Field Localities in the Book Cliffs to Understand Sequence Stratigraphic Concepts

William W. Little[1,2] and David A. Little[1]

[1]W.W. Little Geological Consulting, LLC, 185 West 200 South, Wellington, Utah 84542
[2]Department of Geology, Brigham Young University – Idaho, 525 South Center Street, Rexburg, Idaho 83460-0510
Corresponding email: wwlittle@gmail.com

Utah Geosites
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M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors

COVER IMAGE: Outcrop of coastal-plain or delta-top deposits within the upper Aberdeen Member equivalent (Kba-equiv) of the undifferentiated Blackhawk Formation. The outcrop is capped by the undifferentiated Blackhawk Formation (Kb undif).

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Utah Geosites showcases some of Utah's spectacular geology, both little-known localities and sites seen by visitors to Utah's many national and state parks and monuments. The geosites reflect the interests of the many volunteers who wrote to share some of their favorite geologic sites. The list is eclectic and far from complete, and we hope that additional geosites will be added in the coming years. The Utah Geological Survey also maintains a list of geosites https://geology.utah.gov/apps/geosights/index.htm.

We thank the many authors for their geosite contributions, Utah Geological Association members who make annual UGA publications possible, and the American Association of Petroleum Geologists—Rocky Mountain Section Foundation for a generous grant for desktop publishing of these geosite papers.

Design and desktop publishing by Jenny Erickson, Graphic Designer, dutchiedesign.com, Salt Lake City, Utah.

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Presidents Message

I have had the pleasure of working with many different geologists from all around the world. As I have traveled around Utah for work and pleasure, many times I have observed vehicles parked alongside the road with many people climbing around an outcrop or walking up a trail in a canyon. Whether these people are from Utah or from another state or country, they all are quick to mention to me how wonderful our geology is here in Utah.

Utah is at the junction of several different geological provinces. We have the Basin and Range to the west and the Central Utah Hingeline and Thrust Belt down the middle. The Uinta Mountains have outcrops of some of the oldest sedimentary rock in Utah. Utah also has its share of young cinder cones and basaltic lava flows, and ancient laccoliths, stratovolcanoes, and plutonic rocks. The general public comes to Utah to experience our wonderful scenic geology throughout our state and national parks. Driving between our national and state parks is a breathtaking experience.

The "Utah Geosites" has been a great undertaking by many people. I wanted to involve as many people as we could in preparing this guidebook. We have had great response from authors that visit or work here in the state. Several authors have more than one site that they consider unique and want to share with the rest of us. I wanted to make the guidebook usable by geologists wanting to see outcrops and to the informed general public. The articles are well written and the editorial work on this guidebook has been top quality.

I would like to personally thank Mark Milligan, Bob Biek, and Paul Inkenbrandt for their editorial work on this guidebook. This guidebook could not have happened without their support. I would like to thank Jenny Erickson for doing the great desktop publishing and the many authors and reviewers that helped prepare the articles. Your work has been outstanding and will certainly showcase the many great places and geology of Utah. Last, but not least, Thank you to the American Association of Petroleum Geologists, Rocky Mountain Section Foundation for their financial support for this publication.

Guidebook 48 will hopefully be a dynamic document with the potential to add additional "geosites" in the future. I hope more authors will volunteer articles on their favorite sites. I would like to fill the map with locations so that a person or family looking at the map or articles will see a great location to read about and visit. Enjoy Guidebook 48 and enjoy the geology of Utah.

Peter J. Nielsen
2019 UGA President

INTRODUCTION

The Book Cliffs of Utah and Colorado have become the premier location globally to study and teach principles of sequence stratigraphy. Continuous, well-exposed, and easily-accessible outcrops along both depositional dip (mountain to sea) and depositional strike (along the shore) make it possible for detailed three-dimensional reconstruction and analysis of sedimentary successions. Most types of clastic sedimentary systems are found in the Book Cliffs. These include river (braided, meandering, and anastomosed), delta (river- and wave-dominated), estuary, beaches, and seafloor, demonstrating a complete sediment delivery system from near the mountains to the ocean basin. These characteristics make the Book Cliffs an excellent classroom to study the interrelationship between large-scale changes in sea level, tectonic processes that build mountains and form sedimentary basins, and the sedimentary deposits that fill those basins.

This article differs somewhat from others in this volume in two ways: 1) It does not focus on a single location but includes a series of 25 related localities found along an approximately 100-mile stretch of the Book Cliffs, extending from north of the city of Helper southeastward to west of the town of Thompson Springs (Figure 1). Localities are arranged first by topic then by location, with driving directions and GPS coordinates given at the end of the main text. 2) The focus of this article, teaching concepts of sequence stratigraphy, makes it difficult to write meaningfully in a jargon-free manner; therefore, a brief generalized introduction is given to describe the study of sequence stratigraphy for all audiences, and the remaining text is written in a more technical fashion.

SIMPLE DESCRIPTION OF SEQUENCE STRATIGRAPHY

Stratigraphy is the study of layered rock, in most cases sedimentary rock. In a sedimentary succession, each layer is like a chapter in a book, in that it records the history for a specific interval of time. In the case of sedimentary layers, that history includes the manner in which sediment accumulated within a particular setting; for instance, adjacent to the channel of a river or along a shoreline. The boundaries between layers are surfaces that denote episodes during which sediment did not collect, such as between flooding events for a stream, or where sediment collected but was later removed by erosion. These surfaces represent a “gap” in time for which there is no record. If these gaps are of significant duration, they are called unconformities. Unconformities are commonly the consequence of changes in sea level. When sea level rises, space is created above the previous layer into which additional sediment can be deposited, forming a new layer on top of the old. If sea level falls, previously deposited sediment is eroded and carried to a new location farther seaward. Sequence stratigraphy, therefore, is a study of the history of sea-level changes as preserved in sedimentary layers and the unconformities between them.

The fundamental unit of sequence stratigraphy is a sequence, which refers to a predictable vertical pattern of layering developed during a single cycle of sea-level rise and fall. It is this pattern (sequence) which gives the study its name. For the Book Cliffs, these layers tend to be thinner and more muddy at the base, becoming thicker and more sandy toward the top. Additionally, the bottom layers mostly record environments from deeper water or from a more seaward position than those above, which represent environments more landward. In other words, in a highly simplistic manner, lower layers are likely to represent the ocean bottom, middle layers beaches, and capping layers rivers. A sequence is typically bound both on bottom and on top by erosional unconformities that developed during times when base-level fell and are called sequence boundaries. The individual layers within a sequence form mostly during a stepwise rise in sea level and are known as parasequences. A parasequence forms when the rising sea level creates new space and then pauses long enough for that space to be filled with sediment before the sea rises again.

Sequence stratigraphic concepts are well described in a number of sources (e.g., Coe, A., 2002, is an excellent resource for those new to sequence stratigraphy; Mitchum and others, 1977; Van Wagoner and others, 1988, 1990; Van Wagoner, 1995a; Neal and Abreu, 2009; Catuneanu and others, 2011; Posamentier and Allen, 1999; and Abreu and others, 2014 present more technical perspectives).

Technical Description of Sequence Stratigraphy

In a little more technical sense, sequence stratigraphy refers to the depositional pattern developed during a single cycle of base-level fluctuation (Figure 2A). More precisely, it predicts the order (sequence) in which progradational depositional events (parasequences) stack in response to changes in the balance between the rate at which accommodation is produced or destroyed and the rate at which that space is either filled by sediment, bypassed, or reduced through erosion. This relationship causes parasequences to assemble in progradational (forward stepping), aggradational (vertically stacked), and retrogradational (backstepping) sets separated by discontinuity surfaces (Figure 2B through 2D). These surfaces reflect either an increase in accommodation exceeding the capacity of sediment to fill that space (flooding surface), which is marked by an abrupt landward shift in sedimentary facies; an increase in space that is less than the rate of filling (type 2 sequence boundary), shown by a basinward shift in sedimentary facies in the form of a normal progradational pattern; or an actual loss of accommodation associated with a drop in base level and erosion of earlier deposits (type 1 sequence boundary), generated by a forced regression. It is important to note that depending on scale and tectonic setting, processes other than a simple fluctuation of base level, such as a variation in sediment supply, delta-lobe switching, or channel development and abandonment, can produce strati-

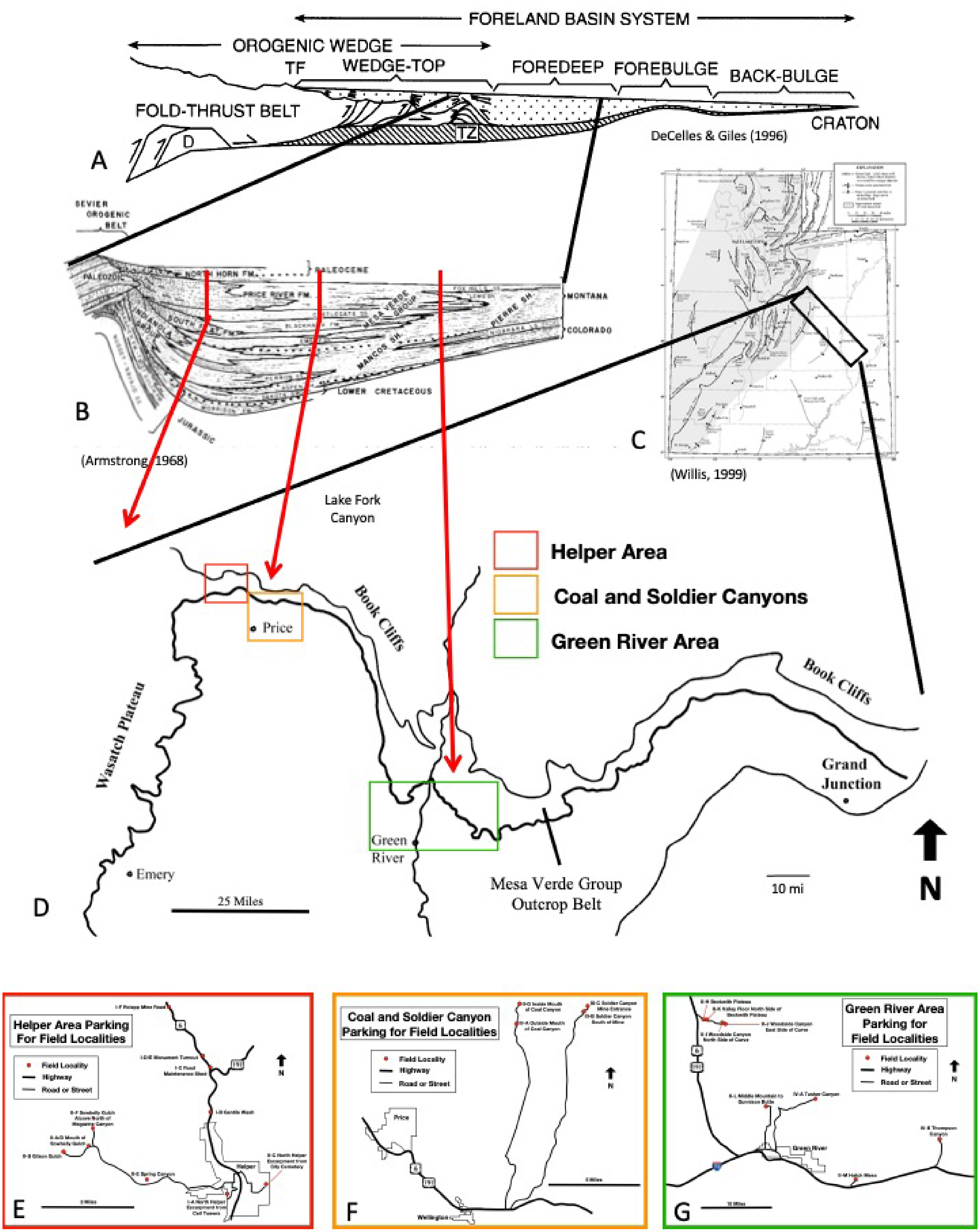

*Figure 1. **A)** Conceptual model of an idealized thrust belt/foreland basin system. (From DeCelles and Giles, 1996) **B)** Dip-oriented cross section showing generalized stratigraphy of the Cretaceous Western Interior foreland basin. (From Armstrong, 1968) **C)** Index map showing the region covered by field localities in this report. (From Willis, 1999) **D) Expanded view of C. E, F, and G)** Detailed index maps showing localities (red dots) discussed in this report. Driving directions and GPS coordinates are given at the end of the report.*

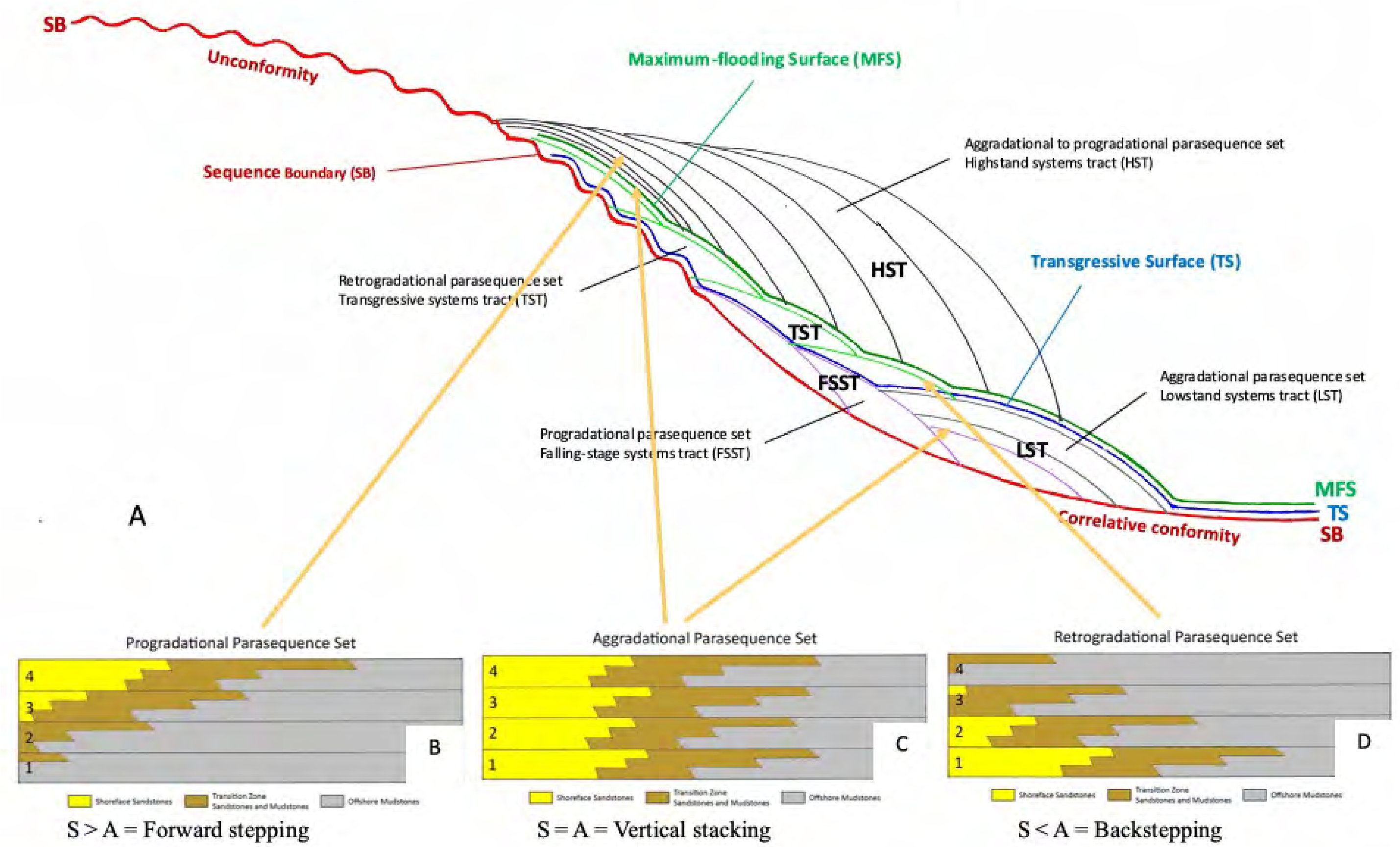

*Figure 2. A) Conceptual sequence-stratigraphic diagram illustrating relationship between parasequence stacking patterns and associated surfaces referred to throughout this report. Abbreviations are as follows: SB (sequence boundary), TS (transgressive surface), MFS (maximum-flooding surface), FSST (falling-stage systems tract), LST (lowstand systems tract), TST (transgressive systems tract), HST (highstand systems tract). Parasequences can stack in **B)** a forward-stepping pattern, **C)** a vertically-stacked pattern, or **D)** a backstepping pattern, depending on the relative balance between sediment supply (S) and accommodation production (A). (B, C, and D modified from Van Wagoner and others, 1990).*

