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EDITED BY PAUL KARL LINK AND BART J. KOWALLIS

V O L U M E 4 2 • 1 9 9 7

PART **2** TWO

MESOZOIC TO RECENT GEOLOGY OF UTAH

Edited by

Paul Karl Link and Bart J. Kowallis

BRIGHAM YOUNG UNIVERSITY GEOLOGY STUDIES

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Editor

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Cover photos taken by Paul Karl Link.

Top: Upheaval Dome, southeastern Utah.

Middle: Lake Bonneville shorelines west of Brigham City, Utah.

Bottom: Bryce Canyon National Park, Utah.

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Preface

Guidebooks have been part of the exploration of the American West since Oregon Trail days. Geologic guidebooks with maps and photographs are an especially graphic tool for school teachers, University classes, and visiting geologists to become familiar with the territory, the geologic issues and the available references.

It was in this spirit that we set out to compile this two-volume set of field trip descriptions for the Annual Meeting of the Geological Society of America in Salt Lake City in October 1997. We were seeking to produce a quality product, with fully peer-reviewed papers, and user-friendly field trip logs. We found we were bucking a tide in our profession which de-emphasizes guidebooks and paper products. If this tide continues we wish to be on record as producing "The Last Best Geologic Guidebook."

We thank all the authors who met our strict deadlines and contributed this outstanding set of papers. We hope this work will stand for years to come as a lasting introduction to the complex geology of the Colorado Plateau, Basin and Range, Wasatch Front, and Snake River Plain in the vicinity of Salt Lake City. Index maps to the field trips contained in each volume are on the back covers.

Part 1 "Proterozoic to Recent Stratigraphy, Tectonics and Volcanology: Utah, Nevada, Southern Idaho and Central Mexico" contains a number of papers of exceptional interest for their geologic synthesis. Part 2 "Mesozoic to Recent Geology of Utah" concentrates on the Colorado Plateau and the Wasatch Front.

Paul Link read all the papers and coordinated the review process. Bart Kowallis copy edited the manuscripts and coordinated the publication via Brigham Young University Geology Studies. We would like to thank all the reviewers, who were generally prompt and helpful in meeting our tight schedule. These included: Lee Allison, Genevieve Atwood, Gary Axen, Jim Beget, Myron Best, David Bice, Phyllis Camilleri, Marjorie Chan, Nick Christie-Blick, Gary Christenson, Dan Chure, Mary Droser, Ernie Duebendorfer, Tony Ekdale, Todd Ehlers, Ben Everitt, Geoff Freethy, Hugh Hurlow, Jim Garrison, Denny Geist, Jeff Geslin, Ron Greeley, Gus Gustason, Bill Hackett, Kimm Harty, Grant Heiken, Lehi Hintze, Peter Huntoon, Peter Isaacson, Jeff Keaton, Keith Ketner, Guy King, Mel Kuntz, Tim Lawton, Spencer Lucas, Lon McCarley, Meghan Miller, Gautam Mitra, Kathy Nichols, Robert Q. Oaks, Susan Olig, Jack Oviatt, Bill Perry, Andy Pulham, Dick Robison, Rube Ross, Rich Schweickert, Peter Sheehan, Norm Silberling, Dick Smith, Barry Solomon, K.O. Stanley, Kevin Stewart, Wanda Taylor, Glenn Thackray and Adolph Yonkee. In addition, we wish to thank all the dedicated workers at Brigham Young University Print Services and in the Department of Geology who contributed many long hours of work to these volumes.

Paul Karl Link and Bart J. Kowallis, Editors

Fluvial-deltaic Sedimentation and Stratigraphy of the Ferron Sandstone

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ABSTRACT

East-central Utah has world-class outcrops of dominantly fluvial-deltaic Turonian to Coniacian aged strata deposited in the Cretaceous foreland basin. The Ferron Sandstone Member of the Mancos Shale records the influences of both tidal and wave energy on fluvial-dominated deltas on the western margin of the Cretaceous western interior seaway. Revisions of the stratigraphy are proposed for the Ferron Sandstone. Facies representing a variety of environments of deposition are well exposed, including delta-front, strandline, marginal marine, and coastal-plain. Some of these facies are described in detail for use in petroleum reservoir characterization and include permeability structure.

INTRODUCTION

The Ferron Sandstone Member of the Cretaceous Mancos Shale is well exposed along the west flank of the San Rafael Swell of east-central Utah (fig. 1). The Ferron Sandstone is a fluvial-deltaic deposit with excellent exposures of a variety of delta facies deposited along the margins of a rapidly subsiding basin. The Ferron Sandstone has been interpreted as an analog for many of the highly productive oil and gas reservoirs in the Alaskan North Slope, Gulf Coast, and Rocky Mountain regions.

The Ferron Sandstone is an eastward-thinning clastic wedge deposited during Turonian-Coniacian (Late Cretaceous) time. The Ferron and equivalent portions of the Frontier Formation in northern Utah and Wyoming record a pronounced and widespread regression of the Cretaceous western interior seaway. In east-central Utah, these deposits accumulated on a deltaic shoreline in a rapidly subsiding portion of the Cretaceous foreland basin. The Ferron consists of a series of stacked, transgressive-regressive cycles which are well displayed in outcrop. Eleven stratigraphic units have been mapped: Clawson, Washboard, Last Chance, and numbers 1 through 8 (in ascending order). These various units define a pattern of seaward-stepping, vertically-stacked, and landward-stepping depositional geometries. This architecture indicates an initial strong supply of sedi-

ment relative to available space where sediment could accumulate, followed by near-balance, and then a relative decrease in sediment supply. Each unit contains in outcrop all, or portions of, the complex of facies that make up a typical fluvial-dominated deltaic deposit. Such facies include deposits of: (1) meandering, distributary, and tidal channels; (2) wave-modified strandlines and fluvial deltas; and (3) transgressive events, bays, lagoons, and flood basins.

The excellent exposures and accessibility of the three stacking patterns and associated complex facies make the Ferron Sandstone an excellent outcrop analog for petroleum reservoirs in fluvial-dominated deltas. The Ferron Sandstone is an excellent model for, and is correlative to, the Cretaceous Frontier Formation, which produces petroleum throughout Wyoming. The Ferron facies are also a good analog for the Tertiary Green River and Wasatch Formations, the major oil and gas producing reservoirs in the Uinta Basin, Utah. In addition to its value as a reservoir analog, sands and coalbeds of the Ferron Sandstone produce gas north of the field trip area in the Wasatch Plateau and along the west-northwest flank of the San Rafael uplift, currently the most active gas play in Utah.

Petroleum industry and U.S. Department of Energy (DOE) analysis of the Ferron Sandstone is also motivated by the need to deal with complex reservoir heterogeneities

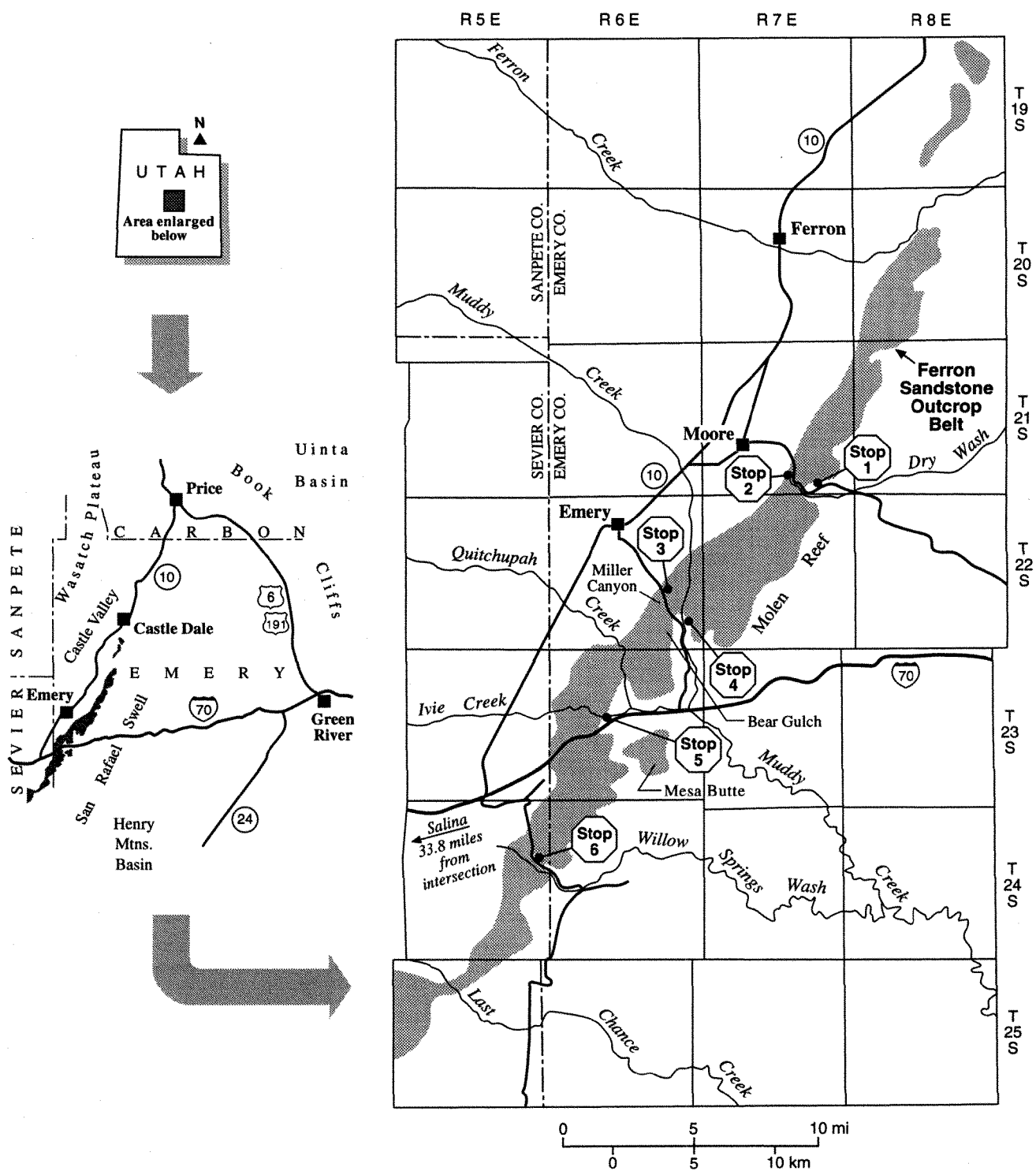


Figure 1. Index map of the Ferron Sandstone outcrop belt (shaded) showing locations of field trip stops.

on an interwell to field scale. These scales are difficult to resolve in reservoir exploration and development activities. Standard industry approaches to field development rely on generic depositional models constrained primarily by data obtained in petrophysical (logging and coring) evaluations of exploration and development wells. The quantity, quality, and distribution of these data are typically insufficient to adequately model the reservoir. Work on the Ferron Sandstone has been predicated on the assumption that detailed outcrop mapping of petrophysical and geological properties of this analog reservoir will provide an additional database for reservoir characteristics used in model simulations.

