

FERRON SANDSTONE DOE ENGINEERING/GEOSCIENCE PROGRAM

Stratigraphic Information

(Recognized as of July, 1995)

Kf: Ferron Sandstone Member of the Mancos Shale

Author: Lupton, 1916

Ferron Sandstone is recognized as a member of the Mancos Shale. No type section has been designated. The name is derived from the town of Ferron, Utah, but it is clear from Lupton's work that he would have chosen the outcrops farther south, east, and south of the town of Emery, as representative of the member where it is most typically developed. The name Ferron Sandstone is presently used on outcrops around the San Rafael Swell, in the Henry Mountains basin, and beneath Castle Valley and the Wasatch Plateau. Controversy exists about whether "Ferron" or "Juana Lopez" is a more appropriate designation for thinly interbedded sandstones and shales of Ferron age on the east side of the San Rafael Swell near the town of Green River and eastward into Colorado.

Kf-Clw: Clawson unit of Ferron Sandstone

Author: Cotter, 1975

The Clawson unit of the Ferron extends from the northern part of San Rafael Swell southward along its western flank, through Molen Reef, finally feathering out westward toward Muddy Canyon in the "Molen Amphitheatre." The Clawson and overlying Washboard units of the Ferron together constitute the "lower Ferron" of Ryer and McPhillips (1983), and the lower part of the "Hyatti sequence" of Gardner (1994). They are shelf sandstones with a northern source. Lowering of sea level during middle Turonian time facilitated southward transport of very-fine and fine-grained sand onto a shoal area that marks the eastern hinge of the foredeep developed in front of the Sevier Orogenic belt. The shoal may represent a peripheral bulge. In addition to feathering out southward, both the Clawson and Washboard units lose sand content and disappear toward the west in the area stretching from the "Molen Amphitheatre" southward to Mesa Butte and westward to the "Tri-Canyon" area and "Cowboy Mesa." A gentle structural flexure has been recognized in this area, suggesting the presence of a down-to-the-west basement fault. The fact that Cretaceous rocks were flexed but not broken by movement on the proposed fault (unlike the younger faults associated with Tertiary extension) suggests that this fault moved during Cretaceous time in response to thrust loading. The westward loss of sand in the Clawson and Washboard units suggest that it was active during lower Ferron deposition. Facies content of shoreline unit: shelf sand body.

Kf-Wsb: Washboard unit of Ferron Sandstone

Author: Cotter, 1975

The Washboard unit extends from the northern part of San Rafael Swell southward to Mesa Butte, slightly farther than does the underlying Clawson unit. Same origin as Clawson unit; same comments apply. Facies content of shoreline unit: shelf sand body.

Kf-LC: Last Chance unit of Ferron Sandstone

Author: this study

The type section of the **Last Chance unit** of the Ferron is at Last Chance Creek, where the shoreline unit, together with overlying Kf-1-Ls, forms vertical cliffs approximately 200 feet high. Kf-Last Chance displays inclined bedsets that appear to onlap, or possibly downlap against a surface that may represent a paleotopographic high, resulting in very rapid seaward thinning to a feather edge. The high may represent the upthrown side of a down-to-the-west fault that was active during Ferron deposition. (A problem with this interpretation is that the thick section represented by Kf-LC can be mapped as having a northwest-southeast trend based on limited subsurface data, whereas faults that formed along the eastern hinge of the foredeep would be expected to have a north-south orientation). No contemporaneous channel deposits have yet been identified. Kf-Last Chance corresponds to the upper part of the "Hyatti sequence" of Gardner (1994). Type section: Limestone Cliffs at Last Chance, NW1/4 section 9, T. 25 S., R. 5 E., Salt Lake Base Line. Landward limit: not known; may be covered by basalt of Fish Lake Plateau. Seaward limit: Limestone Cliffs, approximately NE1/4 section 3, T. 25 S., R. 5 E., Salt Lake Base Line. Facies content of shoreline unit: wave-modified coast, possibly strand plain.

Kf-1: Kf-1 parasequence set of Ferron Sandstone

Author: Ryer, 1981; 1982

Kf-1 extends from outcrops south of Last Chance Creek to the southeastern side of "Cowboy Mesa" in the southern part of the Coal Cliffs. Its landward limit has not been accurately defined. Seven parasequence are presently recognized. The sub-A coal zone belongs to Kf-1. Only minor amounts of coal are contained in it, most of the coal occurring in the Last Chance area. The seaward limit of coal is present at the mouth of the canyon of Quitcupah Creek.

Kf-1-Ls: Kf-1 Limestone Cliffs parasequence of Ferron Sandstone

Author: this study

Kf-1 Limestone Cliffs is defined in the southern part of the Limestone Cliffs, at present only on the basis of oblique air photos. (Kf-1-Ls) extends from Last Chance Creek northward into the Limestone Cliffs. It is probably the youngest parasequence of Kf-1, although relationships south

of Last Chance Creek have not been worked out. Proposed type section: southern part of Limestone Cliffs, somewhere in section 3, T. 25 S., R. 5 E., Salt Lake Base Line. Landward limit: south of Last Chance Creek, position not determined. Seaward limit: Limestone Cliffs, approximately SE1/4 section 34, T. 24 S., R. 5 E., Salt Lake Base Line. Facies content of shoreline unit: not yet determined; wave-modified coast judging by photos.

