The Ferron Sandstone —
Overview and Reservoir Analog
“The bunch,” Lupton’s field team near Cleveland, Utah, circa 1910. Photograph courtesy of the family of C. T. Lupton.
Previous Studies of the Ferron Sandstone

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ABSTRACT

The Ferron Sandstone has, at least by North American standards, a long and rich history of study. Early interest in the Ferron was based on the fact that it contains substantial amounts of mineable coal, the presence of which was noted in the geological literature as early as 1874. A comprehensive documentation of the many coal seams of the Ferron was published in 1916.

Several studies published in the late 1800s and early 1900s established basic correlations between the Ferron outcrops in Castle Valley and equivalent strata in other areas. Initial correlations were done entirely on the basis of similarity of sections — by means of what is commonly called “jump correlation.” This approach led to some errors that were subsequently corrected as the role of biostratigraphy in stratigraphic correlation became increasingly important.

Early attempts to interpret the paleogeographic setting of the Ferron led to interesting but erroneous results. A model of Ferron deposition published in the 1920s evoked southward transport of clastics to form a large, elongated sand-rich body or “plume” centered on Castle Valley. The interpretation was incorrect, stemming from a miscorrelation between Castle Valley and scattered outcrops on the western side of the Wasatch Plateau, but it heralded a theme that would be recurrent in the interpretation of the Ferron.

Discovery of a significant accumulation of natural gas in the Ferron Sandstone at Clear Creek field on the Wasatch Plateau in 1951 accelerated the pace of Ferron study. The Ferron was described in much greater detail, but a correct interpretation of Ferron paleogeography remained elusive. The concept that Ferron strata were deposited by prograding deltas and on adjacent strand plains became firmly established in the literature by well documented sedimentological data. Cyclicity was recognized and the issue of whether the cycles resulted from auto- or allocyclic processes was raised.

The basic stratigraphic framework of the Ferron, as we know it today, was constructed in the late 1970s and early 1980s. Recent studies have addressed the details and the numerous Ferron studies completed during the last 20 years, taken in their entirety, represent one of the most detailed stratigraphic and architectural frameworks available for any clastic unit in the world.

Many recent studies make use of the detailed stratigraphic framework to focus on the petroleum reservoir properties of the various facies recognized in the Ferron, which provides a wealth of well exposed and well understood analogs for petroleum reservoirs elsewhere. At the same time, the Ferron has become an important producer of coalbed methane from the northern part of Castle Valley.

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STRATIGRAPHY

Early Studies of the Ferron

The Ferron Sandstone was described as a member of the Mancos Shale by Charles T. Lupton (1916) in his comprehensive study of the coal resources of Castle Valley. Lupton mentioned the Ferron in an earlier publication (1914), making this the first formal use of the name, but the first meaningful description of the Ferron occurs in his 1916 work. Lupton did not designate a type locality or type section for the Ferron, stating simply that the member “is well developed in the vicinity of Ferron and Emery” (Lupton, 1916, p. 31). In his description of the Ferron, he included a 475-foot- (145-m-) thick stratigraphic section that he had measured through the Ferron in Ivie Creek Canyon, about 8 mi (13 km) south of the town of Emery (Figure 1). It is clear that he considered the Ivie Creek section representative of the Ferron and its coalbeds. Had the designation of a type section been required in the naming of a stratigraphic unit then, as it is today, it is likely that Lupton would have chosen the Ivie Creek section as his type section for the Ferron.

At least two geologists, Hoxie (1874) and Taft (1906), had examined the Ferron outcrops in Castle Valley prior to Lupton’s study. Both had misinterpreted its stratigraphic position, but in different ways. Hoxie (1874) interpreted the coal-bearing Ferron outcrops in the vicinity of Emery to be a down-faulted block of Montana Group strata (the coals, therefore, belonging to what is now known as the Blackhawk Formation — see account by Lupton, 1916, p. 9). Taft (1906) believed that the Ferron in Castle Valley belonged to the Jurassic section (what Lupton [1916] and other early workers referred to as the McElmo Formation, which apparently spanned the Carmel through Morrison Formations of today’s terminology).

Taft’s work was very much reconnaissance in nature, but he did descriptively name some of the stratigraphic units. The Tununk Shale was designated the “Shale of the San Rafael Swell”, the Ferron the “Sandstone of the Red Plateau,” and the Blue Gate Shale the “Shale of Castle Valley.” According to Lupton (1916), Red Plateau is an antiquated name for Cedar Mountain, at the northwestern edge of the San Rafael uplift. The Ferron is not present on Cedar Mountain. Taft had miscorrelated the Ferron with the Jurassic section. These names were not used by any subsequent authors. Taft produced a generalized map of Castle Valley (Figure 2). On it is traced the contact between the Blue Gate Shale and the Ferron Sandstone. The contact is more or less correct between Ivie Creek and Ferron Creek, but farther north is misplaced toward the east.

The transgressions responsible for deposition of the Tununk Shale, the regression that led to deposition of the Ferron, and the transgression that marks the change from Ferron to Blue Gate deposition were widespread events in the Western Interior. Sandy strata equivalent to the Ferron had been recognized in the Henry Mountains basin by Gilbert (1877). He named this unit the Tununk Sandstone and the underlying marine shale the Tununk Shale. The marine shale overlying his Tununk Sandstone he named the Blue Gate Shale and the ridge-forming sandstone above that the Blue Gate Sandstone (Gilbert’s Blue Gate Sandstone, which is equivalent to the Star Point Sandstone of the Wasatch Plateau, has been renamed the Muley Canyon Sandstone by Eaton, 1990). Lupton (1916) miscorrelated the Castle Valley and Henry Mountains basin sections, equating the shale beneath the Ferron in Castle Valley to the Blue Gate Shale, and possibly the Tununk Sandstone and Tununk Shale as well, and the Ferron Sandstone of Castle Valley to the Blue Gate Sandstone of the Henry Mountains basin. The error
probably stems from the very similar appearances of the ridges formed by the Ferron along the Molen Reef and Coal Cliffs outcrops on the west flank of the San Rafael uplift and those formed by Gilbert’s Blue Gate Sandstone around Caineville, in the northern part of the Henry Mountains basin.

Lupton’s (1916) study of the Ferron was very much focused on coal: his description of the rocks of the Ferron is rudimentary and lacks any discussion of facies. Lupton noted the pronounced northeastward thinning and loss of sandstone in the Ferron, but did not offer any interpretation he may have had of how and why such a change takes place. He did comment on the presence of “local unconformities” in the Ferron, one of which he documented in a photograph. The photo (his Plate IIIb) illustrates a fluvial channel scoured into the basal shallow-marine sandstone unit (Kf-1 of Anderson and Ryer, this volume) on exposures along the west side of Blue Trail Canyon, south of I-70. Discordance between the inclined strata of a point-bar deposit within the channel fill and the horizontally bedded sandstone of the underlying shoreface constitutes the evidence for an unconformity. Although Lupton did not discuss the origin of this angular contact in the Ferron, his discussion of a similar feature that he recognized in the Dakota Sandstone makes it clear he understood that the angular “local unconformities” were products of channels cut into pre-existing sediments.

Lupton portrayed Ferron stratigraphy using a series of measured sections (Figure 3) ranging from the Paradise Lake area of the Fish Lake Plateau on the south to the Castle Valley outcrops south of Wellington on the north. Five of the eight sections are hung on his A coal bed. To the northeast, beyond the limit of deposition of the A coal, carbonaceous shale is identified and used as a datum in sections at Short Canyon and Horn Silver Gulch, east of Ferron. This carbonaceous shale, which forms a conspicuous black band on fresh outcrops, is of marine origin and occupies a position between the top of the Washboard unit and the base of Kf-2, gradually changing facies to normal, silty marine mudstone southward along the Molen Reef. Lupton’s northern three sections are hung too high. Although he noted some of the principal lithologic differences between the Ferron sandstones in the northern part of Castle Valley and the coal-bearing Ferron strata in the southern part, he failed to recognized that they occupied slightly different stratigraphic positions.
Despite the above-mentioned correlation problem, plus what are now known to be minor miscorrelations of the coals, Lupton's simple cross section identifies the fact that most of the northeastward thinning of the Ferron occurs in its upper part. It is fairly clear that Lupton did not recognize the lateral equivalence of the upper part of the Ferron and the lower part of the Blue Gate Shale to the northeast. His was a simple, "layer-cake" stratigraphy with the complication that one of the layers varied in thickness.