REGIONAL STRATIGRAPHY

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 (1916) that he would have chosen the outcrops southeast of the town of Emery (fig. 1) 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.

During middle Turonian time, the relatively straight, north-trending western shoreline of the western interior seaway had reached about half way across Utah (Williams and Stelek, 1975). The shoreline configuration changed as it prograded eastward. The rate of progradation was more rapid in northern and southern Utah, less rapid in central Utah, because of geographical variations in subsidence rates and volumes of sediment arriving from the Sevier orogenic belt to the west. The result was a shoreline bend to the west in the Castle Valley area of east-central Utah. Ryer and Lovekin (1986) concluded that this embayment was caused primarily by very rapid subsidence.

We have divided the Ferron Sandstone into mappable units or bodies of rock. Most of these units would be members of the Ferron, if it were elevated to formation status. Eleven mappable units have been recognized on outcrop (fig. 2). We have used a hierarchical system of abbreviations to designate each mappable body of rock. Kf designates Cretaceous Ferron Sandstone. The first dash designates the next hierarchical subdivision, e.g. Kf-2, which is comparable to a member or informal "tongue." Most of these "members" are separated by major flooding surfaces and include smaller-scale progradational units that display distinctive stacking patterns; in essence they are parasequence sets, as defined by Van Wagoner et al., (1990). The lowest two units, Kf-Clawson and Kf-Washboard (fig. 2), have been separated and together informally designated "lower Ferron Sandstone" by Ryer and McPhillips (1983). Ryer and McPhillips' "upper Ferron Sandstone" consists of delta-front units 1–7

(our Kf-1 through 7). We have divided their delta-front unit 1 into Kf-Last Chance (Kf-LC) below and Kf-1 above; in addition, a Kf-8 unit is recognized above Kf-7.

The next dash in our hierarchical scheme designates a higher frequency stratigraphic unit which is mappable and is separated from the rocks above and below by a flooding surface and/or transgressive surface of erosion, and makes up the highest frequency unit mapped within each larger stratigraphic unit or parasequence set (e.g. Kf-2-Muddy Canyon). In most cases these units would fit the definition of a parasequence (Van Wagner et al., 1990), but in some cases, in our opinion, these units do not strictly fit Van Wagner's definition. With these qualifications, we have chosen to use the term parasequence to designate the highest frequency stratigraphic unit recognized and mapped. (For a discussion of earlier Ferron Sandstone stratigraphic nomenclature, see Garrison et al., this volume.)

Other recent studies (Gardner, 1991, 1993, 1995; Barton and Angle, 1995) have not distinguished parasequences in Kf-Clawson, Kf-Washboard, and Kf-7 and 8, although they may exist. Kf-LC contains several parasequences, but it is arguable whether or not a "major" flooding surface is present between it and Kf-1. Internal morphology of Kf-LC indicates it is more aggradational than Kf-1. It is possible for the stacking pattern of a group of parasequences to change from aggradational to progradational without a "major flooding surface." Other characteristics of Kf-LC are distinctive from Kf-1 and discussed later, hence its hierarchical designation. Kf-1 through 7 have associated coal beds, which carry letter designations originally assigned by Lupton (1916).

The oldest unit exposed on the Ferron outcrop belt in Castle Valley is Kf-LC. Kf-LC contains parasequences that are relatively short in overall dip length (1.3 to 0.75 miles [2.1–1.2 km]), rapidly thickening (0 to 60 feet [0–18 m]) with steeply seaward-inclined bed sets (about 5°). The contact with the underlying Tununk Shale, which has a characteristic brown iron stain, is sharp. Kf-LC was deposited in a steeper gradient shoreline topography with abundant sediment supply.

Progradation of Kf-1 and Kf-2 was characterized by an abundant supply of sediment compared to the creation of accommodation space (Gardner, 1995). A relatively small amount of sediment was required to aggrade the coastal plain and a considerable proportion passed north and east through the fluvial systems to reach the shoreline. Rapid supply of sediment at the river mouths promoted the building of fluvial-dominated deltas, the deposits of which are conspicuously more abundant in Kf-1 and Kf-2 than they are in Kf-4 through Kf-7 (Gardner, 1993). It is highly probable that relative sea level rise caused either by eustatic fluctuations or by pulses of basin subsidence, continually affected the area and are the underlying mechanism for inducing both parasequence-set and parasequence-level transgres-

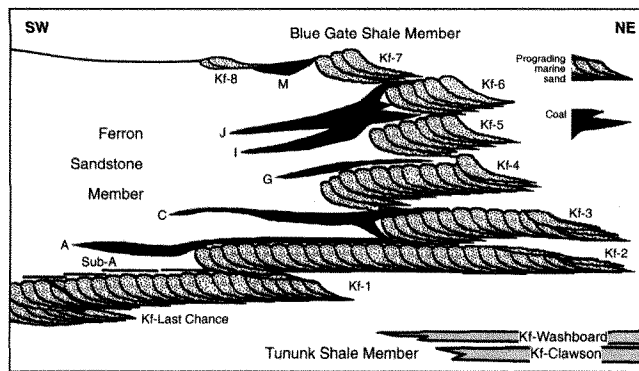


Figure 2. Diagrammatic cross section of the Ferron Sandstone and adjacent members of the Mancos Shale showing the numbering and stacking of the deltaic-front units. Coal zones (black) are designated by letters.

sions and regressions. A delta is very much "at risk" should even a minor rise of relative sea level occur. Transgression of the coast adjacent to a delta diminishes the river's already inefficient gradient, leading inevitably to avulsion of the river, abandonment of the delta, and rapid transgression across the delta plain. Many such transgressions are recognizable in Kf-LC, Kf-1, and Kf-2.

The earliest, proximal part of each parasequence set consists of parasequences deposited on wave-dominated coasts. The relative sea level rise that brought about the parasequence-level transgressions caused reduction of sediment supply to the coast. As the rise slowed and the balance shifted back to progradation, the supply of sediment to the coast increased. Initially, the supply was low, allowing extensive wave reworking. This also explains the pronounced seaward stratigraphic rise of many parasequences just seaward of their pinchouts. The younger, more distal parasequences of Kf-1 and Kf-2 commonly contain more fluvial-dominated deltaic deposits. At these times, the rate of rise of relative sea level was slower and the amount of sediment delivered to the shoreline was correspondingly greater. The supply was great enough to allow progradation of recognizable deltas.

FIELD TRIP OVERVIEW

Geological, physiographical, and cultural features along the field trip route are noted in the road log. The main Ferron Sandstone cliffs and its deeply incised canyons together provide a three-dimensional view of facies variations and transitions. The Ferron Sandstone has excellent exposures along depositional strike; numerous canyons that cut perpendicular to strike offer excellent exposures along the depositional dip direction.

The field trip has two parts, each with a different emphasis: (1) a review of regional stratigraphy and (2) detailed analysis of depositional environments and permeability trends. The primary objective of **Day One** will be to provide a detailed interpretation of the regional stratigraphy of the Ferron Sandstone outcrop belt from Dry Wash to Last Chance Creek (fig. 1). Parasequence designations are based on flooding surfaces which separate notable coarsening-upward depositional sequences. In many cases, landward pinchouts of the marine facies can be observed enclosed within the coastal-plain facies. In Ferron deltaic deposits, parasequence sets/stratigraphic units may be considered as large-scale reservoir blocks because marine and/or delta-plain shales that separate stratigraphic units may act as laterally extensive permeability barriers. The dimensions and depositional environments of selected parasequence sets and the nature of the contacts between parasequences and facies are well displayed at various stops. Bounding surfaces (fluid-flow barriers or baffles), geometries, and depositional environments of these rocks characterize the variability of fluvial-dominated deltaic oil and gas reservoirs. The regional morphological framework can be incorporated into model simulations at the oil and gas field scale.

