Cyclostratigraphy of the Parachute Creek Member: Analysis of Vertical and Lateral Facies and Inorganic Geochemical Variability in the Green River Formation of the Uinta Basin, Utah

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Abstract:

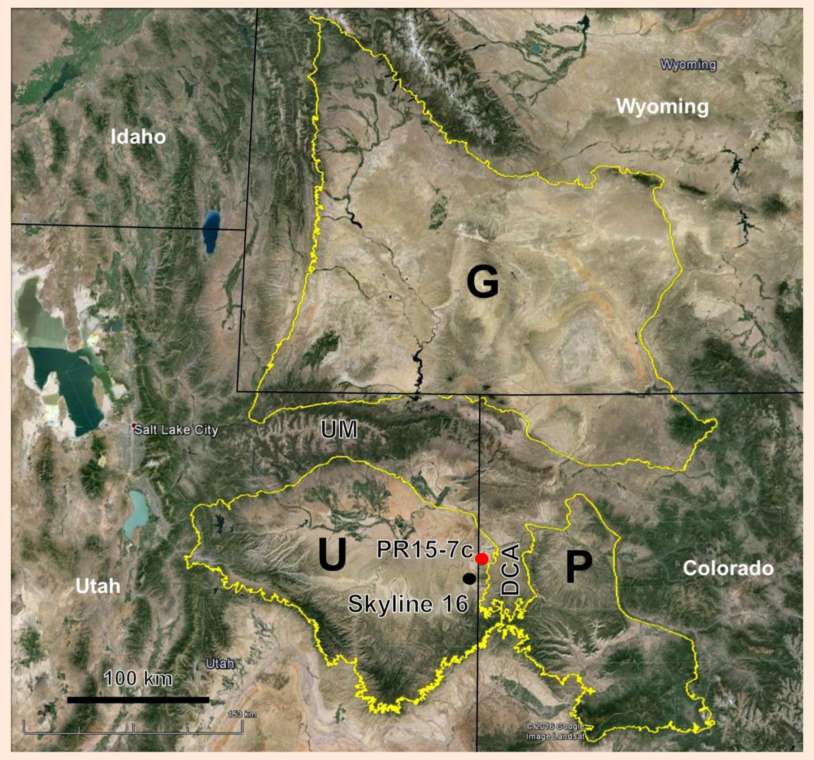
Detailed lithologic description of the Parachute Creek Member of the Green River Formation deposited in Lake Uinta reveals a hierarchy of cyclicity. Decameter-scale cycles of organic-rich and organic-lean lacustrine mudstone and sandstone contain meter-scale and decimeter-scale lake expansion and contraction cycles. These higher frequency cycles are more apparent within organic-rich zones. This is either due to a decrease in lake level fluctuation during deposition of lean zones or because cycles are amalgamated within lake margin deposits, common in these zones. Many cycles can be correlated between two cores separated by 16 km in the eastern Uinta Basin, confirming that these are basin-scale events rather than local facies alternations. Several volcanic tuff layers are interbedded with the lacustrine deposits, which can also be correlated between the two wells, providing chronostratigraphic control. Future geochronology studies of these tuffs can be used to estimate the periodicity of lake expansion-contraction cycles in Lake Uinta. Together, cycle correlations and tuff beds allow us to test if the contact between organic-rich and organic lean zones are time lines as commonly stated, or if they represent time transgressive surfaces.

The stratigraphic correlation produced in this study provides a template to place pXRF-based elemental concentration data in depositional and lithologic context. Elemental abundances were measured every 5 cm on the two cores studied in this project. They provide proxies for detrital input, clay minerology, carbonate type and abundance, redox conditions, and organic matter content. With each data point constrained by lithology, vertical and lateral trends of these proxies within high frequency lake expansion-contraction cycles can be examined, and longer-term trends within individual depositional environments can be studied.

