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.

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F. P. Kiley #2 well
~1,122.5' - Wapella East Field

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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

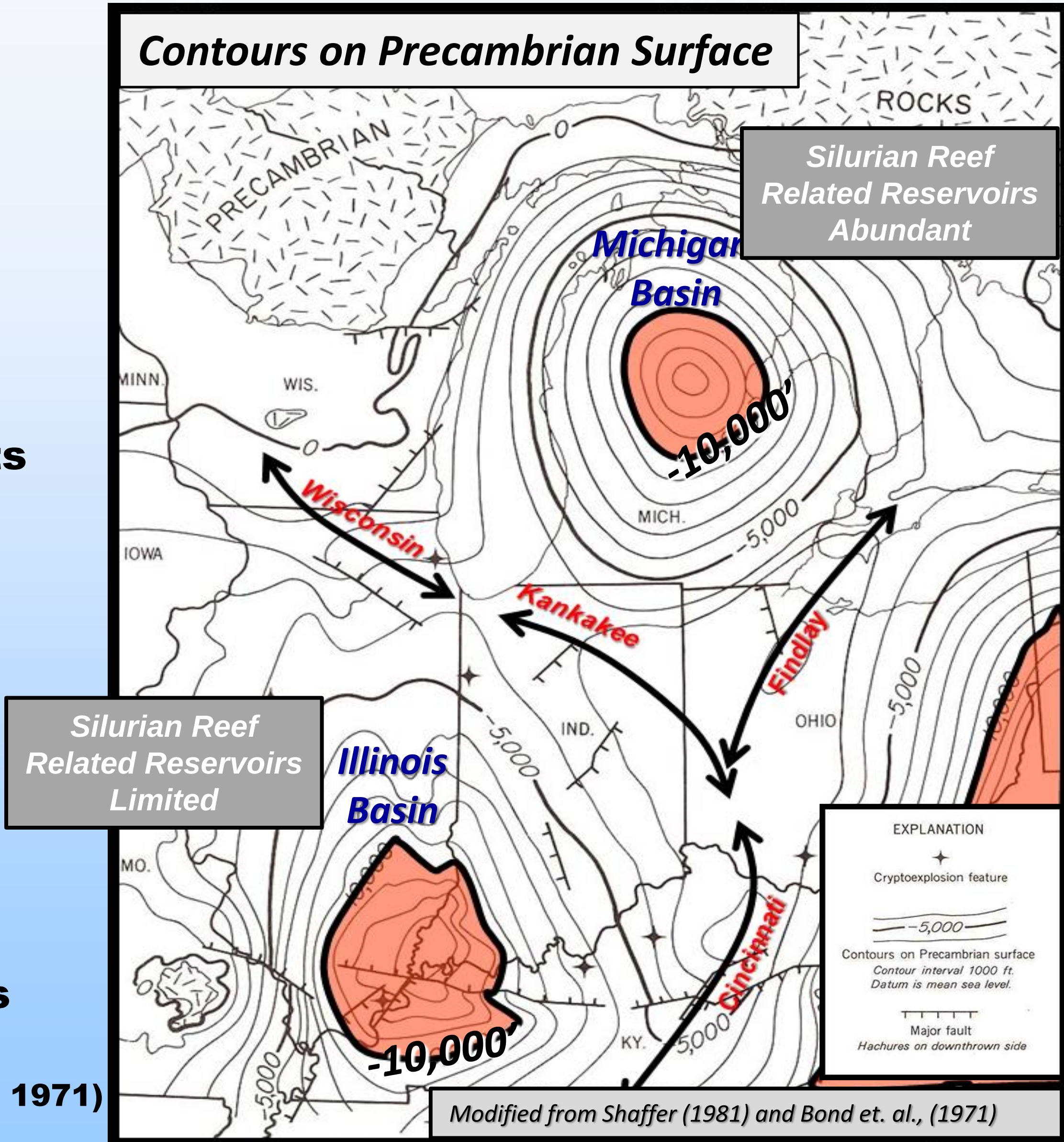
~14,000' to 15,000' deep

- Failed Rift System

- Initiated in Cambrian

- Precambrian to Late Jurassic Sediments

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



Regional Geology

Paleogeography and locations of discrete Silurian reefs and carbonate banks

Focus Fields

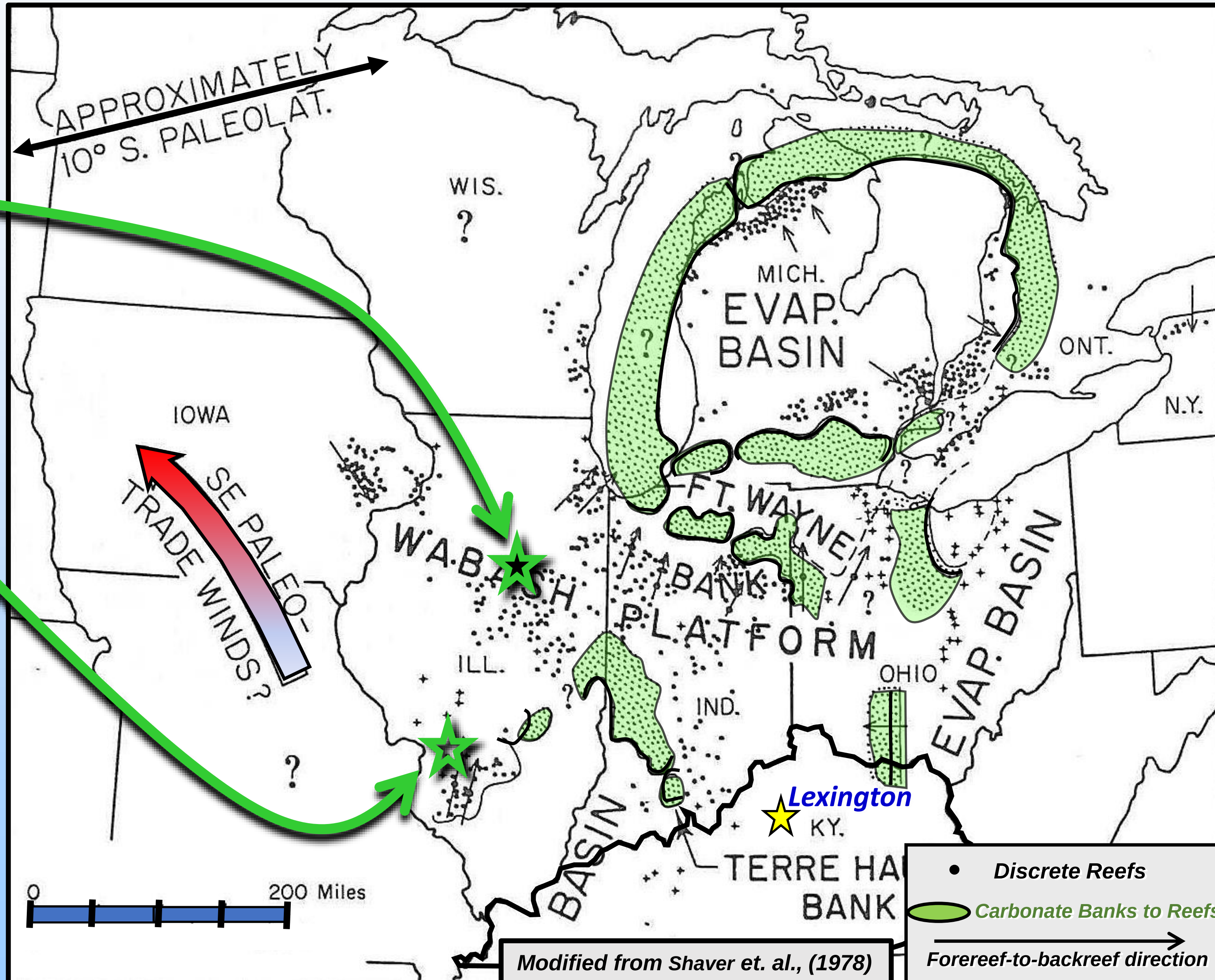
Wapella East

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

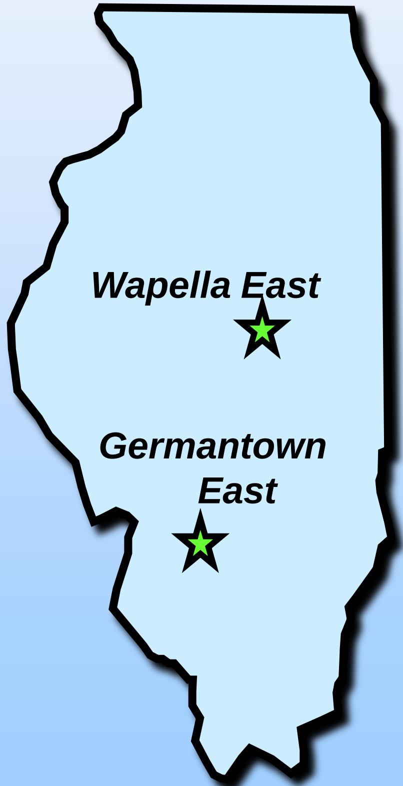
Germantown East

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

(Modified from Howard, 1963)

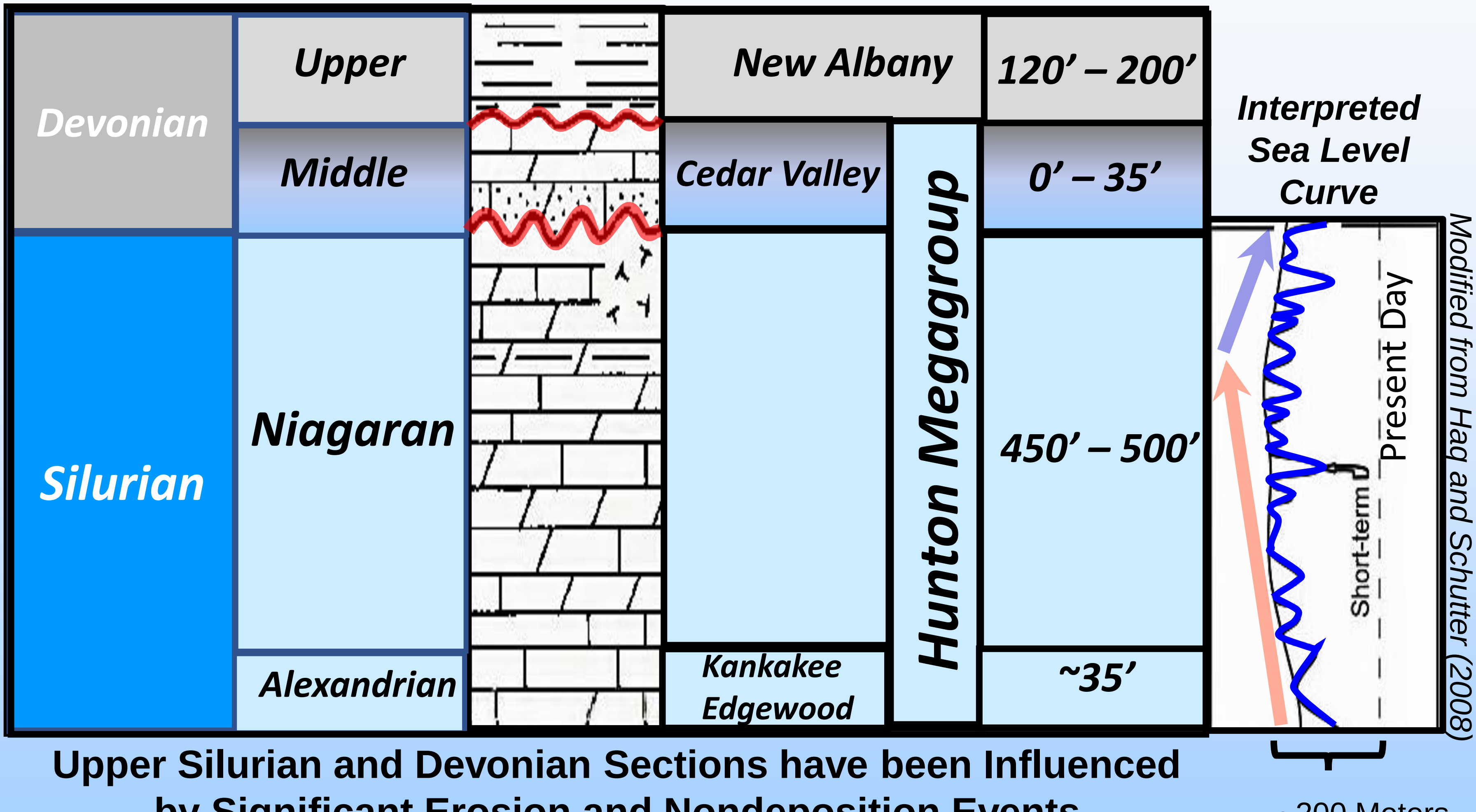


Wapella East Field

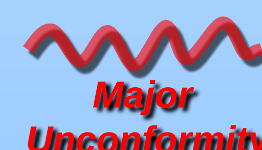


- Discovered December 2, 1962 in DeWitt County, Illinois
- Production from Silurian Reef Dolomites Starting at a Depth of 1,112’ on the Northwest Side of the Illinois Basin
- Initial Production from the Discovery Well was 154 BOPD
- The Wapella East Reservoir is Contained in a Closed Structure with 90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

Stratigraphy



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

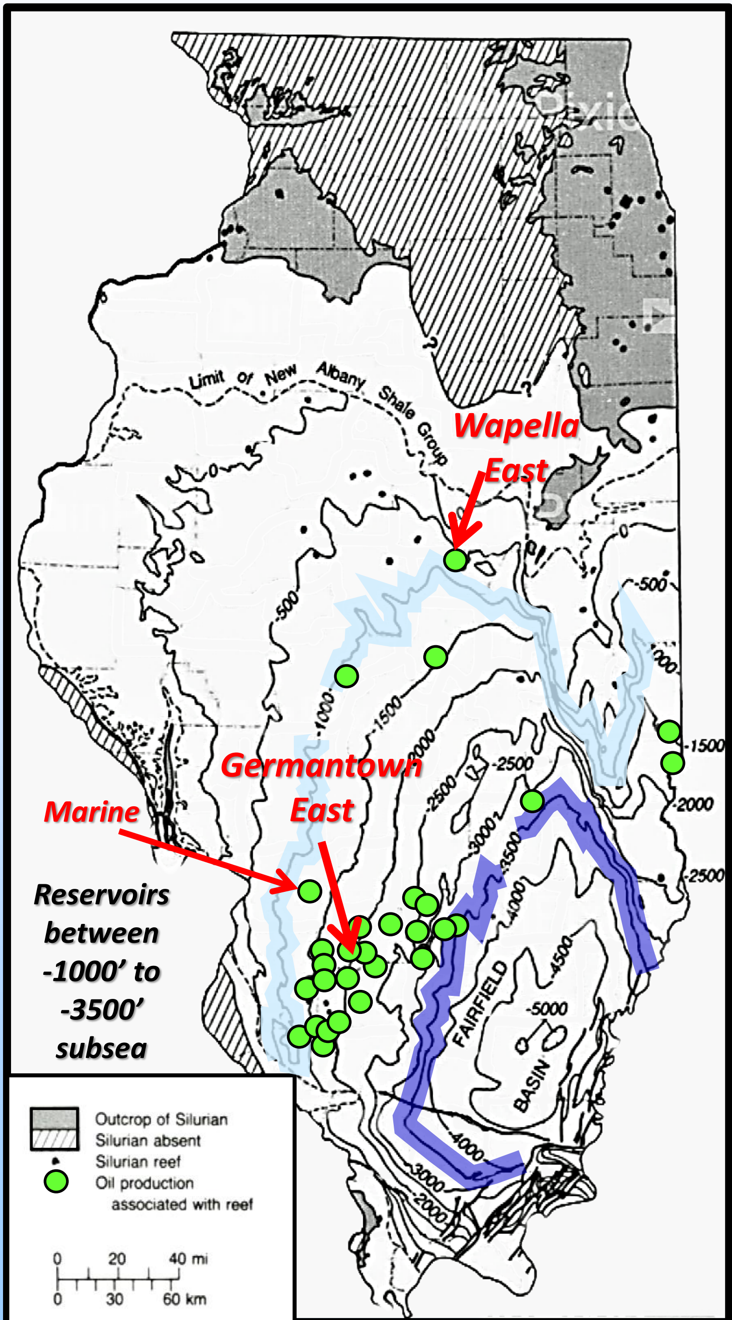


How Much Upper Silurian Section (Time) is Missing?

