Characteristics of Sandy Hyperpycnite Deposits on the Shallow, Southern Margin of Eocene Lake Uinta, the Green River Formation of Northeastern Utah*

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Abstract

Gravity flows play an important role in distributing clastic sediments into lacustrine basins at the front of fluvial-deltaic systems due to the tendency of sediment-laden rivers to plunge along the bottoms of lower-density lake waters. Fluvial derived underflows can be relatively long lived, perhaps on the scale of weeks, and distribute substantial volumes of sand far into the profundal zone of lacustrine systems that are otherwise characterized by chemical sediments and clay and silt sized clastics. This paper examines the properties of these sandy hyperpycnites in the Eocene Lake Uinta (Green River Formation) of the Uinta Basin in Northeastern Utah using outcrop, core, and wellbore data. These deposits are of particular interest due to the developing tight oil play which exploits them using horizontal wellbores. Facies typical of gravity flows display recurring sedimentary structures that represent different flow conditions. A typical bed consists of well sorted, fine and very fine grained sandstone with a flat base that may include clay chips (rip-ups) within massive or low angle cross beds, with planar beds often overlying them. These are overlain by thick beds of climbing ripples with individual ripple trains reaching over two feet in thickness. Climbing ripples are a consistent characteristic of these deposits, occurring even when other sedimentary structures typical of these beds are absent. In proximal areas supercritical climbing ripples can comprise the bulk of the deposit, with subcritical climbing ripples being more common in distal portions of the flow. Thin planar sands and interbedded silts and claystone top out the deposit, with the entire gravity flow ranging from less than a foot to over 15 feet in thickness. Soft-sediment deformation is common, particularly in the basal portions of the deposit, with typically including ball and pillow, flame structures, and convolute bedding. Hyperpicnal sandstone lobes of up to a mile in width and several miles in length have been mapped using well data. Individual lobes branch off larger feeder channels, forming larger fans and fan complexes. These extensive, well sorted sandstone complexes are unlikely to originate in surge-like gravity flows, instead probably represent seasonal sediment-laden fluvial underflows.

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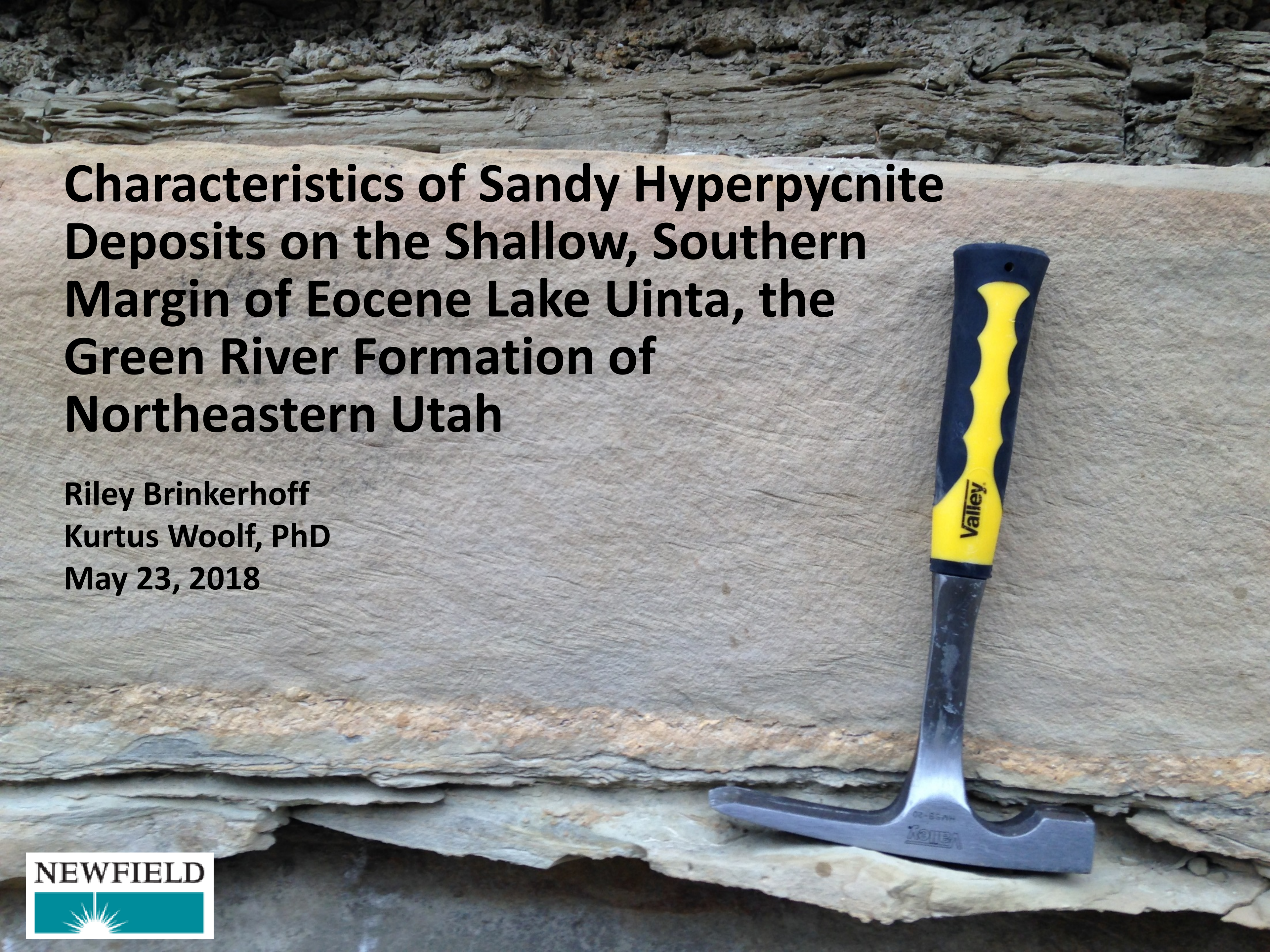

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May 23, 2018

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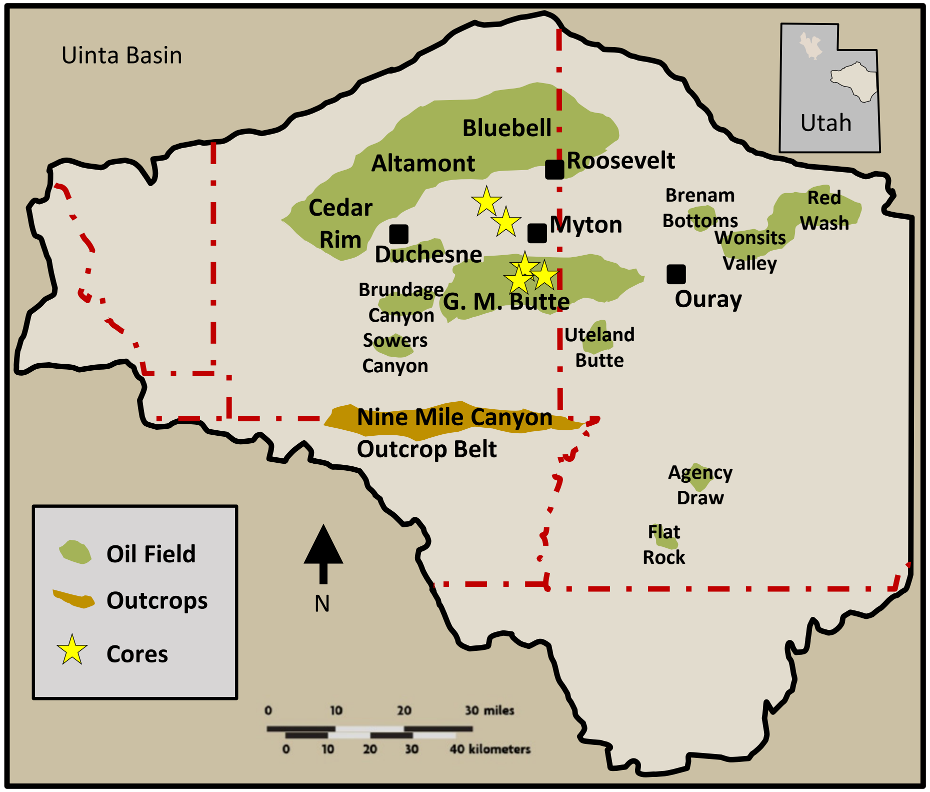
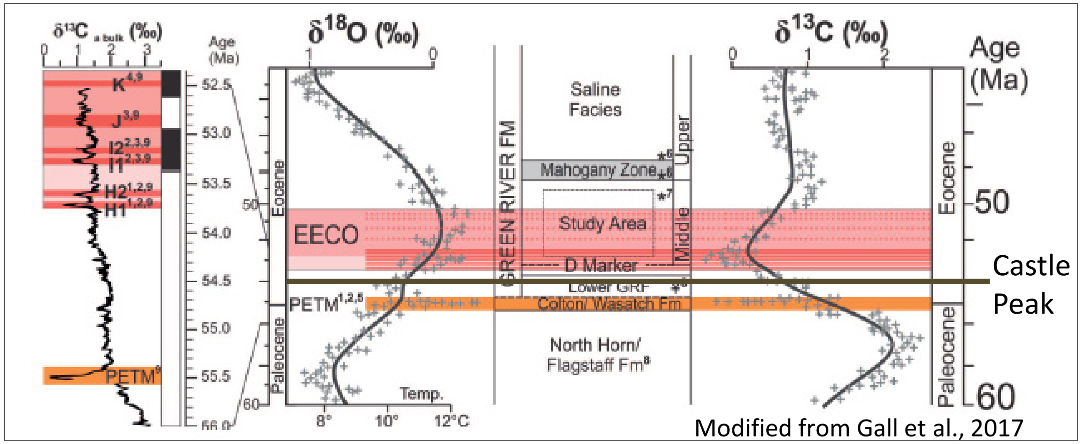
Summary