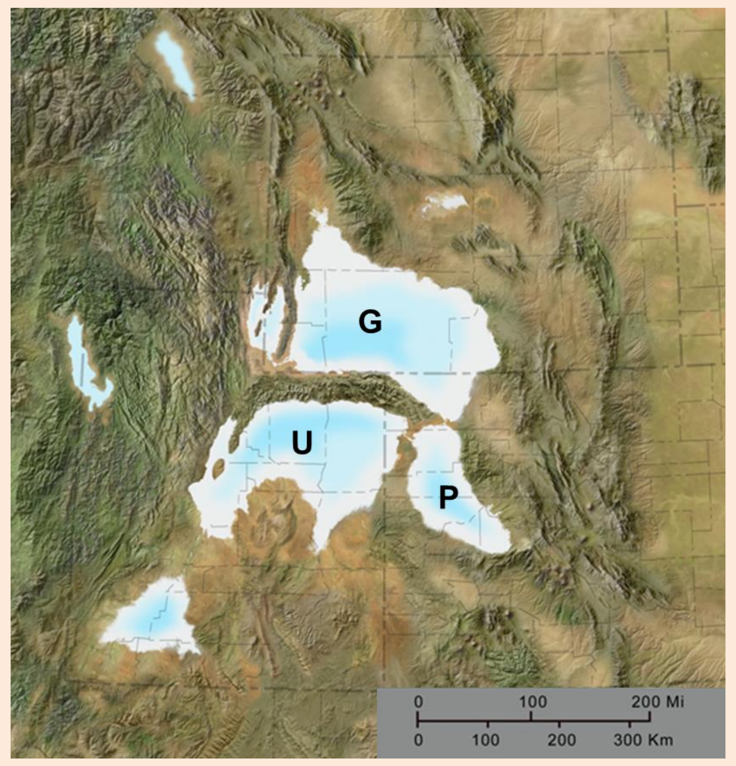
The results of this study help to better understand the evolution of Lake Uinta and the potential driving mechanisms on various scales of lacustrine cyclicity. These contributions to a relatively well-studied lacustrine basin provide useful analogues for more poorly constrained basins.

Geologic Background and Regional Stratigraphy:

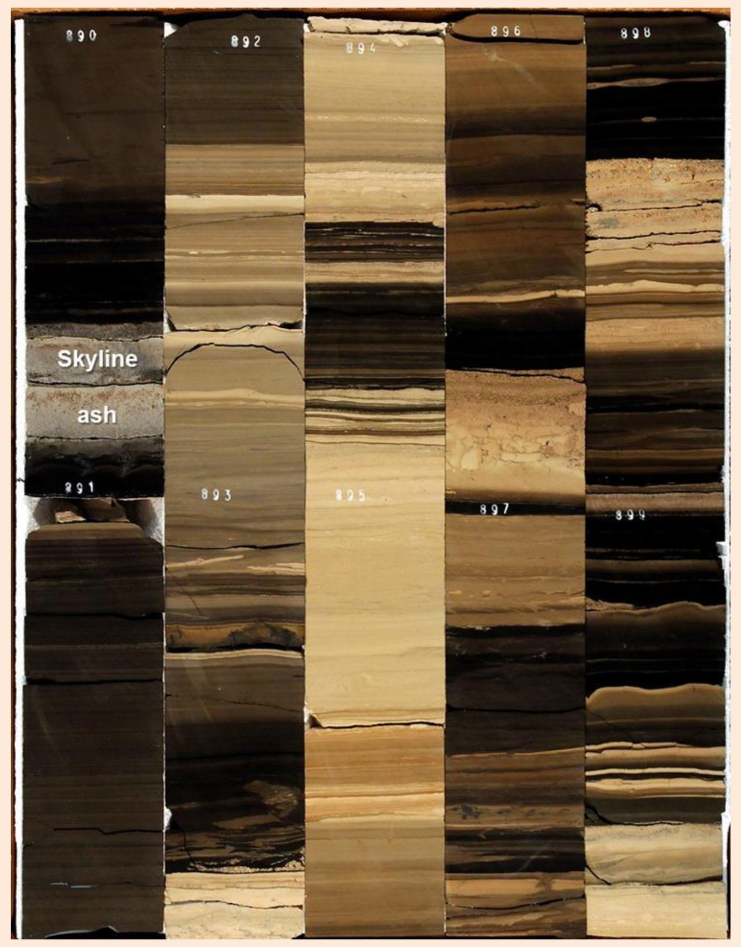
During the Cretaceous, the Uinta Basin of northeast Utah was part of the foreland province that formed east of the Sevier Orogenic Belt, which was subsequently divided during the Laramide Orogeny by basement–cored uplifts. The Uinta Basin is one in a series of basins, including the Greater Green River Basin in WY, and the Piceance Creek Basin in CO, that were filled by large long-lived lakes during the Eocene, recorded by deposition of the Green River Formation.