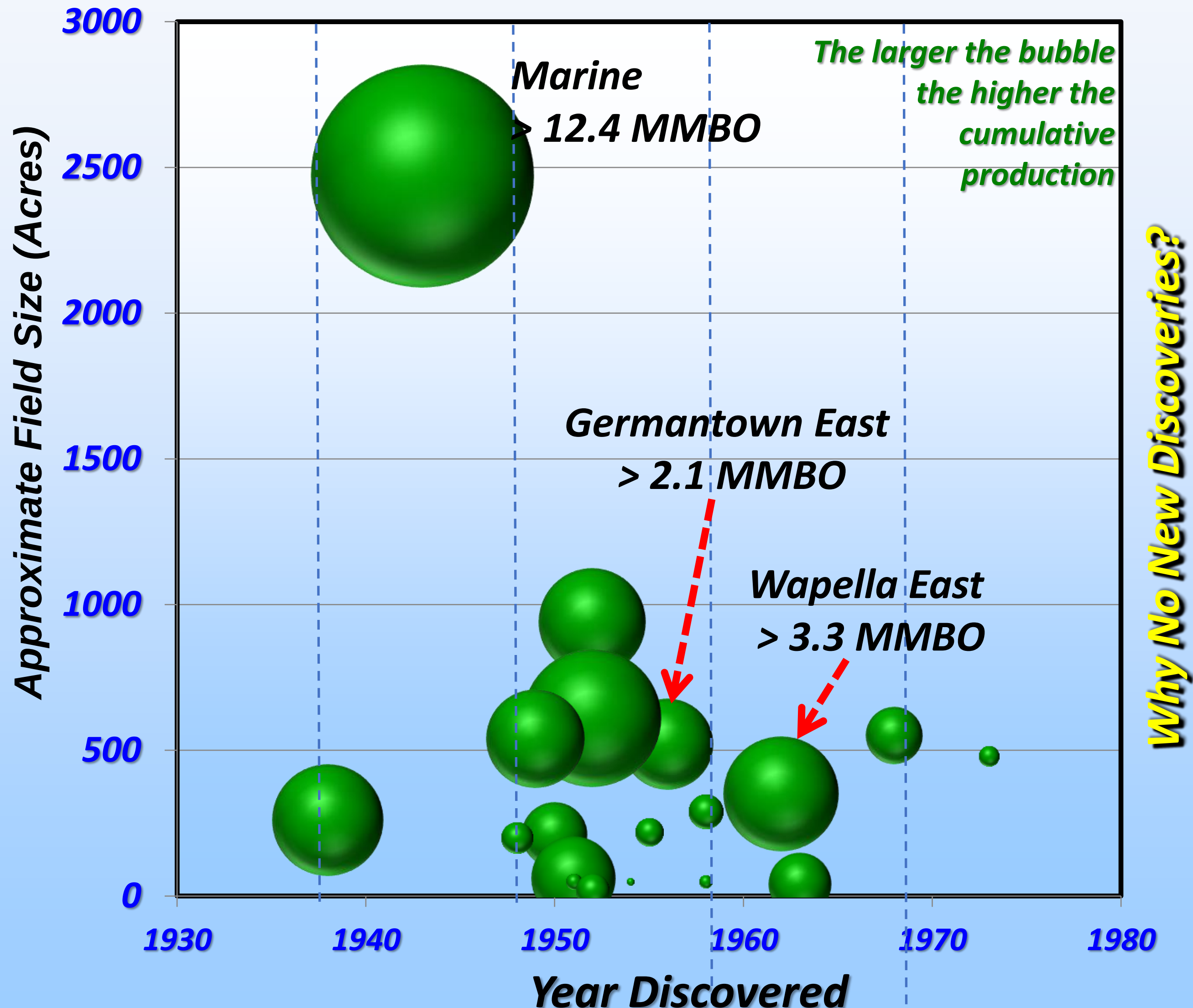
(Modified from Howard, 1963)

20 Silurian Oil Fields

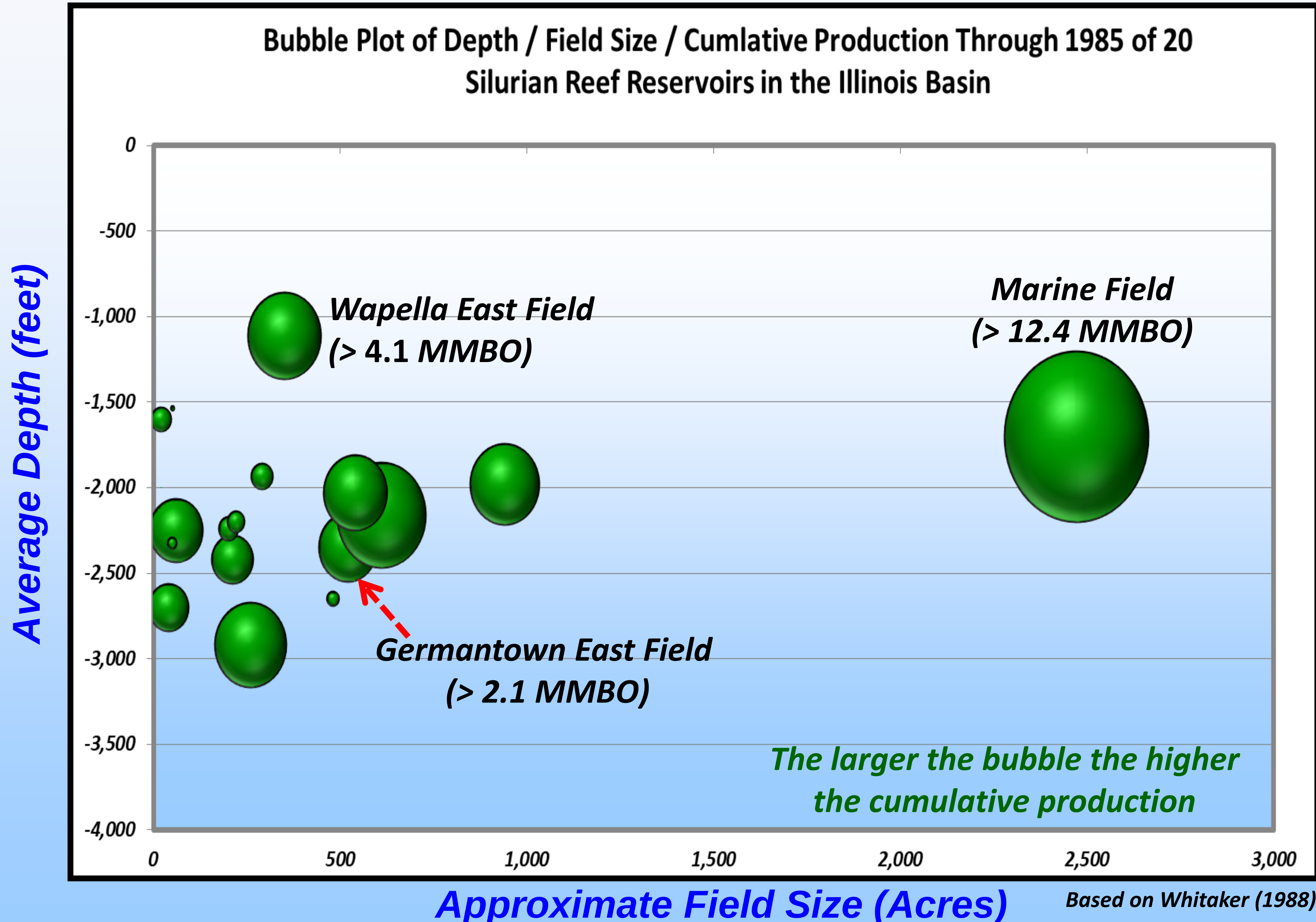
Cumulative Production of ~37 MMBO Through 1985



Based on Whitaker (1988)



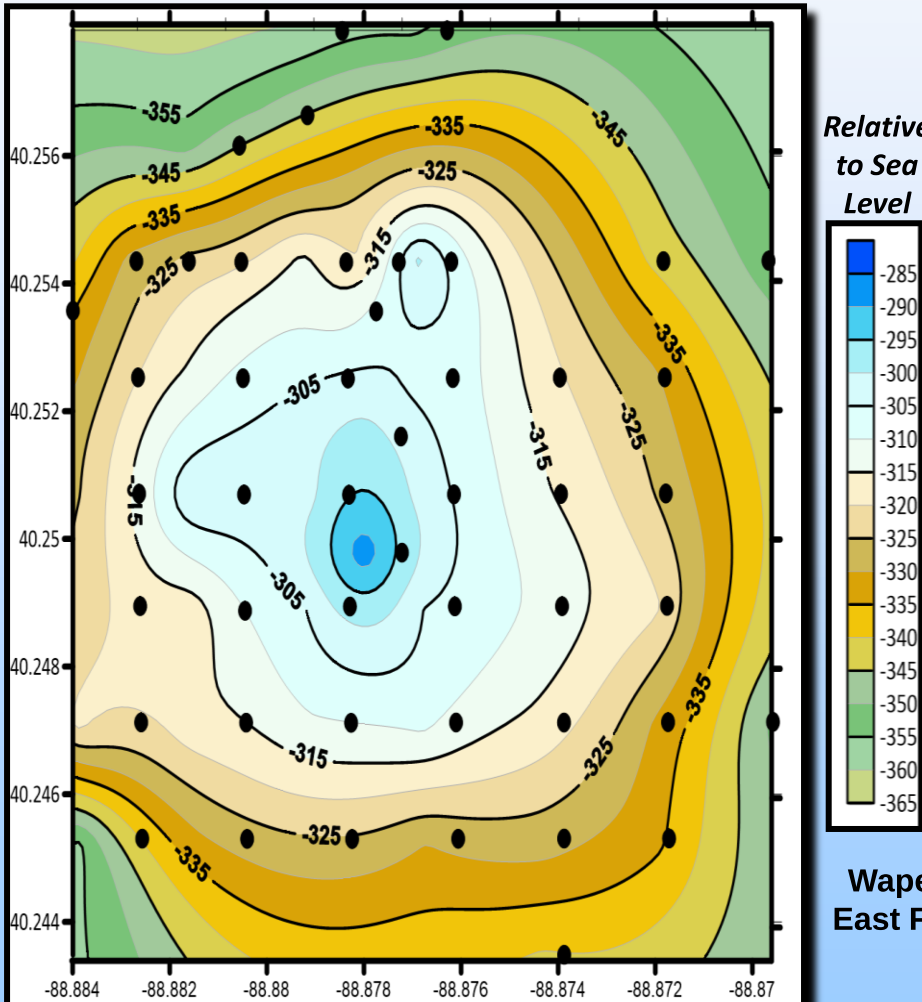
Based on Whitaker (1988)


Bubble Plot of Depth / Field Size / Cumlative Production Through 1985 of 20
Silurian Reef Reservoirs in the Illinois Basin
Average Depth (feet)
0
-500
-1,000
-1,500
-2,000
-2,500
-3,000
-3,500
-4,000
Wapella East Field
(> 4.1 MMBO)
Marine Field
(> 12.4 MMBO)
Germantown East Field
(> 2.1 MMBO)
The larger the bubble the higher
the cumulative production
0
500
1,000
1,500
2,000
2,500
3,000
Approximate Field Size (Acres)
Based on Whitaker (1988)

Wapella East Reservoir

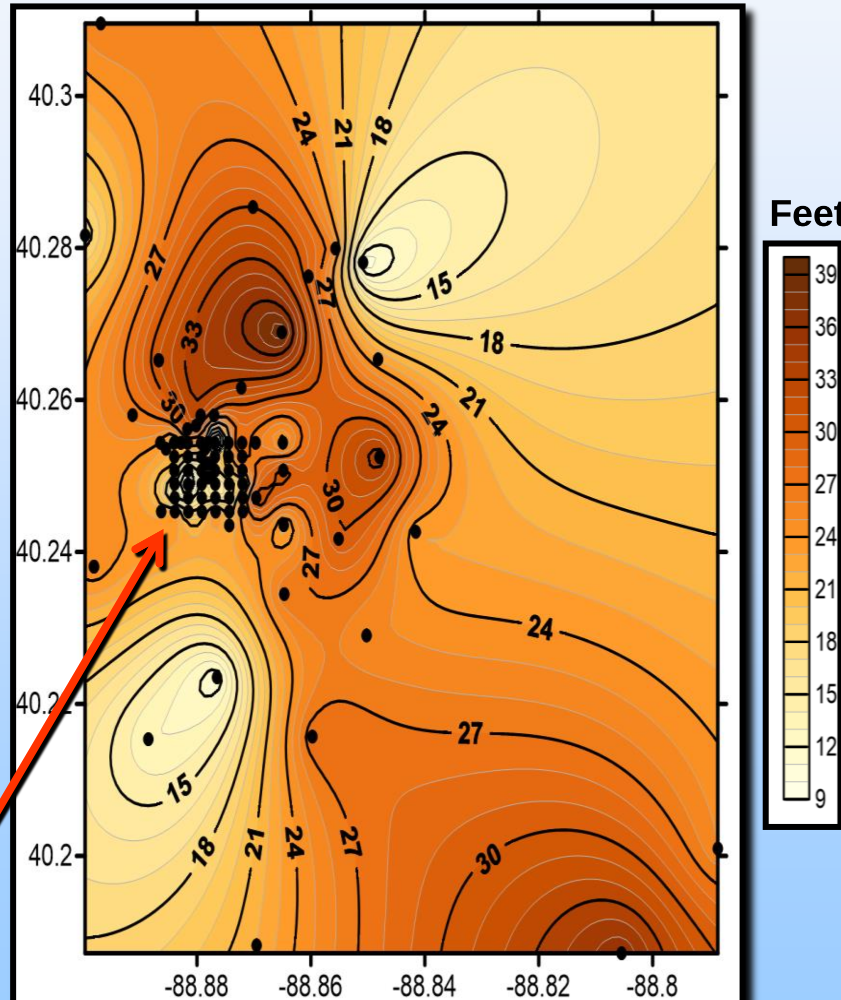
Top of Silurian

Positive Structure with over 90 feet of Relief

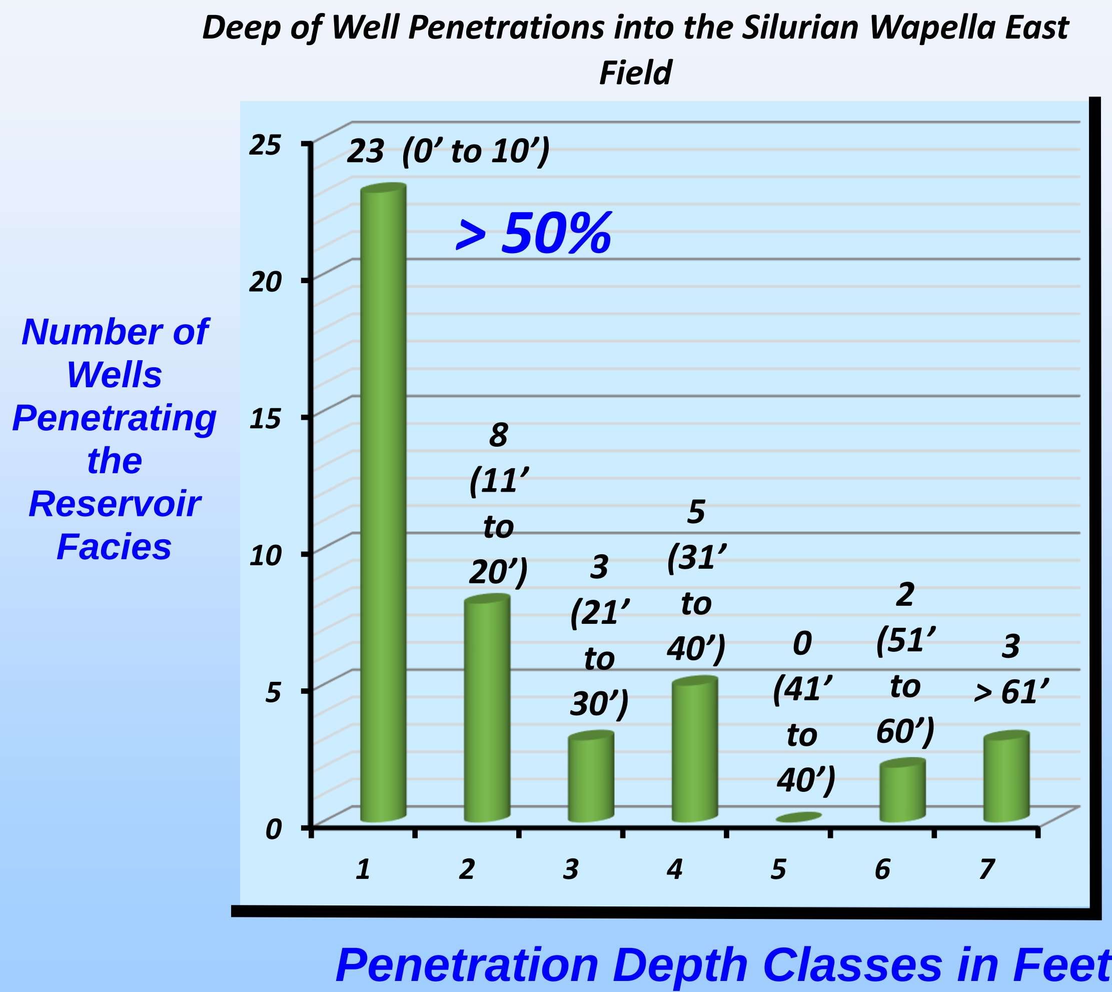


Devonian Isopach

Thins onto the Wapella East Structure



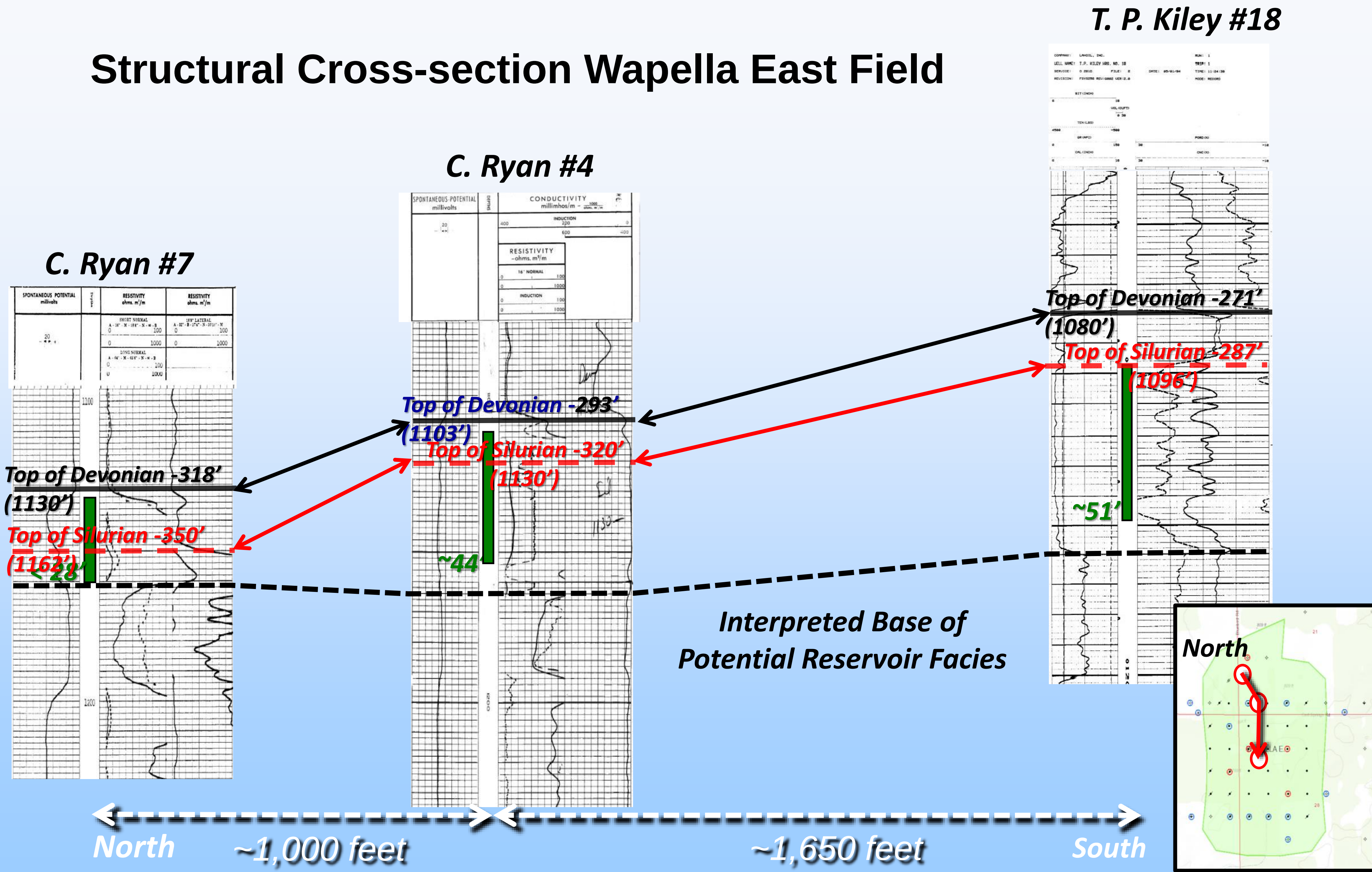
Most Wells do not Penetrate the Majority of the Potential Reservoir Intervals in the Wapella East Reservoir!