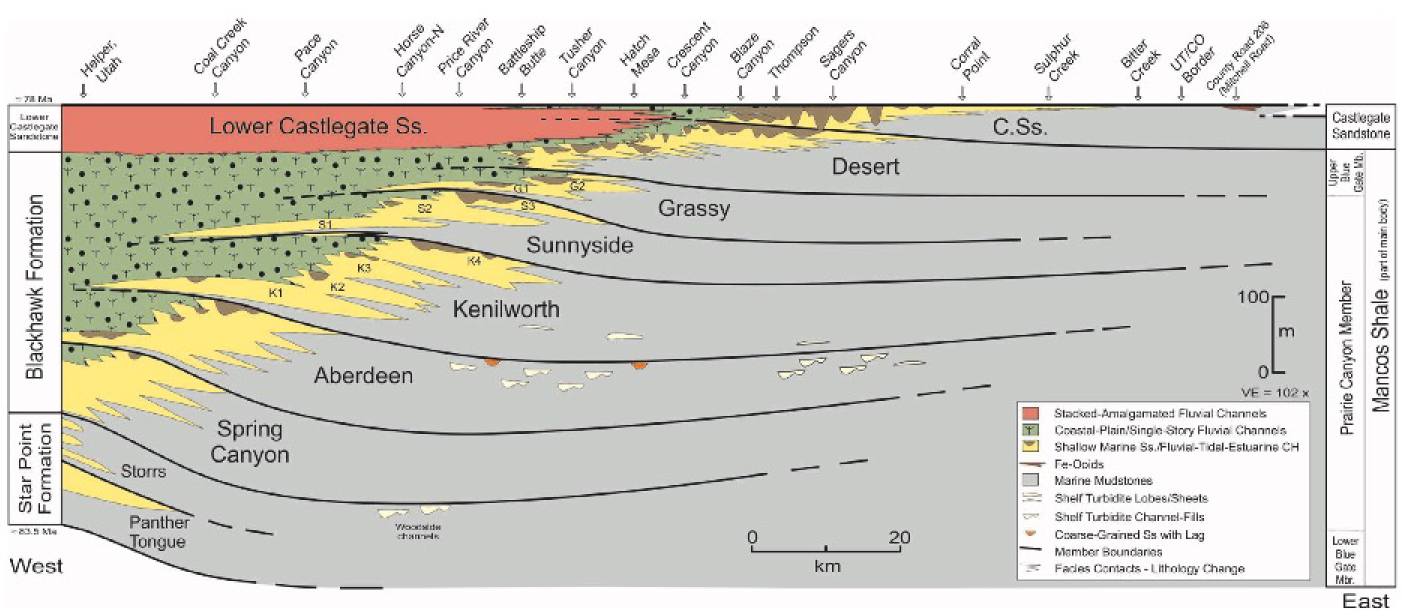

Figure 3. Dip-oriented cross section of the composite sequence made up of the Star Point Sandstone, Blackhawk Formation, and lower Castlegate Sandstone. Names printed within the gray marine mudstone region are formation members. Castlegate Sandstone has been abbreviated C.Ss. Note the overall coarsening upward trend (3rd-order sequence) with smaller-scale coarsening-upward (4th-order) successions contained within. The sawtooth pattern reflects parasequence stacking arrangements within the smaller-scale sequences. (From Pattison, 2018; after Young, 1955; Balsley and Horne, 1980; Cole and others, 1997; and Pattison and others, 2007a)

graphic patterns similar to those discussed in this report; however, a discussion of variations to the basic sequence stratigraphic model are beyond the scope of this paper. This paper concentrates entirely on showing field examples that can be used to illustrate general concepts of sequence stratigraphy in a simplified manner.

Geological Setting

The third-order composite sequence comprised of the early through middle Campanian Star Point Sandstone, Blackhawk Formation, and lower Castlegate Sandstone of the Mesaverde Group is the focus of this report (Figure 3). These formations were deposited as a series of successive progradational sheets into the foredeep portion (Figure 1A, B; DeCelles and Giles, 1996) of the Western Interior foreland basin in response to eastward movement along the Canyon Range and adjoining segments of the Sevier fold/thrust belt to the west (Figure 1C; Villien and Kligfield, 1986; Schwans, 1995). The Western Interior Basin is a foreland basin that subsided and was filled in response to thrust loading in the Sevier Orogenic Belt and dynamic loading associated with subduction of the underlying Farallon Plate (Figure 1B; Bally and others, 1966; Armstrong, 1968; Kauffman and Caldwell, 1993; DeCelles and Coogan, 2006; Liu and others, 2011).

Emphasis in this report is placed on regional sheet sandstone bodies and their capping coal deposits, as they represent easily identifiable progradational depositional events that can be traced from landward pinchouts against coastal-plain deposits to down-dip terminations into marine mudstone (Figure 3). Parasequences in each of the members of the Blackhawk Formation are dominated by prograding shoreface successions associated with wave-dominated deltas, in which prodelta mudstone at the base abruptly overlies shoreface sandstones and coastal plain coals of the previous cycle (Figure 4). Upward through the succession, prodelta mudstone becomes interbedded with thin beds of hummocky to parallel-laminated sandstone (transition zone), which in turn is overlain by amalgamated intervals of hummocky sandstone

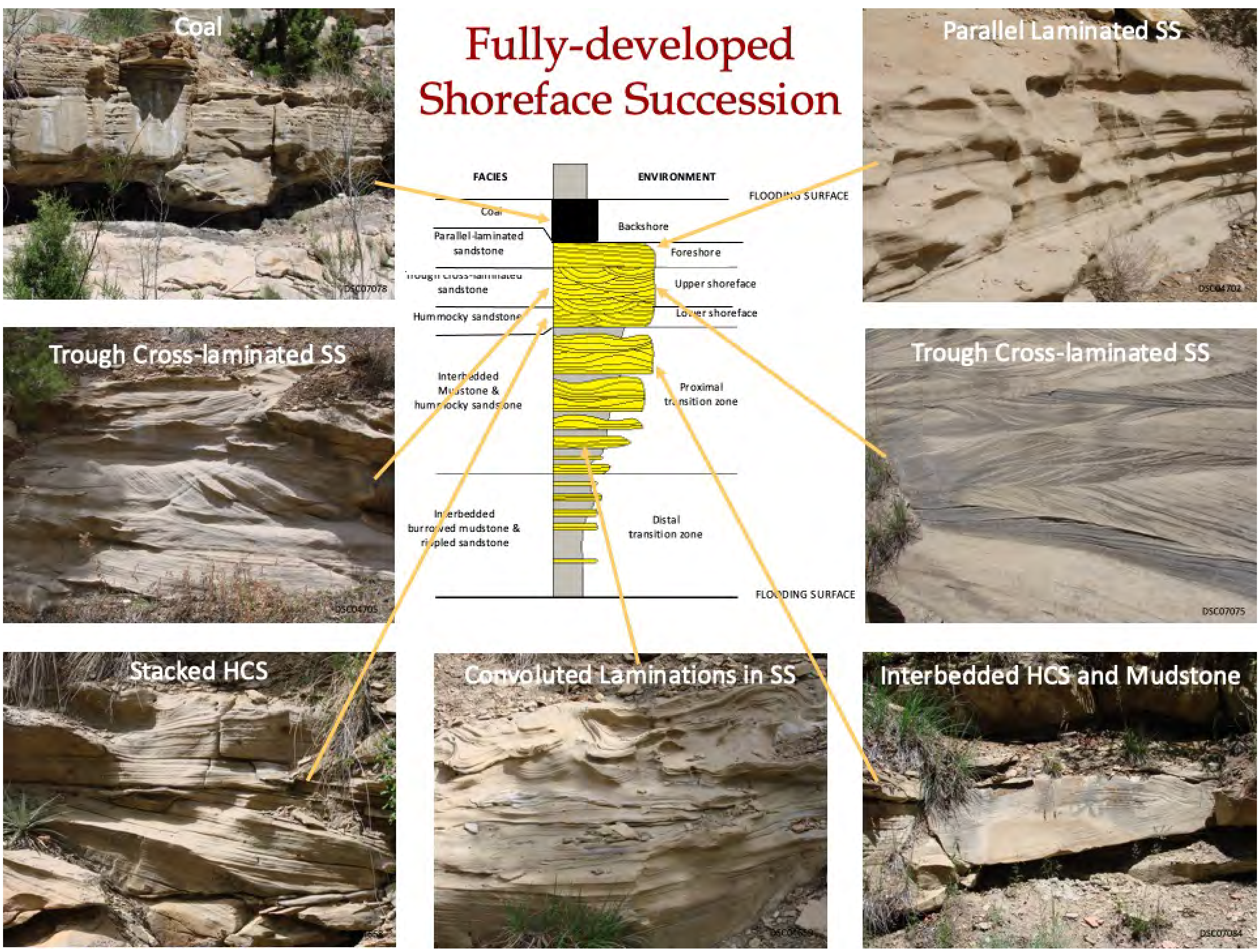

Figure 4. Idealized facies succession for shoreface systems in the Blackhawk Formation. (modified from SEPM Strata; after Van Wagoner and others, 1990). Photographs of a "typical" shoreface succession from the Spring Canyon Member (Sowbelly parasequence) in Gentile Wash. Abbreviations are SS for sandstone and HCS for hummocky stratification.

(lower shoreface), followed by trough cross-laminated sandstone (upper shoreface), then parallel-laminated sandstone (foreshore), and capped by coal (coastal plain). The contact between each parasequence is sharp and at least somewhat erosional.

Report Organization

This report focuses on the Utah portion of the Book Cliffs stratigraphic succession and progresses from onshore to offshore and from stratigraphically oldest to youngest through the Star Point/Blackhawk/lower Castlegate interval, beginning with shoreline and coastal-plain deposits near the town of Helper and ending with small-scale, incised, channel-fill units at Thompson Canyon (Figure 2). The report is divided into four sections: Section I illustrates general principles of sequence stratigraphy as applied to a single vertical profile through the entire third-order sequence, beginning with a hike into Gentile Wash and finishing with stops along U.S. Highway 6; Section II focuses on the concept of a systems tract and examines lateral facies changes, both along depositional strike and down depositional dip, using the same stratigraphic units observed in Section I; Section 3 investigates characteristics of incised channel fill deposits; and Section 4 allows observation of a small-scale (fourth-order) sequence in single outcrops. Driving directions and GPS coordinates for each locality are given at the end of the report.

Significance

Cretaceous deposits of the Book Cliffs region are often cited as an analog for subsurface exploration, particularly in foreland basins, and sequence stratigraphy has become the primary method for correlating and mapping depositional successions, leading to important discoveries of petroleum in fields that had been abandoned, as well as new discoveries. In the search for and development of both coal and hydrocarbons, recognizing facies associations and the manner in which they change laterally and stack vertically aids prediction of the geometry, spatial distribution, continuity, and resource potential of associated rock bodies. The Book Cliffs of east-central Utah include some of the best exposed ancient examples of fluvial, coastal, and marine deposition on Earth, especially with respect to foreland basins. Consequently, these strata are visited each year by hundreds of geologists from across the world. Continuous, undeformed exposures dissected by a large network of canyons with little vegetal cover make it possible to clearly document lateral and vertical facies changes over broad distances, as well as key surfaces that bound stratigraphic successions, both of which are critical aspects to understanding the geometry, spatial distribution, continuity, and resource quality of clastic sedimentary rock bodies. Much of the initial interest in these stratigraphic units was related to the presence of commercial coal seams. Subsequently, these deposits have increasingly become cited as analogs for hydrocarbon exploration, giving a clearer perspective when making interpretations of similar stratigraphic units from cores, logs, and seismic data. The primary purpose of this report is to denote exceptional outcrops that can be used as analogs for clastic depositional facies models and toward understanding and teaching principles of sequence stratigraphy.

FIELD LOCALITIES

Section I: General Characteristics of a Sequence

Locality I-A: North Helper Escarpment (Lithostratigraphic and Sequence Stratigraphic Overview of the Mesaverde Group)

The purpose of this overlook is to gain a general perspective of the Star Point/Blackhawk/lower Castlegate sequence. Descriptions of individual stratigraphic units will be provided in later sections. A complete succession, including all lithostratigraphic units and sequence stratigraphic elements can be seen along the escarpment bordering the north side of the town of Helper, stretching eastward from U.S. Highway 6 for just under 2 miles (3 km) to Kenilworth Wash (also called Helper Canyon; Figure 5).

Figure 5. The north Helper escarpment showing the Mancos Shale (Km), Panther Tongue (Ksp) and Storrs (Kss) Members of the Star Point Sandstone, and Spring Canyon (Kbsc) and Aberdeen (Kba) Members of the Blackhawk Formation. Kb is Blackhawk Formation undifferentiated. Also labelled on the photo are corresponding sequence stratigraphic elements as identified in Figure 4.

The basal part of the escarpment comprises several hundred feet of offshore marine mudstone belonging to the Mancos Shale, with significantly more in the subsurface. About a third of the way up the escarpment (half way up the photo of Figure 5), the first resistant ledge is the Panther Tongue Member of the Star Point Sandstone, interpreted as having been deposited by a river-dominated delta under conditions of forced regression (Howard, 1966; Newman and Chan, 1991; Enge and others, 2010). The lower contact is conformable with the underlying Mancos Shale, forming the lower sequence boundary, which, being conformable, is expressed in this area as a correlative conformity.

Above the Panther Tongue is an interval of interbedded sandstone and mudstone that first forms a relatively thin fining-upward succession, followed by a much thicker accumulation that coarsens upward. The mudstones are tongues of Mancos Shale that thin and pinchout to the west (landward) and sandstones above the Panther were deposited as shoreface successions (Spieker and Reeside, 1925; Clark, 1928; Young, 1955; Balsley and Horne, 1980), each of which represents an individual progradational event (parasequence). Within the first muddy interval are three thin and poorly-developed benches, with each being thinner and less distinct than the lower. These are distal expressions of shoreface parasequences within the Storrs Member of the Star Point Sandstone. Each is silty with a thin cap of sandstone and together form part of a back-stepping parasequence pattern associated with the transgressive systems tract. The upper contact of the Panther Tongue is the transgressive surface, as it marks the first major flooding event following deposition of the lowstand Panther Tongue.

The prominent sandstone ledges in the upper part of the escarpment belong to the Spring Canyon and Aberdeen Members of the Blackhawk Formation. In this part of the section, each sandstone is composed of a more complete shoreface parasequence than that below, and together they represent progressively more proximal shorefaces upward through the section, reflective of a progradational stacking pattern, which is diagnostic of a highstand systems tract. The surface forming the contact between the upper two benches in the Star Point Sandstone is where retrogradation transitions to brief aggradation, followed by progradation and marking the maximum-flooding surface. In this section, aggradation in the lower part of the highstand tract is minor and is expressed by an abrupt turnaround from transgression to regression.

Overlying the shoreface sandstones are coastal-plain deposits of the undifferentiated Blackhawk Formation (Spieker and Reeside, 1925; Clark, 1928; Young, 1955; Balsley and Horne, 1980), which correspond to the Kenilworth through Desert Members, each of which becomes a prominent shoreface succession to the east that is similar in characteristics to the Spring Canyon and Aberdeen Members of this locality. In this report, we include the lower Castlegate Sandstone (distant cliffs out of view on Figure 5) as the capping part of the highstand systems tract, though many workers prefer to place a sequence boundary at the base of the Castlegate (Van Wagoner, 1995b; Yoshida, 2000).

