These associations are concentrated in the coarse bioclastic layers in the carbonate units and are represented by disarticulated and broken pelecypod valves, gastropod shells, and broken echinoderm material. These fossils represent a variety of environments including epifaunal, infaunal, and sessile organisms. They also represent energy levels ranging from a high-energy, firm substrate environment for the echinoids to a lower energy environment for the crinoids and a soft substrate environment for the burrowing organisms. The sparry calcite infilling and replacement of shells shows transportation and winnowing away of the small-sized material, creating a void space, and the pyritization indicates rapid burial before the organic material was destroyed. In units 53, 55, 56, 62, and 67 *Pentacrinus* columnals were found up to 3 inches long; and *Pentacrinus* and *Aviculipectin* are associated in units 53 and 62, indicating similar environments for these two organisms.

INTERPRETATION OF SEDIMENTARY ENVIRONMENTS

Several general conditions are indicated and supported by evidence from the stratigraphic section for the paleoenvironment of the Thaynes Formation: (1) sediments have been deposited in a generally low-energy environment

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EXPLANATION OF PLATE 4
PHOTOMICROGRAPHS

FIG. 1.—Thin section showing placement of coarse bioclastic material over the eroded surface of normal calcisiltite of unit 67. Note burrow in lower left, x5.
FIG. 2.—Thin section showing the placement of coarse bioclastic material on eroded surface of the calcisiltite in unit 72, x5.
FIG. 3.—Coarse bioclastic material composed of pelecypod and gastropod debris in unit 84. Gastropod shown is approximately 1 mm long, x10.
FIG. 4.—Pascichnia burrow through the bioclastic material of unit 84, x5.
FIG. 5.—Pelecypod and gastropod debris in bioclastic material of unit 84. Note the abundance of sparry calcite and smaller size of bioclastic material when compared to Fig. 3, x10.
FIG. 6.—Oolites in unit 98. Note vug in lower left filled with sparry calcite, x10.

and in fairly shallow water; (2) the hypothetical Triassic equator was approximately 5° south of the area of deposition (Dott, 1971), and therefore the climate was probably warm; and (3) because of the position of the equator, the area of deposition was subjected to westerly and southwesterly wind cells that would influence current directions in the formation to a certain extent.

All of the environments represented in the formation were affected by the preceding conditions, and these conditions will be used to interpret the various environments. Three main environments are envisioned in the section: (1) tidal flat, including tidal-channel material, (2) subtidal, and (3) open marine (Text-fig. 6).

Tidal Flat

The tidal-flat sediments are concentrated in the middle member of the section and are also shown by red siltstone and shale in the upper member (Text-figs. 5, 6). This environment in the section is represented by the terrigenous red siltstone and shale. These units are characterized by asymmetrical ripple-marked layers overlying the imbricate cross-bedding of previous sets of ripple marks, and these structures show a bimodal southeast-northwest current direction (Text-fig. 7). This bimodal current direction corresponds to the fluctuations of tidal currents in and out over the tidal flat. Associated with these ripple marks are raindrop imprints, which indicate subaerial exposures—as does the red color of the beds, which is caused by the oxidation of the iron content of the sediment. The "teepee" structures present in the section also indicate a subaerial environment, a prerequisite for the formation of salts.

Deposition and current directions indicated are related to three things: (1) wind directions, (2) long-shore currents, and (3) shoreline configuration. The dominant trend of the depositing current, shown by the ripple marks, is to the southeast, with a minor trend to the northwest. McKee (pers. comm., 1973) and Rigby (pers. comm., 1974) indicate that outgoing tides leave the dominant ripple marks. This observation applied to ripple marks in the section indicates that a factor other than tidal drain is the main control of deposition because the postulated shoreline lies downcurrent to the southeast (Text-fig. 2). The shoreline configuration at this time may have been such that ingoing tides were to the northwest and the outgoing tides to the southeast. Further work is needed to determine the shoreline topography.