Kf-1-IC-a: Kf-1-Indian Canyon-a parasequence of Ferron Sandstone

Author: this study

Kf-1-Indian Canyon-a is defined in the southern part of Indian Canyon, where the Kf/Ktnk contact reaches the canyon bottom. Only the seaward part of (Kf-1-IC-a) is exposed in Indian Canyon. Both seaward and landward limits have been tentatively identified in the Limestone Cliffs on the basis of photomosaics and oblique air photos. Although the Limestone Cliffs exposures would constitute a better type section, Indian Canyon was chosen because of ease of access and because the relationships between units Kf-1-IC-a,b,c, and d are quite clear there. A shortcoming of using Indian Canyon as a type area for (Kf-1-IC-a) is that the unit lacks upper shoreface/foreshore facies in Indian Canyon. A thick, extensively burrowed middle shoreface indicates that it was deposited on a wave-modified coastline. The seaward feather edge can be projected from the Limestone Cliffs through the subsurface to Indian Canyon and trends generally northwestward. The top of (Kf-1-IC-a) may be cut by meanderbelts belonging to (Kf-1-IC-d) locally in the Limestone Cliffs exposures. Type section: Indian Canyon, NE1/4NW1/4 section 26, T. 24 S., R. 5 E., Salt Lake Base Line. Landward limit: Limestone Cliffs, approximately SE1/4 section 34, T. 24 S., R. 5 E., Salt Lake Base Line. Seaward limit: Indian Canyon, SW1/4SW1/4SW1/4 section 24, T. 24 S., R. 5 E., Salt Lake Base Line; Limestone Cliffs, approximately NW1/4SE1/4 section 25, T. 24 S., R. 5 E., Salt Lake Base Line. Facies content of shoreline unit: wave-modified coast, probably strand plain.

Kf-1-IC-b: Kf-1-Indian Canyon-b parasequence of Ferron Sandstone

Author: this study

Kf-1-Indian Canyon-b is defined in Indian Canyon at the south end of the canyon and referred to as "The Wall." Landward and seaward limits of (Kf-1-IC-b) are tentatively defined in the Limestone Cliffs utilizing photomosaics and oblique air photos. The landward pinch-out is not exposed in Indian Canyon; the seaward feather edge is poorly defined in northern part of Indian Canyon owing to similarity of facies content of (Kf-1-IC-b) and overlying (Kf-1-IC-c). The landwardmost part of the transgressive surface of erosion between these two is a remarkably steep surface, well exposed on the east side of Indian Canyon, opposite the south end of "The Wall." Type section: Indian Canyon, east side, just beneath landward pinch-out of the overlying (Kf-1-IC-c), SW1/4SW1/4 section 24, T. 24 S., R. 5 E., Salt Lake Base Line. Landward limit: Limestone Cliffs, approximately NW1/4SE1/4 section 25, T. 24 S., R. 5 E., Salt Lake Base Line. Seaward limit: Indian Canyon, CSW1/4 section 24, T. 24 S., R. 5 E., Salt Lake Base Line;

Limestone Cliffs, approximately CNE1/4 section 25, T. 24 S., R. 5 E., Salt Lake Base Line.
Facies content of shoreline unit: wave-modified coast, probably strand plain.

Kf-1-IC-c: Kf-1-Indian Canyon-c parasequence of Ferron Sandstone

Author: this study

Defined on the west side of Indian Canyon, (**Kf-1-IC-c**) is responsible for forming "The Wall." It extends from south end of "The Wall" in Indian Canyon northward into Willow Springs Wash, feathering out gradually in the Coyote Basin- "Swell Point" area. Because the unit feathers out seaward so gradually, choosing an exact point on the map for its seaward limit is difficult and arbitrary. The landward pinch-out is fairly well exposed on the east side of Indian Canyon, but has been cut out by a channel on the west side. A substantial bay or lagoon existed behind the shoreline unit, as made evident by mudstones bearing oyster shells. A channel mouth or tidal inlet deposit that cuts (Kf-1-IC-c) locally very near its landward pinch-out probably connected this body of water with the sea. (Kf-1-IC-c) is very much a wave-modified unit. Its top is cut locally by meanderbelt deposits that belong to the younger Kf-1-IC-d. Type section: "The Wall" along the west side of Indian Canyon, SW1/4, SW1/4 section 24, T. 24 S., R. 5 E., Salt Lake Base Line. Landward limit: Limestone Cliffs, approximately CNE1/4 section 25, T. 24 S., R. 5 E., Salt Lake Base Line. Seaward limit: South of Coyote Basin, approximately SW1/4NE1/4 section 18, T. 24 S., R. 5 E., Salt Lake Base Line. Facies content of shoreline unit: wave-modified coast, probably strand plain.

Kf-1-IC-d: Kf-1-Indian Canyon-d parasequence of Ferron Sandstone

Author: this study

(**Kf-1-IC-d**) is recognized in the North Fork of Indian Canyon and the northernmost part of "The Wall" in Indian Canyon. It is also present, though difficult to distinguish with certainty, on the cliffs east of the mouth of Indian Canyon ("Boot Point"). Although clearly definable in the field, the boundary between Kf-1-IC-c and Kf-1-IC-d is not a transgressive or "marine-flooding" surface. But the two shoreline sandstone bodies are distinct and have been given different names. (Kf-1-IC-d) prograded toward the northwest and represents a river-dominated delta front deposited in a low-wave-energy setting. The change in depositional style marked by the contact between (Kf-1-IC-d) and underlying (Kf-1-IC-c) is the result of avulsion of a river system into the area and transformation of the wave-modified, straight coastline into a protected bay into which a delta lobe subsequently prograded. The "County Line Channel" studied so extensively by Mobil appears to belong to this unit, as determined by correlation of carbonaceous shales and a thin bed of coal within the sub-A coal zone. (Note: J. Garrison, personal communication, has come to a different conclusion on the basis of his work: that the "County Line Channel" fed (Kf-1-RC)). Type locality: mouth of the North Fork of Indian Canyon, north side, NW1/4NE1/4 section 24, T. 24 S., R. 5 E., Salt Lake Base Line. Landward limit: well defined on west wall of Indian Canyon, SE1/4NW1/4 section 24, T. 24 S., R. 5 E., Salt Lake Base Line and in North Fork of Indian Canyon, NW1/4NW1/4 section 24, T. 24 S., R. 5 E., Salt Lake Base Line.

