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EDWARD COTTER 1975

Deltaic Deposits in the Upper Cretaceous Ferron Sandstone, Utah

ABSTRACT: Deltaic deposits at the base of the Upper Cretaceous regressive clastic wedge known as the Ferron Sandstone Member of the Mancos Shale are exposed in depositional dip section for more than 45 miles (72 km) along the southern part of the Castle Valley in east-central Utah. These deposits were formed as the Late Cretaceous Last Chance Delta prograded northward as a high-constructive lobate complex. In the relatively stable depositional basin the facies were dispersed laterally to produce a deltaic sequence that typically comprises 40 to 80 feet (12 to 24 m) of siltstone, sandstone, and some coal. Thin prodelta deposits at the base are overlain by a thicker, laterally continuous sheet of delta front deposits, and these, in turn, are overlain by the coal-bearing delta plain facies. Delta front beds typically are horizontal or have slight primary inclination to the north, but several delta-front sequences are steeply inclined to the west or north-west. These inclined Gilbert-type deltaic sequences possibly developed as distributary channels issued into a less saline western embayment.

INTRODUCTION

In Late Cretaceous time in eastern Utah, clastic sediments were flushed spasmodically to the east from the Sevier orogenic belt and were deposited in a variety of environments during a series of regression-transgression cycles. The best-known part of the resulting complex stratigraphic sequence is the Mesaverde Group of the Book Cliffs and Wasatch Plateau. At a time slightly earlier than that represented by the Mesaverde Group, the Ferron Sandstone Member of the Mancos Shale was deposited; this occurred in Middle Carlile (Turonian) time in the latter part of the development of the Greenhorn Marine Cycle (Kauffman, 1967; McGookey, 1972). The Ferron Sandstone is stratigraphically equivalent to a number of other sandstone units extending over a broad region of the western interior of North America; this includes part of the Frontier Sandstone of Colorado and Wyoming (McGookey, 1972).

The Ferron Sandstone was named by Lupton (1914, 1916) in the course of investigation of the coal resources of the Castle Valley in east-central Utah. In 1937, Bartram suggested the possibility that the Ferron might be the depositional record of the delta of a large river (Bartram, 1937, p. 907). This idea was refined by both Davis (1954) and Katich (1954) when they showed that the Ferron Sandstone in the southern Castle Valley was a thick clastic wedge of nearshore sediments deposited by rivers flowing from sources that lay to the southwest. The Ferron clastic wedge was referred to as a delta by Hale and Van De Graaff (1964) and Barlow and Haun (1966), and it was given the name "Last Chance Delta" by Hale (1972).

This paper presents a detailed interpretation of the depositional environments of the Last Chance Delta of the Ferron Sandstone based on study of outcrops in the southern part of the Castle Valley in east-central Utah (Figure 1).

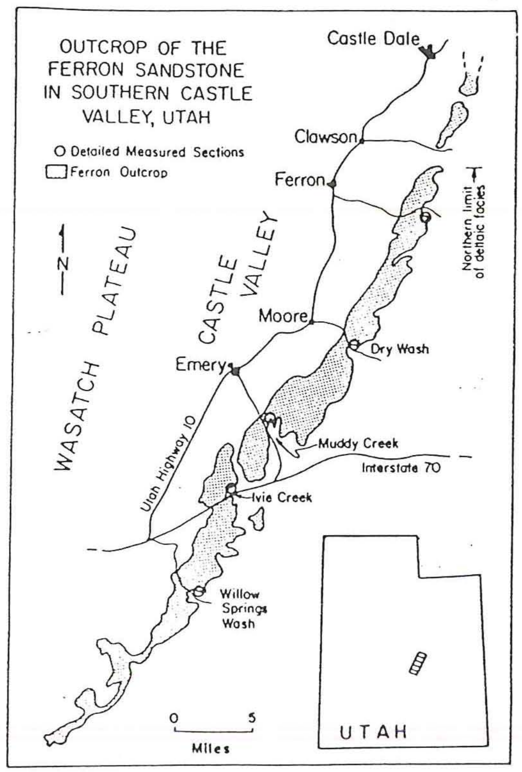

Figure 1. Outcrop belt of the Ferron Sandstone in the Castle Valley of east-central Utah.

FACIES AND ENVIRONMENTS

General Description

The deltaic deposits of the Ferron Sandstone constitute a cliff-forming, coarsening-upward sequence at the base of the Ferron in the southern part of Castle Valley, Utah. They occur almost continuously from the southernmost Ferron exposure northward to the vicinity of the settlement of Clawson, Utah, a distance of about 45 miles (72 km) (Figure 1). Throughout this exposed extent the deltaic sequence is underlain by the Tununk Shale Member of the Mancos Shale and overlain by deposits of the Ferron fluvial facies (Figure 2). The deltaic deposits are generally from 40 to 80 feet (12 to 24 m) thick, although the thickness ranges from less than 20 feet (6 m) to more than 100 feet (30 m) thick. Typically, beds in the deltaic sequence are nearly horizontal or have slight primary inclinations to the north (Figure 3). In some places, however, beds within the sequence are steeply inclined (Figures 4 and 5).

There are two reasons for the coarsening of grain size upward in the deltaic sequence. There are proportionally more sandstone beds upward in the sequence, and the grain size of the sand in those beds increases upward from very fine to fine or medium. Some finer-grained interruptions in the basic coarsening-upward sequence occur within multiple-cycle sequences (Figure 3) and near the sequence top where they are associated with coals (Figures 3 and 4).

