

Oil & Natural Gas Technology

DOE Award No.: DE-FC26-03NT15424

DELIVERABLE 1-2 GEOPHYSICAL WELL LOGS TIED TO CORE DESCRIPTIONS: LISBON FIELD, SAN JUAN COUNTY, UTAH

THE MISSISSIPPIAN LEADVILLE LIMESTONE EXPLORATION PLAY, UTAH AND COLORADO – EXPLORATION TECHNIQUES AND STUDIES FOR INDEPENDENTS

**Submitted by:
Utah Geological Survey
Salt Lake City, Utah 84114**

**Prepared for:
United States Department of Energy
National Energy Technology Laboratory**

July 2007



Office of Fossil Energy

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(Contract No. DE-FC26-03NT15424)

**DELIVERABLE 1-2
GEOPHYSICAL WELL LOGS TIED TO
CORE DESCRIPTIONS: LISBON FIELD,
SAN JUAN COUNTY, UTAH**



by

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US/DOE Patent Clearance is not required prior to the publication of this document.

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INTRODUCTION

The Mississippian Leadville Limestone has produced over 53 million barrels (bbls) (8.4 million m³) of oil from six fields in the northern Paradox Basin region, referred to as the Paradox fold and fault belt, of Utah and Colorado. All of these fields are currently operated by small, independent producers. There have been no new discoveries since the early 1960s, and only independent producers continue to explore for Leadville oil targets in the region, 85 percent of which is under the stewardship of the federal government. This environmentally sensitive, 7500-square-mile (19,400 km²) area is relatively unexplored with only about 100 exploratory wells that penetrated the Leadville (less than one well per township), and thus the potential for new discoveries remains great.

The overall goals of this study are to (1) develop and demonstrate techniques and exploration methods never tried on the Leadville Limestone, (2) target areas for exploration, (3) increase deliverability from new and old Leadville fields through detailed reservoir characterization, (4) reduce exploration costs and risk especially in environmentally sensitive areas, and (5) add new oil discoveries and reserves. These goals are designed to assist the independent producers and explorers who have limited financial and personnel resources.

Exploring for the Leadville Limestone is high risk, with less than a 10 percent chance of success based on the drilling history of the region. Prospect definition requires expensive, three-dimensional (3D) seismic acquisition, often in environmentally sensitive areas. These facts make exploring difficult for independents that have limited funds available to try new, unproven techniques that might increase the chance of successfully discovering oil. We believe that one or more of the project activities will reduce the risk taken by an independent producer in looking for Leadville oil, not only in exploring but in trying new techniques.

Another problem in exploring for oil in the Leadville Limestone is the lack of published or publicly available geologic and reservoir information, such as regional facies maps, complete reservoir characterization studies, surface geochemical surveys, regional hydrodynamic pressure regime maps, and oil show data and migration interpretations. Acquiring this information or producing these studies would save funds and work effort which independents simply do not possess or normally have available only for drilling. The technology, maps, and studies generated from this project will help independents to identify or eliminate areas and exploration targets prior to spending significant financial resources on seismic data acquisition and environmental litigation, and therefore increase the chance of successfully finding new accumulations of Leadville oil.

GEOLOGIC SETTING

Paradox Basin Overview

The Paradox Basin is located mainly in southeastern Utah and southwestern Colorado, with a small portion in northeastern Arizona and northwestern New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast-trending, evaporitic basin that predominately developed during the Pennsylvanian. The basin can generally be divided into three areas: the Paradox fold and fault belt in the north, the Blanding sub-basin in the south-southwest, and the

