PS Lacustrine Microbialite Architectural and Chemostratigraphic Trends: Green River Formation, Eastern Uinta Basin, Colorado and Utah*

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Abstract

Marginal lacustrine carbonates of the Green River Formation are well exposed in the eastern Uinta Basin, where they are interbedded with fluvial and lacustrine sand and shale of the Douglas Creek Member. This study examines the stratigraphic architecture, lithofacies, and chemostratigraphy of the microbialite and other associated carbonate beds in the eastern Uinta Basin, Colorado and Utah. Two facies associations occur within the carbonate units: Lacustrine Margin Carbonates, consisting of six packstone to rudstone lithofacies dominating littoral to upper sublittoral environments; and Lacustrine Microbial Carbonates, consisting of stromatolitic and thrombolitic lithofacies, dominating littoral to lower sublittoral zones. These are consistent with earlier work done by Swierenga et al., (2015) and Sarg et al., (2013) on similar beds in the surrounding area within the Uinta and Piceance basins respectively.

Multiple scales of carbonate cyclicity, indicated by excursions of $\delta^{18}O$ and $\delta^{13}C$ stable isotopes correlate to characteristic microbialite facies. Bed set scale cycles, on the order of 1 to 5 m, are characterized by deepening upward lithofacies that correlate to positive excursions of stable isotopes. Large scale trends, on the order of 10's to 100's of meters, are also observed in this study, and relate microbialite lithofacies to lake stage evolution developed by Tänavsuu-Milkeviciene and Sarg, (2012).

Lake stage 1 (fresh to mesosaline) corresponds to initial sparse microbialite deposition, with low diversity and relatively light $\delta^{18}O$ and $\delta^{13}C$ isotopic values that indicate initial fresh water conditions and relatively low paleo-organic productivity. Lake stage 2 (transitional lake) corresponds to moderate microbialite diversity, larger biostromal and biohermal build ups, and heavier $\delta^{18}O$ and $\delta^{13}C$ isotopic values that characterize more saline conditions and higher paleo-organic productivity in the lake. Lake stage 3 (highly fluctuating lake) contains the highest microbialite diversity and marks the interval of heaviest $\delta^{18}O$ and $\delta^{13}C$ isotopic values; suggesting high paleo-organic productivity and the greatest lake restriction and highest salinity and alkalinity conditions. Lake stage 4 (rising lake) contains the last observed microbialite deposits and marks the lowest microbialite diversity and a reversal in trend of $\delta^{18}O$ and $\delta^{13}C$ isotopic values; indicating freshening conditions and a decrease in paleo-organic productivity.

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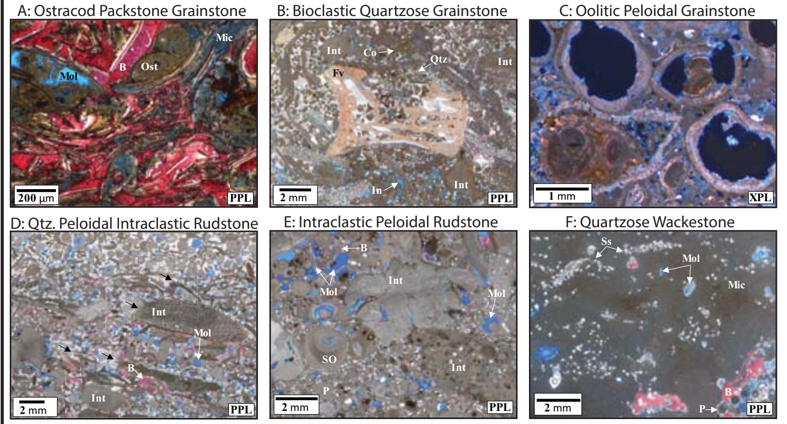
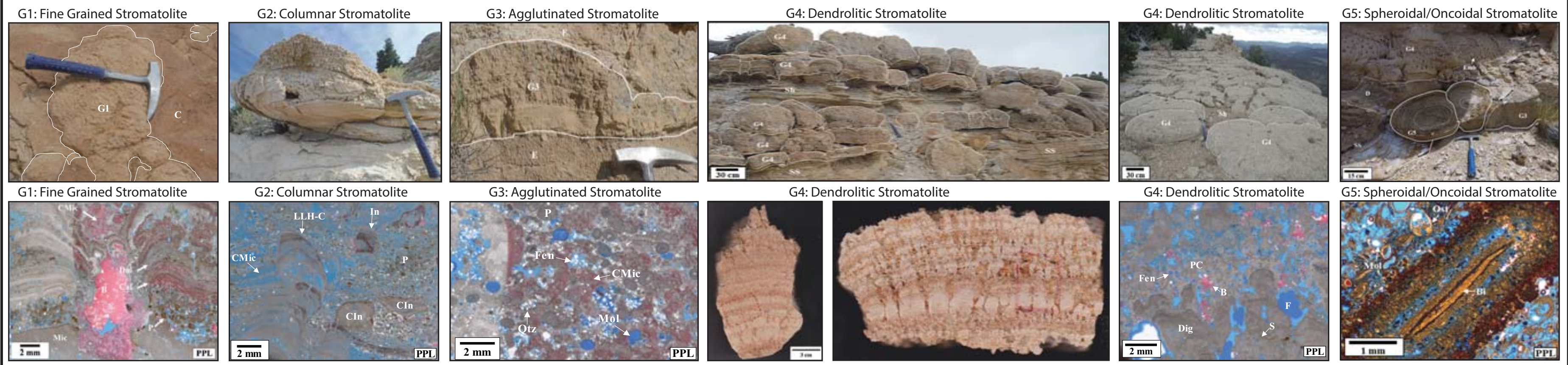
Carbonate Facies Analysis