- Hyperpycnites
  - Long-lived fluvial linked turbidity currents
  - Conditions necessary for a fluvial current to plunge in ancient Lake Uinta
  - Non-plunging systems
- Upper Castle Peak Interval
  - Location within the Green River Formation
  - Descriptions of the interval
  - Geometries of hyperpycnal flows
- Creation of the Castle Peak Shelf
  - Sediment partition
  - Duchesne Fault Zone
- Depositional Model



Highly Seasonal Fluvial Systems

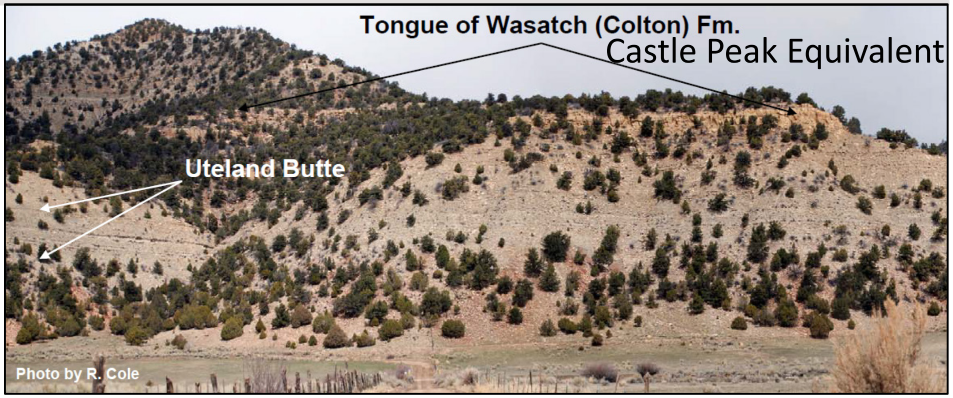
- Castle Peak deposition
  - Early in the Early Eocene Climatic Optimum (EEOC)
  - Semi-arid, seasonal fluvial systems (monsoonal?)
- Large floods
  - Relatively rare (~decadal)
  - Could move immense amounts of sediments
- Ideal system to create large, relatively long-lived hyperpycnal flows



Modified from Gall et al., 2017

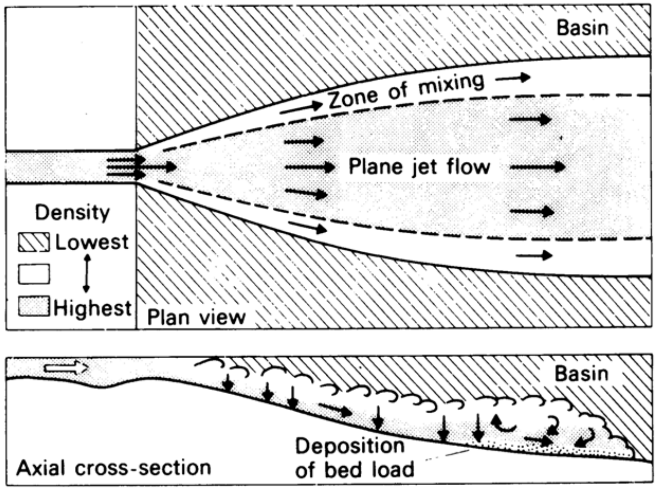
- Largest channels, 10's of m erosion at bases = very high water discharge
- Thickest accretion sets (up to 20 m) = very high sand supply, very high deposition rates
- Bioturbation & paleosol formation common on accretion set boundaries = very episodic with long periods of non-deposition = long dry periods with intense wet periods

Plink-Bjorklund et al., 2010



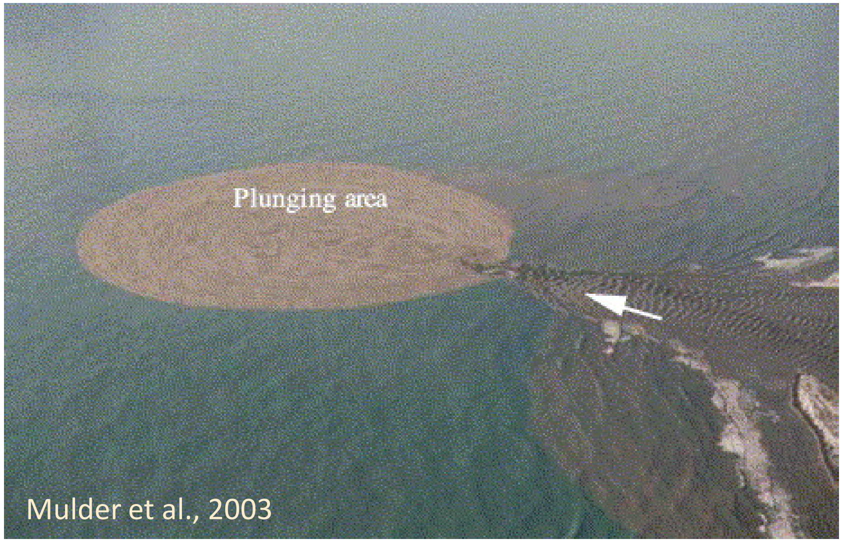
Hyperpycnal Flows

- Hyperpycnal flows occur when sediment-laden rivers enter standing, lower-density water
  - In this case, ancient Lake Uinta
- Not all sediment laden rivers become hyperpycnal flows on encountering a standing body of water:
  - Sufficient density contrast with the surrounding lake water
  - Sufficient lake depth
  - Suitable discharge rate
- Because of their excess density, the flows plunge near the river mouth and continue to travel basin-ward as a turbulent underflow

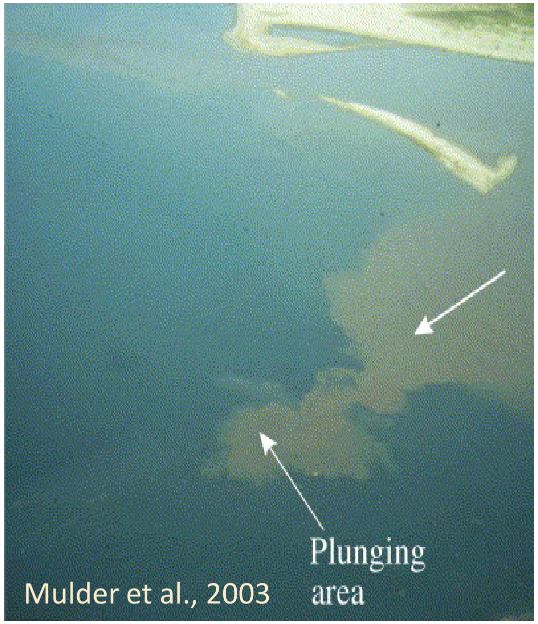


Boggs, 1995

Modern examples of rivers plunging to form hyperpycnal flows



Mulder et al., 2003



Mulder et al., 2003

Conditions for Hyperpycnal Flow

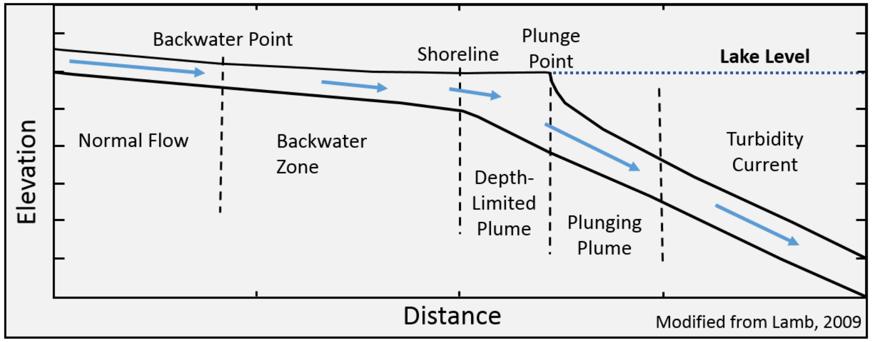
$$F_d = 0.5 = \frac{U/h}{\sqrt{\Delta\rho g h^3/\rho_a}}$$