The primary objective of **Day Two** will be to develop a detailed sedimentological characterization of the facies in the Ivie Creek area just north of Interstate 70 (I-70) (fig. 1). The Ivie Creek area was selected because it contains abrupt facies changes in Kf-1 and Kf-2. Access to the area is excellent because of the close proximity to I-70. Kf-1 in the Ivie Creek area is represented by a fluvial-dominated delta deposit consisting of two stacked parasequences preliminarily identified as Kf-1-Ivie Creek-a and Kf-1-Ivie Creek-c (Kf-1-Iv-a and Kf-1-Iv-c). Kf-1-Iv-a changes from proximal to distal from east to west and is the focus of geologic and permeability characterization. Kf-2 in the Ivie Creek area represents a wave-modified deltaic deposit consisting of lower, middle, and upper shoreface, foreshore, and mouth-bar environments of deposition. Facies of this type are typically found in deltaic reservoirs worldwide. Using a combination of recent drill hole and outcrop data a deterministic three-dimensional view of the rocks within the Ivie Creek area was developed. Detailed stratigraphic sections and cliff-face mapping of rock units on a photomosaic base, combined with petrophysics and outcrop/core permeability data, are the basis for a three-dimensional characterization of these rocks. An evaluation will be presented of how variations in facies influence both compartmentalization and permeability structure. The field trip participants will examine the major reservoir types (mouth-bar complex, wave-modified and fluvial-dominated delta front, distributary channel, and tidal deposits) associated with the Ferron Sandstone.

Much of the information presented on this field trip was gathered by the Utah Geological Survey and associated contractors, who conducted a major DOE-funded study of the Ferron Sandstone from 1993 through 1997. Preliminary findings from the study have been presented by the following: Adams, 1995; Adams et al., 1995a, 1995b; Allison, 1995; Anderson and Ryer, 1995; Dewey et al., 1995; Hucka et al., 1995a, 1995b; Chidsey, 1995; Ryer and Anderson, 1995; Ryer et al., 1995; Snelgrove et al., 1995; Anderson et al., 1996; Chidsey and Allison, 1996; Mattson and Chan, 1996; Snelgrove et al., 1996; and Chidsey, 1997.

ROAD LOG

First Day

MILEAGE
Cumulative Interval

0.0	0.0	Enter eastbound I-70 at junction with U.S. Highway 89, Salina, Utah. Follow road logs of Rigby et al., (1974).
31.7	31.7	View to the east of the San Rafael Swell and Upper Cretaceous Ferron Sandstone Member of the Mancos Shale. Pinnacles of Jurassic Navajo Sandstone on the skyline.
33.8	2.1	Junction of I-70 with Utah Highway 10 (fig. 1). Turn off I-70 and proceed north (left) on Highway 10 towards Emery through Castle Valley. Highway 10 lies on the Blue Gate Shale Member of the Mancos Shale. Boulders of Miocene basalt are strewn over adjacent slopes (Bunnell, 1991). These boulders were eroded from flows to the southwest in the Thousand Lake Mountain area.
35.5	1.7	Ivie Creek. Wasatch Plateau in the distance to the west. Ledge-forming sandstone represents shoreface deposits of the Upper Cretaceous Star Point Sandstone of the Mesa Verde Group (Bunnell, 1991). The Star Point intertongues with the overlying delta- and alluvial-plain deposits of the Blackhawk Formation, the major coal-bearing formation in the Wasatch Plateau and Book Cliffs coal fields. The Masuk Shale Member of the Mancos Shale forms the slopes beneath the Star Point. The Masuk Shale overlies the Emery Sandstone Member in the immediate foreground.

38.5	2.8	Pass by junction of Utah Highway 10 with Hidden Valley coal mine access road to the east.
41.5	3.0	Sevier-Emery County line. Joe's Valley graben fault system to the north on the eastern edge of the Wasatch Plateau.
42.4	0.9	Quitcupah Creek. Browning coal mine in the distance to the east (right).
46.1	3.7	Town of Emery. Continue north on Utah Highway 10.
48.4	2.3	To the left is the site of Texaco's A.L. Jensen 27-9 Ferron coalbed methane well (SE1/4SE1/4 section 27, T. 21 S., R. 06 E., Salt Lake Base Line) drilled in 1995 to a depth of approximately 2,100 feet (640 m). The operator is still evaluating the well.
49.7	1.3	Muddy Creek.
49.9	0.2	Junction with County Road 1612. Turn right onto County Road 1612 toward Moore.
50.5	0.6	Road to Rochester rock art panel to the right.
52.3	1.8	Moore.
52.6	0.3	Turn right toward Dry Wash and continue on county road to the east.
53.1	0.5	Continue straight (east) off pavement towards I-70 at bend in the road (becomes graveled road at this point). Cross the Spanish Trail, a transportation route from 1800 to 1850.
55.5	2.4	Contact between Blue Gate Shale and top of the Ferron Sandstone.
57.2	1.7	STOP 1. Mouth of Dry Wash: overview of Kf-Clawson and Kf-Washboard, and Kf-2 (fig. 3). Kf-Clawson of the Ferron, first described by Cotter (1975a, b), extends from the northern part of San Rafael Swell southward along its western flank, through Molen Reef, finally feathering out westward toward Muddy Canyon. Kf-Washboard (fig. 2) (Cotter, 1975a, b) extends from the northern part of San Rafael Swell southward to Mesa Butte (just south of I-70), slightly farther than does the underlying Kf-Clawson. These units consist of silty, very fine-grained sandstone; they are interpreted as shelf sand bodies with a northern source deposited 10 miles (16 km) or more off-

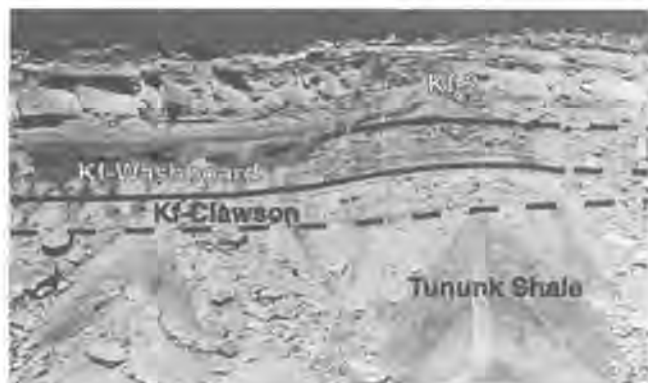


Figure 3. Coal Cliffs (view to the west) near the mouth of Dry Wash at Stop 1 (mile 57.2) with, in ascending order, Kf-Clawson, Kf-Washboard, and Kf-2 outcropping. The upward-coarsening Kf-Clawson and Kf-Washboard are interpreted as two still-stands separated by a relative rise of sea level. Kf-2 consists of interbedded fine-grained sandstone and mudstone, abruptly overlain by cross-bedded, fine- to medium-grained mouth-bar sandstone.

shore, at depths near fair-weather wave base. Extensive burrowing and the presence of large concretions suggest that rates of sedimentation were slow. Lowering of sea level prior to Kf-Clawson and Kf-Washboard deposition 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. The two distinct, upward-coarsening sandstone units suggests that there were two still-stands separated by a relative rise of sea level. In addition to feathering out southward, both Kf-Clawson and Kf-Washboard become less sandy and disappear toward the west. 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 Kf-Clawson and Kf-Washboard suggests that it was active during lower Ferron deposition.

Kf-2 at Dry Wash is composed of two parasequences. The lower parasequence is all delta-front facies and displays upward-coarsening grain size. The lower part of the parasequence consists of interbedded fine-grained sandstone and mudstone; it is abruptly overlain by cross-bedded, fine- to medium-grained sandstone of the upper part. The upper part has a decided fluvial appearance, but lacks the mudstone intraclasts commonly associated with fluvial channel deposits. The top of Kf-2 consists of a series of lenses or pods, the younger lenses cutting out and replacing the older ones. These are interpreted to be mouth-bar and distributary channel deposits of a fluvial-dominated delta.

The younger and overlying parasequence consists of an upward-coarsening sequence of sandy mudstone and sandstone containing a brackish-water fauna representing a bay. The bay-fill sequence is capped by carbonaceous mudstone, carbonaceous sandstone, and a minor amount of coal. These rocks represent the lower split of the C-coal zone (fig. 2). It, in turn, is abruptly overlain by a thin, transgressive lag and lower delta-front deposits of Kf-3. This parasequence is defined on the basis of a shoreline sandstone unit whose landward pinchout of the marine facies 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 pinchout 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 pinchout 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. 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. The facies content of this shoreline unit is wave-modified, probably strand plain in its proximal part.

Turn around and head towards Moore.

- 58.1 0.9 Kf-Clawson at road level.
 58.3 0.2 Kf-2 at bend in the road to the left.
 58.5 0.2 **STOP 2. Dry Wash: depositional environments of Kf-3 (fig. 4).** Cross road and walk up wash to the left.

Kf-3 contains more storm layers than does Kf-2. It also displays hummocky cross-stratification in many places. Like Kf-2, it includes trough cross-bedded sandstone in its upper part. Kf-3, however, includes a sandstone body that has a much more clearly defined erosional base, is coarser grained, contains a variety of burrow types, the most conspicuous of which is *Ophiomorpha*, and displays lateral accretion surfaces inclined toward the northwest. This inclined sandstone body is interpreted to be an inlet or a point-bar deposit on a tidal channel immediately behind the inlet. On the north side of the wash, it is apparent that the inclined, laterally accreted sandstone beds are truncated at their tops by what was originally a horizontal surface. The erosional surface is a transgressive disconformity. It is underlain by a transgressive lag of bioturbated sandstone. The lag, in turn, is overlain by a southward-thinning tongue of offshore-marine shale that separates Kf-3 and Kf-4.

- 58.6 0.1 Ferron Sandstone Kf-4 and Kf-6 (Barton and Angle, 1995) include only prodelta and lower- to middle-delta-front deposits; the shoreline never prograded this far seaward. From a vantage point on top of Kf-4, the gradational seaward termination of Kf-6 can be observed toward the north, where the road crosses the outcrop. Kf-6 sandstone is overlain by the Blue Gate Shale Member of the Mancos Shale. The seaward termination of Kf-4 is only a short distance north of Dry Wash. The seaward feather edge of Kf-5 is present a short distance away on the wall of the canyon visible to the south.
 59.0 0.4 Kf-6. Continue towards Moore.
 61.2 2.2 Return to pavement, continue straight to Moore.
 61.7 0.5 **Moore. Turn left towards Emery at stop sign.**
 64.4 2.7 **Junction with Utah Highway 10, turn left (south) towards Emery.**



Figure 4. Kf-3 in Dry Wash (view to the west from south side of the road) at Stop 2 (mile 58.5) containing hummocky and trough cross-stratification, and bioturbated beds. The thicker bedded sandstones with inclined bedsets to the right are tidal-channel deposits.

