Dolomitization of the Mississippian Leadville Reservoir at Lisbon Field, Paradox Basin, Utah

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The Mississippian Leadville Limestone has produced over 826 BCF of sour gas and 53 MMB of sour oil from six fields in the northern Paradox Basin of Utah and Colorado. Lisbon field in San Juan County, Utah, has accounted for most of the Leadville production to date. Discovered in 1960, Lisbon field has produced nearly 51.8 MMBO and 765 BCFG (cycled gas). The trap is an elongate, asymmetrical, northwest-trending anticline with nearly 2000 ft (600 m) of structural closure. The field is bounded on its northeast flank by a major, basement-involved normal fault with over 2500 ft (760 m) of displacement. In addition, multiple, northeast-trending, normal faults dissect the Leadville reservoir into segments. Several of the best producing wells are located close to these faults. The reservoir drive mechanism is an expanding gas cap and gravity drainage. Gas that was re-injected into the crest of the structure to control pressure decline is now being produced. Early conventional cores have been examined from several of the 23 currently producing (or shut-in) wells, ten abandoned producers, five injection wells and four dry holes within the field.

The Leadville Limestone was deposited as an open-marine, carbonate-shelf system that thins from >700 ft (210 m) in the northwest corner of the Paradox Basin to <200 ft (60 m) in the southeast corner. Crinoid banks, peloid/oolitic shoals, and small Waulsortian mounds developed on upthrown fault blocks or other paleotopographic highs in the Lisbon field area. There is no visible matrix porosity associated with any of the preserved limestones, including those intervals with evidence of subaerial exposure. Karst-related cavities, when encountered in cores, have been completely infilled with sediments that do not display any significant porosity.

Two basic types of dolomite have been seen within the cored wells. The first type (early) consists of "stratigraphic" dolomites that preserve original depositional grains and textures. Very fine (<5 µ), interlocking dolomite crystals with no intercrystalline pore spaces are the norm. Commonly, this type of dolomite can be correlated across the field in several relatively thin intervals. The second type (late) of dolomite is a much coarser (>10-20 µ), later replacement of all types of limestone and earlier "stratigraphic" dolomite. Crosscutting relationships with carbonate bedding and variable dolomite thicknesses across the field are common. Petrographically, the coarse, second dolomite type consists of crystals with thick, cloudy, inclusion-rich cores and thin, clear overgrowths with planar crystal terminations. Often, these coarser dolomites show saddle dolomite characteristics of curved crystal shape and sweeping extinction under cross-polarized lighting. Predating or concomitant with saddle dolomite formation are pervasive leaching episodes that crosscut the carbonate host rocks, with dissolution resulting in late vugs as well as extensive microporosity. Pyrobitumen and sulfide minerals appear to coat most intercrystalline dolomite as well as dissolution pores associated with the second type of dolomite. Extensive solution-enlarged fractures and autobreccias are also common. Most reservoir rocks within Lisbon field appear to be associated with the second, late type of dolomitization and associated leaching events.

Stable carbon and oxygen isotope data indicate that early stratigraphic dolomite was likely associated with reflux by brines whose composition was enriched in ^{18}O compared with late Mississippian seawater. Later dolomitization and dolomite cement precipitation occurred at progressively higher temperatures; however, given reasonable fluid compositions, precipitation temperatures probably exceeded 90°C. Throughout its history of dolomitization, the Leadville Limestone at Lisbon field remained buffered by rock-derived carbon as indicated by a narrow range of carbon isotope values. Dolomite carbon isotopes show no evidence that would indicate influence by meteoric waters.