Facies Association 1: Lake Margin Carbonates

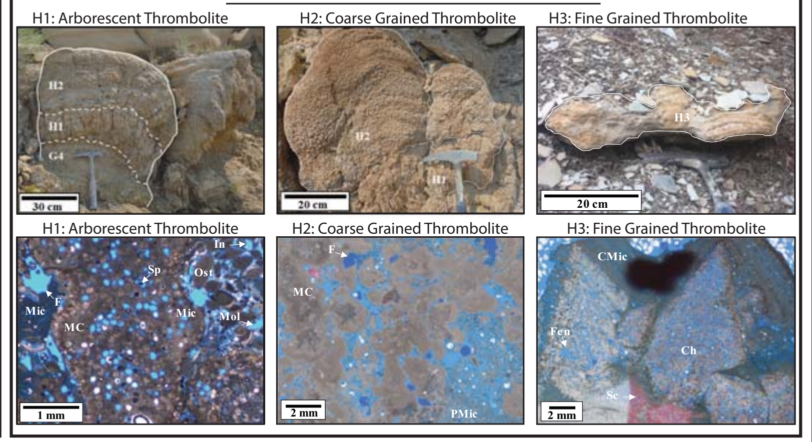


Facies Association 2: Microbial Carbonates

Lithofacies G: Stromatolite Boundstone



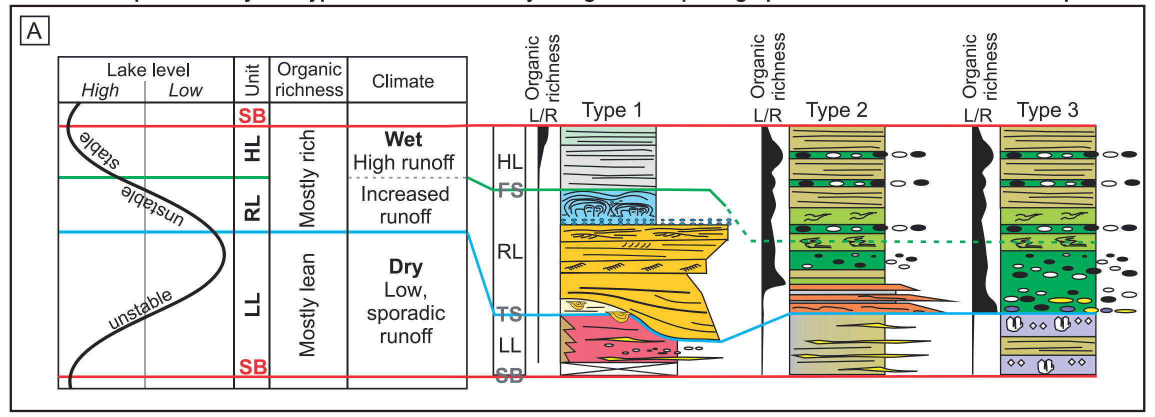
Lithofacies H: Thrombolite Boundstone



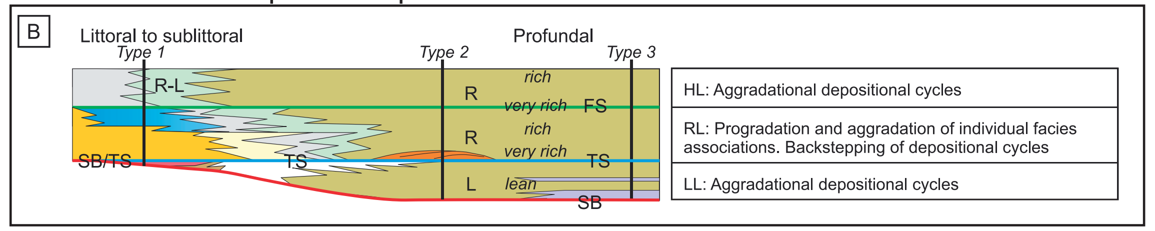
Depositional Framework (Interpretation)

Proposed model of formation of idealized deposition cycles and depositional seqeunces based on changes in catchement (modified from Tanavsuu-Milkeviciene et al., 2017)

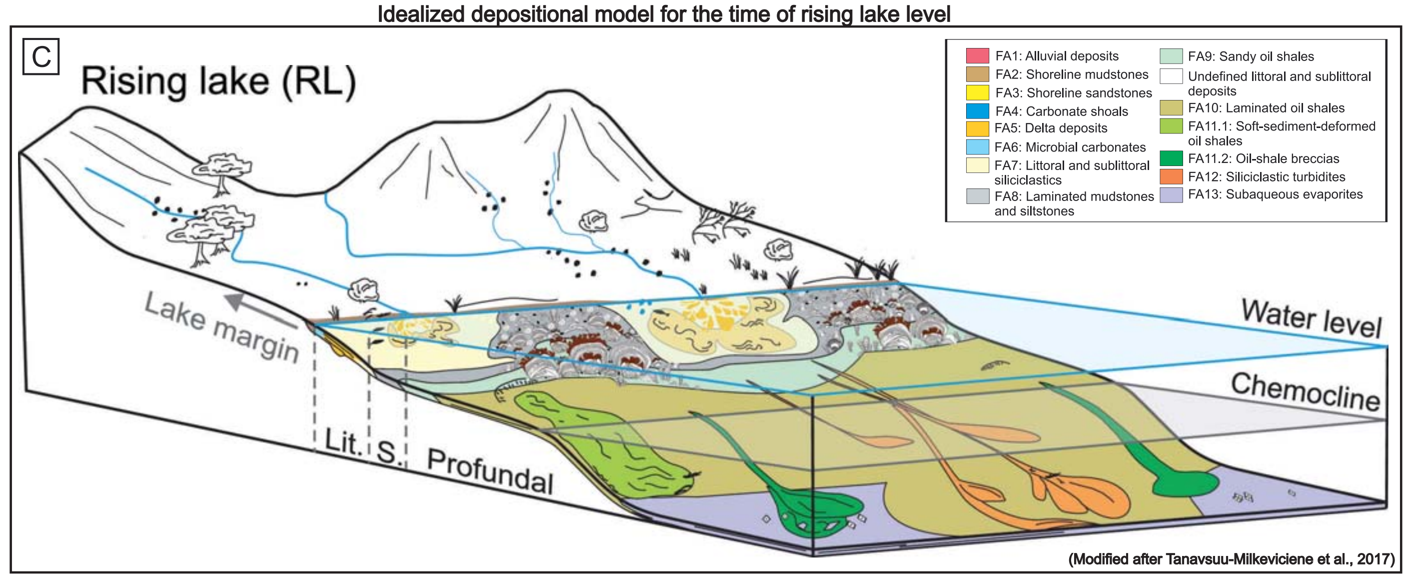
Idealized depositional cycle "Type 1" characterized by fining and deepening upward littoral and sublittoral deposits



Idealized depositional sequence with characteristic facies association distribution



Idealized depositional model for the time of rising lake level



(Modified after Tanavsuu-Milkeviciene et al., 2017)

Facies Summary Table

Facies Association	Lithofacies	Lithofacies	Subfacies	Dominant Fabrics or Grains	Depositional Environment
Lacustrine Margin Carbonates	A	Ostracod Packstone Grainstone	-	Ostracods, quartz, bivalve and gastropod fragments	Upper littoral
	B	Bioclastic Quartzose Packstone-Grainstone	-	Bivalve and gastropod fragments, fish bones, fish scales, fragmented mcirobialite clasts, quartz	Upper to middle littoral
	C	Oolitic Peloidal Packstone-Grainstone	-	Ooids, composite ooids, superficial ooids, peloids	Upper littoral
	D	Quartzose Peloidal Intraclastic Grainstone-Rudstone	-	Quartz, peloids, fragmented microbialite clasts, ooids, intraclasts	Upper to middle littoral
	E	Intraclastic Peloidal Packstone-Grainstone-Rudstone	-	Intraclasts, fragmented microbialite clasts, peloids, ooids	Lower littoral
	F	Quartzose Wackestone	-	Quartz, peloids, micritic matrix,	Lower littoral