F_d	Froude number	ρ_a	Density of lake water
U/h	Velocity averaged over lake depth	g	Gravity acceleration
$\Delta\rho$	Density of current in excess of lake water	h	Lake depth

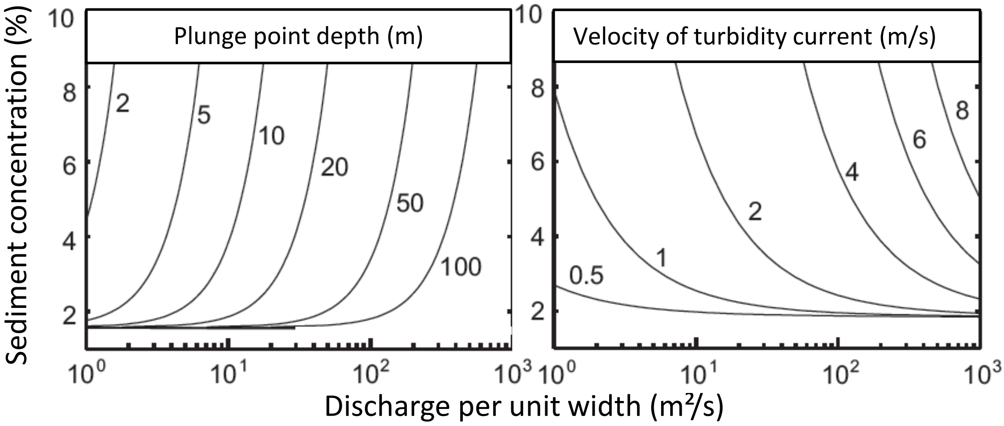
Modified from Lee and Yu, 1997

- Larger discharges will push plunge points into deeper water
- Higher sediment concentrations will plunge at shallower depths and are characterized by faster underflows
  - Fluvial characteristics at Lake Uinta are unclear, but even very high sediment concentrations would need tens of feet of lake depth to plunge into a hyperpycnal flow
  - The lake bottom can be shown to be very flat and relatively shallow

Fluvial discharges will continue to prograde into the lake until they dissipate or reach a Froude number ≥0.5 and collapse as a turbidity current



