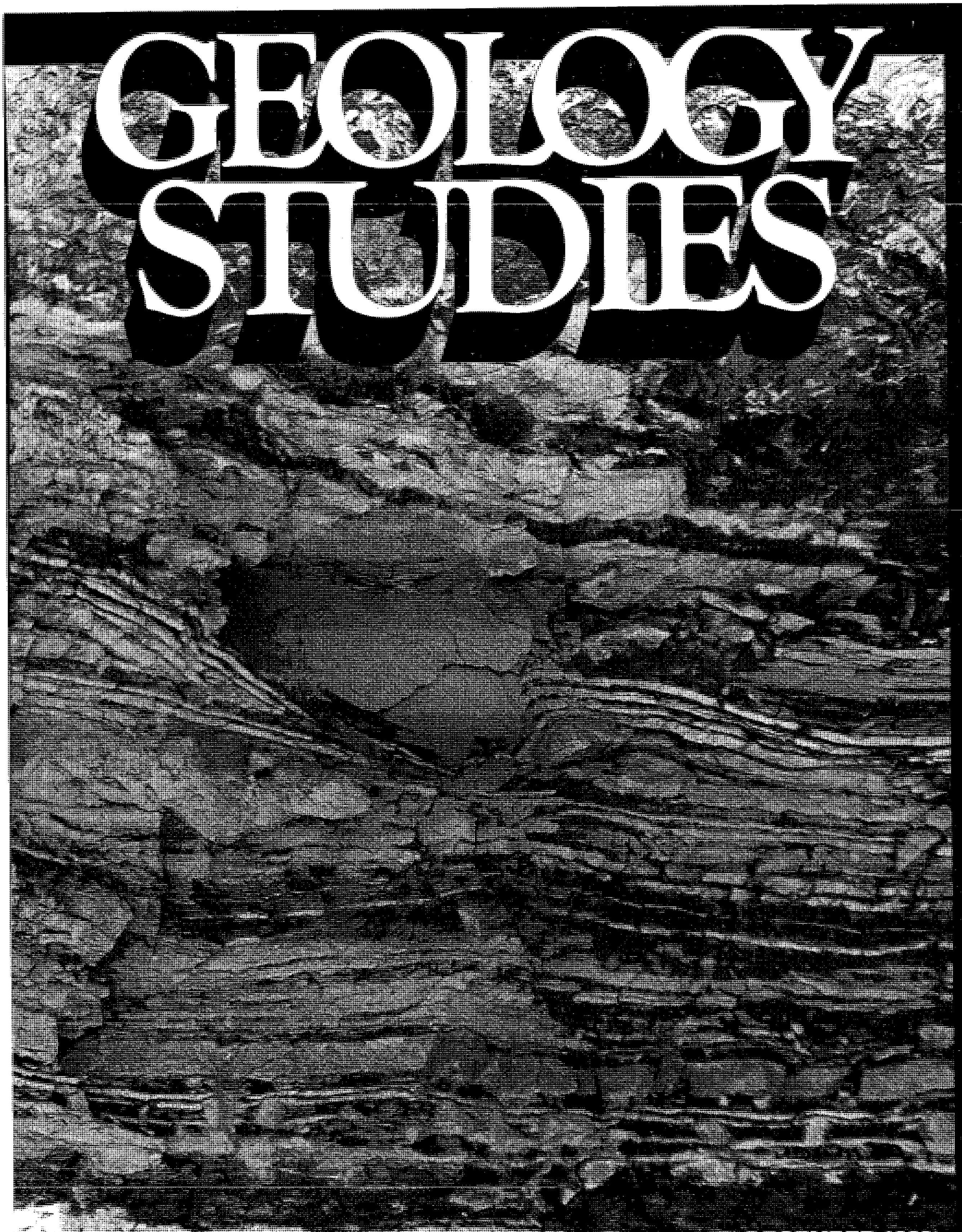
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



VOLUME 29, PART 2

DECEMBER 1982

Brigham Young University Geology Studies

Volume 29, Part 2

CONTENTS

THE GLORY OF GOD IS INTELLIGENCE

Cover: Rafted or foreign cobble that settled into what were soft underlying sediments. From outcrop immediately east of the Sandy Creek Crossing on Blind Trail Wash Road, Garfield County, Utah. Photo courtesy Sidney M. Petersen and Robert T. Pack.

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

Editors

Brigham Young University Geology Studies is published by the Department of Geology. This publication consists of graduate student and faculty research within the department as well as papers submitted by outside contributors. Each article submitted by BYU faculty and outside contributors is externally reviewed by at least two qualified persons.

ISSN 0068-1016

Distributed December 1982

12-82 600 58879

CONTENTS

Depositional Environments of the Upper Cretaceous Ferron Sandstone South of Notom, Wayne County, Utah*

RICHARD BRUCE HILL
Union Oil Company of California, 2000 Classen Center, Oklahoma City, Oklahoma 73106

ABSTRACT.—Exposures of Ferron Sandstone in the Henry Mountains region provide one of the best cross-sectional views of an Upper Cretaceous deltaic sequence in the western United States. Sections were measured at approximately 800-m intervals through the Ferron Sandstone cuestas over a 30-km distance south of Notom, Utah, and average about 80 m thick.

The Ferron Sandstone Member of the Mancos Shale in the Henry Mountains region represents a delta separate from the Last Chance and Vernal deltas to the north, but of the same approximate age. In the Notom area the member contains three minor deltaic pulses and one major sustained delta-building period with its associated upper delta plain environments.

Significant fossils found in this area include shark teeth, a dinosaur bone fragment, *Cercidiphyllum articum* leaves, an irregular echinoid, the ammonite *Prionocyclus macombi,* and a cheilostome bryozoan, the first reported from the Mancos Shale.

Economic possibilities for the area include coal mining, in situ coal gasification, and oil and gas exploration.

INTRODUCTION

Complete sections of the deltaic Ferron Sandstone Member of the Mancos Shale Formation are unusually well exposed around the western flank of the Henry Mountain Basin. These exposures provide one of the best cross-sectional views of an Upper Cretaceous deltaic deposit in the western United States. The Ferron Sandstone is a major producer of natural gas and coal in the Wasatch Plateau and Castle Valley areas in east central Utah. Previous detailed work on the Ferron Sandstone has emphasized these northern deposits. Ferron beds in the Henry Mountains region, the area with which this study is concerned, have been less well treated.

The Ferron Member has been described as a deltaic complex built out into the shallow Mancos Sea during middle Carlile (Turonian) time of the Late Cretaceous (Katich 1954, Cotter 1975). The Ferron Sandstone in northeastern Utah was produced by two deltaic complexes, termed the Vernal and the Last Chance deltas (Cotter 1971, 1975, 1976; Hale 1972). The Ferron Sandstone of the Henry Mountains region, however, represents a separate deltaic pulse (Uresk 1979).

Emphasis of this study has been to gather stratigraphic, lithologic, and paleontologic data to document environments of deposition within the Ferron Sandstone, to discover how the facies of the member are interrelated, and to understand how this sandstone body fits in with those of the Ferron Sandstone to the north.

LOCATION AND GEOLOGIC SETTING

Sections of the Ferron Sandstone studied for the present report are located in southeastern Utah on the Waterpocket Fold at the western edge of the Henry Mountain Basin (fig. 1). Areas studied extend southward from 16 km (10 mi) southeast of Notom, Utah, near Bloody Hands Gap and about 1.6 km (1 mi) north of the Wayne-Garfield County line, to Bitter Spring Creek, along the Waterpocket Fold 45 km (30 mi) south of Notom. The northern part of the area lies east of Capitol Reef National Park, but the southern third of the sections are within the park. The area is on the Notom and Wagonbox Mesa 15-minute topographic quadrangles and includes from section 27 of T. 30 S, R. 8 E, to section 29 of T. 33 S, R. 8 E. Access to the area is by a maintained dirt county and park road leading south from Utah 24 to Notom and Bullfrog Basin and by dirt road from Sandy Ranch through Blind Trail Wash to the Henry Mountains (fig. 1). Unmaintained ranch roads and four-wheel-drive trails from the main roads were used for access to some of the sections.

The Ferron Sandstone, which averages approximately 80 m thick, holds up a series of east-dipping cuestas on the western margin of the Henry Mountain Basin. The valley west of the cuestas is formed in the Tununk Shale Member, and the valley east of the cuestas is in the Bluegate Shale Member of the Mancos Shale (figs. 2, 3).

PREVIOUS WORK

Lupton (1914, p. 128) named the Ferron Sandstone Member from outcrops near the town of Ferron in Castle Valley, Emery County, Utah. This member corresponds to the Tununk Sandstone of Gilbert (1887, p. 4) in the Henry Mountains region. Spieker and Reeside (1925) described the Ferron Sandstone in the Castle Valley area and assigned it a middle Coloradoan (Carlile) age. Hunt (1946, p. 8) mapped the Ferron Sandstone in the Henry Mountains area and described its regional stratigraphy (Hunt 1953, p. 83). Spieker (1949) correlated the Mancos Shale Formation with formations on the west side of the Wasatch Plateau and suggested that the Ferron Sandstone is actually a tongue of the Indianola Group. Katich (1953, 1954) correlated the members of the Mancos Shale in Castle Valley with formations to the west, described their stratigraphy, and determined a source direction for the Ferron Sandstone. He concluded that the Ferron Sandstone is of lower to middle Carlile age.

The heavy mineral suite of the Ferron Member was studied by Knight (1954) in the Castle Valley area. Balsley (1969) described fossiliferous concretions from the Ferron Member in the San Rafael Swell, Balsley and Stokes (1969) described large coprolites found in the Ferron beds near Price and assigned a middle Turonian age to the member.

Cotter worked on the Ferron Sandstone in northern outcrops around the San Rafael Swell, including a paleoflow analysis (1971), a description of deltaic deposits of the member (1975), and a stratigraphic description (1976). He named four depositional units within the Ferron Member in the latter paper. Hale published two significant stratigraphic studies of the Ferron Sandstone and associated formations (Hale and Van DeGraff 1964, Hale 1972). Maxfield (1976) described the foraminifera of the Mancos Shale and recognized zones of foraminiferal occurrence. Cleavinger (1974) and Uresk (1979) have recently published detailed paleoenvironmental analyses of small areas of the Ferron Sandstone. Uresk worked at the northern edge of the Henry Mountain Basin, along Utah 24, east of Caineville.

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, April 1981. Thesis chairman: J. Keith Rigby.

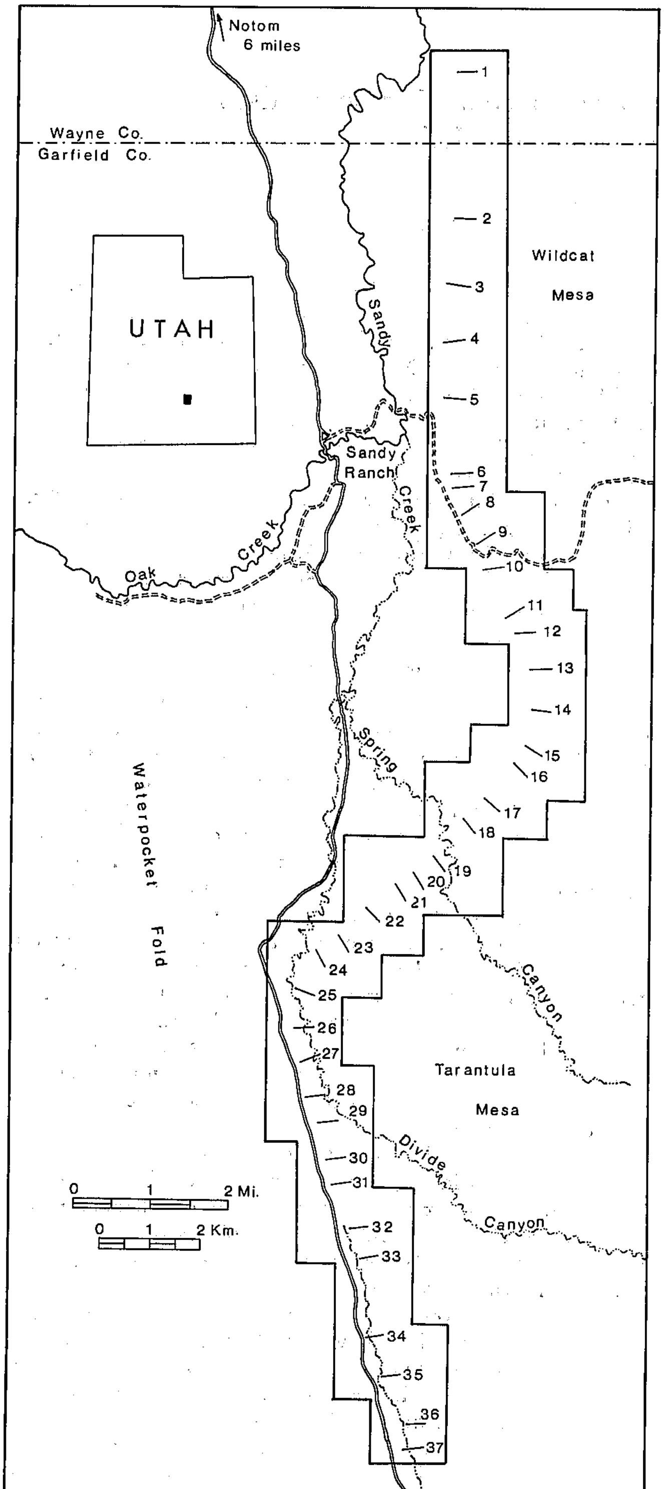


FIGURE 1.–Index map showing location of area and measured sections.

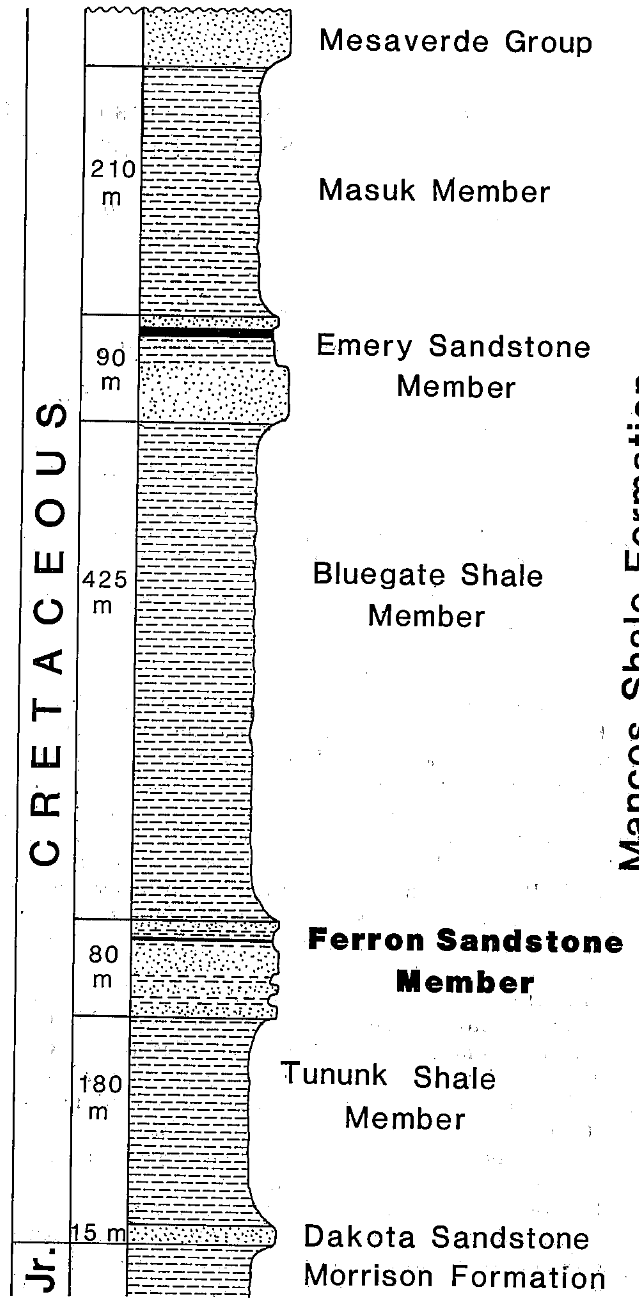


FIGURE 2.–Stratigraphic column showing Upper Cretaceous formations in the Henry Mountains region.

Visher (1965), Davies and others (1971), and Dickinson and others (1972) published significant studies concerning sedimentary environments and vertical and lateral sequences of beds. Pettijohn and Potter (1965), Ferm (1968), and Fisher and others (1969) published classic studies of deltas and sedimentation.

FIELD METHODS

Thirty-seven sections (plate 1) were measured with a Jacob's staff, cloth tape, and Abney hand level. Sections were located at approximately 0.8-km (0.5-mi) intervals where access was possible through the cuesta. Current directions, as indicated by cross-bedding or other directional structures, were measured in the field with a Brunton compass. Grain sizes were determined with the use of a grain-size comparison chart.

Hand samples were taken from units that represent different facies within the Ferron Member. Some sandstone units are so friable that suitable hand samples could not be obtained. Suitable samples of shale or mudstone could rarely be obtained because of their unconsolidated nature.

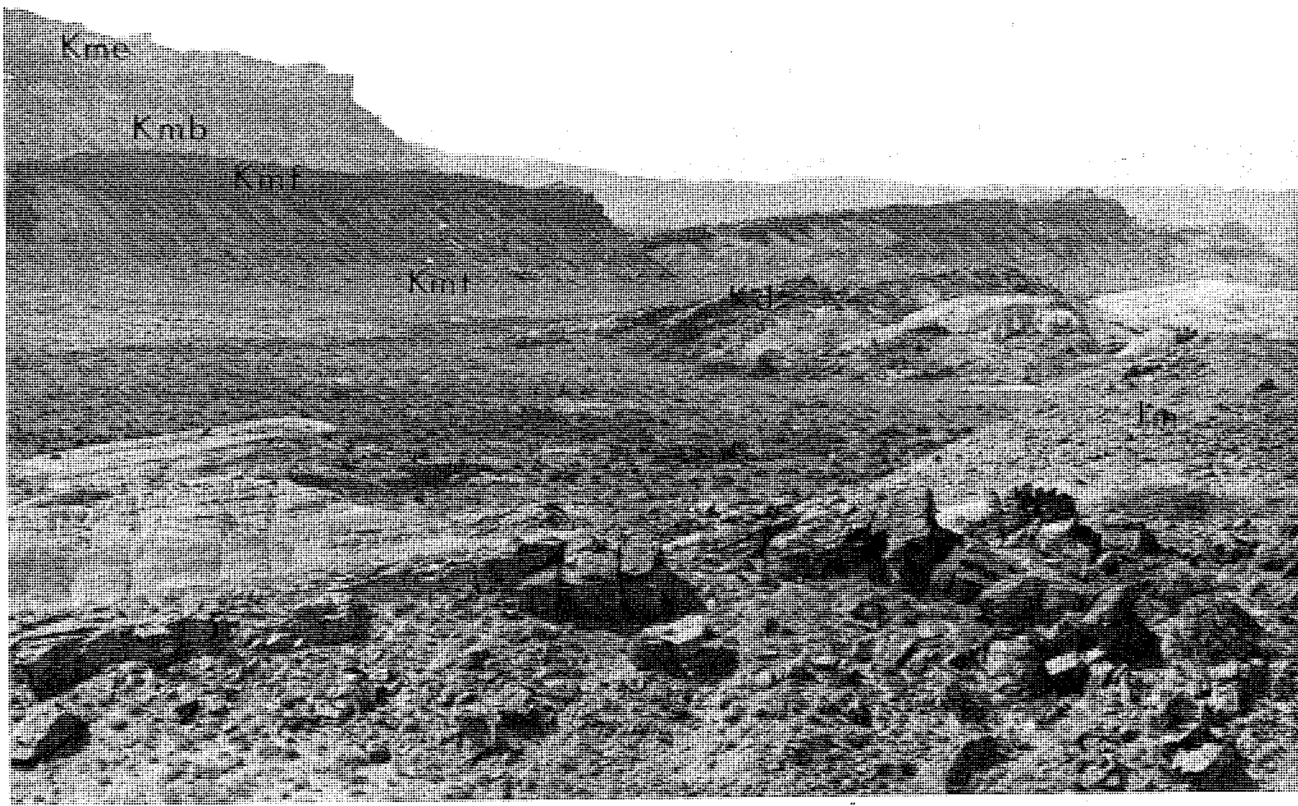


FIGURE 3.—View southeast toward Tarantula Mesa, showing outcrop belt of study area. (Jm-Morrison formation, Kd-Dakota Sandstone Formation, Kmt-Tununk Shale Member, Kmf-Ferron Sandstone Member, Kmb-Bluegate Shale Member, Kme-Emery Sandstone Member). From base of Tununk Shale to base of Emery Sandstone is approximately 700 m.

