MARINE MICROBIAL CARBONATE FACIES, FABRICS, AND PETROLEUM RESERVOIRS IN UTAH

by

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ABSTRACT

Recent discoveries in Early Cretaceous lacustrine microbial carbonates of the deepwater offshore of Brazil (pre-salt Santos Basin reservoirs) as well as other large oil deposits in microbialites reveal the global scale and economic importance of these distinctive reservoirs. Evaluation of the various microbial fabrics and facies, associated petrophysical properties, diagenesis, and bounding surfaces are critical to understanding these reservoirs. Utah has well-documented examples of lacustrine microbialites in the Eocene Green River Formation within the Uinta Basin of northeastern Utah. In addition, Great Salt Lake is a modern hypersaline lake, actively forming microbialites.

A survey of carbonate cores from active Utah oil fields also reveals a variety of previously undocumented marine microbial fabrics, associated carbonate grains, pore types, and reservoir characteristics. The reservoirs, fields, and geologic locations, respectively, are the (1) Jurassic Twin Creek Limestone, Pineview field, thrust belt, (2) Triassic Moenkopi Formation (K-2 Zone, Timpoweap Member), Upper Valley field, Kaiparowits Basin, (3) Pennsylvanian Paradox Formation, Greater Aneth field, Paradox Basin, and (4) Mississippian Leadville Limestone, Lisbon field, Paradox Basin. Like their lacustrine counterparts, these marine rocks display a wide variety of stromatolitic and thrombolitic growth forms, and possible leiolites in mud mounds; associated carbonate grains include ooids, peloids, and oncoids. Porosity has developed in many of the microbial fabrics: intercrystalline, dissolution, interparticle, and extensive microporosity. Microbial dolomite/dolomitization have enhanced porosity and permeability development.

These marine microbial carbonates represent undocumented zones within existing Utah oil and gas fields. They could also become the drilling targets for new potential hydrocarbon plays in Utah and the Rocky Mountain region. These publically available cores at the Utah Core Research Center serve as production-scale analogs for comparison of marine microbialites to the more common freshwater lacustrine microbial reservoirs. This offers the opportunity to better identify marine microbialites and their hydrocarbon potential in the Rockies and elsewhere in the world.

MICROBIALITES IN GREAT SALT LAKE, UTAH & SHARK BAY, AUSTRALIA

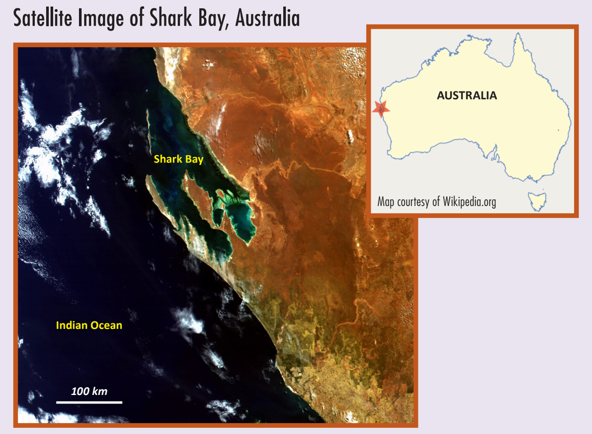
Satellite Image of Great Salt Lake (NASA #STS047-097-021, September 1992)

Rozel Point close up (inset top left), Google Earth image taken May 2010
Bridger Bay close up (inset bottom left), Google Earth image taken July 2010