Because Lupton (1916) designated the Ferron as a member of the Mancos Shale and because this has become standard U.S. Geological Survey usage, subdivisions of the Ferron must be sub-member-level units. Assignment of the Ferron to member status came about as a result of the westward extension of stratigraphic terminology as geologists moved westward during the course of their studies. The Mancos Shale was originally named for outcrops in southwestern Colorado (Cross and Spencer, 1899), where the Mancos lacks sandy mem-
bers. Upon encountering sandstones in the Mancos in Castle Valley, Lupton (1916) chose to distinguish members, rather than to elevate the Mancos to group status and recognize formations within it. In hindsight, this was an unfortunate choice. On the basis of its thickness and wide areal extent, the Ferron Sandstone, the Emery Sandstone, and the marine shale intervals that separate them certainly deserve formation status. Some authors (most notably Hale, 1972) have, in fact, described the Ferron as a formation, but without going through the exercise of formally proposing a change in status.

Although it lacked detailed stratigraphic description, Lupton’s (1916) study of the Ferron provided a sound foundation on which subsequent investigators could build.

Paleoenvironments of Deposition

The first publications that attempted to place the Ferron Sandstone in a paleoenvironmental setting were authored by Spieker and Reeside (1925, 1926). The earlier publication focused on the stratigraphy of Castle Valley and the eastern side of the Wasatch Plateau; the second attempted to correlate the Castle Valley section westward to isolated Cretaceous outcrops on the western margin of the Wasatch Plateau near the towns of Manti and Salina. The papers are interesting for their descriptions of Cretaceous strata, but more importantly, represent a significant conceptual advance, portraying lateral as well as vertical relationships between the units.

Regional Stratigraphy

Spieker and Reeside’s 1925 paper portrays northeastward interfingering of the upper part of the Ferron and the lower part of the Blue Gate Shale, the base of the Ferron being drawn as a horizontal surface in Castle Valley. Citing the presence of coal in drill holes near the town of Price, they noted (p. 438) the “regional tendency of the Cretaceous beds to change westward from marine to littoral, to continental and coal-bearing sediments.” This is the situation pictured, albeit in a very general way, along the Castle Valley outcrops for the upper part of the Ferron.

Spieker and Reeside’s correlations between the Henry Mountains basin, Castle Valley, and the western part of the Book Cliffs are shown in Figure 4. Clearly portrayed is northeastward interfingering of the upper part of the Ferron Sandstone and the lower part of the Blue Gate Shale. Section 1, at the left, is based on Gilbert’s (1877) study of the Henry Mountains basin; sections 2 and 3 represent the southern and northern parts of Castle Valley; section 4, at the right, is at Horse Canyon, in the Book Cliffs. Lupton’s (1916) miscorrelation of the Ferron Sandstone of Castle Valley with the Blue Gate Sandstone of the Henry Mountains Basin is corrected. The Ferron is properly shown as equivalent to Gilbert’s Tununk Sandstone (the name Tununk Sandstone was discarded and replaced with the name Ferron Sandstone Member by Hunt [1946]).

Paleogeography

Spieker and Reeside’s 1926 paper offers a broader paleoenvironmental interpretation of the Ferron than any of the earlier studies. They interpreted the Ferron Sandstone in Castle Valley to represent a sandy peninsula or shoal area in the sea (Figure 5) that extended southward from the area of the present-day Wasatch Mountains and Uinta Basin. A unit of marine shale recognized on outcrops along the western side of the Wasatch Plateau, and subsequently named the Allen Valley Shale by Spieker (1946), was correlated with the Ferron, as were shales of the Mancos east of Castle Valley. The correlation across the breadth of the Wasatch Plateau was incorrect, although the error was not recognized until the 1950s (it remains in Spieker’s landmark 1946 paper detailing Mesozoic and Cenozoic stratigraphy and paleogeography in central Utah). Spieker and Reeside’s (1926) interpretation of Ferron paleogeography is the first of several interpretations in which all or part of the
Ferron in Castle Valley was reconstructed as a southward-extending body with a northern provenance surrounded on three sides by shaley strata.

Study of the Ferron Sandstone Accelerates

Gas was discovered in the Ferron Sandstone at Clear Creek field in the northeastern part of the Wasatch Plateau in 1951 (see Petroleum in the Ferron Sandstone section later in this paper). The discovery prompted the publication of several studies in the 1950s that led to a great improvement in the understanding of Ferron stratigraphy and depositional history.

Katich (1953, 1954) studied the Ferron in the vicinity of the Wasatch Plateau and came to a very different conclusion about Ferron paleogeography than had Spieker and Reeside (1926). The presence of the ammonite Collignoniceras woolgari in both the Allen Valley and Tununk Shales demonstrated their equivalence. The Ferron was shown (Katich, 1953) to be younger than the Allen Valley Shale, being equivalent, instead, to the lower part of the Funk Valley Formation (Spieker, 1946) of the western Wasatch Plateau. Katich’s (1953) paleogeographic map (Figure 6) represents Ferron paleogeography in a much simpler form and resembles most paleogeographic maps produced by later authors. His analysis of cross stratification in fluvial sandstone of the Ferron convincingly demonstrated that fluvial sands of the Ferron on the Castle Valley outcrop belt had a western and southwestern, not a northern, source.

Davis (1954) studied the Ferron and reached many of the same conclusions that Katich had. Davis confirmed a concept that had earlier been reached by Katich (1951) in his dissertation, but which had been retracted in his publication (Katich, 1954): that the Ferron consists of two distinct parts. Davis designated these the lower and upper units of the Ferron.

The lower Ferron consists of gray, fine-grained, calcareous, marine sandstone and siltstone and contains two distinctive horizons bearing large, “cannon-ball” concretions. It extends from “Molen Amphitheater” and the southern part of Molen Reef northeastward to the vicinity of Price, generally varying between 60 and 70 ft (18 and 21 m) in thickness. Davis believed that he could recognize the lower Ferron on wireline logs run in the gas...
wells of Clear Creek field. He correlated the lower Ferron to the uppermost, silty and sandy part of the Tununk Shale in the Henry Mountains basin. Southward thinning and loss of sandstone suggests a northern or northwestern source, although no paleocurrent or other definitive data was cited in support of this interpretation.

The upper Ferron comprises a much wider variety of rocks than does the lower Ferron: shallow-marine sandstone, coal, carbonaceous shale, and fluvial sandstone in lenticular bodies are common. The upper Ferron is about 500 ft (150 m) in thickness south of Emery, feathering out into marine shale northeastward along the Castle Valley outcrops. The paleocurrent data indicating a southwestern source described by Katich (1953) and confirmed by Davis (1954) are all from strata of the upper Ferron.

Davis’ (1954) studies led him to the conclusion that “a decided change in sedimentation took place in the passage from the lower Ferron to upper Ferron time. Deposition from the northwest and western sources became practically insignificant as compared with a new strong supply that began to come from the southwest.” This conclusion has been borne out by all later studies, with one notable exception discussed later.

Edson et al. (1954) described the productive Ferron section in Clear Creek field. Seven sands were recognized in the discovery well, leading to a “1st” (shallowest) to “7th” (deepest) sandstone terminology that was applied to the field. Detailed correlation of the well logs indicates that only the 7th sandstone is continuous throughout the field; all of the other sandstones are lenticular and their number and positions vary between well bores. Although Edson et al. (1954) did not interpret facies and paleoenvironments, it is now clear that the basal sandstone was deposited on the prograding shoreline and that the remaining, shallower sandstones are of fluvial origin.

Knight (1954) studied the heavy mineral content of samples of Ferron Sandstone collected from outcrops and from wells drilled on the Wasatch Plateau. Correlating sandstones between wells at Clear Creek field had proven to be very difficult. Knight’s study was undertaken with the purpose of determining whether or not heavy minerals were of value in establishing correlations between individual sandstone beds of the Ferron in the subsurface. His results are negative, with the exception of one general conclusion that lends support to the paleoenvironmental interpretations of Katich (1953) and Davis (1954): that “confine[ment] of ... garnet to the southern area [southern part of Castle Valley] seems to indicate a sedimentary realm separated by one means or another from that in which the rest of the Ferron was deposited and also a separate, local source area.”

Important papers describing the petroleum geology of late Paleozoic through Early Tertiary strata beneath the Wasatch Plateau and on the western flank of the San Rafael uplift were published by Walton (1954, 1955). The bearing of Walton’s papers on hydrocarbons in the Ferron is discussed later, but one critical point must be mentioned here because it influenced the paleoenvironmental interpretation of some later investigators. Walton (1955, p. 399), in a brief description of the Ferron, stated that the member “has little or no coal [in the northeastern part of the Wasatch Plateau] and appears mostly marine throughout.” Subsequent work has shown that only the basal sandstone section of the Ferron is of shallow-marine origin beneath the northeastern part of the Wasatch Plateau; the remainder is composed of continental strata. Coal is best developed in a position farther to the east. Much the same relationship can be documented on the Ferron outcrops in the southern part of Castle Valley and on the east flank of the Fish Lake Plateau.