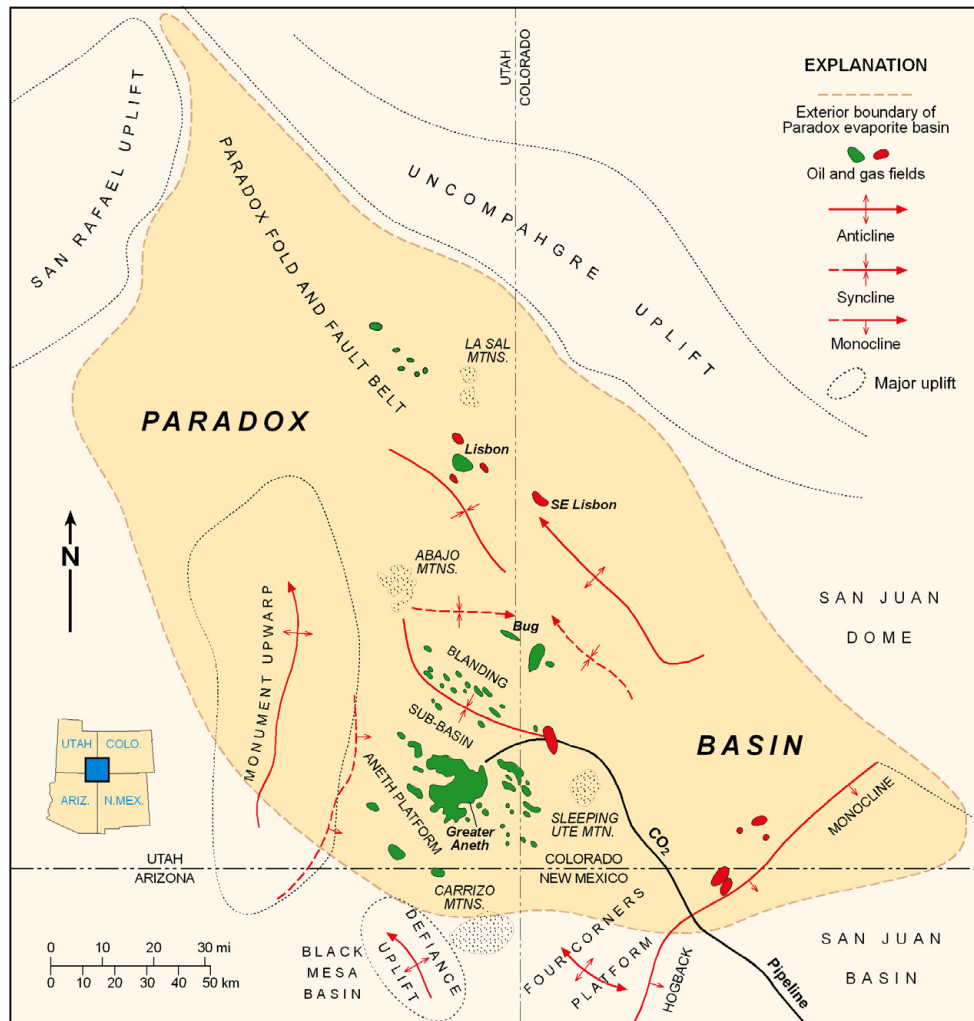


Figure 1. Oil and gas fields in the Paradox Basin of Utah, Arizona, and Colorado.

Aneth platform in southeasternmost Utah (figure 1). The Mississippian Leadville Limestone is one of two major oil and gas reservoirs in the Paradox Basin, the other being the Pennsylvanian Paradox Formation (figure 2). Most Leadville production is from the Paradox fold and fault belt (figure 3).

The most obvious structural features in the basin are the spectacular anticlines that extend for miles in the northwesterly trending fold and fault belt. The events that caused these and many other structural features to form began in the Proterozoic, when movement initiated on high-angle basement faults and fractures 1700 to 1600 Ma (Stevenson and Baars, 1987). During Cambrian through Mississippian time, this region, as well as most of eastern Utah, was the site of typical, thin, marine deposition on the craton while thick deposits accumulated in the miogeocline to the west (Hintze, 1993). However, major changes occurred beginning in the Pennsylvanian. A series of basins and fault-bounded uplifts developed from Utah to Oklahoma as a result of the collision of South America, Africa, and southeastern North America (Kluth and Coney, 1981; Kluth, 1986), or from a smaller scale collision of a microcontinent with south-central North America (Harry and Mickus, 1998). One result of this tectonic event was the uplift of the Ancestral Rockies in the western United States. The Uncompahgre Highlands

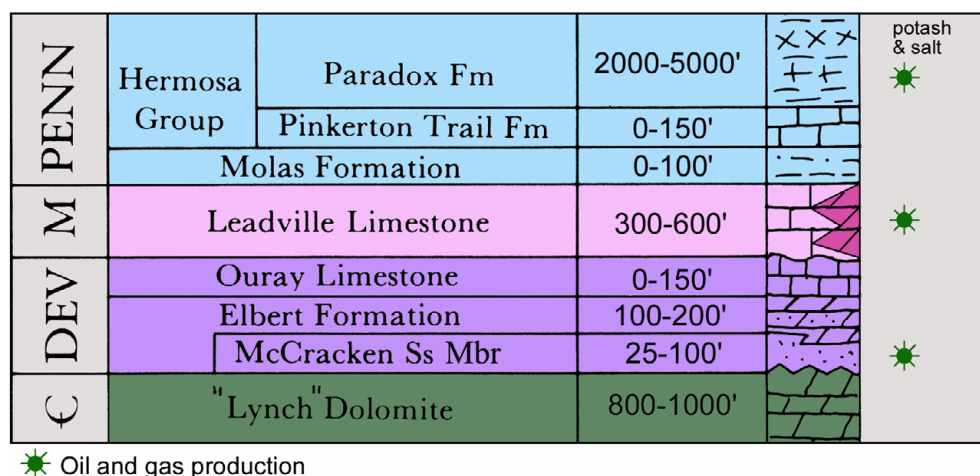


Figure 2. Stratigraphic column of a portion of the Paleozoic section determined from subsurface well data in the Paradox fold and fault belt, Grand and San Juan Counties, Utah (modified from Hintze, 1993).

in eastern Utah and western Colorado initially formed as the westernmost range of the Ancestral Rockies during this ancient mountain-building period. The southwestern flank of the Uncompahgre Highlands (uplift) is bounded by a large, basement-involved, high-angle, reverse fault identified from seismic surveys and exploration drilling. As the highlands rose, an accompanying depression, or foreland basin, formed to the southwest – the Paradox Basin. Rapid subsidence, particularly during the Pennsylvanian and continuing into the Permian, accommodated large volumes of evaporitic and marine sediments that intertongue with non-marine arkosic material shed from the highland area to the northeast (Hintze, 1993).

The Paradox Basin is surrounded by other uplifts and basins, which formed during the Late Cretaceous-early Tertiary Laramide orogeny (figure 1). The Paradox fold and fault belt was created during the Tertiary and Quaternary by a combination of (1) reactivation of basement normal faults, (2) salt flowage, dissolution and collapse, and (3) regional uplift (Doelling, 2000).

Most oil and gas produced from the Leadville Limestone is found in basement-involved, northwest-trending structural traps with closure on both anticlines and faults (figure 4). Lisbon, Big Indian, Little Valley, and Lisbon Southeast fields (figure 3) are sharply folded anticlines that close against the Lisbon fault zone. Salt Wash and Big Flat fields (figure 3), northwest of the Lisbon area, are unfaulted, east-west- and north-south-trending anticlines, respectively.