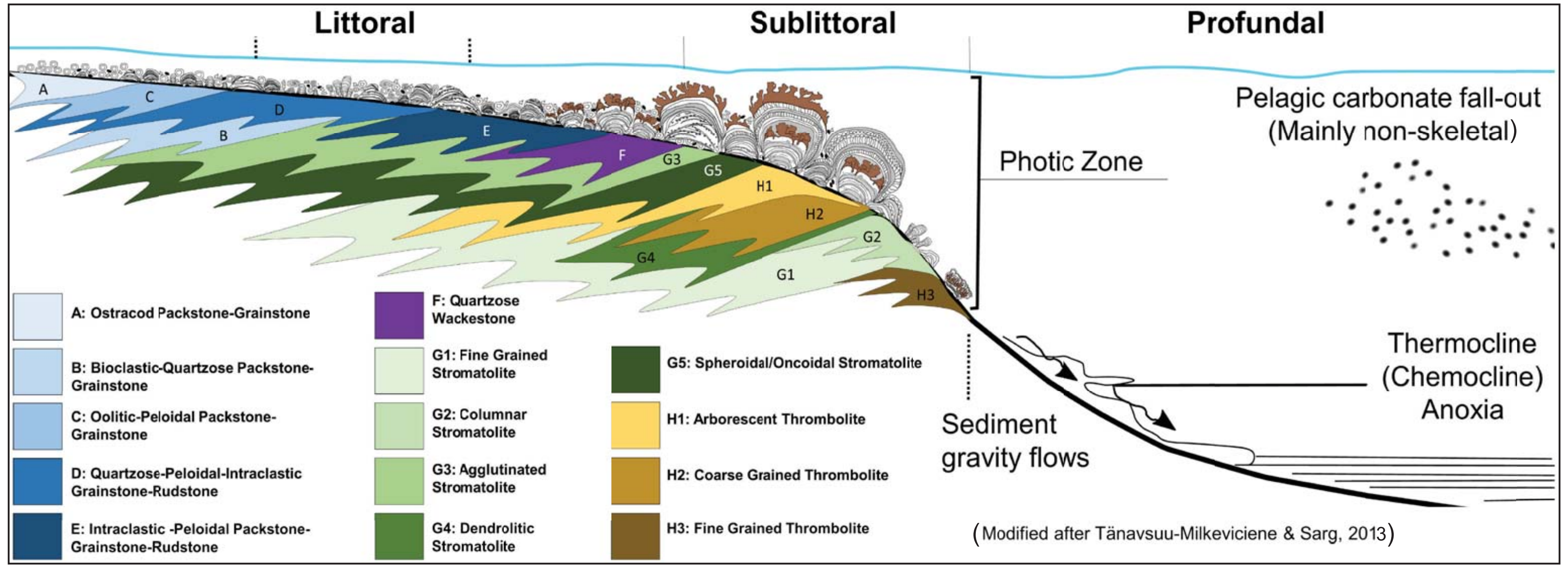
Facies Association	Lithofacies	Lithofacies	Subfacies		Dominant Fabrics or Grains	Depositional Environment
Lacustrine Microbial Carbonates	G	Stromatolites	G1	Fine Grained Stromatolite	Fine to micro lamianted	Lower littoral to lower sublittoral
			G2	Columnar Stromatolite	Columnar, fine to micro-laminated	Lower sublittoral
			G3	Agglutinated Stromatolite	Agglutinated	Upper littoral to upper sublittoral
			G4	Dendrolitic Stromatolite	Dendrolitic, digitate, clotted	Middle sublittoral
			G5	Spheroidal/Oncoidal Stromatolite	Spheroidal, concentrically laminated	Upper to lower littoral
	H	Thrombolite	H1	Arborescent Thrombolite	Coarse clotted	Lower littoral to upper sublittoral
			H2	Coarse Grained Thrombolite	Coarse clotted	Middle sublittoral
			H3	Fine Grainted Thrombolite	Fine clotted	Lower sublittoral

Depositional Model (Interpretation)

Idealized model of the lateral carbonate facies distribution observed in the Uinta basin.
Two Carbonate Facies Associations:

Facies Association #1 = Lake-Margin Carbonates
- Lithofacies A, B, C, D, E, and F
- Grain dominated packstones, grainstones, and rudstones
- Upper to middle littoral (shoreface) depositional environment

Facies Association #2 = Lacustrine Microbial Carbonates
- Lithofacies G (stromatolite) and H (thrombolite)
- Dominated by biohermal and biostromal build ups
- Middle littoral (shoreface) to lower sublittoral (fair-weather wave base to storm wave base) depositional environment

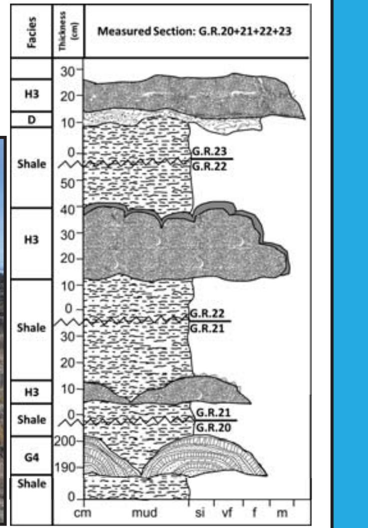


(Modified after Tänavsuu-Milkeviciene & Sarg, 2013)

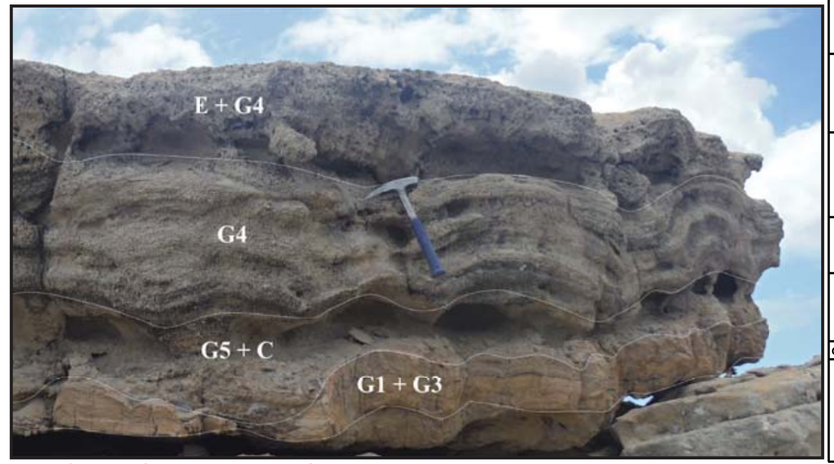
Depositional Cycles

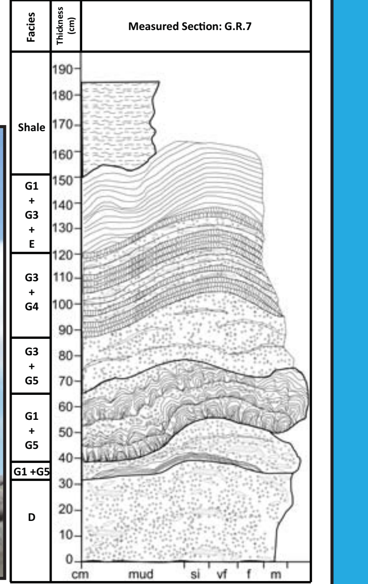
Vertical Facies Trends and Deepening Cycles

Lake Stage 4 (Rising Lake) carbonate cycle:
- Low microbialite diversity
- Small microbialite megastructures
- Dominated by oil shale

