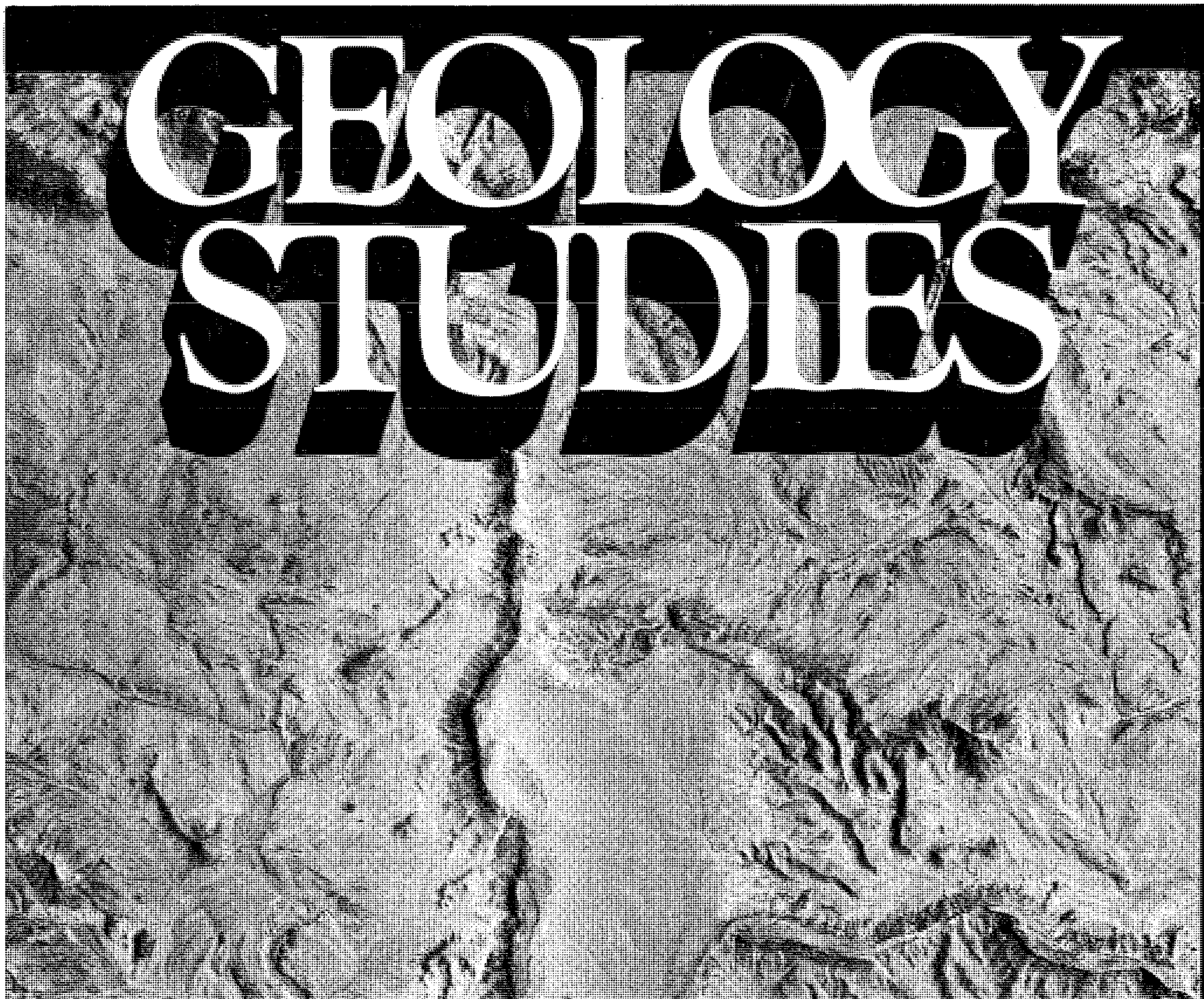
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



VOLUME 27, PART 1

AUGUST 1980

BRIGHAM YOUNG UNIVERSITY GEOLOGY STUDIES

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THE GLORY OF GOD IS INTELLIGENCE

Cover: Aerial photograph showing exhumed stream paleochannels in the Cedar Mountain Formation near Green River, Utah. Courtesy Daniel R. Harris.

A publication of the

Department of Geology

Brigham Young University

Provo, Utah 84602

Brigham Young University Geology Studies is published 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.

ISSN 0068-1016

Distributed August 1980

8-80 600 43937

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Paleoenvironments of the Lower Triassic Thaynes Formation near Diamond Fork in Spanish Fork Canyon, Utah County, Utah*

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ABSTRACT.—Cyclic sediments of the Thaynes Formation in the southern Wasatch Mountains of central Utah, with a total thickness of 359 m, represent a prograding sequence of lower to upper Spathian (late Early Triassic) time. Conodonts in the Thaynes Formation help date the section.

Marine, subtidal, intertidal, and supratidal sedimentary environments are represented in the Thaynes Formation. The lower portion of the Thaynes Formation is dominated by rocks of marine to subtidal environments, with high proportions of limestone and green siltstone. The middle portion of the formation is principally red and green sandstone and siltstone which were deposited in subtidal to intertidal flat environments. The upper part is dominated by red sandstone and a few algal limestones and was deposited in intertidal flats to supratidal environments.

Ripple marks and cross-bed sets are fairly common in the clastic units and indicate a dominant ebbflow of tidal currents toward the northwest. Burrows and a variety of other trace fossils—including pascichnia, repichnia, and domichnia, together with scattered occurrences of foraminifera, sponges, brachiopods, bivalves, gastropods, echinoids, crinoids, ostracodes, fish, and conodonts—indicate intertidal to normal marine conditions.

Cyclic repetition of lithology is representative of minor transgressions and regressions superimposed upon the regional upward regression of the Thaynes Formation. This regression marks the destruction of the Cordilleran miogeosyncline in Lower Triassic time.

INTRODUCTION

Outcrops of the Lower Triassic Thaynes Formation in Utah are largely restricted to the Wasatch Mountains and the western end of the Uinta Mountains although thin, discontinuous outcrops occur elsewhere. In Utah, the formation attains a maximum reported thickness of more than 738 m (Smith 1969) in the lower Weber Canyon area, 40 km northeast of Salt Lake City but thins moderately rapidly to the south and east. Its reported thickness in the study area is 351 m (Young 1976). It grades into the Moenkopi Formation in the Uinta Mountains and southward where it becomes more continental. The Thaynes Formation is mostly composed of interbedded limestone, siltstone, shale, and mudstone which were deposited in open marine to tidal flat environments (Kummel 1954, p. 460–61).

On a regional scale, the Thaynes Formation was deposited in a more miogeosynclinal environment in the northern Wasatch Mountains, as opposed to a more nearshore to shelf environment south and east (Clark 1957, p. 2196–97). This kind of deposition is indicated by increasing continental red bed sequences in these directions. The Thaynes sediments mark the last marine transgression into the Cordilleran miogeosyncline before its destruction during the Early Triassic. The thickest section of the Thaynes Limestone crops out near Fort Hall, Idaho. A euxinic, black shale basin existed in that area during several pulses of Thaynes deposition. The formation also crops out in southwestern Montana, much of eastern Idaho, and western Wyoming.

This study was undertaken to develop a model to demonstrate the more continental nature of the southwesternmost outcrop of the Thaynes Formation, as well as to show the relationships of lithology, sedimentary structures, paleontology, and paleocurrent directions as they apply to this model.

Location

The study area is located in Spanish Fork Canyon, approximately 32 km southeast of Provo, Utah, in sections 16 and 17, T. 9 S, R. 4 E, on the Spanish Fork Peak and Billies Mountain 7.5-minute quadrangles, in Utah County, Utah. The area is easily accessible from the east and west via U.S. 6 and 50 from Price or from Springville and Spanish Fork (fig. 1). The study concerns outcrops along this highway and along the county road which leads northeastward along Diamond Fork. These outcrops total 297 m in thickness, approximately half of which are covered slope. The lower 62 m of the formation were not studied because of poor exposure.

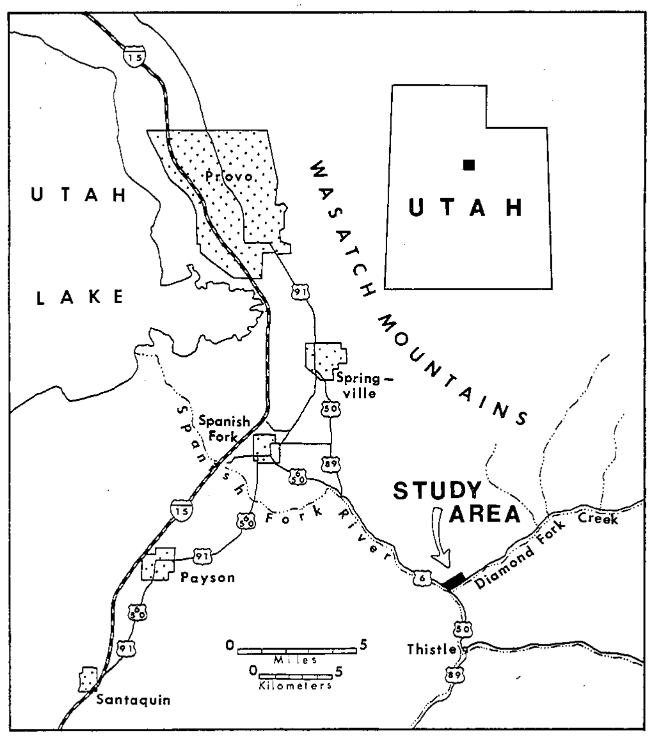


FIGURE 1.—Index map of study area.

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, August 1979. Thesis chairman: J. Keith Rigby.

Geologic Setting and Stratigraphy

The Uncompahgre Uplift, a late Paleozoic to Triassic positive area southeast of the study area, probably supplied most of the terrigenous sediments to form the rocks of the Thaynes Formation (Kummel 1954, p. 443, and Hintze 1973, p. 57). The depositional area of Thaynes beds was along the eastern margin of the Cordilleran miogeosyncline, a sinking trough which existed from the Cambrian. Interbedded marine and nonmarine units of the Thaynes Limestone mark the last phase of miogeosynclinal behavior, for the trough was destroyed in the Middle to Late Triassic. Continental strata overlie these partially marine beds.

The Thaynes Formation is gradationally underlain by the Dinwoody Formation or Woodside Shale of Lower Triassic age in northeastern and central Utah. Thaynes beds are conformably overlain, and in places interfinger, with the Ankareh Shale of Middle to Late Triassic age (Kummel 1954, p. 451) (fig. 2). Thaynes rocks are laterally equivalent to the Moenkopi Formation of southern and eastern Utah. Rocks of this age are missing because of erosion over much of western Utah although Thaynes Limestone has been recognized locally (Clark 1957, p. 2198).

The Thaynes Formation, in outcrops in the study area and other parts of north central Utah, is divided into three members, all of which are equivalent to the sandstone-limestone facies of Kummel (1954) in southeastern Idaho. These three more southern members are: (1) a lower sandstone-limestone-siltstone member, (2) a middle red silty member, and (3) an upper siltstone-limestone member.

Five ammonoid zones have been recognized in the Thaynes beds (Smith 1932, Siberling 1968) and allow correlation with Triassic rocks of areas outside Utah. These zones, from the base up, are as follows: (1) *Meekoceras,* (2) *Anasibirites,* (3) *Tirolites,* (4) *Columbites,* and (5) *Prohungarites.* The *Meekoceras* zone defines the base of the Thaynes in southeastern Idaho but occurs about 90 m above the base in the Wasatch Mountains of north central Utah (Clark 1957, p. 2213). This zone was not noted in the study area although *Meekoceras* has been reported from here. The well-exposed rocks of the study section probably include beds equivalent to the *Tirolites* through *Prohungarites* zones although the ammonoids which mark these zones were not found in the study area.

Seven conodont zones have been recognized recently in the Thaynes Formation of the Wasatch Mountains east of Salt Lake City, Utah (Solien 1979, p. 284). These zones are, from the base up, as follows: (1) *Furnishius,* (2) *Parachirognathus–Furnishius,* (3) *Parachirognathus,* (4) *Neogondollela milleri,* (5) *Platyvillosus,* (6) *Neospathodus collinsoni,* and (7) *Neogondollela jubata.* They represent zones 6 through 12 of 13 conodont zones recognized in different parts of the world as representative of the Lower Triassic (Scythian).

The first conodont zone (Range Zone 7A of Solien) recognized in the Thaynes Formation near Salt Lake City occurs about 16 m above the base of the Thaynes beds and therefore does not define its lower boundary. However, Range Zone 9 of Solien (*Neogondollela milleri*) does define the upper limit of the Smithian Stage. It also marks the extinction of 11 conodont species, while Range Zone 10 (*Platyvillosus*), which marks the base of the Spathian Stage, is based upon the appearance of 7 new species (Solien 1979, p. 294).

