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Contents

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J. Keith Rigby

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Lateral Facies and Paleoecology of Permian Elephant Canyon Formation, Grand County, Utah*

FORREST M. TERRELL
Mountain Fuel Supply Co., Denver, Colorado

ABSTRACT.—Study of lithologies and faunal assemblages of repetitive, often laterally contiguous, red beds and marine deposits of the lower Elephant Canyon Formation (Wolfcampian) has revealed nine major environments of deposition in what is generally regarded as an arid climate: (1) shallow open marine, (2) marine bars, (3) interdistributary bay or estuarine, (4) prodelta, (5) supratidal, (6) tidal flat, (7) mud flat, (8) fluvial channel, and (9) dune.

Sediments were deposited on the northern margin of the retreating Paradox Basin sea, which was rapidly being dominated by clastic debris shed from the Uncompahgre Uplift to the north. A prograding delta complex is regarded as the overall mechanism controlling deposition. Coastal areas of the northwestern Gulf of California are believed to be nearly analogous.

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*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Sciences, August 1972.

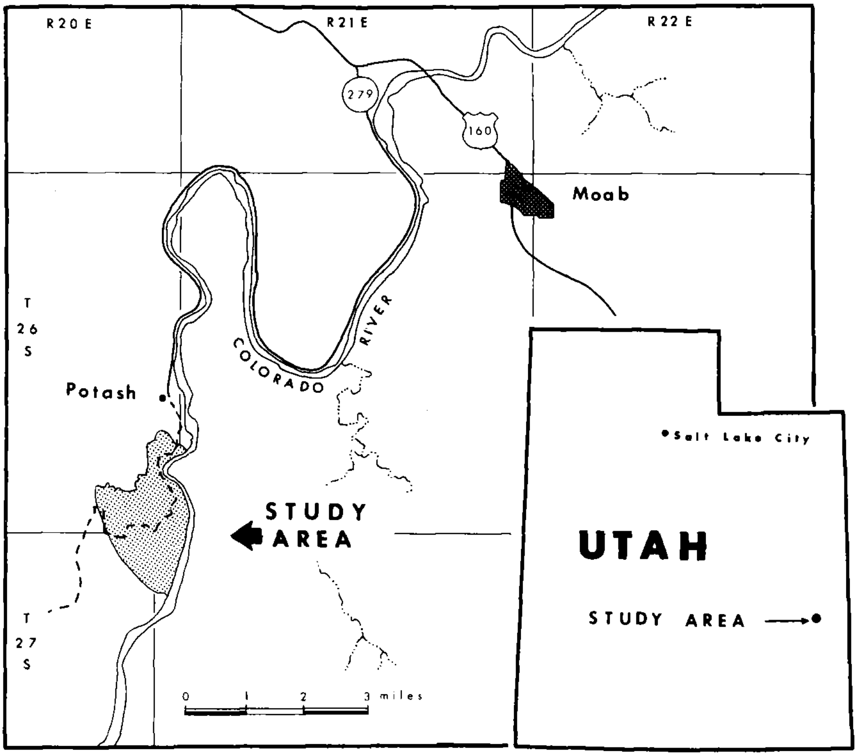
INTRODUCTION

Previously rarely recognized intertonguing and often laterally contiguous red-bed and marine deposits form a major part of Early Permian (Wolfcampian) "Rico facies of the lowermost Cutler Formation," now known as the Elephant Canyon Formation (Baars, 1962). These repetitive, nearly cyclic, transitional marine to nonmarine carbonate and clastic rocks record details of the filling of the Paradox Basin with clastic debris from the adjacent Uncompahgre highland and the accompanying retreat of the sea. These details for one area are here described in terms of lithologies and faunal assemblages from which a series of depositional environments are interpreted. A delta complex in an arid environment is envisioned as the mechanism controlling deposition in this area and possibly much of the area in other parts of the northern Paradox Basin which is today represented by similar strata.

LOCATION

The area is located on the Cane Creek Anticline, on the west side of the Colorado River, centering around Sec. 36, T. 26 S., R. 20 E. (Text-fig. 1). Utah State Highway 279, which runs through the area, is paved to Potash, Utah, but continues as an unpaved, but graded, year-round road beyond this point. The southern unpaved portion of the road is slippery during or after heavy rains. The northern margin of the study area is about one mile southwest of the Texas Gulf Sulphur Potash plant where the unpaved road climbs steeply from the river margin onto the flank of the Cane Creek Anticline. Nearly the entire study area is controlled by Texas Gulf Sulfur, Potash Division, Utah, from whom permission should be obtained before entering.

This area was chosen for study primarily because the sequence of rocks is well exposed in large areas of nearly bedding-plane exposures and in numerous gullies where vertical sequences can be seen, and because the rocks have not been subjected to major postdepositional tectonic complications.



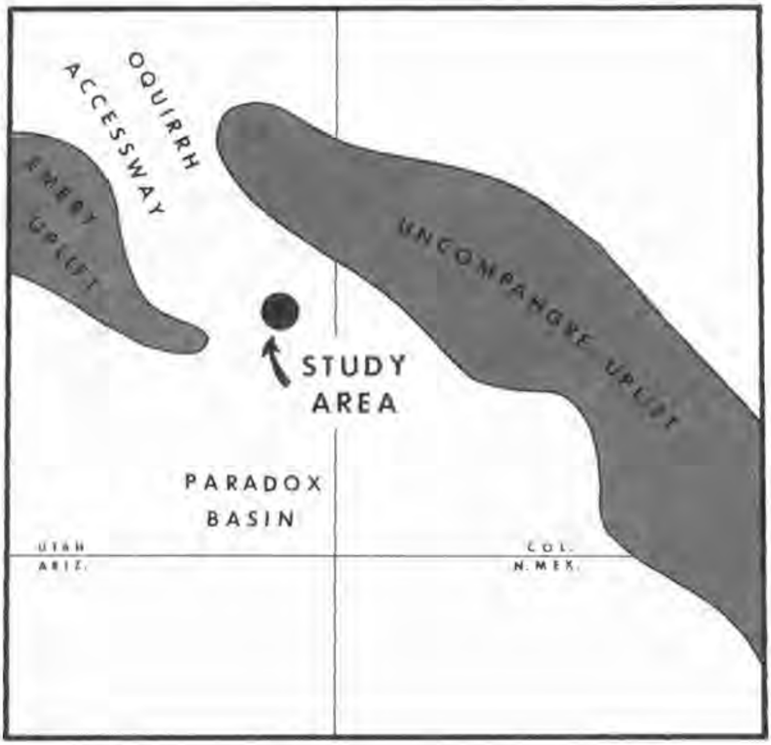
TEXT-FIGURE 1.—Index map.

GEOLOGIC SETTING

The area is in the eastern part of the relatively stable Colorado Plateau, on the Cane Creek Anticline, one of several salt anticlines in the region. The area has undergone little but regional warping except for localized gentle uparching caused by salt flowage. An accompanying joint system is related to salt flowage, as are several minor parallel normal faults that have displacements usually less than 10 feet.

The Uncompahgre Uplift is north and east of the study area, and the Emery Uplift is to the west across the Paradox Basin, most of which is south of the studied sequence (Text-fig. 2). The Oquirrh Accessway on the northwest connected the Paradox Basin to the main marine basins of central and western Utah. The Uncompahgre Uplift and perhaps the Emery Uplift contributed great clastic wedges which gradually filled the Paradox Basin to above sea level, causing the ultimate retreat of the sea from the basin. Details of the succession of environments in one area produced by this filling and accompanying retreat of the sea are the prime concerns of this paper.

The Elephant Canyon Formation (Wolfcampian) consists of a "heterogeneous sequence of tan to light gray brown finely crystalline to sugary, cherty limestones and cream to tan, finely crystalline to chalky, cherty dolomites interbedded with fine-grained orthoquartzose sandstone, red siltstone, arkose,



TEXT-FIGURE 2.—Paleotectonic Map.

and thin beds of anhydrite" (Herman and Sharps, 1956, p. 82). Regionally, it disconformably overlies beds ranging from Mississippian (?) on the Emery Uplift to the Virgilian Honaker Trail Formation in the study area (Baars, 1962, p. 172; and personal communication, 1972). Baars (1962) has described and illustrated the Elephant Canyon Formation as conformably overlying and interfingering with the Cedar Mesa Sandstone. It also interfingers with Halgaito red beds southward and with lower Cutler rocks eastward.

DEVELOPMENT OF STRATIGRAPHIC NOMENCLATURE—PREVIOUS WORK

The terminology of these strata has had a long and perhaps unnecessarily complex evolution and in some ways still remains unsatisfactory. Strata in the study area have been identified as the "Rico Formation" by various workers in the area, including McKnight (1940); Lewis and Campbell (1965); and Joesting, Case, and Plouff (1966). Similar-appearing rocks in the Rico Mountains of Colorado were earlier termed the "Rico Formation" by Cross in 1899. These Colorado rocks were later shown to be, in part, Pennsylvanian and, in part, Permian (Henbest, 1948: Wengerd, 1957; and Kunkel, 1958). After more regional studies had been done, it was realized that using the term "Rico" was not regionally consistent and that perhaps the "Rico Formation" was not even a valid mappable formation (Wengerd and

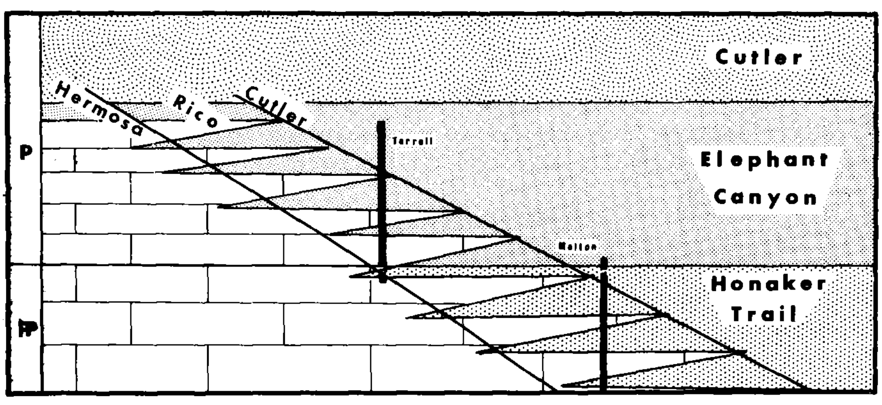
Strickland, 1954). Turnbow (1955), Herman and Sharps (1956), Herman and Barkell (1957), and Wengerd (1958), apparently dissatisfied with the terminology, either abandoned the term entirely or used "Rico facies" for beds overlying the Pennsylvanian Honaker Trail Formation (Wengerd and Matheny, 1958).

Baars (1962) recommended that both "Rico Formation" and "Rico facies" be abandoned and instead that *Pennsylvanian strata* be assigned to the Honaker Trail Formation and *Permian strata* to the Elephant Canyon Formation. His proposal has been generally accepted and is followed here because it is essential to a correct interpretation of the paleogeography and paleotectonics of the Paradox Basin. The nomenclature is strongly influenced by paleontologically defined boundaries rather than by distinctive lithologies, making field mapping difficult.

A parallel study on similar-appearing Pennsylvanian rocks of the Honaker Trail Formation in "Rico facies" is being conducted concurrently by Robert Melton, approximately 15 miles to the north in Moab Canyon, near the headquarters of Arches National Park. The generalized relation of the "Rico-Hermosa" and the "Elephant Canyon-Honaker Trail" terminologies to the two studies is shown in Text-figure 3.

METHODS OF STUDY

Field Methods.—A large-scale geologic map with a scale of one inch equals 490 feet was prepared, using a high-altitude aerial photograph as a base, showing areal distribution of individual beds of carbonate and clastic rocks in the Elephant Canyon Formation. Clastic units were not subdivided but were separately measured for the detailed sections. Limestone units were of primary interest because it was felt that their lithologic and paleontologic variation was regionally more significant than variation in clastic units. Each limestone, distinctive enough to be easily recognized throughout the area,



TEXT-FIGURE 3.—Generalized drawing showing relation of this study to the "Honaker Trail-Elephant Canyon" terminology, the "Rico-Hermosa" terminology, and Melton's study (1972).

served as a key unit in each cycle. This difference is especially valuable because other lithologic types appear almost identical in each cycle.

Each limestone unit was sampled with unweathered one- to two-pound samples at grid intersects of approximately 300 feet, as permitted by outcrops. Detailed sampling was done to enable quantification at each point of such factors as grain size, sorting, lithology, and fauna, and to allow generation of contoured maps for each parameter for each unit. But because lateral variation was not as significant within any given unit as had been anticipated originally, such maps were not produced. However, it is still felt that this approach would be useful if applied on a more regional basis.

Individual units were walked out, and notes were recorded nearly continuously by means of a portable cassette tape recorder. This greatly facilitated the study because any idea was easily recorded before it was forgotten. Thickness of the unit was recorded at each collection site, along with lithology, sedimentary structures, trace fossils, and faunal content.

Laboratory Methods.—Laboratory work involved fossil identification and thin-section study. Fossils were cleaned using an Airbrasive unit and a small air-driven chisel. Thin sections and acetate peels were made as needed for identification.

More than 100 thin sections were prepared. Samples which were not well indurated were impregnated in a vacuum oven with Scotchcast Electric Resin #3, a two-part thermosetting epoxy resin. They were cured overnight before thin sectioning.

NOMENCLATURE USED

Most colors used in descriptions have been matched to a color chart prepared by the Rock Color Chart Committee and published by the Geological Society of America (1951). Descriptive grain-size terms are those of the Modified Wentworth Grade Scale proposed by Dunbar and Rogers (1966). Carbonate classification is a modified form of that suggested by Folk (1959). Cross-bed terminology follows that suggested by McKee and Weir (1953).