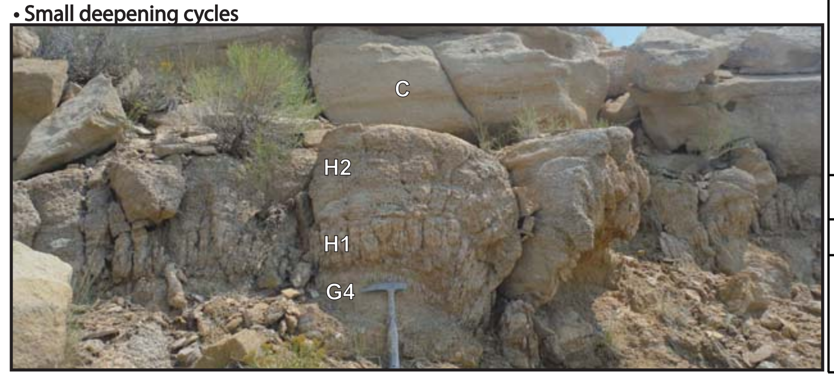


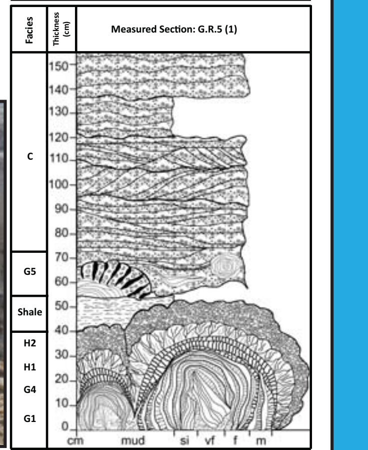
Lake Stage 3 (Highly Fluctuating Lake) carbonate cycle:
- Highest microbialite diversity,
- Large microbialite megastructures
- Distinct deepening cycles



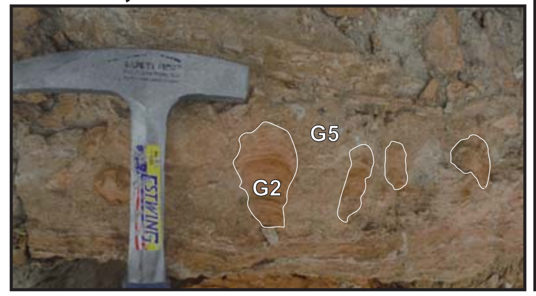


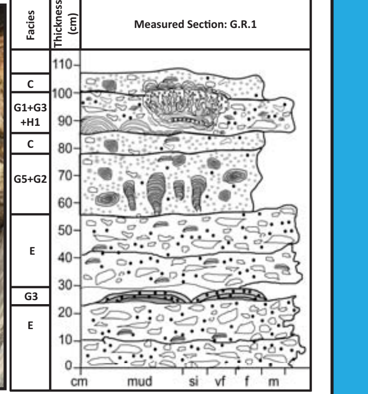
Lake Stage 2 (Transitional Lake) carbonate cycle:
- Moderate microbialite diversity
- Large microbialite megastructures
- Small deepening cycles





Lake Stage 1 (Fresh Lake) carbonate cycle:
- Low microbialite diversity
- Small microbialite megastructures
- Indistinct cycles





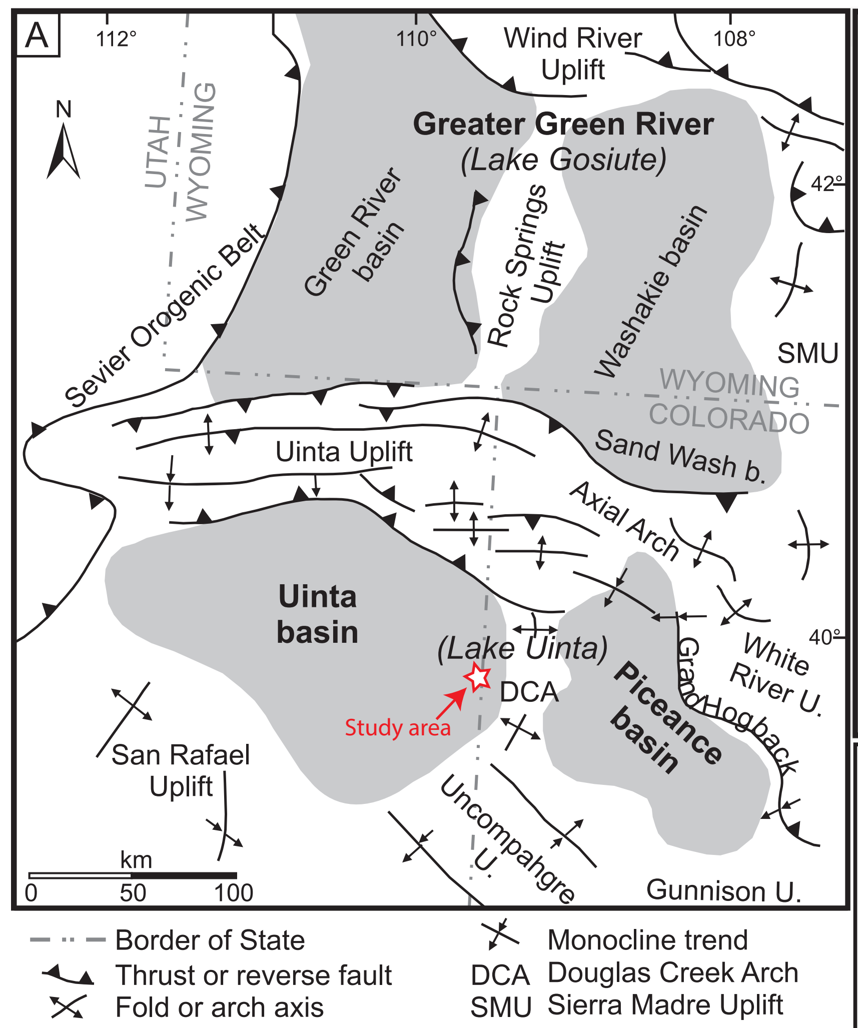
Abstract

Marginal lacustrine carbonates of the Green River Formation are well exposed in the eastern Uinta basin, where they are interbedded with fluvial and lacustrine sand and shale of the Douglas Creek Member. This study examines the stratigraphic architecture, lithofacies, and chemostratigraphy of the microbialite and other associated carbonate beds in the eastern Uinta basin, Colorado and Utah. Two facies associations occur within the carbonate units: Lacustrine Margin Carbonates, consisting of six packstone to rudstone lithofacies dominating littoral to upper sublittoral environments; and Lacustrine Microbial Carbonates, consisting of stromatolitic and thrombolitic lithofacies, dominating littoral to lower sublittoral zones. These are consistent with earlier work done by Swierenga et al., (2015) and Sarg et al., (2013) on similar beds in the surrounding area within the Uinta and Piceance basins respectively. Multiple scales of carbonate cyclicity, indicated by excursions of δ18O and δ13C stable isotopes correlate to characteristic microbialite facies. Bed set scale cycles, on the order of 1 to 5 m, are characterized by deepening upward lithofacies that correlate to positive excursions of stable isotopes. Large scale trends, on the order of 10's to 100's of meters, are also observed in this study, and relate microbialite lithofacies to lake stage evolution developed by Tänavsuu-Milkeviciene & Sarg, (2012).