Ferron Deltas

Cretaceous paleogeography was reconstructed for a broad area including northeastern Utah, northwestern Colorado and southwestern Wyoming by Hale and Van De Graaff (1964). Castle Valley lies at the southwestern edge of their maps. Hale and Van De Graaff (1964, p. 129) mapped a large “eastward bulging delta-like feature” centering on the Uinta Basin and Uinta Mountains and extending eastward just beyond the Utah-Colorado state line. They referred to it as the “Vernal delta.” Their map shows a narrow embayment on the southern flank of the delta, stretching southwestward from the area north of Price to the vicinity of Clear Creek field. Although Hale and Van De Graaff offered no evidence to support the existence of this embayment, there can be little doubt that it’s origin lies in Walton’s (1954 and 1955) assertions that the Ferron at Clear Creek field is mostly or entirely of marine origin.

Hale (1972) studied subsurface data from wells drilled during the 1950s and early 1960s in the search for gas beneath the Wasatch Plateau and combined them with original outcrop studies to arrive at a new interpretation of Ferron paleogeography and depositional history. He elaborated on Davis’ (1954) concept of two distinct members of the Ferron, although he defined them in a different way. He revived Spieker and Reeside’s old idea of a southwest-extending peninsula, though in a different location. Two paleogeographic maps (Figures 7 and 8) summarize Hale’s concepts.

Hale (1972) recognized two geomorphic features on which predominantly sandy sediments accumulated during early Ferron time: the “Castle Valley bar” in the north, a west-southwestward extending peninsula supplied with sediment from the Vernal delta and fed by long-shore drift, and the “Last Chance delta,” a northeastward extending deltaic complex fed from the southwest and named for exposures along Last Chance Creek.
Figure 7. Hale's (1972) interpretation of early Ferron paleogeography. The critical feature in this map is the Castle Valley bar, which separated the large Sanpete Valley embayment from the Cretaceous seaway. From Hale, 1972.
Figure 8. Hale's (1972) interpretation of late Ferron paleogeography. Sea-level rise and transgression has obliterated the Castle Valley bar. From Hale, 1972.
on the east side of the Fish Lake Plateau. A large inlet situated at the town of Ferron separated the two and allowed exchange of marine water with the “Sanpete Valley embayment,” which lay to the west of both features. The Sanpete Valley embayment is the most significant feature in this interpretation, defining the northwestern margin of the Last Chance delta and the western margin of the Castle Valley bar. The only evidence Hale offered for the existence of the Sanpete Valley embayment is Walton’s (1954, 1955) statement that the Ferron at Clear Creek field is entirely of marine origin. Aware that the Ferron includes coal in many of the wells that penetrated the embayment section, Hale (1972) rationalized that the “few thin carbonaceous shales and coaly streaks are ... carbonaceous matter derived from [an] adjacent paludal environment.”

Hale defined the “Lower Ferron,” a member-level unit, to include the deposits of the Castle Valley bar and the Sanpete Valley embayment, plus time-equivalent deposits in the lower part of the Last Chance delta. Rise of relative sea level subsequently submerged the Castle Valley bar and the area of the Sanpete Valley embayment to become part of the Mancos seaway. The “Upper Ferron” includes the younger part of the Last Chance delta. Davis (1954; and Katich, 1951, before him) had interpreted the lower Ferron to be an older, northern depositional system and the upper Ferron a younger, southern system. Hale’s interpretation of contemporaneity of the northern Ferron system and the lower part of the southern deltaic system is quite different. Subsequent work would show the earlier interpretations of Katich and Davis to be correct. Although Hale’s (1972) interpretation of paleogeography was rejected, his Vernal and Last Chance deltas have been recognized, at least as generalized features, by most students of the Ferron who followed.

Cotter conducted a study of the entire Ferron outcrop belt during the early 1970s. His work culminated in a series publications (Cotter, 1971, 1975a, 1975b, 1976) that offered interpretations of Ferron stratigraphy and depositional history that were considerably more refined than the preceding interpretations. Cotter’s interpretations incorporated important concepts that evolved from numerous studies of depositional processes in modern alluvial plain, coastal, and shallow-marine settings that had been completed during the 1960s.

Cotter (1975a) defined four mappable “units” (Figure 9) on the Ferron outcrops of northern Castle Valley. These strata correspond to the lower Ferron of Davis (1954). Most important are the Clawson unit and overlying Washboard unit, which are laterally continuous over most of the length of the Castle Valley outcrops. They constitute two upward-coarsening depositional units composed predominantly of very fine to fine-grained, silty sandstone that has been extensively burrowed in most areas. They bear the distinctive “cannon ball” concretions described by previous authors. Cotter (1975a, 1975b, 1976) documented the fact that these two units disappear southward by facies change into normal marine shale in the uppermost part of the Tununk Shale. He clearly demonstrated that they occupy a position stratigraphically beneath the coal-bearing strata of the
Cotter interpreted the Clawson and Washboard units as representing a low-energy coast where sand, transported southward by longshore drift from the Vernal delta (Figure 11), accumulated on barrier islands similar to Sapelo Island, Georgia.

Cotter (1975b, 1976), like Katich, Davis, and Hale before him, interpreted the coal-bearing strata of the upper Ferron to represent a generally eastward to northeastward prograding delta, to which he applied Hale’s (1972) name “Last Chance delta.” Cotter offered a very specific interpretation of the delta: it “formed as a broad, fan-shaped complex comprising numerous coalescing and overlapping subdelta lobes” (Cotter, 1976, p. 481) representing a high-constructive lobate delta. Cotter recognized the cyclic character of progradation of the Ferron shoreline (Figure 12) and found in his deltaic interpretation an explanation for the cyclicity: the process of deltaic progradation followed by subsequent abandonment and transgression. His interpretation (Figure 13) shows two hypothetical delta lobes superimposed on a map of the Ferron outcrops in southern Castle Valley. Although the figure is generalized, it clearly indicates that progradation and abandonment of delta lobes might explain shoreline regressions and transgressions of 5 mi (8 km) or more, enough to explain the youngest “deltaic facies” sandstone pictured in Figure 10. Cotter’s work contains the first clear conceptualization of cyclicity in the deltaic deposits of the Ferron and represents the first attempt to explain the origin of the cyclicity.

Another important advance in Cotter’s work was the recognition that the shoreline of the Last Chance delta did not advance uniformly eastward or northeastward. Some of the shorelines prograded northwestward or even westward, and these shoreline deposits share an important characteristic: whereas the shorelines that

**Figure 10.** Relationship between lower and upper Ferron strata (from Cotter, 1975a). The lower Ferron, composed primarily of the Clawson and Washboard units, is clearly distinguished as older than the upper Ferron deltaic strata. After Cotter, 1975a.

**Figure 11.** Paleogeography of the lower Ferron as interpreted by Cotter (1976). The Clawson and Washboard units accumulated along a strand-plain/barrier-island coast and were nourished by sand transported southward from the Vernal delta. From Cotter, 1976.
prograded generally eastward display very gentle seaward dips, those that prograded northwestward to westward commonly display much greater dips, in some instances reaching 15 degrees. Cotter (1975b) cited the outcrops along the north side of Ivie Creek as an example of this phenomenon, documenting the steep westward dips with several photographs. He interpreted the steep delta fronts as forming where fresh, sediment-laden water from the Last Chance distributary channels flowed into embayments in which the salinities were reduced.

Cotter used the term “Gilbert delta” to refer to steep delta fronts he observed locally in the Ferron. The term derives from the morphologies of Pleistocene deltas deposited in glacial Lake Bonneville and described by Gilbert (1885). Gilbert deltas are characterized by steep delta-front strata bounded below and above by low-angle to flat “bottom-set” and “top-set” beds. The “type” Gilbert deltas deposited on the shoreline of Lake Bonneville formed where streams characterized by high bed loads reached and rapidly mixed with the fresh water of the lake. Along marine coasts, fresh water from river mouths generally overflows the denser, saline water, resulting in salinity stratification and development of a fresh-water plume. Cotter speculated that a shallow, restricted embayment, perhaps like the Sanpete Valley embayment of Hale (1972), but more likely much smaller, contained (at least periodically) low-salinity water, facilitating rapid mixing and, therefore, steep slopes. This question is addressed further in the description of the Ivie Creek area by Anderson et al., this volume.

