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Contents

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Paleontology and Paleoecology of the Curtis Formation in the Uinta Mountains Area, Daggett County, Utah*

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ABSTRACT.—The Oxfordian Curtis Formation represents the last major expansion of the epeiric seas into Utah during Late Jurassic. A measured section in Finch Draw, near Flaming Gorge Reservoir, exposes two well-defined members within the Curtis Formation. The non-resistant lower member, approximately 69 feet thick, consists of glauconitic, calcareous siltstone, sandstone, and non-calcareous shale. Casts and molds of pelecypods are present in most beds, belemnites are common, and ammonites are present but rare. Naticacean gastropods, crinoid ossicles, echinoid spines, holothuroids, and foraminifera make up most of the microfossils and all have been glauconitized. Pelecypod shells show little alteration where the sediments are highly calcareous. Sediments are laminated to thin-bedded, and a few uppermost layers are cross-bedded.

The resistant upper member of the Curtis Formation in Finch Draw consists of approximately 82 feet of oolitic and sandy limestone. Rhynchonellid brachiopods are present throughout the unit and produce coquinoid limestone horizons. Some pelecypods, gastropods, and crinoid ossicles are also present. Well-defined crossbeds and ripple marks are developed in the upper member.

The lower member was deposited in water below normal wave base. The water was periodically turbid. Deposition was slow, allowing formation of glauconite. Pelecypods were able to thrive. Periods of quiescence allowed formation of interbedded organic-rich shale.

Sea level appears to have lowered during deposition of the upper member, with an increase in current activity, higher concentration of $CaCO_3$, and formation of oolites. The thick-shelled rhynchonellid brachiopods were deposited in this environment.

Curtis deposition ceased and continental deposits of the overlying Morrison Formation define the upper boundary.

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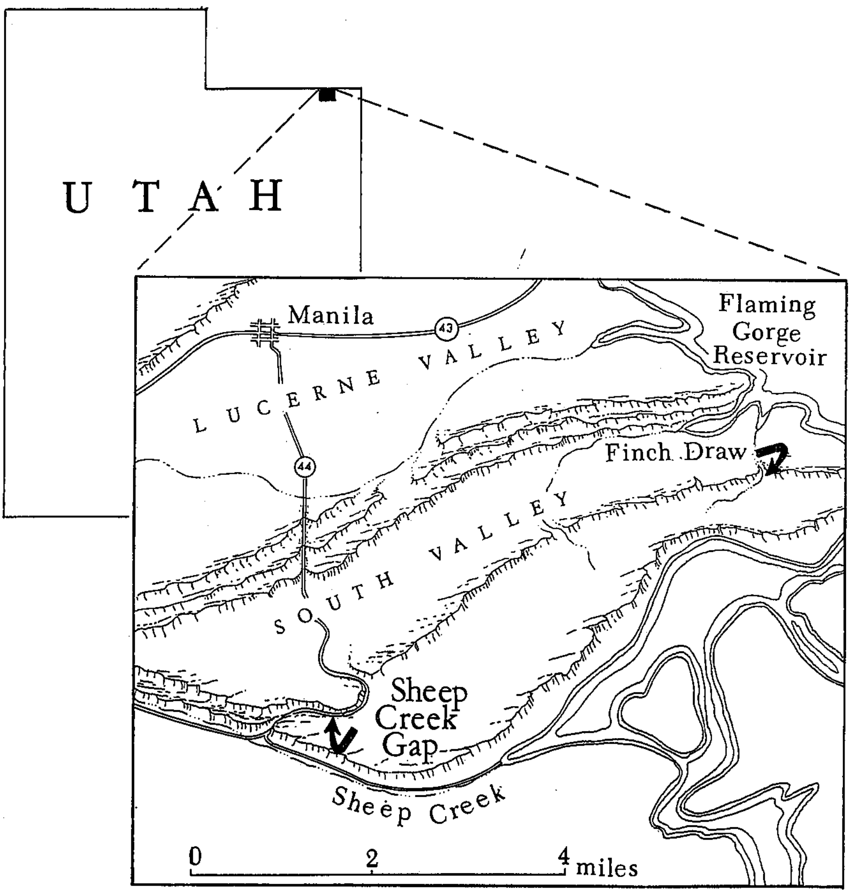
*A thesis submitted to the faculty of the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science.

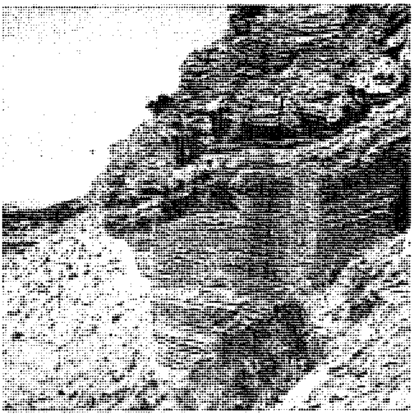
INTRODUCTION

Location and Geologic Setting

This paleoecological study of the Curtis Formation was made of exposures south of Manila, Daggett County, Utah (Text-fig. 1). The Curtis Formation is expressed by northward dipping beds forming an east-west cuesta. The steep south slope is carved on usually nonresistant siltstone and sandstone strata, and the overlying ridge and dip slope are formed by resistant oolitic limestone. The best exposure of Curtis rocks for measurement and collecting is located in Finch Draw, about five miles east of Utah Highway 44, near the shores of Flaming Gorge Reservoir where the Curtis Formation is 151 feet thick (Plate 1, fig. 2). A second excellent exposure is located in Sheep Creek Gap on Highway 44 about four miles south of Manila, where a partial section of 143 feet was measured (Plate 1, fig. 1).



TEXT-FIGURE 1.—Index map and localities of studied sections of the Curtis Formation in northeastern Utah.



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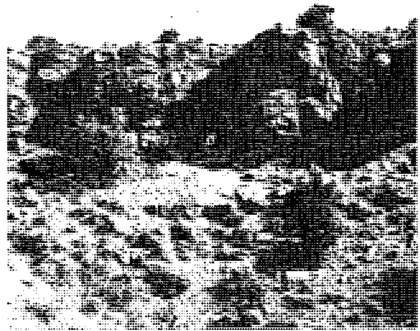

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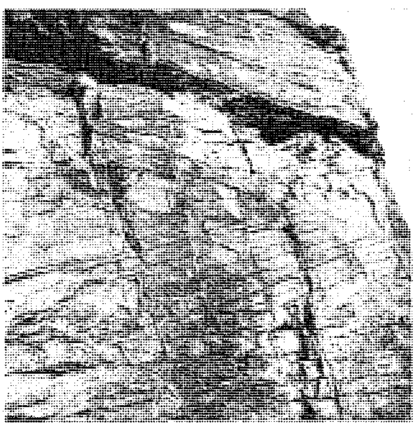

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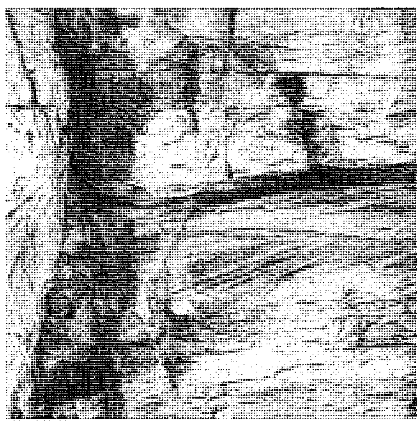

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PLATE 1

SEDIMENTARY STRUCTURES AND FIELD VIEWS

FIG. 1.—Exposure of Curtis Formation near measured section, Sheep Creek Gap.
FIG. 2.—Exposure of described section of Curtis Formation, Finch Draw.
FIG. 3.—Planar crossbedding exposed in unit FD-29 of the upper member, Finch Draw.
FIG. 4.—Crossbedding exposed in unit FD-28 of the upper member, Finch Draw.

The Curtis Formation represents deposits of the last major expansion of epeiric seas during Late Jurassic time. Imlay (1948, p. 17) has placed the Curtis Formation in the *Cardioceras cordiforme* ammonoid faunal zone which is correlated with the Lower Oxfordian of Europe. Imlay (1952, pp. 960-962) has also correlated the Curtis Formation with the Stump Sandstone of southeastern Idaho ,the Swift Formation of western Montana, the "upper Sundance" of central Wyoming, part of the Summerville Formation in the San Rafael Swell area, and the Wanaka Formation of the San Juan Mountain area of Colorado.

The Curtis Formation overlies the Callovian Entrada Sandstone with a knife-edge contact that appears to be conformable. The Entrada Sandstone is marine in this area as evidenced by large marine pelecypods and *Pentacrinus* columnals in the rocks. The two formations are easily distinguished since the Entrada Sandstone is a reddish orange sandy siltstone and the Curtis Formation is a glauconitic green sandy siltstone.

Overlying the Curtis Formation is the non-marine Morrison Formation mostly of Kimmeridgian age. The base of the Morrison Formation consists of variegated mudstone and has a sharp, but many times obscured, contact with the Curtis Formation.

Previous Work

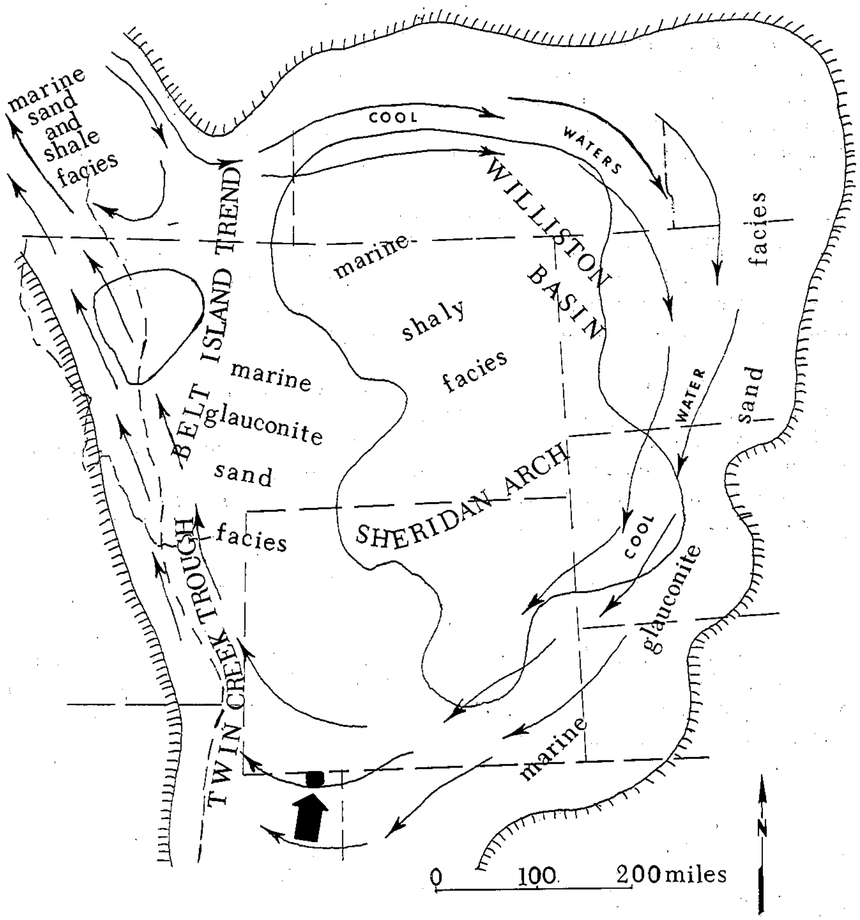
In their regional studies of the 1870's, Clarence King, S. F. Emmons, and J. W. Powell made note of the Mesozoic strata in the Uinta Mountains area but did not designate the Curtis Formation as such.

The Curtis Formation was named for exposures at Curtis Point on the northeast side of the San Rafael Swell, in southeastern Utah, by Gilluly and Reeside (1928, p. 78). There they described green-gray conglomerate, shale, and heavy-bedded gray sandstone in the section.

Thomas and Krueger (1946, p. 1278) in describing the early Mesozoic stratigraphy of the Uinta Mountains used Heaton's (1939, p. 161) classification of Stump Formation in sections measured in Weber River, Duchesne River, and Lake Fork areas, and Curtis Formation in sections measured in Vernal, Skull Creek, Split Mountain, and Manila areas. Thomas and Krueger compared lateral variations in lithology in early Mesozoic formations, but no paleoecological interpretations were offered. Imlay (1957, p. 498-501), in his paper on the paleoecology of the Jurassic seas, has done more to reconstruct the paleoenvironment of the Curtis Formation than any of the previous workers. Using marine Jurassic fossils and measured sections from the western United States, he zoned the Jurassic into eight principal faunal zones. His work, however, has been regional and not related to local paleoecological conditions.