Circular Microbial Mats Exposed During Low Lake Level, Bridger Bay

Photo by Michael Vanden Berg, Utah Geological Survey

Satellite Image of Shark Bay, Australia



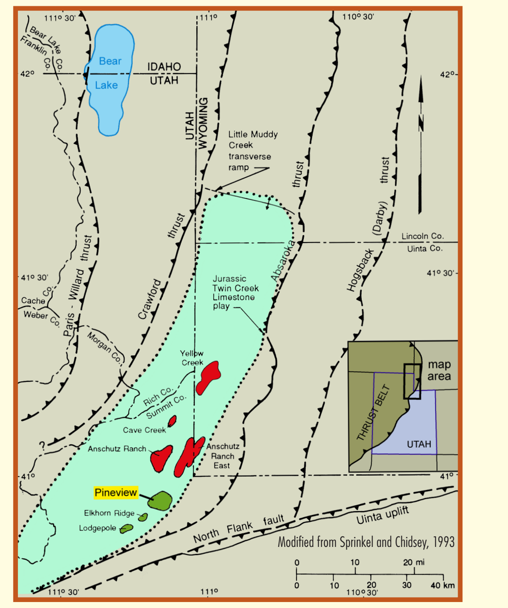
MODIS image courtesy of NASA

Shark Bay Stromatolites that are 2,000–3,000 Years Old

Photo courtesy of jazzmarazz.wordpress.com

JURASSIC TWIN CREEK LIMESTONE, PINEVIEW FIELD, NORTHERN UTAH THRUST BELT

Location of Fields that Produce Oil (green) and Gas (red) from the Jurassic Twin Creek Limestone, Utah and Wyoming



Modified from Sprinkel and Chidsey, 1993

Major thrust faults are dashed where approximate (teeth on hanging wall). The Twin Creek Limestone play area (light green) is shown within the dotted lines.

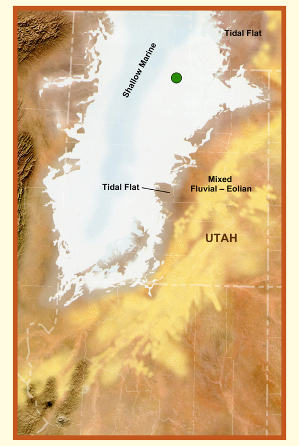
Stratigraphic Column of Jurassic Section, Northern Utah Thrust Belt

Age	Formation		Thickness
K	Kelvin Formation		up to 5700'
JURASSIC	Stump Formation		60-250
JURASSIC	Preuss Sandstone		900-1500
JURASSIC	Twin Creek Ls	Giraffe Creek Mbr	110-230
JURASSIC	Twin Creek Ls	Leeds Creek Member	1000-1300
JURASSIC	Twin Creek Ls	Watton Canyon Mbr	400
JURASSIC	Twin Creek Ls	Boundary Ridge Mbr	100-250
JURASSIC	Twin Creek Ls	Rich Member	420-540
JURASSIC	Twin Creek Ls	Sliderock Member	100-230
JURASSIC	Twin Creek Ls	Gypsum Spring Mbr	210
JURASSIC	Nugget Sandstone		1100-1500
Ŧ	Ankareh Formation	Wood Shale Tongue	520
Ŧ	Ankareh Formation	Higham Grit & Timothy SS Mbr	40-200
Ŧ	Ankareh Formation	Lanes Shale Tongue	470-700

✱ Oil and gas production (marked beside Watton Canyon Mbr through Gypsum Spring Mbr)

Modified from Hintze and Kowallis, 2009

Paleogeography during Middle Jurassic



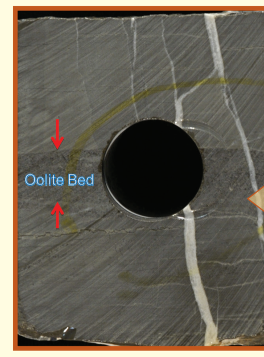
The green dot represents the approximate location of Pineview field (not palinspastically restored). Modified from Blakey and Ranney, 2008.

WATTON CANYON MEMBER*

Lime mudstone with mm-scale microbial laminations

Note the vertical (bed normal) stylolites and the healed fractures. (8759 ft., porosity = 1.4%, permeability = 0.01 mD).

