Spatial Variability of Reservoir Properties in a Stratigraphically Complex Geological Sequestration Target: The Devonian Sylvania Sandstone, Michigan Basin, USA*

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Search and Discovery Article #80101 (2010)
Posted September 24, 2010

*Adapted from oral presentation at AAPG Rocky Mountain Section 58th Annual Rocky Mountain Rendezvous, Durango, Colorado, June 13-16, 2010

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Abstract

The Devonian Bois Blanc and Sylvania Sandstone formations are prospective, saline reservoir geological sequestration (GS) targets in the central Michigan Basin, USA. Reservoir quality in the Sylvania is well documented by extensive brine mining since the late 19th century. The Bois Blanc and Sylvania are overlain by confining layers of the Devonian Amherstburg and Lucas formations, and this GS system is present throughout a region with high CO_2 emissions (>~20 Mmt/year), making it an important target for large scale GS feasibility investigations. Previous estimates of regional geological sequestration capacity (RGSC) have substantial uncertainty due to stratigraphic/lithologic complexity in these units. In order to reduce RGSC uncertainty, a detailed stratigraphic and petrophysical study of 5 cored wells, 50 conventional core analyses, and 115 modern well logs was undertaken. These studies indicate that reservoir heterogeneity is primarily due to lateral and vertical lithofacies variations amongst siliceous, shallow-shelf carbonates of the Bois Blanc lithofacies and interfingering, reworked, aeolian quartzose littoral sandstone of the Sylvania lithofacies. Core to wireline log calibration using gamma ray, density, neutron porosity, and photoelectric effect logs provides confident discrimination amongst tripolitic chert, sandstone, and carbonate lithofacies.

Isolith maps and cross sections indicate that Sylvania Sandstone lithofacies dominate in southeast Lower Michigan and are transitional to mixed sandstone, tripolitic chert, and carbonates towards the northwest and are replaced completely by tripolitic chert and carbonates lithofacies in northwestern Lower Michigan. Core analysis indicates that sandstone lithofacies have moderate to good porosity (Ø) and high permeability (K) and are excellent injection targets. Tripolitic chert lithofacies have high Ø and low to moderate K and questionable injection potential. All other lithofacies have low Ø and K. Substantial regional variation in the thickness of sandstone lithofacies may further limit sites suitable for CO_2 injection. Detailed reservoir characterization studies indicate approximately 730 million metric tons of RGSC in the Sylvania Sandstone in central Lower Michigan. Reservoir characterization studies are focused not only on RGSC but also on the identification of regional reservoir compartments and risks associated with overpressuring during large-scale deployment of regional CO_2 injection wells.

Selected Reference

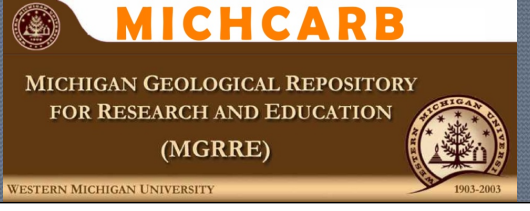
Gardner, W.C., 1974, Middle Devonian stratigraphy and depositional environments in the Michigan Basin *in* Special Papers Michigan Basin Geological Society: v. 1, 46 p.

Spatial Variability of Reservoir Properties in a Stratigraphically Complex Geological Sequestration Target:

The Devonian Sylvania Sandstone, Michigan Basin USA

Farsheed Rock and Dave Barnes

American Association of Petroleum Geologists - Rocky Mountain Section,
June 13-16, 2010, Durango, Colorado



Presenter's Notes:

Acknowledgment: Charlotte Sullivan and Michael Jacobs for the invitation to make this presentation.

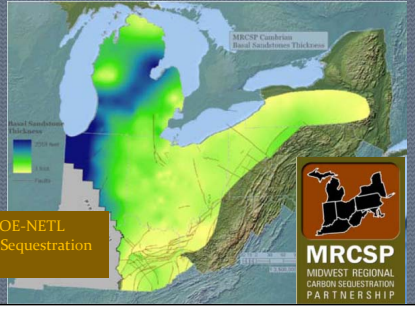
Michigan's Deep GS Injection Zones

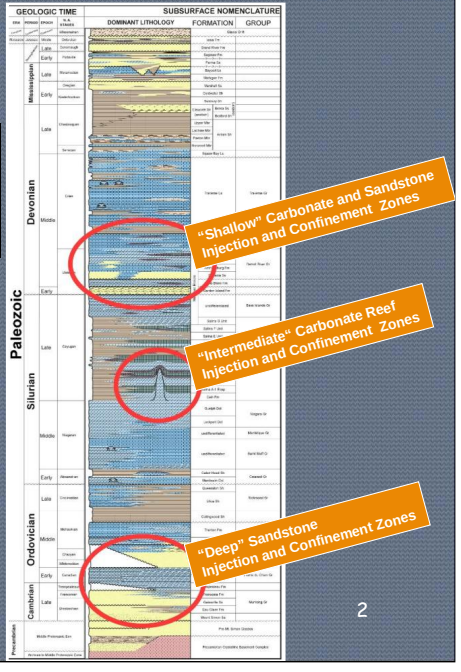
As much as 16,000ft of bedrock sedimentary strata (below glacial drift)