Many fossils were collected from the measured sections. Special precautions were taken when collecting and preparing leaves, ammonites, and bivalves from the shale and siltstone units because of the fissile nature of the matrix. Once removed from matrix, these samples were wrapped in tissue paper and bound with tape to prevent breakage while being transported. They were later treated with Gelva, an acetone-soluble plastic hardener. Bivalves, gastropods, and shark teeth, imbedded in indurated sandstones, were prepared in the laboratory with a small chisel, hammer, and pneumatic drill. Fossils are deposited in the fossil collections of the Geology Department at Brigham Young University.

LABORATORY METHODS

Thin sections were prepared of nearly all the hand samples. With the exception of 11 of the more indurated samples, all of the samples had to be impregnated with epoxy before sectioning. A vacuum chamber and Hillquist thin-section epoxy were used to harden the loose sandstones. The same epoxy mixture was used for cementing the billets onto the slides.

To examine the maceral content of the coal, four coal pellets were made with standard procedure.

ACKNOWLEDGMENTS

J. Keith Rigby served as thesis chairman and assisted throughout the course of this study. W. Kenneth Hamblin served as minor committee chairman. Harold J. Bissell assisted in preparation and interpretation of coal pellets. W. D. Tidwell identified those plant fossils which were well enough preserved.

I owe a sincere debt of gratitude to students of the 1978 and 1980 BYU geology field camp who measured many of the sections used in this study. I also wish to thank the Golden, MacLean, and Keith Durfey families of Salina and Bicknell, Utah, for their friendship and hospitality to me while I conducted fieldwork in the area.

A grant from Conoco, Inc., provided financial support for this project.

LITHOLOGIES

The Ferron Sandstone is composed of interbedded sandstone, siltstone, shale, and coal with local units of pebble conglomerate. Shale units are most common near the bottom and top of each section. The lowest sandstone bed greater than 10 cm thick was used to mark the base, and the uppermost similar major sandstone unit was used to mark the top of the member (fig. 4). Because the sandstone units are discontinuous laterally, the top and bottom of each section vary slightly from section to section. Total measured thicknesses of the Ferron Member within the area range from 36 to 128 m and show a general thinning toward the south (plate 1).

Shale

Shale units throughout the study area are silty and sandy and weather to slopes. Gray shale of the Tununk Member be-

FIGURE 4.–View of section 10 toward the south, showing coarsening upward from marine shales to fluvial sandstones. Ferron Sandstone is 94 m thick in section 10.

comes siltier upward toward the base of the Ferron Sandstone. Sandy and silty shale layers within the Ferron Member shift from brownish gray near the base to reddish gray and gray at the top, reflecting the shift in environmental conditions of deposition.

Tununk Shale

The upper 10 m of the Tununk Shale grade upward toward the Ferron Sandstone from silty to sandy shale, with a corresponding increase, both in number and in thickness, of sandstone and siltstone layers. The beds, gray on the fresh surface, but brownish gray on weathered surfaces, become lighter as sand, silt, and plant debris increase. Veinlets and stringers of secondary gypsum are common throughout shale beds that are thinly laminated to laminated except where bioturbated. The middle of the Tununk Shale yielded marine bivalves.

Lower Shale Units

Shale units in the lower part of the Ferron Member are similar to the Tununk Shale. They are predominantly silty and sandy, are medium grayish brown on the fresh surface, and weather light grayish brown. They are horizontally laminated except where soft-sediment deformation and bioturbation have disrupted the bedding. Plant debris is abundant, and a few whole leaves are present, as, for example, in unit 4 of section 11. Bivalves, ammonites, a bryozoan, and fish scales were found in shale in section 19, unit 8. Tool marks are common in the thin siltstone and sandstone laminae, as well as in beds within the shale at the base of the Ferron Member, as in unit 6, section 17 (fig. 5). Secondary gypsum is present, along with a few limonite concretions. The basal surfaces of these shale units are generally sharp, but the tops grade into siltstone and sandstone.

Upper Shale Units

Upper shale layers are generally more greenish brown on fresh surfaces than lower shale units and are commonly interbedded with coal and ironstone. Exceptionally well exposed sequences of these beds are found in sections 1, 2, and 4 (plate 1). These upper shales change gradually from greenish brown at the base (units 37 to 46, section 2) to interbedded greenish brown and gray (units 47 to 60, section 2), and finally to gray at the top (units 61 to 65, section 2).

A common vertical sequence in these beds is for shale to grade upward into carbonaceous shale and coal, then back into carbonaceous shale, and then into siltstone. The upper siltstone grades upward into shale and the cycle begins again. A good example of this cycle is found in unit 22 of section 1 (plate 1).

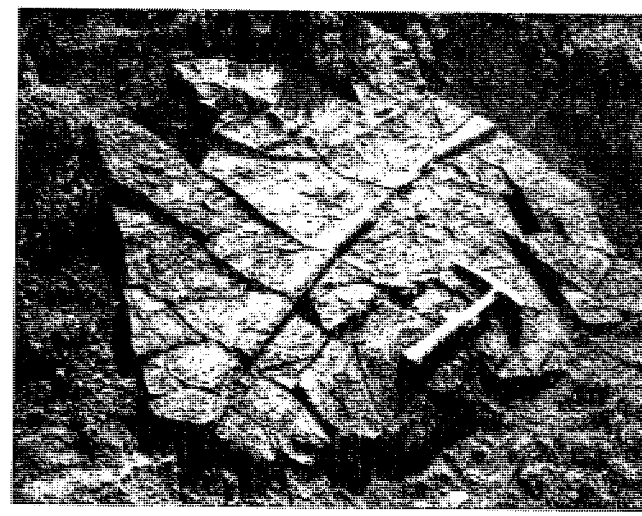


FIGURE 5.–Tool marks in siltstone layer of unit 6, section 17.

This vertical gradation also occurs laterally, except that the siltstone grades laterally into sandstone instead of more shale.

Another common vertical sequence, as seen in units 20 to 25 of section 4, is for shale to grade into siltstone and sandstone. Shale occurs abruptly on top of the sandstone, and the sequence repeats above the sandstone (plate 1).

Shale units are generally lenticular, 1 to 4 m thick, and extended laterally for 1 to 2 km. The beds are laminated to thinly laminated, but bioturbation and rooting are common in local horizons. Plant fragments are particularly abundant.

Carbonaceous Shale

Carbonaceous shale, often associated with coal layers in the upper part of the Ferron Sandstone, is generally medium brown, silty, and laminated and commonly contains primary compaction slickensides. It is an intermediate in the vertical and lateral gradation from shale to coal. Exceptionally thick accumulations (2.5 m) of carbonaceous shale, such as in unit 18 of section 21, occur in some of the sections. The only fossils found in these beds are macerated plant fragments and occasional poorly preserved leaves.

Coal

Coal seams in the Notom area average about 0.5 m thick, and the thickest seam measured is 1.2 m (fig. 6). These bitu-

FIGURE 6.–Unit 43 of section 19 is the thickest coal seam in the Notom area (1.2 m). It grades rapidly upward from sandstone at the base to carbonaceous shale, to coal, then back to carbonaceous shale and sandstone.

minous coals vary from black to dark brownish gray and have an earthy to bright luster. They contain thin silty interbeds and fracture cubically. Yellow sulfate and limonite staining is common on the cleat of the coal. Gypsum is occasionally present as stringers and veinlets. Where the coal is exposed, it usually weathers to a dark gray to dark purplish gray band on the slope. Coal beds are confined to the upper Ferron Sandstone and are laterally discontinuous. Upper and lower surfaces of the coal beds usually grade into carbonaceous shale, except where channels have cut down into the coal from above, as in section 7, units 19 and 20, and section 18, units 20 and 21. The coal generally contains moderate amounts of sulfur and silt. Silty laminae are common in some coal seams.

Mudstone

Mudstone occurs mostly in the lower part of the Ferron Member where it is interbedded with siltstone and shale, as in section 11, units 2, 4, 5, and 6. It is usually light brownish gray to medium gray, silty, and laminated and contains ironstone concretions. Mudstone units exhibit spheroidal weathering where exposed in cliff faces but elsewhere form slopes. Individual beds are 10 to 40 cm thick and extend laterally for only a few tens of meters. Contacts with surrounding units are horizontal and sharp to gradational (section 14, unit 2). No fossils were found in the mudstone layers except for plant debris and a few small (1 cm thick, 6 cm long) coal pods.

Calcareous Mudstone

Calcareous mudstone occurs interbedded within shale layers in beds seldom thicker than 15 cm. It is usually reddish brown on weathered surfaces, owing to the high iron content, but is medium to dark brownish gray on fresh surfaces. These rocks are not silty in contrast to most other units in the Ferron Sandstone, and form thin, resistant, semi-ledge layers in the shale slopes. Contacts are sharp. Calcareous mudstone layers usually grade laterally into ironstone layers. No fossils were found in these rocks.

Siltstone

Siltstone occurs as thin layers (5 to 30 cm thick) within shale beds or as part of a texturally gradational sequence. Contacts with surrounding units, therefore, are mostly gradational. These rocks are usually laminated to very thinly bedded and occasionally exhibit shaly splitting. Where the siltstone is calcareous it forms a ledge, but elsewhere it is expressed as a slope.

Siltstone in the lower part of the Ferron Member occurs as thin gradational beds within shale layers or just below or above sandstone beds. It is grayish brown on a fresh surface and weathers lighter. The beds are laminated and locally exhibit wavy bedding (fig. 7), as in section 25, unit 1. They are tabular to podlike and thicken and thin laterally. Basal surfaces are generally horizontal except where deformed by sandstone loading (section 20, unit 12). Siltstones may contain small quantities of very fine sand and are highly bioturbated in most instances. They commonly contain limonite concretions. Ripplemarks and tool marks, such as those in unit 6 of section 17, show transport directions to the east and southeast. Plant debris intercalations are abundant, but some whole leaves were found, along with a few bivalves.

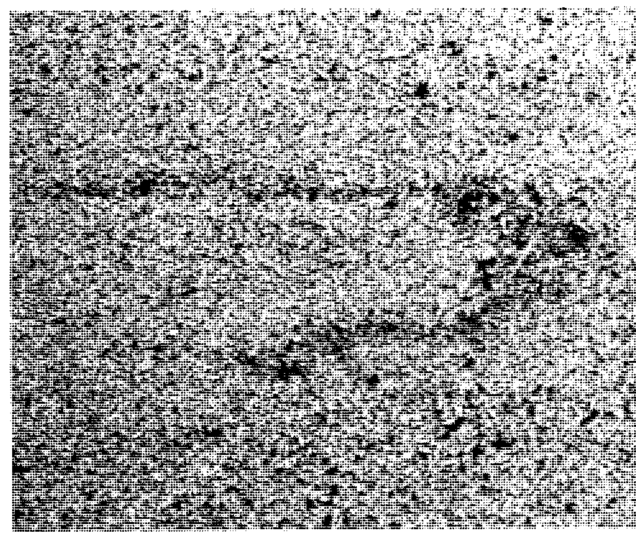


FIGURE 7.–Contorted bedding from unit 1 of section 25, X7.5.

In the upper part of the Ferron Member, siltstone layers are lenticular and extend laterally for only short distances. They are also thin, but lack sedimentary structures other than rare ripple marks, bioturbation, and rooting impressions. Limonite concretions and plant debris are abundant, and carbonized root traces are only locally abundant, such as in section 25, unit 17.

Sandstone

Composition

Most sandstone units are moderately well sorted, and composed (60–96%) of subangular, fine-grained quartz and chert sand. Few of the units are coarser than medium grained. The Ferron Member in the Notom area averages 45 percent sandstone and conglomerate, 32 percent shale, and 23 percent siltstone. In the central part of the study area, where deposition was concentrated, the percentage of sandstone is greater.

Quartz grains in many of the units have a microshattered structure when seen in thin sections, although other grains next to them are not shattered (fig. 8). These quartz grains are most likely from a Precambrian source and have not been transported far. Their texture suggests that they would break down rapidly during movement.

In addition to chert and quartz grains, the sandstones contain other minor constituents. Plant and wood fibers (fig. 9) are common in nearly every unit. Glauconite is locally com-

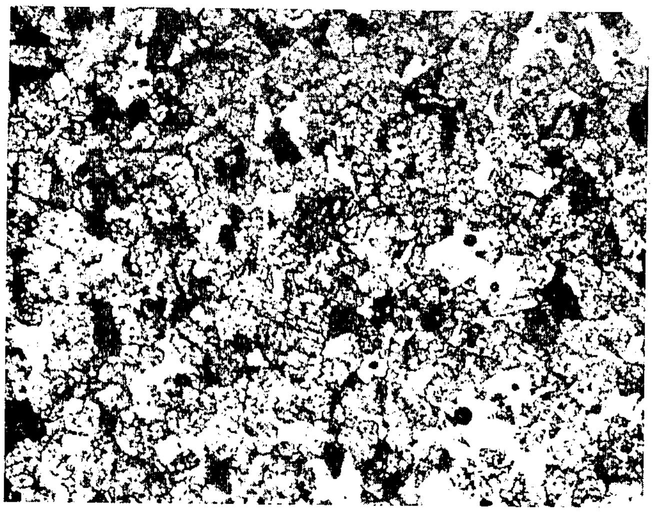


FIGURE 8.—Shattered quartz grains, some of the darker grains are not shattered, unit 15, section 11, X5.7.

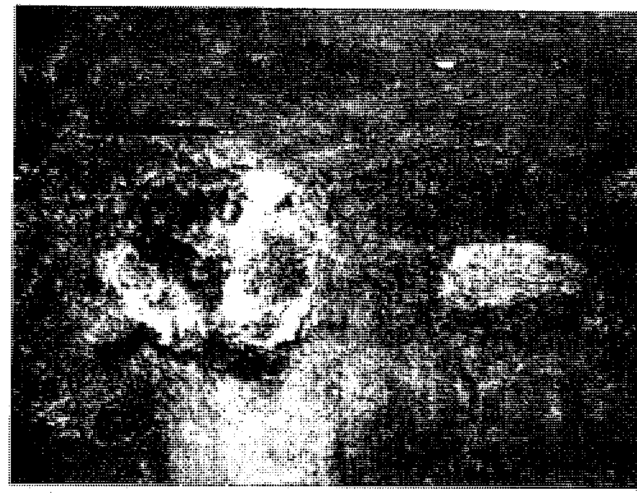


FIGURE 10.—Gypsum clasts in coarse-grained sandstone, unit 20, section 25. Largest clast is 35 cm in diameter.

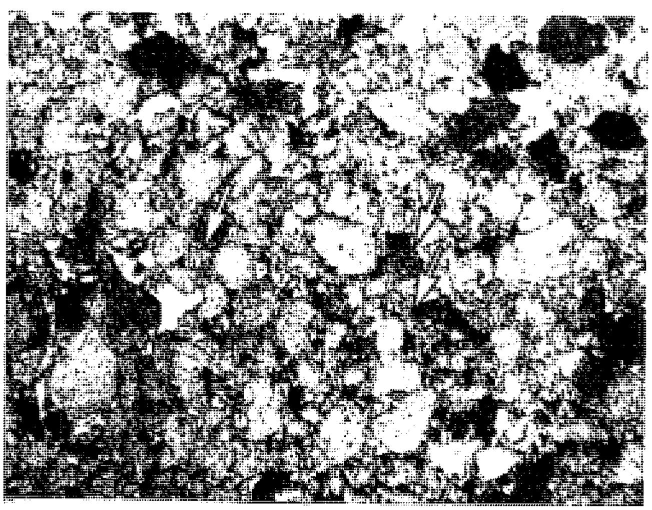


FIGURE 9.—Wood fibers in medium-grained sandstone, unit 8, section 11, X5.7.

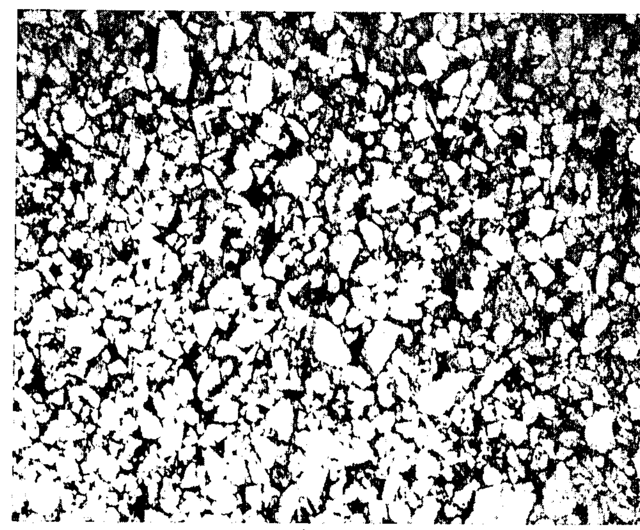


FIGURE 11.—Medium-grained sandstone cemented by dolomite. Dolomite is stained dark in this photo, unit 50, section 19, X13.

mon, particularly in lower units of the Ferron Sandstone. Detrital carbonate grains occur in several of the units as well. Feldspar is a common constituent, although generally no greater than about 10 percent and often only 1 to 3 percent of the total grains. The feldspar probably had an igneous origin, for it is associated with other igneous-derived minerals, such as biotite. Biotite in some units shows an early stage of breakdown. Polycrystalline quartz grains also suggest an igneous or metamorphic origin.

Sandstones of the member are fairly immature, for most have significant feldspar and biotite content. These rocks were also deposited fairly close to their source, as indicated by the persistence of shattered quartz grains, unweathered igneous minerals, angularity of the grains, and presence of some large gypsum clasts (fig. 10) in one of the sandstone units. These gypsum fragments were probably derived from the Carmel or equivalent formations exposed a short distance away.