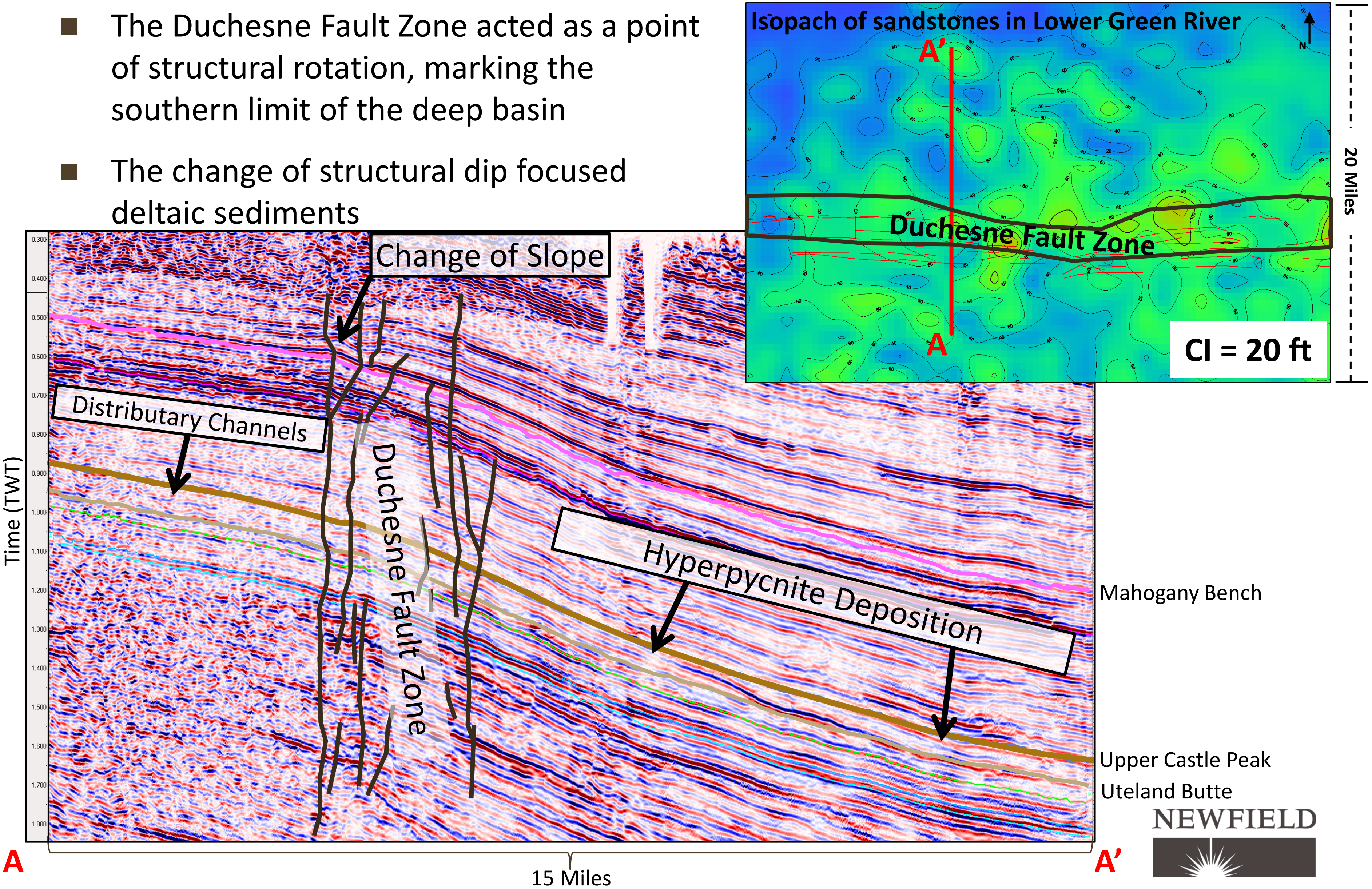
Modified from Lamb, 2009



Lamb and Mohrig, 2009

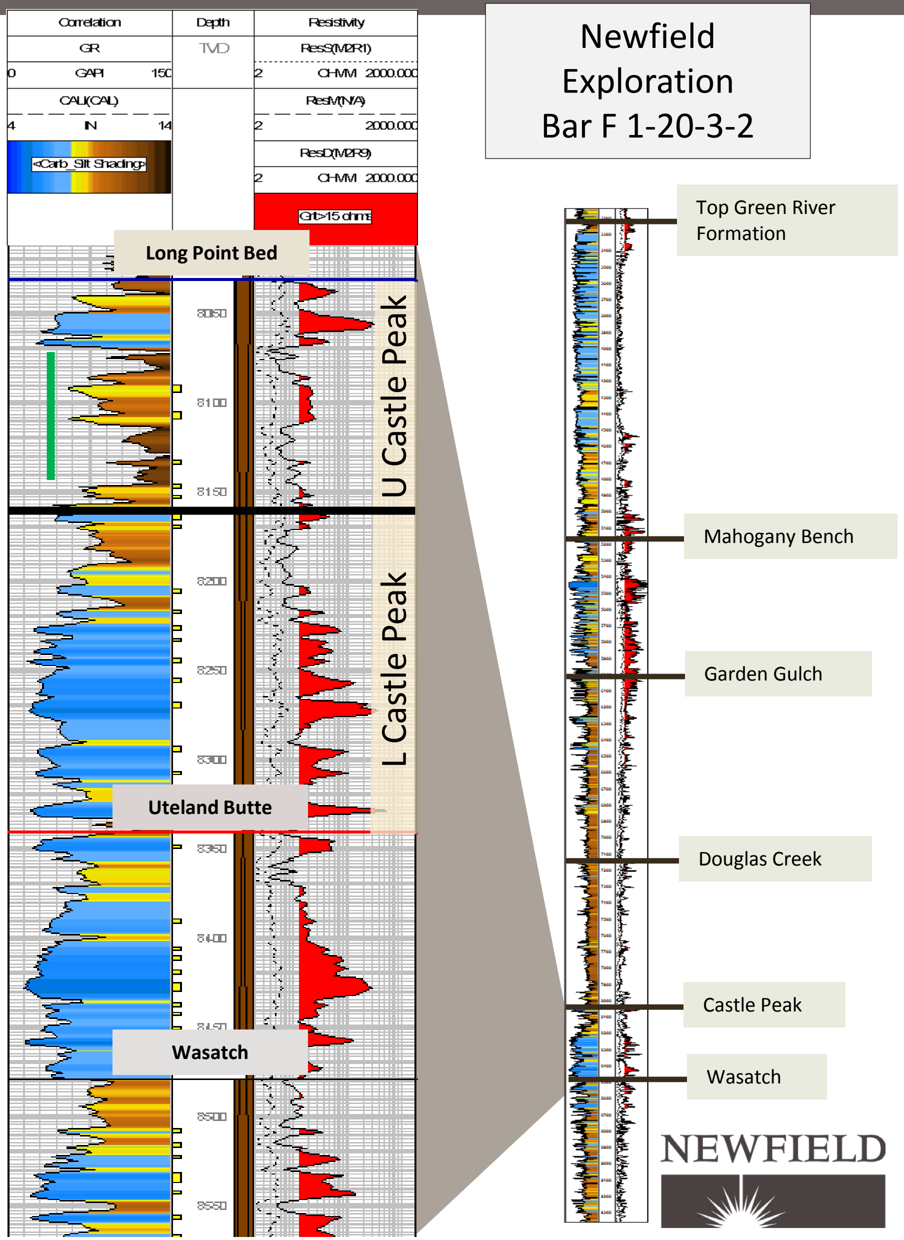
Duchene Fault Zone Slope Change

- The Duchesne Fault Zone acted as a point of structural rotation, marking the southern limit of the deep basin
- The change of structural dip focused deltaic sediments



Sandstones in a Carbonate World

- In the central portion of the Uinta Basin, carbonates dominate the Lower Green River and Upper Wasatch
- Within the Upper Castle Peak is a 75 ft thick package of very fine to fine grained sandstones interbedded with silt and mudstones
- Proved to produce oil
- Labeled here as the Upper Castle Peak



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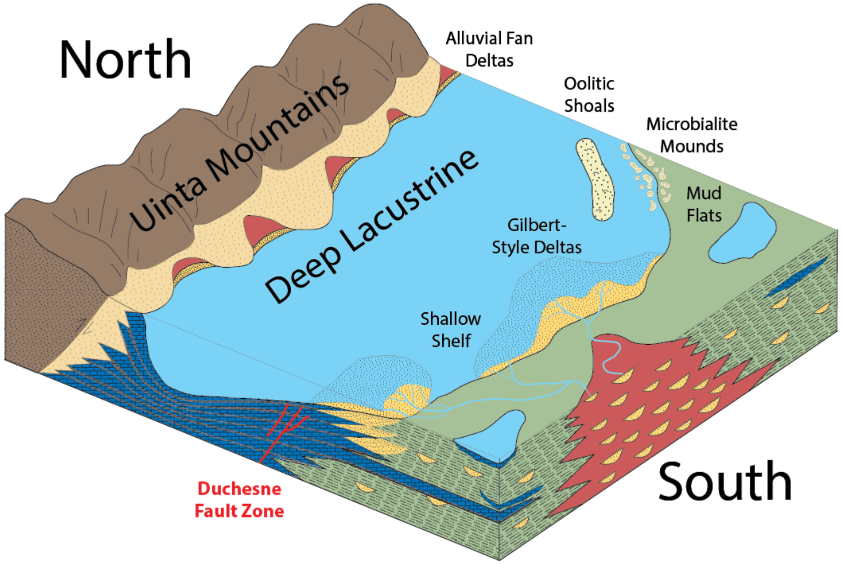
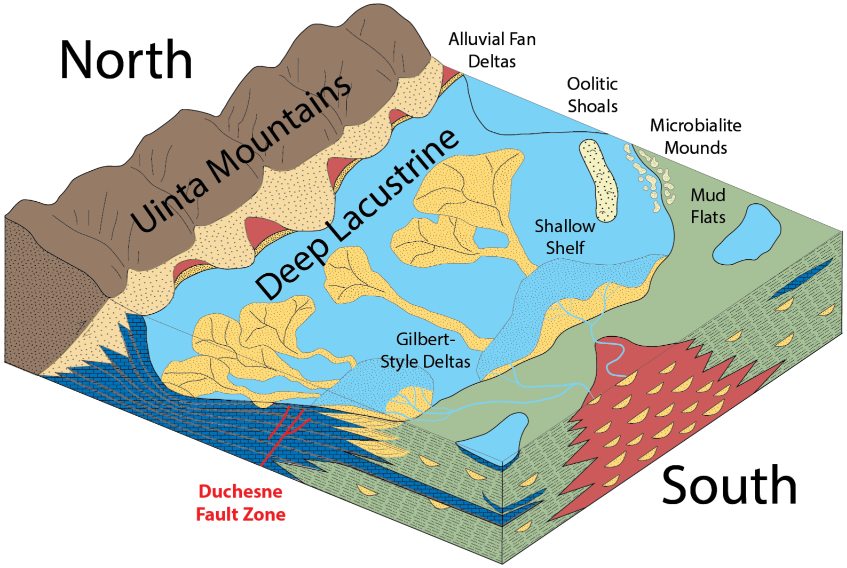
Lacustrine Depositional Models

Lower Castle Peak Depositional Model



- Gilbert-style deltas forming on the shallow shelf proximal to the hinge line at the Duchesne Fault Zone
- Deep lacustrine environment clear of clastics and depositing carbonates

Upper Castle Peak Depositional Model

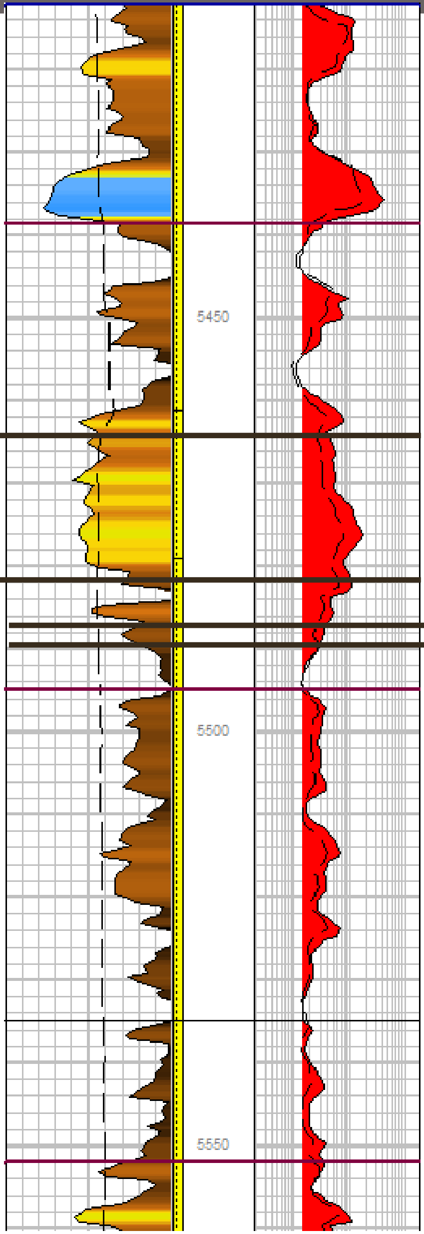


- Sediment reaches the hinge line at the Duchesne Fault Zone and travels as hyperpycnites to the basin floor
- Carbonates are no longer deposited as clastics cloud the water