Regional Leadville Facies

The Mississippian (late Kinderhookian through Osagean to early Meramecian time) Leadville Limestone is a shallow, open-marine, carbonate-shelf deposit (figure 5). The western part of the Paradox fold and fault belt includes a regional, reflux-dolomitized, interior bank facies containing Waulsortian mounds (Welsh and Bissell, 1979). During Late Mississippian time, the entire carbonate platform in southeastern Utah and southwestern Colorado was subjected to subaerial erosion resulting in formation of a lateritic regolith (Welsh and Bissell, 1979). This regolith and associated carbonate dissolution is an important factor in Leadville reservoir potential (figure 6). Solution breccia and karstified surfaces are common, including possible local development of cavernous zones (Fouret, 1982, 1996).

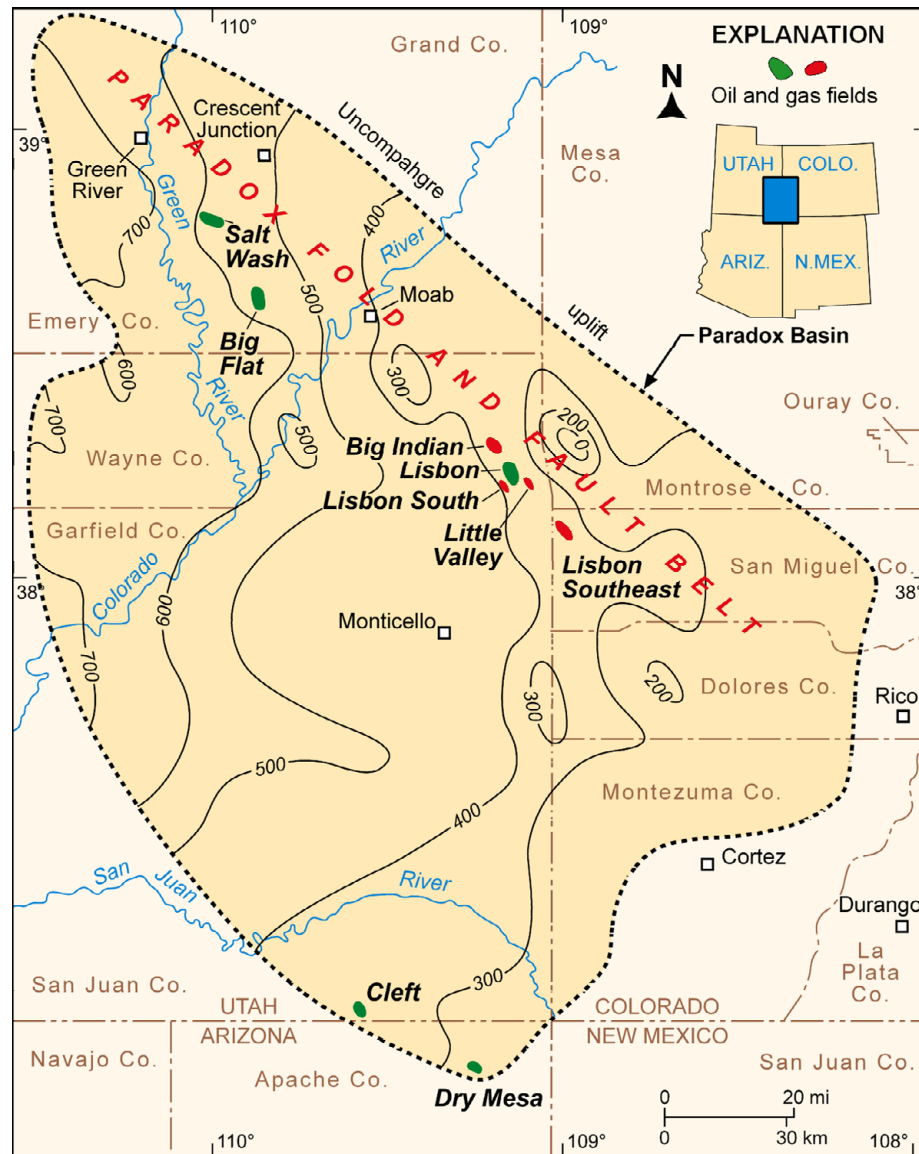


Figure 3. Location of fields that produce from the Mississippian Leadville Limestone, Utah, Arizona, and Colorado. Thickness of the Leadville is shown; contour interval is 100 feet (modified from Parker and Roberts, 1963).

The Leadville Limestone thins from more than 700 feet (230 m) in the northwest corner of the Paradox Basin to less than 200 feet (60 m) in the southeast corner (Morgan, 1993) (figure 3). Thinning is a result of both depositional onlap onto the Mississippian cratonic shelf and erosion. The Leadville is overlain by the Pennsylvanian Molas Formation and underlain by the Devonian Ouray Limestone (figure 2).

Periodic movement along northwest-trending faults affected deposition of the Leadville Limestone. Crinoid banks or mounds, the primary reservoir facies (figure 5), accumulated in shallow-water environments on upthrown fault blocks or other paleotopographic highs. In areas of greatest paleorelief, the Leadville is completely missing as a result of non-deposition or subsequent erosion (Baars, 1966).