ACKNOWLEDGMENTS

The author would like to acknowledge the greatly appreciated assistance and guidance provided by Dr. J. K. Rigby, committee chairman, who gave freely of his time as needed, whether for field or laboratory work, writing, or encouragement. Also appreciated are the advice and critical comments offered by Dr. L. F. Hintze, who read the manuscript and served as a committee member.

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Special appreciation is given to my wife, Marcie, for her service as field assistant, lab technician, and typist, and for her unceasing support and encouragement.

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LITHOLOGIES ENCOUNTERED

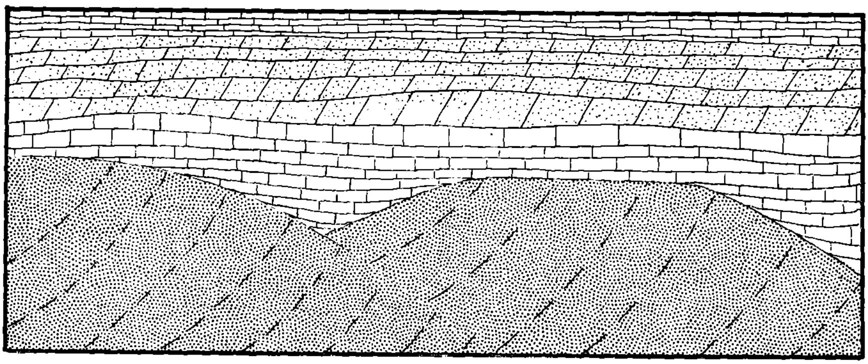
Sandstones

Sandstone is the dominant rock in the study area, and five major types are recognized: (1) dark red sandstone, (2) pale orangish red sandstone, (3) pink calcareous sandstone, (4) light gray green micaceous sandstone, and (5) arkosic sandstone. Arkosic sandstone includes coarse-grained, dark maroon arkose; fine-grained, reddish brown arkose; and light tan to white arkose of variable grain size.

Dark Red Sandstone.—Dark red, fine- to medium-grained, cross-bedded quartz sandstones occur in Units 15c, 17, and 22. Sets of cross strata are trough-shaped but dip nearly uniformly to the south, and vary in height from 4 to 20 feet, averaging 15 feet. Smaller sets are truncated by those above. Large sets are often disturbed by convoluted bedding, apparently caused by slumping. Grain size varies from 0.125 to 0.25 millimeter in diameter, with the larger size containing abundant mica primarily on the upper surface of cross sets. Red coloration in this fine-grained, densely packed sandstone is due to hematite (?) staining. No direct or indirect evidence of organic activity was found in this sandstone.

Exposures of this type of sandstone at point A on the geologic map in Unit 17 permit observation of the three-dimensional geometry of the normal occurrence of this lithology (Pl. 1, fig. 1). In cross section the unit appears as a series of large, flat-bottomed, semilenticular bodies (Text-fig. 4). Thickness of the unit varies from approximately 10 to 25 feet. The "lenses" are approximately 1,000 feet wide, are separated by 200- to 300-foot-wide troughs, and are elongate in a nearly east-west direction approximately perpendicular to the cross-bedding direction. Length of the "lenses" cannot be determined because they terminate in the subsurface.

Pale Orangish Red Sandstone.—Pale orangish red, cross-bedded, often micaceous quartz sandstone with grain size varying from 0.125 to 0.25 millimeter in diameter occurs in Units 10, 13b, 15c, 17c, and 19b. This type of sandstone either overlies a fine-grained arkose or overlies and grades with dark red sandstone, differing from the latter primarily in color. The lighter color



TEXT-FIGURE 4.—Schematic north-south cross section of Unit 18, illustrating a regressive sequence of strata and showing two-dimensional geometry of inferred dunes.

is caused by numerous reduced zones and a slight increase in calcareous cement. The reduced zones occur along boundaries between cross strata and in locally extensive, though indistinct, 2- to 5-inch-diameter burrow systems characteristic of the *Ophiomorpha* assemblage (Pl. 1, fig. 2). Sets of cross strata are commonly 3 to 6 feet high, but rarely up to 10 feet high. Sets show a much less constant dip direction, and contorted bedding is less common than in the dark red sandstone. Smaller set height probably resulted in less convolute bedding. Three-dimensional geometry of this lithologic type cannot be seen, but in two dimensions it shows the same semilenticular nature as the dark red sandstone, though on a much smaller scale.

Pink Calcareous Sandstone.—Light to dark pink, bioturbated, cross-bedded, calcareous sandstone occurs only at the base of Unit 18. Texturally and mineralogically it is similar to the dark red sandstone, except for increased calcareous cement and occasional laminae of sandy biosparite. Fragments of echinoids and occasionally unbroken gastropod shells add a coarse fraction to the normally 0.125- to 0.25-millimeter grain size. Thickness of the unit varies from 6 to 20 feet, with the greatest thicknesses filling troughlike depressions in the underlying sandstone (Pl. 1, fig. 1). Cross strata are at a lower angle than in the underlying sandstone and have variable dip direction. Much of this sandstone may have been reworked from the underlying sandstone by marine action. Sand dominates in the basal part of this unit, but carbonate content increases upward until the unit changes into the overlying sandy, bioturbated oosparite.

Light Gray Green Micaceous Sandstone.—Light gray green micaceous sandstone occurs only in Unit 3. It is 36 feet thick and is a slope former, which makes it difficult to observe in most localities. Grain size is nearly constant throughout the entire unit at 0.125 to 0.25 millimeters, except for the upper 3 or 4 feet, which is almost a thin-bedded siltstone. A carbonaceous, locally almost coaly, layer with abundant plant remains of the *Calamites* assemblage occurs in this upper part. Plants occur less abundantly in the lower part of the unit and are generally associated with zones of rip-up clasts of sandstone one to three inches in diameter. Nature of the outcrops does not permit detailed observation, but the two- to six-inch-high cross-beds appear to be related to climbing ripples.

Coarse-grained, Dark Maroon Arkose.—Dark red to maroon, coarse-grained arkose occurs in Units 7, 9a, 12, 19c, 20, 21b, and 23. Grain size varies from 0.25 to 7.0 millimeters in diameter, the large-sized fraction being almost entirely feldspar fragments that frequently occur near the base of the unit or occasionally as "floating" pebbles throughout the immature sediments of the units. No evidence of organic activity was encountered in this lithology. Sedimentary structures include planar and trough cross-beds, convolute bedding, and load casts. Cross-bed dip direction varies irregularly from locality to locality. Scour channels from 20 to 150 feet wide are common in this lithology. occurring (1) in isolated channels (Pl. 1, figs. 5, 6), best seen at points C and D on the geologic map, (2) in sheets composed of series of adjacent channels which have often cut into each other, and (3) in sheets with erosive bases not related to distinct channels. At point F on the geologic map a scour channel contains a 60-foot-long conifer log. The basal portion of these rocks was deposited on erosional surfaces on underlying units, producing large rip-up intraclasts (Pl. 3, fig. 1), best seen at point E on the geologic map.

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EXPLANATION OF PLATE 1
OUTCROPS IN MAP AREA

FIG. 1. Paleotopography of Unit 18.
FIG. 2. Orangish red, burrowed, cross-bedded sandstone (near bottom of figure), *Arenicolites* zone (near center of figure), and bar sand of Unit 20b.
FIG. 3. Unit 20b can be observed to pinch out to the south.
FIG. 4. Details of cross-bedding in Unit 20b.
FIG. 5. Large asymmetrical, arkose-filled channel in Unit 23.
FIG. 6. Large, nearly symmetrical, arkose-filled channel in Unit 7. Note figure on lower left of channel for scale.

Fine-grained, Reddish Brown Arkose.—Fine-grained to very fine-grained, reddish brown arkose occurs in Units 9b, 11, 12, 13a, 15a, 19a, 20, and 21a. This generally weakly lithified arkose contains a variety of sedimentary structures, but they are obscured by rapid erosion and slope debris in units seldom thicker than 5 feet. Planar cross-beds, micro-cross-laminations, and poorly defined vertical burrows, 0.25 to 0.50 inch in diameter, occur. The sand grains are very angular, are densely packed, and vary from approximately 0.25 to 0.50 millimeter in diameter. This immature sandstone has minor amounts of calcareous cement and grades laterally into carbonate rocks in Unit 12 but also grades into coarse-grained, dark red to maroon arkose in Unit 20. Indistinct burrows are the only evidence of organic activity.

Light Tan to White Arkose.—Light tan to white, cross-bedded arkose occurs only in the middle of the argillaceous limestone of Unit 20 and only on the northern margin of the study area. Coarse-grained (0.5 to 7.0 millimeters in diameter) and fine-grained (0.06 to 0.25 millimeter in diameter) sandstone sets of cross strata alternate so that each coarse-grained set is overlain by a related fine-grained set (Pl. 1, fig. 4). Sets are arranged in a shinglelike pattern, and in any given vertical section only three pairs of gently dipping coarse- and fine-grained sets are encountered. In general, the upper portion of the 3-foot-high cosets is coarser than the lower portion. Trace fossils of the *Scolicia* assemblage occur throughout this sandstone but are more abundant and more diverse in the finer-grained part of the cosets, especially at point B on the geologic map. They are described in the section on trace fossils. Dip direction of the sets gradually shifts from 200° on southern exposures of the unit to 150° on the east-northeastern margin. No outcrops were located on the north, and the western margin is unbedded. This unit pinches out to the west, south, and northeast (Pl. 1, fig. 3); however, the original eastern and southern limits of the sandstone body have been removed by erosion.

Conglomerate

Conglomerate is rare, occurring primarily at the base of dark maroon, coarse-grained arkose. Conglomerate occurs in arkose (Pl. 3, fig. 2) in Units 7, 12, 20, and 23, and with light gray green micaceous sandstone in Unit 3. Clasts vary in size from pebbles to boulders up to one foot in diameter. Very fine to coarse pebble-sized clasts composed almost entirely of fragments of large feldspar crystals occur as "floating" pebbles in or on apparent lag deposits near the base of scour channels that were filled with dark red to maroon, coarse-grained arkose. Pebble- to boulder-sized clasts occur as rip-up clasts or intraformational conglomerates at the base of these same arkose units, or locally in light gray green micaceous sandstone. Intraclasts do not occur in channels cut into limestone.

Siltstone

Tan to light brown micaceous siltstone occurs only in Unit 6 where it is thin bedded, micro-cross-laminated, and approximately 9 feet thick. It contains numerous coarser lentils of very fine micaceous sandstone which exhibit "micro-scour" features. No organic activity was evident in this lithology.

Shale and Mudstone

Shale is quantitatively an anomalously minor lithologic type in the study area when compared to cyclic marine and nonmarine deposits elsewhere. A mottled shale of intercalated dark maroon and dark gray green laminae occurs in Unit 5. It is best observed in a road cut near the boat landing at J L Eddy, for it is a slope former elsewhere in the study area. The shale is nearly devoid of fossil evidence except for occasional dark brown meandering patterns, which may be obscure organic trails, on parting surfaces. Rare oxidized impressions of what appear to be macerated plant remains also occur on parting surfaces.

The term *mudstone* is here applied to poorly indurated rocks composed of variable amounts of clay, silt, and fine-grained sand which easily disaggregate to a "mud" in water. These dark reddish brown rocks in the study area are normally slope formers and thus can seldom be observed in detail. Units 9c, 17a, and 19a are of mudstone and are commonly less than four feet thick. The only sedimentary structures observed in this lithology are megaripplelike forms which might also be related to load casts. No fossils were noted.

Carbonate Rocks

Although carbonate rocks are a relatively minor part of the total rock column studied, they are important from the viewpoint of paleoenvironmental interpretations because they enable distinction of many physical and chemical environmental parameters. Ten different carbonate lithologies encountered include (1) argillaceous biomicrite, (2) bryozoan biomicrite, (3) silty biomicrite, (4) cherty biosparite, (5) biopelsparite, (6) fusulinid biosparite (coquina), (7) sandy, bioturbated oosparite, (8) oodolosparite, (9) gray brown sandy biodolosparite, and (10) dark brown to black, cherty, crinkled "algal mat" limestone.

Argillaceous Biomicrite.—An argillaceous biomicrite approximately 4 feet thick occurs in Unit 8 and ranges from 4 to 10 feet thick in Unit 20 as it thickens southward. Both of the light to dark gray units are slope formers and are difficult to observe in the study area. However, Unit 8 does have a basal, more calcareous, and more resistant minor ledge-forming portion (8a). Unit 8 is generally darker than Unit 20 but is not so extensively burrowed. Both units contain somewhat similar faunal assemblages.

Bryozoan Biomicrite.—A three- to four-foot-thick, light gray, poorly indurated, argillaceous bryozoan biomicrite containing the *Dictyoclostus-Lophophyllidium* assemblage occurs in Unit 4. It consists of fragments of bryozoans and of crinoids in an argillaceous matrix, and it immediately overlies fusulinid biosparite. Although no sedimentary structures were recognized, *Wilkingia* burrows filled with reddish gray oxidized sediment and crushed crinoid debris are common.

Silty Biomicrite.—A light reddish gray, clayey to silty, extensively burrowed biomicrite occurs in Unit 12 and is intercalated with and locally dominated by red siltstone (Pl. 3, figs. 4, 5, and 6). Thickness varies from 6 to 40 inches but averages 20 inches. Very angular pebble-size fragments of a dark gray sparite occur in the upper part of this lithology, giving it the appearance of a solution breccia. A very limited and relatively sparse fauna of molluscs of the *Myalina* assemblage and gastropods of the *Natiria* assemblage occurs in this lithology. Extensive bioturbation was likely caused by gastropods which are often found in the burrows.