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

Significant Deepening Potential Likely!

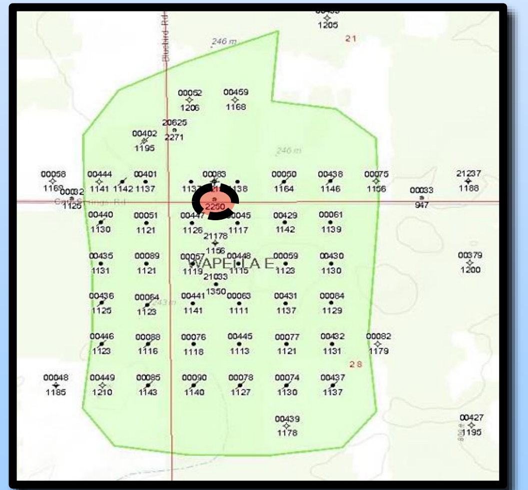
Structural Cross-section Wapella East Field



Wapella East Field

Multiple Reservoir Zones!

Challenging!



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

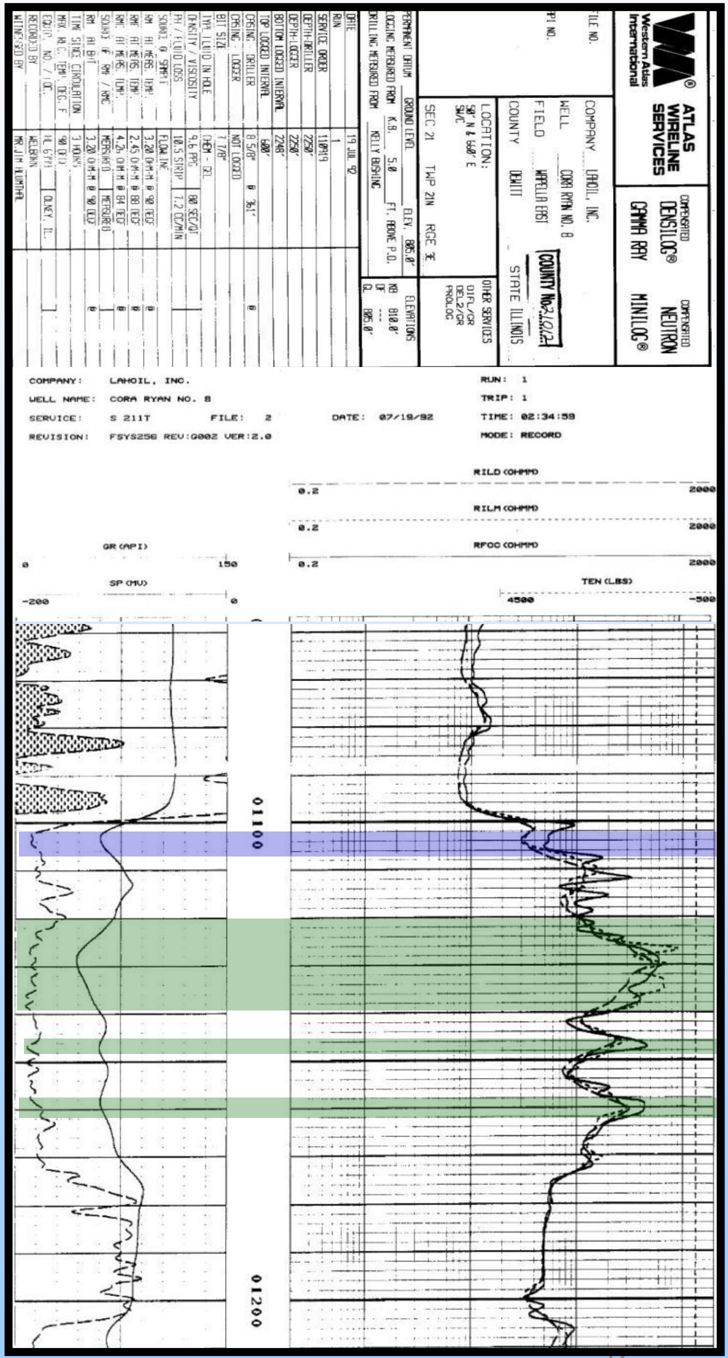
Interpretation

Multiple Reservoir Zone

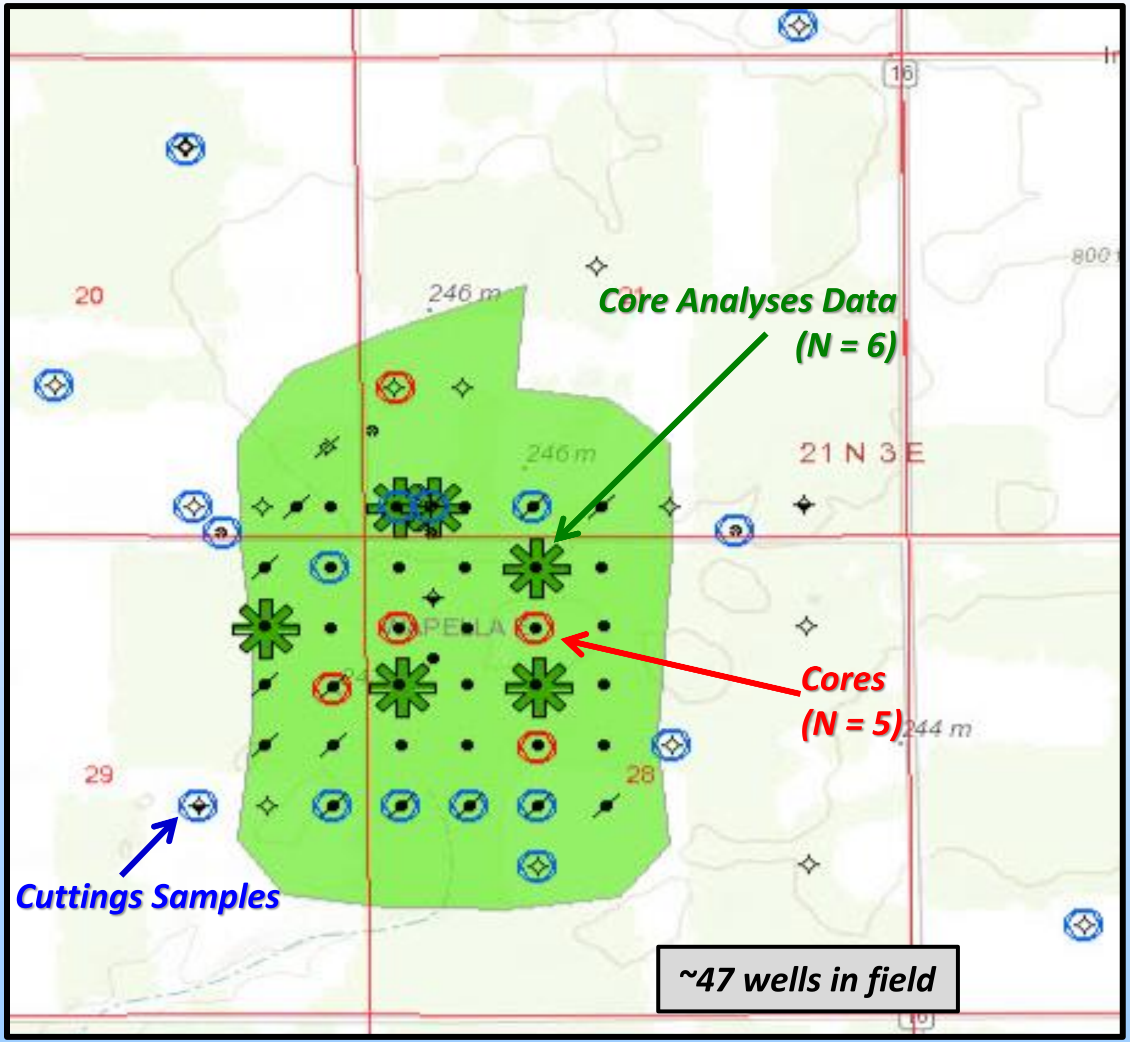
~73' Gross

~32' (Net Pay)

Upper 5' Flushed



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



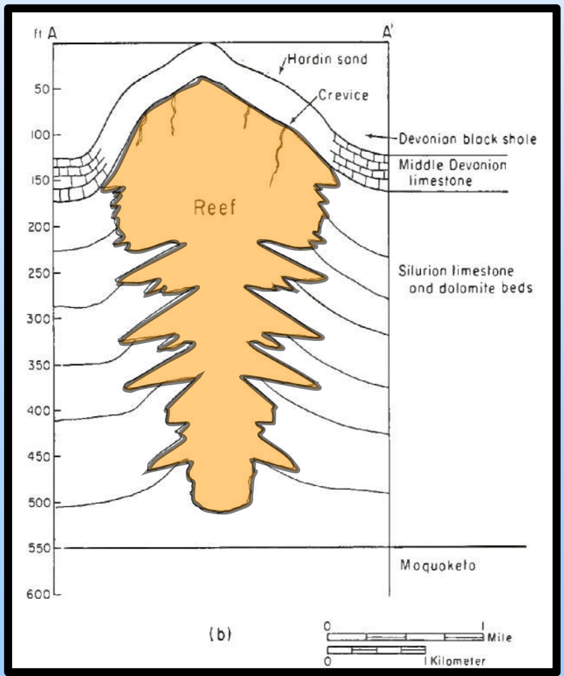
Modified from: Illinois Oil and Gas Resources Interactive Map

- *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 materal.*
- *Still can provided important depositional and diagenetic reservoir information!*

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!

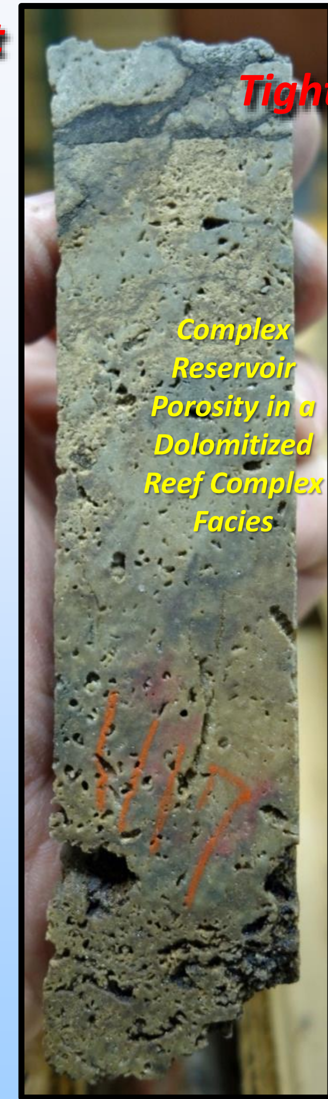


Modified from: Bristol, H. M., (1974), Silurian Pinnacle Reefs and Related Oil Production in

Core T. P. Kiley #3 Well Depth = ~1,110'

Core L. Kiley #2 Well Depth = ~1,109'

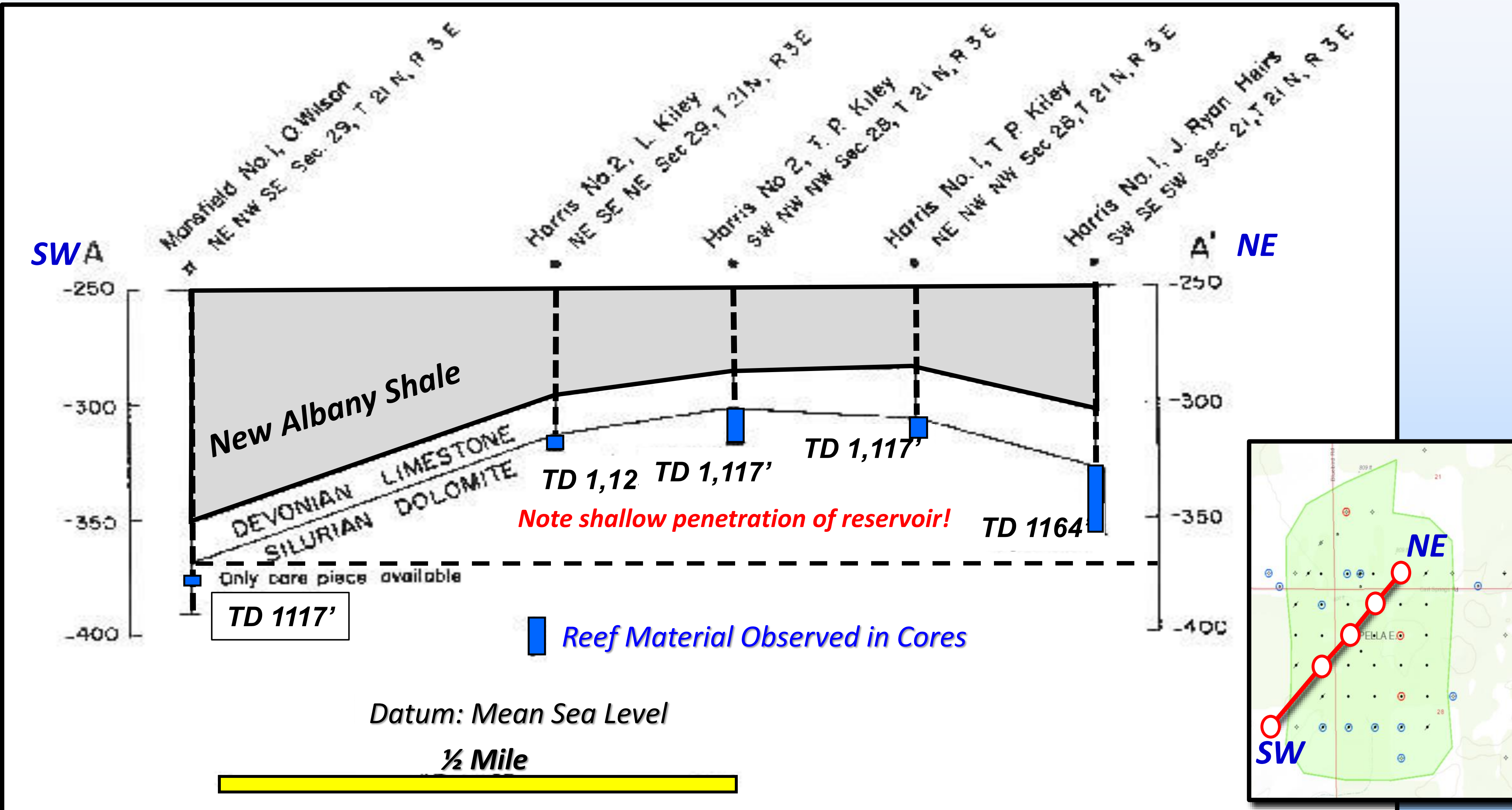
Core L. Kiley #2 Well Depth = ~1,115'



Core L. Kiley #2 Well Depth = ~1,117'

SW to NE Geological Cross Section Wapella East Reservoir

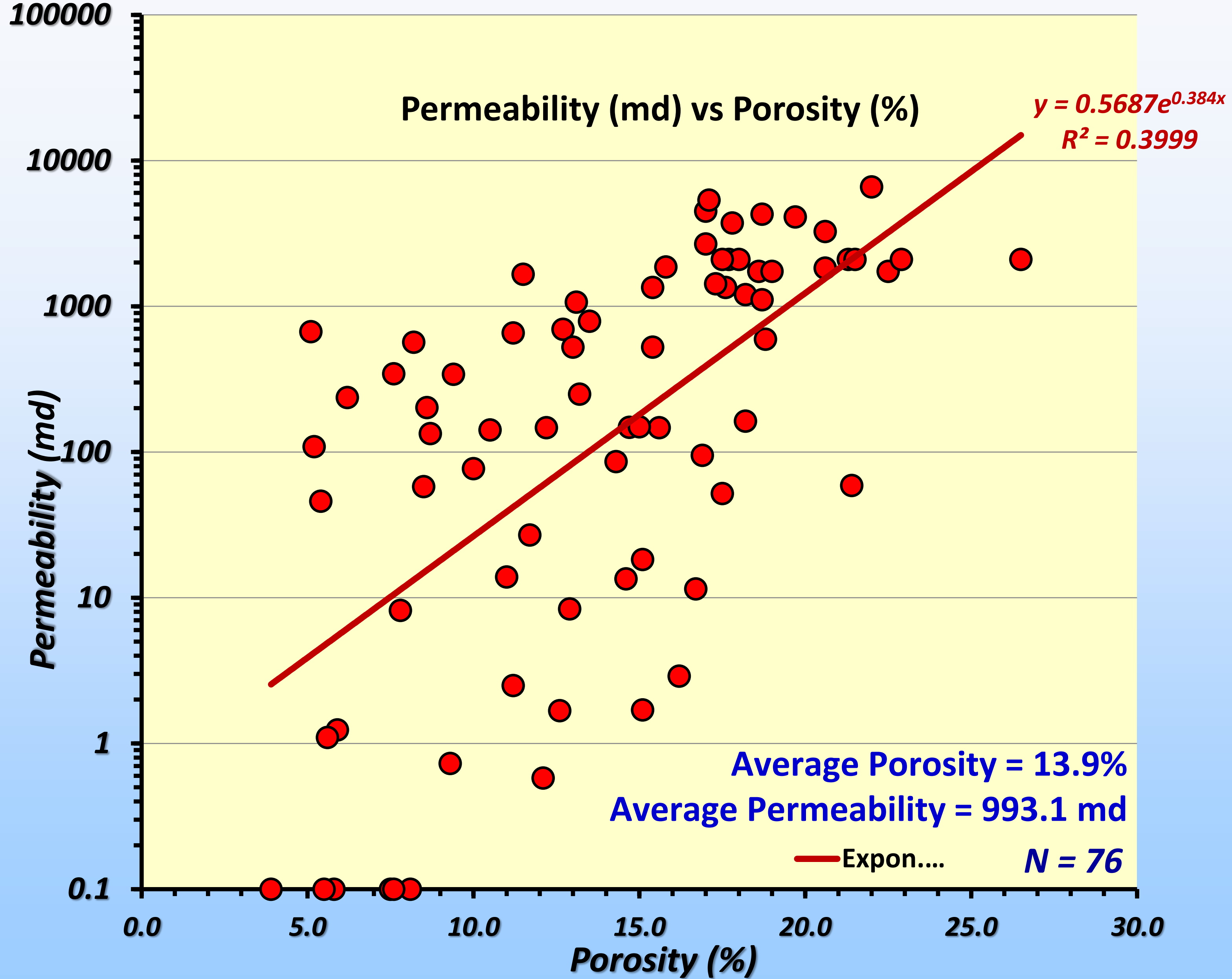
Reef Influence Recognized Shortly after Discovery – Examination of Core



Modified From: Howard, R. H., (1963) Wapella East Oil Pool, De Witt County, Illinois A Silurian Reef, Illinois State Geological Survey, Circular 349, 15p.