A comprehensive paper on the geology of the Dinosaur National Monument was presented by Untermann and Untermann (1954), in which the Curtis Formation was described and general geology discussed.

Hansen (1965, p. 82) measured a section of the Curtis Formation in Finch Draw in his study of the Flaming Gorge area. He described an upper unit of oolitic limestone and sandstone and a lower unit of sandstone, siltstone, and oolitic limestone. He identified some brachiopods, pelecypods, and cephalopods but did not discuss their environmental significance.



TEXT-FIGURE 2.—Generalized map showing current and sediment distribution during Curtis time. (modified from Peterson, 1957)

Pipiringos of the U. S. Geological Survey is presently working on the stratigraphic relationships of Mesozoic strata in the area of Flaming Gorge (Imlay, personal communication).

Methods of Study

Field study consisted of finding the best exposed sections of the Curtis Formation and measuring the individual units in succession. A stratigraphic column was described, and representative samples were collected from each unit. Photographs were taken of each area measured.

In the laboratory the collected fossils were classified and related to the stratigraphic column. Fossils were also counted as to numbers and kinds in each sample where possible, and using a square-centimeter grid, fossils were counted for density relationships. Available brachiopods were measured as to width and a size-frequency curve was derived where possible. Fossils, ichnofossils, sedimentary structures, and thin sections of the rock types were photographed. Insoluble residues were made from each sample and the results are illustrated in a graph. Clay minerals were X-rayed for determination, and petrographic studies were made on the thin sections of each rock sample.

Acknowledgments

I would like to thank Dr. Morris S. Petersen who served as chairman of my committee and offered so much time and assistance to this study. Dr. W. Kenneth Hamblin is appreciated for serving on my committee and Drs. J. Keith Rigby, Harold J. Bissell, and W. Revell Phillips for their advice and encouragement.

I am grateful to my brother, Grant Hoggan, for assisting me with the field work, and to Thomas F. White for the use of his car as a field vehicle.

I would especially like to express my appreciation to my wife, Karen, for her effort and constant encouragement during this study.

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STRATIGRAPHY AND SEDIMENTATION

Petrology of the Curtis Formation

The following described section was measured at Finch Draw six miles southeast of Manila, Utah (Text-fig. 1) Lateral variations are noted from a partial supplementary section measured at Sheep Creek Gap approximately four miles south of Manila, Utah, on Utah Highway 44.

FINCH DRAW SECTION

Unit No.	*Thickness in Feet* *Unit*	*Cumulative*	*Description*
Jurassic Entrada Sandstone Lower Member Curtis Formation			
FD1 /	5	5	Siltstone, arenaceous, glauconitic, calcareous; green-gray, weathers light green-gray; quartz glauconite and clay; very fine sand-to silt-size; poorly sorted; calcite cement; poorly bedded; forms slope; *Pachyteuthis "densus"* (Meek and Hayden); *Pentacrinus* ossicles, naticacean gastropods, and foraminifera present as internal molds of glauconite; fragment of vertebrate jaw bone at Sheep Creek Gap
FD2	1.5	6.5	Limestone, arenaceous; green-gray, weathers light green-gray; calcite, quartz, and glauconite; very fine sand-size grains and fine crystalline limestone; poorly sorted; poorly bedded; forms ledge; *Pachyteuthis "densus"* (Meek and Hayden), *Pentacrinus* ossicles, naticacean gastropods, *Pinna* sp., *Trigonia* sp.; *Isocardia?, Oxytoma?, Protocardia?* occur as internal molds; paschichnia burrows as described by Seilacher (1964, p. 299)
FD3	3.5	10	Siltstone, arenaceous, glauconitic, calcareous; green-gray, weathers gray-brown to green; quartz, glauconite, and clay; very fine sand- to silt-size;

			poorly sorted; calcite cement, laminated to thin-bedded; forms slope; *Pachyteuthis "densus"* (Meek and Hayden), *Pentacrinus* ossicles, naticacean gastropods, and *Protocardia?;* paschichnia burrows
FD4	1	11	Siltstone, arenaceous, glauconitic calcareous; light green-gray, weathers brownish gray, top one inch rusty brown; quartz, and glauconite; very fine sand- to silt-size; poorly sorted; calcite cement; poorly bedded; forms ledge; *Pachyteuthis "densus"* (Meek and Hayden), naticacean gastropods; *Arctica?, Protocardia?,* and *Trigonia* sp. as casts; paschichnia burrows
FD5	1	12	Siltstone, arenaceous, glauconitic, calcareous; light green-gray, weathers brown-gray, quartz and glauconite, very fine sand- to silt-size; poorly sorted; calcite cement; poorly bedded; forms ledge; *Pachyteuthis "densus"* (Meek and Hayden), *Ostrea* sp., *Nucula* sp.; paschichnia burrows
FD6	.5	12.5	Limestone, silty, glauconitic; light green-gray, weathers light brown-gray; calcite quartz and glauconite; very fine sand- to silt-size; fine crystalline calcite; poorly sorted; poorly bedded; forms ledge; coquinoid *Pachyteuthis "densus"* (Meek and Hayden), *Cardioceras?, Ostrea* sp., *Nucula* sp., *Gryphea* sp., *Lima* sp., *Astarte?, Pleuromya?*
FD7	5.5	18	Siltstone, arenaceous, glauconitic, calcareous; gray-green, weathers light gray; quartz and glauconite; very fine sand- to silt-size; poorly sorted; calcite cement; poorly bedded; forms slope; *Pachyteuthis "densus"* (Meek and Hayden),*Pentacrinus* ossicles, gastropods, pelecypod fragments, possible crustacean fragments, molds and casts.
FD8	.5	18.5	Siltstone, arenaceous, glauconitic, calcareous; gray-green, weathers light gray; quartz, glauconite, and clay; very fine sand- to clay-size; poorly sorted; calcite cement; poorly bedded; forms ledge; coquinoid, gastropods, echinoid spines, *Lima* sp., *Pinna* sp., *Camptonectes?*
FD9	1.5	20	Siltstone, arenaceous, glauconitic, calcareous; gray-green, weathers brown-gray; quartz and glauconite; very fine sand-size; poorly sorted; calcite cement; poorly bedded; forms slope; pelecypod molds and casts; paschichnia trails
FD10	1	21	Siltstone, arenaceous, glauconitic, calcareous; gray-green, weathers brown-gray; quartz, glauconite, and clay; very fine sand- to clay-size; poorly sorted; calcite cement, laminated, bedded to massive; forms ledge; *Pachyteuthis "densus"* (Meek and Hayden), *Gryphaea* sp., *Camptonectes?, Protocardia?,* trails
FD11	5	26	Siltstone, arenaceous, glauconitic, calcareous; gray-green, weathers gray-brown; quartz, glauconite, and clay; very fine sand- to clay-size; poorly sorted; calcite cement; poorly bedded; forms slope; *Pachyteuthis "densus"* (Meek and Hayden), *Lima* sp., *Ostrea* sp., *Pholadomya?, Arctica?, Pleuromya?*
FD12	2	28	Siltstone, glauconitic, calcareous; gray-green, weathers gray-brown; quartz and glauconite; silt-size; poorly sorted; calcite cement; poorly bedded; forms ledge; *Pachyteuthis "densus"* (Meek and

			Hayden), naticacean gastropods, *Arctica?, Camptonectes?*, brachiopods?, paschichnia tubes
FD13	1	29	Siltstone, arenaceous, glauconitic, calcareous; gray-green, weathers light brown; quartz and glauconite; very fine sand- to silt-size; poorly sorted; calcite cement; poorly bedded; forms slope; *Pentacrinus* ossicles, naticacean gastropods, *Lima?*
FD14	1	30	Siltstone, arenaceous, glauconitic, calcareous; gray-green, weathers gray; quartz, glauconite, and clay; very fine sand-to clay-size; poorly sorted; calcite cement; bedding appears disturbed by bioturbation; forms ledge
FD15	4	34	Siltstone, arenaceous, glauconitiic, calcareous; gray-green, weathers gray-brown; quartz, glauconite, and clay; very fine sand- to clay-size; poorly sorted; calcite cement; poorly bedded; forms slope; naticacean gastropods, *Pentacrinus* ossicles, *Ostrea* sp.
FD16	1.5	35.5	Interbedded siltstone and sandstone, glauconitic, calcareous; gray-green, weathers gray-brown; quartz, glauconite, and biotite; poorly sorted siltstone, well sorted sandstone; calcite cement; bedded, laminated; forms ledge; coral-like organisms, burrows
FD17	10	45.5	Interbedded sandstone, glauconitic, calcareous; and shale, noncalcareous; sandstone light gray to green, weathers gray-green; shale gray, weathers light gray; quartz, glauconite, and clay; sandstone and shale well sorted; calcite cement in sandstone; sandstone and shale laminated; forms slope; paschichnia burrows and gastropods in sandstone; shales unfossiliferous
FD18	1.5	47	Sandstone, glauconitic, calcareous; gray-green, weathers light gray-green; quartz and glauconite; very fine sand-size; well sorted; calcite cement; thin bedded; forms ledge; apparently unfossiliferous
FD19	22	69	Interbedded sandstone, silty, glauconitic, calcareous; and shale, noncalcareous; gray-green sandstone, weathers light gray-green; gray shale, weathers light gray; quartz, glauconite, and clay; very fine sand-size and clay-size; sandstone and shale well sorted; calcite cement in sandstone; laminated sandstone and shale; forms slope; unfossiliferous
Upper Member Curtis Formation			
FD20	12	81	Limestone, oolitic, clay pebbles; light brown, weathers rusty brown; calcite; quartz and glauconite as nuclei; less than one millimeter diameter; fair sorting; calcite matrix; poorly bedded, massive beds one to two feet thick, crossbedded and ripplemarked; forms ledge; pelecypod and gastropod molds and casts
FD21	2	83	Shale, noncalcareous; dark gray, weathers light gray; clay minerals and organic material; clay-size; well sorted; thin laminae one eighth inch; forms slope; unfossiliferous
FD22	3	86	Limestone, oolitic, mud pebbles; light brown, weathers brown-gray; calcite, quartz and glauconite nuclei; less than one millimeter diameter

			oolites; one and one-half centimeter diameter mud pebbles; fair sorting; calcite matrix; medium crossbeds with one to two-foot sets; forms ledge; pelecypod molds and casts on bedding planes
FD23	1	87	Limestone, mud pebbles, pelletoid, oolitic; light brown, weathers gray-brown; calcite, quartz and glauconite as nuclei in oolites, calcareous glauconite in pebbles; oolites less than one millimeter diameter, pebbles two and one-half centimeter diameter; fair sorting; calcite matrix; massive thin bedded; forms ledge; *Camptonectes?;* laterally at Sheep Creek Gap mud pebble conglomerate with five to eight centimeter pebbles of laminated clay material; dark gray shales are well burrowed with paschichnia burrows
FD24	11	98	Sandstone, quartzitic, glauconitic; light green, weathers gray-green; quartz, and glauconite; very fine sand size; well sorted; little friable calcite cement; no apparent crossbeds but beds appear truncated by overlying beds; forms ledge in some places, slope in others; burrows and shell fragments; appears three feet thick at Sheep Creek Gap
FD25	1	99	Limestone, oolitic, fossiliferous; gray-green, weathers rusty brown; calcite, quartz and glauconite as nuclei; less than one millimeter diameter ooids; fair sorting one-half to one-foot beds; forms ledge; *Pachyteuthis "densus"* (Meek and Hayden), naticacean gastropods, pelecypods, brachiopod fragments; laterally forms one foot coquina beds of *Kallirhynchia myrina* (Hall and Whitfield)
FD26	2	101	Limestone, oolitic, fossiliferous; gray-brown, weathers brown; calcite, quartz and glauconite as nuclei of ooids; sand-size less than one millimeter diameter; fair sorting; crossbedded with one foot sets; forms ledge; pelecypod and brachiopod fragments
FD27	3	104	Limestone, oolitic, fossiliferous; gray-brown, weathers brown; calcite, quartz, and glauconite; sand-size less than one millimeter diameter; fair sorting; thin one-half inch beds; forms ledge; *Kallirhynchia myrina* (Hall and Whitfield) gastropods; *Pentacrinus* ossicles, ostracods
FD28	4	108	Limestone, oolitic, fossiliferous; gray-green, weathers brown; calcite, quartz, and glauconite; sand-size less than one millimeter diameter; well sorted; crossbedded one-foot sets; forms ledge; *Kallirhynchia myrina* (Hall and Whitfield)
FD29	5	113	Limestone, oolitic; gray-brown, weathers brown; calcite, quartz and glauconite; sand-size less than one millimeter diameter; well sorted; crossbedded one- to two-foot sets; forms ledge; coquina beds one-half foot thick, brachiopod shell debris
FD30	9	122	Limestone, oolitic , fossiliferous; gray-brown, weathers brown; calcite, quartz, and glauconite; sand-size less than one millimeter diameter; well sorted; cross-bedded one- to two-foot sets; forms ledge; *Kallirhynchia myrina* (Hall and Whitfield), foraminifera
FD31	3	125	Limestone, oolitic, coquinoid; gray, weathers brown; calcite, quartz, and glauconite; sand-size

