Depositional Architecture of a Turbiditic Sandstone Complex, Lower Green River Formation, Uinta Basin, Utah

Matthew A. Jones[1], Joshua T. Sigler[1], Lucas J. Fidler[1], Tanner A. Posy[2], and Dusty L. Parker[2]

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[1]XCL Resources, LLC; (mjones@xclresources.com), (josh@xclresources.com), (luke@xclresources.com)
[2]Epoch Geoservices, LLC; (tannerp@epochgeoservices.com), (dustyp@epochgeoservices.com)

Abstract

The Green River Formation of Utah records multiple episodes of Eocene lacustrine deposition within the Uinta Basin. Numerous members of the Lower Green River formation (LGR) have been successfully exploited for oil production utilizing horizontal drilling and hydraulic fracturing techniques over the last decade. One such member is the informal Castle Peak member of the LGR. The Castle Peak member has been produced from over 50 laterals within the Uinta Basin with Estimated Ultimate Recoveries (EURs) from Castle Peak laterals ranging from 50,000 to 1,000,000 barrels of oil. The most prolific Castle Peak Laterals are located within the Central Basin subregion, where a series of sand-dominated turbidites, informally referred to as the Bar F sandstone, have been identified. Due to a relatively limited number of legacy wellbore penetrations and associated petrophysical logs within the Central Basin subregion, the lateral extent and aspect ratio of individual turbiditic beds and bedsets within the Bar F sandstone is relatively poorly understood. This study attempts to utilize well logs, cuttings, mass-spectrometry and geosteering profiles from a high-density development drilling pattern to resolve the depositional architecture of Castle Peak with a focus on the Bar F sandstone. To conduct this analysis, bedset-scale correlations were made across numerous clastic depositional bodies for every well drilled within a development cube to develop a series of high-resolution subsurface correlations throughout the Central Basin. To further confirm correlations, drill cuttings were analyzed to compare elemental concentrations across these numerous bodies with the intent of evaluating any changes in provenance. Additional evidence for compartmentalization was evaluated utilizing high-resolution mud gas ratios from vertical and lateral wellbores. This study distinguishes multiple lenticular, turbiditic complexes within the Bar F sandstone depositional fairway and proposes a generalized relationship between Bar F sandstone thickness and Castle Peak lateral productivity.

Keywords: Uinta Basin, Green River Formation, Castle Peak formation, turbidite, horizontal.

<u>Future Work:</u>

- Build HCA model with XRF
- Compare Bar-F thickness, mass spec and XRF ratios to production results

- Continue to build out bed sets based on new data acquired via development program
- Compare results to wells in other Zones within the Upper & Lower Castle Peak to determine best zone to drill?

Conclusions:

- Sand is there if you have least 20’ of Bar-F thickness
- Hyperpycnal Flow model is valid and is being implemented in Development planning
    - Long tabular clinoforms
- XRF shows similar sand and mudstone composition throughout basin despite variability in sands GR readings
    - West reads higher than East

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Abstract

Keywords: Uinta Basin, Green River Formation, Castle Peak formation, turbidite, horizontal, XRF, Mass-Spectrometry

The Green River Formation of Utah records multiple episodes of Eocene lacustrine deposition within the Uinta Basin. Numerous members of the Lower Green River formation (LGR) have been successfully exploited for oil production utilizing horizontal drilling and hydraulic fracturing techniques over the last decade. One such member is the informal Castle Peak member of the LGR. The Castle Peak member has been produced from over 50 laterals within the Uinta Basin with Estimated Ultimate Recoveries (EURs) from Castle Peak laterals ranging from 50,000 to 1,000,000 barrels of oil. The most prolific Castle Peak Laterals are located within the Central Basin subregion, where a series of sand-dominated turbidites, informally referred to as the Bar F sandstone, have been identified. Due to a relatively limited number of legacy wellbore penetrations and associated petrophysical logs within the Central Basin subregion, the lateral extent and aspect ratio of individual turbiditic beds and bedsets within the Bar F sandstone is relatively poorly understood. This study attempts to utilize well logs, cuttings, and geosteering profiles from a high-density development drilling pattern to resolve the depositional architecture of Castle Peak with a focus on the Bar F sandstone. To conduct this analysis, bedset-scale correlations were made across numerous clastic depositional bodies for every well drilled within a development cube to develop a series of high-resolution subsurface correlations throughout the Central Basin. To further confirm correlations, drill cuttings were analyzed to compare elemental concentrations across these numerous bodies with the intent of evaluating any changes in provenance. Additional evidence for compartmentalization was evaluated utilizing high-resolution mud gas ratios from vertical and lateral wellbores. This study distinguishes multiple lenticular, turbiditic complexes within the Bar F sandstone depositional fairway and proposes a generalized relationship between Bar F sandstone thickness and Castle Peak lateral productivity.

A very big thank you to the following:

Acknowledgements

- The XCL Team
- EPOCH
- Impac
- Prior Researchers
- My Wife CJ
- The Oil-Patch
- Go Pokes!

(https://imgflip.com/i/3karij)

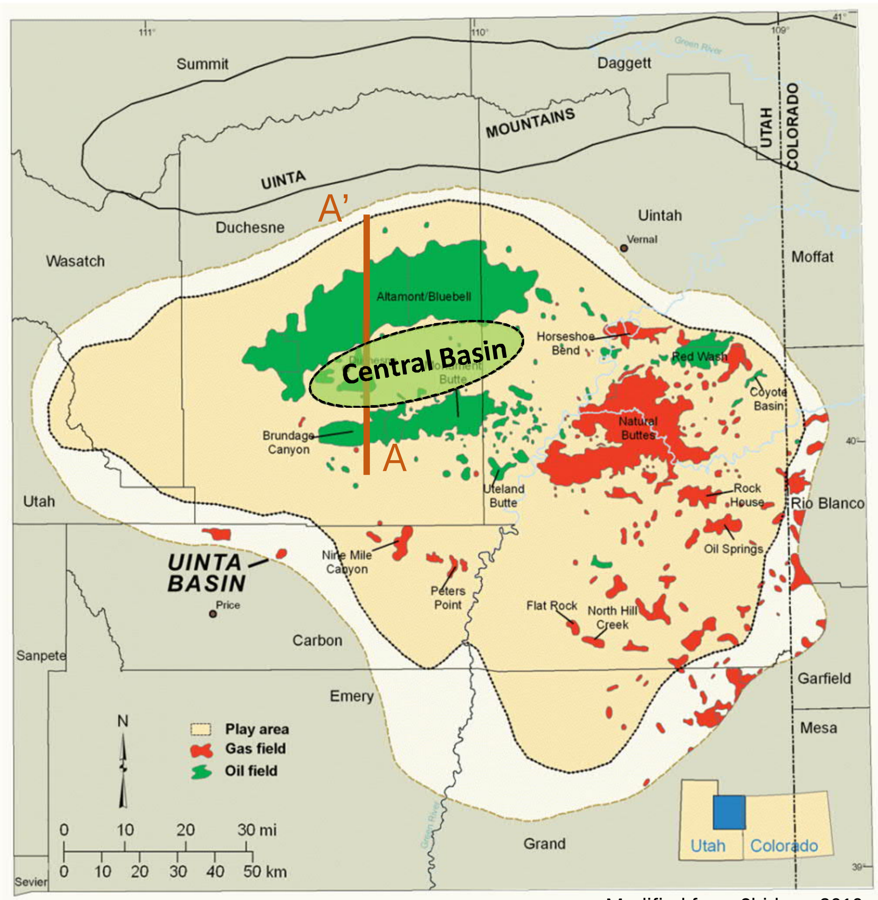
AGENDA

Presentation Overview

- Acknowledgements
- Uinta Basin Overview
- Lower Green River Depositional Setting
- Castle Peak Depositional System aka the 'Bar-F'
- Bar F Stratigraphic Architecture
- XCL Development Activity & Data Acquisition
- Detailed Bar F Interpretation
- Integration of well-site data
- Implications for Future Work

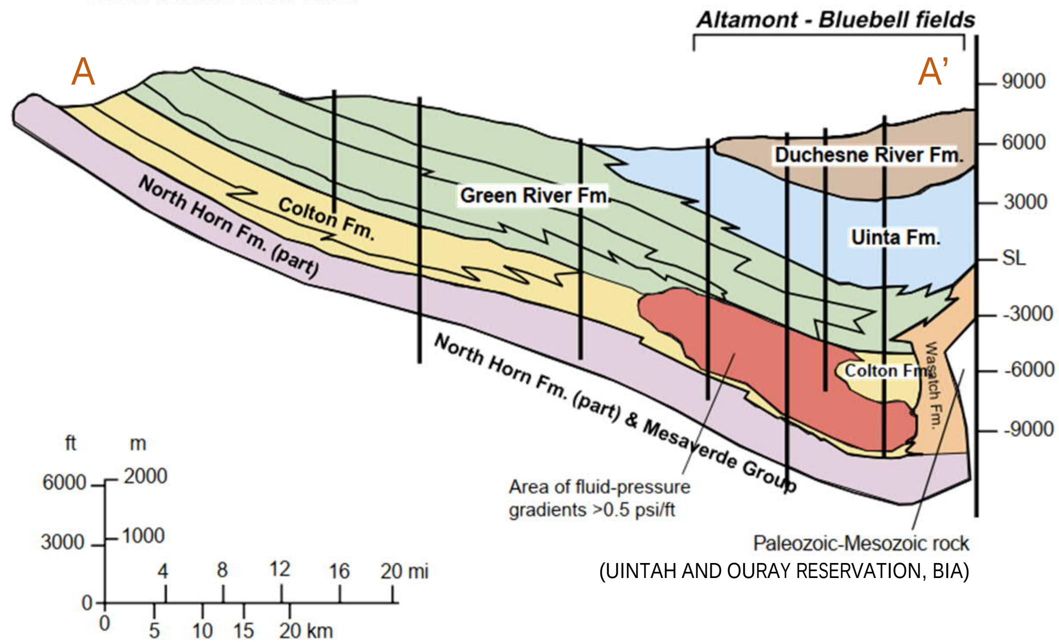
Uinta Basin Overview

Green River Fm - World Class Source Rock



Modified from Chidsey, 2010

- Uinta Basin oil production at Altamont/Bluebell since 1970's and Monument Butte since 1980's
- Vertical production from Eocene Green River/Colton (Wasatch)/Flagstaff formations
- Lacustrine Green River Formation deposited into Lake Uinta directly south of Uinta Mountains
- Asymmetric basin configuration resulted in deepest lacustrine deposits stacking up in North Central Uinta Basin