While the first occurrence of *Platyvillosus costatus,* together with *Neospathodus triangularis, Neospathodus homeri,* and *Neogondollela jubata,* is considered by Sweet and others (1971) to mark the base of Range Zone 10, and hence the base of the Spathian Stage in North America, Solien (1979) considers the presence of *Neospathodus triangularis* alone to mark the base of Range Zone 10 in the Wasatch Mountains near Salt Lake City. In this area *N. homeri* and *N. jubata* occur later than *N. triangu-*

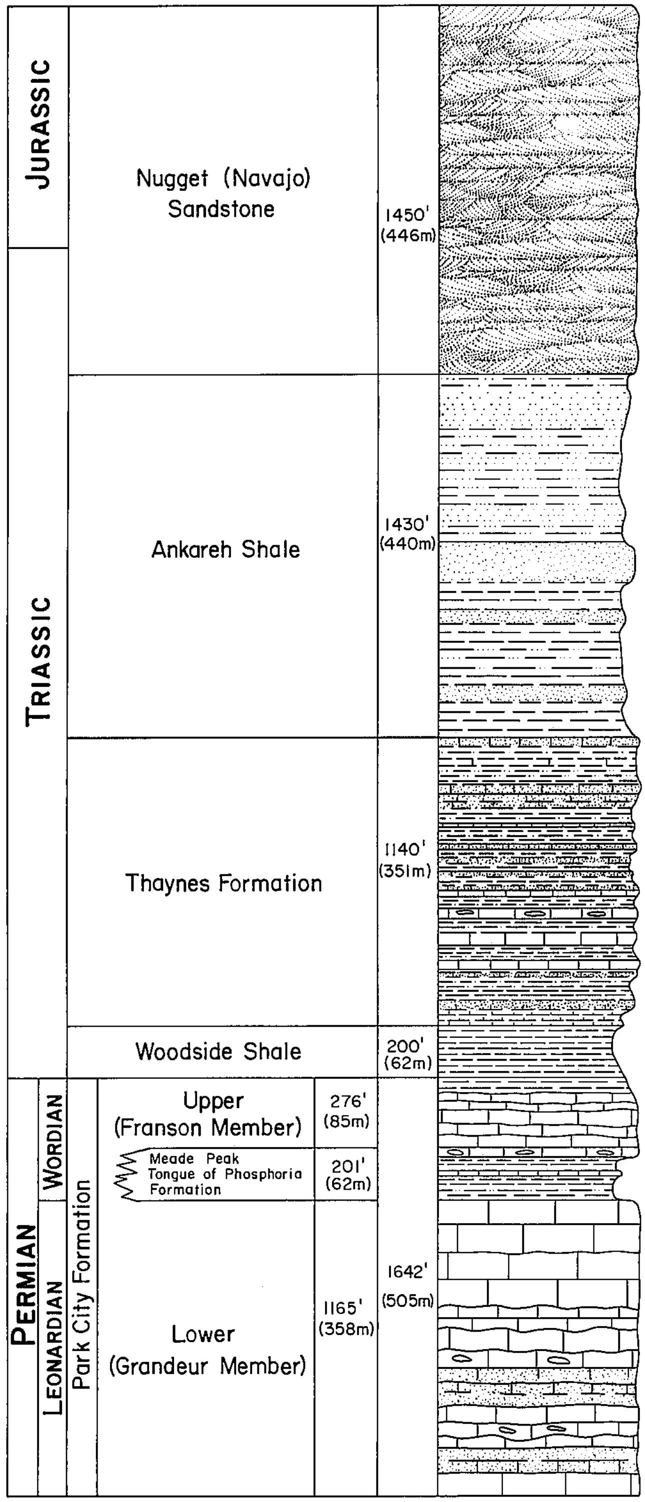


FIGURE 2.–Stratigraphic column showing relationships of Thaynes Formation to associated formations in Spanish Fork Canyon.

laris, and *P. costatus* does not occur but is replaced by *Platyvillosus asperatus,* which appears in the middle of Range Zone 10.

Three of the lowermost limestone beds in the measured section of the study area contain the *Platyvillosus asperatus* (Clark and others 1964) fauna which is distinctive of the upper half of Range Zone 10 of the Lower Triassic of Solien (1979, p. 294). The fauna occurs from 5.7 to 9.1 m above the base of the measured section, or approximately 67.7 m from the base of the Thaynes Formation in the study area. This is in contrast to its occurrence 256 m above the base of the Thaynes Formation east of Salt Lake City (Solien 1979, p. 294). *P. asperatus* (Clark and others 1964) therefore probably defines the upper limit of Range Zone 10 in the study area as about 71.1 m above the base (fig. 3).

Neospathodus homeri (Bender 1967?), which first occurs 279 m above the base of the Thaynes in Solien's Salt Lake section, is common in the upper one-fourth of Range Zone 10, plus all of Range Zone 11, and the lower two-thirds of Range Zone 12 (Solien 1979, p. 295). Lowest noted occurrence of this conodont is in unit 61 in the Spanish Fork section, 24.6 m above the base of the measured section, but it may occur below that point since no units between unit 31 and unit 61 were sampled for conodonts (fig. 3). The presence of *N. homeri* (Bender 1967?) in unit 61 is possibly indicative of Range Zone 11. No diagnostic conodonts were found to indicate the boundary between Range Zones 11 and 12. This lack may be attributed to an almost complete absence of clean carbonates above unit 139.

On the basis of the occurrence of *Platyvillosus asperatus* (Clark and others 1964) at the base of the described section in the study area and the presence of *N. homeri* (Bender 1967?), it may be concluded that the rocks representative of the Thaynes Formation there are of the Spathian Stage (upper Scythian) of the Lower Triassic (fig. 3).

Previous Work

The Thaynes Formation was named by Boutwell (1907, p. 448) after Thaynes Canyon in the Park City mining district, 121 km north of the study area. However, because the Thaynes Canyon exposures are largely faulted, intruded, or metamorphosed, a better-preserved section on the north side of Big Cottonwood Canyon, 5 km to the west, was used to describe the formation, and it is here at the type section that the Thaynes beds are 366 m thick. Boutwell (1907, p. 448) noted three major lithologic units within the Thaynes Formation: a lower limestone-sandstone-shale sequence, a middle red shale member, and an upper member principally made up of calcareous sandstone and limestone.

Although the Thaynes Limestone was initially dated as Permian (Boutwell 1907, p. 450), Boutwell later (1912) placed the formation within the Lower Triassic, where it is still included.

Smith (1932, p. 7–11) recognized the *Meekoceras* zone as the basal fossil zone of the Thaynes Limestone of southeastern Idaho and divided that zone into 3 subzones. The third of these subzones, the *Anasibirites* subzone, was later recognized as a separate zone. Smith also recognized the *Tirolites* and *Columbites* zones in the Thaynes Limestone of the same area. A *Prohungarites* zone was later recognized by others as being contained within the Thaynes beds in southeastern Idaho (Kummel 1954, p. 454). Therefore, five zones have been recog-

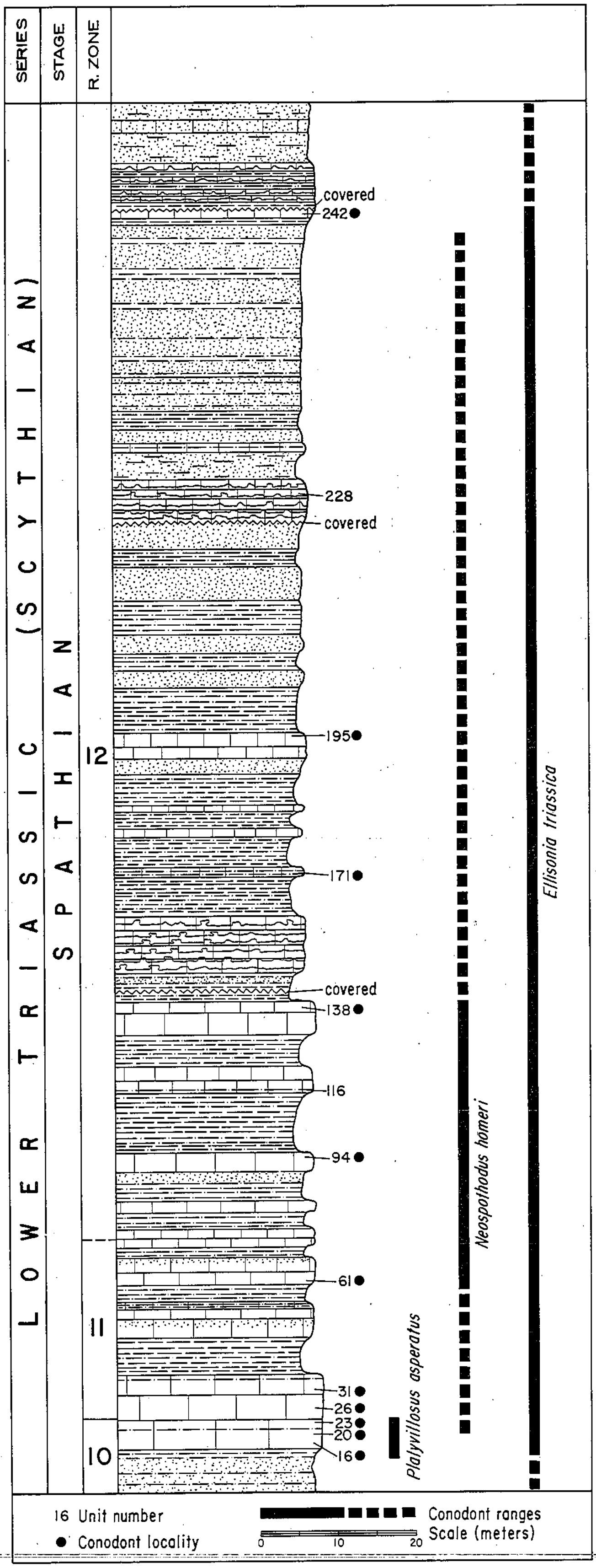


FIGURE 3.—Conodont zonation and age assignment of rocks of study area. Solid line represents actual conodont occurrence; dashed line, projected occurrence.

nized in the Thaynes of southeastern Idaho, but Kummel (1953, p. 49) noted the absence of diagnostic fossils in the Thaynes Formation of the Wasatch Mountains, and attributed it to intertonguing of red beds.

Kummel (1954) wrote extensively on the regional stratigraphy and paleontology of the Thaynes rocks in southeastern Idaho and northern Utah. He divided the Thaynes Limestone into seven facies or tongues including a lower limestone, a lower black limestone, a tan silty limestone, an upper black limestone, a sandstone-limestone, the Portneuf Limestone, and the Timothy Sandstone. Only the sandstone-limestone facies occurs in the present study area.

Clark (1954, p. 2192–2219) described the marine Triassic stratigraphy of western Utah and eastern Nevada and indicated that the Thaynes Limestone and other Lower Triassic formations marked the last marine deposition in the Cordilleran miogeosyncline. He states that thicknesses for the Thaynes redbeds range from 289 to 631 m, with marine rocks thinning toward the south and east.

Scott (1950, 1959) considered the Thaynes Limestone to be the only commonly fossiliferous formation within the Triassic System in Utah, and he grouped it and its bounding formations (Woodside Shale and Timothy Formation [Ankareh Shale]) into the Moenkopi Formation where the Thaynes Limestone pinches out east and southeast of the Wasatch Mountains. He also considered the Thaynes rocks to have been deposited in a marine to nonmarine miogeosyncline that graded into nonmarine shelf environments of the Moenkopi Formation east of the Wasatch Mountains.

Bissell (1959, p. 161–62) made brief mention of the Thaynes Limestone where it is locally involved in folds and faults of the Uinta and southern Wasatch Mountains.

Bromfield (1968, p. 17–18) briefly discussed the Thaynes Formation in the Park City mining district and synthesized Boutwell's findings, but added little new information on paleontology or detailed stratigraphy of the Thaynes beds.

Smith (1969), in a regional study of the Thaynes Formation in Utah, described and correlated six sections within an 80-km radius of Salt Lake City, but he did not include the Spanish Fork Canyon exposures in his investigations. Because of similar lithologies, Smith grouped the Dinwoody Shale with the other rocks designated as the Moenkopi Group by Scott (1959). The Thaynes Formation was still included in this group. Smith also proposed the name "Decker Tongue of Ankareh Shale" to replace "Middle Red" of Boutwell (1907, p. 448) for the middle member of the Thaynes Formation.

Newman (1974) studied the formation and reached conclusions on the depositional environments of the Thaynes Limestone near Midway, Utah, about 80 km northeast of the present study area. Although he measured the exposed section in some detail, he observed that fossils are rare and generally in a poor state of preservation.

Solien (1979) correlated seven conodont zones of the Thaynes Formation east of Salt Lake City with those of other authors in Pakistan, Israel, Australia, and Nevada, and proved their biostratigraphic value in correlating the Lower Triassic marine units of the Great Basin.

Geologic maps covering parts of the present study area were prepared by Baker (1972) and Young (1976). Rawson (1957) mapped the adjacent area to the southwest.

Methods

Field studies were conducted from September through November 1978 and in March 1979. Paleocurrent data were field-checked in April 1979. The detailed section was measured with a Brunton compass and a 15-m cloth tape. Two hundred fifty-seven units were described and sampled. Strike and dip measurements were taken on all described units. Attitudes of sedimentary structures were documented, including ripple marks and larger cross-bed sets in each unit where they were recognized. Attitudes and directions of all such structures were rotated back to a horizontal position by stereographic projection methods to determine original paleocurrent directions.

Units were separated at lithologic boundaries or at prominent color changes. Color designations of rock units were based on the GSA color chart. Field classification of clastic units was modified after that proposed by Ingram (1953), using the Wentworth grade scale, as summarized by Dunbar and Rogers (1957). Field and laboratory classification of carbonate units is that of Dunham (1962), as modified by Embry and Klovan (1971).

Seventy-five thin sections were prepared as representative of each lithology and to document sedimentary structures, fossils, and textures. Epoxy hardener and a vacuum pump were employed in order to impregnate loosely consolidated clastic units prior to sectioning. This process met with marginal success, in the fine-textured rocks in particular.

Thirteen carbonate units at selected intervals were processed for conodonts and other fossils. Glacial (acetic) acid was used to etch the rock, after which the heavy fraction containing the conodonts and other fossils was separated with a heavy liquid. This process yielded a fairly abundant conodont fauna in some samples.