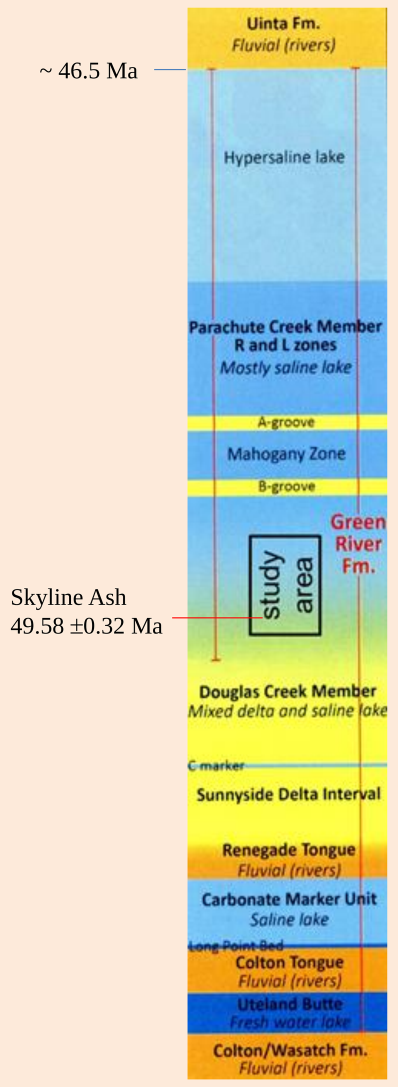
Location of basins containing the Green River Formation and cores studied in this project. The location of the Uinta Basin (U), Piceance Creek Basin (P) Greater Green River Basin (G), Uinta Mountains (UM), and Douglas Creek Arch (DCA) are noted.



Paleogeographic reconstruction of lakes in the Green River Formation-bearing basins during the Eocene (50 Ma) Modified from Blakey (2016).



Skyline Ash (890.75 ft from Skyline 16 core dated at 49.58 ±0.32 Ma (Smith & Carroll, 2015). Note the interbedded nature of facies.



Generalized stratigraphic column of the Green River Formation and associated formations of the Uinta Basin, showing the approximate interval of this study (M. Vanden Berg, p/c).

The Parachute Creek Member has been divided into organic-rich and organic-lean zones.

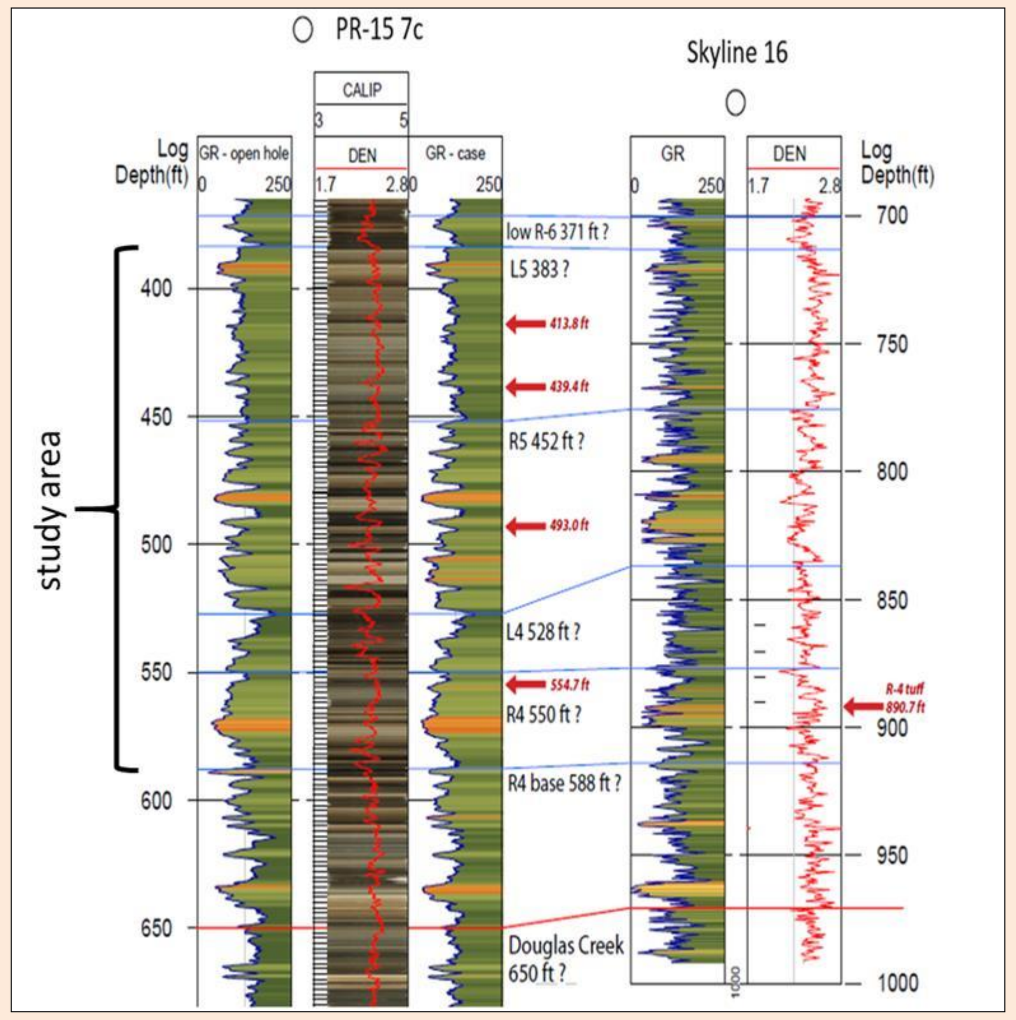
Large-Scale Sediment Packaging:

Organic lean zone (L4) from Skyline 16 Core.