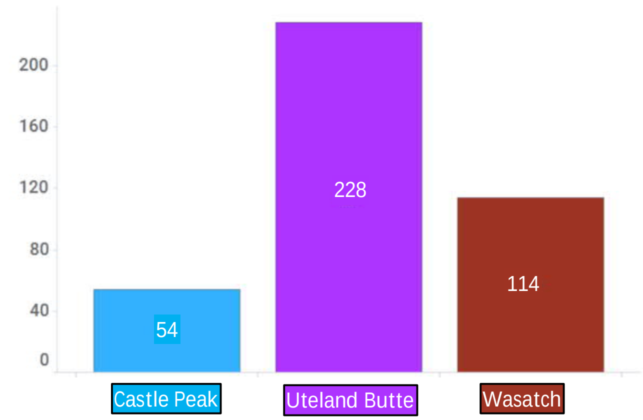
(UINTAH AND OURAY RESERVATION, BIA)

Uinta Basin Horizontal Production

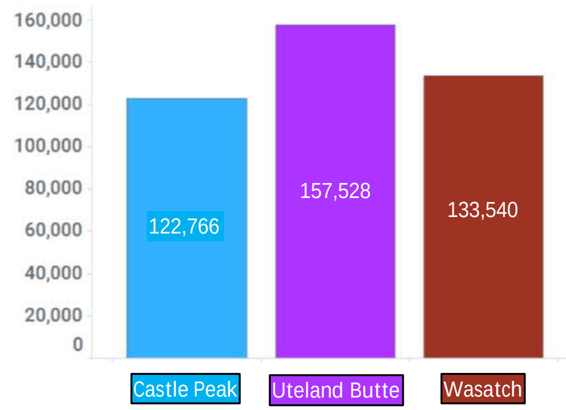
It's Not Just the Uteland Butte

- Stable Eocene lacustrine system results in multiple stacked horizontal development benches
- ~75 MMBO produced from horizontal wells from Green River petroleum system since 2012
- Horizontal development focused on the Uteland Butte with secondary Wasatch production
- Don't sleep on the Castle Peak!

Horizontal Well Count

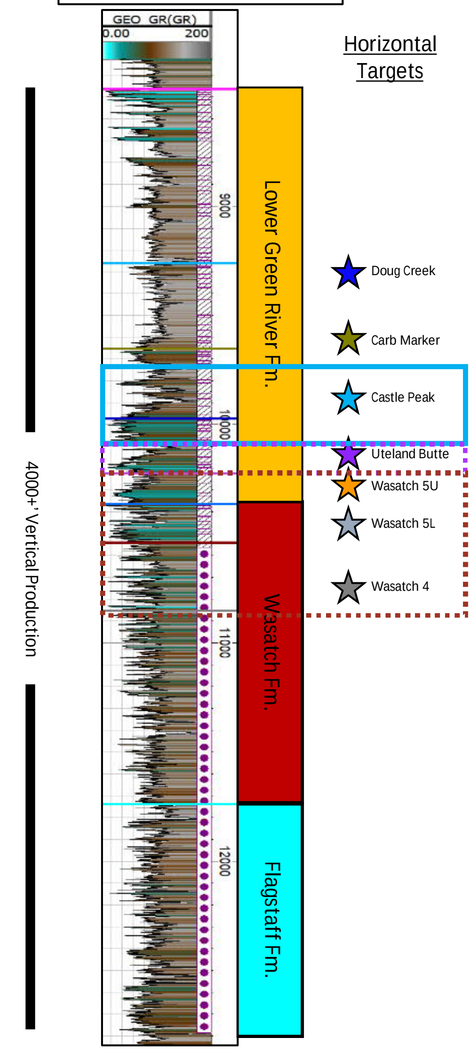


One Year Cum Production*



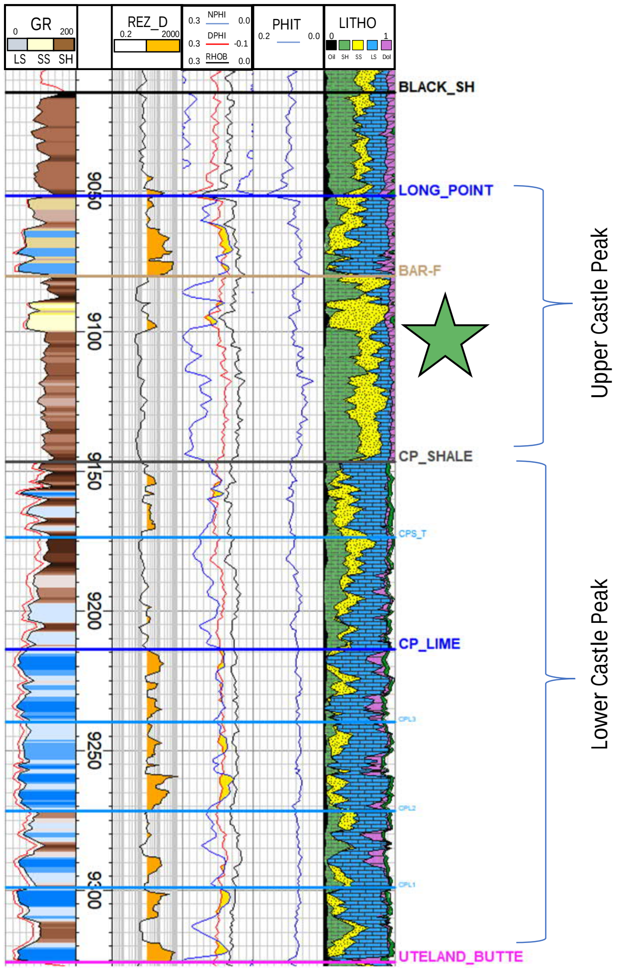
*Data Filtered to Horizontal Completions since 2018

Uinta Basin Type Log

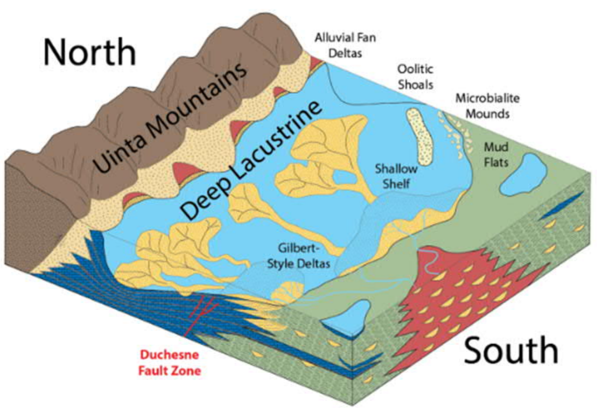


Upper Castle Peak Geology

Sand deposits in a Carbonate World



- Deep basinal expression of Upper Castle Peak unit as described by Brinkerhoff and Woolf (2018):
  - Dense fossiliferous limestone – Long Point member
  - Series of fine-grained sandstones interbedded with silt and mud – Bar-F member
- Bar-F underlain by calcerous mudstones and limestones of the Castle Peak shale and Castle Peak Lime (Lower Castle Peak unit)
- Consistent with observations across XCL Acreage in deep basin
- Bar-F is unusual in the Lower Green River
- Clastic system in stark contrast to the carbonate-dominated systems that surround it
- This fundamental depositional shift is interpreted to be the result of shifting hyperthermal climate patterns preceding the Early Eocene Climatic Optimum (Birgenheier et al., 2019)
- Brinkerhoff and Woolf (2018) proposed linked clastic depositional systems for the Upper Castle Peak unit:
  - Fluvial-deltaic deposition near the lake margin (Monument Butte)
  - Distributary hyperpycnal flows across the deep lake basin (Central Basin)