Acknowledgments

The writer thanks J. Keith Rigby, who served as thesis chairman; James L. Baer, who served as committee member; and Jess Bushman, who aided in clastic rock identification. Appreciated also is the help rendered by Morris S. Petersen, who aided in fossil identification, and David L. Clark of the University of Wisconsin, who aided in conodont classification.

Financial assistance for part of field and laboratory expenses was provided by grants from the Society of Sigma Xi and the Brigham Young University Research Fund.

Special thanks are given to my wife, Joann, for her help during fieldwork and for her assistance in typing various drafts of the thesis.

LITHOLOGY

Terrigenous clastic rocks of the Thaynes Formation in Spanish Fork Canyon include fine-grained sandstone, siltstone, and shale deposited in nearshore environments. Terrigenous rocks predominate in the middle and upper portions of the measured section and comprise 72 percent of the total thickness. Carbonate rocks, although environmentally significant as indicators of marine conditions, comprise a minor part of the section.

Sandstone

Sandstone comprises 27 percent of the total thickness in the measured section. Essentially all the sandstone units are very fine grained, and characteristic modal sand grains are from 0.06 to 0.15 mm in diameter. Practically all sandstones of the measured section contain at least minor calcite cement and are commonly interbedded with siltstone or carbonate units. Composition, fossils, and sedimentary structures are more or less the same for each sandstone unit.

Five types of sandstones are differentiated by color, which is thought to be indicative of minor differences in environments. They are (1) grayish red to pale red purple and pink, (2) yellowish orange to moderate brown, (3) olive gray to greenish gray, (4) yellow to grayish yellow, and (5) pale yellowish green to light greenish gray sandstone.

Red to Purple Sandstone

Grayish red to pale red purple and pink sandstone occurs in many units. Characteristic beds occur, for example, in units 214, 233, and 241. Thicknesses of these kinds of sandstones range from 0.2 to 7 m, with a more common thickness of 0.5 to 1.5 m. Constituent grain sizes are mostly from 0.06 to 0.10 mm in diameter, and, not uncommonly, these sandstones grade upward and downward into coarse siltstones. Quartz (90–98%) is the dominant mineral type, and calcite (2–10%) is the cementing agent. Minor minerals include clay-size minerals (1–2%) and less than 1 percent each of mica, feldspar, dolomite, and possibly glauconite. Most grains are angular to subangular, but some are subrounded. The red to purple color is due to hematitic stain in the cement and around individual grains.

These sandstones are typically dense, but unit 207 is extremely dense and well cemented. Units 214, 216, and 221 are weakly cemented. The red to purple sandstone is moderately sorted and is characteristically laminated to thin bedded. However, bedding is destroyed in at least part of units 250 to 253 as a result of bioturbation. Even in those units which exhibit bedding, it is not continuous throughout, and contacts are usually gradational. Several units, such as 188, 202, 216, 239, 241, 250, 252, and 253, exhibit minor cross-bedding (fig. 4) probably due to ripple marks. Clams, *Aviculopecten,* and gastropods occur in some of these units.

The reddish sandstones are commonly interbedded with pale greenish yellow siltstone (as in unit 241) or with sandy to algal carbonate units. These units, as evidenced by their coloring, sedimentary structures, and associated lithologies, probably represent a dominantly subaerial, but partly very shallow subaqueous intertidal flat to supratidal environment.

Orange to Brown Sandstone

Yellowish orange to moderate brown sandstones are most characteristically represented by units 67 and 151. Units of this lithology range from 0.05 to 0.20 m thick, with a most common thickness of 0.10 m. Characteristic grains range from 0.06 to 0.20 mm in diameter, with an average near coarse silt-size, approximately 0.06 to 0.07 mm in diameter. The brown sandstone units are mostly composed of detrital quartz grains (85–95%) held together by limonite-stained calcite cement (5–10%). Minor mineral constituents include feldspar (1%), dolomite (1%), and various clay minerals (less than 1%). Dolomite occurs as rhombs 0.005 to 0.05 mm in diameter. The detrital grains are angular to subangular. Induration of these units is very good to poor, probably because of the amount of calcite cement.

These units are moderately to strongly calcareous and are generally laminated to thin bedded, where bedding is evident. Unit 152, however, has uneven medium beds. Contacts with interbedded rocks are generally sharp, although those of units 88 and 221 are gradational. Cross-bedding is present in units 188 and 232 (fig. 4). Burrowing or other trace fossils were not noted in any of the units. Bivalve molds are present in unit 232, but fossils were not noted in the other units.

The brownish sandstones are mostly interbedded with or are in direct contact with pale red sandstones and siltstone. Brownish rocks, because of their somewhat reduced oxidation state (brown color), fossils, and cross-beds most likely represent a slightly more aqueous (subtidal) environment than do the red to purple sandstones.

Olive Gray to Greenish Gray Sandstone

Gray sandstones occur in units 4, 5, 6, 7, and 207. These units are from 0.05 to 1.6 m thick, with an average thickness of 0.6 m. Grain sizes of characteristic samples range from 0.06 to 0.30 mm. Quartz (85–90%) is the dominant detrital grain, and these grains are angular to subrounded. Calcite (5 to 10%) is the cementing agent. Dolomite comprises 1 to 3 percent of the grains and occurs as rhombs 0.01 to 0.08 mm in diameter. Minor clay-sized particles (2%) and feldspar (1%) are present in the matrix.

This sandstone is not well indurated in units 4, 5, 6, and 7. Unit 207 is extremely dense, quartzitic, and well cemented. Because of the relative abundance of clay-sized material with the quartz, sorting is mostly poor to fair. Units 4, 5, 6, and 7 are very thin bedded, and units 5 and 7 show low cross-bed sets (fig. 5). Unit 207 lacks evident stratification. Contacts with enclosing units are gradational. These sandstone units lack apparent bioturbation and fossils. Cross-bedding and color indicate a dominantly subaqueous environment.

Yellow to Grayish Yellow Sandstone

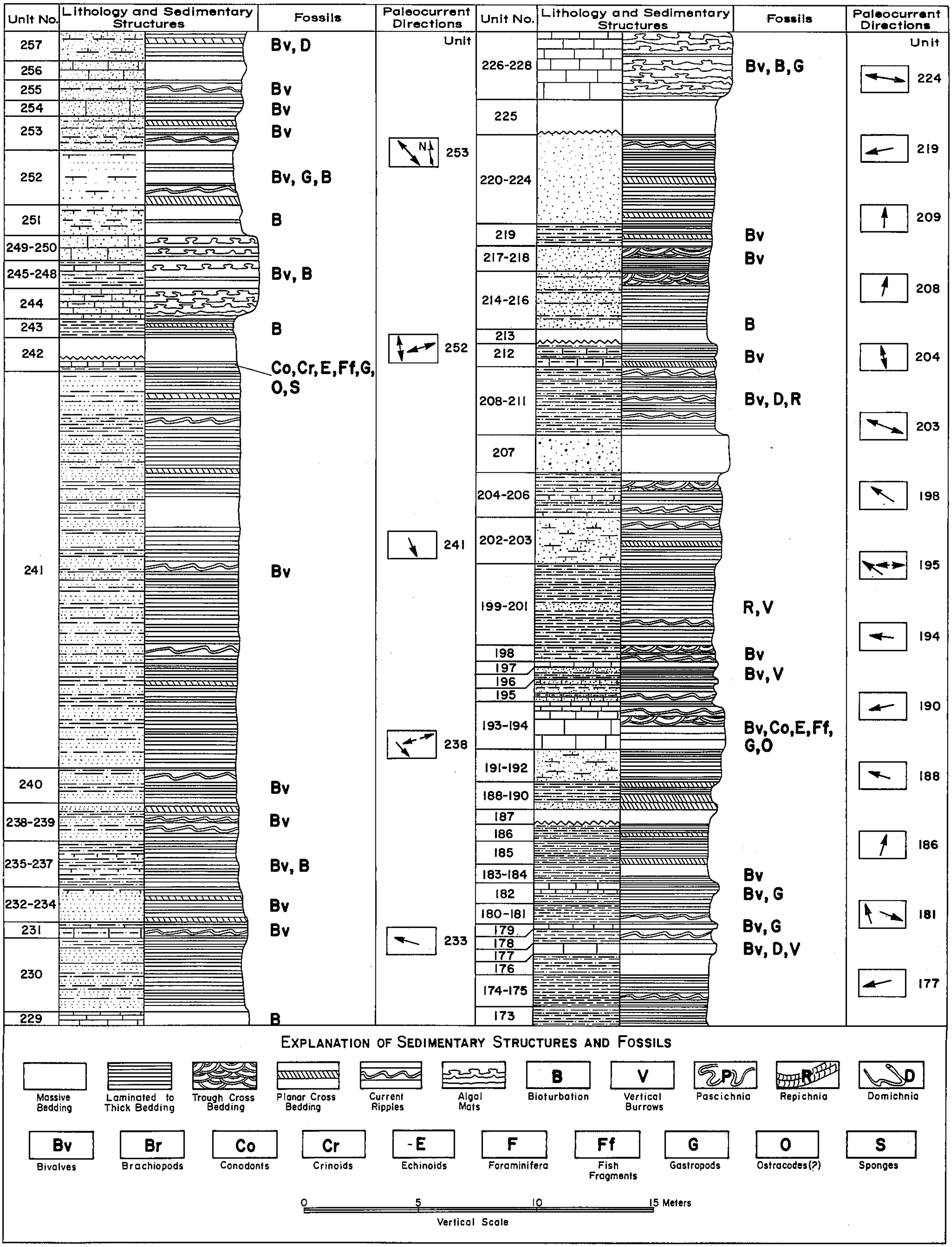
Yellow sandstone occurs in units 1, 3, 9–11, and 13. These units range from 0.2 to 0.9 m thick, with an average thickness of 0.3 to 0.5 m. Grains range from 0.06 to 1.0 mm, with an average grain size of 0.08 mm. They range from angular to subrounded, with the larger grains more rounded than smaller ones. Quartz (85–95%) is the dominant mineral constituent, but minor amounts of clay-sized particles (2%), feldspar (1%) and dolomite (1%) are common. Calcite (5–10%) is the cementing agent. Limonitic stain gives rise to the yellow color in these rocks.

The yellow sandstone units are moderately to poorly cemented and calcareous, have poor to fair sorting, and are not well indurated. Unit 3 (fig. 4) has well-defined cross-bed sets 1 cm thick, but all other yellowish sandstones have well-expressed, very thin laminar beds. Contacts of these sandstone units are gradational to sharp. Where gradational, they grade mostly into gray siltstone or sandstone. The color of the sandstones and their association with gray sandstone and siltstone indicate a dominantly subaqueous environment punctuated by occasional pulses of sheetlike currents.

Very Pale Yellowish Green to Light Greenish Gray Sandstone

Pale green sandstone occurs in various units. Characteristic beds occur in units 215, 241, and 257. The thickness of these units ranges from 0.25 to 1.2 m, with an average thickness of 0.4 to 0.8 m. Grain size of characteristic samples from these units ranges from approximately 0.06 to 0.50 mm in diameter with an average grain size of about 0.08 mm. Constituent grains are mostly angular to subrounded. Larger grains are subrounded. Detrital grains consist dominantly of quartz (85–95%). Calcite (5–15%) occurs mostly as the cement, although feldspar comprises 2 percent of the grains, and minor clay particles, mica, and dolomite together represent about 1 percent of the grains.

Pale green sandstone beds are mostly only moderately indurated, but units 215, 217, 218, 220, and 222 are particularly weakly indurated. Sorting is fair to moderate, and all these sandstones are moderately to very calcareous. Stratification is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Lithology and Sedimentary Structures
Fossils
Paleocurrent Directions
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Laminated to Thick Bedding
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Br Brachiopods
Co Conodonts
Cr Crinoids
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F Foraminifera
Ff Fish Fragments
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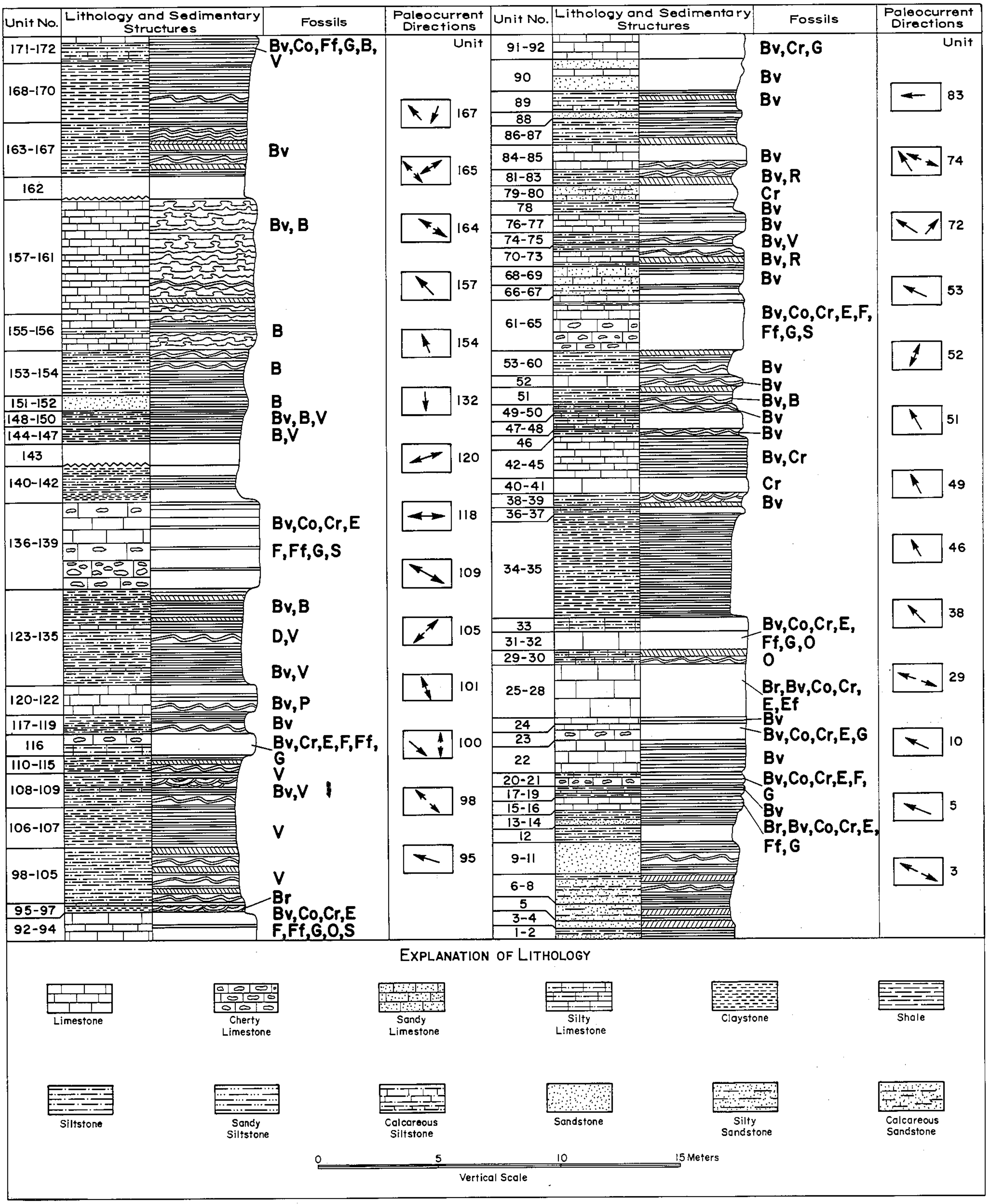