Organic rich zone (R5) from Skyline 16 Core.

Organic rich and lean zones were first defined based on Fisher assay oil yields, sonic, and density logs (Donnell and Blair, 1970; Cashion and Donnell, 1972). This study focuses on the R4/L4 and R5/L5 couplets.

Current Correlations of the R4/L4 and R5/L5 Zones:



From Vanden Berg and Birgenheier (2016).

Methodology:

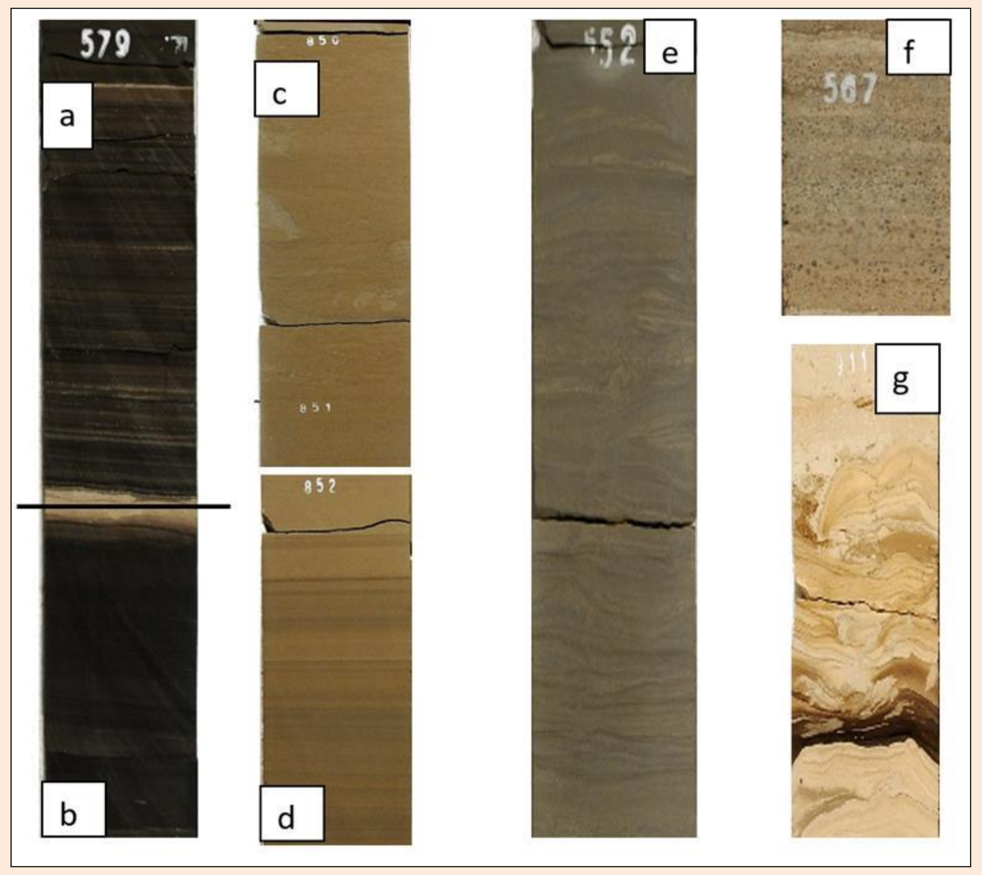
Detailed sedimentological core descriptions will serve as a template to investigate changes in elemental concentrations based on handheld x-ray fluorescence (XRF) spectroscopy using a Bruker Tracer III-SD pXRF Handheld Spectrometer. Petrographic analyses of 38 thin sections will aid in facies recognition and mineral identification.

XRF spectroscopy is a process whereby electrons are ejected from their atomic orbital positions by incident x-rays. As a result, electrons from a higher orbital drop down and release an x-ray that is detected by the spectrometer; the energy of these fluoresced x-rays is characteristic for each element. The raw spectrum can be converted to concentrations for each element based on calibration to known standards (Rowe et al., 2012). For this study, data was collected at the scale of 7.62 centimeter increments (3 inches), which is smaller than the average thickness of individual lake expansion-contraction cycles. Certain intervals were also targeted for high resolution data collection (2.5-4.0mm) to investigate variability within facies and across facies boundaries.