			less than one millimeter diameter; well sorted; cross-bedded one- to two-foot sets; forms ledge; *Pentacrinus* ossicles, brachiopod, gastropod, and ostracod debris; laterally at Sheep Creek Gap five-foot shell bank with silt and sand as interstitial material; brachiopods, pelecypods, and gastropods
FD32	3	128	Limestone, oolitic; gray, weathers brown; calcite, quartz, and glauconite; sand-size less than one millimeter diameter; well sorted; ripple-bedded, micro-crossbeds one to two centimeter sets; forms ledge; brachiopod fragments
FD33	8	136	Limestone, oolitic; gray, weathers gray-brown; calcite, quartz, and glauconite; sand-size; well sorted; crossbedded; forms ledge; brachiopod debris
FD34	4	140	Sandstone, calcareous, glauconitic; gray, weathers gray-brown; quartz and glauconite; very fine sand-size; well sorted; calcite cement; laminated, three to six millimeters thick, large trough cross-beds; forms ledge; unfossiliferous
FD35	3	143	Sandstone, oolitic, calcareous; gray, weathers gray-brown; quartz, glauconite, and calcite; fine sand-size grains; well sorted; calcite matrix; even-bedded; forms ledge; brachiopod debris
FD36	4	147	Limestone, oolitic; gray, weathers brown; calcite, quartz, and glauconite; sand-size less than one millimeter diameter ooids; well sorted; cross-bedded one- to two-foot sets; forms ledge; brachiopod debris
FD37	4	151	Limestone, oolitic gray, weathers brown; calcite and quartz; very fine sand-size; well sorted; massive beds; forms ledge; unfossiliferous

Jurassic Morrison Formation

Mineralogy

Quartz is the most common detrital mineral present in the Curtis Formation. It occurs as very fine sand- to silt-size grains from one eighth millimeter to one thirty-second millimeter. Most of the grains are subspherical and subrounded to subangular. The quartz grains appear to be poorly sorted except in the friable sandstone units where they are fairly well sorted. The sphericity and roundness of the grains indicate a reworking of the grains prior to deposition. Much finer quartz grains exist in many burrows present in the sediments. Very fine quartz grains form the nuclei for the accretion of calcium carbonate in the formation of ooids in the oolitic limestone beds of the upper member.

A modern analogue to the very fine sands that occur in the lower member is found in sublittoral marine sediments today. Although the grains of sand found in a sublittoral environment tend to be better sorted and better rounded than those in a littoral environment, this characteristic can be quite variable depending on local conditions (Pettijohn, Potter, and Siever, 1966, p. 188).

Calcite is present as cement in the clastic units of the lower member and occasionally as matrix material in limestone units. Shells of pelecypods, gastropods, brachiopods and crinoid ossicles contribute considerably to the calcite content of some units. Coquinoid beds are common with bioclastic debris forming from 50 to 60 percent of the rock material. Sparry calcite is present in some recrystallized shells and forms the infilling deposits in others. Shells were probably dissolved during diagenesis to produce the calcite for cement in the clastic sediments.

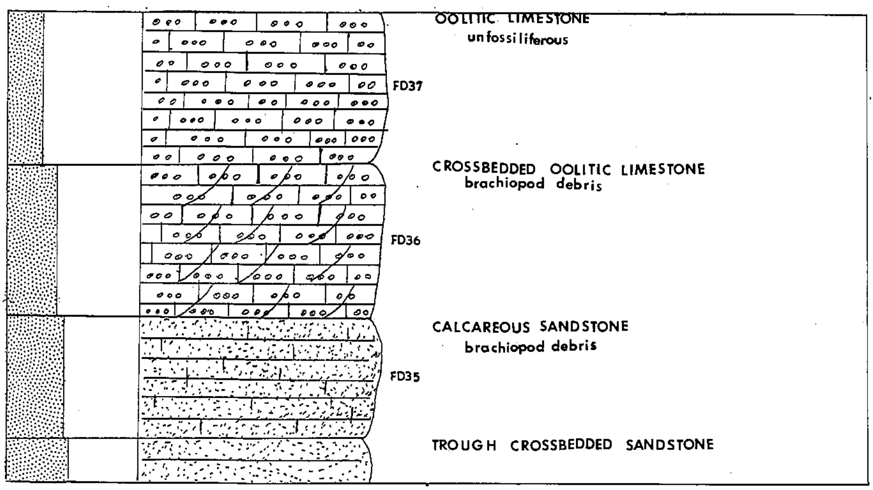
Oolites and coated pellet grains compose a great part of the beds in the upper member. Most of these are less than one millimeter in diameter. Calcium carbonate appears to have been abundant at the time of formation of these units. Calcareous algae possibly contributed to the carbonate content of the sediments as well. Insoluble residues show the fluctuations in the amount or occurrence of calcium carbonate present in the different units in the section (Text-fig. 3).

Calcite is common as cementing material in most marine sediments today and forms as oolites in ideal conditions in both marine and nonmarine environments. Agitated warm water, calcium carbonate concentrations near the saturation point, and an alkaline pH condition appear to be essential in oolite development. These conditions are present along the shores of the Great Salt Lake of Utah and the Bahama oolite banks in the West Indies.

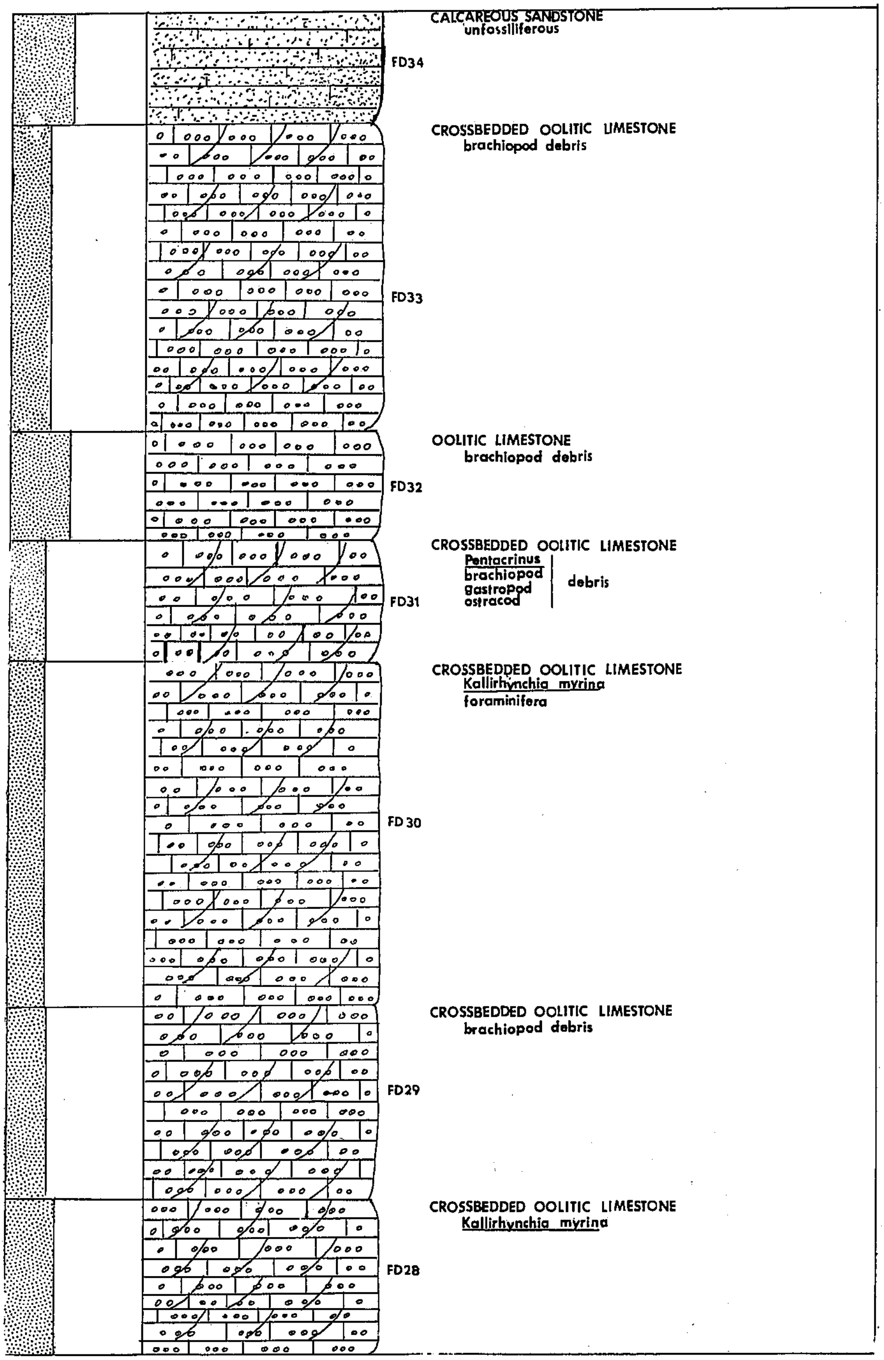
In the Bahama oolite shoals moderate to high velocity currents are present. Oolites compose up to 90 percent of the shoals. Grain movement is necessary for the coated grains to develop. The grain movement is indicated directly by seemingly incessant rapid migration of small sand ripples and abundance of large pararipples (Purdy, 1964, p. 255-56).

Glauconite occurs in the Curtis Formation as very fine sand-size to silt-size grains from one-eighth to one thirty-second millimeter in diameter. The grains are vitreous, subrounded, and poorly sorted; and commonly they are lobate or botryoidal shaped. Glauconite is commonly present as infilling material for gastropods, crinoid ossicles, foraminifera, and what are apparently holothuroid sclerites. According to Takahashi (1939, p. 506) this is a common occurrence of the mineral glauconite.

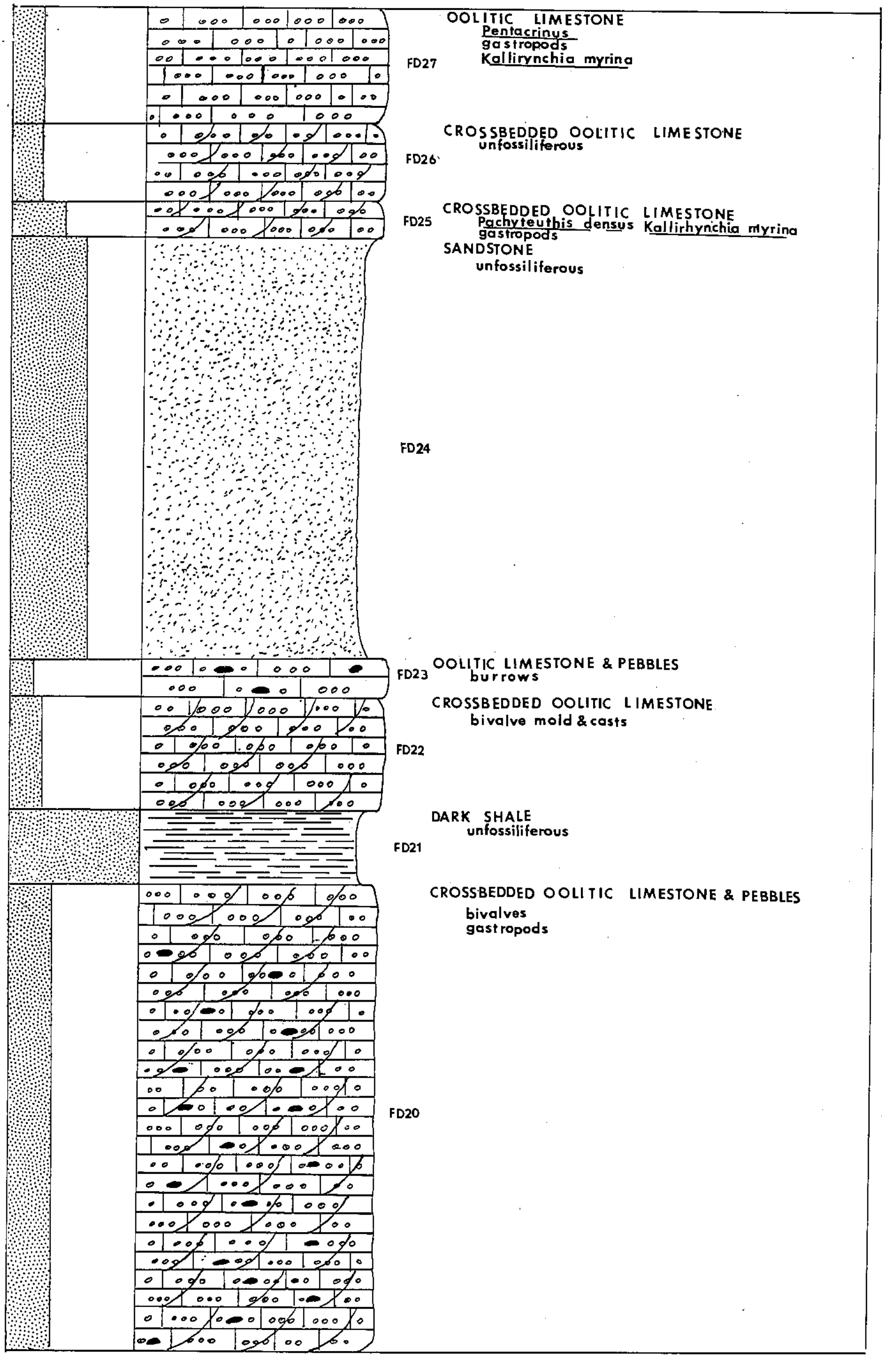
Glauconite is more abundant in the lower member, giving it a green-gray appearance. There seems to be greater concentration of glauconite in the inter-