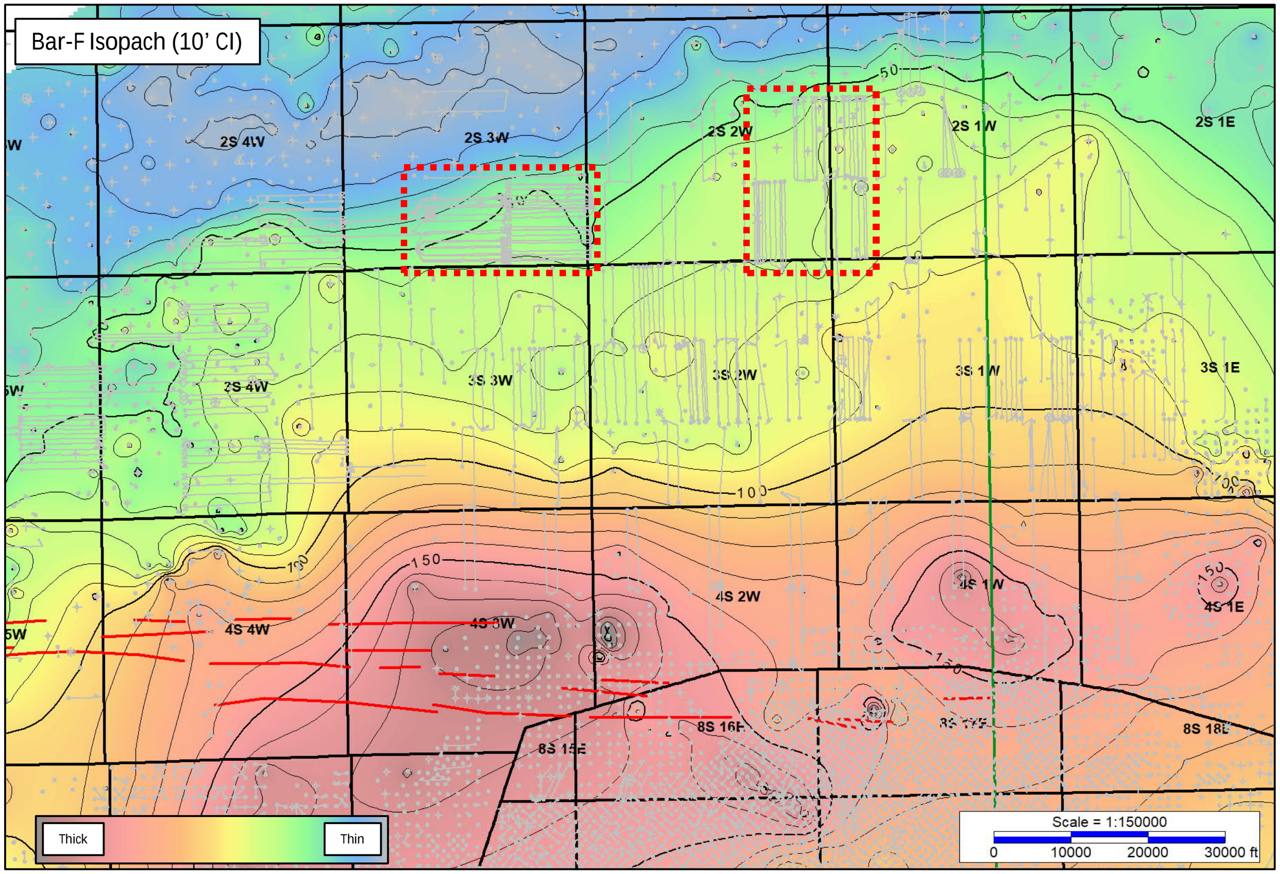


Brinkerhoff and Woolf, 2018

Data Density Drives Discovery

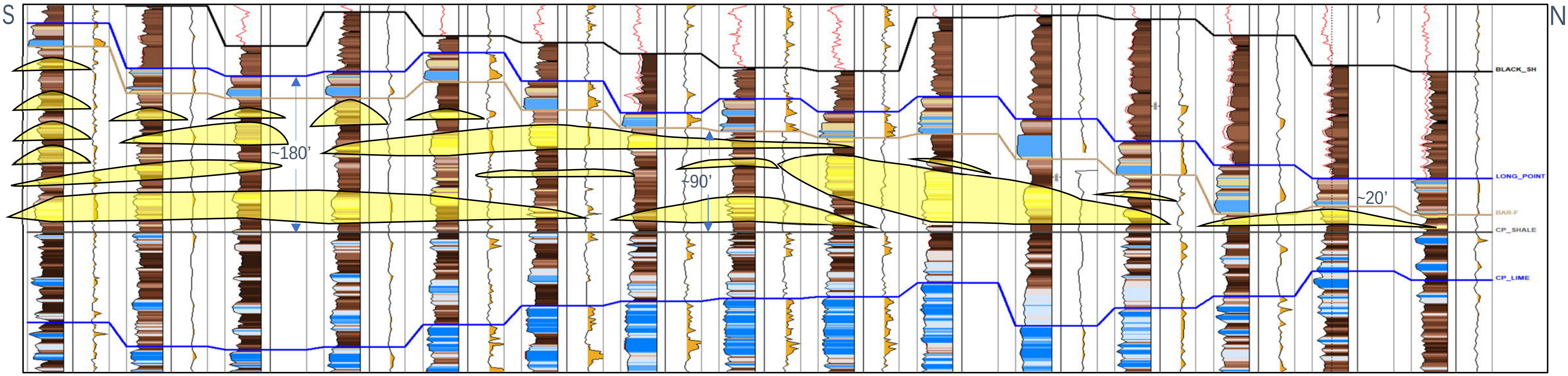
More wells makes better maps

- 3 years of delineation and development drilling gives XCL Resources an unparalleled look at Upper Castle Peak deposition
- 2020 Pilot Hole with Core combined with multiple cube development runs provides resolution at multiple scales
- Stratigraphic detail presented from bed scale to 2-mile x 4-mile detailed correlations to regional depositional patterns

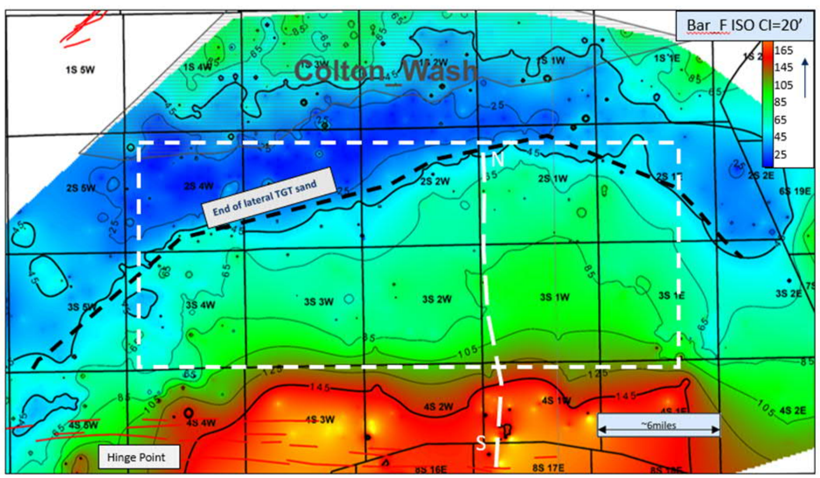


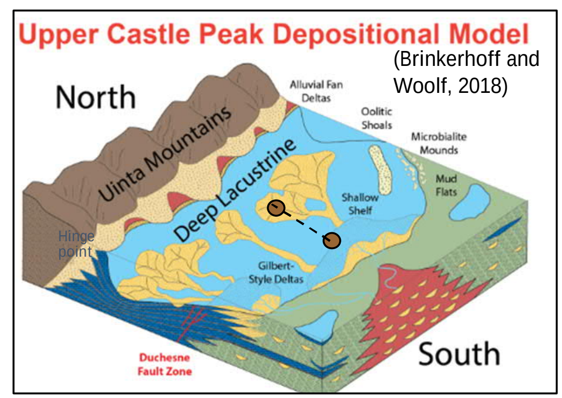
Upper Castle Peak Deposition

From hinge to point to northern edge



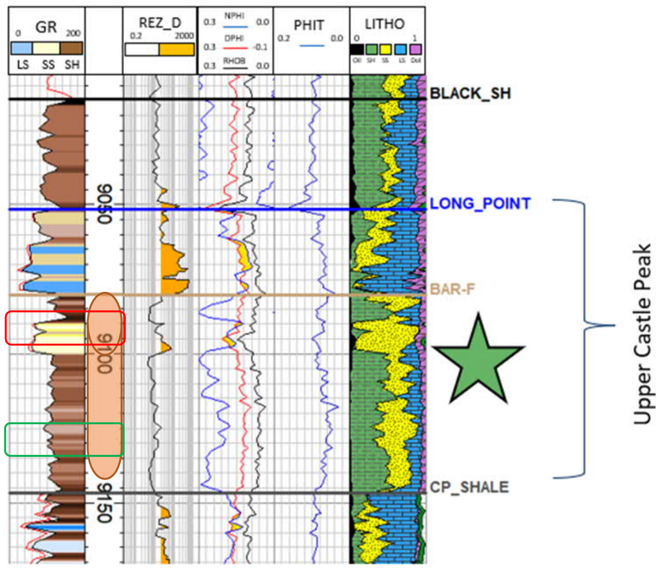
- From south to north the Bar-F diminishes
- Sand is sourced from the south
  - Evidence of sand moving east to west???
- Highly variable fining upward sand packages are observed

