Microbial Carbonates from Core and Outcrop, Tertiary (Eocene) Green River Formation, Uinta Basin, Utah

David E. Eby, Eby Petrography & Consulting, Inc., Denver, Colorado

ABSTRACT

Recent discoveries in Early Cretaceous microbialites in the deepwater offshore of Brazil (Santos Basin) and reservoirs in other large oil fields in microbialites reveal the global scale and economic importance of these distinctive carbonates. Evaluation of the various microbial fabrics and facies, associated petrophysical properties, diagenesis, and bounding surfaces are critical to understanding these reservoirs. Utah is unique in that representative outcrop analogs of microbial reservoirs are present and can be examined for detailed study. The Eocene Green River Formation from the Uinta Basin of eastern Utah contains excellent examples of microbial carbonates.

The Uinta Basin is a major depositional and structural basin which subsided during the early Cenozoic along the southern flank of the Uinta Mountains. Freshwater lakes developed between the eroding Sevier highlands to the west and the rising Laramide-age uplifts to the north, east, and south. The Green River Formation, consisting of up to 6000 ft of sedimentary rocks, accumulated in and around Lake Uinta. These major depositional facies are associated with lake sediments: algal/microbial laminae, and open lenticulate. The open lenticulate is represented by nearshore and offshore mudstones and shale-mud-supported carbonates, including microbialites.

Analysis of newly acquired Green River cores reveals a variety of microbial fabrics and related features. The overall section consists of medium gray siltstones and mudstones to light brown dolomitic mudstones with dark brown clay-rich and black organic-rich zones. Within the dolomitic mudstone are well-displayed, porous, microbial laminae and stromatolites with bulbous heads. Grainstones composed of oooids and coated grains are common. The Green River Formation (def.) = calcareous structures accreted as a result of bacterial or algal activity. The Green River Formation (right bar) consists of microbialites and related facies, which may be comprised of bacteria, fungi, protists, archaea, or algae, or evidence thereof, and are preserved in the sedimentary record.

MICROBIAL TYPES OBSERVED IN THE GREEN RIVER FORMATION:

- Stromatolites (def.) = laminated, biosedimentary structures, with calcification due to the growth of cyanobacteria.
- Thrombolites (def.) = calcareous structures with a clotted microstructure and no internal laminae, built by cyanobacterial microbes. (from Greek word “thrombo” = a clot)
- Oncolites (def.) = term for the spherical, layered structures formed by the activity of cyanobacteria. Similar to thrombolites but instead of forming columns they form approximately spherical structures. Often the oncoids form around a central nucleus, such as a shell particle, and the calcium carbonate structure is precipitated by encrusting microbes.
- Tufa/Travertine (def.) = a porous or fossiliferous deposit of calcium carbonate which occurs as a result of chemical precipitation from groundwater.

DEFINITIONS:

- Organosedimentary deposits that have accreted as a result of a benthic microbial community trapping and binding of detrital sediment and/or forming the locus of mineral precipitation.
- Microbial Carbonates (def.) = a porous or fossiliferous deposit of calcium carbonate which occurs as a result of chemical precipitation from groundwater.
Graphical Description for the Lower Portion of the Skyline 16 Core

Well name: Skyline 16

Mineralogy of Selected Microbialite and Grainstone Samples from the Skyline 16 Core

Core Photos of Skyline 16 Core Samples Analyzed by X-Ray Diffraction

Microbialites:

Stromatolites

THROMBOLITES

Tufa/Travertine

Oolites

Pisolites

PELOIDAL/SKELETAL

DOLOMITES:

EVAPORITE DISSOLUTION:

RESERVOIR ANALOGS FROM SKYLINE 16 CORE

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

SKYLINE 16 CORE
OUTCROP EXAMPLES

Four spectacular outcrops were studied in the eastern Uinta Basin (south of Vernal, Utah) for the distribution and lateral continuity of microbialites and related carbonate facies.