Seaward limit: "Swell Point", SE1/4 section 8, T. 24 S., R. 6 E., Salt Lake Base Line. Facies content of shoreline unit: river-dominated delta, specifically a delta lobe that built into a bay that was well protected from fair-weather waves.

Kf-1-RC: Kf-1-Rock Canyon parasequence of Ferron Sandstone

Author: this study

Kf-1-Rock Canyon is defined on the cliffs south of Rock Canyon area. Outcrops of Kf-1-Rock Canyon in this area are only fair, being partially covered with debris, but become better in the cliffs to east, on the south side of "Overhand Point." (Kf-1-RC) has a well defined landward pinch-out on the south-facing cliffs east of Coyote Basin, on the south side of "Swell Point." There, it splits the sub-A coal zone, one split of carbonaceous mudstone passing below the transgressive surface, and the other passing onto the root-penetrated top of (Kf-1-RC). A tidal channel deposit rich in oysters, some of which are in growth position, cuts (Kf-1-RC) near its pinch-out. The seaward limit of (Kf-1-RC) has not yet been determined, but it appears that it extends all the way to Ivie Creek. If so, its seaward feather edge is present near the northern end of Blue Trail Canyon, where strata of (Kf-1-Iv-a) onlap it from the north. The landward part of (Kf-1-RC) is strongly wave modified, and this may well be true for the entire unit. Type section: south side of "Swell Point", CSE1/4 section 8, T. 24 S., T. 6 E., Salt Lake Base Line. Landward limit: south side of "Swell Point", NW1/4SE1/4 section 8, T. 24 S., R. 6 E., Salt Lake Base Line. Facies content of shoreline unit: wave-modified coast; proximal part probably strand plain; distal part may include deltaic deposits.

Kf-1-Iv: Kf-1-Ivie Creek parasequence of Ferron Sandstone

Author: this study

Kf-1-Ivie Creek is localized in the Ivie Creek-Quitcupah Creek Canyon area. It has been referred to as Kf-1-Ivie Creek-a in our detailed analysis of the Ivie Creek case-study site. Unit (Kf-1-Iv-b) may be dropped, however, because it probably represents no more than a phase of slow sedimentation following abandonment of the delta represented by the former (Kf-1-Iv-a). Thus, it does not warrant parasequence designation. Without the -b unit, the -a designation will be dropped. (Kf-1-IV) is characterized by distinctive, steeply-sloping clinoform surfaces in the younger of its two recognizable parts. This active deltaic deposit has an arcuate shape, having prograded toward the south at the mouth of Blue Trail Canyon, toward the west in the amphitheatre north of Ivie Creek, and toward the north in the southern part of Quitcupah Canyon. It disappears to the east, across the mouth of Quitcupah Canyon, but exactly how it does this and its relationship to (Kf-1-QC) are not yet clear. It is possible that the odd characteristics of (Kf-1-Iv) can be attributed to its location at the flexure described for the Clawson unit. If this flexure marks the hinge of the foredeep, flexure of strata caused by movement of a basement fault may have brought about the deep-water bay into which (Kf-1-Iv) prograded, the meanderbelt from which its feeder channel came having been situated on the high side of the flexure. Type section: amphitheatre north of Ivie Creek, SW1/4NE1/4 section 16, T.

23 S., R. 6 E., Salt Lake Base Line. Landward limit: not yet determined; relationships to strata on Cowboy Mesa remain unclear. Seaward limit: west side of Quitchupah Canyon, SW1/4SW1/4 section 16, T. 23 S., R. 6 E., Salt Lake Base Line.

Kf-1-QC: Kf-1-Quitchupah Canyon parasequence of Ferron Sandstone

Author: this study

Kf-1-Quitchupah Canyon is defined in Quitchupah Creek Canyon. It is best developed in the area where Kf-1 approaches and dives beneath the alluvium at the canyon floor. It may include the beds previously included in Kf-1-Ivie Creek-c. Relationships on the west side of Quitchupah remain somewhat unclear, despite a great deal of study. If more than one parasequence is ultimately distinguished, (Kf-1-QC-a) and (Kf-1-QC-b) are possible names for them. Relationships between units recognized in Quitchupah Canyon and those on Cowboy Mesa also remain unclear owing to very complicated stratigraphy. (Kf-1-QC) may be the youngest parasequence of Kf-1, in which case it includes the strata that feathers out seaward on the southeast side of "Cowboy Mesa." Type section: Quitchupah Creek Canyon, SE1/4 section 4, T. 23 S., R. 6 E., Salt Lake Base Line. Landward limit: not presently defined. Beds of apparent shallow-marine origin exposed above (Kf-1-Iv) in the amphitheatre north of Ivie Creek (attributed earlier to (Kf-1-Iv-d)) may belong to (Kf-1-QC). Pronounced thickening is present along the walls of Quitchupah Creek Canyon.

Kf-2: Kf-2 parasequence of Ferron Sandstone

Author: Ryer, 1981; 1982

Kf-2 is characterized by very complicated stratigraphy at the parasequence level. The transgressive surface that marks the boundary between (Kf-2-MC-a) and (Kf-2-MC-b) is extensive enough that it might be justifiable to divide Kf-2 into two parasequence sets (Kf-2-early and Kf-2-late?) utilizing this surface. The associated A-coal zone contains thick coal beds south of Willow Springs Wash and in the Quitchupah Creek Canyon area. Much of the thickness of the C-coal bed, originally assigned to Kf-3, has recently been determined to belong to the youngest part of Kf-2. The seaward limit of C-coal deposition is in the Dry Wash area, the lower split of the coal (previously referred to as A-coal) extending somewhat farther than the upper split, which is present in Kf-3. Considering the widespread distribution and substantial thickness of the main A- and C-coal seams, Kf-2 probably ranks as the most important coal-bearing parasequence set (or sets) of the Ferron. Old, abandoned mines that produced coal for local consumption are numerous and range from Willow Springs Wash on the south to "Grassy Valley" on the north. The "Reefer 3" mineral claim and adit on the south side of Dry Wash are on carbonaceous mudstones of the lower split of the C-coal zone.