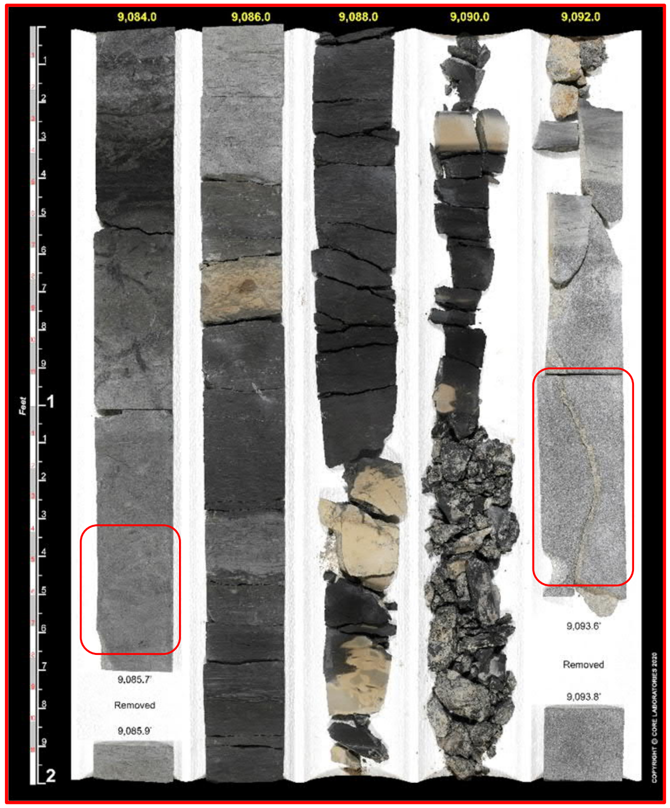


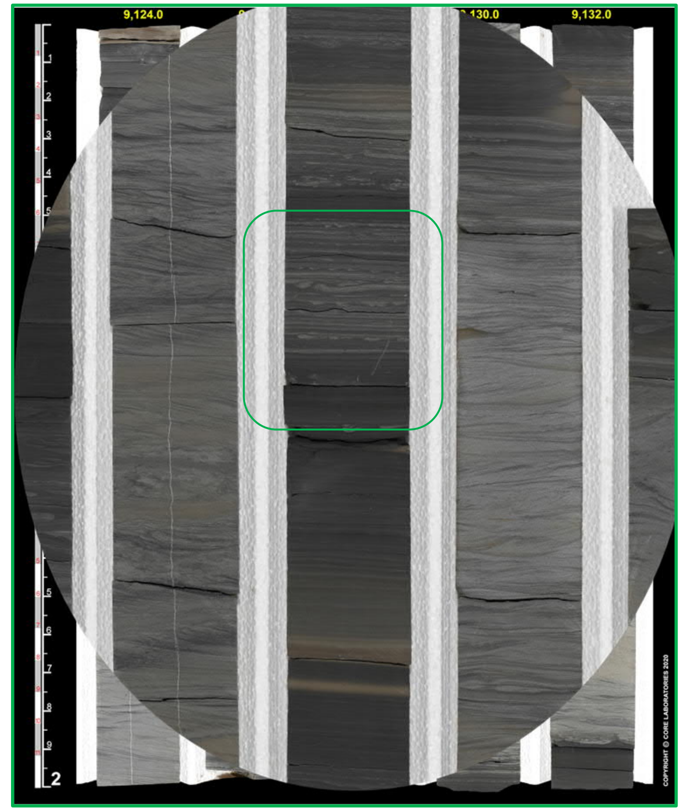


Bar_F Sedimentology

Example of hyperpycnal flow from core





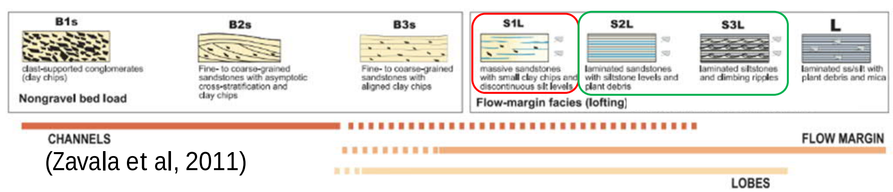


Upper Castle Peak Core Lithology:

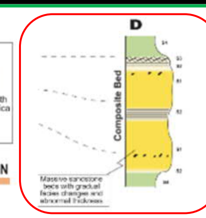
Long Point (LP): Ostracod lime mudstone to wackestone, medium gray, fossiliferous, argillaceous limestone, and minor dark gray, highly calcareous, silty shale.

Bar-F: Greenish gray, laminated to bioturbated, non-calcareous to slightly calcareous, organic-lean, silty shale and light gray.

Castle Peak Shale (CPS): Dark gray, calcareous, silty shale; minor greenish gray to variegated, organic-lean, silty shale; minor medium gray, fossiliferous limestone (lime mudstone, wackestone, and packstone)



(Zavala et al, 2011)



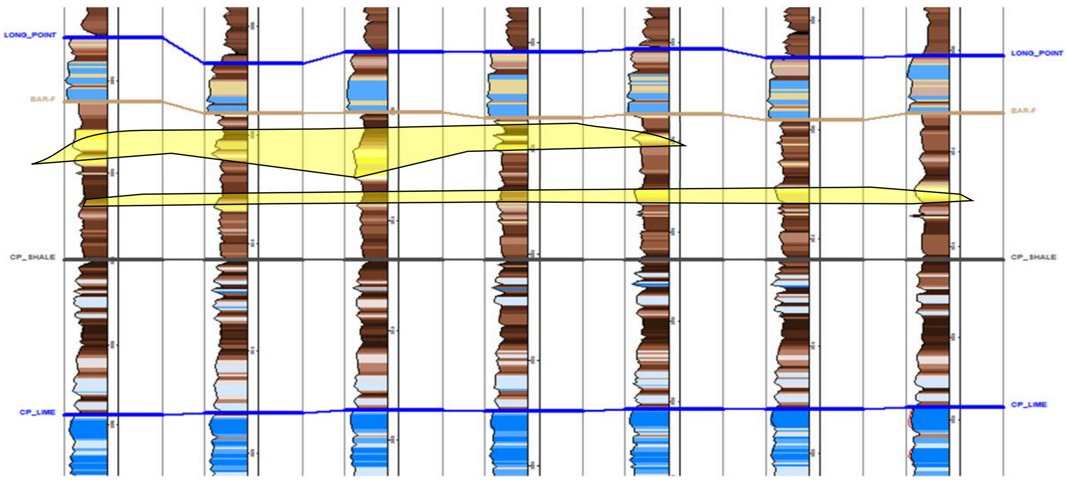
Lobe Architecture

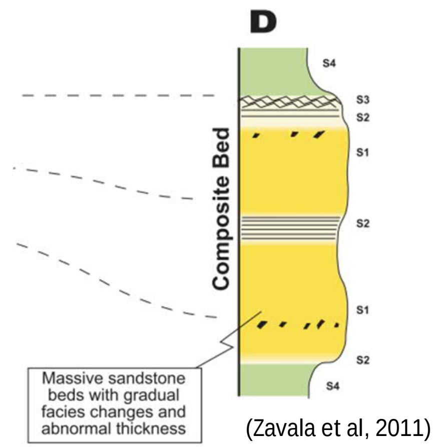
Strike Section

A

Bar-F Deposition

A’





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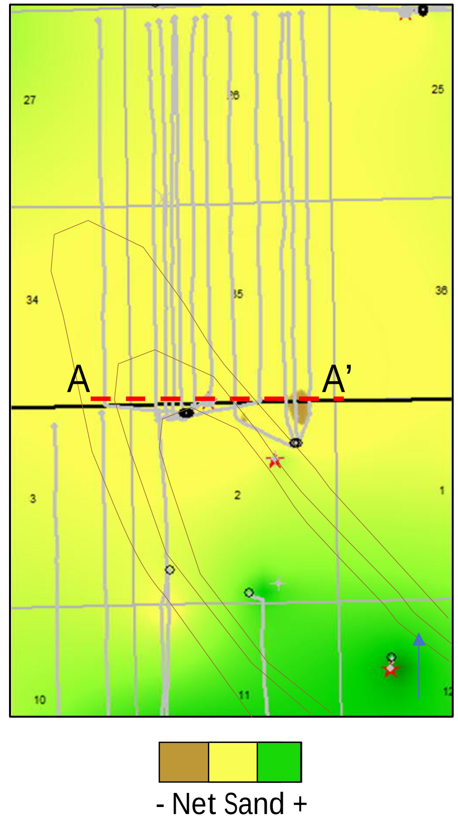
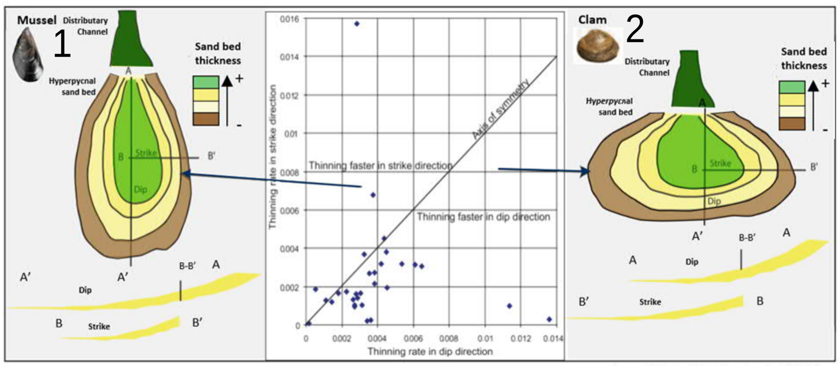


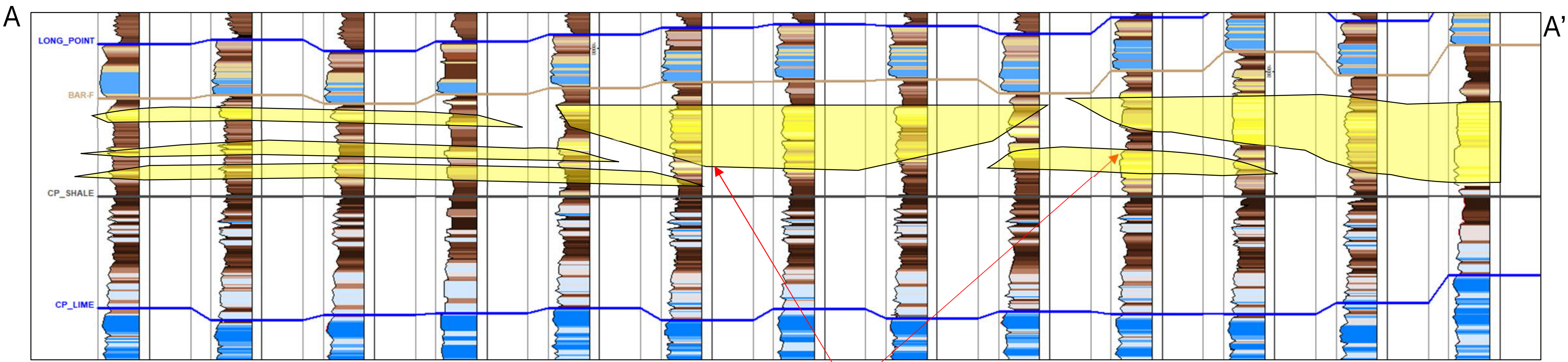
1. Lower angle and higher discharge rate
   - Thinning faster in strike direction
   - Composite sand sheets
2. Supported by steeper dips and less confinement
   - Composite sand sheets