CONDO SECTION

Microbialite and Evaporite Examples in Condo Section

- A - View of Bowling Ball hill. Note the location of the dolomitized “Bowling Ball” stromatolite zone in the lower right portion of the outcrop. (Plane light)
- C - Fresh rock surface of a dominantly microbialite facies near Bowling Ball hill. Many of the nuclei (see red arrows) of these pisoids are broken ooids (which are also present in the white patches). (Plane light)
- B - Cross section through a representative oncoid from a microbial bed near Bowling Ball hill. Note the presence of gastropods and stromatolitic heads. (Plane light)
- D - View of the external morphology of a typical pisoid from the Bowling Ball hill. Note that the pisoids are encrusted with calcite. (Plane light)

Microbialite Examples from Bowling Ball Hill

- A - View of Bowling Ball hill. Note the location of the dolomitized “Bowling Ball” stromatolite zone in the lower right portion of the outcrop. (Plane light)
- B - Cross section through a representative oncoid from a microbial bed near Bowling Ball hill. Note the presence of gastropods and stromatolitic heads. (Plane light)
- C - View of a typical pisoid from the Bowling Ball hill. Note the presence of gastropods and stromatolitic heads. (Plane light)

HELLS HOLE SECTION

Outcrop Views

- A - Aerial view of the Hells Hole section (see location on panel C). Microbialite outcrops are concentrated mostly in the lower half of the 530 m core section. Microbriodes and associated carbonate facies are shown in blue. (Plane light)
- B - View of a portion of the Hells Hole section in which microbialites and associated carbonate facies are present. (Plane light)
- C - Outcrop view of representative thin section containing microbialite bed in the right side (black band). (Plane light)

FLASH FLOOD SECTION

Outcrop Views

- A - Aerial view of the Flash Flood section (see location on panel B). Microbialite outcrops are concentrated mostly in the lower half of the 530 m core section. Microbriodes and associated carbonate facies are shown in blue. (Plane light)
- B - View of a portion of the Flash Flood section in which microbialites and associated carbonate facies are present. (Plane light)
- C - Outcrop view of representative thin section containing microbialite bed in the right side (black band). (Plane light)
**Microbialites**

**General Characteristics**

- **Remnant of Pleistocene Lake Bonneville**
- **32nd largest lake in the world (largest freshwater lake in the United States after the Great Lakes)**
- **Averages 75 miles (121 km) long by 35 miles (56 km) wide**
- **Surface Elevation: about 4200 ft (1200 m)**
- **Lake Level Fluctuations: 1 to 2 ft (0.3-0.6 m) annually on average**
- **Maximum Depth: about 33 ft (10 m)**
- **Volume: 75,390,000 acres-ft (18,980 km³)**
- **Salinity: south arm = 12 to 14%, north arm = 24 to 26% (near its salt-saturation point)**
- **Chemical Composition: chloride = 34.5%, sodium = 32.8%, sulfate = 7.2%, magnesium = 3.3%, potassium = 2.6%, calcium = 0.2%**

**Evaporites**

- **Calcium carbonate sedimentary structures**
- **Highest point in the world**
- **Salt Lake City**
- **Salt Lake City**
- **Great Salt Lake**
- **Antelope Island**
- **Rozel Point**

**View of Great Salt Lake**

- **Microbialite Examples: Antelope Island**
  - Partially submerged stromatolite, Rozel Point
  - Close-up view of clotted microbialite head interior and open constructional pores
  - View of clotted microbialite head interior and open constructional pores
  - Close-up view of clotted microbialite head interior and open constructional pores
  - Close-up view of clotted microbialite head interior and open constructional pores

**Carbonate Grains Associated with Microbialites**

- **Antelope Island**
  - ooids, coated grains, intraclasts composed of ooids, pellets, oolitically coated volcanic fragments
  - Microbial and oolitically coated volcanic fragments
  - Microbial and oolitically coated volcanic fragments
  - Microbial and oolitically coated volcanic fragments
  - Microbial and oolitically coated volcanic fragments

**Examples of Grains and Cements: Antelope Island**

- **Calcite crystals**
- **Micritic cements**
- **Micritic cements**
- **Micritic cements**
- **Micritic cements**

**Examples of Grains and Cements: Rozel Point**

- **Ooids with crystals**
- **Ooids with crystals**
- **Ooids with crystals**
- **Ooids with crystals**
- **Ooids with crystals**

**Satellite Image of Great Salt Lake**

**Stromatolite Areas in Great Salt Lake**

**Stromatolites near Hat Island, Great Salt Lake**

**Reservoir Analogs**

- **Great Salt Lake, Utah: A Modern Analog**
- **Reservoir Analogs**
- **Microbialite Examples: Antelope Island**
- **Microbialite Examples: Rozel Point**
- **Carbonate Grains Associated with Microbialites**
- **Examples of Grains and Cements: Antelope Island**
- **Examples of Grains and Cements: Rozel Point**
- **Evaporites**
- **Satellite Image of Great Salt Lake**
- **Stromatolite Areas in Great Salt Lake**
- **Stromatolites near Hat Island, Great Salt Lake**
GENERAL FIELD DATA

- **Producing Reservoir**: Eocene Green River Formation (E2 bed)
- **Depositional Environment**: near-shore, shallow water, lacustrine stromatolitic carbonate buildup
- **Type of Trap**: combination stratigraphic (microbial mound) with updip structural pinchout
- **Olistostrome Horizon**: Permeated – Cretaceous Moumouane Group
- **Surface Formation**: Tertiary (Eocene) Uinta Formation
- **Spacing**: Federal unit
- **Current Operator**: XTO Energy Inc.