Potential chemical changes that can be observed from XRF spectroscopy include:
1) Proxies for siliciclastic input such as Si/Al, Ti, Al, K, Cr, and Zr
2) Carbonate content based on Ca concentrations
3) Variations in the Mg/Ca ratio as a proxy for dolomite and calcite abundance which may relate to lake water chemistry or diagenesis
4) Th/U, Mo, Mn as redox proxies
5) Th/K and Al as a proxy for clay mineralogy/content

(Tribovillard et al., 2006; Rowe et al, 2008; Birgenheier & Vanden Berg, 2009; Keighley, 2013; Saboda, 2014)

Lithofacies:

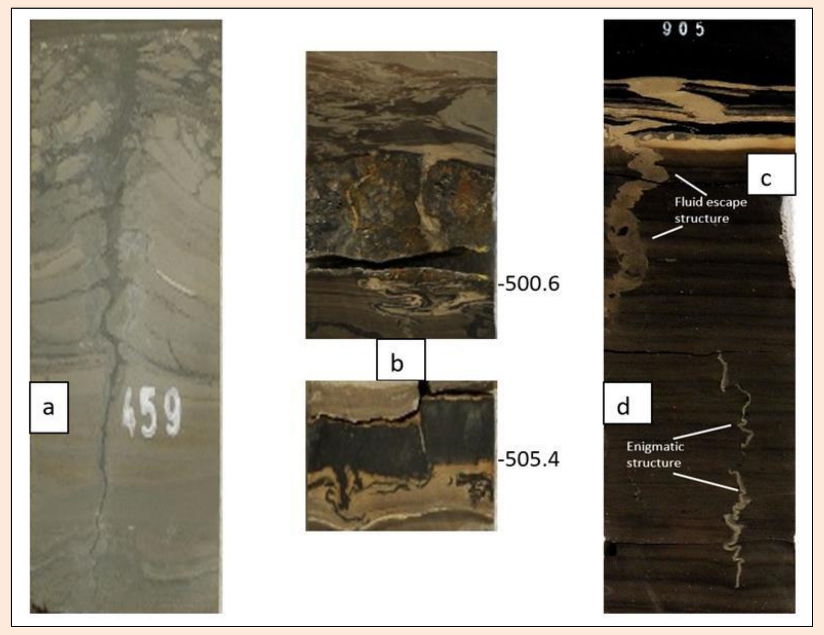


Facies observed in Parachute Creek Member (Skyline 16 and PR-15 7c core).

a) laminated kerogen-rich mudstone;
b) massive kerogen-rich mudstone;
c) massive kerogen-poor mudstone;
d) laminated kerogen-poor mudstone
e) siltstone/sandstone;
f) ooid/ostracod grainstone;
g) interbedded carbonate mud and sand (local potential chemical or biological stromatolites).

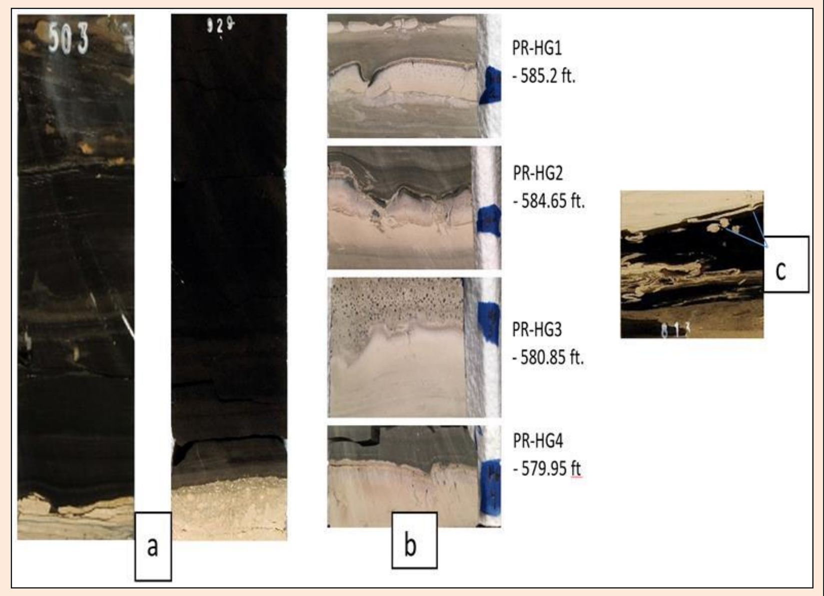
- Within organic rich zones, laminated oil shales, wavy-bedded calcareous and siliciclastic sandstones, and mudstones containing desiccation cracks stack into vertical packages which comprise meter and sub meter-scale lake expansion-contraction cycles.