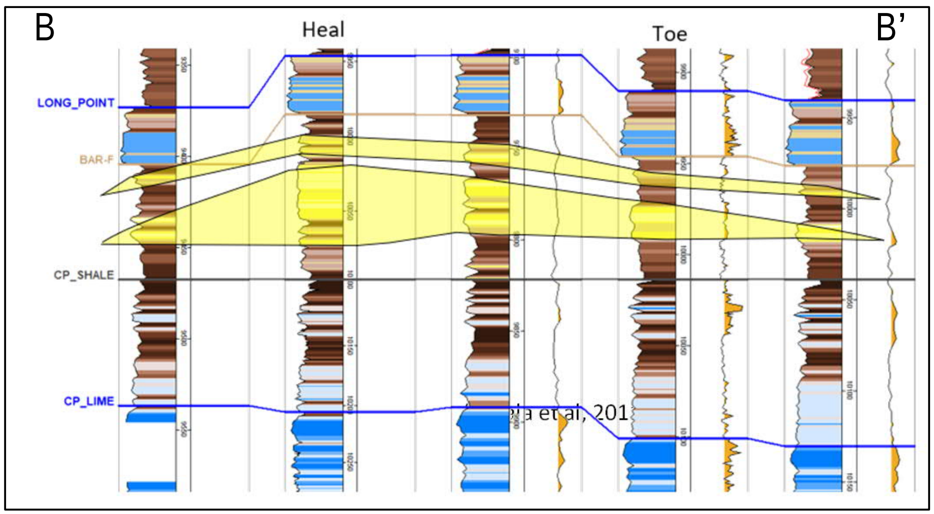


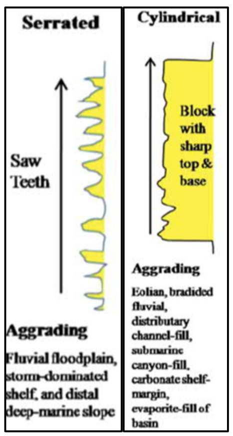
(modified, Olariu et al, 2010)

Bar-F Channel Architecture

Strike and Dip

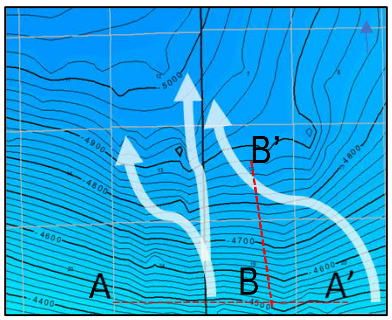






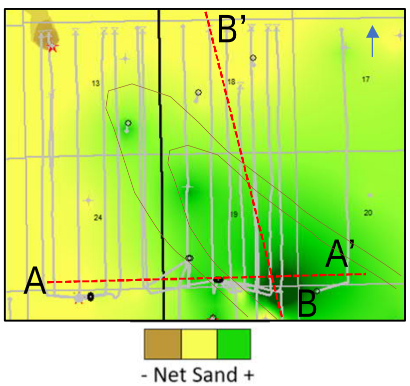
(Emery, D. and K. J. Myers. 1996)

Castle Peak STRX 20'



- Sand wants to accumulate in areas of deep relief

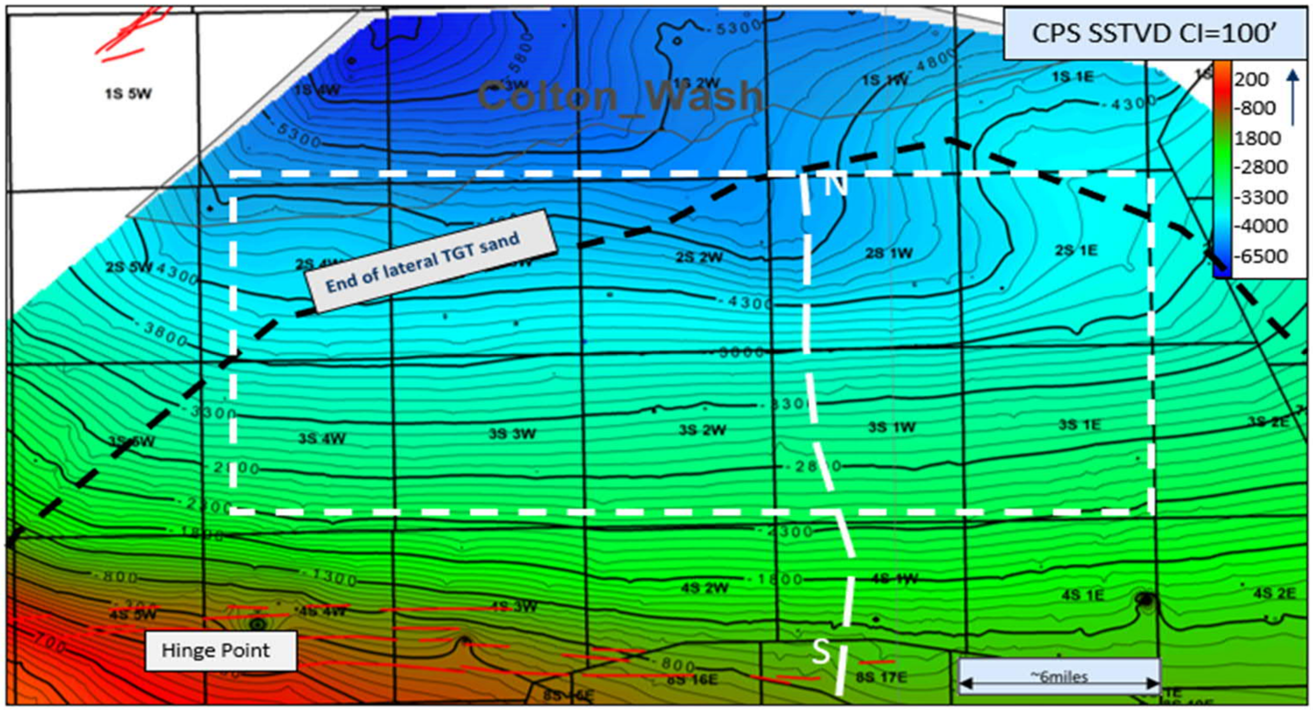
N2G Sand



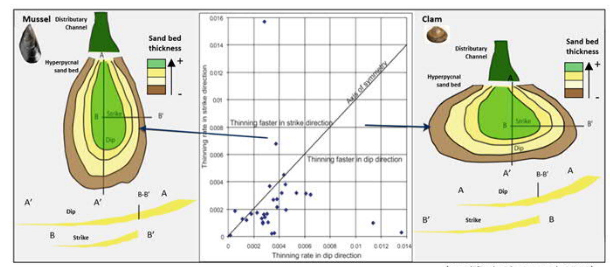
- Confined lobe

Bar-F System Map and Lobe Architecture

Where is the sand…



- Structure, Dip, Isopach
- Sand Deposition
- Does sand move east to west?
- Flows are extended in dip direction versus strike direction
  - Beds dip to north @ ~3°
  - Evidence for fluvial dominated delta lobes



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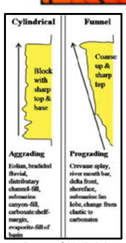

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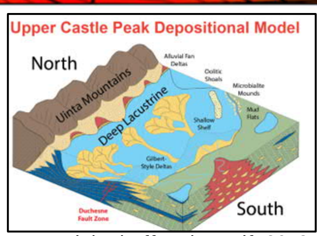

Brinkerhoff and Woolf, 2018


Lower angle and higher discharge rate


Supported by steeper dips and less confinement

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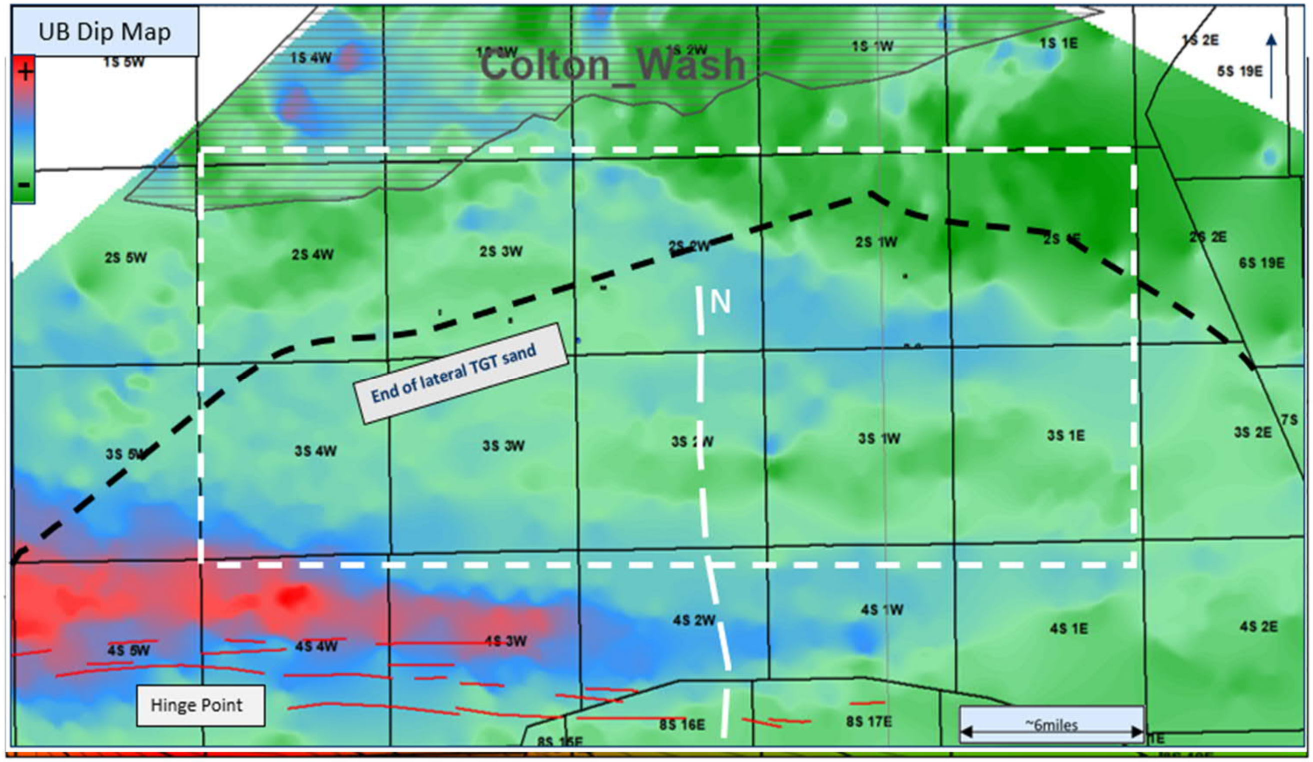