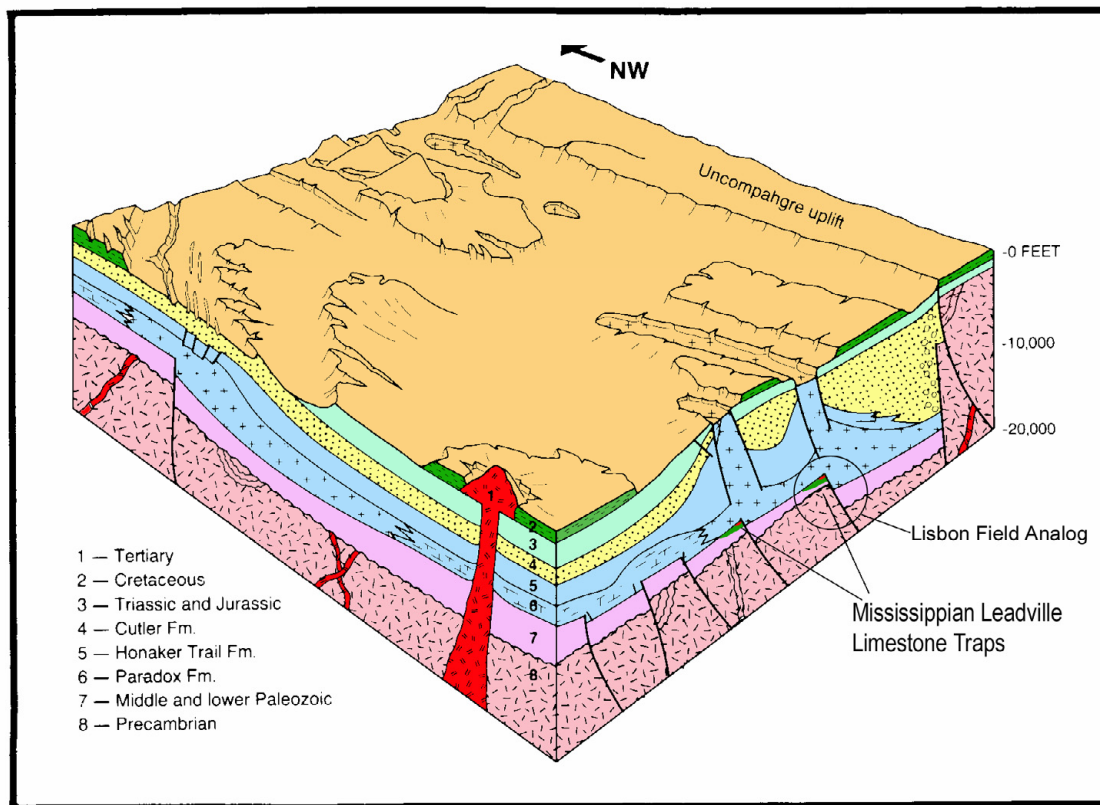


Figure 4. Schematic block diagram of the Paradox Basin displaying basement-involved structural trapping mechanisms for the Leadville Limestone fields (modified from Petroleum Information, 1984; original drawing by J.A. Fallin).

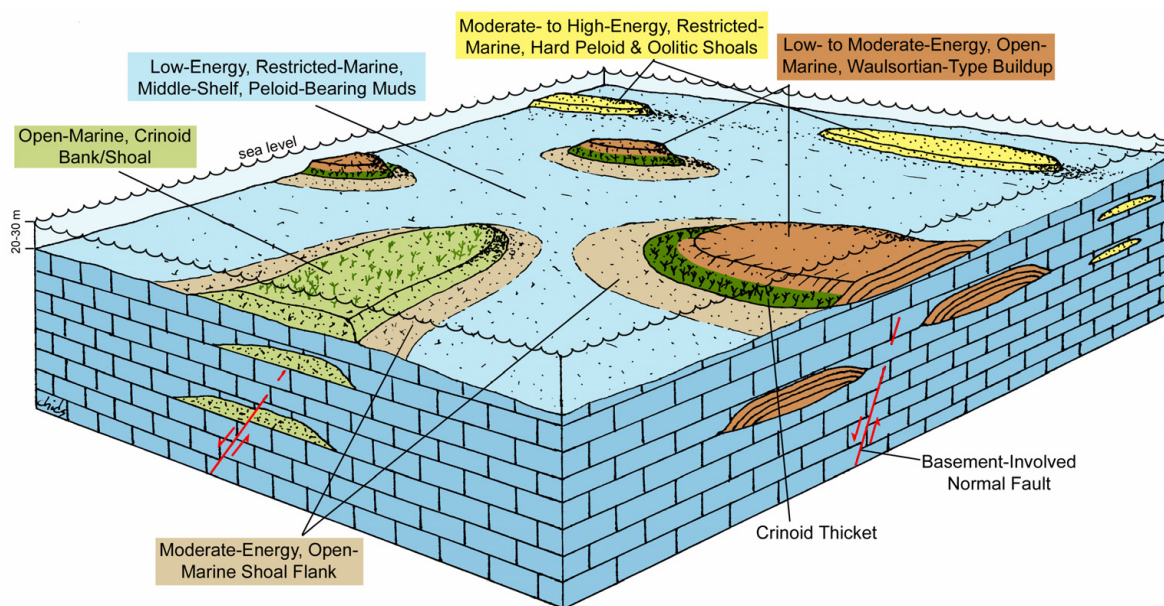


Figure 5. Block diagram displaying major depositional facies, as determined from core, for the Leadville Limestone, Lisbon field, San Juan County, Utah.