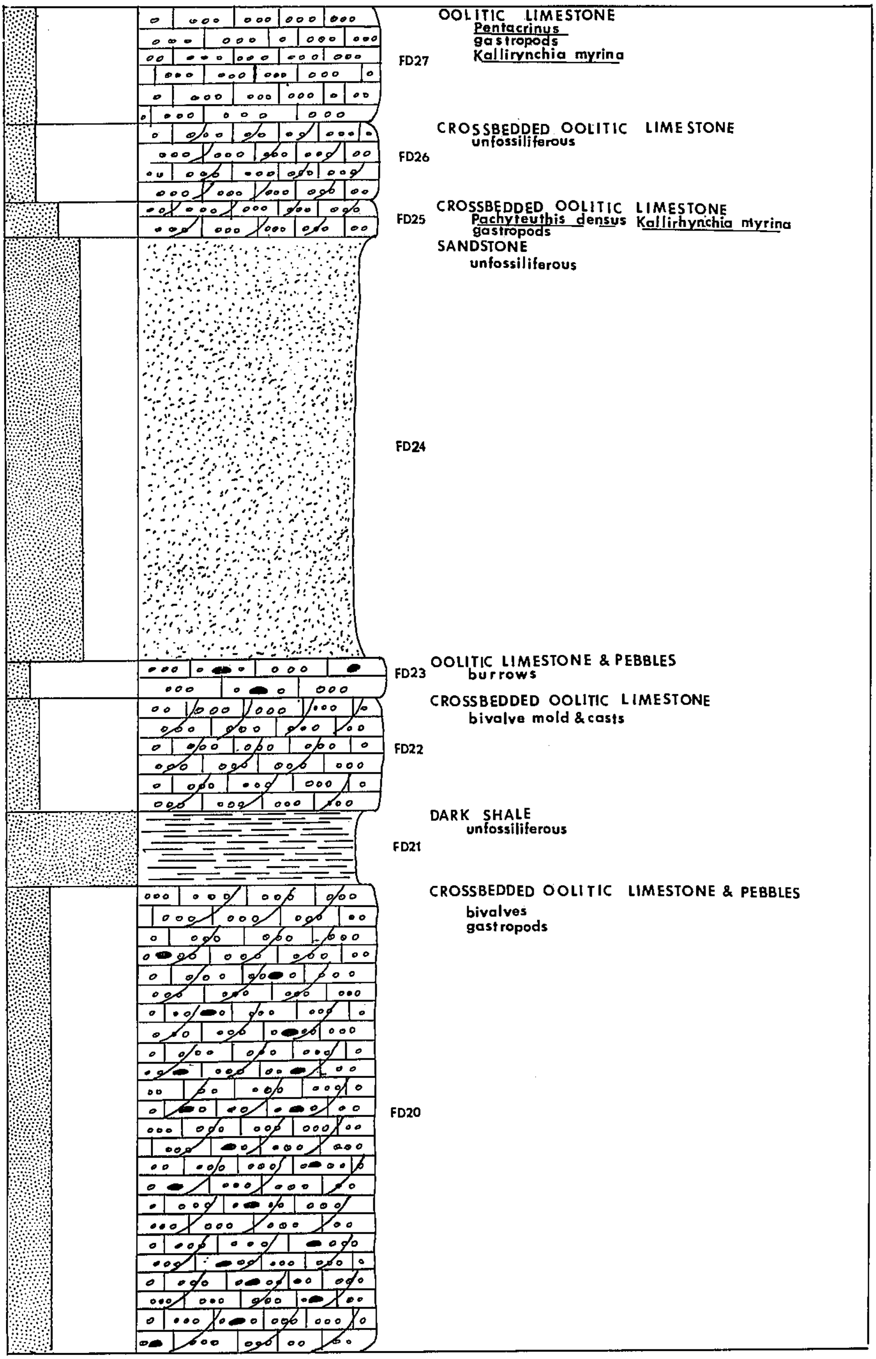
TEXT-FIGURE 3.—Measured section at Finch Draw.



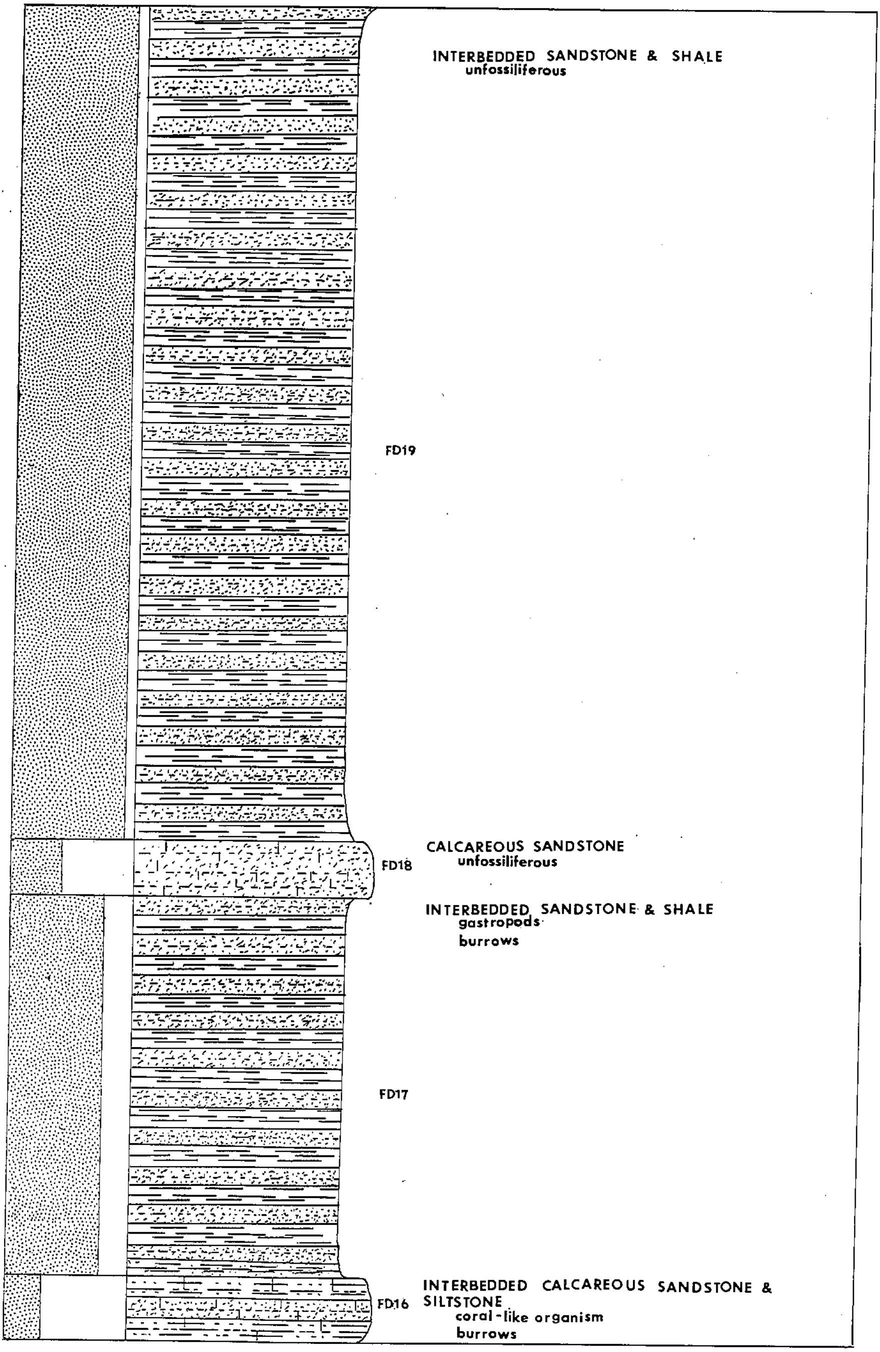
TEXT-FIGURE 3.—(continued).



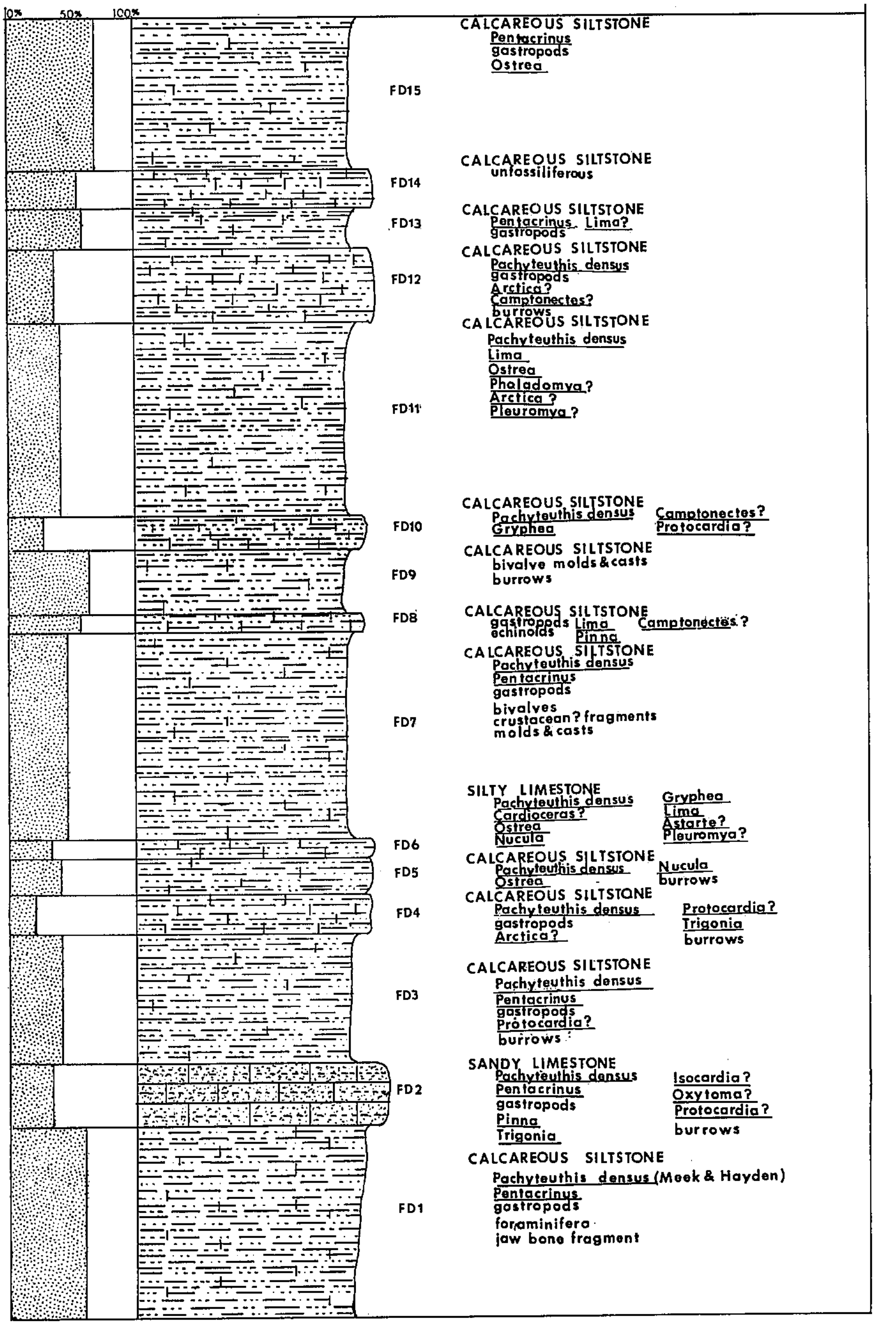
TEXT-FIGURE 3.—(continued).



