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J. Keith Rigby

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Paleoenvironments of Deposition of the Upper Cretaceous Ferron Sandstone near Emery, Emery County, Utah*

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ABSTRACT.—Environments of deposition of the Ferron Sandstone in east-central Utah shifted rapidly both laterally and vertically in response to regression and transgression of the Mancos Sea during the Upper Cretaceous. These shifts accompany deposition of clastic wedges near and into the western margin of the sea. Environments in which the Ferron Sandstone accumulated include open marine, offshore, interdistributary bay, barrier island, lagoon, and lower deltaic plain. Interpretations of environments were based on the geometry and on the vertical and horizontal relationships of rock units in over 100 measured stratigraphic sections. Lithologies present in the Ferron Sandstone include sandstone, mudstone, carbonaceous mudstone, coal, and coquina.

The area of concern is located 10 miles south of Emery, Utah, on the west flank of the San Rafael Swell in the central portion of the 140-mile-long Ferron Sandstone outcrop. The sandstone is 475 feet thick in the study area, but it thickens to over 800 feet 8 miles to the south and thins to less than 20 feet 70 miles to the north and east. It is underlain by the Tununk Member of the Mancos Shale and overlain by the Blue Gate Shale Member.

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*A thesis presented to the Department of Geology of Brigham Young University in partial fulfillment of the requirements for the degree Master of Science, April 1973. J. Keith Rigby, thesis chairman.

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INTRODUCTION

The Ferron Sandstone is one of several clastic sedimentary wedges deposited in and near the west edge of the Mancos Sea during the Upper Cretaceous. Outcrops of the Ferron Sandstone are found in a belt 10 miles wide for a distance of 140 miles in east-central Utah. The westernmost occurrence in the Wasatch Plateau is a major gas producer. General environments of deposition for the Ferron Sandstone have been described in publications concerned with the regional depositional history of Upper Cretaceous rocks in east-central Utah. The purpose of this study on the Ferron Sandstone was to document environments of deposition of individual rock units and to construct the depositional history of the Ferron Sandstone in a small area near the central portion of the outcrop belt. The resulting model may then be extended laterally by further study to determine suitable environments for gas and coal accumulations in the Ferron Sandstone. The study may also be used as a model for comparison in other paleoenvironmental studies and to determine where gas and coal form in rock units deposited in similar environments.

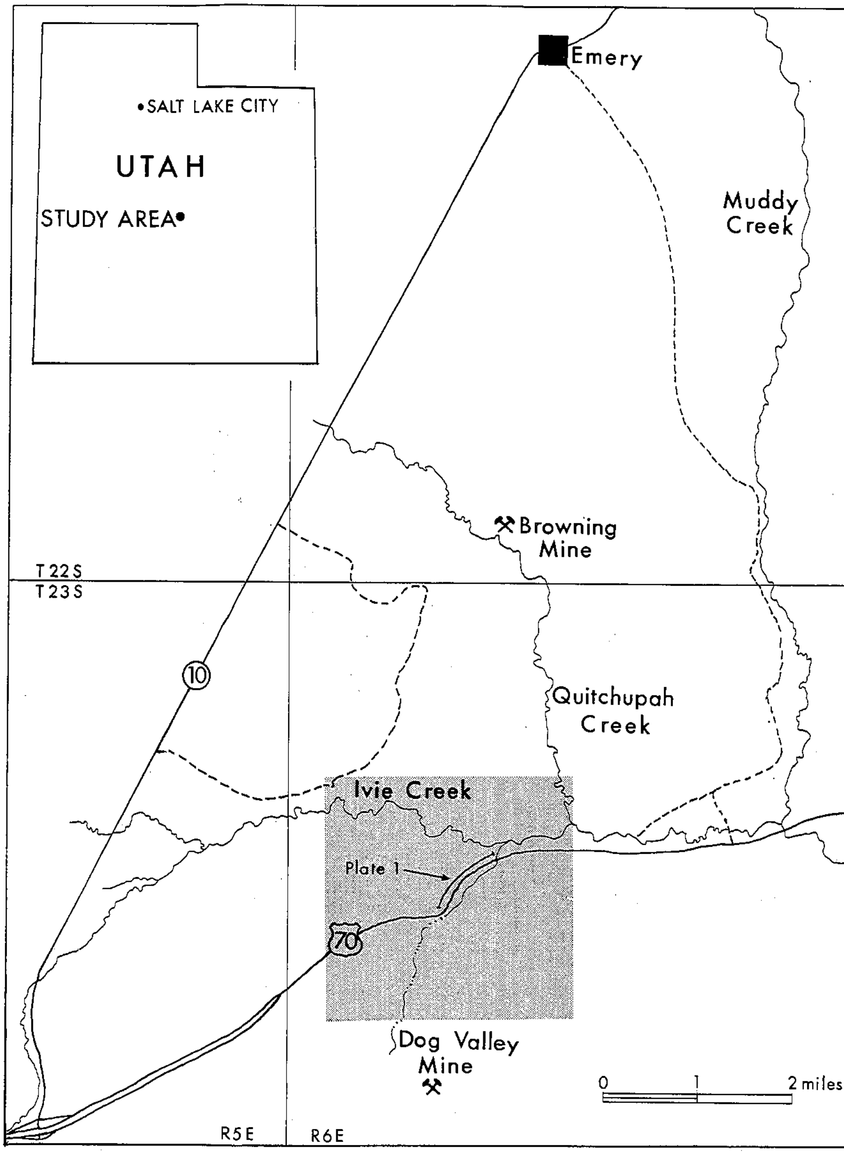
The Ferron Sandstone is a Coloradoan member of the Upper Cretaceous Mancos Shale in east-central Utah (Text-fig. 1). The Tununk Shale Member underlies the Ferron Sandstone, and the Blue Gate Shale Member overlies it (Text-fig. 2). Excellent exposures of the sandstone member along stream canyons (Pl. 2, fig. 1) and road cuts 10 miles southeast of Emery, Utah, on Interstate 70 allowed study of the geometry, internal structure, and lateral facies relationships for each rock unit comprising the Ferron Sandstone Member. The member is composed of interbedded sandstone, mudstone, carbonaceous mudstone, coal, and coquina. Shale with interbedded sandy layers is exposed directly below the Ferron Sandstone Member in the uppermost portion of the Tununk Shale Member.

Field measurements and observations enabled environments of deposition to be determined and a geologic history of the area to be constructed. As herein interpreted, depositional environments of Ferron Sandstone rock units and the Upper Tununk Shale include open marine, offshore, interdistributary bay, barrier island, lagoon, and lower deltaic plain.

Location

The study area is located 10 miles southeast of Emery, Emery County, Utah, and 5 miles east of the Utah Highway 10 interchange on Interstate 70 (Text-fig. 1). Most of the area is in Sections 16 and 20, Township 23 South, Range 6 East. Access is provided by Interstate 70, which crosses near the center of the area. A gravel road along Muddy Creek provides access to the canyon along Quitchupah Creek. Jeep trails extend into the area north and south of the interstate highway, east of Utah Highway 10, and south from Emery.

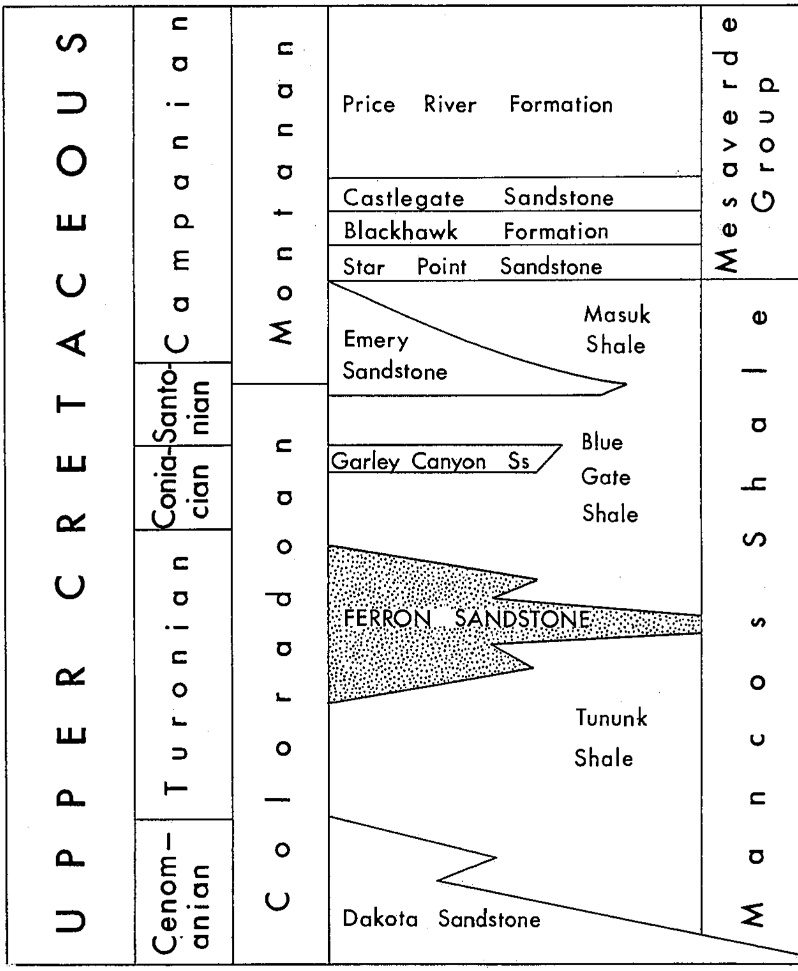
Ferron Sandstone outcrops extend from the Henry Mountains in south-central Utah northward along Castle Valley and then eastward along the Book Cliffs for a total distance of 140 miles. The Ferron Sandstone forms a cuesta in the westward-dipping rocks on the west flank of the San Rafael Swell.