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

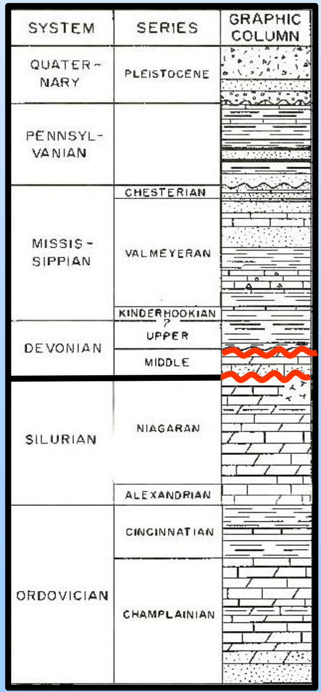


Large Scatter in Paired Porosity and Permeability Measurements Indicating Significant Reservoir Heterogeneity

- 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

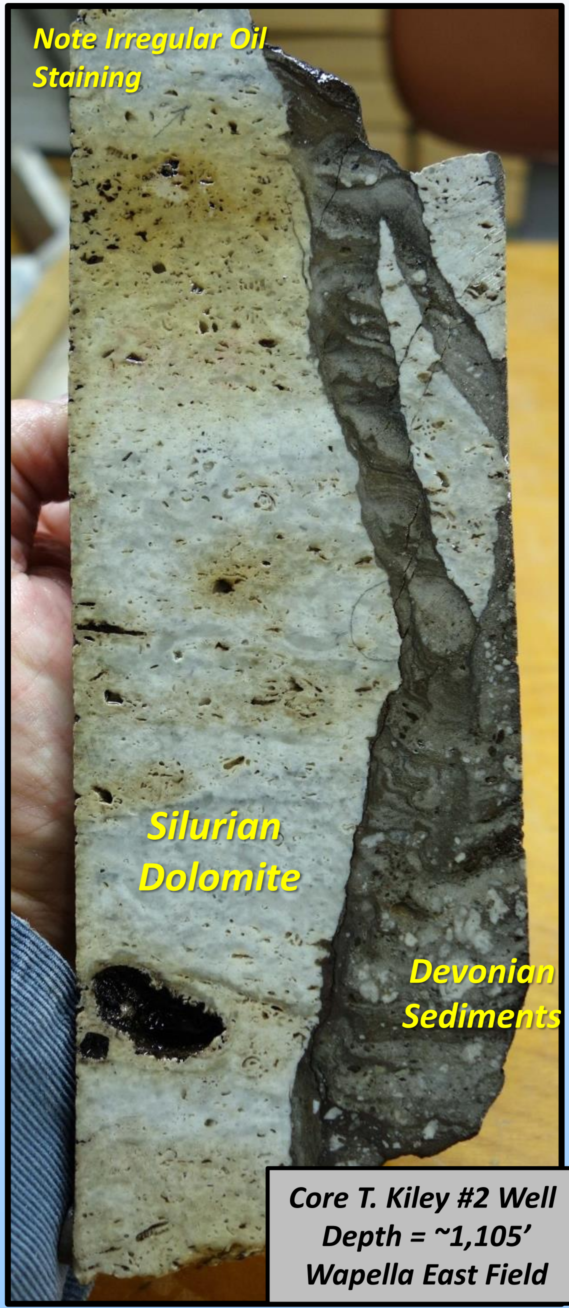
- Porosity development is interpreted to be associated with the unconformity



Devonian 1,085' to 1,101' interval

Erosional Unconformities

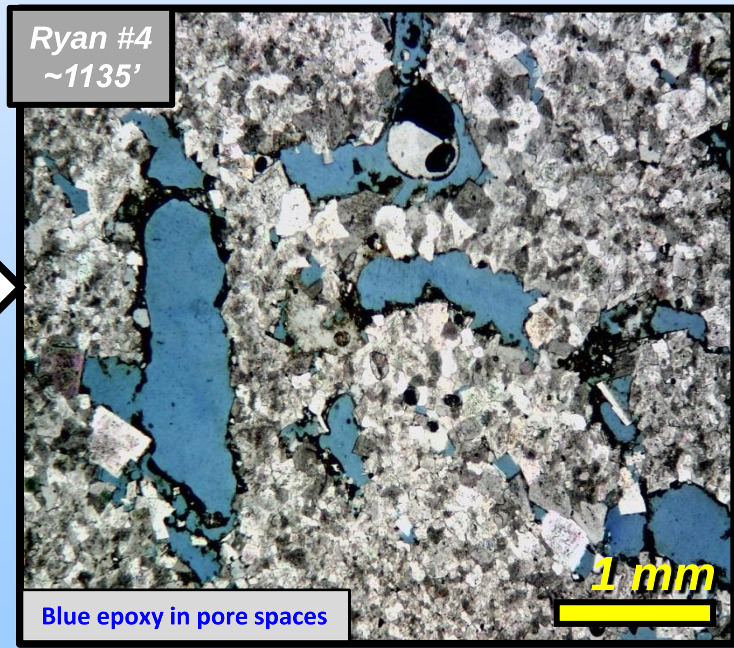
Core T. Kiley #2 Well
Depth = ~1,102'
Wapella East Field

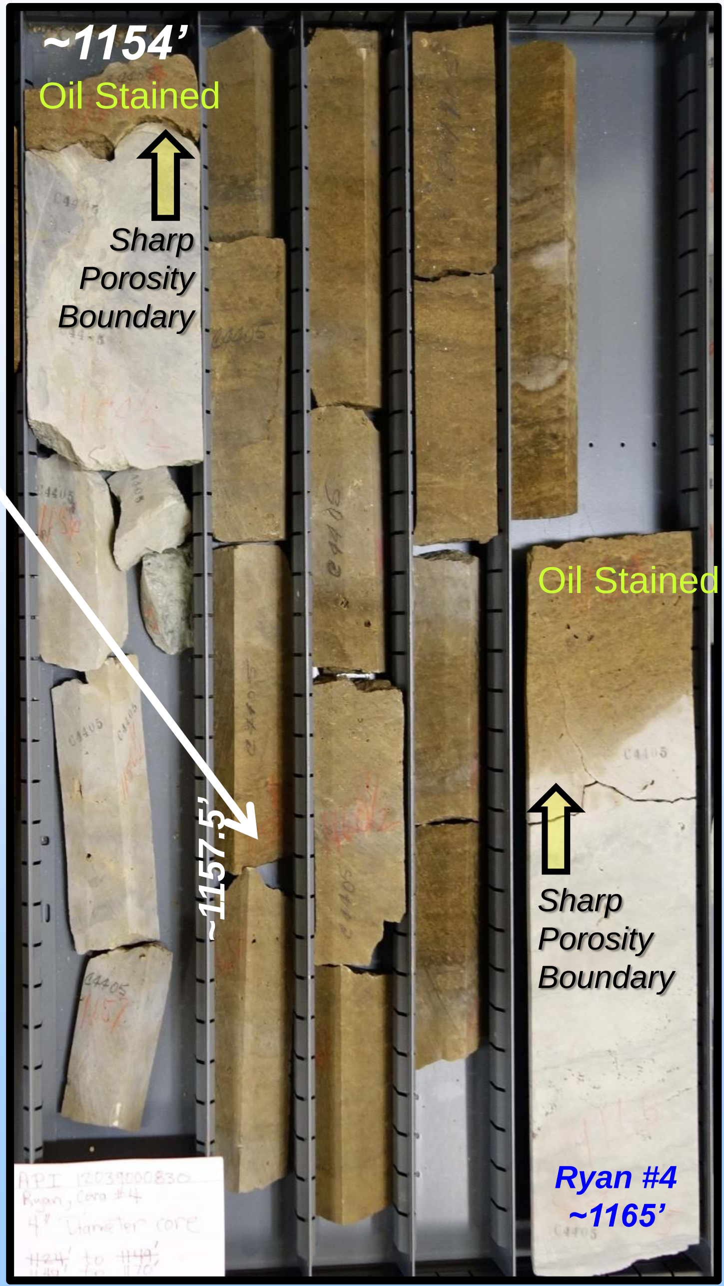


Core T. Kiley #2 Well
Depth = ~1,105'
Wapella East Field

Wapella East Reservoir Heterogeneity

At Core and Thin Section Scales





Wapella East Field Study Conclusions

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

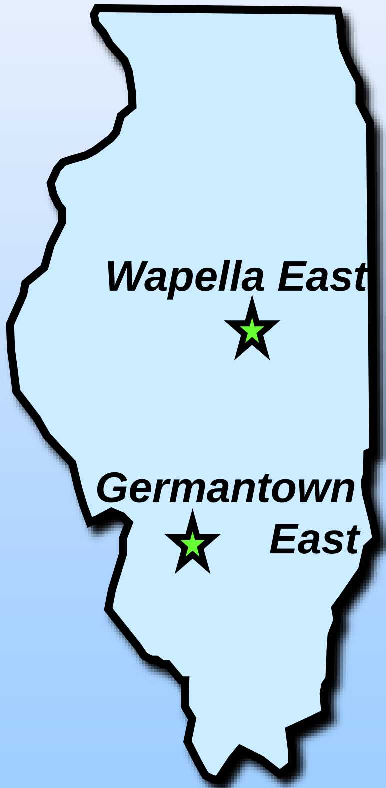
2. The erosional unconformity at the top of the Silurian has removed section and influenced reservoir porosity development and distribution – Amount of erosion unknown

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

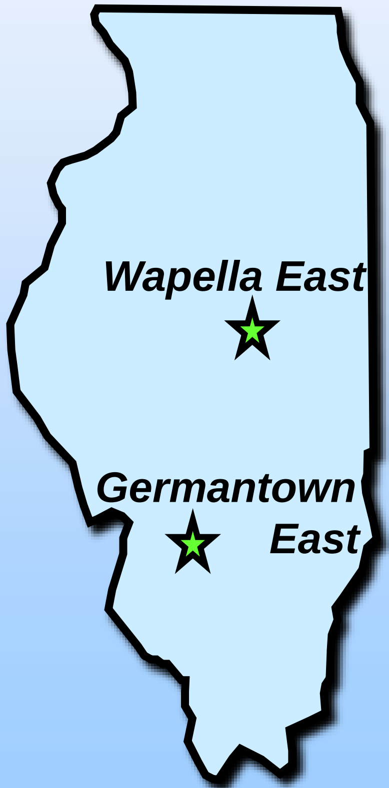
Wapella East Field

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***

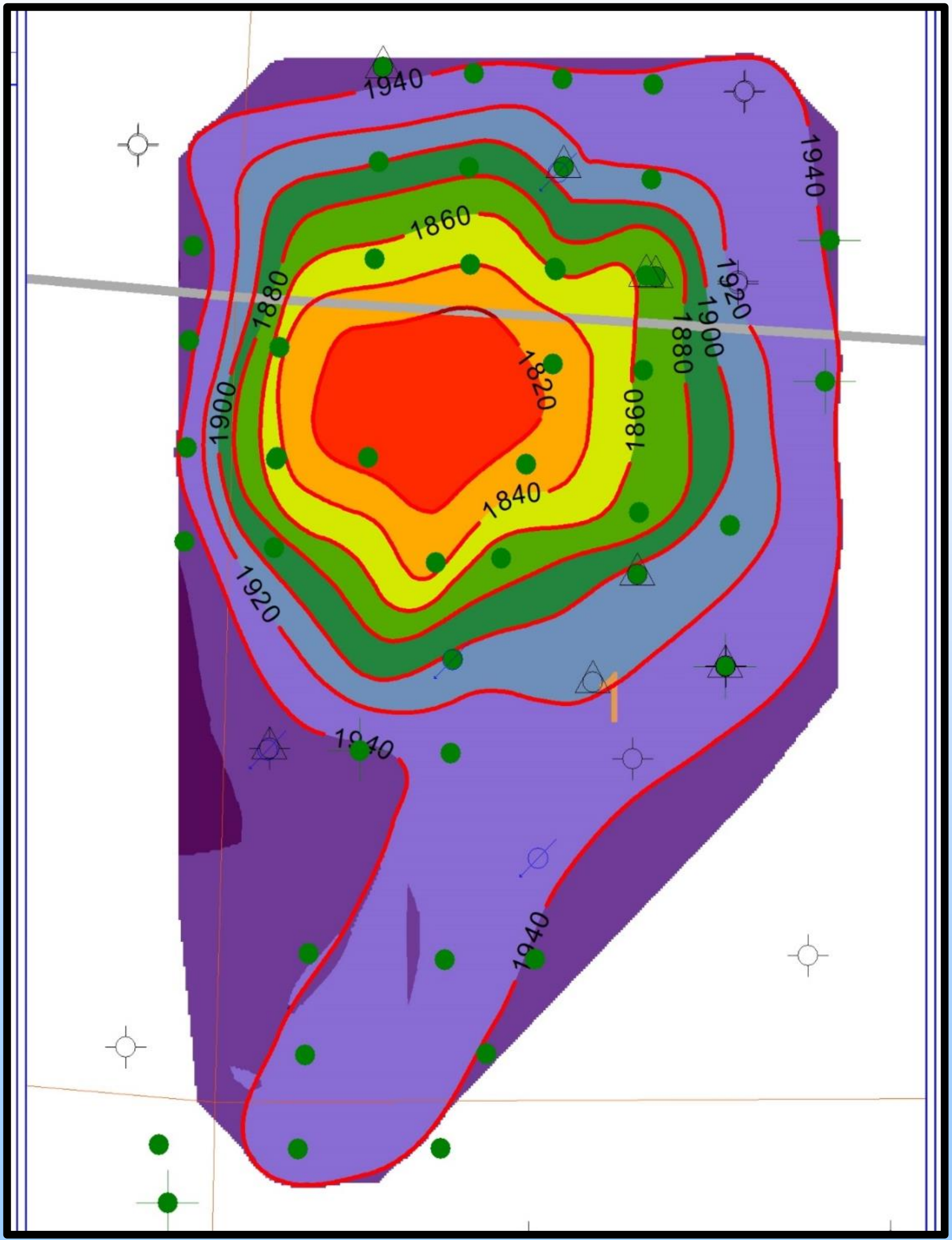
GERMANTOWN EAST FIELD



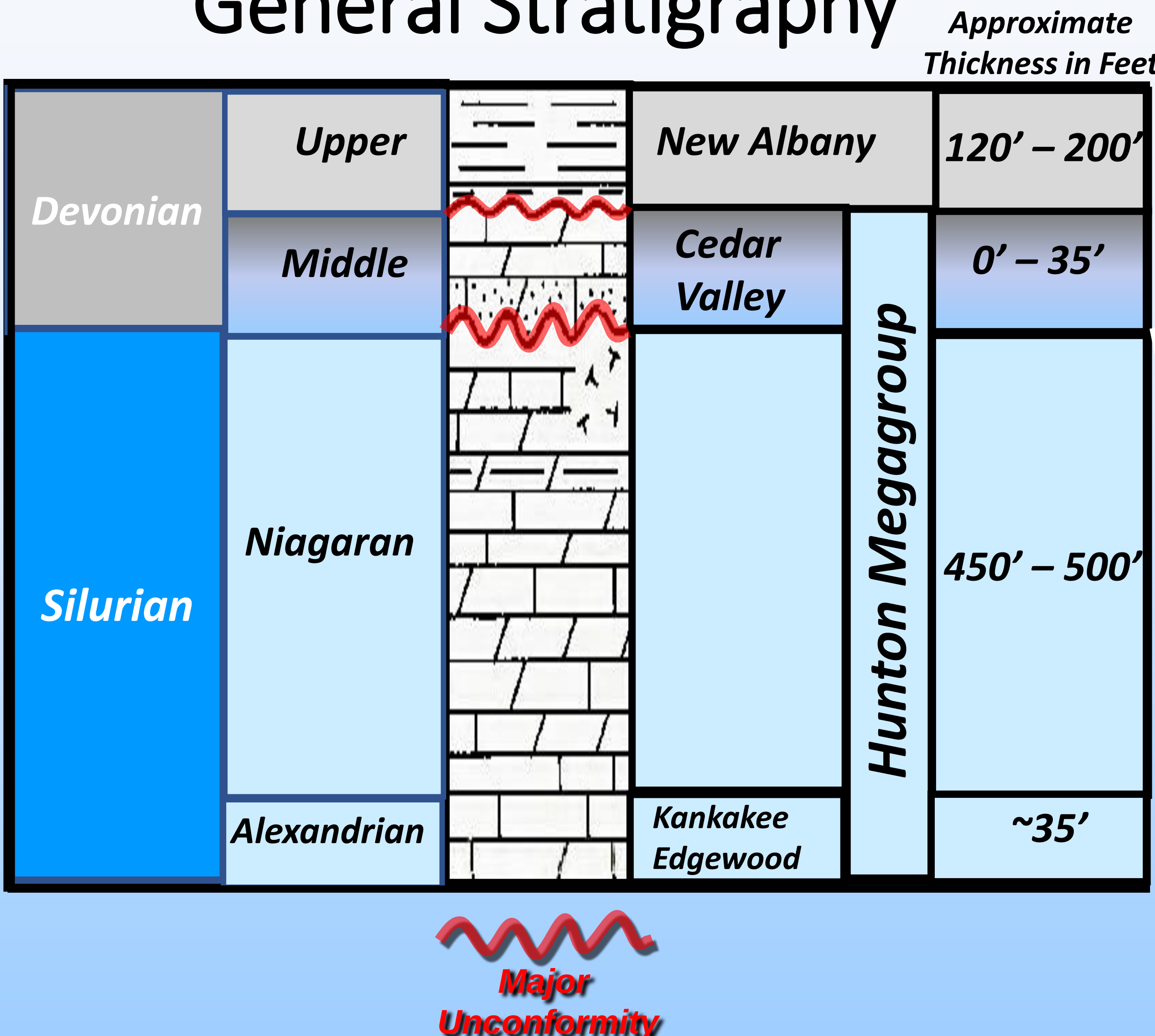
ACRES: 520
CUMULATIVE PRODUCTION (2009): ~2.4MMBO
Depth: 2300' – 2400'
Closure: (Top Hunton): 100-120'
Lowest perf'ed interval
API: 40
Drive: water , with later water flood