TEXT-FIGURE 3.—(continued).



TEXT-FIGURE 3.—(continued).



TEXT-FIGURE 3.—(continued).

bedded sandstones of the lower member than in any other part of the section. Some of these dark green beds are up to three or four inches thick. Interlamination of quartz and glauconite grains defines the foresets of some of the crossbedded units. Glauconite grains also occur as nuclei in the ooids of the oolitic limestone beds but are not as common as quartz in the formation of the ooids.

Most of the glauconite appears to be authigenic with little evidence of fracturing or irregularity. The grains tend to be ovoid to subspherical in shape. Authigenic glauconite is formed associated with clays that are composed predominantly of illite (Light, 1952, p. 73-75).

Glauconite forms today in modern seas in a moderately anaerobic environment which appears to be essential for its formation. Sessile benthonic organisms, such as corals and bryozoans that require highly oxygenated waters, are absent from such an environment.

Glauconite is an hydrous silicate of K, Al, Mg, ferrous an dferric iron. It may form, for example, when biotite is altered by oxidation of part of the iron, retention of K, hydration, partial loss of Al, and changes in structure (Galliher, 1953, p. 1351). Biotite, feldspars, and other iron-bearing minerals are considered the source for glauconite. Along the California coast today, glauconite forms at the expense of biotite. Decaying organic matter is important in glauconite formation and helps to maintain a slightly anaerobic reducing environment.

Glauconite usually forms in sublittoral or neritic depths between 10 to 400 fathoms, at temperatures between 8° to 20° C, or a temperate to warm temperate condition (Lochman, 1949, p. 56). Some glauconite appears to form where cold and warm currents meet and in somewhat agitated water, with periods of quiescence, in an area of relatively little sedimentary influx (Hadding, 1932).

Biotite occurs as very small black flakes in some of the beds but is usually inconspicuous. It is restricted to the lower member where glauconite and quartz materials predominate. Biotite is associated genetically and spacially with glauconite formation in modern seas and is derived as a detrital sediment from surrounding source areas.

Illite was detected by X-ray analysis, and appears to be the dominant clay mineral in the sediments along with vermiculite. Illite and other clay minerals compose up to 10 percent of some silt units and is higher in the shale units. Fine clay material also fills many tubes and burrows, and is found in some gastropod shells producing internal molds.

Illite is a common mineral in modern marine sediments, forming from 50 to 100 percent of total clay minerals in some areas of the sea floor. It is found at many latitudes from subarctic to subtropical climates. It appears to form *in situ* in marine conditions from the alteration of smectite, a variation of halloysite, or it may be transported into the environment after forming on land from weathering of acidic igneous rocks. The mineral illite forms in the Mississippi River Delta particularly in areas of slow sedimentation (Melney and Early, 1958, p. 331).

Sedimentary Structures

The sedimentary structures that are common in the Curtis Formation are crossbedding, microcrossbedding, ripple marks, imbricate conglomerate, and organism burrows. Planar crossbedding is present primarily in the upper unit associated with oolitic limestone (Plate 1, figs. 3,4). Most of the sets of crossbeds are from one to two feet thick and form troughs near the top of the member.

Random measurements of crossbed orientation indicate the currents were generally from the south-southeast. Accurate directions are not available because of poor exposures of the crossbeds. The crossbedded units are separated by flat tabular units, apparently sheet deposits.

Microcrossbedding is prevalent in some units with sets up to one inch thick. Current ripple marks are relatively low relief reaching maximum of one inch in height and are present on many bedding planes and even occur on the foresets of some crossbeds (Plate 2, fig. 1). The weathering of some units enhances definite ripple bedding. Clay pebble conglomerates are found in the upper unit and in places are imbricated, with the pebbles dipping toward the east (Plate 2, fig. 2).

Crossbeds and ripple marks are common in most modern marine and fluvial environments and indicate prevailing current directions at the time of deposition. Imbrie and Buchanan (1965, p. 156, 157) describe very similar crossbedded sequences in the carbonate sands of the Bahamas. They also mention flat sheet deposits separating the truncated surfaces, which form in the upper flow regime and on shallow beach or level bottoms (Imbrie and Buchanan, 1965, p. 172).

Conglomerates are associated with fine sediments in modern seas where turbidity currents have moved the larger materials into an environment of low energy, or perhaps where storm waves have broken up fine bottom sediments and developed pebbles by transporting and rounding the materials more or less *in situ*. The pebbles in the upper memeber do not appear to be concretionary; therefore, *in situ* formation of these large clasts is improbable. The large clay boulders in the lower member are probably concretions due to the concentration of fine materials around a nucleus. These commonly occur in shale units (Weller, 1960, p. 116). Similar concretions are known to contain fossil organisms in some instances (Imlay, 1947, p. 497).

Source of Sediments

Imlay (1957, p. 477) indicates that Oxfordian sediments were derived almost entirely from the west and south except for a small area in northwestern Colorado. Peterson (1957, p. 403) shows on his map an emergent area to the west. His map (Text-fig. 2) also shows possible current distribution during Oxfordian time, currents which would influence the kinds and distribution of sediments. It might also indicate where glauconite could form, where incoming cool marine waters met warmer restricted waters as suggested by Hadding (1932). Such current patterns would also affect oolite formation since more $CaCO_3$ would be dissolved in incoming cool water and could precipitate as the waters became warmer inland.

FAUNAL RELATIONSHIPS

Faunal Composition

Invertebrates
- Foraminifera
  - Planispirally tightly coiled foraminifera (internal mold)
- Coelenterates
  - coral-like form (cast)
- Brachiopods
  - *Kallirhynchia myrina* (Hall and Whitfield)

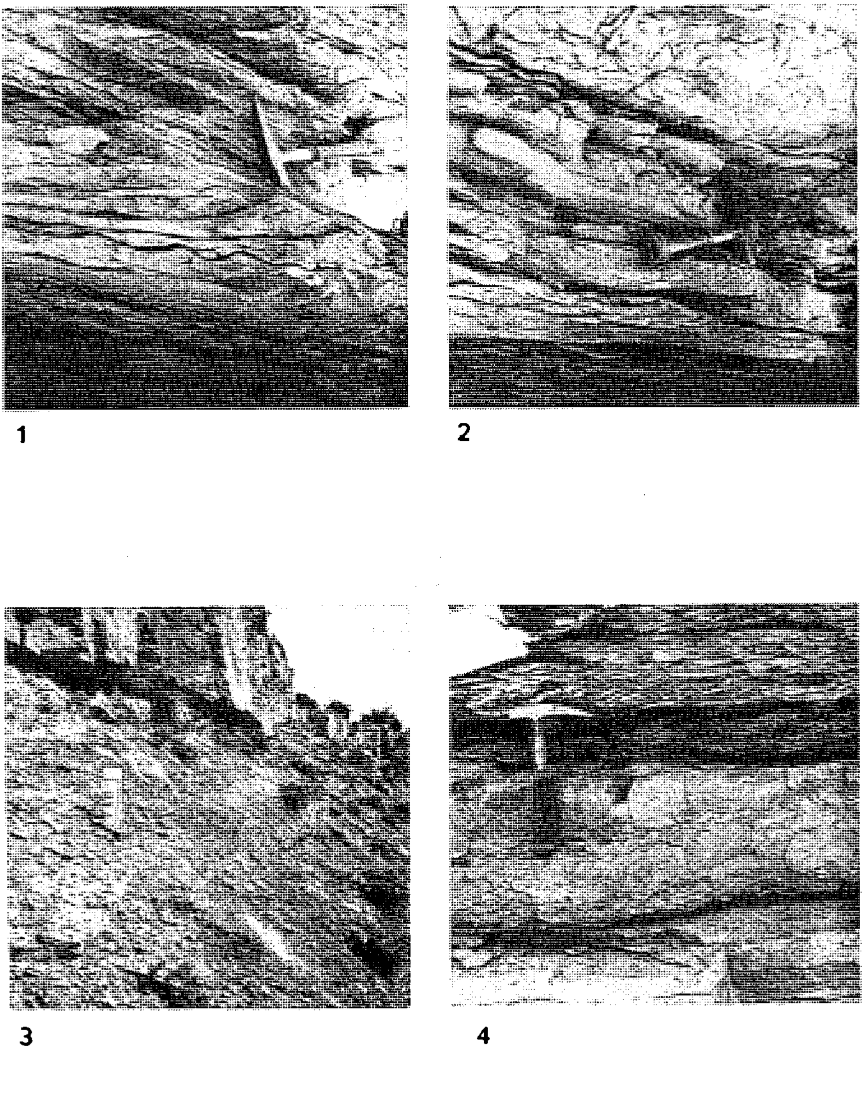


PLATE 2

SEDIMENTARY STRUCTURES AND FIELD VIEWS

FIG. 1.—Current ripple marks on crossbed foresets in upper member, Sheep Creek Gap.
FIG. 2.—Imbricated conglomerate with pebbles inclined toward the west in upper member, Sheep Creek Gap.
FIG. 3.—Shell bank in upper member, Sheep Creek Gap.
FIG. 4.—Coquina bed of brachiopods in upper member, Sheep Creek Gap.

Bivalves
- *Arctica?*
- *Astarte?*
- *Camptonectes?*
- *Gryphaea* sp.
- *Isocardia?*
- *Lima* sp.
- *Mytilus?*
- *Nucula* sp.
- *Ostrea* sp.
- *Oxytoma?*
- *Pholadomya?*
- *Pinna* sp.
- *Pleuromya?*
- *Protocardia?*
- *Trigonia* sp.

Gastropods
- naticacean gastropods

Cephalopods
- *Cardioceras?*
- *Pachyteuthis "densus"* (Meek and Hayden)

Worms
- serpulids

Arthropods
- crustaceans
- ostracods

Echinoderms
- echinoid spines
- holothuroid sclerites
- *Pentacrinus* ossicles

Vertebrate
- jaw bone fragment

Preservation

A significant part of the fauna in the lower member of the Curtis Formation is preserved as casts and molds. Microfossils including gastropods, foraminifera, coral-like forms, and holothuroid sclerites are usually present as internal molds of glauconite (Plate 5). Some gastropods have clay minerals or limonite material as the infilling sediment in the internal molds. Bivalves are commonly preserved as internal and external molds and casts. Most of the forms preserved as molds and casts are thin-shelled forms, although there are exceptions to this generalization. This preservation may be due to the ease with which the thinner shells can be removed by currents or dissolved *in situ*. The *Cardioceras?* present is a cast. The single crustacean-like form is preserved as a cast and an external mold and appears to have been disarticulated prior to burial.

Many unbroken bivalve shells are preserved as recrystallized calcite shell material. *Pachyteuthis "densus"* (Meek and Hayden) is preserved by recrystallization, the remains of the organisms consisting only of rostra. Echinoid spines and *Pentacrinus* columnals are also preserved this way. Some bivalve shells illustrate in thin section the diagenesis of the calcite to sparry calcite. Brachiopod shells usually show some degree of recrystallization.

Commonly the brachiopods *Kallirhynchia myrina* (Hall and Whitfield) are essentially unaltered and show remains of pearly calcium carbonate material on the outside of the shells. Brachiopod material is composed of broken shell debris in many coquina beds.

The jaw bone fragment seems to be permineralized since it is darker and heavier than normal bone would be. The porous nature of the bone material is obscured, which also would indicate permineralization.

Conditions exist in littoral and neritic environments in the modern seas which would allow preservation similar to those types present in the Curtis Formation. Glauconite, a mineral found in the neritic zone, forms as infilling in many marine microfossils today. Modern environments of low energy commonly contain unbroken shells of benthic organisms, while broken shells are characteristic of high energy environments. Broken and unbroken shells in the Curtis Formation indicate a similarity between modern environments and those present when the formation was deposited.

Ichnofossils

Ichnofossils, or biogenic sedimentary structures, are abundant in the lower member of the Curtis Formation. These trace fossils consist of four major types. The first is common in the arenaceous silty units and is characterized by horizontal trails or burrows filled with sediment somewhat finer than the surrounding sediment. Such structures are classified as paschichnia by Seilacher (1964, p. 299) since they represent winding trails or burrows of vagile deposit feeders in search of food. Most of these are from 15 to 25 millimeters in diameter and appear in full relief in the sediments (Plate 7, fig. 1, 2). Associated with these horizontal burrows are vertical burrows in which the organism searching for food burrows up through the overlying sediments. These burrows appear to be smaller, with an average diameter of eight millimeters.