TEXT-FIGURE 1.—Index map.

Castle Valley, a strike valley carved in Upper Mancos Shale along the east side of the Wasatch Plateau, is to the west of the cuesta.

Excellent exposures of the Ferron Sandstone are present in canyons along Ivie and Quitchupah Creeks (Text-fig. 1). These streams have eroded through the Mancos Shale and have produced canyons 300 feet deep, following re-



TEXT-FIGURE 2.—Correlation chart of Upper Cretaceous formations in the Castle Valley area.

gional uplift during the Laramide Orogeny and later epeirogenic warping. Construction of Interstate 70 provided additional fresh vertical exposures through the Ferron Sandstone Member. These road-cut exposures allow observation of internal structures in the softer sedimentary units that elsewhere have been masked by weathering and erosion. Exposures along the canyons and road cuts, being nearly perpendicular to each other, allowed the Ferron Sandstone in this limited area to be studied in three dimensions.

Previous Works

Lupton (1916) published the first major geologic report on the Castle Valley coal beds and named the Ferron Sandstone Member. He measured numerous stratigraphic sections along the outcrop in Castle Valley, southeast of Emery, Utah, where coal units are of economic thickness. One of these sections was measured in the study area along Ivie Creek. Lupton gave the coal beds letter designations, "A" through "M", which also are used in this report.

Spieker (1946, 1949) summarized the general depositional history and stratigraphic nomenclature of Upper Cretaceous formations of east-central Utah but did not conduct any detailed work in the present study area. A regional paleontologic and stratigraphic study of Castle Valley was conducted by Katich (1951). He concluded that the source of the Ferron Sandstone was to the southwest and that the member was deposited in valley-flat, swamp, and littoral environments.

In a study of cross-bedding in the Ferron Sandstone, Cotter (1971) concluded that the source area of the sandstone was south and southwest of Castle Valley. He concluded that the "Ferron River" was 300 feet wide and 25 feet deep, with meander lengths of 2,500 to 4,100 feet.

The latest published work concerning the Ferron Sandstone is by Hale (1972). His study documents general stratigraphic relationships in the Wasatch Plateau and presents a stratigraphic model for Upper Cretaceous rocks. The Ferron Sandstone was emphasized in this study. Hale concluded that the source area of the Ferron Sandstone in the southern part of Castle Valley was near the Fish Lake Plateau, 30 miles southwest of the present study area, and that distributaries deposited sediment to the northeast in a lobate deltalike mass that Hale called the "Last Chance Delta." His interpretation was that sediments were deposited in deltaic, littoral, and marine environments until the end of Ferron time, when the Last Chance Delta finally was buried during deposition of the marine Blue Gate Shale Member.

Acknowledgments

I would like to express my thanks and appreciation to Dr. J. Keith Rigby who willingly gave of time and knowledge in assisting the author in this study of the Ferron Sandstone, and to Blair Maxfield, who helped in the identification of microfossils. Special recognition goes to my parents for their encouragement and interest. The manuscript was critically reviewed by Dr. W. K. Hamblin, Dr. L. F. Hintze, and Dr. J. L. Baer.

Monetary assistance for field and laboratory expenses was provided by research grants from Mountain Fuel Supply Company, the Research committee of the American Association of Petroleum Geologists, and the Brigham Young University Geology Department through funds from Marathon Oil Company and Mobil Oil Corporation.

Methods of Study

Over 100 stratigraphic sections were measured in road cuts along Interstate 70 and north of the road cuts along Ivie Creek to determine the geometry of rock units and facies relationships. Locations of representative stratigraphic sections are illustrated on Text-figure 4. Stratigraphic sections along the nearly vertical road cuts were measured with a theodolite. A steel tape and an Abney hand level were used in measuring climbable sections in the less-accessible areas along Ivie Creek. More than 150 attitudes of cross-beds and other sedimentary structures were measured with a Brunton Compass. Samples were taken from measured sections for analysis.

Stratigraphic sections were used to construct a fence diagram (Text-fig. 4) and a detailed cross section (Pl. 1). The fence diagram shows the three dimensional geometry and facies relationships of rock units along interstate highway road cuts and along Ivie Creek. Location of representative stratigraphic sections and number designations of major rock units are also indicated. The detailed cross section illustrates rock-unit relationships in the interstate highway road cuts and shows the number designation of the individual rock units. Unit-number designations of Plate 1 and Text-figure 3 are the same. One-hundred-foot distances are recorded with tick marks on Plate 1 to aid in the description and field identification of rock units. The opening of a large culvert which crosses Interstate 70 is located approximately 10 feet west of 0-feet on Plate 1. Footage 4,740, at the northeast end of Plate 1, is at the prominent corner of the lower sandstone cliff at the lower end of the road cut for the westbound lane.

Thin sections were used to confirm field identification of rocks and to investigate sedimentary microstructures. Weakly consolidated rocks were impregnated with 3M Scotchcast Electrical Resin Number 3 in a vacuum oven and were then cured overnight before thin-sectioning.

Macrofossils were coated with clear fingernail polish to prevent flaking during preparation. Specimens were cleaned with a small air-driven chisel and hand picks.

Samples that might have contained foraminifera were disaggregated and washed through a 115-mesh sieve. The remaining material was sorted, and microfossils were picked and identified.

LITHOLOGY OF THE FERRON SANDSTONE

The Ferron Sandstone is composed of interbedded sandstone, mudstone, carbonaceous mudstone, coal, and coquina that exhibit rapid facies changes in the study area. Thickness of the Ferron Sandstone ranges from 780 feet, 8 miles south of the study area in Last Chance Canyon (Hale, 1972, p. 31), to 450 feet in the study area and 100 feet at the north end of Castle Valley (Katich, 1954, p. 46).

Shale with interbedded sandy layers in the study area directly below the Ferron Sandstone Member is the uppermost part of the Tununk Shale Member of the Mancos Shale. It will be included in the discussion on lithology because facies relationships of the shale with the lower units of the Ferron Sandstone are important in interpreting paleoenvironments that are present.

The unit number designations and 100-foot intervals illustrated on Plate 1 will be used in describing rock units in the following discussion and for orientation in the field. Text-figure 3 provides a summary of cross-bed trends and sedimentary structures observed in units forming the Ferron Sandstone.

Shale

Shale with interbedded sandy layers in the upper part of the Tununk Shale (Unit 1; Pl. 2, fig. 1) is medium to dark gray on a fresh surface and light to medium gray when weathered. Interbedded sandy layers increase in number and thickness upward toward the base of the Ferron Sandstone. The contact between the central portion of unit 2 and the lowermost sandstone body in the Ferron Sandstone is sharp, but toward the edges of the sandstone the transition from sandstone to sandy shale is gradual. Concretions 0.5 to

2.0 feet in diameter are randomly distributed in the shale; but of those sampled, none contained fossils. No fossils were found in the sandy shale either, although Lupton (1916) and Katich (1951) report finding marine fossils in the Tununk Shale.

Sandstone

Sandstones throughout the study area were divided into two major sequences, lower and upper sandstones (Pl. 1; Text-fig. 3), on the basis of lithology. Each sequence will be discussed separately.

Lower sandstone.—The lower sandstone is divided into two distinct parts on the basis of dip direction of cross-beds. Unit 2 (Pl. 1), the lowermost part, is 20 feet thick; and the upper part, units 9 to 12 (Pl. 1), is nearly 60 feet thick. Both portions of the lower sandstone are buff to light gray on a fresh surface and tan to yellow brown when weathered. A light gray color is common when the sandstone is associated with organic material. The sandstones are mature and are composed of well-sorted quartz grains, 0.125 to 0.25 mm in diameter, that are rounded to subrounded.

Unit 2 is lens shaped and convex upward and has a flat nonerosional base resting on the transitional sandy shale. Toward the central part of the outcrop, the contact between the sandstone and underlying shale is sharp. At the east edge of the exposure, the sandstone thins and grades into sandy shale. The westward thinning edge grades into mudstone. The central portion of the sandstone is thick-bedded with large-scale planar cross-beds; but toward the edges of the unit, the sandstone becomes thin-bedded and contains interbedded sandy shale.