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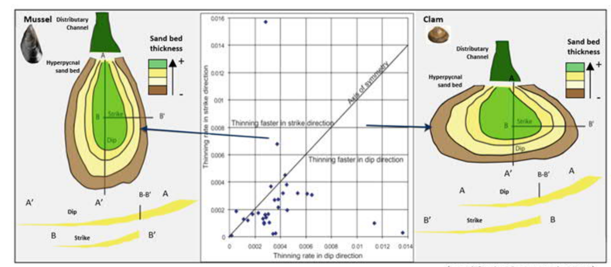

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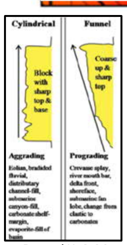

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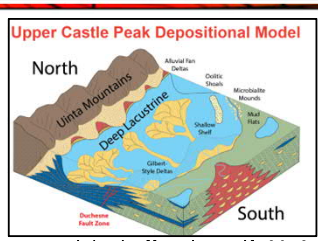

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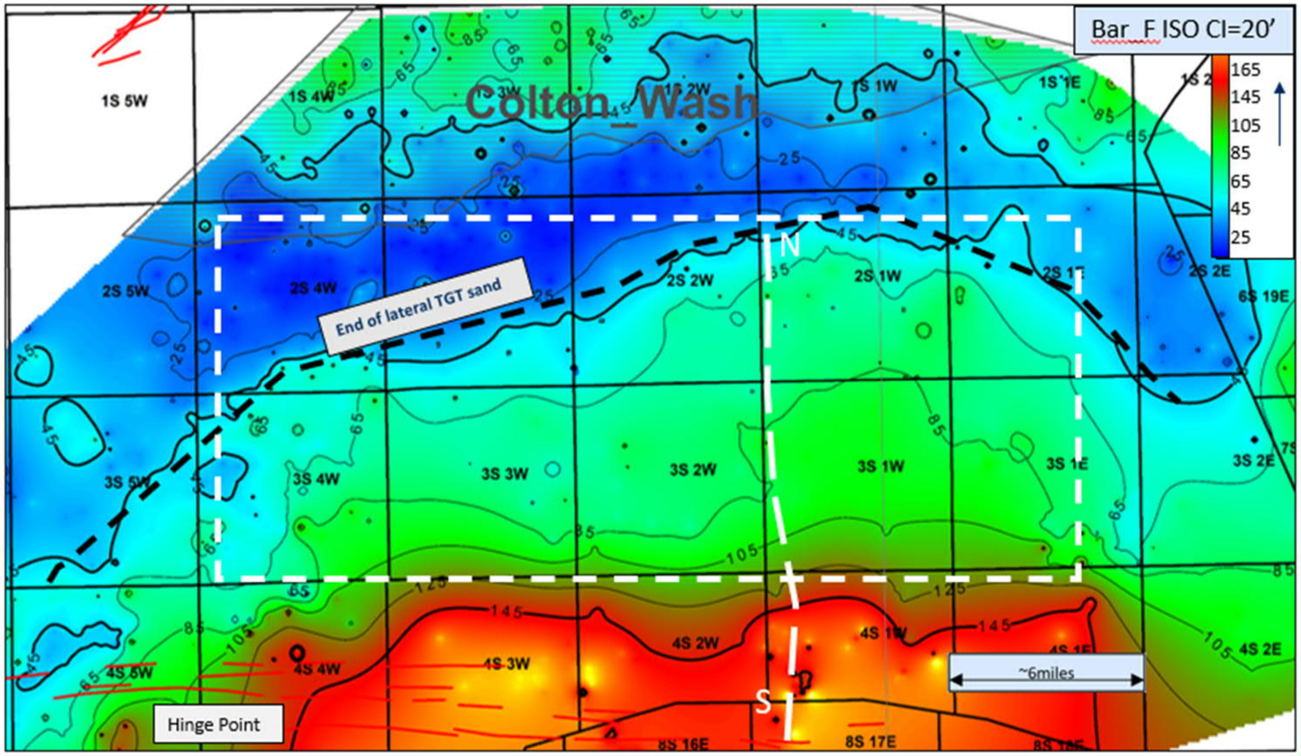

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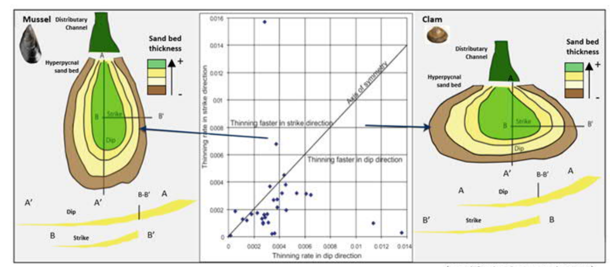

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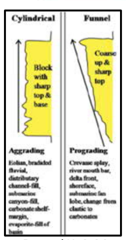

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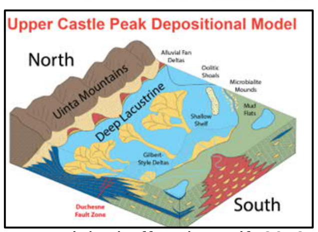

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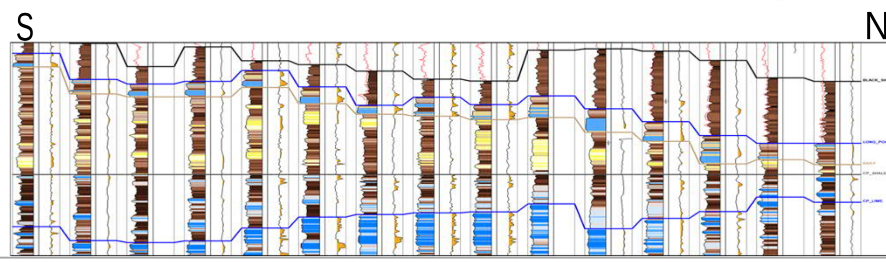

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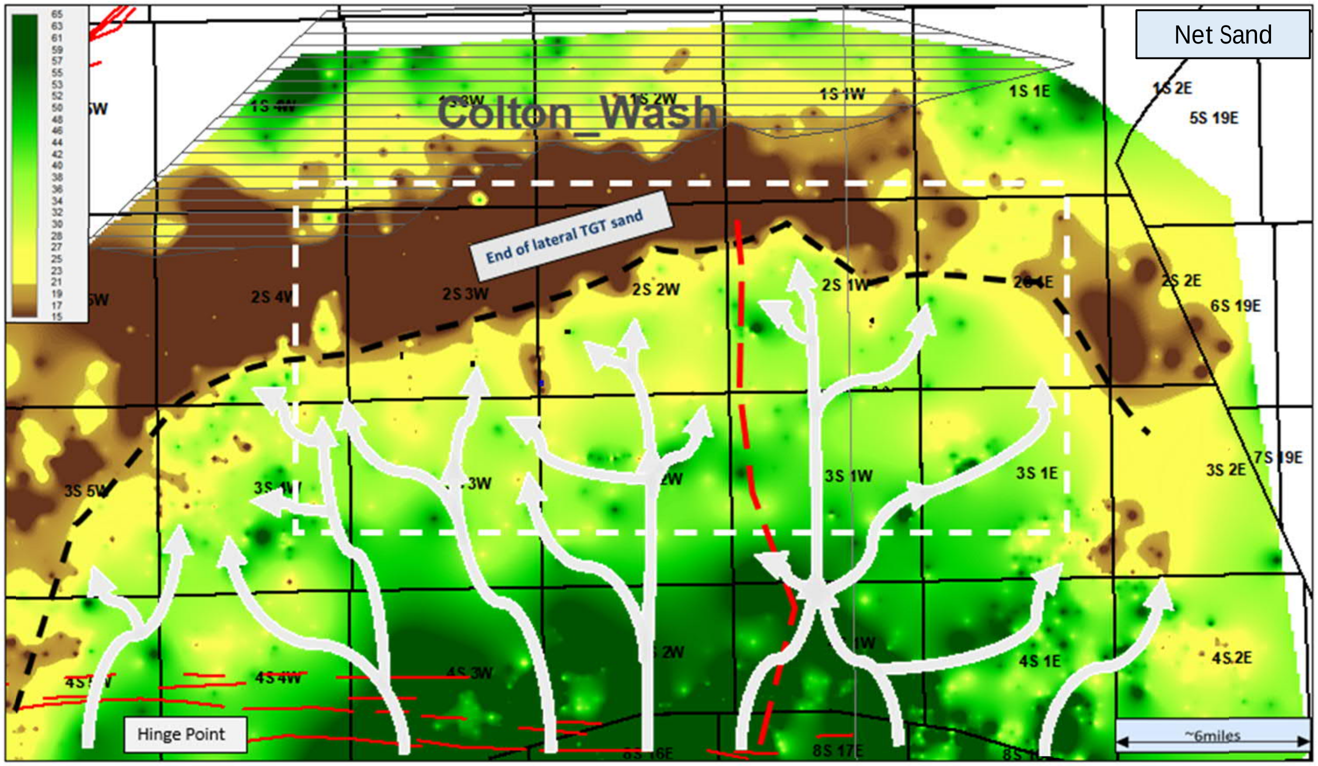

