MICROBIAL CARBONATES IN CORES FROM THE TERTIARY (EOCENE) GREEN RIVER FORMATION, UINTA BASIN, UTAH, U.S.A.

Analogues for Non-Marine Microbialite Oil Reservoirs Worldwide (June, 2013)

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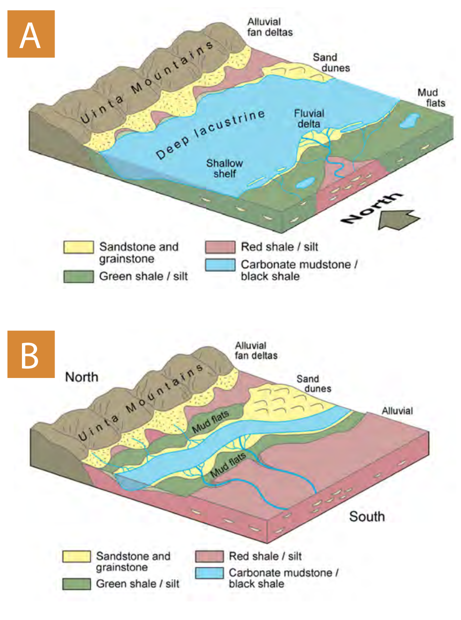
GREEN RIVER FORMATION
DEPOSITIONAL SETTING

Ancient Eocene Lake Basins

Location of the Skyline 16 core and West Willow Creek field.

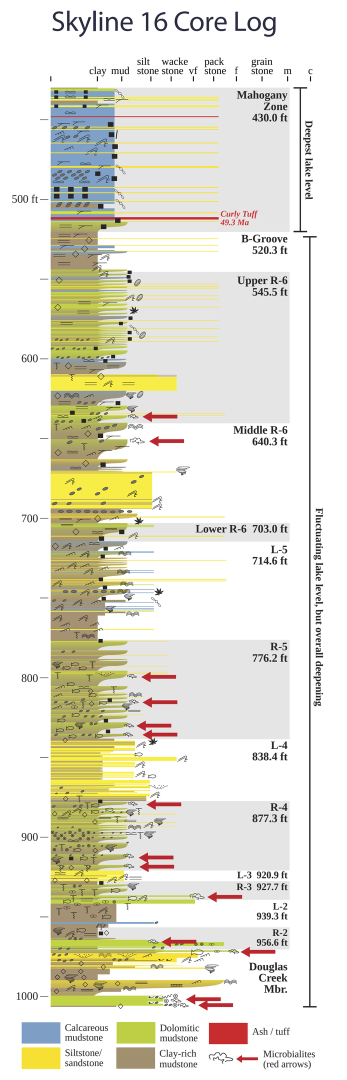
Generalized Depositional Setting for Lake Uinta



A – High-lake levels and B – Low-lake levels. The Uinta Mountains were the source for the sediments in the northern portion of the lake while sediments in the southern portion of the lake were sourced from the much larger Four Corners area.

From Morgan and others, 2003

Skyline 16 Core Log



SKYLINE 16 RESEARCH CORE
RESERVOIR ANALOGUES FROM THE UPPER GREEN RIVER FORMATION

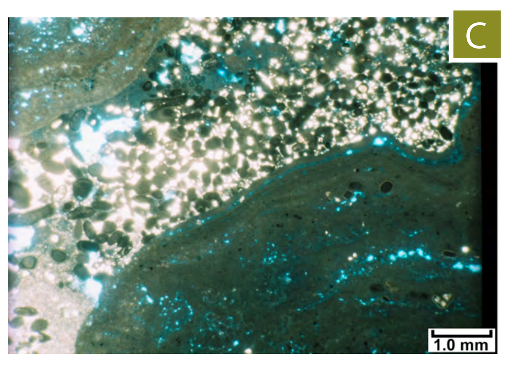
Thin section examination of dolomitic microbialites and associated carbonate facies in the Skyline 16 core research display a nice variety of analogues for porosity types, hydrocarbon storage potential, and flow potential.