Kf-2-WS: Kf-2-Willow Springs parasequence of Ferron Sandstone

Author: this study

Kf-2-Willow Springs is defined on the north side of Willow Spring Wash, at its mouth. The landward edge of (Kf-2-WS) is present in the same area, a short distance west of the mouth. Thickening of the unit toward the northeast onto the point that lies north of the mouth of the wash occurs rapidly, surprisingly so since the amount of overall climbing of Kf-2 from here to where it passes beyond the seaward edge of Kf-1 is relatively small. The landward pinch-out is cut by a shale-filled channel, possibly of tidal origin. The seaward extent of (Kf-2-WS) has not yet been determined, but probably is present in the vicinity of "Swell Point." Along the east-facing cliffs south of Coyote Basin, the tip of (Kf-2-WS) has been eroded and replaced by predominantly fine-grained deposits, some of which include "inclined heterolithics" indicative of channel deposition. This scour may be related to the areally more restricted scour that is present near the pinch-out. Relationships here require more study. A younger erosional surface that cuts (Kf-2-RC-a and b) in Coyote Basin area reaches the top of (Kf-1-WS) locally. Type locality: mouth of Dry Wash, north side, CSE1/4 section 18, T. 24 S., R. 6 E., Salt Lake Base Line. Landward limit: mouth of Dry Wash, north side, CSW1/4 section 18, T. 24 S., R. 6 E., Salt Lake Base Line. Seaward limit: not known accurately, approximately at "Swell Point", SE1/4 section 18, T. 24 S., R. 6 E., Salt Lake Base Line. Facies content of shoreline unit: wave-modified coast, probably strand plain.

Kf-2-RC-a: Kf-2-Rock Canyon-a parasequence of Ferron Sandstone

Author: this study

Kf-2-Rock Canyon-a is distinguished on the south side of "Swell Point." There, Kf-2 thickens dramatically toward the east with addition of first (Kf-2-RC-a) and then (Kf-2-RC-b) over a short distance. (Kf-2-RC-a) and (Kf-2-RC-b) are readily distinguished only near their landward pinch-outs. There, on the south side of "Swell Point", a lenticular channel deposit that cuts into the top of (Kf-2-RC-a) is in turn bevelled off by the transgressive surface of erosion at the base of (Kf-2-RC-b). Elsewhere, the two shoreline units lie one above the other, sharing a contact that places middle shoreface on middle shoreface, making them essentially indistinguishable. For this reason, it will be difficult or impossible to determine the seaward extent of (Kf-2-RC-a). The landward pinch-outs of both units were eroded and replaced by sandy, fluvial strata, so their exact locations are not known. Type section: south side of "Swell Point", SW1/4SW1/4 section 8, T. 24 S., R. 6 E., Salt Lake Base Line. Landward limit: south side of "Swell Point", approximately SW1/4SW1/4 section 8, T. 24 S., R. 6 E., Salt Lake Base Line. Seaward limit: not known; possibly near or north of Rock Canyon. Facies content of shoreline unit: not determined, probably wave-modified delta.

Kf-2-RC-b: Kf-2-Rock Canyon-b parasequence of Ferron Sandstone:

Author: this study

See discussion of (Kf-2-RC-a). **(Kf-2-RC-b)** appears to extend northward a great distance, perhaps all the way to Ivie Creek. If this proves to be so, (Kf-2-RC-b) and (Kf-2-Iv-a) may be equivalents. Type section: south side of "Swell Point", SW1/4SW1/4 section 8, T. 24 S., R. 6 E., Salt Lake Base Line. Landward limit: south side of "Swell Point", approximately SW1/4SW1/4 section 8, T. 24 S., R. 6 E., Salt Lake Base Line. Seaward limit: not known; may extend to Ivie Creek. Facies content of shoreline unit: not determined, probably wave-modified delta.

Kf-2-Iv-a: Kf-2-Ivie Creek-a parasequence of Ferron Sandstone

Author: this study

(Kf-2-Iv-a) is distinguished in the amphitheatre north of Ivie Creek. It is separated from overlying (Kf-2-Iv-b) by a surface that was initially interpreted to be a "marine-flooding surface" because it appeared to separate two vaguely upward-coarsening depositional sequences. Truncation of channel deposits in the lower part of Ivie Creek Canyon has subsequently been recognized at the top of (Kf-2-Iv-a), firming up the initial interpretation. (Kf-2-Iv-a) appears to be a wave-modified unit. Its relationship to (Kf-2-RC-b) is unclear and it is possible that these two units are equivalents. Suggested type section: near mouth of Ivie Creek Canyon, NE1/4SE1/4 section 17, T. 23 S., R. 6 E., Salt Lake Base Line. Landward limit: not yet determined. Seaward limit: not yet determined. Facies content of shoreline unit: not determined, probably wave-modified delta.

Kf-2-Iv-b: Kf-2-Ivie Creek-b parasequence of Ferron Sandstone

Author: this study

Kf-2-Iv-b. See comments for (Kf-2-Iv-a). Suggested type section: Same location as (Kf-1-Iv-a), near mouth of Ivie Creek Canyon, NE1/4SE1/4 section 17, T. 23 S., R. 6 E., Salt Lake Base Line. Landward limit: not yet determined. Seaward limit: not yet determined. Facies content of shoreline unit: not determined, probably strand plain and wave-modified delta.