Thin bed of ooids (between red arrows) within a massive lime mudstone exhibiting microbial laminae



Note the vertical fractures healed with white calcite. (8761 ft.).

Photomicrograph (plane light) of the core image to the left showing contact between an oolitic grainstone bed and microbial lime mudstone

Note the rounded quartz silt grains (in white).

*UPRR No. 3-3 well, NW SE Sec. 3, T. 2 N., R. 7 E., Summit County, Utah

RICH MEMBER*

Microbial boundstone/oolitic grainstone displaying a clotted thrombolitic fabric

Note that anhydrite has filled space between possible solution-collapse breccia and fractures. (8983.5 ft., porosity = 1.4%, permeability = 0.08 mD).

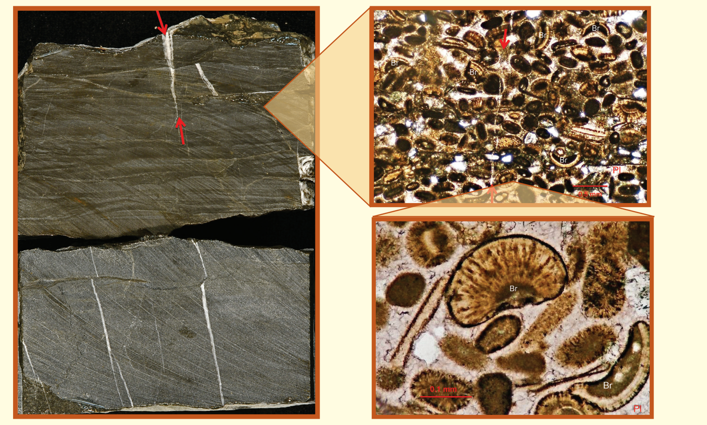
Microbial boundstone that displays a thrombolitic texture

Note the mineralized vertical and oblique fractures (in white). (8990 ft., porosity = 5.1%, permeability = 4.5 mD).

Microbial mudstone displaying a laminated stromatolite structures

Note the displacive and replacive white anhydrite nodules as well as vertical fractures healed with anhydrite. (8993.6 ft., porosity = 2.7%, permeability = 0.22 mD).

Oolitic grainstone bound and laminated by microbial structures



The ooids within this interval display syndepositional breakage and "cerebroid" margins. These ooids probably formed within a hypersaline lagoon.

Photomicrograph of oolitic/skeletal grainstone with abundance of broken ooids (Br)

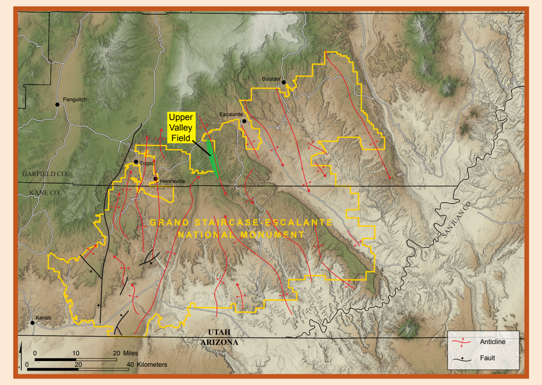
The broken ooids (Br) are probably indicative of formation under elevated salinity. Broken ooids are common in modern Great Salt Lake hypersaline carbonate sediments.