Details Emerge

Ryer conducted a comprehensive study of the Ferron outcrops in the southern part of Castle Valley and available drill-hole data from Castle Valley and the Wasatch Plateau during the late 1970s. The results of this study were presented in a series of papers published by Ryer and various collaborators during the early 1980s (Ryer, 1980; Ryer et al., 1980; Ryer, 1981a, 1981b, 1982a, 1982b, 1984; Ryer and McPhillips, 1983). The emphasis of Ryer’s work was the recognition and mapping of packages of strata representing “major cycles of sedimentation” in the Ferron. These cycles were designated “4th order” cycles (Ryer, 1984) building on the terminology of Vail et al. (1977). Five delta-front units representing 4th order cycles (Kf-1 through Kf-5 of Anderson and Ryer, this volume) were initially recognized (Figure 14). Each was distinguished on the basis of an overall upward-coarsening shoreline sandstone unit plus equivalent delta-plain strata. The deposits of each cycle contain a widespread bed of coal, for which the letter designations of Lupton (1916) were retained.

Two additional shoreline sandstone bodies were identified by Ryer in the vicinity of Emery (Kf-6 and Kf-7 of Anderson and Ryer, this volume), but were not associated with 4th-order cycles because of their very limited dimensions in the depositional dip direction. Kf-6 and Kf-7 were elevated to the same status as Kf-1 through Kf-5 in Ryer’s later publications (Figure 15). Like Cotter, Ryer interpreted the Ferron to be the product of deltaic sedimentation, specifically river-dominat-
ed, lobate deltas. Wave-modified deposits of the shore-faces that lay between active delta lobes were also distinguished.

Ryer (1981a) analyzed the relationships between the coalbeds of the Ferron and the equivalent delta-front sandstone units. The concept of “stratigraphic rise” played a key part in his analysis, as it has in more recent studies. Progradation of a shoreline during a period of relative rise of sea level results in what can be termed stratigraphic rise of a shoreline sandstone unit. During progradation, the position of recognizable facies boundaries move upward relative to some horizontal datum. Recognizable horizontal data in the rock record are rarities (an example would be a layer of volcanic ash preserved in a peat deposit). In practice, stratigraphic rise is most easily recognized on the basis of seaward thickening of the unit of marine shale beneath and seaward of the shoreline deposit. Greater stratigraphic rise is reflected by more rapid basinward thickening of a marine shale unit. In Figure 16, stratigraphic rise is reflected by

![Diagram of stratigraphic sections](image.png)

**Figure 14.** Generalized southwest to northeast cross section of the Ferron defining Ryer’s (1981a) delta-front units. Two additional delta-front units lying near the landward edge of delta-front unit no. 5 were identified, but were not assigned numbers owing to their small size. The final two units, near the left edge of the diagram, do not exist. From Ryer, 1981a.

![Diagram of stratigraphic sections](image.png)

**Figure 15.** Ryer (1991) updated his generalized cross section of the Ferron, recognizing delta-front units no. 6 and no. 7 as of equal importance to nos. 1 through 5. Compare to Figure 14. After Ryer, 1991.
the upward shift of the boundary between upper shoreface and middle shoreface strata. The thicknesses of the delta-front sandstone units is closely related to stratigraphic rise: thicker sandstone units record higher rates of relative sea-level rise during progradation; thinner units record lower rates. The older delta-front sandstones of the Ferron (Kf-1 and Kf-2 of Anderson and Ryer, this volume) are thinner and extend farther basinward than the younger delta-front sandstone units (Kf-3 through Kf-7; Figure 15), suggesting that the rate of relative sea-level rise in central Utah increased through Ferron deposition. Ultimately, the rate of relative sea-level rise accelerated, resulting in a final, rapid transgression of the sea southwestward across the Last Chance delta. Several subsequent studies by other authors developed these concepts further.

Utilizing outcrop relationships as a guide, Ryer and McPhillips (1983) correlated the Ferron in the subsurface of the Wasatch Plateau. They rejected Hale’s (1972) concepts of a Castle Valley bar and a Sanpete Valley embayment, tying the lower Ferron sandstone westward and southwestward to the basal sandstone of the Ferron in the subsurface. They interpreted the Clawson and Washboard units of Cotter (1975a) as distal lower Ferron sands deposited on the shelf during a lowstand of sea level. Most importantly, they argued that the Vernal and Last Chance deltas were not true deltas, but larger-scale geomorphic features related to tectonics. The Ferron shoreline, they argued (Ryer and McPhillips, 1983) “received sediment from numerous rivers that built deltas on a much smaller scale than the Last Chance and Vernal deltas as [defined by Hale, 1972]. These small deltas coalesced laterally to produce continuous sheets of delta-front sandstone as the shoreline prograded.”

The origin of the Vernal delta was addressed in greater detail by Ryer and Lovekin (1986). They argued that the conspicuous seaward bulge of the shoreline in northeastern Utah and southwestern Wyoming that had been named the Vernal delta by Hale (1972) owed its origin to movement on the ancestral Uinta Mountain uplift.

Figure 16. “Stratigraphic rise” is a consequence of rise of relative sea level during progradation. (A) Transgression of the sea onto a coastal plain has ended and progradation has just begun. A transgressive surface of erosion (tse), a shallow-water portion of the marine flooding surface, is marked by the heavy line. The stippled body represents a prograding shoreface. (B) Progradation has occurred during a period of relative sea level stability. No stratigraphic rise is discernable. (C) Progradation has occurred during a period of rising sea level. The amount of stratigraphic rise, “x,” corresponds to the upward rise of a facies boundary, here the boundary between the shoreface sand and overlying coastal-plain sediments, relative to a datum parallel to the original sea level.
Uplift of this feature during earliest Late Cretaceous time had earlier been documented by Weimer (1962). As the Ferron-Frontier shoreline prograded eastward to what is now the Uinta Basin and Uinta Mountains, subsidence occurred, but at a slower rate than in areas to the north and south. This differential subsidence, Ryer and Lovekin argued, is the cause of the bulge in the shoreline. A negative line of evidence was also presented. They cited the northern Andes in South America as a modern analog for the Sevier Orogenic Belt in Utah and Wyoming and inferred the spacing of drainages that would have existed in Utah during Ferron-Frontier deposition. Features as large as the Vernal and Last Chance “deltas,” they concluded, could not have been deposited by individual rivers (Figure 17).

A series of seven drill holes cored through the Ferron just west of the outcrop belt by ARCO in 1982 were the subject of a study by Thompson (1985). The principal findings are described in a paper by Thompson et al. (1986). The study focused primarily on the interpretation of facies and depositional environments represented in the core. Six outcrop sections located close to the cores were measured in order to augment the core interpretations. Thompson et al. (1986), like Cotter (1975b) and Ryer (1981a), interpreted the Ferron to represent lobate, river-dominated deltas (Figure 18). Although their description and interpretation of sedimentary features in cores are excellent, their study presents only a very general picture of Ferron stratigraphy. A cross section depicting the stratigraphy in and between five of the ARCO drill holes (Figure 19) distinguishes facies very broadly. No attempt was made to distinguish and correlate the coal seams mapped and named by Lupton (1916) or the individual delta-front sandstone bodies defined by Ryer (1981a).

Of particular interest is Thompson et al. (1986) identification of sandy shelf “plume” deposits in the Ferron. Their model, shown in Figure 20, recognizes bodies of sand deposited on the shelf by a south- or southwest-flowing current and nourished by sediment delivered from a delta front situated up-drift. The model is based on an interpretation by Coleman et al. (1981) of a sand body located in the Mediterranean Sea off and down-drift of the mouth of the Damietta Branch of the Nile Delta. The sand body was interpreted to be a Holocene deposit formed by transport of sand from the river mouth onto the adjacent shelf by an eastward flowing current. Palmer and Scott (1984) elaborated on the model (Figure 21) and applied the concept of a sandy shelf “plume” to explain sandstones in the Upper Cretaceous La Ventana Tongue of the Cliffhouse Sandstone in the San Juan Basin. Later, Scheihing and Gaynor (1991) re-examined data for the Damietta shelf “plume” and argued that it is not a Holocene deposit formed on the shelf, but rather a Pleistocene deposit that accumulated along the shoreline, brought by longshore drift from the

Figure 17. Comparison of Ferron paleogeography in Utah with the present-day drainage pattern on the eastern flank of the Andes in northern South America. The Andes are made to coincide with the Cretaceous Sevier orogenic belt. On the basis of this comparison, Ryer and Lovekin (1986) concluded it was unlikely that the Vernal and Last Chance deltas could have been the deltas of individual rivers. From Ryer and Lovekin, 1986.

