Fluvial Architecture and Longitudinal Variance in the Late Cretaceous Castlegate Formation, Book Cliffs, UT

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Abstract

The upper Campanian Castlegate Sandstone in the Book Cliffs of Utah is a highly amalgamated fluvial sandstone well known as a reservoir analog for oil and gas. It comprises the lower Castlegate, the formation capping Bluecastle Tongue, and the floodplain-rich middle Castlegate deposits. The Castlegate is among the most studied fluvial deposits in the world. Despite this, there has yet to be a fluvial architecture analysis completed for these deposits which consider the longitudinal variance within the Castlegate fluvial system. This project assesses the average channel depth and discharge for the lower Castlegate, allowing analysis of the relationship between channel depth and discharge and their effect on facies distribution, depositional style and fluvial architecture in the outcrops. The lower Castlegate Sandstone is a tributary fluvial system with paleocurrents oriented primarily W-NW to E-SE comprised of stacked braided fluvial sands updip, and large, higher flow straight-meandering trunk channels downdip. Distal outcrops show three distinct depositional styles with the first representing a period of highstand during which carbonaceous floodplain and small channels of 0.5-1 m in depth and maximum 4 m in width were deposited; The second represents a localized tectonic uplift with large channels of ~15 m in width and depth and lateral accretion sets scaled accordingly, and finally the capping units of small amalgamated sands composed of classic braided style channels which represent an overall apparent progradation of the Lower Castlegate fluvial system.

Introduction

The Castlegate Sandstone in the Book Cliffs, Utah is among the greatest exposure of fluvial deposit in the world, and one of the datasets used to create the conventional sequence stratigraphic model. This unit is comprised of the basal Lower Castlegate, the middle Castlegate, and the unit capping Bluecastle Tongue. The middle and Bluecastle units of the Castlegate split and appear further up-section in the Eastern Book Cliffs, whereas the lower Castlegate remains as the capping unit of the underlying Blackhawk Fm throughout the study area; For this reason, the lower Castlegate will be the focus of this study. The Castlegate was deposited during the Campanian of the late Cretaceous in which the fluvial system flowed from the Sevier Orogeny in the West to the retreating Western Interior Seaway in the East. This system deposits into the foreland basin created during the compressional regime that built the Sevier Orogen to the west. The Castlegate is most well-known by its type-section as a highly-amalgamated fluvial sandstone and is considered an analog for similar deposits around the world, but downdip the fluvial architecture and depositional style varies greatly from that of the type-section. A great point of contention is whether this fluvial system fed the marine tongues within the marine strata of the Book Cliffs or is representative of a later time period with a basal sequence boundary at its base. The Castlegate has been extensively studied in the past; Despite this, the Castlegate has yet to undergo a highly detailed fluvial architecture study considering the longitudinal variance within the system. This study evaluates the temporal and longitudinal variance within the Castlegate and will aide in the determination of the true fluvial style of the river system throughout its longitudinal cross-section and how it reacted to autogenic and allogenic inputs.