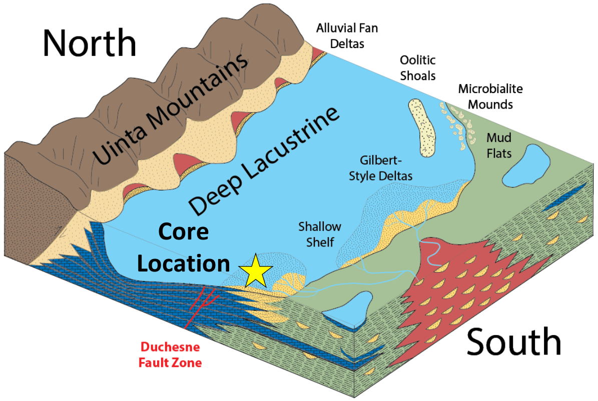
Upper Castle Peak Marginal Lacustrine Siliciclastics

- Upper flow regime beds in distributary channel sandstones
- Finer grained floodplain deposits with root traces, coals, paleosols and shales containing oysters

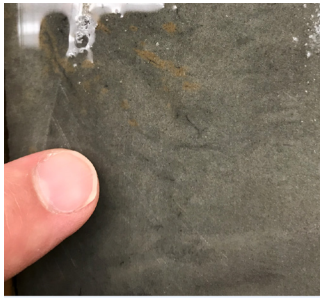
18 ft.



Lower Castle Peak Depositional Model

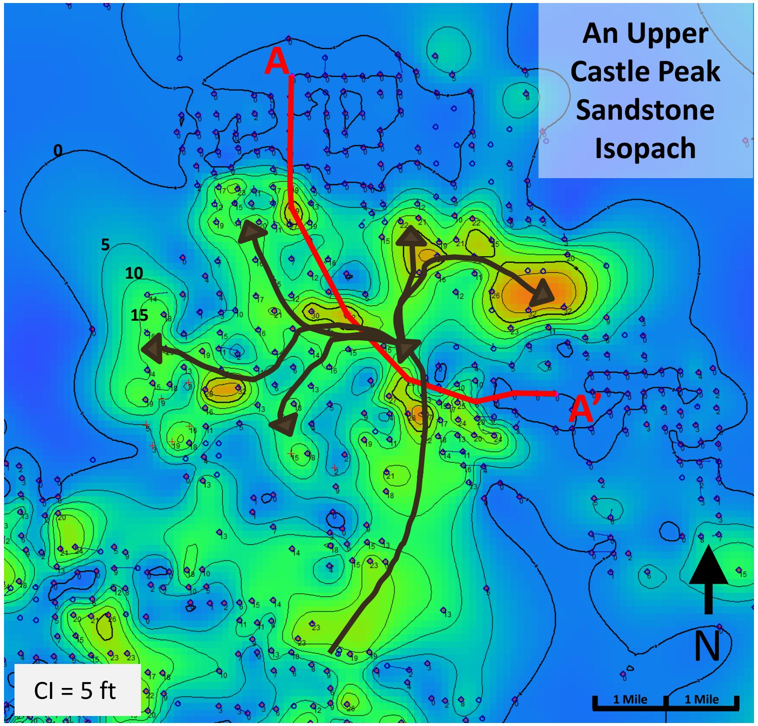


Crevasse splay deposits with root traces

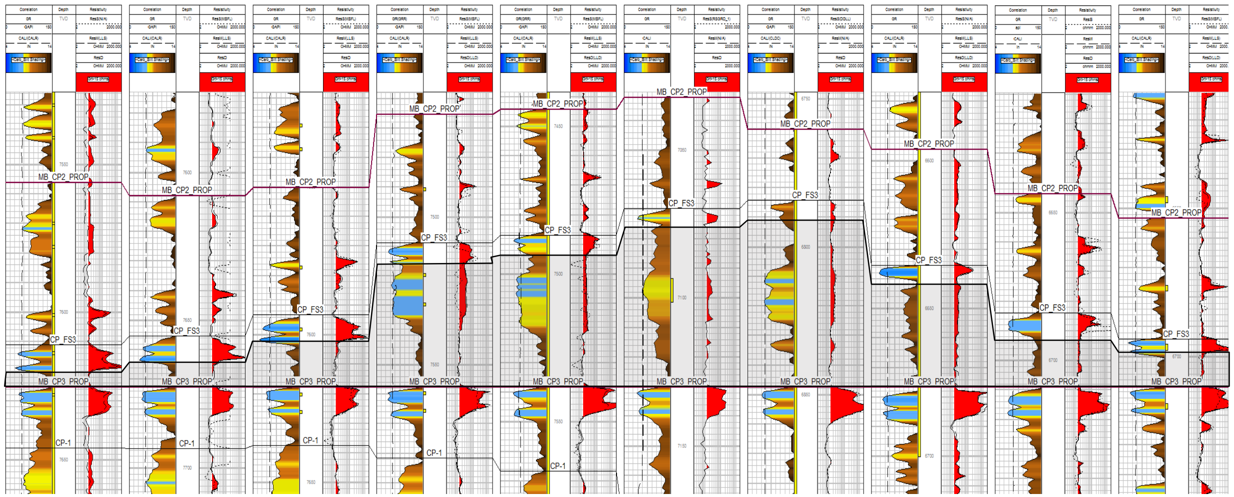


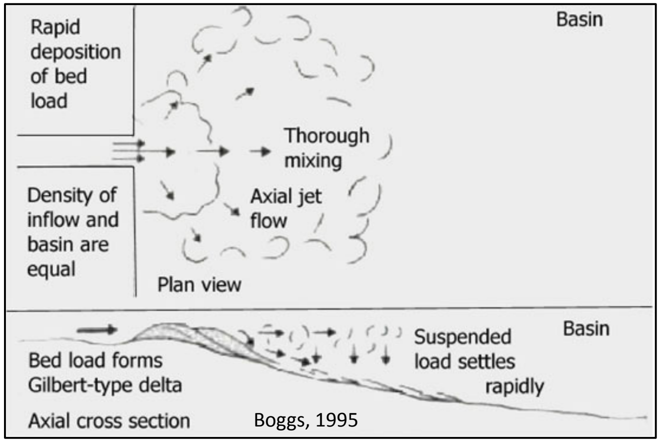
Progradation in Non-Plunging Systems

- Fluvial systems that don’t develop the conditions necessary to plunge, likely due to shallow lake levels, prograde rapidly, depositing mouth bars and terminal distributary channels
- Sediments were trapped near the deltaic systems, allowing clear-water carbonate systems to develop in the lake center



An Upper Castle Peak Sandstone Isopach

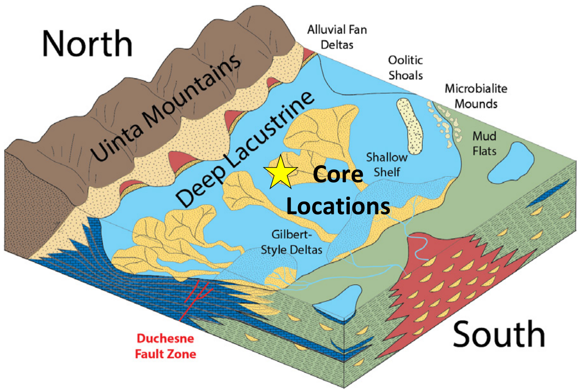




Boggs, 1995

Upper Castle Peak Deep Lacustrine Siliciclastics

Upper Castle Peak Depositional Model



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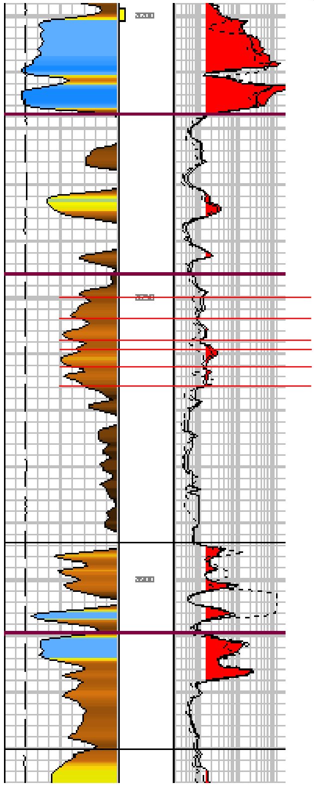