Figure 18. The Last Chance delta is interpreted by Thompson et al. (1986) to be a river-dominated delta with moderate wave influence (from Thompson et al., 1986). The ternary diagram they used was modified from Galloway, 1975.
Figure 19. (A) Ferron Sandstone outcrop belt in Castle Valley (from Cotter, 1975b). (B) Location of Ferron drill holes, surface sections, and cross section. (C) Southwest to northeast cross section (shown on Figure 19B) showing correlations between five core holes drilled through the Ferron by ARCO. Drill hole 82-6 is situated near Ivie Creek; 82-8 is southeast of Ferron. Interfingering of facies is shown, but is highly generalized and, in some areas, simply incorrect. Modified from Thompson et al., 1986.
Regardless of whether or not the sand body associated with the Damietta Branch accumulated as a shelf plume, the shelf plume model itself has merit. For the Ferron, the sand plume model was invoked to explain the origin of the lower Ferron, which Thompson et al. (1986) interpreted as a large plume derived from the Vernal delta (Figure 22), and also to explain some more localized sandy strata in the basal part of the upper Ferron (their Last Chance delta; Figure 23). In some respects, the model of Thompson et al. (1986) is strikingly similar to the Castle Valley bar interpretation of Hale (1972) and also resembles the peninsula interpretation of Spieker and Reeside (1925); Figure 5. The main difference is that the shelf plume is interpreted to have existed mainly to the east of the present-day outcrop belt, on what is now the San Rafael uplift, whereas Hale’s Castle Valley bar was located mainly to the west of the outcrop, in the subsurface. Cotter (1976) (Figure 11) invoked southward transport on the shelf to explain some lenses of sandstone that he assigned to the lower Ferron (his Woodside unit; Figure 10) on the northeast flank of the San Rafael
uplift, but his shelf-sand interpretation was applied at a much smaller scale than was the Vernal delta plume model of Thompson et al. (1986).

Ryer (1987) proposed a general model that distinguished different origins for the lower Ferron and upper Ferron (the paper was finally published in 1993a; a revised version appeared in 1994.). Ryer argued that the effects of both sea-level change and variations in the flux of clastics from the Sevier orogenic belt can be distinguished in the Ferron. The lower Ferron was deposited primarily as the result of a lowering of eustatic sea level. Rise of sea level led to deepening of water and accumulation of marine mudstone above the Washboard unit. Slowing of subsidence and possibly structural rebound of the foredeep that lay immediately to the east of the Sevier orogenic belt led to an increase in the flux of sediment across the foredeep to the shoreline in central Utah during late Turonian time. The coarse-grained Calico Bed of the Kaiparowits Plateau records this event in southwestern Utah; the Coalville Conglomerate of the Frontier Formation records it in northern Utah. The increased flux of sediment caused progradation of the upper Ferron shoreline in Castle Valley, despite continued rise of sea level. The distinctive, river-dominated deltas of the upper Ferron, which are unusual in the Upper Cretaceous section of the Western Interior, are the product of this rapid sediment influx. In this interpretation, relative sea level and the flux of sediment from the orogenic belt to the shoreline are decoupled, the latter being largely a function of regional tectonics instead of rejuvenation of streams during a period of relative sea level fall. Failure to take this phenomenon into account may explain the very disparate results of recent sequence stratigraphic studies of the Ferron, as described later.

Molenaar and Cobban (1991a, 1991b) collaborated to synthesize their knowledge, gained through many years of study, of Cretaceous strata on the south and east sides of the Uinta Basin. The Ferron outcrops lie at the southwestern margin of the area they considered in their report and there are no findings that materially altered previous interpretations of the Ferron in Castle Valley. Some of their conclusions regarding areas to the north and east, however, are of interest.

Molenaar and Cobban (1991a, 1991b) named a bed of sandstone that is present near the middle of the Tununk Shale on the northeast flank of the San Rafael uplift and into eastern Utah the Coon Spring Sandstone Bed. Included in it is the Woodside Unit of the Ferron defined by Cotter (1975a) (Figure 10). The Coon Spring Sandstone Bed contains the ammonite Collignoniceras woolgari, dating it as early middle Turonian in age.
A cuesta-forming unit of black marine shale containing varying amounts of very fine grained, platy, thin-bedded sandstone in eastern Utah had previously been assigned to the Ferron by many workers (for example Hintze and Stokes, 1964). Molenaar and Cobban reassigned it to the Juana Lopez Member of the Mancos, arguing that it is much more like the Juana Lopez of areas to the east and southeast than it is to the Ferron in Castle Valley. Their cross sections, one of which incorporates subsurface data between Emery and the northern plunge of the San Rafael uplift (Figure 24) show the Juana Lopez Member as being essentially equivalent to the upper Ferron.

**Ferron Reservoir Analogs and Sequence Stratigraphy**

Numerous studies of the Ferron undertaken in the late 1980s and early 1990s filled in many of the details that were lacking in earlier studies. Analysis was done at a considerably finer scale and the focus shifted to determining the distributions of properties relevant to production of fluids from petroleum reservoirs. This was the result of two primary factors: (1) previously completed studies provided a sound stratigraphic framework within which such detailed studies could be efficiently conducted; and (2) analysis of petroleum reservoir types and the amounts of mobile but unrecovered petroleum that they contain pointed to fluvial-dominated sandstones as an important, underdeveloped resource (Tyler, 1988; Ray et al., 1991).

The landward pinchouts of two of the delta-front units of the Ferron, Kf-2 and Kf-6 of Anderson and Ryer (this volume), were described by Anderson (1991a, 1991b). This study addressed the character of stratigraphic traps that might be formed by these features and compared them with landward pinchouts of highly wave-dominated shoreline deposits of the Blackhawk Formation in the Book Cliffs. Anderson’s description of the Kf-2 landward pinchout at the mouth of Willow Springs Wash (Figure 25) is notable in that it discriminates sub-facies within the landwardmost part of the Kf-2 delta-front sandstone body and characterizes them, at least in general terms, as to their relative reservoir quality.
Five drill holes were cored southeast of Emery as part of a study of Ferron unit Kf-2 in the Muddy Creek Canyon area by Ryer in 1992. The initial results of the study were presented in a field trip guidebook (Ryer, 1993b) and core workshop notes (Gustason et al., 1993). The study addressed the origin of several parasequences in Kf-2. Permeability data from the cores and adjacent outcrops in Muddy Creek Canyon were compiled and analyzed by Mobil Exploration, but these results remain proprietary.

Ryer studied outcrops in Indian Canyon, south of Willow Springs Wash, with the purpose of distinguishing autocyclic from allocyclic origins of several parasequence-level units defined there. Preliminary results were reported by Ryer (1993a, 1993b, 1993c). Exposures in Indian Canyon record an abrupt change from wave-modified shoreline to fluvial-dominated deltaic deposits. The bedding surface across which this change occurs has many of the characteristics of a marine-flooding surface, yet lacks any evidence of transgression of the shoreline or of relative sea level rise. Ryer interpreted the change to represent autocyclic shifting of a river system into the Indian Canyon area and subsequent progradation of a fluvial-dominated delta. This concept figures prominently in the approach discussed by Anderson and Ryer (this volume) to more regional analysis of the Ferron.

Comprehensive studies of the Ferron were conducted by Gardner as part of a Ph.D. dissertation (Gardner, 1993) at the Colorado School of Mines. Gardner contributed a large amount of new data and many innovative interpretations, as well as a complete review and, in some cases, rethinking of previous interpretations. Gardner’s studies of the Ferron are summarized in two papers published in 1995 (Gardner, 1995a, 1995b). Both deal with tectonic and eustatic controls on sedimentation of mid-Cretaceous strata: the first addresses most of the Rocky Mountain region (exclusive of Montana); the second focuses on central Utah. Many of Gardner’s detailed stratigraphic descriptions and interpretations of the Ferron remain unpublished and can be found only in his dissertation (Gardner, 1993) and in guidebooks reproduced for various field trips (Gardner, 1992; Gardner et al., 1994).

Gardner (1995b) defined a hierarchy of cycles related to base-level rise and fall (Figure 26). The Ferron represents the base-level fall-to-rise turnaround of a “long-term cycle” (the 2nd order cycle of Vail et al., 1977). Four “intermediate-term cycles” (3rd order) were distinguished and named for characteristic fossils (Gardner, 1995a). The lower Ferron of Castle Valley plus a thick, basal sandstone unit included in the Ferron on its southernmost outcrops near Last Chance Creek are assigned to the Hyatti sequence (named for the ammonite Pyionocyclus hyatti). The upper Ferron constitutes the Ferronensis sequence (named for the ammonite Scaphites ferronensis).