Tidal channels (?) are postulated in several places (units 12, 14, 25, 87, and 88) in the section. These occur as thin beds of light red sandstone 2 to 6 feet thick (Pl. 1, fig. 2) and are associated with red siltstone units. These sandstone beds are commonly bioturbated, and bedding characteristics are destroyed, with the exception of some foreset bedding in unit 14 and some ripple marks in unit 25.

Regression to a tidal-flat environment occurs often in the upper marine member with the appearance of red siltstone and shale that exhibit characteristics previously discussed.

Subtidal Environment

Marginal marine or subtidal environments are represented in the section by fine-grained, green clastic beds in both the lower and upper members. These units generally occur interbedded between a red siltstone and a carbonate unit (Text-fig. 5) and indicate either partial transgression from the tidal-flat environment or the beginning or end of a transgressive phase of deposition.

The green color of these units indicates reduction of iron such as occurs in subaqueous conditions. All but two of these green clastic units are calcareous. These units are commonly ripple marked, again showing a general southeast trend of deposition. Ripple marks in these units tend to be better formed than those in the red beds and have a superficial symmetrical shape.

The energy in this environment was quite low, as indicated by much matrix and by the trace fossils present. Double pascichnia-type trails are found, and crinoid columnals are present in several units and indicate a low-energy, muddy-type substrate (Smith, 1969). Dominichnia, or dwelling burrows, are also common and indicate a subaqueous low-energy environment. Deposits of this environment are deleted several times where they might be expected in the section (Text-fig. 6), and tidal-flat deposits occur directly on marine units. Environmental characteristics here are similar to those described in the offshore-shoreface environment by Howard (1972, p. 218). The dominant directional structures were probably produced by wind-driven and longshore currents. Much of the bedding in these rocks has been destroyed by bioturbation, leaving only ripple marks (both current and megaripples). These units are important elements in the normal depositional cycles resulting from regressive-transgressive deposition.

Marine

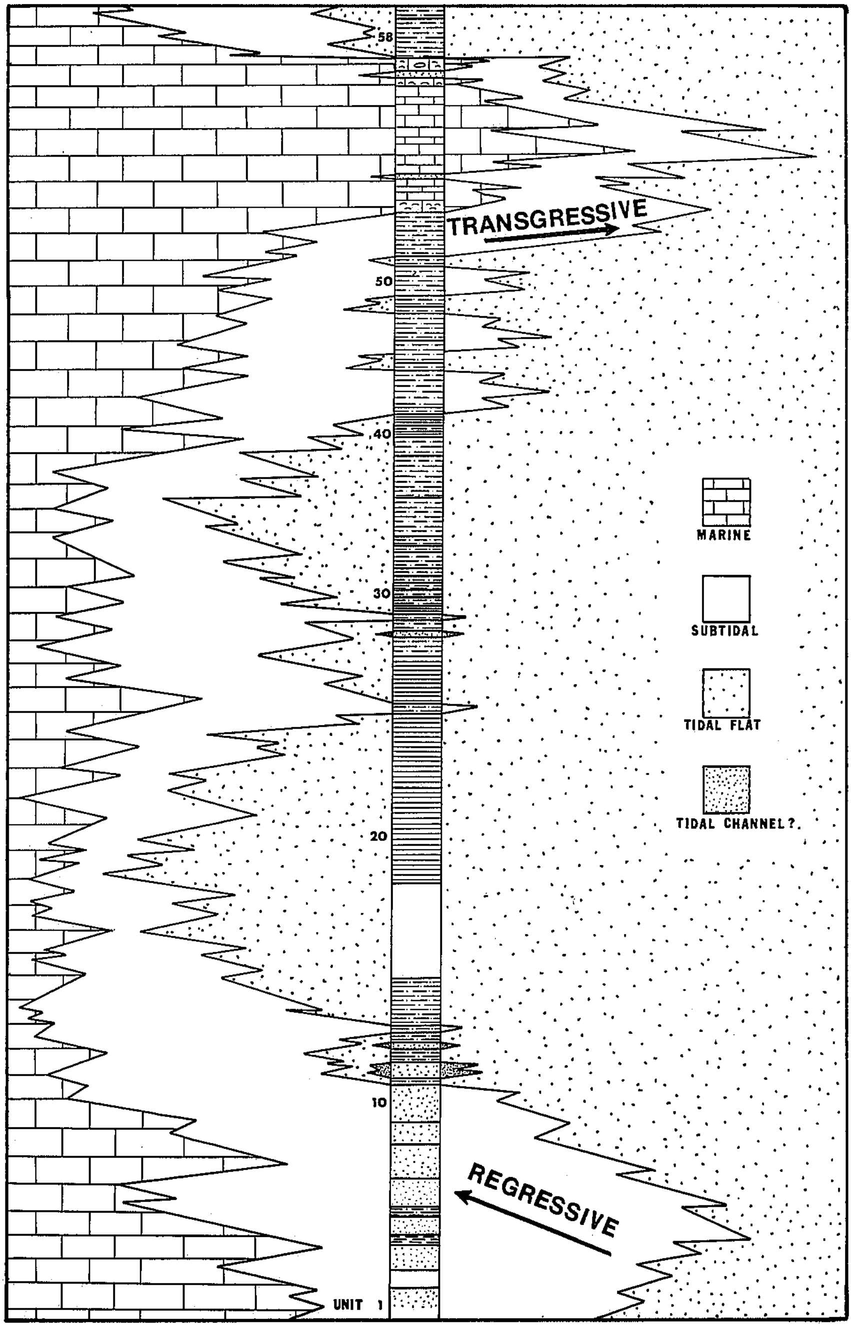
Transgressive marine units dominate in the upper member of the formation and indicate a low-energy, shallow, warm-water marine environment. The carbonate material is quite sandy (10 to 20 percent), indicating that currents were still close enough to shore to carry clastic material and to produce ripple marks, cross-bedding, and flute casts. (Pl. 2, fig. 4).