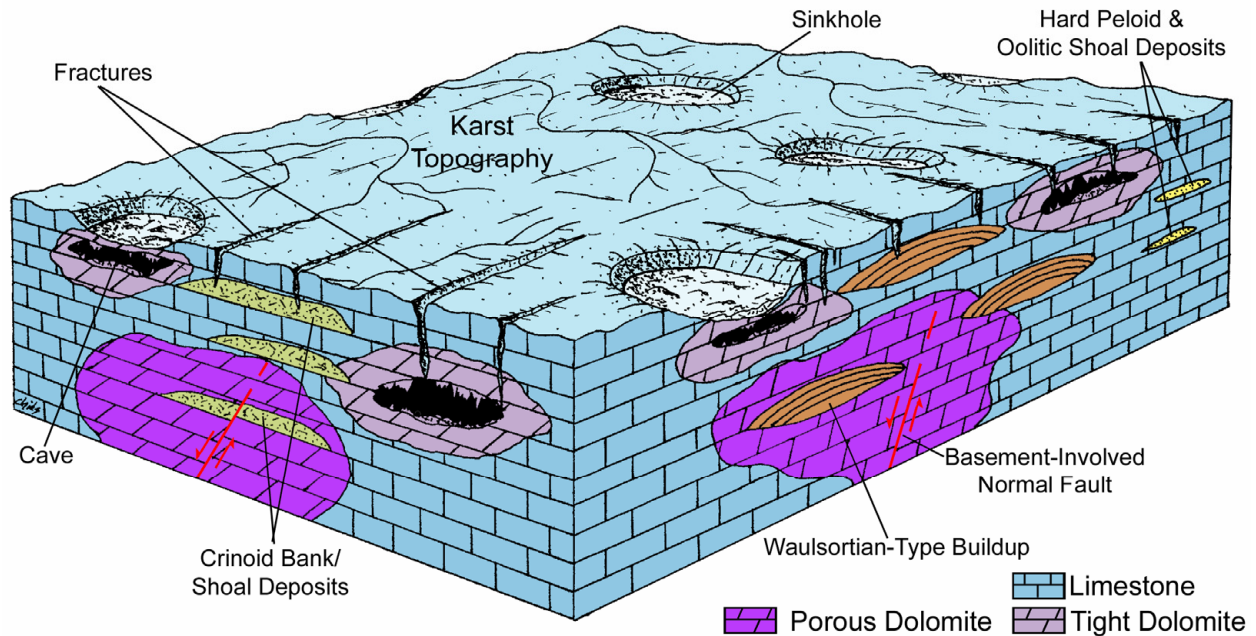


Figure 6. Block diagram displaying post-Leadville karst and fracture overprint.

The Leadville Limestone is divided into two members separated by an intraformational disconformity. The dolomitic lower member is composed of mudstone, wackestone, packstone, and grainstone deposited in shallow-marine, subtidal, supratidal, and intertidal environments (Fouret, 1982, 1996). Fossils include crinoids, fenestrate bryozoans, and brachiopods. Locally, mud-supported boundstone creates buildups or mud mounds (Waulsortian facies), involving growth of “algae” (Wilson, 1975; Ahr, 1989; Fouret, 1982, 1996). The upper member is composed of mudstone, packstone, grainstones (limestone and dolomite), and terrigenous clastics also deposited in subtidal, supratidal, and intertidal environments (Fouret, 1982, 1996). Fossils include crinoids and rugose coral. Reservoir rocks are crinoid-bearing packstone (Baars, 1966).

LISBON CASE STUDY FIELD, SAN JUAN COUNTY, UTAH

Introduction and Field Synopsis

Lisbon field, San Juan County, Utah (figure 3) accounts for most of the Leadville oil production in the Paradox Basin. A wealth of Lisbon core, petrographic, and other data is available to the UGS. The reservoir characteristics, particularly diagenetic overprinting and history, and Leadville facies can be applied regionally to other fields and exploration trends in the Paradox Basin. Therefore, we selected Lisbon as the major case-study field for the Leadville Limestone project. This evaluation included data collection, plots of petrophysical data (core-plug porosity and permeability), and geophysical well logs tied to core descriptions as summarized in this report.

The Lisbon trap is an elongate, asymmetric, northwest-trending anticline, with nearly 2000 feet (600 m) of structural closure and bounded on the northeast flank by a major,

basement-involved normal fault with over 2500 feet (760 m) of displacement (Smith and Prather, 1981) (figure 7). Several minor, northeast-trending normal faults divide the Lisbon Leadville reservoir into segments.

Producing units in Lisbon field contain dolomitized crinoidal/skeletal grainstone, packstone, and wackestone fabrics. Diagenesis includes fracturing, autobrecciation, karst development, hydrothermal dolomite, and bitumen plugging. The net reservoir thickness is 225 feet (69 m) over a 5120-acre (2100 ha) area (Clark, 1978; Smouse, 1993). Reservoir quality is greatly improved by natural fracture systems associated with the Paradox fold and fault belt. Porosity averages 6 percent in intercrystalline and moldic networks enhanced by fractures; permeability averages 22 millidarcies (mD). The drive mechanism is an expanding gas cap and gravity drainage; water saturation is 39 percent (Clark, 1978; Smouse, 1993). The bottom-hole temperature ranges from 133 to 189°F (56-87°C).