Most of the sandstones of the Ferron deltaic deposits are lithic wackes (Gilbert, 1954), with greater than ten percent argillaceous matrix, subangular grains, and poor to moderate sorting. Some sandstones in the uppermost parts of the deltaic sequence are better sorted and have more rounded grains.

Interpretation of Depositional Environments

At essentially all exposures along the outcrop belt the Ferron deltaic sequence consists, from base to top, of three major facies: prodelta, delta

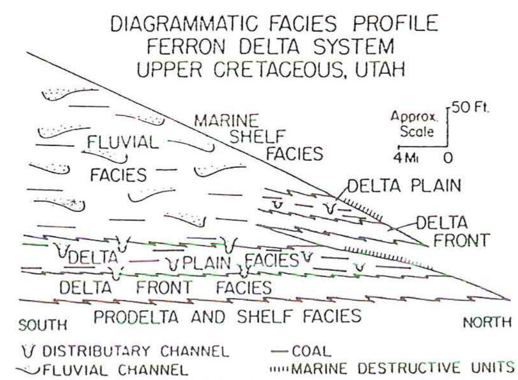

Figure 2. Summary facies profile illustrating diagrammatically the northward progradation of two cycles of development of the Last Chance Delta. Deltaic clastic wedge is underlain by Tununk Shale Member of the Mancos Shale and overlain by the Blue Gate Shale Member of the Mancos Shale. Profile is from south to north along Castle Valley outcrop belt (Figure 1).

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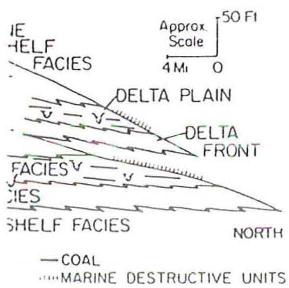

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Figure 3. Typical Last Chance deltaic sequence. Transition from underlying prodelta shale and siltstone at the base of the vertical scarp, through two coarsening-upward delta front cycles, and into delta plain deposits, including coal. Topmost beds include destructive delta margin sandstone. Delta front deposits show slight depositional inclination to the right (north). Thickness of deltaic sequence approximately 50 feet (15 m). Located about 7 miles (11 km) east of Emery, Utah.

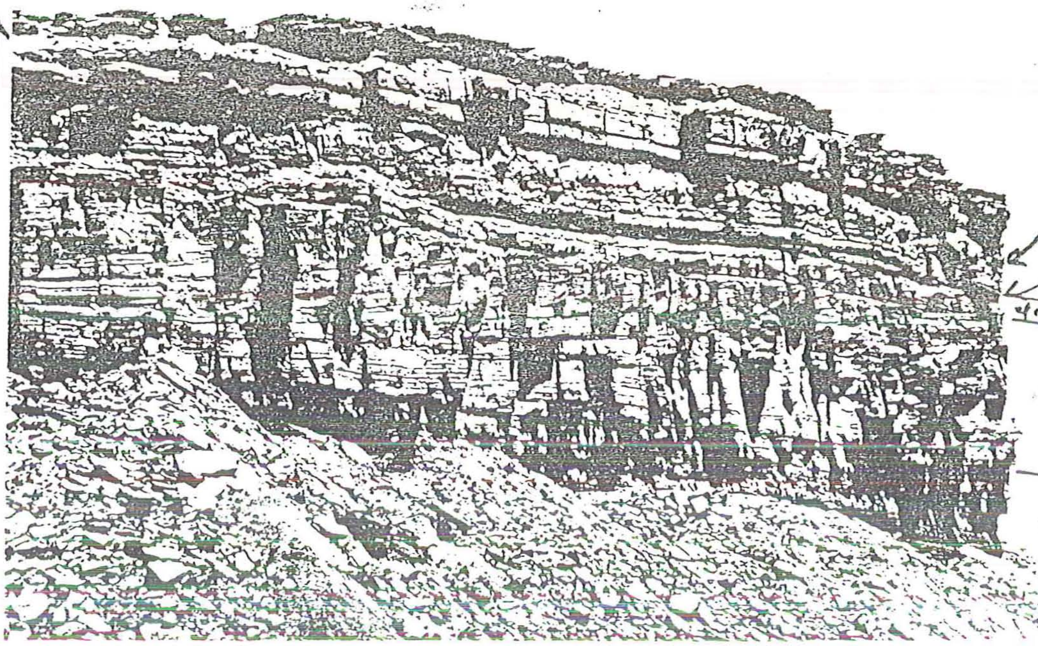

Figure 4. Thin prodelta facies overlain by steeply inclined delta front sandstone, and topped by delta plain facies. First five feet of horizontal strata above inclined strata are interpreted to be distributary mouth bar crest deposits; these are overlain by coal, carbonaceous shale, bioturbated siltstone and sandstone, cross-bedded sandstone, and well-sorted burrowed sandstone. South-facing scarp along north side of Ivie Creek, about seven miles south of Emery, Utah. Entire sequence approximately 80 feet (24 m) thick.