A branching paschichnia occurs in the Curtis Formation which is similar to *Paleodictyon* (Seilacher, 1964, p. 310). Very fine sediments distinguished the burrows from surrounding materials. The burrows average from seven to ten millimeters in diameter and express epirelief.

A common, yet restricted, form of ichnofossil is another paschichnia which resembles *Planolites montanus* (Seilacher, 1964, p. 306). These burrows are restricted to the dark gray shales in the upper part of the lower member of the Curtis Formation and were found only in the measured section at Sheep Creek Gap. The equivalent related shales at Finch Draw lack fossils of this kind. The burrows occur as sandfilled, full relief features in the finer shales and average two millimeters in diameter (Plate 7, fig. 4). *Planolites montanus* is identified as burrows winding throughout the shale units, along the bedding planes, or sometimes cross-cutting the thin shales and extending from one bedding plane to another (Plate 7, fig.7).

Ichnofossils are commonly attributed to burrowing deposit feeders such as bivalves, gastropods, worms, echinoids, or holothuroids. Their presence indicates an aerobic environment. Sedimentary rates are also indicated since intense burrowing would occur only on surfaces exposed for a long time.

Burrows are an indication of the amount of consolidation in the sediments at the time of activity since softer bottoms would be more intensely burrowed than more compacted layers.

Physical protection is a major concern of benthic animals in littoral and very shallow water environments. Therefore, infaunal organisms are common in these environments. In deeper waters and quiet zones where food particles settle, deposit feeders become more important (Seilacher, 1964, p. 313).

Faunal Association

Distribution

Characteristic faunas distinguish the lower and upper members in the Curtis Formation in Finch Draw. The lower member, from unit FD1 to FD20,

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PLATE 3
PHOTOMICROGRAPHS

FIG. 1.—Glauconitic sandstone, very fine-grained, appears structureless, unit FD24 in Finch Draw, X25.

FIG. 2.—Glauconitic sandstone, glauconite appears as large gray masses with finer sand and silt material, lowermost unit in Sheep Creek Gap, X25.

FIG. 3.—Skeletal, oolitic limestone showing gastropod shell filled with clastic material, Calcite matrix, foraminifer appears at bottom, upper member Sheep Creek Gap, X25.

FIG. 4.—Oolitic limestone containing algal filaments, pellets, and coated quartz grains, calcite matrix, from same unit as Fig. 3, X25.

PLATE 4
PHOTOMICROGRAPHS

FIG. 1.—Oolitic limestone, faecal pellets, algal bodies, and coated grains in calcite matrix, unit FD32, upper member in Finch Draw, X12.

FIG. 2.—Oolitic limestone showing faecal pellets, algae and ooids in calcite matrix, unit FD33, upper member in Finch Draw, X25.

FIG. 3.—Oolitic limestone showing brachiopod skeletal fragments, algae and ooids in calcite matrix, unit FD22, upper member in Finch Draw, X25.

FIG. 4.—Oolitic limestone showing graded bedding produced in small crossbeds, ooids in calcite matrix, unit FD23, upper member in Finch Draw, X12.

PLATE 5
CURTIS MICROFOSSILS

FIG. 1.—Internal mold of gastropod, genus unidentified, orthostrophic conispiral shape, lower member in Finch Draw, actual size one millimeter wide.

FIG. 2.—Planispirally tightly coiled foraminifera, glauconite internal mold, unit FD3 in lower member Finch Draw, actual size 0.2 millimeters wide.

FIG. 3.—Glauconite cast of *Pentacrinus* columnal, unit FD2 in Finch Draw, actual size one millimeter wide.

FIG. 4.—Abraided echinoid spine, unit FD8 in Finch Draw, actual size 0.5 millimeter long.

FIG. 5.—Glauconite cast of coral-like organism, unit FD16 in Finch Draw, actual size 0.5 millimeter wide.

FIG. 6.—Internal mold unidentified gastropod, conispiral, orthostrophic shape, unit FD4 in Finch Draw, actual size two millimeters long.

FIG. 7.—Echinoid spine, lower member Sheep Creek Gap, actual size one millimeter long.

FIG. 8.—Internal mold naticacean gastropod, unit FD14 in Finch Draw, actual size one millimeter long.

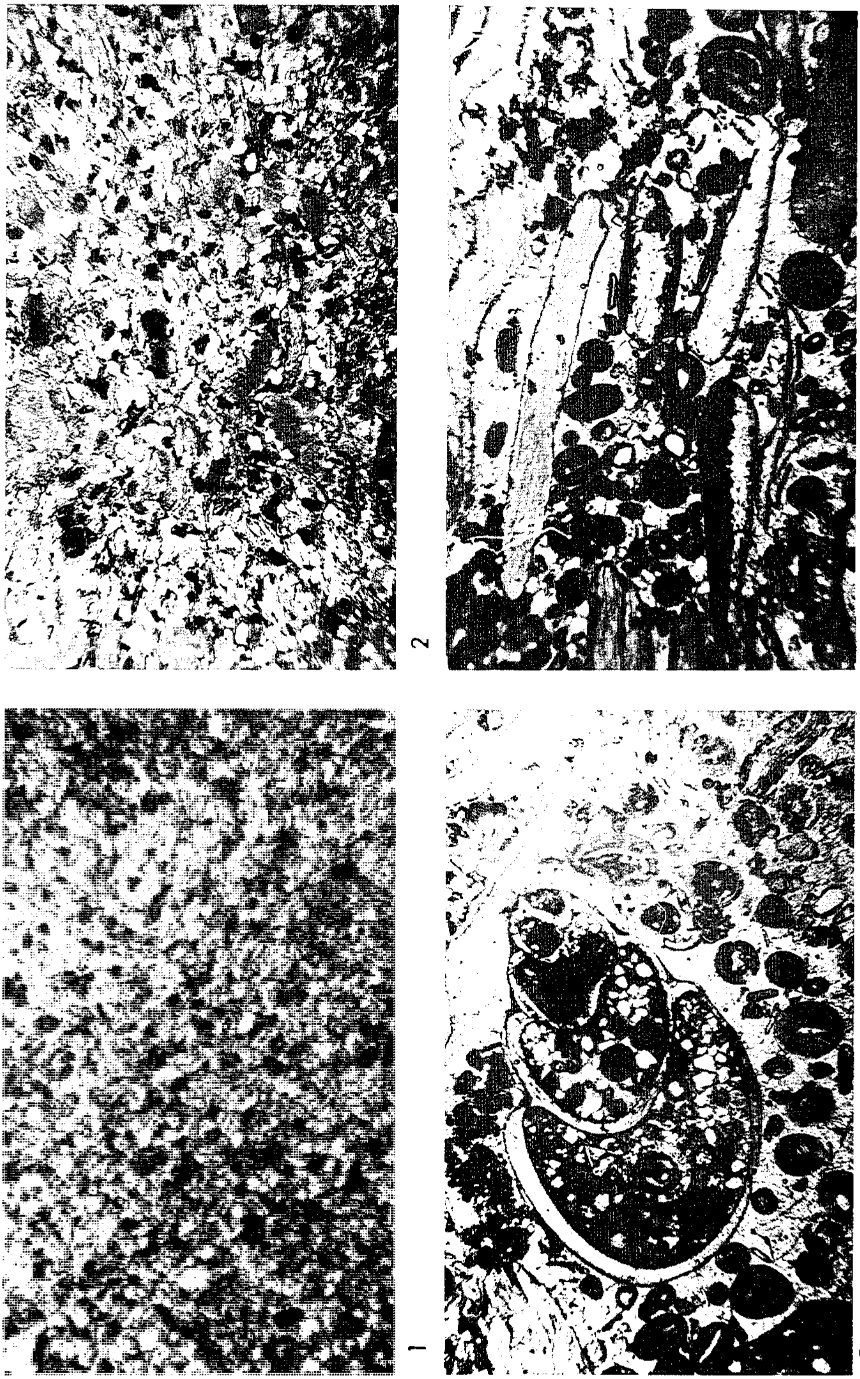

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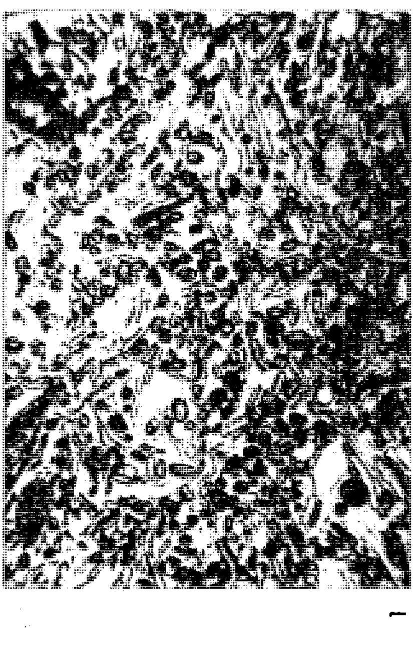
PLATE 3



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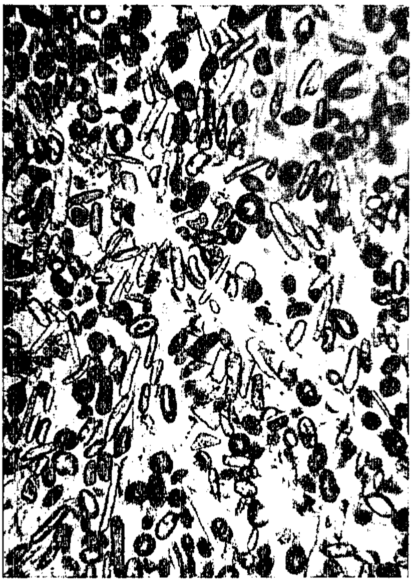

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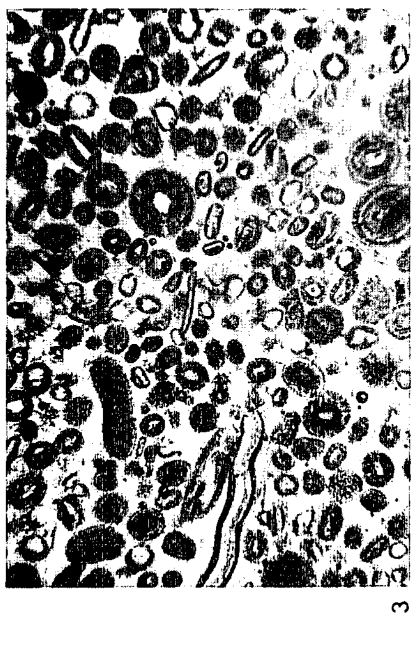

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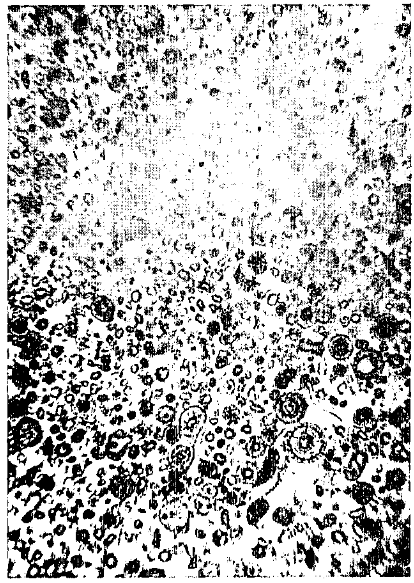