MICROBIALITES

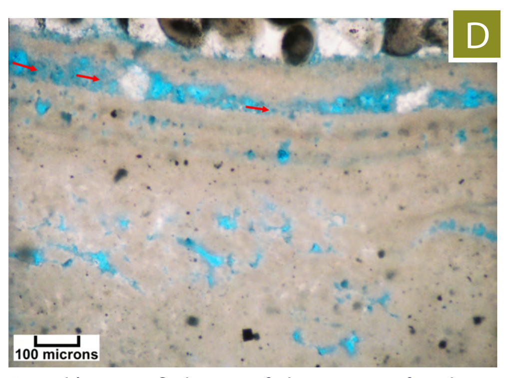
STROMATOLITES

A - Branching digitate stromatolites that grew on a substrate of peloidal dolomite displaying erosional relief. Grey layers of silt grains and ooids fill the space between the microbial "digits". 972.8-973.3 ft.

B - Large stromatolite domal head in which the synoptic relief diminishes upwards. Oolitic/peloidal sediments fill the space between stromatolites. The stromatolite grew on an oolitic/pisolitic/oncolitic substrate. 964.5-966.0 ft.

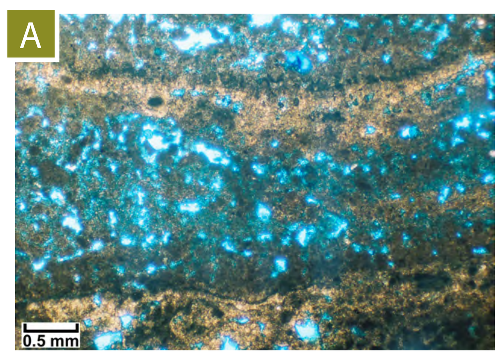


C - Stromatolitic laminae within small digitate heads seen in the core photo at left. On right note vague internal microbial laminations and the porosity (in blue) within the heads. Quartz silt (in white) and ooids fill the space between the heads. 973.0 ft. (Plane light)



D - Highly magnified view of the margin of a digitate stromatolite head shown in the core photo at left. Note the well-defined laminae as well as the preservation of filamentous cell remains in the porous areas between the laminae (see red arrows). 973.0 ft. (Plane light w/ white card)

THROMBOLITES



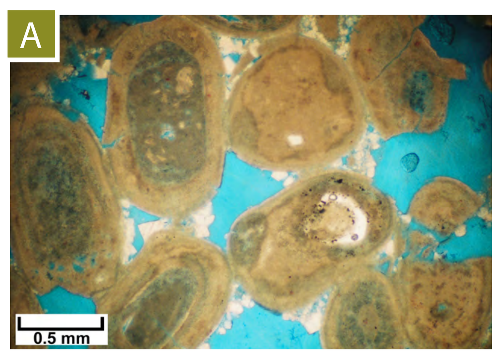
A - Excellent preserved primary porosity within a thrombolitic interval. Megascopic pores are intimately associated with clotted constructional fabrics. Note also the small primary vugs. 1002.2 ft. (Plane light)

B - Low-relief thrombolites associated with ooids and microbialite rip-up clasts. Small primary vugs are also present. Thrombolites seem to preserve greater amounts of megascopic porosity than stromatolites. Red arrow indicates the location of micrograph shown above. 1002.0-1002.5 ft.

C - Low-relief thrombolitic head (in the lower half of the core segment) draped with stromatolitic laminae and thin beds of rip-up clasts. 936.7-937.1 ft.

GRAINSTONES

OOLITES

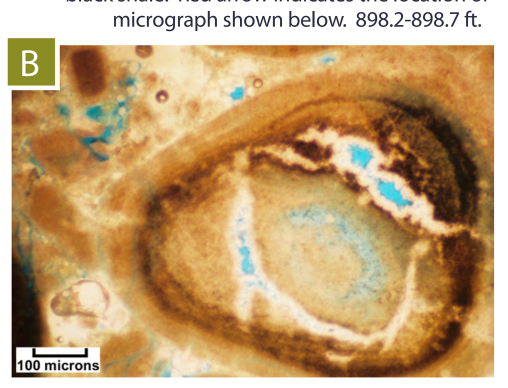


A - Excellent preserved interparticle porosity (blue) between very lightly cemented ooids. Note the small amounts of sparry calcite cement crystals (in white) lithifying this oolite. 1003.0 ft. (Plane light w/ white card)

B - Porous oolites with bedding defined by grain size differences. Primary interparticle porosity is visible within the coarser beds. Red arrow indicates the location of micrograph shown above. 1002.6-1003.0 ft.

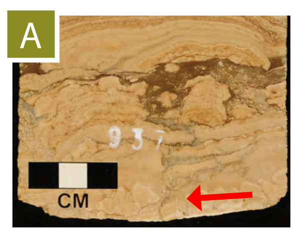
PISOLITES

A - Grainstone beds capped with a thin pisolitic bed. Above the pisolites, with a very sharp contact, is a laminated black shale. Red arrow indicates the location of micrograph shown below. 898.2-898.7 ft.



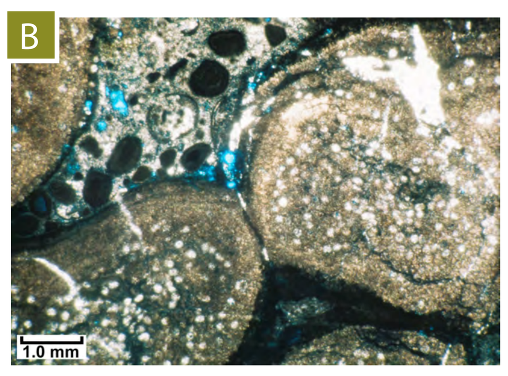
B - An individual pisoid within a cemented bed containing peloids and oolitically coated grains. Note the partially open microfractures ("septarian cracks") within the pisoid as well as some preserved pores between grains. 898.4 ft. (Plane light w/ white card)

ONCOLITES

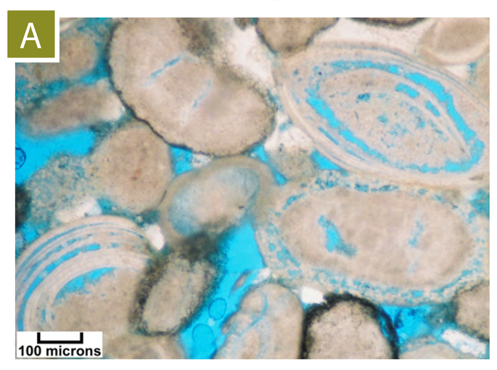


A - A layer of oncoids overlain by thrombolites and stromatolites. Red arrow indicates the location of micrograph shown below. 936.9-937.1 ft.

B - Cross section through portions of several oncoids. Note the clotted texture (with spherical cell structures) within the oncoid interiors, overlain with dense laminated oncoid margins. Ooids and coated grains are present between the oncoids. 937.0 ft. (Plane light)

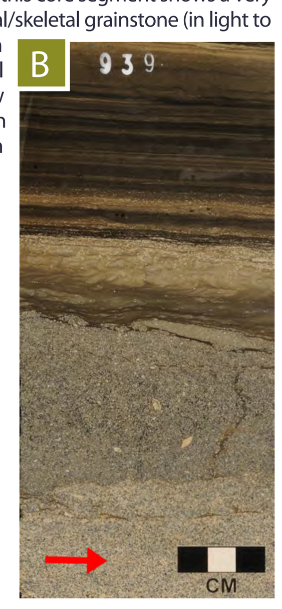


PELOIDAL/SKELETAL

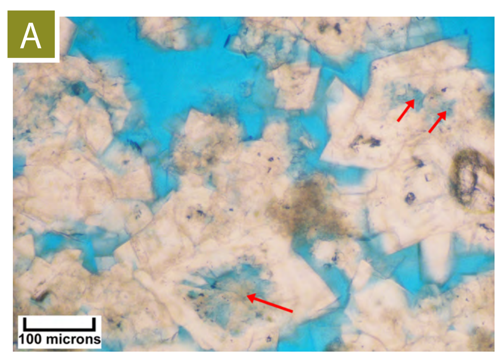


A - Abundant preserved interparticle and intraparticle pore space is displayed in this peloidal/skeletal calcarenite. The skeletal grains are articulated and single valve ostracods. 939.5 ft. (Plane light w/ white card)

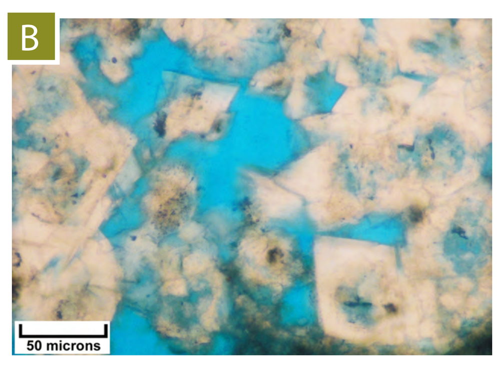
B - The lower half of this core segment shows a very porous peloidal/skeletal grainstone (in light to medium grey) overlain by a sharp erosional contact. Red arrow indicates the location of micrograph shown above. 939.0-939.6 ft.



DOLOMITE

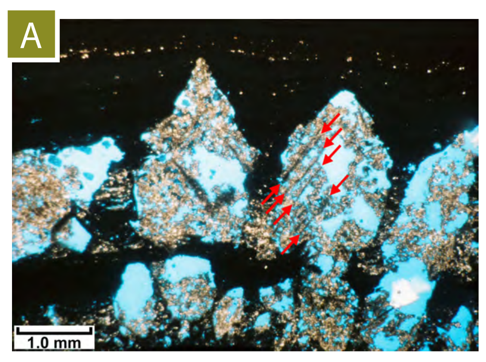


A - Excellent porosity can be seen between clusters of dolomite crystals. Note also the presence of hollow dolomite rhombs (see red arrows). 650.7 ft. (Plane light w/ white card) (core photo at right [C])

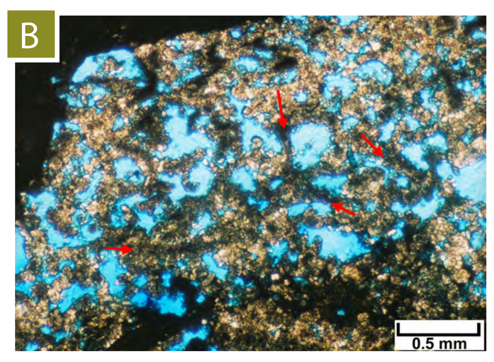


B - Well-connected pores are present between individual dolomite crystals and small crystal clusters. Hollow dolomite rhombs are common. 650.5 ft. (Plane light w/ white card) (core photo at right [C])

EVAPORITE CRYSTAL DISSOLUTION(?)



A - Cluster of evaporate crystal molds (?) that are preserved in growth position, surrounded by dense carbonate mud. The molds are partially filled with a porous, lacy microbial fabric (in light brown). Note preserved clay drapes that form along evaporate crystal growth faces (see pairs of red arrows). 650.7 ft. (Plane light)



B - Micrograph of an interconnected lacy microbial fabric in which filamentous cellular remains are preserved in dark brown (see red arrows). 650.7 ft. (Plane light)

C - Irregular layers of porous microbialite filling voids that are associated with possible evaporite crystal molds. Red arrow indicates the location of micrographs shown above. 650.5-651.2 ft.

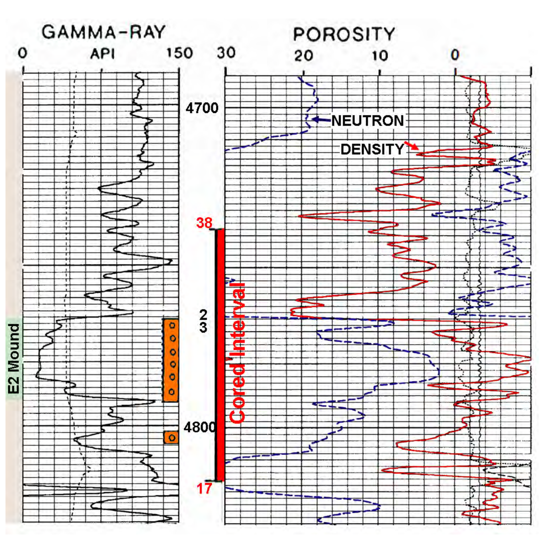
D - Outcrop view of similar evaporite crystal molds seen in the Skyline 16 core. Note the crystal-like structure on the stromatolite dome. Near Evacuation Creek, eastern Utah.