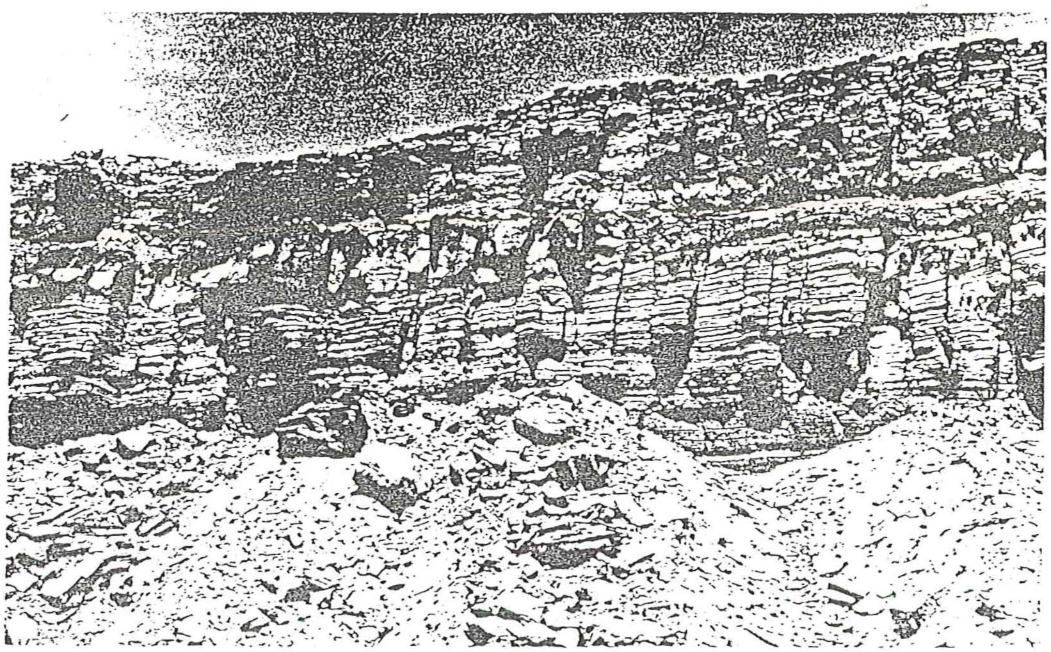

Figure 5. Scarp located along north side of Ivie Creek, several hundred yards west of Figure 4 with continuous outcrops between. Distributary mouth bar crest deposits thicken into channel form estimated to be about 15 feet (4.5 m) thick.

front, and delta plain. There is little possibility of determining the regional distribution of the identified facies and subfacies because of the roughly two-dimensional nature of the outcrop, approximately parallel to the interpreted direction of delta progradation.

Prodelta Facies. The features of the prodelta of the Ferron-Last Chance Delta are matched by their modern counterpart environment in both the relatively fine-grained, high-constructive Mississippi Delta and the coarser, more wave- and tide-dominated, high-destructive Niger Delta. Comparison of the characteristics of the prodelta deposits of the Last Chance Delta and of the Mississippi and Niger deltas is presented in Table 1.

Delta Front Facies. Characteristics of the coarsening-upward, sandstone-dominated delta front facies of the Ferron-Last Chance Delta indicate that its deposition occurred as a series of coalesced distributary mouth bar crests and their associated distal bars. The lithologies and the types and vertical sequence of sedimentary structures support this diagnosis.

The presence and persistence of even parallel lamination in the lower parts of the delta front facies and along the extent of the steeply inclined foreset beds (Figures 4, 5, and 6) suggest deposition in the distal bar environment, where sedimentation must have occurred principally by a vertical "settling out" process from the overlying water mass (Weimer, 1973, p. 76). Rapid deposition, with little marine reworking, is shown by the abundance of plant debris, by the relatively poor sorting, and by the paucity of biogenic structures.

The trough cross-laminated upper part of the delta front facies was deposited in the higher-energy distributary mouth bar crest environment. The bar crest cut deeper into the underlying distal bar during flood breaching.

The facts that the sandstone-dominated delta front facies is essentially continuous laterally (for about 45 miles [72 km] down depositional dip) (Figure 2) and that it contains within it cer-

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Table 1. COMPARISON OF FERRON-LAST CHANCE DELTA PRODELTA FACIES AND MODERN PRODELTA DEPOSITS

DEFINITION

The prodelta is the most distal subaqueous part of a delta; it lies seaward of the delta front and landward of the shelf and is where fine terrigenous sediment is deposited principally from suspension as the first record of an advancing delta.

FERRON-LAST CHANCE DELTA

A 5 to 10 foot (1.5 to 3 m) thick transitional zone at the base of the deltaic sequence. From the underlying bioturbated, dark gray Tununk Shale upward there is a gradual increase in the number and thickness of thin, very fine-grained sandstone beds (Figures 3, 4, 5).

In sequences containing steeply inclined beds (Figures 4, 5), the transitional prodelta beds form the horizontal bottomset tails to the inclined delta front foreset beds. This change from near horizontal to steeply inclined occurs where the ratio of sandstone to interbedded bioturbated shale is about 1:1. This ratio is arbitrarily used as the upper limit of the prodelta facies in those parts of the sequence that do not have steep inclinations.

Most of the sandstone beds are even parallel laminated (Campbell, 1967); additional sedimentary structures include ripple lamination (mainly in the upper parts of some sandstone beds), ripple drift cross lamination, and a minor amount of small-scale convolute lamination. Some of the sandstone beds are graded.

Biogenic structures are rare in the sandstone beds, body fossils are very scarce, but comminuted plant debris is abundant.