- 67.6 3.2 **Enter Emery, turn left on to 300 East.**
 68.0 0.4 Continue south past 400 South in Emery. TRC Minerals to the right processes carbonaceous shale from the Ferron Sandstone for use as potting soil and health tonics.
 68.4 0.4 **Turn left onto Miller Canyon Road toward I-70.** Thousand Lake Mountain and Boulder Mountain can be seen on the skyline to the south.
 70.9 2.5 Enter Miller Canyon. Channel sands and overbank deposits of Kf-5 and shoreface sandstone of Kf-7 are exposed at the head of the canyon.
 71.1 0.2 Access road to one of several carbonaceous shale mines in the G-coal zone on the right.
 71.4 0.3 **STOP 3. Miller Canyon: stratigraphy of Kf-4 and Kf-2 (fig. 5).** Walk southeast along the sandstone bench at road level, north side of the canyon.

The Miller Canyon road descends through the stratigraphic section, hence, the description of the stratigraphy moves from top to bottom.

Compared to the stratigraphic units that preceded it, Kf-4 thickens very rapidly seaward, indicating a high rate of relative sea-level rise during its deposition (Ryer, 1981; 1982). Regionally, two parasequences are recognizable within this unit. The overlying G-coal zone only locally contains more than a few feet of coal,



Figure 5. Transgressive deposits above the C-coal zone of Kf-4 in Miller Canyon near the Christensen mine on the east side of the Miller Canyon road at Stop 3 (mile 71.4).

probably because peat accumulation could not keep up with the rapid relative rise of sea level that characterized this unit. For about 20 years carbonaceous mudstones of the G-coal zone have been mined in Miller Canyon to produce a soil conditioner, locally referred to by the trade name "Live Earth."

Only the older parasequence of Kf-4 is represented by marine facies in Miller Canyon. The lower parasequence is a wave-modified shoreline sandstone body and forms high cliffs. The landward pinchout of the main facies of this parasequence is located about 0.5 mile (0.8 km) south of Bear Gulch (fig. 1), but is somewhat obscured because the upper part of the unit is scoured into by a younger meanderbelt deposit. This meanderbelt deposit is very widespread, being recognized for several square miles around the Miller-Muddy Creek Canyon area and east to the eastern limit of the outcrop. It is relatively coarse-grained, being made up of medium- to coarse-grained sandstone that locally includes granules and, rarely, pebbles. The landward-most part of the lower parasequence 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. The basic facies content is wave-modified shoreline-strand plain proximally to wave-modified delta distally.

Marine facies of Kf-3 are not present in this area, the landward pinchout of the marine facies is located to the east.

At this locality Kf-2 contains four parasequences. We will use the nomenclature established by Anderson (1993), Gustason (1993), and Ryer (1993). The top parasequence is Kf-2-Muddy Canyon-b (Kf-2-MC-b). Kf-2-MC-b is defined on the basis of a shoreline sandstone unit that has a distinctive white color. The landward pinchout of Kf-2-MC-b marine facies is present in the southern Coal Cliffs just north of Bear Gulch, and south of the mouth of Miller Canyon. Near the pinchout, the unit is characterized by large-scale, inclined surfaces that dip to the north, essentially parallel to the trend of the pinchout (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, to more than 75 feet (23 m). It extends eastward into Molen Reef, where it is a major cliff former, and northward to Dry Wash (about 9 miles [14.5 km]). This unit is widely distributed compared to most Ferron parasequences. The facies content of this shoreline unit is a wave-modified coast proximally, probably strand plain; and deltaic deposits distally. A thin A-coal zone lies above this unit. This coal zone pinches out just northeast of Miller Canyon.

Kf-2-Muddy Canyon-a (Kf-2-MC-a) forms ledges and lesser cliffs above the higher cliffs formed by Kf-2-Miller Canyon-b (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 delta facies of Kf-2-MC-a has been cut out by meanderbelt deposits. Although very sandy in some areas, much of the meanderbelt deposits consist of laterally accreted sands with minor siltstone and mudstone. Two distinct meanderbelt units are distinguished on the basis of paleocurrent directions. The landward pinchout of marine facies of Kf-2-MC-a is

located south of Miller Canyon near the southern termination of the Coal Cliffs. In the Miller-Muddy Canyon area 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. The facies content of this shoreline unit is a fluvial-dominated delta and probably represents a low-wave-energy delta that prograded into a protected bay.

Kf-2-Mi-b includes the shoreline sandstone that forms the massive cliffs in the lower parts of Miller and Muddy Creek Canyons (Anderson, 1993; Gustason, 1993; Ryer, 1993). It appears to be a very strongly wave-modified unit. It thins toward the northwest, finally disappearing into marine shale in the southern part of Molen Reef along with overlying Kf-2-MC-a parasequence. 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. The facies content of this shoreline unit is wave-modified, probably strand plain in proximal part.

The bottom parasequence in Kf-2 in this area is Kf-2-Miller Canyon-a (Kf-2-Mi-a). The boundary between this unit and the 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 apparent where it has beveled the tops of the rotated blocks, which are common enough to facilitate tracing the contact throughout the area. Its seaward feather-edge can be approximately located in Miller Canyon and in

the lower part of Muddy Creek Canyon. It has a general northeast trend, suggesting that this parasequence built northwestward, probably as a deltaic lobe.

Kf-2 in Miller Canyon (fig. 6) view to east but west of Muddy Creek.

Junction of Muddy Creek with Miller Canyon.

STOP 4. Lunch.

From the lunch stop, dramatic seaward (eastward) thickening of the top parasequence of Kf-2 can be observed. On the west the thin white-capping sandstone is visible, while this same sand is nearly 30-feet (9-m) thick on the east wall of the canyon. The underlying meanderbelt-dominated facies of Kf-2-MC-a is well exposed in all cliff faces. Some Kf-2-MC-a-aged channels have cut across the top of the underlying shoreface of Kf-2-Mi-b and deep into these deposits. Note how much thicker Kf-2 is in this area compared to our earlier stop at Dry Wash.

Kf-2 is fertile ground for a classic problem in sequence stratigraphy. The scours into delta-front and wave-dominated shoreface deposits observed here can be traced intermittently for tens of miles to the south and several miles to the north along the outcrop. Does this represent a drop in relative sea level? Similar "cannibalization" of shoreline sands is present in Kf-1, 3, 4, and 5. During normal progradation of a shoreline some scouring into older shoreline deposits is expected as fluvial systems feeding the seaward prograding shoreline move across a low-gradient delta-plain. Evidence of emergence, such as rooted coal in the bottom of mud-filled channels, or part way up in a channel-fill sequence; low-angle slopes to the edge of "valley-fill" deposits; regionally correlatable transgressive deposits within the "incised valley" would indicate a drop in sea level as the agent for channel incision. Some workers in the Ferron feel they have observed sufficient evidence to call upon a relative sea-level drop within Kf-2 (Garrison, personal communication, 1996) and Barton (1997) implies more frequent occurrence of minor sea-level drops during Ferron deposition.

72.0	0.6
72.4	0.4
72.8	0.4



Figure 6. View down Miller Canyon (north side) near the junction with Muddy Creek showing Kf-2 and its four parasequences between Stops 3 and 4 (mile 72.0).

76.5	3.7	Junction with I-70. Turn right (west) on I-70 towards Salina.
77.8	1.3	Mesa Butte to the south, capped chiefly by Kf-1 and Kf-2. There is a very limited area of C-coal zone on the mesa. The lowest ledge-forming unit in the east-facing cliffs is Kf-Washboard.
78.3	0.5	Quitichupah Canyon to the north.
78.8	0.5	STOP 5. Ivie Creek Amphitheater: the fluvial-dominated Kf-1 and wave-modified Kf-2 (fig. 7). Turn off I-70, drive down slight embankment, and park along the right-of-way fence. We will examine the Kf-1 and Kf-2 today and walk through the outcrop tomorrow.

Kf-1 is represented by two parasequences in the Ivie Creek area. Kf-1-Ivie-a (Kf-1-Iv-a) is characterized locally by distinctive, steeply inclined bedsets (clinoforms) that accumulated on a prograding lobe of the delta. This deltaic lobe has an arcuate shape based on mapping of clinoforms in the Ivie Creek area. The lobe prograded toward the south (just south of I-70), toward the west in the amphitheater north of Ivie Creek, and toward the north in the southern part of Quitichupah Canyon. It is possible that the odd characteristics of Kf-1-Iv-a can be attributed to its location at the flexure described for Kf-Clawson. If this flexure marks the hinge of the foredeep, flexure of strata caused by movement of a basement fault may have created the deep-

water bay into which Kf-1-Iv-a prograded (fig. 8); the distributary system from which its feeder channel came was situated on the high side of the flexure. The seaward limit of Kf-1-Iv-a is mapped in mid-Quitichupah Canyon. This fluvial-dominated deltaic deposit changes from proximal to distal east to west across the amphitheater in the Ivie Creek area. Clinoforms in the delta front dip 10° to 15° and pinchout laterally within a mile (1.6 km) down depositional dip (fig. 9).