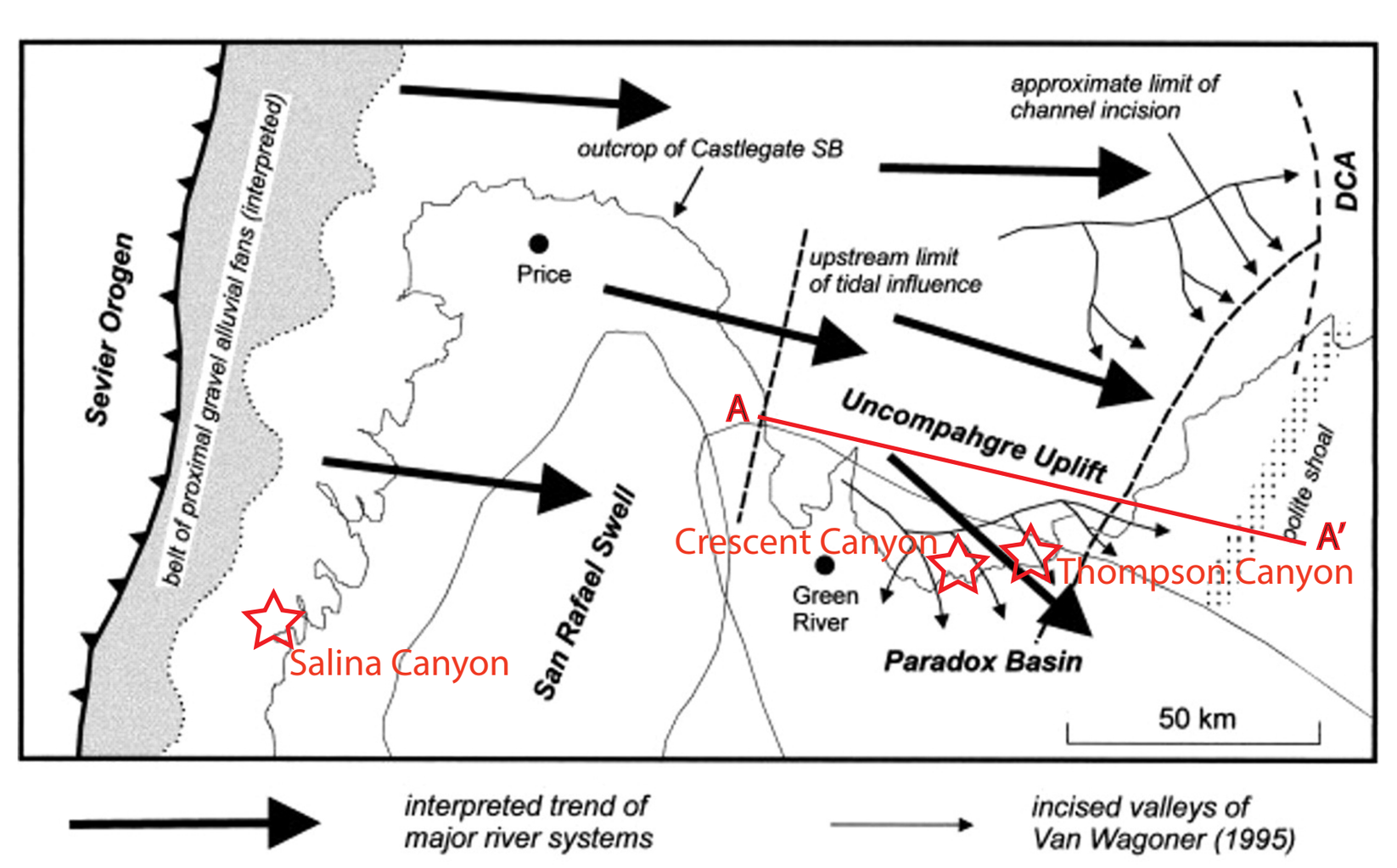


Figure 1:
Map showing river orientation of the Lower Castlegate Sandstone. Encatchment area and sediment supply from the Sevier Orogen to the West, and terminates in the Western Interior Seaway to the East. Modified from Miall & Arush, 2001

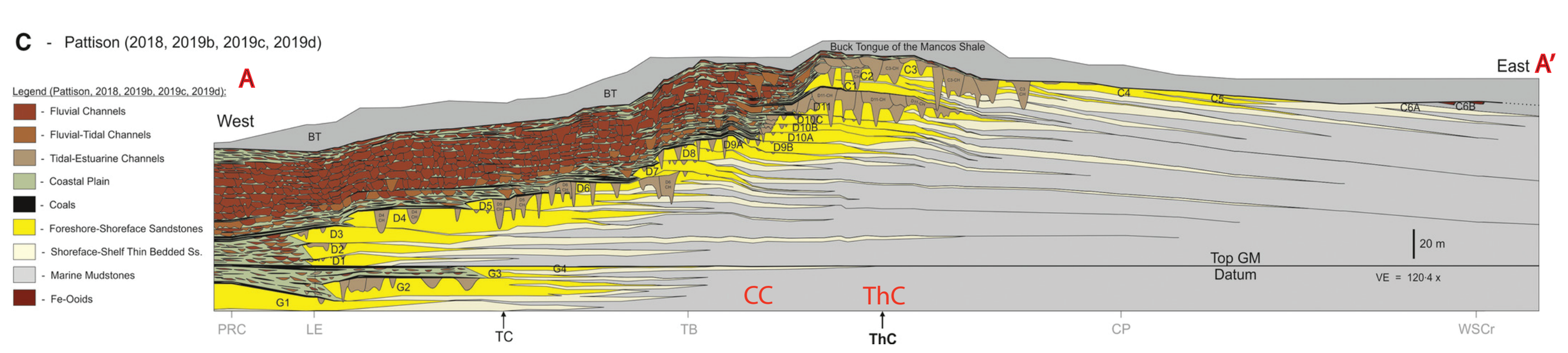


Figure 2: Longitudinal cross-section of the Desert Member and Lower Castlegate SS. Cross Section shown from A-A' in figure 1. Cross section follows cliff-line. Modified from Pattison, 2020.