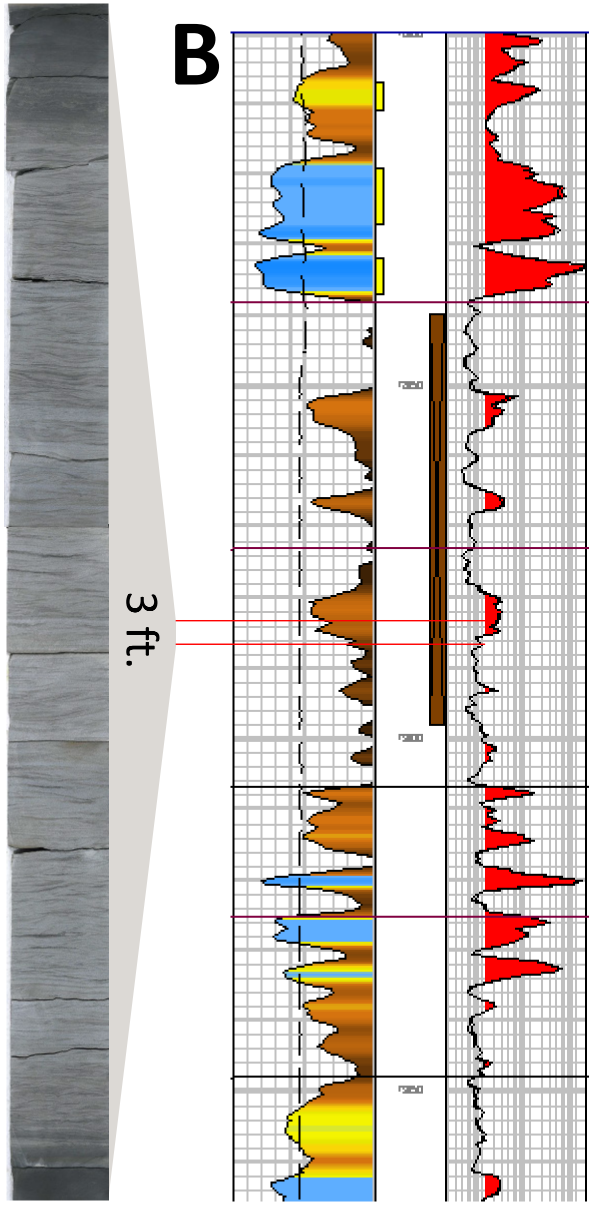
Limestone

Higher energy flow

Individual fining upward hyperpycnites 3 – 5 ft. thick

Limestones Interbedded with clastic mud and siltstones

B



Mudstone

Minor bioturbation (planolites, chondrites, nerites)

Fining upward

Climbing ripples

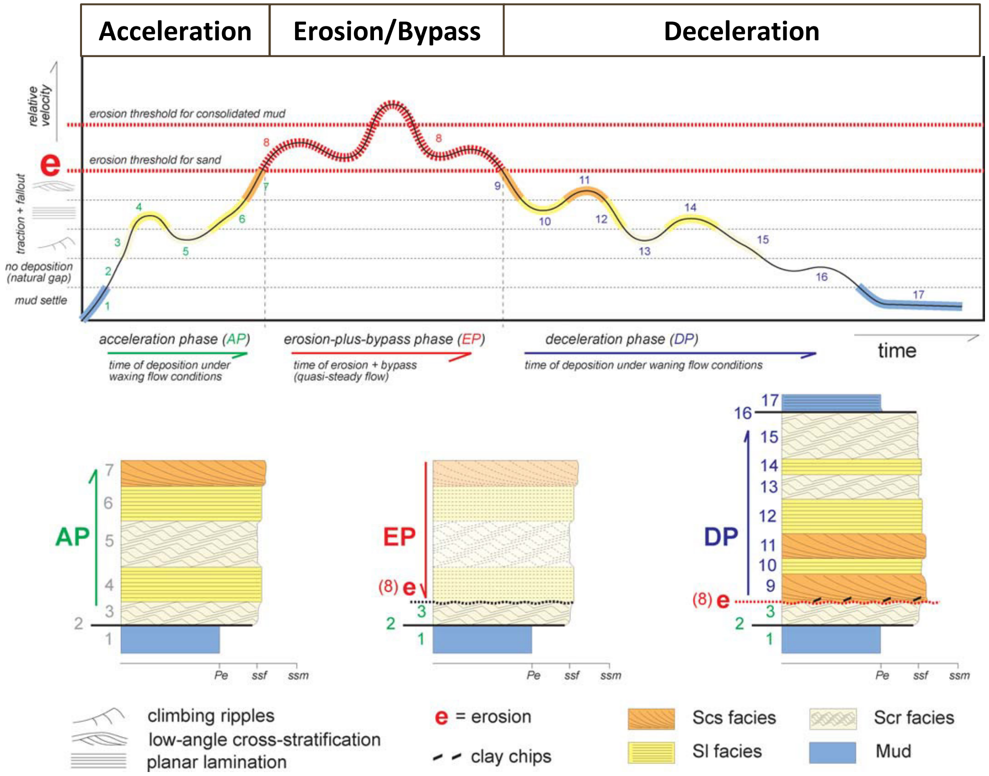
Minor planar laminations interbedded with ripples

Coarsening upward

Sharp Based

Fluvial Charged Hyperpycnal Flows

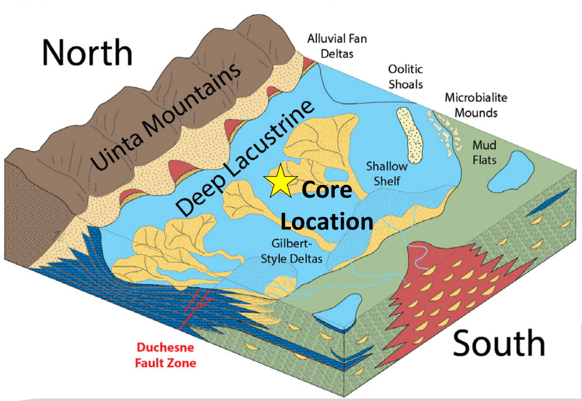
- Long lived, fluvial-linked turbidity currents will experience changing flow regimes over time, which could lead to a single flow experiencing multiple bedding types
- Hyperpycnal flows in lacustrine systems undergo three phases (Zavala 2006)
  1. Acceleration
  2. Erosion-plus-bypass
  3. Deceleration
- These phases are linked to fluvial discharge and will vary accordingly