The overlying sand-rich and coarsening-upward facies of the Kf-1-Ivie Creek-c (Kf-1-Iv-c) also vary in thickness within the area. In contrast to Kf-1-Iv-a, delta-front deposits of this parasequence dip less than 5°. Kf-1-Iv-c laps onto the more distal parts of Kf-1-Iv-a in the western part of the Ivie Creek area and represents the distal portion of another delta lobe, probably originating from the southwest. The upper section of Kf-1-Iv-c is continuous across the entire Ivie Creek area and represents a fluvial-dominated delta. Kf-1-Iv-c contains loading features near the mouth of Ivie Creek. It thickens to the north as Kf-1-Iv-a pinches out. As with most parasequences, small channels cut into the top of Kf-1-Iv-c. A consistent zone of brackish-water-rich fossils is found above the marine delta-front sandstones of Kf-1-Iv-c. These deposits often grade to *Crassostrea coquinas* which sometimes split the sub-A coal. A flooding surface has been identified at the top of the sub-A coal. The boundary with the overlying Kf-2 is drawn at the change from delta plain to lower shoreface deposits.

Kf-2 contains three parasequences at Ivie Creek: Kf-2-Ivie Creek-a, b, and c (Kf-2-Iv-a, Kf-2-Iv-b, and Kf-2-Iv-c). These parasequences show less lateral variation in facies than Kf-1 parasequences, possibly because wave processes were dominant. Kf-2-Iv-a is the oldest parasequence in Kf-2 and grades from proximal facies of a shoreface on the west to its pinch out before reaching Quitichupah Creek on the east. Kf-2-Iv-b has a similar west to east variation in facies. This parasequence has distinctive seaward inclined beds near Quitichupah Canyon and appears to have

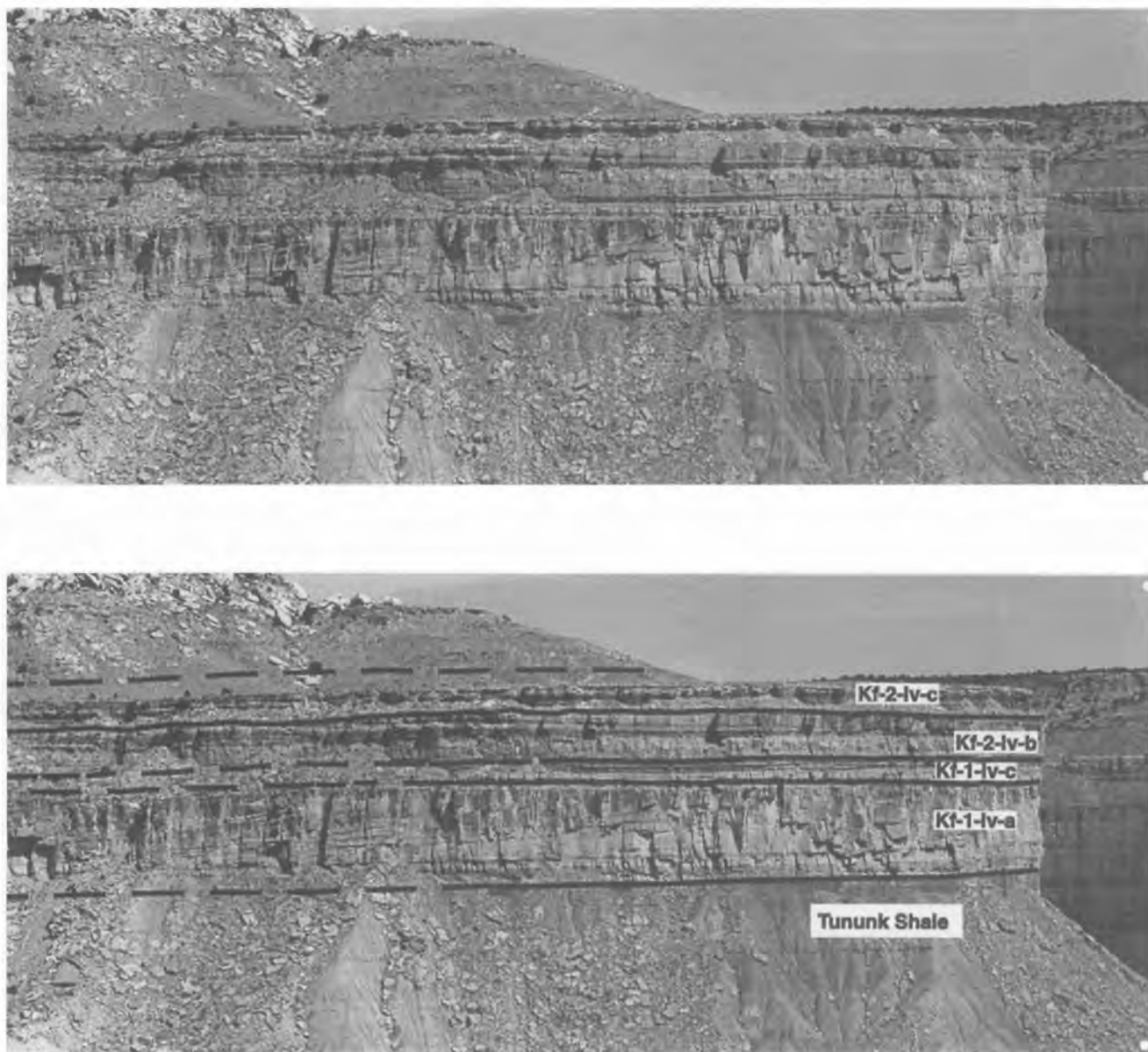


Figure 7. Photomosaics (view to the north near I-70), unannotated (top) and annotated (bottom), of the Ivie Creek area at Stop 5 (mile 78.8) displaying contrasting delta-front architectural styles. On the annotated photomosaic black lines separate the parasequences of Kf-1 and Kf-2, designated with letters. Kf-1-iv-a has steeply inclined (10 to 15°) clinoforms representing fluvial-dominated deposition. Kf-2-iv-b has gently inclined ($< 3^\circ$) clinoforms representing wave-modified deposition.

considerable lateral continuity along the strike of the outcrop. Kf-2-iv-c has the landward pinchout of its marine facies well exposed in the I-70 road cut and upper Ivie Creek Canyon. Connecting these two points indicates a more north-south trend for the shoreline. A remarkable transition from shoreface to bay deposits is also well exposed in this area.

In the Ivie Creek area, deposition of sandstones in Kf-1-iv-a was from the south-southeast to north-northwest, whereas the general coarsening in grain size of Kf-2 to the west and the presence of a landward pinchout of the marine facies in Kf-2-iv-c suggests that this unit was deposited from west to east. Kf-2 contains more and cleaner sand, indicat-

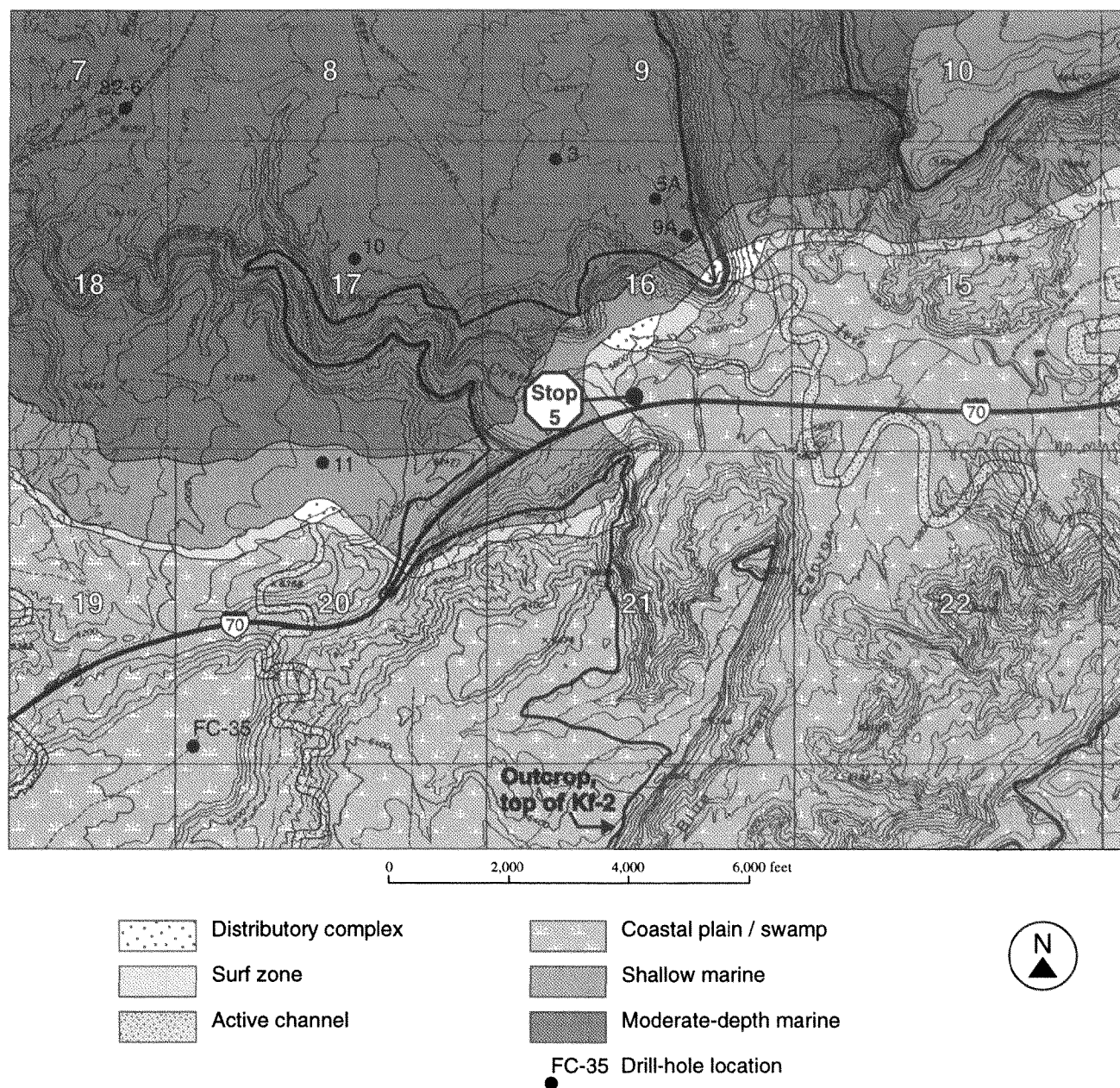


Figure 8. Paleogeographic interpretation of the third of five time steps of Kf-1-Iv-a parasequence in the Ivie Creek area. River channels flowing from the south and southeast deposited sands into a protected embayment in the northwest part of the area.