Reservoir and Production Data

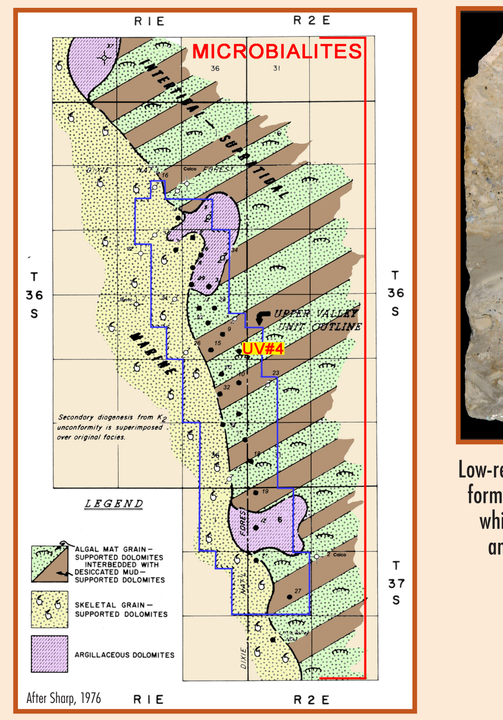
- Major Reservoir – fractured limestone
- Trapping Mechanism – fault propagation/ fault-bend anticline
- Productive Area – 2080 acres
- Net Pay – 200 ft
- Porosity – 2 to 4%, enhanced by fracturing
- Permeability – 4 to 30 mD
- Water Saturation – 15 to 35%
- Type of Drive – solution gas
- Cumulative Production (as of December 1, 2013) – 9,210,397 barrels of oil (BO), 11.6 billion cubic feet of gas (BCFG)
- Secondary Recovery Projects – horizontal drilling (1997)
- **The Microbialite Contribution to Total Reservoir Volume is yet to be determined**

TRIASSIC MOENKOPI FORMATION (K-2 ZONE, TIMPOWEAP MEMBER), UPPER VALLEY FIELD, KAIPAROWITS BASIN

Location of Upper Valley Field and Structures in the Laramide-Age Kaiparowits Basin

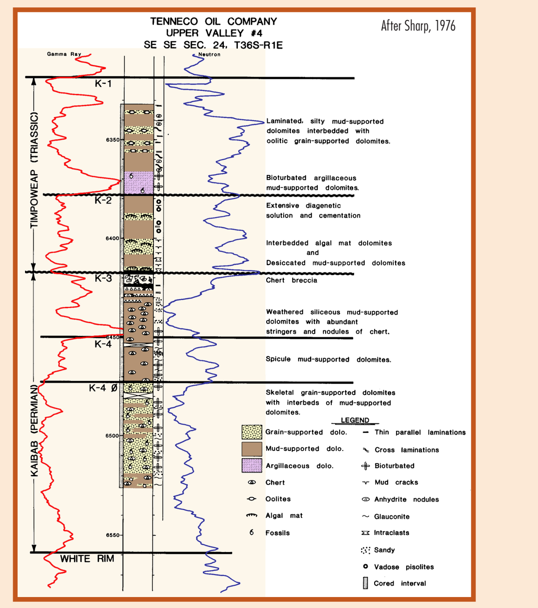


Facies Distribution within the K-2 Zone (Timpoweap Member)