The rocks were deposited in a low-energy environment, as indicated by laminate fine bedding and fine-textured material. All the marine carbonate units have layers of coarse bioclastic material that suggest deposition by high-energy surges such as storms, which intermittently affected a normally low-energy environment. Coarse bioclastic material is found only at the bottom or the top of the carbonate units and would indicate that the material was deposited while water depth was shallow enough for storm activity to effectively transport, winnow, and deposit the material over an eroded surface on the fine-grained sediments (Pl. 4, fig. 1). This is also suggested by the occurrence of coarse layers immediately over, or just beneath, subtidal units when transgression or regression was rapid and water depth shallow. The middle part of all carbonate units lacks the coarse bioclastic layers and indicates deposition in a deeper, quieter environment.

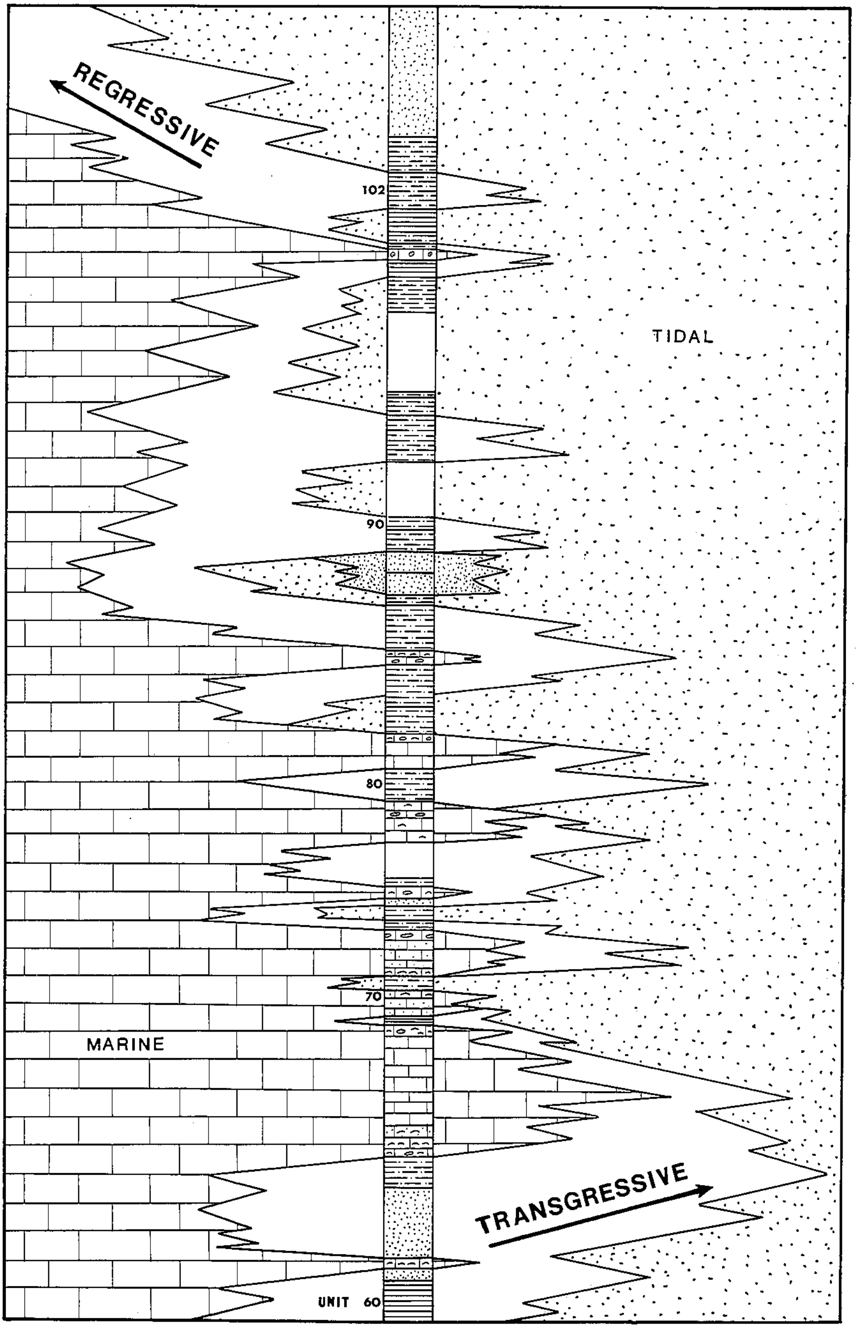
Marine units have only sparse fossils outside of the bioclastic layers, and most of these are crinoid columnals and free-swimming pectins such as might be expected in calm water. Many of the marine units are burrowed by benthonic organisms and show pascichina and repichnia feeding burrows in the organic rich, muddy substrate.

SEDIMENTARY MODEL

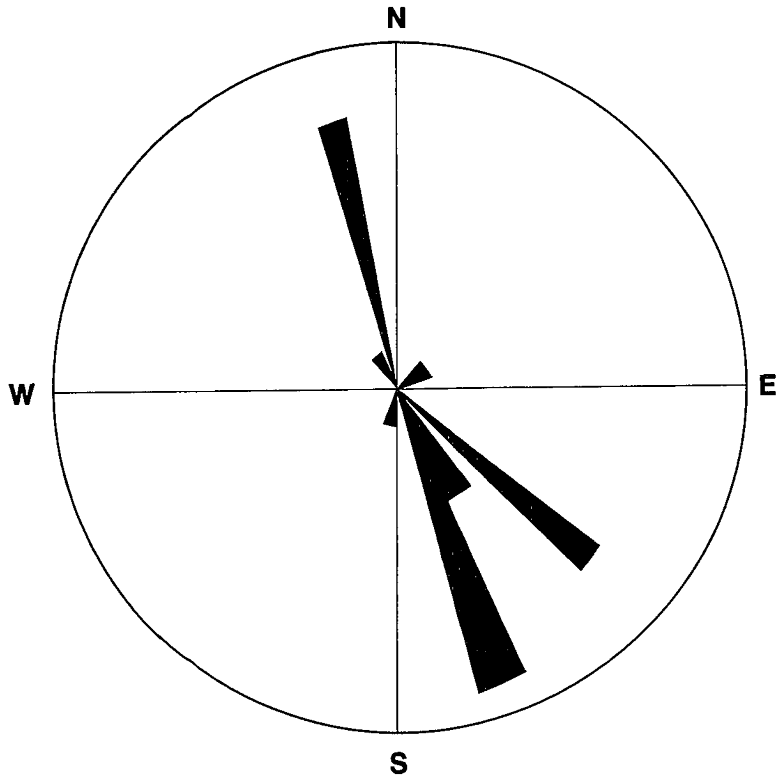
The Thaynes Formation was deposited in a stable environment of deposition with a generally low-energy index. Shallow, warm marine or subaerial tidal-flat conditions prevailed, and most of the sedimentation occurring in the area was allocyclic (Beerbower, 1964, p. 32). Clastic deposition dominates in the section, the clastic-carbonate ratio being 5 to 1; and because clastic sedi-