Methods

• 8 Outcrops were studied and where available, strat columns were measured with the collection of lithology, thickness, sedimentary structures, grain size, sorting, and overall architecture.
• Many photographs of each outcrop have been collected, and then imported into Agisoft where they were converted into 3d models to be used for interpretation. These models were then transformed into orthomosaics to be used to draw figures and interpretations.
• Fluvial Architecture Analysis (Holbrook, 2001) has been used on the finalized orthomosaics. Fluvial strata are confined by bounding surfaces that have a hierarchical order, starting off with the bounding surfaces of individual sedimentary structures, and working up to bounding surfaces that contain single channels, multiple channels (valleys), bounding surfaces that may contain multiple valleys, and large-scale sequence boundaries that are traceable throughout the longitudinal extent of the unit. This will allow for the analysis of the fluvial style of the river, to what extent and how incision changed within the system, which can then be related back to autogenic and allogenic inputs.

Salina Canyon

Key

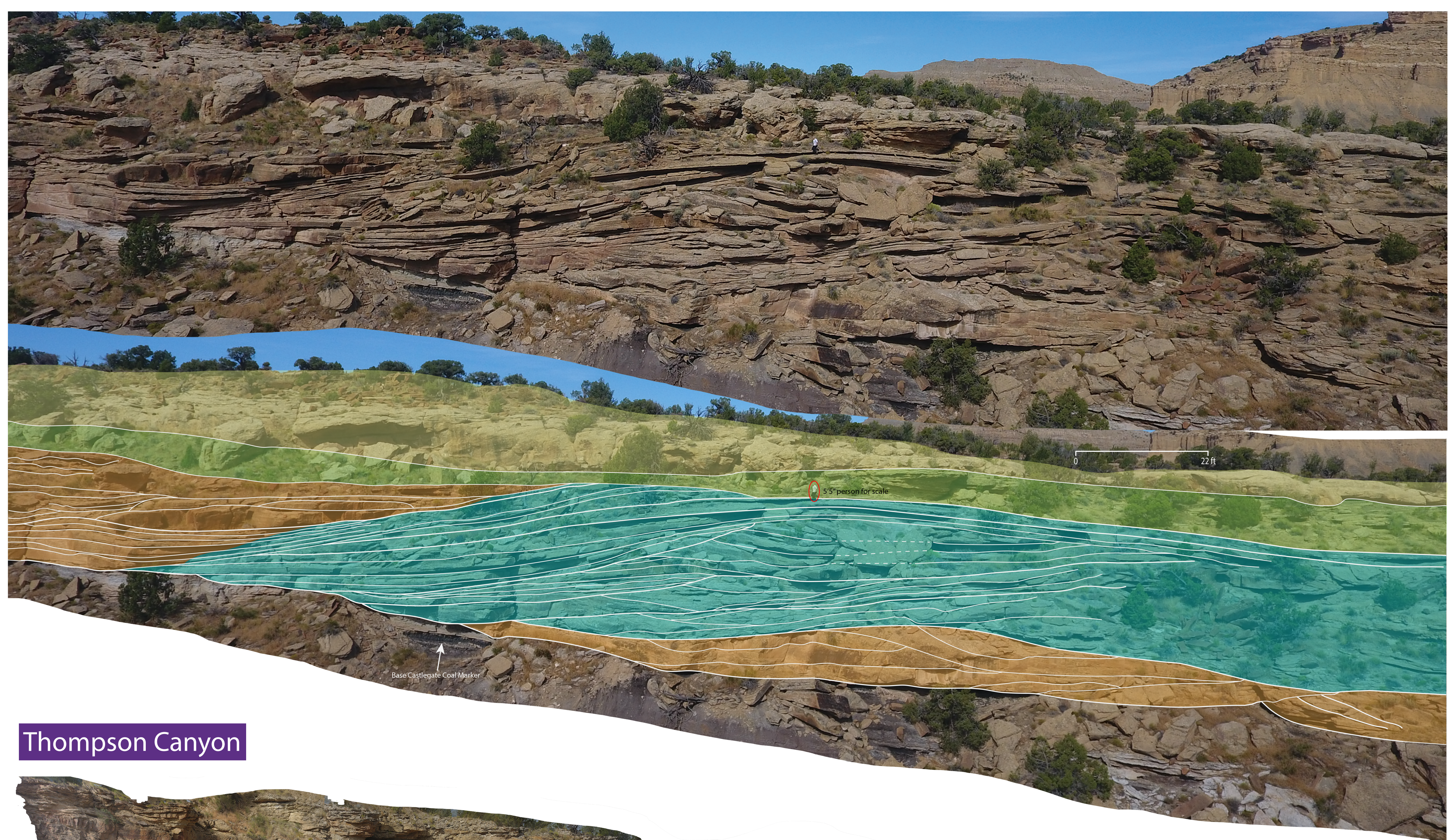
(yellow)	Amalgamated braided fluvial sands
(orange)	Heterolithic channel fill
(blue)	Heterolithic lateral accretion set
(green)	Undifferentiated backshore muds
(pink)	Heterolithic tidally-influenced distributary channels and muds