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PLATE 4

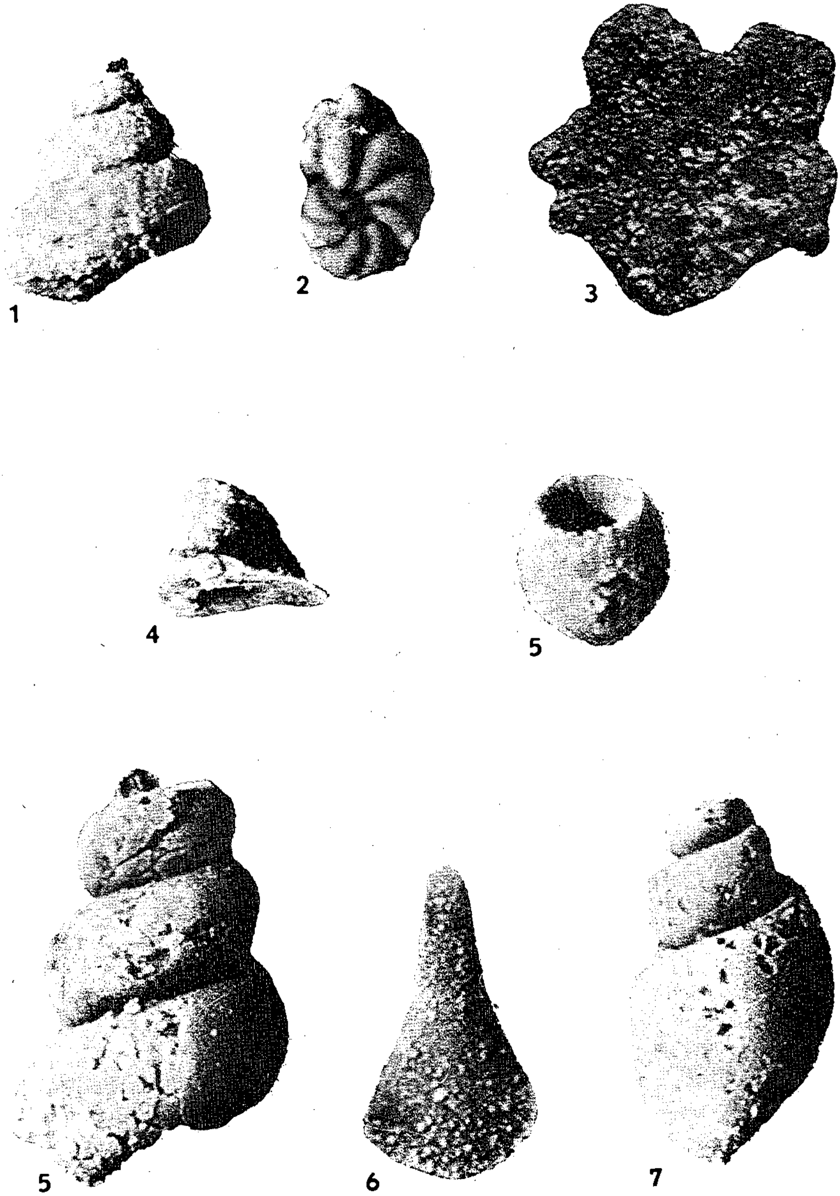

PLATE 5

is largely a bivalve, crinoid, gastropod, and cephalopod fauna; whereas the upper member, from unit FD20 to FD37, is characterized by an absence of these organisms and the abundance of rhynchonellid brachiopods.

Bivalves are the most abundant organisms in the lower member. They are common in the arenaceous siltstones but are concentrated in those units that have greater amounts of calcium carbonate. This does not appear to be due to selective preservation. Benthonic forms are not always present in each unit but seem to occur sporadically. Apparently the living assemblages varied from time to time during deposition of the lower member independent of the bottom sediments making up the substrata. *Pinna* sp., *Trigonia* sp., *Isocardia?*, *Oxytoma?*, and *Protocardia?* constitute the lowermost assemblage of bivalves. *Pinna* sp., *Trigonia* sp., and *Protocardia?* are also present in units higher in the section where they are associated with *Arctica?*, *Lima* sp., *Camptonectes?*, and *Gryphaea* sp., *Isocardia?* and *Oxytoma?* are present only in lower unit FD2. In a silty limestone of unit FD6 *Ostrea* sp., *Nucula* sp., *Gryphaea* sp., *Lima* sp., *Astarte?*, and *Pleuromya?* compose another distinctive assemblage.

PLATE 6

CURTIS FOSSILS

All natural size except where noted.

FIG. 1.—Cast of *Trigonia,* unit FD2 in Finch Draw.
FIG. 2.—*Camptonectes?*, lower member Sheep Creek Gap.
FIG. 3.—*Kallirhynchia myrina* (Hall and Whitfield), common in upper member Curtis Formation, ventral view.
FIG. 4.—Fragment of *Pachyteuthis "densus"* (Meek and Hayden), common in lower member Curtis Formation.
FIG. 5.—Cast of crustacean-like organism appendage, unit FD7 in Finch Draw.
FIG. 6.—*Mytilus?*, bivalve, coquina beds, upper member Sheep Creek Gap, X1.5.
FIG. 7.—Internal mold *Arctica?*, unit FD4 in Finch Draw, left valve.
FIG. 8.—Cast of *Pleuromya?*, unit FD11 in Finch Draw, left valve.
FIG. 9.—Cast of *Protocardia?*, unit FD3 in Finch Draw, left valve.
FIG. 10.—Cast of *Unio?*, lower member Finch Draw, right valve.
FIG. 11.—Cast of *Pinna,* unit FD2 in Finch Draw, right valve.
FIG. 12.—Mold of *Trigonia,* unit FD6 in Finch Draw.
FIG. 13.—Cast of *Pleuromya?*, unit FD11 in Finch Draw, right valve.

PLATE 7

ICHNOFOSSILS AND FIELD VIEWS

All natural size except where noted.

FIG. 1 and 2.—Paschichnia burrows, unit FD2 in Finch Draw, horizontal, full relief burrows.
FIG. 3.—Paschichnia burrows sand infilling in shale, resembles Seilacher's *Planolites montanus,* shale units in Sheep Creek Gap.
FIG. 4.—Burrow on bedding plane, horizontal with full relief, in shale-sandstone units, Sheep Creek Gap.
FIG. 5.—Pebble conglomerate in upper member Sheep Creek Gap, note small belemnite at left, X 0.5.
FIG. 6.—Bedding plane showing *Kallirhynchia myrina* (Hall and Whitfield) accumulation, this bedding plane used for grid count, upper member Sheep Creek Gap.
FIG. 7.—Paschichnia burrow, vertical sand infilling in shales, shale units in Sheep Creek Gap.

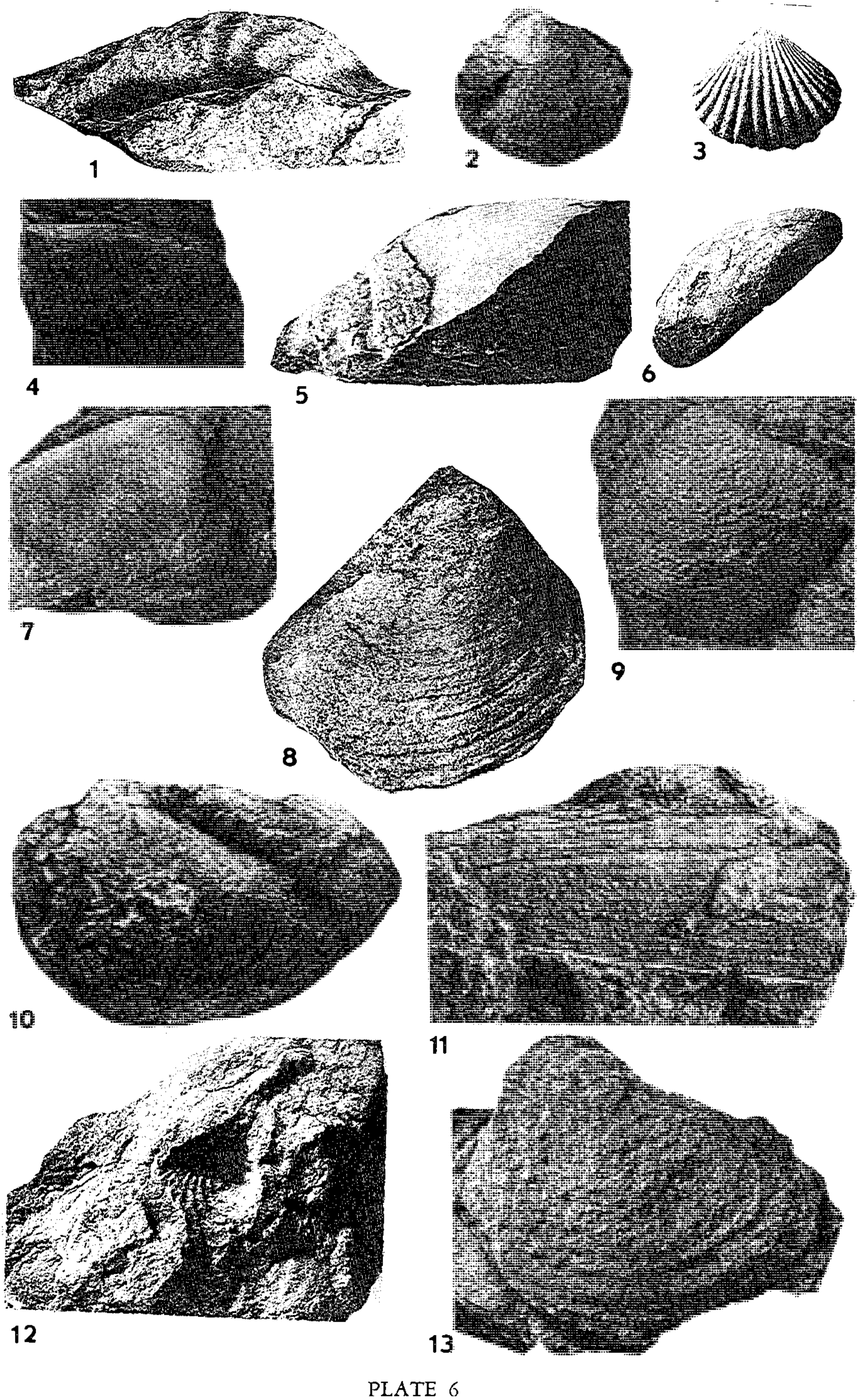

PLATE 6

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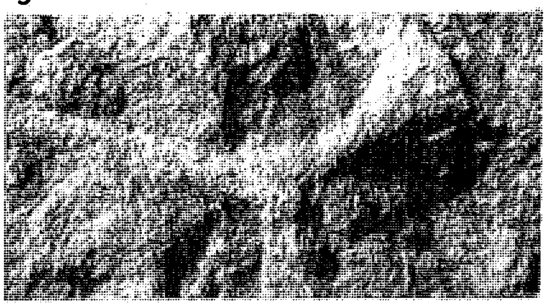

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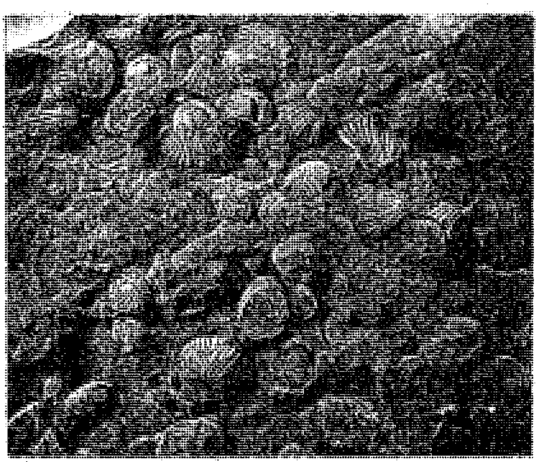

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PLATE 7

Ostrea sp. occurs commonly in many assemblages, and *Lima* sp. constitutes a major part of others.

Gastropods averaging lengths less than one millimeter are commonly associated with the bivalve faunas in the lower member. Each fine clastic unit, with exception of the interbedded shales, seems to contain these small gastropods. No boring of bivalve shells was noted in this section, but elsewhere in younger rocks bivalves are often bored by gastropods.

The ammonoid *Cardioceras?* is present in only one unit as small casts approximately 20 millimeters in diameter. The occurrence of more of these forms would be expected since conditions are similar in other units. *Pachyteuthis "densus"* (Meek and Hayden) is ubiquitous in the lower unit except in the shale units. The occurrence of these nektonic forms seems to be restricted by lithology but this restriction is probably due to selective preservation.

Pentacrinus ossicles from one to four millimeters in diameter are present in most of the siltstone units of the lower member and occasionally in the limestone units of the upper member. They occur as disarticulated columnals and sometimes are present as glauconite casts (Plate 5). Echinoid spines were found in a single unit but are likely present in other units also.

The brachiopod *Kallirhynchia myrina* (Hall and Whitfield) is the most abundant fossil in the upper member from unit FD20 to FD37. These forms occur as random specimens in some units or as coquina beds up to six inches thick in unit FD29. Usually the shells show some degree of abrasion, but a few beds contain entire shells. In Sheep Creek Gap a lenticular shell bank is exposed containing *Kallirhynchia myrina* (Hall and Whitfield), the bivalve *Mytilus?*, and gastropods (Plate 2, fig. 3). This is in the unit equivalent to unit FD33 in Finch Draw. This unit in Sheep Creek Gap contains a large amount of silt and clay as matrix. Oolitic limestones occur above and below the unit.

The fragment of a vertebrate jaw bone was collected from near the base of the lower member in Sheep Creek Gap. Careful search failed to yield additional bone material.

Density

The density of the different organisms is difficult to ascertain objectively since few bedding planes are well exposed. Locally some counts could be made, but these counts may not be representative. In the upper member in Sheep Creek Gap a surface area of approximately 20 square inches was counted using a one-inch grid. In 20 square inches there were 55 *Kallirhynchia myrina* (Hall and Whitfield). Thirty-nine specimens were oriented with the plane of commissure horizontal to the substrate and 16 specimens were oriented with the commissure either tilted or vertical in relation to the substrate. The average shell size is approximately 15 millimeters in width. A unit underlying the bed produced 12 molds of bivalves which averaged 20 to 25 millimeters in length in an area 12 square inches. They appeared oriented with the plane of commissure horizontal to the substrate.