Sedimentary Structures:



Mud cracks and similar structures observed in the Parachute Creek Member (Skyline 16 and PR-15 7c core).

a) subaerial desiccation cracks;
b) cracks beneath tuff beds, possibly related to subaqueous desiccation;
c) fluid escape structure;
d) enigmatic structure (potential floating mud crack).



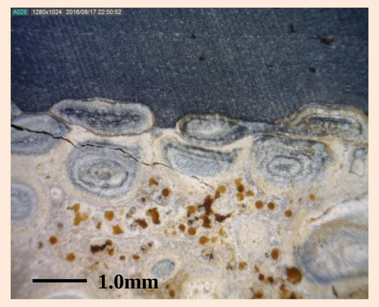
Other features observed in the Parachute Creek Member (Skyline 16 and PR-15 7c cores).

a) rip-up clasts below kerogen-rich mudstone;
b) potential hardgrounds*;
c) probable burrows.

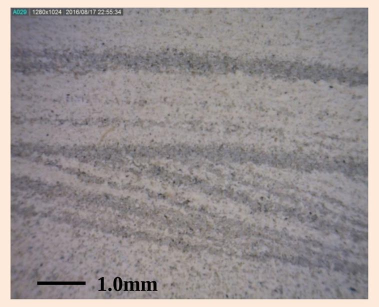
*XRF analysis was conducted across 10 hardground surfaces total (5 from each core). All are mostly calcareous, and feature relatively high Mg and Ca (wt. %) compared to background values.

Magnified Facies and Sedimentary Structures:

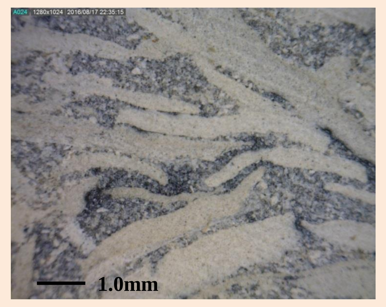
Skyline 16:



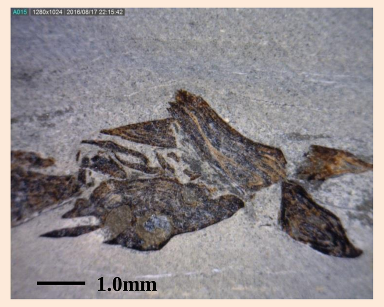
Ooid/ostracod grainstone w/ yellow wax kerogen filling interstitial pores. Overlain by massive kerogen-rich mudstone. Note compacted ooids. 898.30 ft. depth.



Very fine sandstone w/ small-scale cross-stratification. 810.75 ft. depth.

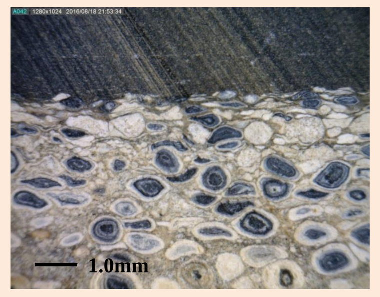


Angular mud rip-up clasts at 780.60 ft. depth. Rip–up clasts occur throughout both cores near cycle boundaries, and vary from rounded to angular clasts.

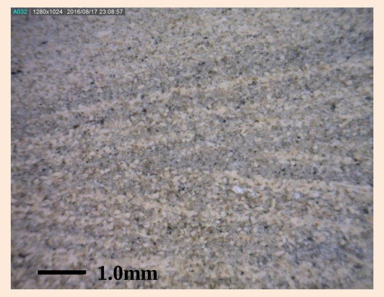


Gar fish scales found within laminated kerogen-poor mudstone at 837.40 ft . Gar scales occur in both cores, and are found in organic rich and lean zones.

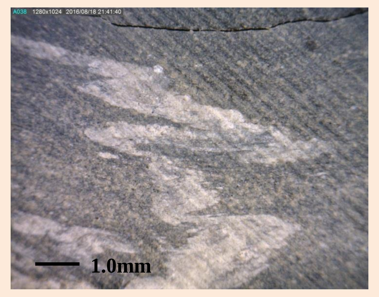
PR-15 7c:



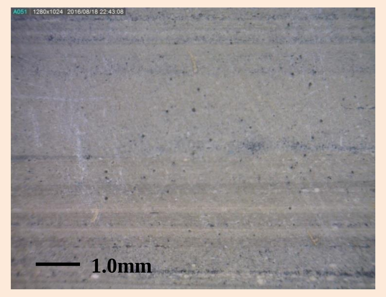
Ooid/ostracod grainstone (near flooding surface) overlain by massive kerogen-rich mudstone. Note compacted ooids. 580.70 ft. depth.