Lisbon field was discovered in 1960 with the completion of the Pure Oil Company No. 1 NW Lisbon USA well, NE1/4NW1/4 section 10, T. 30 S., R. 24 E., SLBL&M (figure 7), with an initial flowing potential of 179 bbls of oil per day (BOPD) (28 m³) and 4376 thousand cubic feet of gas per day (124 MCMPD). The original reservoir field pressure was 2982 pounds per square inch (psi [20,560 kPa]) (Clark, 1978). There are currently 22 producing (or shut-in wells), 11 abandoned producers, five injection wells (four gas injection wells and one water/gas injection well), and four dry holes in the field. Cumulative production as of March 31, 2006,

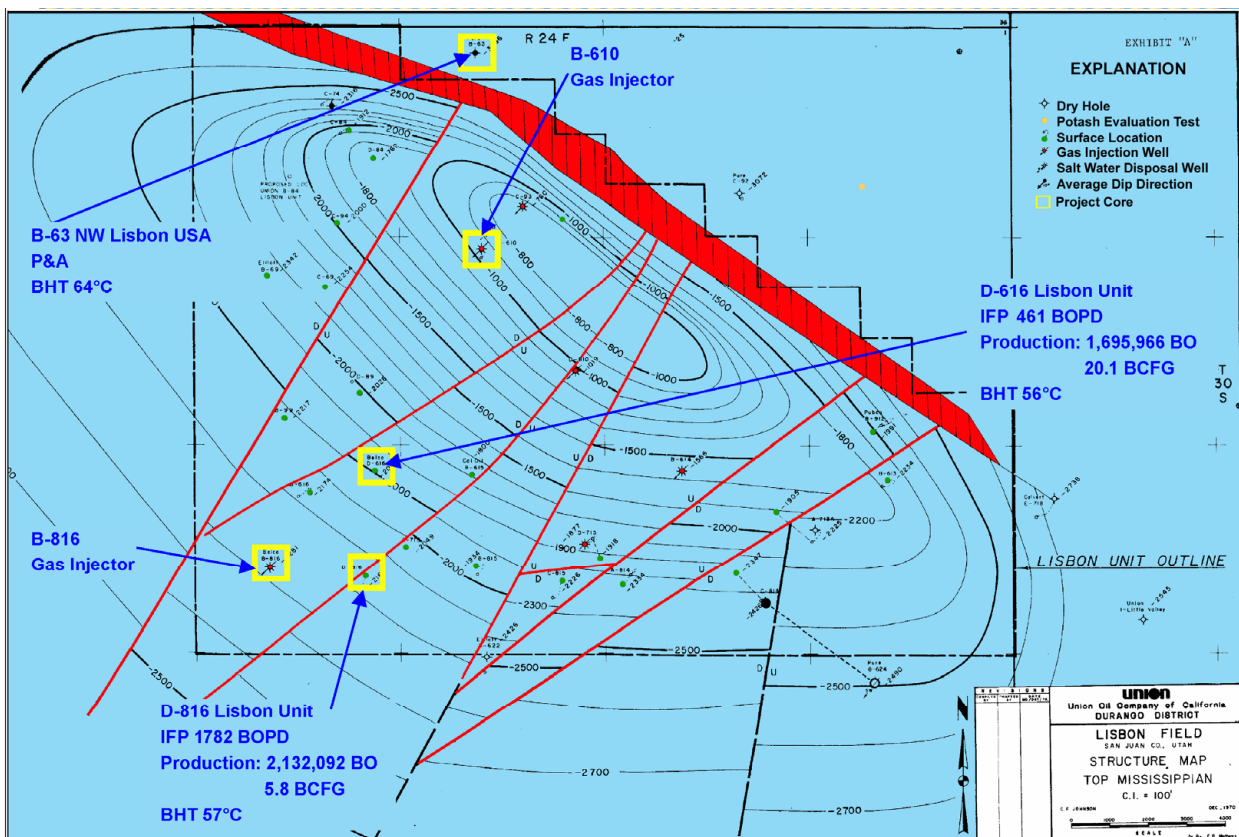


Figure 7. Top of structure of the Leadville Limestone, Lisbon field, San Juan County, Utah (modified from C.F. Johnson, Union Oil Company of California files, 1970; courtesy of Tom Brown, Inc.). Also displayed are wells from which cores were described in this study.

was 51,145,231 bbls of oil (8,132,092 m³), 785.4 billion cubic feet of gas (BCFG) (22.2 BCMG) (cycled gas), and 50,073,622 bbls of water (7,961,706 m³) (Utah Division of Oil, Gas and Mining, 2006). Gas that was re-injected into the crest of the structure to control pressure decline is now being produced.

Three factors create reservoir heterogeneity within productive zones: (1) variations in carbonate fabrics and facies, (2) diagenesis (including karstification), and (3) fracturing. The extent of these factors and how they are combined affect the degree to which they create barriers to fluid flow.

Data Collection and Compilation

Geophysical well logs, cores and cuttings, reservoir data, various reservoir maps, and other information from Lisbon field development wells were collected by the UGS. Well locations, formation tops, production data, completion tests, basic core analysis, porosity and permeability data, and other data were compiled and entered in a database developed by the UGS. This database, INTEGRAL, is a geologic-information database that links a diverse set of geologic data to records using MS AccessTM. The database is designed so that geological information, such as lithology, petrophysical analyses, or depositional environment, can be exported to software programs to produce cross sections, strip logs, lithofacies maps, various graphs, and other types of presentations. The database containing information on the geological reservoir characterization case study as well as later regional correlations will be available at the UGS's Leadville Limestone project Web site at the conclusion of the project.

GEOPHYSICAL WELL LOGS TIED TO CORE DESCRIPTION

All available conventional cores from Lisbon field (figure 7) were photographed and described (table 1). Special emphasis was placed on identifying the flow unit's bounding surfaces and depositional environments. The core descriptions follow the guidelines of Bebout and Loucks (1984), which include (1) basic porosity types, (2) mineral composition in percentage, (3) nature of contacts, (4) carbonate structures, (5) carbonate textures in percentage, (6) carbonate fabrics, (7) grain size (dolomite), (8) fractures, (9) color, (10) fossils, (11) cement, and (12) depositional environment. Carbonate fabrics were determined according to Dunham's (1962) and Embry and Klovan's (1971) classification schemes.