Kf-2-Iv-c: Kf-2-Ivie Creek-c parasequence of Ferron Sandstone

Author: this study

The type area of **(Kf-2-Iv-c)** is the mouth of Ivie Creek Canyon. This unit undoubtedly warrants designation as a parasequence inasmuch as the associated transgressive surface is clearly recognizable both in Ivie Creek Canyon and to the south in the I-70 roadcut. The pinch-out of (Kf-2-Iv-c) trends just slightly west of north. The shoreline sandstone unit displays some interesting and unusual changes at the mouth of Ivie Creek Canyon, changing over about 100 yards from a strongly wave-modified shoreface unit to a much lower wave energy unit that contains mud interbeds and finer sand, and that has a silvery-gray color on outcrop. This change suggests a change from a coast directly facing the sea to one that was sheltered from wave

energy. In some respects, this resembles the change from (Kf-1-IC-c) to (Kf-1-IC-d). The relationships between (Kf-2-Iv-c) and (Kf-2-Mi-a,b) are presently unknown. It can be speculated, however, that (Kf-1-Mi-a) represents the western margin of a major delta that provided the sheltering from wave energy (see below). Suggested type section: Ivie Creek Canyon, NW1/4SE1/4 section 17, T. 23 S., R. 6 E., Salt Lake Base Line. Seaward limit: not determined. Facies content of shoreline unit: wave-modified coast, probably shoreface in the proximal part, transforming to low-wave-energy coast, possibly ay shoreline.

Kf-2-Mi-a: Kf-2-Miller Canyon-a parasequence of Ferron Sandstone

Author: Anderson, 1993; Gustason, 1993; and Ryer, 1993

The type area of **Kf-2-Miller Canyon-a** is the mouth of Miller Canyon. The boundary between this unit and overlying Kf-2-Mi-b is difficult to recognize in many places, but is very apparent where rotated slump blocks, which are generally restricted to (Kf-2-Mi-a) in this area, are present. The transgressive surface is perfectly apparent where it has bevelled the tops of the rotated blocks, which are common enough to facilitate tracing the contact throughout the "Tri-Canyon" area. The landward limit of (Kf-2-Mi-a) has not been determined. Its seaward feather-edge can be approximately located in Miller Canyon and in the lower part of Muddy Creek Canyon, near the "Upper Gooseneck." It has a general northeast trend, suggesting that this parasequence built northwestward, probably as a deltaic lobe. The deltaic complex from which this lobe built may have provided the sheltering from wave energy noted for (Kf-2-Iv-c). Rotated blocks are present in (Kf-2-Mi-a) in the Coal Cliffs south of Miller Canyon, in the lower part of Muddy Creek Canyon, and are particularly well exposed in "Grassy Canyon." A few are present on the east side of "Dino Head Point" on the western margin of the "Molen Amphitheatre." Failure of the rotated blocks is consistently toward the northwest, the direction that the delta lobe appears to have prograded. The abundance of rotated blocks, which are relatively rare entities elsewhere in the Ferron, in the particular area may once again be related to a zone of flexure. Tilting toward the west may have encouraged failure of the delta-front. Type section: near mouth of Miller Canyon, south side, NE1/4NE1/4 section 36, T. 22 S., R. 6 E., Salt Lake Base Line. Landward limit: not determined. Seaward limit: Miller Canyon, NE1/4SW1/4 section 26, T. 22 S., R. 6 E., Salt Lake Base Line; Muddy Creek Canyon, CNW1/4 section 24, T. 22 S., R. 6 E., Salt Lake Base Line. Facies content of shoreline unit: river-dominated delta.

Kf-2-Mi-b: Kf-2-Miller Canyon-b parasequence of Ferron Sandstone

Author: Anderson, 1993; Gustason, 1993; and Ryer, 1993

Kf-2-Mi-b includes the shoreline sandstone that forms the massive cliffs in the lower parts of Miller and Muddy Creek Canyons. It appears to be a very strongly wave-modified unit. The landward pinch-out of (Kf-2-Mi-b) has not yet been located. It thins toward the northwest into "Grassy Canyon" and the "Molen Amphitheatre", finally disappearing into marine shale in the southern part of Molen Reef along with overlying (Kf-2-MC-a). In Muddy Creek Canyon (but not yet elsewhere), it is possible to subdivide (Kf-2-Mi-b) into two subunits bounded by a

distinctive surface. The southern subunit is wave modified, the northern one very strongly wave modified. The surface that separates these subunits could be a transgressive surface, but the overlying transgressive surface beneath (Kf-2-MC-a) has removed any direct evidence. In the absence of compelling evidence to the contrary, it is assumed the surface marks some change of autocyclic origin. Type section: same as (Kf-2-Mi-a), near the mouth of Miller Canyon, south side, NE1/4NE1/4 section 36, T. 22 S., R. 6 E., Salt Lake Base Line. Landward limit: not determined. Seaward limit: Molen Reef, CSE1/4 section 29, T. 22 S., R. 7 E., Salt Lake Base Line. Facies content of shoreline unit: wave-modified, probably strand plain in proximal part; may include deltaic deposits in medial and distal parts.

Kf-2-MC-a: Kf-2-Muddy Canyon-a parasequence of Ferron Sandstone

Author: Anderson, 1993; Gustason, 1993; and Ryer, 1993

Kf-2-Muddy Canyon-a forms ledges and lesser cliffs above the grander cliffs formed by (Kf-2-Mi-b) throughout most of the lower part of Muddy Creek Canyon and into the southern Coal Cliffs to the south. Most of the thickness of (Kf-2-MC-a) has been cut out by meanderbelt deposits. Although very sandy in some areas, much of the meanderbelt deposit consists of "inclined heterolithics." Two distinct meanderbelt units are distinguished on the basis of paleocurrent directions, the southern one being the younger of the two. At one locality on the west side of Muddy Creek Canyon north of the "Lower Gooseneck", the fluvial erosional surface rises to reveal a river-dominated delta-front sequence. On the east side of "Dino Head", near the southern mouth of "Pinion Jay Valley", the meanderbelt deposit ends and the delta-front unit, only about 20 feet in thickness, appears. It grades from marine mudstone at the base to predominantly sandstone in the upper part and can be traced continuously through the "Molen Amphitheatre" to a point where it disappears into marine shale in the southern part of Molen Reef. Although a landward pinch-out of (Kf-2-MC-a) cannot be located because of the fluvial erosion, there can be no question that the surface that separates (Kf-2-MC-a) from the underlying (Kf-2-Mi-b) is a transgressive surface: it places offshore marine shale directly upon upper shoreface sandstone and, locally, has planed off small channels within the top of (Kf-2-Mi-b). Type section: southern part of Muddy Creek Canyon, NW1/4SW1/4 section 24, T. 22 S., R. 6 E., Salt Lake Base Line. Landward limit: cannot be determined owing to erosion by fluvial facies. Facies content of shoreline unit: river-dominated delta; probably represents a low-wave-energy delta that prograded into a protected bay.

