

# **PS Integrating a Deterministic Lithology Model for Subsurface Correlation, Eocene Green River Formation, Uinta Basin, Utah\***

**Julia E. Peacock<sup>1</sup> and J. Frederick Sarg<sup>2</sup>**

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## **Abstract**

The Green River Formation of the Uinta Basin is an Eocene lacustrine system comprised of carbonates, siliciclastics, and rich oil shales. Log evaluation is difficult, due to the formation's complex mineralogy and thin interbedded nature of diverse rock types. Historically, log correlations have used a zoned model, which excludes detail and suggests continuity that is misleading on a bed-by-bed basis. Methods to determine lithology at a finer scale by using advanced logging tools and stochastic models require specialized software, expert users, and can be cost prohibitive. However, a simple, deterministic model can be applied which utilizes widely available logging measurements: gamma ray, density, neutron porosity, and photoelectric effect. This four mineral solution gives an output of volume percent of quartz, calcite, dolomite, and mixed clay. To obtain these volume percentages, log-based calculations yield an apparent matrix density (RHOMaa) and an apparent photoelectric cross section (UMaa). These values are plotted on one of two mineral identification triangle plots: 1) quartz-calcite-dolomite; or 2) quartz-calcite-clay. The triangle utilized is determined by the gamma ray value, with low gamma ray values ("cleaner" or less clay) using the first triangle and high gamma ray values ("shaley" or more clay) using the second. The quartz and clay triangle end points are considered "floating" and are adjusted using elemental analysis on the formation. These volume percentages are normalized to sum 1, and have been filtered for adverse logging conditions. The final result is similar to elemental analysis logging tools and is obtained at a lower cost utilizing commonly available software suites. The volume percentages allow for more detailed correlations that better convey this complex lithologic system and clearly show vertical variability and stratigraphic changes from littoral to profundal lake environments. Lithofacies clearly identified by the resulting volume percentages include clean carbonate beds and oil shales. High-feldspathic content rocks generally require a more mobile quartz end point, but result in the identification of thin siliciclastic beds. Calibration of lithology is accomplished by using gamma ray and XRF data derived from nearby analogous carbonate and siliciclastic outcrops, and wireline log suites tied to core.

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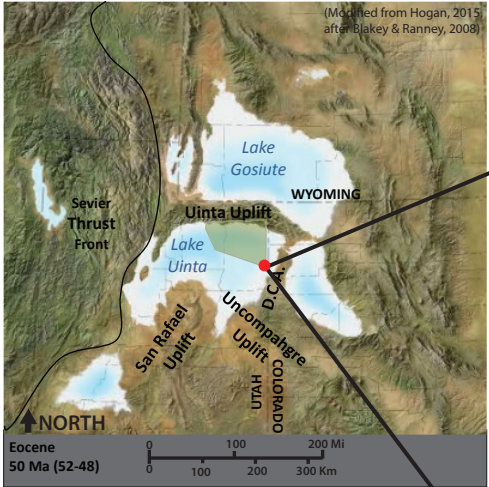
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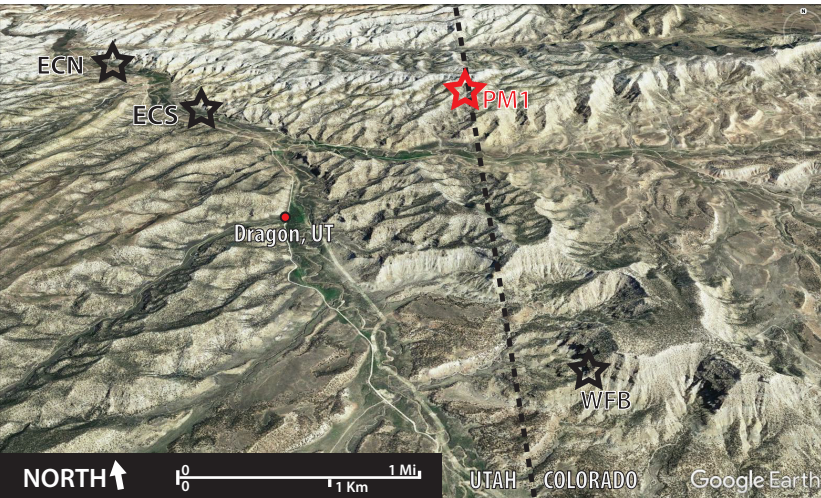
ABSTRACT

The Green River Formation of the Uinta basin is an Eocene lacustrine system comprised of carbonates, siliciclastics, and rich oil shales. Log evaluation is difficult, due to the formation's complex mineralogy and thin interbedded nature of diverse rock types. Historically, log correlations have used a zoned model, which excludes detail and suggests continuity that is misleading on a bed-by-bed basis. Methods to determine lithology at a finer scale by using advanced logging tools and stochastic models require specialized software, expert users, and can be cost prohibitive. However, a simple, deterministic model can be applied which utilizes widely available logging measurements: gamma ray, density, neutron porosity, and photoelectric effect. This four mineral solution gives an output of volume percent of quartz, calcite, dolomite, and mixed clay. To obtain these volume percentages, log-based calculations yield an apparent matrix density (RHOMaa) and an apparent photoelectric cross section (Umaa). These values are plotted on one of two mineral identification triangle plots: 1) quartz-calcite-dolomite; or 2) quartz-calcite-clay. The triangle utilized is determined by the gamma ray value, with low gamma ray values ("cleaner" or less clay) using the first triangle and high gamma ray values ("shaley" or more clay) using the second. The quartz and clay triangle end points are considered "floating" and are adjusted using elemental analysis on the formation. These volume percentages are normalized to sum 1, and have been filtered for adverse logging conditions. The final result is similar to elemental analysis logging tools and is obtained at a lower cost utilizing commonly available software suites. The volume percentages allow for more detailed correlations that better convey this complex lithologic system and clearly show vertical variability and stratigraphic changes from littoral to profundal lake environments. Lithofacies clearly identified by the resulting volume percentages include clean carbonate beds and oil shales. High-feldspathic content rocks generally require a more mobile quartz end point, but result in the identification of thin siliclastic beds. Calibration of lithology is accomplished by using gamma ray and XRF data derived from nearby analogous carbonate and siliclastic outcrops, and wireline log suites tied to core.