Lake stage 1 (fresh to mesosaline) corresponds to initial sparse microbialite deposition, with low diversity and relatively light δ18O and δ13C isotopic values that indicate initial fresh water conditions and relatively low paleo organic productivity. Lake stage 2 (transitional lake) corresponds to moderate microbialite diversity, larger biostromal and biohermal build-ups, and heavier δ18O and δ13C isotopic values that characterize more saline conditions and higher paleo-organic productivity in the lake. Lake stage 3 (highly fluctuating lake) contains the highest microbialite diversity and marks the interval of heaviest δ18O and δ13C isotopic values; suggesting high paleo-organic productivity and the greatest lake restriction and highest salinity and alkalinity conditions. Lake stage 4 (rising lake) contains the last observed microbialite deposits, and marks the lowest microbialite diversity and a reversal in trend of δ 18O and δ13C isotopic values; indicating freshening conditions and a decrease in paleo organic productivity.

Field Area

Outcrop location of White Face Butte (WFB) and Park Canyon (PC)



Field area location on the margin of eastern Uinta basin along the Utah-Colorado border. A) Base map indicating the field location in northeastern Utah; adopted from Swierenga et al., 2015. B) Google earth image of both field locations: White Face Butte (WFB) outcrop that is located near the corner of the intersection of Dragon road and county road 109. Park Canyon (PC) outcrop, located roughly 8 miles NNW of White Face Butte. Red lines represent the traverses taken for field sample collection, descriptions, and photos.

Project Objectives

- **Document vertical and lateral variation in microbial deposits:**
  - **Megastructure - Macrostructure - Microstructure**
- **Compare carbonate bed cyclicity within the Uinta to the Piceance basin**
  - **Lithofacies cyclicity - Isotope cyclicity**
- **Investigate paleo water chemistry through chemostratigraphic trends**
  - **Overall oxygen and carbon stable isotope trends**
  - **Bed set scale trends - Microfacies scale trends**
- **Relate local observations to the overall history of Lake Uinta**
  - **Using the larger stratigraphic framework developed by Tänavsuu-Milkeviciene & Sarg, (2012)**

Hypotheses

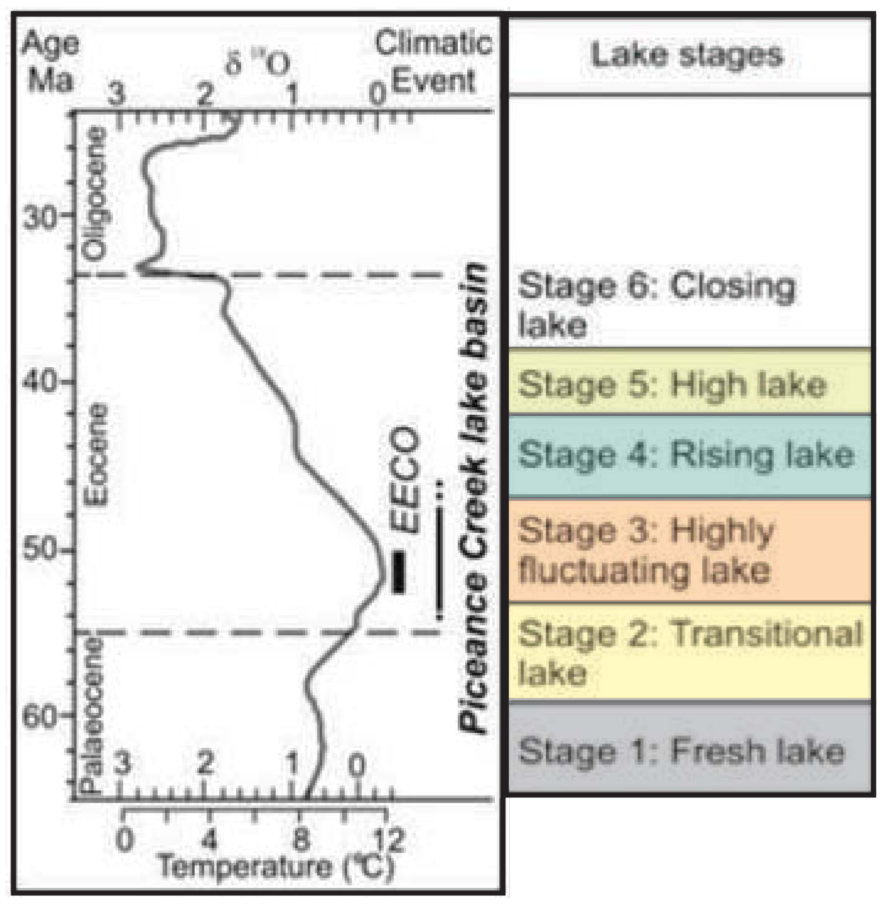
- **Hypothesis 1**: overall microbialite deposits reflect chemostratigraphic evolution of the paleo lake.
- **Hypothesis 2**: meter to several meter scale microbialite bed sets display distinct depositional trends.
- **Hypothesis 3**: millimeter to centimeter scale microbialite microtextures reflect changes in paleo lake water chemistry.