Kf-2-MC-b: Kf-2-Muddy Canyon-b parasequence of Ferron Sandstone

Author: Anderson, 1993; Gustason, 1993; and Ryer, 1993

Kf-2-Muddy Canyon-b is defined on the basis of a shoreline sandstone unit that has a distinctive white color. The landward pinch-out of (Kf-2-MC-b) is present in the southern Coal Cliffs just north of "Bear Gulch", at the mouth of Miller Canyon, and is almost reached in the bend opposite the "Lower Gooseneck" in Muddy Creek Canyon. Near the pinch-out, the unit is characterized by large-scale, inclined surfaces that dip to the north, essentially parallel to the

trend of the pinch-out (strike of inclined surfaces perpendicular to shoreline trend). The surfaces are interpreted to represent a series of tidal inlets that were driven northward by longshore drift. Equivalent flood tidal delta and lagoonal deposits have been tentatively identified in Miller Canyon and "Bear Gulch." (Kf-2-MC-b) thickens rapidly eastward, attaining thicknesses in excess of 75 feet in "Grassy Canyon." It extends eastward into Molen Reef, where it is a major cliff former, and northward to Dry Wash. Its seaward limit has not been precisely identified. The areal distribution of this unit is very large compared to most Ferron parasequences, and it is possible that it can be divided. Type section: southern part of Muddy Creek Canyon, NW1/4SW1/4 section 24, T. 22 S., R. 6 E., Salt Lake Base Line. Landward limit: southern Coal Cliffs north of "Bear Gulch", CSE1/4 section 35, T. 22 S., R. 6 E., Salt Lake Base Line; mouth of Miller Canyon, NE1/4NE1/4 section 35, T. 22 S., R. 6 E. and SE1/4SE1/4 section 26, T. 22 S., R. 6 E., Salt Lake Base Line; Muddy Creek Canyon, SW1/4SE1/4 section 23, T. 22 S., R. 6 E., Salt Lake Base Line. Seaward limit: near Dry Wash, approximately NE1/4SW1/4 section 2, T. 22 S., R. 7 E., Salt Lake Base Line, if (Kf-2-MR) is determined to constitute a parasequence (see below). Facies content of shoreline unit: wave-modified coast in proximal part, probably strand plain; may include deltaic deposits in distal part.

Kf-2-MR: Kf-2-Molen Reef

Author: this study

The Kf-2 cliffs in the Molen Reef outcrops south of Dry Wash include two distinct upward-coarsening units. They appear to constitute distinct parasequences, the lower being (Kf-2-MC-b), and the upper (Kf-2-MR), but no clear evidence has yet been found to demonstrate that the boundary between them is a transgressive surface. The name is listed here in anticipation that it will be assigned parasequence status. Type section: Molen Reef south of Dry Wash, NW1/4 section 11, T. 22 S., R. 7 E., Salt Lake Base Line. Landward limit: not determined, but approximately NE1/4 section 15, T. 22 S., R. 7 E., Salt Lake Base Line. Seaward limit: not determined; somewhere north of Dry Wash. Facies content of shoreline unit: probably deltaic.

Kf-2-DW: Parasequence Kf-2-Dry Wash

Author: this study

Kf-2-Dry Wash is defined on the basis of a shoreline sandstone unit whose landward pinch-out crosses the northern edge of the cliffs of the Molen Reef south of Dry Wash and intercepts the cliffs on the north side of the wash, defining a northwest shoreline trend. The pinch-out is less distinct than most others, possibly because of development of a flood tidal delta in this area. A large lagoon/bay complex lies landward of the pinch-out and can be traced for several miles southward in the Molen Reef outcrops and westward to the limit of Kf-2 outcrops in Dry Wash. The lagoon/bay unit is bracketed by splits of the lower C coal that under- and overlie it. The seaward limit of (Kf-2-DW) has not been determined. It is, at present, the youngest known parasequence of Kf-2. Numerous channel deposits, including three large, lenticular channel bodies in Dry Wash and several in the Molen Reef cliffs appear to belong to (Kf-2-DW). Type

section: cliffs north of Dry Wash, SW1/4 section 35, T. 21 S., R. 7 E., Salt Lake Base Line. Landward limit: Dry Wash, SW1/4 section 2, T. 22 S., R. 7 E. and SW1/4SW1/4 section 35, T. 21 S., R. 7 E., Salt Lake Base Line. Seaward limit: not determined. Facies content of shoreline unit: wave-modified, probably strand plain in proximal part; distal part not yet studied.

Kf-3: Kf-3 parasequence set of Ferron Sandstone

Author: Ryer, 1981; 1982

Shoreline sandstones of **Kf-3** extend from the "Molen Amphitheatre" northward beyond Dry Wash. At present, only two parasequences are distinguished. It is likely that one or more additional parasequences will eventually be defined in the northern part of the area of distribution of Kf-3. Much of the thickness of the C-coal bed, previously considered as belonging to Kf-3, has now been reassigned to Kf-2. The uppermost approximately one foot of coal of the C-coal zone, including the thick tonstein bed, extends over the top of (Kf-3-MR-a) near the mouth of "Gnat Canyon" in the "Molen Amphitheatre." Details of coal correlations farther north have not been worked out. With reassignment of most of the coal of the C-coal zone to Kf-2, Kf-3 becomes one of the leanest parasequence sets in the Ferron with respect to its coal content.

