DELIVERABLE 1-4
FIELD MAPS AND CROSS SECTIONS:
LISBON FIELD, SAN JUAN COUNTY, UTAH

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

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Utah Geological Survey
Salt Lake City, Utah 84114

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DELIVERABLE 1-4
FIELD MAPS AND CROSS SECTIONS:
LISBON FIELD,
SAN JUAN COUNTY, UTAH

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CONTENTS

INTRODUCTION ........................................................................................................................ 1

GEOLOGIC SETTING ................................................................................................................1
Paradox Basin Overview................................................................................................... 1
Regional Leadville Facies................................................................................................. 4

LISBON CASE- STUDY FIELD, SAN JUAN COUNTY, UTAH.............................................. 6
Introduction and Field Synopsis ....................................................................................... 6
Data Collection and Compilation...................................................................................... 8

LOG-BASED CORRELATION SCHEME ................................................................................. 8

RESERVOIR MAPPING ........................................................................................................... 10

ACKNOWLEDGMENTS .......................................................................................................... 11

REFERENCES ........................................................................................................................... 11

FIGURES

Figure 1. Oil and gas fields in the Paradox Basin of Utah and Colorado ......................... 2

Figure 2. Stratigraphic column of the Paleozoic section in the Paradox fold and fault belt,
Grand and San Juan Counties, Utah ................................................................................. 2

Figure 3. Location of Mississippian Leadville Limestone fields, Utah and Colorado .... 3

Figure 4. Schematic block diagram of basement-involved structural traps for the Leadville
Limestone fields................................................................................................................ 5

Figure 5. Block diagram displaying major depositional facies for the Leadville Limestone,
Lisbon field ...................................................................................................................... 5

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

Figure 7. Map of top of structure, Leadville Limestone, Lisbon field, San Juan County, Utah.. 7

Figure 8. Gamma ray-sonic log, Leadville Limestone, Lisbon field, San Juan County, Utah .... 9

Figure 9. Schematic east-west structural cross section, Lisbon field, San Juan County, Utah.... 9
APPENDIX

Figure A-1. Isochore Zone 1, Leadville Limestone, Lisbon Field.................................A-2
Figure A-2. Isochore Zone 2, Leadville Limestone, Lisbon Field.................................A-3
Figure A-3. Isochore Zone 3, Leadville Limestone, Lisbon Field.................................A-4
Figure A-4. Isochore Zone 4, Leadville Limestone, Lisbon Field.................................A-5
Figure A-5. Zone 1 Porosity, Leadville Limestone, Lisbon Field.................................A-6
Figure A-6. Zone 2 Porosity, Leadville Limestone, Lisbon Field.................................A-7
Figure A-7. Zone 3 Porosity, Leadville Limestone, Lisbon Field.................................A-8
Figure A-8. Zone 4 Porosity, Leadville Limestone, Lisbon Field.................................A-9
Figure A-9. Bottom Hole Temperature, Leadville Limestone, Lisbon Field...............A-10
Figure A-10. Initial Flowing Potential, Leadville Limestone, Lisbon Field...............A-11
Figure A-11. Cumulative Oil Production, Leadville Limestone, Lisbon Field........A-12

PLATES

Plate 1. South-to-North Stratigraphic Cross Section: Lisbon to Big Indian Fields ........ in pocket
Plate 2. West-to-East Stratigraphic Cross Section: Lisbon Field ...................... in pocket
INTRODUCTION

The Mississippian Leadville Limestone has produced over 53 million barrels (bbls) (8.4 million m$^3$) 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 independent producers. 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 7500-square-mile (19,400 km$^2$) 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 hydrocarbons in 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 also 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. This project provides this information to save independents cash and staffing resources which they 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 part in northeastern Arizona and northwestern New Mexico (figure 1). The Paradox Basin is an elongate, northwest-southeast-trending, evaporitic basin that predominantly 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 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).
Figure 1. Oil and gas fields in the Paradox Basin of Utah and Colorado.

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).

<table>
<thead>
<tr>
<th>Hermosa Group</th>
<th>Paradox Fm</th>
<th>2000-5000’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pinkerton Trail Fm</td>
<td>0-150’</td>
</tr>
<tr>
<td></td>
<td>Molas Formation</td>
<td>0-100’</td>
</tr>
<tr>
<td>D E V</td>
<td>Leadville Limestone</td>
<td>300-600’</td>
</tr>
<tr>
<td>M P E N N</td>
<td>Ouray Limestone</td>
<td>0-150’</td>
</tr>
<tr>
<td></td>
<td>Elbert Formation</td>
<td>100-200’</td>
</tr>
<tr>
<td></td>
<td>McCracken Ss M</td>
<td>25-100’</td>
</tr>
<tr>
<td></td>
<td>“Lynch” Dolomite</td>
<td>800-1000’</td>
</tr>
</tbody>
</table>

Oil and gas production
Figure 3. Location of fields that produce from the Mississippian Leadville Limestone, Utah and Colorado. Thickness of the Leadville is shown; contour interval is 100 feet (modified from Parker and Roberts, 1963).
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 between 1700 and 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 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 that 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 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 (Fourret, 1982, 1996).