Cum Production thru 6/04

1.5 MMBO
11.7 BCFG

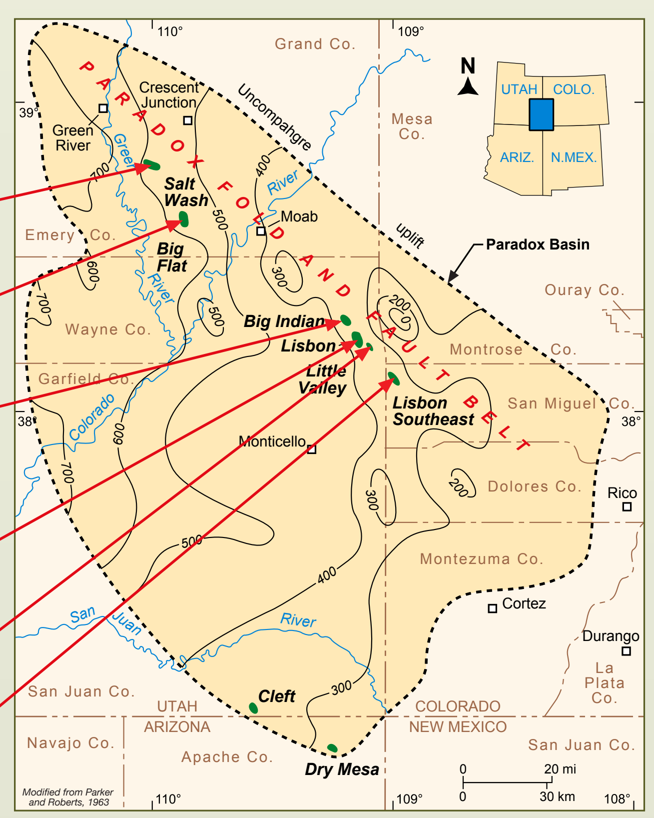
83,469 BO
.052 BCFG

178,160 BO
26.4 BCFG

Lisbon Field
51.1 MMBO
769 BCFG

137,848 BO
17.3 BCFG

8,819 BO
16.1 BCFG

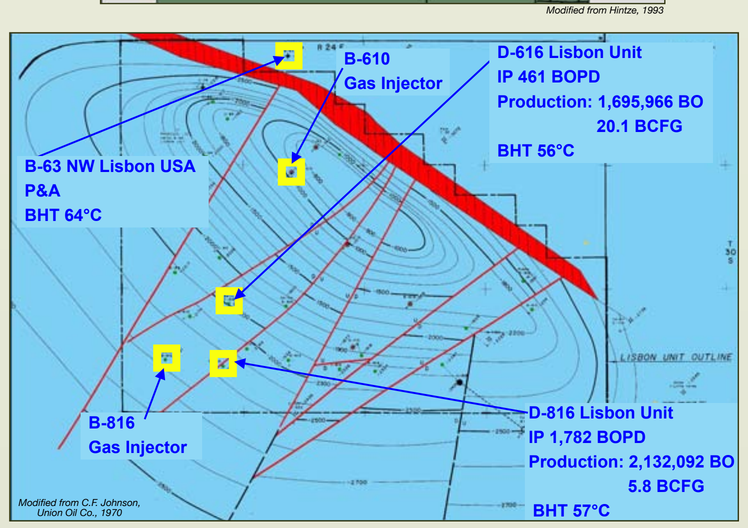


Regional map showing productive fields in the Leadville Limestone within the Fold and Fault Belt of the Paradox Basin. Lisbon field has the largest oil and gas accumulation to date.

Stratigraphic Column of the Paleozoic Section
Paradox Fold and Fault Belt

PENN	Hermosa Group	Paradox Fm	2000-5000'		potash & salt
PENN	Hermosa Group	Pinkerton Trail Fm	0-150'		
PENN	Molas Formation		0-100'		
M	Leadville Limestone		300-600'		✱
DEV	Ouray Limestone		0-150'		
DEV	Elbert Formation		100-200'		
DEV		McCracken Ss M	25-100'		✱
Є	"Lynch" Dolomite		800-1000'		

Modified from Hintze, 1993



Structure map of Lisbon field. The field is an elongate, asymmetrical, NW-trending anticline with ~ 2000 ft (600 m) of structural closure. The field is bounded on its NE-flank by a major, basement-involved normal fault (in red) with >2500 ft (760 m) of displacement. Note the multiple, NE-trending faults dissect the Leadville reservoir into several segments. Some of the best producing wells (e.g. cored wells D-616 and D-816) are located close to these faults. The cored wells used in this study are shown as □*s.*

Field/Oil & Gas Characteristics

Lisbon Field

- 23 Producing (or shut-in) Wells
- 10 Abandoned Producers
- 5 Injection Wells
- 4 Dry Holes

Oil Characteristics

- Oil Gravity – 54-62.6° API
- Sulfur – 0.2%
- Color – Yellow to Red

Gas Characteristics

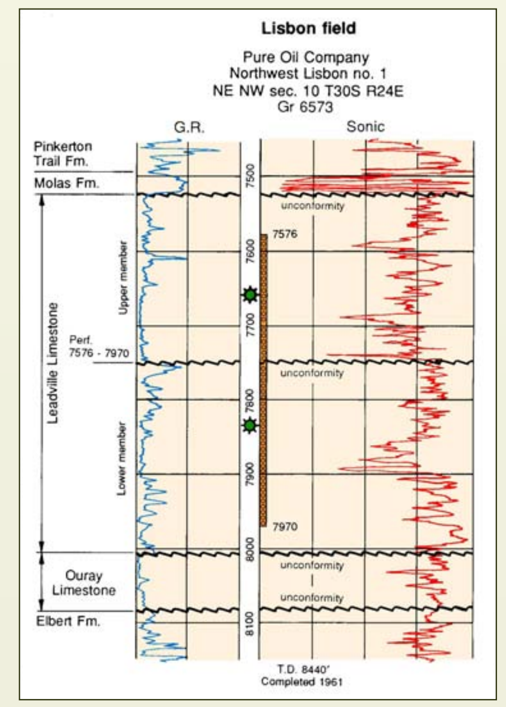
- H_2S – 1.2%
- CO_2 – 21% (rn. 2.2-35.6%)
- Helium – trace-1.1%
- BTU – 470