Kf-3-MR-a: Kf-3-Mlen Reef-a parasequence of Ferron Sandstone

Author: this study

The type area for (**Kf-3-Mr-a**) is the large "Molen Amphitheatre." The landward pinch-out of (Kf-3-Mr-a) is very well exposed on the cliffs just to the west of the mouth of "Gnat Canyon." The pinch-out takes place into the C-coal zone, with about 1 foot of coal passing above, and the remaining 6 to 7 feet passing below. Only 100 feet to the south, there is no trace of the unit within the C-coal zone, which carries its full compliment of tonsteins. This is a remarkable situation. In the majority of cases, transgression of the sea across the Ferron coastal/delta plain led to formation of bays or lagoons that are preserved landward of the pinch-outs of the subsequently deposited shoreline sandstones. In the case of (Kf-3-Mr-a), the transgressing shoreface cut into and partially eroded a mass of peat. The top of the peat must have lay far enough above sea level to preclude inundation southwest of the shoreline. Peat accumulation was only briefly interrupted, if at all, before progradation of the shoreline occurred. Several well-exposed, lenticular channel deposits filled with "inclined heterolithics" complicate the stratigraphy of (Kf-3-MR-a) in the vicinity of its landward pinch-out. Type section: at mouth of "Gnat Canyon" NE1/4SW1/4 section 30, T. 22 S., R. 7 E., Salt Lake Base Line. Landward limit: just W of mouth of "Gnat Canyon": CSW1/4 section 30, T. 22 S., R. 7 E., Salt Lake Base Line. Seaward limit: not determined. Facies content of shoreline unit: wave-modified, probably strand plain in proximal part; distal part may include deltaics.

Kf-3-MR-b: Kf-3-Molen Reef-b

Author: this study

Kf-3-Molen Reef-b lies above (Kf-3-MR-a) in the "Molen Amphitheatre", being separated from it by a thin zone of carbonaceous mudstone. The landward pinch-out of (Kf-3-MR-b) occurs on the floor of "Gnat Canyon" and so is not exposed, although its position can be determined to within one to two hundred feet. As is true for (Kf-3-MR-a), channels are numerous in the landward part of (Kf-3-MR-b). (Kf-3-MR-a) and (Kf-3-MR-b) merge to form the Kf-3 cliff along the Molen Reef, but the parasequences have not yet been distinguished there. Thus, the seaward extent of these two parasequences are not known. (Kf-3-MR-b) is strongly wave modified in its landward part. Suggested type section: east side of "Gnat Canyon" where it merges into the cliffs of the "Molen Amphitheatre." Type section: "Molen Amphitheatre", east of "Gnat Canyon", NE1/4 section 31, T. 22 S., R. 7 E., Salt Lake Base Line. Landward limit: at mouth of "Gnat Canyon", NE1/4SW1/4 section 30, T. 22 S., R. 7 E., Salt Lake Base Line. Seaward limit: not determined. Facies content of shoreline unit: wave-modified coastline, probably stand plain, in proximal part; distal part may include deltaics.

Kf-4: Kf-4 parasequence of Ferron Sandstone

Author: Ryer, 1981; 1982

Compared to the parasequence sets that preceded it, **Kf-4** thickens very rapidly seaward, indicating a high rate of relative sea level rise during its deposition. Two parasequences are recognizable, although a third may prove to be distinguishable in the "Fracture Canyon" area. The associated G-coal zone only locally contains more than a few feet of coal, probably because peat accumulation could not keep up with the rapid relative rise of sea level that characterized this unit. Carbonaceous mudstones of the G-zone have been mined to produce a soil conditioner, locally referred to by the trade name "Live Earth", for about 20 years in Miller Canyon, although that mine appears to now be inactive.

Kf-4-Mi: Kf-4-Miller Canyon parasequence of Ferron Sandstone

Author: this study

The type area of (**Kf-4-Mi**) is the mouth of Miller Canyon, where its shoreline sandstone body forms high cliffs. The landward pinch-out of (Kf-4-Mi) occurs just south of "Bear Gulch", but is somewhat obscured because the upper part of the unit is replaced by a meanderbelt deposit. The meanderbelt deposit is very widespread, being recognized throughout the "Tri-Canyon" area and eastward into the "Molen Amphitheatre." It is also relatively coarse-grained, being made up of medium- to coarse-grained sandstone that locally includes granules and, rarely, pebbles. The landwardmost part of (Kf-4-Mi) is strongly wave modified and this is probably true of the unit as a whole, although it is difficult to tell with the upper part of the unit removed. Type section: southern Coal Cliffs at the mouth of Miller Canyon, SE1/4SE1/4 section 26, T. 22 S., R. 6 E., Salt Lake Base Line. Landward limit: in Coal Cliffs south of "Bear Gulch", SW1/4NE1/4 section

2, T. 23 S., R. 6 E., Salt Lake Base Line. Seaward limit: not determined, probably in southern part of Molen Reef. Basic facies content: wave-modified shoreline--strand plain in proximal part to wave-modified delta in distal part.