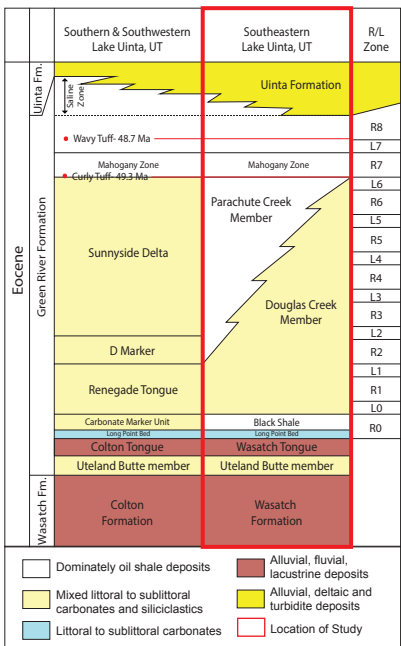
GEOLOGIC SETTING



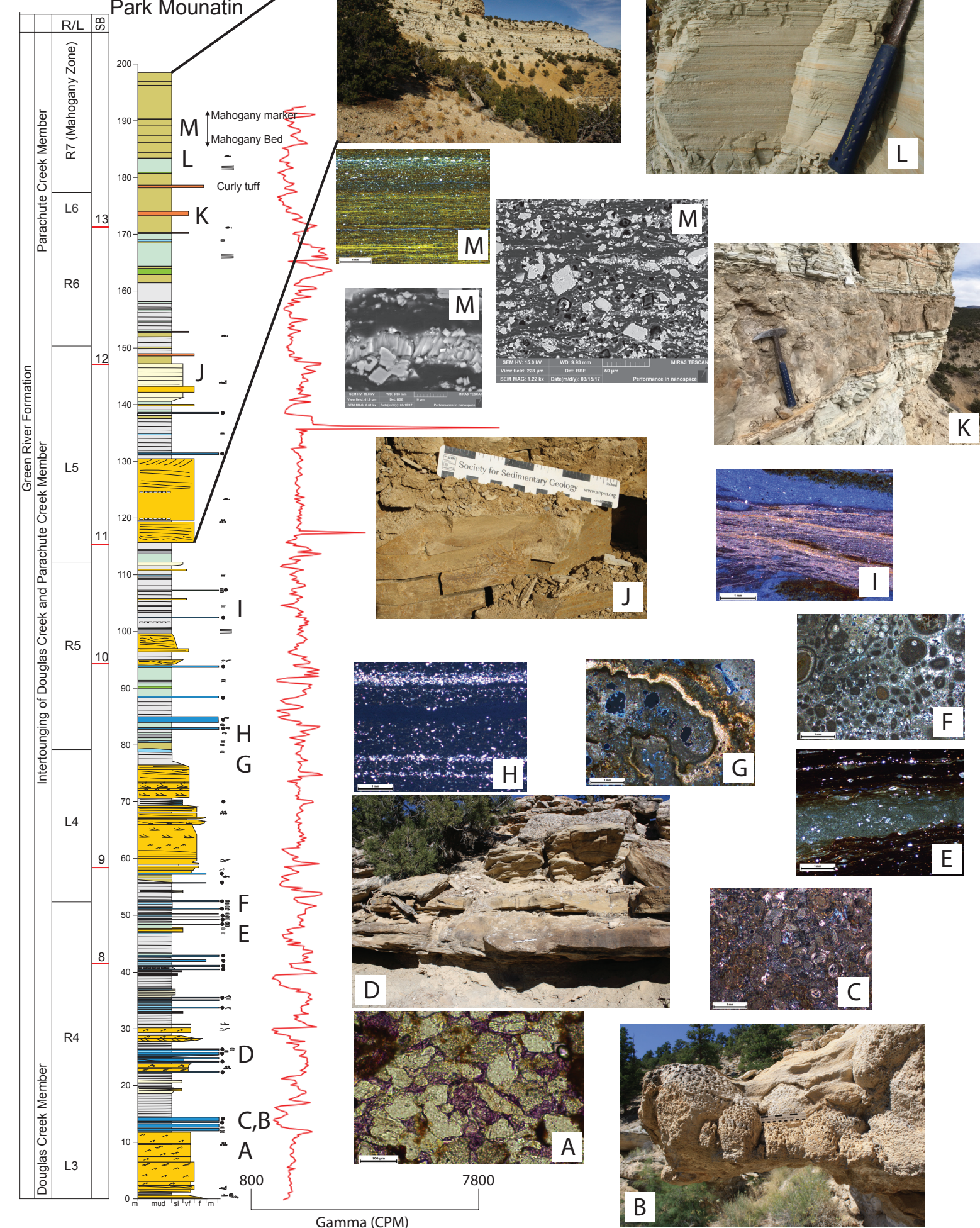
Approximate Location of Outcrop Study Area  
Study Area for Core and Well Logs