*Table 1. List of well conventional slabbed core examined and described from the Leadville Limestone, Lisbon field, San Juan County, Utah.**

Well	Location	API No.	Core Interval (feet)	Thin Sections
Lisbon D-816	NE SE 16, T. 30 S., R. 24 E.	43-037-16253	8417-8450	15
Lisbon D-616	C NE NE 16, T. 30 S., R. 24 E.	43-037-15049	8300-8702	13
NW Lisbon B-63	NE NW 3, T. 30 S., R. 24 E.	43-037-11339	9934-10,005	14
Lisbon B-816	NE SW 16, T. 30 S., R. 24 E.	43-037-16244	8463-8697	22
Lisbon B-610	NE NW 10, T. 30 S., R. 24 E.	43-037-16469	7590-8030	18

*Repository: Utah Core Research Center.

Geological characterization on a local scale focused on reservoir heterogeneity, quality, and lateral continuity, as well as possible compartmentalization within Lisbon field. This utilized representative core and modern geophysical well logs to characterize and initially grade various untested intervals in the field for possible additional completion attempts.

The typical vertical sequence or cycle of lithofacies from Lisbon field, as determined from conventional core, was tied to its corresponding log response (plates 1 through 5). These sequences graphically include (1) carbonate fabric, pore type, physical structures, texture, framework grain, and facies described from core; (2) plotted porosity and permeability analysis from core plugs; and (3) gamma-ray and neutron-density curves from geophysical well logs. The graphs can be used for identifying reservoir and non-reservoir rock, determining potential untested units suitable for completion or possible horizontal drilling projects, and comparing field to non-field areas.

ACKNOWLEDGMENTS

Funding for this research was provided as part of the Advanced and Key Oilfield Technologies for Independents (Area 2 – Exploration) Program of the U.S. Department of Energy, National Petroleum Technology Office, Tulsa, Oklahoma, contract number DE-FC26-03NT15424. The Contracting Officer's Representative is Virginia Weyland. Support was also provided by Eby Petrography & Consulting, Inc., Littleton, Colorado, and the Utah Geological Survey.

Core and petrophysical data were provided by Tom Brown, Inc. (now Encana Corp.). James Parker of the Utah Geological Survey (UGS) drafted figures and Cheryl Gustin, UGS, formatted the manuscript. This report was reviewed by David Tabet and Robert Ressetar of the UGS.

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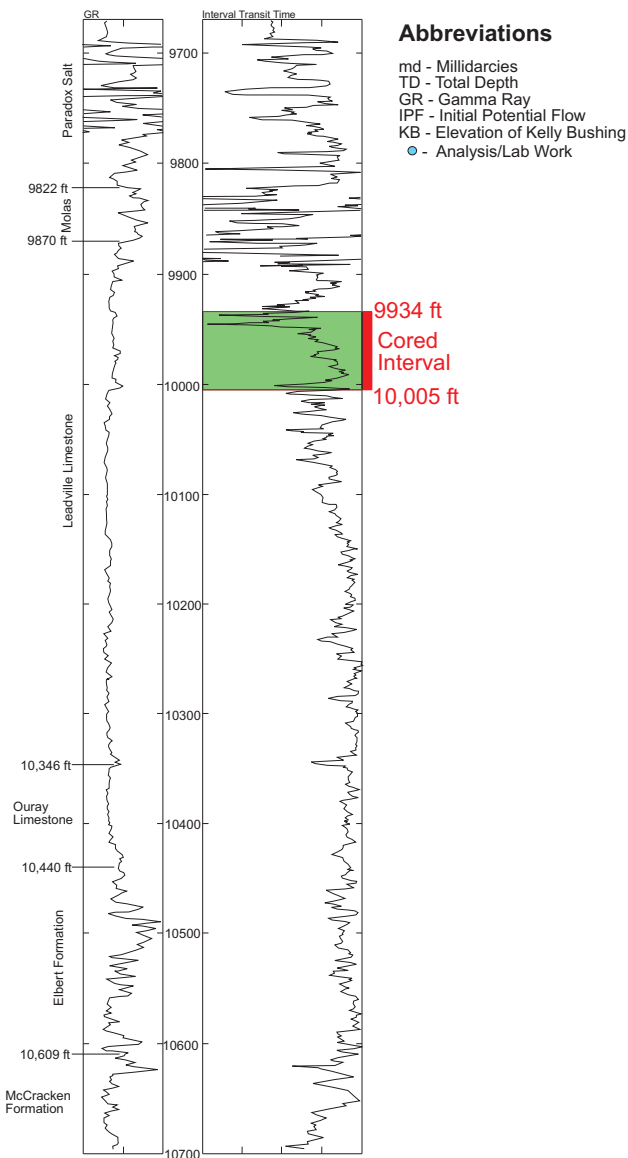