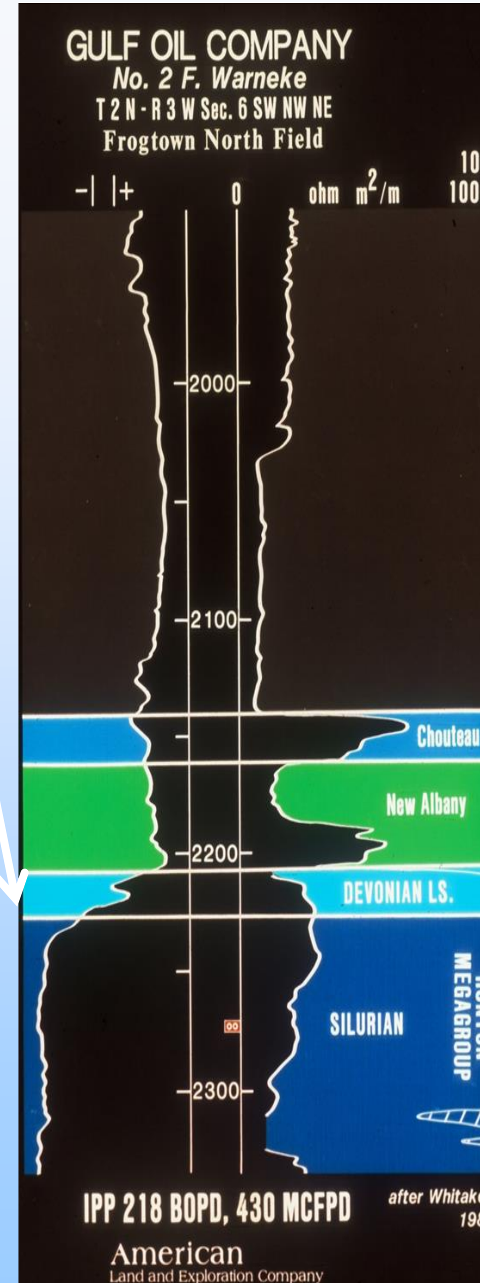
GERMANTOWN EAST
TOP HUNTON STRUCTURE MAP
C.I. = 20’

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

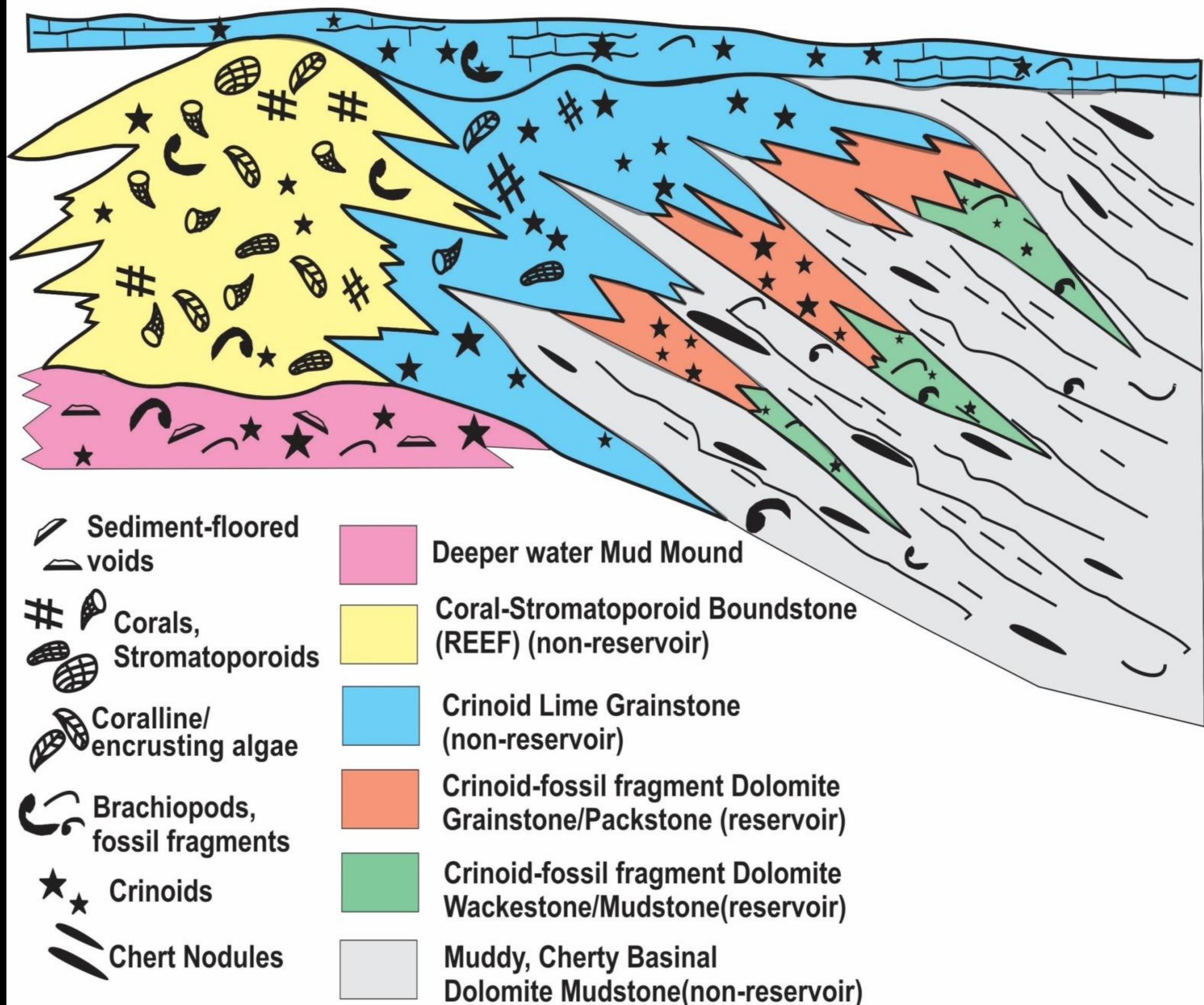


General Stratigraphy





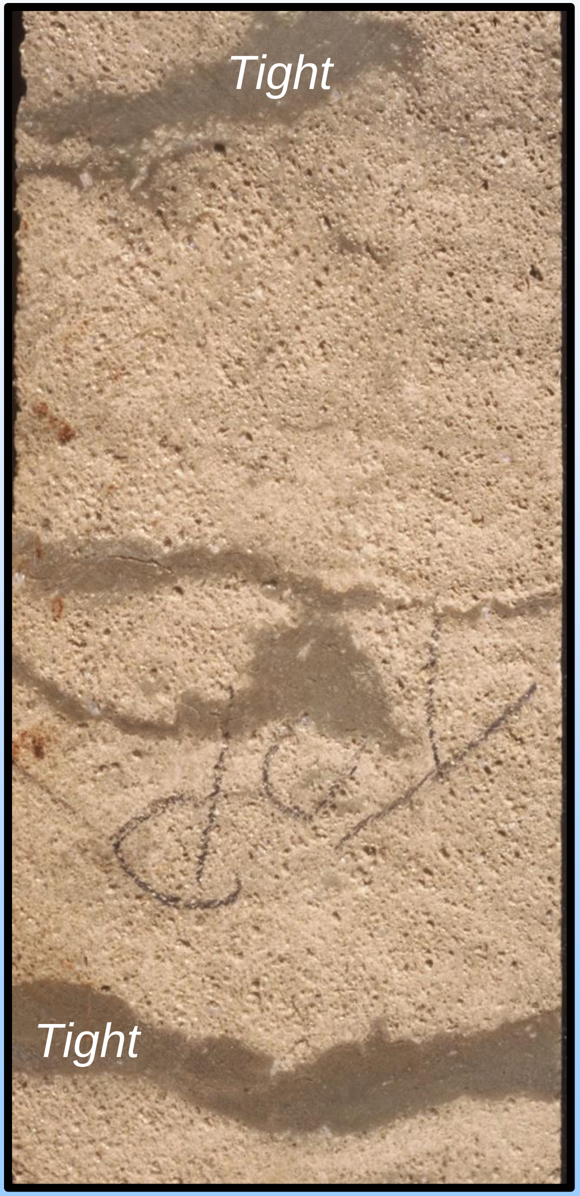
GERMANTOWN EAST REEF-RESERVOIR MODEL

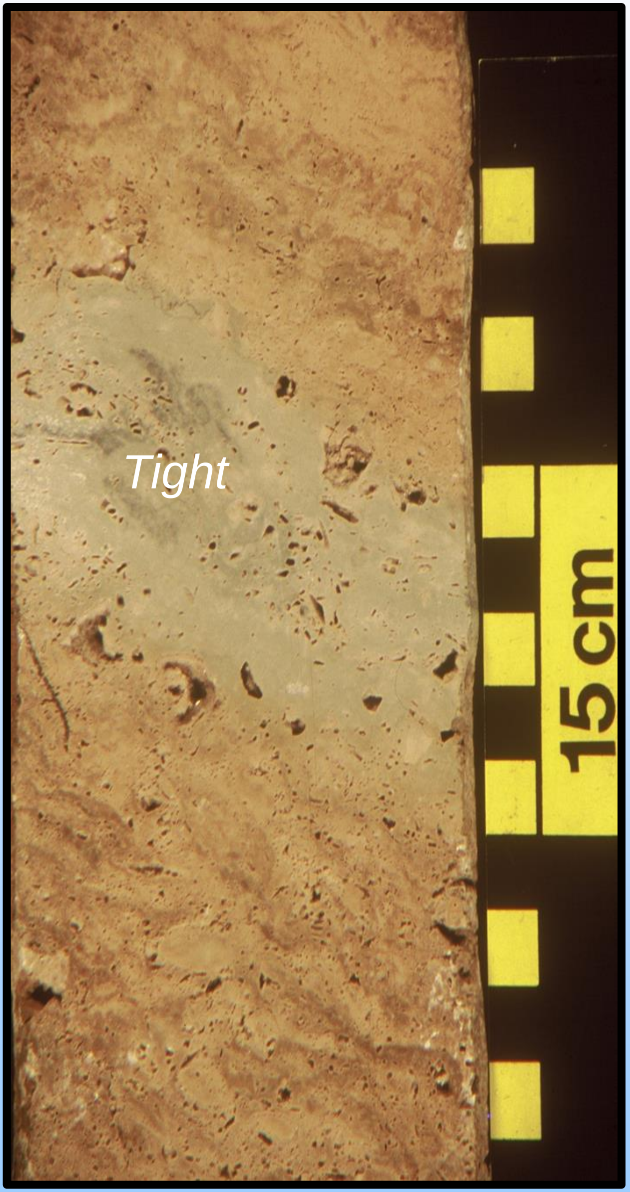


Crinoid Dolomite Packstone Reservoir Facies

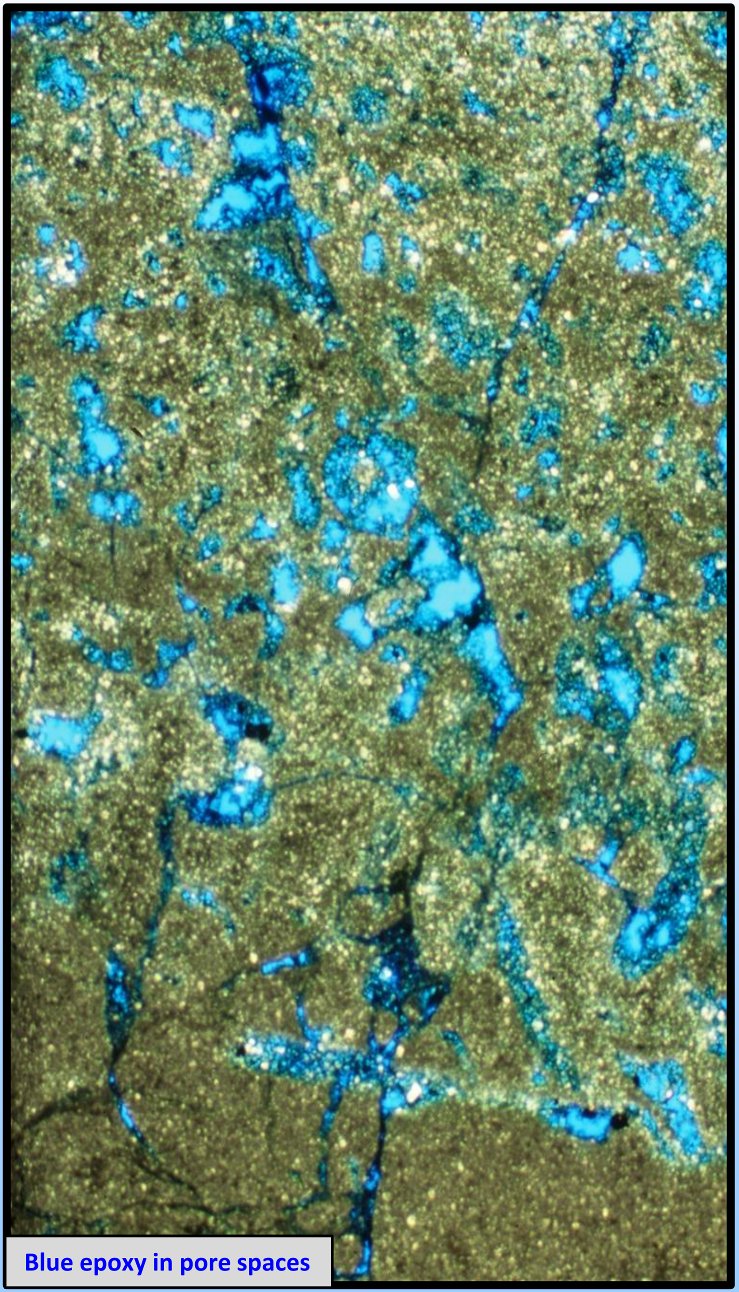
Germantown East Reservoir

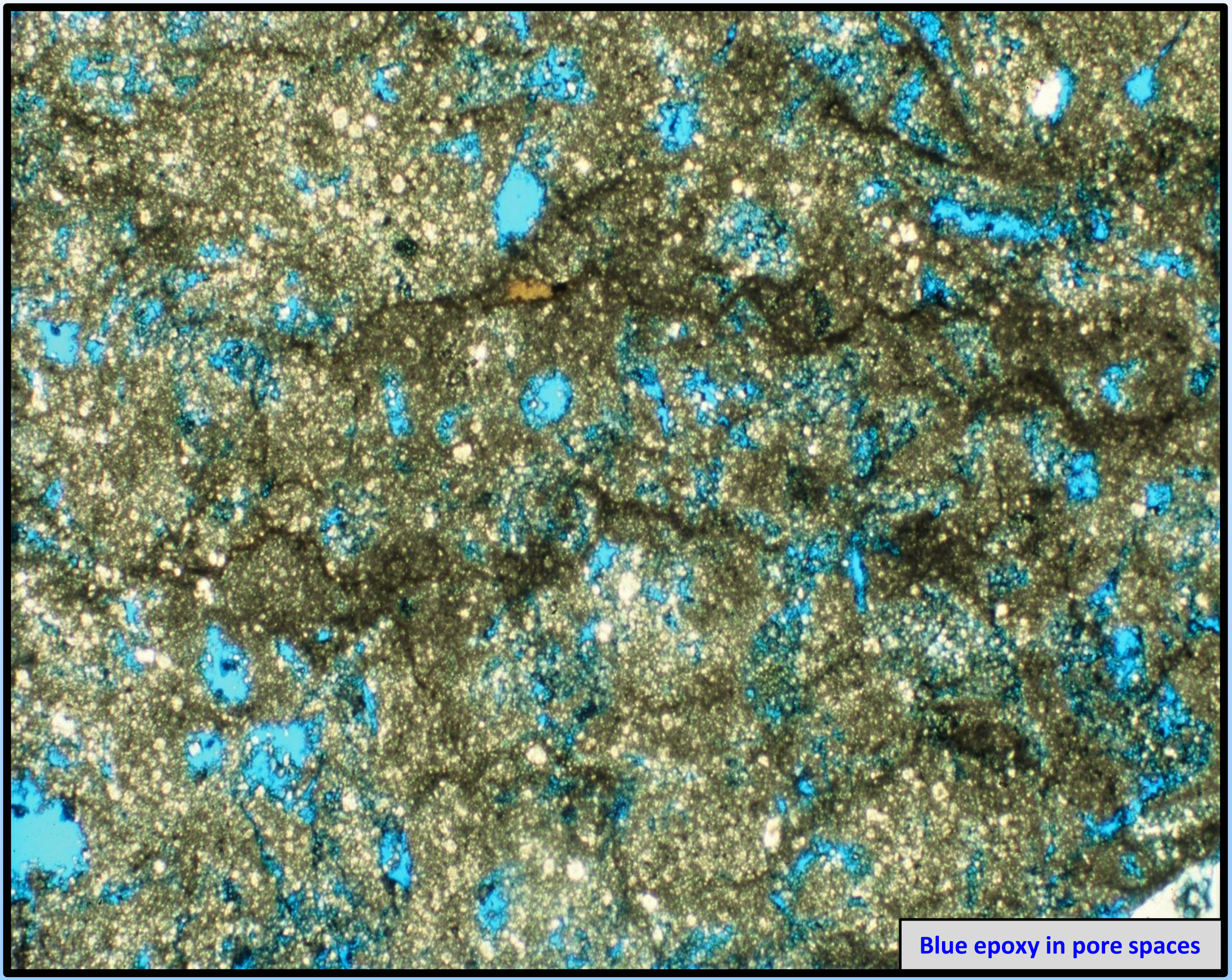
- *Interxline and mesovuggy (moldic) porosity
- * muddy dolomite permea-bility barriers





Dolomite Mudstones with late-diagenetic dissolution & porosity enhancement





Crinoid Dolomitic Packstone Reservoir Facies with Intercrystalline and Moldic Porosity
Germantown East Field