FIGURE 4.–Detailed stratigraphic section of study area. Fossils and individual paleocurrent directions (arrows) are keyed to units in which they occur.

generally thin and regular through unit 224, but units 230 and above are mostly laminated. Foreset cross-beds and/or ripple marks are evident in most units of the greenish beds where bedding has not been destroyed. Contacts are usually gradational, and pale red to pinkish purple sandstone beds are commonly interbedded and even interlaminated with the pale green sandstone.

Bioturbation and burrows are well expressed in units 251, 252, and 257 (fig. 4), but the massive character of part of nearly every unit indicates extensive bioturbation. Molds of clams and *Aviculopecten* are abundant on bedding planes in units 217, 239, 241, 252, 253, 255, and 257. They are mostly convex up and are the only fossils in these beds.

These sandstone units are typically interbedded with red to purple sandstone and siltstone but also occur bounded by carbonate wackestone. The pale green color of these units, their extensive bioturbation, often with pale green burrows surrounded by pale red sediment, their association with marine units, and the high percentage of calcite cement combine to strongly suggest a reducing, subaqueous environment.

Siltstone

Siltstone accounts for one-third of the total thickness in the measured section and is the principal lithology of the Spanish Fork section of the Thaynes Formation. Siltstone units are associated with sandstones and tend to be coarse grained in the upper two-thirds of the measured section above unit 186, but are more fine grained and typically interbedded with shale and limestone in the lower one-third of the section. Composition and sedimentary structures are fairly uniform in all siltstones, but fossils are more abundant in the green and red siltstones.

The siltstone types, each indicating a somewhat different environment, were differentiated by their colors: (1) brownish red to pale red to pale red purple, (2) olive to greenish gray and grayish yellow green, and (3) yellow, brown, and grayish orange.

Brownish Red to Pale Red and Pale Red Purple Siltstone

Brownish red to pale red purple siltstone occurs in 43 of the 257 units in the measured section. Units 154 and 208 (fig. 4) are characteristic of this siltstone. Thicknesses of these units vary from 0.05 to 2.0 m, with most being from 0.3 to 0.8 m thick. Modal grain size in most of them is coarse siltstone and approaches very fine-grained sandstone, but ranges from 0.0039 to 0.06 mm in diameter. Very fine-grained sand, up to 0.13 mm in diameter, comprises up to 40 percent of some of the units. Subangular to angular quartz predominates (85–95%), but calcite (10–15%), feldspar (1%), clay-size particles (1%), and dolomite (less than 1%) also occur. The red color is due to hematite stain in the matrix and around each grain.

These siltstones are mostly well indurated. They are distinctly calcareous in the upper two-thirds of the measured section, but those in the lower one-third are poorly indurated to moderately dense and less well cemented. Stratification is irregular, but, where present, the units are laminated to very thin bedded. At least half the units show ripple marks as small-scale foreset cross-beds, trough cross-beds, or flaser bedding. Raindrop imprints occur in unit 154 in the pale red siltstone. Contacts between units are usually gradational, but tend to be sharp when they are with shale or clean carbonate units.

Bioturbation is fairly common and may be associated with bivalves, which are quite abundant in these siltstones. Several of these units, such as unit 209, contain well-expressed pascichnid-type double trails (fig. 6). Gastropods are also present.

Commonly associated lithologies include algal wackestones, greenish gray siltstone or sandstone, and shales. Sedimentary structures, red color, associated lithologies, and fauna and flora are indicative of a shallow subaqueous to subaerial environment, such as an intertidal flat.

Olive to Greenish Gray and Grayish Yellow Green Siltstone

This lithology is present in 46 units and is exemplified by units 102 and 166. These units range in thickness from 0.05 to 1.6 m and have average thicknesses of 0.3 to 0.7 m. Grain size varies from 0.0039 to 0.06 mm, with most grains being approximately 0.02 to 0.06 mm in diameter. While quartz is again the dominant mineral grain (85–95%), muscovite is locally abundant (up to 10%), and clay-size particles may comprise from 1 to 5 percent of the detritus. Calcite (5–10%) is the cementing agent.

The units are well cemented and dense where associated with carbonate wackestones, but those associated with shale

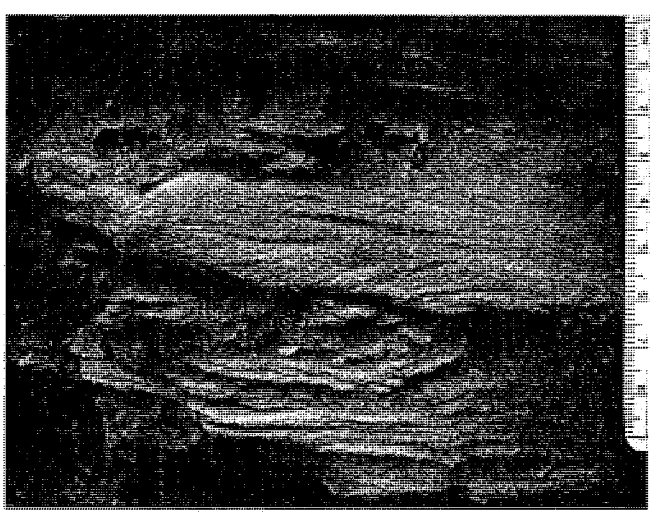

FIGURE 5.–Low cross-bed sets in gray to green sandstone of unit 5.

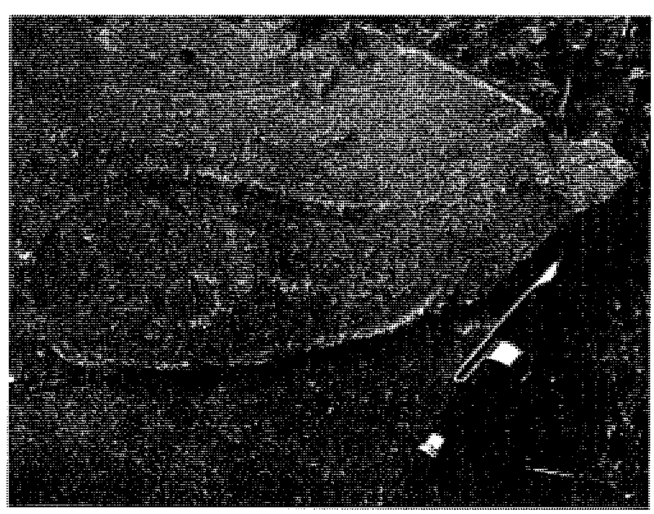

FIGURE 6.–Double-trail pascichnia in red siltstone of unit 209.

and finer-grained siltstones tend to be less well cemented and less dense. Most of these siltstones are laminated to thin bedded, but a few are medium or thick bedded.

Flaser bedding was noted in units 6, 109, and 198, and ripple marks and small-scale foreset or trough cross-beds were noted in about half the other units. The upper and lower contacts of most units are sharp, although they are gradational where interbeds of different colored siltstone units occur. Bioturbation is present in various units, several of which contain well-preserved vertical or horizontal burrows. While the green to gray color indicates a reducing environment, the presence of bivalves, ripple marks, burrowing, and small-scale cross-bedding indicates a shallow marine, low-energy subtidal environment.

Yellow, Brown, and Grayish Orange Siltstone

Yellow to brown siltstone units are similar to the red and green siltstone units in most respects other than their colors. However, yellowish units tend to be slightly finer grained (.01 to 0.06 mm average diameter) and contain only vertical burrows. These units are, with few exceptions, interbedded with reddish siltstones and wackestones and were, therefore, probably deposited in an alternating subaerial-subaqueous environment, such as an intertidal flat.

Shale

Shale constitutes only 11 percent of the thickness of the lithologic units and is relatively minor in the section. It occurs principally in the lower half of the measured section, and shale units range from less than 0.05 to 1.6 m thick. Most individual units are less than 0.6 m thick. Green to gray shale predominates in the section, but red, brown, and yellow shale beds also occur. The red, greenish gray, brown, and yellow shales are usually either interbedded with each other or occur with siltstones of the same color. They are noncalcareous to weakly calcareous.

Some bioturbation is evident, and vertical burrows are present in the more silty units. Molds and steinkerns of clams occur on bedding planes in units 17, 118, 125, 135, and 164, and *Aviculopecten* are present in units 17, 118, and 133 (fig. 4). This is in contrast to the relative absence of bivalves in the shales of the Thaynes Formation near Cascade Springs, west of Midway, Utah (Newman 1974, p. 73). The lithologic relations, the burrows, and the presence of bivalves indicate a very low-energy, subaqueous to subaerial environment, possibly the quieter areas of a tidal flat.

Claystone and Mudstone

Claystone and clastic mudstone, as used here, refer to nonfissile rocks made of clay- to silt-sized particles. These lithologies are typical of units 95, 96, 140, 142, and 169 and are grayish brown to reddish brown. They lack visible sedimentary structures and fossils and may represent highly bioturbated shales. They were probably deposited in a very quiet, shallow subaqueous environment.

Limestone

Limestone constitutes 28 percent of the total thickness of the formation, but predominates in the lower third of the measured section where it comprises almost half of the total thickness. Six major lithologies are recognizable, including (1) carbonate mudstone, (2) wackestone, (3) packstone, (4) grainstone, (5) floatstone, and (6) bindstone.

Carbonate Mudstone

Carbonate mudstones occur in units 15 and 92 and range from lenses 0.05 m thick to a unit 1.1 m thick. They are olive brown to brownish red on fresh fractures, and weather to olive gray. Detrital grains make up less than 10 percent of the units, but bivalve shells and crinoid ossicles filled with mud are locally abundant, possibly indicating higher energy surges in a normally quiet environment. Unit 92 is stylolitic and grades upward into a slightly higher energy wackestone. Mudstone of unit 15 grades upward into a packstone whose base shows graded bedding representative of a storm surge. The basal part of this graded bed contains mostly mud clasts (rip-up clasts) and crinoid debris 0.50 to 2.50 mm long, but grades upward into mainly mudstone clasts 0.25 mm or less.

Wackestone

Wackestone is the dominant carbonate lithology of the study area. At least 10 percent of the rock is detrital grains, but it is dominantly mud supported. Colors range from pale red purple to pale greenish gray, medium dark gray, and moderate yellowish brown. These units are laminated where abundant quartz silt and sand grains are present. More nearly pure carbonate units tend to be massive. Weathered surfaces often have a sandy to silty texture. Where interbedded with other carbonate units, wackestone beds contain abundant fossils, including calcite-replaced bivalve shells; echinoid spines; and assorted crinoid debris, including columnals, calyx plates, and brachial plates. Gastropods, conodonts, brachipods, ostracodes, foraminifera, and fish fragments also occur. Much of this fossil material, except for mostly calcite-replaced bivalves, has been replaced by secondary silica. Sponge spiculites are present in chert nodules in units 61, 62, 92–94, and 136–139 (fig. 7).

Glauconite is extremely abundant as a residue from acetic-acid-treated samples of unit 61. Glauconite is formed from micaceous minerals or bottom muds rich in iron, in shallow marine waters of normal salinity, and it is formed in areas of slow sedimentation, usually with the help of organic matter (Pettijohn 1975, p. 426, after Cloud 1955). Unit 61 overlies a dense, massive siltstone.