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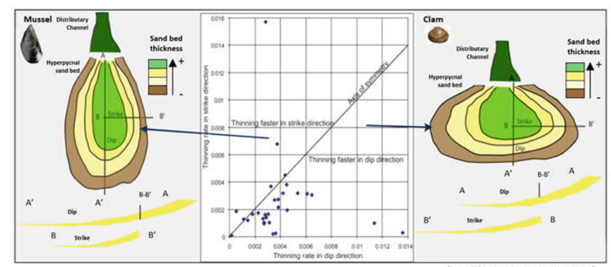

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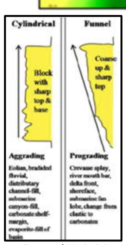

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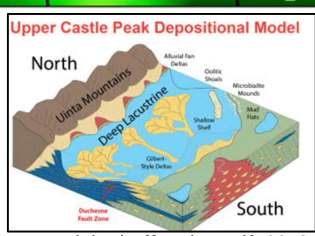
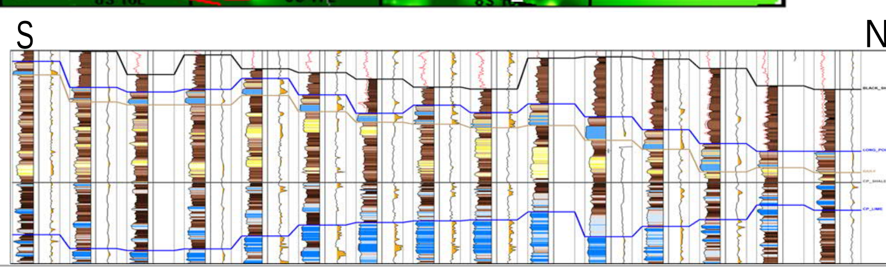


Brinkerhoff and Woolf, 2018

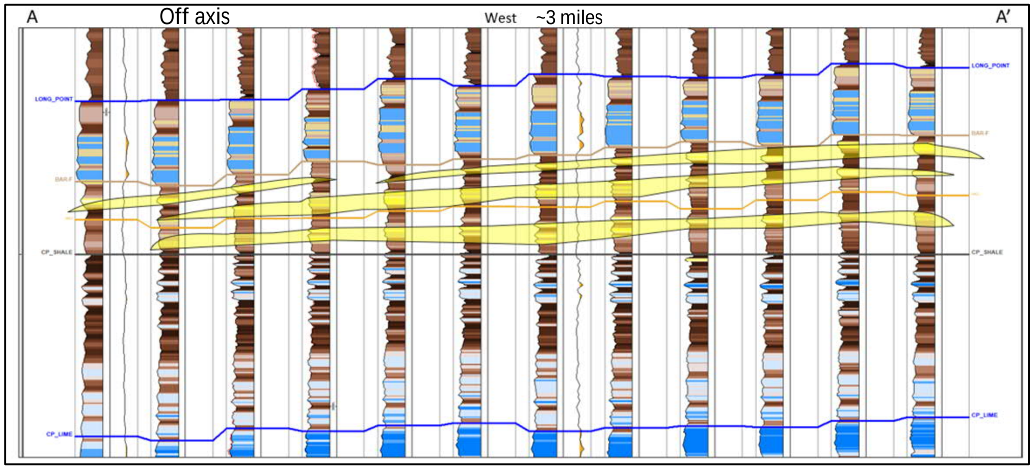


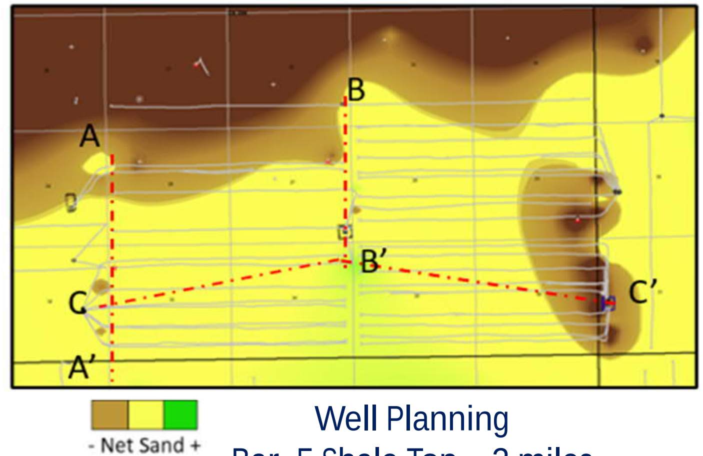
Lower angle and higher discharge rate

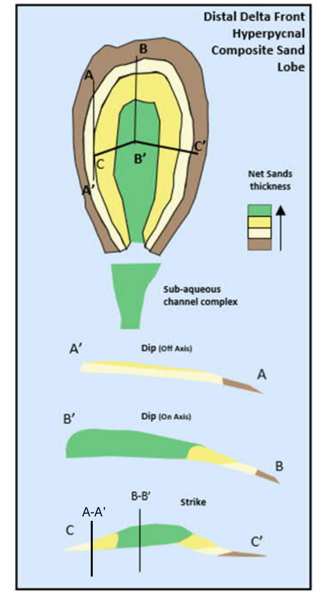
Supported by steeper dips and less confinement

Bar-F Lobe Architecture

Strike and Dip→ Connecting the dots



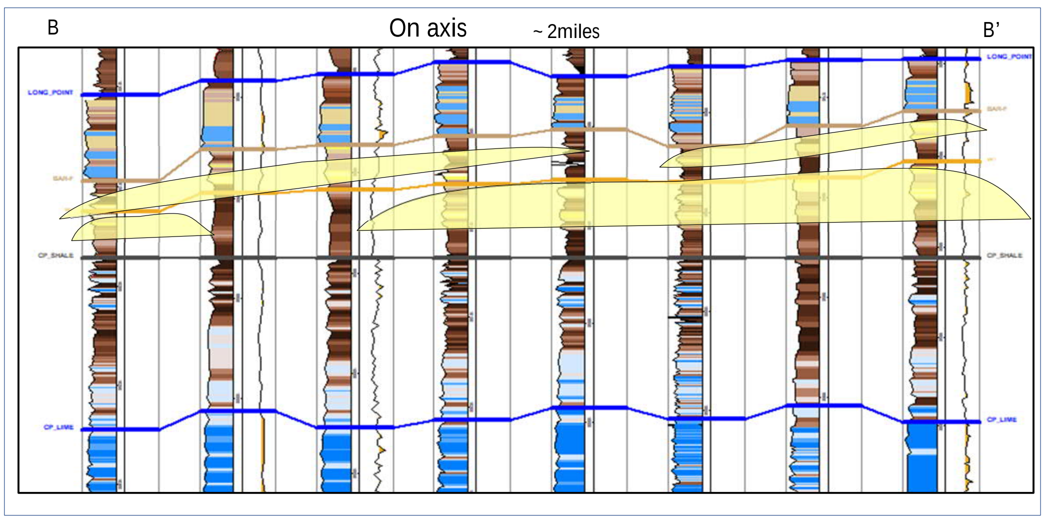


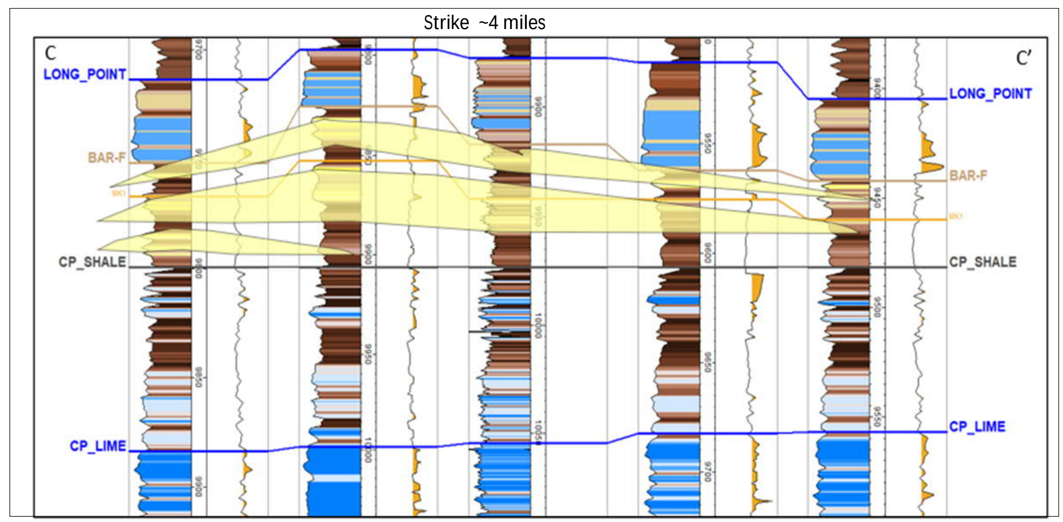


Well Planning

Bar_F Shale Top ~ 2 miles

- On Strike- dips range of +/- 0.2 to 0.5°
- On Dip- dips range of +/- 2° to 5°





Geo-steering in Bar-F Sands

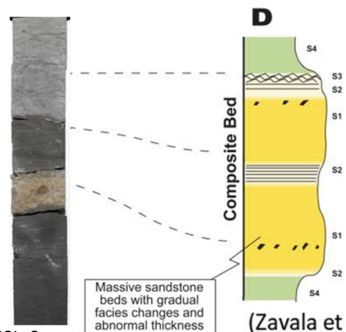
Navigating turbiditic/hyperpycnal flows along dip