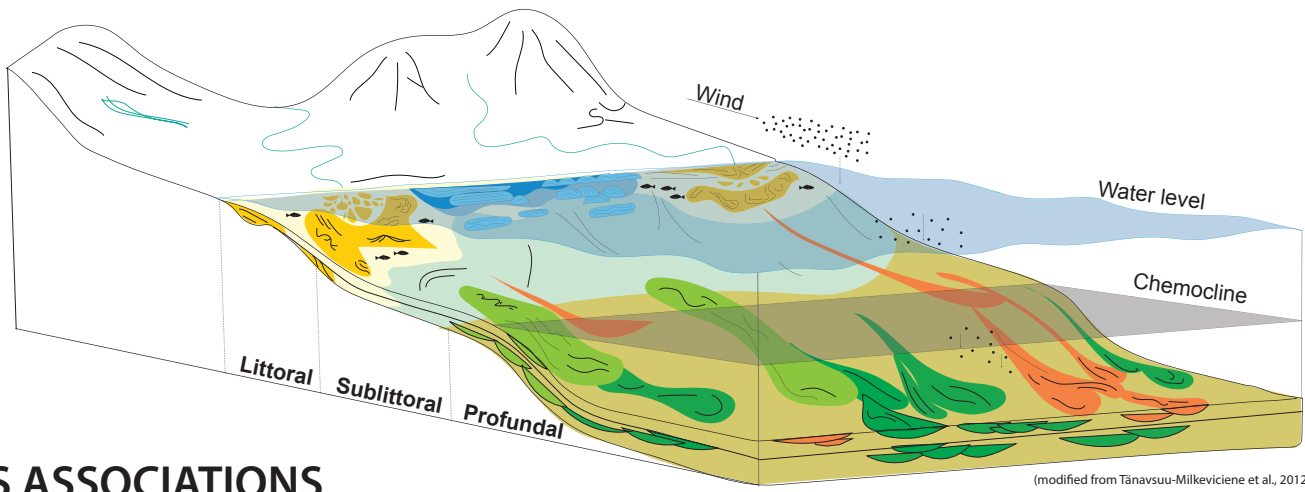
STRATIGRAPHY



MEASURED SECTION



UINTA BASIN DEPOSITIONAL MODEL



FACIES ASSOCIATIONS

Facies Association	Description	Facies	EOD
1 Carbonate shoals	Laterally extensive, sharp-based beds of carbonate wackestones to grainstones and coquina beds. Vertically associated with microbial carbonates (FA3).	Bioclast dominated limestone, nonskeletal limestone	Littoral to sublittoral
2 Microbial Carbonates	Thinly laminated or massive limestones occurring due to microbial growth. Laterally extensive beds or discontinuous columns. In association with carbonate shoals (FA1) and can overlay delta (FA2) deposits.	Microbial carbonates, nonskeletal limestone	Littoral to sublittoral
3 Calcareous mudstone	Thinly laminated or massive lime mudstones occur as laterally extensive beds or discontinuous columns. Associated with carbonate shoals (FA1) and microbial carbonates (FA3). Encased by laminated mudstones and siltstones (FA7) or oil shales (FA8, FA9, FA10).	Nonskeletal limestone	Littoral to sublittoral
4.1 Delta, mouth bar	Gradationally based (wave-dominated) or sharp based (fluvial-dominated), laterally continuous sandstone bodies. Vertically associated with turbidite (FA11) deposits. Encased by littoral to sublittoral siliciclastics (FA6) or laminated mudstones and siltstones (FA7).	Wave-ripple cross-laminated, climbing ripple cross-laminated, current-ripple cross-laminated, cross-stratified, plane-parallel, laminated, structureless	Littoral to sublittoral
4.2 Delta, channel	Laterally discontinuous sandstones or heterolithic successions of interbedded mudstones and sandstones. Encased laterally by littoral and sublittoral siliciclastics (FA6) or laminated mudstones and siltstones (FA7).	Cross-stratified, plane-parallel, laminated	Littoral to sublittoral
4.3 Delta, Turbidites	Sharp based, fining upward units. Associated with other delta deposits (FA2).	Cross-stratified, current-ripple cross-laminated, climbing ripple cross-laminated, laminated, structureless	Littoral to sublittoral
5 Littoral to sublittoral siliciclastics	Very-fine sand-rich deposits from the proximal portion of areas with higher input. Vertically associated with delta (FA2) deposits.	Climbing ripple cross-laminated, current-ripple cross-laminated, wave-ripple cross-laminated, laminated, homogeneous	Littoral to sublittoral
6 Laminated mudstones and siltstones	Mud and silt-rich deposits from the distal portion of areas with higher input. Vertically associated with delta (FA2) and littoral to sublittoral sandstones (FA6).	Laminated, plane parallel, homogeneous	Littoral to sublittoral
7 Sandy oil shales	Laminated silt-rich, kerogen-rich oil shale. Laterally and vertically associated with carbonate shoals (FA1) and microbial carbonates (FA3). Occur basinward from littoral to sublittoral siliciclastics (FA6) and pass laterally into laminated oil shales (FA9).	Laminated silt-rich oil shale, illitic oil shale	Littoral to sublittoral
8 Laminated oil shale	Laterally extensive units of rhythmically laminated oil shale deposits formed basinward from littoral to sublittoral facies associations (FA1 to FA8).	Finely laminated oil shale, illitic oil shale, Wavy laminated oil shale	Profundal
9.1 Gravitational oil shale: soft sediment deformed oil shale	Laterally discontinuous deposits containing soft sediment folds and overturned strata. Generally associated with oil shale breccias (FA10.2).	Soft sediment disturbed oil shale, Wavy laminated oil shale	Profundal
9.2 Gravitational oil shale: oil shale breccias	Laterally discontinuous deposits of matrix supported breccia. Encased laterally and vertically by laminated oil shales (FA9) and soft sediment deformed oil shale deposits (FA10.1).	Oil shale breccia	Profundal
10 Siliclastic turbidites	Normally graded or ungraded sandstone to siltstone units. Occurring basinward from delta (FA2) deposits. Vertically associated with laminated oil shales (FA9). Locally, vertically linked to soft-sediment-deformed (FA10.1) oil shale deposits.	Plane-parallel, laminated, structureless	Profundal
11 Tuff	Structureless deposits of lithified volcanic ash. Encased by laminated oil shales (FA9) and locally overlain by gravitational oil shales. Generally found in upper Green River Formation.	Tuff	Other