The Leadville Limestone thins from more than 700 feet (230 m) in the northwest corner of the Paradox Basin to less than 200 feet (70 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).
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.
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).

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; Fouret, 1982, 1996; Ahr, 1989). 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, and construction of various maps (top of structure, thickness, porosity, and so forth) and cross sections 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 compartments.

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; original water saturation was 39 percent (Clark, 1978; Smouse, 1993). The bottom-hole temperature ranges from 133 to 189ºF (56-87ºC).

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.
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 (IFP) of 179 bbls of oil per day (BOPD) (28 m³) and 4376 thousand cubic feet of gas per day (124 MCMGD). The original reservoir field pressure was 2982 pounds per square inch (psi [20,560 kPa]) (Clark, 1978). Currently, 20 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 are in the field. Cumulative production as of March 1, 2007, was 51,154,824 bbls of oil (8,133,617 m³), 790.9 billion cubic feet of gas (BCGF) (22.4 BCMG) (cycled gas), and 50,262,600 bbls of water (7,991,753 m³) (Utah Division of Oil, Gas and Mining, 2007). Hydrocarbon gas that was re-injected into the crest of the structure to control pressure decline is now being produced; acid gas is still re-injected.

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 Access™. 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 page, http://geology.utah.gov/emp/leadville/index.htm, at the conclusion of the project.

LOG-BASED CORRELATION SCHEME

The typical vertical sequence or cycle of depositional facies from Lisbon field, as determined from conventional core, was tied to the corresponding gamma-ray and neutron-density curves from geophysical well logs (figure 8). The correlation scheme enabled us to identify the major zone contacts, seals or barriers, baffles, producing or potential reservoirs, and depositional facies. These contacts were used to produce field cross sections (figure 9 and plates 1 and 2) and a variety of structure and isochore maps (figures 7, and A-1 through A-8 in the appendix).

Seals or barriers include thick shales of the Molas Formation, which overlies the Leadville Limestone. Baffles are those rock units that restrict fluid flow in some parts of the field but may develop enough porosity and permeability in other parts, through diagenetic processes or facies changes, to provide a conduit for fluid flow or even oil storage. Baffles are found throughout the Leadville stratigraphic section. The four reservoir zones defined in this study (1 through 4, from top to bottom) are those units containing 8 percent or more porosity based on the average of the neutron and density porosity values (see plates 1 and 2).
Figure 8. Typical gamma ray–sonic log of the Leadville Limestone, Lisbon field discovery well, San Juan County, Utah. See figure 7 for location of Lisbon field wells.

Figure 9. Schematic east-west structural cross section, Lisbon field. Modified from Clark, 1978.
Depositionally, rock units are divided into crinoid banks/shoals, Waulsortian-type carbonate buildups (mounds) (bafflestone, bindstone, grainstone, and packstone), and inter-bank/shoal and inter-mound seals or barriers (mudstone and shale). Associated with Waulsortian carbonate-buildup rock units are flank/off buildups (floatstone, rudstone, wackestone, and mudstone). Porosity units, and reservoir or potential reservoir layers, are identified within the crinoid banks/shoals and carbonate-buildup and flank/off-buildup intervals. The crinoid banks/shoals and carbonate-buildup units, and some of the flank/off-buildup units contain all productive reservoir facies.

The correlation scheme was used for (1) predicting changes in reservoir and non-reservoir rocks across the field, (2) comparing field to non-field areas, (3) estimating the reservoir properties and identifying facies in wells which were not cored, and (4) determining potential units suitable for horizontal drilling projects. It can be applied to other fields in the Paradox Basin, both those with cores and without.

**RESERVOIR MAPPING**

We constructed isochore maps of reservoir zones 1 through 4 in the Leadville Limestone for Lisbon field (figures A-1 through A-4). These field maps incorporate zone tops and thickness from all geophysical well logs in the area. We generated the net feet of porosity isochore maps for reservoir zones 1 through 4 (figures A5 through A8) of the Leadville for those parts of the reservoir units containing 10 percent or more porosity based on the average of the neutron and density porosity values. While 8 percent or more porosity defines the reservoir zones, we used 10 percent or more porosity for greater definition of the zones mapped. The maps display well names, Leadville completions, and interval thickness for each well.