A small, lens-shaped, convex upward, sandstone body (Pl. 1, 3,850-footage; Text-fig. 4), 10 feet high and 50 feet wide, was observed on the westward thinning edge of unit 2. Planar cross-beds dip to the east and the west from the center of the sandstone structure.

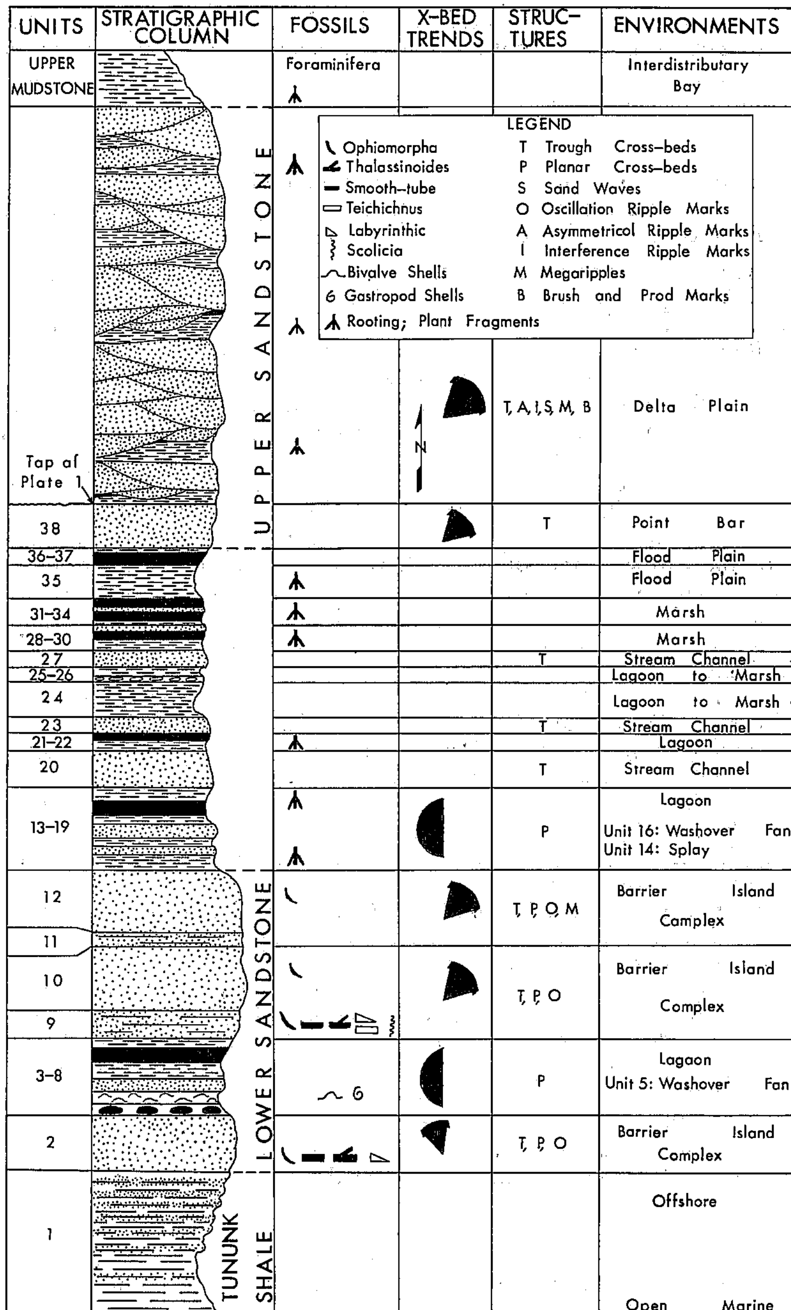
Large-scale planar cross-beds (Pl. 2, fig. 2) of unit 2 dip to the west at 5° to 12° and have a strike azimuth of 315° to 007° (Text-fig. 3). Oscillation ripples and megaripples, with a strike azimuth of 10°, were observed in thicker sandstone beds of unit 2.

Trace fossils are present in unit 2, and extensive bioturbation is present in siltier portions of the unit. Ichnofossils will be discussed in the section on trace fossils. No other fossils were found in unit 2.

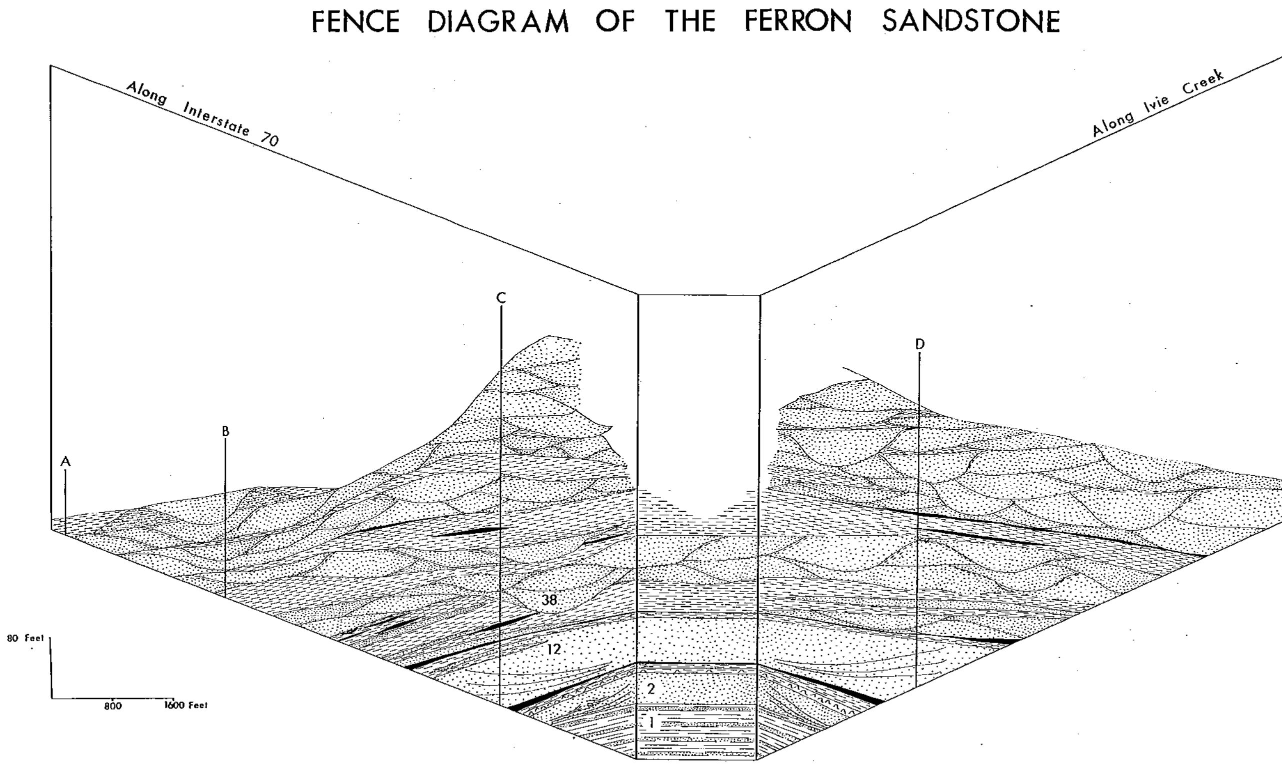
Unit 9 (Pl. 1) is a platy, flat-based, fine-grained sandstone that rests on mudstone and coal. Interbedded sandy shale and siltstone layers are present in the unit. The unit thins and grades eastward into the base of the more massive unit 10. Trace fossils and bioturbation are abundant in this rock unit near the 2,700-foot mark illustrated on Plate 1.

Unit 10 (Pl. 1) is lens shaped and convex upward, has a flat, nonerosionnal base, and rests on sandstone and mudstone. Interbedded sandy shale layers are present at the edges of the unit but grade into sandstone toward the interior of the sandstone body. Planar cross-beds in unit 10 dip eastward at 6° to 19°, with a strike azimuth of 11° to 52° (Text-fig. 3). Oscillation ripple marks were observed in the thick sandstone beds of unit 10. Few trace fossils and only limited bioturbation were observed in the rock unit.

Unit 11 (Pl. 1) is similar to unit 9 and is composed of platy sandstone that grades into the basal portion of the massive sandstone of unit 12. Some bioturbation was observed in the unit.



TEXT-FIGURE 3.—Summary chart of fossils, trace fossils, cross-beds, sedimentary structures, and depositional environments observed in rock units comprising the Ferron Sandstone.



TEXT-FIGURE 4.—Fence diagram of the Ferron Sandstone, showing three dimensional relationships of rock units of the Ferron Sandstone along Interstate-70 road cuts and Ivie Creek. Major rock-unit designations and position of representative stratigraphic sections (A-D), included in the appendix, are shown. Unit number designations are the same as on Plate 1.