Discovery Well

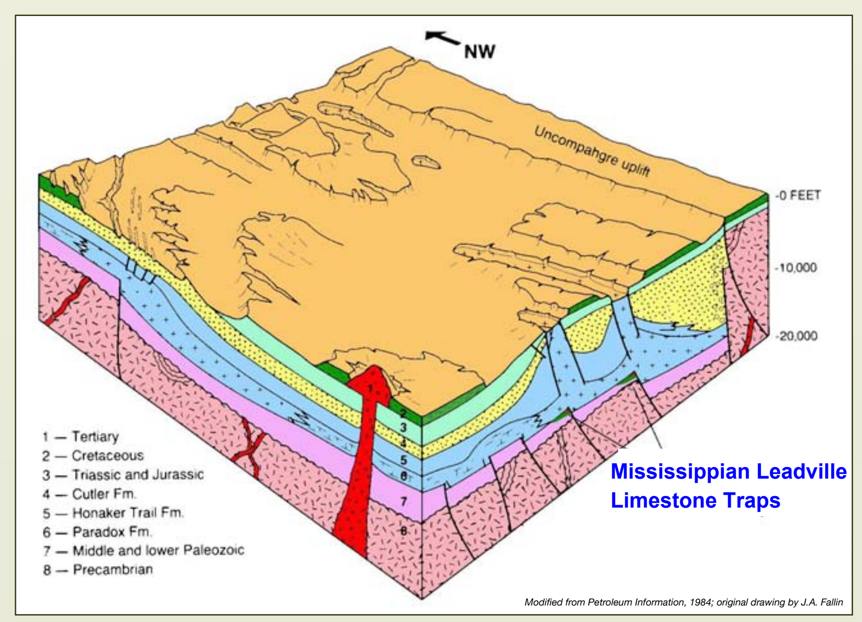
- Pure Oil Company, #1 NW Lisbon USA
- T.D. – 8440 ft
- Completed January 5, 1960
- IPF – 4376 MCFG, 179 BOPD
- Initial Pressure – 2713 psia
- GOR – 1417-3153:1

Reservoir Data

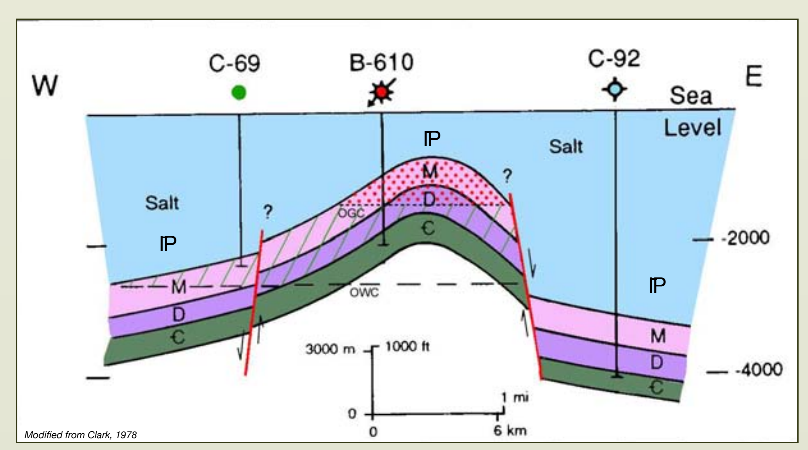
- Productive Area – 5120 acres
- Net Pay – 225 ft
- Porosity – 1-21%, average 5.5%
- Permeability – 0.01-1100 mD, average 22 mD
- Water Saturation – 39%
- Bottom-hole Temperature – 53°C to 73°C
- Type of Drive – Expanding Gas Cap and Gravity Drainage



Type log for the discovery well at Lisbon field. Almost all of the intervals of porosity in the wireline logs are associated with dolomitization and dissolution of the massive Leadville Limestone.



Block diagram showing the generalized nature of basement-involved faulting in Leadville fields like Lisbon in the northeastern Paradox Basin.



A very generalized structural W-E cross section of Lisbon field. Note the juxtaposition of the Mississippian (M) section against the Pennsylvanian (IP) section evaporates (salt).