We plotted the bottom-hole temperature for most wells in Lisbon field (figure A-9). The maps also include faulting. Contoured temperatures identify possible patterns in temperature data. All wells with available core show evidence of hydrothermal dolomitization. The presence of hydrothermal dolomite and its relationship to reservoir temperature and faulting are critical in identifying diagenetic trends.

We conducted production analysis for Lisbon field by compiling data through two principal tasks: (1) review of existing well-completion data, and (2) determination of production history from monthly production reports available through the Utah Division of Oil, Gas and Mining. We merged this information with geological characterization data and incorporated into the interpretation of reservoir diagenesis (Chidsey and others, 2005a, 2005b, 2005c; Eby and others, 2005).

Well-test data can provide key insights into the nature of reservoir heterogeneities, and also provide "large-scale" quantitative data on actual reservoir properties and facies from the Lisbon case-study reservoir. Although a number of well tests have been conducted in all of the target reservoirs, only the IFP well tests provide quantitative reservoir property information. We plotted IFP well tests for each well (figure A-10). Oil production from Lisbon field has shown a steady decline since peaking in the 1970s. We plotted cumulative production for each well (figure A-11). These plots are used to determine possible production “sweet spots” and their relationship to faulting and reservoir diagenesis.
ACKNOWLEDGMENTS

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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 Michael Hylland of the UGS.

REFERENCES


APPENDIX

FIELD MAPS, LISBON FIELD, SAN JUAN COUNTY, UTAH
Figure A-1

Isochore Zone 1
(Contour interval 50 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

• Oil well
◇ Dry hole
_gas Injection well
D Minor fault
□ Major fault

Well name
Interval thickness (ft)
Surface location
Bottom-hole location
NDE = Not deep enough
Figure A-2

Isochore Zone 2
(Contour interval 50 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah
Figure A-3

Isochore Zone 3
(Contour interval 50 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah
Isochore Zone 4
(Contour interval 50 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- Dry hole
- Gas injection well
- Minor fault
- Major fault

Well name
Interval thickness (ft)
Surface location
Bottom-hole location
NDE = Not deep enough
Figure A-5

Zone 1 - Feet of Porosity >10%
(Contour interval 20 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah
Zone 2 - Feet of Porosity >10%
(Contour interval 20 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah
Figure A-7

Zone 3 - Feet of Porosity >10%
(Contour interval 20 feet)
Leadville Limestone

Lisbon Field
San Juan County, Utah
Figure A-8

**Zone 4 - Feet of Porosity >10%**
(Contour interval 20 feet)

**Leadville Limestone**

Lisbon Field
San Juan County, Utah
Figure A-9

Bottom-Hole Temperature
(Contour interval 10 degrees Fahrenheit)

Leadville Limestone

Lisbon Field
San Juan County, Utah
Figure A-10

Initial Flowing Potential
Leadville Limestone

Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- Dry hole
- Gas injection well
- Minor fault
- Major fault
- Well name
- Surface location
- Bottom-hole location
- NDE = Not deep enough

100 to 500 BOPD
500 to 1000 BOPD
1000 to 1500 BOPD
>1500 BOPD
2-4.4 MMCFGPD
Figure A-11
Cumulative Oil Production
Leadville Limestone
Lisbon Field
San Juan County, Utah

EXPLANATION

- Oil well
- Dry hole
- Gas injection well
- Minor fault
- Major fault

Well name
Surface location
Bottom-hole location
NDE = Not deep enough

- <100 MBO
- 100 to 1000 MBO
- 1000 to 5000 MBO
- >5000 MBO

0 2000 4000 Feet
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KB 6589 feet
API: 43-037-16469

**Public Oil Company**

- NEI/4SW1/4 section 12, T.30 S, R.24 E, SLBLM

KB 6372 feet
API: 43-037-15769

**Pure Oil Company**

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KB 6569 feet
API: 43-037-11342

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**Plate 2. West-to-East Stratigraphic Cross Section: Lisbon Field**

Modified from Parker (1961).

**Abbreviations**

- MCFPD = thousand cubic feet of gas per day
- BOPD = barrels of oil per day
- BOPH = barrels of oil per hour
- BW = barrels of water
- WAEW = water and gas cut water
- SWAEW = slightly water cut water
- SGOW = slightly gas cut oil
- SGOW = slightly gas cut oil
- SWAOEM = water & gas cut oil
- TST = gas to surface

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