Locality I-B: Gentile Wash (Hike through a Sequence – Panther Tongue through Spring Canyon Members)

Gentile Wash provides an opportunity to hike through and observe closely all parts of the sequence, from the underlying Mancos Shale, across the sequence boundary near the mouth of the wash, into the forced-regressive lowstand deposits of the Panther Tongue, across the transgressive surface, through the retrogradational parasequence set of the transgressive systems tract in the Storrs Member, and across the maximum-flooding surface into the progradational parasequence stacking pattern of the lower highstand systems tract found in the Spring Canyon Member (Figure 6). The hike begins at the mouth of Gentile wash and continues for about 1.25 miles (2 km) up the wash.

Figure 6. Stratigraphic section in Gentile Wash. The bottom of the photo is approximately the top of the Panther Tongue. Named parasequences within the Spring Canyon Member are identified with "PS" to assist with correlation to other localities.

Sequence boundary (Mancos Shale/Panther Tongue Member contact): A sequence boundary is defined as a subaerial unconformity and its correlative marine conformity (Mitchum and others, 1977). A subaerial unconformity develops as base level drops during a forced regression. Simultaneously, basinward, deposition is continuous, producing a time-equivalent conformable succession of strata, the lower boundary of which is considered the correlative conformity. The Panther Tongue in the subsurface, northward of Gentile Wash, shows a downstepping pattern, consistent with a forced regression (Posamentier and Morris, 2000; Hwang and Heller, 2002). Exposures at Gentile Wash are of the final downward and most basinward step; therefore, at this locality the sequence boundary shows a simple shallowing-upward, conformable succession from the Mancos Shale into the Panther Tongue (Figure 7).

Figure 7. Conformable contact (correlative conformity) between the Mancos Shale (Km) and the Panther Tongue Member (Ksp), marking the basal sequence boundary (SB) for the Star Point/Blackhawk/lower Castlegate sequence.

Falling-stage to lowstand systems tracts – river-dominated delta-front and channel-mouth bar deposits (Panther Tongue Member): The Panther Tongue Member was deposited as a river-dominated delta during the falling-stage to lowstand systems tracts. It is bound by the sequence boundary below and transgressive surface above. Interpretation as a river-dominated deltaic deposit is based on a coarsening-upward pattern, a lobate shape, and clinoforms that dip basinward. Three subdivisions, based on facies associations, are evident at the mouth of Gentile Wash: 1) A basal interval of thinly interbedded sandstones dominated by Bouma sequences and bioturbated mudstones, 2) A middle section of thin sandstones characterized by parallel laminations, and 3) a capping interval of lens-shaped sandstones that can be structureless, parallel laminated, trough cross laminated, or a mixture of the three (Figure 8). Sandstones in the capping portion can be amalgamated or separated by thin mudstones. The succession represents an upward progression from lower delta-front turbidites and storm beds at the base through upper delta front amalgamated turbidite deposits into reworked channel-mouth bar and interdistributary bay deposits.

Transgressive surface (Panther Tongue Member/Mancos Shale contact): The primary evidence for a transgressive surface at the top of the Panther Tongue is an overlying lens of Mancos Shale in sharp contact, indicating the first significant rise in base level and subsequent drowning of the shoreline following the forced regression (Figure 8b). Other evidences include an undulatory and erosional surface, oscillatory ripples, mud-clast and wood-fragment molds, intense bioturbation, and shell fragments, demonstrating high-energy reworking of the former subaerial surface by waves, followed by colonization by burrowing organisms (Figure 9).

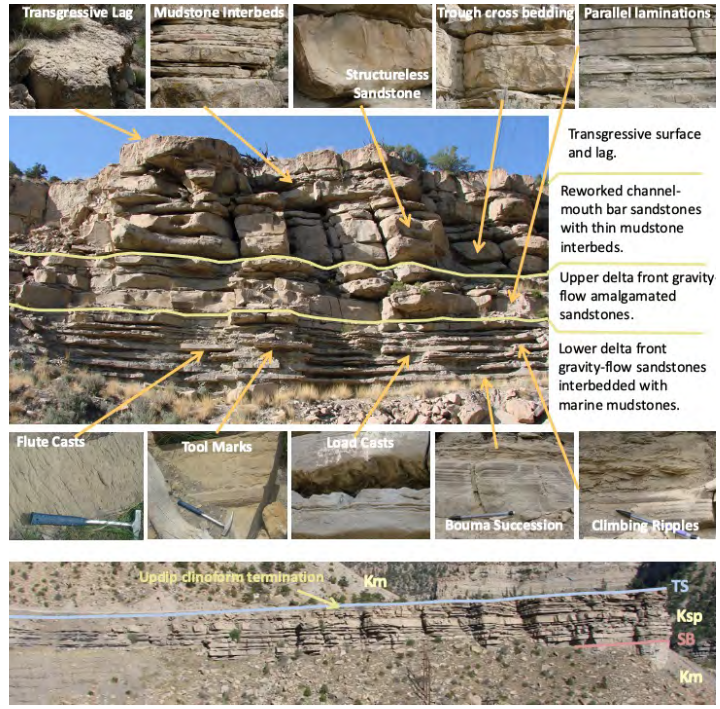

*Figure 8. **A)** Facies and major divisions of the Panther Tongue in strike-oriented view at the mouth of Gentile Wash. **B)** Expression of clinoforms in depositional dip orientation, located across U.S. Highway 6 at the mouth to Panther Canyon. SB is the sequence boundary at the base of the Panther Tongue Member (Ksp) and marks the contact with the underlying Mancos Shale (Km). The Panther Tongue Member is capped by the transgressive surface (TS) and overlain by a thin wedge of the Mancos Shale.*

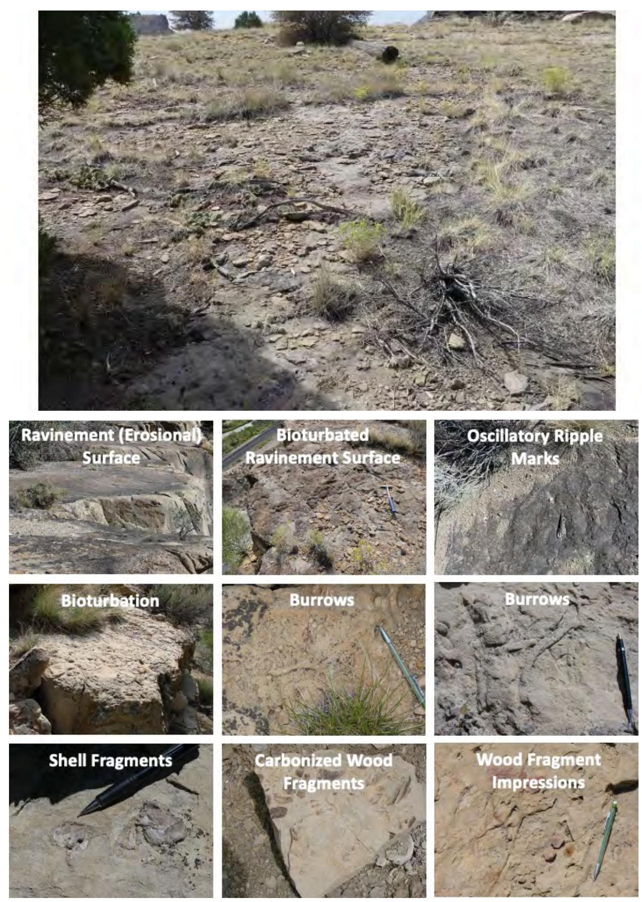

Figure 9. Upper surface of the Panther Tongue Member at Gentile Wash and Sowbelly Gulch showing characteristics common to a transgressive surface of erosion.

Transgressive systems tract (Storrs Member): In Gentile Wash, the Storrs Member consists of three distal shoreface successions, the lower two of which are progressively less well developed than the previous moving upward from the Panther Tongue, suggesting a smaller amount of progradation for each succeeding parasequence, leading to a retrogradational stacking pattern characteristic of a transgressive systems tract (Figure 10). The lowermost parasequence consists of interbedded mudstone and ripple-bedded sandstone at the base (distal transition zone), grading upward into interbedded mudstone and hummocky sandstone (proximal transition zone), and capped by a thin interval of amalgamated hummocky sandstone beds (lower shoreface). The middle and upper parasequences are similar but lack the amalgamated sandstone part of the section.

Figure 10. Backstepping (retrogradational) to vertically-stacked (aggradational) parasequence (PS) pattern in the Storrs Member (Kss), followed by a strongly forward stepping (progradational) pattern in the Spring Canyon Member. The change from retrogradation to a very brief interval of aggradation in the upper Storrs Member marks the maximum-flooding surface (MFS). Km refers to thin interbedded intervals of the Mancos Shale. Parasequences (PS) are numbered in the Storrs Member and named in the Spring Canyon Member.

Maximum-flooding surface (Storrs Member): By definition, the maximum flooding surface is placed where parasequence stacking changes from a retrogradational to an aggradational or progradational pattern (Van Wagoner and others, 1988). Figure 10 shows two parasequences within the Storrs Member that exhibit nearly equal degrees of development, suggesting the shoreline had stabilized and ceased its landward translation. Parasequences both above and below these are more completely developed. Distally, maximum flooding surfaces are characterized by slow deposition of fine-grained sediment under quiet, deep-water conditions. Often, they are exemplified more by a "condensed interval," in which a thin sedimentary deposit represents an extended period of time (Galloway, 1989). In a landward direction, particularly in a foreland basin setting, the maximum flooding surface is likely to grade into a thick succession of fluvial strata.

Early highstand systems tract (Spring Canyon Member): Though the highstand systems tract is significantly thicker than the others and encompasses the remainder of the Blackhawk Formation and possibly the lower part of the Castlegate Sandstone, this hike ends near the top of the Spring Canyon Member, in the lower part of the tract (Figure 10). Stratigraphically higher units, namely the Aberdeen Member and undifferentiated Blackhawk Formation, along with the Castlegate Sandstone, will be observed from outcrops along U.S. Highway 6. Above the maximum flooding surface, each parasequence within the Spring Canyon Member becomes progressively coarser grained and more completely developed, until one of the upper parasequences, known as the Sowbelly Parasequence, consists of a complete shoreline succession, from interbedded mudstones and hummocky sandstones of the transition zone to amalgamated hummocky and contorted sandstone beds in the lower shoreface, followed by trough cross-laminated sandstone of the upper shoreface, then parallel-laminated sandstone in the foreshore (Figure 3; Kamola, 1987; Kamola and Van Wagoner, 1995). This parasequence is capped by coal of the coastal plain. The upper contact of the coal bed is the flooding surface beneath the next (Hardscrabble) parasequence. Parasequences above the Sowbelly show less of the lower (distal) parts of the succession and more of the upper (proximal) facies.

Locality I-C: Road-maintenance shed (early highstand systems tract continued - Spring Canyon and Aberdeen Members): The Spring Canyon and Aberdeen Members of the Blackhawk Formation are alike in character (Figure 11). Each consists of stacked parasequences similar to those observed in Gentile Wash. The primary difference between this locality and that of Gentile Wash is parasequences in the Aberdeen Member preferentially develop only the upper parts of shoreface successions, because deposits represent progressively more proximal environments upward through the section. Therefore, there is less of the hummocky sandstone of the lower shoreface, virtually none of the interbedded mudstone characteristic of the transition zone, and more of the trough cross-bedded and parallel laminated sandstones of the upper shoreface and foreshore, respectively, as well as a greater number of coal beds capping the parasequences.

Locality I-D: Monument turnout (late highstand systems tract – Blackhawk Formation, upper Aberdeen Member equivalent): At the base of the road cut on the west side of U.S. Highway 6 (Figure 12), wave-dominated shoreface parasequences in the Aberdeen Member are similar to those of the Spring Canyon Member at Gentile Wash. These are overlain by coastal-plain or delta-top deposits of the undifferentiated Blackhawk Formation that have been correlated to incised channel-fill deposits in the upper part of the Aberdeen Member farther to the east (Pattison and others, 2007b; Kamola, pers. comm. 2014). Shallow fluvial environments are indicated by channel-form sandstone bodies that show strong

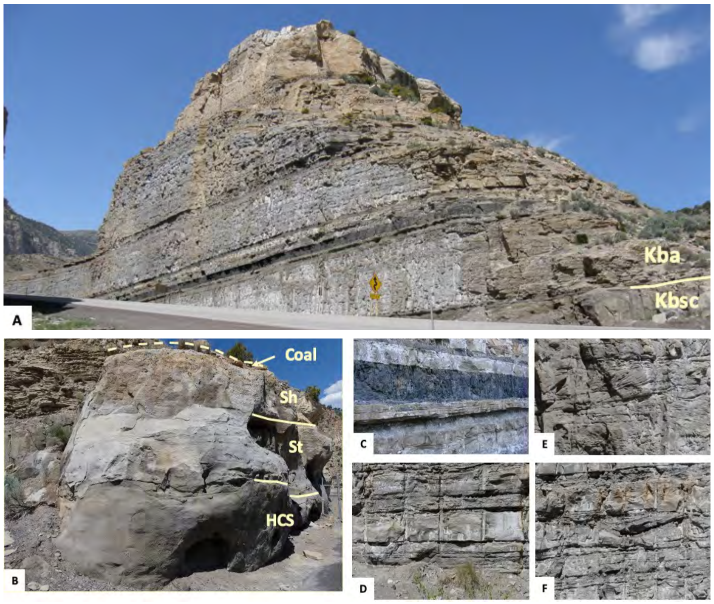

Figure 11. A) In this roadcut, the capping (Helper) parasequence of the Spring Canyon Member (Kbsc) and the Aberdeen (Kba) Member of the Blackhawk Formation are alike in character. B) A relatively complete parasequence at the top of the Spring Canyon Member (Helper parasequence). Lithofacies are labeled HCS for hummocky-stratified sandstone, St for trough cross-stratified sandstone, and Sh for horizontally-laminated sandstone. C) Close up of a coal seam, of which the upper contact forms the boundary between the Spring Canyon and Aberdeen Members. D through F) Details of parasequences in the Aberdeen Member. Note the predominance of trough cross stratification and parallel laminations and absence of hummocky laminations. F shows a small channel, possibly the result of a small outlet channel across the foreshore.

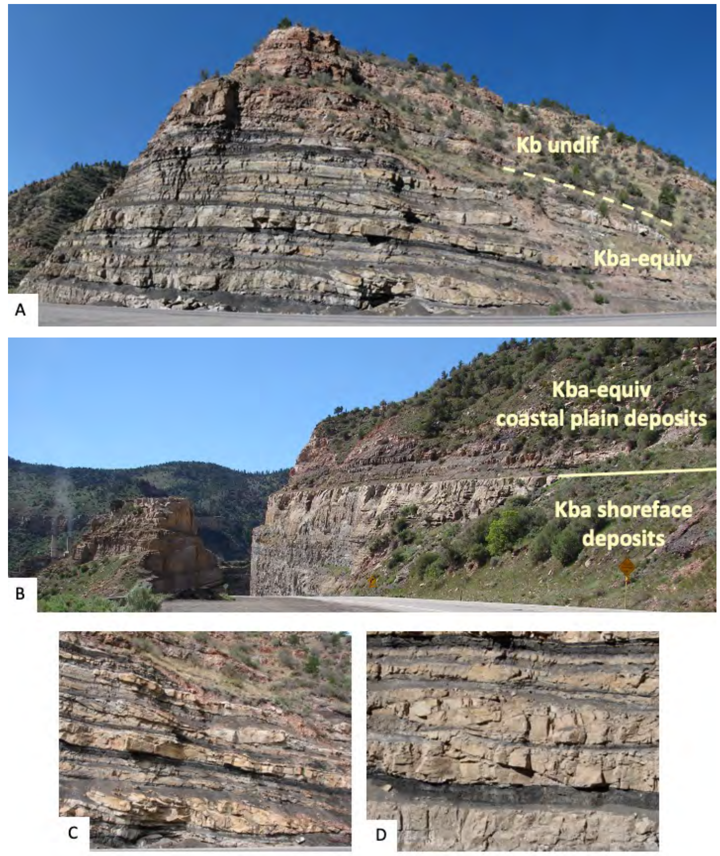

Figure 12. A) Outcrop of coastal-plain or delta-top deposits within the upper Aberdeen Member equivalent (Kba-equiv) of the undifferentiated Blackhawk Formation. The outcrop is capped by the undifferentiated Blackhawk Formation (Kb undif). B) Contact with the underlying Aberdeen Member (Kba). C and D) Filled distributary channel deposits within delta-front sandstones. Note heterolithic bedding and lateral accretion surfaces.

lateral accretion throughout the exposure. Current and climbing ripples are common in likely splay deposits. Tidal influence is evidenced by heterolithic bedding along the lateral accretion surfaces within the channel forms, and possible wave influence is suggested by trough, cross, and parallel laminations within thin sheet-like bodies.