Unit 12 (Pl. 1) is lens shaped and convex upward and has a flat nonerosional base. Undulations shown in Plate 1 are a function of great vertical exaggeration. The unit is underlain by the platy sandstone of unit 11 and the massive bedded sandstone of unit 10. Cross-beds observed in the unit (Text-fig. 3) dip to the east parallel to beds in unit 10.

Upper sandstone.—The upper sandstone (Unit 38, Pl. 1; Pl. 2, fig. 1; and Text-fig. 3) is the major part of the Ferron Sandstone in the study area, but it is not well exposed in the road-cut section of Plate 1. This is the youngest sandstone of the member and caps much of the study area (Text-fig. 4). The upper sandstone does not have a sheetlike geometry but occurs in lenses and pods separated by mudstone, carbonaceous mudstone, and/or coal. Lenses of sandstone typically are 30 to 40 feet thick and 300 to 600 feet wide with some lenses having a stream channellike cross-section (Pl. 3, fig. 4). Associated mudstone units may be 40 feet thick.

The sandstone is buff to light gray on a fresh surface and tan to yellow brown when weathered. The light gray to very light gray color of the sandstone occurs when the sandstone is associated with organic material. Stutzer (1940) reports that reducing solutions from organic-rich rocks reduced iron in underlying sandstones and bleached the rock light gray to gray white. A brick-red color of some sandstones in the study area is caused by the oxidation of iron in rocks associated with burning of underlying coals.

Sand grains range in size from a maximum diameter of 15 mm, seen in beds along Dog Valley Wash south of the interstate highway, to 0.15 to 0.50 mm at the interstate highway and 0.125 to 0.25 mm along Ivie Creek. Two trends in grain size are recognizable. Sand grains decrease in size toward the north and also become smaller upward within sandstone lenses. Some samples are distinctly bimodal, and all grains are subrounded to subangular.

Troughlike cross-beds (Pl. 4, fig. 3), 1.5 to 25 feet wide, are abundant in the upper sandstone and in some instances are nearly planar. Strike azimuths of 106° to 173° (Text-fig. 3) were measured for the cross-beds, which decrease in size and number upward in the lenses. The upper portions of lenses are thin bedded and contain asymmetrical ripple marks. Interference ripple marks in the study area were seen associated with the upper portions of lenses. Longitudinal sand waves (Pl. 4, fig. 2) with a direction azimuth of 30° are present in a sandstone lens in the upper sandstone near Ivie Creek. Slumping of unconsolidated sediment resulted in soft sediment deformation in some beds (Pl. 4, fig. 1).

Limited bioturbation and only a few trace fossils were found in the upper sandstone in siltier portions. No other fossils were found.

EXPLANATION OF PLATE 2
OUTCROPS OF THE FERRON SANDSTONE

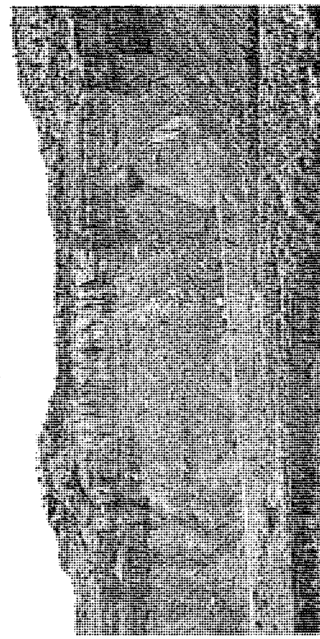
FIG. 1—View of Ferron Sandstone between Ivie and Quitchupah Creeks. Lower marine shale, lower sandstones, and upper sandstones are visible in the figure. Slope zones indicate associated mudstones.

FIG. 2.—View of large-scale planar cross-beds dipping westward in the lower barrier sandstone and a tidal channel cutting into the sandstone.

FIG. 3.—Tidal channel cutting through the upper and middle barrier sandstone.

PLATE 2

1



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Coquina

A coquina of bivalves and gastropods (Unit 4; Pl. 1) is located above the westward-thinning edge of unit 2 and is exposed in the road cuts and in Ivie Creek Canyon. The coquina bed has a maximum thickness of 6 feet. A dark gray mudstone matrix surrounds the fossils. The coquina grades eastward into mudstone. Westward, it dips beneath the surface. No microfossils were found in processed samples.

Gastropods in the coquina bank are *Turritella* sp.; and bivalves are *Corbicula* sp., *Corbula* sp., *Cardium* sp., and *Gryphaea* sp. A northward change from the *Corbicula, Corbula,* and *Cardium* assemblage to one dominated by *Gryphaea* occurs between the interstate highway and Ivie Creek.

Mudstone

Mudstones of the Ferron Sandstone occur in three associations: lower mudstones are associated with the lower, more sheetlike sandstones; middle mudstones are associated with the upper, lenticular sandstones; and the upper mudstones were deposited as the last unit in the Ferron Sandstone.

Lower mudstone.—Lower mudstones (Units 6, 8, 13, 15, 17, 19, 21, 24, and 26, Pl. 1) are light brown to medium gray in a fresh outcrop and commonly weather light to medium gray. These rocks are nonfissile and weakly consolidated. Mudstone beds are widespread in the area and thicken westward from units of the lower sandstone. These mudstones become more arenaceous near sandstone units, owing to a mixing of facies. Ironstone, composed of siderite and clay (Williamson, 1967), is locally abundant in lower mudstone units. Clay balls with 2-inch diameters are locally present. Fragments of reedlike plants and leaf impressions are present in the lower mudstone units. Carbonized root impressions (Pl. 4, fig. 5) are very abundant in unit 24 near the 800-foot mark of Plate 1.

Middle mudstone.—Color and parting of the middle mudstones (Units 28, 31, 35, and 37, Pl. 1) are the same as in lower mudstone units, but only minor amounts of ironstone are present in these upper beds. Thickness and lateral continuity of the mudstone vary abruptly, and units are usually interbedded with the upper sandstone. No fossils were found in these mudstones.

Upper mudstone.—The upper mudstone units of the Ferron Sandstone were the last units of the member to be deposited (Text-fig. 4) before burial by Blue Gate Shale. The upper mudstone is dark brown to light gray in fresh

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EXPLANATION OF PLATE 3
OUTCROPS OF THE FERRON SANDSTONE

FIG. 1.—View of lagoonal coals and mudstones with interbedded fluvial sandstones at the 900-foot mark on Plate 1.

FIG. 2.—Medium scale troughlike cross-beds of the foreshore facies in the upper barrier sandstone at the 2,700-foot mark on Plate 1.

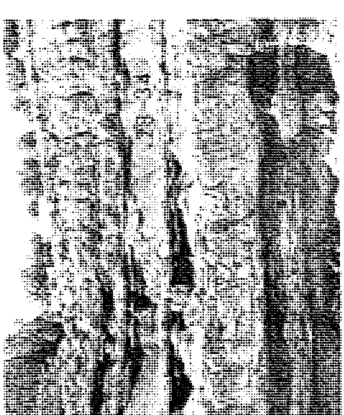
FIG. 3.—Thinly interbedded fine-grained sandstone and silty shale of the lower foreshore facies of the middle barrier sandstone near the 2,700-foot mark on Plate 1.

FIG. 4.—View of channellike cross section exposed in highway road cut. A natural levee deposit is visible above the sandstone, left center of the figure.

PLATE 3

3

2



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exposures and light brown to light gray when weathered. This mudstone is widespread and interfingers and grades upward into the Blue Gate Shale in the study area. Small fragments of plants are present in the unit; and when samples were disaggregated with a soap-and-water solution, a hydrocarbon film formed on the surface of the solution.

No macrofossils were found in the unit, but prisms of *Inoceramus* shells and fragments of echinoid spines were identified in disaggregated samples.

Foraminifera present in the upper mudstone include: *Nodosaria* sp., *Frondicularia* sp., and *Lenticulina* sp.

Carbonaceous Mudstone

Carbonaceous mudstone in the Ferron Sandstone has a dark brown to dark gray color on fresh outcrops, and weathered samples are light brown to medium gray. Such mudstone is found near coal units associated with upper and lower sandstones in mudstone units 3, 6, 17, 19, 21, 24, 28, 31, 35, and 37 of Plate 1. Thicknesses of the carbonaceous mudstone range from a few inches to 5 feet. Abundant carbonized plant fragments and rooting impressions occur in this lithology. No micro- or macrofossils were found in the samples collected.

Coal

Coal beds (Pl. 3, fig. 1) occur in both the upper and lower sandstones. The upper coal beds vary abruptly in thickness and lateral continuity. Lupton's "I" coal along Ivie Creek is 5 feet thick but grades laterally into carbonaceous mudstone and mudstone within a distance of 300 feet. Lower coals, associated with the lower sandstone, are more uniform in distribution and thickness than upper coals.