Very fine to fine sandstone w/ small-scale cross-stratification. 508.75 ft. depth.



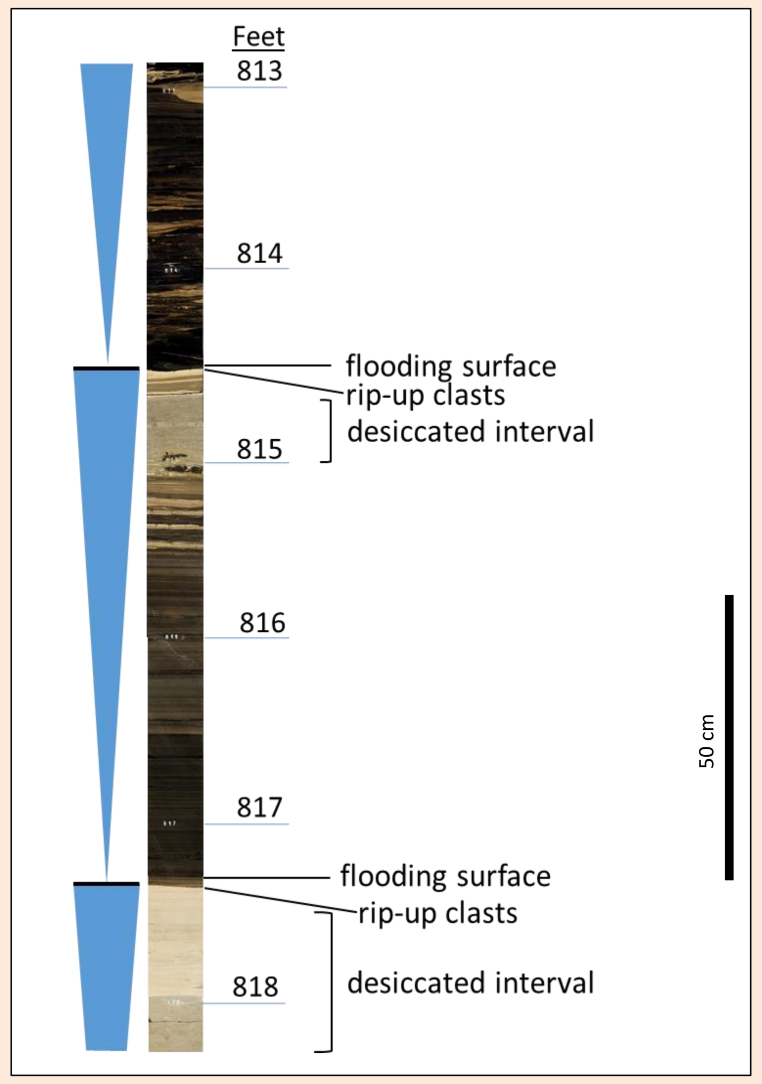
Mud crack filled w/ fine carbonate sand, occurring within a laminated kerogen-rich mudstone at 584.65 ft. depth.



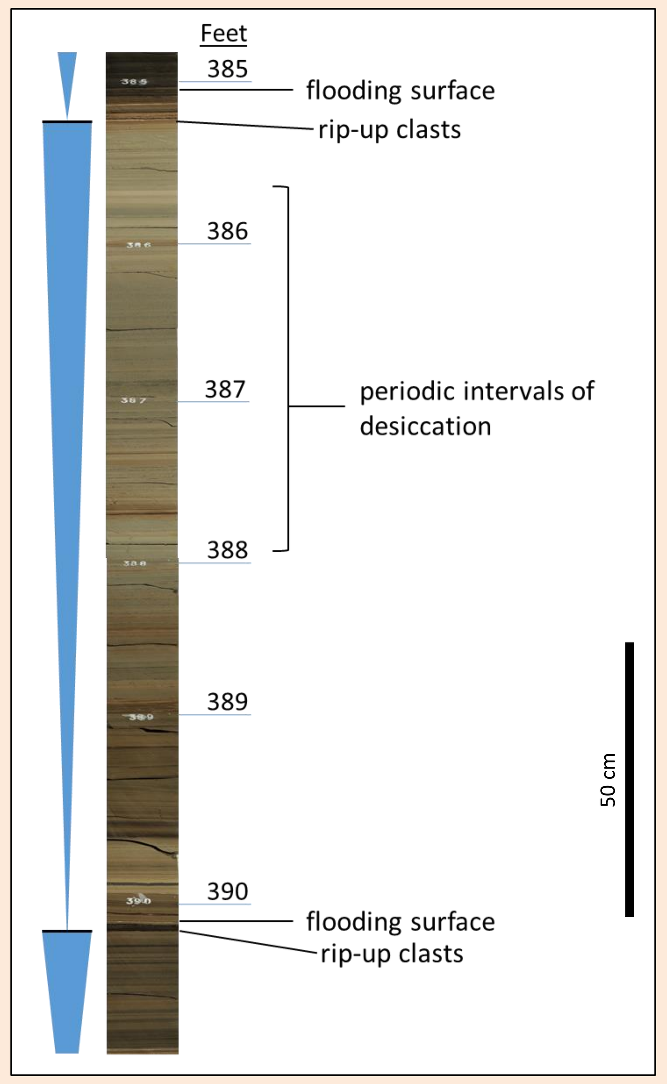
Partially laminated kerogen-poor mudstone at 441.25 ft. depth. Commonly found in the lean zones of both cores.