Locality I-E: Monument turnout (late highstand systems tract continued – Blackhawk Formation undifferentiated and Castlegate Sandstone): On the hillside across the Price River to the east of the turnout, the Blackhawk Formation above the Aberdeen Member has not been subdivided into members but is referred to as Blackhawk Formation undifferentiated (Figure 13). These strata were deposited as an overall coarsening-upward succession of coastal-plain then fluvial deposits, culminating in the lower Castlegate Sandstone. The Blackhawk undifferentiated section correlates eastward to the Kenilworth, Sunnyside, Grassy, and Desert Members of the Blackhawk Formation (Young, 1955), each of which is stratigraphically higher than the member beneath, extends farther basinward before terminating into the Mancos Shale than the member below, and, in general lithological character, resembles the Spring Canyon and Aberdeen Members of Gentile Wash and the U.S. Highway 6 road maintenance shed localities. On this hillside, the Castlegate Sandstone is approximately 260 feet (80 m) thick and consists of discontinuous, overlapping sheets of sandstone up to 23 feet (7 m) thick (e.g., Adams and Bhattacharya, 2005; McLaurin and Steel, 2007). Similar to members in the Blackhawk Formation, the lower Castlegate Sandstone, which in this locality was deposited by braided streams, also transitions eastward into coastal plain, then shoreface, and finally, near the Colorado border, pinches out into the Mancos Shale.

Most workers interpret the base of the lower Castlegate Sandstone as a sequence boundary based on a regional-scale erosional surface that further down dip is overlain by a basinward shift in facies, possible evidence for onlap (e.g., Van Wagoner and others, 1990; Van Wagoner, 1995a), and a change in sandstone composition across the boundary from lithic to quartz arenite (Horton and others, 2004). However, lack of a significant transition in alluvial architecture across the boundary (Adams and Bhattacharya, 2005), correlation with syntectonic sheetflood deposits of the Indianola Group landward (Lawton, 1986a, b), and an overall coarsening upward succession similar to that of tectonically-driven

Figure 13. Above shoreface parasequences of the Aberdeen Member (Kba) are coastal-plain deposits of the upper (undifferentiated) Blackhawk Formation (Kb undif), which are overlain by braided fluvial deposits of the Castlegate Sandstone (Kc). These units form the final progradation and capping portion of the Star Point/ Blackhawk/lower Castlegate sequence.

fluvial cycles in foreland deposits of the Kaiparowits Basin (Little, 1995, 1997) suggest this section might be far enough inland to have been unaffected by eustatic base-level fluctuation and, rather, represents continued coarsening-upward and basinal progradation as the capping part of the sequence.

Locality I-F: Rolapp mine road (late highstand systems tract concluded - Castlegate Sandstone): At this locality, fluvial characteristics of the Castlegate Sandstone are plainly visible (Figure 14). Overall, the Castlegate is thought to have been formed by shallow braided streams (Van De Graaff, 1972), as evidenced by sand-rich deposits that are thin and laterally discontinuous; however, many of the channel forms also show signs of lateral migration, more indicative of meandering channels, suggesting at this locality the Castlegate might be somewhat of a hybrid between the two, showing a transition from braiding upstream to more of a meandering pattern downstream.

*Figure 14. **A)** Shows the nature of the contact between the Blackhawk Formation (Kb) below and lower Castlegate Sandstone (Kcl) above. Complex, discontinuous and lenticular to sheet-like nature of sandstone bodies and presence of lateral accretion surfaces are both well expressed. Kcm refers to the middle Castlegate Sandstone, which is part of the overlying sequence and not addressed in this paper. **B)** Close up of the lower Castlegate Sandstone, taken immediately to the left of A.*

Section II: Lateral Facies Changes (Systems Tracts)

The concept of a systems tract is that depositional systems are physically and contemporaneously linked along the same basin margin (Galloway, 1989). Within a systems tract, changes in facies and facies associations occur in both along-strike and down-dip directions. In order to illustrate lateral variations in sedimentation, the same units described in Part I of this report are traced and observed at other localities.

Lateral Facies Changes in the Panther Tongue

Thoughts regarding the character of river-dominated deltas in the subsurface are evolving from the traditional digitate model exemplified by a few prominent distributary channels separated by vast interdistributary bays, such as the modern Mississippi River Delta, to a more lobate pattern in which potentially numerous channels fan from a trunk stream at a wide range of scales, mostly shallow and with highly variable orientations. These latter deposits are dominated by channel-mouth bars that show evidence for simultaneous accretion in down-dip, along-strike, and up-dip directions as they grow subaerially in all directions, making for a complex pattern of variably-oriented clinoforms (Van Heerden, 1983; Olariu and Bhattacharya, 2006). Modern examples that have been used as analogs for the Panther Tongue are the Atchafalaya and Wax Lake river deltas of the Gulf Coast (Olariu and Bhattacharya, 2006); in that distributary channel fill deposits of the Panther Tongue show a complex overlapping relationship at multiple scales, being essentially channel fills within channel fills with a wide range of orientations. In Spring Canyon, three scales of channel forms have been identified within the Panther Tongue (Figure 15). The outcrop itself is a channel-form body of sandstone about 80 feet (25 m) thick in the center. Within the overall channel form is a relatively thick sandstone lens that pinches into channel-mouth bars both to the east and to the west from the mouth of Sowbelly Gulch. A third, smaller-scale, set of channel forms showing a wide dispersal range is scattered throughout the outcrop from Gilson Gulch on the west to a short distance east of Sowbelly Gulch.

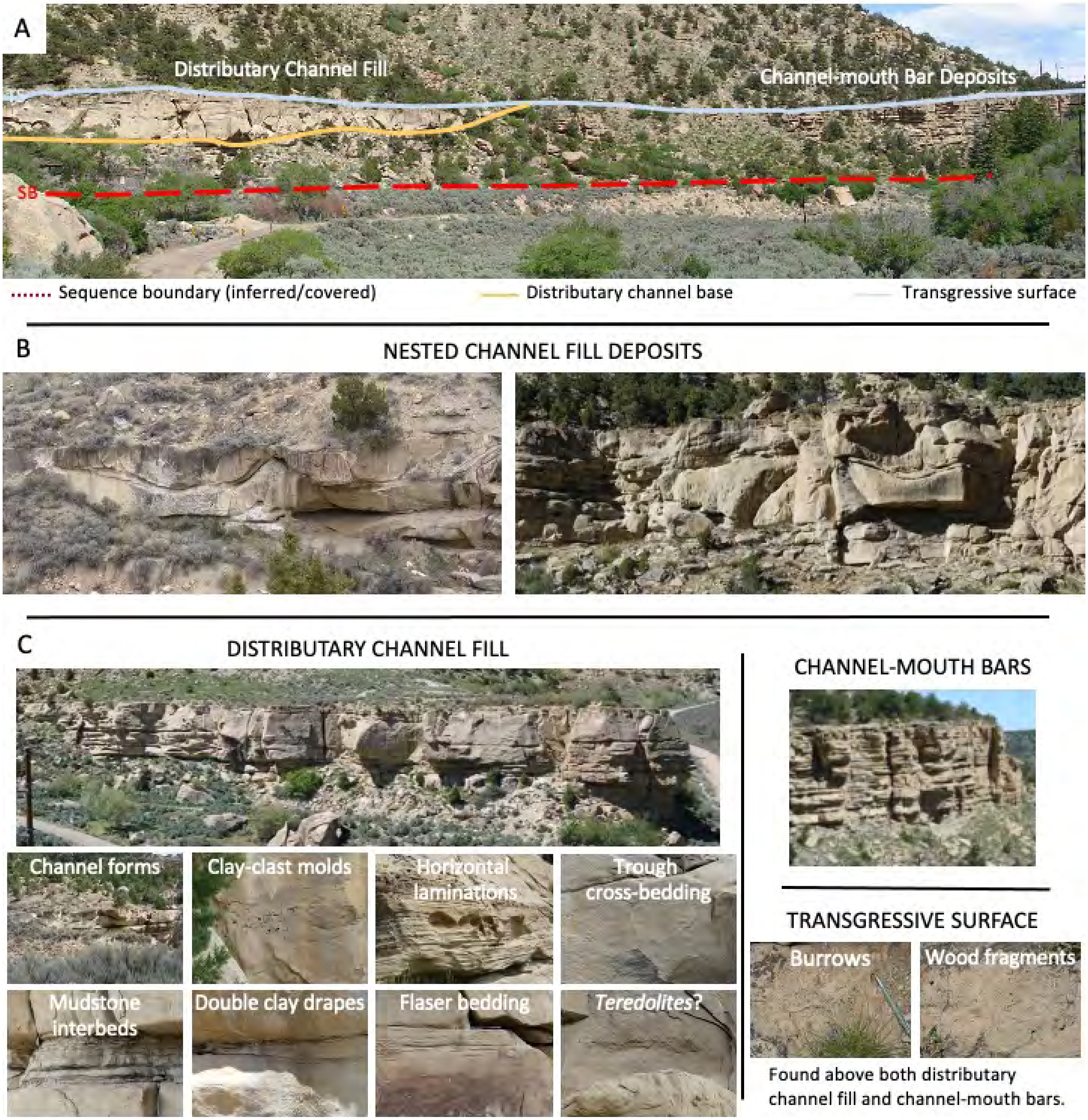

Figure 15. A) Panther Tongue distributary channel fill pinch out into a channel-mouth bar succession toward the east (right) side of the photo on the east side of Sowbelly Gulch. The base of the Panther Tongue is a sequence boundary and the upper contact is a transgressive surface overlain by the Mancos Shale. B) The distributary channel fill consists of multiple generations of intrachannel bars and smaller-scale channel fills. The left photo is from just inside the mouth to Sowbelly Gulch and shows channels with an approximate east-west orientation. The right photo is from the north side of Spring Canyon road between Sowbelly Gulch and Gilson Gulch, with channels oriented north-south. C) Facies and bedding characteristics of the Panther Tongue Member at the mouth to Sowbelly Gulch.

Figure 16. *Clinoforms in the Panther Tongue Member on the east side of the mouth to Gilson Gulch.*

Locality II-A: Mouth of Sowbelly Gulch (distributary channel fill deposits): The mouth of Sowbelly Gulch in Spring Canyon (Figure 15) is approximately 3 miles (4.5 km) west of the mouth to Gentile Wash along depositional strike. Over that distance, the character of the Panther Tongue Member changes significantly in that the ratio of reworked channel-mouth bars (top of the unit) to delta-front gravity flows (base of unit) is much higher in the Spring Canyon area than at Gentile Wash, suggesting a more proximal setting at Spring Canyon. This can be seen clearly along the north side of the canyon about 0.25 mile (0.4 km) to the east of Sowbelly Gulch, where the section is dominated by channel-mouth bars and has only a thin interval of delta-front deposits at the base. Across the mouth of the gulch and extending both to the east and to the west, channel-mouth bars have been incised by a series of distributary channels, which were subsequently filled with intrachannel bar deposits. Sedimentary structures within the channel fill include clay clast molds at the base of some beds and trough- or horizontally-laminated sandstone within the beds, suggestive of unidirectional channelized flow. Other characteristics are indicative of tidal influence, such as thin mudstone interbeds, double mud drapes, flaser bedding, and possibly the trace fossil *Teredolites*. Some intervals appear structureless, but this may be due to uniformity of grain size or weathering that has obscured structures, rather than a true absence. A prominent characteristic of the distributary channel fills is that they show repeated channelization and filling at multiple scales with highly variable orientations. Similar to Gentile Wash, the upper surface of the Panther Tongue, with respect to both distributary channel and channel-mouth bar deposits, is slightly eroded, highly burrowed, and contains small fragments of wood and bivalve shells, supporting the interpretation of a marine flooding surface. It is overlain by a thin interval of Mancos Shale, which again demonstrates the first major marine encroachment following deposition of the Panther Tongue, reinforcing interpretation as the transgressive surface for the sequence.

Locality II-B: Gilson Gulch (clinoforms): Northward-dipping clinoforms in the Panther Tongue at Gilson Gulch have traditionally been considered as lateral accretion surfaces of a deltaic distributary channel (Figure 16; Balsley and Horne, 1980; Carroll, 1987; Forzoni et al., 2015). This interpretation has been challenged, suggesting the clinoforms might, instead, have been formed by the upstream accretion component of channel-mouth bars (Olariu and Bhattacharya, 2006). The reinterpretation is based on an overall southward progradation of the shoreline during deposition of the Panther Tongue and an abundance of structureless to horizontally-laminated sandstone in these deposits. On the other hand, there is a significant component of trough cross-laminated sandstone, and the 80-foot-thick (24 m) channel fill that is prominently exposed on the north side of Spring Canyon would need to abruptly thin to zero within a distance of less than 350 feet (107 m) in the direction of transport, as, other than a very small exposure, it is not found on the south side of the canyon. This suggests the clinoforms might actually be lateral accretion surfaces associated with an east-west oriented bend in the main distributary channel. A detailed study of paleocurrent directions needs to be conducted to resolve this discrepancy.

Locality II-C: North Helper escarpment from Helper city cemetary (scale of down-dip facies change): The north Helper escarpment can be viewed from a vacant lot on the north side of the Helper city cemetery to gain perspective of the rate of down-dip facies change within a systems tract (Figure 17). This is significant in order to understand how quickly changes might occur in the subsurface at reservoir or aquifer scale. The down-dip distance in the exposure is deceiving, as the outcrop has a strongly oblique orientation that is just off from depositional strike. From the 80-foot-thick (24 m) section of distributary channel sandstone at the mouth of Sowbelly Gulch to muddy prodelta deposits on the triangular hillside just east of the escarpment is a distance of approximately 4.7 miles (7.6 km), but represents only about 0.6 mile (1 km) in down-dip direction. The length of the escarpment is close to 1.75 miles (2.8 km), but involves around only 0.25 mile

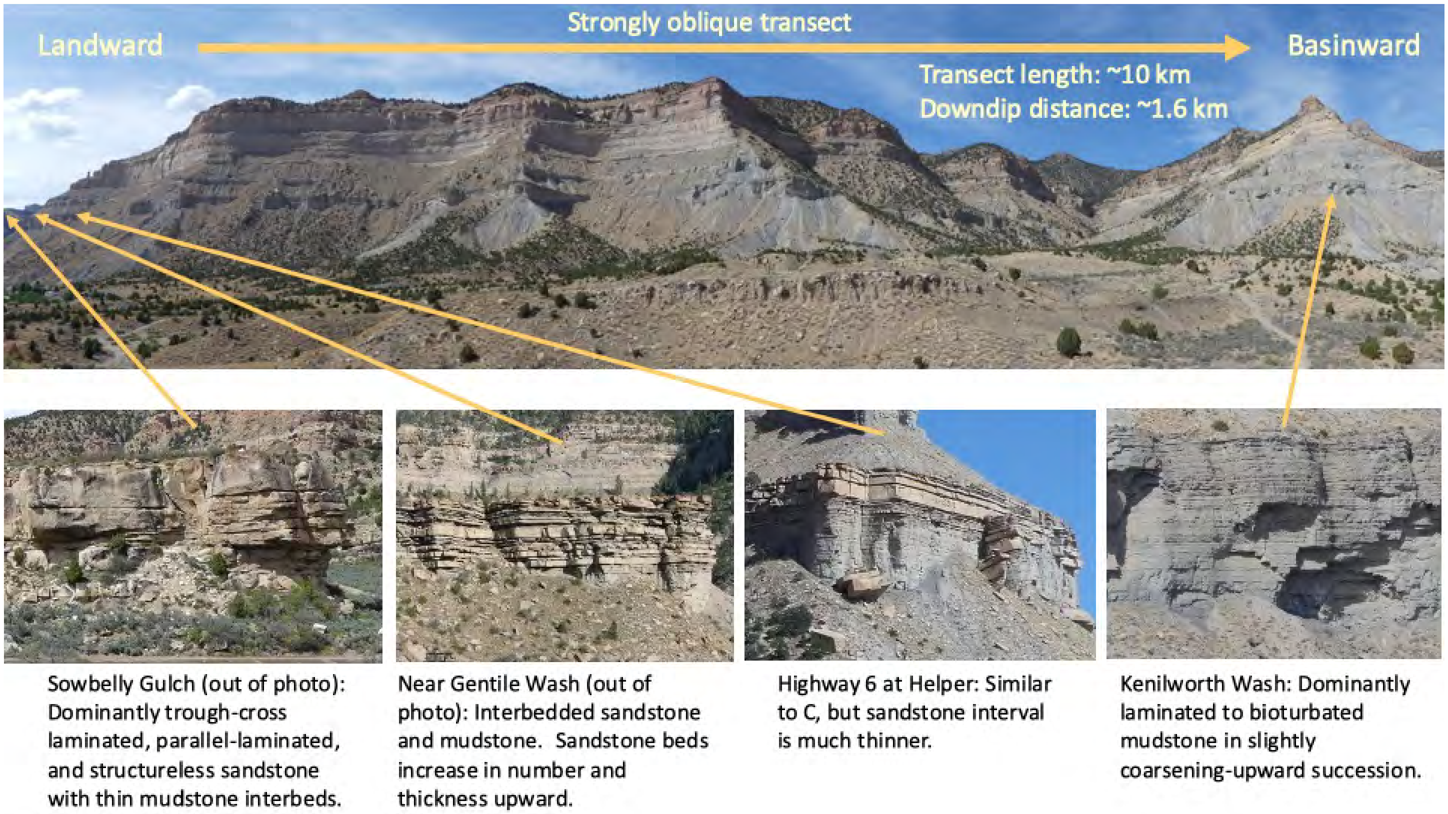

Figure 17. *North Helper escarpment showing landward to basinward facies changes for the Panther Tongue Member in a strongly oblique, close to strike-parallel, orientation.*

(0.4 km) of dip direction; therefore, facies changes are even more rapid than they appear from this outcrop. Despite the minor amount of down-dip distance exhibited along the escarpment, facies changes in the Panther Tongue are quite evident, as they are still dominated by sandstone on the west end adjacent to U.S. Highway 6, becoming almost entirely mudstone by the triangular hill at the eastern end.

Lateral Facies Changes in the Storrs Member

Locality II-D: Mouth of Sowbelly Gulch (Distal to proximal comparison): On the west side of the mouth of Sowbelly Gulch, above the Panther Tongue, are three thin ledges containing coarsening-upward facies associations, each of which begins with mudstone at the base and is capped by sandstone (Figure 18). They belong to the Storrs Member and are the same parasequences observed in the Storrs Member at Gentile Wash. Similar to the Gentile Wash section, each of these coarsening-upward intervals is more poorly developed than the one beneath, in that each progressively lacks more of the upper part of the succession. However, being a more proximal location at Sowbelly Gulch, these deposits overall are coarser grained and better developed than their more distal exposures at Gentile Wash, indicating an updip change in facies. Both localities show a back-stepping parasequence pattern representative of a transgressive systems tract, in which accommodation formed more quickly than it was filled. The top of the Storrs Member is placed where parasequences begin to demonstrate increasingly more complete formation, marking a change from a retrogradational to a strongly progradational parasequence stacking pattern. The uppermost parasequence in the Storrs is only slightly less-well developed than the preceding, making this interval nearly aggradational, placing the maximum-flooding surface at the boundary between them.

Figure 18. *Retrogradational to aggradational parasequences within the Storrs Member (Kss) on the west side of the mouth to Sowbelly Gulch. Ksp and Km refer to the Panther Tongue Member and Mancos Shale, respectively. Parasequences are marked by P1, P2, and P3. The transgressive (TS) and maximum-flooding (MFS) surfaces are shown by a blue and a green line, respectively.*

Lateral Facies Changes in the Spring Canyon Member

Locality II-E: Spring Canyon (landward shoreface pinchout): Ascending a small hill immediately on the north side of Spring Canyon Road and looking toward the distant high ridge to the north, two white-capped sandstones outcrop on the eastern end of the ridge (Figure 19). The higher of the two sand bodies (Hardscrabble parasequence) disappears along the hillside a short distance to the west. Using binoculars, the landward pinchout of the upper sandstone can be seen where it terminates into an equally-thick succession of thinly-interbedded sandstones and mudstones, in which sandstone beds dip westward (landward). This terminal end of the sand body is interpreted as a barrier bar deposit (Van Wagoner and others, 1990). To the west of the bar are back-barrier deposits formed by washover fans and quiet-water lagoonal deposition. To the east, the parasequence transitions into a highly progradational shoreface succession. The lower sandstone is the Sowbelly parasequence observed at the end of the hike in Gentile Wash.

Figure 19. Landward pinch out of the Hardscrabble parasequence (PS) within the Spring Canyon Member, labeled with associated environments.

Barrier islands form as base level rises, the longshore sediment source is reduced, and waves rework former shoreface and foreshore deposits into barrier islands that migrate landward. Upon a slowing of base-level rise (or an increase in sediment supply), the back-barrier lagoon fills with sediment, and the barrier island transforms to a progradational beach system. The back-barrier lagoon fills on its landward (proximal) side by bayhead deltas, from the seaward (distal) side by washover fans, and throughout by suspension settling of mud. The Spring Canyon view point affords observation of the distal side of the Hardscrabble lagoon. The more proximal portion can be seen at Sowbelly Gulch.

Locality II-F: Sowbelly Gulch alcove north of "Magazine Canyon" (Back-barrier deposits): At the top of the old tramline in the alcove on the east side of the road just north of Magazine Canyon are well-exposed back-barrier deposits associated with the Hardscrabble parasequence (Figure 20). This is the same parasequence observed approximately 1 mile (1.6 km) more distally with binoculars on the north side of Spring Canyon. The lower parasequence boundary here is formed between coal underneath and lagoonal mudstone above. Sandstones in this interval are quite different from those seen up close in parasequences at Gentile Wash, in that they are thinly bedded, beds are lenticular in geometry, and the facies association is comprised of trough cross laminations and climbing, symmetrical, flat-topped, flaser, and interference ripple patterns. These features, along with the thin interbeds of mudstone, indicate highly variable energy conditions and tidal influence, probably associated with bayhead delta progradation into a lagoon.

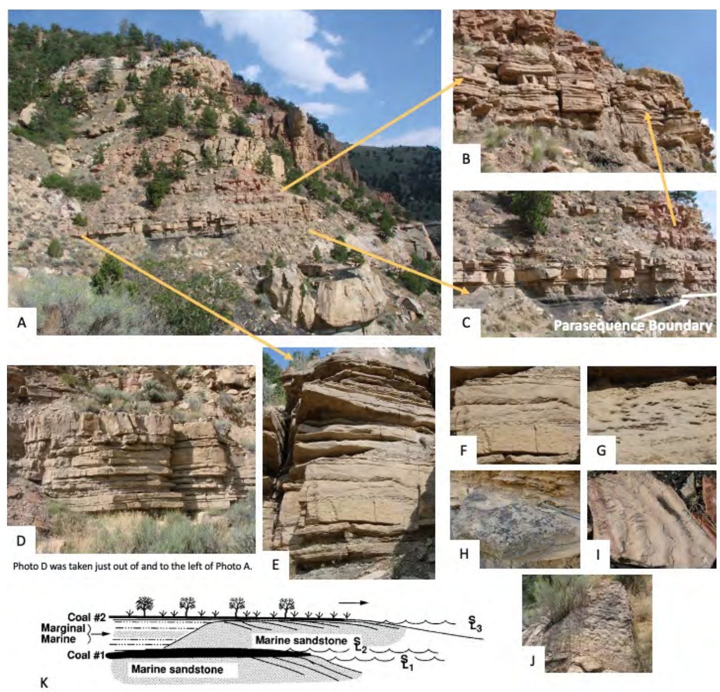

*Figure 20. A) Back-barrier lagoon deposits of the Hardscrabble parasequence within the Spring Canyon Member. **B and C** are enlargements of the upper and lower portions of the unit, respectively. In C, the parasequence boundary, between coal below and lagoonal mudstone above, can be seen. **D and E** show the thin, lenticular nature of bedding for the sandstone portion of the unit. F through I are close-up views of common sedimentary structures found within the sandstones, including flaser- and trough- cross lamination **(F)**, climbing ripples **(G)**, symmetrical ripples **(H)**, flat-topped ripples **(I)**, and oscillatory ripples (J). These features, along with thin beds of mudstone, indicate highly variable energy conditions and probable tidal influence. K is a generalized model (Kamola and Van Wagoner, 1995) for Blackhawk barrier and back-barrier deposits, in which SL1, SL2, and SL3 indicate sequential positions of sea level. A bayhead delta could be added to the proximal margin.*

Lateral Facies Changes in the Aberdeen and Kenilworth Members

Locality II-G: Inside the mouth of Coal Canyon (progradational parasequence stacking pattern): Coal Canyon gives an opportunity to examine the upward and basinward shift of parasequences typical of the progradational stacking pattern in a highstand systems tract. Because this is private property with a locked gate, we will focus on the overall pattern as can be seen from outside the gate. From a distance, the stratigraphy of this locality appears nearly identical to that in Gentile Wash, however, here, the Spring Canyon Member parasequences that formed prevalent sandstone-dominated cliffs in Gentile Wash consist mostly of thinly-bedded mudstone with a thin cap of hummocky-laminated sandstone, similar to the Storrs Member at Gentile Wash (Figure 21; compare with Figure 6). The Storrs Member equivalent at this locality is in the subsurface and has completely graded laterally into the Mancos Shale. The pronounced shoreface successions visible in the ledges surrounding the mouth to Coal Creek Canyon belong to the Aberdeen and Kenilworth Members. At Gentile Wash, the Aberdeen Member formed thinner shoreface successions dominated by the presence of only the upper, more proximal parts. Here, parasequences in the Aberdeen show complete facies successions from offshore mudstone at the base, through shoreface and foreshore sandstones, to interbedded mudstone and sandstone or coal of coastal-plain environments, similar to the Spring Canyon Member at Gentile Wash. The lower part of the Kenilworth Member also includes parasequences similar to those of the Spring Canyon at Gentile Wash, with upper parasequences continuing to be composed of coastal-plain deposits, similar to the entire Kenilworth succession viewed from the monument turnout along U.S. Highway 6. As with underlying units, farther eastward, the Aberdeen and Kenilworth Members progressively grade down dip into the Mancos Shale, and the overlying Sunnyside through Desert Members, which here are primarily coastal plain in nature, become the well-developed shoreline successions, though the Sunnyside Member does include a small scale, fourth-order marine incursion (Figure 1).

Figure 21: Aberdeen (Kba) and Kenilworth (Kbk) Members of the Blackhawk Formation (Kb) near the mouth of Coal Creek Canyon. Notice similarity to the Spring Canyon and Aberdeen Members in Gentile Wash, as shown in Figure 6.

Locality II-H: Beckwith Plateau (progradational parasequence stacking pattern): The purpose of this locality is to further reinforce the concept of a progradational parasequence stacking pattern in the highstand systems tract, as we progress upward through the section and move farther into the basin. In the more proximal Helper area, the lowest prominent sandstone was the Panther Tongue Member (Figure 5). The Spring Canyon and Aberdeen Members also exhibited prominent cliff-forming shoreline parasequences in that area (Figure 6). Higher units consisted of coastal-plain fluvial deposits, overlain by a thick braided river system in the Castlegate Sandstone (Figure 13). The Panther Tongue disappears into the Mancos Shale near the town of Kenilworth, and the Spring Canyon Member does the same near the mouth of Coal Canyon, where the prominent sandstone ledges are the stratigraphically higher Aberdeen and Kenilworth Members (Figure 21). By the Beckwith Plateau, the Aberdeen and lower Kenilworth Members have also transitioned eastward into Mancos Shale (Figure 1), and the lowest cliff face is in the upper part of the Kenilworth Member, which, along with the overlying Sunnyside, Grassy, and Desert Members consists of a series of shoreface parasequences (Figure 22). The thin ledge at the top of the plateau is the Castlegate Sandstone, which has thinned significantly since the Helper region, has become finer grained, and is more characteristic of a coarse-grained meandering system.

From the Helper region to this locality, we have traveled obliquely to depositional dip; therefore, facies changes are actually much more rapid than they might have appeared from the few observation points. At this stop, both dip- and strike -oriented exposures can be viewed simultaneously (Figure 22A and 22B). Depositional units in the eastern cliff face show little variation for a long distance along outcrop in terms of either lithology or thickness; however, the ledges forming the north side of the Beckwith Plateau show a significant thinning of sandstone from west to east. This is particularly evident in the Kenilworth Member (basal sandstone) that thins to the east and separates into three thinner sandstone ledges separated by tongues of the Mancos Shale.

Locality II-I: Woodside Canyon – north side of curve (Kenilworth Member – Wave-modified delta front): The uppermost two parasequences of the Kenilworth Member are exposed on the north side of Woodside Canyon road (Figure 23) and together superficially appear similar to the Panther Tongue at Gentile Wash (Figure 8), in that there is an interval at the base consisting of thinly interbedded sandstones and mudstones, and the succession coarsens upward into thicker lenticular bodies of sandstone capped by a flat surface and overlain by a tongue of the Mancos

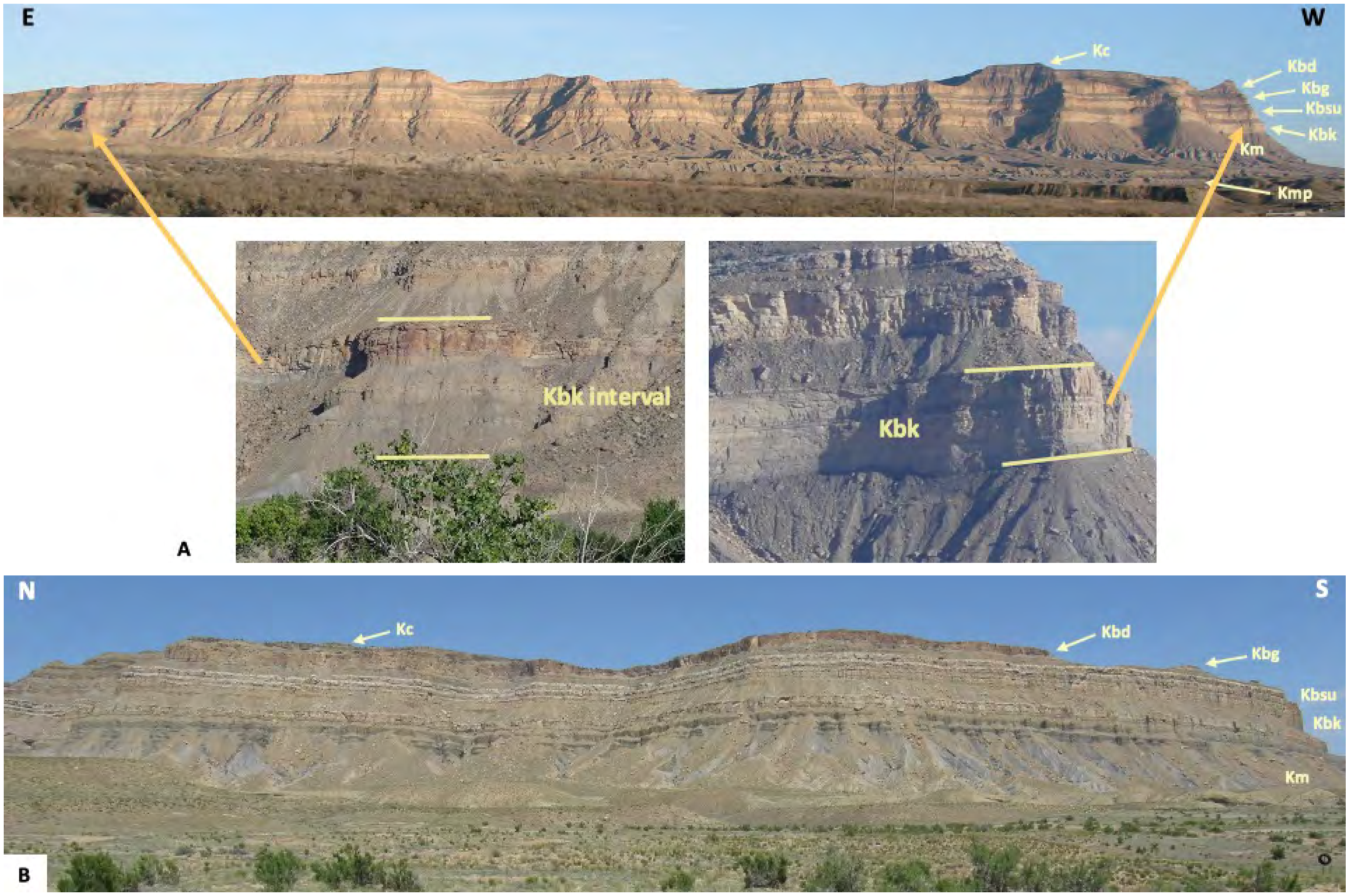

*Figure 22. **A)** Depositional-dip oriented photo of the upper Blackhawk Formation along the northern escarpment of the Beckwith Plateau. The Kenilworth Member (lowest ledge-forming sandstone, Kbk) thins eastward (basinward) and splits from one thick ledge to three thinner resistant intervals interbedded with tongues of the Mancos Shale (Km), of which only the uppermost is still dominated by sandstone. **B)** Depositional-strike oriented view of the same units along the escarpment on the north side of Woodside Canyon. Depositional units show little variation in thickness or lithology. Other abbreviations refer to the Prairie Canyon (Kmp), Sunnyside (Kbsu), Grassy (Kbg), and Desert (Kbd) Members of the Blackhawk Formation and to the Castlegate Sandstone (Kc).*

Shale. However, close inspection shows facies within the Kenilworth Member to differ significantly from those of the Panther Tongue. At the base of this outcrop, the thin sandstones interbedded with mudstones are hummocky- to horizontally-laminated, suggesting storm deposition, rather than the Bouma successions that dominated the basal Panther Tongue. These are overlain by amalgamated hummocky- to parallel-laminated sandstone beds and followed by a thick interval of trough cross-laminated sandstone. These characteristics indicate wave energy was the prevailing agent, rather than sediment gravity flows. The lenticular geometry of beds in the upper part of the unit are the result of wave-reworked channel-mouth bars. Near the top of the outcrop, rather than coal, this parasequence is topped by a thin interval of mudstone and sandstone interbeds, with significant burrowing of both lithologies and indications of tidal currents, such as double mud or carbonaceous material drapes. Sandstones are ripple

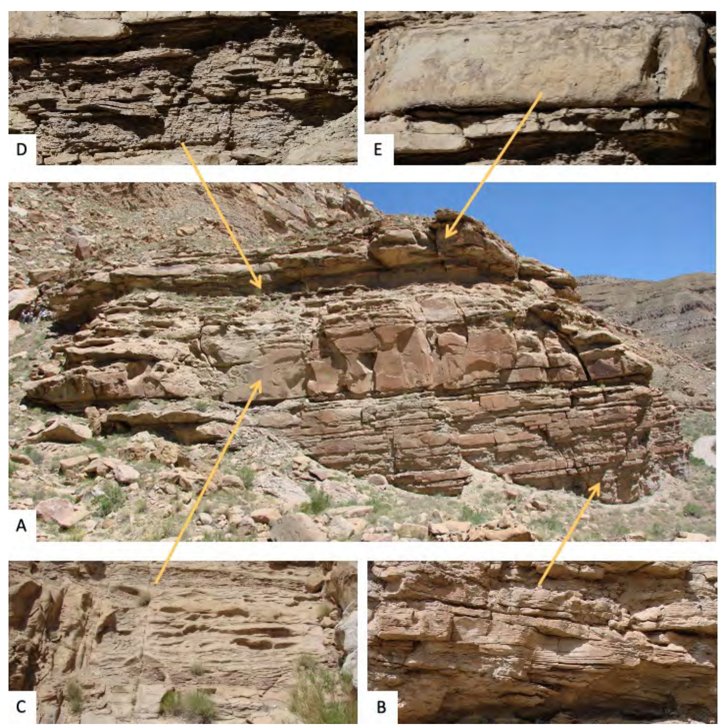

*Figure 23. **A)** Complete wave-dominated deltaic succession in the upper part of the Kenilworth Member in Woodside Canyon. **B)** Close up of hummocky sandstone interbedded with mudstone in the lower part of the outcrop. **C)** Upper shoreface trough cross-laminated sandstone from the upper portion of the exposure. **D)** Fine-grained back-barrier deposits. **E)** Parallel-laminated foreshore deposits of the uppermost parasequence.*

Figure 24. Lens-shaped distributary channel-fill sandstone bounded laterally by channel-mouth bar sandstone lenses and overlain by a finer-grained back-barrier succession within the upper Kenilworth Member.

laminated and can have a pinch-and-swell geometry, indicative of rapid deposition into an otherwise quiet-water, mud-dominated environment. In addition to heavy bioturbation, the upper surface of the muddy deposits contains an abundance of small wood fragment casts. This muddy interval was deposited in a back barrier setting, similar to that of the Hardscrabble parasequence observed in Sowbelly Gulch. Following either a minor flooding event or simple delta-lobe switching and compaction, the uppermost parasequence formed a relatively thin deposit almost entirely of horizontally-laminated sandstone, most likely produced within a foreshore environment. This was followed by another, much more significant base-level rise, placing a thick tongue of the Mancos shale between the Kenilworth and Sunnyside Members.

Locality II-J – east side of curve: Woodside Canyon (Kenilworth Member – distributary channel): Approximately 0.25 mile (0.4 km) to the southeast of the Kenilworth delta-front exposure, at the same stratigraphic level as the lower, thicker parasequence, is a thick lens-shaped sandstone body encompassed on both sides by thinner lens-shaped sandstones (Figure 24). The thicker sandstone appears to be an abandoned distributary-channel fill, whereas, the smaller sandstones are channel-mouth bar deposits similar to those in the delta front. The same fine-grained capping interval and overlying foreshore sandstone of the uppermost parasequence are also present at this locality. A similar matching deposit to the southwest, across the Price River, suggests the paleoflow was to the northeast.

Locality II-K: Valley floor north side of Beckwith Plateau (Prairie Canyon Member – "detached lowstand deposits"): Relatively thin, isolated bodies of sandstone, forming low benches near the base of the Beckwith Plateau and totally encased by Mancos Shale (Figure 25A), have been interpreted by some as detached lowstand deposits (Hampson and others, 1999, 2001). It is thought they might have formed during forced regressions, being fed through bypass channels cut into marine mudstone. Others consider them to have formed as isolated highstand shelf deposits produced by turbidites (Pattison, 2005a, b). Dominant facies include horizontally-laminated and hummocky sandstone, with a considerable amount of contorted bedding. They are often burrowed on the upper surface and show no signs of subaerial exposure. Some of these have collectively been referred to as the Prairie Canyon Member of the Mancos Shale

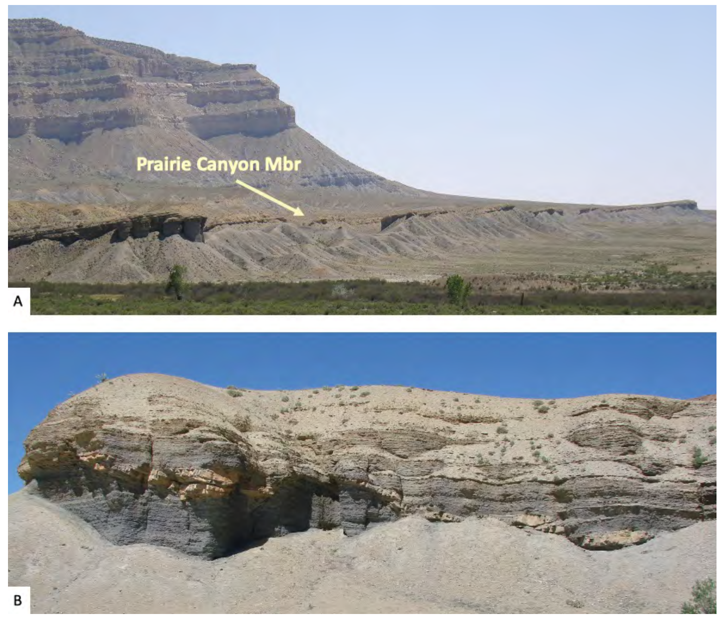

Figure 25. A) The Prairie Canyon Member of the Mancos Shale is expressed as low benches associated with the Aberdeen and Kenilworth Members of the Blackhawk Formation. B) Channel forms within the Mancos Shale that are possibly backfilled lateral equivalent feeder channels to the benches in A.

and have been correlated to the Aberdeen and Kenilworth Members of the Blackhawk Formation (Newman, 1985; Swift and others, 1987; Pattison, 2005a). On the north side of the road at this locality are small lens-shaped sandstones within the Mancos Shale, which are possibly examples of backfilled bypass channels (Figure 25B).

Locality II-L: Middle Mountain to Gunnison Butte (Kenilworth Member - down-dip parasequence pinchout): The cliff face to the north is the south side of a ridge that extends eastward from Middle Mountain to Gunnison Butte (Figure 26). This is nearly along depositional strike from Locality II-H on the north side of the Beckwith Plateau; therefore, this view shows the same down-dip relationships but can be seen a little more closely, particularly with the aid of binoculars. The down-dip pinchout of the three upper parasequences of the Kenilworth Member can be easily traced from complete shoreface successions for the upper two near the base of Middle Mountain on the west to mostly interbedded bioturbated mudstone and thin silty intervals of the distal transition zone at Gunnison Butte to the east. The view from this locality gives perspective on the scale over which these facies as-

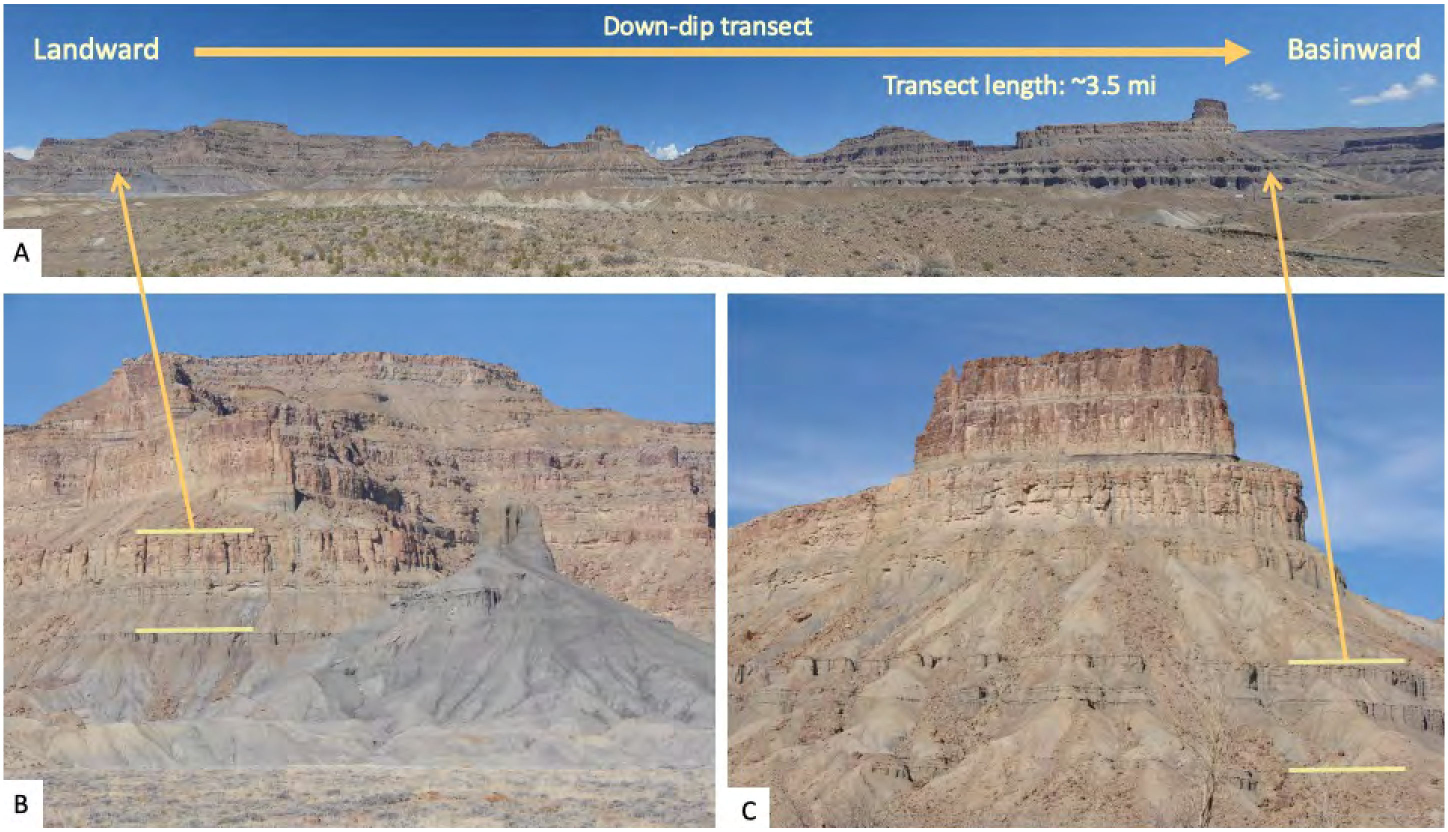

Figure 26. Down dip cross-section of the Kenilworth Member through Castlegate Sandstone (A). The focus here is on the lowest resistant bed (B), forming the top two parasequences of the Kenilworth Member, which thins and eventually transitions basinward into the Mancos Shale (C). Yellow lines bracket this interval at Middle Mountain on the landward and Gunnison Butte on the basinward ends of the outcrop.

sociations can change in a reservoir. The outcrop orientation here is close to true depositional dip, so perceptions will be much more accurate than earlier observations. The muddy resistant intervals at the base of the plateau, as well as those on at the base of Battleship Butte on the south side of the road, are distal remnants of the lower parasequences of the Kenilworth Member.

Locality II-M: Hatch Mesa (Prairie Canyon Member – "detached lowstand deposits" continued): Thin, up to about 3-foot-thick (1 m), sandstones with sharp lower and upper contacts form broad, lobate bodies contained completely within the Mancos Shale (Figure 27). The most common facies association is structureless sandstone overlain by parallel-laminated sandstone, though some exposures consist entirely of stacked thin beds of parallel-laminated sandstone. These suggest high energy and rapid deposition. Contorted bedding and water-escape structures are abundant, indicating water saturation. Below the sand bodies are thinly-bedded, coarsening-upward successions of fine-grained sediment reminiscent of distal shoreface deposits. These characteristics have led to an interpretation of subaqueous "fans" deposited on a marine "shelf" during either forced regressive or highstand episodes of base-level change (Hampson and others, 1999, 2001; Pattison, 2005a, b). The sand bodies are abruptly overlain by marine mudstone of the Mancos Shale.

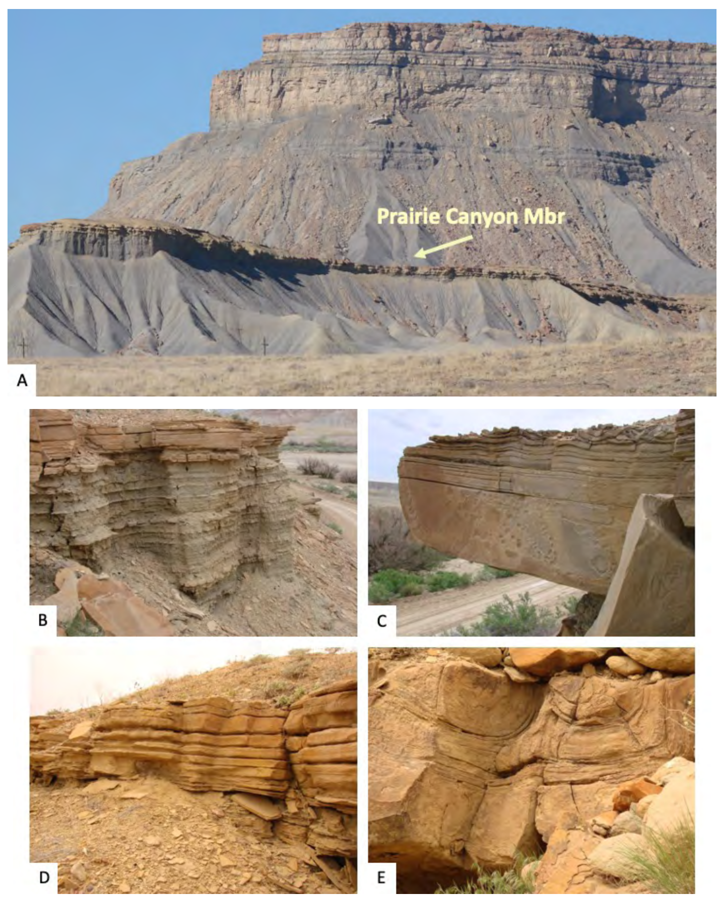

Figure 27. A) The Prairie Canyon Member (low bench) at Hatch Mesa. B) Contact with underlying distal shoreface deposits. C) Typical facies association of structureless sandstone overlain by parallel-laminated sandstone. D) Secondary, but also common facies association of stacked beds of parallel-laminated sandstone. E) Soft-sediment deformation, including water-escape structures.

Section III: Incised Channel Fill Deposits

Within the overall third-order sequence represented by the Star Point/Blackhawk/lower Castlegate succession are scattered and complex lens-shaped outcrops up to several miles wide that fill depressions cut into underlying and adjacent shoreface sandstones. These deposits consist of several stacked parasequences, each ranging from a few feet to a few tens of feet in thickness. Fill environments vary from poorly developed shoreface units to multistory fluvial successions. Both are heavily influenced by tidal processes, as shown by abundant reactivation surfaces, double mud or carbonaceous material drapes, flaser to wavy and lenticular bedding, heterolithic deposition, sigmoidal cross bedding, small-scale channel forms, and extensive burrowing. They are commonly capped by coal. These successions accumulated in estuarine settings, and successions can either fine or coarsen upward, depending upon openness of the shoreline to marine conditions on the basinward side and the relative contribution by fluvial systems at the landward margin. Lower contacts are sharp, erosional, and considered to be fourth-order sequence boundaries (Miall, 1993; O'Byrne and Flint, 1996; Davies and others, 2006; Gani and others, 2015). Laterally, between incised channels, the basal contact is often parallel to underlying shoreface deposits above an interfluve surface. Interfluve deposits tend to show a stronger terrestrial component than those found within the channels. An example of an interfluve succession is the earlier-described upper Aberdeen Member on the west side of U.S. Highway 6 at the monument turnout (Locality ID).

Incised Channel Fill at top of the Aberdeen Member

Locality III-A: Outside the mouth of Coal Canyon (distant observation of incised channel geometry – Aberdeen Member): On the north side of Coal Canyon at the top of the Aberdeen Member, the uppermost shoreface parasequence and part of the next lower parasequence are truncated, and the incision is filled with tidally-influenced estuarine deposits (Figure 28). Using binoculars, above the incised channel surface can be seen inclined heterolithic strata, suggestive of a tidally-influenced fluvial succession. Near the top of the channel fill, on the south end, is a thicker, lens-shaped channel-fill sandstone. A similar succession can be observed closely in Soldier Canyon (Localities III-B and III-C), as described below.

Locality III-B: Soldier Canyon – both sides of highway south of coal mine entrance (tidally-dominated shoreline deposits – upper Aberdeen Member): The basal part of the same incised channel fill seen at the top of the Aberdeen Member on the hillside at the mouth of Coal Canyon (Locality III-A) is exposed at road and creek level in Soldier Canyon (Figure 29). Tidal influence on shoreline systems is demonstrated by parasequences that fine upward from subtidal hummocky- and sigmoidally cross-laminat-

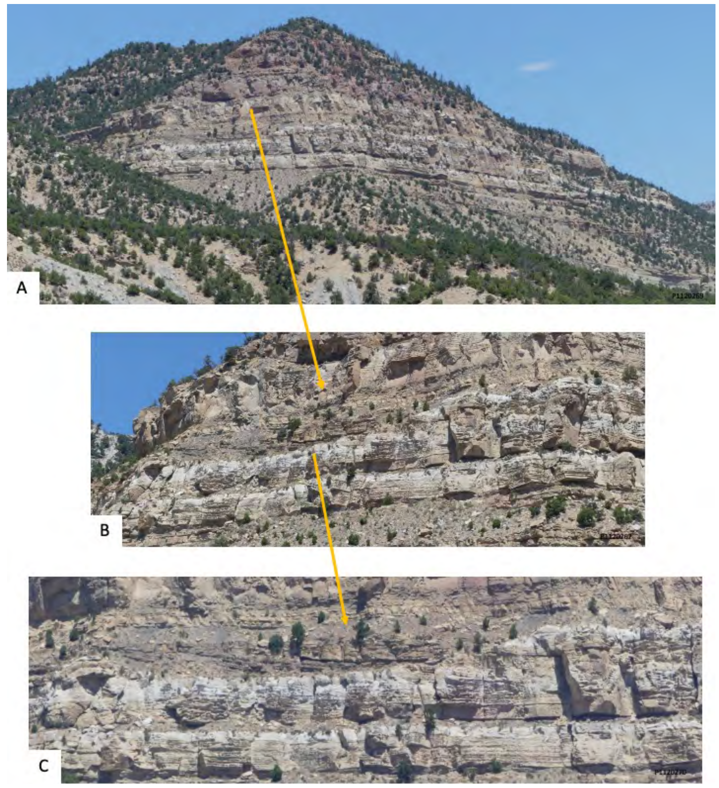

Figure 28. Distant (A) and closer (B, C) views of an incised channel and fill at the top of the Aberdeen Member. Fluvial lateral accretion surfaces are evident in the closest (C) view.

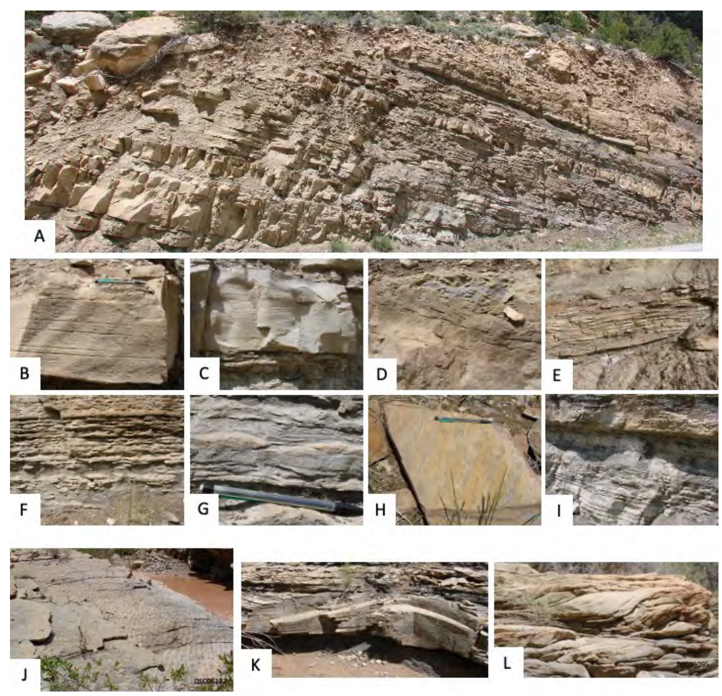

Figure 29. A) Roadcut exposure of tidally-influenced shoreline deposits, including horizontally laminated (B), hummocky (C, K), and sigmoidally-laminated (D, L) sandstone of the subtidal region; heterolithic bedding (E), flaser-laminated sandstone (F, G), and ripple marks (H, J) from the intertidal zone, and coastal plain coal (I). Photos J through L are from the creek bed on the south side of the road.

ed sandstone to thinly interbedded mudstones and sandstones of the intertidal zone. These thin sandstones are mostly flaser- to lenticularly-laminated, with lesser trough cross lamination, features indicative of alternating higher and lower energy conditions. Each parasequence is capped by a carbonaceous shale or coal.

Locality III-C: Soldier Canyon – east side of highway at former coal mine entrance (tidally-dominated fluvial deposits – upper Aberdeen Member): The upper part of the incised channel fill is well exposed at the former mine entrance, across the highway from the now closed Soldier Canyon coal mine facility (Figure 30). These deposits are similar to those observed by binoculars at the mouth to Coal Canyon (Locality III-A), dominated by inclined heterolithic stratification, having accumulated, in part, through lateral accretion, suggesting tidally-influenced fluvial deposition. Thin lenses of sandstone are flaser laminated and contain water escape structures. The succession is capped by mudstone that accumulated in overbank and swamp environments. Above the channel-fill succession is the same shoreface parasequence seen at the base of the Kenilworth Member in Coal Canyon; therefore, the contact between the Aberdeen and Kenilworth Members is a flooding surface.

Section IV: Identification of a "Complete" Small-scale Sequence in Single Outcrops

Locality IV-A: Tusher Canyon (Desert Member and lower Castlegate Sandstone): On the northwest side of a major bend in the Tusher Canyon streambed/road is a complete fourth-order sequence within the upper part of the Desert Member (Figure 31). The lower contact (sequence boundary) is well expressed at the southwestern edge of the channel fill and clearly shows erosion along the base and margin. Beneath and lateral to the erosional surface, are stacked shoreface deposits of the lower Desert Member, identified by hummocky-laminated sandstone. The fill above the sequence boundary consists of multistoried lens-shaped sand bodies. Channel fill sandstone is coarser grained than underlying shoreface deposits, is characterized by low-angle trough cross stratification, some thin interbeds of mudstone, asymmetrical (current) ripples and thin veneers of carbonaceous material. The fill deposits include molds of fossilized tree trunks with Teredolites burrows, indicating tidal influence. Laterally (northeastward) from the sandstone lenses, the succession becomes dominated by inclined, thinly interbedded sandstones and mudstones. Sandstones in this interval are structureless to trough cross stratified,

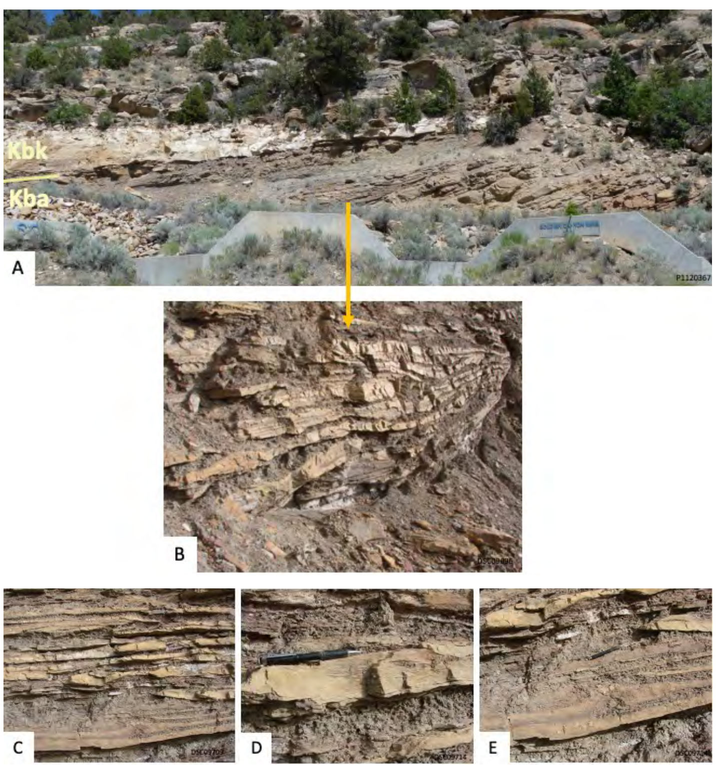

*Figure 30. **A)** Hillside exposure of an incised-valley fill (IVF) capping the Aberdeen Member (Kba). The light-colored bed above is the basal shoreface parasequence of the Kenilworth Member (Kbk). Photo B shows a close up of heterolithic bedding located at the base on the west (right) side of the outcrop. **Photos C** (pinch-and-swell bedding), **D** (flaser lamination), and **F** (water-escape structure) are from near the right margin of Photo B.*

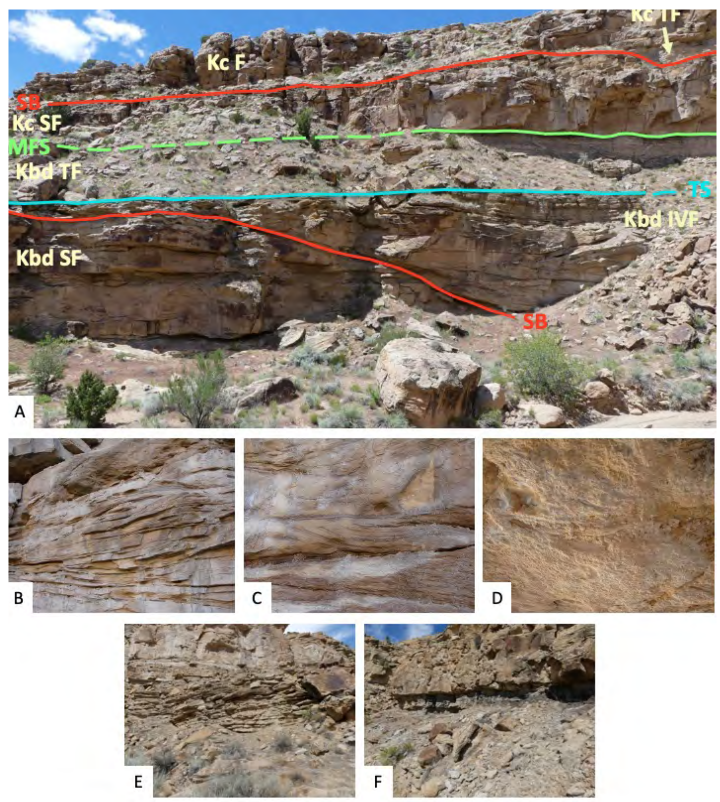

*Figure 31. Incised-channel fill in Tusher Canyon. **A)** Major sequence stratigraphic surfaces. Abbreviations: Kbd (Desert Member), Kc (Castlegate Sandstone), SF (shoreface), IVF (incised channel fill), F (fluvial), TF (tidally-influenced fluvial), SB (sequence boundary), TS (transgressive surface), and MFS (maximum flooding surface). **B)** Bedding characteristics within the incised channel fill. **C)** Double mud and carbonaceous material drapes, **D)** Bioturbation and wood fragment molds. **E)** Heterolithic bedding of tidally-influenced fluvial deposits. **F)** Coal bed found below the maximum flooding surface.*

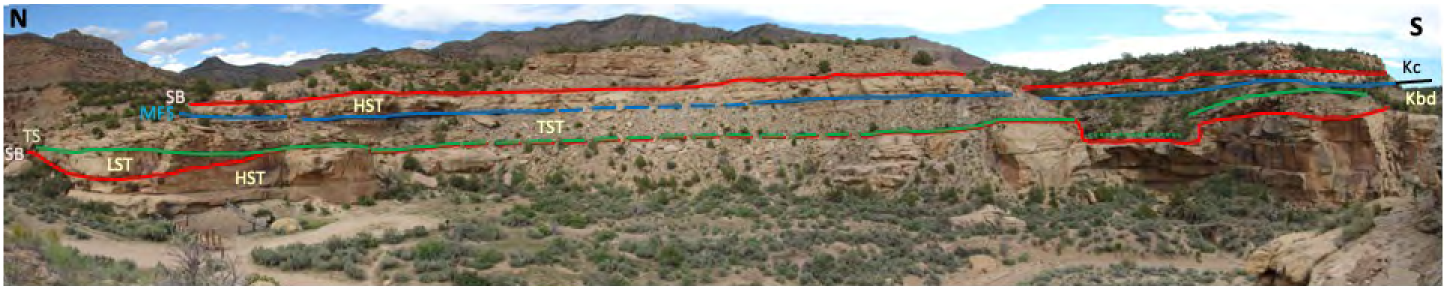

Figure 32. *Incised-channel fill in Thompson Canyon showing sequence stratigraphic surfaces and systems tracts. Abbreviations as indicated in earlier figures.*

with common ripple bedding on their surfaces and load casts at the base. These are likely splay systems that developed onto a very wet floodplain or into a shallow interdistributary bay.