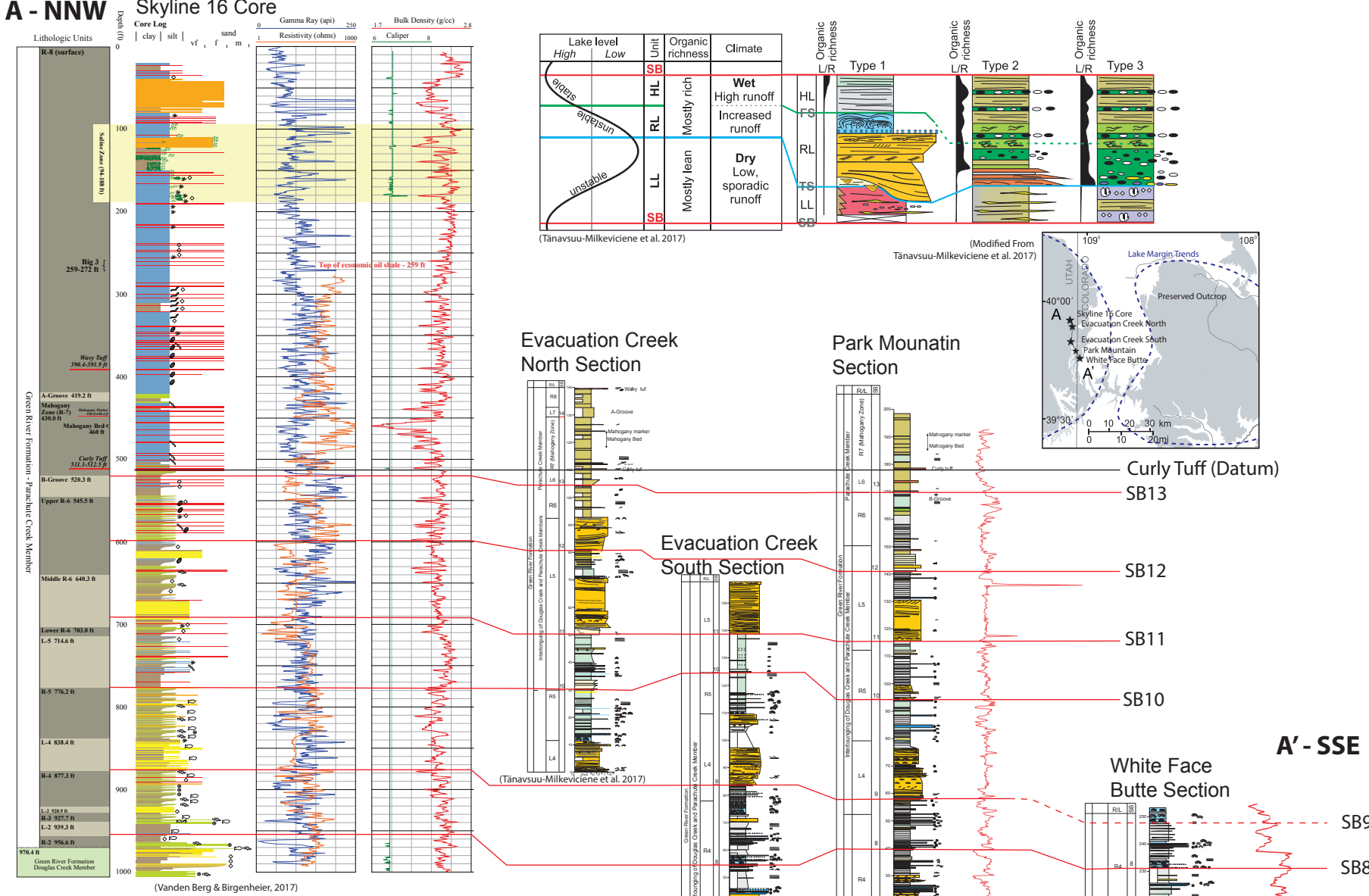


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Colorado School of Mines, Department of Geology and Geological Engineering

## CORE AND OUTCROP CROSS-SECTION



**Well name: Skyline 16**  
 Operator: UGS/U. of Utah/Sage Geotech  
 Location: T11S, R25E, Sec. 10,  
 UTM E 661445, UTM N 4415109 (NAD83)  
 Ground elevation: 6014 ft  
 Year drilled: 2010  
 Cored interval: 4 inch diameter  
 Core housed at the Utah Core Research Center

**Core Log Explanation**

Calcareous mudstone - slightly dolomitic/clay-rich	Nahcolite (NaHCO <sub>3</sub> ) nodule
Siltstone / sandstone	Small shortite/nahcolite crystals
Clay-rich mudstone - slightly calcareous/dolomitic	Pyrite / Marcasite
Dolomitic mudstone - slightly clay-rich	"Worm" fossil
Probable ash / tuff	Plant material
	Lithophyodermis sp. (botfly larvae)
	Fish remains
	Microbialites
	Abundant fractures filled with shortite [Na <sub>2</sub> Ca(CO <sub>3</sub> ) <sub>2</sub> ]
	Insect fossils
	Ooids

(Vanden Berg, & Birgenheier, 2017)

**Outcrop Explanation**

**Shoreline Facies**

- Paleosols
- Fluvial deposits

**Littoral to Sublittoral Facies Associations**

- FA1: Carbonate shoal
- FA2: Microbial carbonate
- FA3: Calcareous mudstone, microbialites
- FA4: Delta
- FA6: Littoral to sublittoral sandstones
- FA7: Sandstones and siltstones
- FA8: Sandy oil shales

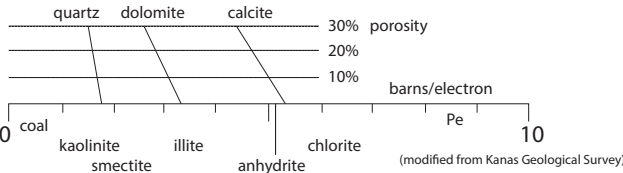
**Profundal Facies Associations**

- FA9: Laminated oil shale
- FA10: Gravitational oil shale
- FA11: Siliciclastic turbidite

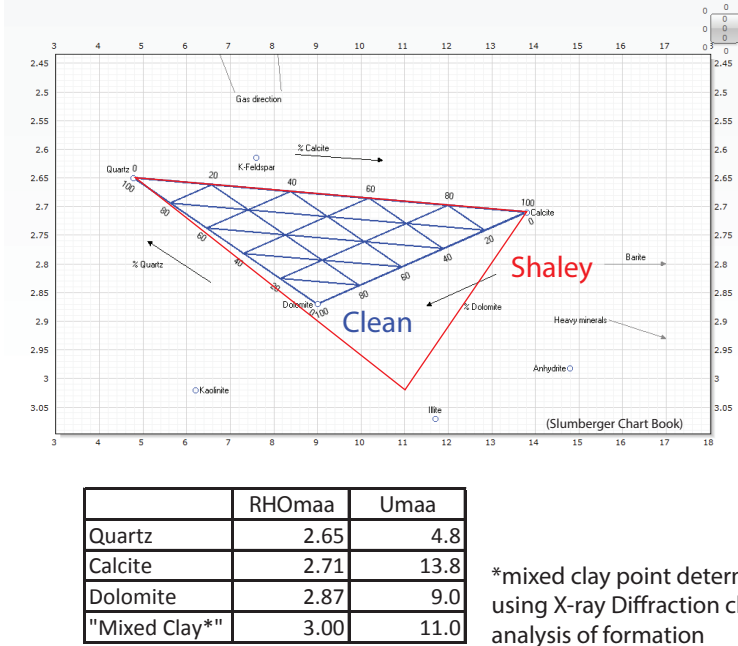
(Modified and Adapted from Tanavsuu-Milkeviciene et al. 2012)