In certain local areas or units secondary dolomite is a significant constituent of the sandstone (fig. 11). Although dolomite does cement the sand in these local areas, the major cementing agents throughout the Ferron Member are limonite (fig. 12) and secondary calcium carbonate. Limonite cement commonly fills pore spaces, or at least constricts them, occasionally giving the sand a salt-and-pepper appearance (fig. 13). Porosity in these limonite-cemented sandstones averages about 8 percent. Upper bleached sandstones of the Ferron Member are poorly cemented and friable and have up to 30 percent porosity. In local horizons, such as in unit 42 of section 22, secondary compaction cracks have developed which locally increase the porosity (fig. 14).

The sandstones can be divided into two groups, those that occur in the lower part of the Ferron Sandstone and those that occur in the upper beds of the member.

Lower Sandstones

Lower sandstones are distinguished from upper sandstones by a general absence of large trough cross-beds thicker than 10 cm and an abundance of soft-sediment deformed structures. These lower sandstone beds are generally medium orange brown on a fresh surface, but weather to a light orange brown. They are thin bedded to laminated, are generally less than 1.5 m thick, and form ledges and cliffs. They are very fine to fine

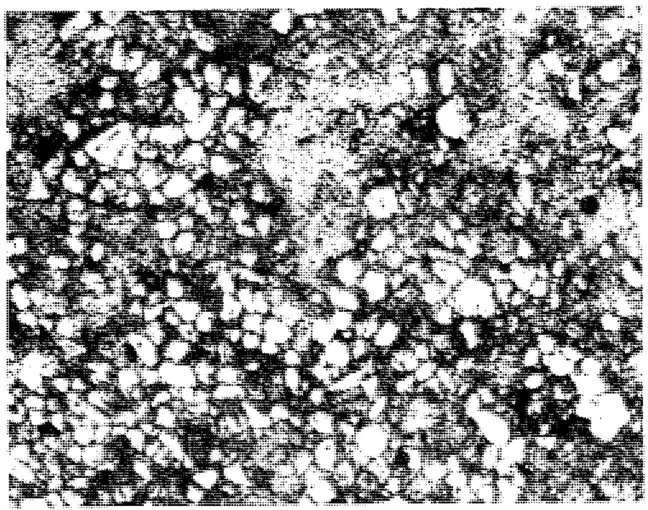


FIGURE 12.–Limonite-cemented sandstone, unit 21, section 5, X10.

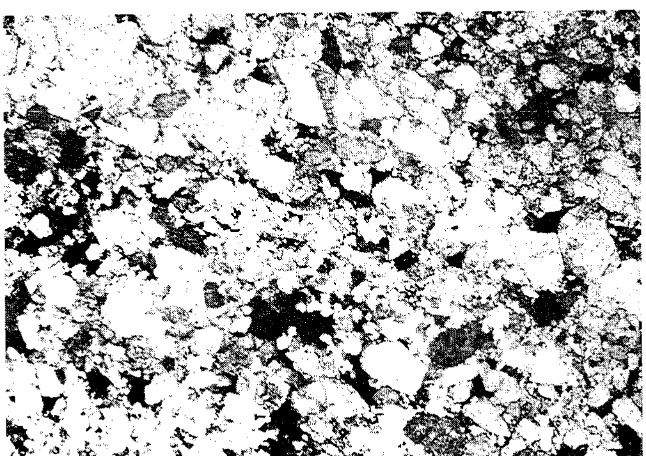


FIGURE 13.–Limonite and hematite filling pores in sandstone. This gives sandstone a superficial salt-and-pepper appearance, unit 8, section 29, X13.

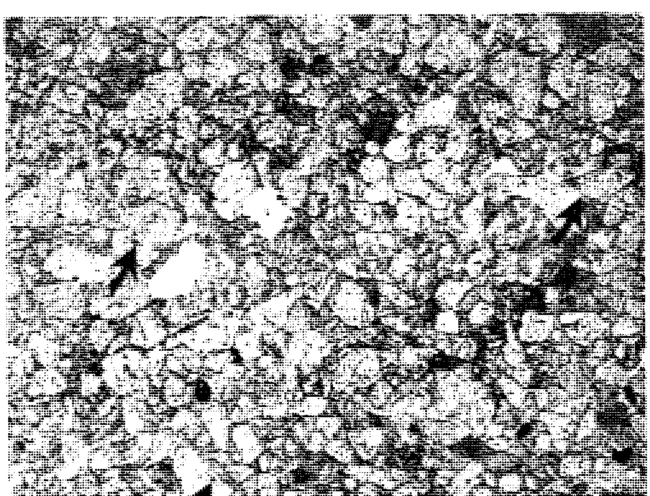


FIGURE 14.–Secondaty compaction cracks around grains, unit 42, section 22, X8.

grained and exhibit soft-sediment deformation of ball-and-pillow type (fig. 15). Examples are found in the cuesta face throughout the area, but some spectacular examples are found in unit 2 of section 13 and unit 2 of section 14. Some of these pillows are 3 m thick (fig. 16). In some areas where soft-sediment deformation is present, spring pits are occasionally observed (fig. 17).

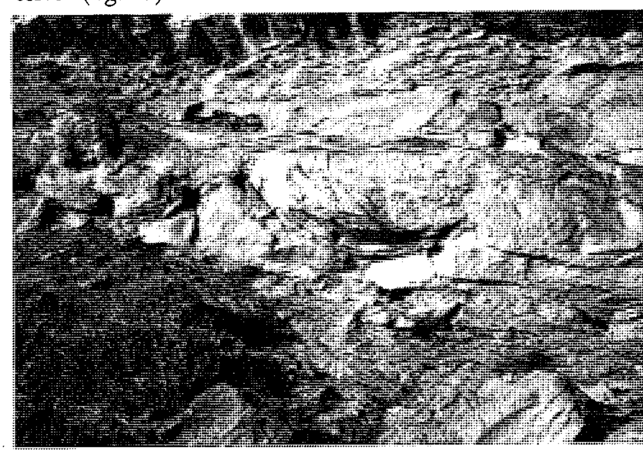


FIGURE 15.–Ball-and-pillow type soft-sediment deformation in unit 3 of section 9.

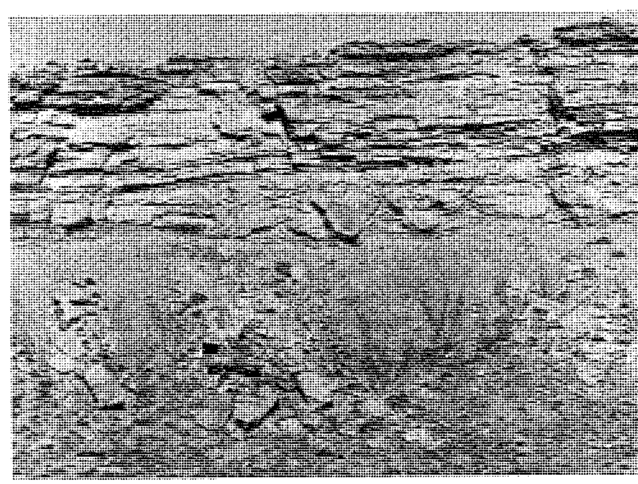


FIGURE 16.–Ball-and-pillow type soft-sediment deformation in unit 2 of section 13. The most prominent pillow in the photo is about 3 m thick.

FIGURE 17.–Spring pits in sandstone of unit 17, section 1.

Lower sandstones can be broken down further into two subtypes: horizontally bedded and cross-bedded. Horizontally bedded sandstones, such as units 6, 8, and 13 of section 34, are limonite cemented and calcareous, and contain limonite and calcareous concretions from 0.5 to 8 cm in diameter (fig. 18). Laminations of organic debris are also abundant. Large horizontal and vertical burrows are common and are locally abundant enough to totally obliterate bedding. A few leaves were found in these beds.

The horizontally bedded sandstones often contain clay laminations. Basal surfaces are generally gradational from shale to sandstone, except in areas of soft-sediment deformation where the basal contacts are sharp. The geometry of these beds is generally sheetlike to tabular. Individual beds between sections 5 and 10 can be followed for 3–4 km (plate 1).

Lower cross-bedded sandstones, such as units 6 and 7 of section 9, are somewhat lighter colored on a fresh surface than are the horizontally bedded sandstones, but they weather the same. They also contain limonite concretions and organic laminations. Trace fossils are present, but they are primarily vertical burrows and are not abundant (fig. 19). Cross-beds range from ripple laminations 7 mm thick (unit 10, section 29) to trough cross-beds 6 cm thick (unit 5, section 19). Transport directions differ from bed to bed, but generally are toward the east, varying between northeast and southwest. Cross-bedded sandstones are tabular to pod shaped and extend laterally for a few hundred meters. They grade laterally into horizontally bedded very fine-grained sandstone and siltstone, but vertically are often in direct contact with shales, such as in section 10, unit 12. Occasionally there is a thin siltstone layer less than 10 cm thick either above or below sandstones.

Fossils are locally abundant in lower sandstones, as in unit 3 of section 11, which contains bivalves, gastropods, ammonites, seeds (?), and an echinoderm. These fossils were not broken up, but were irregularly oriented throughout the unit, and the bivalve shells were disarticulated. Some sandstone units between sections 19 and 25, at the bottom of the Ferron Sandstone, are light gray, cross-bedded, and medium grained, and contain abundant shark teeth, skate teeth, sawfish teeth, fish scales, and occasional small fish bones.

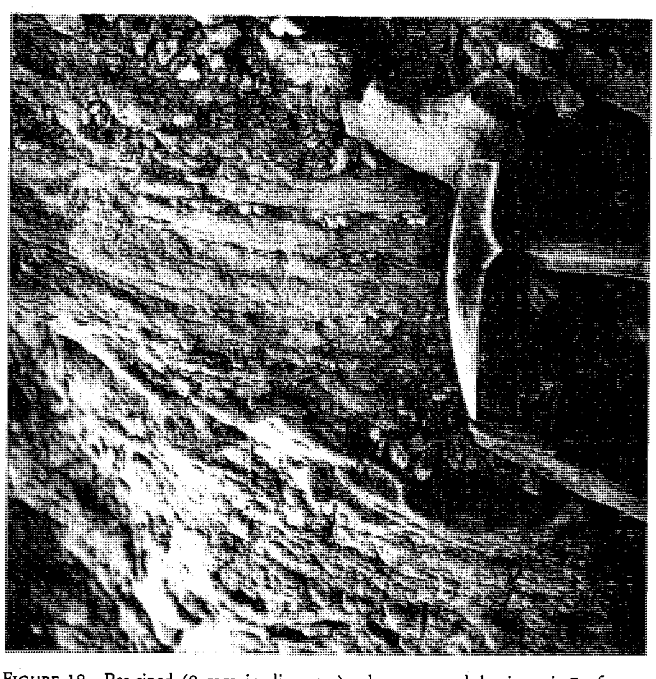


FIGURE 18.—Pea-sized (8 mm in diameter) calcareous nodules in unit 7 of section 11.

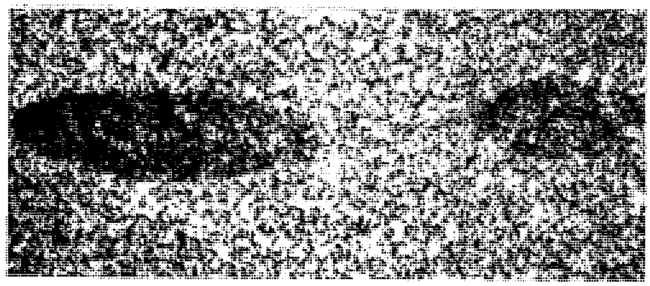


FIGURE 19.—Oblique section through a vertical burrow in unit 2 of section 25, X7.3.

Upper Sandstones

Upper sandstones are characterized by abundant trough cross-bed sets 5 cm to 1 m thick (section 11, unit 13, fig. 20). Upper sandstones were deposited by currents flowing south to southeast generally subparallel to the outcrop belt (fig. 21C). Individual cross-bed sets tend to become smaller upward, and the sandstone units become finer grained. These sandstones are light brown to light gray and weather darker. Abrupt lateral variations from light gray to light brown within a single unit are secondary. Color is possibly due to hydrocarbon bleaching of light areas.

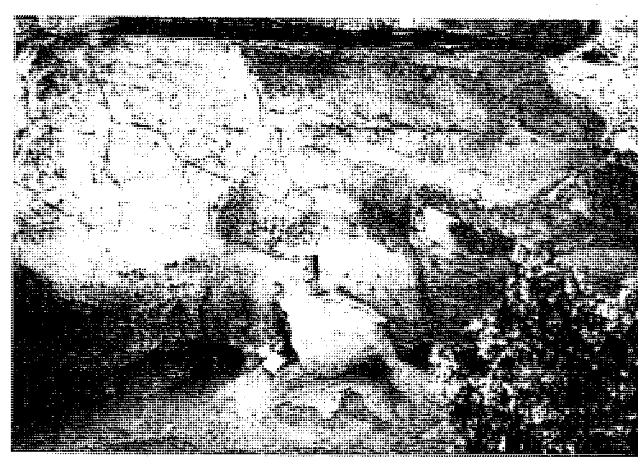


FIGURE 20.—Cross-bedding in unit 20, section 25. Cross-bed sets are about 80 cm thick. In other sections, such as in section 12, the cross-bed sets are up to 1 m thick.

These sandstones are poorly sorted and fine to medium grained, although a few beds are coarse to very coarse grained. They form cliffs and are the units that hold up the cuestas. Surficial weathering produces hexagonal patterns where jointing is prominent (fig. 22). Ironstone concretions are common and range up to 1.5 m in diameter (fig. 23). They are probably the result of precipitation of iron from iron-saturated fluids that percolated through the unconsolidated sediments (Hemingway 1968). Ammonia given off by decaying organic matter possibly assisted this process.

Ripple marks are common, as are rip-up clasts and clay pebbles. In areas where the sandstone has cut down into shale and carbonaceous shale deposits, chunks of shale have been ripped

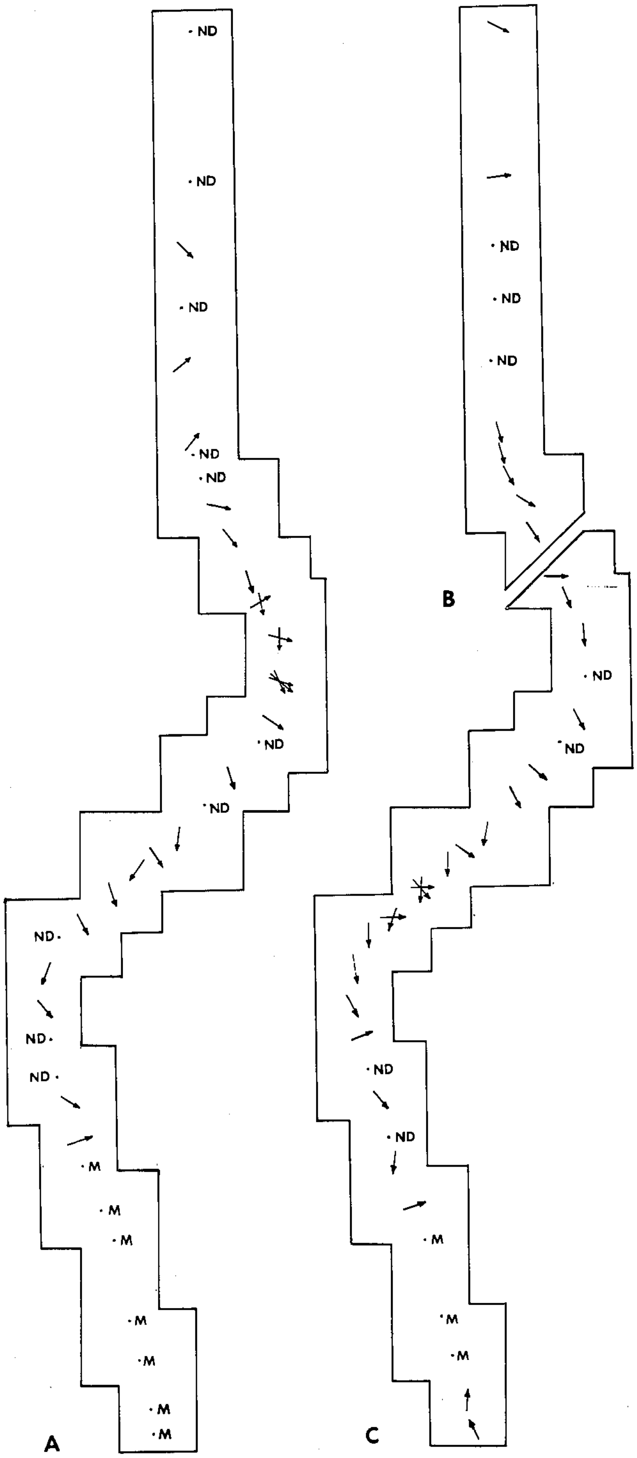


FIGURE 21.–Average current directions for, A, lower middle, B, middle, and C, upper Ferron Sandstone units. ND, no data; M, missing or buried in equivalent shale.

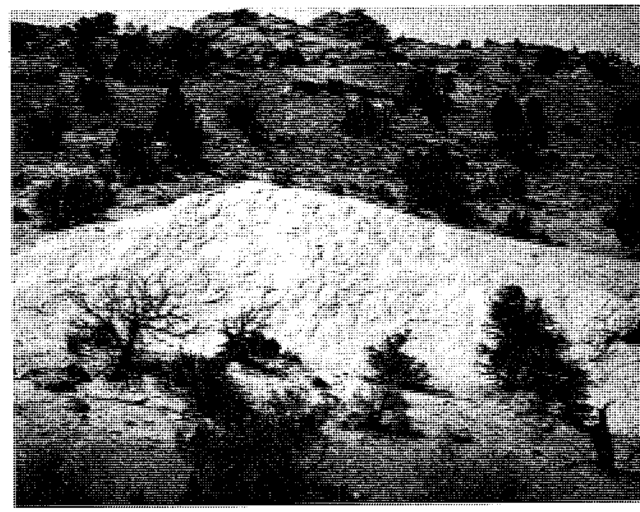


FIGURE 22.–Hexagonal patterns produced by weathering along joints in unit 38 of section 19, common in upper sandstones near Spring Canyon. Hexagons average approximately 80 cm across.

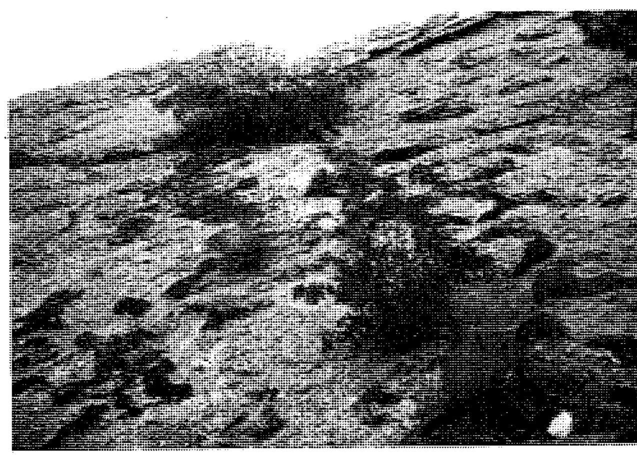


FIGURE 23.–Ironstone concretions on top of unit 13 of section 9. These concretions average 10 cm in diameter and 100 cm long, but others in the Notom area are up to 1.5 m in diameter.