Bioturbation, shown in units 28, 172, and 177, is also present in many other units and is evidenced by disrupted, irregular beds. Unit 177 contains domichnia and abundant vertical bur-

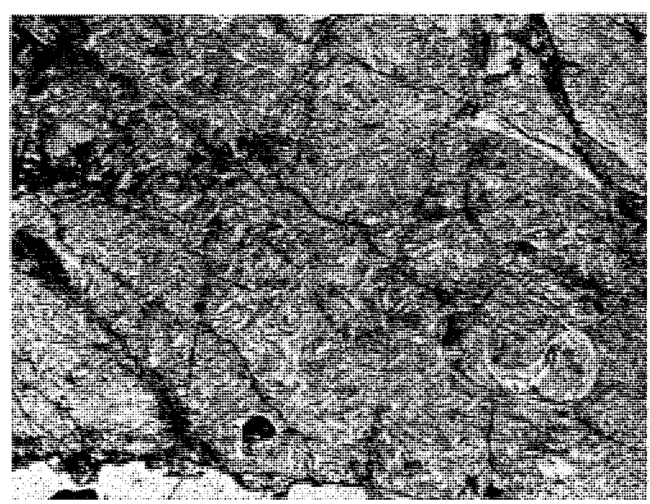

FIGURE 7.—Photomicrograph of sponge spiculite of unit 94. Note gastropod in lower right. X10.

rows (fig. 8). Stylolites are present in units 22, 23, 62, 63, and 94. They are formed during compaction and cementation of carbonate rocks and occur as tiny ribbons of carbonaceous material or iron minerals. Solution activity as the result of inhomogeneities in the rock fabric or composition creates tiny, irregular fractures in the rock, thus allowing the iron or carbonaceous material to move into these areas because of their lower pressure, as suggested elsewhere by Park and Shock (1968, p. 187–88). Evidence of storm surges also exists. Mud clasts, often with bivalve and ostracode fragments, are contained within wackestone (fig. 9).

Packstone

A carbonate rock, packstone is typically grayish red to pale red purple in the Thaynes section, although some medium gray to greenish gray units do occur. They typically weather pale reddish brown. Unit 16 is an example. Fragments of crinoids, echinoids, and bivalves, together with algal and fecal pellets, are the detrital grains (fig. 10). Some lime mud and quartz detritus are also present in the matrix. Unit 126 is stylolitic, but the other packstone units are not. Packstones are mostly medium bedded to massive, with some showing laminations due to minor depositional breaks. Fossils from the units are essentially the same as those in the wackestones, but they are more commonly replaced by secondary calcite. Burrows are present in some of these units.

Grainstone

Grayish red to light olive gray grainstone occurs in units 20, 116, and 120. Sparry calcite forms most of the cement and replaces bivalves, ostracodes, and gastropod shells, as well as crinoid fragments (fig. 11). The high concentration of coarse bioclastic debris suggests these beds were deposited under abnormally high-energy conditions, such as during storm surges across a shallow marine shelf. These coarse units are overlain by shale or siltstone, which indicate quieter conditions.

Floatstone

Floatstone occurs in units 26, 31, and 41. These units contain over 10 percent mud clasts and coarse crinoid or bivalve debris, the latter largely replaced by calcite. Both sparry calcite and lime mud form the cement and matrix. These rocks are pale red and olive gray, are from 0.25 to 0.4 m thick, and are representative of a high-energy, shallow marine environment.

Bindstone

This lithology occurs only in the upper half of the formation, and individual units vary from 0.05 to 1.8 m thick. Average thicknesses are 0.40 to 1.2 m. These bindstones are almost entirely algal stromatolites. They are typically pale red purple and pinkish purple and are often mottled with pale yellowish green. Outcrops appear flaggy and form ledges. The color patterns and interrupted algal mat laminae indicate much bioturbation. Bivalve debris and mud clasts (flat pebble conglomerate) are associated with some of these mats.

Flat pebble conglomerate is formed when dried-out lime mud of algal mats and the levees of tidal channels are torn up, abraded, and redeposited in areas of current activity on the floors of tidal channels. It may also be formed when mud chips from lime mud or algae are buried more or less in situ by rapidly deposited sediment (Shinn et al. 1969, p. 1221). Most portions of all three algal stromatolite horizons of the Thaynes Formation in Spanish Fork Canyon have mud clasts within them. Unit 228 shows evidence of a storm surge which probably tore up these clasts from a fairly dry surface and deposited them in a fining-upward sequence just below an algal mat (fig. 12).

Bindstones are associated with red shale, red calcareous siltstone, and red sandstone, and indicate an intertidal environment (Logan 1964, p. 82).

FIGURE 8.–Domichnia (U-shaped feeding and living burrows) and vertical burrows in wackestone of unit 177.

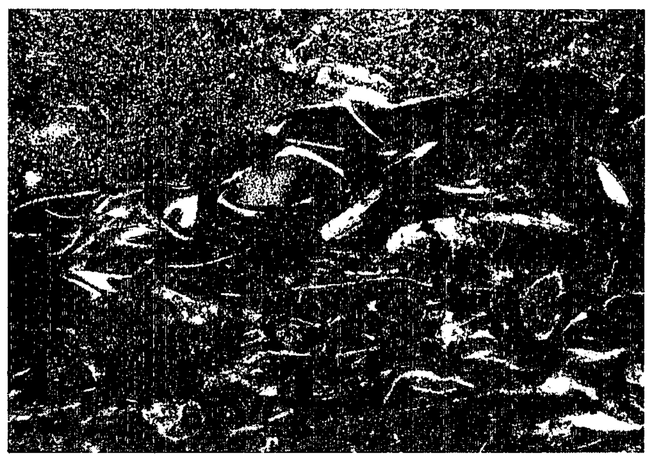

FIGURE 9.–Mud clast with bivalve and ostracode valves within wackestone of unit 32. X10.

FIGURE 10.–Crinoid ossicles with algal and fecal pellets in packstone of unit 16. X10.

CYCLIC PATTERNS

Several cyclic patterns of lithologic sequences are apparent in the Thaynes Formation (fig. 13). These sequences involve cyclic repetition of various rock types, cyclic repetition of colors, or combinations of both. Both three and five-element cyclic patterns occur in the measured section. Five-element cyclic sequences occur in the lower and middle portions of the measured section, but three-element cycles occur throughout. These repeating patterns aid in the environmental interpretation of the Thaynes Formation.

Three-element cycles occur in different lithologies in the lower part of the formation. They involve color changes from red to green to red or from green to red to green in silty limestones, siltstones, shales, and occasionally in sandstones. Cycles may also involve different lithologies with or without accompanying color changes and represent minor transgressive-regressive or regressive-transgressive sequences. These cycles often repeat and may locally grade into more clastic-free limestone where transgressive. They are terminated by a relatively major transgression or regression. In the middle part of the section, the three-element cycle occurs mainly in shale and siltstone and consists of the following: (1) red shale or siltstone, (2) green shale, siltstone, or sandstone, and (3) red shale or siltstone (fig. 13). It may also alternate from red to green to red with the same lithologies. Cycles are again terminated by a longer transgression or regression. A sequence typical of the three-element cycle in the middle portion of the measured section occurs in unit 178 and typically occurs as a "sub-cycle" within the five-element cycles. Three-element cycles in the upper part of the measured section are usually restricted to color changes within a sandstone or siltstone and often repeat numerous times. The combined effect of these cycles throughout the measured section suggests a major overprinting of a shoaling environment upward in the section, with clastics becoming both more common and coarser grained (fig. 12).

Five-element cycles are also representative of minor transgressive-regressive sequences but are somewhat more pronounced. These cycles are common in the lower and middle portions of the measured section. They consist of (1) red shale or siltstone, (2) green shale or siltstone, (3) limestone with coarse bioclastic layers or layers showing bioturbation, (4) green shale or siltstone, and (5) red shale or siltstone. Units 169–174 show this cyclic pattern (fig. 14). The middle wackestone is highly bioturbated, especially near the top, and is followed by a green siltstone and then a red shale. A variation of this cycle occurs where a red shale or siltstone directly overlies the carbonate unit, or where the upper green siltstone or shale is overlain by a limestone. The former circumstance represents a rapid regression, whereas the latter represents rapid transgression following a shortened regression. These variations are actually more common than the complete five-element cycle and probably represent a moderately quick fluctuation of the ancient shoreline environments.

Bioturbation and vertical U-shaped burrows in the upper part of some silty limestones of the five-element cycle (fig. 14)

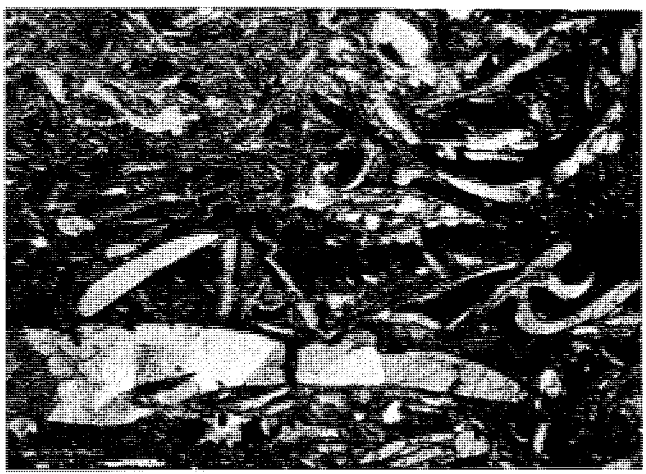

FIGURE 11.–Photomicrograph of grainstone of unit 20. Sparry calcite replaces bivalve and ostracode valves which were probably concentrated by storms. X5.

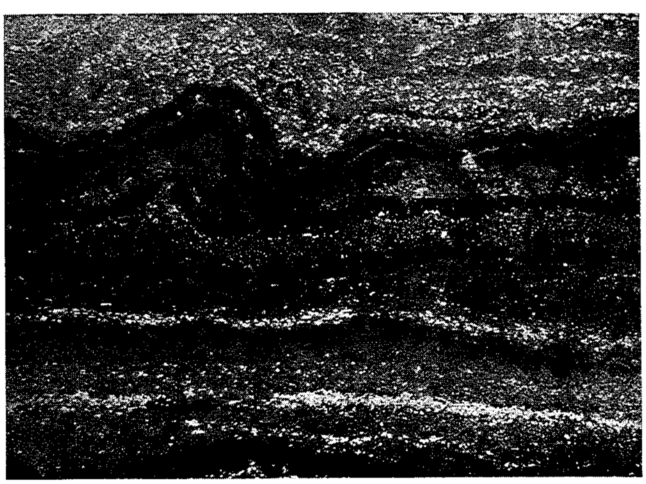

FIGURE 12.–Photomicrograph of algal stromatolite of unit 228. X5.

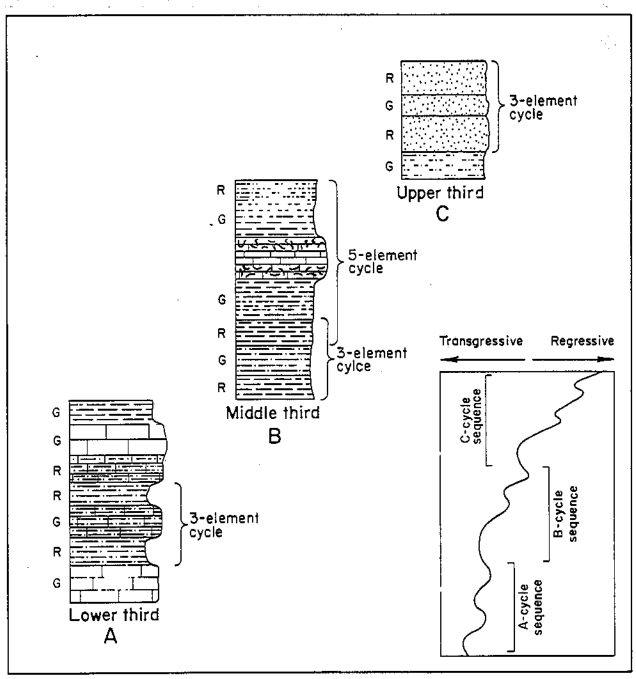

FIGURE 13.–Generalized representation of 3- and 5-element cycles of measured section. Cycles help illustrate major regression of Thaynes Formation. Curves representative of cycles are generalized in box at lower right and do not represent every cycle present.

indicate that water depth was probably not great (Frey 1975, p. 16) because steinkerns of the burrowing clams are often found at various orientations on the tops of these bioturbated units, and these units grade into ripple-marked shale or siltstone. Calcite-replaced bioclastic debris (mostly bivalve shells) at the base or top of other limestone beds in the five-element cycle (fig. 13) indicates that the shells may have been concentrated by single, high-energy events, such as storms. Water depths apparently were sufficiently shallow that the storm surges were able to rework the bottom.

SEDIMENTARY STRUCTURES

Primary sedimentary structures which occur in the Thaynes beds in the study area in Spanish Fork Canyon are principally related to sediment transport. Sedimentary structures of significance include ripple marks, cross-bedding, flaser bedding, and lenticular bedding.

FIGURE 14.–Typical 5-element cycle in units 169 to 174 in middle third of measured section. Dark unit in center of picture (left letter A) is basal red shale to siltstone. Ledge former is highly bioturbated, silty wackestone (letter C) with abundant bivalve shells at base.

FIGURE 15.–Symmetrical current ripples in coarse siltstone of unit 167. Foresets of respective ripples dip in directions indicated by pencil points to the northwest and southwest. X6.

Ripple Marks

Ripple marks are caused by currents interacting with sediments on a noncohesive surface. They are the most common sedimentary structures in the Thaynes Formation, especially in the silty and sandy units of the middle portion. Two types of ripples are differentiated: (1) current ripples, and (2) oscillation ripples. Both occur in the measured section.

Current ripples are produced by unidirectional currents. Crests of current ripples are asymmetrical and regularly spaced. The steeper lee side of such ripples is often away from the shoreline, possibly indicating the direction from which the sediments of the tidal flat environment were derived. Wavelengths of current ripples in the study area range from 2 to 8 cm and are generally classified as small current ripples (wavelength less than 30 cm) as defined by Reineck and Singh (1973, p. 29). They are generally straight crested and indicate low velocities. Some current ripples, such as those in unit 167 in the measured section (fig. 15), appear symmetrical on outcrop, but are current produced because internally their foreset beds are all in the same direction. Some small current ripples of the middle portion of the measured section have crests which are undulatory to discontinuous. These types of ripples are classed as undulatory to lingoid by Reineck and Singh (1973, p. 31) and occur in units 198 and 209 (fig. 16).