- Images taken using a *Dino-Lite Edge* high-resolution camera.

Lacustrine Expansion-Contraction Cycles:



Lake expansion-contraction cycles on the order of 80 cm (~2.5 ft) within an organic-rich zone (R5) of the Parachute Creek Member from Skyline 16 Core (~813-818 ft).



Lake expansion-contraction cycle on the order of 160cm (~5 ft.) within an organic-lean zone (L5) of the Parachute Creek Member from PR-15 7c Core (~385-390 ft).

Key Observations:

- Individual expansion-contraction cycles occur at the 10 to 100 cm. scale in Skyline 16 and PR-15 7c.
- Cycles in organic rich zones are typically thinner than those in organic lean zones.
- Cycle boundaries are commonly marked by a transgressive lag overlain by kerogen-rich mudstone or other deeper water facies. The transgressive lag can be composed of (but is not limited to):
  - Ooid/ostracod grainstones.
  - Mud rip-up clasts.
  - Subaerial desiccation cracks.

Triangles represent individual lake expansion-contraction cycles.

Future Work:

- Finalize stratigraphic correlations at various scales including rich-lean zone couplets, individual lake expansion-contraction cycles, and marker tuffs.
- Convolve time lines (cycle boundaries and tuffs) with rich-lean zone boundaries to investigate the potential chronostratigraphic significance of these units.
- Fully integrate sedimentological descriptions with geochemical proxy data to better understand the history of lake water evolution and provenance change.
- Conduct Fourier analysis on the XRF dataset to investigate potential nested cyclicity. This cyclicity can then be combined with future geochronology studies of interbedded tuffs to investigate the periodicity of these cycles.

References:

Birgenheier, L.P., 2009. Core-based integrated sedimentologic, stratigraphic, and geochemical analysis of the oil shale bearing Green River Formation, Uinta Basin, Utah. Oil and Natural Gas Technology. Prepared for United States Department of Energy, National Energy Technology Laboratory for April 2011.

Blakey, R., Western North America paleogeographic maps; Eocene (50Ma). Accessed on 31 August, 2016. < http://cpogeosystems.com

Pietras, J.T. and Carroll, A.R., 2006, High-resolution stratigraphy of an underfilled lake basin: Wilkins Peak Member, Eocene Green River Formation, Wyoming, U.S.A. SEPM Journal of Sedimentary Research, v. 76, pp. 1197-1214.

Rowe, H.D., Loucks, R.G., Ruppel, S.C., and Rimmer, S.M., 2008, Mississippian Barnett Formation, Fort Worth Basin, Texas: Bulk geochemical inferences and Mo–TOC constraints on the severity of hydrographic restriction: Chemical Geology, v. 257, p. 16–25.

Rowe, H., Hughes, N., and Robinson, K., 2012, The quantification and application of handheld energy-dispersive x-ray fluorescence (ED-XRF) in mudrock chemostratigraphy and geochemistry: Chemical Geology, v. 324, p. 122-131.

Saboda, S.R., 2014, Inorganic geochemistry of the Trenton Limestone-Utica Shale contact based on XRF data [M.S. Thesis]: University at Buffalo, State University of New York, 82 p.

Vanden Berg, M. D., and Birgenheier, L. P., 2016. Evaluation of the Upper Green River Formation's Oil Shale Resource in the Uinta Basin, Utah. Utah Oil Shale- Science, Technology and Policy Perspectives.

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Sedimentological Descriptions and XRF Synthesis: