Depositional History, Lateral Variability, and Diagenesis of Microbial Carbonates, Three Mile Canyon and Evacuation Creek, Eastern Uinta Basin, Utah

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ABSTRACT

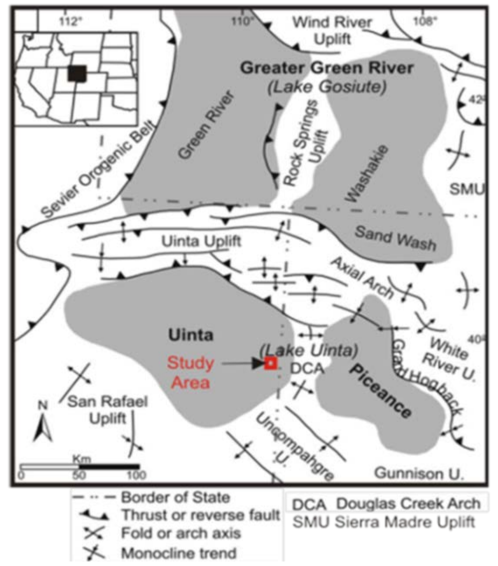
The Eocene Green River Formation was deposited in several Laramide foreland basins in the Rocky Mountain region. The formation is well known for its abundance of high-grade oil shale. In the Uinta basin, Green River hydrocarbons are being produced from large fields such as Altamont-Bluebell, Monument Butte, and Red Wash. Pre-salt discoveries in offshore Brazil and Angola have also helped bring recent focus to microbial carbonates as hydrocarbon reservoirs. Lacustrine systems are extremely variable, being controlled both by climate and tectonics. Continuous and well-exposed outcrops are invaluable for characterizing these important reservoirs.

This study describes and interprets a continuous, three mile carbonate outcrop within the R5 section of the Green River Formation in Three Mile Canyon, Utah, on the eastern edge of Eocene Lake Uinta. This canyon is currently a tributary of Evacuation Creek, an area well known for its excellent exposures of the Green River Formation. The units exposed in Three Mile Canyon are marginal lacustrine deposits of shale, deltaic sandstone, and littoral to sublittoral carbonates.

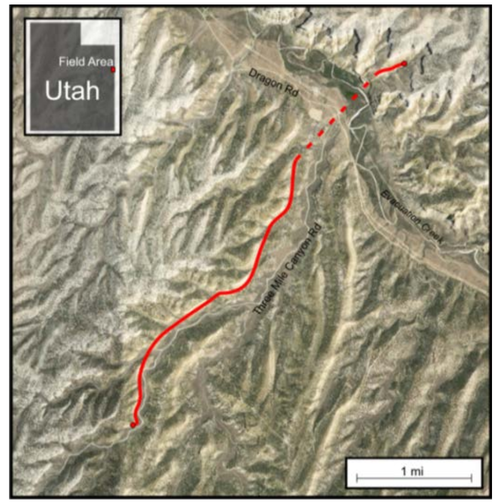
The study outcrop follows an obliquely basinward transect through shore to nearshore facies. The carbonate unit geometries display a lateral transition from large-scale (several meter) laterally linked stromatolite and thrombolite heads, to thin (cm-scale) planar laminations with smaller isolated microbial mounds. Moving basinward toward Evacuation Creek, the unit pinches out into low grade oil shales.

The carbonate consists of two facies associations: (1) microbial and (2) marginal lacustrine carbonates. The microbialites are comprised of stromatolite, thrombolite, and dendrolite fabrics. Non-microbial carbonates occur in association with these, and consist of five lithofacies that record changing energy conditions associated with water depth. Facies transitions appear to describe two overall deepening-upward cycles, with localized shallowing sequences. Thin section analysis reveals that the carbonates have undergone a complex diagenetic history that began syndepositionally and continued through burial, including micritization, dissolution, neomorphism, dolomitization, mechanical and chemical compaction, calcite cementation, dolomite cementation, and dedolomitization. Significant porosity has been created and preserved through these processes.

FIELD AREA

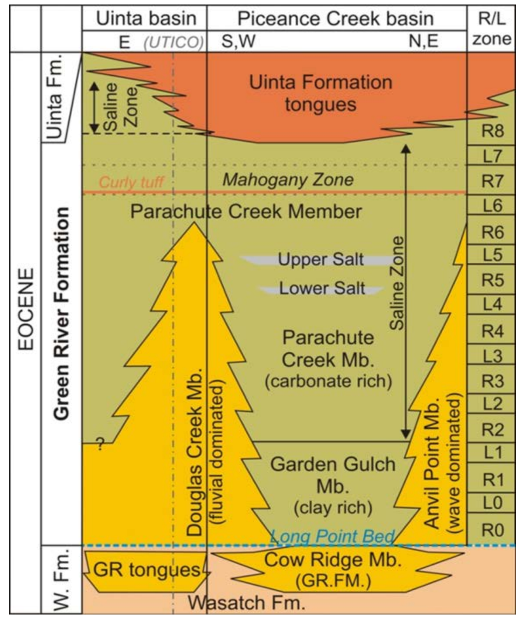


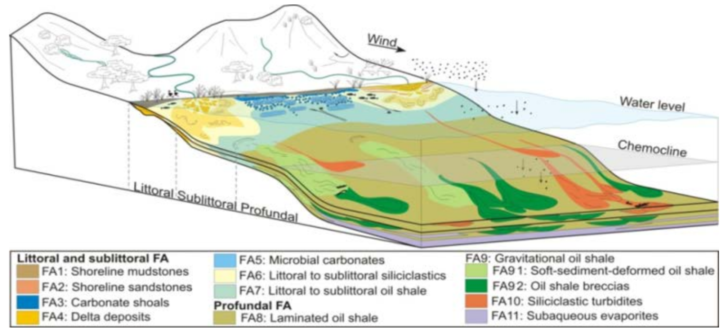
Structure map by Dickinson et al., 1986, modified by Kati Tänavsuu-Milkeviciene



Red line follows outcrop studied. From left to right, line moves down canyon, from more proximal to more distal paleo-shoreline facies.

STRATIGRAPHY



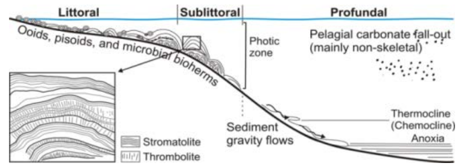


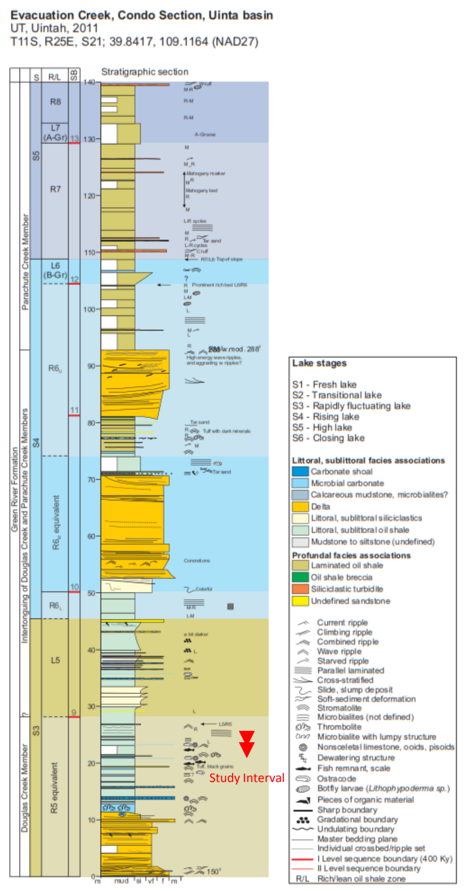
Above: General depositional environment model and lateral facies relationships of the siliciclastic and carbonates of the Green River Formation in the Piceance basin (Tänavsuu-Milkeviciene and Sarg, 2012).

Left: Stratigraphic section for Uinta and Piceance Basins (from Tänavsuu-Milkeviciene and Sarg, personal communication).

Below: Specific depositional environment for microbialite and associated carbonates (Suriamin et al., 2013).

Far Below: Measured section near study area on NE side of Evacuation Creek. Study interval noted.



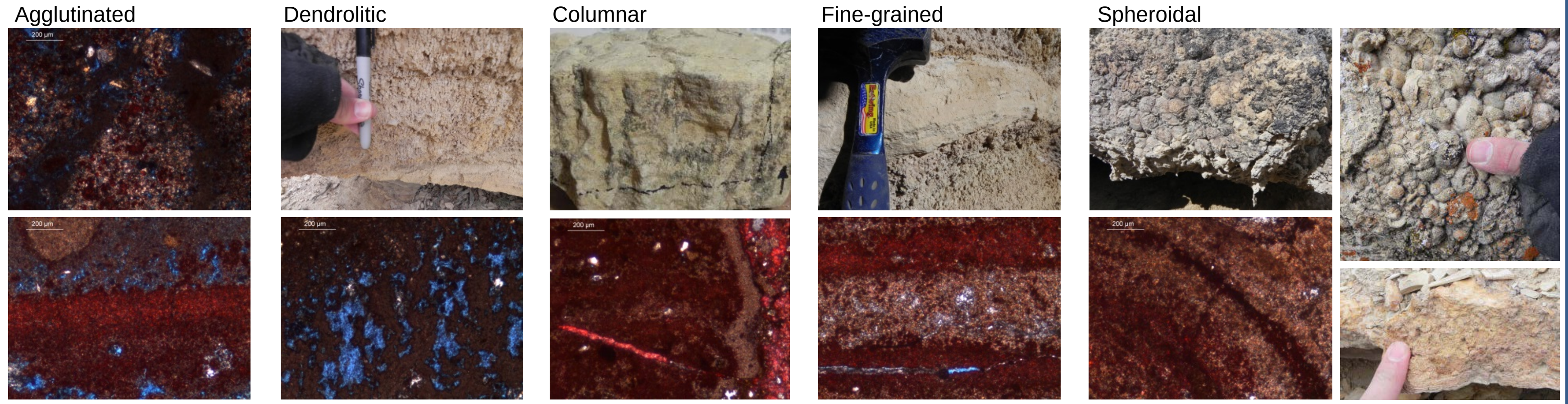


Measured section courtesy of Kati Tänavsuu-Milkeviciene

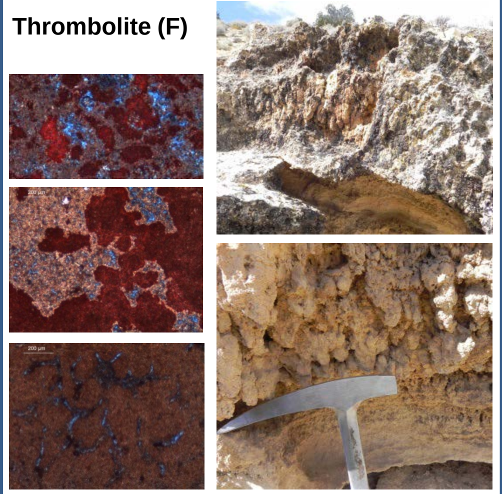
FACIES & FACIES ASSOCIATIONS

Facies Association	Lithofacies	Label	Dominant Fabrics or Grains	Description	Depositional Environment
Lacustrine Microbial Carbonates	Stromatolite	G	Agglutinated, columnar, dendrolitic, fine-grained, & spheroidal	Domal to planar. Laterally-linked hemispheroids, isolated hemispheroids, planar laminations, and spheroids. Head nuclei may be ooilitic, quartzose, or intraclastic. Thickness from 0.1-3 meter. Vuggy, interparticle, and fenestral porosity.	Lower littoral to upper sublittoral
	Thrombolite	F	Clotted	Large-scale (meters) domal, laterally continuous in upper deepening cycle, laterally discontinuous elsewhere. Thickness from 0.1-1 meter. Vuggy and interparticle porosity.	Lower littoral to upper sublittoral
Marginal Lacustrine Carbonates	Quartzose Intraclast Rudstone	E	Brecciated microbial and charophyte clasts, quartz	Only grains are intraclasts and silt-sized quartz. Intraclasts are microbial in origin, and feature well-developed concentric lamination	Middle to lower litttoral
	Peloid Intraclast Ostracod Wackestone to Packstone	D	Peloids, brecciated microbial and charophyte clasts, ostracod shells, rare skeletal grains	Increasing mud content. Intraclasts almost exclusively peloidal/aggregate grain or microbial. Some skeletal grains such as arthropod fragments also present	Lower litttoral
	Ooid Peloid Ostracod Intraclast Rudstone to Packstone	C	Ooids, peloids, aggregate grains, ostracods, intraclasts, rare skeletal grains	Poorly sorted mix of peloids, ooids, aggregate grains, ostracods, and small to large intraclasts.	Upper littoral
	Quartzose Ooid Intraclast Rudstone to Grainstone	B	Ooids, quartz, brecciated microbial and charophyte clasts	Poorly sorted mix of ooids, quartz and large (mm-cm) intraclasts. Ooid nuclei are quartz, peloids, ostracods, and aggregate grains	Middle to upper litttoral
	Quartzose Ooid Grainstone	A	Ooids, quartz	Loosely-packed, well-sorted ooids with silt-sized quartz grains. Ooids are moslty undeformed. Nuclei are quartz, peloids, ostracods, and aggregate grains	Upper littoral

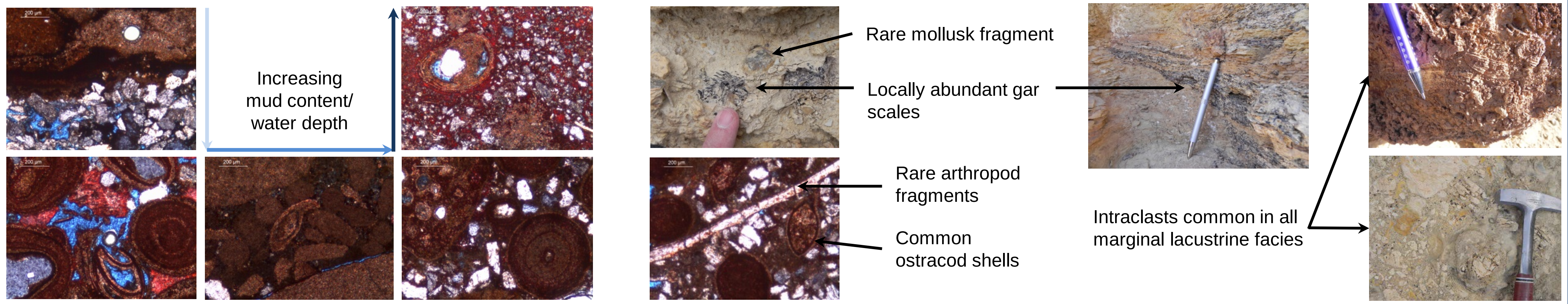
Stromatolite (G)



Thrombolite (F)



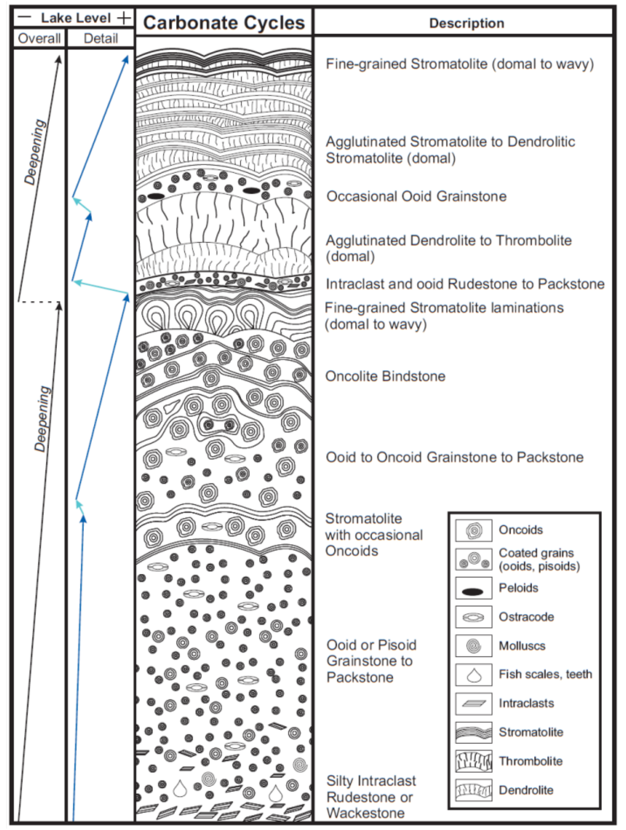
Marginal Lacustrine Carbonates (A-F)

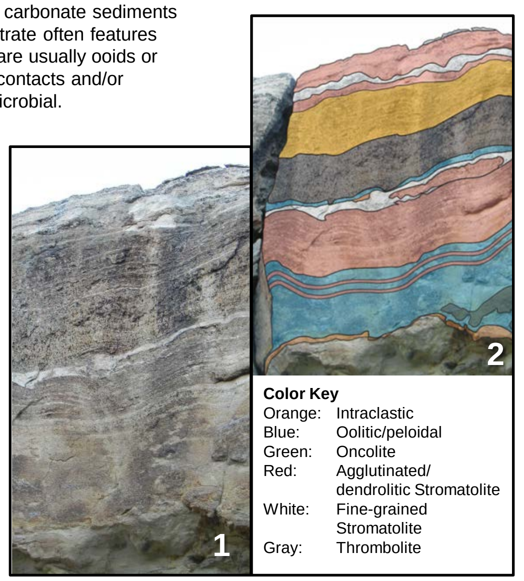


DEPOSITIONAL HISTORY

Below: Uninterpreted **(1)** and interpreted **(2)** composite detail photographs of typical facies progression. Unit thickness: 12.5 ft. Photo taken near the top of canyon section to show complete facies distribution at maximum unit thickness.

Above: A) Blocky sand substrate allows sharp, mostly planar contacts. First carbonate sediments are usually ooids or intraclasts. **B)** Finer, cross-stratified sand substrate often features sharp but erosional carbonate contacts. First carbonate sediments are usually ooids or intraclasts. **C)** Shaley or muddy substrate features indistinct basal contacts and/or sediment loading features. First carbonate sediments are usually microbial.

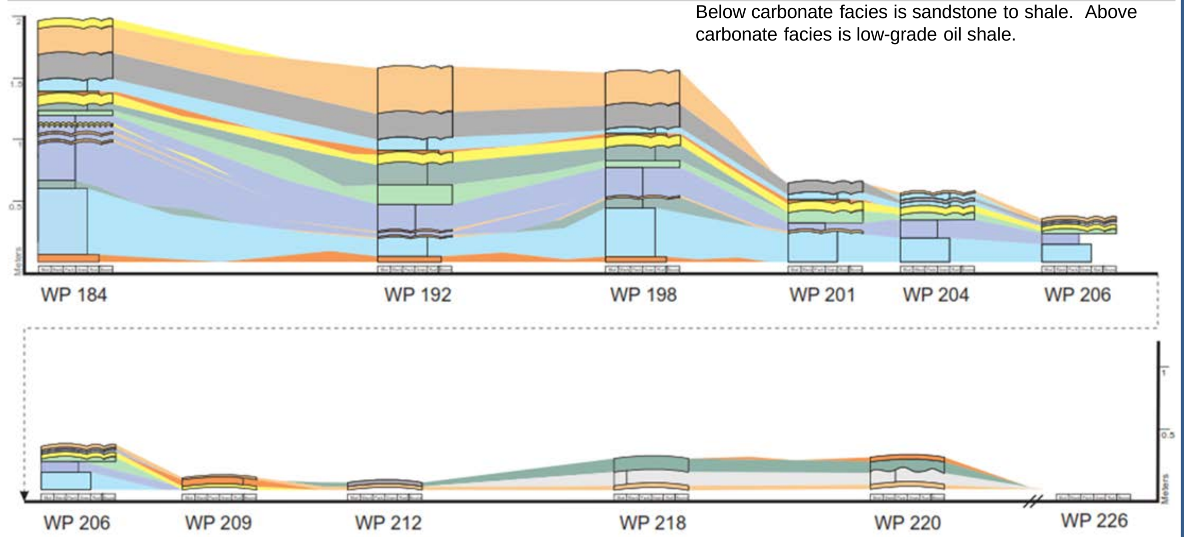


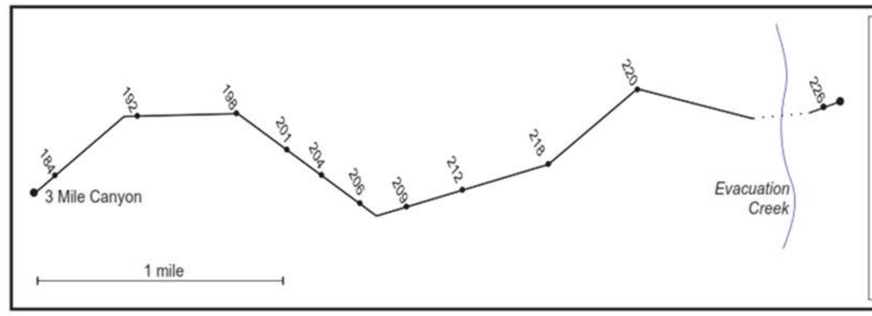


Color Key
Orange: Intraclastic
Blue: Oolitic/peloidal
Green: Oncolite
Red: Agglutinated/dendrolitic Stromatolite
White: Fine-grained Stromatolite
Gray: Thrombolite

Left: Idealized carbonate facies cycles. Shows two overall deepening upward trends. Local shallowing trends are found throughout the outcrop. General cycles have basal intraclast layer, followed by ooids, peloids, ostracods, and occasional skeletal elements. Mud increases through these facies. This is followed by spheroidal (oncolite) and occasional laminated stromatolite or thrombolite, capped by agglutinated, dendrolitic and/or fine-grained stromatolite.

Below: Generalized stratigraphic model shows facies stacking and lateral trends from upper Three Mile Canyon (WP 184) to Evacuation Creek (between WP 220 and 226) from left to right. Moving left to right also denotes an obliquely basinward progression. Below carbonate facies is sandstone to shale. Above carbonate facies is low-grade oil shale.





LATERAL VARIABILITY

Photo A: Panorama of up-canyon end of microbialite atop thick deltaic sandstone. Unit goes into subsurface to left of photo.
Photo B: Detail composite image of microbial unit at same location. Note fine-grained white streak through middle denoting top of first deepening cycle. Unit thickness: 12.5 ft.

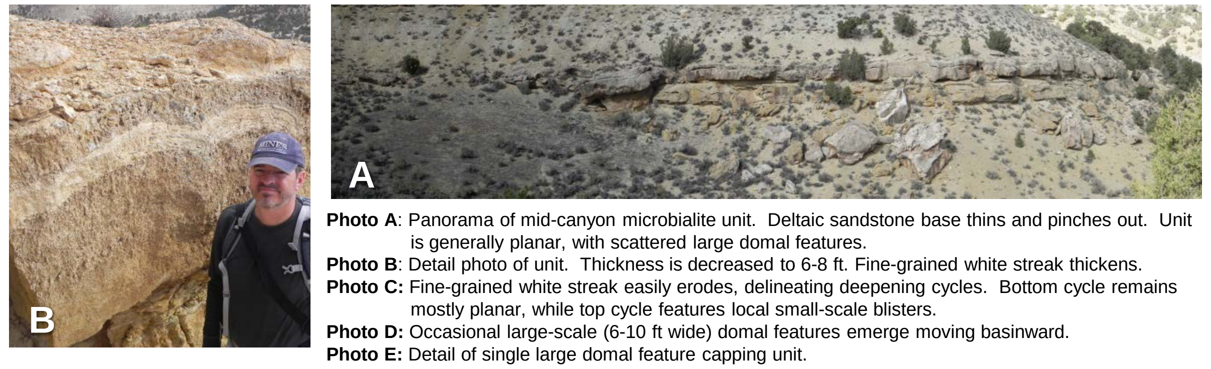
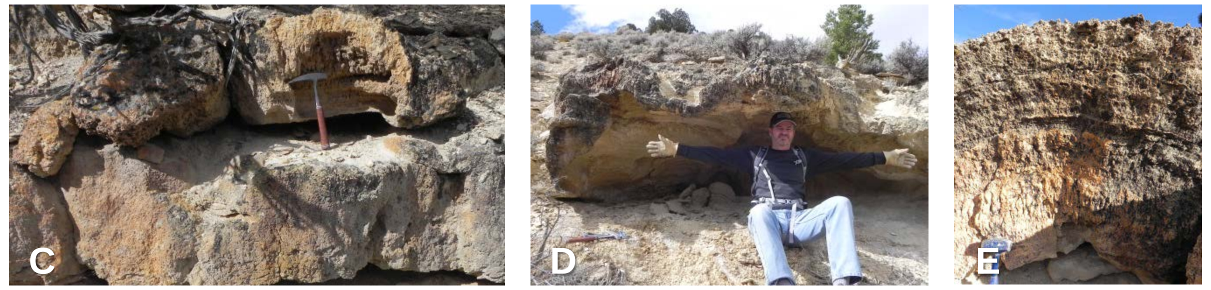


Photo A: Panorama of mid-canyon microbialite unit. Deltaic sandstone base thins and pinches out. Unit is generally planar, with scattered large domal features.
Photo B: Detail photo of unit. Thickness is decreased to 6-8 ft. Fine-grained white streak thickens.
Photo C: Fine-grained white streak easily erodes, delineating deepening cycles. Bottom cycle remains mostly planar, while top cycle features local small-scale blisters.
Photo D: Occasional large-scale (6-10 ft wide) domal features emerge moving basinward.
Photo E: Detail of single large domal feature capping unit.



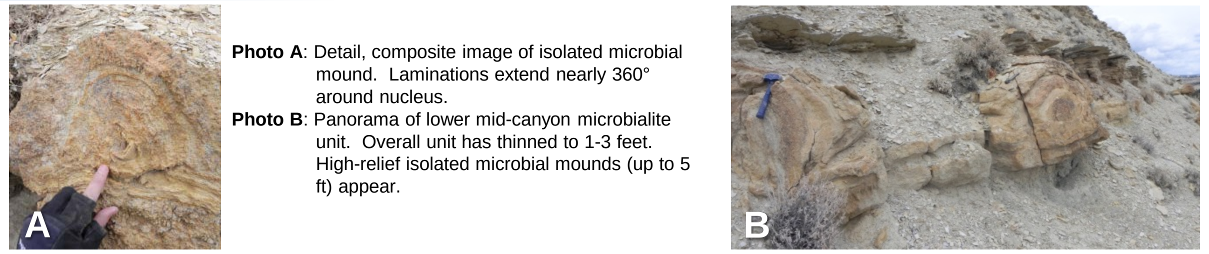
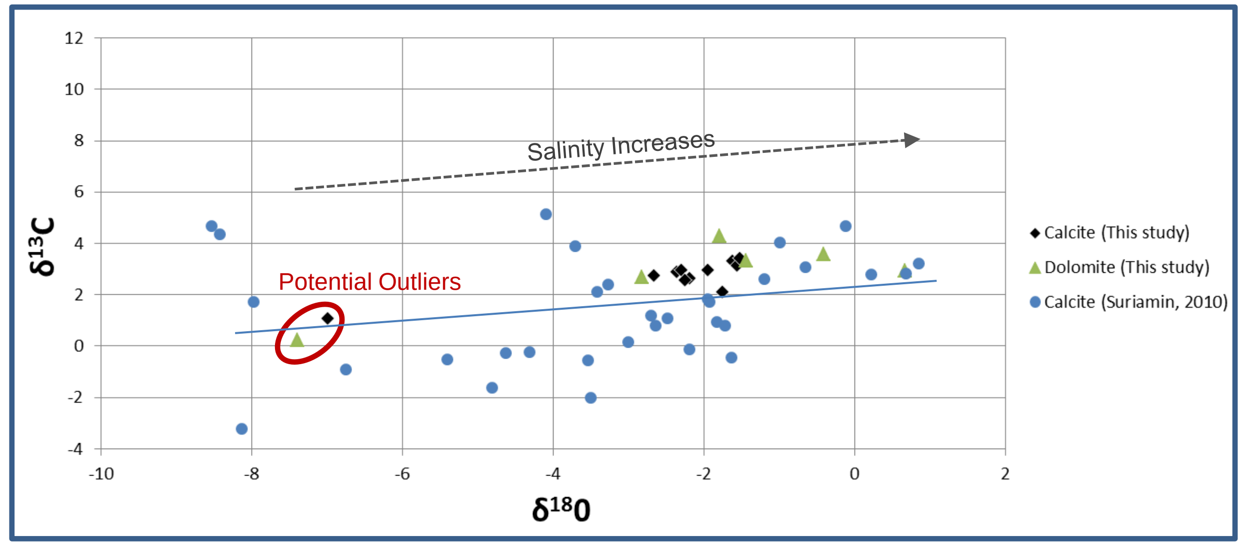


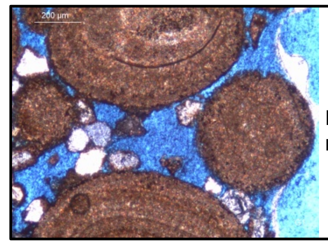
Photo A: Detail, composite image of isolated microbial mound. Laminations extend nearly 360° around nucleus.
Photo B: Panorama of lower mid-canyon microbialite unit. Overall unit has thinned to 1-3 feet. High-relief isolated microbial mounds (up to 5 ft) appear.

Photo A: Down-canyon microbial unit has thinned to 1-3 inches. Moving laterally, unit disappears and reappears several times. Remnant fine-grained white streak still divides unit into two cycles.

STABLE ISOTOPES

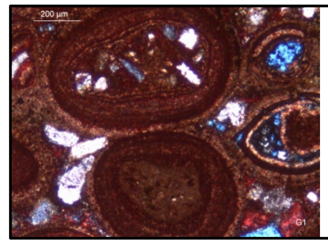


DIAGENESIS



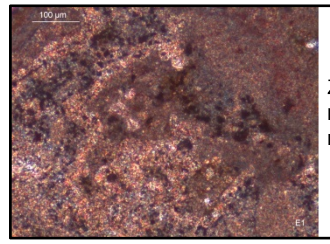
Micritization

Partial and complete micritization of ooids.



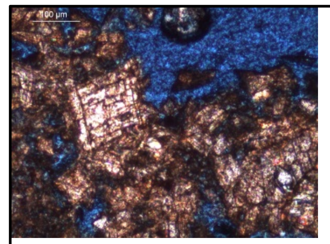
Dissolution

Dissolution of ooid nuclei. Also note micritization of outer cortices.



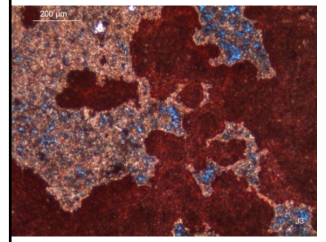
Neomorphism

Zonal aggrading neomorphism from micrite to microspar.

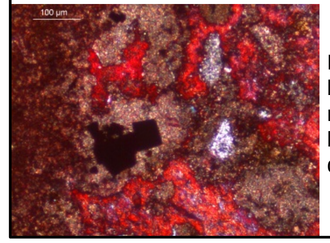


Dolomitization

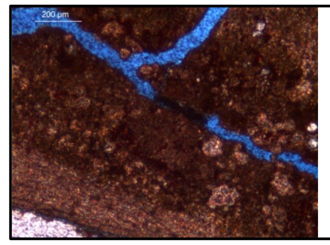
Large, well-ordered deep burial dolomite rhombs.



Selective dolomitization of more porous zones. Denser thrombolitic mesoclots remain calcitic.

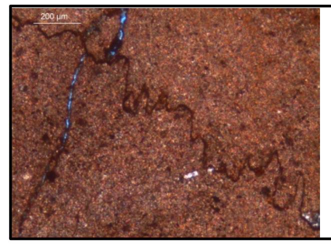


Pyrite precipitation from bacterial sulfate reduction. Common in biologically-mediated dolomitization.



Mechanical Compaction/ Fracturing

Large unfilled fractures in an intraclast. Crushed grains also locally common.

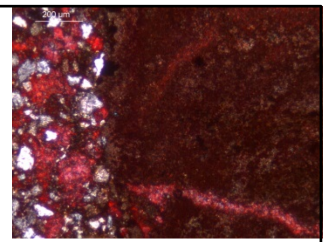


Chemical Compaction

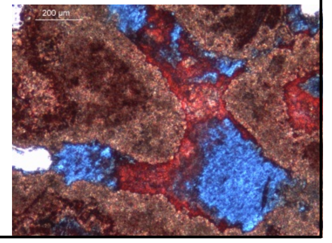
Stylolites from deep burial pressure dissolution. Microstylolites and sutured grains also locally common

Calcite Cementation

Poikilotopic calcite cement fills fractures and interparticle pore space.

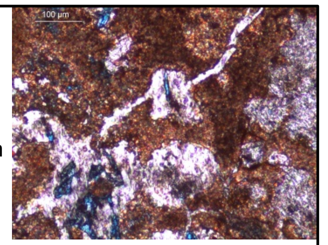


Meteoric meniscus cements are generally uncommon.

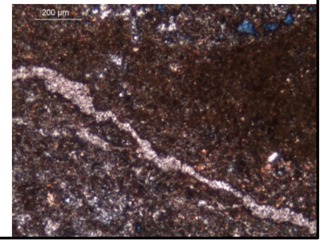


Dolomite Cementation

Clear dolomite cements fill after fractures and on grain/fabric boundaries

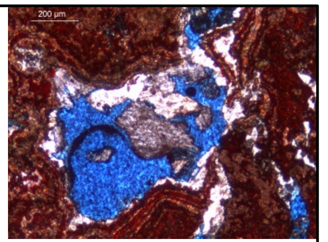


Cloudier dolomite cement fill in fractures and interparticle pores

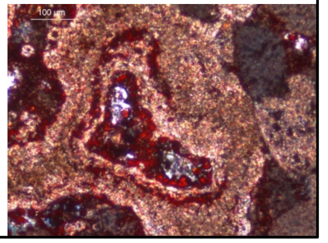


Mixing Zone Cementation

Alternating bands of calcite and dolomite cement buckled and filled in with dolomite cement

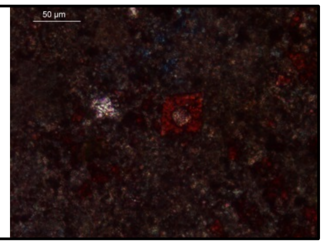


Alternating bands of calcite and dolomite cement as pore is exposed to dynamic mixing zone waters.



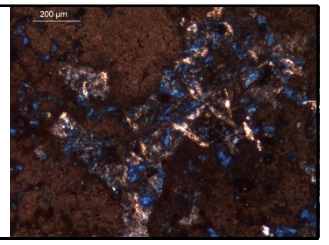
Dedolomitization

Large dedolomite rhomb floating in dolomite matrix. A very common feature.

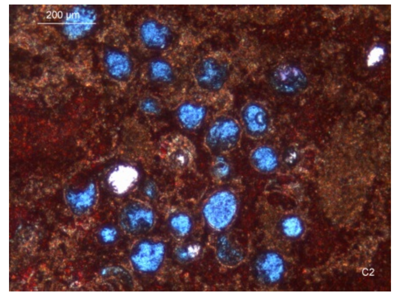


Gypsum Precipitation

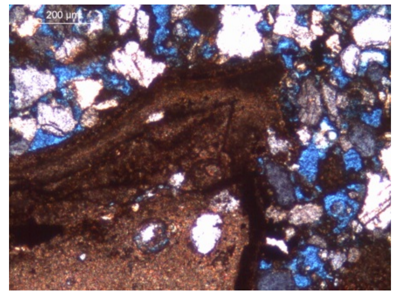
Very late gypsum precipitation in vuggy pores.



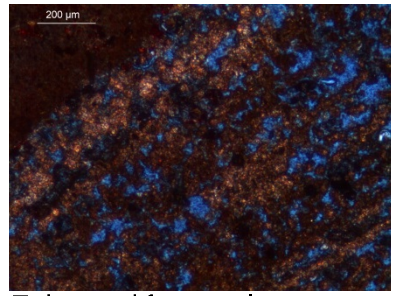
POROSITY



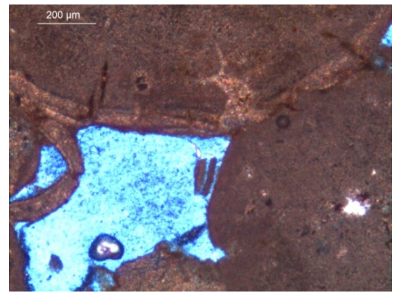
Intraparticle (after oogonia)



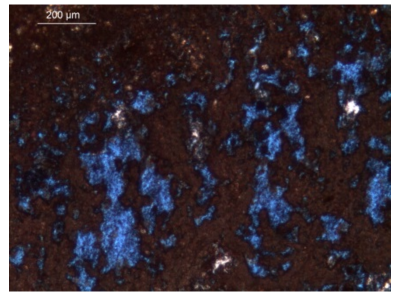
Interparticle



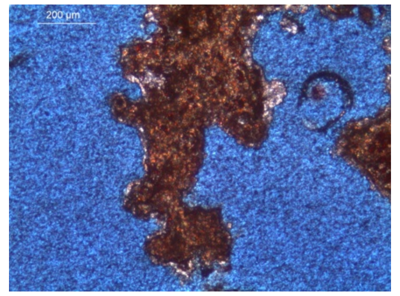
Enhanced fenestral



Interparticle & fracture



Dendrolitic framework



Vuggy framework

CONCLUSIONS

1) Carbonates in Three Mile Canyon and Evacuation Creek are interpreted to be deposited in a lake margin setting, in the littoral to sublittoral zones.

3) The carbonate unit in the study forms two overall deepening upward trends, with smaller, local shallowing sequences.

4) An idealized deepening upward sequence begins with intraclast rudstone followed by ooid grainstone to packstone. Moving upward, mud, peloids, ostracods, and superficial ooids become more prevalent. This transitions upward into thrombolite or agglutinated and/or spheroidal stromatolite, followed by dendrolitic and fine-grained stromatolite.

5) Small-scale lateral variations are common.

6) Carbonate diagenesis was varied and began syndepositionally and continued into the burial environment.

7) Dolomitization of primary calcite is pervasive. At least some early dolomitization was probably organogenic.

8) Stable isotope analysis shows slightly saline to saline lake conditions

Acknowledgments

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