Ripples produced by the action of waves on a noncohesive surface are symmetrical to asymmetrical, straight crested, and often show bifurcation. Their ripple indices (length/height) are

FIGURE 16.–Undulatory to lingoid current ripples in red siltstone of unit 198. Brunton points in direction of current movement, to the northwest.

most often between 6 and 8, and ripple symmetry indices (stoss-side length/leeside length) are usually below 1.8. In contrast, current ripples have indices 8 to 15 and symmetry indices of 2.0. Wave-formed ripples are present in several units, and are especially well displayed in units 52 and 204. Ripple lengths of up to 12 cm were noted in unit 204, and cross-bedding in two directions was noted beneath the ripples, with those toward the southeast (restored) dominating.

Cross-bedding

Cross-bedding is the most common feature noted in the study area and is usually associated with ripple marks. Small-scale cross-bedding, as defined by Reineck and Singh (1973, p. 85), is less than 5 cm thick and predominates in the measured section. In most units the small-scale cross-beds were found to dip in one direction only. The small-scale cross-beds of unit 5, for example, dip to the northwest (fig. 5). Such cross-bedded units are made up of foresets representing the lee-side laminae produced from the migration of small-current ripples, and have small-ripple bedding. The upper and lower surfaces of the foresets are surfaces of erosion, indicating a fairly low sediment availability but much reworking (Reineck and Singh 1973, p. 87). One unit (unit 233) was found to contain cross-bed sets greater than 5 cm thick. Cross-beds of this unit are up to 12 cm thick and are termed "large-scale cross-beds" (Reineck and Singh 1973, p. 87).

Micro-cross-lamination occurs only in siltstone and fine-grained sandstone (Hamblin 1961, p. 399), and individual cross-beds are only a few millimeters thick. This structure was noted in unit 89 (fig. 17), a reddish calcareous siltstone, with micro-cross-laminations being 5 mm thick. Smith (1976, p. 132) noted the presence of several of these units with small-current ripple marks in the Entrada Sandstone, but it was not noted in the Thaynes Formation.

Flaser Bedding

Streaks of mud are preserved completely in troughs but only partially on the crests of ripple beds consisting of siltstone or fine-grained sandstone in flaser bedding. Flaser bedding implies periods of current activity alternating with more quiet periods. Sand is deposited as ripples during current activity, and mud in suspension is deposited mostly in ripple troughs when the current ceases. Ripple crests are eroded, and new sand ripples are formed over old ripples and mud when a new current cycle starts (Reineck and Singh 1973, p. 99). Flaser beds were noted in units 109, 194, 198, and 212 and are associated with small-scale ripple beds and siltstones.

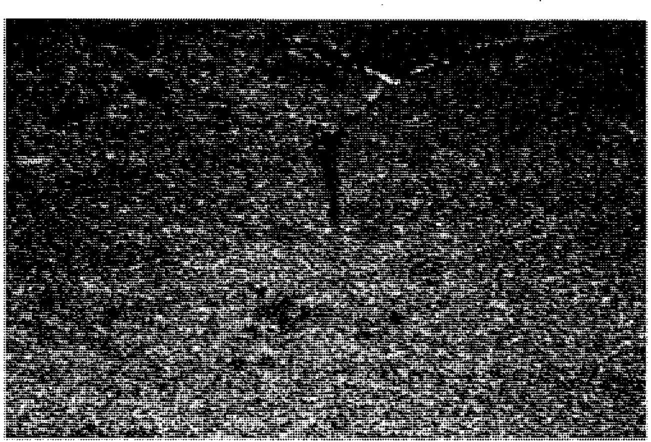

FIGURE 17.—Micro-cross-lamination in red siltstone of unit 89. X6.

Lenticular Bedding

Lenticular bedding is similar to flaser bedding, but ripple beds occur as isolated pods within the more abundant mudstone. Thus the mud supply is greater than with flaser bedding, and the sand supply is small. Both these types of bedding, because of their special circumstances of formation, are most common in subtidal and intertidal zones, and their genesis is related to the tidal rhythm of alternating currents and slack water (Reineck and Singh 1973, p. 101). Lenticular bedding is present in units 6, 8, and 164. Gypsum rosettes and ball-and-pillow structures are associated with this feature in unit 6. Ball-and-pillow structures form when a muddy layer beneath a sandy one is partly broken, allowing a "pillow" of sand or silt to be partially incorporated within it (Reineck and Singh 1973, p. 77).

Paleocurrent directions obtained from all of the above sedimentary structures indicate a dominant current motion to the northwest (fig. 4), although bimodal readings 180° apart in northwest and southeast directions are fairly common.

PALEONTOLOGY

Occurrence and Preservation

Four types of fossils occur in the Spanish Fork section of the Thaynes Formation: (1) body fossils, (2) steinkerns (internal molds), (3) algal stromatolites, and (4) ichnofossils (trace fossils).

Preservation of body fossils is excellent to poor. While some of these types of fossils are concentrated as fragments in limestone units of the lower beds of the measured section, the better-preserved specimens occur as whole valves or shells. They occur with great irregularity through some of the purer limestones. Samples from thirteen representative limestone units were prepared with a 10 percent solution of acetic acid, with most of them yielding a variety of silicified, well-preserved fossils. About half the different kinds of body fossils were identifiable to genus level, and some were identifiable to species level.

Details on fossils preserved as steinkerns are generally not so well preserved as on the body fossils, although these internal molds are often made from fairly complete valves. A variety of bivalves and gastropods are preserved in this way.

Ichnofossils occur in various states of preservation. Chert has filled some burrows in the more impure limestone units, but clastic material such as silt or mud has typically filled burrows in shales to fine-grained sandstones.

Fossils are keyed to the various stratigraphic units within which they are found in figure 4. The paleoenvironmental significance of the fossils will be discussed later in this paper.

Body Fossils

Elements of foraminifera, sponges, brachiopods, bivalve shells, crinoids, echinoids, ostracodes, fish fragments, and conodonts occur as body fossils in limestones of the lower beds of the measured section. Bivalves and crinoid and echinoid fragments are commonly concentrated within bioclastic layers, but the exact position of other small body fossils in these units is difficult to determine because of their microscopic size and their relative scarcity on weathered surfaces.

Crinoids

Crinoid elements are perhaps the most abundant silicified body fossils in the measured section, but their occurrence is mostly restricted to the more calcareous lower part. In contrast, Smith (1969, p. 99) noted their presence in only the upper portion of the Thaynes in northern Utah. Well-preserved columnals up to 5 mm in diameter (unit 20) of the crinoid form genus *Pentacrinus* are common on weathered surfaces of the bioclastic portions of limestones. Columnals are also common and fairly well preserved in some of the residues of samples prepared with acetic acid. These columnals vary from pentagon to star-shaped, depending upon the portion of the column from which they come. Lumen of these columnals varies from round to pentagon shaped, and the crenelli are abundant. Crinoid column segments up to 2 cm long occur on weathered surfaces of several units, including units 31 and 137.

Round crinoid columnals are fairly common also and locally exceed *Pentacrinus* in abundance. Except for possessing a round lumen, they have no distinctive characteristics to make them identifiable, but calyx and brachial plates from a few units seem to be associated with them, as well as with *Pentacrinus.*

Echinoids

Echinoid elements, principally spines, are also mostly restricted to the lower part of the formation but are apparently more widely ranging than the crinoid material. Echinoid fragments occur in eleven of the thirteen etched limestone samples and are seen occasionally on weathered surfaces. Only one nearly complete spine, 1.3 cm long, was found on the weathered surface of unit 136. Most fragments tend to be well preserved, long, circular in cross-section, and tapered toward the top. They have longitudinal rows of minute "thorns" running the length of the spine, between which numerous pores are present. They also have a "milled" ring and a cupped base. Five evenly spaced, silicified muscle or ligament scars which helped anchor the spines were noted on some of the specimens. A few bladelike echinoid spines were noted. These probably belong to *Anaulocidaris,* of the family Miocidaridae. Some echinoid spines were replaced by glauconite in units 193 and 242.

Interambulacral plates are present in units 20, 23, and 94. They are generally silicified and are characterized by a round areole with a central raised primary tubercle. The central area is surrounded by a ring of scrobicular tubercles. The nature of the spines and interambulacral plates suggests classification of the echinoids within the Miociridae. Further classification is impossible because of the fragmental nature of the specimens. The echinoid material encountered in this section of the Thaynes is similar to that reported by Newman (1974, p. 80) in the Thaynes Formation near Midway, Utah.

Conodonts

A fairly abundant conodont fauna was recovered from nine representative limestones. Some of the conodonts are important biostratigraphically. Bar, blade, and platform types are present, and all are well preserved. Most specimens are bar types and are usually broken because of their delicate nature. Species present in the samples include *Ellisonia triassica* (Muller 1956), *Neospathodus homeri* (Bender 1967?), and *Platyvillosus asperatus* (Clark, Sincavage, and Stone 1964). The former two species probably range through more than half the formation but are particularly abundant in the lower 55 m of the measured section. They are more abundant in the clean limestone samples than in the terrigenous units. *Ellisonia triassica* (Muller 1956), in particular, is abundant and moderately well preserved, and it occurs in all the conodont-bearing samples. Several "elements" of this conodont were found in the Thaynes beds, including elements U, LA, LB, and LF. These elements are considered to replace the former genera *Hindeodella, Hibardella, Neoprioniodus, and Lonchodina* (Sweet 1970, p. 236). The U element, considered the original *Ellisonia triassica* (Sweet 1970, p. 235), is the most common in the measured section. It is characterized by a cusp whose bar bifurcates anteriorly to support two rows of three or four denticles each, inclined posteriorly. Posteriorly, behind the cusp, a fairly long bar supports five to seven denticles which are also inclined posteriorly, the last two of which are larger, broader based, and laterally, as well as apically, discrete. Very well-preserved specimens of the LF element were found in unit 242. A single LF element was the only conodont found in the silty wackestone of unit 171. Because *E. triassica* ranges throughout the Lower Triassic and was almost ubiquitous in the measured section, it is of little detailed biostratigraphic importance.

The species *Neospathodus homeri* (Bender 1967?) was found in unit 61 and may also be present in unit 138. This species was found by Solien (1979, p. 283) to range from roughly the upper one-fourth of Range Zone 10 through most of Range Zone 12 in the Salt Lake Thaynes section (fig. 3). *N. homeri* (Bender 1967?) is a bowed bladelike form whose basal margin is downcurved. The blade supports from six to sixteen denticles, but no more than six were noted on the specimens recovered because no complete blade was found.

The platform-type conodonts in the measured section are represented by the biostratigraphically important species *Platyvillosus asperatus* (Clark, Sincavage, and Stone 1964). This conodont occurs only in units 16, 20, and 23, and therefore defines the upper half of Range Zone 10 in the study area (fig. 3). Since unit 16 is within 0.3 m of the basal limestone unit of the measured section, it can be concluded that the entire measured section falls within the Spathian Stage of the Scythian Series (Lower Triassic). This stage would probably include conodont Range Zones 10 through 12 of Solien (1979, p. 283) (fig. 3).

Platyvillosus asperatus is characterized by a roughly leaf-shaped platform whose perimeter is bevelled on the ventral side. On the dorsal side, the platform is characterized by tiny raised surfaces. These occur only on the perimeter of the specimen from unit 20 but are scattered over the top of the platform in the specimen from unit 23. A specimen from unit 16 lacks the raised surfaces, and it, with the one from unit 20, may represent juvenile forms.

Foraminifera

Branching, twisting agglutinate foraminiferal tests occur in etched samples from five different limestone units. Such tests are fairly abundant and well preserved in these units and are common in most relatively clean limestones of the lower part of the section. Some specimens are fairly complete. Their distinctive character suggests that they belong to *Radicula* or *Dendrophrya* of the Astrorhizidae. Both genera lack septae and a distinct central chamber and have a fine-grained, agglutinate outer layer, with apertures at the open end of tapering or tubular branches.

Brachiopods

Brachiopods are among the few fossils which could be detected without the aid of a microscope, but even these specimens are small, ranging from 2 to 11 mm long. They are smooth-shelled, have a short, gently curved hinge line, and a small obtuse-angle interarea. They have a characteristic rounded, prominent foramen. Externally, at least, the specimens bear a strong resemblance to *Terebratula thaynesiana* (Girty in Mansfield 1927) and *Protogusarella smithi* (Chatterton and Perry 1979) but cannot be placed with confidence in either genus. Internal structure was not determined, and many features of the outer shell were obscured either by imperfect preservation or by weathering.

Fish Fragments

Fish fragments occur in ten of the prepared limestone units and are well preserved. Dermal spines, in particular, are abundant in some units. Other fish material includes teeth, scales, and unidentified bony material, possibly vertebrae. All these elements are silicified and are generally less than 1 mm across.

Sponges

An as yet undescribed lyssakid hexactinellid sponge (Rigby 1968, p. 178) occurs in two fairly prominent limestone beds (fig. 18). Sponges also occur as spiculites that are best preserved within chert nodules of units 61–62, 92–94 (fig. 7), and units 136–139, all within the lower calcareous part of the formation. Hexactine spicules occur with monaxons in the spiculites. A few tiny monaxons occur in residues from units 94, 138, and 242. They may be from either hexactinellids or demosponges.