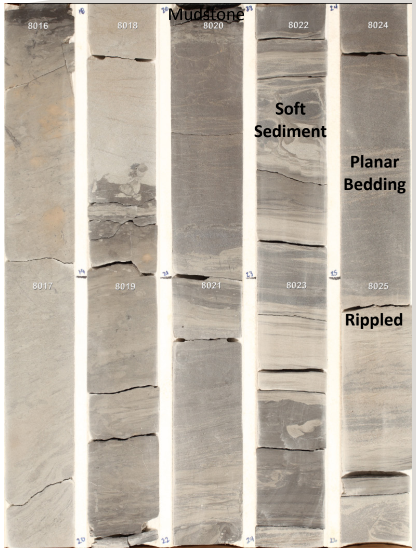


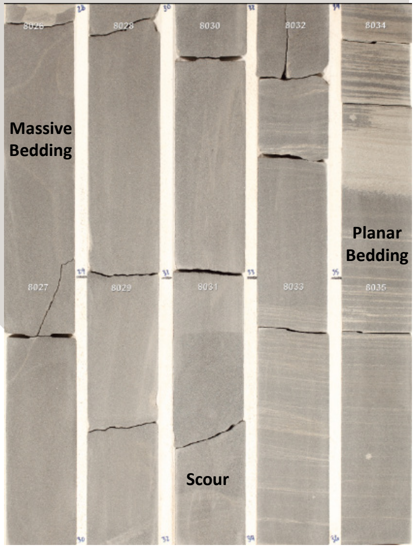
Zavala et al., 2006

Upper Castle Peak Deep Lacustrine Siliciclastics

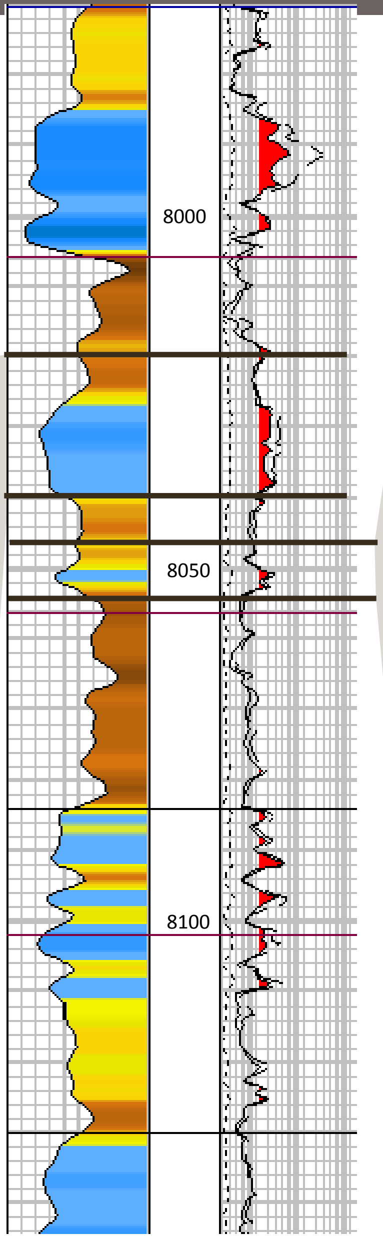
Upper Castle Peak Depositional Model



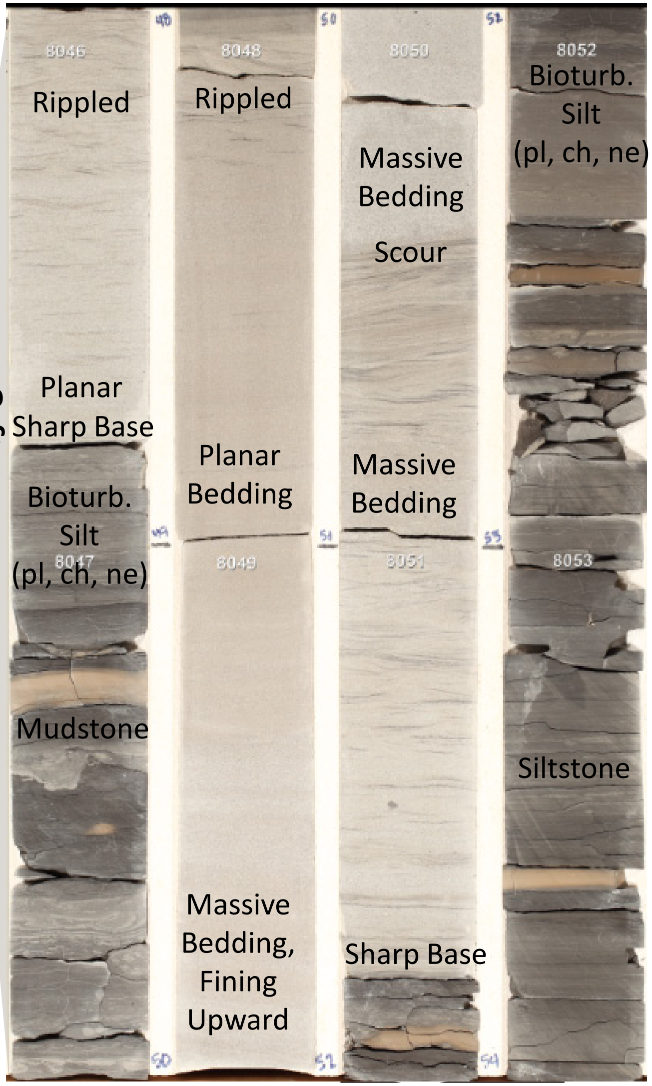




20 ft.



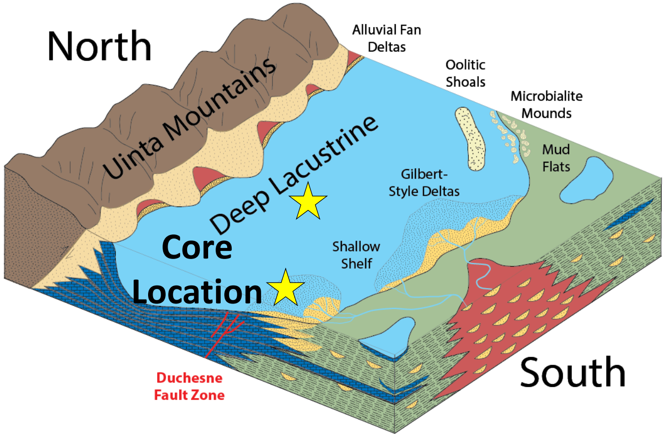
8 ft.

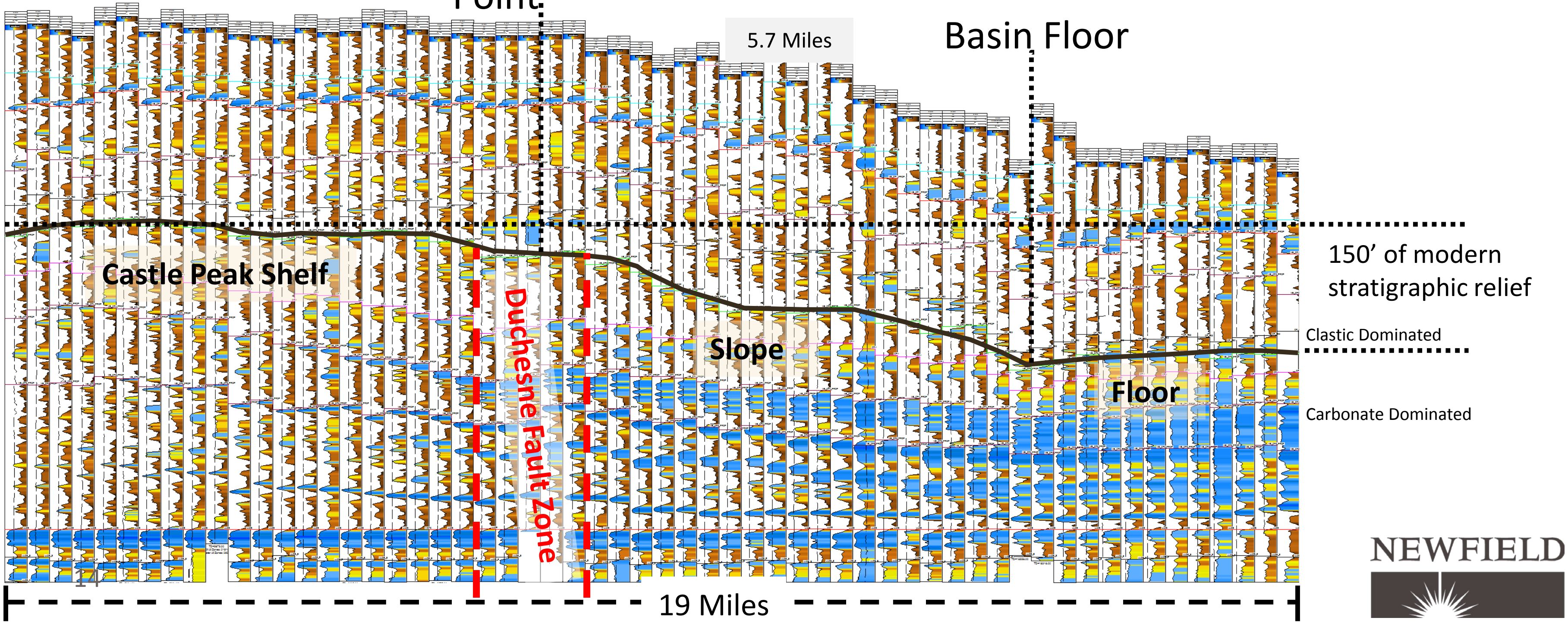


Relief on the Castle Peak Shelf

- **Compaction rates vary by lithology and depth of burial, but if we assume an averaged 40% reduction in interval thickness, ancient relief on the Castle Peak shelf would have been ~210'**
  - **For the slope, that would be about ~0.7°, which is significantly steeper than lacustrine hyperpycnites from other basins**
- **No significant erosion on the shelf margin**