E - Plan view of stromatolite similar to outcrop photo above. Notice the crystal molds are only located on the dome of the stromatolite. Evacuation Creek, eastern Utah.

WEST WILLOW CREEK FIELD
A PRODUCING MICROBIAL RESERVOIR IN THE UINTA BASIN

FIELD OVERVIEW

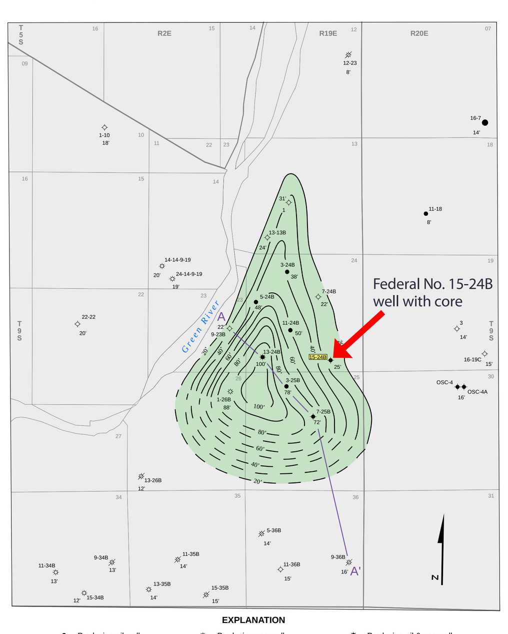
Compensated Neutron-Formation Density and Gamma-Ray Log, Federal No. 15-24B Well, West Willow Creek Field



Cumulative Production: 15,639 BO, 5025 MCFG, and 8674 BW (abandoned in 2007).

The red bar displays the cored interval; the perforated interval is indicated by circles on the outside right of the left column.

Isopach Map of the E$_2$ Carbonate Bed, West Willow Creek Field



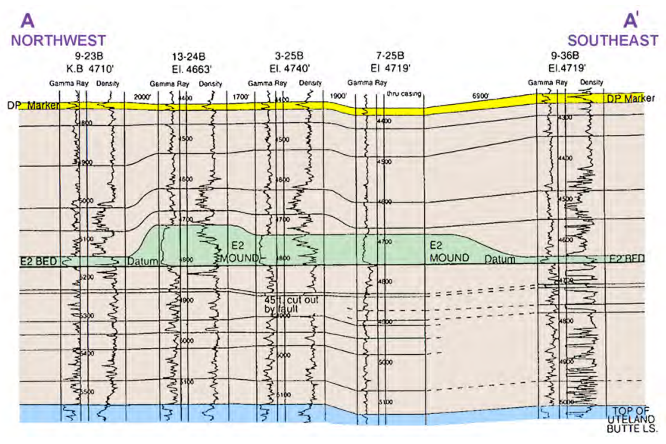
Cross section A-A' is shown in figure below.

Modified from Osmond, 2000

Reservoir & Production Data

- Producing Wells – 6
- Abandoned Producers – 2
- Dry Holes – 2
- Monthly Production (October 2012) – 690 BO, 9,353 MCFG, and 56 BW
- Cumulative Production (as of October 2012) – 1,117,999 BO, 11.8 BCFG, and 62,132 BW
- Estimated Original Oil in Place – 8 MMBO
- Estimated Original Gas in Place – 2.95 BCFG
- Secondary Enhanced Oil Recovery Program – pressure maintenance (reinjection of casing head gas into the gas cap); gas injection ceased in 1997 because of premature gas cap breakthrough in structurally lower producing oil wells.
- Productive Area – 560 acres (230 ha)
- Gross Pay – 25 to 100 ft (8-20 m)
- Average Porosity – 8 to 18%
- Permeability – 0 to 4.1 mD

Stratigraphic Cross Section, West Willow Creek Field

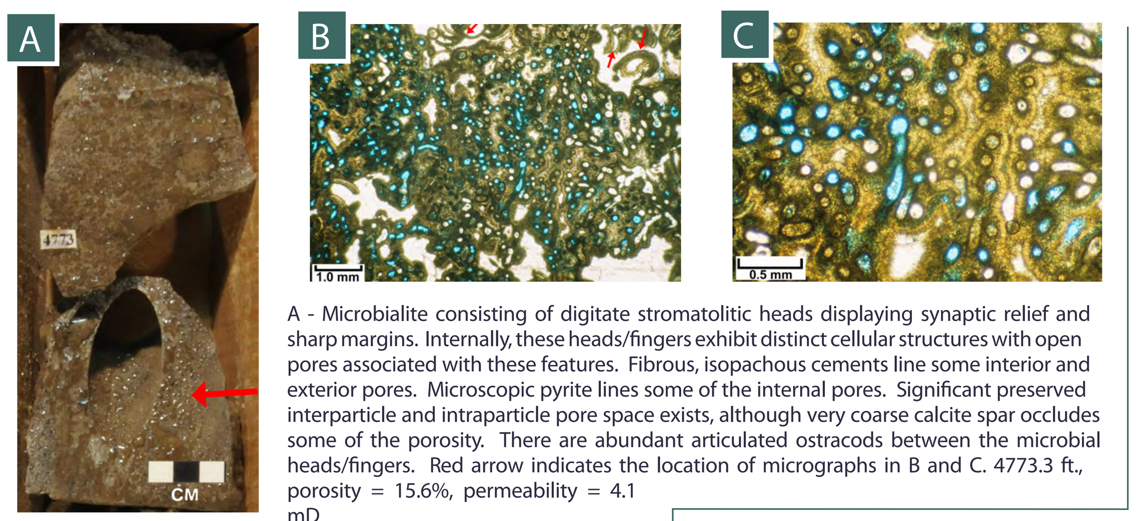


Line of cross section A-A' is shown on figure above.

Modified from Osmond, 2000

FEDERAL NO. 15-24B WELL
E$_2$ CARBONATE BED, GREEN RIVER FORMATION

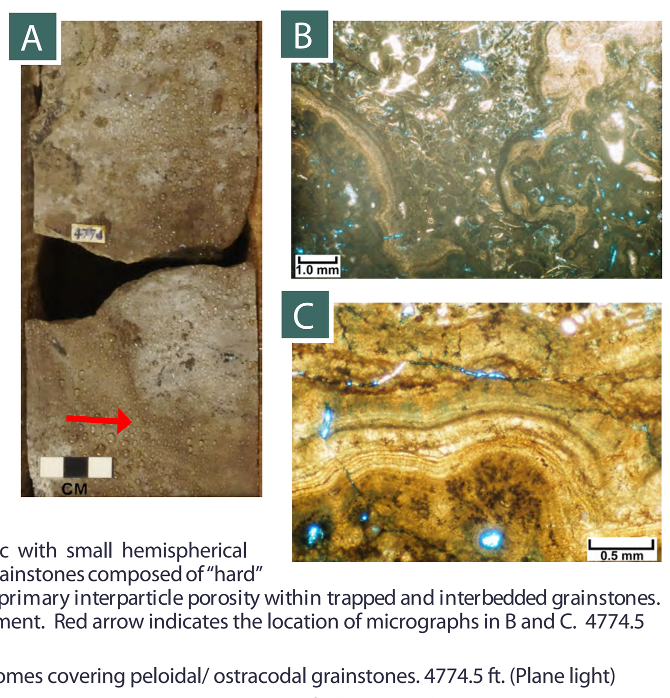
STROMATOLITES



A - Microbialite consisting of digitate stromatolitic heads displaying synaptic relief and sharp margins. Internally, these heads/fingers exhibit distinct cellular structures with open pores associated with these features. Fibrous, isopachous cements line some interior and exterior pores. Microscopic pyrite lines some of the internal pores. Significant preserved interparticle and intraparticle pore space exists, although very coarse calcite spar occludes some of the porosity. There are abundant articulated ostracods between the microbial heads/fingers. Red arrow indicates the location of micrographs in B and C. 4773.3 ft., porosity = 15.6%, permeability = 4.1 mD