RESERVOIR FACIES AVERAGE PHI/K and SWii's

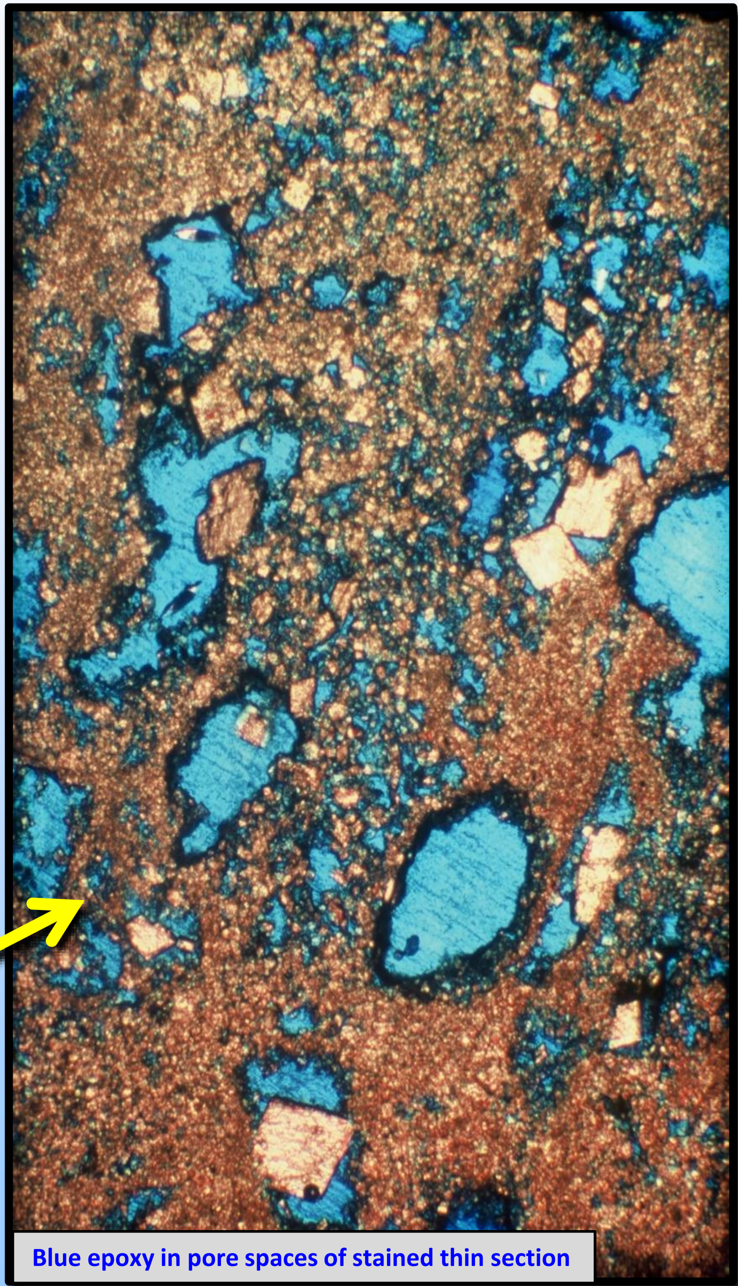
N = 30

Dolomite Mudstone/Wackestone Facies

POROSITY	PERMEABILITY	Swii
19%	10.1md	18.2

Dolomite Packstone/Grainstone Facies

POROSITY	PERMEABILITY	Swii
14%	12.6md	21.4



Blue epoxy in pore spaces of stained thin section

Dolomite Mudstone with abundant Intercrystalline Porosity

RESERVOIR FACIES
AVERAGE
PHI/K and SWii's

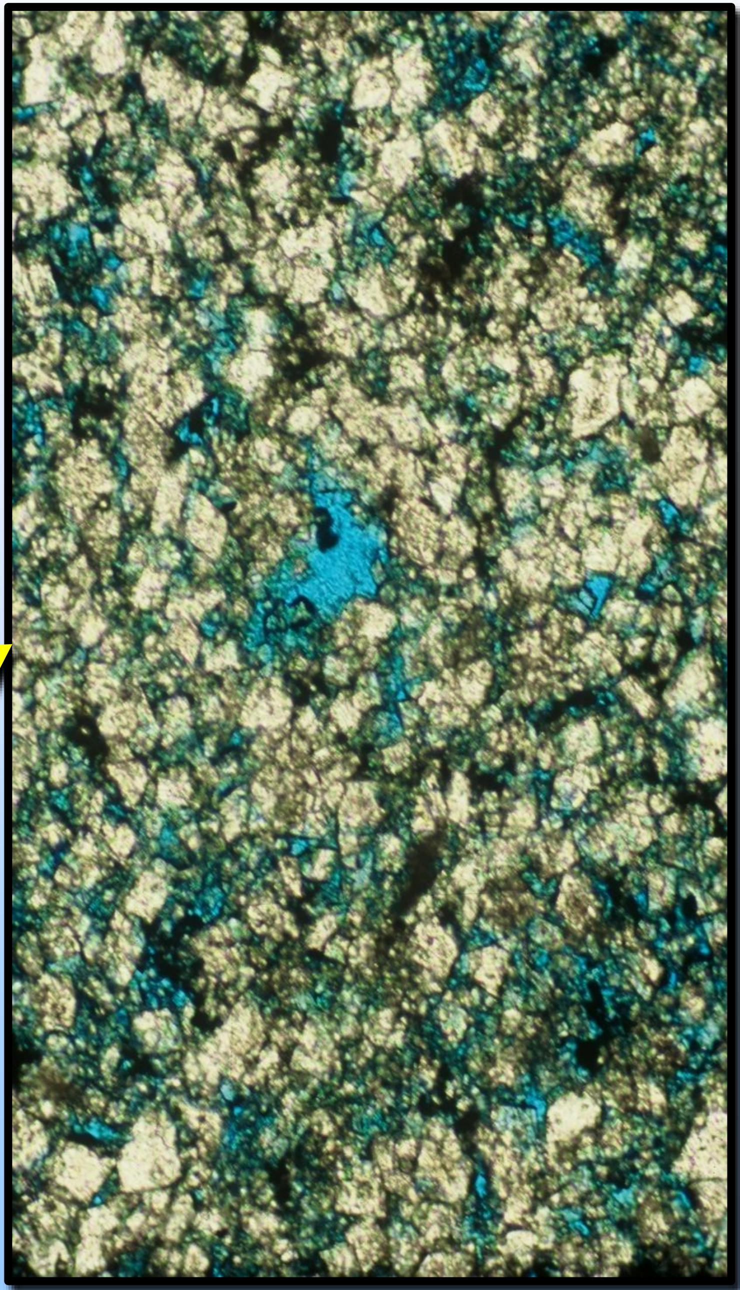
N = 30

Dolomite Mudstone/Wackestone Facies

POROSITY	PERMEABILITY	Swii
19%	10.1md	18.2

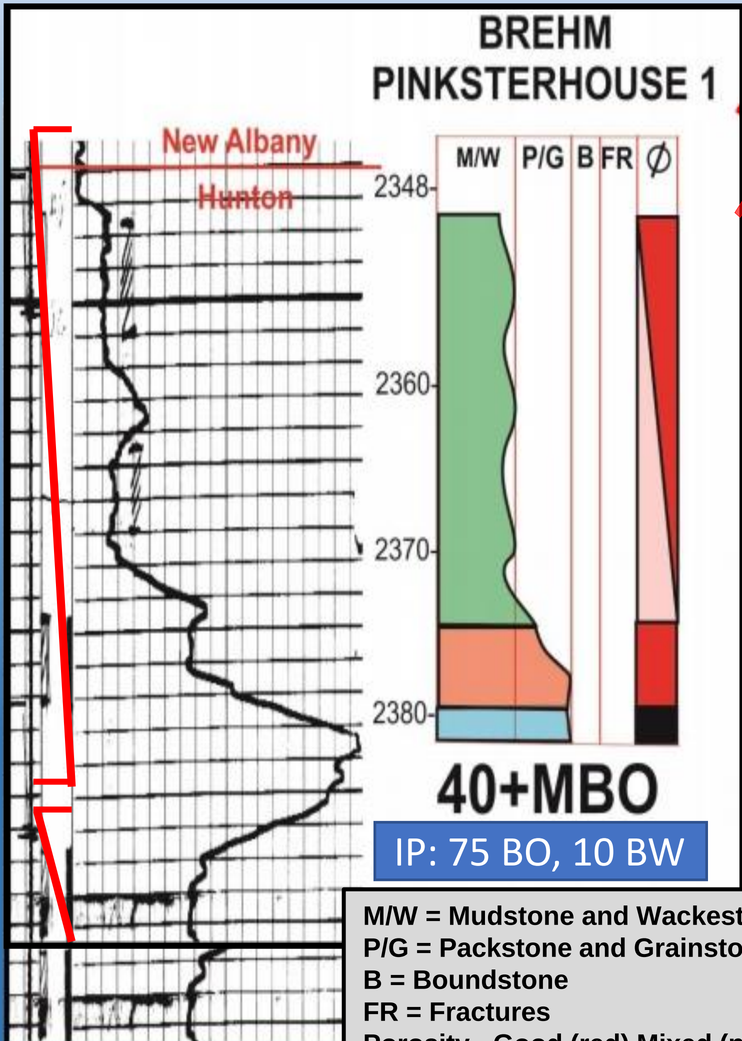
Dolomite Packstone/Grainstone Facies

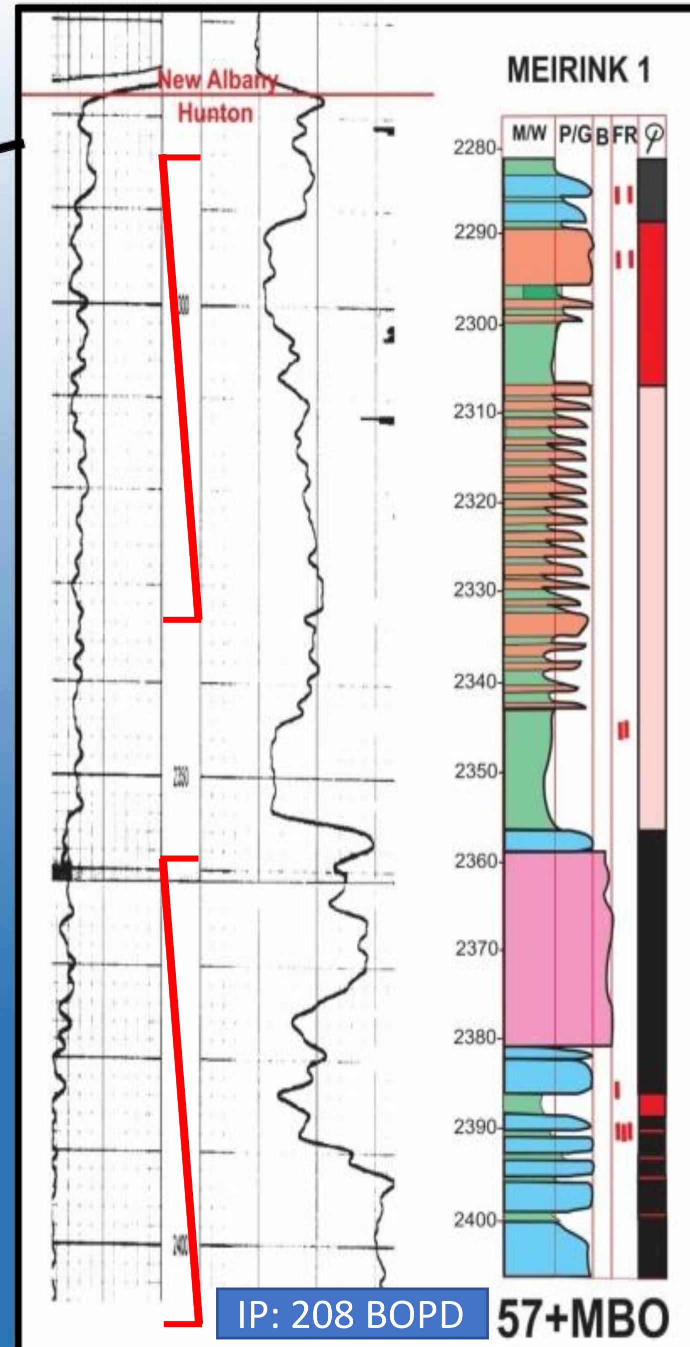
POROSITY	PERMEABILITY	Swii
14%	12.6md	21.4



ROCK/RESERVOIR VARIABILITY

Germantown East Reservoir





Deeper water Mud Mound

Coral-Stromatoporoid Boundstone (REEF) (non-reservoir)

Crinoid Lime Grainstone (non-reservoir)

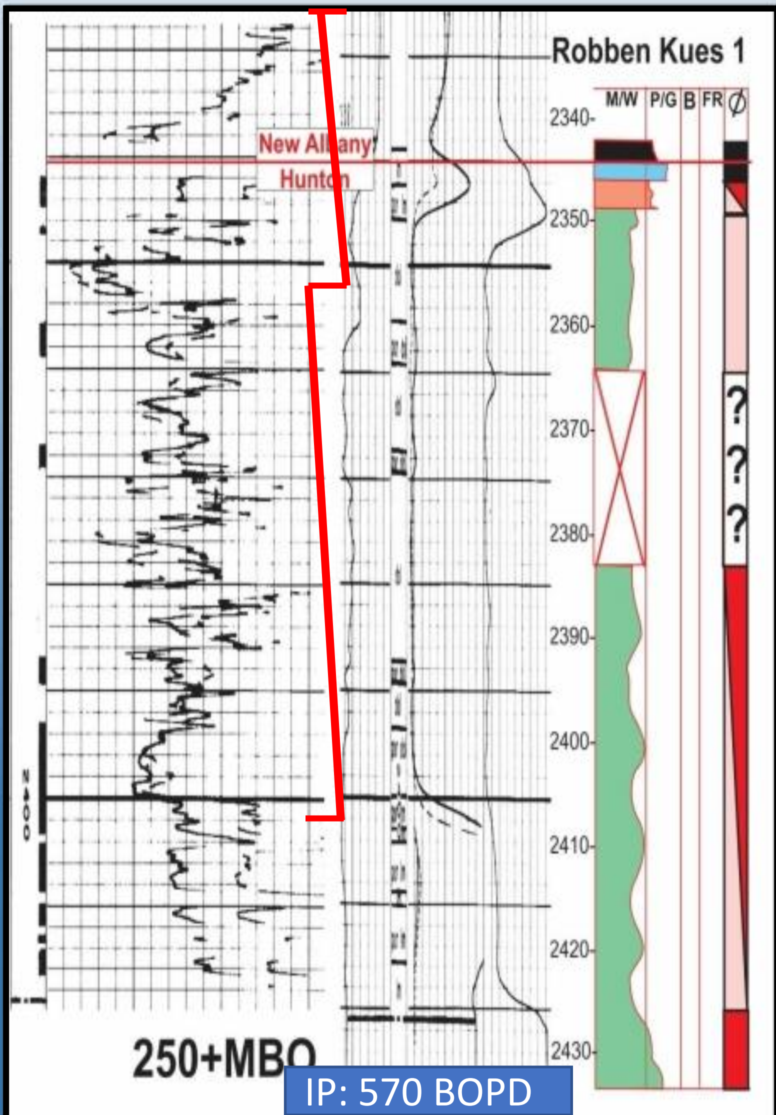
Crinoid-fossil fragment Dol. Grainstone/Packstone (reservoir)

Crinoid-fossil fragment Dol. Wackestone/Mudstone (reservoir)

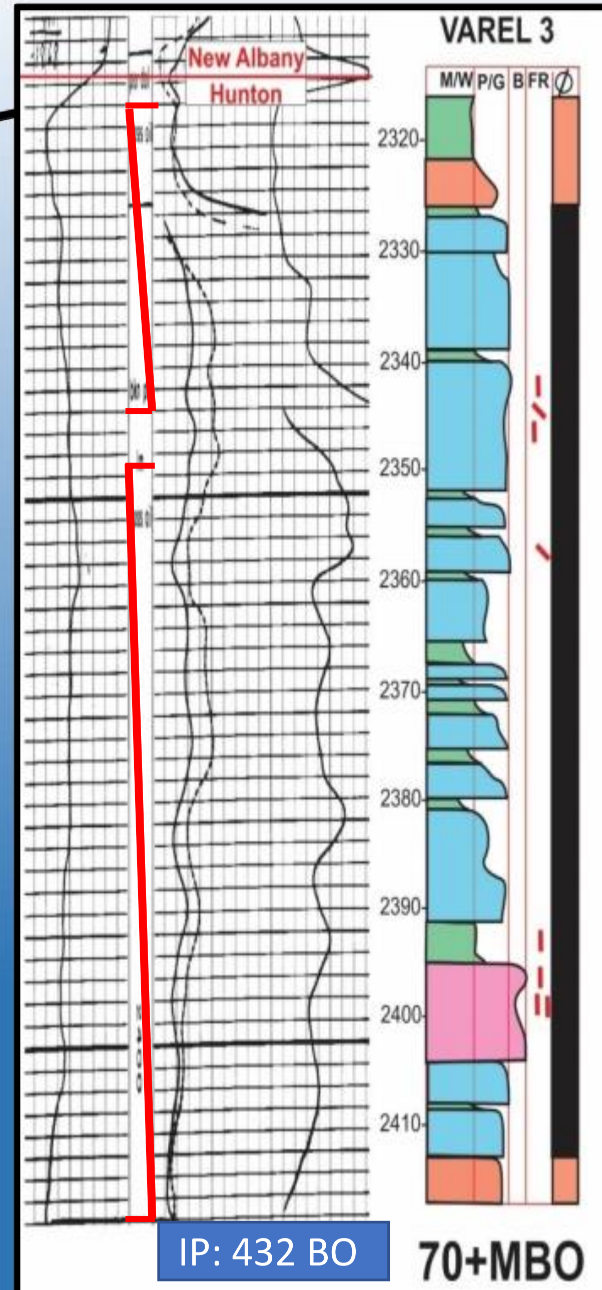
Muddy, Cherty Basinal Dol Mudstone (non-reservoir)

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

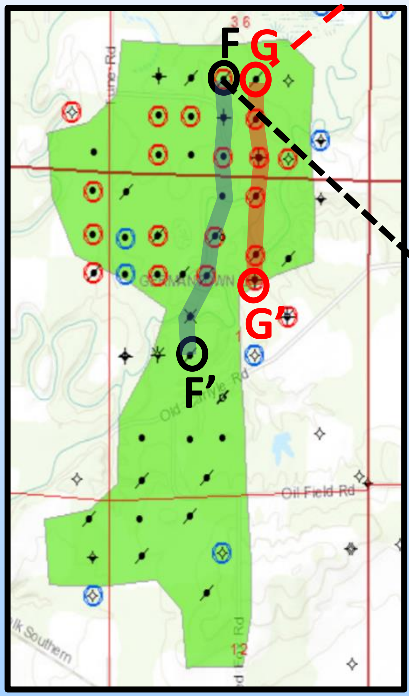
ROCK/RESERVOIR VARIABILITY
Germantown East Field