Cherty Biosparite.—Dense, dark gray biosparite occurs as a three-foot unit interbedded with algal-like structures and chert in the upper portion of Unit 4. The algal-like structures occur in elongate one- to three-inch-thick lenses which locally drape over inverted coral heads (Pl. 6, fig. 5). Internally they resemble the stromatolite form $\frac{\text{SH-V LLH-S LLH-C SH-V}}{\text{LLH-C}}$ of Logan et al. (1964) (Pl. 2, fig. 3). Dark brown to black chert occurs throughout the limestone as irregular nodules and lenses of various forms and sizes, though it is never greater than four inches thick. The *Wellerella-Caninia* assemblage occurs in this lithology.

Biopelsparite.—Dark gray, porous, biopelsparite (Pl. 2, fig. 1), usually less than one foot thick, caps Unit 4, commonly filling depressions in the underlying biomicrite. The pellets are 0.25 to 0.50 millimeter in diameter and may have originated as algal-coated grains or as fecal pellets. The mode of their formation cannot be determined positively because all microstructure of the coating has been destroyed. Pellets with cores of bryozoan fragments are common. Nearly conical "plug-shaped" burrows of an unidentified organism with a diameter as great as two inches and a length of up to four inches originate in this lithology and extend down into the underlying biomicrite, carrying this biopelsparite with them (Pl. 6, figs. 1, 2).

Fusulinid Biosparite.—The basal 6 to 10 inches of Unit 4 is a fusulinid biosparite (coquina) (Pl. 2, fig. 4). The fusulinids, which are dominantly *Triti-*

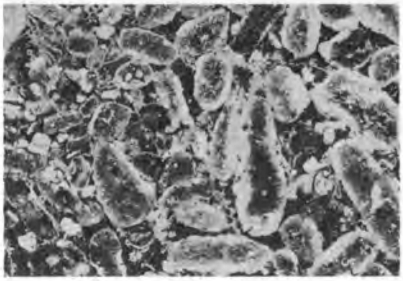
EXPLANATION OF PLATE 2
PHOTOMICROGRAPHS OF LITHOLOGIES AND ORGANISM RELATIONSHIPS

All figures except figure 6 are negative prints.

FIG. 1. Biopelsparite of Unit 4, BYU 979.
FIG. 2. Oodolosparite of Unit 18c, BYU 974.
FIG. 3. Stromatolitic algae of Unit 4, BYU 978.
FIG. 4. Fusulinid biosparite (coquina) of basal Unit 4, BYU 977.
FIGS. 5, 7.—Longitudinal and sagital sections of *Tabulipora* with overgrowth of *Tabulipora.* Note white band of silt, BYU 972.
FIG. 6. *Myalina* shell with borings, 1x, BYU 962.
FIG. 8. *Stenopora* (?) overgrowth around crinoid columnal, BYU 973.

EXPLANATION OF PLATE 3
OUTCROPS IN THE MAP AREA

FIG. 1. Large rip-up clasts at base of arkose of Unit 23.
FIG. 2. Feldspar pebble conglomerate in Unit 7.
FIG. 3. Small arkose channel cut into Unit 20a.
FIGS. 4-6, Series of photographs of Unit 12, showing gradual northwesterly change from a carbonate-dominated rock to a silt and fine-sand size, clastic-dominated rock.



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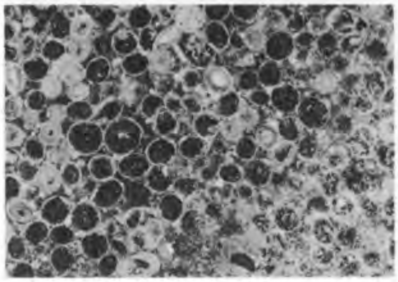

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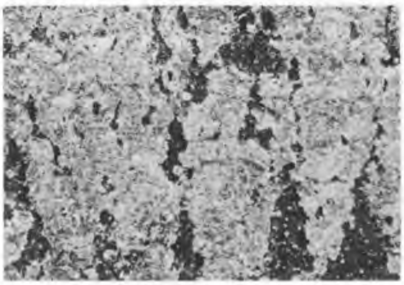

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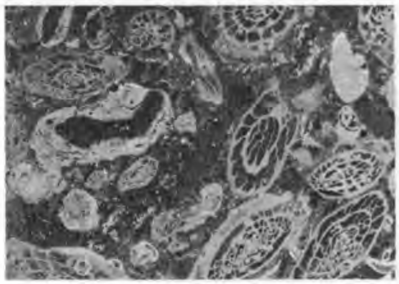

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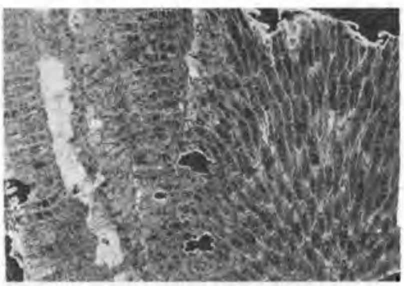

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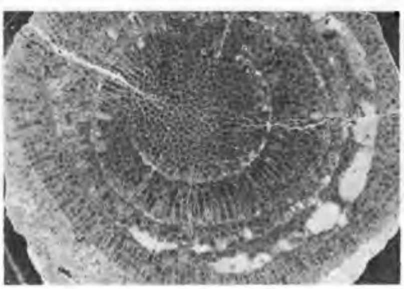

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PLATE 2

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PLATE 3

cites, are generally whole and unabraded. However, the associated crinoids and dominantly fenestrate bryozoans are generally fragmented. This relatively uniformly thick bed contains little terrigenous material and no obvious sedimentary structures.

Sandy Bioturbated Oosparite.—Light pinkish gray, extremely bioturbated, sandy oosparite occurs in the central part of Unit 18. It varies from three to six feet thick. Extensive burrowing was possibly done by a variety of gastropods of the *Euconospira* assemblage which are often found in the 0.5- to 2-inch-diameter burrows. Extensive stylolite development has reduced most of the rock to a rubble zone of burrows that were less affected by the solution and that give the bed the appearance of a solution breccia (Pl. 6, fig. 3).

Oodolosparite.—Very light gray to white, finely crystalline oodolosparite (Pl. 2, fig. 2) occurs as a bed approximately two feet thick in the upper part of Unit 18. Oolites vary from 0.25 to 0.50 millimeter in diameter. This bed is also cut by abundant stylolites, though not as extensively as the underlying bioturbated oosparite. The only evidence of fossils found in these relatively barren rocks is occasional dark brown to black fragments of algal-like crusts and very rare porous fragments of an unidentified arthropod.

Gray Brown Sandy Biodolosparite.—Gray brown sandy biodolosparite approximately two feet thick occurs in Unit 14. This is a relatively rare rock type in the study area. Echinoderm fragments are abundant, and fusulinids are rare in this lithology. No sedimentary structures were recognized.

Dark Brown to Black, Cherty, Crinkled "Algal Mat" Limestone.—Dark brown to black, cherty, crinkled "algal mat" limestone one to two inches thick caps Unit 18. This thin, frequently eroded lithology appears to exhibit desiccation cracks; however, confirmation is not possible with the typically poor exposures. This hypothesis is supported by the fact that chiplike fragments of this "algal mat" do occasionally occur in the underlying oodolosparite. Algal origin of the lithology is uncertain as the "algae" have not been identified; however, in character and occurrence it is very similar to that from the Persian Gulf described as the "crinkled algal zone" (Kendall and Skipwith, 1968).

LITHOLOGIC RELATIONS

Lithologies previously described which occur only once in the stratigraphic section will not be discussed further. Other lithologic types often occur repeated in significant, recognizable patterns.

The coarse-grained dark maroon arkose occurs scouring into dark red sandstone, pale orangish red sandstone, fine-grained reddish brown arkose, siltstone, mudstone, and often other coarse-grained dark maroon arkoses. This lithology does not occur at regular systematic intervals but occurs intermittently whenever the energy level of the medium transporting the land-derived sediments is great enough. It does not occur in lithologies whose depositional environment is interpreted as being open marine or not dominated by land-derived sediment input.

These coarse-grained dark maroon arkoses are frequently underlain and occasionally overlain by fine reddish brown arkose if not removed by basal scouring. Occasionally the fine reddish brown arkose occurs as a sheet, not vertically associated with the coarse-grained dark maroon arkose, but locally laterally contiguous with it (Unit 20 north of the mapped area). As the fine-grained reddish brown arkose trends toward lower energy levels, it gradually fines and becomes calcareous until it subtly grades laterally into silty carbonate rocks. This may be represented vertically by the carbonate rocks bounded on either the top or the bottom, or both, by the fine arkose. Lateral change from fine arkose to carbonate rocks can be observed in Unit 20 and repeatedly in Unit 12.

Each channel-forming, coarse-grained dark maroon arkose is directly overlain by a sandy carbonate lithology. Similar nonchanneling arkoses are overlain by either the pale orangish red sandstone or the dark red sandstone, both of which are believed to be derived from the arkose. Carbonate rocks may occur separating the pale orangish red sandstone into two parts.

For a description of each lithology in the stratigraphic section, refer to Appendix 1. The stratigraphic section is graphically illustrated in Text-figure 5.

PALEONTOLOGY

Occurrence, Preservation, and Orientation

The studied strata are some of the more fossiliferous beds in Utah and, as such, are frequently collected by "rock hounds" and "fossil hunters." Because the extensive local collecting might have caused sampling bias, only the nearly inaccessible sites were used for collecting representative suites of fossils. Most samples collected for photographing were found weathered out of their matrix and in loose rubble; however, their stratigraphic position was verified by locating other samples in outcrop. Fossils other than ichnofossils occur almost exclusively in carbonate Units 4, 8, 12, 14, 18, and 20. Units 2, 3, and 23 contain only plant remains.

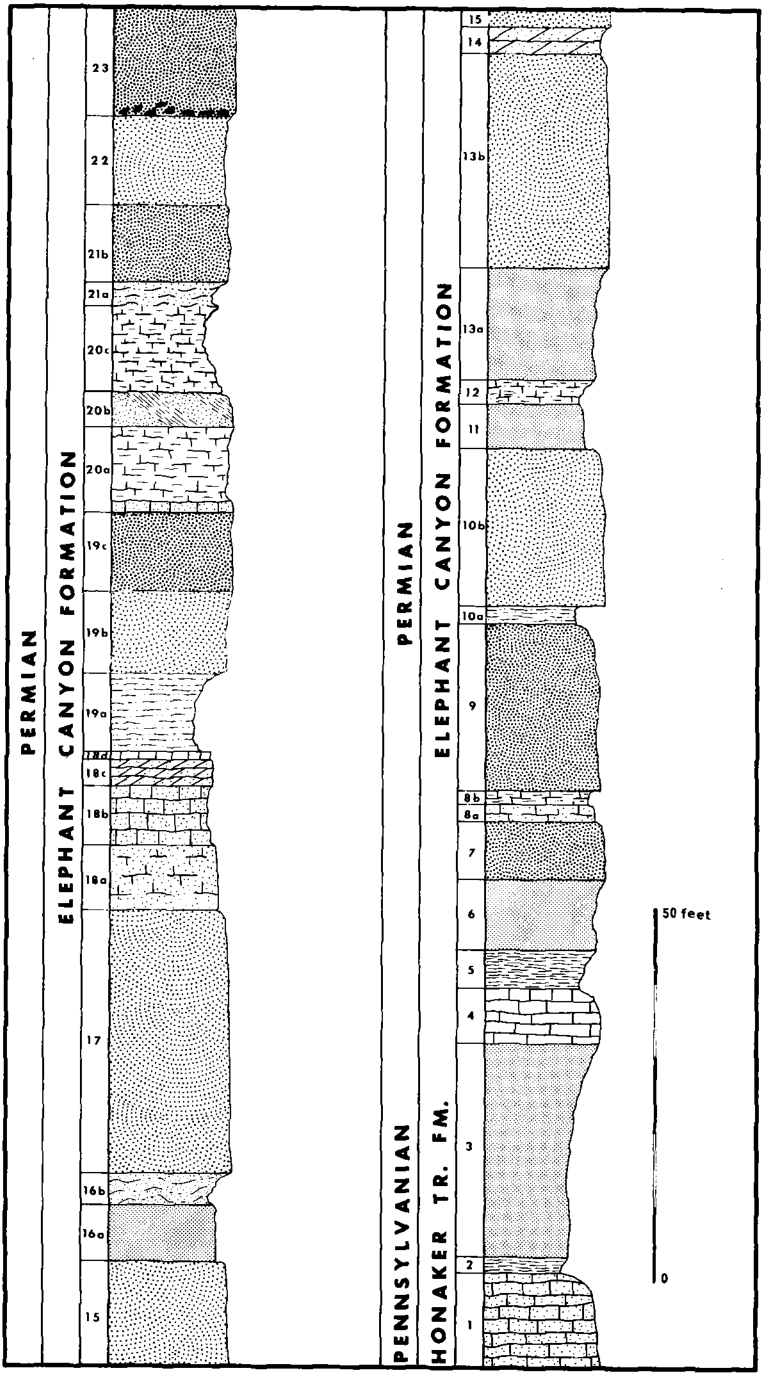
The generally well-preserved fauna is silicified in Unit 4, but is calcareous elsewhere. Woody plant and algae-like remains have been replaced by silica or occasionally by calcite, but other plants generally occur as clasts, frequently lined with a carbonaceous film. Gastropods are nearly always preserved as internal casts and molds. Trilobites occur as disarticulated fragments, except for one complete, enrolled specimen of *Ameura* (Pl. 8, figs. 22 and 23).

Orientation of specimens is often an important help in environmental interpretations. Orientations which are considered significant occur in Units 4 and 20. In Unit 4, 4- to 10-inch-diameter *Syringopora* coralla occur both in their normal, upright position and overturned (Pl. 6, fig. 5). In this same unit, echinoderm fragments occur in small clusters which typically taper off to the southeast, suggesting current movement in that direction. Productid brachiopods in Unit 20 and occasionally in Unit 8 occur in growth position, frequently with nearly one-inch-long delicate spines intact.