Methods

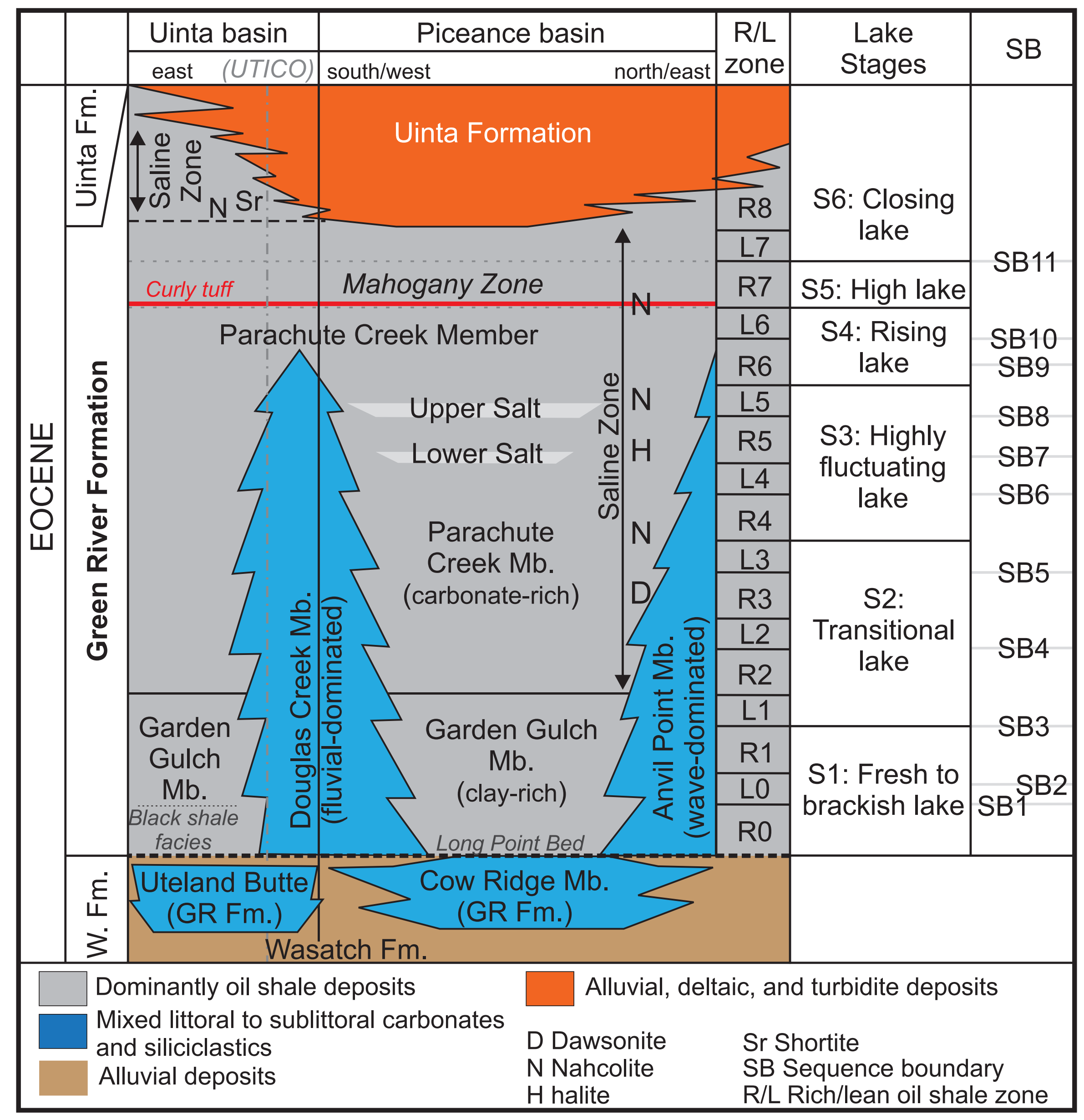
Facies Analysis:
- **23** measured sections
- **188** Polished slabs:
- **110** Thin-sections:
  - Microbialite classification:
    - Megastructure
    - Mesostructure
    - Microstructure

Stable Isotope Analysis:
- **δ13C** trends:
  - Reflect paleo-productivity and biologic processes
- **δ18O** trends:
  - Reflect lake inflow to evaporation ratios

Stratigraphy

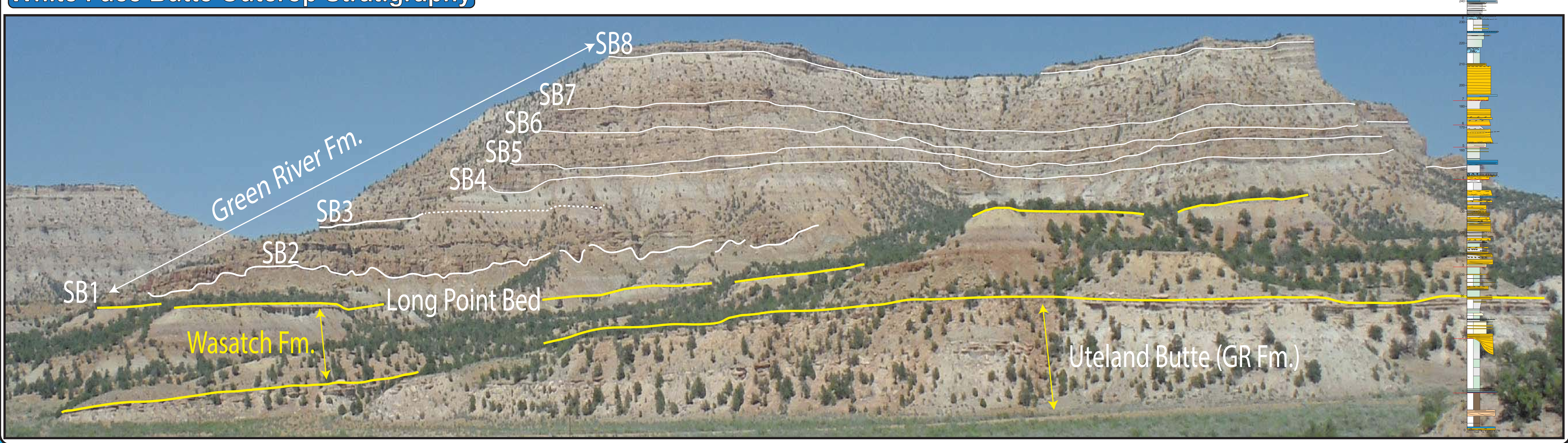


Left: Eocene climate curve after Zachos et al., 2008 correlated to time of Green River Formation deposition.
Right: Lake stage model developed by Tänasuu-Milkeviciene & Sarg,(2012)

