Silurian Reef Reservoir Heterogeneity in the Illinois Basin with a Focus on Germantown and Wapella East Fields: Reservoir Quality Variability as a Result of Differences in Depositional Environments, Diagenesis and Erosional Truncation at the End of the Silurian

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Abstract

As part of an ongoing investigation of the Silurian Reef reservoir systems in the Illinois Basin, we focus on Germantown Field and Wapella East Field in the Illinois Basin. The Wapella East Field was discovered at a depth of 1,112 feet on December 2, 1962. The discovery well was the T. P. Kiley #1 well with an initial production of 154 BOPD. Commercial oil production has been from Silurian reef-associated carbonates. The Wapella East has produced more than 4.1 MMBO. It has an areal extent of approximately 550 acres. The maximum observed gross pay interval is ~73 feet, and the thickest observed net pay (greater than 10% porosity) is ~49 feet. Measured core porosities ranged from 3.9% to 26.5%. Permeabilities ranged from 2.5 md to 6,670 md. A total of 45 wells have been drilled in the productive portion of the field with only four wells penetrating the complete reservoir interval. Less than half of these wells penetrated greater than 10 feet into the reservoir. There has been limited pressure support from the underlying aquifer. The reservoir facies consists of a dolomitized reefal facies similar to those in Silurian reef reservoirs of the Michigan Basin. Erosional truncation at the top of the Silurian in the East Wapella Field is interpreted to have been significant.

Silurian reef field complexes of the Illinois Basin Western Shelf are very different from the Wapella East Field model. They produce from depths ranging from 2,000’ to 3,000’. They ubiquitously consist of a reef core of limited extent (i.e. 10-40 acres) composed of coral-stromatoporoid boundstones with separate-vug porosity, some of which are connected by fractures. Primary reservoir quality in these facies is generally reduced as a result of early submarine cementation that occludes much of the initial pore space. Producing wells from these facies have low cumulative oil production. These reef masses are capped and rimmed by crinoid lime grainstones, all tightly cemented, that grade laterally and downslope into avalanche deposits of several fining-upward cycles of crinoid dolomitic lime-dolomite packstones and wackestones. These packstone/wackestone packages are the most productive zones in the reef complex, and production per well is upwards of 250,000 BO. A limited porosity and permeability data set from Germantown Field, the most detailed of all the reef studies we have done,
indicate porosity and permeability range from 7% to 25%, and 2 md and 66 md, respectively, for these facies. Dolomite in this reservoir system probably was formed early in the burial history of the reefs, but reservoir quality appears to have been enhanced by later-stage burial dissolution and multi-stage dolomitization. The internal architectures of the Silurian reef complex reservoirs in the western and northern Illinois Basin are very heterogeneous. Secondary recovery programs in the form of re-drilling the reservoir complex, and implementation of waterflood programs can potentially make these fields profitable again.

Selected References


Silurian Reef Reservoir Heterogeneity in Illinois Basin with a Focus on Germantown and Wapella East Fields. Reservoir Quality Variability as a Result of Differences in Depositional Environments, Diagenesis and Erosional Truncation at the End of the Silurian.

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Main Points

- Geological characterization of Wapella East and Germantown East Silurian Reef reservoirs in the Illinois Basin

- Reservoir characterization and petroleum engineering technologies have advanced since discovery and development of these reservoirs in the 1950’s and 1960’s.

- Significant redevelopment opportunities may be associated with these complex reef reservoir systems.

- Continuation of the investigation of Silurian Reef Systems in the Michigan and Illinois Basins will pay dividends.
Regional Geology

**Illinois Intracratonic Basin**

~14,000’ deep

- Failed Rift System

- Initiated in Cambrian

- Precambrian to Pennsylvanian Sediments

**Michigan Intracratonic Basin**

~14,000’ to 15,000’ deep

- Failed Rift System

- Initiated in Cambrian

- Precambrian to Late Jurassic Sediments

- Center of basin moved through time (Ells, 1971)

Contours on Precambrian Surface

Modified from Shaffer (1981) and Bond et. al., (1971)
Regional Geology
Paleogeography and locations of discrete Silurian reefs and carbonate banks

Focus Fields

Wapella East
Silurian Reef Complex
Discovered 1962
DeWitt County, IL
Harris No. 1 well
IP ~154 BOPD
> 3.3 MMBO cum. Prod.

Germantown East
Silurian Reef Complex
Discovered 1956
Clinton County, IL
Holtgrave No. 1 well
IP ~177 BOPD
> 2.1 MMBO cum. Prod.