		ing a more wave-modified environment of deposition. Kf-1 is more heterolithic, indicating a fluvial-dominated environment of deposition.
79.1	0.3	I-70 roadcut, Kf-1 (fig. 10)
79.5	0.4	I-70 roadcut, sub-A coal, and Kf-2/Kf-1 contact on right.
79.8	0.3	Note the landward pinchout of the marine

		facies of Kf-2-Iv-c. By looking back toward the east, one can trace the rapid thickening of marine shoreface facies as the unit prograded to the east. Also note that the marine sandstone pinches out into coastal-plain facies of the A-coal zone C-coal zone with Kf-4 alluvial-plain facies above.
79.9	0.1	



Figure 9. An east-west oriented photomosaic of the Ivie Creek amphitheater viewed from Stop 5 (view to the north), showing typical clinoform geometries in Kf-1-iv-a.



Figure 10. Photomosaic near I-70 at Stop 5, view to the south, showing both Kf-1 and Kf-2. A major distributary channel (center of photo) has cut down to near the base of Kf-2.

80.2	0.3	Large channel sandstone which created a split in I-coal zone on south side of I-70 (see Ryer and Langer, 1980).
80.7	0.5	Carbonaceous shale of the Ferron Sandstone and overlying Blue Gate Shale in roadcut on south side of I-70.
81.8	1.1	Sevier/Emery County line.
82.5	0.7	Walker Flat.
84.4	1.9	Deep roadcut in Blue Gate Shale.
84.9	0.5	Junction with Utah Highway 10. Leave I-70 and turn left (south).
85.0	0.1	Continue south off pavement towards Willow Springs.
86.9	1.9	Bear right (south) at the V in the road.
89.3	2.4	Entering Willow Springs Wash. Begin stratigraphic descent through alluvial-plain facies equivalent with Kf-3 through Kf-8. See van den Bergh (1995) and van den Bergh and Sprague (1995) for an attempt at correlating parasequence sets into the alluvial-plain facies.
90.2	0.9	Little dug-out building on left side of road is one of several relicts left from an old mine in the A-coal zone. The A-coal zone achieves its greatest thickness in this area and to the south.
90.8	0.6	STOP 6. Willow Springs Wash/Indian Canyon: sequence stratigraphy and depositional environments of Kf-1 and Kf-2 (fig. 11).

Kf-2 is found on the north side of Willow Spring Wash, at its mouth. The landward edge of the marine facies of Kf-2 is present in the same area, a short distance east of a large channel cut into Kf-1 called the "County Line channel" (Anderson, 1991). 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. It is possible that the rapid thickening of Kf-2 is related to truncation by eroding channels. The landward pinchout of the marine facies is cut by a shale-filled channel, possibly of tidal origin. The original depositional limit of Kf-2 marine facies is likely farther to the west. The seaward extent of Kf-2 has not yet been determined, but it probably is present in the Molen Reef area about 30 miles (48 km) to the northeast. Along the east-facing cliffs, about 0.5 mile (0.8 km) north of Willow Springs Wash, the top of Kf-2 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 pinchout. The facies content of this shoreline unit is a wave-modified coast, probably a strand plain.

Indian Canyon, south of Willow Springs Wash, contains excellent exposures of Kf-1. Kf-1 is divided into four mappable units, Kf-1-Indian Canyon-a through d (Kf-1-IC-a through d), which display a forward-stepping arrangement. The transgressive (or "flooding") surfaces that separate the parasequences are overlain, at least in part, by mudstone units that may act as permeability barriers between sandstone bodies. Rocks in these units contain prodeltaic; lower, middle, and upper shoreface; foreshore; and fluvial-dominated delta-front deposits.



Figure 11. The "County Line channel" (view to the east) of Kf-1 in the Willow Springs Wash area at Stop 6 (mile 90.8). The channel is very late Kf-1 aged but older than the upper portion of the sub-A coal. The channel is about 60 feet (18 m) thick where it cuts into the uppermost parasequence of Kf-1.

91.1	0.3	View of Indian Canyon to the west.
91.5	0.4	View of Henry Mountains to the south.
92.2	0.7	Junction of Mussentuchit and Last Chance Roads. Bear right towards Last Chance. View to the north of Kf-2 (on the south-facing side of Willow Springs Wash). Here one can see an important trend in the seaward-stepping Kf-2 of the Ferron Sandstone. Note the thickening and increase in sandy facies in Kf-2 from west to east. This trend is readily observable in the Willow Springs Wash, and Quitcupah to Molen Reef areas. There is a corresponding east to west increase in the presence of "cannibalization" of delta-front sandstones by meanderbelt and distributary systems. These phenomena could be explained by a migrating flexure line of subsidence with time from west to east. West of the flexure line the basin is being uplifted, while east of the line the basin subsides. This creates more accommodation space on the east and increased cannibalization of previously deposited delta-front units on the west. This localized and subtle subsidence is superimposed onto a general sea-level rise through Kf-2 deposition.
96.2	4.0	Limestone Cliffs. The type section of Kf-LC is at Last Chance Creek and to the north into the next canyon. The shoreline unit, together with overlying Kf-1 (non-marine facies), forms vertical cliffs approximately 200 feet (60 m) high. Kf-LC dis-

96.6 0.4

98.3 1.7

111.9 13.6

145.7 33.8

MILEAGE	
Cumu- lative	Inter- val

0.0 0.0

33.8 33.8

42.2 8.4

44.6 2.4

plays 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 north-west-southeast trend based on limited sub-surface 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.

Last Chance anticline. Descend through the Cretaceous Cedar Mountain Formation, and Jurassic Morrison, Summerville, Curtis, Entrada, and Carmel Formations. A minor amount of gas was produced from fractured zones in the Triassic Moenkopi Formation along the crest of the structure. Note the northwest-trending dike on the west side of the road.

Turn around in center of Last Chance anticline and return to I-70.

Junction with I-70. Turn west onto I-70 towards Salina.

Enter Salina. End of Day 1.

ROAD LOG

Second Day

Leave Salina east on I-70.

Junction of I-70 with Utah Highway 10.

Ranch Exit 97. Leave I-70. Turn left (north), crossing I-70. Return west-bound I-70 towards Salina.

Ivie Creek Amphitheater. Turn off I-70, driving down slight embankment. We will begin our day hike into the Ivie Creek amphitheater and lower canyon areas. Moderate to strenuous climbing will be required over the 2.5 mile (4.0 km) hike. Cross fence that runs along I-70 and proceed down steep embankment. Cross Ivie Creek and climb slight embankment on the north side. Proceed along trail