B - Overview of microdigitate microbialite head with internal cellular structure. Calcite spar occurs between and partially replaces microbialite structures. Ostracods occur in space between heads (see arrows). Porosity in blue. 4773.3 ft. (Plane light)

C - Microbialite boundstone with early isopachous fibrous cements lining pores. Note preserved interparticle and intraparticle pores. 4773.3 ft. (Plane light)

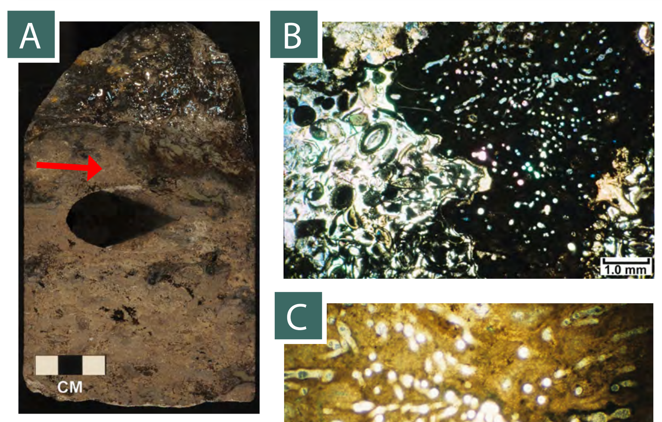


A - Laminated (stromatolitic) microbialite fabric with small hemispherical "heads" that have grown on top of or "trapped" grainstones composed of peloids, ooids, and ostracods. Good to excellent primary interparticle porosity within trapped and interbedded grainstones. Minor late cement plugging by coarse calcite cement. Red arrow indicates the location of micrographs in B and C. 4774.5 ft., porosity = 7.4%, permeability = 1.0 mD

B - Portions of two hemispherical stromatolitic domes covering peloidal/ostracodal grainstones. 4774.5 ft. (Plane light)

C - Close-up view of well-laminated, dense (stromatolitic) microbialite head. 4774.5 ft. (Plane light)

THROMBOLITES



A - Dense, dark-colored thrombolitic microbialite heads with significant vertical synoptic relief. Sharp, laminated margins with interiors of the heads composed of clotted and cellular structures. Between the heads are ostracods and calcite spar cement. The red arrow indicates the location of micrographs in B and C. 4771.5 ft., porosity = 1.9%, permeability = 0.03 mD

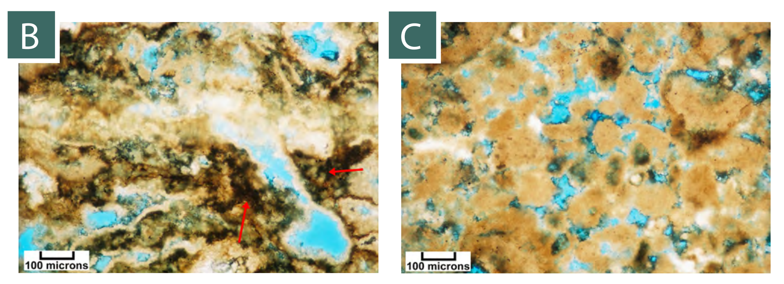
B - Steep-sided margin of a massive thrombolitic head with ostracods filling cavity between the margins of the head. 4771.5 ft. (Plane light)

C - Tubular or filamentous textures within the same thrombolitic head. 4771.5 ft. (Plane light)

A - Clotted (thrombolitic) fabric with laminated (stromatolitic) crusts that together form small heads and "fingers." Occasional small oncolites occur in layers between heads. Other fill between heads includes "hard" peloids, ooids (some regenerated), and ostracods. Good matrix porosity (and oil staining) within heads and in the grainstone fill between heads. The red arrow indicates the location of micrographs in B and C. 4776.4 ft., porosity = 10.2%, permeability = 0.62 mD.