## PHOTOELECTRIC FACTOR CURVE

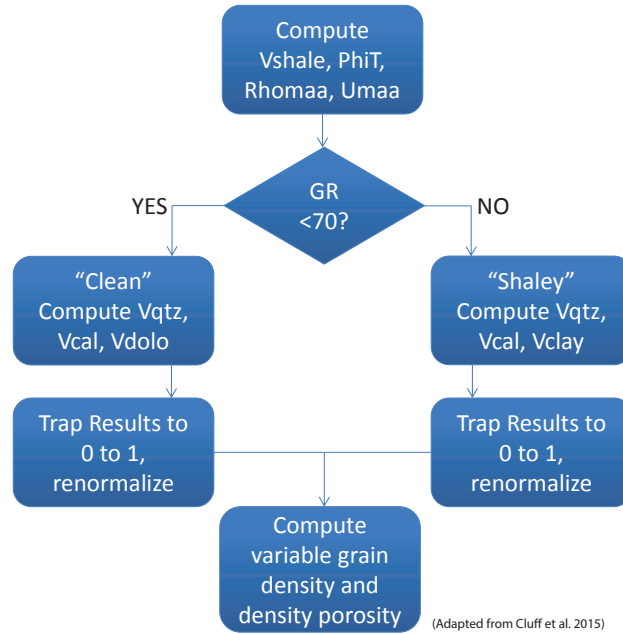
The photoelectric index (PE) is a continuous measurement taken along with the density log. The values recorded are direct reflections of the rock's aggregate atomic number, measured in barns per electron. This atomic number is indicative of the mineralogy. PE is less pore-volume effected than the density or neutron tool, and also has a finer vertical resolution than density or neutron tools. This is of interest when it is used with the neutron and density logs to calculate porosity and quantitatively resolve complex lithology of thin beds.



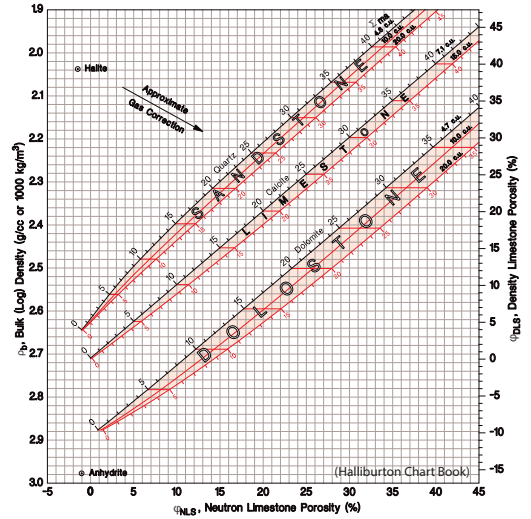
## RHOMaa-Umaa CROSS PLOT



## PETROPHYSICAL WORKFLOW



## NEUTRON DENSITY CROSS PLOT

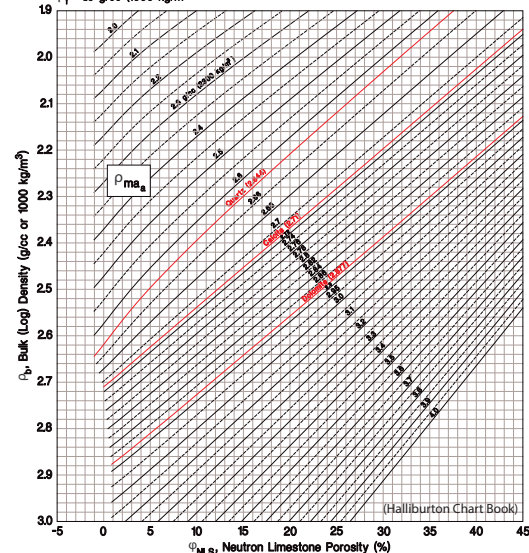


EQUIVALENT CALCULATIONS

$$\Phi_{INDxplot} \approx \frac{\Phi_{IN} + \Phi_{ID}}{2}$$

$$\Phi_{ID} = \frac{RHOMatrix - RHOB}{RHOMatrix - RHOfuid}$$

## APPARENT MATRIX DENSITY CROSS PLOT



EQUIVALENT CALCULATIONS

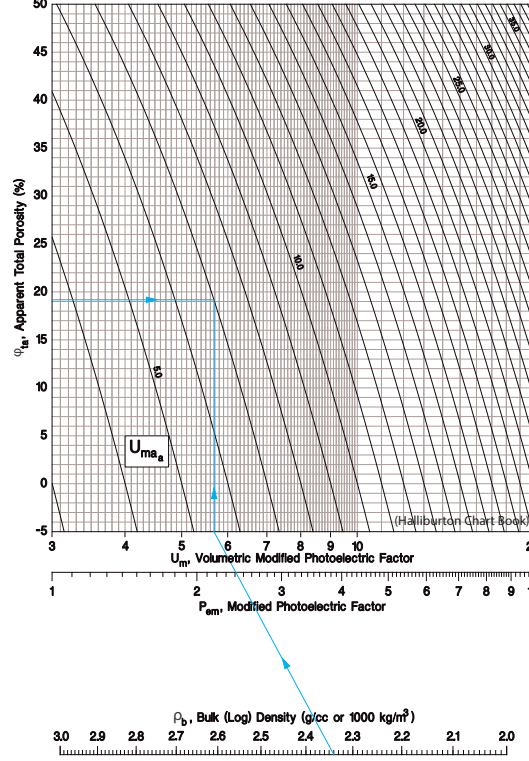
$$Rhoma = \frac{RHOB - (\Phi_{INDxplot} * RHOfuid)}{1 - \Phi_{INDxplot}}$$

$$RHOMaa = V\%_{quartz}RHOMaa_{quartz} + V\%_{calcite}RHOMaa_{calcite} + V\%_{dolomite}RHOMaa_{dolomite} + V\%_{clay}RHOMaa_{clay}$$

$$RHOMaa_{clean} = V\%_{quartz}RHOMaa_{quartz} + V\%_{calcite}RHOMaa_{calcite} + V\%_{dolomite}RHOMaa_{dolomite}$$

$$RHOMaa_{shaley} = V\%_{quartz}RHOMaa_{quartz} + V\%_{calcite}RHOMaa_{calcite} + V\%_{clay}RHOMaa_{clay}$$