A complete list both of genera found and of their occurrence is given in Table 1. Identified specimens are illustrated on Plates 7 and 8.

Ichnofossils

Ichnofossils (trace fossils) are common in nearly all units of the study area and frequently are the only evidence of organisms in clastic units. Domichnia, fodinichnia, repichnia, and pascichnia (Seilacher, 1946) are present in



TEXT-FIGURE 5.—Stratigraphic Section.

TABLE 1
FAUNAL DISTRIBUTION

Form Name	Unit 4	8	12	14	18	20
Protozoa						
Dunbarinella (?) sp.	R	–	–	R	C	R
Triticites sp.	A	C	R	R	R	R
Coelenterata						
Caninia sp.	C	–	–	–	–	–
Chaetetes sp.	–	–	–	–	–	R
Lophophyllidium sp.	C	–	–	–	–	–
Syringopora sp.	C	–	–	?	–	–
Bryozoa						
Archimedes sp.	R	–	–	–	–	–
Fenestella (?) sp.	C	C	–	–	–	C
Fistulipora sp.	–	–	–	–	–	C
Polypora sp.	C	C	–	–	–	–
Tabulipora sp. A	–	C	–	–	–	A
Tabulipora sp. B	–	–	–	–	–	C
Stenopora sp. A	A	C	–	–	–	A
Stenopora sp. B	–	–	–	–	–	R
Brachiopoda						
Ambocoelia expansa (?)	–	R	–	–	–	–
Chonetes granulifer	–	A	–	–	–	C
Chonetina sp.	–	R	–	–	–	R
Composita ovata (?)	–	C	–	–	–	–
Composita subtilita	C	C	–	–	–	–
Composita trilobata (?)	–	C	–	–	–	–
Composita (?) sp.	R	–	–	–	–	–
Derbyia crassa	R	C	–	–	–	C
Derbyia (?) sp.	C	–	–	–	–	C
Dictyoclostus sp.	C	–	–	–	–	–
Juresania nebrascensis	–	C	–	–	–	C
Linoproductus magnispinus	–	A	–	–	–	A
Linoproductus planiventralis (?)	–	C	–	–	–	R
Linoproductus prattenians	–	A	–	–	–	C
Marginifera sp.	R	C	–	–	–	R
Neospirifer sp.	C	C	–	–	–	R
Neospirifer sp. A	C	C	–	–	–	R
Neospirifer sp. B	C	–	–	–	–	–
Neospirifer (?) sp. A	–	–	–	–	–	R
Neospirifer (?) sp. B	C	–	–	–	–	–
Orbiculoidea sp.	C	–	–	–	–	–
Wellerella sp.	C	–	–	–	–	–
Mollusca—Gastropoda						
Anomphalus sp.	–	R	–	–	–	R
Bellerophon sp.	–	C	R	–	R	C
Euconospira sp.	–	C	?	–	A	C
Helicospira sp.	–	–	R	–	–	–
Holopea sp.	–	–	C	–	–	–
Ianthinopsis sp.	–	R	–	–	–	R
Loxonema sp.	–	R	–	–	–	–
Natiria sp.	–	–	C	–	–	–
Pharkidonotus sp.	–	A	R	–	–	C
Straparollus sp.	–	R	–	–	–	R
Worthenia (?) sp.	–	R	–	–	–	R
Mollusca—Cephalopoda						
Metacoceras sp.	–	–	–	–	–	R
Unidentified specimen	–	–	–	–	–	R

Table 1 (Continued)

Mollusca—Bivalvia						
Acanthopectin (?) sp.	–	R	–	–	–	–
Edmondia sp.	–	C	–	–	–	C
Limatula sp.	–	C	–	–	–	C
Modiolus sp.	–	–	–	–	–	C
Myalina sp. A	?	R	A	–	–	C
Myalina sp. B	–	–	–	–	–	C
Myalina sp. C	–	–	–	–	–	R
Parallelodon sp.	?	R	–	–	–	?
Pinna sp.	R	R	–	–	–	R
Pseudomonotis (?) sp.	–	R	–	–	–	R
Pteronites sp.	–	C	–	–	–	C
Schizodon (?) sp.	–	C	–	–	–	C
Septimyalina sp.	–	R	–	–	–	?
Wilkingia sp. A (large)	R	C	–	–	–	A
Wilkingia sp. B (small)	–	C	R	–	–	C
Arthropoda						
Ameura (?) sp.	–	R	–	–	–	R
Ditomopyge sp.	–	R	–	–	–	R
Unidentified arthropod	–	R	R	–	–	R

TABLE 2
TRACE FOSSIL DISTRIBUTIONS

	Form Name													
	Teichichnus (?)	*Ophiomorpha* (?)	*Arenicolites*	*Thalassinoides* (?)	plug-shaped	rod-shaped	gastropod (?)	*Wilkingia* burrows	flaring spreite structures	*Arthrophycus* (?)	meandering	*Scolicia*	horizontal	smooth tubes
Class														
Domichnia	x	x	x	x	x	x	x	..	..	..	..	..	..	..
Fodinichnia	..	..	..	..	..	x	x	x	x	x	x	..	..	..
Repichnia	..	..	..	..	..	..	..	..	..	..	..	x	x	x
Pascichnia	..	..	..	..	..	..	..	..	..	..	..	x	x	x
Cubichnia	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Unit No.														
2	..	..	..	..	..	..	..	..	..	..	..	..	x	x
3	..	..	..	..	..	..	..	..	..	..	..	..	x	x
4	..	..	..	..	..	..	..	x	..	..	..	..	..	x
5	..	..	..	..	..	..	..	..	..	..	x	..	..	..
8a	..	..	..	..	..	..	x	x	..	..	..	..	..	..
8b	..	..	..	..	..	..	x	x	x	..	..	..	..	..
9	..	..	..	..	..	?	..	..	..	..	..	..	..	..
10b	..	x	..	..	..	..	..	..	..	..	..	..	..	..
11	..	..	..	..	..	?	..	..	..	..	..	..	..	..
12	..	..	..	..	..	..	..	x	..	..	..	..	..	..
15	..	x	..	..	..	..	..	..	..	..	..	..	..	..
18b	..	..	..	..	..	..	x	..	..	..	..	..	..	..
19b	..	x	..	..	..	..	..	..	..	..	..	..	..	..
20a	..	..	x	x	..	..	..	x	..	..	..	..	..	..
20b	x	..	..	..	x	..	..	..	..	?	..	x	x	x
20c	..	..	x	x	..	..	..	x	..	..	..	..	..	..
21a	..	..	..	..	..	?	..	..	..	..	..	..	..	..

the study area, but no cubichnia were recognized. A complete listing of occurrences of trace fossils in the study area is given in Table 2.

Domichnia

A trace fossil similar to *Teichichnus* (Pl. 4, fig. 1) occurs in both the fine and coarse portions of Unit 20b but is most common in the coarser sandstone.

Indistinct *Ophiomorpha*-like trace fossils occur in Units 10b, 15, and 19b, where they produce reduced pale gray green zones in the normally pale orangish red, cross-bedded sandstone. Often only the upper 3 to 10 feet of the units will be occupied by this form.

Arenicolites is a very characteristic domichnid form which occurs only in the basal sandy biosparite of Unit 20a (Pl. 4, figs. 5 and 6). Its U-shaped tubes, 0.25 to 0.75 inch in diameter, are spaced at regular intervals of 3 to 5 inches. The length of the burrow, about 1 foot, is approximately equal to the thickness of this rock type. Vertical, full-relief burrows, 0.5 to 1.0 inch in diameter and similar to the "rod-shaped burrows" described by Howard (1966), occur in the fine akrose of Units 9 and 11. These forms are not well preserved, because the rocks in which they occur are easily eroded to slopes. If they are not *Arenicolites,* they may be related, but poor preservation does not enable recognition of the U-shaped form if present. These burrows have been interpreted elsewhere as either domichnia or fodinichnia of polychaete worms (Howard, 1966, p. 50, 51). Another burrow of similar geometric form but 3 to 4 inches in diameter occurs in Unit 20b (Pl. 4, fig. 2). It is of uncertain affinities.

Units 8a, 8b, 12, and 18b contain abundant irregularly formed vertical, horizontal, or inclined, full-relief burrows, 0.5 to 1.0 inch in diameter, which weather out as elongate, irregular cylinders, (Pl. 6, fig. 3). *Bellerophon* and *Euconospira* are frequently found inside these fillings in Units 8 and 18, but neither are thought to have made the burrows. They may have been washed into or may have lived in the burrows which were made by other organisms. These either domichnid or fodinichnid impressions are listed as "gastropod (?) burrows" in Table 2. Burrows in the silty biomicrite of Unit 12 occur in strata nearly barren of shells, though occasionally the gastropod *Natiria* is found in the disturbed strata.

Numerous burrows, 15 to 20 millimeters in diameter, Y-shaped, and branching, occur as convex hyporeliefs along silty partings in Unit 20a (Pl. 4, fig. 4). These are similar in appearance to *Thalassinoides.*

Fodinichnia

Burrows interpreted as fodinichnia occur in Units 4, 8a, 8b, 20a, and 20c. A single burrow similar to *Arthrophycus* was found in Unit 20a. In addition, poorly preserved, dark reddish brown, meandering trails one to two millimeters wide occur on parting surfaces of shale in Unit 5. These are of uncertain origin but appear to represent a food-gathering or moderately uniform searching pattern.

Large two- to four-inch diameter, irregularly formed horizontal, vertical, and inclined full-relief burrows occur in Units 8a, 8b, 20a, and 20b (Pl. 5, fig. 7). These burrows frequently contain the bivalve *Wilkingia,* a burrowing form (Pl. 5, fig. 1). Because of this close relationship, these burrows will here be called *Wilkingia* burrows. Individual *Wilkingia* burrows can often be followed for five or six feet in outcrop through the silty biomicrite

1

2

3

4

5

6

EXPLANATION OF PLATE 4

TRACE FOSSILS

FIG. 1. *Teichichnus*-like burrow from Unit 20b.
FIG. 2. Common large cylindrical burrow of uncertain affinities from Unit 20b.
FIG. 3. "Smooth tube" trails from Unit 20b.
FIG. 4. *Thalassinoides*-like burrows from Unit 20b.
FIG. 5. Top of *Arenicolites* burrows from Unit 20a.
FIG. 6. Cross section through a series of *Arenicolites* burrows from Unit 20a.

1

2

3

4

7

8

EXPLANATION OF PLATE 5
TRACE FOSSILS

FIG. 1. *Wilkingia* in burrow, 0.3x, BYU 964.
FIG. 2. *Spreite* structure trail, 1.0x, BYU 954.
FIG. 3. *Wilkingia* burrow with concentrated echinoderm debris 0.25x, BYU 980.
FIG. 4. Spreite structure, 1.0x, BYU 955.
FIG. 5. *Gyrodithes*-like burrow associated with *Wilkingia* burrows.
FIG. 6. *Scolicia* trail with medial ridge.
FIG. 7. *Wilkingia* burrow.
FIG. 8. *Scolicia* trail.

1

2

3

4

5

6

EXPLANATION OF PLATE 6

OUTCROPS

FIG. 1. Conical burrows carrying biopelsparite down into biosparite of Unit 4.
FIG. 2. Biopelsparite-filled burrows in Unit 4.
FIG. 3. Rubble zone of burrows in Unit 18.
FIG. 4. Extensively bioturbated lithology of Unit 20a.
FIG. 5. Overturned *Syringopora* head in Unit 4.
FIG. 6. Stromatolitic algae of Unit 4.

of Units 20a and 20c. Large two- to four-inch burrows filled with echinoderm debris and red silt occur in the bryozoan biomicrite of Unit 4 (Pl. 5, fig. 3) and also contain *Wilkingia.* These are considered to be another form of *Wilkingia* burrow developed in response to a slightly different environment. Spiraling *Gyrodithes*-like burrows with a similar diameter occur with *Wilkingia* burrows in Unit 20a and b (Pl. 5, fig. 5), but whether this form is a part of *Wilkingia* burrows or represents activity of a different organism is uncertain.

A semicircular trace fossil 0.5 to 0.75 inch in diameter with a medial trough occurs in Unit 8b (Pl. 5, fig. 2). This trace fossil frequently terminates in a flaring *spreite* structure (Pl. 5, fig. 4) and will be referred to as the "flaring *spreite* burrow." Because of poor preservation in the easily eroded unit, this trace fossil was never seen in place and is of uncertain affinities.

Repichnia and Pascichnia

Because of the difficulty in separating repichnid and pascichnid forms they are here grouped together for discussion. Forms assigned to either repichnia or pascichnia are found in Units 2, 3, 4, and 21b.

Scolicia of two types occur in Unit 20b. One type is a convex epirelief one to two inches wide with a distinct median ridge (Pl. 5, fig. 6). The second type is similar but lacks a median ridge (Pl. 5, fig. 8). Both forms occur in the siltstone and fine sandstone layers of this unit, and both are believed to be trails that represent repeated sediment displacement by the organism crawling over the surface of the substrate. The second type may be more closely related to the "chevron trails" described by Howard (1966).

Small, sinuous, nonbranching, horizontal trails one to two centimeters in diameter occur as convex-epirelief and full-relief impressions in Units 3 and 4 and, rarely, in Units 9 and 11. They may be related to the "horizontal trails" described by Howard (1966), though somewhat smaller.

Forms similar to the "smooth tubes" described by Howard (1966) occur in the fine micaceous sandstone and siltstone of Units 2 and 3 (Pl. 4, fig. 3). These unornamented, full-relief to convex-epirelief forms frequently occur in clusters and may be casts of the excreta of an organism with habits comparable to the modern holothuroids.