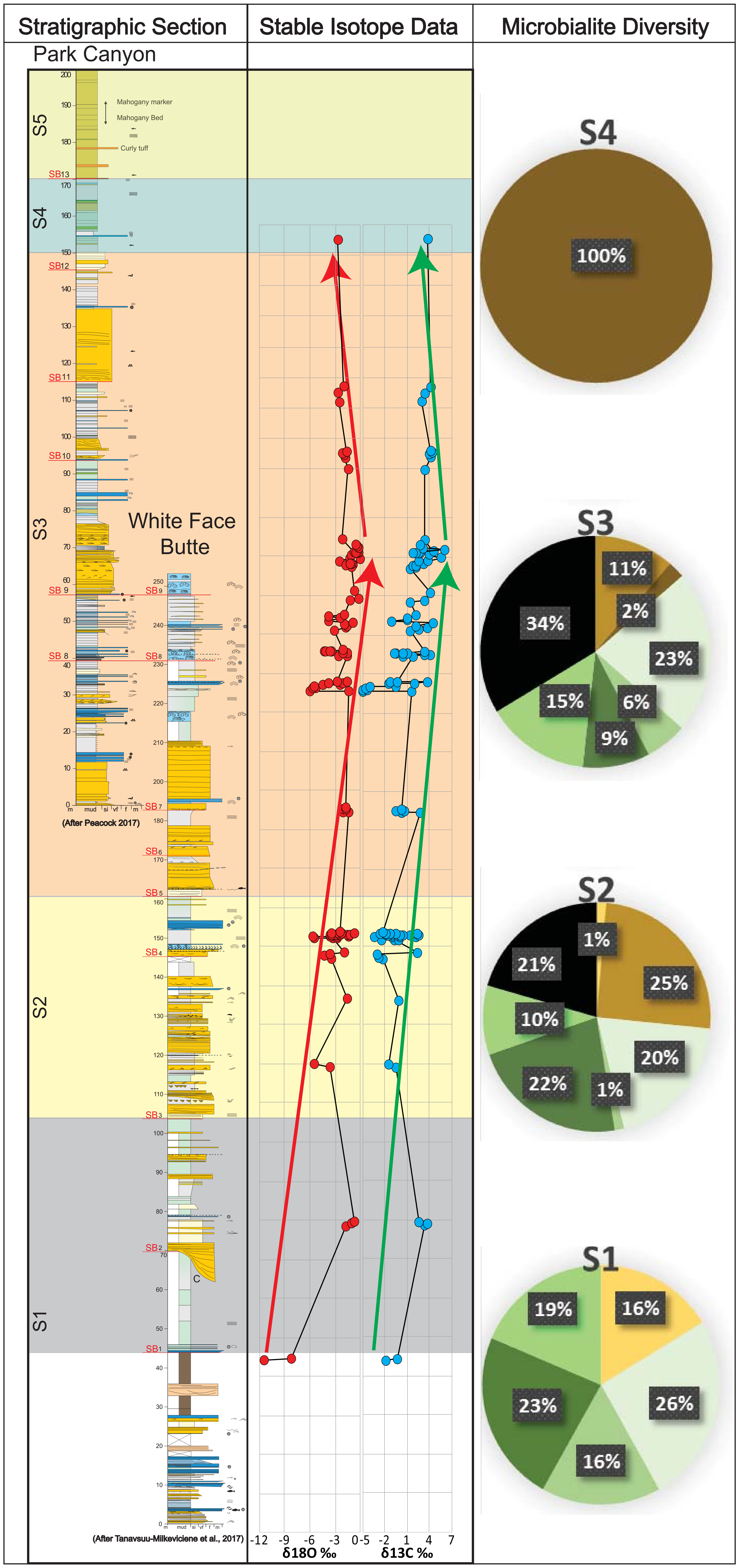


Lithostratigraphic subdivision with defined organic-rich (R) and organic-poor (L) zones, lake stages, and sequence boundaries of the lower and middle Eocene deposits in the Piceance basin and eastern part of the Uinta basin. (modified after Johnson et al. 2010a; Johnson et al. 2010b; Self et al. 2010c; Ta¨navsuu-Milkeviciene and Sarg 2012, 2015; Rich and Lean zones after Cashion and Donnell 1972, 1974; Long Point Bed after Johnson 1984).