Thickness of the coal beds in the study area range from 0.5 feet to 8 feet; however, five miles north of the study area at the Browning Mine, the "I" coal is 22 feet thick. The "I" coal there has a dull to vitreous luster and is brittle and well jointed. Some portions of the coal beds are platy with minor amounts of plant material present. When weathered, most of the coal will break into small cubes. Williamson (1967) reports that coals with the above characteristics may be classified as bituminous.

Lupton (1916) reported that the coal beds in Castle Valley compared favorably with other Cretaceous coals in Wyoming, Colorado, and Utah. No large-scale mining has occurred in the study area, but mines are currently operating north and south of the area.

TRACE FOSSILS

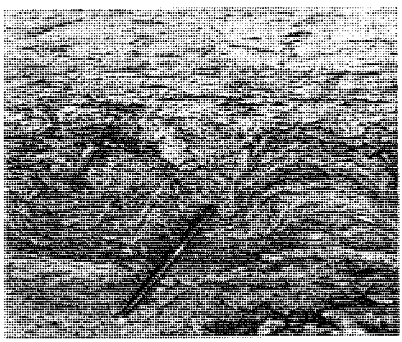
Trace fossils are abundant in siltier portions of lower sandstone units 2, 9, and 11 (Pl. 1). In the more massive portions of units 2, 10, and 12 (Pl. 1), only a few trace fossils were observed. Trace fossils present in the area include *Ophiomorpha, Thalassinoides, Teichichnus,* smooth-tube burrows, labyrinthic burrows, and *Scolicia.*

Seilacher (1964) proposed five general categories for classifying trace fossils: dominichnia—permanent shelters for vagile and hemisessile organisms; fodinichnia—burrows made by hemisessile animals as a permanent shelter and while searching for food; pascichnia—winding trails of vagile bottom dwellers searching for food; repichnia—trails or burrows of organisms passing through

EXPLANATION OF PLATE 4

SEDIMENTARY STRUCTURES AND TRACE FOSSILS

FIG. 1.—Soft sediment deformation in the upper sandstone near Ivie Creek.
FIG. 2.—Sand waves, trend azimuth of 30°, in the upper sandstone south of Ivie Creek.
FIG. 3.—Troughlike cross-bedding in an upper sandstone lens along Ivie Creek.
FIG. 4.—Smooth-tube and labyrinthic burrows.
FIG. 5.—Carbonized root impressions near the 800-foot mark on Plate 1.
FIG. 6.—*Ophiomorpha* burrow in lower foreshore facies of the middle barrier sandstone near the 2,700-foot mark on Plate 1.



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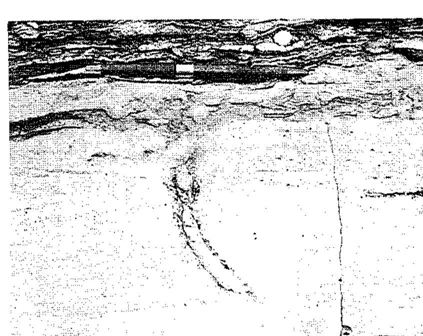


6

the area; cubichnia—shallow resting places for vagile animals. Howard (1966) described trace fossils in the Upper Cretaceous Panther Sandstone of the Book Cliffs and Wasatch Plateau and included names and specific descriptions of the ichnofossils. Howard (1971, 1972) also studied relationships of trace fossils to environments of deposition.

Seilacher's general categories and Howard's more specific identification of trace fossils and related depositional environments of Upper Cretaceous rocks will be used in describing trace fossils of the study. Text-figure 3 provides a summary of trace fossils found in each unit of the Ferron Sandstone.

Dominichnia

Ophiomorpha.—One of the most common trace fossils in the study area is *Ophiomorpha* (Pl. 4, fig 6). A modern analog, according to Howard (1966), is the burrow of the shrimp *Callianassa.* Burrows in the area are 8 to 18 mm in diameter and are characterized by a bumpy surface caused by fecal pellets tamped into the walls of burrows. *Ophiomorpha* has both vertical and horizontal orientations in the study area. The burrow may be straight or slightly curved when vertical, with small mounds of sediment marking the opening of the vertical burrow; but it may be straight or winding when horizontal. A suspension feeding animal is considered to have made the burrow, and this type of organism cannot live in highly turbid water.

The burrow was observed in thin sandstone layers interbedded with siltstone or silty shale of unit 9 (Pl. 3, fig. 3; and Text-fig. 3) at the 2,700-foot mark on Plate 1. Similar thin sandstone beds with interbedded siltstone in the Panther Sandstone are assigned by Howard (1972) to the lower shoreface facies of the littoral zone. Numerous *Ophiomorpha* burrows are present in this facies.

Ophiomorpha is the only burrow observed in the thicker-bedded sandstone of units 2, 10, and 12. Clean, well-sorted, fine- to medium-grained sandstone with medium-scale trough and planar cross-bedding in the Panther Sandstone is assigned by Howard (1972) to the upper shoreface to foreshore facies.

Thalassinoides.—The burrow has a smooth surface, with a circular to elliptical cross section 6 to 20 mm in diameter, and is enlarged where branching of the burrow occurs. *Thalassinoides* burrows are found in dirty siltstones to fine-grained sandstones (Text-fig. 3) in the upper offshore to lower shoreface facies.

Fodinichnia

Teichichnus.—*Teichichnus* is a vertical, bladelike burrow that consists of a series of spreite. The burrow is always in a vertical plane and has a maximum depth of 23 mm. *Teichichnus* was observed in a medium-grained dirty sandstone of the upper lower shoreface facies in unit 9 (Text-fig. 3). Howard (1966) and Mayberry (1971) have described the burrow in the younger Upper Cretaceous Blackhawk Formation.

Smooth-tube burrow.—Vertical and horizontal smooth tubular burrows (Pl. 4, fig. 4) are found in the study area. These burrows have a diameter of 8 to 15 mm and are found in rock units (Text-fig. 3) of the upper offshore to lower shoreface facies. Vertical orientations of the burrows appear to be (1) escape routes of organisms that were buried by rapid sedimentation or (2) escape burrows abandoned after the exhaustion of food on the horizon at which the organism resided. The upward movement enabled the animal to reach a new feeding horizon, at which level the orientation of the burrow is again horizontal.

Pascichnia

Labyrinthic burrows.—Labyrinthic burrows (Pl. 4, fig. 4) occur in silty and fine-grained sandstones (Text-fig. 3) of the lower shoreface facies, are 6 to 12 mm in diameter, and branch off from horizontal smooth-tube burrows. Some such burrows become quite regularly patterned, owing to the organism's moving from side to side as it gleaned organic detritus from the sediment. These burrows are the passages the animal used to extend its feeding area.

Scolicia.—A bilaterally symmetrical concave trail, 10 to 12 mm wide, was left in fine-grained sandstone (Text-fig. 3) of the lower shoreface facies. Howard (1966) states that some *Scolicia* trails are similar to modern gastropod trails. According to Seilacher's classification, the trail might also be a repichnia.

ENVIRONMENTS OF DEPOSITION

Shale

Unit 1, the uppermost portion of the Tununk Shale, has flat bedding, with interbedded sandy layers increasing in number and thickness upward toward the Ferron Sandstone. Marine fossils have been collected in the lower beds by Katich (1951) and Lupton (1916). It has been interpreted as an offshore facies and is similar to prodeltaic sediments described by Coleman and Gagliano (1965). The unit is a transition facies between basal sandstone units of the Ferron Sandstone and shale, deposited as an open-marine facies, in the lower part of the Tununk Shale Member. In this study, unit 1 will be referred to as "transitional marine shale." These beds were examined only incidentally in the study.

Sandstone

Lower sandstone.—Unit 2 of the Ferron Sandstone is lens shaped and convex upward, with a flat, nonerosional base and a large length-to-width ratio. To the east, the sandstone thins and grades into transitional marine shale of unit 1; to the west, mudstone and carbonaceous mudstone. Large-scale planar cross-beds dip to the west in the sandstone unit. Smaller-scale cross-beds that are present in the thicker-bedded sandstone become troughlike (Pl. 3, fig. 2) and resemble cross-beds in foreshore facies of the Panther Sandstone (Howard, 1972). Oscillation ripple marks and megaripples are found in the unit in thicker-bedded sandstone. Trace fossils present in the Ferron Sandstone are the same as ichnofossils which are indicative of lower shoreface to foreshore facies in the Panther Sandstone (Howard, 1972).

Many of the characteristics of the unit 2 sandstone coincide with barrier-island models of deposition envisioned by Davies, Etheridge, and Berg (1971); Howard (1971); and Dickinson, Berryhill, and Holmes (1972). Some characteristics of barrier-island sand bodies that are mentioned in these reports are: (1) landward and seaward thinning, (2) elongation parallel to depositional strike, (3) underlying marine or nonmarine sediments, (4) a nonerosional base, (5) upward transition from lower shoreface to shallower marine facies,

(6) tidal channels, and (7) an increase in grain size from the lower shoreface to the beach facies.