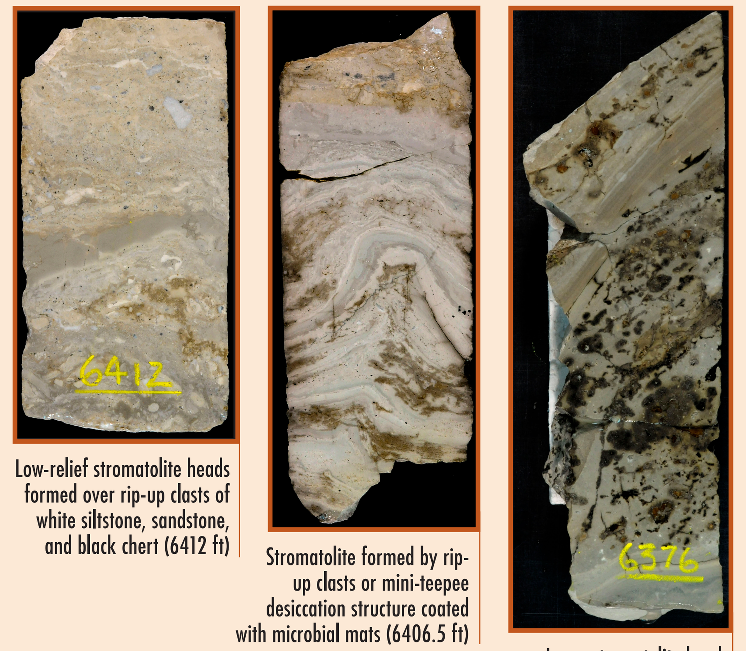
After Sharp, 1976

Type Log (Upper Valley No. 4 Well) of the Timpoweap Member of the Triassic Moenkopi Formation and Permian Kaibab Limestone



After Sharp, 1976

STROMATOLITES*



Low-relief stromatolite heads formed over rip-up clasts of white siltstone, sandstone, and black chert (6412 ft)

Stromatolite formed by rip-up clasts or mini-teepee desiccation structure coated with microbial mats (6406.5 ft)

Large stromatolite head (partial) over a moldic dolomite (possible fossil molds) at the top of the K-2 Zone (6376 ft), Timpoweap Member

THROMBOLITES AND CRYPTALGAL LAMINITES*

Small thrombolite with oil staining (6377.5 ft)

Flat cryptalgal (microbial) laminites with desiccation features and vertical fractures; some minor anhydrite (6409.5 ft)

Reservoir and Production Data

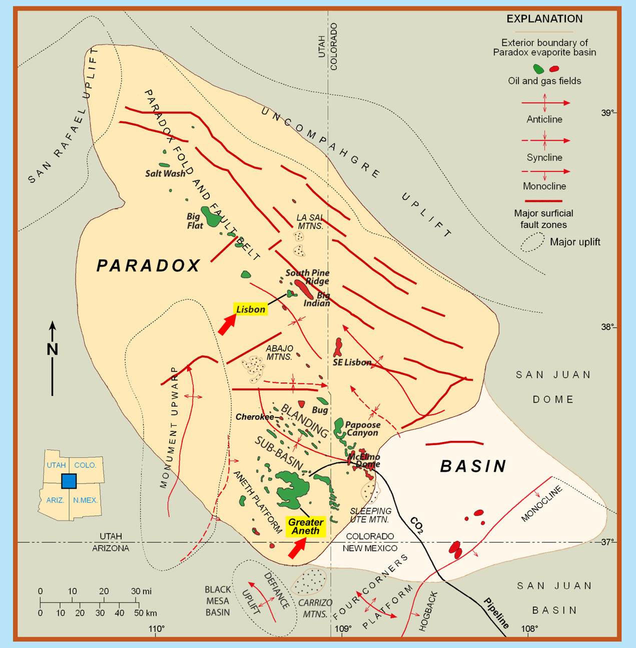
- Major Reservoir – Permian Kaibab Limestone, K-4 Porosity Zone (skeletal grain-supported dolomite)
- Trapping Mechanism – anticline with a hydrodynamically displaced oil column
- Productive Area – 3360 acres
- Net Pay – 75 ft
- Porosity – 11 to 27%, average 18%
- Permeability – up to 300 mD, average 100 mD
- Water Saturation – 25 to 32%
- Type of Drive – water drive
- Cumulative Production (as of December 1, 2013) – 28,484,609 BO, 0.13 BCFG
- Secondary Recovery Projects – water injection

Note: Microbialite facies are occasionally present in the Permian Kaibab (K-4 Porosity Zone) Reservoir unit

*Upper Valley No. 4 well, SE SE Sec. 24, T. 36 S., R. 1 E., Garfield County, Utah