TEXT-FIGURE 6.—Rock units in studied section showing repetition of environments



and transgressive-regressive sequences in the formation.



TEXT-FIGURE 7.—Composite rose diagram of current directions in the stratigraphic section. The main southeast current is shown with a minor northwest current indicating bimodal directions of deposition.

ments were derived from a low-relief source area (McKee et al., 1959, p. 24), most of the clastic material is characteristically fine grained.

The dominantly marine and subtidal lower member of the section transgressed over the tidal-flat material of the Woodside Shale as basin subsidence became faster than the rate of sedimentation. Such a development produced a shift from the red beds of the Woodside to subtidal green clastic beds and marine units of the lower Thaynes Formation. As subsidence slowed or as sedimentation accelerated, regression again occurred, and deposits grade from open marine into subtidal material. As regression continued, the subtidal beds of the lower member became interbedded with tidal-flat red beds showing a series of mixed environments. With total regression the terrigenous tidal material prograded seaward as described by Lucia (1972) in his shoreline model, resulting in the middle tidal-flat member of the formation.

In the upper member subsidence again accelerated and transgression occurred with the deposition of subtidal and marine units over the tidal-flat material of the middle member. These marine units represent warm, shallow, low-energy waters showing occasional storm activity in the coarse bioclastic material. Clastic deposition still dominated in the transgressive phase of the upper member, but most of the clastic material is of subtidal environment.

Gradual gradation into the tidal-flat material of the overlying Ankareh Formation shows a second period of major regression of the Triassic sea. This last regression is probably connected to the end of the Cordilleran miogeosyncline in Lower Triassic time.

CONCLUSIONS

The Thaynes Formation represents two major marine transgressions and regressions in the Lower Triassic. The regressions are characterized by the thick tidal-flat red beds of the Woodside Shale, the middle member of the Thaynes and the Ankareh formations. The transgressive sequences were characterized by warm, shallow seas and by the deposition of subtidal, fine-grained clastic material and open-marine carbonate units. These marine transgressions were the last marine material deposited in this part of the Utah miogeosyncline (Hintze, 1973, p. 54) before destruction of the Cordilleran miogeosyncline.

The lithologic relations, sedimentary structures, and fossil associations found in the Thaynes Formation will be useful as indicators of shelf sequences in outcrop and subsurface interpretation.

APPENDIX

Stratigraphic section measured along the Midway-Cascade Springs road. The section was started in a large U-shaped bend in the road above Decker Spring and approximately one mile from the pass, and ends at the top of the formation in the pass.

Unit	*Description*	*Feet/ Unit*	*Total Feet*
104	Sandstone: red to red brown; very fine to fine grained; noncalcareous; massive to thin bedded; well sorted, good porosity; subangular grains; trough-shaped cross-beds; mottled surface; burrowing in places.	52	710.91
103	Siltstone: red to purple; noncalcareous; ripple marks; small sandstone lenses; green; very fine grained, well sorted; bimodal current.	9.33	658.91
102	Siltstone: green; weathers pink to brown; noncalcareous; salt-and-pepper surface; calcite veins; thin bedded; bioturbated.	9.5	649.58
101	Shale: red to purple; silty; well to moderately sorted; noncalcareous; finely laminated; ripple marked; grades to green color at top; gradational contact with lower unit.	5.75	640.08
100	Siltstone: green; weathers pink to brown; massive; calcareous; vuggy; moderately sorted.	2.75	634.33
99	Siltstone: green; weathers brown; salt-and-pepper surface; fair sorting; thin bedded; noncalcareous; outcrop badly broken up; sandy.	1.33	631.58
98	Limestone: white to green; chalky; soft, crumpled beds; oolitic.	2.5	630.25