**Discovery Well**

- Mapco Inc, No. 7-28B well
- **T2 compression**: 9-28B (2014 m)
- Completed: November 7, 1981
- **IPF**: 21 BOPD and 5 BWPD

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

**Production & Reserves**

- **Producing Wells**: 5
- **Abandoned Producers**: 3
- **Dry Holes**: 2
- **Monthly Production (May 1, 2015)**: 546 BO, 7628 MCF/d, and 117 BW
- **Cumulative Production (as of May 1, 2015)**: 1,135,498 BO, 12.1 BCF/d, and 69,955 BW
- **Estimated Original Oil in Place**: 8 MMBO
- **Estimated Original Gas in Place**: 2.95 BCFG
- **Secondary Enhanced Oil Recovery Program**: pressure maintenance (rejection 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.

**Compensation Details**

- **Neutron-DensityGR**: $N_{PHI}$ - Neutron Porosity
  - $D$ - Resistivity Deep

**E: CARBONATE BED. GREEN RIVER FORMATION**

**Isopach Map of the E2 Carbonate Bed**

**Isopach Map of the Interval Between the E2 Carbonate Bed and Top of the Uintland Butte Limestone**

**Structure Contour Map, Base of the E2 Carbonate Bed**

**Stratigraphic Cross Section**

**Reservoir Data**

- **Productive Area**: 560 acres (230 ha)
- **Gross Pay**: 25 to 100 ft (8-30 m)
- **Net Pay**: 10 to 40 ft (3-12 m)
- **Net to Gross**: 0.4
- **Geometry of Reservoir Rock**: mound, 1240 acres (500 ha)
- **Hydrocarbon Column**: 200 ft (60 m)
- **Average Pore Pressure**: 4 to 18% (psi)
- **Permeability**: 0 to 60 md
- **Water Salinity**: TD (mg/l) = 73,741; chemical components: calcium = 10,000; sulfate = 2844, bicarbonate = 404, calcium = 2844, magnesium = 194, iron = 2, sodium = 27,119
- **BIHT**: 14°F (64°C)
- **Type of Drive**: gas cap expansion
- **Initial Reservoir Pressure**: 1530 psi

**Petrography**

- **Lithology**: limestone to dolomite, stromatolitic and thrombolitic, eustacial to oolitic grainstone, rudstone, boundstone, packstone, and wackestone
- **Pore Types**: interparticle, intraparticle, shelter, intercrystalline, vuggy, and abundant microporosity
- **Diagnosis**: cementation and early dolomitization

**Core Description: E2 Carbonate Bed, Federal No. 15-24B Well**

**Major Characteristics of the E2 Carbonate Bed, Federal No. 15-24B Core**

**Isopach Map of the E2 Carbonate Bed**

**Isopach Map of the Interval Between the E2 Carbonate Bed and Top of the Uintland Butte Limestone**

**Structure Contour Map, Base of the E2 Carbonate Bed**

**Stratigraphic Cross Section**

**GEOLOGICAL LOGS**

**Core Plug Analysis**

**Geological Core**

**Cumulative Production**: 1941,415 BO, 765,400 MCF/d, and 212,257 BW (abandoned in 2007); Utah Division of Oil, Gas, and Minning, well records.
THROMBOLITIC MICROBIALITES

- A - Cored thrombolitic fabric with early isopachous fibrous cements that together form hard bedrock "heads." Occasional ostracods and calcite spar cement. 4773.3 ft., porosity = 15.6%, permeability = 4.1 mD

- B - Cross section of a radiating pustular microbialite crust with layers of good matrix preservation and internal characteristics. Radial, concentric microtextures are common and are often lined with acicular radial cements. 4747.6 ft., Plane light

- C - Orientation towards a clotted microbialite fabric with small thrombolitic internal characteristics. Radial, concentric microtextures are common and are often lined with acicular radial cements. 4787.5 ft., Plane light