Flow decreases upwards
Single flow event

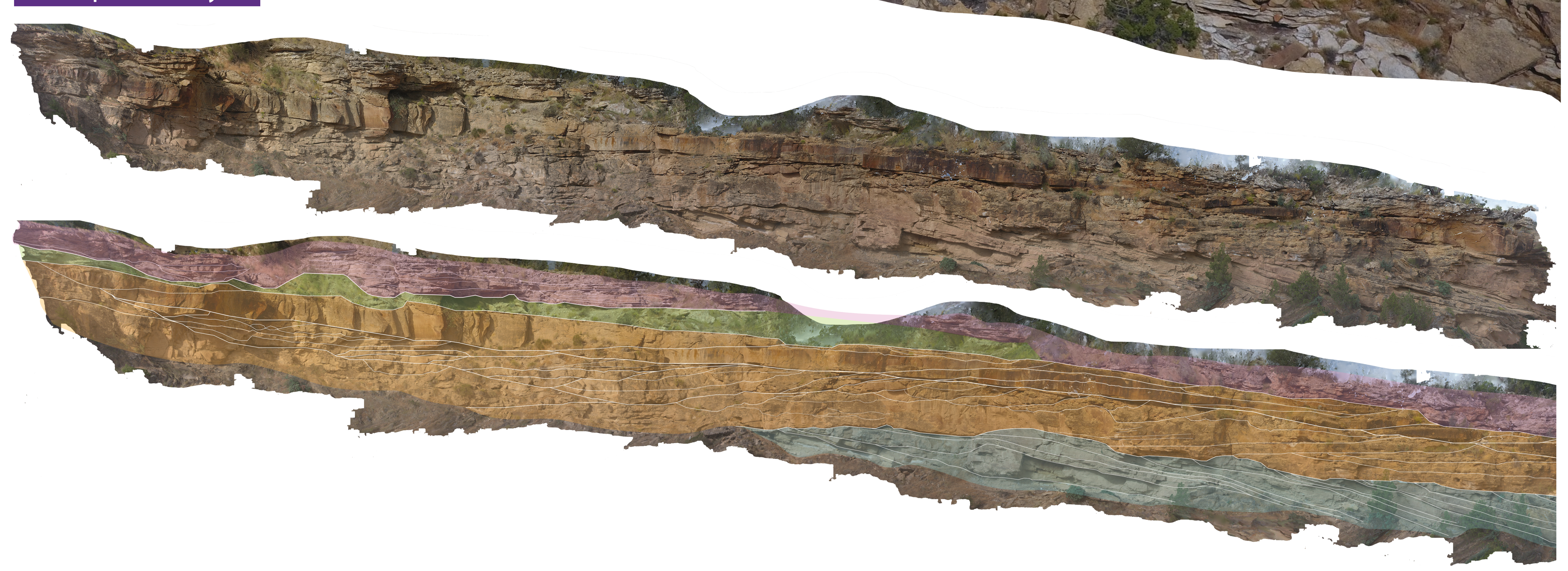
Proximal

Distal

Crescent Canyon



Thompson Canyon



Discussion/Interpretations:

Proximal: Proximal outcrops of the Castlegate Sandstone are composed of amalgamated braided sands with a typically sheety fluvial architecture with some localized valley-scale scour surfaces which are shallow and very wide, indicative of minimal incision. Salina Canyon, being the most proximal outcrop in this study, shows the largest grain-size and the highest flow regime of any outcrop. These sheet flows are representative of single flow events as seen in the close-up photo showing an upward-waning of flow regime