Gardner designated the level of cyclicity represented by the numbered delta-front sandstones of Ryer (1981a)
“short-term cycles” (4th order). Gardner designated these units as genetic sequences (GS) — GS 1 through GS 7 of the upper Ferron (Figure 27) following the numbering system of Ryer (1981a) (the deposits of genetic sequences are referred to in some of Gardner’s work as “stratigraphic cycles” [SC], for example SC 1, SC 2, and so forth; in the remainder of this discussion, the Kf terminology is substituted for the GS or SC designation). Kf-1 through Kf-3 were recognized as displaying a forward-stepping pattern that represents base-level fall; Kf-4 displays a vertically-stacked pattern representing the turnaround and beginning of base-level rise; and Kf-5 through Kf-7 display a backward-stepping pattern representing a sustained period of base-level rise. A smaller level of cyclicity, that is essentially equivalent in scale to the “parasequence” of Van Wagoner (1995), was also distinguished. Gardner’s thesis and guidebooks include numerous, very well documented examples of this level of cyclicity (Gardner, 1992, 1993; Gardner et al., 1994).

Gardner, like previous students of the Ferron, recognized that the Ferron includes deposits of fluvial-dominated deltas. He noted a pattern, however, that previous workers had not described: the shoreline sandstones of Kf-1 through Kf-3 consist largely of fluvial-dominated deltaic deposits, whereas those of Kf-4 through Kf-7 consist predominantly or even entirely of wave-dominated deltaic deposits. One of Gardner’s innovative contributions to understanding the Ferron is his analysis of this phenomenon in terms of volumetric partitioning of sediment between various paleoenvironments. Figure 28 summarizes the concept of volumetric partitioning. Volumetric partitioning offers an explanation for the distribution of fluvial- and wave-dominated delta-front deposits in the Ferron. Stated in the simplest possible terms, Gardner’s explanation for the distribution of fluvial- and wave-dominated deltaic deposits is as follows:

During the lowering of base level associated with deposition of Kf-1 through Kf-3, most of the sediment was conveyed through the fluvial systems to the shoreline. Because of the high rate of delivery of sediments at the river mouths, wave energy was insufficient to cause major reworking of the deltaic deposits which, as a result, took on classic lobate to bird-foot, fluvial-dominated forms. Slow aggradation of sediment in the coastal plain behind the shoreline led to accumulation of relatively thin, widespread, largely single-storied channelbelt deposits.
During the rising of base level associated with deposition of Kf-4 through Kf-7, rivers aggraded the coastal plain more rapidly. More sediment was tied up in channelbelt deposits, which are thick and multistoried, and in the fine-grained deposits of the adjacent flood basins. The amount of sediment conveyed throughout the fluvial systems to the shoreline was reduced. Because of the lower rates of accumulation of sediment at the river mouths, wave energy was sufficient to rework the deltas, leading to cuspate, wave-dominated morphologies.

Gardner subsequently became an employee of the Bureau of Economic Geologists (BEG), The University of Texas at Austin. Based largely on Gardner’s findings, the BEG identified the Ferron as a good analog for a number of important Neogene reservoirs in the Texas Gulf Coast productive province. The BEG, with funding from the Gas Research Institute (GRI) and DOE, and later with direct financial support from oil and gas companies, focused on the stratigraphy, sedimentology, and permeability structure of a number of stratigraphic units rep-
resenting significant reservoir facies. Numerous geoscientists from the BEG contributed to the project. Barton, however, was the principal contributor of most of the new stratigraphic concepts. The initial object of study by the BEG was a sandy channelbelt deposit plus underlying delta-front strata of Kf-5 exposed in Muddy Creek Canyon. Study of Kf-5 was later extended northward to include all of the Kf-5 outcrops east and north of Muddy Creek Canyon. Additional case studies were initiated in deposits of Kf-2 at Ivie Creek and at Dry Wash. The final phase of the BEG study of the Ferron involved the detailed stratigraphy of the entire Ferron section between I-70 and Dry Wash.

Many results and conclusions of the BEG work can be found in various interim reports (Barton and Tyler, 1991), in reports published by the GRI (Fisher et al. 1993a, 1993b), in the Ph.D. dissertation of Barton (1994), and in unpublished field trip guidebooks (Barton and Tyler, 1995).

Barton, initially working jointly with Gardner and then independently, compiled very detailed stratigraphic information and large permeability data sets for a number of sites in the Ferron. Working at a more regional scale, Barton (1994) recognized two errors that had initially been made by Ryer and propagated by Gardner: (1) the seaward limit of Kf-1 occurs in the southern part of the Coal Cliffs north of I-70, not in the southern part of Molen Reef as previously mapped; and (2) the seaward limit of Kf-6 occurs just north of Dry Wash, close to the seaward limit of underlying Kf-5, farther northeastward than previously thought. Barton came to the realization that unit Kf-2, as previously defined, constitutes more than one “4th order” or “short-term” cycle of sedimentation. The details of one of Barton’s (1994) subdivisions of Kf-2 is summarized in Figure 29.

The report by Barton and Tyler (1995) includes a new and fundamentally different interpretation of the origins of parasequence-level units in the Ferron. Like many other workers, they interpreted parasequences as products of fluctuations in relative sea level. Ryer and Gardner had done the same, but had concluded that rates of lowering of sea level had always been exceeded by the overall rate of basin subsidence. Interpreted this way, eustatic fluctuations are represented by varying rates of relative sea-level rise: falling eustatic sea level results in a slower rate of relative sea-level rise and progradation; rising eustatic sea level results in a more rapid rate of relative sea-level rise and transgression. Barton and Tyler (1995) argued that the Ferron preserves evidence of relative sea-level lowering based on relationships within the lower, forward-stepping part of the Ferron deltaic complex. Following a period of progradation under conditions of rising relative sea level, in their interpretation, sea level fell, leading to incision of channel systems and seaward shift of the shoreline to a more distal and lower position. Subsequent rise of sea level led to upward and then forward building of the shoreline, formation and filling of a bay/lagoon complex, and filling of valleys. One of the most important implications of this interpretation is that rivers incised into pre-existing sediments during periods of relative sea-level fall to form valleys: many of the deposits, previously interpreted as simple channelbelts laid down on an aggrading alluvial plain or delta plain were reinterpreted as valley fills.

![Figure 29. Detailed outcrop work and analysis of photomosaics allowed Barton (1994) to distinguish numerous depositional episodes, which he equated to parasequences, within Kf-2 between Miller Canyon and Dry Wash (after Barton, 1994).](image-url)
Beginning in 1993, Utah Geological Survey (UGS) began an extensive study of the Ferron Sandstone from Last Chance Creek to Ferron Creek. The objective of the UGS project was to develop a comprehensive, quantitative characterization of the Ferron as a fluvial-deltaic reservoir analog. The study included reservoir-scale models and reservoir simulations (see Forster et al., Jarrett et al., and Mattson and Chan, in this volume). This project also involved regional stratigraphic and facies analysis and case-studies (see Anderson et al., Dewey and Norris, Ryer and Anderson, in this volume). Other results and conclusions of the UGS project can be found in various annual and open-file reports published by the DOE and UGS (Chidsey and Allison, 1996; Chidsey, 1997; Anderson et al., 1997a; Anderson et al., 1997b; Chidsey et al., 1998; Chidsey, 2001; Anderson et al., 2002).

An interpretation of Ferron stratigraphy published by Schwans (1995) is radically different than anything that preceded it. Schwans distinguished a major unconformity — a sequence boundary — on outcrops of the Ferron at I-70. His unconformity lies near the base of Kf-1, such that the Ferron exposed there lies with an erosional, unconformable contact on the Tununk Shale. Carried into the subsurface using well control, Schwans’ unconformity defines a large, east-trending paleovalley. In general terms, Schwans’ model calls for a pronounced drop of relative sea level in central Utah during middle Turonian time, an eastward shift in the position of the shoreline to the present-day San Rafael uplift, and fluvial erosion of a broad valley. During a subsequent rise of sea level, the valley flooded to form a large estuary within which the bulk of the Ferron, as exposed in Castle Valley, accumulated.