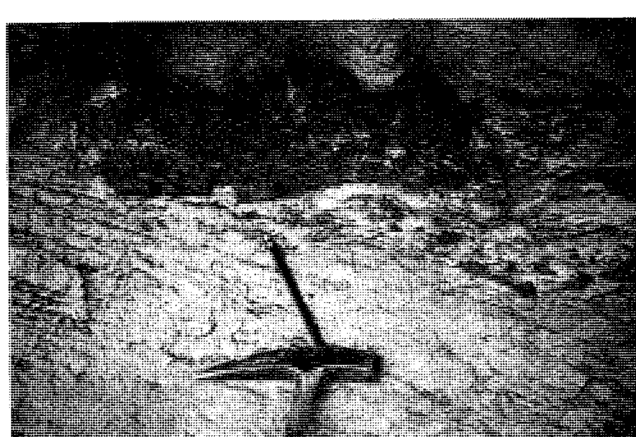


FIGURE 24.–Carbonaceous shale rip-up clast in bottom part of channel-fill sandstone of unit 20, section 25. It is 50 cm long and 15 cm wide.

up and incorporated into the bottom part of the sandstone. Most of the clasts are 1 to 3 cm in diameter, like those at the base of unit 15 in section 12, but some are up to 50 cm long and 15 cm wide, like ones in unit 22 of section 25 (fig. 24).

The basal surfaces of upper sandstone units are sharp and are convex upward (fig. 25). Such a configuration is due to fluvial erosion cutting channels into lower units. Bases of these channel fills are generally coarse- to medium-grained sandstone, which grades upward to fine- and very fine grained sandstone at the top (section 14, unit 14). In some units, such as unit 18 of section 4, this textural gradation continues upward into siltstone and silty shale (plate 1). Some channels were only 1 m deep and 15 to 25 m wide (section 6, unit 22), but some, like those in unit 13 of section 11 and unit 7 of section 24, were nearly 20 m deep and probably many hundreds of meters wide. This channeling and filling produced sandstone deposits that are somewhat sheetlike in overall view, but this sheet is actually composed of a myriad of pods and shoestringlike sandstone bodies.

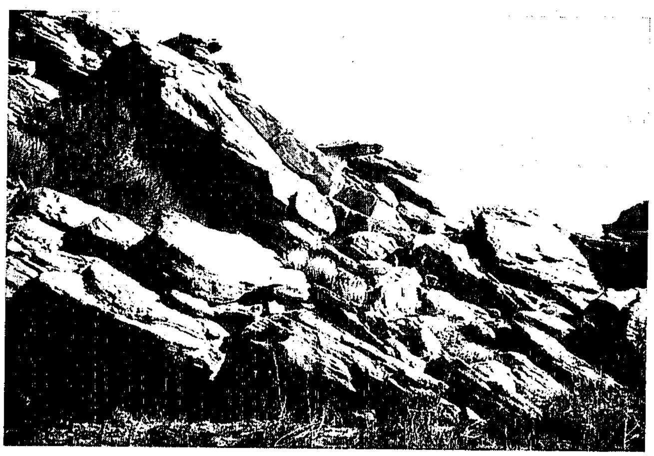


FIGURE 25.–Small channel cut into unit 19 of section 6 is 10 m wide and 1 m deep.

Laterally, the sandstone becomes finer grained and more argillaceous. Ironstone concretions become more abundant until the sandstone is limonite cemented. If beds are traced farther in the same direction, the sandstone gives way to bedded ironstone that becomes more and more calcareous away from the sandstone lenses. A similar lateral gradation was described by Uresk (1979) from upper Ferron Member deposits near Caineville, Utah. An excellent example of this textural gradation is found in section 7, unit 21, where a very fine-grained sandstone that is bioturbated and contains ironstone concretions grades through this sequence toward the north. By the time this unit reaches section 6 (unit 26), it is a thin ironstone layer (plate 1).

Upper sandstones are only rarely burrowed but are commonly rooted. Rooting locally disrupts bedding. Root impressions at certain horizons have been replaced by limonite and are etched out of the more friable sandstone, as is the case with roots found in unit 15 of section 7. In units 17 and 19 of section 25, however, roots have been carbonized and are not as prominent as those that are limonite replaced. Carbonized roots are more common throughout the entire area than limonite-replaced roots.

Upper sandstone beds also contain petrified logs, which are both limonite and silica replaced; some macerated plant debris; and a dinosaur bone.

Conglomerate

Conglomerate lenses and layers are confined primarily to the upper part of the Ferron Sandstone (section 5, unit 27, and section 24, unit 12, for example). Conglomerates appear medium orange brown on weathered surfaces because of limonitic cement. They are composed of limestone, quartzite, chert, and clay pebbles that vary in diameter from 3 mm to 5 cm. Conglomerate units are poorly sorted, cross-bedded, and generally limonite cemented or heavily iron stained. They contain wood fragments and coal clasts up to 3 cm in diameter. The beds are usually pod to shoestring shaped, commonly with a channeled basal surface. Within such units there is a tendency to fine upward from conglomerate at the base to coarse sand at the top, as in unit 23 of section 21. The beds average about 80 cm thick, with few lenses thicker than 2 m. The conglomerate lenses extend laterally for only a few tens of meters and grade into sandstone. Conglomerate grades upward into sandstone, but usually has a sharp basal contact with either sandstone or shale beds. Conglomerate units hold up ledges.

No fossils were found in any of the upper conglomerate layers, but one thin, fine-grained conglomerate lens in the middle of section 12 (unit 14) produced ten shark teeth. This lens is somewhat different in that it is only 20 cm thick and grades laterally, in a distance of 50 m, from conglomerate to shale then back to conglomerate. A thin carbonaceous shale unit just below is continuous over the entire distance.

Conglomerate also occurs within sandstone units as thin layers at the bases of individual cross-beds. A good example of such a pattern occurs in unit 15 of section 12. The bed grades upward into sandstone, but the next cross-bed set above abruptly truncates it.

Some of the limestone pebbles in the conglomerate contain crinoid fragments and certainly were derived from erosion of late Paleozoic rocks. One chert pebble was collected and sectioned that contains abundant sponge spicules, again indicating a probable late Paleozoic source.

PALEONTOLOGY

The Ferron Sandstone has a varied flora and fauna but is not abundantly fossiliferous. Bivalves, gastropods, and a few ammonites have been reported from several outcrops in the Castle Valley area. Spieker and Reeside (1925) list the ammonoids *Scaphites, Prioncyclus, Priontropis* and the oysters *Ostrea,* and *Inoceramus* from the Ferron Sandstone. Katich (1953) also reported ammonoids in the Ferron Sandstone. Balsley and Stokes (1969) briefly describe some unusual coprolites from the member. Cleavinger (1974) identified the gastropod *Turritella*; the bivalves *Corbicula, Corbula,* and *Cardium*; the formanifera*Nodosaria, Frondicularia,* and *Lenticulina*; and the trace fossils *Ophiomorpha, Thalassinoides, Teichichnus,* and *Scolicia* from the Ferron Sandstone near Interstate 70 on the western flank of the San Rafael Swell. Cotter (1975) reported these same trace fossils and, in addition, *Rosselia* and two forms of *Teichichnus.* The only foraminifer reported from the Ferron Member by Maxfield (1976, p. 79) is *Planulina.*

The only fossils previously reported from outcrops of Ferron Sandstone in the Henry Mountain Basin are *Inoceramus* molds and petrified wood (Hunt 1953). Uresk (1979) reported finding petrified wood, fish scales, and a single shark tooth in slope debris from the member in outcrops along Utah 24.

Only two beds in the present study are fossiliferous: unit 3 of section 11 and unit 8 of section 19. Unit 3 of section 11, a delta-front sandstone, contains the bivalves *Inoceramus, Granocardium, Crassatella* (?), *Corbula* (?), and *Corbicula* (?); the gastropods *Turritella* and *Collonina* (?); an acteonid gastropod; the ammonite *Prioncyclus*; and an irregular echinoid (fig. 26). The fossiliferous bed in unit 8 of section 19, a silty shale layer in a

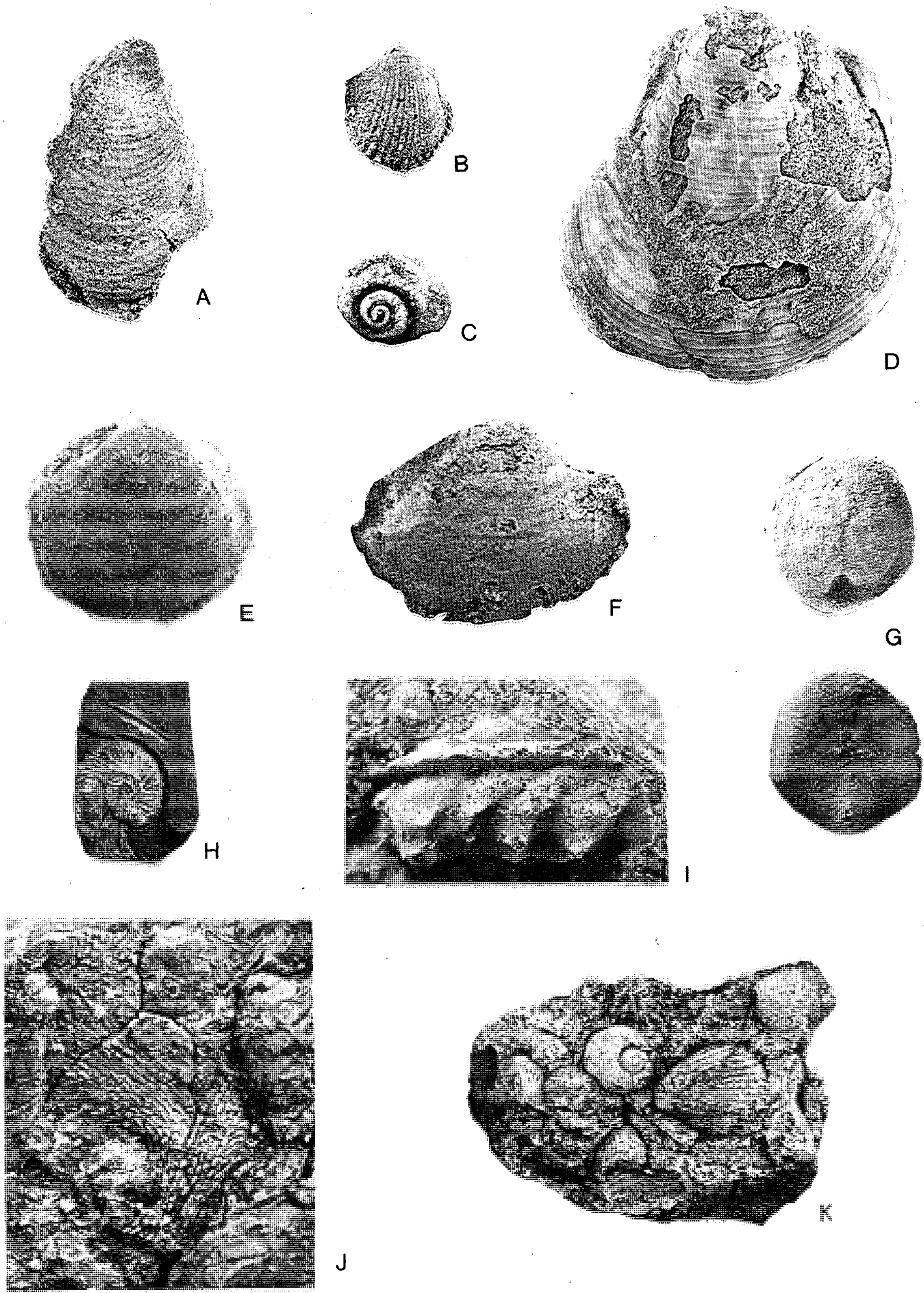


FIGURE 26.–Invertebrate fossils: A, *Inoceramus* sp., BYU 2874, from unit 3, section 11, X2; B, *Granocardium* sp., BYU 2873, from unit 3, section 11, X2; C, *Colonina* (?) sp., BYU 2876, from unit 3, section 11, X3; D, *Inoceramus* sp., BYU 2875, from unit 5, section 23, X1; E, *Corbula* (?) sp., BYU 2872, from unit 3, section 11, X2; F, *Corbicula* (?) sp., BYU 2871, from unit 6, section 10, X2; G, irregular echinoid, BYU 2879, from unit 3, section 11, X2; H, *Prionocyclus macombi* Meek, BYU 2878, from unit 8, section 19, X2; I, *Prionocyclus macombi* Meek, BYU 2877, from unit 3, section 11, X2; J, probable anascan cheilostome bryozoan, BYU 2880, from unit 8, section 19, X5; K, portion of unit 3, section 11, showing disoriented relationship of fossil assemblage, BYU 2881, X2.

prodelta sequence, contains *Inoceramus, Prioncyclus,* a cheilostome bryozoan (figs. 26J and 27), and fish scales. Identifying some of the bivalves is difficult because the shell has weathered away in many, leaving only crude casts and molds.

Granocardium and *Corbicula* (?) were found in unit 6 of section 10. Abundant shark, skate, and sawfish teeth were recovered from the basal sandstone units of sections 19–22, such as units 3 and 5 of section 20. The teeth represent at least four and possibly six genera including *Enchodus, Otodus, Ptychodus, Squalicorax,* and less certainly *Sclerorhynchus* (?) and *Lamna* (?) (fig. 28). The largest tooth is 2.4 cm long, and the smallest is 1 mm long. Shark teeth found in unit 14 of section 12 represent only two genera, *Enchodus* and *Otodus.*

The flora that grew on the Notom delta must have been abundant and varied, but few identifiable plant fossils were found. Macerated plant debris and fragments are abundant in nearly every unit of the Ferron Member, but the only specifically identifiable leaves are of *Cercidiphyllum articum* (fig. 28I). An unidentified dinosaur bone (fig. 29) was found associated with plant debris in unit 22 of section 25.

Trace fossils are common throughout the Ferron Member, but are most abundant in the lower sandstones. No detailed study of the trace fossils was made, but different types were noted, including *Ophiomorpha, Thalassinoides, Teichichnus,* and some possible *Scolicia. Ophiomorpha* burrows were found in the clean distributary mouth bar and distributary channel sandstones. The other traces were found primarily in what are interpreted to be distal sandstones and bar-finger sandstones.

An attempt was made to find time-definitive foraminifera or other fossils from the basal Bluegate Shale. Only a tiny gastropod protoconch and a minute *Gyroidina globosa* were found in unit 27 of section 7. The latter ranges throughout the Tununk Shale and Bluegate Shale Members. A possible ostracode was found in the uppermost Tununk Shale of unit 1, section 11.

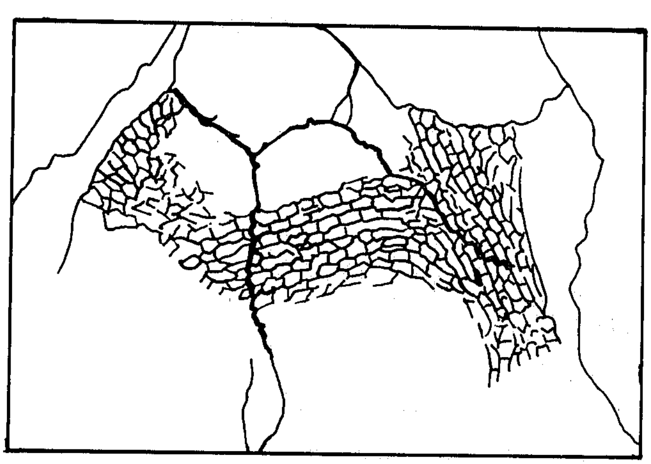


FIGURE 27.–Probable anascan cheilostome bryozoan, BYU 2880, from unit 8, section 19, X7.5.

The Ferron Sandstone of Castle Valley is of middle to late Turonian age, as determined by Katich (1953) and Maxfield (1976), among others. *Prioncyclus macombi* (figures 26H and 26I) from unit 3 of section 11 and unit 8 of section 19, in the lower Ferron Member, indicates an early late Turonian age for those rocks.

Both Ryder (1975) and Maxfield (1976) indicated that a major unconformity exists above the Ferron Sandstone, below or within the lower Bluegate Shale. Ryder (1975, p. 1255) noted that a basal coarse conglomerate bed, up to one foot thick, occurs in the vicinity of this unconformity in the area around Swap Mesa. Lenticular conglomerate occurs at the top of a few measured sections, but there is no evidence of a widespread conglomerate at the top of the Ferron Sandstone or in the basal part of the Bluegate Shale in the western outcrop belt of the Henry Mountain Basin.

DEPOSITIONAL SIGNIFICANCE

The Ferron Sandstone exhibits an overall coarsening upward pattern, from the fine-grained upper Tununk Shale up to conglomeratic sandstones near the top of the sequence. Fossils in the lower part of the member are marine, and those at the top are generally freshwater or terrestrial. This distribution, when combined with geometry, trends, and patterns of the sandstone bodies, indicates that the Ferron Sandstone was deposited as a delta complex in a shallow sea. Lessard (1971) states that the Mancos Sea was from 90 to 180 m (300 to 600 ft) deep. Thickness, depth of entrenchment, and lateral facies relationships suggest that it was certainly no deeper than that and was possibly much shallower where this part of the Ferron Member was deposited. A maximum depth of about 20 to 25 m (65 to 80 ft) was determined by thicknesses of distributary channels and the depth they cut into delta-front sediments.

Tununk Shale

Cleavinger (1974), Cotter (1976), Hale (1927), Maxfield (1976), and others consider the Tununk Shale to be a shallow marine deposit. Evidence gathered in this study reaffirms this conclusion. Gray thinly laminated shales containing marine fossils and parallel-crested ripple marks in siltstone layers indicate a shallow marine environment. Articulated shells of *Ostrea* and *Inoceramus* were recovered from the shale, but they came from the middle of the Tununk Member. A few poorly preserved leaves were found immediately beneath the Ferron Sandstone in section 5, unit 1. The increase upward of silt, sand, and plant debris reflects the increasing proximity of the area to the advancing delta front. Parallel-crested ripple marks occur in thin siltstone layers within the upper part of the Tununk Shale. According to Donaldson and others (1970), they indicate a shallow depth and reworking of bottom sediments by wave action. Burrows are rare in the shale, and evidence of bioturbation is almost nonexistent. The uppermost siltier part of the Tununk Shale is considered here to represent deposits gradational from open marine into a prodelta environment.

Ferron Sandstone

Mudstone

The Tununk Shale grades into the mudstone layers which in some places are very silty. The mudstones, such as those in units 1 and 2 of section 11, are interpreted to be prodelta sediments because they are gray, thinly laminated, silty shales with abundant plant debris, but more importantly because of their vertical and lateral relationships to shale, siltstone, and sandstone in the coarsening-upward sequence. The mudstones lie immediately below delta-front sandstones and above bay or open marine shales. Similar relationships were described by Donaldson and others (1970) in the modern Guadalupe Delta of Texas.