B - Close-up view of clotted (thrombolitic) texture (see red arrows) with layers of good matrix porosity lined with isopachous cements. 4776.4 ft. (Plane light w/ white card)

C - Excellent interparticle porosity between "hard" peloids and ooids which occur between thrombolitic "heads." 4776.4 ft. (Plane light w/ white card)

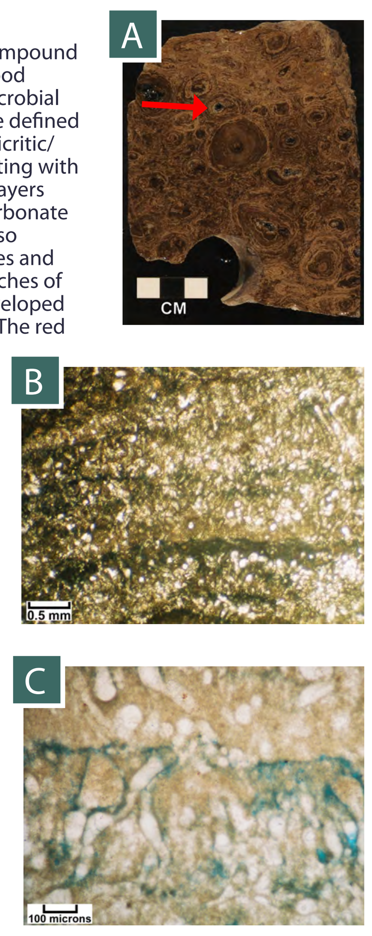


ONCOLITES

A - Oncolitic rudstone composed of large compound oncoids displaying good internal laminated microbial coatings. Laminae are defined by alternating dark micritic/organic layers alternating with thicker light-colored layers containing detrital carbonate sediment. Oncoids also display internal tubules and filamentous textures. Patches of microporosity are developed within the oncolites. The red arrow indicates the location of micrographs in B and C. 4779.5 ft., porosity = 5.6%, permeability = 0.12 mD.

B - Multiple dark/light layer couplets within an oncoid. Note the abundance of tubules/filaments within the thicker light layers. Microporosity occurs in the dark layers. 4779.5 ft. (Plane light)

C - Microporosity developed along and around microtubules within an oncoid cortex. 4779.5 ft. (Plane light w/ white card)



CONCLUSIONS

- The lacustrine Eocene Green River Formation in the Uinta Basin, Utah, contains excellent examples of microbial carbonates – stromatolites, thrombolites, and grainstones – which can serve as analogues for highly productive non-marine microbial reservoirs worldwide.
- The newly acquired Skyline 16 Green River research core displays (1) low-relief stromatolites and thrombolites, (2) excellent primary megascopic and microporosity within microbial fabrics, (3) porous dolomite, (4) grainstone composed of ooids, pisoids, peloids, and skeletal material with abundant interparticle and intraparticle porosity, (5) sharp contacts between grainstones and microbialites, and (6) possible evaporite crystal molds within dense, carbonate mud.
- The West Willow Creek field produces oil from a small microbial mound (E$_2$ carbonate bed) within the Green River Formation—the only such known field in the Uinta Basin. Microbialite heads with consist of stromatolitic crusts with thrombolitic internal characteristics. Associated grainstones between laminated microbial fabrics are composed of peloids, ooids, and ostracods providing good to excellent interparticle porosity. Oncolites are another significant component to the microbial system.
- The entire Skyline 16, Federal No. 15-24B (West Willow Creek field), and other cores containing microbial carbonates are available for examination at the Utah Geological Survey's Core Research Center in Salt Lake City, Utah. These cores will also be featured during a core workshop "Microbial Reservoirs and Analogues from Utah," which will include a field trip to Great Salt Lake and Green River Formation outcrops, that we will present in conjunction with the Rocky Mountain Section meeting of the AAPG held in Salt Lake City, Utah, September 22-24, 2013.