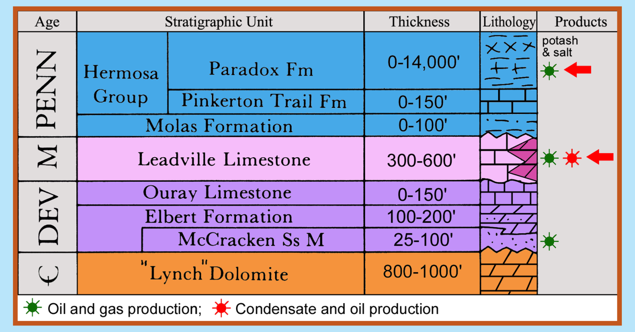
PENNSYLVANIAN PARADOX FORMATION, GREATER ANETH FIELD & MISSISSIPPIAN LEADVILLE LIMESTONE, LISBON FIELD, PARADOX BASIN

Oil and Gas Fields in the Paradox Basin of Utah, Colorado, and Arizona



Play areas in the Paradox Basin colored light orange; Greater Aneth and Lisbon fields are highlighted.
Modified from Harr, 1996

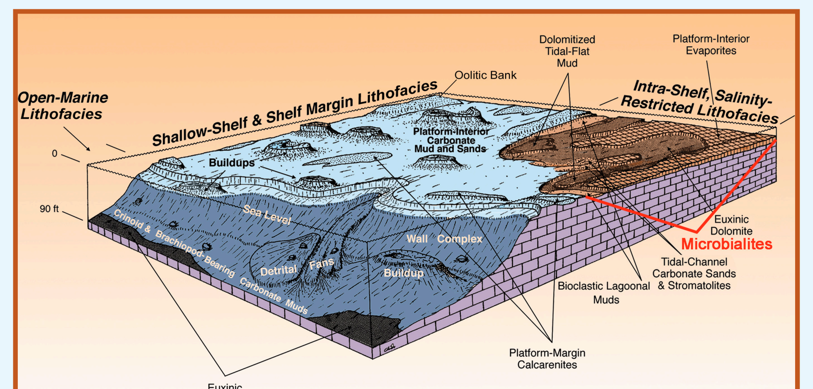
Stratigraphic Column of the Paleozoic Section in the Paradox Basin



Modified from Hintze and Kowallis, 2009

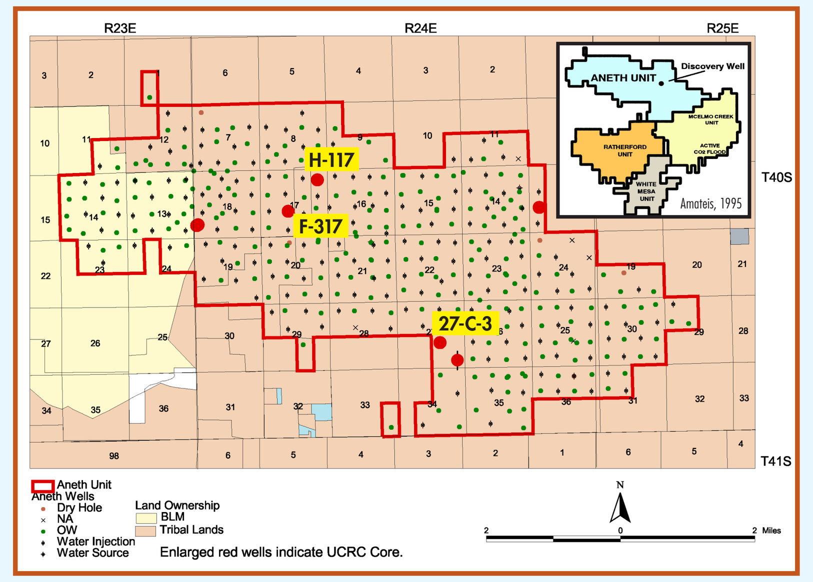
GREATER ANETH FIELD

Depositional Environments of the Desert Creek Zone, Paradox Formation, within the Aneth Platform Area