Calcareous Mudstone

Calcareous mudstone layers, such as in unit 2 of section 27, are thin deposits of a relatively quiet-water environment of the

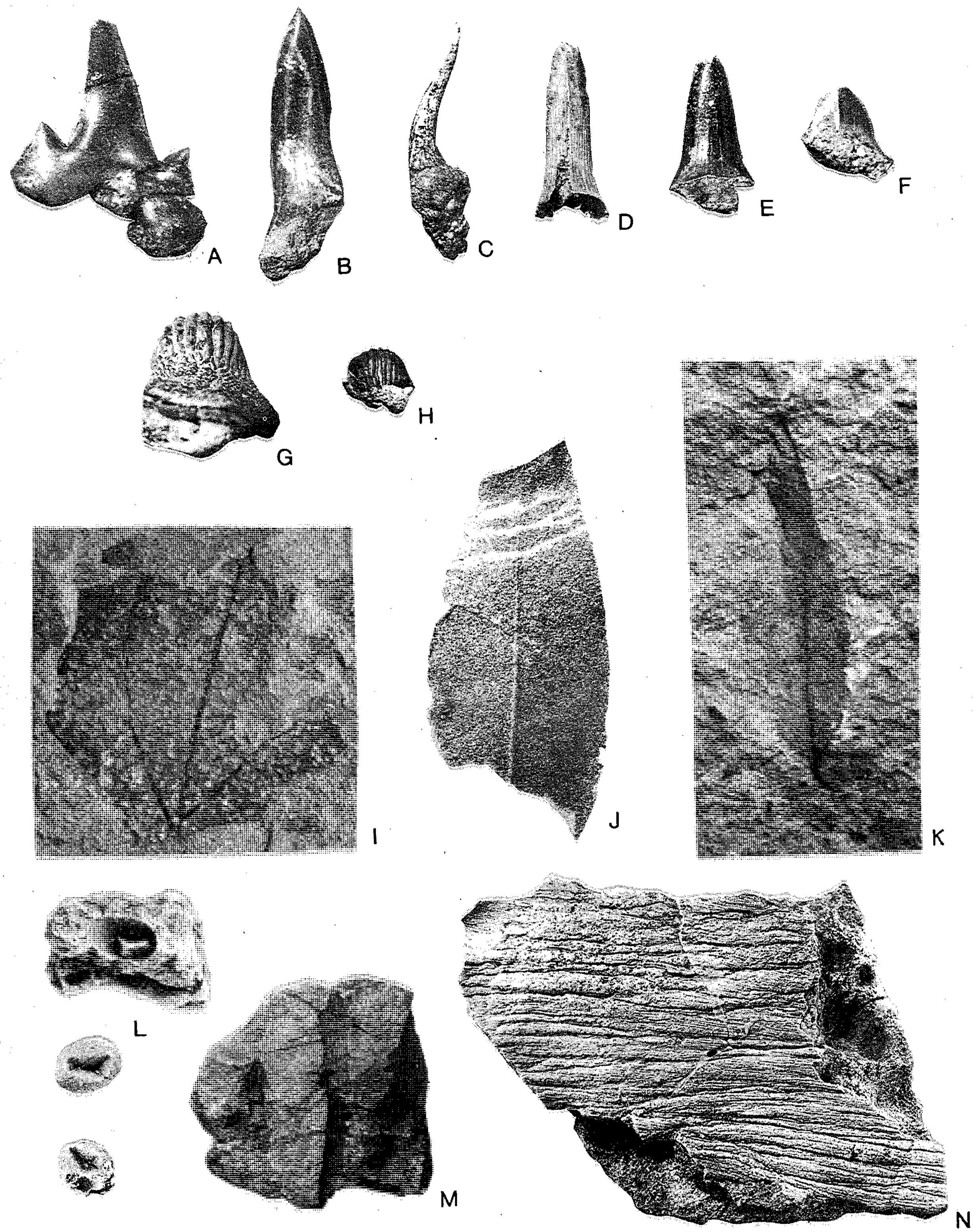


FIGURE 28.–Vertebrate and plant fossils: A, *Otodus* sp., BYU 2882, from unit 6, section 22, X2; B, *Sclerorhynchus* (?) sp., BYU 2884, from unit 5, section 19, X2; C, *Enchodus* sp., BYU 2885, from unit 6, section 20, X2; D, *Enchodus* sp., BYU 2886, from unit 14, section 12, X2; E, *Otodus* (?) sp., BYU 2883, from unit 14, section 12, X2; F, *Squalicorax* sp., BYU 2887, from unit 6, section 20, X2; G, *Ptychodus* sp., BYU 2888, from unit 5, section 19, X2; H, *Ptychodus* sp., BYU 2889, from unit 6, section 20, X2; I, *Cercidiphyllum articum,* BYU 2890, from unit 1, section 5, X1.5; J, *Salix*-like leaf, BYU 2891, from unit 1, section 5, X2; K, *Salix*-like leaf, BYU 2898, from unit 4, section 11, X2; L, possible seeds, BYU 2893, from unit 3, section 11, X2; M, limonite-replaced root trace, BYU 2894, from unit 15, section 7, X1; N, wood cast, BYU 2895, from unit 48, section 19, X0.5.

FIGURE 29.—Unidentified dinosaur bone in channel fill sandstone of unit 20, section 25. It is 27 cm long, 9 cm wide tapering to 6 cm, and the condyle is approximately 3 cm high. May possibly be part of a neural spine from a sauropod.

prodelta. The relative absence of silt, the lateral relationship of the mudstone to ironstone beds, the calcareous nature, and general lack of sedimentary structures indicate a quiet-water interpretation. The calcareous mudstone probably accumulated in a protected area between distributaries.

Siltstone

Siltstone beds in the lower part of the Ferron Member are highly bioturbated and deformed layers. They contain ripple marks and tool marks (section 18, unit 8), indicating that water movement was relatively vigorous. Bivalves in these layers (section 9, unit 7), along with associated glauconite, indicate that these beds were still deposited under primarily marine influence. Some of the bivalves are articulated, and others are disarticulated. Ripple-bedding and plant debris are common in these layers. These beds thin seaward and thicken and coarsen toward distributaries. Unit 3 of section 10 is a good example. In some areas the siltstone is overlain by distributary mouth bar sandstone (section 9, unit 8). All this evidence indicates these siltstones are probably distal delta-front deposits, seaward of distributary mouth bars.

Donaldson and others (1970) describe sandy siltstone, pod-shaped, ripple- and tool-marked deposits, similar to Ferron units that contain abundant burrows and plant debris, as being deposited in a tidal channel that connected a lake to an interdistributary bay. In areas where ripple marks and tool marks are particularly abundant, as in unit 6 of section 17, a similar interpretation may be correct for the Ferron beds.

Shale

Two prominent, laterally continuous shale beds (units 3 and 6 of section 10, for example) can be identified in nearly every section of the lower part of the Ferron Sandstone (plate 1). These beds are almost identical to beds of the upper Tununk Shale except that they are somewhat siltier. Bivalves, ammonites, leaves, and a bryozoan have been recovered from these shales. They are interpreted to be deposits of two episodes of shallow marine transgression when delta deposition shifted elsewhere. Such a shift could have been a response to abandonment of a delta lobe and subsequent subsidence of the area. Parker (1956) describes similar deposits from the Mississippi River Delta as typical of the outer marine shelf part of the delta.

Lower Sandstones

Lower sandstones are divided into two groups, cross-bedded and horizontally bedded. Cross-bedded lower sandstones are interpreted to be distributary mouth bars. They grade into the horizontally bedded sandstones that are interpreted to be delta front sandstones, including distal bars, and bar finger sandstone. The description of delta front deposits by Reineck and Singh (1973) fits these sandstones almost perfectly. Evidences for such a conclusion, in addition to gross geometry, cross-bedding and ripple marks, are that soft-sediment deformation is common at the base of all such units (fig. 30), and basal surfaces are gradational to sharp and are convex upward in the vicinity of distributaries. Bivalves, ammonites, gastropods, and an echinoderm, found in unit 3 of section 11, and large burrows, such as those in unit 13 of section 34, indicate a marine association for these deposits. Plant debris is abundant, and occasional wood fragments are rounded. Faunal remains are sparse in the immediate vicinity of distributaries.

FIGURE 30.—Ball-and-pillow type soft-sediment deformation in unit 3, section 9. Such structures are in lower sandstones in the Notom area.

A sandstone unit, 0.5–1.5 m thick, in the basal part of the Ferron Member between Spring Canyon and Divide Canyon is believed to be a distributary mouth bar. The sandstone is medium grained, fairly clean, and cross-bedded. It also contains abundant shark teeth and sawfish teeth. Shale above it contains ammonites and bivalves.

Shale-Siltstone

Shale and siltstone are interbedded with sandstone and coal in the upper part of the member. Uresk (1979) described similar upper beds of the Ferron Sandstone near Caineville as deposits of interfingering channels, natural levees, lakes, interdistributary bays, and swamps. The same interpretation applies to upper rocks in this area. Shales are representative of lacustrine and interdistributary bay environments. The gradual change upward from greenish brown shale to gray shale, as described previously from section 2, indicates a shift from lacustrine to marine-dominated conditions. Vertical and lateral sequences, described above, represent changes in environments where distributary channels built out into previously low backswamp, lacustrine, and bay areas, but then shifted to other areas, allowing backswamp conditions to develop again. Vertical sequences, such as in unit 22 of section 1, are interpreted to represent shifts from carbonaceous marshy conditions to shaly lacustrine or bay conditions, then back to marsh conditions again (plate 1).

Evidences to indicate that darker shales are marine dominated are their gradational basal contact, lenticular and parallel bedding, local bioturbation, and ripple marks in some of the siltstone lenses.

More evidence supporting the interpretation that the lighter colored shales are lacustrine includes a gradational base, siltstone lenses, and only very few burrows, but more importantly, the lateral stratigraphic relationships. Ironstone beds, often found associated with these shales, are interpreted to be marginal lacustrine deposits that grade laterally into limonite-cemented sandstone (backside of the levee), to sandstone with ironstone nodules (natural levee), and finally into distributary channel-fill sandstone. Uresk (1979) described similar facies changes in the upper Ferron Sandstone near Caineville, and Hemingway (1968) mentioned similar relationships in coal-bearing areas.

Ironstone accumulations may result when iron colloid-laden fresh water interacts with marine to brackish water (Krauskopf 1967, p. 261). The iron precipitates from solution as hydrous ferric oxide, then later may be reduced to ferrous iron on contact with organic matter in or near the bottom sediments. Bacteria may also be major agents in precipitation of iron.

Coal and Carbonaceous Shale

Coal was a product of a swamp environment, the plants of which are recorded by an abundance of leaves and leaf debris. Swamps that existed during deposition of the Ferron Sandstone were probably populated by conifers, palms, ferns, and angiosperms, judging from recovered fossil plant fragments. According to Tidwell (1975), such an assemblage is typical of Upper Cretaceous swamp environments.

The highly reducing nature of the swamp is indicated by the high (2%) sulfur content of the coal. The swamps occasionally experienced minor influxes of sediment, as recorded by the silty laminations common in coal seams. Conditions on the delta plain were not stable since only minor thicknesses of coal accumulated. Thickest accumulations of coal (greater than 1 m) occur between Spring Canyon and Divide Canyon, such as in unit 20 of section 21. Coal is often underlain or overlain by layers of carbonaceous shale or sandwiched between them. The carbonaceous shale represents an environment on the fringes of the swamp which had a moderate influx of silt and sand.

Upper Sandstones and Conglomerates

Channel fills, as seen in section 1, units 12 and 15, and point-bar sequences, an example of which is in section 11, unit 13, are quite common in upper sandstone (fig. 31). These units are interpreted as fills of distributary channels and meandering streams, and as natural levees. Evidence for this interpretation is their eroded bases, large trough cross-beds, sharply convex-upward basal surface, general fining-upward textural gradation, ripple marks, clay clasts, and the shoestring geometry of many of the units. Plant debris, petrified wood, and a dinosaur bone were found in upper sandstone units. Rarely, as in unit 25 of section 25, the cut bank of a stream channel is preserved, and the lateral relationship of channel to natural levee is readily apparent. Scour-and-fill structures (section 12, unit 17) and load casts (section 19, unit 24) can be seen in some of these sandstone units.

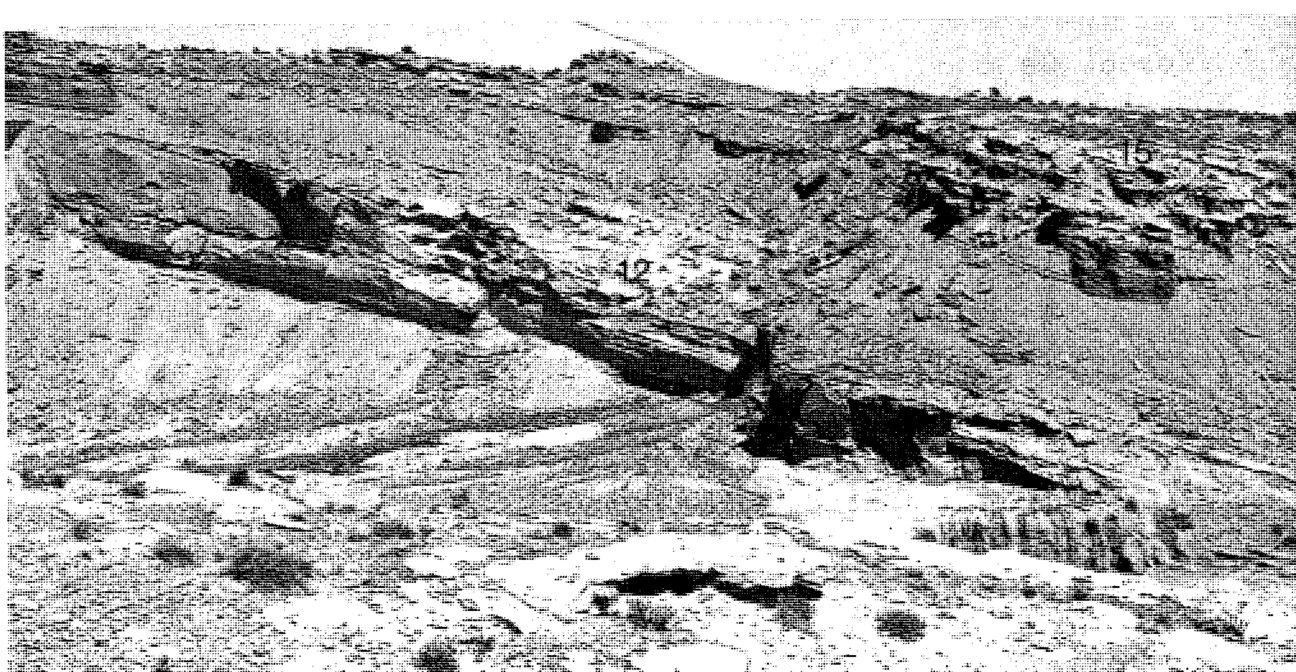


FIGURE 31.–Channel fills in section 1. Lower, unit 12; upper, unit 15. Similar channel fills are common in upper sandstone units.

Laterally the porous channel-fill sandstones grade into natural levees (unit 15 of section 7 is a good example). The levees are generally finer grained, with more clay, and are less porous. Common rooting and local bioturbation distinguish them from the channel fills.

One carbonized root trace in a fine- to medium-grained, moderately well sorted sandstone of unit 14, section 9, was found in contact with a quartzite pebble 5 cm long and 2.3 cm in diameter. The pebble was probably lodged in the roots of a tree that floated downstream and became incorporated in the sediments near the mouth of a distributary. Except for this one root, this sandstone unit contains no root impressions.

Some of the upper coarse sandstone and conglomerate units are interpreted as wave-reworked barrier-island or barrier-beach deposits, much like the Chandeleur Islands of the modern Mississippi River Delta. These clean, moderately well to moderately poorly sorted sandstones and conglomerates are interpreted as a result of waves reworking sediments of an abandoned delta lobe. Such deposits in this area are indicative of the final subsiding and destructional phase of the Notom delta.

DEPOSITIONAL HISTORY

From Late Jurassic until Late Cretaceous western Utah underwent the Sevier orogeny. During Late Cretaceous time the area which now includes much of the Colorado Plateau and a broad region to the southeast and north continued to subside, allowing the Mancos Seaway to form from the Arctic Ocean to the Gulf of Mexico. Material shed from the Sevier orogenic belt during the Late Cretaceous was deposited along the western margin of part of this shallow seaway, locally producing lobate deltas. The Ferron Sandstone represents one of several of these coarse clastic deltaic pulses into the Mancos Sea.

The Notom delta is but one of several deltaic lobes that make up the Ferron Sandstone and roughly equivalent units (fig. 32). It is a birdfoot delta much like the Last Chance delta, but it experienced less reworking of the sediments by wave action during building phases than equivalent systems to the north. The Notom delta extends from near the southern edge of the San Rafael Swell, on the north, to approximately 8 km south of Bitter Creek Divide, on the south, and covers the northern three-fourths of the Henry Mountain Basin. It built south and eastward into the shallow Mancos Sea in six phases.

The first phase of delta building is most evident in the outcrop belt between Spring and Divide Canyons (fig. 33). The subaerial part of the delta did not reach this far during this phase, but distributary mouth bars did accumulate in the area. They contain shark teeth, as in section 21, unit 2, for example. These medium-grained to conglomeratic sandstones are sandwiched between two thick marine shale units, indicating that the delta built into that area for a short time, but then ceased (plate 1). The main body of the delta was still far to the northwest.

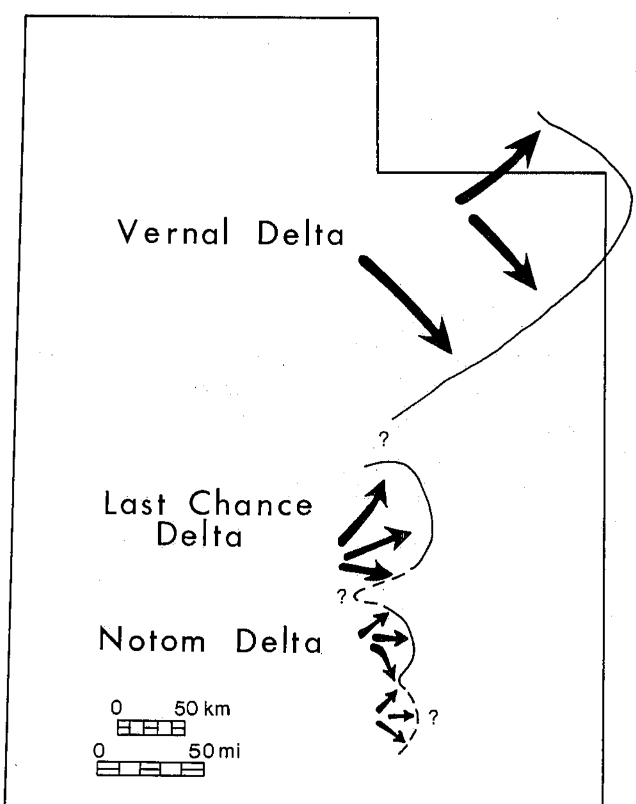


FIGURE 32.–Relationship of Notom delta to other delta lobes of the Ferron Sandstone and roughly equivalent units (after Cotter 1976).