(Modified from Howard, 1963)
Wapella East Field

- Discovered December 2, 1962 in DeWitt County, Illinois
- Production from Silurian Reef Dolomites Starting at a Depth of 1,112’ on the Northwest Side of the Illinois Basin
- Initial Production from the Discovery Well was 154 BOPD
- The Wapella East Reservoir is Contained in a Closed Structure with 90 to 100 feet of Relief that is Situated on a Southward Plunging Structural Nose
- Over 4.1 MMBO Cumulative Production

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Upper Silurian and Devonian Sections have been Influenced by Significant Erosion and Nondeposition Events

How Much Upper Silurian Section (Time) is Missing?

(Modified from Howard, 1963)
20 Silurian Oil Fields
Cumulative Production of ~37 MMBO Through 1985

- **Marine**: 12.4 MMBO
- **Wapella East**: > 3.3 MMBO
- **Germantown East**: > 2.1 MMBO

**Why No New Discoveries?**

Based on Whitaker (1988)

- Reservoirs between -1000' to -3500' subsea

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The larger the bubble the higher
the cumulative production

Bubble Plot of Depth / Field Size / Cumulative Production Through 1985 of 20
Silurian Reef Reservoirs in the Illinois Basin

Wapella East Field
(> 4.1 MMBO)

Germantown East Field
(> 2.1 MMBO)

Marine Field
(> 12.4 MMBO)

Based on Whitaker (1988)
Wapella East Reservoir

Top of Silurian
Positive Structure with over 90 feet of Relief

Devonian Isopach
Thins onto the Wapella East Structure

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Most Wells do not Penetrate the Majority of the Potential Reservoir Intervals in the Wapella East Reservoir!

Makes it impossible to build a modern, detailed carbonate reservoir model!

Significant Deepening Potential Likely!

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Structural Cross-section Wapella East Field

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Top of Devonian - 318' (1130')
Top of Silurian - 350' (1160')

~1,000 feet
~1,650 feet

Interpreted Base of Potential Reservoir Facies
Wapella East Field
Multiple Reservoir Zones!

120392101200
C. Ryan #8
TD = 2,250’
9/16/1992
SWDW

Challenging!

Interpretation
Multiple Reservoir Zone
~73’ Gross
~32’ (Net Pay)
Upper 5’ Flushed

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Map of Wells with Geological Samples and/or Data in or Near The Wapella East Field - Data is Limited

➢ Note that the wells with core material and the wells that have core analyses do not correlate with each other.

➢ Cores present sometimes only represent a subsample of the original core material.

➢ Still can provided important depositional and diagenetic reservoir information!

Modified from: Illinois Oil and Gas Resources Interactive Map

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Complex and Heterogeneous Pore Systems Developed in Dolomitized Reef Complex of the Wapella East Reservoir

Confirms Early Interpretation of R. H. Howard (1963)
In his initial geological study of the Wapella East Reservoir

Very Good Insight for 1974!

Modified from: Bristol, H. M., (1974), Silurian Pinnacle Reefs and Related Oil Production in Wapella East Reservoir

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Note shallow penetration of reservoir!

TD 1,117’

Reef Material Observed in Cores

Datum: Mean Sea Level

½ Mile

Core Analyses from the Silurian reservoir Interval in four (4) wells from the Wapella East Field, Illinois

- T. P. Kiley #16
- T. P. Kiley #12
- T. P. Kiley #10
- C. Ryan #1

Large Scatter in Paired Porosity and Permeability Measurements Indicating Significant Reservoir Heterogeneity

Average Porosity = 13.9%
Average Permeability = 993.1 md

Exponential regression:
\[ y = 0.5687e^{0.384x} \]
\[ R^2 = 0.3999 \]

N = 76

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Evidence of major erosional Unconformity at the top of the Silurian (How much time is missing is unknown!)

Reservoir porosity is secondary and consist of intercrystalline, vuggy and moldic pores

Porosity development is interpreted to be associated with the unconformity
Wapella East Reservoir Heterogeneity
At Core and Thin Section Scales

Ryan #4 ~1135'

Blue epoxy in pore spaces

Ryan #4 ~1157.5'

Ryan #4 ~1165'

Oil Stained

Sharp Porosity Boundary

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Wapella East Field Study Conclusions

1. The Wapella East Reservoir is a positive relief, dolomitized Silurian reef complex

2. The erosional unconformity at the top of the Silurian has removed section and influenced reservoir porosity development and distribution – Amount of erosion unknown

3. The reservoir facies consist of dolomitized boundstones, grainstones to wackestones – common porosity types include intercrystalline, moldic, vuggy and fracture

4. The reservoir has a complex internal geometry with a limited water drive and a likely low primary recovery efficiency
Wapella East Field
The Challenges of Characterizing a Carbonate Reservoir with Limited Data

- Majority of wells do not penetrate more than 10 feet into the reservoir interval
- Majority of well logs are old SP and Resistivity Types with limited value
- Available core analyses do not correspond to available core material that can be examined
- Available core material represents only a subsample of the original cores
ACRES: 520
CUMULATIVE PRODUCTION (2009): ~2.4MMBO
Depth: 2300’ – 2400’
Closure: (Top Hunton): 100-120’
Lowest perf’ed interval
API: 40
Drive: water, with later water flood
GERMANTOWN EAST
TOP HUNTON STRUCTURE MAP
C.I. = 20’

ACRES: 520
CUMULATIVE PRODUCTION (2009):
~2.4MMBO
Depth: 2300’ – 2400’
Closure: (Top Hunton): 100-120’
Lowest perf’ed interval
API: 40
Drive: water, with later water flood drive
Coral-Stromatoporoid Boundstone

- Encrusting algae and early submarine cements occlude most primary porosity

Deeper water Mud Mound
Coral-Stromatoporoid Boundstone (REEF) (non-reservoir)
Crinoid Lime Grainstone (non-reservoir)
Crinoid-fossil fragment Dolomite Grainstone/Packstone (reservoir)
Crinoid-fossil fragment Dolomite Wackestone/Mudstone (reservoir)
Muddy, Cherty Basinal Dolomite Mudstone (non-reservoir)
Crinoid Dolomite Packstone Reservoir Facies

Germantown East Reservoir

*Interxline and mesovuggy (moldic) porosity

* muddy dolomite permeability barriers
Dolomite Mudstones with late-diagenetic dissolution & porosity enhancement

Blue epoxy in pore spaces
**Crinoid Dolomitic Packstone Reservoir Facies with Intercrystalline and Moldic Porosity**  
**Germantown East Field**

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**RESERVOIR FACIES**

**AVERAGE**

**PHI/K and SWi’s**

<table>
<thead>
<tr>
<th></th>
<th>Dolomite Mudstone/Wackestone Facies</th>
<th>Dolomite Packstone/Grainstone Facies</th>
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</thead>
<tbody>
<tr>
<td><strong>N</strong></td>
<td>30</td>
<td></td>
</tr>
<tr>
<td><strong>POROSITY</strong></td>
<td>19%</td>
<td>14%</td>
</tr>
<tr>
<td><strong>PERMEABILITY</strong></td>
<td>10.1md</td>
<td>12.6md</td>
</tr>
<tr>
<td><strong>Swii</strong></td>
<td>18.2</td>
<td>21.4</td>
</tr>
</tbody>
</table>

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Blue epoxy in pore spaces of stained thin section
Dolomite Mudstone with abundant Intercrystalline Porosity

**RESERVOIR FACIES AVERAGE**

<table>
<thead>
<tr>
<th>Facies</th>
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ROCK/RESERVOIR VARIABILITY
Germantown East Reservoir

Deeper water Mud Mound
Coral-Stromatoporoid Boundstone (REEF) (non-reservoir)
Crinoid Lime Grainstone (non-reservoir)
Crinoid-fossil fragment Dol. Grainstone/Packstone (reservoir)
Crinoid-fossil fragment Dol. Wackestone/Mudstone (reservoir)
Muddy, Cherty Basinal Dol Mudstone (non-reservoir)

M/W = Mudstone and Wackestone
P/G = Packstone and Grainstone
B = Boundstone
FR = Fractures
Porosity - Good (red) Mixed (pink)

IP: 208 BOPD
57+MBO

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ROCK/RESERVOIR VARIABILITY
Germantown East Field

Deeper water Mud Mound
Coral-Stromatoporoid Boundstone (REEF) (non-reservoir)
Crinoid Lime Grainstone (non-reservoir)
Crinoid-fossil fragment Dol. Grainstone/Packstone (reservoir)
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Muddy, Cherty Basinal Dol Mudstone (non-reservoir)

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North to South Facies Cross-sections of Germantown East Reservoir

Reef Facies Limited Reservoir Quality

Perf Zones

Reef Facies Limited Reservoir Quality

Perf Zones
West to East Facies Cross-sections of Germantown East Reservoir

Reef Facies Limited Reservoir Quality

Perf Zones
Reservoir Heterogeneity of Germantown East Reservoir Reflected in Net Pay and Cumulative Production Maps