ASSEMBLAGES OF ORGANISMS—ENVIRONMENTAL SIGNIFICANCE

The biota of the study area are grouped into a series of assemblages characterized by a distinct set of organisms and lithology. Thirteen such assemblages are recognized in the study area: (1) *Dictyoclostus-Lophophyllidium,* (2) *Wellerella-Caninia,* (3) *Wilkingia,* (4) *Linoproductus,* (5) *Chonetes,* (6) *Myalina,* (7) *Natiria,* (8) *Euconospira,* (9) *Triticites,* (10) *Calamites,* (11) *Scolicia,* (12) *Arenicolites,* and (13) *Ophiomorpha* (?). These assemblages represent a succession of distinct depositional environments for which many limiting parameters can be deduced.

Dictyoclostus-Lophopyllidium Assemblage.

This assemblage occurs only once stratigraphically in the study section, but is common in beds stratigraphically below the studied sequence. It occurs in the three- to four-foot argillaceous bryozoan biomicrite of Unit 4. Organisms which occur in this assemblage are *Dictyoclostus, Composita, Derbyia, Marginifera, Fenestella* (?), *Archimedes, Stenopora, Lophophyllidium, Triticites, Pinna,* and *Wilkingia* along with abundant echinoderm and fenestrate bryozoan fragments. Although many of these organisms occur in other units and other assemblages, *Dictyoclostus* and *Lophophyllidium* are distinctive and common.

Wellerella-Caninia Assemblage

The *Wellerella-Caninia* assemblages occurs only in the upper part of Unit 4, a dense, dark gray biosparite, approximately three feet thick. Depressions in this lithology are filled with the overlying biopelsparite. Organisms comprising this assemblage include several species of *Wellerella, Neospirifer, Triticites, Syringopora Caninia,* and stromatolic algae of the form $\frac{\text{SH-V LLH-S LLH-C SH-V}}{\text{LLH-C}}$ (Logan et al., 1964). Remains of unidentified echinoids occur in small clusters at regular intervals, suggesting that these were the sites of expiration of the organisms.

All of these organisms are indicative of marine waters of normal salinity. This two- to four-inch thick stromatolite growth form has been interpreted elsewhere as indicative of shallow water, with the mat perhaps subaerially exposed at times (Logan et al., 1964).

The energy level must have been moderately high, at least intermittently, because 4- to 10-inch *Syringopora* coralla, generally in growth position, are occasionally overturned (Pl. 6, fig. 5). The presence of biopelsparite also indicates a moderately high energy level.

Terrigenous material is almost totally absent from this unit, which, with other factors described, would indicate that this was a very shallow, open-marine environment far removed from a clastic source.

Wilkingia, Linoproductus, and *Chonetes* Assemblages

The three assemblages characterized by *Wilkingia, Linoproductus,* and *Chonetes* together contain representatives of nearly every genus recognized in this study. These three assemblages are closely related stratigraphically and paleontologically and occur in somewhat similar lithologies. However, separation into three assemblages appears justified because the "end-members" from which the assemblages receive their names are usually concentrated into particular facies, while the "accessory members" of the assemblages, consisting of various genera of brachiopods, gastropods, echinoderms, bivalves, cephalopods, bryozoans, and arthropods, and of wood (?) fragments are generally transitional, occurring in all three assemblages. Table 1 shows the total fauna of these assemblages which occurs in Units 8 and 20.

The *Chonetes* assemblage occurs in Unit 8b, primarily at the base, in a dark agrillaceous limestone to calcareous argillite. "End-members" of this assemblage are *Chonetes, Pharkidonotus,* and *Bellerophon,* though *Linoproductus* is common. The basal bed characterized by this assemblage is almost entirely composed of *Chonetes.*

The *Linoproductus* assemblage is characterized by *Linoproductus, Juresania* and *Marginifera* in addition to the "accessory members" and is best developed in Unit 20a above the *Arenicolites* assemblage. A major portion of Unit 20a is transitional between the *Wilkingia* assemblage, and the *Linoproductus* assemblage distinctions being somewhat difficult to make. However, it appears that the *Linoproductus* assemblage is best developed in the less clastic, thinner-bedded portions of the unit. The *Linoproductus* assemblage also appears to be transitional with the *Chonetes* assemblage of Unit 8b where it overlies the latter, but it is not well developed. Turbidity and fine grain size may be the factors controlling the *Chonetes* assemblage, for it occurs in finer-grained rocks than does the *Linoproductus* assemblage.

The *Wilkingia* assemblage is best developed in Units 20a and 20b, although *Wilkingia* occurs in most of the carbonate units studied. This assemblage is dominated by the bivalves *Wilkingia, Edmondia, Myalina, Pinna,* and *Limatula.*

Occurrence of these assemblages with the argillaceous to silty biomicrite is considered to represent a shallow interdistributary bay or estuarine depositional environment. This is further illustrated by the occurrence of a shallow arkosic channel which eroded into Unit 20a (Pl. 3, fig. 3) and the probably storm-generated sand bar four feet high in Unit 20b. While these features could occur in other environments, the normally protected environment of an estuary or interdistributary bay seems more likely. It is possible that the *Chonetes* assemblage could have developed in a prodelta environment or in an extremely low-energy portion of an estuary.

Myalina Assemblage

This assemblage occurs locally in Unit 12, a silty biomicrite. *Myalina* dominates this assemblage which also contains rare *Pharkidonotus, Natiria, Holopea, Helicospira, Bellerophon, Wilkingia,* and unidentified arthropod fragments. While these other forms occur with *Myalina* occasionally, they are more common in the *Natiria* assemblage. Abundant *Myalina* commonly occurs alone. *Myalina* is considered to have been either an epibissate or a semi-endobissate bivalve. Locally abundant clusters tend to indicate that the form was somewhat gregarious.

Unit 12 has considerable lateral variation and is dominated locally by either carbonate or clastic deposits. The *Myalina* assemblage occurs in those portions of carbonate rock with abundant silt-size clastic particles. Where carbonate sediments begin to dominate, *Wilkingia* and *Helicospira* are added to the assemblage. Where clastic deposits dominate, there are no fossils.

Natiria Assemblage

The *Natiria* assemblage is closely associated with the *Myalina* assemblage (Text-fig. 6) but dominates in those portions of Unit 12 which have slightly more terrigenous clastic content. This assemblage contains abundant *Natiria* and *Holopea,* and rare *Helicospira, Pharkidonotus, Bellerophon,* and *Wilkingia.* Occasionally, vertical hollow tubes, 0.25 to 0.50 inch in diameter and with a carbonaceous lining, occur in the more clastic portions of the *Natiria* assemblage. These are possibly *in situ* casts of plants.

That Unit 12 was probably deposited in shallow water is indicated by a solution breccia near its upper surface and by the presence of plant (?) casts. Modern gastrapods related to *Natiria* occupy shallow tidal flats and feed by plowing through the sediment. This unit is extensively bioturbated and mottled.

Euconospira Assemblage

The *Euconospira* assemblage occurs in light pinkish gray, extensively bioturbated, sandy oosparite of Unit 18b and consists of *Euconospira* and rare

Bellerophon, occasional echinoderm and bivalve fragments, and locally abundant *Dunbarinella* (?). Burrows in this unit often contain gastropods. However, these gastropods seem to have occupied burrows made by another organism. This unit is interpreted as being transitional between a tidal flat (represented by the underlying strata) and a marine oolite shoal (represented by the overlying strata).

Triticites Assemblage

The occurrence of this assemblage might properly be called the *Triticites* bed because few other forms occur in association and it occurs only once in the study section, at the base of Unit 4 in a fusulinid biosparite (coquina), but it occurs in several other beds in older rocks below the investigated sequence. Forms occurring in this assemblage include *Triticites, Wedekindelina, Dunbarinella* (?), and other unidentified nonfusulinid foraminifera, along with occasional bryozoan and echinoderm fragments. This assemblage and this lithology represent a relatively high energy marine environment. Workers have regarded the occurrence of fusulinids as bathymetrically significant but have attributed them to a variety of depths: 100-180 feet (Elias, 1937, p. 410), less than 30 feet (Imbrie, Laporte, and Merriam, 1959, p. 78), nearly 50 feet (Laporte, 1962, p. 540), 5-50 feet (Tasch, 1957, p. 396), and 1-5 meters (Stevens, 1971). The higher energy level suggested by the present study would favor a depth above wave base, a shallower depth. Depths proposed by Stevens (1971) are felt to be comparable to those of this fusulinid coquina.

Calamites Assemblage

Unit 3 contains locally abundant plant remains and shows promise of becoming an important locality. Flora seems to indicate an Upper Pennsylvanian age of this bed, but further work is needed. Faculty and graduate students of the Brigham Young University Botany Department are undertaking a more extensive study of the flora. Preliminary identification of part of the flora indicated the occurrence of *Pecopteris* sp., *Calamites sukowi, Calamites* sp., *Annularia stellate, Odontopteris* sp., *Artisia* sp., *Cordaites* sp., *Lepidopholios* sp., *Lepidodendron* sp., lycopod remains and conifer logs (Tidwell, Thane, and Terrell, 1972).

Because this unit is poorly exposed, it is difficult to reconstruct its environment of deposition. However, (1) no marine fauna is present, (2) sediment is terrigenous, (3) characteristic floral assemblage is present, (4) flora is often localized in zones associated with basal intraclasts, and (5) structures similar to climbing ripples are present. These combined factors indicate a nonmarine, probably fluvial-dominated environment that may be envisioned as a sand-laden, aggrading, perhaps braided stream with the deposits representing point bars and channel-fill deposits.

Scolicia Assemblage

The *Scolicia* assemblage occurs in the light tan to white, cross-bedded arkose of Unit 20b and consists of the trace fossils *Teichichnus* (?), *Arthrophycus* (?), *Scolicia,* "plug-shaped forms," "horizontal forms," and "smooth tube forms" and marks this important lithology. This arkose unit consists of a series of cross sets of alternating coarse- and fine-grained material. *Teichichnus* (?) and the "plug-shaped" forms occur only in the coarser cross sets. *Scolicia, Arthrophycus* (?), "horizontal forms," and "smooth tube" forms occur only in the finer-grained cross sets. Forms found in this assemblage indicate relatively high energy of depositional environment (Howard, 1966).

Sandstone geometry, lithology, relation to associated carbonate rocks, faunal distribution, and assemblage of trace fossils tend to indicate a high-energy marine environment superposed upon a relatively low-energy marine environment (Unit 20a, c). Cross sets of coarse- and fine-grained sandstone alternating with the finer sandstone that is extensively burrowed suggest alternate periods of very high and lower energy, such as might be caused by periodic storms. This pattern would fit very well for a near-shore marine bar. A terrigenous clastic source is also located in Unit 20 with the relations as shown in the generalized diagram of Text-figure 6.

Arenicolites Assemblage.

The *Arenicolites* assemblage occurs at the base of Unit 20a, a sandy biosparite which overlies an arkose. *Arenicolites* is the only trace fossil recognized; however, unidentifiable fragments of a variety of fossils, dominantly bivalves, are also contained in this assemblage. *Arenicolites* and similar U-shaped burrows have been regarded as the protective domichnid burrow of an organism, most likely a worm, living in the high-energy, shallow-water, shore zone (Howard, 1966 and Goldring, 1971). This interpretation fits well with observed relationships of the *Arenicolites* assemblage in the study area, for high energy is indicated by the fragmented fossil remains and to some degree by the sandy texture.

EXPLANATION OF PLATE 7
BRACHIOPODS AND GASTROPODS

FIG. 1. *Chonetina* sp. (?) 2x BYU 936.
FIG. 2. *Squamularia* sp. 2x BYU 947.
FIG. 3. *Composita* (?) 2x BYU 986.
FIG. 4. *Neospirifer* (?) 2x BYU 949.
FIG. 5. *Chonetes granulifer* 1x BYU 940.
FIG. 6. *Wellerella* sp. 2x BYU 951.
FIG. 7. *Neospirifer sp.* 1x BYU 953.
FIG. 8. *Neospirifer* (?) 1x BYU 988.
FIG. 9. *Orbiculoidea subtrigonalis* (?) 1x BYU 927.
FIG. 10. *Wellerella* sp. 2x BYU 950.
FIG. 11. *Ambocoelina expansa* (?) 2x BYU 952.
FIG. 12. *Linoproductus* 0.5x BYU 960.
FIG. 13. *Composita* (?) 2x BYU 948.
FIG. 14. *Composita*
FIG. 15. *Composita* sp. 1x BYU 956.
FIG. 16. *Dictyoclostus* sp. 0.3x BYU 944.
FIG. 17. *Juresania nebrascensis* 1x BYU 932.
FIG. 18. *Juresania nebrascensis* 1x BYU 931.
FIG. 19. *Linoproductus prattenianus* (?) 1x pedical valve, BYU 939.
FIG. 20. *Linoproductus prattenianus* (?) 1x brachial valve, BYU 930.
FIG. 21. *Composita trilobata* (?) 1x BYU 933.
FIG. 22. *Pharkidonotus* sp. 1x BYU 929.
FIG. 23. *Ianthinopsis* (?) sp. 1x BYU 928.
FIG. 24. *Straparollus* sp. 2x BYU 957.
FIG. 25. *Derbyia crassa* 1x BYU 942.
FIG. 26. *Helicospira* sp. 2x BYU 970.
FIG. 27. *Holopea* (?) 1x BYU 969.