After Chidsey and others, 1996

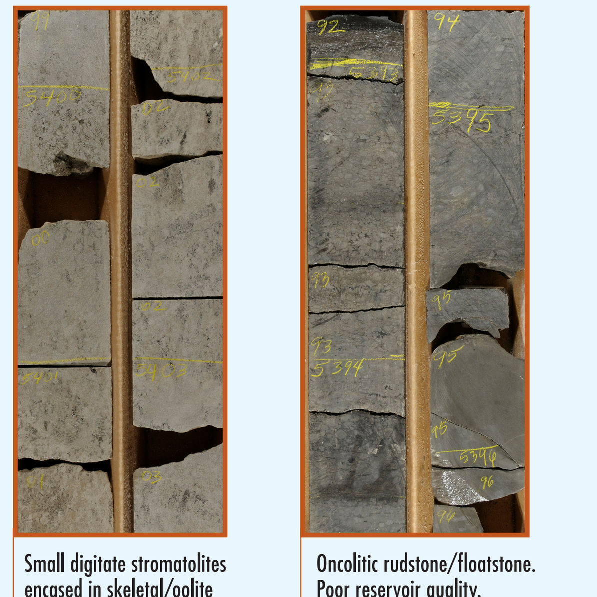
Land Ownership and Base Map of Wells in the Aneth Unit



*Aneth Unit (A.U.) No. F-317 well, NW SW Sec. 17, T. 40 S., R. 24 E., San Juan County, Utah
†Aneth Unit No. H-117 well, NE NE Sec. 17, T. 40 S., R. 24 E., San Juan County, Utah
‡Aneth Unit No. 27-C-3 well, NW SE Sec. 27, T. 40 S., R. 24 E., San Juan County, Utah

Reservoir and Production Data

- Major Reservoir – oolitic and skeletal grainstone, phylloid-algal bafflestone
- Trapping Mechanism – stratigraphic, carbonate buildup
- Productive Area – 48,260 acres
- Net Pay – 50 ft
- Average Porosity – 10.2%
- Permeability – 3 to 30 mD, average 10 mD
- Water Saturation – 24%
- Type of Drive – solution gas
- Cumulative Production (as of December 1, 2013) – 470,339,323 BO, 418.8 BCFG
- Secondary Recovery Projects – waterflood, carbon dioxide flood, horizontal drilling
- **The Microbialite Contribution to Total Reservoir Volume is yet to be determined**



Small digitate stromatolites encased in skeletal/oolite grainstone. Good reservoir quality. A.U. F-317*: 5399.7-5403.5 ft.

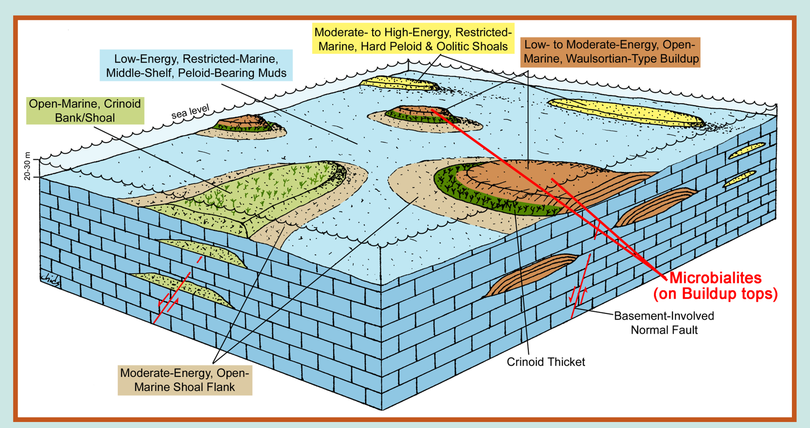
Oncolitic rudstone/floatstone. Poor reservoir quality. A.U. H-117†: 5392.8-5395.7 ft

Porous thrombolitic/stromatolitic grainstone. Note black bitumen lining pores. A.U. H-117†: 5400.8-5401.4 ft.