## APPARENT MATRIX PHOTOELECTRIC CROSS PLOT



EQUIVALENT CALCULATIONS

$$Umaa = \frac{(Pe * RHOB) - (\Phi_{INDxplot} * Ufluid)}{1 - \Phi_{INDxplot}}$$

$$Umaa = V\%_{quartz}U_{quartz} + V\%_{calcite}U_{calcite} + V\%_{dolomite}U_{dolomite} + V\%_{clay}U_{clay}$$

$$Umaa_{clean} = V\%_{quartz}U_{quartz} + V\%_{calcite}U_{calcite} + V\%_{dolomite}U_{dolomite}$$

$$Umaa_{shaley} = V\%_{quartz}U_{quartz} + V\%_{calcite}U_{calcite} + V\%_{clay}U_{clay}$$

UNITY CALCULATION

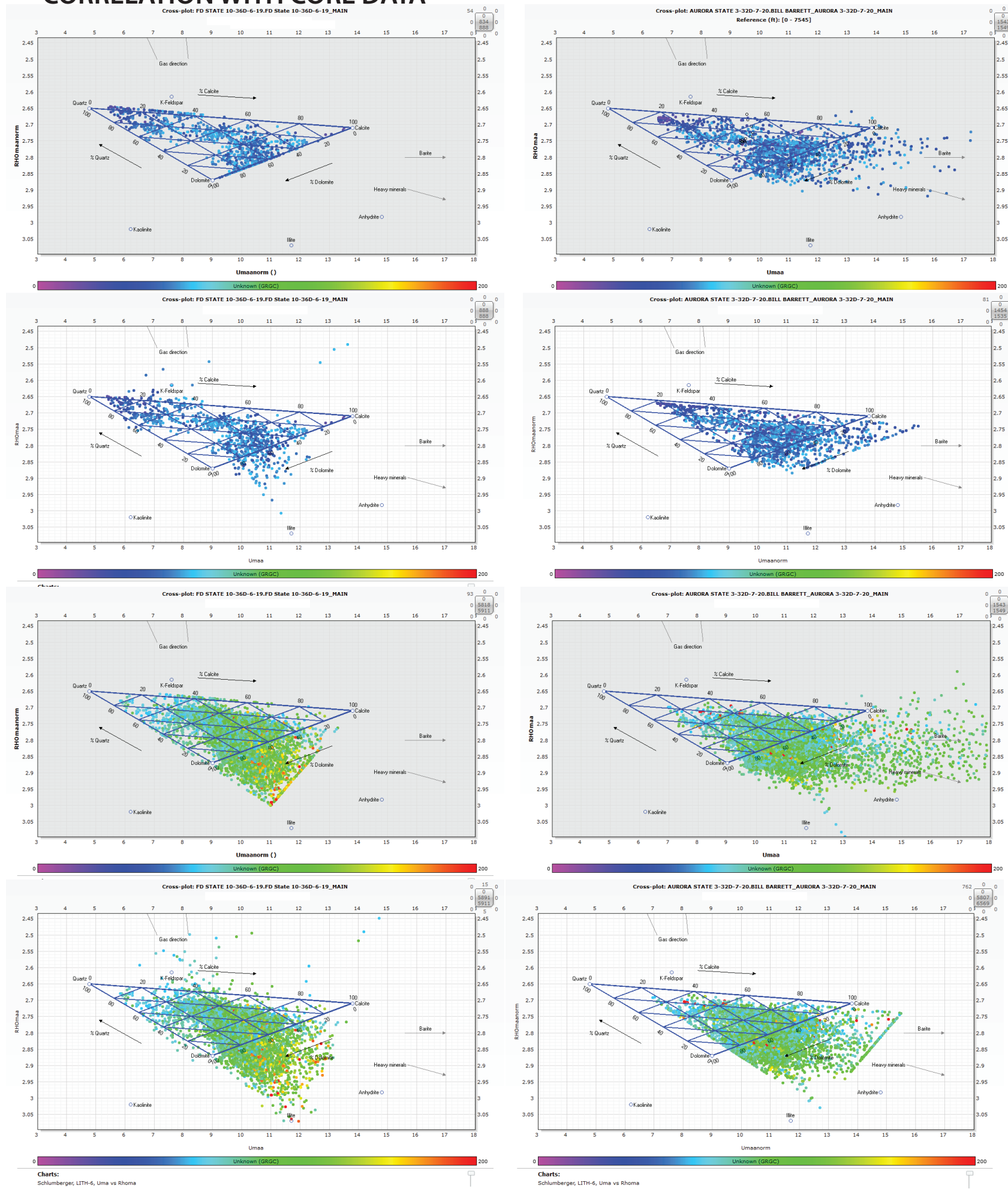
$$Unity 1 = V\%_{quartz} + V\%_{calcite} + V\%_{clay}$$