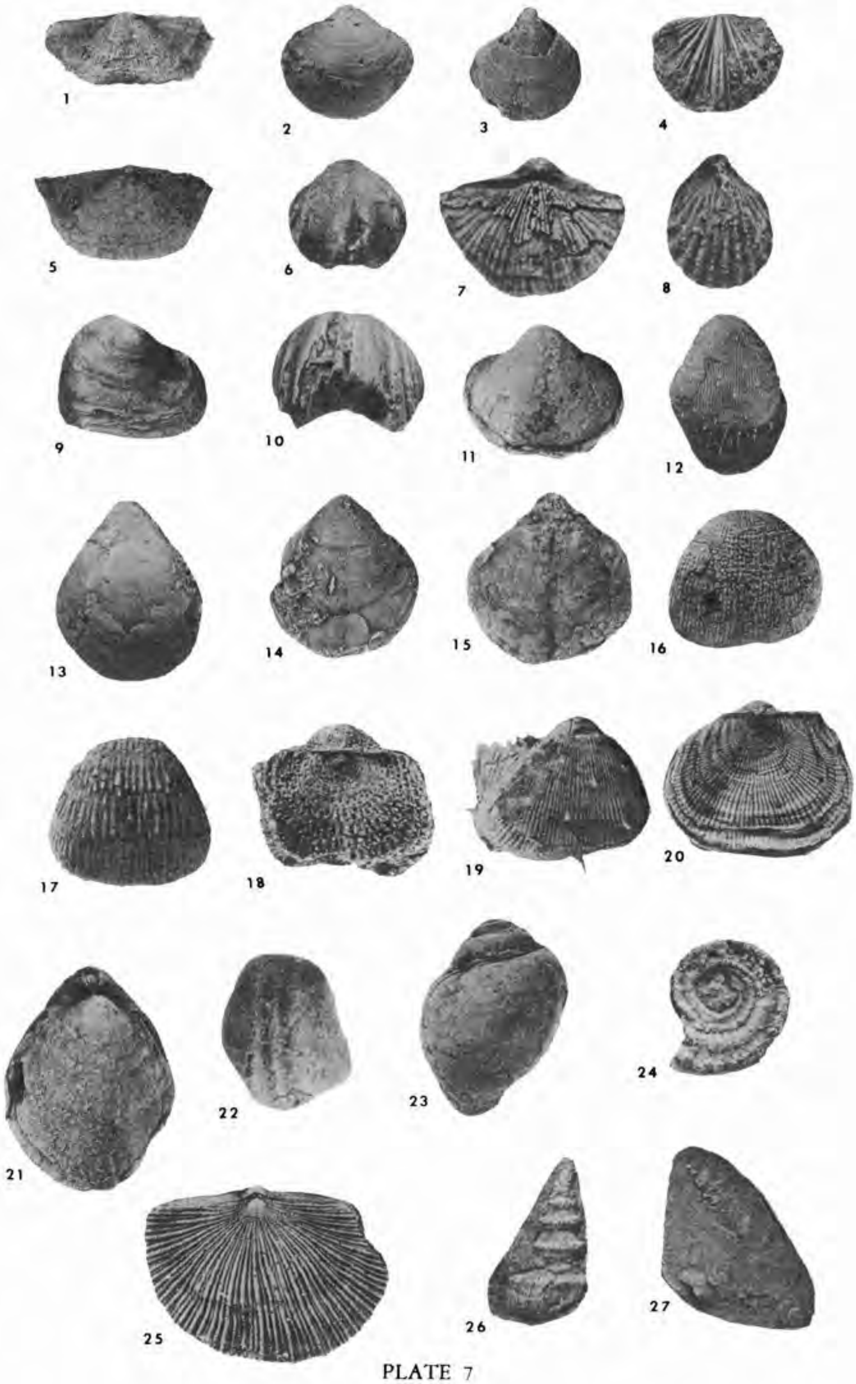


PLATE 7

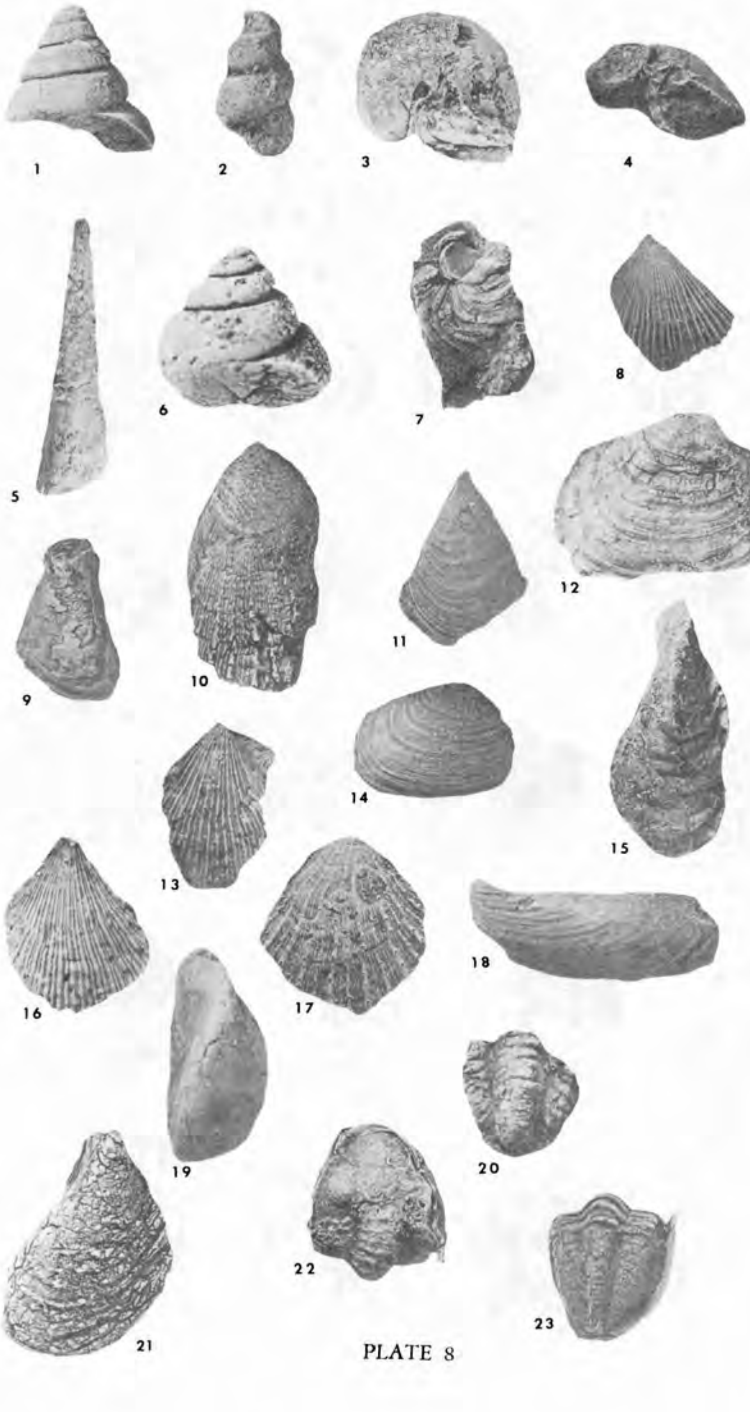


PLATE 8

Because this assemblage is underlain by a fluvial arkose and overlain by a silty biomicrite to biosparite, it probably represents the beginning of a marine transgression of a subsiding distributary system.

Ophiomorpha (?) Assemblage

Ophiomorpha-like burrows occur regularly and systematically within the orangish red cross-bedded sandstones of Units 10b, 13b, and 19b and should be regarded as a distinct assemblage. Although other trace fossils may occur in these rocks, the only form noted in this study is the *Ophiomorpha*-like burrows.

The grain size, geometry, and cross-bed pattern previously described for these sandstones, together with the extensive burrow development frequently only in the upper part of the sandstone, suggest that the environment of deposition may have been a submarine bar. The *Ophiomorpha*-like burrows probably developed during a nearly stable period or during a period of minimum bar mobility. Their limitation to the upper part of the sandstone probably indicates the maximum depth to which the constructing organism could penetrate.

PALEOECOLOGY

Relationships Between Organisms. A common relation exists between crinoids and the bryozoan *Stenopora* (?) in most of the carbonate units in which they occur together. As shown in Plate 2, figure 8, a portion of a crinoid columnal is encrusted by the bryozoan *Stenopora* (?). The overgrowth probably occurred while the crinoid was alive, because the bryozoan growth is equally well developed around the circumference of the columnal section but not on the ends. Thus, the columnal must have been in an upright position

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EXPLANATION OF PLATE 8
GASTROPODS, BIVALVES AND ARTHROPODS

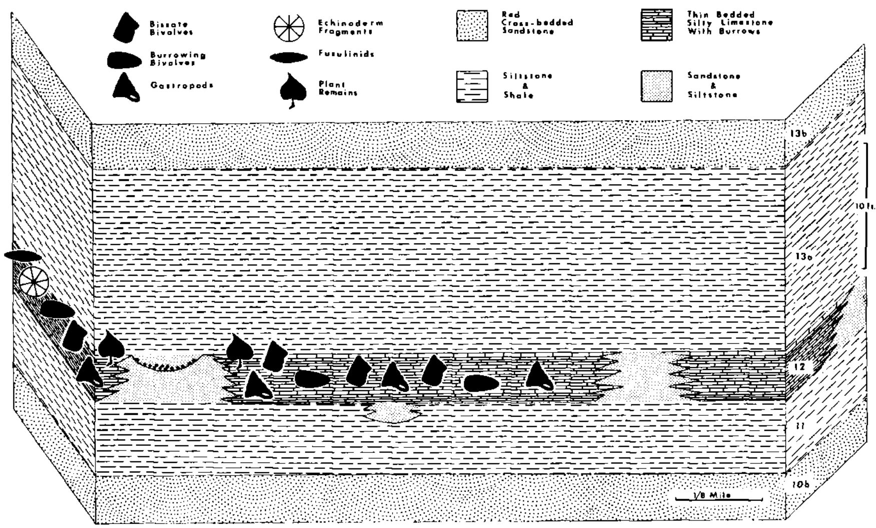
FIG. 1. *Euconospira* sp. 1x BYU 934.
FIG. 2. *Loxonema* (?) sp. 2x BYU 946.
FIG. 3. *Bellerophon* 1x BYU 945.
FIG. 4. *Natiria* 1x BYU 935.
FIG. 5. *Pteronites* sp. 0.3x BYU 968.
FIG. 6. *Worthenia* (?) sp. 2x BYU 938.
FIG. 7. Unidentified cephalopod 0.5x BYU 941.
FIG. 8. *Limatula* (?) 1x BYU 983.
FIG. 9. *Myalina* 1x BYU 966.
FIG. 10. *Pseudomontis* (?) 1x BYU 981.
FIG. 11. *Modiolus* 0.5x BYU 963.
FIG. 12. *Schizodus* (?) 1x BYU 987.
FIG. 13. *Limapecten* (?) 1x BYU 984.
FIG. 14. *Edmondia* (?) sp. 1x BYU 967.
FIG. 15. *Myalina* 0.5x BYU 958.
FIG. 16. *Aviculopecten* 1x BYU 985.
FIG. 17. *Acanthopecten* (?) 1x BYU 982.
FIG. 18. *Wilkingia* sp. 1x BYU 965.
FIG. 19. *Parallelodon* (?) 1x BYU 959.
FIG. 20. *Dityomopyge* (?) 2x BYU 937.
FIG. 21. *Myalina* sp. 1x BYU 961.
FIG. 22. *Ameura* sp. 1x BYU 943.
FIG. 23. *Ameura* sp. 1x BYU 943.

during growth of the bryozoan. This relationship may have been commensal, affording the bryozoan a firm place to attach and grow but not seriously affecting the crinoid. However, it could have become exploitative if the bryozoan interfered with life processes of the crinoid either by overgrowth or by greatly increased weight.

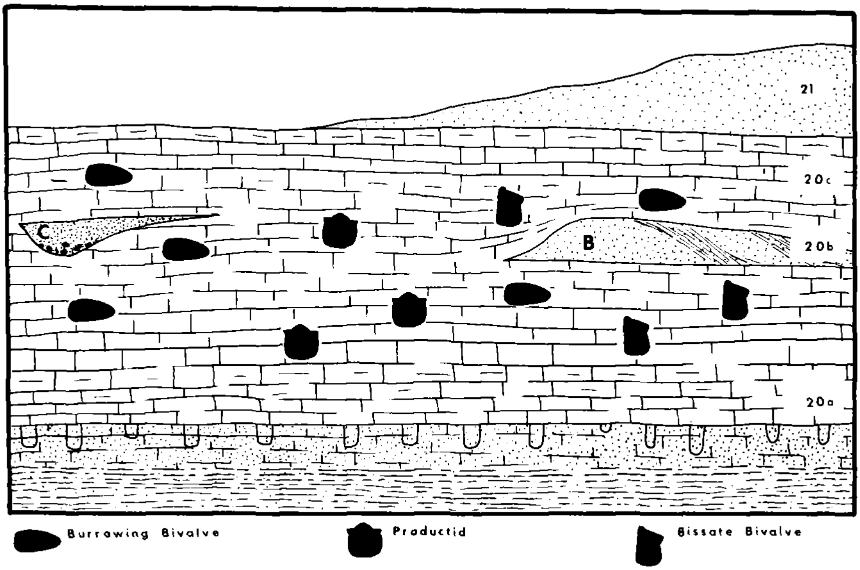
Tabulipora also appears to have overgrown *Tabulipora* in other specimens (Pl. 2, figs 5 and 7). The contact between the original bryozoan and the overgrowth is marked by a thin zone of silt, suggesting that the original bryozoan colony was possibly killed by turbidity. The original bryozoan remained in an upright position, however, because the overgrowth is uniformly developed around its circumference. This overgrowth may represent recovery of the colony after near extinction or may represent an extinct colony overgrown by a newly established or a less-affected neighboring colony.

Modern bivalve shells are frequently bored by a variety of organisms, commonly by clionid sponges. *Myalina* in the study area has been bored in a similar fashion (Pl. 2, fig. 6), but the fossil organism responsible for the boring is unknown. This relationship was probably commensal, because the bore holes affect only the external portion of the *Myalina* shell.