Thinning rapidly along strike and dip

Proactive steering with in-depth mapping

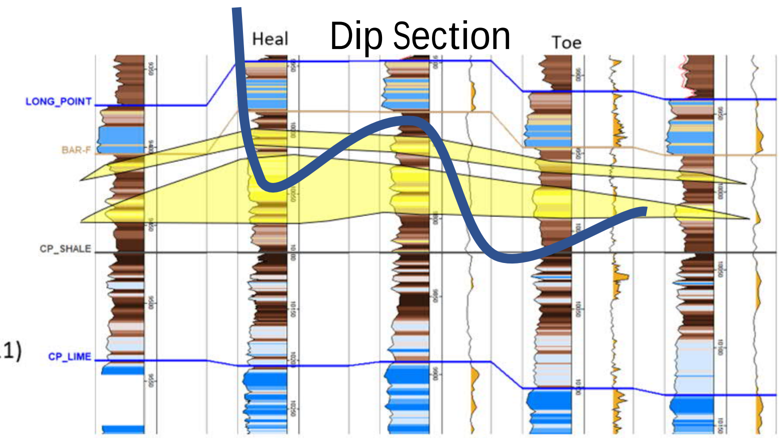
Quality markers helped anchor geo-steering interp

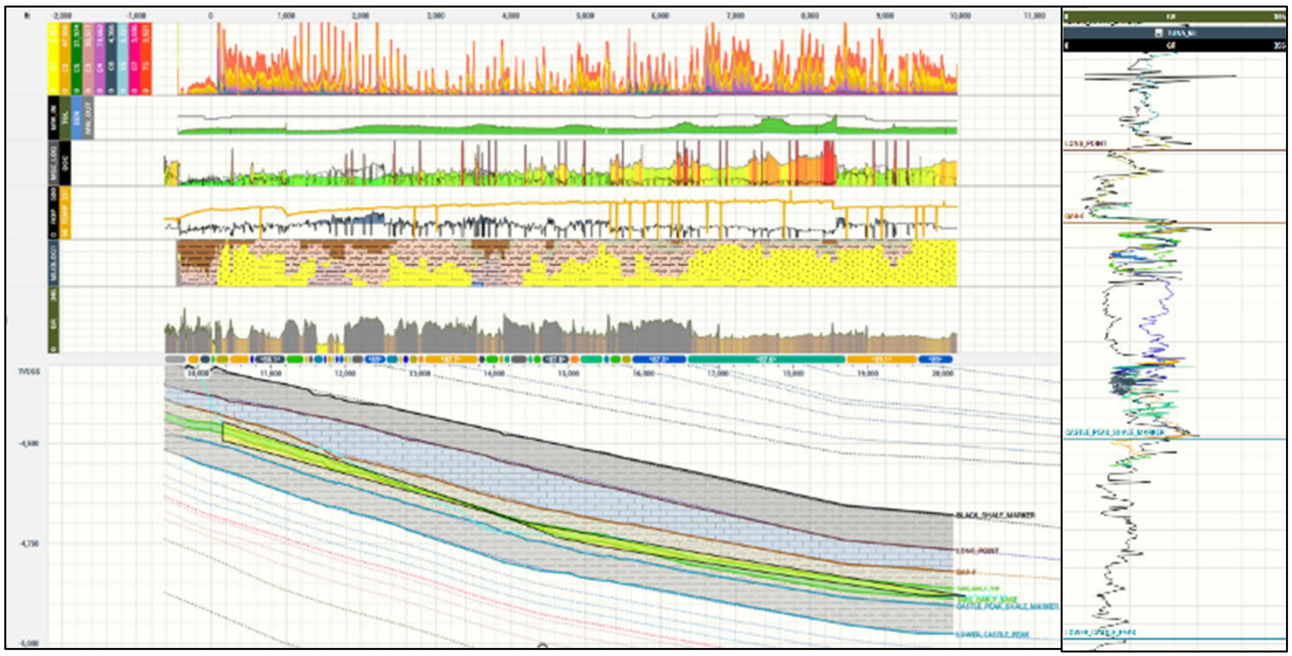
- Thinning is based on control points

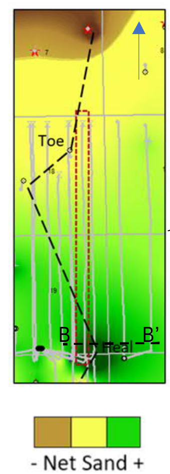


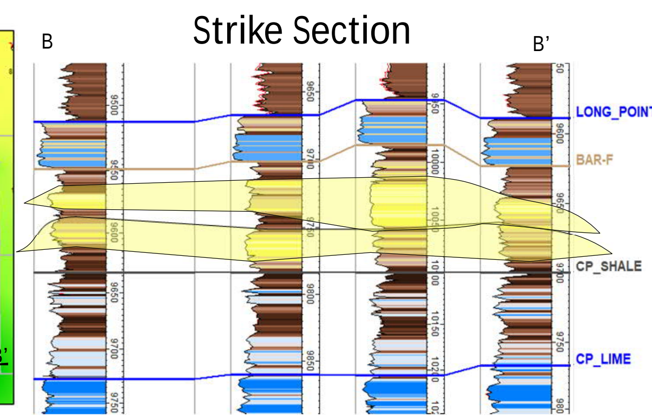
XCL Core

(Zavala et al, 2011)





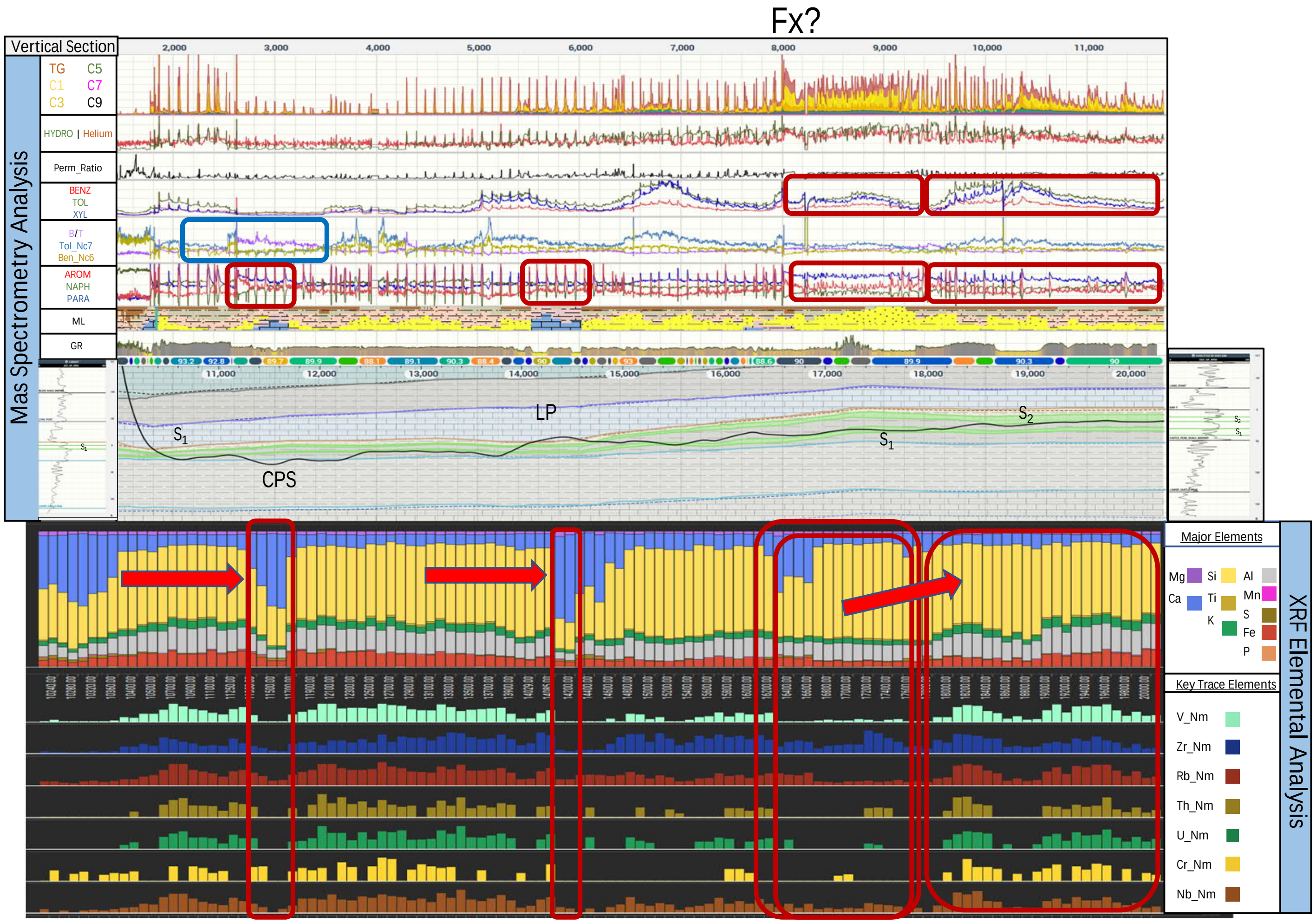




- Composite sand beds, evidence??

Using XRF to fine-tune in geo-steering

Navigating turbiditic/hyperpycnal flows along strike



- Major elements Si and Ca content help tell us when we are in predominately sand
- Minor/Prod/Redox proxies indicate detrital material organic richness
- Mass Spec helps define gas compartments and potential higher SW zones

Future Work & Conclusions

Future Work:

- Build HCA model with XRF
- Compare Bar-F thickness, mass spec and XRF ratios to production results
- Continue to build out bed sets based on new data acquired via development program
- Compare results to wells in other Zones within the Upper & Lower Castle Peak to determine best zone to drill?

Conclusions:

- Sand is there if you have least 20’ of Bar-F thickness
- Hyperpycnal Flow model is valid and is being implemented in Development planning
  - Long tabular clinoforms
- XRF shows similar sand and mudstone composition throughout basin despite variability in sands GR readings
  - West reads higher than East

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