MODERN PRODELTA DEPOSITS

Mississippi Delta (Coleman and Gagliano, 1964, 1965; Fisher et al., 1969; Gould, 1970)

Repetitious alternations of (1) silt with parallel and lenticular laminations and occasional cross laminations and current ripples, and (2) dark, organic, highly burrowed mud.

Toward the landward transition with the delta front environment the laminated silt is more common and more thickly bedded. Toward the seaward transition with shelf sediments the burrowed mud dominates.

Plant debris can be common. The few scattered shells that might be present are susceptible to later leaching.

Niger Delta (Allen, 1965, 1970)

Interbedded clayey silt that is commonly bioturbated and coarse silt or very fine sand in beds that have even laminations and small-scale cross laminations.

There is a transition seaward in which the coarser layers thin and become less numerous and the bioturbated clayey silt and silty clay become dominant.

Plant debris is common.

Some sand layers are graded.

tain multiple progradational cycles (Figure 3) indicate that the Last Chance Delta evolved with numerous, coalescing, sand-rich, lobate subdeltas. The great lateral continuity of the delta front facies might suggest that it was deposited under the influence of wave action and longshore currents in the form of delta front sheet sands (Gould, 1970). However, the shoreface characteristics typical of delta front sheet sands, in particular the abundant biogenic structures, are scarce to absent in delta front facies of the Last Chance Delta.

Table 2 contains the details of the comparison of the features of the delta front facies of the Last

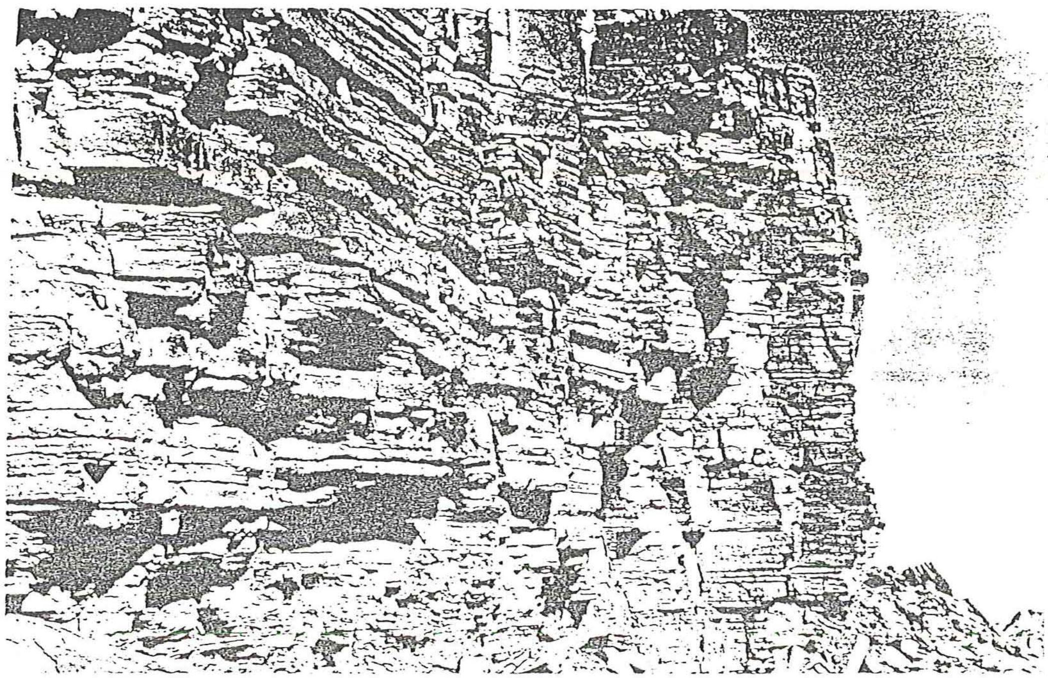

Figure 6. Closer view of steeply inclined delta front deposits of Figure 4. Hammer in left-central part of photograph indicates scale.

Chance Delta and of various modern deltas.

Delta Plain Facies. At the top of the Last Chance Delta sequence, the delta plain facies has a greater variety of rock types and facies geometries than the underlying delta front and prodelta facies. There is an excellent correlation between the characteristics of the delta plain facies of the Last Chance Delta and modern delta plain deposits. Details of this comparison are shown in Table 3.

While the Last Chance Delta was actively prograding, a network of distributary channels flowed generally to the north. The preserved remains of these channels are seen both as narrow, symmetrical channelform sandstones and as broader, less symmetrical deposits (Figure 7). In either case it is difficult to reconstruct more than a very rough approximation of the dimensions of the original distributary channels.

The distributary channels flowed through extensive flood basins which consisted mostly of standing water bodies (lakes, bays, sounds, or lagoons) in which organically mottled siltstone accumulated. In some places in the flood basin, marshes and swamps covered broad areas. They are the origins of the delta plain coals that are an important part of the reserves of the Ferron Sandstone (Lupton, 1916; Doelling, 1972).