Five Principal Leadville Depositional Facies

High Energy, Open-Marine Shoal

Crinoidal/Skeletal Grainstone/Packstone with Rugose Corals

Moderate Energy, Restricted Marine

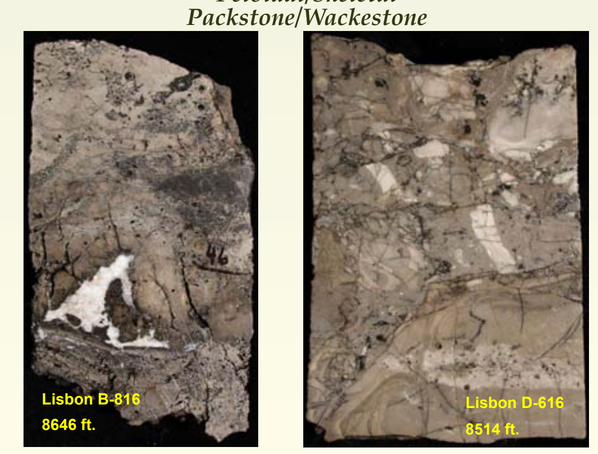
"Hard" Peloid Shoals, Peloidal Grainstone/Packstone

Moderate Energy, Open-Marine Shoal Flank Facies

Peloidal/Skeletal Packstone/Wackestone

Moderate- to Low-Energy, Open Marine Buildup Facies

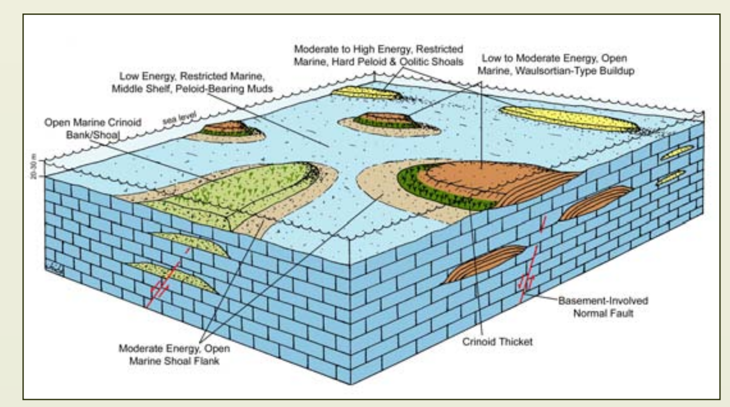
(Possible "Waulsortian" Facies) Peloidal/Skeletal Packstone/Wackestone



Low-Energy, Restricted Marine, Middle Shelf

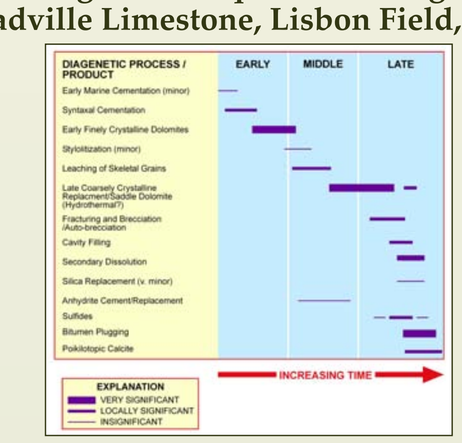
Skeletal/"Soft" Peloidal Wackestone/Mudstone

Leadville Depositional Environments



A generalized depositional block model

Ideal Diagenetic Sequence Through Time, Leadville Limestone, Lisbon Field, Utah

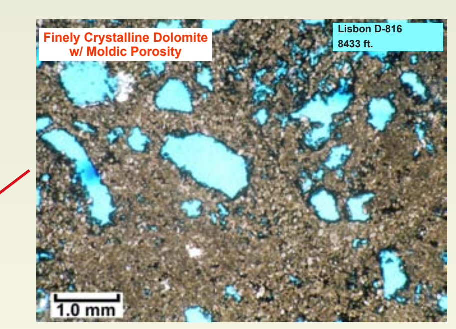


The early diagenetic history of the Leadville sediments, including some early dolomitization and leaching of skeletal grains, resulted in low porosity and/or low permeablility rocks. Most of the porosity and permeability associated with hydrocarbon production was developed during deeper subsurface dolomitization and dissolution. Some of these important subsurface processes are shown in the purple bars above.

Dolomitization and Porosity Development in the Leadville Limestone

Early and Late Stages of Dolomitization

Representative plane light view of coarser replacement dolomite (both euhedral rhombs and occasional "saddle" overgrowths). The black (opaque) areas are the result of pyrobitumen films and minor sulfide precipitation.



Representative view of the tight, finely crystalline dolomite with isolated grain molds. Most of this fabric selective dolomite formed early in the diagenetic history of the skeletal/peloid sediment.

Conventional core slab showing tight, fabric selective, very fine early dolomite as well as porous, coarser late dolomite. Most of the late dolomite crystal faces are coated with films of pyrobitumen. Hence, most of the areas of crosscutting coarser dolomites are black in this view. Note the position of the thin section which captures the contact between low-permeability early dolomite (upper right part of the thin section box) and high-permeability late, "black dolomite" (lower left).