97	Shale: red to green; silty; thin bedded; noncalcareous; contorted beds; finely laminated; forms slope; ripple marks; bimodal current.	4	627.75
96	Claystone: red to purple, some green lenses; well sorted; noncalcareous; appears ripple marked; forms slope; bimodal current.	9	623.75
95	Covered: appears to be red siltstone or fine-grained sandstone.	21	614.75
94	Siltstone: green; slightly calcareous; fair to well sorted; salt and pepper surface; fore-set cross-beds; bimodal current; bioturbated in parts.	1.5	593.75
93	Siltstone: red to purple; well sorted; noncalcareous; slope former; small sandstone lenses, green, slightly calcareous.	4.33	592.25
92	Siltstone: green; calcareous; irregular, badly broken beds; calcite veins; small vugs; salt and pepper surface; sandy; burrowed.	12	587.92
91	Covered: appears to be red siltstone or fine-grained sandstone.	15	575.92
90	Siltstone: green, weathers brown; thin bedded; well sorted; irregular bedding; fine cross-beds; small shaly beds.	2.5	560.92
89	Siltstone: green; calcareous; well sorted; irregular bedding surfaces; ripple marks, minor ripples and megaripples.	5.5	558.42
88	Sandstone: red; calcareous; very fine grained; well sorted; subangular to subrounded grains; irregular bedding; bioturbated.	6	552.92
87	Sandstone: red to light red brown; thin bedded; calcareous; vugs with calcite filling; some siltstone lenses; gradational contact with lower unit.	5.5	546.92
86	Siltstone: red to purple; thin bedded; noncalcareous; well sorted; slope former; some sandstone lenses.	2.5	541.42
85	Siltstone: green; noncalcareous; very fine grained; vugs with calcite filling; soft; ripple marks; fossiliferous at top; burrowed.	11.5	538.92
84	Limestone: light brown to brown gray; massive; sandy; bioclastic layer at tip, chert associated with fossil material, weathers vuggy.	3.5	527.42
83	Siltstone: red to purple, green at top; noncalcareous; thin bedded; some sandstone lenses; brown to red, fine grained; noncalcareous; well sorted.	11	523.92
82	Siltstone: green; calcareous; thin bedded; good to fair sorting; some sandstone lenses.	7	512.92

81	Limestone: gray to dark gray; massive; fine to medium crystalline; vuggy from weathering; sandy; bioclastic layer in top; cherty; upper surface burrowed.	8.5	505.92
80	Siltstone: green; thin bedded; very calcareous; sandy; some sandstone lenses, green, very fine grained.	8	497.42
79	Limestone: light gray; medium crystalline; massive; weathers vuggy; fossiliferous; cherty.	11	489.42
78	Covered: probably siltstone or shale.	9	478.42
77	Siltstone: green; noncalcareous; thin bedded; sandy; slope former; small vugs; small sandstone lenses, green, noncalcareous, fossiliferous (bivalves).	2	469.42
76	Limestone: gray to gray brown; massive; bioclastic layer in top; chert nodules and infillings of burrows; fine to medium crystalline.	2.75	467.42
75	Sandstone: brown, weathers light brown; fine grained; noncalcareous; well sorted; ripple marks; bioturbated.	2	464.67
74	Siltstone: purple to light brown green; noncalcareous; thin bedded; well sorted; slope former.	3.5	462.67
73	Siltstone: green; noncalcareous; thin bedded; well sorted; gradational contact with above unit.	1.5	459.17
72	Limestone: light gray to light brown; very sandy; thin bedded and becomes massive; bioclastic layer at base of unit; fossiliferous; chert nodules; weathers vuggy; small conglomerate layer.	11.5	457.67
71	Siltstone: red to purple; thin bedded; noncalcareous; small sandstone lenses.	3.75	446.17
70	Limestone: gray; fine crystalline; thin bedded; very sandy; irregularly bedded; fossiliferous; some small sandstone lenses.	2	442.42
69	Limestone: gray to light gray; sandy; fine crystalline; some foreset bedding in mid unit.	4	440.42
68	Shale: green; silty; calcareous; slope former; weathers light green.	2	436.42
67	Limestone: gray to dark gray; weathers brown; sandy; finely crystalline; thin bedded; weathering has caused vugs; bioclastic layer at top; fossiliferous (pectins, crinoids); burrowed.	27	434.42
66	Limestone: dark gray; sandy; weathers to brown sandy surface; thin bedded; fossiliferous; finely crystalline.	2.5	407.42