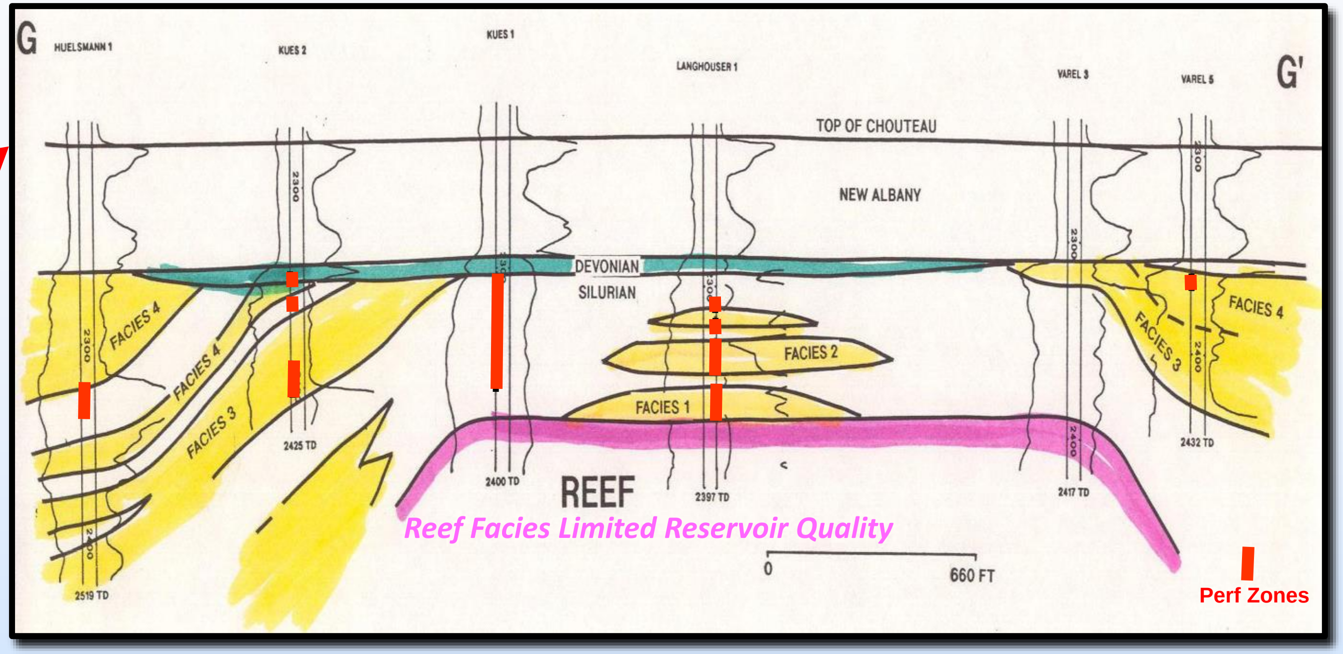


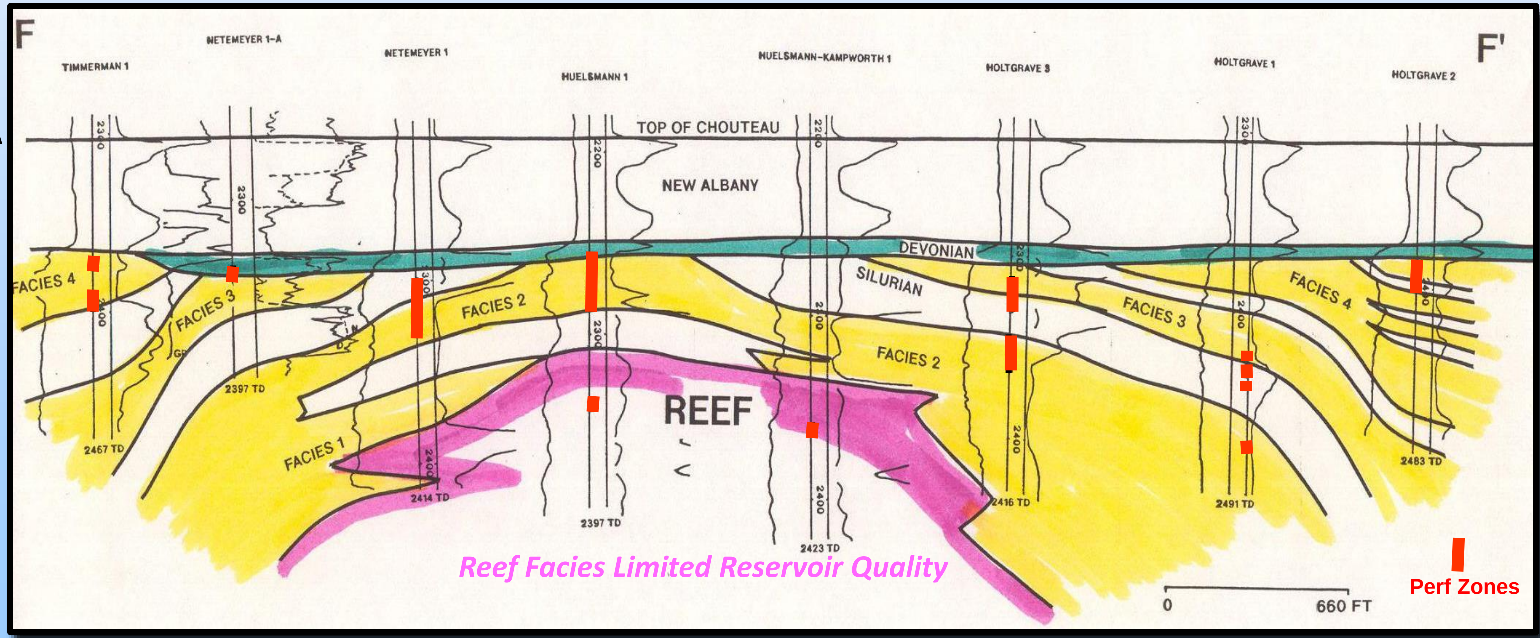
- Deeper water Mud Mound
- Coral-Stromatoporoid Boundstone (REEF) (non-reservoir)
- Crinoid Lime Grainstone (non-reservoir)
- Crinoid-fossil fragment Dol. Grainstone/Packstone (reservoir)
- Crinoid-fossil fragment Dol. Wackestone/Mudstone (reservoir)
- Muddy, Cherty Basinal Dol Mudstone (non-reservoir)



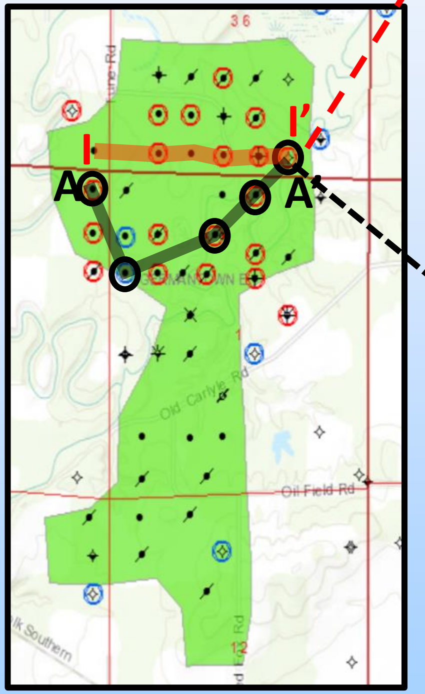
North to South Facies Cross-sections of Germantown East Reservoir

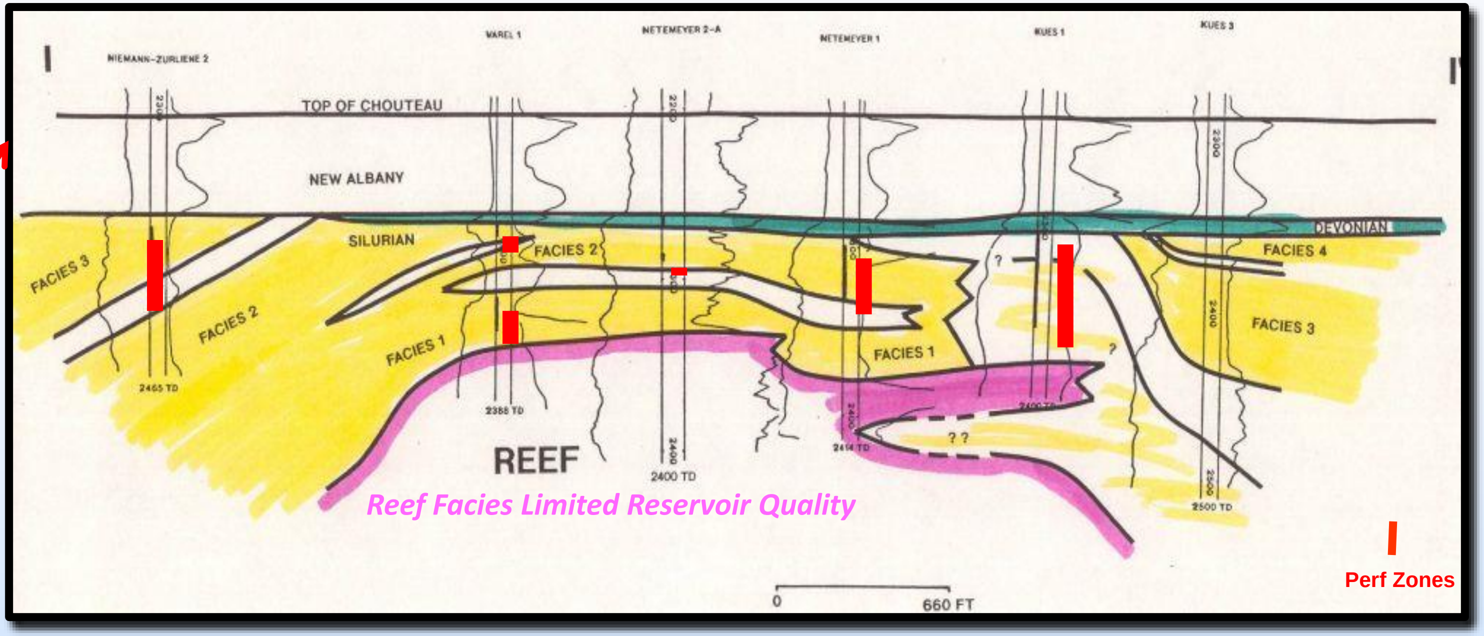


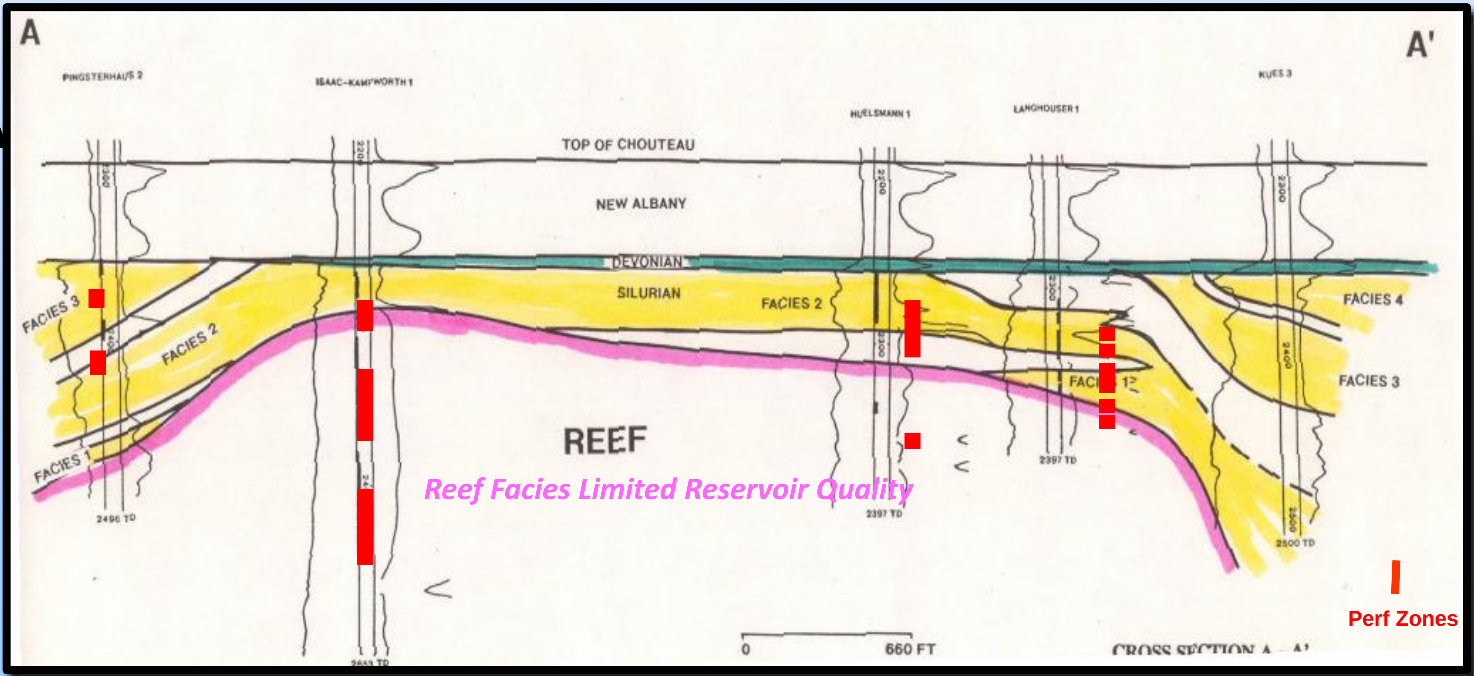




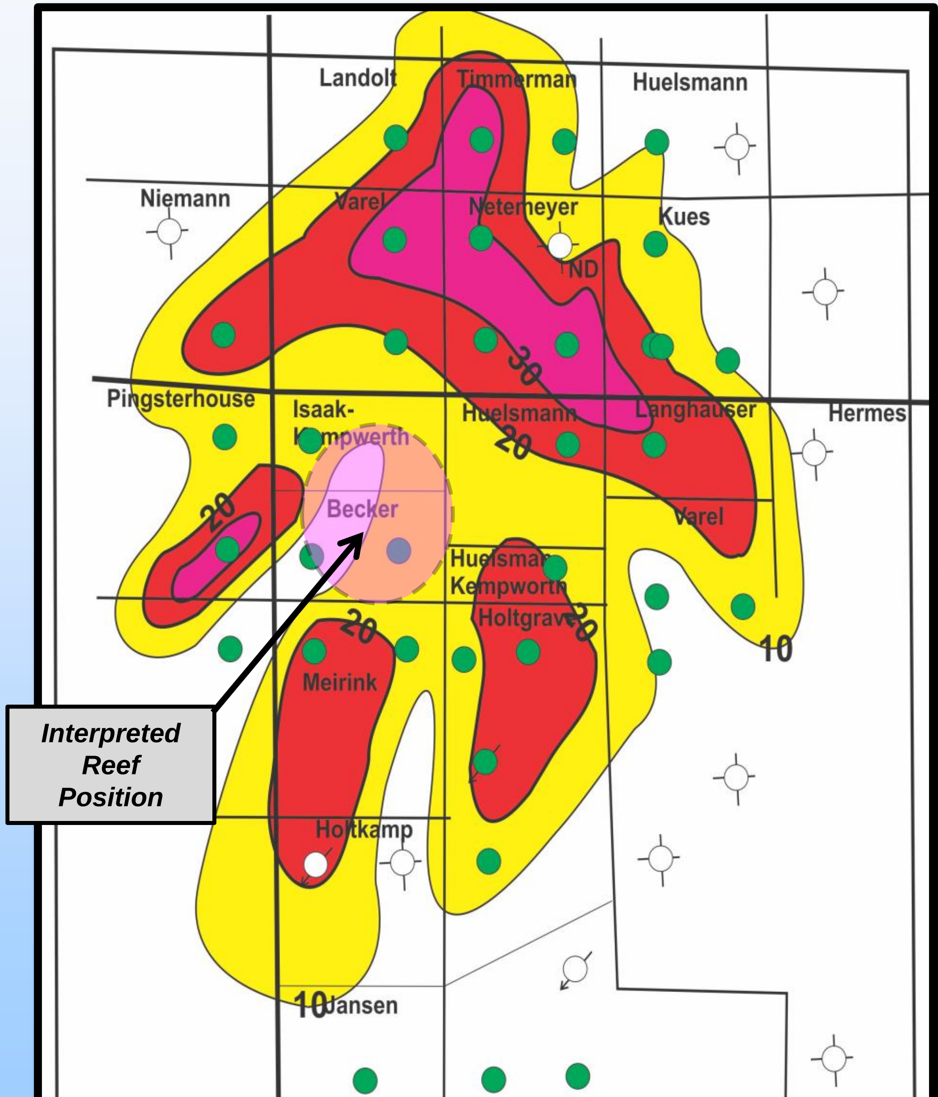
West to East Facies Cross-sections of Germantown East Reservoir





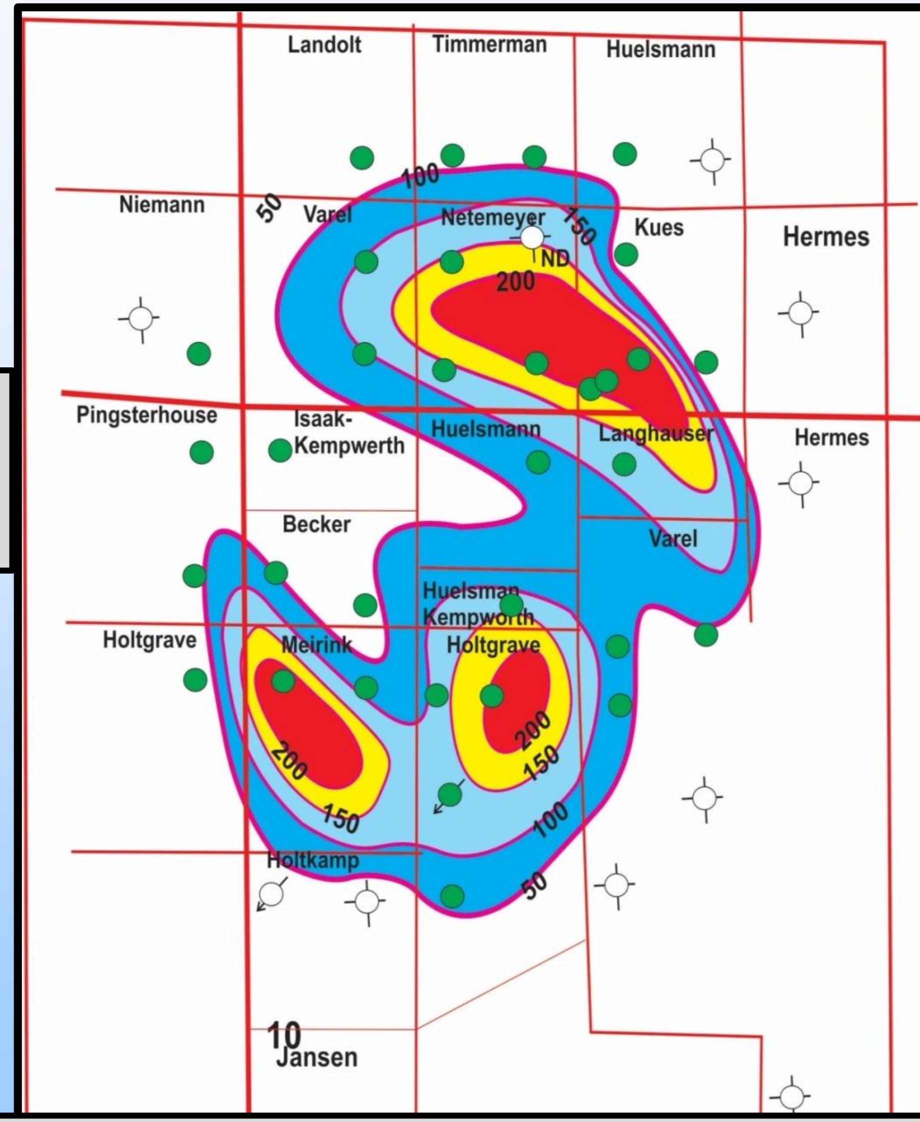


Reservoir Heterogeneity of Germantown East Reservoir Reflected in Net Pay and Cumulative Production Maps