Ostracodes

Small double-valved organisms, less than 1 mm in diameter, are present in residues of units 94, 116, and 193. They are especially abundant in unit 193. They appear similar to bivalves but have smooth, sometimes overlapping, valves and a bulbous area near the hinge lines. These factors, together with their extremely small size, suggest that they are ostracodes. Single ostracode valves were also noted in thin sections of units 29, 32, and 92 (fig. 9).

Steinkerns

Steinkerns of bivalves frequently occur throughout the section, in each major lithology. Steinkerns of gastropods occur in all rock types but the shales. Because of generally poor preservation, only a few of the bivalves could be identified, even to family level, and steinkerns of the gastropods were not subdivided.

Bivalves

Clams and the pectinoid bivalve *Aviculopecten* are the most common steinkerns in the Thaynes Formation. They occur in all lithologies but are especially common on bedding planes, convex up in the silty units. Possibly three or four species of *Aviculopecten* are present. These fossils range up to 4 cm long. This genus, in particular, occurs in all lithologies, both as molds in clastic units and as calcite-replaced body fossils in limestones. Limestones locally are coquinoid units in bioclastic layers from the abundant *Aviculopecten* valves (fig. 11). This pectinoid is characterized by radially plicate or costate valve surfaces, a straight hinge line, and a flanged valve on either side of the beak. Bissate in its early life, this bivalve may have become free swimming as an adult (Newell 1969, p. N333). Such a living habit may explain its widespread occurrence.

A myalinid or mytilid bivalve is common in the measured section. Its modern analogs are sedentary byssate forms that favor shallow seas, have a high tolerance for salinity variations, are gregarious, and can live for up to a month exposed to the air (Cox 1969, p. N5).

Clams similar to the genera *Astartila* and *Pleuromya* are also present. All these fossils are restricted to the terrigenous clastic units but are more common in the coarser-grained ones. Steinkerns of these bivalves are locally abundant on bedding plane tops, some concave up and others down, as if concentrated by somewhat turbulent current action.

In general, clams in the study area are restricted to the clastic units whereas the apparently less facies-controlled pectinoid *Aviculopecten* occurs in both carbonate and clastic units. Both clams and pectinoids occur throughout the measured section. These findings are consistent with those of Smith (1969, p. 94, 96) in various Thaynes outcrops in northern Utah, with the exception that myalinids were encountered in some carbonate units in the upper member. Newman (1974, p. 78–79) did not mention the presence of other than pectinoid forms (*Aviculopecten*) in the Thaynes section near Midway, Utah, these being mostly restricted to the upper member.

Gastropods

Gastropods occur in all the samples etched with acetic acid but, because of their small size, were seen only occasionally on the outcrops. They were also noted in thin section (fig. 7). Gastropods probably occur in virtually all carbonate units in the formation, as well as in many of the siltstones. One specimen 3 mm high was noted, but most are 1 mm or less high and are commonly broken.

The small size of gastropods in the Thaynes Formation has previously been noted (Newman 1974, p. 80; Smith 1969, p. 93). In the Spanish Fork section many of the gastropods are protoconchs that average 1 mm in diameter. These protoconchs were probably only early whorls of much larger gastropods which were sorted from the larger adult shells. Both deviated paucispiral and heterostropic protoconchs occur, the former averaging 1 mm high, but the latter measuring mostly 0.3 mm or less. Both of these types of protoconchs are characteristic of the Class Opisthobranchia, but are not necessarily restricted to it (Cox 1960, p. I114). However, opisthobranchiates typically have smaller shells. Gastropods of the study area are mostly internal molds and difficult to identify.

Types of coiling includes pseudoplanispiral, high orthostrophic conispiral, and low orthostrophic conispiral. The latter two forms by far predominate in the samples and are usually advolute or involute.

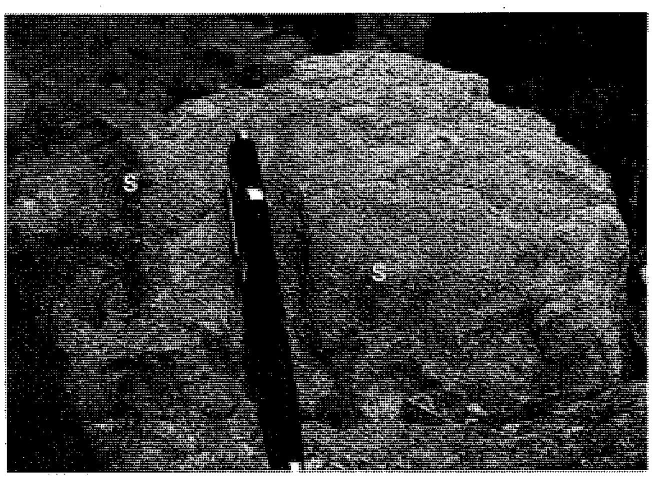

FIGURE 18.–Lyssakid hexactinellid sponges (labeled S) in growth position on wackestone of unit 62.

Although many of the gastropods are steinkerns, a few of them, especially the smaller ones, are silicified body fossils. They are still not well enough preserved nor complete enough to be easily identifiable, however. A few gastropods in units 116 and 138 appear to be partially replaced by hematite, and some in unit 61 are partially pyritized.

Algal Stromatolites

Algal mat structures occur in at least two beds in the upper part of the Thaynes Formation in Spanish Fork Canyon and in one bed in the middle part. These structures form in a very shallow-water environment, probably within the intertidal or near intertidal zone (Logan 1964, p. 82).

In contrast to the "algal head" and more bulbous type algal structures which form in higher-energy environments farther from shore, the algal mats found in the measured section are a slightly lower-energy feature. These algal mats contain laminations, only fractions of a millimeter to only a few millimeters thick, that are closely spaced. They were probably produced by blue-green algae whose mucilaginous secretions help to form a trapping mechanism for lime mud and sand grains (Wilson 1975, p. 82). The calcareous organic structure is not well expressed, and the wavy laminations reflect intermittent terrigenous mud accumulation. Occasionally these laminations arch upward (fig. 12) like patterns seen in stromatolites elsewhere.

Ichnofossils

Ichnofossils and bioturbation are fairly common throughout the Thaynes beds in Spanish Fork Canyon but are more common in the middle and upper beds. Bioturbation is especially common in the calcareous sandstones and siltstones of upper units where other trace fossils are destroyed, as well as in some of the silty wackestones of the middle units.

Domichnia or U-shaped dwelling burrows (Seilacher 1964, p. 299) and vertical burrows are commonly associated in the Thaynes beds. They occur in shaly siltstone and silty limestone. They are very well expressed in the top of unit 177 where the rate of sedimentation was apparently not so rapid as to fill in the burrows of the clams which probably produced them (fig. 8).

Feeding burrows (pascichnia) and locomotor-trails (repichnia) (Seilacher 1964, p. 198) occur in the lower and middle beds and are most common in calcareous siltstones and silty shales. Unit 120 yielded numerous pascichnid-type winding trails with no apparent relief, but double-trail pascichnia such as those of unit 209 (fig. 6) are hypo-relief features, projecting several mm above the surface on which they occur. These particular trace fossils reflect a grazing search for food by vagile mud eaters and probably indicate a very low-energy environment with even deposition. Unit 83 yielded well-preserved repichnia which are square in cross section and represent "trails or burrows left by vagile benthos during directed locomotion" (Seilacher 1964, p. 298).

PALEOENVIRONMENT

Paleoclimate

The Spanish Fork section of the Thaynes Formation represents rocks which were deposited in an open marine to tidal flat environment, which became increasingly more continental in nature from middle Early to late Early Triassic (upper Scythian) time. Paleomagnetic studies (Irving 1979, p. 685) indicate that this area was at 5° to 10° N latitude at the time the Thaynes beds were deposited. Such a proximity to the equator would indicate nearly uniform, warm year-round temperatures. Precipitation of calcium carbonate also suggests a fairly warm climate. Limited evidence of a semiarid climate at the base of the formation is present where tiny gypsum rosettes occur in unit 6, but evaporitic rocks were not noted elsewhere.

Currents and Energy Levels

Cross-bedded and ripple-marked clastic units in the measured section indicate that the dominant direction of current movement was to the northwest, and perhaps was produced by ebb currents. These data are consistent with a postulated craton to the southeast (Hintze 1973, p. 57). The craton is considered to have been the source of the terrigenous clastic units within the Thaynes Formation. Ripple complexes which show currents both to the southeast and to the northwest are fairly common and demonstrate flooding and ebbing of tidal cycles.

Most rocks of the measured section are interpreted to have been deposited under low-energy conditions. The predominance of angular to subangular clastic grains and the occurrence of very fine sand- to clay-size particles in laminated to thin-bedded rocks indicate a low-energy regime for their deposition. Small-scale cross-bedding and ripple marks indicate slightly higher-energy levels. Some of the limestone beds contain coarse, abraded shells of bivalves, up to 2 cm in diameter, which suggest at least pulses of fairly high energy (energy index IV of Plumley and others 1962, p. 88). The silty to sandy limestones of the section (fig. 19), however, are indicative of fairly low to moderate energies (energy index II and III). The micritic carbonate clay-sized to silt-sized particles in the matrix indicate a minimum of winnowing by currents. These rocks have an admixture of less than 50 percent terrigenous clastic particles. Most finely crystalline, fairly pure limestones of the section are low-energy phenomena (energy index I of Plumley and others 1962) (fig. 19).

SEDIMENTARY MODEL

The Thaynes Formation was deposited on an open low-energy coast, upon which deposits of marine, subtidal, intertidal, and supratidal environments are all recognized in the Thaynes Formation in the Spanish Fork Canyon section.

Marine

Echinoderm-bearing limestones are representative of normal marine, warm-water conditions that were mainly of low energy but were punctuated by storm surges. Limestones of the section were mostly deposited below effective wave base as evidenced by a scarcity of ripple marks and cross-beds.

These clearly marine units form nearly half the thickness of the lower third of the measured section (units 1 to 143, fig. 4), and are abundantly fossiliferous. Fossils occur in most units and include foraminifera, sponges, brachiopods, bivalves, gastropods, echinoids, crinoids, ostracodes, fish, and conodonts.

Tubular, branching foraminifera, such as those represented in the study area, are usually sessile and dwell in quieter water, often on a substrate with maximum exposure to currents and light (Wilson 1975, p. 71). Brachiopods favor normal marine conditions and occur only in the section in relatively clean limestones of units 16 and 26. While conodonts do occur in silty wackestone in the section, they are much more abundant in the clastic-free units (fig. 3) and probably indicate nearly normal marine salinities. Crinoids and echinoids, which typically occur in normal marine waters, are restricted to limestones in the measured section. Fish, sponges, ostracodes, bivalves, and gastropods, while not restricted to normal marine conditions in the fossil record, do help to indicate such conditions when as-

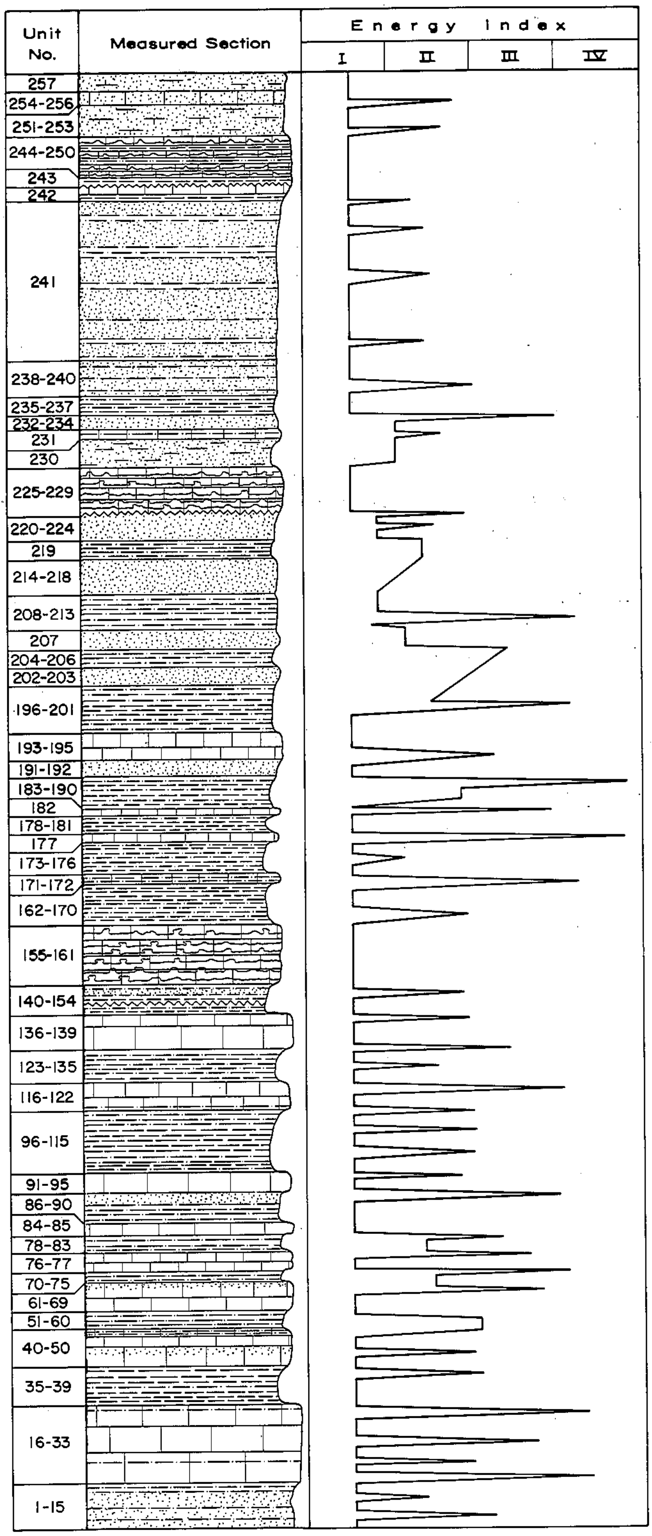

FIGURE 19.—Energy index of rocks of measured section. Modified after Pumley and others (1962).

sociated with the other fossils in the limestones of the study area. Only bivalves and gastropods occur in rocks other than limestones.