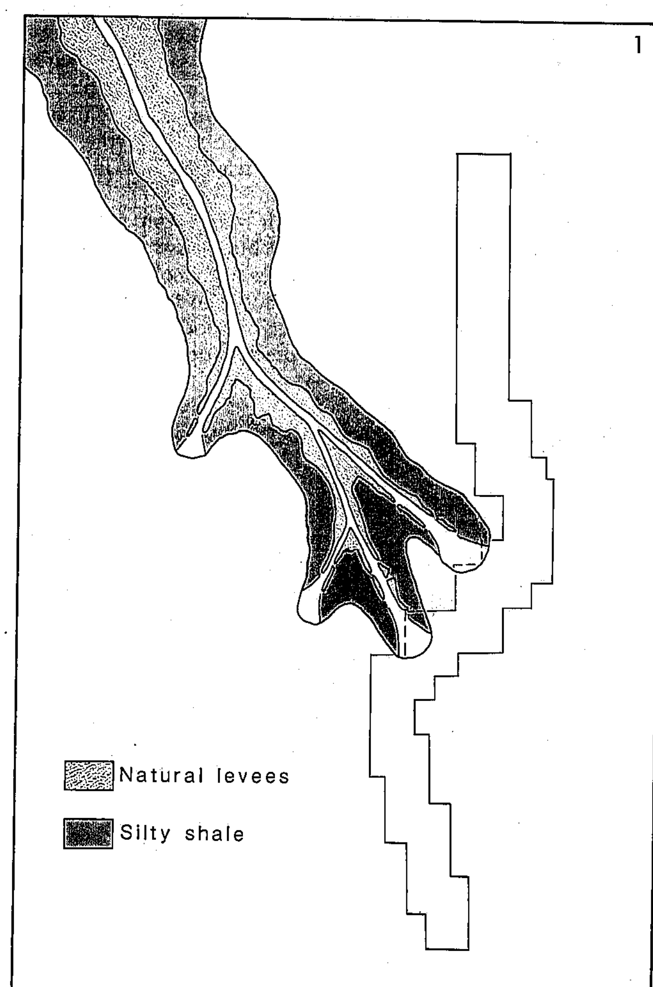


FIGURE 33.–Schematic diagram of delta deposition during phase 1; distributary mouth bars were produced in the area between Spring Canyon and Divide Canyon.

Following a period of little sedimentation, delta building recommenced as phase 2 and concentrated sandy and silty deposit in the area between sections 5 and 16 (fig. 34). During phase 2, distal delta-front sand, distributary mouth bars, and occasional distributary channel fills accumulated up to 11 m thick, as in section 8, units 2 through 7. Several beds of varying lithology thus accumulated during this phase when smaller distributaries built first in one direction, then another, then back again. A good example of such shifts occurs in outcrops between sections 9 and 11 (plate 1). A small distributary built eastward toward section 10, with the delta prograding far enough that a distributary mouth bar accumulated in the section 10 area before the stream shifted. The bar is well shown in unit 2 of section 10, where it is cross-bedded and burrowed. The bar sandstone extends laterally northward to section 9, unit 2, and southward to section 11, units 2 and 3, where the sandstone is burrowed and ripple marked and contains abundant bivalves and gastropods, and the sediment is deformed. The distributary was abandoned, and a short period of marine shale deposition followed (section 9, units 2–3; section 10, unit 3; and section 11, unit 4).

Another distributary started emptying into this area following the brief marine interlude. This stream formed a distributary mouth bar centered in section 11 (unit 5) and extended laterally northward to section 10. The last part of that bar is the upper beds of unit 3 of section 10.

Still another small distributary bar was later deposited in the same area as units 6 and 7 of section 9. These units are cross-bedded. The bar extends northward and grades into a sandstone that contains bivalves and burrows in unit 5 of section 10. Donaldson and others (1970, p. 116) described lateral change from a cross-bedded or burrowed sandstone, lacking fossils, to one that is burrowed with abundant fossils as typical of distributary mouth bars in the Recent Guadalupe Delta of Texas. Similar lateral change in sandstone character is common throughout the lower part of the Ferron Member in deposits of phase 2. Transport directions during this interval were generally toward the east and southeast. Phase 2 deposition was terminated, and marine conditions prevailed for a short time when a thin marine shale and siltstone were deposited.

Phase 3 began as a main distributary shifted back toward the south again (fig. 35) and deposited a delta lobe farther southeastward than those of phase 2. The subaerial part of the later delta just reached the area represented by outcrops between sections 17 and 24 in the vicinity of Spring Canyon. Distributary channels and channel fills are prominent in these sections (fig. 36), where they cut down into delta-front sediments such as seen in units 12 through 15 of section 21.

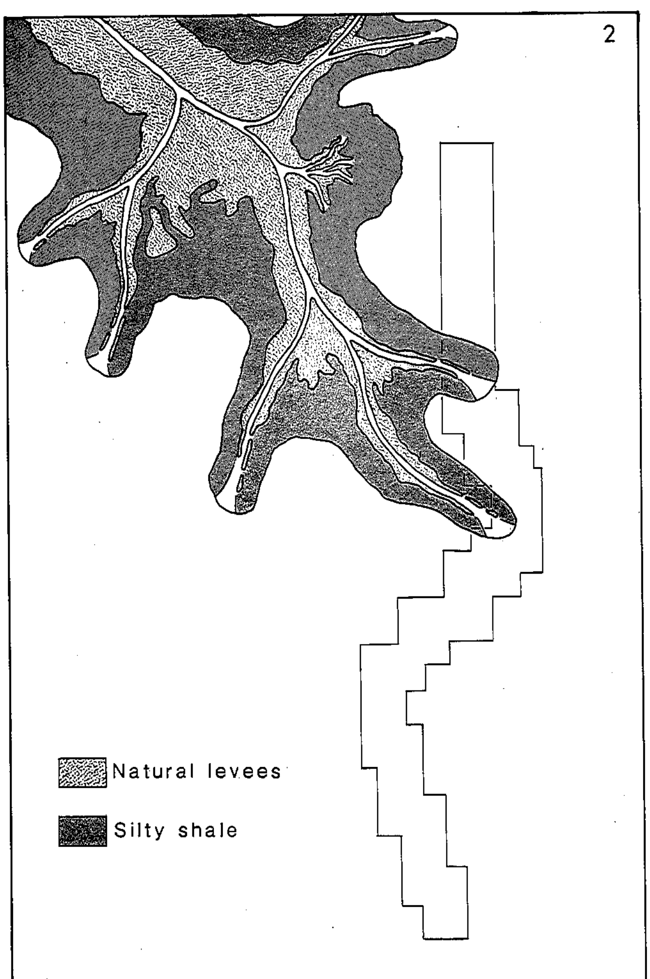


FIGURE 34.–Schematic diagram of delta deposition during phase 2. Delta-front deposits accumulated between sections 5 and 16.

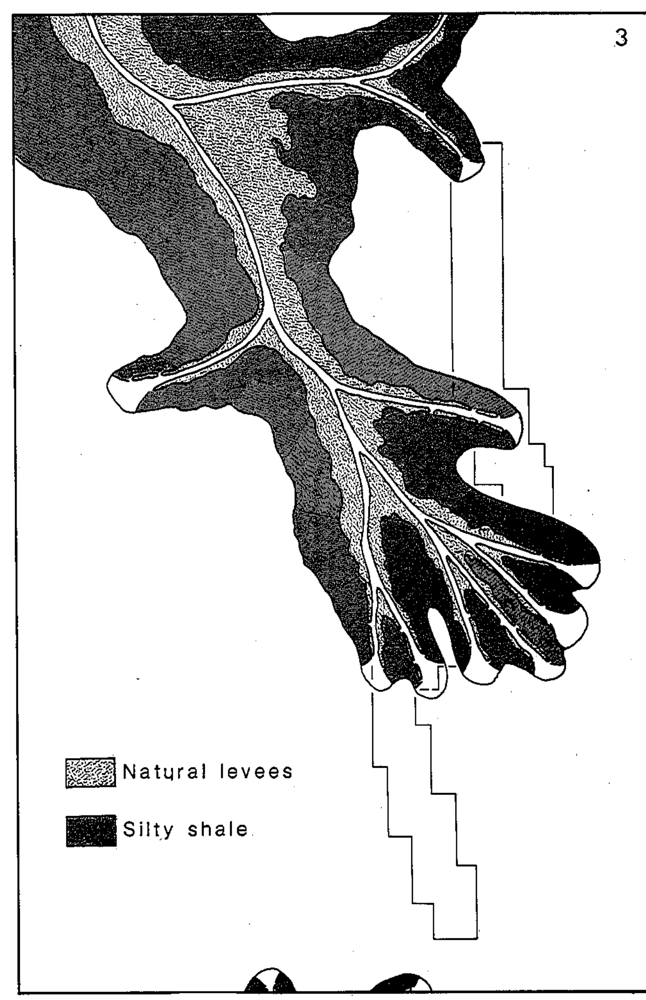


FIGURE 35.–Schematic diagram of delta deposition during phase 3, which produced distributaries that extended over the area between sections 18 and 25.

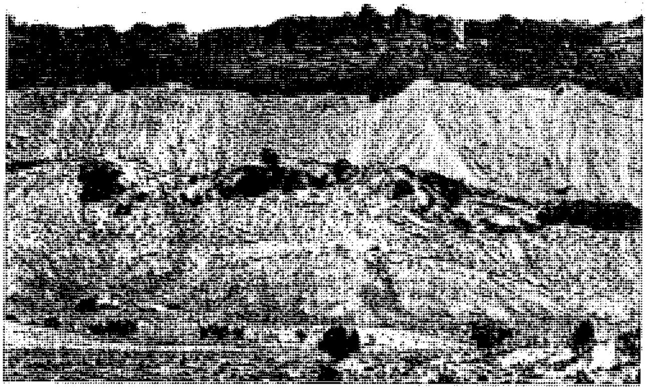


FIGURE 36.–Distributary channel-fill sandstones cut down into delta-front deposits (section 21). Channel fills are approximately 16 m thick.

A good example of the accumulated vertical sequence is represented in sections 21 and 22 (plate 1). After deposition of thick marine shale represented in these more southern sections, the area became the site of a rapidly prograding delta. The section grades up from prodelta clay (section 21, units 3–9, and section 22, units 5–10), to distal delta-front sand and distributary mouth bars (section 21, units 10–12, and section 22, units 11–21), and finally to channel-fill sandstone.

Such a section is a typical coarsening-upward sequence of a delta, as described by Gould (1971, p. 17–28) for the Mississippi Delta. Much of the upper part of this gradational sequence is missing in section 21 (units 13–15) because a major distributary channel cut through the area. Sandstone in the latter channel fill is 16 m thick and cuts down through most of the prograding section. Four such major channels are recognizable in deposits of phase 3 now exposed in the cuesta face (fig. 36).

At this same time another delta lobe was building eastward and northeastward south of the Notom delta. Sandy siltstone and very fine grained sandstone were deposited in this more southern delta, but there was limited interaction between the two during this third phase of Ferron Sandstone deposition.

Deposits of these first three phases or pulses of sedimentation laid the foundation for the Notom delta to prograde rapidly southeastward over the whole area during phases 4 and 5. Northern sections, which were relatively unaffected by coarse clastic sediments during phase 3, began to experience rapid sedimentation during phase 4, similar to that documented in southern sections for phase 3. During phase 4 the major Notom delta continued to prograde southeastward until the subaerial part covered much of the outcrop area (fig. 37) from Notom southward to near Bitter Creek Divide.

Typical lower delta plain features, such as natural levees, distributary channels, swampy areas, lagoons, and interdistributary bays, are documented by upper Ferron rocks. The relationships are particularly well documented in sections 6 and 7 (units 10–22 and units 7–15, respectively) both vertically and laterally (plate 1). After buildup of delta-front sandstone, deposits of channels and associated environments of the delta plain accumulated.

Excellent examples of gradation from channel fill to natural levee, to backswamp, then back to channel fill again, occur in sections 6 and 7. The channel fill in section 6, unit 14, is overlain by fine-grained, limonite-cemented sandstone of the natural levee (unit 15), which grades into siltstone and silty shale

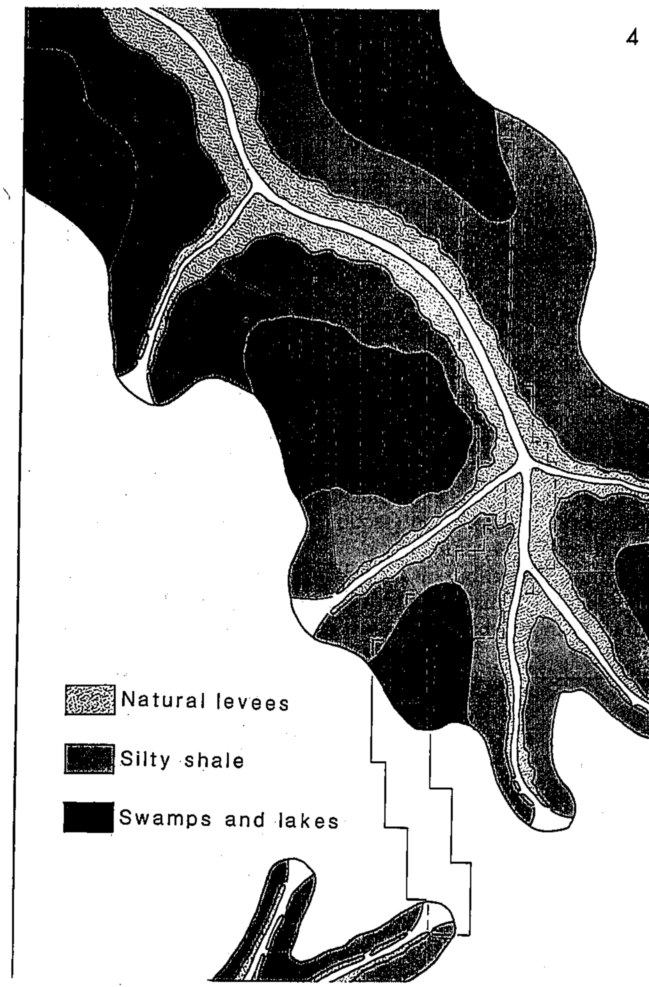


FIGURE 37.–Schematic diagram of delta deposition during phase 4, when lacustrine shale and distributary sandstone deposits accumulated.

(unit 16) and coal (unit 17) of the backswamp. The rocks grade rapidly back into sandstone of a natural levee (unit 18) and finally into another channel fill (unit 19) on top of the coal. A similar depositional sequence occurs in units 11–15 of section 7. The basal surface of these channels is sharp, and oftentimes the channels were cut down into the natural levee and backswamp deposits and incorporated chunks of these sediments in the basal part of the fill (fig. 38).

Phase 4 is characterized by repeated similar sequences. Minor variations were produced here and there as distributaries shifted over the delta surface. The pattern seems to have been one of buildup of high, leveed stream courses by the distributaries then a shift into adjacent low backswamp areas, which were then built up until the distributary shifted into another low area.

During phase 4 the Notom delta began to interact with the delta to the south. They began to influence the same intermediate area with alternating periods of deposition one on top of the other which produced herringbonelike cross-beds in some of the delta-front sandstones (section 37, unit 9).

Phase 4 continued uninterrupted into phase 5, and the boundary between the two is somewhat arbitrary. They are generally separated at the base of the first significant lacustrine

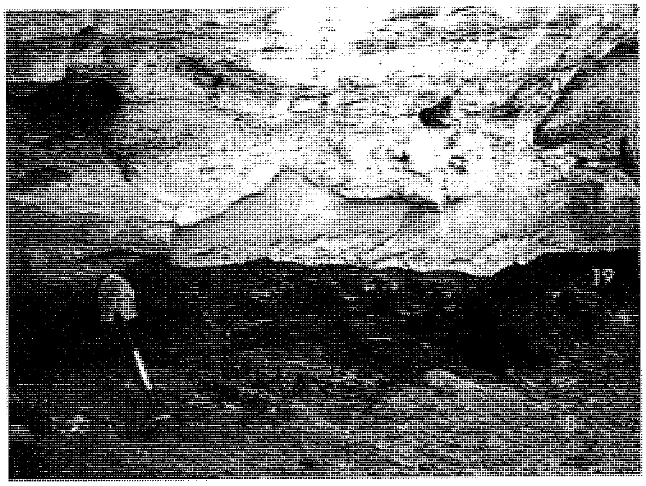


FIGURE 38.–Channel of unit 20, section 25, cut down into carbonaceous shale of unit 19 and incorporated chunks of the shale in the basal part of the channel fill, causing an irregular basal surface.

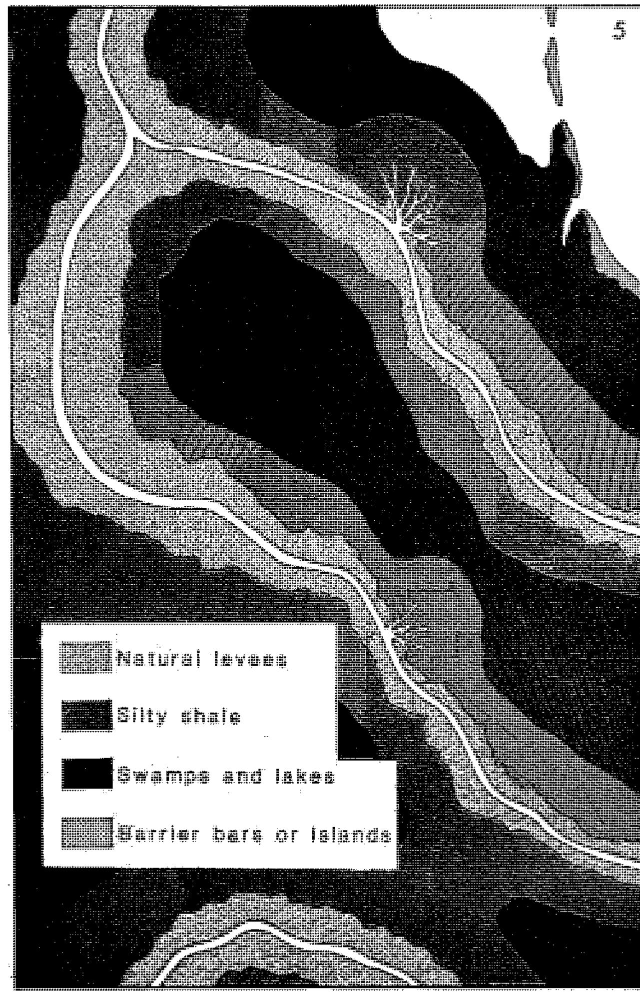


FIGURE 39.–Schematic diagram of delta deposition during phase 5, characterized by extensive lacustrine shale and coal deposits. Phase 6 is recognized by marine shales and barrier sandstones as seen in upper right corner of diagram.

shale and coal. The phase break thus varies from section to section because widespread lacustrine or coal swamp conditions did not begin at the same time in all areas.

Phase 5 (fig. 39) marks a time of delta stability, for it did not build much farther seaward but retreated and finally was submerged and buried by marine Bluegate Shale of phase 6. Uppermost Ferron rocks of phase 5 are comparable to that part of the member studied by Uresk (1979). Section 1 includes a particularly good depositional record of these delta-plain environments (units 20–24) and contains lacustrine shale, marine shale, ironstone, carbonaceous shale, coal, and a few siltstone and sandstone lenses (plate 1). This upper segment records the fluctuations from freshwater lacustrine conditions (gray green to olive green shale) to marine bay conditions (medium gray shale), from moderately rapid sedimentation (sandstone and siltstone) to slow sedimentation (ironstone and shale), and from lacustrine or marine conditions to swampy or marshy conditions. Similar local environments and lenticular sequences occur in the upper Ferron Sandstone in all the sections except where they have been cut out by Recent streams or buried by alluvium. Details of these rocks vary from section to section, but the same kinds of rocks repeat throughout. The area from section 1 to section 4 (just south of Bloody Hands Gap), however, was one of dominantly slow sedimentation where lacustrine or bay conditions prevailed during phase 5.