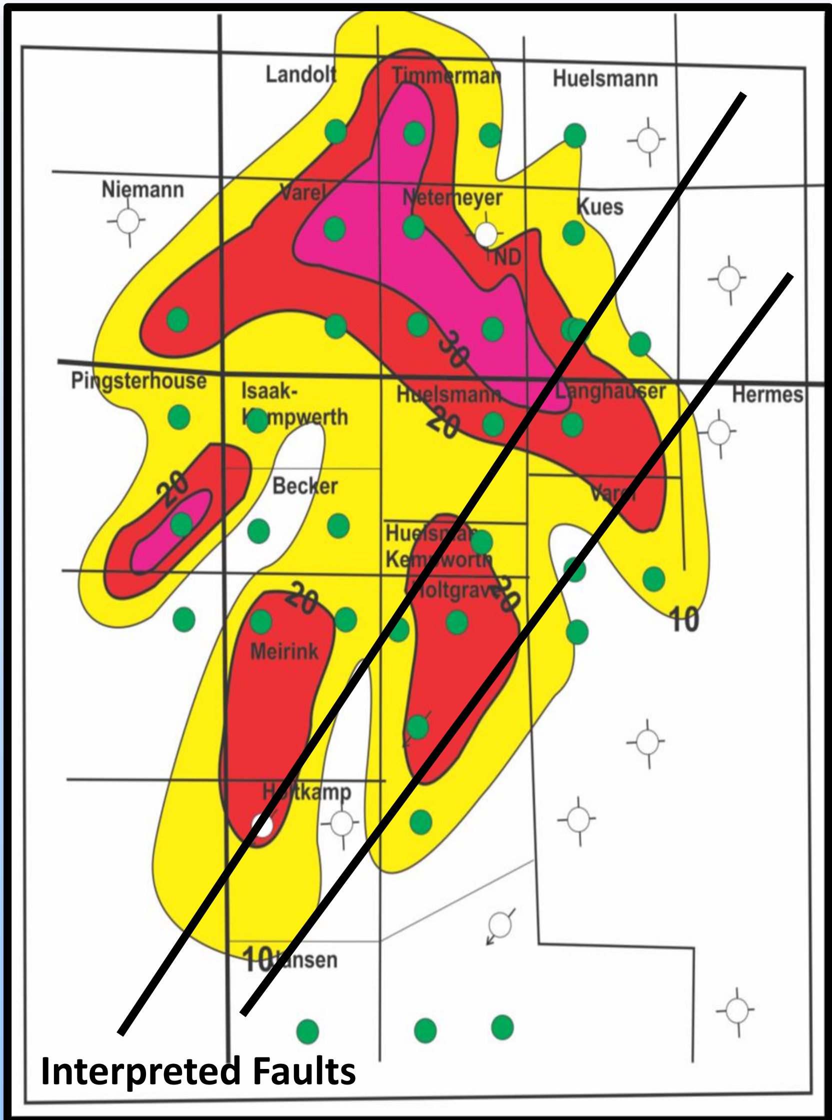
Total Net Pay (All Non-Reef Facies (C.I. = 10')

Flanking Facies most Productive



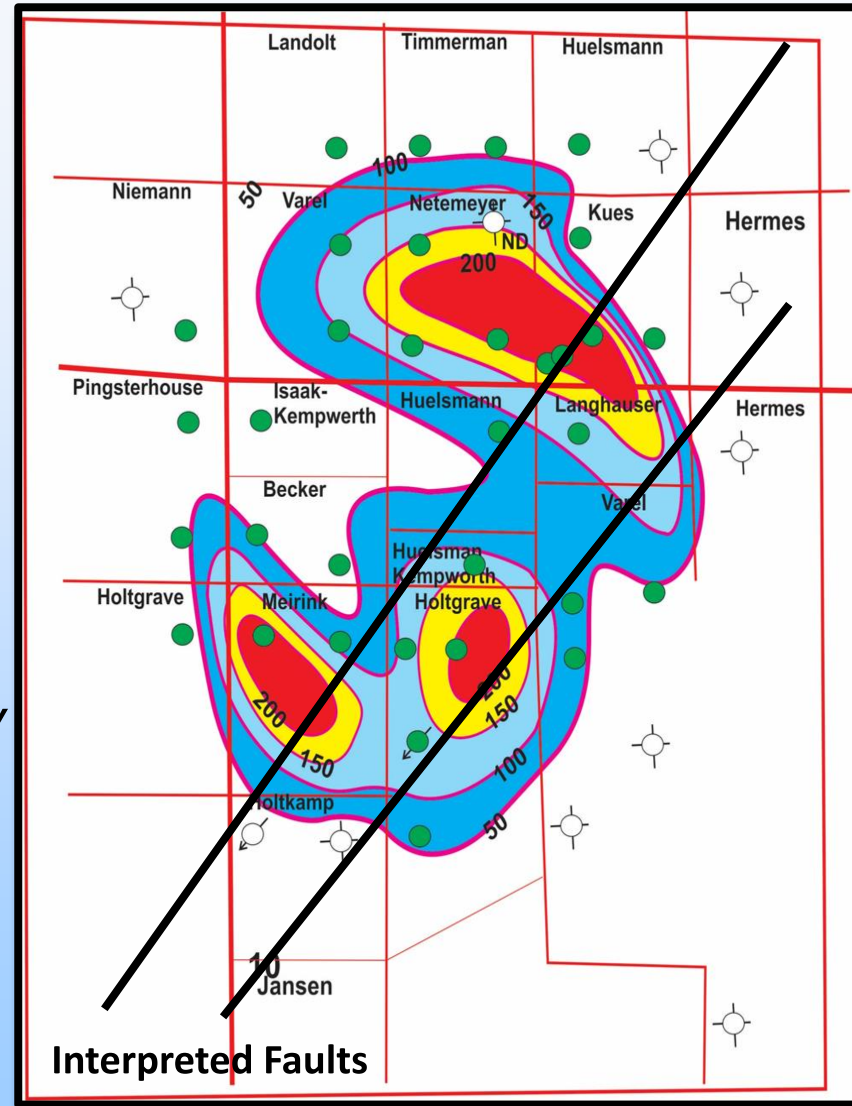
CUMULATIVE PRODUCTION (C.I. = 50 MBO)

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

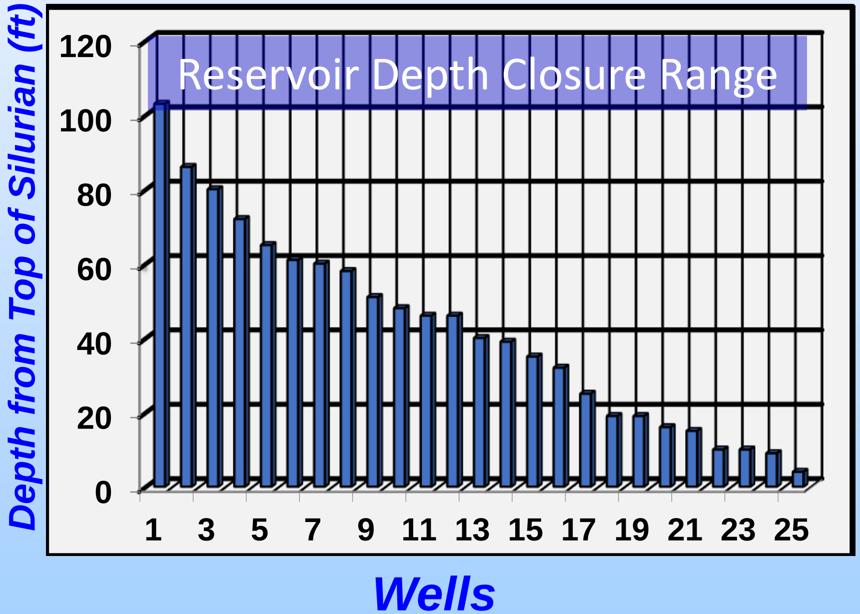
4. Fracturing plays a significant role in deliverability and water-flood design

5. An improved reservoir model was developed for the field

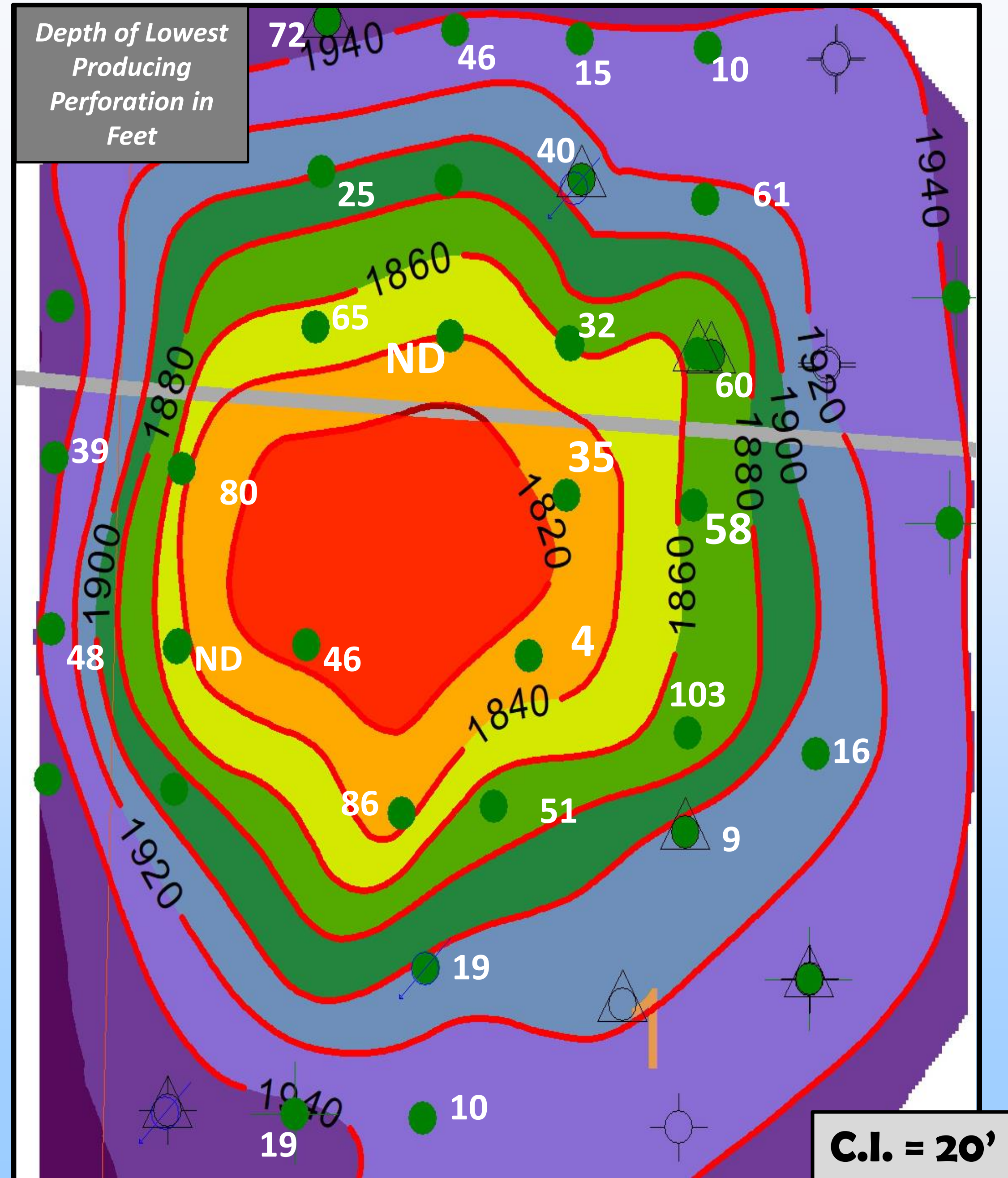
GERMANTOWN EAST

TOP HUNTON STRUCTURE MAP

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



Deeper Potential Likely!



Redevelopment Potential?

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

Only the Recompletions were Implemented during Reservoir Redevelopment!

New Locations

New Wells (9)

Huelsman lease	330 NL, 330 WL, NE, NW, Sec. 1.
Huelsman lease	990 NL, 330 WL, NE, NW, Sec. 1.
Huelsman lease	990 NL, 990 WL, NE, NW, Sec. 1.
Varel lease	330 SL, 330 WL, SW, SW, Sec. 36.
Varel lease	990 SL, 330 WL, SW, SW, Sec. 36.
Varel lease	330 SL, 330 WL, NW, NE, Sec. 1.
Langhauser lease	330 NL, 330 EL, NW, NE, Sec. 1.
Meirink lease	330 SL, 330 EL, SW, NW, Sec. 1.
Isaak-Kampwerth	330 NL, 990 WL, NW, NW, Sec. 1.

Deepen Wells (7)

Deepenings	Target
Netemeyer #2-A	Deeper reef flank
Pingsterhaus #1	Deeper reef flank
Pingsterhaus #2	Deeper reef flank
Kampwerth-Varel #1	Deeper reef flank
Meirink #1	Deeper reef flank
Varel #1 (sec. 36)	Deeper reef flank
Varel #2 (sec. 36)	Deeper reef flank

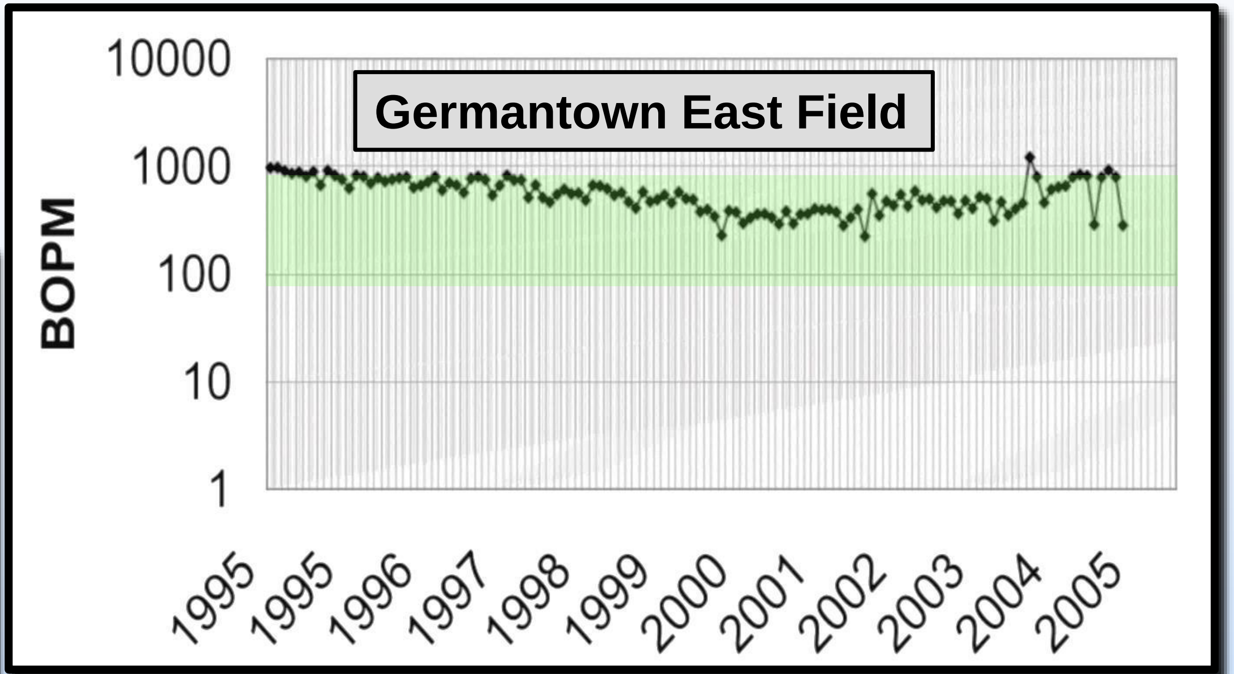
Recompletions (6)

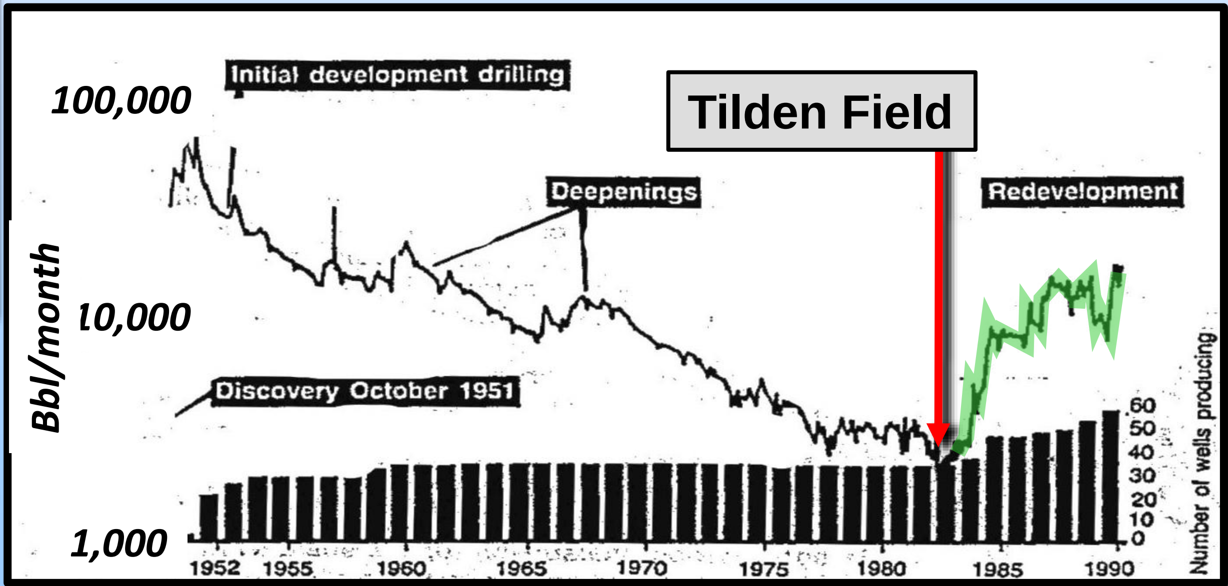
Recompletions	
Holtgrave #4	Facies 1, 2334-45 Facies 2, 2305-12
Becker #1	Facies 2, 2350-70
Becker #2	Facies 1, 2300-2308
Kampwerth-Varel #1	Reef core, 2424-32
Varel #2 (Sec. 36)	Facies 2, 2372-80
Netemeyer #2	Facies 3, 2368-74

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

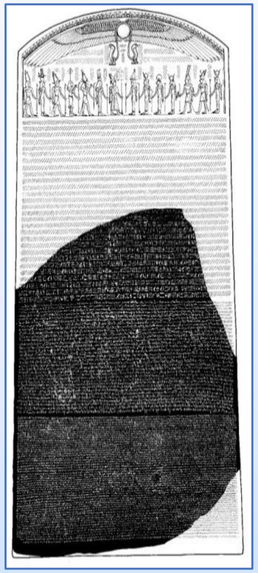
- Reservoir Quality is Highly Variable in Both Reservoir (Depositional and Diagenetic Controls)

- 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


Modified from: www.britishmuseum.org

Rosetta Stone

- 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"

See: Grammer et. al., (2017) and Prezbindowski et. al., (2017)

Pipe Creek Junior Quarry –

Acknowledgements

The authors are grateful to:

- ***Jim Truettner (owner of Western Interior, Inc., who operated Germantown East Field from 1994-2014) for release of all data, including the 1994 Swager and Assoc. Engineering Report on Germantown East Field.***

- ***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.***