When active progradation ceased, delta lobes foundered, and the destructive processes of

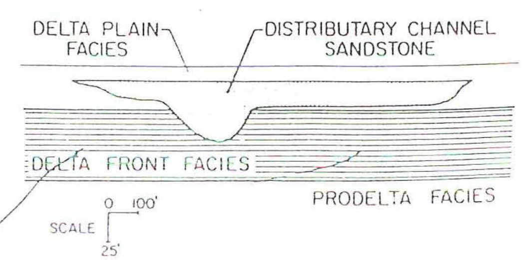

Figure 7. Diagrammatic cross section of distributary channel exposed on south-facing cliff along Willow Springs Wash. Vertical exaggeration 4x.

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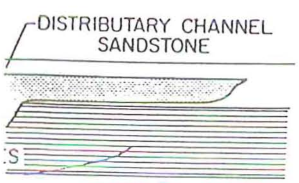

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Table 2. COMPARISON OF FERRON-LAST CHANCE DELTA FRONT FACIES AND MODERN DELTA FRONT DEPOSITS

DEFINITION

The delta front environment is the shallower, coarser, and, in part, steeper subaqueous part of a delta, extending from the delta plain seaward to the transition with the prodelta environment. There are two subenvironments of the delta front. Major sand deposition occurs on the *distal bar*, which is away from channel currents and deeper than normal wave influence. Sand is also deposited in the upper part of the delta front on the *distributary mouth bar crest*, which is scoured and winnowed by channel currents and/or by wave and tidal action.

FERRON-LAST CHANCE DELTA

Along the entire outcrop of the deltaic sequence (Figures 1 and 2) the delta front facies is continuous, generally about 40 feet (12 m) thick, and dominantly sandstone, with occasional thin interbeds of siltstone.

Changes upward from the basal transition with the prodelta facies include: (1) increase in grain size of the sandstone from very fine to fine and, in some places, medium, (2) increasing thickness of individual sandstone beds, (3) siltstone beds become thinner and less numerous, (4) dominant sedimentary structure changes from even parallel lamination to trough cross lamination.

Sandstone beds are typically sheetlike and have nearly horizontal or very low primary inclinations (Figure 3). Slight differences in angles of inclination cause some beds to wedge out updip or downdip.

At several localities the sandstone beds have relatively steep primary dips, up to about 15 degrees. On the south-facing Ferron scarp north of Ivie Creek (Figure 1) the steeply inclined delta front sandstone imparts to the deltaic sequence a Gilbert-type delta form with bottomset, foreset, and topset beds (Figures 4 and 5). The delta front facies includes not only the steeply inclined beds but also a relatively thin zone of horizontal beds of trough cross-laminated sandstone that in places cuts down into the underlying steeply dipping beds (Figures 4 and 5).

The general direction of inclination of the gently dipping beds is northward. In contrast, the steeply dipping beds are inclined toward the northwest or west.

Channelform zones of sandstone occur in this facies. Very small channels, that were probably formed as frontal splays, occur low in the sequence, sandwiched among the sheetlike sandstones. The thin zone of trough cross-laminated sandstone at the top of this facies in places cuts down lower in the sequence (Figure 5). These also might result from frontal splays in which the distributary mouth bar crest environment is cut deeper into the distal bar environment. And finally, distributary channels of the delta plain facies can cut deeply into the delta front facies (Figures 2 and 7).

The major sedimentary structure is even parallel lamination (Figure 6), and there are subordinate amounts of trough and planar cross lamination, ripple lamination, ripple drift cross lamination, several varieties of contorted lamination, and some graded beds. Toward the upper part of this facies the beds of sandstone are thicker and the most common sedimentary structure becomes trough cross lamination. All channelform sandstone zones are dominated by trough cross lamination.

Biogenic structures are uncommon, but *Ophiomorpha* and *Thalassinoides* were found at a number of places.

Finely comminuted plant material is present in most beds; it is particularly abundant in many of the intercalated siltstone beds.

Table 2. Continued
COMPARISON OF FERRON-LAST CHANCE DELTA FRONT FACIES AND MODERN DELTA FRONT DEPOSITS

MODERN DELTA FRONT DEPOSITS

References: Van Straaten, 1959; Coleman and Gagliano, 1964, 1965; Fisher et al., 1969; Donaldson et al., 1970; Gould, 1970; Kanes, 1970; Manka and Steinmetz, 1971.

Distal Bar Deposits

Alternating coarser (fine sand, very fine sand, or coarse silt) and finer (coarse silt or silty clay) layers that become thinner and finer grained distally.

The most common sedimentary structure reported is even parallel lamination. Cross lamination (mostly trough) and ripple lamination are found. Contorted bedding is present in many distal bars, and grading can be found in coarser layers.

Plant debris is common; sometimes there are scattered shells; and the degree of burrowing is variable.

Channels and gullies are not uncommon. These have been attributed to frontal splay processes during floods, to mass movement (Shepard, 1960), and to turbidity currents (Van Straaten, 1959).

Distributary Mouth Bar Crest Deposits

Well-sorted sediment of bed-load size.

Predominantly unidirectional or multidirectional trough cross lamination and subordinate ripple lamination. Local scour-and-fill, some slumping, and contorted bedding are all noted.

Breaches cut into the bar crest during floods can be repaired by a combination of channel and marine processes between the floods. The coarser sediment removed from the bar crest by this flood scour is splayed distally to accumulate on the distal bar or in the prodelta.

In such a high-energy environment as this, shells and biogenic structures are rare, and plant debris accumulates mostly in the uncommon finer layers.