While the possibility exists that all the fossils in the limestones were transported in from other environments, it is thought improbable because of their life-styles and the fact that associated lithologies represent environments more hostile to their existence. The foraminifera, sponges, crinoids, and possibly brachiopods were probably sessile forms. The other fossils, such as the gastropods, pectens, fish, and conodont-bearing organisms, were probably vagile.

Periodic high-energy events are evidenced by beds of coarse, fragmented, and sometimes abraded fossil material at the base or top of some limestone units. Fossils in these coarse units typically include bivalves (*Aviculopecten*) and crinoids. Positions of these coarse bioclastic units above or below fine-grained limestones suggest that the coarse layers were deposited above the wave base since the fine-grained lime mud has been selectively removed, probably by winnowing, and the coarse layers left as lag deposits. These coarse-grained units, as well as the silty, bioturbated wackestone (fig. 13), are overlain by normal marine carbonates if they are part of a transgressive phase or by subtidal to intertidal siltstones or shales if part of a regressive phase.

Subtidal

Most units of gray to greenish gray sandstone, siltstone, and shale, as well as very silty or sandy limestones of the measured section, are interpreted to have been deposited in a subtidal environment. This environment includes all sediments deposited below normal low-tide level (Shinn and others 1969, p. 1203). Although subtidal sediments are not commonly subaerially exposed, they were deposited within effective wave base in the study area. Rippled sandstone units are fairly common in this environment, as noted by Gebelein (1969, p. 67), and may have been produced by currents with a surface velocity greater than 20 cm/sec. These normally subaqueous sediments have iron compounds that have been reduced to gray colored iron sulfides as reported from elsewhere by Shinn and others (1969, p. 1215).

Ripple marks and small-scale cross-beds in the subtidal sediments of the study area commonly indicate a northwesterly current trend, probably indicative of the dominant ebb flow of tidal currents. Some bimodal current ripple marks, with foreset beds dipping both northwest and southeast, also occur. Such cross-bedding patterns are interpreted to indicate both ebb and flood of tidal currents. Bioturbation, often in the form of vertical burrows, domichnia, or repichnia, has destroyed bedding and is fairly common in the subtidal units. The only fossils found in rocks deposited as subtidal units are pectinoids, a few clams, and occasional gastropods. The dominantly marine environment of the subtidal sediments is also indicated by a fairly high content of calcite cement, as opposed to its less prevalent occurrence in terrigenous clastic units.

Rocks of a subtidal environment are common in the middle portion of the measured section, where green to gray siltstone and sandstone comprise about 50 percent of the total thickness. A predominance of green versus red siltstones in the lower portion of the section also indicates that rocks of the subtidal environment are fairly common there. The coarser-grained clastic rocks of this environment typically occur interbedded between red siltstone or shale and a silty limestone unit, indicating either limited regression or transgression in a shallow marine environment.

Intertidal

The intertidal zone includes all sediments deposited between normal low and normal high tide (Shinn and others 1969, p. 1204). This zone is often divided into three subzones: (1) sand flats (low tidal flat sands), (2) mixed flats (mid flat), and (3) mud flats (high tidal flat clay) (Reineck 1972, p. 147; Klein 1971, p. 2289). The sand flats typically contain tidal channels, small-scale current ripples, and interference (lingoid) ripples. Small-scale cross-sets in the former often show bimodal current directions. Trails and burrows, flaser bedding, lenticular bedding, interbedding, and interlaminations of sand or silt and mud are typical of the mixed flat environment, and the mud flat is typified by thick mud layers with thin layers or laminae of sand or algal mats. Many of these features are listed by Wilson (1975, p. 81) as characteristic of "Standard Facies Belt 8," which deals with intertidal environments.

All three intertidal flat subenvironments are recognized in the Thaynes Formation in Spanish Fork Canyon. Sediments which represent these three subenvironments owe their brown to red colors to iron which has been oxidized in that realm above normal low tide, in the intertidal zone (Shinn and others 1969, p. 1215). Sediments representative of an intertidal flat in the study area are some of the brown to red sandstones and coarse siltstones, the interlaminated green sandstones to shales, and the algal limestones. These rocks occur mostly in the middle and upper portions of the measured section.

The sand-flat subenvironment is represented by nearly all the brown siltstones and sandstones and some of the coarse red siltstones and red sandstones in the measured section. These units are often thin bedded and ripple marked and show evidence of both wave and current action. Small-scale cross-bed sets are sometimes opposed and thus show bimodality of currents (ebb and flow). Most of the cross-bed sets, however, show a dominant current movement to the northwest and suggest that this is the ebbing direction. Lingoid ripples, which indicate sheetlike emergence runoff in water depths of less than 0.5 m (Klein 1971, p. 2289), are present in the study area and suggest runoff toward the northwest and north in the red siltstones of units 198 and 209 (figs. 4, 16). Tidal channels, a fairly common feature of the sand-flat portion of most intertidal flats, are rare in the study area. One possible channel occurs in unit 189, where a strongly cross-bedded siltstone lens is exposed. This siltstone is alternately red and green. Cross-beds in and around the presumed channel dip to the northeast and southwest. A scarcity of intertidal flat channels has been noted in the fossil record (Ginsberg and Klein 1973, p. 20).

The mixed-flat subenvironment of the intertidal flats is represented by admixtures of shales and siltstones in the study area. These units are often interlaminated and may be green, red, or brown. Closely related flaser and lenticular bedding indicates a mixed flat and occurs most abundantly in the middle portion of the measured section. These types of bedding are indicative of the low-energy currents common on some mixed flats. Individual layers contain low-angle cross-sets within silty pods. Alternating red and green siltstone or shale units are interlaminated in the Thaynes section and are often only a few centimeters or less thick. They are indicative of this environment and are interpreted to have been deposited by alternating flooding and ebbing tides. These units may contain vertical U-shaped burrows. Bedding planes sometimes contain pectinoid and clam molds, usually concave up, and double pascichnia trails (fig. 6).

Deposits of the mud-flat portion of the intertidal flat in the study area consist of thinly laminated red to brown shale, silty shale, or claystone, and pinkish purple to pale purple algal mat limestone. Green and yellow shale, when interlaminated with brown or red beds, may also indicate this environment. Energy levels were extremely low in this environment, as evidenced by the clay-sized particles which settled out to form muds in protected areas. Some of the fine particles were trapped by algae and incorporated into their crinkled mats where layers are separated by trapped particles (fig. 12). Algal-mat limestone beds are intimately associated with red to brown shale in units 243 and 249. Abundant rip-up clasts of shale also are often associated with algal-mat limestones. Mud-flat sediments may also be present as end members of the transgressive-regressive three- and five-element cycles, especially in the middle third of the formation. The dominant red color of these units is attributed to long periods of subaerial exposure between burial by exceptional high tides.

Supratidal

Mostly thin-bedded red sandstone and siltstone predominate in the upper third of the measured section. They are interpreted to represent the supratidal zone. This zone includes those sediments deposited above normal high tide, but not higher than the highest storm tide (Shinn and others 1969, p. 1204).

The coarse red clastic units representing this zone contain occasional bivalves, mostly mytilids, but other organisms are even more rare. Bioturbation was not noted. Ripple marks are absent from these units, but a few cross-beds were noted, with foresets dipping very gently to the southeast. The overall paucity of fossils, the lithology, and the sedimentary structures indicate that the rocks of this environment were dominated by nonmarine processes, and the effect of a marine environment on them was minimal.

SUMMARY

The Thaynes Formation, as exposed in Spanish Fork Canyon, represents a major regression that records the end of marine deposition in the Cordilleran miogeosyncline in Early Triassic time (figs. 1, 20). The regressive nature of the formation is readily apparent from the lithologic relations as one proceeds upward in the section. The dominantly low-energy open marine to subtidal rocks of the lower third of the formation (units 1–143) in the measured section represent a transgression over the terrigenous-dominated underlying Woodside Shale. Periodic tidal flat sedimentation does occur, however, as a portion of five-element cycles in the lower beds.

The middle third of the measured section (units 144–225) represents dominantly subtidal to tidal (intertidal) flat sedimentation, as suggested by the lithology, numerous sedimentary structures, and cyclic sequences typical of these environments. Thin limestones, the middle members of these five-element cycles, represent the apex of minor transgressions within a principally regressive sequence. A dominantly northwest current is evident in this part of the section and suggests ebb currents. Some bimodal current ripple marks suggest deposition in ebbing and flooding currents on a tidal flat. A thick red-bed sequence, represented by the covered slopes of unit 225, may mark an essentially complete regression of the shore at the top of the middle third of the measured section.

The upper third of the section (units 226–257) starts with algal limestones. These are interpreted to be deposits of intertidal flat sequence. The thick sequence of red sandstones and siltstones of unit 241 probably represents a supratidal sequence. What are considered to be normal marine limestones at the

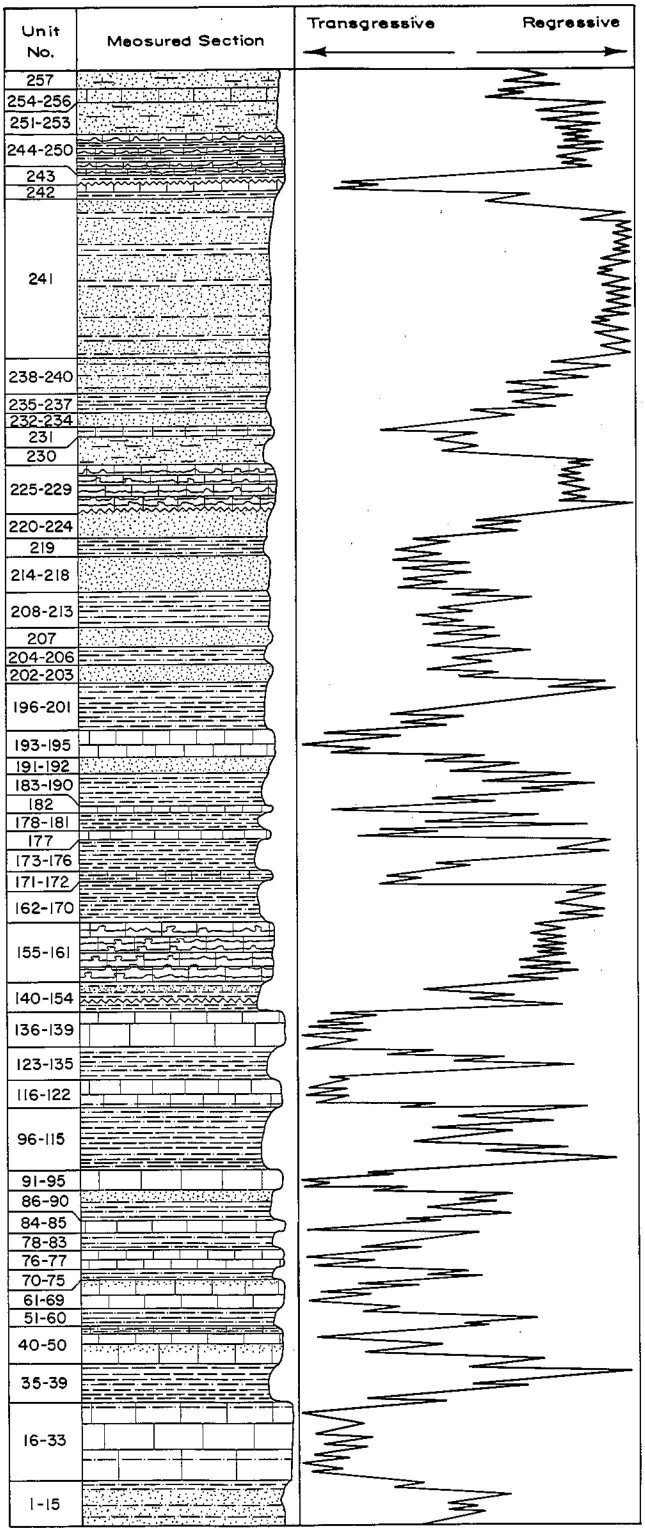

FIGURE 20.—Transgressive-regressive sequences in Thaynes Formation, showing repetition of environments and overall regression upward in the sequence.

base of the covered sequence of unit 242 represent a minor transgression within the major regression of these units.

The occurrence of conodont Range Zone 10, 72.5 m from the base in the measured section, as opposed to 256 m above the base in Solien's (1979, p. 294) Salt Lake City section, is good evidence for thinning of the Thaynes Formation toward the southeast, an expected result with the shoreline advancing in that direction.

The intertidal flat deposits of the Thaynes Formation are similar to those of The Wash, an intertidal flat area fully exposed to the ocean on the east coast of Great Britain. The upper portions of the intertidal flat of The Wash are characterized by silty clays to silty sands which are well laminated and contain matted filaments of algae like those of the Thaynes Formation. The middle portion of The Wash is well rippled and has abundant trails and burrows like part of the Thaynes sequence. The lower portion of The Wash contains small symmetrical ripples oriented both parallel and perpendicular to shore, has abundant interference ripples, and has thicker bedded and more poorly stratified sand. Sediments of The Wash (Evans 1965, p. 215) contain some features not noted in the intertidal Thaynes beds, however. Sediment size is somewhat coarser, and it is at a higher latitude than that proposed for the Thaynes Formation. In gross aspects, however, the two are similar.

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