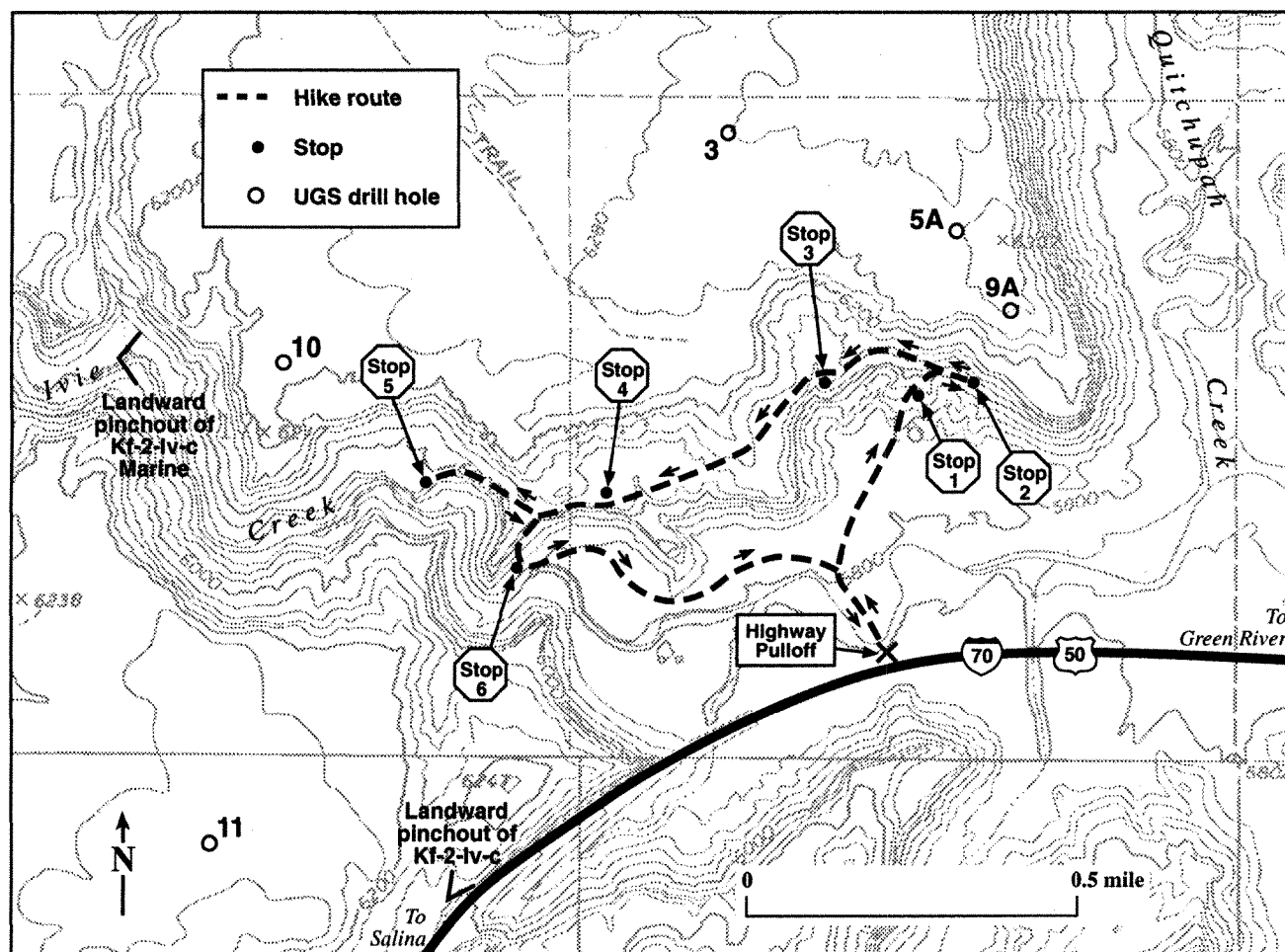


Figure 12. Index map to the Ivie Creek area showing topography, hike route, and stops. Base map from U.S. Geological Survey Mesa Butte and Walker Flats 7.5' topographic maps; contour interval is 40 feet (12 m).

towards the Ivie Creek amphitheater to the northwest following the map in fig. 12 to the base of Kf-1-Iv-a. Begin ascending up a steep slope in the Tununk Shale following the measured section on fig. 13.

IVIE CREEK HIKE—STOP 1: Climoform Facies of Kf-1-Iv-a

The clinoform section of Kf-1-Iv-a (fig. 9) is classified into four facies: clinoform proximal (cp), clinoform medial (cm), clinoform distal (cd), and clinoform cap (cc). Facies cp, cm, and cd are assigned to clinoforms only, and facies cc is a capping facies above the clinoforms (fig. 14). The cc facies is the result of reworking the tops of the clinoforms and the addition of new sediment.

Facies cp is mostly fine- to medium-grained sandstone. The chief sedimentary structure is low-angle cross-stratifi-

cation with minor horizontal and trough cross-stratification and rare hummocky bedding. The facies is dominantly thick to medium bedded, well to moderately indurated, with permeabilities ranging from 2 to 600 millidarcies (mD) and a mean of about 10 mD. The inclination of bed boundaries is generally greater than 10° . This facies is interpreted to be the highest energy and most proximal to the sediment input point. The steep inclinations are interpreted to represent deposition into a relatively localized deep area in an open bay environment. The dominance of low-angle cross-stratification with inclinations within the bed or clinoforms in an up-depositional dip direction indicates the influence of on-shore wave energy.

Facies cm is dominantly sandstone with about 5 percent shale. The sandstone is primarily fine-grained with slightly more fine- to very-fine-grained than fine- to medium-grained. Horizontal beds dominate with some rippled,

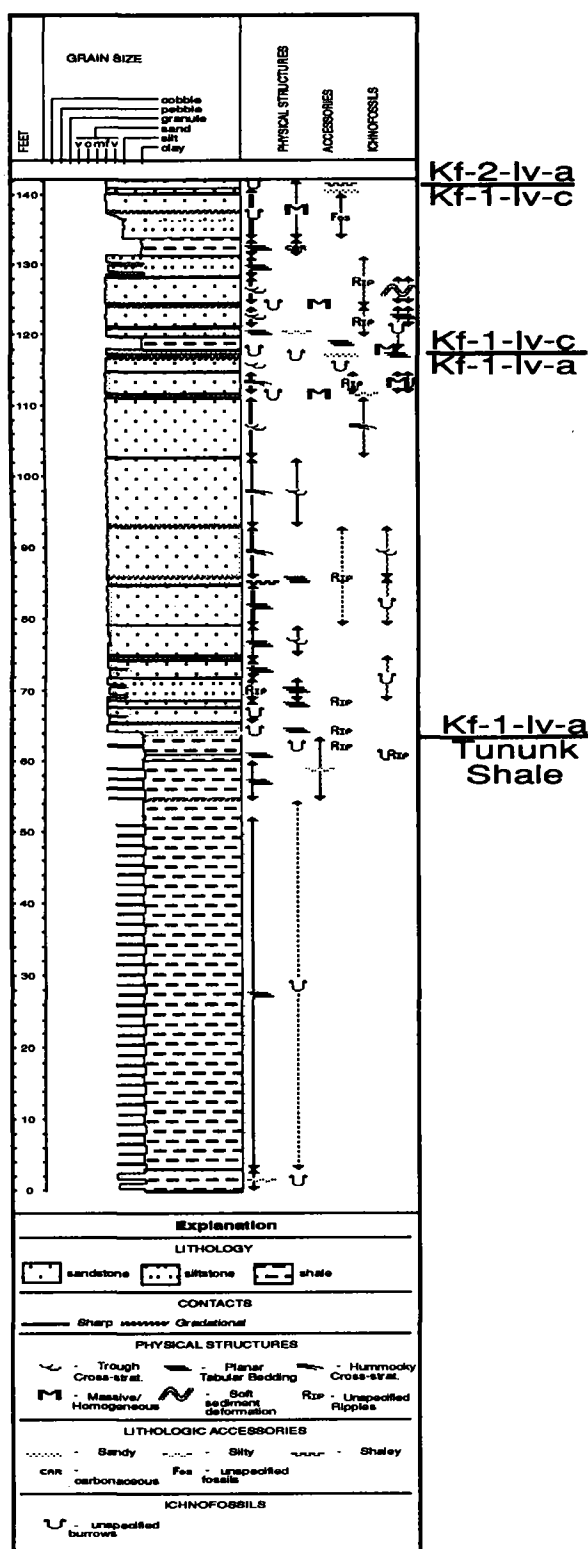


Figure 13. Stratigraphic section from the Ivie Creek amphitheater of Kf-1 (originally at a scale of 1 inch = 10 feet [2.54 cm = 3 m]) showing lithology, nature of contacts, sedimentary structures, ichnofossils, and parasequence designations.

trough and low-angle cross-stratification. Bed thicknesses range from laminated to very thick, but most are medium. The beds are generally well to moderately indurated, but are occasionally friable. The permeability values range from non-detectable to 100 mD with the mean about 3 mD. Inclination on the clinoform boundaries is between 2 and 10°. Facies cm is generally transitional between facies cp and cd, but occasionally is present at the erosional truncation or offlapping boundary of the clinoforms, with no visible connection to facies cp.

Facies cd is sandstone (sometimes silty) with about 10 percent shale. The sandstone grain size is dominantly fine- to very-fine-grained, with considerable variation. Sedimentary structures in this facies are chiefly horizontal laminations and ripples in medium to thin beds. The beds range from well indurated to friable. Average facies cd permeability is just at the instrument detection limit of 2 mD, but ranges up to 80 mD. This facies is gradational with facies cm and represents the deepest water and lowest energy deposition within the clinoform. It can be traced distally into prodelta to offshore facies.

Facies cc consists of very-fine- to fine-grained, thick- to medium-bedded sandstone. The beds are horizontal, with some trough and low-angle cross-stratification. Burrows and other trace fossils are rare. The sandstone is mostly well indurated, with permeabilities ranging from non-detectable to 100 mD with a mean of about 2 mD. This facies is present stratigraphically above the truncated clinoforms near the top of the parasequence and where bed boundaries show little to no inclination. The cc facies is interpreted to represent an eroded and reworked delta top.

Figure 8, the paleogeographic interpretation, represents the third step of the five depositional time steps of Kf-1-iv-a. The main delta lobe was located to the east and north-east. That delta lobe allowed a protected embayment to develop in the northwest part of the Ivie Creek area. The clinoforms represent deposition into the embayment fed by river channels from the southeast.

IVIE CREEK HIKE—STOP 2: Bounding Surfaces of Kf-1-iv-a and Depositional Environments of Kf-1-iv-c

Fluid-flow communication likely occurs between clinoforms (or parasequences) where shales are absent due to erosion or non-deposition. Porosity and permeability values, dependent on facies distribution, vary laterally and vertically within a clinoform. Bounding surfaces between clinoforms designated proximal or medial facies contain two common lithologic elements: (1) finer-grained, poorer cemented, and less resistant lithology than the overlying and underlying units, and (2) laminations of carbonaceous material which are consistently poorly cemented and become planes of

weakness which are expressed in the recessive outcrops of the bounding surfaces. Most of the bedding in the bounding surfaces is horizontal to slightly irregular. On occasion clearly recognizable wave-ripple laminations are found along with some flaser bedding. Often some portion of the bounding surface contains gypsum veinlets.

Bounding surfaces found associated with a proximal-to-proximal facies contact are generally somewhat thinner than those associated with a medial-to-medial facies contact. Lithologically, the contact in the proximal facies is sandier and thinner, but where the bounding surface is fairly thick (>0.30 feet [10 cm]) it shows an increase in finer-grained rocks. The amount of silt and shale within the bounding surface is related more to the thickness of the surface than the over- and underlying facies designations. The distal facies in the clinoforms are all similar in permeability and essentially act as strong baffles or barriers to flow.