A sandstone body, 200 feet wide and 10 to 15 feet thick at its thickest, with a channellike cross section and an eroded base (Pl. 2, fig. 2), cuts into the lower barrier sandstone between Ivie and Quitchupah Creeks. It is interpreted as a tidal channel deposit. Direction of transport was to the southwest.

A convex-upward sedimentary structure, 50 feet wide and 9.7 feet high (Pl. 1 and Text-fig. 4), with a flat nonerosional base, is exposed in the Interstate 70 road cut in unit 2 at approximately 3,850 feet on Plate 1. Planar cross-beds dip to the east and the west from the central, more massive, portion of the sandstone body. The structure is interpreted as representing a small sand bar that formed on the westward-thinning edge of the lower barrier island. Height of the sand bar, 9.7 feet, suggests a minimum depth of water at the time of deposition.

Sandstone of unit 5 thins and grades westward into mudstone and has a slightly erosional base. Planar cross-beds within the sandstone dip westward at 5° to 10° (Text-fig. 3). The unit is composed of platy bedded, fine grained sandstone and siltstone and contains marine shell fragments and fragments of plants. The composition, platy nature, faunal and floral assemblage, and slightly eroded base are similar to characteristics of washover fans described by Dickinson, Berryhill, and Holmes (1972) that form when high water washes sediment across the barrier island and deposits it in the lagoon.

Unit 9 is a platy, fine-grained sandstone with interbedded silty shale (Pl. 3, fig. 3) that grades upward and eastward into the more massive sandstone of unit 10. Cross-beds dip to the east at 10° to 15° (Text-fig. 3). Unit 9 is similar to the lower foreshore facies of the Panther Sandstone (Howard, 1972). The trace-fossil assemblages of unit 9 (Text-fig. 3), including *Ophiomorpha,* smooth tubes, *Thalassinoides,* and *Teichichnus,* coincides with the assemblage in lower foreshore facies of the Panther Sandstone. Unit 9 is interpreted as being lower shoreface sediments associated with a barrier-island sandstone in unit 10.

Unit 10, like unit 2, has a flat, nonerosional base, a convex-upward lens shape, and a large length-to-width ratio; and it grades westward into lagoonal sediments and eastward into transitional marine shale. Large-scale planar cross-beds dip eastward at 6° to 19°. Oscillation ripple marks were observed in the unit in the thicker-bedded sandstone. The trace-fossil assemblage (Text-fig. 3) has a facies range from lower shoreface to foreshore or beach facies as compared to the Panther Sandstone (Howard, 1972). Fewer trace fossils are found in unit 10 than in the underlying sandstones. Unit 10 is interpreted as a barrier-island accumulation and is referred to as the "middle barrier sandstone" of the Ferron Sandstone.

Unit 11 is a platy, fine grained sandstone with interbedded silty shale that grades eastward and upward into the more massive sandstone of unit 12. Cross-beds dip eastward at 10° to 15°. The unit is interpreted as lower shoreface sediments associated with the more massive unit 12.

Unit 12 has a flat, nonerosional base, a convex-upward lens shape, and a large length to width ratio, and it grades westward into lagoonal sediments and eastward into transitional marine shale. Planar cross-beds dip eastward at 6° to 19°. No trace fossils were observed in the sandstone unit. Unit 12 is interpreted as being a barrier-island accumulation and is referred to as the "upper barrier sandstone" of the Ferron Sandstone.

A sandstone unit with a channellike cross-section and an eroded base cuts through the upper and middle barrier sandstones in the cliff south of the interstate highway (Pl. 2, fig. 3). This sandstone has a coarser texture and is more massive than the upper and middle barrier sandstones, and it disrupts and cuts across the planar cross-bedding of the barriers. This lens of sandstone is interpreted as being a tidal channel deposit.

Unit 16 is composed of platy siltstone and sandstone. The unit thins and grades westward into mudstone and has a slightly eroded base. Planar cross-beds in unit 16 dip westward, indicating a general westward movement of the unit into the lagoon behind the upper barrier island. The unit is interpreted as being a washover fan deposited by high water. Westward from the 2,700-foot mark in the highway road cut (Pl. 1), the washover fan is identifiable as separate from the upper barrier sandstone.

Upper sandstone.—Unit 38 (Pl. 3, fig. 4) represents the upper sandstone. The sandstone beds are biconvex and are lens shaped and pod shaped, and a few channel-shaped cross sections are visible in some lenses in the area (Text-figs. 3, 4). These pods average 30 feet in thickness and are 300 to 600 feet wide. Quite often the sandstone is in contact with mudstone units. Coal found in association with sandstone has caused local bleaching or has burned and formed reddish clinkers, staining the sandstone.

Grain size generally decreases upward in individual lenses. The base contains the coarsest material with minor trough cross-bedding. Trough cross-beds become abundant above the coarse sediment and then lessen toward the top of each lens, but some of the cross-beds appear to be planar in the middle portion of the lenses. At the top of lenses, thin, horizontal, fine-grained sandstone beds are present. No cross-bedding was observed in these beds. Sandstone bodies that have stream-channel cross sections have the same characteristics as do the pods and lenses.

Cotter (1971) proposed that the upper sandstone was deposited by migrating point bars. Physical characteristics, mentioned above and observed in the field by the author, indicate the same mode of deposition for the sandstones. Visher (1965) presented the following vertical sequence of deposits in his fluvial model: (1) a basal zone of coarse sand or gravel, (2) well-sorted sand with trough or planar cross-bedding and dunes or sand waves present, (3) horizontally bedded fine sand and silt with no cross-bedding present, and (4) a very fine sand or silt ripple cross-bedded zone that may or may not be present. McGowen and Garner (1970) report the lithologic sequence of a modern point bar as having essentially the same characteristics. Allen (1965) indicates a general upward fining of grain size in point bars. Visher (1972) and McGowen and Garner (1970) constructed block diagrams of meandering streams, showing the relationship of the sand bodies to the alluvial plain sediments. The resulting cross sections show lenses and pods of sandstone and interbedded mudstone that correspond to the geometry and facies relationships observed in the upper sandstone of the Ferron Sandstone in the study area.

Sandstone bodies with channellike cross sections are few in the area, owing to reworking of the sediments by the meandering streams. Grain size in some local exposures appears to grade upward from fine to coarse across the bases of sandstone units, but several obscure eroded boundaries help produce this illusion.

Natural levee deposits usually are not preserved because eventually they are destroyed by the meandering of streams. A portion of a levee is visible in

Plate 3, figure 4 on top of the channel on the left side. The levee is composed of gently dipping interbedded fine-grained sandstone and mudstone. Allen (1965) states that levees are commonly thin, gently dipping beds of interbedded coarse and fine sediments with small-scale trough cross-beds.

Units 20, 23, and 27 are stream channel deposits that cut into mudstone that lies above or behind barrier islands. This interpretation is based on the geometry of the sandstone bodies, their eroded bases, and the lithologic sequence, which is the same as found in the lenses and pods of unit 38.

Units 14, 30, and 33 have a convex-upward shape with a flat nonerosional base. These units are thought to be splay deposits that thin at their edges and grade into mudstone. Allen (1965) characterized a splay deposit as having a tonguelike geometry that is deposited over finer material and grades into finer sediment at the edges. Wanless and others (1970) indicate that splay deposits have flat noneroded bases. A splay may be formed during the flood stage of a stream when a crevasse occurs in a natural levee, allowing sediment to be transported into the lower surrounding area.

Coquina

Unit 4 is a molluscan coquina that formed in the lagoon behind the lower barrier sandstone and that grades eastward into mudstone.

The assemblage of mollusks in the coquina exposed along the interstate highway road cut is mainly *Corbicula* and *Corbula,* while only the genus *Gryphaea* is present in an equivalent coquina at Ivie Creek. This transition may have been caused by a change in the water chemistry of the lagoon. *Corbicula* and *Corbula* are reported to have lived in brackish to normal marine water; *Gryphaea,* in normal marine water only. Restricted circulation in the lagoon could account for the variation in assemblages. A tidal inlet, such as shown in Plate 2, figure 2, may have allowed marine water into the lagoon and allowed *Gryphaea* to flourish near the present site of Ivie Creek.

Mudstone and Carbonaceous Mudstone

Lower mudstone.—Units 6, 8, 13, 15, 17, 19, 21, 24, and 26 were deposited behind barrier-island sand accumulations. Unit 6 is associated with the lower barrier sandstone; and units 8, 13, 15, 17, 19, 21, 24, and 26 are associated with the upper barrier sandstone. The mudstone units thin toward the barrier sandstones and onlap the sandstones where they pinch out. Consequently, the mudstone units are thickest away from the barrier sandstones.

Interpretation of the lower sandstones as barrier-island features suggests that the associated lower mudstones were deposited in lagoons behind the barrier islands. These mudstones become more sandy toward the barrier sandstones because of mixing and because washover fans are interbedded with the units. Landward, sandstone-filled stream channels and splay deposits are present. Abundant plant fragments are also present in the mudstone.