Table 3. COMPARISON OF FERRON-LAST CHANCE DELTA PLAIN FACIES AND MODERN DELTA PLAIN DEPOSITS

DEFINITION

The delta plain is "the principal subaerial part of a delta and includes minor subaqueous environments such as channels and lakes . . . it comprises distributary and tidal channels, natural levees, and flood basins (swamps, marshes, lakes, bays, and gathering streams)." (Bernard and LeBlanc, 1965, p. 162). Following delta lobe abandonment, "a series of arcuate barriers or delta margin islands are thrown up by reworking of underlying sandy delta front deposits; these will transgress landward as the delta founders." (Fisher and Brown, 1972, p. 44).

FERRON-LAST CHANCE DELTA

General

The delta plain facies consists mainly of horizontal strata of sandstone, siltstone, and some coal organized with a greater variety of rock types, thicknesses, and facies geometries than the underlying delta front and prodelta facies.

Relative amounts and thicknesses of the major rock types vary from place to place, and the constituent subfacies are organized in a variety of channel, lenticular, and sheetlike forms.

Thickness of entire delta plain facies ranges from zero to more than 40 feet (12 m).

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Table 3. Continued

COMPARISON OF FERRON-LAST CHANCE DELTA PLAIN FACIES AND MODERN DELTA PLAIN DEPOSITS

Distributary Channels and Levees

Large, sandstone-filled channels have their flat tops at various positions within the delta plain facies and their concave-upward bases extending down to various levels, even well down into the delta front facies (see example in Figure 7). General direction of sediment transport was from south to north.

The channels are cross sections of ribbons of sandstone that are elongated approximately south-north. Some channel cross sections are relatively narrow and symmetrical (width:depth ratios of about 10:1); others are much broader and less symmetrical (Figure 7).

Trough cross lamination is by far the most common sedimentary structure in all channels. It occurs from at or near the base to within a few feet of the top, where it is replaced by ripple lamination and ripple drift cross lamination.

Grain size is uniform through most of the channel and decreases in the uppermost few feet. The average grain size varies from one channel to another, being medium in some, fine in others.

Lower parts of some channels contain numerous inclusions of coal and shale, concentrated in places along poorly defined bedding planes. Coal inclusions range in size from thin films to large blocks, in a few of which *Teredo*-like borings occur.

Natural levee deposits have not been identified conclusively. Some thin zones containing irregular to wavy beds of rippled sandstone and interbedded siltstone were noted to wedge out laterally. It is possible that burrow mottling has made levee deposits indistinguishable from associated flood basin deposits.

Flood Basin – Standing Water Bodies

The most abundant rock type in the delta plain facies is dark brown to medium brown siltstone that is extensively mottled, leaving only crude remnants of the original primary horizontal stratification. The mottling is the result of both animal burrowing and plant root penetration.

Abundant fragments of mollusks and/or high concentrations of wood (coal) particles, both large and small, are scattered throughout some zones.

Flood Basin – Marshes and Swamps

Plant remains are very abundant in the delta plain facies, not only as coaly clasts or comminuted debris, but also as numerous discrete coal beds.

Individual coal beds range in thickness from a fraction of a foot to more than 10 feet (3 m), and commonly there is more than one bed at a given locality.

Details of the number and correlation of the coal beds is available in Lupton (1916). Reserve estimates have recently been updated by Doelling (1972).

Lateral continuity of some coal beds is quite extensive, although Lupton's (1916) correlation of some beds over more than 20 miles (32 km) has not been checked.

Destructive Delta Margin Sands

These occur at the top of the delta plain facies in zones from 6 inches (15 cm) to 6 feet (1.8 m) thick.

Sandstone is well-sorted, thin- to medium-bedded, typically fine-grained, and has even parallel lamination and some broad trough cross lamination.

Biogenic structures, while not destroying the primary stratification, are nevertheless rather common. They comprise principally vertical *Ophiomorpha* tubes, horizontal branching networks of *Thalassinoides*, and, less commonly, the funnellike *Rosselia* (Cotter, 1973).

Table 3. Continued
COMPARISON OF FERRON-LAST CHANCE DELTA PLAIN FACIES AND MODERN DELTA PLAIN DEPOSITS

MODERN DELTA PLAIN DEPOSITS

Distributary Channels and Levees

References: Coleman and Gagliano, 1965; Fisher et al., 1969; Allen, 1970; Oomkens, 1970.

Coarsest bedload sizes near the base and through most of the channel deposit. The finer sizes are near the top. Sand is poorly to moderately well sorted.

Angular clay clasts and plant debris, including logs, are common, particularly near the base.

Trough cross lamination is very common throughout most channel deposits, and ripple lamination, if present, is in the finer-grained upper part. Gravity-induced slumps, folds, and faults are present in some channels.

Natural levees flank the distributary channels. The grain size of the levee deposits decreases laterally away from the channel into the adjacent flood basin. If any of the sedimentary structures survives the commonly intensive mottling caused by plant roots and burrowing organisms it is likely to be ripple lamination, particularly ripple drift cross lamination.

Distributary channels are typically relatively straight, and their levee deposits flank the upper part of the channel deposit. If there was any channel meandering, levee deposits would cap the channel point bar deposits.

Flood Basin – Standing Water Bodies

References: Coleman et al., 1964; Coleman and Gagliano, 1965; Allen, 1970.

Varieties of these water bodies are not consistently named. Among them are bays, lagoons, sounds, and lakes. They are either partly or completely open to the sea, or inland and more restricted.