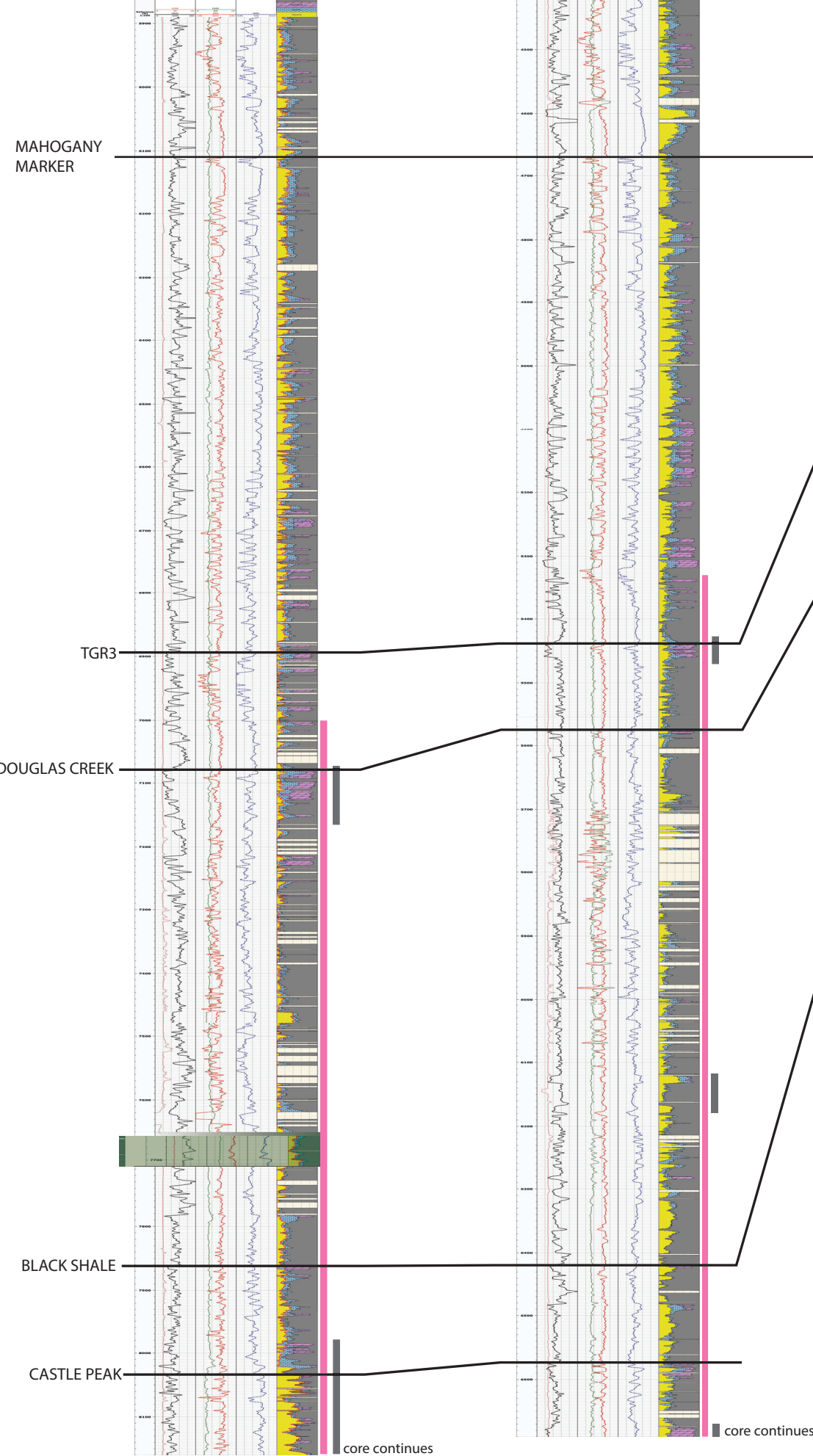
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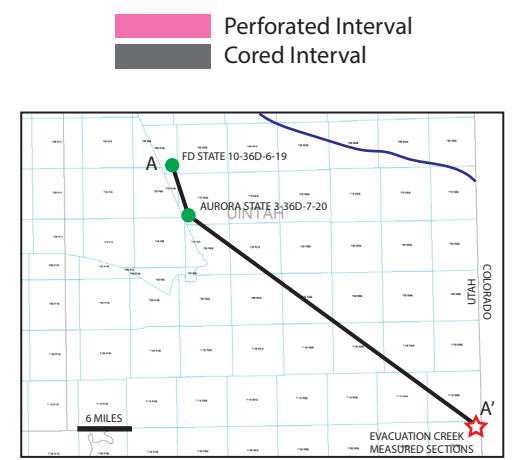
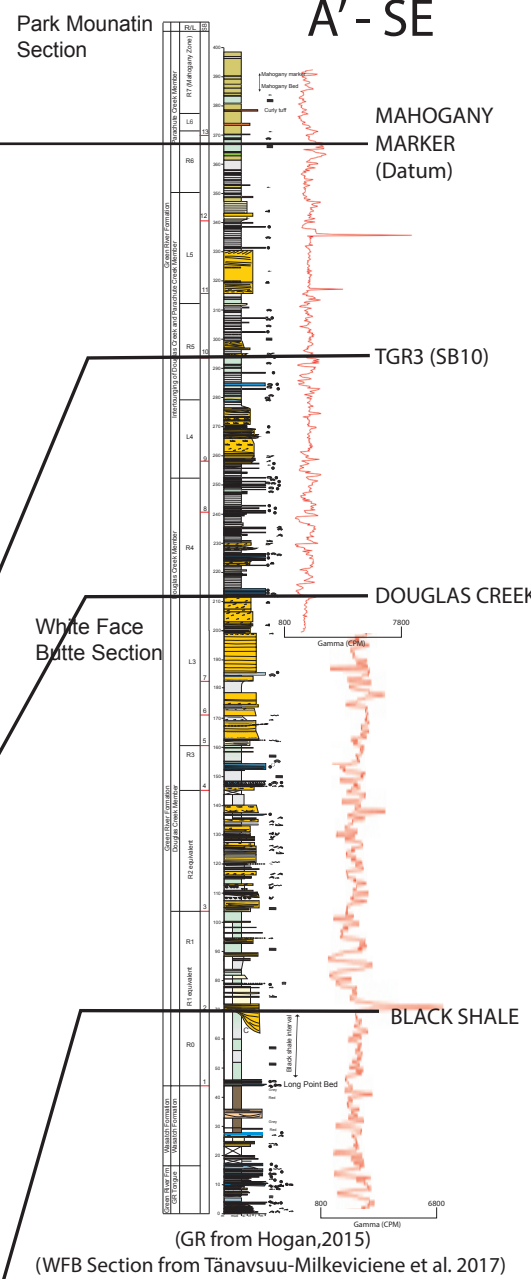
## CORRELATION WITH CORE DATA