Locality IV-B: Thompson Canyon (Desert Member and lower Castlegate Sandstone): Observed from a bedrock bench located directly on top of the yellowish petroglyphs on the west side of Thompson Creek, a complete fourth order sequence similar to that studied at Tusher Canyon can be seen in the alcove to the east of Thompson Creek, with a few differences from that in Tusher Canyon (Figure 32). Along the base of the alcove are stacked shoreface sandstones of the lower Desert Member, characterized by hummocky and trough cross laminations that are separated by continuous, planar contacts. These deposits are the capping part of a fourth-order highstand systems tract within the lower Desert Member. At the north end of the alcove, the lower Desert Member shoreface deposits are cut by an angular erosional surface and overlain by a thick lenticular sandstone body that contains lateral-accretion clinoforms, is coarser grained than the sand units beneath the surface, and contains few visible sedimentary structures. These are the lower sequence boundary and lowstand systems tract, respectively, both part of the upper Desert Member. In the upper part of this sand lens is a second inclined erosional surface, above which sand beds are thinner, show more distinct lateral accretion, contain mud drapes on some lateral accretion surfaces, are distinctly cross bedded, and include a significant degree of contorted bedding. Laterally (south) of the upper part of the sand lens are inclined heterolithic strata very much like those described at Tusher Canyon. Here, they form a clear coarsening-upward succession that includes abundant water-escape structures, climbing ripples, well-developed load casts, and ball and pillow structures, indicating rapid deposition under very wet and variable energy conditions. Together, the upper sandstone and adjacent heterolithic deposits appear to have formed as tidally-influenced channel fill and splays onto a ponded floodplain or into an interdistributary bay. The upper part of the sand lens and associated heterolithic strata together form the transgressive systems tract, also within the upper Desert Member. The boundary at the facies change within the thick sandstone lens, continuing along the base of the heterolithic strata is the transgressive surface. Incision by the sequence boundary through shoreface deposits is also apparent at the south side of the alcove; however, in the southern cut, the incised channel is filled entirely by inclined heterolithic strata of the transgressive systems tract. Between the two ends of the alcove is an interfluve surface, where the sequence boundary and transgressive surface merge. The upper sandstone-heterolithic unit are overlain by a thin interval of carbonaceous mudstone and coal, which in turn is covered by thin sandstone sheets dominated by trough cross bedding, some of which has been highly contorted. These sandstone sheets above the coal indicate a return to shoreface conditions, and the contact between them and the underlying coal represents the most significant marine transgression for this sequence and, therefore, the maximum flooding surface. This is also the contact between the Desert Member below and Castlegate Sandstone above. A second, stratigraphically higher, interval of heterolithic strata, similar to that already described, but with thinner sandstone beds and scattered small sandstone channel fills, overlies the shoreface units and is again capped by coal and carbonaceous mudstone. Teredolites borings and brackish water bivalves within this unit indicate a significant tidal influence. Terrestrial strata overlying shoreface units without intervening foreshore deposits mark the upper boundary for this fourth-order sequence. Note that both sequence boundaries in this outcrop are examples of where lithostratigraphic and sequence stratigraphic bounding surfaces do not coincide. The entire outcrop is capped by a coarser-grained, trough cross-bedded sandstone with distinct lateral accretion development and an erosional basal contact belonging to a purely fluvial interval of the lower Castlegate Sandstone.

SUMMARY

The Star Point/Blackhawk/lower Castlegate sequence in the Book Cliffs region of east-central Utah provides an excellent field laboratory to view features and teach concepts associated with sequence stratigraphy. All major aspects of a stratigraphic sequence are well expressed and easily accessible. This report progresses through a complete third-order sequence from its base to the upper boundary and simultaneosly moves from proximal to distal localities within the basin. Particular emphasis is placed on the nature of sequence stratigraphic surfaces, the character of stacking patterns, lateral changes in facies association within a sequence, the special case of incised channel fill deposits above a sequence boundary, and recognition of small-scale (fourth-order) sequences within the larger-scale third-order sequence. Together, these features provide a detailed three-dimensional stratigraphic reconstruction in terms of accommodation production and filling in a foreland basin setting.

DRIVING DIRECTIONS AND GPS COORDINATES

Field localities are arranged in the body of the report according to topic, rather than order in which they would be encountered traversing from a single starting to ending point. In this log, they are listed first according to the report section under which they are initially encountered. Second, to avoid repetition of driving directions, closely spaced localities are grouped by general area (e.g. Spring Canyon), followed by locality number (e.g., II-A); therefore, localities from more than one section of the report might be listed under the same general area. Within a general area, directions to localities are mostly described in the order in which they appear in the report body, not by proximity to a reference point. Driving directions for each locality start at U.S. Highway 6, except those in vicinity of the town of Green River, which begin at Main Street. Distances to each locality are estimated from Google Earth and tied to an easily identified point along the route. These are followed by GPS coordinates.

Section I Localities

Helper City Cell Towers
From U.S. Highway 6, near the north end of the town of Helper, take Exit 232 (North Main Street). Turn west onto North Main Street. Drive one block and turn south (left) onto Uintah Street. Turn west (right) where Uintah Street dead ends into Hill Street. At the end of Hill Street turn south (left) onto Duchesne Street. At the base of the hill turn east (left) onto Reservoir Street, which will curve to the south as it climbs the hill. Shortly after the curve, turn west (right) at Gun Club Road (second unmarked street, identified by a red fire hydrant). Climb the road to the hilltop. After cresting the hill, take a small utility road to the north, just past the second water tank. See GPS coordinates under Locality I-A.

Locality I-A (observation point for the north Helper escarpment): Park at the end of the loop next to the cell towers. Walk to the edge of the hill to observe the escarpment across the valley that runs along the north side of the town of Helper. GPS coordinates are 39°41'04.7"N 110°51'44.8"W.

Gentile Wash
The entrance to Gentile Wash is located on the west side of U.S. Highway 6 at mile post 231.

Locality I-B (Gentile Wash hike): Park just inside the mouth to Gentile Wash. Hike the road into the wash. Localities are described in the order they are encountered during the hike and can be identified by accompanying photographs. GPS coordinates for the canyon mouth are 39°42'41.73"N 110°52'4.77"W.

U.S. Highway 6 North of Helper:

Locality I-C (UDOT road maintenance facility): Park in the lot on the east side of the highway at mile 229.8. GPS coordinates are 39°43'40.17"N 110°52'1.82"W.

Locality I-D ("monument turnout"): Park in the large turnout on the east side of the highway at Mile 229.4. GPS coordinates are 39°43'55.73"N 110°52'14.71"W. Discussion is of the roadcut on the west side of the highway.

Locality I-E: Same as ID, but discussion is of the hillside across Price River on the east side of the highway.

Locality I-F (Rolapp mine road): Park at the turnout on the west side of the highway at Mile 227.8. GPS coordinates are 39°45'5.70"N 110°53'10.72"W.

Sections II and III Localities

Spring Canyon
From U.S. Highway 6 turn south onto a small paved road located about 0.25 miles (0.4 km) north of the official North Main Street exit. This is also North Main Street but is not marked at its intersection with the highway. Drive between the Pick & Rail Market on the north (right) side of North Main Street and the gift/rock shop on the south (left) side to where North Main Street curves to the east (left), and make an immediate right turn onto Bryner Street, heading south. Turn west (right) onto Canyon Street and continue into Spring Canyon. Distances are approximated from the intersection of Canyon and Bryner Streets to GPS coordinates for each locality:

Locality II-A (mouth of Sowbelly Gulch): Distance from Bryner Street is 3.85 miles (6.20 km). GPS coordinates are 39°41'59.96"N 110°55'17.23"W. Park at the Spring Canyon rest stop.

Locality II-B (Standardville/mouth of Gilson Gulch): Distance from Bryner Street is 4.55 miles (7.32 km). GPS coordinates are 39°41'52.70"N 110°55'55.59"W. Park at the entrance to the eastern Standardville road.

Locality II-C: This stop is not in Spring Canyon. See directions to Helper city cemetery below.

Locality II-D: Same as Locality II-A.

Locality II-E (observation point for unnamed ridge east of Peerless mine): Distance from Bryner Street is 2.00 miles (3.22 km). GPS coordinates are 39°41'20.72"N 110°53'47.01"W. Park along Spring Canyon Road, and hike 0.1 miles (0.16 km) to near hilltop on the north side of the road.

Locality II-F (alcove in Sowbelly Gulch north of "Magazine Canyon"): Distance from Spring Canyon Road (not Bryner Street) is 0.41 (0.66 km). GPS coordinates are 39°42'20.76"N 110°55'12.04"W. Park to side of Sowbelly Gulch road.

Helper City Cemetery
From U.S. Highway 6, take Exit 232 (North Main Street), and turn east onto North Main Street. North Main Street curves to the south (right). Continue to Janet Street and turn east (left). After crossing the railroad, turn south (right) onto 2nd East/Webley Street. Second East curves to the east and becomes Spruce Street. Past the city park, Spruce Street turns into Cemetery Road and ends at the cemetery.

Locality II-C (observation point for the north Helper escarpment): Park at the east end of the large open space on the north side of the cemetery. GPS coordinates are 39°41'15.82"N 110°50'44.33"W.

Coal Canyon
From U.S. Highway 6, at about Mile 249.1, turn north onto paved East Coal Creek Road. After about 3.2 miles (5.1 km), the paved road becomes North Coal Creek Road, and East Coal Creek Road is a right turn, where it continues to the north as a long, straight, well-maintained gravel road. This turn is easy to miss and is about 0.60 miles (0.97 km) after crossing a small bridge with metal side and overhanging girders. Distances are approximated from where East Coal Creek Road becomes gravel.

Locality II-G (locked gate inside mouth of Coal Canyon): Distance from paved road is 8.80 miles (14.16 km). GPS coordinates are 39°42'11.26"N 110°40'42.90"W. Park at the small turnout just outside the gate.

Locality III-A (outside mouth of Coal Canyon): The incised channel fill at the top of the Aberdeen Member on the north side of the mouth to Coal Canyon can be seen clearly from Coal Creek Road over a distance of about 2 miles (3.2 km) centered at 7 miles (11 km) from the paved road or GPS coordinates 39°41'13.07"N 110°40'54.92"W.

Woodside Canyon
From U.S. Highway 6, at about Mile 278.1, turn east onto Woodside-Lower Price River Road, just north of the old Woodside City townsite. Distances to field locality stops are estimated from the intersection with Highway 6.

Locality II-H (Beckwith Plateau observation point): Distance from Highway 6 is 1.65 miles (2.66 km). GPS coordinates are 39°15'24.63"N 110°19'19.73"W. Park at intersection with minor side road that connects from the south (right) side.

Locality II-I (north side of curve in road): Distance from Highway 6 is 4.65 miles (7.48 km). GPS coordinates are 39°15'4.13"N 110°16'18.87"W. Park next to a small cliff face of coarsening-upward sandstone on north (left) side of road, shortly before a curve in the road to the south (right).

Locality II-J (east side of curve in road): Distance from Highway 6 is 5.05 miles (8.13 km). GPS coordinates are 39°14'56.40"N 110°15'56.17"W. Park inside fenced area on the east (left) side of the road, a short distance south of the curve.

Locality II-K (valley floor north side of Beckwith Plateau): Distance from Highway 6 is 2.1 miles (3.4 km). GPS coordinates are 39°15'20.85"N 110°18'49.72"W. Park next to a hill of Mancos Shale on the north (left) side of the road.

The Cove/Blue Castle Road
From Main Street in the town of Green River, turn north onto Long Street. Drive 6.75 miles (10.86 km) and turn west (left) onto a dirt road just north of a low bench on the west side of Long Street. Continue to the top of the ridge and along the dirt road toward The Cove and Blue Castle.

Locality II-L (Middle Mountain to Gunnison Butte observation point): Distance from Long Street is 0.68 miles (1.09 km). GPS coordinates are 39° 4'58.83"N 110° 9'32.09"W. Park where a smaller road intersects and heads to the southwest toward Battleship Butte.

Hatch Mesa
Take I-70 Exit 175. Turn north onto Ruby Ranch Road, which shortly curves to the west and becomes old U.S. Highway 6. About 0.25 miles (0.40 km) from the I-70 offramp, turn north (first right) onto BLM Road 225.

Locality II-M (Hatch Mesa): Distance from beginning of BLM Road 225 is about 1.50 miles (2.41 km). GPS coordinates are 38°56'12.45"N 109°55'30.19"W. Outcrops extend for some distance along a low bench on the west (left) side of the road.

Soldier Canyon
Near Mile 249.2 at the east end of the town of Wellington, from U.S. Highway 6, turn north onto North 2200 East. This becomes Soldier Creek/Nine-mile Canyon Road.

Locality III-B (Roadcut on west and creek bed on east sides of the road south of mine entrance): Distance from U.S. Highway 6 to a roadcut on the north side of the road is 12.31 miles (19.81 km), with GPS coordinates of 39°41'48.83"N 110°36'53.80"W. Park across the road from the outcrop. For creek bed exposures, follow a path on the south (right) side of the road that begins at a chainlink fence just east of the roadcut down the hillside to the creek at GPS coordinates 39°41'50.94N"110°36'49.80"W.

Locality III-C (Former mine entrance): Distance from U.S. Highway 6 is 12.65 miles (20.36 km). GPS coordinates are 39°42'1.66"N 110°36'40.54"W. Park in the old roadway at the mine's former entrance.

Section IV Localities

Tusher Canyon
From East Main Street near the eastern end of the town of Green River, turn north onto Hastings Road, which changes to Beach Road. Drive 7.50 miles (12.07 km) from the intersection with East Main Street and turn east (right) onto a well-maintained gravel road. There is no sign, but this is BLM Road 156. In 1.53 mi (2.46 km), the road enters Tusher Creek bed, continue to the north (left).

Locality IV-A (northwest side of a major bend in the creek bed/ road): Distance from where Road 156 enters Tusher Creek bed is 5.05 miles (8.13 km). GPS coordinates are 39° 6'1.70"N 110° 1'50.89"W.

Thompson Canyon
From Interstate I-70, take Exit 187 (Thompson Springs). After exiting the freeway, turn north onto Sego Canyon/Thompson Canyon Road and continue into the canyon.

Locality IV-B (Thompson Canyon Petroglyph parking lot): Drive 4.40 miles (7.08 km) from I-70 to a large pullout on the west (left) side of the road. It is just past a cattle guard to the north of a parking/rest stop for petroglyphs and a fenced coral for loading cattle. Walk northward across the creek bed to a trailhead at the base of cliffs on the west side of the creek, near where the hillside curves to the east. Follow the trail southward to a ledge directly over a petroglyph panel. The hike is about 0.25 miles (0.40 km). GPS coordinates for the parking spot are 39° 1'8.04"N 109°42'37.14"W.

ACKNOWLEDGMENTS

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