Deposits are usually dark gray to black organic mud, with thin silt laminae that were introduced during floods.

Intense burrowing commonly obliterates the primary stratification, producing a churned and homogenized sediment composed of silty clay or clayey silt, with usually abundant plant remains and shells.

Variations in lithology, grain size, and biota arise because of differences in proximity to channel levees and differences in the degree of restriction of water circulation.

Flood Basin - Marshes and Swamps

Marshes and swamps are periodically inundated areas which can be quite extensive, covering up to 90 percent of the delta plain (Fisher et al., 1969, p. 18).

Growth and accumulation of plants (nonwoody in marshes, woody in swamps) is interrupted by the inundations, which introduce clays and silts. Such thin introduced clay and silt laminae are obliterated by plant root disruption and intensive animal burrowing.

Deposits are peats and organic clays.

Destructive Delta Margin Sands

References: Fisher et al., 1969; Allen, 1970; Donaldson et al., 1970; Kanes, 1970; Oomkens, 1970.

These are usually well-sorted sands that have the even parallel or low-angle cross lamination typical of beach and shoreface deposits.

Burrowing can be quite extensive, and burrows of the *Callianassa* type are common.

Shells can also be common, with their fragments ranging in amounts from a scattered few to cross-laminated coquinas.

In some cases plant debris is present, and there might be intercalated thin clay beds.

marine origin reworked the delta front sands into destructive delta margin sands that were veneered back over the delta plain facies. This incomplete transgressive sand sheet has many of the features of beach and shoreface deposits, and it is found as a thin well-sorted sandstone sequence at the top of the delta plain facies.

DISCUSSION

Steeply Inclined Sequences

The erroneous idea that delta fronts should have steep foreset beds became widely accepted after 1885, when G. K. Gilbert described deltaic deposits that had been constructed into glacial Lake Bonneville (Gilbert, 1885). However, it became clear that there are very few ancient deltas that have this "Gilbert-type" anatomy. Some of the reported examples of steeply inclined delta front foreset beds in ancient deltaic sequences (aside from Pleistocene ice-dammed or pluvial lakes) include those of Cretaceous (Taylor, 1963; Howard, 1966; Carrigy, 1971; MacKenzie, 1971), Carboniferous (Collinson, 1968, 1969), and Eocene (Van Eden, 1970) age.

Gilbert-type deltas have been suggested to develop under conditions of flow in which the density of the inflowing fluid is similar to that of the receiving basin fluid (Bates, 1953; Fisher et al., 1969). Such flow, in the opinion of Bates (1953, p. 2130-2131), "can best take place where a river flows into a well-mixed lake having a water temperature about the same as that of the river. Shallow embayments in the region of a marine littoral delta can also be the site of such deposition if the salt water in such basins is completely flushed out by the marked influx of river water."

The Last Chance Delta in several places left delta front deposits that are steeply inclined, in the manner of a Gilbert-type delta (Figures 4 and 5). In each instance the delta front beds dip toward the northwest or west in contrast to the more generally northward dips of the gently inclined sequences. And in the case of the Ivie Creek occurrence there is to the west of the steeply inclined delta front facies a laterally equivalent very fine-grained, bioturbated sandstone that is possibly a lagoonal deposit. Such a marginal embayment or lagoon has been postulated by others (Hale and Van De Graaff, 1964, p. 129, Figure 5; Hale, 1972).

This leads to the attractive consideration that the steep delta front foreset beds developed as fluid from the Last Chance distributary channel system flowed into a westerly embayment in which the salinity had been significantly reduced. Fluid flow into more normal salinity waters produced the more common gently inclined sequences.

Nature of the Delta

Because of the linearity of the Ferron Sandstone outcrop belt in the Castle Valley (Figure 1) in a direction generally parallel to that of delta progradation, many aspects of the three-dimensional facies geometry are difficult to decipher and incorporate into a picture of delta evolution. However, it is possible to say that the Last Chance Delta formed as a broad, fan-shaped complex comprising numerous coalescing and overlapping subdelta lobes. This is indicated by the sand-rich nature of the delta front facies, by the cyclic nature of progradation at many places (e.g., Figure 3), and by the variations of style of delta front accumulation (gentle versus steep primary inclinations).

The exposed part of the Last Chance Delta prograded generally northward into the Late Cretaceous Mancos sea. This direction of growth is illustrated in a general manner by Hale and Van De Graaff (1964, Figure 5) and Hale (1972, Figures 2 and 3). The progradation produced a sequential northward displacement of the facies tract (Figure 2), and it is also indicated by the generally northward inclination of the delta front beds, by the south-to-north orientation of distributary channels, and by the south-to-north orientation of current-produced sedimentary structures in a variety of facies. A minor amount of progradation of at least a few subdelta lobes toward the west or northwest produced the steeply inclined delta front sequences discussed above.

Whether the Last Chance Delta also had an easterly component of progradation cannot be determined from the Castle Valley outcrops of the Ferron Sandstone alone. In the region of the Henry Mountains, Utah, located to the southeast of the Castle Valley, deltaic deposits at the base of the Ferron Sandstone near Caineville Wash indicate progradation generally to the east. If this Ferron deltation near the Henry Mountains is approximately contemporaneous with the Last Chance Delta of the Castle Valley, it would indicate a much larger delta complex than can be interpreted from the Castle Valley Ferron alone.