Oil-saturated thrombolitic/stromatolitic boundstone with skeletal grainstone lenses. Fair to good reservoir quality. A.U. 27-C-3‡: 5734.0-5734.5 ft.

LISBON FIELD

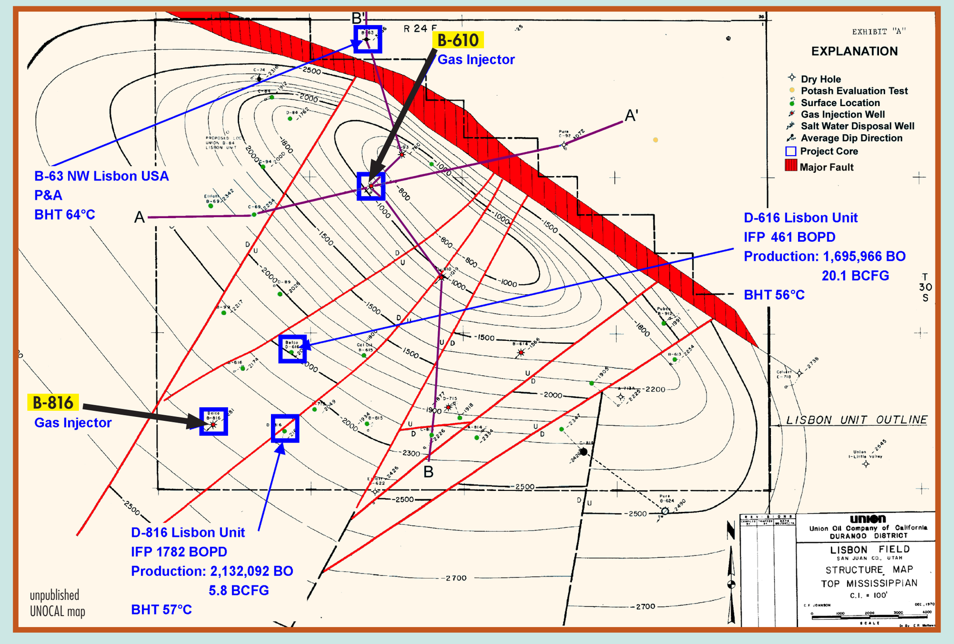
Major Depositional Facies of the Mississippian Leadville Limestone, Paradox Basin



Reservoir and Production Data

- Major Reservoir – dolomotized skeletal grainstone and packstone with extensive diagenesis
- Trapping Mechanism – faulted anticline
- Productive Area – 5120 acres
- Net Pay – 225 ft
- Porosity – 1 to 21%, average 5.5%
- Permeability – 0.01 to 1100 mD, average 22 mD
- Water Saturation – 39%
- Type of Drive – combination pressure decline and water drive
- Cumulative Production (as of December 1, 2013) – 51,322,632 BO, 608 BCFG
- Secondary Recovery Projects – controlled pressure decline (crestal gas injection)
- **The Microbialite Contribution to Total Reservoir Volume is yet to be determined**

Top of Structure of the Leadville Limestone, Lisbon Field



*Lisbon B-610 well, NW NW Sec. 10, T. 30 S., R. 24 E., San Juan County, Utah
†Lisbon B-816 well, NE SW Sec. 16, T. 30 S., R. 24 E., San Juan County, Utah

Stromatolitic boundstone/bindstone dominated by muddy fabrics. Note laminated rip-up clasts. The black areas are bitumen-lined pores. Lisbon B-610*: 7858-7862 ft.

Stromatolitic lamination binding lime mud. Note desiccation features and microfractures. Black bitumen lines open pores and fractures. Lisbon B-610*: 7983-7990 ft.

Stromatolitic packages alternating with rip-up clasts and eroded heads. Silicification of thin intervals can be seen in lighter rocks. Bitumen lines some of the open pores and fractures. Lisbon B-816†: 8579-8637 ft.

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DISCLAIMER

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