Dickinson, Berryhill, and Holmes (1972) report that sediments in a lagoon are commonly silt- and clay-size particles and that the units become sandier toward the barrier with interbedded features such as washover fans. Sediments toward the landward side would reflect the depositional conditions present on the land and near-shore shallow water of the lagoon. Abundant plant fragments also would be present in the mudstone.

Carbonaceous mudstone is associated with the lagoonal mudstone but occurs mainly in close proximity to coal beds. These carbonaceous rocks have the same characteristics as does the lagoonal mudstone but contain a greater abundance of organic debris.

Ironstone, unit 25, is found in the lower mudstone units. Interpretation of the lower mudstones as being formed in lagoons suggests that the ironstone was deposited in a lagoonal environment. Ferm and Williams (1969) indicate that ironstone may form in brackish to marine environments. Ironstone commonly is found in close proximity to the thinning edge of a clastic sedimentary body.

Middle mudstone.—Units 28, 31, 35, and 37 on Plate 1 represent mudstones associated with the upper fluvial sandstones of the area. These mudstones are lenticular and horizontally laminated. Plant fragments are present in the units. Coarser sediments may be found interbedded with the mudstones.

Carbonaceous mudstone is also associated with middle mudstones. The occurrence of plant fragments and a slightly darker color are the only differences between them.

Mudstones mentioned above are interpreted as being flood-plain and backswamp deposits. Visher (1965) stated that backswamp and flood-plain sediments are silt- and clay-sized with horizontal laminations that contain abundant plant material. Both rock-unit types are irregular in thickness and lateral continuity. Allen (1965) mentioned the same characteristics and further stated that because of flooding of the stream, coarser sediments may be interbedded with mudstones.

Lack of continuity in the mudstone units is caused by destruction of the flood-plain and backswamp areas by stream migration and by deposition of the sediments in irregular basins.

Upper mudstone.—The upper mudstones are the top units of the Ferron Sandstone and were deposited before complete transgression of the Mancos Sea. This mudstone is thinly laminated with an alternation of clay and silt laminae. Abundant organic material is present in some laminae and absent from others. When organic-rich samples were disaggregated, a film of liquid hydrocarbon formed on the solution's surface. Marine foraminifera were identified from the unit, and some ironstone was observed associated with the mudstone. The unit interfingers with the normal marine gray Blue Gate Shale.

The upper mudstone was probably deposited as interdistributary sediments in an area that had restricted circulation of normal marine water such as that described by Coleman and Gagliano (1965) or Visher (1965).

Coal

Unit 3 is bone-coal and carbonaceous mudstone deposited in the lower lagoon. The coal changes to a sandy mudstone toward the east. Reedlike plants formed the carbonaceous material present. Sand that mixed into the mudstone diluted the organic material and probably was derived from material washed over the lower barrier sandstone.

Unit 7 is the "A" coal seam of Lupton (1916). The "A" coal was deposited in the lagoon behind the lower barrier sandstone and is widespread and uniform in the study area. It is 7.6 feet thick along Ivie Creek but pinches out onto the barrier near Quitchupah Creek. Reedlike plants compose the carbonaceous material forming the coal deposited when the lagoon was shallow and marshy. Wanless and Baroffio (1969) discuss coals formed in similar lagoonal marshes behind barrier islands.

Lupton's "C" coal is unit 18 of the study area along the interstate road and Ivie Creek. It has uniform thickness in the study area and extends throughout the Emery coal field. Reedlike plants also form this unit. The "C" coal was deposited in the lagoon or marsh behind the upper barrier sandstone as the lagoon filled with sediments.

Unit 22, Lupton's "H" coal, grades to the west into bone coal along the interstate highway road cut (Pl. 1) and is discontinuous within the study area. Stream channel deposits are present above and below the coal and the associated mudstone units. The association of fluvial sandstone bodies with unit 22 suggests that the lagoon behind the upper barrier island was almost completely filled with sediment, thereby creating a fluvially influenced marsh or swamp in which the coal was deposited.

Units 29, 32, 34, and 36 on Plate 1 are a series of lenticular coal beds that pinch out rapidly into carbonaceous mudstone in the study area. The coal complex is identified as Lupton's "I" coal. The "I" coal is very thick—up to 22 feet thick in the Browning mine, five miles north of the area. This coal may have been deposited in backswamps or oxbows of a fluvial system like those described by Wanless and Baroffio (1969) for some coals in southeastern Illinois. Variable thickness and lateral continuity as well as association with fluvial sandstones support the interpretation.

CONCLUSIONS AND PALEOENVIRONMENTAL HISTORY

As the Mancos Sea advanced across east-central Utah, clastic wedges were deposited in and adjacent to the western margin of the sea. The Ferron Sandstone is one of these wedges deposited during the Upper Cretaceous. Text-figure 5 summarizes a somewhat idealized paleoenvironmental and depositional history of the Ferron Sandstone in the Ivie Creek area, and Text-figure 3 provides a summary of depositional environments observed in units forming the Ferron Sandstone.

EXPLANATION OF TEXT-FIGURE 5

TEXT-FIGURE 5.—Schematic block diagrams, showing the paleoenvironmental and depositional history of the Ferron Sandstone. Width of the blocks is approximately 1.5 miles. North is toward the top of the illustration. Unit number designations are the same as on Plate 1.

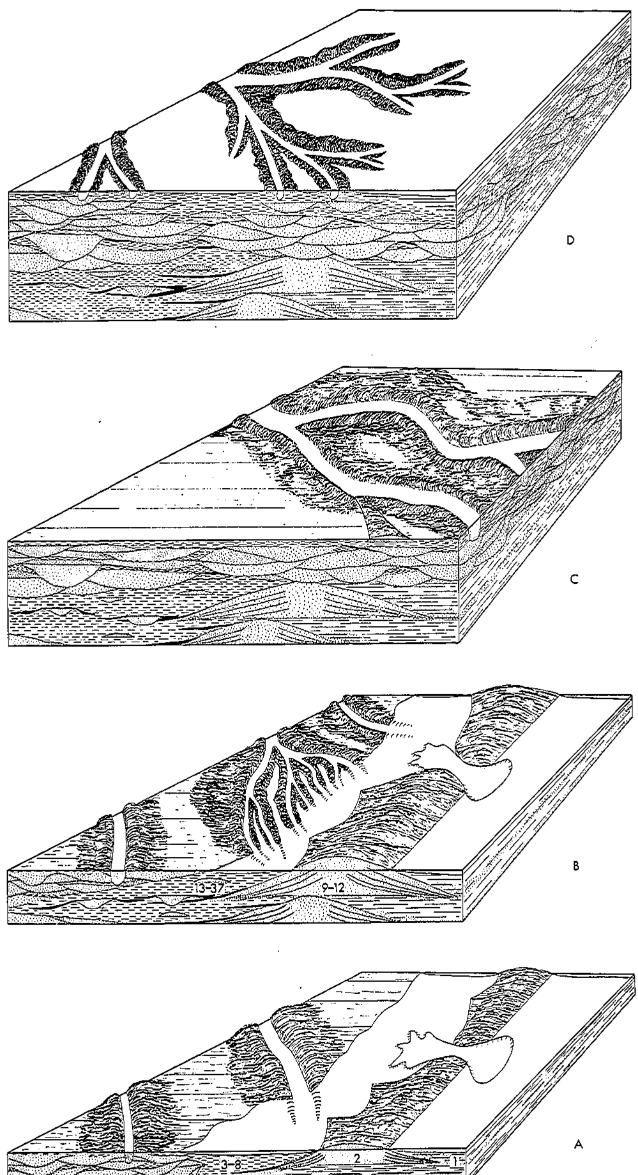
Block A. Formation of lower barrier island and associated lagoon. (A tidal inlet has breached the barrier island. Distributaries are depositing sediment into the lagoon.)

Block B. Formation of the middle and upper barrier islands and breaching of the barrier by a tidal inlet. (A large distributary system is filling the lagoon.)

Block C. Creation of a large alluvial plain with natural levees, splay deposits, and backswamps. (A fluvial system has swept over the barrier island position.)

Block D. Formation of interdistributary bays in late Ferron time before ultimate burial by the Mancos Sea. (Subsidence overcomes the sedimentation rate, causing transgression of the Mancos Sea.)

TEXT-FIGURE 5



Block A.—Subsidence of east-central Utah resulted in invasion of marine water from the southeast, but the westward advance of the sea was blocked by debris transported from the Sevier geanticline in central Utah (Hintze, 1973). The first marine Cretaceous unit to be deposited in the Castle Valley area is the Tununk Shale Member of the Mancos Shale. An increase in sandy layers upward toward the Ferron Sandstone Member has been interpreted as a transitional unit, unit 1, deposited near the Upper Cretaceous shoreline and the leading edge of an eastward-expanding coarse clastic wedge.