White Face Butte Outcrop Stratigraphy

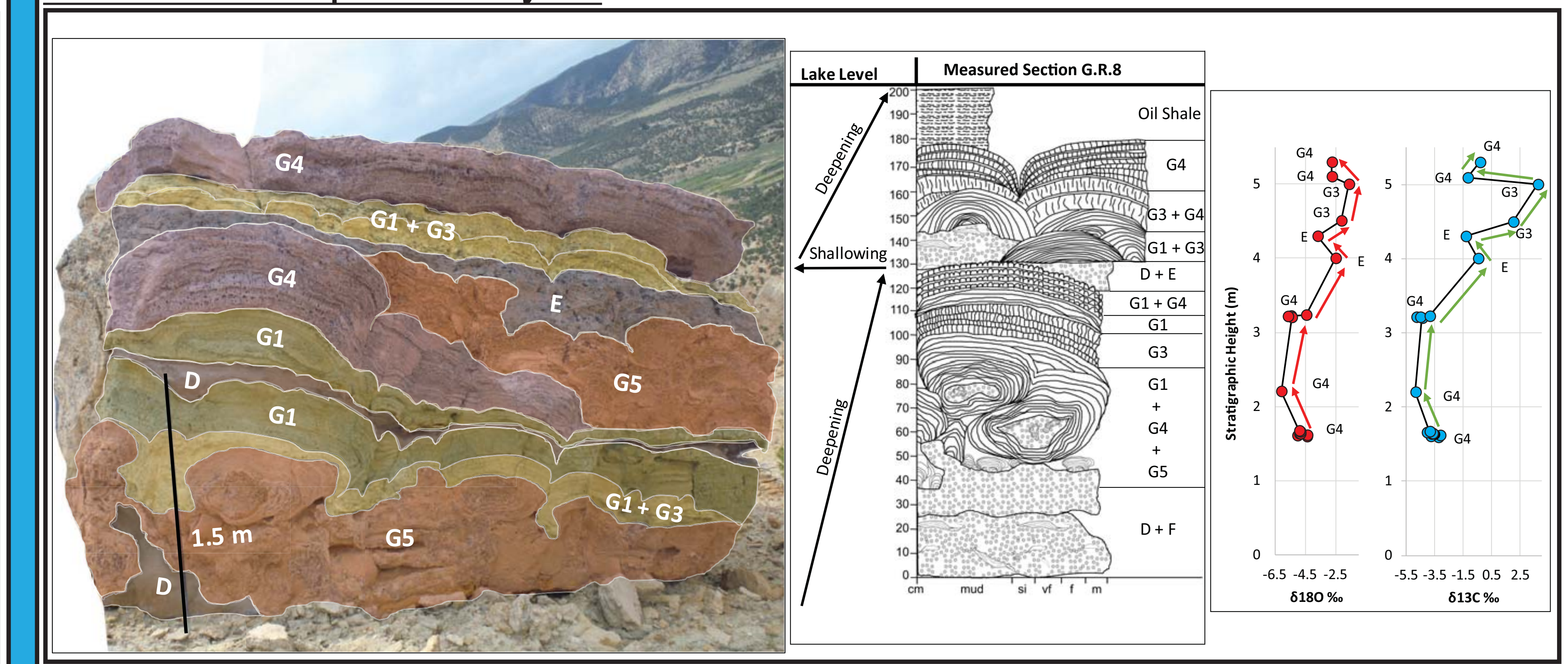


Stratigraphic Trends



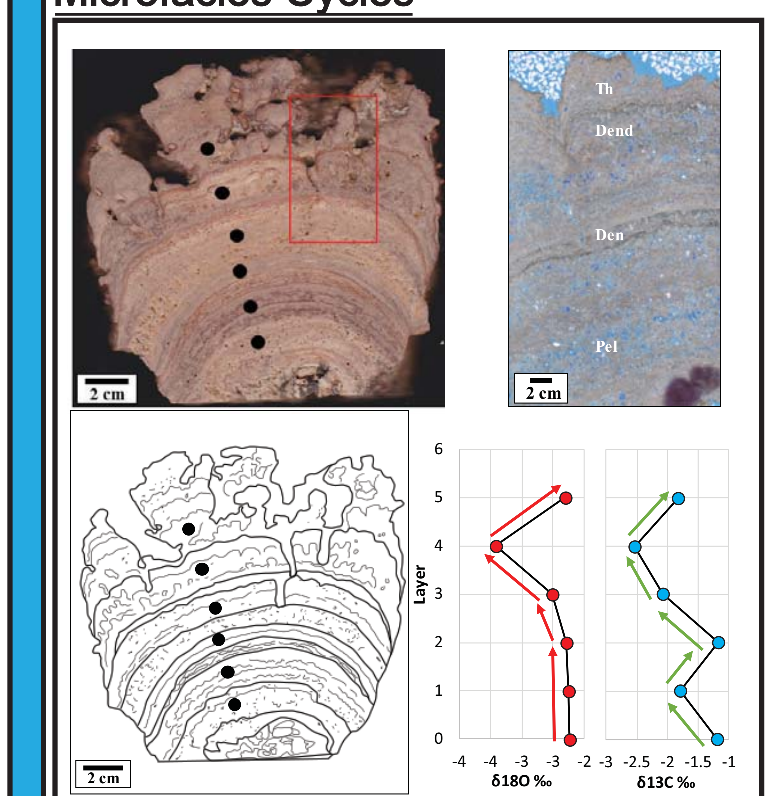
Stable Isotopes

Bed Set Scale Depositional Cycles



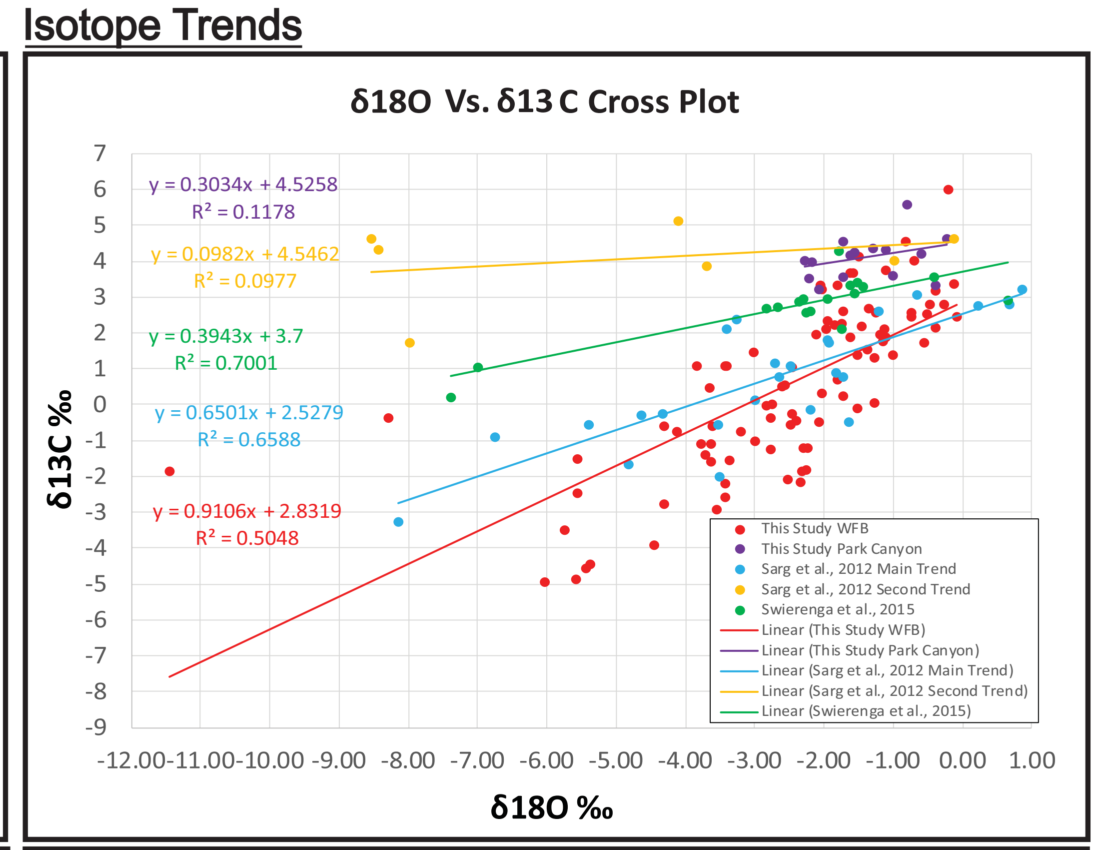
Bed set G.R.8. Left: Interpreted outcrop picture of bed set G.R.8. Blue = lithofacies D and F (quartzose-peloidal-intraclastic grainstone-rudstone and quartzose wackestone); Red = lithofacies G5 spheroidal/oncoidal stromatolite); Yellow = lithofacies G3 and G1 (agglutinated and fine grained stromatolite); Green = lithofacies G1 (crinkly laminated stromatolite); Purple = lithofacies G4 (dendrolitic stromatolite). **Center:** Measured section of G.R.8 representing typical carbonate cycles observed at the White Face Butte outcrop; black arrows indicate relative lake levels, showing two deepening upward cycles interpreted through lithofacies and isotopic analysis. **Right:** δ18O and δ13C isotopic profiles for 9 beds representing deepening upward cycles in bed set G.R.8.

Microfacies Cycles



Sample G.R.5.25.8, showing a domal fine grained stromatolite (lithofacies G1) overlain by an arborescent thrombolite (lithofacies H1) with associated isotope data targetting the different microtextures.

Isotope Trends



Data in red represent the carbonate beds at the White Face Butte (WFB) outcrop for this study. The data in purple represent the carbonate beds at the Park Canyon outcrop for this study. The data in blue represents Sarg et al., 2012's main trend from the Douglas Creek outcrop in the Piceance basin. Data in yellow represents Sarg et al., 2012's second trend from the Douglas Creek outcrop in the Piceance basin. Data in green represent Swierenga et al., 2015's study from Evacuation Creek within the Uinta basin.

Pie Chart Key:

- Arborescent Thrombolite
- Coarse Grained Thrombolite
- Fine Grained Thrombolite
- Fine Grained Stromatolite
- Columnar Stromatolite
- Spheroidal/Oncoidal Stromatolite
- Agglutinated Stromatolite
- Dendrolitic Stromatolite

Measured Section Key

Lake stages (S)

S1 - Fresh to Mesosaline Lake
S2 - Transitional Lake
S3 - Highly Fluctuating Lake
S4 - Rising Lake
S5 - High Lake
S6 - Closing Lake

Littoral to sublittoral facies associations

- Paleosols
- Fluvial deposits
- Carbonate shoal
- Microbial carbonate
- Calcareous mudstone, microbialites
- Delta
- Littoral to sublittoral sandstones
- Littoral to sublittoral mudstones/silts
- Littoral to sublittoral oil shales

Conclusions

Large scale chemostratigraphic trends:

- Overall increase in basin closure
- Overall increase in organic productivity
- Overall increase in paleo lake salinity
- Overall increase in microbialite diversity

Lake stage microbialite trends:

- S1: low diversity, small megastructures, lack of dendrolites
- S2: moderate diversity, large megastructures
- S3: most diversity, largest megastructures, abundance of dendrolites
- S4: lowest diversity, small megastructures, lack of stromatolites

Bed set scale cycles:

- Meter-scale deepening-up cycles
- Repeated positive excursions of δ18O
- Indicating increased paleo lake salinity
- Repeated positive excursions of δ13C
- Indicating an increase in paleo organic productivity
- Upward increase in microbialite megastructure size
- Upward decrease in grainy lake margin carbonates
- Indicating increased paleo lake water depths

Microbialite microtextures:

- Large diversity within microbialite microtextures
- No correlation to paleo lake chemistry using stable isotopes
- Preserve carbonate bed set scale cyclicity