Phase 5 was the time when thickest Ferron coal deposits formed in the Henry Mountains region. These coals accumulated on the low-relief surface of the fairly stable delta. Coal swamps developed in low, poorly drained areas between distributaries and along margins of the many lakes and bays of the delta plain. Conditions of accumulation were never stable or widespread enough to allow thick extensive coal to accumulate. Maximum thicknesses of coal are generally less than 1 m, and lenses are usually 1 or 2 km wide.

As the Notom delta reached its greatest extent, the river was diverted by avulsion much like the well-documented shifts of the Recent Mississippi River Delta (Gould 1970), and the delta no longer had a sediment supply. The delta began to subside during phase 6 and to be reshaped by wave action. This final destructive phase is probably responsible for the coarse sandstone layer preserved at the top of a few of such sections as section 1, unit 24, and section 5, unit 27. This sandstone is interpreted to have been a beach or barrier-island accumulation of a current that flowed toward S 5° W to 15° W. Hunt and others (1953) proposed the same interpretation for these late sandstones, and Uresk (1979) reported similar sandstones in the uppermost Ferron Member near Caineville. Gray marine Mancos Shale transgressed over deposits of the Notom delta, and shallow marine conditions again spread far to the west.

The depositional history of the Ferron Sandstone in this area was reconstructed with data from the correlated measured sections (plate 1), and the relationships represented there were interpreted in three dimensions. Some problems of correlation and interpretation arise from the lenticular nature of the entire section. Many units in upper beds extend for only a few tens of meters. Correlation of all units from one section to another therefore is nearly impossible, although many units in the lower part do have some lateral extent. Correlation of units was done by stratigraphic position, by comparison of lithologies, and by field observation.

ECONOMIC POSSIBILITIES

Coal

Coal is mined out of the Ferron Member in the Castle Valley area where seams are up to 6.7 m thick (Cleavinger 1974, p. 260). Coal is also mined from the Ferron Member at Factory Butte at the northern end of the Henry Mountain Basin, where the coal is from 0.9 to 5.5 m thick (Uresk 1979, p. 92). A few small-scale mines also were opened in the Henry Mountains area, but are now abandoned (Doelling 1975). Only one, the Stanton Mine on Swamp Mesa, mined Ferron coal. These mines produced coal for local use and were not economically significant.

Ferron coal in the Notom to Bitter Creek area is bituminous to subbituminous and occurs in relatively thin beds that average only 0.6 m thick. Coal beds occur in rock deposited in a backswamp environment in the upper part of the member. Coal is often associated with lacustrine and interdistributary bay shales and natural levee sandstones and siltstones. Beds are generally continuous laterally for less than a few hundred meters (fig. 40).

Little of the coal in the area could be recovered by strip mining because the coal beds dip from 15° to 40° under uppermost Ferron Sandstone and Bluegate Shale. Overburden thicknesses in the middle of the basin range up to 800 m, making the coal essentially not recoverable. The U.S. Bureau of Mines and U.S. Geological Survey (1976) consider coal beds less than 1.5 m thick and buried under 900 m of overburden or less to be of unknown potential. Most Ferron coal in this area is in that category. (Coal beds have to be greater than 1.5 m thick and buried under less than 300 m of overburden before they are considered to have high development potential. Moderate potential coal beds are defined as being greater than 1.5 m thick and covered with 300 to 600 m of overburden.)

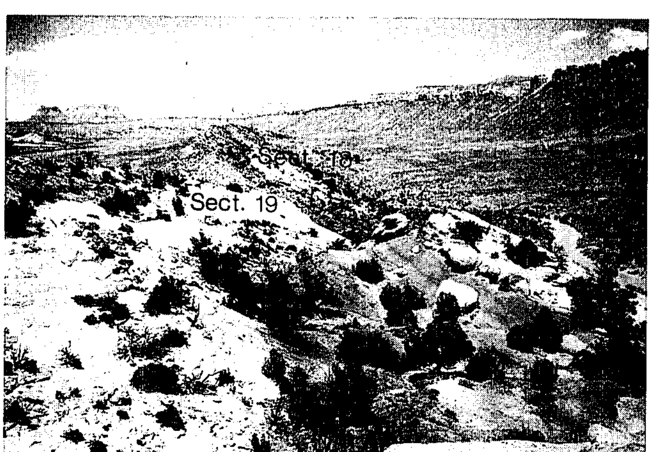


FIGURE 40.–View of section 19 and looking north toward section 18, showing lateral extent of coal beds and fluvial sandstone layers. Tallest junipers are approximately 3 m tall.

Ryer (1979) reports that coal beds in the Ferron Member in Castle Valley tend to be thickest just landward of the delta-front sandstone pinch-out. If that relationship holds true for Ferron coal in the Henry Mountain area, some of the beds may thicken toward the east and southeast away from the outcrops. Coal was reported in the upper part of the Ferron Sandstone in the West Henry Mountains Corporation 22-7 Federal-Apple Well in section 22, T. 31 S, R. 9 E at a depth of 131 m.

Another possibility that appears more feasible is in situ gasification of the coal. Federally defined parameters for such development are that the coal bed be at least 1.5 m thick, be buried beneath 90 to 900 m of overburden, and be dipping from 15° to 90°. All of these requirements are met by coal beds in sections 19, 20, and 21, except thickness. Where exposed, these beds are 0.8 to 1.2 m thick, but they may thicken towards the center of the basin. Neither thickness nor quality of coal is known in the subsurface.

Coal pellets were prepared of the upper coal in unit 43 of section 19 to determine the maceral content. Percentage composition, determined by averaging one hundred point counts for the four pellets, averages 41 percent vitrinite, 23 percent pseudovitrinite, 13 percent fusinite, 7 percent semifusinite, 3 percent macrinite, 1 percent exinite, 2 percent resinite, 2 percent pyrite, and 8 percent silt. The percentages are weighted toward vitrinite and pseudovitrinite and indicate a high volatile, high Btu coal that could be used commercially, notwithstanding the high pyrite content.

Quality of the coal is decreased by increased content of fusinite, pyrite, and silt. Fusinite is a high carbon, low hydrogen maceral which is noncombustible and is left as ash when the coal is burned. Pyrite is an iron sulfide, and, when it is burned, the sulfur forms sulfur oxide compounds which pollute the air. Pyrite content was not precisely determined, but is probably within the range of 0.7 to 2.29 percent reported by Uresk (1979, p. 90). Silt is also a noncombustible contaminant, but it could be removed.

Doelling (1975) concluded coals of the Ferron Member in the Henry Mountain field are high volative C bituminous coal. They have an average proximate analysis of 5 percent moisture, 35.3 percent volatile matter, 42.9 percent fixed carbon, 15.3 percent ash, 2.85 percent sulfur and 11575 Btu/lb.

Mining the coal of the Ferron Member in the study area is probably not economically feasible. Further study should be made to determine the feasibility of in situ gasification of these coals in the basin to the east of the outcrop belt, for such utilization appears to be a definite economic possibility.

Petroleum

The Ferron Sandstone is a major oil and gas producer in the Castle Valley and Wasatch Plateau areas, but it is not a producer in the Henry Mountains region. Four wells east of the study area have been drilled through the Ferron Member into early Mesozoic or late Paleozoic formations. No oil or gas shows were reported in the Ferron in any of these wells. The sandstones have low porosities because of clay matrix in the pores. Uresk (1979, p. 93) reported dead oil in one hand sample from near Caineville.

The only sandstones that have satisfactory porosities in the study area are the somewhat discontinuous distributary mouth bars and channel fills. The delta-front sandstones have low porosities because clay or limonite fills the pores. The only satisfactory reservoir sandstones therefore would appear to be the upper fluvial sandstones.

The Ferron Sandstone is shallowly buried in the Henry Mountain Basin and crops out around its margins and around intrusions in the mountains. Stratigraphic traps may occur in the basin in upper Ferron sandstones because many of these bodies pinch out laterally and are associated with organic-rich shales. Equivalent rocks under the volcanic cover of the Awapa Plateau should also be considered. There the Ferron Sandstone grades into or becomes part of the Straight Cliffs Formation or the Indianola Group and may contain more fluvial-dominated, cleaner, porous sandstone. Very few wells have been drilled through the volcanic rocks of the plateaus. Tilted fault blocks or structures shown by recent seismic surveys should be tested in the Ferron interval.

Other

Uranium and titanium minerals and jet deposits have been reported from the Ferron Sandstone in the Henry Mountains region. None of these minerals, however, were found in any significant concentration in the Notom area.

CONCLUSION

The Ferron Sandstone in the Notom area represents a delta separate from the Last Chance and Vernal deltas to the north, but of the same approximate age as based on fossil occurrence and stratigraphic relationships. These delta complexes built out into the Mancos Sea from the west in a series of shifting depositional pulses. Rapid progradation of the Notom delta, as recorded in the middle part of the member, was due to infilling of this part of the shallow sea and to the rather slow subsidence of the area. Coarse clastic sedimentation decreased abruptly during uppermost Ferron deposition because the volume of the main distributary dropped or the distributary shifted to another area. The delta was submerged by compaction and subsidence. Marine conditions gradually spread across the area until the Mancos Sea covered the delta and spread far to the west.

The probable source area for Ferron sediments was western Utah, in uplifts produced by the Sevier orogeny. Grains from Precambrian sources could have had their origin in many ranges along the disturbed belt, for Precambrian rocks were widely exposed. Source areas for the igneous minerals could have been Jurassic or Cretaceous intrusions in western Utah and eastern Nevada. Volcanic rocks, now long gone, above the intrusions could also have been sources for the igneous grains. Nearby, downwind, volcanic activity is documented by the numerous bentonitic beds throughout the underlying Tununk Shale and overlying Bluegate Shale.

Other grains, such as chert and limestone, may have been shed directly from late Paleozoic sources or as retransported grains from Triassic and Jurassic formations.

The Mississippi River Delta has been used as a modern analog for detaic sedimentation. The Guadalupe River Delta of the Texas Gulf Coast perhaps serves as a better model of Ferron Sandstone deposition in the Notom delta. (1) The volume of the rivers and discharge of sediments seem to be similar. Channel fills, an indication of river size, average 5 m thick and approximately 100 m wide. (2) The distance from the source area to the basin is comparable, approximately 500 km versus 680 km for the Guadalupe River (Donaldson and others 1970, p. 113). (3) Both deltas were built into shallow water that is relatively little affected by waves and tides. (4) Subsidence seems to be minimal or at least slow in both areas, as suggested by the relative thinness of units and the rapid progradation of the delta. (5) Distributary channels were occasionally cut down into bay or delta-front sediments, as in units 13–15, section 21. (6) Growth of both deltas was by building, abandoning, and reworking of subdeltas in several stacked sequences. (7) Vertical and lateral relationships and scales appear similar. Thickness of delta-plain deposits of the Guadalupe Delta, excluding channel fills, averages 3 m (Donaldson and others 1970, p. 117). Comparable delta-plain deposits of the upper Ferron Sandstone average 8 m thick. The Guadalupe Delta is approximately 15 km long and 5 km wide. The Notom delta was much larger, however, probably as much as 50 km wide.

APPENDIX

Section 1

NW ¼, NE¼, section 34, T. 30 S, R. 8 E, Wayne County, Utah.
Dip 14° E, strike N 4°E.

Unit		*Unit Thickness (meters)*	*Cumulative Thickness (meters)*
Top of Ferron Sandstone, alluvium above.			
24	Sandstone, light gray, cross laminated, coarse grained, limonite stained, friable at bottom, high ledge former, calcareous cement.	1.0	1.0
23	Sandstone, medium-dark reddish brown, coarse to gritty sand, forms ledges, laminated at top, very porous, cross laminated, 97% quartz, 2% dark minerals, 1% iron oxide and chert, units 23 and 24 are possible barriers.	1.1	2.1
22	Shale interbedded with carbonaceous shale, capped with ironstones, 50% shale, 50% carbonaceous shale, shale is light olive brown, carbonaceous shale is medium gray with black and reddish ironstone, slope former, possible marine bay.	26.4	28.5
21	Sandstone, light reddish brown, fine grained, poorly cemented with calcareous cement, very porous, cross laminated, 1% iron concretions (1 cm diameter), forms low ledges.	0.7	29.2
20	Coal, low-grade bituminous, possible backswamp environment.	0.5	29.7
19	Sandstone, medium grained, light gray, thin bedded, interbedded with shale, forms a slope.	3.1	32.8
18	Shale, medium reddish brown, weathers light reddish brown, forms slopes, possible lacustrine environment.	0.6	33.4
17	Sandstone, light gray, limonite stained, with interbedded carbonaceous shale and coal lenses, coarsens upward.	2.5	35.9
16	Sandstone, reddish brown at top and forms ledge, lower 0.9 m is light tan slope, poorly indurated, silty, limonitic cement.	1.2	37.1
15	Sandstone, reddish brown, porous, cross-bedded, forms cliffs, possible channel-fill sanstone.	2.5	39.6
14	Sandstone with interbedded mudstone, light reddish brown, fine grained, soft-sediment deformation, porous, secondary gypsum, forms ledges, possibly splay.	2.2	41.8
13	Shale, light brownish gray, fissile, forms slope with silty ledge 0.2 m from top, possible lacustrine environment.	6.6	48.4
12	Sandstone, light tan weathers lighter, massive with some cross-bedding, ripple marks fine grained, calcareous, laminated at top, limonite stained, bioturbated, current direction = S 70° E, possible distributary mouth bar and channel fill.	16.2	64.6
11	Sandstone, very fine grained, light tan, very porous, ledge forming, interbedded with medium gray shale, coarsens upward, limonite concretions, soft-sediment deformation, possible delta front.	8.2	72.8
10	Mudstone, calcareous, light medium gray, forms ledge, increasingly gypsiferous towards top; reddish brown sandstone cuts through unit, it is fine grained, 98% quartz.	1.1	73.9
9	Sandstone, very fine grained, light tan, calcareous, porous, grades into unit 10, forms low ledges.	1.1	75.0

8	Shale, interbedded silty shale; shale is light gray, fissile, cross laminated. Silty shale, light yellowish brown, 80% shale, forms slope, possible prodelta environment.	2.5	77.5
7	Shale, same as unit 8 but is 80% silty shale, forms ledges.	2.8	80.3
6	Shale, medium brown gray, papery, calcareous, slope former.	2.3	82.6
5	Sandstone, light yellowish brown, well sorted, fine grained, silty, forms ledges, grades into interbedded shale and sandstone to the east, possible delta front.	3.9	86.5
4	Shale and siltstone interbedded, shale is medium brownish gray, papery and lenticular, silt is light brownish gray, mudcracks at top, forms cliffs, possible prodelta.	4.3	90.8
3	Sandstone and siltstone interbedded, sandstone is light reddish brown, laminated, fine grained, well sorted, silty; silt is light brown, fissile, calcareous; both sandstone and siltstone beds are 0.4 m thick, forms cliffs, possible delta front.	8.8	99.6
2	Sandstone and siltstone interbedded. Same as unit 3 except sandstone beds are 0.4 m thick, and siltstone beds are 0.6 m thick, forms slope.	5.5	105.1
Base of Ferron Sandstone, top of Tununk Shale			
1	Shale, dark brownish gray, fissile, papery, gypsiferous, slope forming, weathers lighter gray, bentonitic.	5.0+	110.1

Section 6

NE ¼, SW ¼, section 21, T. 31 S, R. 8 E, Garfield County, Utah.
Dip 23 E, strike N 5° W.

31	Shale, medium brown gray, weathers light brown, 1% gypsum on beds, forms slope.	5.0+	5.0
Top of Ferron Sandstone, base of Bluegate Shale			
30	Sandstone, yellow brown, weathers orange brown, coarse grained, quartz sand, upper half of unit is sandstone, light gray, contains 1% dark grains, 90% quartz, angular-subangular, low ledge former, possible barrier-bar sandstone.	0.6	5.6
29	Sandstone, light yellow brown, very fine grained, quartz sand interbedded with shale, medium gray, weathers light gray, capped by 0.1 m of coal and fissile shale, forms slope.	2.2	7.8
28	Shale, greenish yellow, a little ironstone, middle of unit is fissile olive brown, slope former.	2.3	10.1
27	Shale, medium light brown, fissile, limonite stained, weathers light yellow brown, dark red brown ironstone forms caps on slopes, units 26–28 may represent marine bay environments.	1.7	11.8
26	Shale, medium gray, fissile, some limonite stains, slope former, unit is capped by dark red brown ironstone on tops of eroded slopes.	0.8	12.6
25	Coal, mottled black and yellow orange, sulfurous, forms slope, backswamp.	0.3	12.9
24	Shale, mottled brown gray, weathers medium gray, plant debris, forms slopes, possible lacustrine environment.	0.3	13.2
23	Sandstone, light gray, weathers light yellow gray, coarse grained, coarsens upward, cross-beds 0.1 to 0.2 m thick, 30% iron concretions, plant fragments, slope former.	4.6	17.8
22	Sandstone, light gray, weathers orange brown, calcareous, coarsens upward, medium to coarse grained, 90% quartz, 10–15% concretions, iron replaced petrified wood, forms ledges, units 21–23 are channel fill.	2.4	20.2
21	Sandstone, light gray, medium to fine grained, quartz sand, low ledge former.	3.2	23.4
20	Shale, lenticular, with light gray sandstone lens, shale is sandy, calcareous, light gray, forms slope.	2.5	25.9
19	Sandstone, yellow brown to tan, medium grained, subangular–subround, 90% quartz, slight calcareous, cross-bedded, 1% concretions, massive cliff former, channel-fill sandstone.	6.4	32.3
18	Sandstone, with interbedded shale, light yellow grey, calcareous, sandstone stands up as small ledges, forms slope.	1.3	33.6
17	Coal, black, shaly, argillaceous, pinches out 5 m to the south, slope former, backswamp.	0.4	34.0
16	Shale, sandy, fines upward, some lenses of very fine grained quartz sand, shale is red gray, sandstone lenses are light gray, weathers yellow brown, forms slope, possible lacustrine environment.	1.2	35.2
15	Sandstone, light gray, friable near bottom, calcareous cemented near top, angular–subangular, forms slope.	1.0	36.2
14	Sandstone, yellow brown, medium to coarse grained, coarsens upward, subangular to subround, well sorted, calcareous, cross-bedded, honeycomb weathering, forms cliff, channel fill.	12.0	48.2
13	Sandstone, yellow brown, slabby, massive, honeycomb weathering, medium to fine grained; cross-bedded, S 53° E, forms ledge.	1.7	49.9
12	Sandstone, light gray, medium grained, clean quartz sand, cross-bedded in lower part, forms ledge, possible distributary mouth bar.	2.4	52.3
11	Sandstone, yellowish brown, fine grained, calcareous nodules, thin to massive bedded, cliff former.	7.7	60.0
10	Sandstone, light brown gray, thin-bedded, soft-sediment deformation, gypsiferous, fine to medium grained, cliff former, possible delta front.	1.6	61.6
9	Siltstone, shaly, light gray, coarsens upward, laminated, gypsiferous, ripple marks, ledge former.	1.5	63.1
8	Shale, interbedded with fissile sand, light brown to yellow brown, some gypsum, sandstones are fine grained, slope former, possible prodelta.	14.2	77.3
7	Shale, medium gray, gypsiferous, fissile, slope former, possible shallow marine environment.	3.0	80.3
6	Sandstone, light yellow brown, fine to medium grained, coarsens upward, laminated, cliff former.	5.8	86.1
5	Sandstone, yellow brown to tan, fine grained, massive to laminated, cross-bedded, soft-sediment deformation, ripple marks rare, forms cliff, possible distributary mouth bar.	2.1	88.2
4	Sandstone, very fine grained, yellow brown, ledge former, soft-sediment deformation, plant fragments, possible delta front environment.	2.1	90.3
3	Shale, sandy, laminated, fissile, light brown to medium gray, calcareous, forms slope, possible prodelta shale.	1.1	91.4

2	Sandstone, fine to very fine grained, massive, light brown, calcareous, ledge former.	1.1	92.5

Base of Ferron Sandstone, top of Tununk Shale

1	Shale, silty to sandy, calcareous, light brown to light tan, forms slope.	2.5	95.0

Section 19

NW ¼, SW ¼, section 16, T. 32 S, R. 8 E, Garfield County, Utah (35 m northeast of section 16–17 marker).