Interpreted Reef Position

Total Net Pay (All Non-Reef Facies (C.I. = 10'))

Flanking Facies most Productive

CUMULATIVE PRODUCTION (C.I. = 50 MBO)
INFLUENCE OF REGIONAL FRACTURE TREND ON WATERFLOOD DESIGN

Evidence for Faults

- Aeromagnetic Survey
- Linear Analysis
- Dye Tracer Study of Reservoir
Germantown East Study Conclusions

1. The reef and flanking crinoid lime grainstone facies are not significant reservoir units due to early cementation.

2. Downslope flanking Crinoid Dolomite Packstones and Dolomite Wackestone/Mudstone avalanche units are reservoir facies and are interpreted to be the result of early and later-stage dolomitization and dissolution events.

3. Stratigraphic variability is extreme.

4. Fracturing plays a significant role in deliverability and water-flood design.

5. An improved reservoir model was developed for the field.
GERMANTOWN EAST
TOP HUNTON STRUCTURE MAP

Lowest producing Perf’s (closure = 100’-120’)

Depth from Top of Silurian (ft)

Reservoir Depth Closure Range

Wells

Deeper Potential Likely!

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Redevelopment Potential?

**EAST GERMANTOWN WORK PROGRAM**
(from Swager & Assoc., 1994)

Only the Re completions were implemented during Reservoir Redevelopment!

- **New Wells** (9)
- **Deepen Wells** (7)
- **Re completions** (6)

Redevelopment Potential?

<table>
<thead>
<tr>
<th>New Locations</th>
<th>New Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 N., 900 W., N., N. W., Sec. 1.</td>
<td>900 N., 900 W., N., N. W., Sec. 1.</td>
</tr>
<tr>
<td>Varvel lease</td>
<td>Varvel lease</td>
</tr>
<tr>
<td>Holmbergh lease</td>
<td>Holmbergh lease</td>
</tr>
</tbody>
</table>

**SUGGESTED EAST GERMANTOWN WORK PROGRAM**
(from Swager & Assoc., 1994)

- **New Wells** (9)
- **Deepen Wells** (7)
- **Re completions** (6)

Redevelopment Potential?

- **New Wells** (9)
- **Deepen Wells** (7)
- **Re completions** (6)

**Varvel #2 (Sec. 36)**
-- 2372-80

**330 W., 330 W., N., N. W., Sec. 1.**

**Holmbergh lease**

**Varvel lease**

**Redevelopment Potential?**

- **New Wells** (9)
- **Deepen Wells** (7)
- **Re completions** (6)
Redevelopment Potential Tested

**Economic Success!**

- **Germantown East Field** (Clinton County)
  - Discovered July 1956
  - Redesign of water flood
  - Stabilized production at ~1,000 BOPM

- **Tilden Field** (Randolph County)
  - Discovered October 1951
  - Redevelopment started in 1984 and resulted in a ~5,000 BOPM increase in production
Comparison of Wapella East and Germantown East Silurian Reservoirs

Talking Points

- Wapella East Reservoir Dolomitized - Germantown East only Partially Dolomitized
- Reservoir Quality Generally Higher in Wapella East
- Reservoir Quality is Highly Variable in Both Reservoir (Depositional and Diagenetic Controls)
- Wapella East Reservoir is Located at the Northern Edge of the Illinois Basin (more erosion) - Germantown East Reservoir is Located in the Southwest Area of the Illinois Basin
- Comparison with Analog Models Helps to Fill in Between the Reservoir Control Points
- Both Reservoirs have Redevelopment Potential
The Re-evaluation and Redevelopment Cycle in Reservoir Geology

➢ We continue to improve our understanding of carbonates
➢ Technology continues to advance providing new data and insights
➢ Depositional and diagenetic models improve with time

Pipe Creek Junior Quarry One of Our “Rosetta Stones”

Acknowledgements

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➢ The Illinois Geological Survey staff for their assistance in our studies of the geological samples and geological data collection efforts.

➢ All the professional geologist that have studied and published their findings on the Silurian Reef reservoirs in Illinois. They have provided a great wealth of data, observations and interpretations for future geologists to build on.

➢ Jon Havens and Irving Materials, Inc. for allowing access to and supporting the Pipe Creek Junior Quarry studies that provided us with the impetus to continue our studies of selected Silurian Reef reservoirs into the Illinois Basin.