Kf-4-MR: Kf-4-Molen Reef parasequence of Ferron Sandstone

Author: this study

(Kf-4-MR) is defined on the basis of a shoreline sandstone unit that forms a striking, white wall throughout the "Molen Amphitheatre" area. The landward pinch-out of (Kf-4-MR) is well exposed just west of the mouth of "Gnat Canyon", almost directly above the landward pinch-out of (Kf-3-MR-a). Pronounced landward thinning toward the pinch-out is also evident in "Pinion Jay Valley" and in the area north of "Molen Point." (Kf-4-MR) is extremely wave modified in its landward part. The more distal part, however, may include some lower-wave-energy shoreline deposits, some of which may represent river-dominated deltas. It may be that the latter constitute one or more additional, as yet undefined parasequences. Type section: Molen Reef, SE1/4SW1/4 section 29, T. 22 S., R. 7 E. or along white, south-facing wall in "Molen Amphitheater", SE1/4SE1/4 section 30, T. 22 S., R. 7 E., Salt Lake Base Line. Landward limit: mouth of "Gnat Canyon", NE1/4SW1/4 section 30, T. 22 S., R. 7 E., Salt Lake Base Line. Seaward limit: not determined. Probably extends most of the way up Molen Reef toward Dry Wash, where a younger parasequence may be present. Basic facies content: wave-modified shoreline--strand plain in proximal part to wave-modified delta in distal part.

Kf-5: Kf-5 parasequence set of Ferron Sandstone

Author: Ryer, 1981; 1982

Kf-5 thickens rapidly seaward from its landward limit in Muddy Creek Canyon. Its seaward feather edge lies in "Fracture Canyon" just south of Dry Wash. Kf-5 has, to date, defied division into parasequences. Almost everywhere, the upper part of the shoreline sandstone of Kf-5 has been cut out and replaced by meanderbelt deposits (among them the channel deposits so extensively studied by the Texas Bureau of Economic Geology in Muddy Creek Canyon, Grassy Valley, and "Cedar Canyon"). The presence of the meanderbelt deposits preclude recognition of the landward pinch-outs of any parasequences that Kf-5 contains. Most of the shoreline strata of Kf-5 appear to represent a wave-modified coast, probably a wave-modified delta front. The I-coal zone accumulated in a swamp, probably a "raised mire" that existed along the western margin of the Kf-5 meanderbelt that trends northward to northeastward across Muddy Creek Canyon. Coal in the I-zone reaches its maximum thickness in the area at and south of Christiansen Wash, where it combines with the overlying J-coal to form a 30-foot-thick seam. Although the A- and C-coal zones probably include more coal because of their greater areal distributions, the I-coal bed is the only one that has been mined on a large scale. The lower 20 feet of coal has been extensively mined by conventional, room-and-pillar techniques at the Emery mine. The upper 10 feet of coal, which tends to be higher in sulfur, has been left as roof. Consol estimates that about 100 million tons of combined I-J coal is strippable in the area south

of Emery. Carbonaceous mudstones of the I-zone are being mined as "Live Earth" south of "Bear Gulch". Type section: none. Considered to be a parasequence set at present. If Kf-5 is ultimately considered to constitute a single parasequence, a good type section would be the west side of Muddy Creek Canyon, NE1/4SW1/4 section 13, T. 22 S., R. 6 E., Salt Lake Base Line. Landward limit: Muddy Creek Canyon, somewhat obscured because of overlying meanderbelt, approximately NW1/4 section 24, T. 22 S., R. 6 E., Salt Lake Base Line. Seaward limit: "Fracture Canyon", SW1/4 section 24, T. 21 S., R. 7 E., Salt Lake Base Line. Facies content of shoreline unit: river-dominated delta.

Kf-6: Kf-6 parasequence set of Ferron Sandstone

Author: Ryer, 1991

Kf-6 extends from the upper part of Muddy Creek Canyon to Dry Wash. No parasequences are recognized at this time and it is likely that none will be. Contemporaneous channels are rare or absent and all of the shoreline strata of Kf-6 appear to have accumulated along a wave-dominated coast, probably a strand plain. Kf-6 is difficult to study in detail owing to the fact that it is generally exposed only on the lower part of the Molen dip slope and because outcrops are generally poor between the few significant canyons. Both the landward pinch-out at the head of Muddy Creek Canyon and the seaward feather edge at Dry Wash, however, are particularly well displayed. Type section: uppermost part of Muddy Creek Canyon, SE1/4NW1/4 section 13, T. 22 S., R. 6 E., Salt Lake Base Line. Landward limit: uppermost part of Muddy Creek Canyon, SE1/4NW1/4 section 13, T. 22 S., R. 6 E., Salt Lake Base Line. Seaward limit: Dry Wash, NE1/4NW1/4 section 34, T. 21 S., R. 7 E., Salt Lake Base Line. Facies content of shoreline unit: wave-modified coastline, probably strand plain.

Kf-7: Kf-7 parasequence set of Ferron Sandstone

Author: Ryer, 1991

The landward limit of **Kf-7** lies somewhere in the vicinity of Christiansen Wash, although it cannot be defined for lack of good outcrop and the fact that it has been cut out by a major meanderbelt deposit. It reaches a seaward feather edge in the northern part of Muddy Creek Canyon. No parasequences are presently distinguished and, because of outcrop limitation, it is likely that none will be. All well exposed parts of the shoreline unit of Kf-7 are of lower and middle shoreface strata. Dominance of hummocky-swaley cross stratification and planar lamination coupled with moderate bioturbation point to a wave-modified shoreline. The presence of the thick, multi-storied, contemporaneous meanderbelt deposit at Christiansen Wash demonstrates that a large river was actively feeding sediment to (Kf-7) in the area between Christiansen Wash and Miller Canyon. Type section : west side of Muddy Creek Canyon, NW1/4SW1/4 section 24, T. 22 S., R. 6 E., Salt Lake Base Line. Landward limit: cannot be determined owing to fluvial erosion, approximately at Christiansen Wash, NW1/4 section 33, T. 22 S., R. 6 E., Salt Lake Base Line. Seaward limit: upper part of Muddy Creek Canyon, SE1/4NW1/4 section 13, T. 22 S., R. 6 E., Salt Lake Base Line. Facies content of shoreline unit:

wave-modified shoreline, probably strand plain in proximal part and certainly wave-modified delta in distal part.