There is much disagreement with Schwans’ interpretation and to fully critique it would require a lengthy discussion. In short, it can be argued that Schwans force fitted a sequence stratigraphic model that, despite its merits, cannot be properly applied to the Ferron. Particularly revealing in understanding the origin of this interpretation is the fact that the list of references cited in the paper (Schwans, 1995) does not include a single one of the studies of the Ferron that have been described here. It includes, instead, references to all of the widely recognized papers defining the principles of sequence stratigraphy, particularly the numerous papers published on the Blackhawk Formation in the nearby Book Cliffs. The implications of this are clear: only the standard sequence stratigraphic model can be correct; any previous studies of the Ferron are meaningless. Schwans transported the Blackhawk model to the Ferron without adequately studying the Ferron strata. This work epitomizes what the author regards as a period of chaos in the study of the Ferron, as discussed below.

Initial results of an on-going Ferron study conducted by Garrison and van den Bergh have been published in extended abstract form (Garrison and van den Bergh, 1996; van den Bergh and Garrison, 1996) and in a field trip guidebook (Garrison et al., 1997). Their project shared one of the same goals as the BEG and UGS studies: to divide the Ferron into genetic units at the level of the parasequence.

Figure 30 shows Garrison and van den Bergh’s stratigraphic framework. It distinguishes four sequences within the Ferron consisting of 33 parasequences organized into 11 parasequence sets. There are some subtle, but important, differences between this and previous correlations schemes. Three unconformities (sequence boundaries) identified within the Ferron are defined primarily on the basis of erosional relief that is present at the bases of channelbelts. The relief on the contacts, apparently, is attributed to subaerial erosion and development of topography, rather than to simple local variation in the amount of scouring that occurred during emplacement of the channelbelts.

Another new aspect of Garrison and van den Bergh’s interpretation is the arrangement of parasequences in Kf-7 and Kf-8 (Figure 30). In each, younger parasequences are positioned landward of older ones such that the parasequence sets are back-stepping or retrogradational. Previous workers who studied these units did not recognize the internal organization described by Garrison and van den Bergh.

Sequence Boundaries and Chaos in Ferron Stratigraphy

The last decade has seen a fundamental change in how geologists look at the Ferron: not just in how they go about looking at it, but also in what kinds of things they see when they look. This change is a direct result of the rise and widespread acceptance of sequence stratigraphy.

From the early work of Lupton (1916) through the fleshing-out of the details of Ferron stratigraphy provided by Gardner (1993) and Barton (1994), each student of the Ferron essentially built upon the work of his or her predecessors. Each publication provided new details and more refined interpretations. To be sure, there were misinterpretations that were subsequently set right, but overall, there was a smooth progression forward. During the 1990s, an increasing number of geologists approached study of the Ferron with a different question in mind: How does what we see in the Ferron fit the tenets of sequence stratigraphy? Many geologists have looked at the Ferron in this new way, although only a few have fully documented their conclusions in publications. The new way of looking at things has led to a very different result: each worker sees something different than the other; no two are in agreement.

Gardner (1993, 1995a) made the first well-documented effort to define the sequence stratigraphy of the Ferron. An essential conclusion of his analysis is that no
unconformities exist in the Ferron. The three sequences he distinguished in the Turonian-Coniacian section of central Utah are, instead, based on surfaces that he believes are correlative to unconformities defined in other parts of the Western Interior (e.g., “correlative conformities”). All of the deltaic, upper Ferron strata that have been the subject of recent outcrop studies belong to the youngest of Gardner’s sequences (his Ferronensis sequence). The correlative conformity that serves as its base coincides with the top of Kf-Washboard (the top of the lower Ferron). The upper boundary of the sequence remains undefined.

Seven sequence boundaries that correspond to unconformities, listed here in descending stratigraphic order, have been identified recently in the deltaic strata of the upper Ferron:

4. van den Bergh and Sprague (1995) recognized an unconformity in the more landward part of Kf-2 in the area south of Coyote Basin (north of Willow Springs Wash).
5. Barton and Tyler (1995) distinguished several minor erosional surfaces that they believe are characterized by subaerial erosion in Kf-2. Though minor, they must still be considered sequence boundaries.
6. Shanley and McCabe (1991, 1995) extend an unconformity they recognize in the Straight Cliffs Formation of the Kaiparowits Plateau to a position somewhere low in the Ferron in the Castle Valley outcrops. Their initial interpretation (verbal communication, 1998) is that it corresponds to the top of Kf-1 at Ivie Creek.
7. Schwans (1995) defined a sequence boundary near the base of Kf-1 at Ivie Creek and subsequently correlated it over a broad area using wireline logs.

Thus, seven studies identified seven unconformities, no two of which are the same. There has been a total lack of agreement among those seeking to distinguish unconformity bounded sequences within the Ferron. Does this mean that no unconformities exist in the Ferron? Certainly not. It does, however, indicate that if unconformities are present, they are quite subtle. Study of the Ferron will certainly continue and perhaps a consensus will be reached.

COAL IN THE FERRON SANDSTONE

Coal has long played an important role in the economy of central Utah. The coalbeds of the Ferron have always been of minor importance compared to the coals of the Blackhawk Formation in the nearby Wasatch Plateau, but nonetheless have been important as a
source of coal for local use. Only one mine, Consolidation Coal Company's Emery Mine, which was active from the mid-1970s to the mid-1990s, has produced coal on a large, commercial scale from the Ferron (8.5 million tons). The following is a brief review of the history of study of coal in the Ferron. Not included are studies addressing geochemical aspects of Ferron coal.

The first written documentation of coal in Castle Valley occurs in a report issued by the Wheeler Survey. R.L. Hoxie of the Army Corps of Engineers recorded in his journal of October 11, 1853, that “specimens of coal were brought in from the hills near the camp.” Lupton interpreted the location of the camp as being near the head of the canyon of Muddy Creek. The J coalbed (Lupton correlated it to his I seam, defined farther south) is conspicuously exposed at many localities along the canyon walls in this area. It is almost certain that Hoxie collected the samples he described from this seam.

Forrester (1892) collected samples from coalbeds in Ivie Creek and Quitchupah canyons and published proximate analysis. It is likely that his samples came from the I coalbed and from either the A or C coal beds of Lupton’s (1916) terminology. Forrester interpreted the coal-bearing strata as belonging to the Montana Group (that is, the Mesaverde Group), dropped into this position several miles east of the main Mesaverde outcrop belt by faulting. The Joe’s Valley-Paradise graben lies between the Ferron and Mesaverde outcrop belts in the area south of Emery, although it is not apparent that the structure was recognized by Forrester. If it was, it would have lent credibility to his interpretation. It is likely, however, that a more important factor was the presence of coal. The presence of coal was known in Mesaverde Group strata throughout much of the Colorado Plateau, whereas strata between the base of the Mesaverde and the top of the Dakota are generally shale and lack coal. That the coal-bearing strata at Ivie Creek and Quitchupah Canyons do not belong to the Dakota is obvious to anyone visiting the southern Castle Valley outcrops. It is likely that Forrester simply assumed any coal younger than the Dakota must belong to the Mesaverde and devised a structural interpretation to fit his preconception.

Taft (1906) briefly examined some of the Ferron outcrops near Emery. He reached the conclusion that “...coal, which is of little economic importance, is known to occur only to the east and southeast of Emery.” His statement that coal is unimportant in the Emery area is somewhat surprising inasmuch as his map shows the locations of the Casper and Bear Gulch mines. Taft presumably visited these mines, both of which exploited sections of the C coal bed that exceed 6 ft (2 m) in thickness. Furthermore, he collected a sample of coal from what is now known as the Cowboy mine, south of Emery, where the I coalbed is 5–6 ft (1.5–2 m) thick.

Lupton’s (1916) study of the coal geology and coal resources of Castle Valley stands as the first of two primary reference on coal in the Ferron. Lupton conducted his field work during two periods: July 17 through October 7, 1911, and September 9 through November 2, 1912. This represents a total of 138 days. His field party consisted of himself plus five other men, several of whom apparently were locals. One cannot help but be impressed by the amount of work completed, particularly given the poor condition of roads in the area at that time and the fact that the party lacked adequate topographic maps and had to survey most of their locations.

Lupton (1916) named the significant coal beds of the Ferron, assigning them letters of the alphabet, in ascending stratigraphic order. The thickest and, therefore, economically most important coal beds are the A, C, and I. The C and I coal beds were being mined at the time of Lupton’s visits and he had encountered a prospect dug into the A coal along Quitchupah Creek. Based on his many outcrop measurements of coal thicknesses, Lupton (1916) estimated a total coal resource of 1.43 trillion tons (1.3 x 10¹² Mg).