The Last Chance Delta prograded into marine water that was approximately 40 feet (12 m) or less deep, as indicated by the widespread occurrence of the 40 foot (12 m) thick delta front facies. Because the basin was relatively stable, the facies are very broadly distributed and not stacked vertically. The prodelta deposits of the Last Chance Delta are very thin in comparison to those of rapidly subsiding basins (Fisher et al., 1969). Some subsidence, however, must have occurred during deltation to allow accumulation of the observed delta plain facies, and to prevent distributary channels from cutting through the entire delta front facies. Continuation of subsidence after delta abandonment permitted encroachment of the sea over the delta plain and led to the deposition of thin destructive delta margin sands.

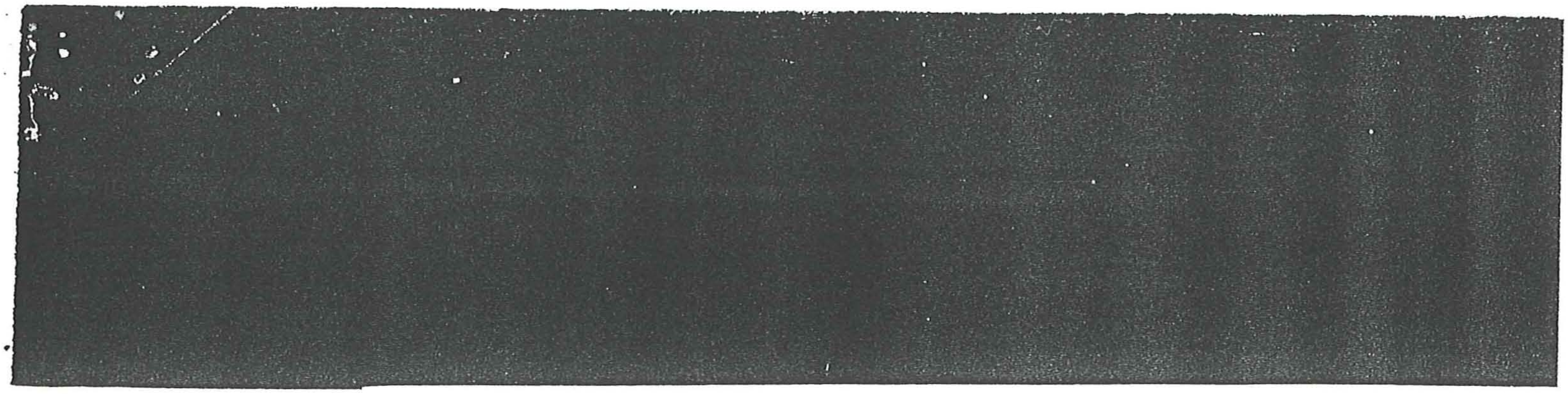
The extensive development of fluvially-influenced progradational and aggradational facies, along with the relatively minor reworking by marine processes, classify the Last Chance Delta as a high-constructive delta (Fisher, 1968; Fisher et al., 1969). Because of the high sand content of the delta front facies and the nearly continuous nature of the distal bar deposits, the Last Chance Delta can be further considered a high-constructive lobate delta (Fisher et al., 1969). The degree of marine reworking during active delta progradation, while relatively minor, was still sufficient to produce an essentially continuous fringe of sand in the delta front environment.

Subsurface Relations

There has been a significant number of wells that produce natural gas from the subsurface Ferron Sandstone west of of the Castle Valley outcrop belt (Edson et al., 1954; Kuehnert, 1954; Walton, 1954; Hale, 1972). These wells are not producing from deposits of the Last Chance Delta but from those of another depositional system with a source to the northwest (Hale, 1972, Figure 2). Because this more northerly system is also a deltaic complex, there is some value in considering the little that is known about the facies relationships of the gas accumulation as a possible model for the Last Chance Delta.

The relationships depicted by Hale (1972) show this northerly depositional system as a northwestward-thickening clastic wedge. At the base there is a thick, continuous sheet of sandstone that is overlain by a more complex pattern of shale, sandstone, and coal. Only the lowest sandstone zone is continuous from well to well (Edson et al., 1954). Higher sandstones are laterally discontinuous and are more directly associated with coals. The subsurface pattern by itself manifests a deltaic depositional system very much like that of the Last Chance Delta. This can be seen by a comparison of cross sections of the northern system (Hale, 1972, Figures 5, 6, and 7) with cross sections of the Last Chance Delta (Figure 2 of this paper; Hale, 1972, Figure 4). This interpretation agrees with regional paleogeographic relationships that show this northerly depositional system to be the southwesterly part of a large deltaic complex called the Vernal Delta (Hale and Van De Graaff, 1964; Barlow and Haun, 1966; Maione, 1971).

In the framework of this northerly deltaic depositional system, the laterally continuous basal sandstone zone is most likely the delta front facies of the Vernal Delta. Higher sandstone zones are distributary and fluvial channel deposits. Published reports of relationships in the Ferron Sandstone of the Wasatch Plateau gas fields present rather sketchy and, in some respects, conflicting information (Edson et al., 1954; Walton, 1954). It appears that a significant portion, though not all, of the gas is produced from relatively tight and almost impermeable sandstone in the laterally continuous delta front facies at the base of the Vernal Delta sequence. Additional gas production is from the higher, less widespread, distributary and fluvial channel sandstones.



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