Kf-1-Iv-c is capped by unidirectional, trough-cross-bedded sandstone. Above the cross-bedded sandstone are 10 to 15 feet (3–6 m) of bay-fill deposits. These deposits consist of carbonaceous mudstone; thin, rippled-to-bioturbated sandstone and siltstone; fossiliferous mudstone to sandstone; oyster coquina; and ash-rich coal. Although not mapped, the upper portion of this bay to coastal-plain interval is related younger marine progradations or parasequences found north and east of the Ivie Creek area.

IVIE CREEK HIKE—STOP 3: Sequence Stratigraphy and Depositional Environments of Kf-2

The base of Kf-2-Iv-a consists of interbedded sandstones and shales in prodelta to lower shoreface environments. In some places along the basal contact of the parasequence a thin (1 foot [0.3 m]) bed of transgressive deposits is present. Kf-2-Iv-a shoals to middle shoreface. The flooding surface and parasequence boundary is difficult to recognize because there is no offset in facies. The overlying Kf-2-Iv-b is also middle shoreface. Kf-2-Iv-a becomes thin and unrecognizable a short distance to the east. Kf-2-Iv-b exhibits gently seaward inclined beds which are very conspicuous when viewed east along the outcrop. The parasequence has at least two sub-cycles of grain size coarsening and bed thickening upward. These units are intensely bioturbated.

Kf-2-Iv-c is separated from the underlying Kf-2-Iv-b by a siltstone to shale interval which varies in thickness across the Ivie Creek area. Generally the entire parasequence fines from west to east. In the Ivie Creek amphitheater, Kf-2-Iv-c is interpreted as a bay-fill deposit (although it is devoid of body fossils). At the top of the sequence is a thin, medium-grained carbonaceous sandstone which may represent the migration of a low-energy beach (foreshore de-

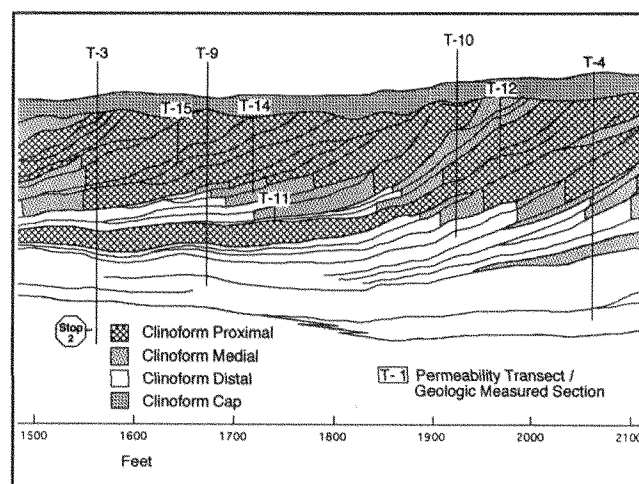


Figure 14. Scaled cross section, oriented west to east, showing clinoform facies assigned to Kf-1-Iv-a from the Ivie Creek amphitheater based on a portion of the interpreted photomosaic. Vertical lines represent permeability transect and measured section locations.

posits) across the bay fill prior to capping by coastal-plain deposits and deposition of the overlying A-coal zone (which is locally burned).

IVIE CREEK HIKE—STOP 4: Lateral Facies Changes in Kf-2

Kf-2-Iv-a is thicker here than at our last stop. It consists of a thin sequence of lower shoreface heterolithics overlain by about 28 feet (8.5 m) of middle-shoreface deposits.

Kf-2-Iv-b consists of horizontally bedded, silty sandstone at the base and unidirectional, trough-cross-bedded sandstone toward the top. In a road cut along I-70 and in Ivie Creek Canyon, this unit displays trough sets which become horizontally bedded in a down-dip direction (east). These deposits are interpreted as mouth-bar deposits.

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 landward pinchout of the marine facies of Kf-2-Iv-c is found northwest of this stop (see fig. 12) and trends just slightly east of south toward I-70. The shoreline sandstone unit displays some interesting and unusual changes at the mouth of Ivie Creek Canyon, changing over about 300 feet (90 m) 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. The facies content of this shore-line unit is a wave-modified coast, probably shoreface in the proximal part, transforming to a low-wave-energy bay. There is evidence for bay-head deltas and tidal channels feeding the bay to the northeast, in Quitcupah Canyon.

IVIE CREEK HIKE—STOP 5: Shoreface Deposition of Kf-2-Iv-a, b and c

Kf-2-Iv-a is exposed in the vertical cliff at the base of Kf-2. At this location, a distributary channel deposit has cut into the upper half of the shoreface deposits. The coarser (medium-grained) channel is easy to distinguish from the darker-colored shoreface deposits.

Kf-2-Iv-b (fig. 15) is dominated by unidirectional, trough-cross-bedded sandstone of the mouth-bar complex which continues farther up the canyon and is present in core from the UGS drill hole No. 11 0.5 mile (0.8 km) to the southwest. This stop offers an opportunity to walk through Kf-2-Iv-b and c.

Kf-2-Iv-c forms the 10-foot (3.1-m) cliff at the top of the alcove. Excellent upper-shoreface facies are exposed. The top of the unit is rooted by the overlying coastal-plain vegetation. Root casts are commonly visible at the top of this unit. Just a few tens-of-feet up the canyon from the stop, there is a thin, but well developed, carbonaceous shale at the top of Kf-2-Iv-b, with the flooding surface for Kf-2-Iv-c immediately above.

IVIE CREEK HIKE—STOP 6: Distributary Channels and Rotated Blocks in Kf-1

Kf-1-Iv-a now lies several tens-of-feet below the parasequence boundary. Recall that it filled an embayment and was sourced from the south to the southeast. Kf-1-Iv-c has thickened dramatically from our first stop. Here it is anomalously thick due to large slump features or rotated blocks. Failure of the rotated blocks is consistently toward the north to 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 this particular area may be related to a zone of flexure. Tilting toward the northwest may have encouraged failure of the delta-front. Rotated blocks are also present in the lowest parasequence of Kf-2 in the Coal Cliffs south of Miller Canyon and in the lower part of Muddy Creek Canyon.

Kf-1-Iv-c has onlapped Kf-1-Iv-a. It represents a slightly younger episode of progradation filling space that Kf-1-Iv-a delta left unfilled, likely due to avulsion of the sediment source.

On return to the vehicles, note the cross-sectional view of a channel in Kf-1-Iv-c on the second point east of here.

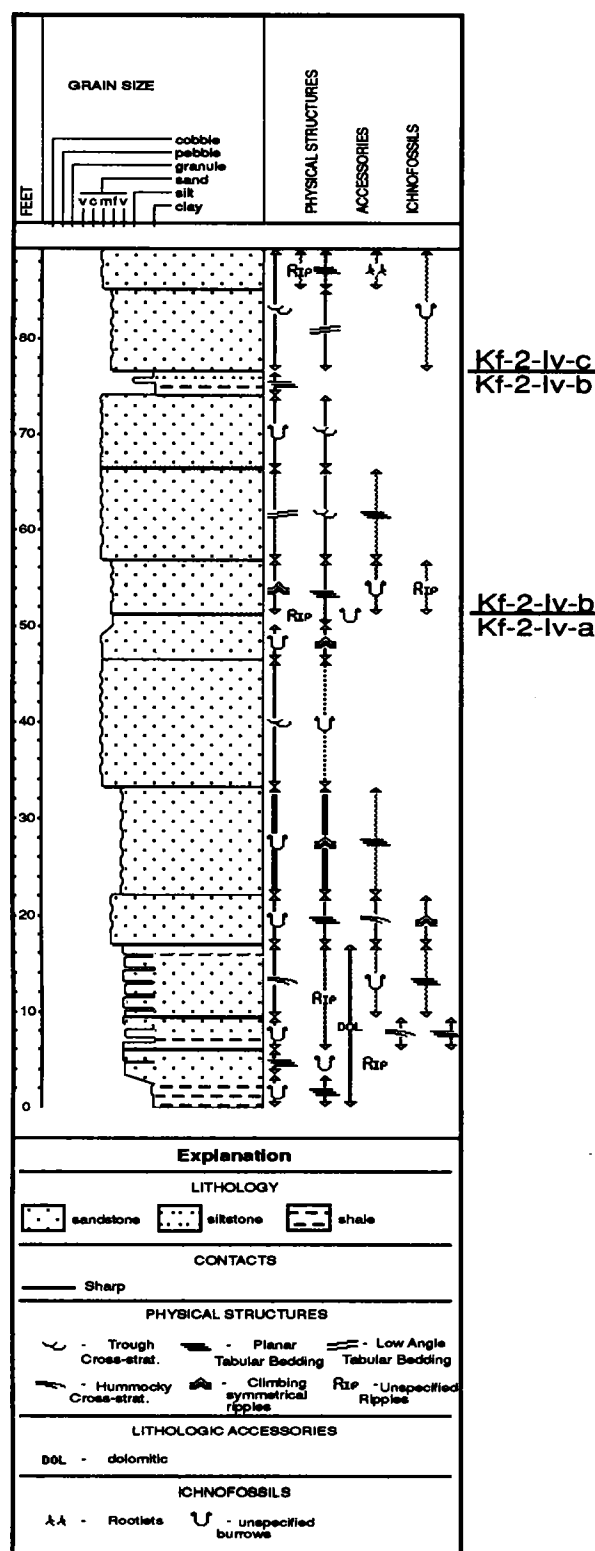


Figure 15. Stratigraphic section from Ivie Creek Canyon of Kf-1 and Kf-2 (originally at a scale of 1 inch = 10 feet [2.54 cm = 3 m]) showing lithology, nature of contacts, sedimentary structures, ichnofossils, and parasequence designations.

End of Day 2. Return to vehicles. Go westbound on I-70 to junction with Utah Highway 10. Return to Salt Lake City via Price on U.S. Highway 6.

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