- D - Cross section of a pustular microbialite crust with layers of good matrix preservation and internal characteristics. Radial, concentric microtextures are common and are often lined with acicular radial cements. 4751.8 ft., Plane light

- E - Cored thrombolitic fabric containing early isopachous fibrous cements that together form hard bedrock "heads." Ostracods are another common feature in the cores. 4774.5 ft. (Planepol light)

- F - Cored thrombolitic fabric containing early isopachous fibrous cements that together form hard bedrock "heads." Ostracods are another common feature in the cores. 4784.2 ft. (Plane light)

- G - Cored thrombolitic fabric containing early isopachous fibrous cements that together form hard bedrock "heads." Ostracods are another common feature in the cores. 4744.7 ft. (Plane light)

- H - Cored thrombolitic fabric containing early isopachous fibrous cements that together form hard bedrock "heads." Ostracods are another common feature in the cores. 4770.9 ft. (Plane light)

- I - Cored thrombolitic fabric containing early isopachous fibrous cements that together form hard bedrock "heads." Ostracods are another common feature in the cores. 4770.9 ft. (Plane light)

- J - Cored thrombolitic fabric containing early isopachous fibrous cements that together form hard bedrock "heads." Ostracods are another common feature in the cores. 4770.9 ft. (Plane light)

ONCOLITES

- A - Cored oncoid boundstone with early isopachous fibrous cements. 4770.9 ft., porosity = 0.4%, permeability = 0.02 mD

- B - Cross section of a pustular microbialite crust with layers of good matrix preservation and internal characteristics. Radial, concentric microtextures are common and are often lined with acicular radial cements. 4751.8 ft., Plane light

- C - Cross section of a pustular microbialite crust with layers of good matrix preservation and internal characteristics. Radial, concentric microtextures are common and are often lined with acicular radial cements. 4751.8 ft., Plane light

- D - Cross section of a pustular microbialite crust with layers of good matrix preservation and internal characteristics. Radial, concentric microtextures are common and are often lined with acicular radial cements. 4751.8 ft., Plane light

- E - Cored oncoid boundstone with early isopachous fibrous cements. 4770.9 ft., porosity = 0.4%, permeability = 0.02 mD

- F - Cross section of a pustular microbialite crust with layers of good matrix preservation and internal characteristics. Radial, concentric microtextures are common and are often lined with acicular radial cements. 4751.8 ft., Plane light

- G - Cross section of a pustular microbialite crust with layers of good matrix preservation and internal characteristics. Radial, concentric microtextures are common and are often lined with acicular radial cements. 4751.8 ft., Plane light

- H - Cross section of a pustular microbialite crust with layers of good matrix preservation and internal characteristics. Radial, concentric microtextures are common and are often lined with acicular radial cements. 4751.8 ft., Plane light

- I - Cored oncoid boundstone with early isopachous fibrous cements. 4770.9 ft., porosity = 0.4%, permeability = 0.02 mD

- J - Cross section of a pustular microbialite crust with layers of good matrix preservation and internal characteristics. Radial, concentric microtextures are common and are often lined with acicular radial cements. 4751.8 ft., Plane light

SUMMARY & CONCLUSIONS

- The lacustrine Eocene Green River Formation of the Uinta Basin, Utah, contains excellent examples of microbial carbonates—stromatolites, thrombolites, oncoids, and tufa/travertine—which can serve as analogs for highly productive non-marine microbial reservoirs worldwide.

- The newly acquired Skyline 16 Green River core displays (1) low-relief stromatolites and thrombolites, (2) excellent primary megasopic pores and micro-pores within microbial fabrics, (3) porous dolomite associated with lacy tufa/travertine, (4) grainstones composed of ooids, pisoids, peloids, and skeletal material with abundant interparticle and intraparticle porosity, (5) sharp contacts between grainstones and microbialites, and (6) everted crystal molds within dense, black organic-rich sediments.

- Outcrops of the Green River Formation in the eastern part of the Uinta Basin display many of the microbial features observed in core. Thrombolitic heads contain large, open, constructional pores. Well-developed laminations in thrombolitic heads have abundant primary porosity between microbial filaments. Pisoids, ooids, oncoids, ostracods, and peloids are frequently observed in the cores. Thrombolitic heads often consist of stromatolitic crusts with thrombolitic internal characteristics. Associated grainstones between thrombolitic microbes are composed of peloids, ooids, and ostracods providing good to excellent interparticle porosity. Oncoids 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 Utah Core Research Center in Salt Lake City, Utah.