Lupton’s report includes some minor miscorrelations of coal beds. The most significant miscorrelation involves the A coal, stratigraphically the lowest seam designated. Another coal zone, older than Lupton’s A coal, exists in the middle and southern parts of the coal field, but this fact was unrecognized (this lowest coal zone now has the awkward designation “Sub-A’). Coal of this zone in the Last Chance Creek and Paradise Lake areas were miscorrelated with the A coal, the miscorrelation occurring in the rugged outcrops of the Limestone Cliffs south of Willow Springs Wash.

Lupton documented the fact that coal is a minor component of the Ferron on outcrops north of a line extending east from Emery and becomes absent entirely a short distance north of Dry Wash as the Ferron becomes increasingly dominated by marine facies. Although coal is absent on many of the Ferron outcrops in the middle and northern parts of Castle Valley, it does occur in the Ferron to the west, in the subsurface. The presence of Ferron coal in the Price area was noted by Spieker and Reeside (1925). They reported that drilling along the Rio Grande Railroad about 10 mi (16 km) west of the Ferron outcrops indicated about 200 ft (61 m) of predominantly sandy Ferron section containing several coal beds, one of them 7.5 ft (2.3 m) thick. Additional data about the thicknesses and stratigraphic positions of the coals near Price were published by Gray et al. (1966). Situated at depths too great for economic mining, these coal beds would later become the focus of an active program of coalbed methane development.

Doelling (1972) published an analysis of the Emery coal field as part of his comprehensive treatise on coal in Utah. His is the second principal work on Ferron coal. Although it contributes little data on the thicknesses and
areal extents of coal seams beyond what can be found in Lupton (1916), it does present a much broader picture of Ferron coal, including considerable information about coal quality. Doelling (1972) confirmed Lupton’s estimate of coal resources, and in addition distinguished measured, indicated, inferred, and potential reserves. Measured and indicated reserves total 758 million tons (688 Mg). Color maps corresponding to U.S. Geological Survey 7.5 minute quadrangles (although with different names) portray the surface geology at a scale of approximately 1:42,000.

Ryer (1981a) placed the principal coalbeds of the Ferron into their depositional setting and recognized an important genetic relationship between coals and their equivalent shoreline sandstone units: the greatest thicknesses of coal are present at and landward of the landward pinchouts of the shoreline sandstones (Figure 14). Thick coal tends to occur in pods whose long axes are perpendicular to the shoreline trend. These pods represent flood basin and swamp areas bounded along depositional strike by sand-rich channelbelt deposits. Ryer et al. (1980) used laterally continuous beds of altered volcanic ash to document these relationships in the C coal bed of the Ferron (Figures 31 and 32). The details of the physical and chemical properties of the altered volcanic ash layers are addressed by Triplehorn and Bohor (1981) and Bohor and Triplehorn (1993).

Coal in the Ferron in the subsurface near Price was analyzed by Bunnell and Hollberg (1991). Their work predated the development of coalbed methane in this area and their interest in the coal was from the perspective of a mineable resource, rather than in its contained methane. They utilized the model proposed by Ryer (1981a) to explain the thickness distributions of the four to five coal zones recognized there. The Ferron in the area they studied is about 200 ft (60 m) thick. The shoreline orientation was north-northeast to northeast. Of particular interest is the strongly “back-stepping” or “retrogradational” pattern that the shoreline sandstone bodies of the Ferron display (Figure 33). As is the case on outcrops of the upper Ferron farther south in Castle Valley, maximum thicknesses of coal occur in the vicinities of landward pinchouts (Figure 34).

PETROLEUM IN THE FERRON SANDSTONE

The Ferron Sandstone has been a target of oil and gas exploration since 1921, when the Phillips No. 1 Huntington well was completed as a dry hole on the Huntington anticline, located in Castle Valley near the town of Huntington (Kuehnert, 1954). The first significant shows of oil in the Cretaceous section were reported in the Dakota Sandstone in a well drilled at Gordon Creek in 1922. The first commercial success occurred on the Clear Creek anticline, where Byrd-Front, Inc. discovered gas in sandstone reservoirs of the Ferron in 1951 (Edson et al., 1954; Tripp, 1991a, 1993a) (Figure 35). Gas was subsequently discovered in sandstones of the Ferron at Flat Canyon anticline (Flat Canyon field) in 1953 (Tripp, 1993b), at Joes Valley in 1953 (Tripp, 1993c), at Ferron anticline in 1957 (Tripp, 1990a, 1990b, 1991b, 1993a) and Indian Creek/East Mountain field, now part of Flat Canyon field, in 1981 (Laine and Staley, 1991) (Figure 35). The Ferron was found to contain gas and extremely light oil (56° API) on the southern part of the Flat Canyon field, this constituting the only significant occurrence of producible liquids from the unit (Laine and Staley, 1991; Sprinkel, 1993).

Of these discoveries, Clear Creek field is by far the most important. Clear Creek field has produced over 114 bcf (3.2 billion m³) of gas, far surpassing the 11.7 bcf (331 million m³) of gas produced from Ferron field, the second in importance (Utah Division of Oil, Gas and Mining, 2003). Flat Canyon and Joes Valley fields have pro-
Figure 32. Diagrammatic cross section showing the depositional history of the C coal bed and associated units. The C coal was interpreted to have formed entirely during progradation of Kf-3, an interpretation that must be revised following discovery of the fact that the Kf-3 pinches out landward into the C coal, such that its lower part formed during the latest part of deposition of Kf-2 and perhaps partly during the transgression that ended Kf-2 (from Ryer et al., 1980.)
Cumulative oil production from Flat Canyon field is 16,686 bbl (2653 m³) (Utah Division of Oil, Gas and Mining, 2003). The discovery of Clear Creek field played a significant role in stimulating study of the Ferron. As discussed earlier, the Ferron at Clear Creek was found to include a basal sandstone unit characterized by good lateral continuity, overlain by a thicker section containing discontinuous sandstones. The difference in these two sandstone types was of considerable interest. The dissertation by Katich (1951), completed in the same year the field was discovered, provided a picture of the Ferron stratigraphy on outcrop. The discovery provided an impetus for studies integrating the outcrop and basic subsurface observations by Katich (1954) and Davis (1954).

Coal miners long knew that methane in coalbeds posed a serious risk of explosion, and the U.S. Bureau of Mines began research on this problem when it was created in 1910 (Irani et al., 1977). Early research by the U.S. Bureau of Mines focused on quantifying the amount of methane released in active coal mines to alleviate the health and safety problems created by the gas (Diamond and Levine, 1981). In the late 1970s, following two interruptions in petroleum supply from the Middle East, the DOE and the GRI began researching new and unconventional sources of natural gas. Based on the U.S. Bureau of Mines measurements of large volumes of methane in coal beds, the DOE and the GRI began researching new and unconventional sources of natural gas. Based on the U.S. Bureau of Mines measurements of large volumes of methane in coal beds, the DOE and the GRI began researching new and unconventional sources of natural gas. Based on the U.S. Bureau of Mines measurements of large volumes of methane in coal beds, the DOE and the GRI began researching new and unconventional sources of natural gas.

Preliminary coalbed gas resource estimates by the DOE were completed for all major coal basins in the United States by 1982. These early studies focused subsequent research and development efforts on five basins: Black Warrior, central and northern Appalachians, Piceance, and San Juan (ICF, 1990). Utah’s coalbed gas potential was discounted because little was known of the deep coal resources.

Early coalbed gas work in Utah, during the late 1970s and early 1980s, consisted of UGS studies to measure the gas content of coals in the major Utah coal fields (Davis and Doelling, 1976, 1977; Doelling et al., 1979; Smith, 1981; Smith, 1986; Keith et al., 1990a, 1990b, 1990c, 1990d; and Keith et al., 1991), and a few individual production test wells drilled in the Book Cliffs coal field by Mountain Fuel (Allred and Coates, 1980, 1982). Studies in the 1990s by the UGS helped define the structure, thickness, depth, extent, and maturity of the coal deposits, and the coalbed gas resources of the Ferron Sandstone (Figure 36) (Tripp, 1989; Gloyn and Sommer, 1993; Sommer et al., 1993; Tabet and Burns, 1996; Tabet et al., 1996).

The Ferron coalbed methane play (traps, reservoir characteristics, fields, production, and reserves) is described by Lamarre, Montgomery et al., and Klein et al., in this volume.

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Figure 35. Location of gas fields (solid black) productive from the Ferron Sandstone and net sandstone-thickness map, Wasatch Plateau/Castle Valley. Contour interval is 100 ft. Thick lobes of sandstone indicate areas of deltaic deposition (from Sprinkel, 1993; modified from Tripp, 1989).
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