65	Limestone: gray to dark gray; thin bedded; bioclastic layer at top; fossiliferous; chert nodules.	5	404.92
64	Siltstone: dark gray; massive; cross-bedded; irregularly bedded; weathers brown.	8	399.92
63	Sandstone: green to green brown; very fine grained; burrowed; finely laminated; very calcareous.	19	391.92
62	Limestone: dark gray; weathers brown; massive; fine to medium crystalline; fossiliferous.	2.25	372.92
61	Sandstone: light brown; noncalcareous; very fine grained; thin bedded; bioclastic layer at top; fossiliferous.	2.5	370.67
60	Shale: green; noncalcareous; flute casts; finely laminated; irregular bedding; small micritic lenses.	13	368.17
59	Siltstone: olive brown; micritic texture; thin bedded; shaly, minor shale lenses; sandy in parts; flute casts in top.	6.33	355.17
58	Siltstone: brown to buff; thin bedded; calcareous; laminated; irregular bedding; vuggy; cross-bedding.	11	348.84
57	Limestone: gray to brown; massive; fine to medium crystalline; weathers vuggy; some fossil material; chert nodules.	3.5	337.84
56	Sandstone: light brown; calcareous; very fine grained; laminated; some fossils (*Pentacrinus*).	.5	334.34
55	Limestone: dark gray; massive; fine crystalline bioclastic layer at top of unit; fossiliferous (*Pentacrinus*); vuggy; upper unit sandy and burrowed.	32	333.84
54	Sandstone: yellow green; noncalcareous; soft; blocky; contact with above unit unconformable.	1.75	301.84
53	Limestone: gray to bluish gray; massive; weathers to buff; bioclastic layer at base; fossiliferous; coarse crystalline; some burrowing.	24	300.09
52	Siltstone: olive green; sandy; noncalcareous; thin bedded; finely laminated; ripple marked.	10.5	276.09
51	Siltstone: buff; slightly calcareous; irregular bedding; calcite veins.	3	265.59
50	Siltstone: red to red brown; thin bedded; calcareous; vuggy; finely laminated; green at top.	7.5	262.59
49	Siltstone: gray; weathers brown to green; thin bedded; ripple marked; noncalcareous; sandy.	3.5	255.09

48	Siltstone: green; sandy; slightly calcareous; thin bedded; ripple marked; limonite.	1.33	251.59
47	Siltstone: green to red; very calcareous; thin bedded; finely laminated; ripple marked; small sandy lenses; vuggy; some fossil material; limonite.	6.57	250.26
46	Siltstone: green; slightly calcareous; thin bedded; ripple marked; irregular bedding surface.	7	243.51
45	Siltstone: red to green; varicolored in places; thin bedded; ripple marked; gypsiferous.	2	236.51
44	Siltstone: green, calcareous; thin bedded to massive; ripple marked; sandy.	9.5	234.51
43	Siltstone: red to green; calcareous; finely laminated; unconformable contact with above unit.	1.6	225.01
42	Shale: purple; noncalcareous; finely laminated; slope former.	2	223.41
41	Claystone: red to green; noncalcareous; massive; slope former.	1	221.41
40	Shale: red; noncalcareous; micacious; finely laminated; slope former.	1.5	220.41
39	Siltstone: red; calcareous; gypsiferous; vuggy; laminated.	4	218.91
38	Siltstone: red to purple; slightly calcareous; finely laminated; small sandstone lenses; some ripple marks.	11	214.91
37	Siltstone: red; calcareous; sandy; slope former; gradational contact with above.	10	203.91
36	Siltstone: purple; thin bedded; slightly calcareous; ripple marks; gradational contact with above unit; bimodal current directions.	2.5	193.91
35	Siltstone: red; thin bedded; noncalcareous; sandy; slope former.	1.5	191.41
34	Siltstone: red; calcareous; massive; gypsum crystals; vuggy; gradational contact with above unit.	4	189.91
33	Siltstone: red to purple; noncalcareous; thin bedded; finely laminated; gradational contacts.	2	185.91
32	Siltstone: red; noncalcareous; thin bedded; finely laminated; small foreset crossbeds.	.75	183.91
31	Claystone: red; calcareous; massive; soft, slope former; interfingers with unit 30.	1.33	183.16
30	Siltstone: red to green at top; thin bedded; flute casts; slightly calcareous; finely laminated; micacious; teepee structures; bimodal currents.	1	181.83
29	Siltstone: red; calcareous; thin bedded; ripple marks; slope former.	1.33	180.83