Geophysical Logs				Core Plug Analysis				Conventional Core																										
Gamma Ray API Units	Depth (feet)	Interval Transit Time			Permeability (md)			Porosity (%)			SEM	Fluid Inclusions	Isotope	Epi-Fluorescence	Catholuminescence	Thin Sections	Feet	Fabric				Pore Type	Physical Structures	Texture				Framework Constituents		Fractures	Cement	Color	Facies	Remarks
0	10	80	60	40	01	.1	1	10	100	1000	0	4	8	12	16			boundstone	grainstone	packstone	wackestone	mudstone												
	9940																															9934-9936.3: Mostly black limestone with white fossil fragments, originally a crinoidal-brachiopod skeletal grainstone that has been extremely leached and impregnated with bitumen. No remaining visible porosity. Contains some coated grains.		
	9950																															9936.3-9965.1: Light to medium gray dolomite, highly altered original pelletal mudstone/wackestone. Burial alteration consists of intense fracturing, pseudo brecciation (auto brecciation) in which there is the appearance of fine-grained dolomitic clasts surrounded by black shale matrix and clasts. The apparent black shales are mostly bitumen impregnated peloidal dolomite, some scattered metallic sulfides. Key question: is this a karst breccia or burial hydrokarst auto breccia?		
	9960																																	
	9970																															9965.1-9966.5: Moderate brown dolomite, pelletal wackestone/packstone, generally laminated, possible desiccation cracks and rip-up clasts, unaltered, finely crystallized, bed parallel and vertical stylolite in medium amplitude, microfractures filled with calcite. No visible porosity, no bitumen.		
	9980																															9966.5-9993.5: Medium brown to black dolomite, highly altered original pelletal mudstone/wackestone. Highly fractured with dissolution and impregnated with bitumen giving a pseudo shale appearance. Some of the fractures healed with calcite. Very little visible porosity. Dolomite before alteration laminated. Meteoric, karst, hydrokarst, auto brecciation? One zone of silicified autoclasts at 9967.2-9967.6 feet.		
	9990																															9993.5-9995.5: Light gray to brown dolomite, pelletal packstone/grainstone with no visible skeletal grains, well-bedded on a centimeter scale. Contains some fracture swarms lined with calcite and bitumen, unaltered.		
	10000																															9995.5-10,000.2: Light gray to light brown dolomite, original depositional fabric consisted of peritidal wackestone/packstone, which have now been altered to auto breccias and bitumen impregnated micro intercrystalline porosity. Intensely fractured with fractures plugged by calcite and bitumen. Some gray-green shale clasts at 9998.3-9998.5 feet. No visible porosity.		
																																10,000.2-10,005: Black dolomite with light gray to white remnants consisting of crinoidal and skeletal packstone/grainstone. Most of the rock has been etched and impregnated with bitumen, heavily altered with pseudo breccia appearance. Appear to be a good micro intercrystalline reservoir.		

Plate 1

Northwest Lisbon USA C-2 (B-63)
NENW Section 3, T30S, R24E
KB 6803 feet

**TD 10,706 feet
P&A
Completed: 1-8-1961**



Explanation									
Lithologic Composition		Texture		Pore Types		Abundance		Physical Structures	
	Limestone		Skeletal Grains	Mo	Moldic		Pervasive		Stylolites
			Micrite	BC	Inter-crystal		Abundant		Fractures
	Dolostone		Peloid	Vug	Vug		Rare		Coated Grains
Framework Constituents				Mi	Microporosity				Sulfide Minerals
				Fr	Fracture				Rip-up Clasts
									Clasts
★ - Crinoids									
☞ - Brachiopods									
									Bitumen
									Breccia

Plate 4

Belco State 2 (D-616)

C NENE Section 16, T30S, R24E

KB 6229 feet

TD 8730 feet

IPF: 68 BOPD

Completed: 10-13-1960

Abbreviations

- ms - Mudsstone
- TS - Sandstone
- CS - Carbonate
- IPF - Initial Potential Flow
- KB - Elevation of Kelly Bushing
- Analysis/Lab Work

Lithologic Composition	Texture	Pore Types	Abundance	Physical Structures
Limestone	Skeletal Grains	Mo Moldic	Pervasive	Stylolites
Dolomite	Micrite	BC Intercrystal	Abundant	Fractures
	Peloid	Vug Vug	Rare	Sulfide Minerals
	Ooid	Mi Microporosity		Silicified
		Fr Fracture		Anhydrite, Mosaic
				Bitumen
				Clasts
				Calcareous
				Coated Grains
				Cherty

Framework Constituents

- ★ - Crinoids
- ✎ - Brachiopods
- ☐ - Bryozoans
- ☐ - Sponges
- ☐☐☐ - Ooids

Geophysical Logs						Core Plug Analysis						Conventional Core																
Gamma Ray API Units		Perforated Interval	Depth (feet)	Interval Transit Time		Permeability (md)		Porosity (%)		SEM	Fluid Inclusions	Isotope	Epi-Flourescence	Catholuminescence	Thin Sections	Feet	Fabric		Pore Type	Physical Structures	Texture		Framework Constituents	Fractures	Cement	Color	Facies	Remarks
0	160			100	70	40	0	20	40	60	80	0	4	8	12	16		boundstone grainstone packstone wackestone mudstone										
			8420																									
			8430																									
			8440																									
			8450																									

Lisbon Pure D-816

NESE Section 16, T30S, R24E

KB 6108 feet

TD 8666 feet

IPF: 1782 BPD, no gas, no water

Completed: 11-1-1962

GR

Paradox Salt

8196 ft

Molas

8290 ft

Leadville Limestone

8100

8200

8300

8400

8500

Resistivity

Interval Transit Time

Conductivity

8417 ft

Cored Interval

8450 ft

Abbreviations

md - Millidarcies
TD - Total Depth
GR - Gamma Ray
IPF - Initial Potential Flow
KB - Elevation of Kelly Bushing
● - Analysis/Lab Work

Lithologic Composition

Limestone

Dolostone

Texture

Skeletal Grains

Micrite

Peloid

Pore Types

Moldic

Intercrystal

Vug

Microporosity

Fracture

Framework Constituents

Crinoids

Unidentified Fossils

Abundance

Pervasive

Abundant

Rare

Physical Structures

Stylolites

Fractures

Sulfide Minerals

Slickensides

Anhydrite, Mosaic

Bitumen

Calcareous