Lower Castle Peak Depositional Model





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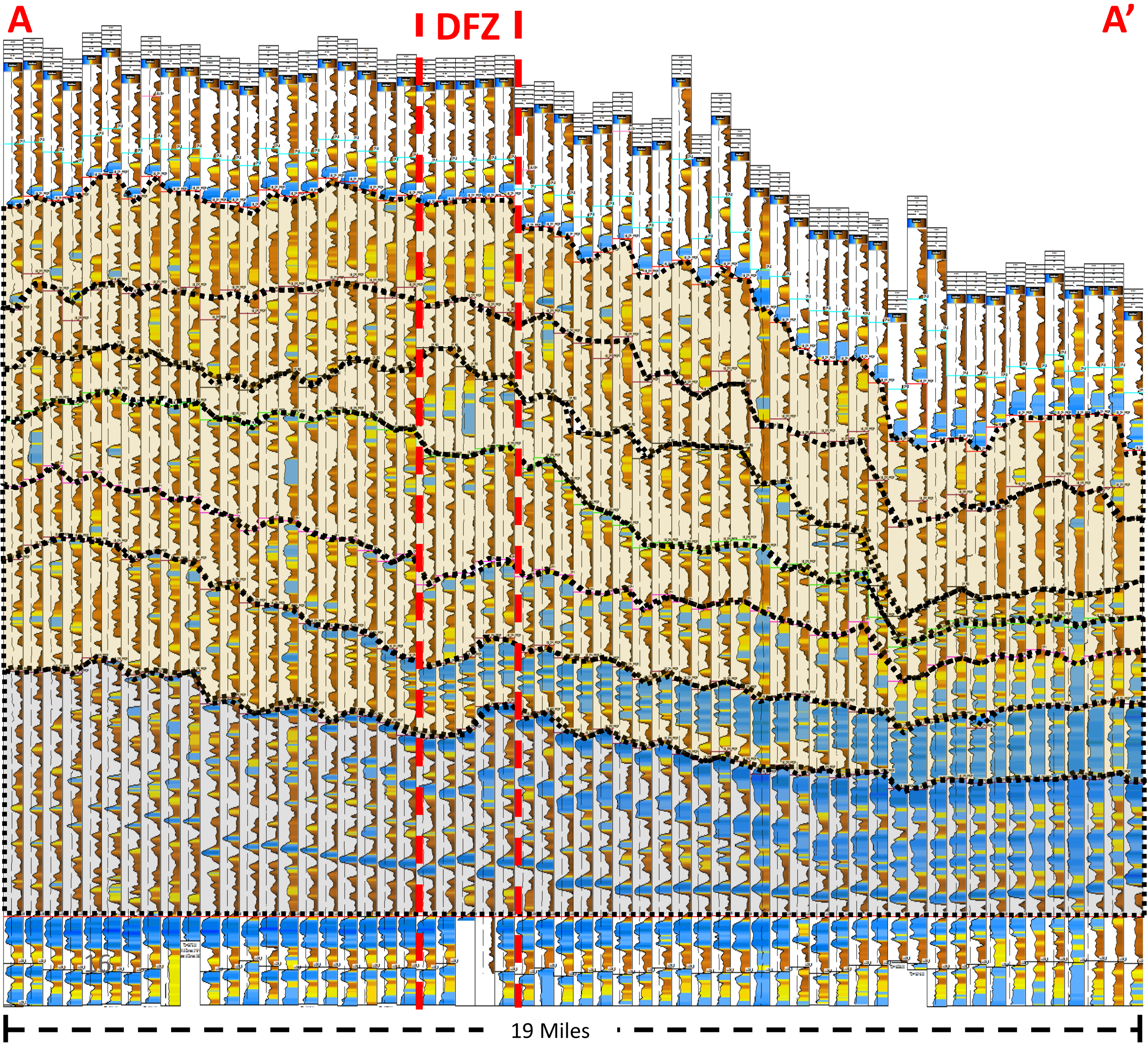
Hyperpycnal or Fluvial?

- We suggest a hyperpycnal origin based on the following observations
  - Cores on the shelf commonly contain coals, paleosols and roots, with minor shales containing oysters
  - Cores off the shelf these are replaced with laminated shales with nerites and planolites with an absence of oysters or other terrestrial indicators
  - The bulk of the individual sand beds fine upward through a classic Bouma-like sequence, in bioturbated to laminated shales
  - No incision on the shelf margin has been observed, as might be expected from the base-level fall that would be necessary (~210’) for fluvial systems to be deposited
  - The geometry of
    - distributary channels
    - identifiable delta
    - sands that fall on a slope with thinner, tabular shapes

Castle Peak Deposition



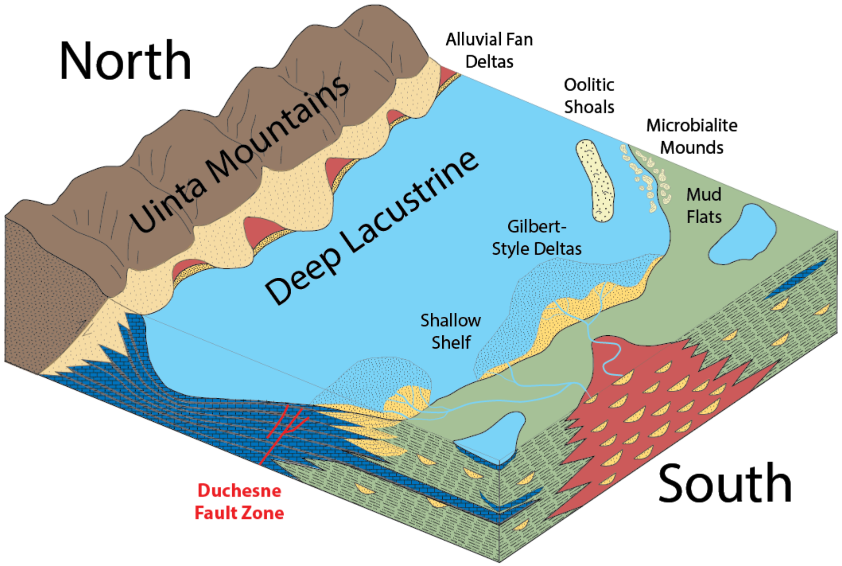
- Clastics disperse dacross the basin floor through hyperpycnal flows
- The carbonate factory is shut off as clastics cloud the water column

- Clastic input progrades further north
- Weaker carbonate system with more clay input

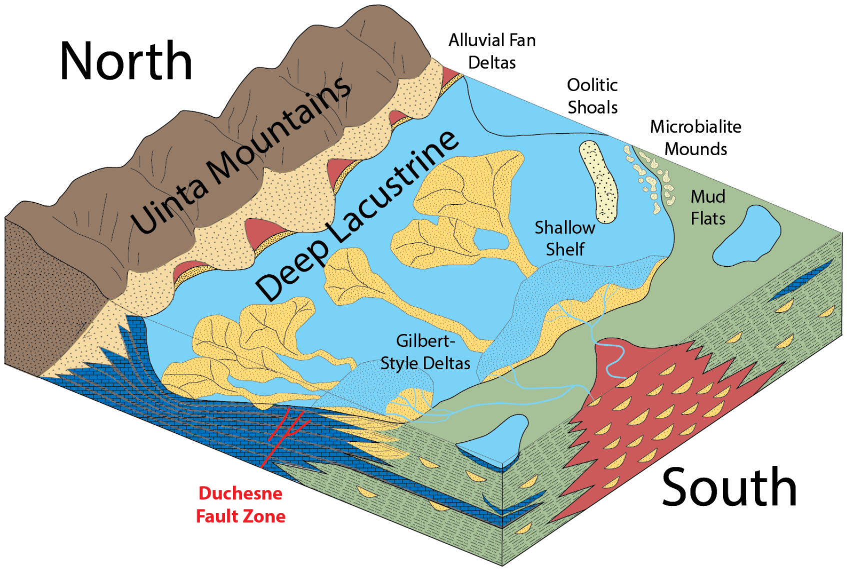
- Clastic sediments are trapped on the flat Uteland Butte surface
- Hyperpycnites into the deeper basin do not develop
- A carbonate factory develops in the clear water in the center of the basin

Conclusions

Lower Castle Peak Depositional Model



Upper Castle Peak Depositional Model



- Fluvial systems that discharge into portions of the lake without sufficient depth to develop a plunge zone prograde rapidly through mouth bar and terminal distributary channel deposits
  - Clastic sediments are largely trapped nearshore
  - Lake water column is clear in basin center, allowing carbonates to accumulate into thick limestone beds
- Clastic wedge builds out to Duchesne Fault Zone, which acts as a hinge line for a change in slope break
- The clastic shelf, coupled with relief created by the Duchesne Fault Zone, creates sufficient water depth near the mouths of prograding deltas to develop a plunge zone with coupled turbidity currents during seasonal floods
- Hyperpycnal flows flush siliciclastic sediments far into the basin, slowing deltaic progradation and allowing a stable shoreline to develop

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