Distal: There is evidence of localized large-scale scour surfaces in the distal outcrops of the Castlegate, mostly comprised of large, single-story, straight-meandering trunk channels showing tidal influence. Locally two or more of these large incising channels can be seen with one single amalgamated scour, creating a small valley fill. These deposits tend to be heterolitic and most frequently overlye backshore mud and coal deposits or incise into upper shoreface deposits. There are also occurances of coal and carbonaceous muds nested within the Castlegate section beyond Green River, which may be representative of a flooding surface in the system. These interbedded muds and coals may also be interpreted as an avulsion of the underlying main trunk channel. This tidal indluence and Waltherian relationship with the surrounding marine/near-marine strata contradicts the work of Van Wagonner (1995), who stated that the Castlegate fluvial system was disconnected from the WIS to the East. This data implies that the Castlegate system was in fact tied to the marine strata downdip, and likely fed the underlying Desert Member shorefaces in the eastern portion of the Book Cliffs (Pattison, 2019), and was not a later system passing over the marine strata and thinning to the East as is implied in many other longitudinal cross-sections created of the Book Cliffs. This eastward thinning may also beconcluded to simply reflect the loss of much of the fluvial sands to the Desert Member shorelines that were fed by the system, leaving the most distal Castlegate deposits to be reflective of only the very capping units of the Castlegate in locations such as Thompson and Crescent Canyons. In Crescent and Thompson Canyons above the large-scale meandering channels and backshore coal deposits lies another unit of thinly-bedded highly amalgamated channel and bar deposits. This unit contains both mid-channel and side-attached bar forms, implying a braided system; These braided deposits are representative of an increase in distance from the shoreline when compared to the underlying trunk channels (Pattison, 2019). This is inidicative of an overall regression of the system, interpreted to be primarily driven by tectonic uplift driving increase in sediment supply, forcing the shoreline to auto-retreat.

There are many studies that determine there is a sequence boundary at the basal surface of the Castlegate which is traceable throughout the Book Cliffs (Fouch et al., 1983; Miall, 1993, 2014, 2016; Van Wagoner, 1995; Adams and Bhattacharya, 2005;, eg.) separating the Castlegate from the underlying marine strata. Other arguments state that there is not one continuous sequence boundary at the base of the Castlegate, but localized autogenic scour surface that are not linked (Pattison, 2018, 2019 a, b, c, d, 2020); This interpretation challenges the conventional sequence stratigraphic model, connecting the marine strata of the underlying Blackhawk Fm with the terrestrial deposits of the Castlegate spatially and temporally, but the dataset is thorough and difficult to negate and fits within the dataset of this study.

Conclusions

• The Castlegate system does in fact feed the marine shoreline strata in the Book Cliffs, concurrently resulting in the Eastward thinning of the Castlegate as the basal portions of the system have since transformed into marine deposits.
• Some Desert Member channels seen incising into the upper shoreface deposits of the (ex. Thompson Canyon) are genetically and temporally related to the Castlegate fluvial system.
• Large incising trunk channels are each representative of a very short time period (or very low levels of sinuosity/avulsion) within the Castlegate system, hence their localized nature
• Data supports the theory that there is no IVF within the Castlegate (Pattison, 2018, 2019, a,b,c,d, 2020). There are multiple sequences within the Castlegate system, but there is not one continuous basal scour bounding all sequences. Some sequences are completely removed in the more distal outcroppings of the Castlegate as they have reached and fed their paleoshorelines, leaving only the upper sequences.
• Apparent vertical stacking and increased bar thickness in the Lateral Accretion Complex seen in Crescent Canyon supports indicated some level of RSL fall or reduction in accomodation aiding the auto-retreat. This fits into data collected by Pattison (2020) relating the stratal architecture of the low ascending regressive shoreline deposits the later Castlegate parasequences showing evidence of allogenic sediment supply as well as autogenic base-level fall

Further Studies/Questions

- Palynology/Micropaleontological study of the coals and carbonaceous muds within the Castlegate and those separating the Castlegate and Desert Mbr
- Provenance study of the Castlegate fluvial deposits and the Desert Member shoreface deposits rectifying their genetic relationship
- Deltaic evidence from a Castlegate system that was pushing so much sand out into the shoreline? Or were they reworked by longshore currents in the WIS and plastered onto the paleo-shorelines?
- Better time restraints on Castlegate deposition considering new sequence stratigraphic model

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