Dip 23° E, strike N 55° E.

Top of Ferron Sandstone, base of Bluegate Shale.

50	Sandstone, pale brown, weathers pale yellow brown, laminated to very thin bedded, medium to coarse grained, poorly sorted, subangular to subrounded, quartz 85%, cross-bedded, S 5° W, forms ledge, possible barrier-bar sandstone.	0.3	0.3
49	Shale, dusky brown, weathers grayish brown, papery, iron concretions, sharp lower contact, forms slope, possible marine bay environment.	4.1	4.4
48	Sandstone, pale orange brown, weathers very light brown, medium to very coarse grained, poorly sorted, angular to subround, laminated, very porous, 85% quartz, cross-bedded (0.4m thick), forms rounded ledge, S 15 W, concretions, wood casts.	5.1	9.5
47	Sandstone (same as unit 48 except without concretions, wood casts, or a current direction), units 46–48 are channel-fill sandstones.	4.7	14.2
46	Sandstone, light brownish orange, weathers to pale yellowish orange, medium to coarse grained, laminated, subround to subangular, porous, concretions (0.4 m diameter), cross-bedded, horizontal and vertical burrows common, clay rip-up clasts, 85% quartz, forms a ledge.	0.9	15.1
45	Shale, carbonaceous, dusky yellow brown, weathers grayish brown, laminated, coal partings, slickensides, forms a slope, limonite staining, possible marginal backswamp environment.	0.8	15.9
44	Shale, medium brown, weathers grayish brown, laminated, slightly silty, forms slope with 5 cm carbonaceous shale at base, possible lacustrine environment.	2.9	18.8
43	Coal, dull, blocky, sulfur and limonite stained, bituminous, gradational lower contact, forms a low ledge, backswamp.	1.2	20.0
42	Shale, dark gray, weathers medium gray, laminated, carbonaceous, silty, gradational lower contact, forms a slope, possible lacustrine environment.	1.8	21.8
41	Siltstone, grayish brown, weathers pale brown, laminated, argillaceous, plant debris, forms slope.	0.4	22.2
40	Coal (same as unit 43), thickens to the northwest, backswamp.	0.8	23.0
39	Sandstone, light yellow gray, weathers very light gray, fine-grained, laminated, rounded to subrounded, 98% quartz, porous, cross-bedded (0.3 m thick), horizontal and vertical trace fossils, forms rounded ledge, plant casts common.	1.4	24.4
38	Sandstone (same as unit 39), current direction is S 5° W, units 39–36 are channel-fill sandstones.	5.3	29.7
37	Sandstone, grayish orange, weathers brownish orange, fine grained, 80% quartz, porous, well sorted, cross-bedded (0.1 m thick), horizontal and vertical trace fossils, upper part bioturbated, forms low ledge.	2.0	31.7
36	Sandstone, very pale orange, weathers grayish orange, fine grained, laminated, rounded, cross-bedded (25 cm thick), porous, well sorted, 95% quartz, forms low ledge.	3.1	34.8
35	Sandstone, grayish orange, weathers pale yellow brown, fine grained, laminated, rounded, 90% quartz, porous, well sorted, cross-bedded (8 cm thick), vertical and horizontal trace fossils, forms low ledge, possible natural levee.	0.7	35.5
34	Siltstone, interbedded shale; siltstone 60%, light brownish gray, weathers light gray, laminated, calcareous; shale 40%, dark greenish gray, weathers light gray, silty, forms a slope, possibly the backside of a natural levee.	2.4	37.9
33	Sandstone, grayish orange, weathers pale yellowish brown, very fine grained, laminated, rounded, 80% quartz, calcareous, porous, well sorted, some horizontal and vertical burrows, cross-bedded (5 cm thick), S 55° W vector, forms low ledge, possible natural levee.	0.4	38.3
32	Siltstone, interbedded shale (same as unit 34).	2.1	40.4
31	Siltstone, interbedded shale (same as unit 34), 50% siltstone, 40% shale, 10% sandstone, fine grained, pale orange, laminated, bioturbated, ripple marks indicate W 25° S direction.	1.5	41.9
30	Sandstone, very pale orange, weathers pale yellowish brown, fine grained, laminated, rounded, cross-bedded (25 cm thick), S 17° W, well sorted, calcareous, porous, 75% quartz, bioturbated, forms low ledge.	1.7	43.6
29	Sandstone (same as unit 30), S 30° W, 95% quartz, some limonite concretions, forms low ledge, units 28–30 are possible channel fill.	2.4	46.0
28	Sandstone (same as unit 30), cross-beds 15 cm thick with no direction determinable, 80% quartz.	1.9	47.9
27	Sandstone, pale brownish orange, weathers light brown, fine grained, laminated, rounded, 99% quartz, cross-bedded (20 cm thick), S 20° W, porous, forms low rounded ledge, possible distributary mouth bar.	1.9	49.8
26	Sandstone, yellowish orange, weathers pale orange, fine grained, laminated, calcareous, limonite stained, ripple marks (SE vector), porous, forms low ledge, possible delta front sandstone.	0.7	50.5
25	Sandstone (same as unit 30), limonite concretions, units 24 and 25 are channel-fill sandstones.	3.3	53.8
24	Sandstone (same as unit 30), cross-beds 10 cm thick, S 10° W, load casts, rip-up clasts, 5 mm mudstone at base.	1.5	55.3
23	Sandstone, very pale orange, weathers same, fine grained, laminated, cross-bedded (30 cm thick), S vector, rounded, porous, calcareous, forms rounded ledge.	1.8	57.1
22	Sandstone, pale yellowish orange, weathers light grayish orange, fine grained, laminated, rounded, calcareous, limonite stained, plant debris, cross-bedded (20 cm thick), S 15° W, ironstone concretions, porous, forms upper part of cliff, units 21–23 are possible distributary mouth bars.	1.9	59.0

21	Sandstone, grayish orange, weathers very pale orange, fine grained, laminated, rounded, plant debris, porous, ripple marks at base (W 15° N), soft-sediment deformation, 35% silty shale interbeds, medium gray, fossil leaves and plant debris, occasional trace fossils, forms a cliff.	0.9	59.9
20	Sandstone (same as unit 21), cross-beds 4 cm thick, SW vector, 20% silty shale, forms a ledge.	1.6	61.5
19	Sandstone, grayish orange, weathers very light brown, calcareous, very fine grained, laminated, subrounded, porous, limonite stained, plant debris, bioturbated, horizontal and vertical burrows, 15% silty shale, medium gray, soft-sediment deformation, ripple marks in sandstone, W vector, forms cliff.	0.7	62.2
18	Sandstone (same as unit 19), 10% shale interbeds, units 17 and 18 are possible delta-front sandstones.	1.4	63.6
17	Sandstone (same as unit 19), light brownish gray, weathers light gray, ripple marks (W 10° S).	0.6	64.2
16	Siltstone, dark yellow brown, weathers light brown, calcareous, very thin bedded, plant debris, limonite stained, horizontal burrows, forms slope.	0.8	65.0
15	Siltstone (same as unit 16), with 20% dark brownish gray shale, slightly bioturbated, slightly carbonaceous.	2.5	67.5
14	Siltstone, interbedded shale, 45% siltstone, brownish gray, weathers medium gray, thinly laminated to laminated, slightly carbonaceous, 55% shale, dark brownish gray, weathers medium gray, thinly laminated, gypsum, forms slope, possible prodelta.	2.0	69.5
13	Shale, dark brownish gray, weathers medium light gray, thinly laminated, plant debris, 30% brownish gray siltstone, forms slope, shallow marine environment.	6.5	76.0
12	Sandstone, pale orange, weathers very light gray, calcareous, fine grained, laminated, rounded, cross-bedded upper 30 cm (5 cm thick), lower 30 cm limonite cemented, forms small ledge, possible distributary mouth bar.	0.6	76.6
11	Sandstone, grayish orange, weathers light grayish orange, very fine grained, laminated to very thin bedded, 15% medium gray siltstone, some coaly partings, soft-sediment deformation, forms rounded ledge.	0.9	77.5
10	Siltstone, medium gray, weathers medium light gray, laminated, limonite stained around coal partings, 1% coal, 20% medium gray shale, slightly carbonaceous, forms slope, units 9–11 are delta-front deposits.	5.1	82.6
9	Siltstone, interbedded shale, 60% medium gray siltstone, weathers medium light gray, laminated, 35% medium dark gray shale, plant debris, laminated, 5% ironstone interbeds, grayish brown, weathers orange brown, calcareous, forms slope.	4.5	87.1
8	Shale, greenish gray, weathers medium light gray, laminated, 10% medium gray siltstone, limonite stained, fossils: ammonites, bivalves, a bryozoan, and plant fragments; forms slope, possible prodelta environment.	8.6	95.7
7	Shale, medium gray, weathers light gray, laminated, slightly silty at top, forms slope.	4.9	100.6
6	Shale, medium gray, weathers light gray, slightly carbonaceous, forms slope, possible marine shale.	7.5	108.1
5	Sandstone, grayish orange, weathers light orange brown, medium to coarse grained, poorly sorted, subangular to subrounded, 97% quartz, sharp lower contact, some rip-up clasts, fossils: shark teeth, skate teeth, fish vertebrae, fish scales; forms ledge, possible distributing mouth bar.	0.3	108.4
4	Siltstone, light brownish gray, argillaceous at bottom, sandy at top, laminated, 5% carbonaceous shale partings, forms slope, possible delta front deposit.	0.2	108.6
3	Sandstone, very pale orange, weathers yellowish gray, calcareous, medium grained, poorly sorted, subangular to subrounded, 98% quartz, cross-bedded (6 cm thick), S 10° W, large vertical burrows, sharp lower contact, fossils: same as unit 5; forms ledge, possible distributary mouth bar.	1.8	110.8
Base of Ferron Sandstone, top of Tununk Shale.			
2	Shale, light greenish gray, weathers light brown, laminated, silty shale interlaminae, 2% coaly partings, some limonite staining, forms slope, possible prodelta deposits.	1.8	110.8
1	Shale, dark gray, weathers medium gray, laminated, gypsum, limonite staining, forms slope.	5.0	115.8

Section 33

NE ¼, NW ¼, section 20 (unsurveyed), T. 33 S, R. 8 E, Garfield Co., Utah.
Dip 50° E, strike N 12° W.

7	Alluvium	5.0	5.0
6	Sandstone, light red brown, weathers same, ripple marks, cross-beds nearly as thick as unit, medium grained, friable, very porous, 95% quartz, limonite and calcareous cement, forms ledge, possible delta-front sandstone.	1.1	6.1
5	Sandstone, medium reddish brown, weathers same, mottled, seems bioturbated, thin bedded, fine grained, 97% quartz, one poorly preserved bivalve, forms ledge, possible delta-front sandstone.	0.6	6.7
4	Shale, interbedded sandstones; shale is grayish brown, weathers light brown, fissile, sandy, becomes more carbonaceous upward, some ironstone; sandstones are medium brown, weather same, forms slope, possible prodelta.	4.6	11.3
3	Siltstone, interbedded sandsrone, shaly, light brown to medium reddish brown, weathers light gray to light brown, limonite cement, grades from silt at bottom to medium grained in the middle to fine-grained at top, thinly laminated, limonitic concretions in upper sandstone, ledge former, caps cuesta, possible delta-front deposits.	1.9	13.2
Base of Ferron Sandstone, top of Tununk Shale			
2	Shale, sandy, medium brown, weathers light reddish brown, fissile, grades upward into sandstone at top of unit, very calcareous, forms slope.	9.2	22.4
1	Shale (same as unit 2).	14.0	36.4

REFERENCES CITED

Balsley, J. K., 1969, Origin of fossiliferous concretions in the Ferron Sandstone, southeastern Utah: Master's thesis, University of Utah, Salt Lake City.

Balsley, J. K., and Stokes, W. L., 1969, Unusual coprolites from the Upper Cretaceous Ferron Sandstone, east-central Utah: Earth Science Bulletin, v. 2, no. 2, p. 5–6.

Cleavinger, H. B., 1974, Paleoenvironments of deposition of the Upper Cretaceous Ferron Sandstone near Emery, Emery County, Utah: Brigham Young University Geology Studies, v. 21, pt. 1, p. 247–74.

Cotter, E., 1971, Paleoflow characteristics of a Late Cretaceous river in Utah from analysis of sedimentary structures in the Ferron Sandstone: Journal of Sedimentary Petrology, v. 41, no. 1, p. 129–38.

__________, 1975, Late Cretaceous sedimentation in a low energy coastal zone: The Ferron Sandstone of Utah: Journal of Sedimentary Petrology, v. 45, no. 3, p. 669–85.

__________, 1976, The role of deltas in the evolution of the Ferron Sandstone and its coals, Castle Valley, Utah: Brigham Young University Geology Studies, v. 22, pt. 3, p. 15–42.

Davies, D. K., Ethridge, F. G., and Berg, R. R., 1971, Recognition of barrier environments: American Association of Petroleum Geologists Bulletin, v. 55, p. 550–65.

Dickinson, K. A., Berryhill, H. L., Holmes, C. W., 1972, Criteria for recognizing ancient barrier coastlines: In Rigby, J. K., and Hamblin, W. K. (eds.), Recognition of ancient sedimentary environments, Society of Economic Paleontologists and Mineralogists Special Publication 16, p. 192–214.

Doelling, H. H., 1975, Geology and mineral resources of Garfield County, Utah: Utah Geological and Mineralogical Survey Bulletin, 107, 175p.

Donaldson, A. C., Martin, R. H., and Kanes, W. H., 1970, Holocene Guadalupe Delta of Texas Gulf Coast: In Morgan, J. P. (ed.), Society of Economic Paleontologists and Mineralogists Special Publication 15, p. 107–37.

Ferm, J. C., and Cavaroc, V. V., Jr., 1968, A nonmarine sedimentary model for the Allegheny rocks of West Virginia: In Klein, G. D. (ed.), Late Paleozoic and Mesozoic continental sedimentation, northeastern North America, Geological Society of America Special Paper 106, p. 1–20.

Fisher, W. L., Brown, L. F., Jr., Scott, A. J., McGowen, J. H., 1969, Delta systems in the exploration for oil and gas: a research colloquium, Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas, 78p.

Gilbert, G. K., 1877, Report on the geology of the Henry Mountains: U.S. Geographical and Geological Survey, Rocky Mountain Region (Powell), 160p.

Gould, H. R., 1970, The Mississippi Delta complex: In Morgan, J. P. (ed.), Deltaic sedimentation modern and ancient, Society of Economic Paleontologists and Mineralogists Special Publication 15, p. 3–30.

Hale, L. A., 1972, Depositional history of the Ferron Formation, central Utah: Utah Geological Association, Publication No. 2, Plateau-Basin and Range Transition Zone, Central Utah, p. 29–40.

Hale, L. A., and Van DeGraff, F. R., 1964, Cretaceous stratigraphy and facies patterns–northeastern Utah and adjacent areas: Intermountain Association of Petroleum Geologists, 13th Annual Field Conference Guidebook, p. 115–38.

Hemingway, J. E., 1968, Sedimentology of coal-bearing strata: In Murchison, D., and Westoll, T. S. (eds.), Coal and coal-bearing strata: New York, American Elsevier, 418p.

Hunt, C. B., 1946, Guidebook to the geology and geography of the Henry Mountain region: Utah Geological Society Guidebook, no. 1, 51p.

__________, 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geological Survey Professional Paper 228, 234p.

Katich, P. J., 1953, Source direction of Ferron Sandstone in Utah: American Association of Petroleum Geologists Bulletin, v. 37, no. 4, p. 858–61.

__________, 1954, Cretaceous and early Tertiary stratigraphy of central and south-central Utah with emphasis on the Wasatch Plateau area: Intermountain Association of Petroleum Geologists, 5th Annual Field Conference Guidebook, p. 42–54.

Knight, L. L., 1954, A preliminary heavy mineral study of the Ferron Sandstone: Brigham Young University Research Studies, v. 1, no. 4, 31p.

Krauskopf, K. B., 1967, Introduction to geochemistry: New York, McGraw-Hill, 721p.

Lessard, R. H., 1971, Micropaleontology and paleoecology of the Tununk Member of the Mancos Shale: Geological Society of America Abstracts with Programs, v. 2, no. 5, p. 340.

Lupton, C. T., 1914, Oil and gas near Green River, Grand County, Utah: U.S. Geological Survey Bulletin 541, p. 128.

Maxfield, E. B., 1976, Foraminifera from the Mancos Shale of east-central Utah: Brigham Young University Geology Studies, v. 23, pt. 3, p. 67–162.

Parker, R. H., 1956, Ecology of foraminifera in southeastern Mississippi Delta area, Bulletin of the American Association of Petroleum Geologists, v. 39, p. 712–52.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1965, Geology of sand and sandstone: A conference sponsored by the Indiana Geological Survey and the Department of Geology, Indiana University, 197p.

Reineck, H. E., and Singh, I. B., 1973, Depositional sedimentary environments: New York: Springer-Verlag, 479p.

Ryder, R. T., 1975, Patterns of Cretaceous shallow marine sedimentation, Coalville and Rockport areas, Utah: Geological Society of America Abstracts with Programs, v. 7, p. 1255.

Ryer, T. A., 1979, Deltaic coals of Ferron Sandstone Member of Mancos Shale–predictive model for Cretaceous coals of western interior: Bulletin of the American Association of Petroleum Geologists, v. 63, no. 3, p. 519.

Spieker, E. M., 1949, Sedimentary facies and associated diastrophism in the Upper Cretaceous of central and eastern Utah: Geological Society of America Memoir 39, p. 55–82.

Spieker, E. M., and Reeside, J. B., Jr., 1925, Cretaceous and Tertiary formations of the Wasatch Plateau, Utah: Geological Society of America Bulletin, v. 36, no. 3, p. 435–54.

Tidwell, W. D., 1975, Common fossil plants of western North America: Provo, Utah, Brigham Young University Press, 197p.

U.S. Bureau of Mines and U.S. Geological Survey, 1976, Coal resource classification system of the United States Bureau of Mines and United States Geological Survey: U.S. Geological Survey Bulletin 1450-B.

Uresk, J., 1979, Sedimentary environment of the Cretaceous Ferron Sandstone near Caineville, Utah: Brigham Young University Geology Studies, v. 26, pt. 2, p. 81–100.

Visher, G. S., 1965, Use of vertical profile in environmental reconstruction: Bulletin of the American Association of Petroleum Gelogists, v. 49, no. 1, p. 41–61.