Burrows believed formed by the bivalve *Wilkingia* are characteristically filled with sediment in which echinoderm fragments occur in greater concentration than in country rock outside the burrow. This occurrence indicates at least two possible relationships between *Wilkingia* and echinoderms. Either *Wilkingia* was actively preying upon the echinoderms or it was simply concentrating these indigestible and large fragments while eating organic material in the finer fraction of the sediment. The latter alternative seems more likely because of the extensive burrow systems of *Wilkingia* and its apparent endobiotic habit.



TEXT-FIGURE 6.—Schematic north-south cross section of Unit 12, showing lateral variation of lithology and fauna.



TEXT-FIGURE 7.—Schematic north-south cross section of Unit 20, showing relation of lithologic variation to faunal variation and distribution.

Distribution of Organisms.—Lateral distribution of organisms is only locally variable within the study area. It is most evident for bryozoans in Units 12 and 20.

Unit 12 is observed to grade laterally, with accompanying faunal changes, from silty biomicrite to very fine-grained arkose and siltstone. The burrowing bivalve *Wilkingia* is found in the more calcareous rocks with the bissate bivalve *Myalina* in the less calcareous rocks. Still less calcareous rocks contain the gastropod *Natiria*. Rocks with virtually no carbonate contain no fossils; however, intermediate between this lithology and that in which *Natiria* occurs, as well as in the *Natiria* facies, there are casts of what appear to be plants. The *Natiria* and *Myalina* assemblages are thought to represent a tidal flat with the most terrigenous portions representing drainage ways from the bordering low land with the plants along their flanks. The *Natiria* assemblage probably represents a slightly more nearly marine environment but one which might have rapid fluctuations in salinity and turbidity. The *Myalina* assemblage is thought to represent a still slightly more marine environment but one that was stable enough for the most hardy forms. The most marine parts of this unit are represented by the *Wilkingia* assemblage, probably as narrow, fingerlike, small open-marine areas that penetrated into the tidal flat.

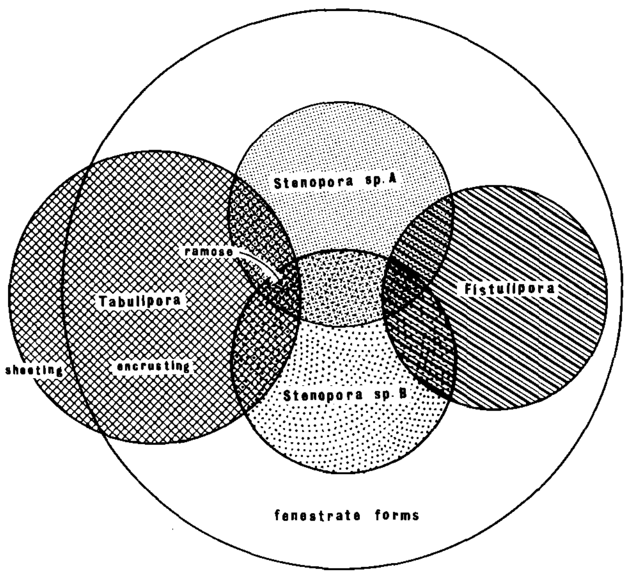
The northernmost exposed portion of this unit contains no fossils but does contain abundant burrows. The southernmost margin contains a more marine fauna composed of *Triticites*, *Wilkingia*, and echinoderm fragments. Thus, in this one unit, in a distance of less than two miles, it is possible to observe laterally equivalent normal marine deposits and terrigenous, nonmarine deposits across an ancient tidal flat. This sequence is crossed three times in a north-south cross section of the area (Text-fig. 6).

The fauna of Unit 20a changes somewhat as the arkosic sand of Unit 20b is approached (Text-fig. 7). Unit 20b contains only fragments of echinoderms but contains abundant trace fossils. Southward, beyond the lateral limits of Unit 20b, *Myalina, Orbiculoidea,* and *Edmondia* are common. Further southward, away from Unit 20b, in Units 20a and 20c, *Linoproductus, Wilkingia,* and *Edmondia* are commonly found associated with a variety of other bivalves, bryozoans, echinoderm fragments, arthropods, and brachiopods.

Bryozoans are found to vary laterally in distribution and association, as is generalized in the Venn diagram of Text-figure 8. Fenestrate bryozoans are found with all other bryozoans except sheeting forms of *Tabulipora* which are found toward the southern margins of the study area. While both *Tabulipora* and *Fistulipora* are associated with two species of *Stenopora, Tabulipora* and *Fistulipora* are not found together. *Tabulipora* tends to occur toward the southern margins, and *Fistulipora* tends to occur near the northern margins of the study area. This is a generalized trend observed over all the carbonate units, but it could be modified by more detailed bryozoan sampling. This distribution is very likely a reflection of ancient energy levels. Sheeting, encrusting, and ramose forms of *Tabulipora;* ramose and encrusting forms of *Stenopora;* and ramose and encrusting forms of *Fistulipora* are encountered in order of interpreted decreasing energy level.

PALEOENVIRONMENTS INTERPRETED FROM SEDIMENTOLOGIC RELATIONS

In the absence of a faunal assemblage or ichnofossil assemblages, several paleoenvironments are interpreted primarily on the basis of the sedimentologic relationships.



TEXT-FIGURE 8.—Distribution and association of bryozoans.

Dark red cross-bedded sandstone, occurring in Units 17 and 22 appears to be reworked material from underlying arkosic rocks. This reworking could have taken place in either a marine environment or an eolian environment. The eolian environment is favored primarily because of the nearly unidirectional cross-bed dip direction and the complete absence of fossils or trace fossils and, to a lesser extent, the sandstone color (Walker, 1967) and geometry. Assuming that this sandstone is an eolian deposit, grain size indicates an average wind speed of three to five miles per hour (Schwarzbach, 1963, p. 74).

Mudstone found in the study area is generally bound above and below by nonmarine rocks and is completely free from fossils of any sort. This indicates to some degree that it too was nonmarine. The exact environment of deposition is difficult to determine but is here considered to be either mud flat or flood plain.

Dark red to maroon arkosic sandstones with channeled bases are obviously fluvial channels. Similar arkoses with scoured bases but not in defined channels are regarded as representing deposition during a flood, when streams were not confined to their beds. Other similar arkoses that are not scoured but that form load casts in underlying silts are regarded as splay sands.

A POSSIBLE DEPOSITIONAL MODEL

Many parameters affect distribution of sediments in a sedimentary model, including basin geometry, tectonism, climate (with its associated control of temperature and hydrographic system), vegetational cover, and the size and lithology of the drainage area. Each of these parameters directly influences sediment input, reservoir energy, and reservoir depth and substrate. The purposes of this section are (1) to qualitatively describe parameters of the Paradox Basin as exemplified in the study area, (2) to relate these parameters to regional basin patterns and tectonism, and (3) to explain in terms of a sedimentary model the repetitive occurrence of paleoenvironments.

Allocyclic and Autocyclic Deposition

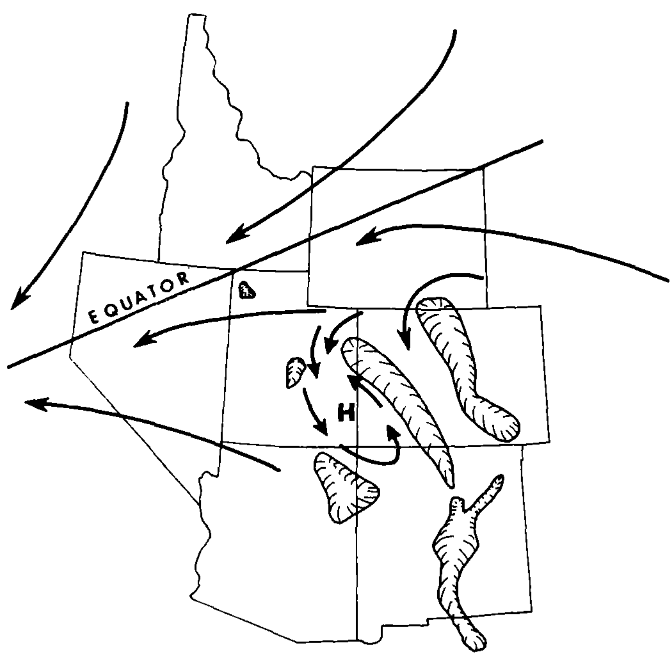
Perhaps the most obvious feature of the sequence of strata studied is the repetitive, nearly cyclic, occurrence of clastic and carbonate rocks. Mechanisms of cyclic sedimentation have long puzzled geologists, whose theoretical explanations vary from worldwide phenomena such as sea-level fluctuations (Wanless, 1963; Wells, 1960) to the idea that some cyclicity may be simply a psychological reflection of a person's training (Zeller, 1964). A useful approach to explaining cyclicity was suggested by Beerbower (1964, p. 32) in the study of alluvial plain sedimentation. He separated mechanisms into "those that require no change in the total energy and material input into a sedimentary system but involve simply the redistribution of these elements within the system, and those that result from changes in the supply of energy or material. The first, hereafter called 'autocyclic' are generated in the depositional prism and include such items as channel migration, channel diversion, and bar migration. The second, or 'autocyclic,' result from changes external to the sedimentary unit, such as uplift, subsidence, climatic variation or eustatic change."

Although it is realized that both autocyclic and allocyclic processes are closely related in their effects and that in any system both are simultaneously producing changes in the basin, it is possible to develop a model by holding either stable and letting the other vary. Because allocyclic processes tend to produce more long-range changes, they will be considered stable while autocyclic processes will be considered variable.

Allocyclic Processes.—No evidence of eustatic changes is available. Uplift occurred to the north in the Uncompahgre Range and produced a flood of generally arkosic sediments from the eroding Precambrian crystalline core (Eardley, 1962, p. 250). Subsidence occurred in the adjacent Paradox Basin and apparently was greatest along a fault zone marginal to the Uncompahgre Uplift (Herman and Barkell, 1957).

Evidence of climate at the time of deposition is varied and somewhat indirect. A warm, arid climate is evidenced by associated evaporite deposits in the basin and by eolian dune deposits. The scarcity of shale and clays and the abundance of coarse arkoses suggest that chemical weathering was minimal and mechanical weathering maximal, indicating an arid climate. Paleomagnetic data have suggested various positions of the equator during this time period (Dietz and Holden, 1970; Dott and Batten, 1971, p. 343; and Runcorn, 1972, p. 34).

One interpretation which seems to fit the climatic pattern is that of Runcorn (1972, p. 34) illustrated in Text-figure 9. If this position is accepted, then paleowind directions should approximate the pattern shown in Text-figure 9, possibly creating a consistent high pressure area over the Paradox Basin and causing frequent northerly winds.

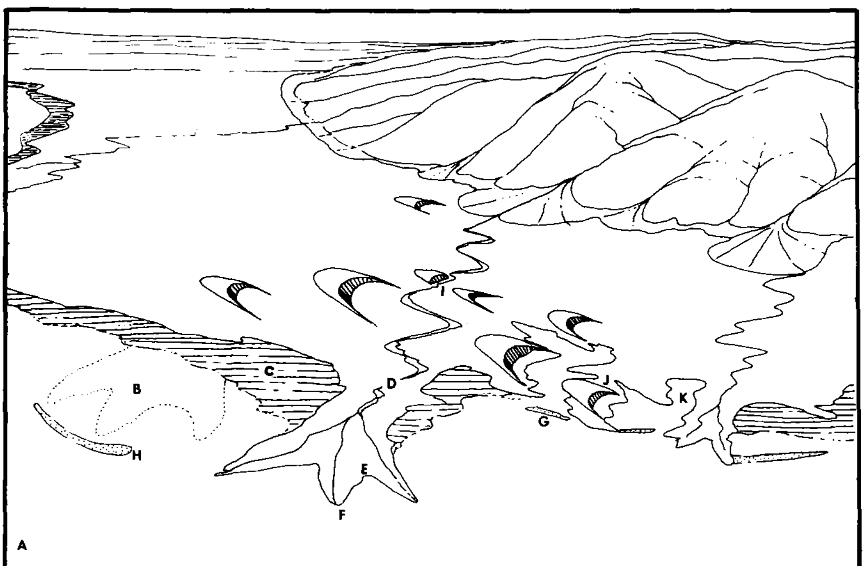


TEXT-FIGURE 9.—Possible paleoclimatic pattern in relation to interpreted position of equator.

The postulated wind patterns of the Paradox Basin are substantiated by the consistent dip direction of the eolian deposits in the study area and by other paleowind directions (Bigarella, 1972, p. 55). Admittedly, the position of the study area in relation to the equator is not where deserts are anticipated today, but regional wind direction and position of the Uncompahgre Uplift suggest a rain-shadow desert. Such a position today would be in a climate which has strongly seasonally controlled rainfall and perhaps monsoons. Such a climate is indicated for the study area during deposition by the apparent torrential nature of some arkose deposits and to some degree by the red coloration of many of the deposits. Such coloration is considered to develop under conditions of alternate wet and dry periods (Walker, 1967).

The sudden change in character of the rocks below Unit 4 to strata that contain more clays and abundant plant remains, and that are devoid of red beds, appears to indicate a change in climate of the depositional environment from relatively humid to arid upward. The cause and nature of this change are unknown.