28	Shale: red to purple; noncalcareous; massive; slope former.	1	179.5
27	Siltstone: green; thin irregular bedding; sandy; calcareous.	.25	178.5
26	Siltstone: red to purple; thin bedded; calcareous; finely laminated; slope former.	2.25	178.25
25	Sandstone: green; very fine grained; calcareous; thin bedded; ripple marked.	.5	176
24	Siltstone: red to purple; slightly calcareous; slope former.	4.5	175.5
23	Shale: red to red brown; noncalcareous; ripple marked; slope former.	10.5	171
22	Shale: green; noncalcareous; slope former.	1.5	160.5
21	Siltstone: green to yellow green; noncalcareous; thin bedded; sandy; finely laminated.	2	159
20	Shale: red to purple; silty; noncalcareous; siltstone lenses at top.	19	157
19	Shale: red to purple; calcareous; thin bedded; small siltstone lenses; slope former.	25	138
18	Covered: probably red siltstone or shale.	37	113
17	Siltstone: red; calcareous; thin bedded; sandy; some sandstone lenses at top.	13	76
16	Siltstone: red; calcareous; blocky; sandy; finely laminated.	.5	63
15	Siltstone: red to purple to green; slightly calcareous; thin bedded; some gypsum crystals; ripple marked; small sandstone lenses.	2	62.5
14	Sandstone: red to red brown; very fine grained; slightly calcareous; massive; minor cross-bedding; calcite vugs; burrowed in upper part.	1.5	60.5
13	Siltstone: red to purple; noncalcareous; some gypsum crystals; ripple marked; calcite vugs.	2.75	59
12	Sandstone: red to pink; very fine grained; slightly calcareous; massive; well sorted; small vugs.	4.25	56.25
11	Siltstone: red; calcareous; finely laminated; slope former; gradational contact with above unit.	1.5	52
10	Sandstone: yellow to tan; very fine grained; calcareous; massive; well sorted; foreset cross-beds.	9	50.5
9	Sandstone: light gray to white; weathers brown; calcareous; very fine grained; well sorted; thin bedded; calcite veins; small shale lenses.	5.5	41.5

8	Sandstone: brown; massive; calcareous; fine grained; well sorted; some cross-bedding; soft.	8	36
7	Sandstone: brown to gray; calcareous; well sorted; massive; very fine to fine grained; laminated trough cross-bedding; large-scale foreset cross-beds.	7	28
6	Siltstone: green; calcareous; sandy; lenticular beds; slope former.	2.25	21
5	Sandstone: gray to brown; weathers brown; very fine grained; calcareous; well sorted; thin bedded.	4.5	18.75
4	Claystone: green; massive; silty; slightly calcareous; small sandstone lenses; some gypsum.	2.75	14.25
3	Sandstone: brown; weathers light green; very fine grained; lenticular beds; well sorted; calcareous; ripple marked (megaripples); massive in places.	6.5	11.5
2	Covered: probably green siltstone.	4	5
1	Sandstone: brown; weathers light green; fine grained; ripple marked; silty; calcareous; thin bedded.	1	1

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