On another bedding plane 17 *Kallirhynchia myrina* (Hall and Whitfield) occur with seven horizontal and 10 tilted or vertical commissures in 42 square centimeters. The specimens averaged 15 millimeters wide (Plate 7, fig. 6).

A size-frequency curve was determined from measuring the width of 72 brachiopods collected from a coquina bed present in the lower part of the upper member in Sheep Creek Gap (Plate 2, fig. 4). The curve and shell condition indicate that the accumulation of shells was due to sorting during transportation prior to deposition.

Diversity

The following table illustrates the amount and kinds of organisms present in selected units of the Curtis Formation. The data are confined to the lower unit where diversity is more apparent.

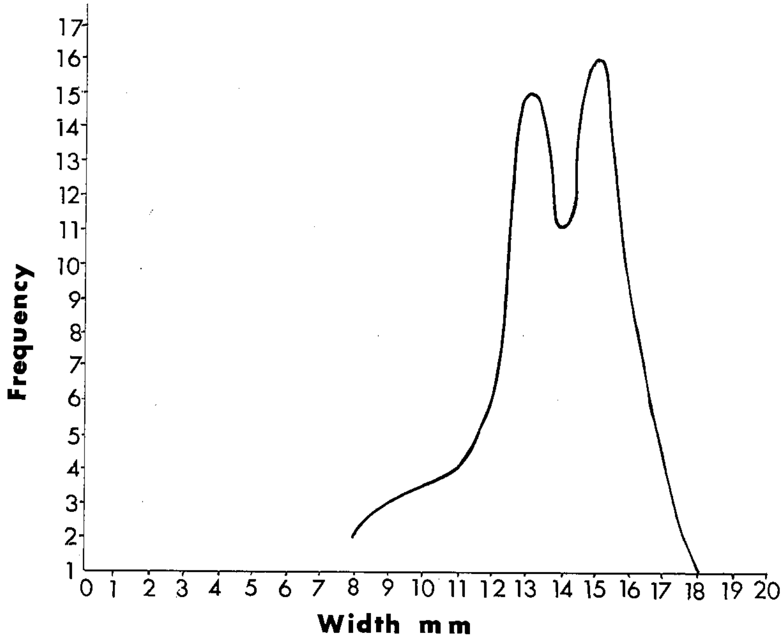
Analogous Modern Faunas

Many of the organisms preserved in the Curtis Formation have living representatives that likely live today in approximately the same environment as their predecessors did in the Late Jurassic sea. The bivalves are well represented as infaunal and epifaunal organisms and may be good indicators of the conditions existing on the bottoms of the Jurassic seas. Their life habitats and environment today are important factors to be considered. H. S. Pratt (1951) gives the following information concerning these factors. *Nucula* uses the foot for burrowing and occurs in both fresh and marine water. *Pinna* rests on the right valve and is attached to the substrate by a byssus, a tough stringy substance that is secreted from glands in the foot. *Pinna* is found from North Carolina to Texas along the Atlantic coast. *Ostrea*, an oyster, rests attached by the left valve to the substrate; the foot is absent, and it occurs in all but cold seas. Pectenid forms, such as *Camptonectes* and *Lima*, may be free-living or attached. In the attached forms the shell rests on the right valve, which is less convex and has a prominent notch. The free-living forms leap and swim by snapping their valves together. These organisms are found in shallow water world-wide

TABLE I

Number of Kinds of Fossils from Selected Units of the Curtis Formation at Finch Draw.

Unit No.	Total	Bivalves	Gastropods	Cephalopods	*Pentacrinus* ossicles	Foraminifera	Echinoid spines
FD1	11	1	4	2	1	3	..
FD2	21	7	4	1	7	..	2
FD3	10	3	4	..	1	2	1
FD4	11	4	5	1	1	..	..
FD5	5	4	..	1	..	..	..
FD6	49	19	..	29	2	..	..
FD7	11	3	4	2	1	..	..
FD8	27	22	1	..	..	1	3
FD10	10	9	..	1	..	..	..
FD11	31	30	..	1	..	..	..
FD12	31	16	10	5	..	..	..
FD13	3	1	1	..	1	..	..
FD14	10	6	3	..	1	..	..



TEXT-FIGURE 4.—Size frequency distribution curve of *Kallirhynchia myrina* (Hall & Whitfield) from coquina bed, upper, member, Sheep Creek Gap.

from the Gulf of California to the Arctic Ocean. *Arctica* is found in deep water from Long Island to the Arctic Ocean.

According to Arkell (1956) *Astarte, Trigonia,* and *Pholadomya* lived together in shallow Jurassic seas; however, today they occur in completely different environments. *Astarte* is restricted to cold boreal waters; whereas *Trigonia* is found in the warm waters of Australia, and *Pholadomya* is found in deeper abyssal depths. *Mytilus* occurs widely in shallow seas, its preferred habitat being from high-water mark to depths of a few fathoms. It is attached by a byssus and is highly gregarious. *Mytilus* can tolerate great variations in salinity and can live many hours exposed to air (Moore, Lalicker, and Fischer, 1952, p. 429).

Nicol (1967, p. 1331) states that large numbers of Antarctic pelecypods never attain a size of more than 10 millimeters. The forms in the Curtis Formation average from 10 to 50 millimeters in length.

Natica, a gastropod related to the forms found in the Curtis Formation, are present in modern seas at depths from 2 to 1290 fathoms. They live in sand and burrow after bivalves, enveloping their prey in their foot and penetrating the shell by drilling a hole with their radula (Pratt, 1951).

Modern brachiopods are usually attached to rocks, and most live in shallow water near continents; however, some also live in deep sea conditions. *Rhynchonella,* for example, is found circumpolarly in shallow water.

Pentacrinus, a deep sea form living in depths from 20 to 500 fathoms, is present in nearly all modern oceans (Pratt, 1951). The occurrence of fossil crinoids suggests moderately shallow seas as the habitat preferred by most species (Moore, Lalicker, and Fischer, 1951, p. 604).

According to Pratt (1951), echinoids, or sea urchins, occur in all modern seas and are most numerous near coasts, but there are also many deep sea forms. They move slowly by means of feet and eat small forms of life and organic remains. Many species pass large quantities of sand and mud through their intestines. Holothuroids, the sea cucumbers, also occur in most seas and are found at all depths. Some species move over the bottom ingesting sand or mud and catching minute organisms. Other species bury themselves in the sand or mud.

Faunal Relationship to Sediments

The type of sediments found on the bottom of the seas greatly affects the kinds and numbers of organisms that inhabit that environment. Epifaunal and infaunal organisms will particularly be directly influenced by the bottom sediments. In the Curtis Formation at Finch Draw, certain faunal assemblages characterize certain type of sediments. In the units of arenaceous siltstone and silty limestone from FD1 to FD18 at least 24 different fossil genera occur. The shale units in Sheep Creek Gap appear to contain only one dominant genus, and the oolitic limestone units of the upper member of the Curtis Formation appear to have three or four genera present.

Apparently the bivalves flourished on the organic-rich sandy and silty bottom sediments. The poorly bedded units attest to the fact that burrowing by infaunal organisms was extensive in these sediments, with epifaunal organisms leaving casts and molds on many bedding plane surfaces. Gastropods also thrived in the environment these sediments provided. Cephalopods, although found almost exclusively in these units, probably were not affected by the sediments except after death. The lack of these forms in the shales may indicate the presence of conditions not conducive to preservation.

Pentacrinus is an attached form, as are some of the bivalves, and would necessitate a substrate with some degree of firmness for attachment. Their occurrence could be an evidence for a thanatocoenose of the organisms rather than a biocoenose.

Kallirhynchia myrina (Hall and Whitfield) occurs in sediments that appear anomolous as a life habitat for that organism based on the fact that they attach during part of their life cycle. The substrate consisting of oolitic limestone or limy sandstone would provide a mobile substrate, and, therefore, would not allow attachment of the juvenile forms of *Kallirhynchia myrina*. Oolites indicate agitated waters and moving sediments for their formation. It would appear difficult for the brachiopod to obtain food and exclude sediments while also being transported by currents as this association indicates.

The amount of organic material in sediments is also critical to the success of most organisms. According to Trask (1939, p. 441) it is generally true that within any given depositional environment, fine-grained sediments contain more organic matter than coarse-grained deposits. The finely particulate organic matter in sea water can settle out of suspension only in areas attended by relatively low current velocities. Weak currents, of course, also favor deposition of silt and clay-sized particles and prevent removal of organic detritus formed at and below the sediment-water interface. Deposit feeders, by definition, feed on bottom deposits of non-living organic detritus and associated microorganisms.

Rate of water renewal is important in determining numbers of suspension feeders on a particular substrate. These organisms depend on currents to replenish the supply of organic detritus on which they feed. Relatively high current velocities are, of course, inimical to the deposition of large quantities of silt and clay-sized particles; therefore, large numbers of suspension feeders will be found on sediment substrates having low silt and clay content. Few suspension feeders will be found in relatively fine-grained substrates (Trask, 1939, p. 444).

If organic material is allowed to build up over a certain concentration, this would contribute to a reducing, anaerobic environment. This being the case, many organisms would find this environment inhospitable, and the resulting rocks would be barren of fossils.

CONCLUSIONS

Lower Member

The uniformity of the lower member of the Curtis Formation indicates a relatively stable condition existed during deposition. The sediments were deposited below normal wave base in fairly low energy conditions. Low energy conditions and a slow sedimentation rate allowed organic material to accumulate on the bottom. The water depth was probably greater than 100 feet, and the temperature probably ranged from 8° C to 20° C. These conditions are indicated by the presence of glauconite which forms today almost exclusively within these limits. Extensive burrowing present in the lower member also indicates that sedimentation was slow and organic material was abundant. Local depressions on the sea floor allowed greater accumulations of organic material in those areas. The concentration of organic material produced anaerobic conditions in some instances. The shale units are evidence of the organic accumulations. The fact that the shales were burrowed in Sheep Creek Gap but not in Finch Draw indicates that locally the shale units were produced in an anaerobic environment in some areas and an aerobic environment in others. The large clay clasts present in the lower member were formed nearly *in situ*.

Organisms accumulated after death in the sediments of the lower member. This is evident by the fact that thick-shelled bivalves such as *Ostrea* and *Gryphaea* are found associated with thin-shelled forms such as *Pinna* and *Camptonectes*. *Pentacrinus* columnals are disarticulated and found in a faunal assemblage indictive of a thanatocoenose. The shale units are barren of organisms except for burrows. The anaerobic condition did not allow preservation of the forms that probably accumulated there.

The large clay concretions formed as accumulations of the finer clastic sediments. Occasionally fossils acted as centers of accumulation for the finer material.

The lower member was probably deposited in an upper neritic, sublittoral, marine environment. The Curtis Sea was apparently at its greatest depth during the deposition of these sediments.

Upper Member

The upper member of the Curtis Formation formed under quite different conditions than did the lower member. The upper sediments were deposited in high energy conditions as indicated by crossbedding, ripple marks, and imbricate conglomerate. Shell debris accumulated in these high energy conditions as the transported shells were broken up and deposited. The formation of oolites, which volumetrically make up the major part of the upper member, indicates that the water was warmer, well agitated, and contained abundant calcium carbonate in solution. The crossbeds of oolitic material are separated by tabular deposits of the same material. They indicate that the depth of water was quite shallow since sheet deposits of oolites occur exclusively in a littoral or sublittoral environment where the bottom is level and current velocity is high. These sediments were probably subject to tidal currents which would explain the reversal of crossbedding direction in some of the units. The conglomerate units in the upper member were formed as wave action removed fine consolidated bottom material and redeposited the clasts as rounded, imbricate sediments.

The lack of deposit-feeding bivalves and abundance of suspension-feeding brachiopods suggests that little organic material was present on the bottom of the new environment. The brachiopods were moderately well sorted by the current action (Text-fig. 4). The shell bank in Sheep Creek Gap was probably a topographic depression on the sea floor where the shells accumulated and acted as a sediment trap for fine silt and clay materials that filled in around them. Belemnites, which are quite common in the lower member, are absent in the upper member. This indicates that the conditions in the warm shallow water were inhospitable for these organisms. From these facts the upper member appears to have formed in a littoral to sublittoral environment.

In summary, the Curtis Formation in the Daggett County area was deposited following transgression of the Oxfordian Sea over the Entrada Sandstone. The lower member was deposited in a neritic environment. The sea withdrew and produced shallow water locally. The upper member was deposited in a littoral, or shallow infralittoral environment.

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