Autocyclic Processes.—Previous workers dealing with cyclic deposits in other areas have attributed them to autocyclic processes active in delta systems (Wanless, 1964; Wanless et al., 1965). In each of these studies the delta system occurred in a relatively humid environment. Rocks of the study area are thought to represent an ancient delta system in an arid climate. This could easily have been produced as the clastic wedge from the Uncompahgre Uplift met the shallow waters of the Paradox Basin. The absence of the coal and clay traditionally associated with ancient deltas is believed to be due to

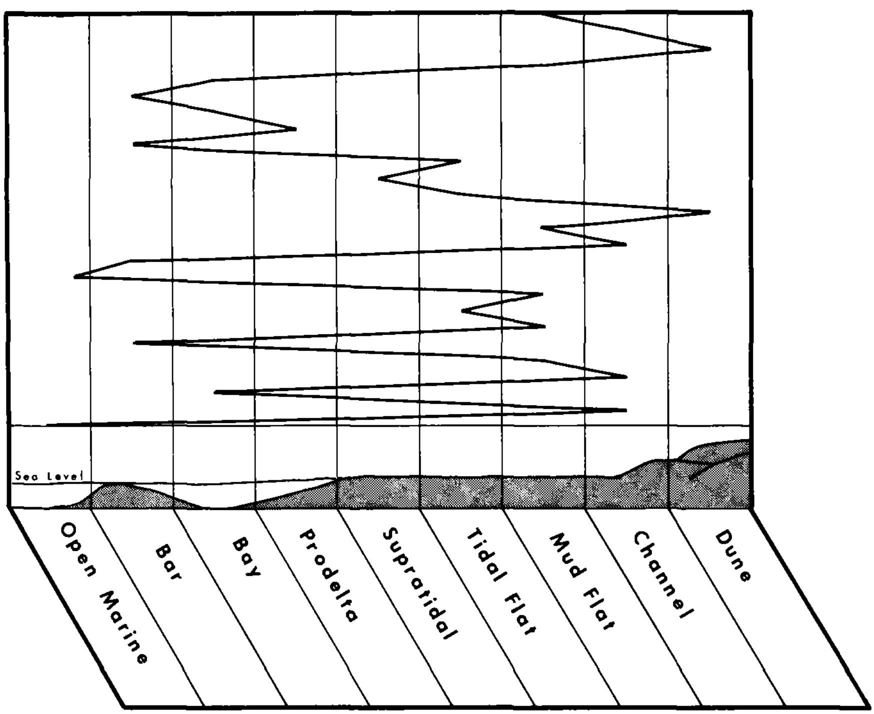


TEXT-FIGURE 10.—Schematic drawing showing relationship of interpreted environments to the delta model. Numbers refer to specific environments discussed in text.

the arid climate, which did not allow production of abundant clays or prolific plant growth.

Autocyclic processes active in this model include delta-lobe progradation, channeling, generation of bars, shifting depocenters, and migration of dune fields. Location of interpreted environments and areas of process actions are shown in a generalized hypothetical model in Text-figure 9.

A shallow open-marine environment is shown at point A on the diagram and is illustrated by Unit 4. Landward, point B represents an area of carbonate deposition over a submerged delta lobe seen in Units 14, 8a, and basal 20a. Point C shows the location of tidal flats interpreted for Unit 12. Arkosic channels of Units 7, 9, 19c, and 23 and associated mud flat and prodelta environments of Units 5, 6, 9, 10a, 11, 13a, 16a, 16b, 21a, and 21b are indicated at points D, E, and F, respectively. Marine bars interpreted for the orangish red sandstone of Units 10b, 13b, 15, and 19b are indicated at point G, while the storm-generated (?) arkosic bar of Unit 20b is indicated by point H. Dune sands of Units 17 and 22 are marked at points I and J respectively. For ease of illustration, dunes are shown diagrammatically as barchans, but they were most likely elongate, perhaps longitudinal dunes. Unit 17 is a dune sand scoured by a channel, while Unit 18 is a dune sequence inundated by the sea. As the sea transgresses, the sequence in Unit 18 goes from a dune, to a shallow tidal flat (?), to an oolite shoal, to an algal mat. Estuarine or



TEXT-FIGURE 11.—Schematic drawing showing cyclic repetition of major environments stratigraphically.

interdistributary bay environments interpreted for Units 8a, 8b, 20a, and 20c are illustrated by point K. Text-figure 11 shows the cyclic nature of environments encountered.

A Modern Analogy

No modern analogy is known which satisfies all the characteristics of the interpreted depositional model; however, by combining aspects of several related modern counterparts it is possible to meet nearly the same criteria as in the interpreted depositional model.

As described by Walker (1967), the area along the coastal plain of northeastern Baja California, Mexico, between Gonzaga Bay and San Felipe, is similar to the environment interpreted for the nonmarine deposits of the model. Climate, sediment, tectonism, source rock, drainage area, and approximate size are similar to that interpreted for the study-area model. A regional cross section through the Potash area would closely resemble that drawn by Walker (1967, p. 356) for Recent, Pleistocene, and Pliocene sediments of northeastern Baja California, Mexico. This analogy fails in detail primarily because the Gulf of California is much too deep and has much too steep a gradient to be comparable to that interpreted for the Elephant Canyon model.

North of San Felipe, Baja California, Mexico, the shallow mud and tidal-flat areas of the Colorado River Delta described by Thompson (1968) are considered analogous to most of the depositional basin marginal to the Paradox Basin in the model. While many aspects of this analogy fit, it fails because the delta area is much too large and the sediment supply too great.

By combining parts of these two modern analogies, however, it is possible to reconstruct an example very similar to that proposed for the study area and much of the northern margin of the Paradox Basin.

APPENDIX 1

MEASURED SECTION OF THE LOWER PART OF THE ELEPHANT CANYON FORMATION NEAR POTASH

Beginning at river bottom at J L Eddy boat dock and continuing northwestward.

Unit No.	*Unit Thickness (feet)*	*Description*	*Cumulative Thickness (feet)*
23	14.5	Arkose: dark red to maroon; medium to coarse grained; southerly trending, trough-shaped cross-beds; boulder-size rip-up clasts in basal contact area.	361.6
22	12.0	Sandstone: dark red; large trough-shaped, southeasterly trending cross-beds.	347.1
21b	10.5	Arkose: dark reddish brown; fine grained; very micaceous.	335.1
21a	3.0	Arkose and mudstone interbedded: dark reddish brown; fine grained; very thin bedded; megaripple-like structures.	324.6
20c	11.7	Limestone, silty biomicrite: medium light gray; extensively burrowed; very fossiliferous.	321.6
20b	4.5	Arkose and very fine quartz sandstone interbedded: light tan to very light gray; coarse to very fine grained; cross-bedded sandstone; abundant trace fossils in fine-grained layers; rare crinoid and bivalve fragments and some plant casts.	309.9

Appendix 1 (Continued)

20a	11.3	Limestone, silty biomicrite: medium-light gray; extensively burrowed; very fossiliferous; basal part sandy.	305.4
19c	10.5	Arkose: dark red to maroon; medium to coarse grained with "floating" fine pebbles of feldspar.	294.1
19b	11.0	Sandstone: pale orangish red; fine to medium grained; trough cross-bedded; variable dip direction; numerous burrows, 2- to 5-inch diameter.	283.6
19a	10.2	Sandstone and mudstone: dark reddish brown; very fine to medium grained.	272.6
18d	0.5	Limestone: cherty, "algal mat," dark brown to black.	262.4
18c	3.3	Dolomite, oodolosparite: very light gray to white; oolites fine to medium grained; abundant stylolites.	261.9
18b	7.6	Limestone, sandy oosparite: light pinkish gray; fine to medium grained; extensively burrowed and stylolitized; locally abundant gastropods.	258.6
18a	8.5	Sandstone: calcareous; light to dark pink; fine to medium grained; considerable lateral variation in thickness.	251.0
17	35.0	Sandstone: dark red; fine to medium grained; large, trough-shaped, generally southerly trending cross-beds.	242.5
16b	4.0	Mudstone: dark reddish brown; very fine to medium grained; megaripple-like structures.	207.5
16a	7.6	Arkose: dark red to maroon; medium to coarse grained.	203.5
15	8.5	Sandstone: pale orangish red; fine to medium grained; trough-shaped cross-beds; variable dip direction; numerous large burrows.	
14	2.4	Limestone, sandy biodolosparite: gray to brown; fossils not abundant.	187.4
13b	28.6	Sandstone: pale orangish red; fine to medium grained; large burrows in upper 8 to 10 feet.	185.0
13a	15.0	Arkose: pale to grayish red; very fine sand-size to coarse silt-size particles; laterally equivalent to Unit 12.	156.4
12	2.4	Limestone, silty to argillaceous biomicrite: medium silt-size to very fine sand-size particles; extensively burrowed; locally fossiliferous.	141.4
11	5.9	Arkose: pale grayish red, very fine sand-size to coarse silt-size particles; laterally equivalent to Units 12 and 13.	139.0
10b	20.9	Sandstone: pale reddish brown; fine to medium grained; large cross-beds with variable dip direction; large burrows in upper part of unit.	133.1
10a	2.0	Mudstone: dark reddish brown; fine to medium grained; very micaceous; numerous burrows, 0.25-inch diameter, vertical.	112.2
9	22.3	Arkose: pale to grayish red; medium sand-size to fine pebble-size clasts; small festoon cross-beds dipping to the southeast.	110.2
8b	1.5	Limestone, argillaceous biomicrite: medium to dark gray; very fossiliferous.	87.9
8a	2.3	Limestone, sandy biosparite: medium to dark gray; very fossiliferous.	86.4
7	7.4	Arkose: dark grayish red; medium to very coarse sand-size with very coarse pebbles of feldspar near	84.1

Appendix 1 (Continued)

		base; festoon cross-beds; base scouring into underlying unit in channellike form.	
6	9.2	Siltstone and very fine sandstone: tan; lateral variation in grain size; micro-cross-laminations.	76.7
5	8.6	Shale: grayish red to greenish gray in alternate laminae of 5 mm. thickness; possible plant remains and organic trails.	
4	7.6	Limestone: dark gray green; locally cherty; variation from basal fusulinid coquina to silty bryozoan biomicrite to upper biosparite.	58.9
3	36.5	Sandstone and siltstone: pale brown to reddish gray green, coarse silt-size to fine sand-size clasts; micaceous; very carbonaceous layers in upper portion; plant remains locally abundant; possible climbing ripples.	51.3
2	1.8	Shale: sandy; pale olive.	14.8
1	13.0+	Limestone: sandy sparite: medium light gray; occasional oolites; no fossils (measurements for top of unit only.	13.0

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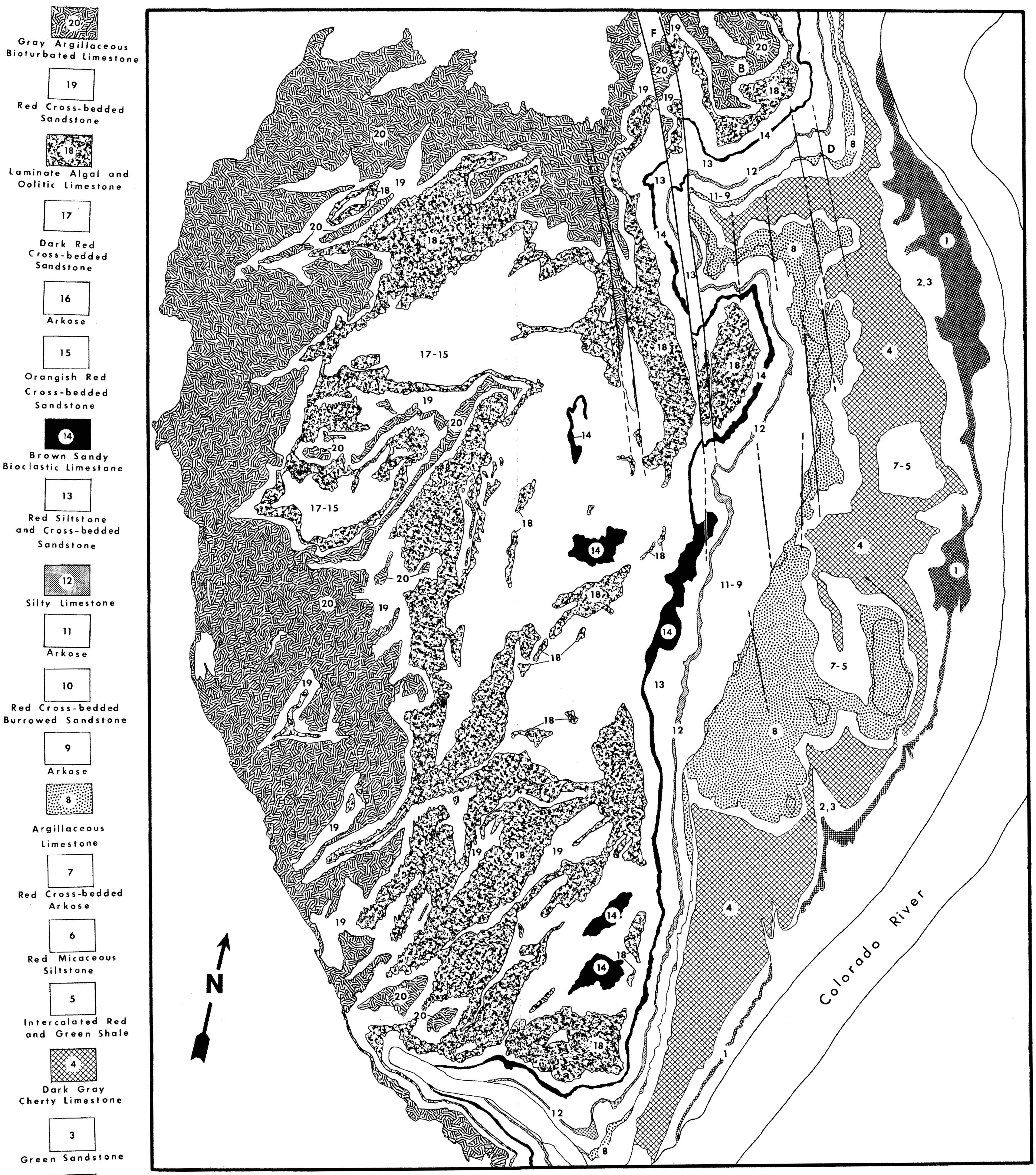

Geology of the Elephant Canyon Fm. Cane Creek Anticline, Utah

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