## A - NW

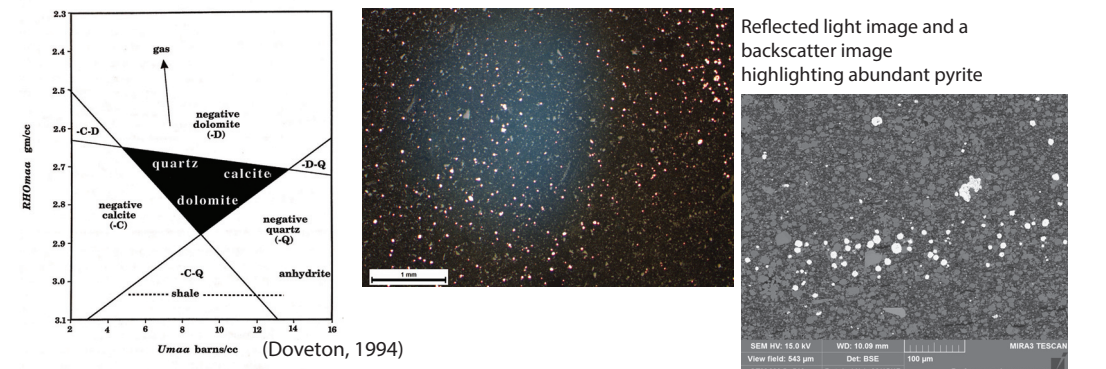


## A' - SE



## PRELIMINARY CONCLUSIONS

- Green River Foramtion contains fine interbeds of diverse lithologies
- RHOmaa-Umaa matrix identification plots yeild a finer scale lithology model at a lower cost than advanced modeling methods
- Umaa values are highly sensitive to borehole conditions and washed out zones must be eliminated
- It is necessary to “normalize” the data to some extent, so that calculations do not yield negative mineral volumes (using Doveton, 1994)
- Not all wells are the same and endpoints are not definite- X-ray Diffraction (XRD) clay analysis is necessary to set the mixed clay point and XRD bulk analysis or core is necessary to check the model’s accuracy
- Clay mineralogies change through the system, it is necessary to change the clay point as the proportions of clays change
- Abundant pyrite can skew end-points- pyrites high density and high photoelectric factor values cause scatter outside of the defined triangle
- Dolomite is present throughout the section, so when shaley intervals are calculated the shale values will appear higher (as only three end-points can be calculated for at one time)



## FURTHER WORK

- Perform XRD clay analysis to identify the clays in the Park Mountain Section
- Further SEM work to examine mineralogy with the EDS and automated mineralogy on thin sections to examine distribution of fine-grained lithologies
- Examine collected X-ray Florescence data to identify elemental trends, and use XRD and automated mineralogy to estimate minerals from elemental data
- Incorporate and correlate more wells, especially more basin-center wells
- High-grade tops to create a denser network of correlations
- Determine clay changes through the formation and create matrices to fit these changes

## ACKNOWLEDGMENTS

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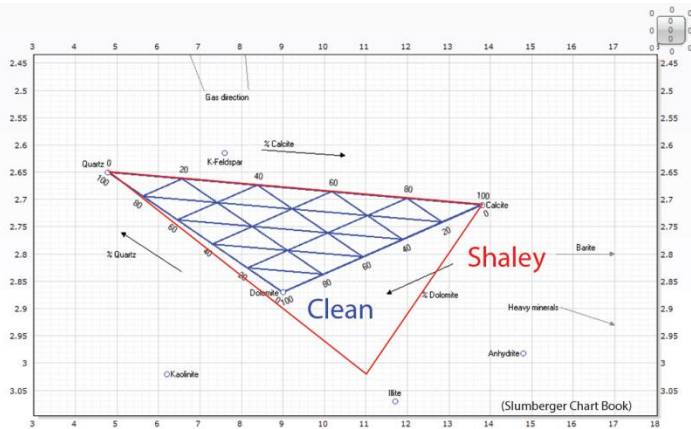


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## POSTER SUMMARY

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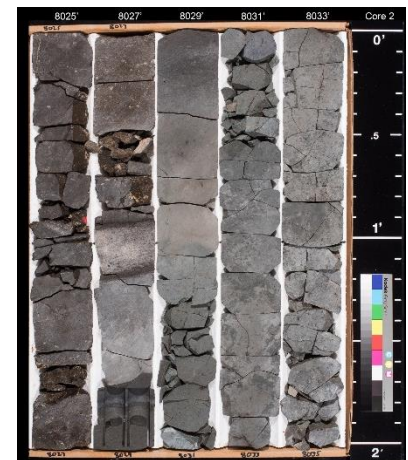
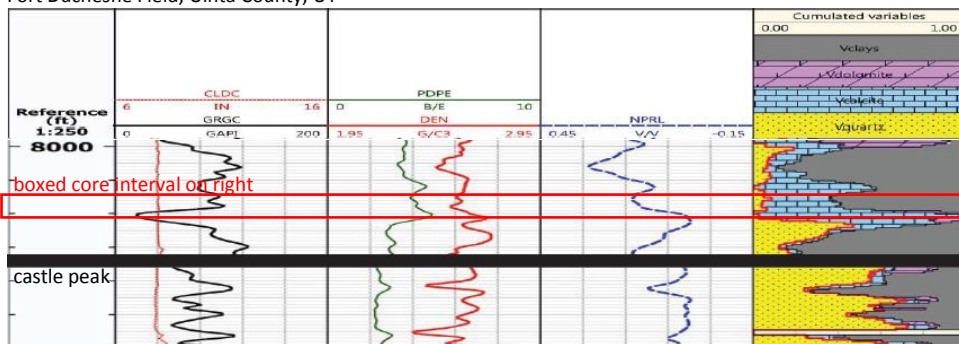
$$Rhoma = \frac{RHOB - (PhiNDxplot * RHOfluid)}{1 - PhiNDxplot}$$

$$Umaa = \frac{(Pe * RHOB) - (PhiNDxplot * Ufluid)}{1 - PhiNDxplot}$$

$$PhiNDxplot \approx \frac{PhiN + PhiD}{2}$$

These values are plotted on one of two mineral identification triangle plots: 1) quartz-calcite-dolomite; or 2) quartz-calcite-clay. The triangle utilized is determined by the gamma ray value, with low gamma ray values ("cleaner" or less clay) using the first triangle and high gamma ray values ("shaley" or more clay) using the second. The quartz and clay triangle end points are considered "floating" and are adjusted using elemental analysis on the formation. These volume percentages are normalized to sum 1, and have been filtered for adverse logging conditions. The result is similar to elemental analysis logging tools and is obtained at a lower cost utilizing commonly available software suites.

Bill Barrett Corp.  
FD State 10-36D-6-19  
Fort Duchesne Field, Uinta County, UT



The volume percentages allow for more detailed correlations that better convey this complex lithologic system and clearly show vertical variability and stratigraphic changes from littoral to profundal lake environments. Lithofacies clearly identified by the resulting volume percentages include clean calcite beds and sandstones. However, from outcrop and core analysis, there is often dolomite present in the presence of clays, but with the three-point system high clay rocks exclude dolomite. This problem causes clay volumes to appear higher when dolomite is excluded. High-feldspathic content rocks generally require a more mobile quartz end point, especially when pyrite or organic matter is present. Calibration of mineralogy end points is accomplished by using gamma ray and XRD data derived from wireline log suites tied to core as well as nearby outcrops. Further work to be completed includes XRD clay analysis on the Park Mountain Section, SEM and automated mineralogy to examine fine-grained lithologies, interpret collected XRF data to estimate minerals from elemental data, calculate and incorporate more well data, and high grade tops to create a denser network of correlations.