Sediment was transported from the southwest and was deposited along this shoreline by longshore currents. These sediments were reworked, and they accumulated in the lower barrier island, unit 2. A low sedimentation rate allowed intensive bioturbation of the sediments.

In the lagoon behind the lower barrier island, fine-grained sediment was deposited, units 3 and 8. Bivalves were present in the lagoon and are now found in a matrix of clay-sized particles, unit 4. The lagoon was partially filled with the clay and interbedded washover sand fans, unit 5. Reedlike plants that lived in the shallow brackish water formed coal and carbonaceous material in organic-rich mudstone, units 3 and 7. Locally, tidal inlets breached the barrier island and allowed normal marine water and coarse sand to be transported through the inlet into the lagoon.

Block B.—A more rapid sedimentation rate, probably related to uplift of the source area during a pulse of the Sevier Orogeny, caused eastward displacement of the sea. The middle and upper barrier islands, units 9 to 12, were formed at this time and tidal channels breached the barriers. A rapid influx of sediment into the lagoon partially filled the basin; and, at the same time, reedlike plants in the marsh formed the associated coal and carbonaceous mudstone units. Infilling of the lagoon was caused by distributaries discharging sediment into the lagoon as a lobate delta front built eastward or northeastward.

Fluvial environments exerted greater influence over the landward side of the lagoon during this phase—as evidenced by stream channel deposits, units 20, 23, 27, and splay deposits, units 14, 30, 33, surrounded by lagoonal mudstone.

Block C.—As the sedimentation rate greatly exceeded the rate of subsidence, a lobate delta was built across the site of the buried barrier islands. A broad alluvial plain of meandering streams with backswamps existed in the area during middle to late Ferron time. According to Cotter (1971), stream meanders were 2,500 to 4,100 feet wide. Reeds and rushes provided carbonaceous material for coal units in the backswamps.

Block D.—The sedimentation rate decreased, and subsidence became dominant during late Ferron time. The Mancos Sea transgressed to the west as less sediment was deposited at the coastline. The fluvial system now formed had only minor distributaries, and the region was mainly interdistributary bays. Activation and abandonment of distributaries caused the interdistributary mudstones of the area locally to interfinger with, or be replaced vertically by, the more normal marine Blue Gate Shale Member of the Mancos Shale. As subsidence continued, the Last Chance Delta of the Ferron Sandstone clastic wedge was buried under normal marine shale.

APPENDIX
MEASURED SECTIONS OF THE FERRON SANDSTONE NEAR EMERY, UTAH

SECTION A—0.5 miles west of 0-footage of Plate 1.

Unit No.	*Description*	*Unit Thickness (feet)*	*Cumulative Thickness (feet)*
1	Mudstone: dark brown to light gray; weathers light brown to light gray; composed of alternate layers of fine grained and silty laminae; plant fragments are present.	23.0 +	23.0 +

SECTION B—100 yards west of 0-footage of Plate 1 on the north side of Interstate 70.

Unit No.	*Description*	*Unit Thickness (feet)*	*Cumulative Thickness (feet)*
5	Sandstone: light yellow-brown; weathers light tan; coarse to medium grained; coarse grained in massive basal portion; trough cross-bedding in middle portion; fine grained, thin bedded sandstone at top of unit.	22.4	133.8
4	Sandstone: light gray; weathers yellow brown; fine to medium grained; trough cross-bedding.	16.5	111.4
3	Mudstone: medium brown; weathers light brown to medium gray; contains interbedded siltstone; irregular in lateral continuity and thickness.	11.2	94.9
2	Sandstone: yellow brown; medium grained; few trough cross-beds; massive bedded.	38.7	83.7
1	Slope zone: covered	45.0	45.0

SECTION C—East side of Dog Valley Wash

Unit No.	*Description*	*Unit Thickness (feet)*	*Cumulative Thickness (feet)*
16	Sandstone: light gray; medium grained	75.4	388.9
15	Mudstone: medium brown; weathers light brown to light gray; laterally discontinuous.	5.6	313.5
14	Sandstone: light gray; medium to coarse grained; some trough cross-bedding present; massive.	11.0	307.9
13	Mudstone: medium brown; weathers light brown to light gray; laterally discontinuous.	16.8	296.9
12	Sandstone: light gray; grades upward coarse to fine grained; trough cross-bedding.	20.0	280.1
11	Sandstone: light gray; weathers light tan; grades upward coarse to fine grained; megaripples; trough cross-bedding.	32.0	260.1
10	Mudstone: dark brown; weathers light gray; laterally discontinuous.	28.0	228.1
9	Sandstone: yellow-brown; weathers light tan to red brown; medium grained; trough cross-bedding present; grades laterally into mudstone.	38.6	200.1
8	Mudstone: medium brown; weathers light blue gray; contains interbedded carbonaceous mudstone and coal; irregular in lateral continuity and thickness.	44.8	161.5
7	Sandstone: buff; weathers light tan to light red brown; fine to medium grained; trough cross-bedding; pinches out laterally.	21.4	116.7
6	Slope zone: covered.	10.2	95.3
5	Sandstone: light yellow brown; weathers light tan; me-		

	dium grained; some trough cross-bedding present; massively bedded.	20.0	85.1
4	Sandstone: light yellow brown; weathers light tan; medium grained; trough cross-bedding present; massively bedded.	9.3	65.1
3	Sandstone: light yellow brown; weathers light gray; fine grained; extensive trough cross-bedding.	15.2	55.8
2	Sandstone: light gray; weathers yellow brown; medium grained; limited trough cross-bedding present; massively bedded.	15.6	40.6
1	Sandstone: locally calcareous; light gray; weathers light tan; medium grained; large-scale planar cross-bedding present; massively bedded; corresponds to sandstone unit 12 of Plate 1.	25.0	25.0

SECTION D—Along Ivie Creek

Unit No.	*Description*	*Unit Thickness (feet)*	*Cumulative Thickness (feet)*
24	Sandstone: light gray; weathers buff to red brown; fine to medium grained; trough cross-beds present in middle of unit; thin-bedded layers at top of unit.	34.2	353.4
23	Sandstone: light gray; weathers buff to red brown; fine to medium grained; trough cross-beds present in middle of unit; thin-bedded layers at top of unit.	45.0	319.2
22	Coal and carbonaceous mudstone: dark brown to black; clay particles intermixed with coal.	4.4	274.2
21	Slope zone: covered.	5.6	269.8
20	Sandstone: light gray; weathers white to yellow brown; fine grained; thin bedded.	7.0	264.2
19	Sandstone: light gray; weathers white to red brown; coarse grained; trough cross-beds present; thin bedded sandstone at top of unit.	17.9	257.2
18	Sandstone: buff; weathers white to yellow brown; fine grained; few trough cross-beds present; thin bedded.	6.6	239.3
17	Sandstone: buff; weathers white to yellow brown; fine to coarse grained; massive basal portion; trough cross-bedding in middle portion; thin-bedded top portion.	12.9	232.7
16	Mudstone: medium brown; weathers light brown; laterally irregular in continuity and thickness.	5.5	219.8
15	Sandstone: red brown; weathers light gray to brown; fine grained; contains interbedded mudstone 0.5 feet thick; sandstone bodies with channellike cross sections present; trough cross-bedding present; soft sediment deformation.	28.0	214.3
14	Coal: subbituminous; clayey; Lupton's "J" coal.	1.7	186.3
13	Carbonaceous mudstone: dark brown; weathers light gray.	0.8	184.6
12	Sandy shale: medium gray; weathers light gray; grades laterally into shale.	3.2	183.8
11	Mudstone: dark brown; weathers light brown; abundant carbonaceous material.	6.6	180.6
10	Sandstone: light gray to buff; weathers yellow brown; fine to medium grained; trough cross-bedding; contains mudstone lenses in lower 7 feet.	32.7	174.0
9	Sandstone: light gray; weathers yellow brown; fine to medium grained; trough cross-bedding; contains sandy shale and mudstone lenses.	25.2	141.3
8	Mudstone: dark brown; weathers light brown; grades laterally into sandy shale.	17.7	116.1

7	Sandstone: light gray; weathers light red brown; fine to medium grained; trough cross-bedding; channellike cross section; shaley sandstone in upper 2 feet.	5.2	98.4
6	Mudstone: medium gray; weathers tan gray.	3.0	93.2
5	Coal: bituminous; vitreous luster; Lupton's "C" coal and unit 18 of Plate 1.	4.4	90.2
4	Carbonaceous mudstone: dark brown; weathers medium brown; laterally continuous.	8.5	85.8
3	Sandstone: light gray to buff; weathers tan to yellow brown; medium grained; large-scale planar cross-beds; medium-scale trough cross-bedding; massive bedded; corresponds to units 2 and 9 to 12 of Plate 1.	63.7	77.3
2	Coal: bituminous; vitreous luster; Lupton's "A" coal and unit 7 of Plate 1.	7.6	13.6
1	Carbonaceous mudstone: dark brown; weathers medium brown; laterally continuous.	6.0	6.0

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