Estimated Deep Saline Formation CO_2 Storage Resource

Deep Saline Formation	Potential CO_2 Storage Resource (million metric tons CO_2)	
	Low Estimate (P15)	High Estimate (P85
Mt. Simon Formation	21,700	
St. Peter Sandstone	8,800	
Medina/Tuscarora Sandstone	7,900	
Rose Run Sandstone	5,700	
Oriskany Sandstone	1,900	
Sylvania Sandstone	1,500	
Wastegate Formation	400	1,800
Basal Conasauga Sandstones	400	1,700
Potsdam Sandstone	1,200	4,500
Rome Trough Sandstones	100	500
TOTAL Deep Saline	49,600	199,100

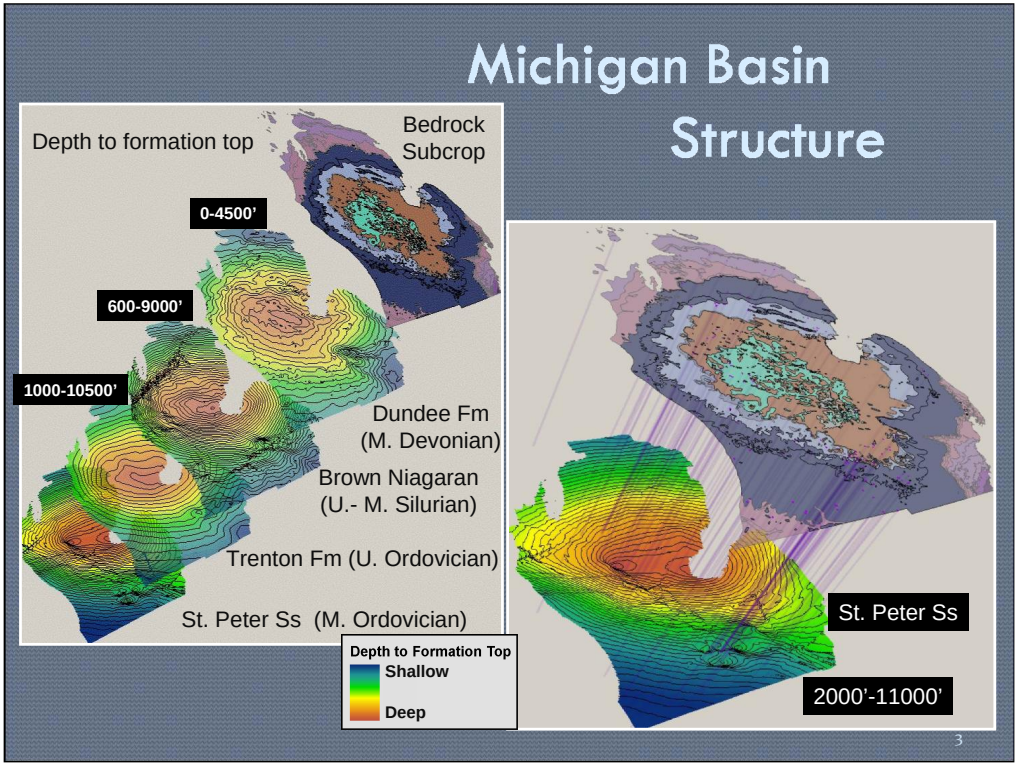
MI Storage Potential ~40Gt
MI Emissions ~96Mt/yr





Presenter's Notes:

Michigan Paleozoic bedrock Stratigraphy and sequestration targets.
MI Annual emissions ~100Mt; Storage Capacity of ~40GT; hundreds of years of storage potential.
Lower Paleozoic main targets with additional Middle Paleozoic targets.



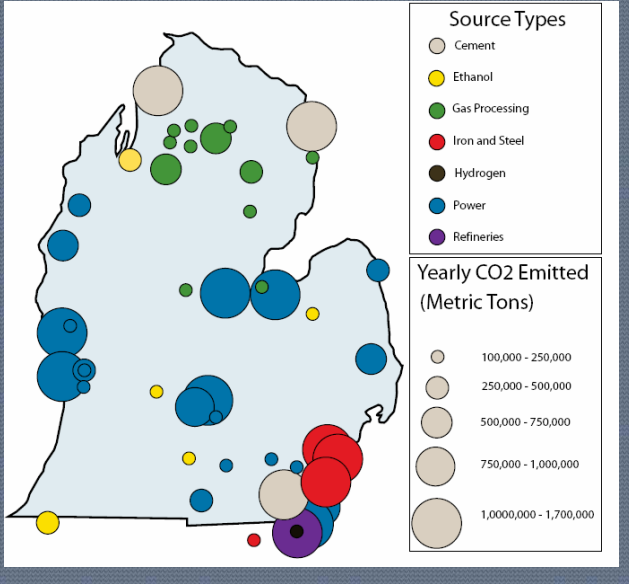
Presenter's Notes:

•Michigan Structure (Paleozoic), basin-centered subsidence pattern, generally.

•Younger units only at sufficient depth for GCS in central basin; older sandstones generally tight due to diagenesis in the central basin and only prospective on the basin margin.

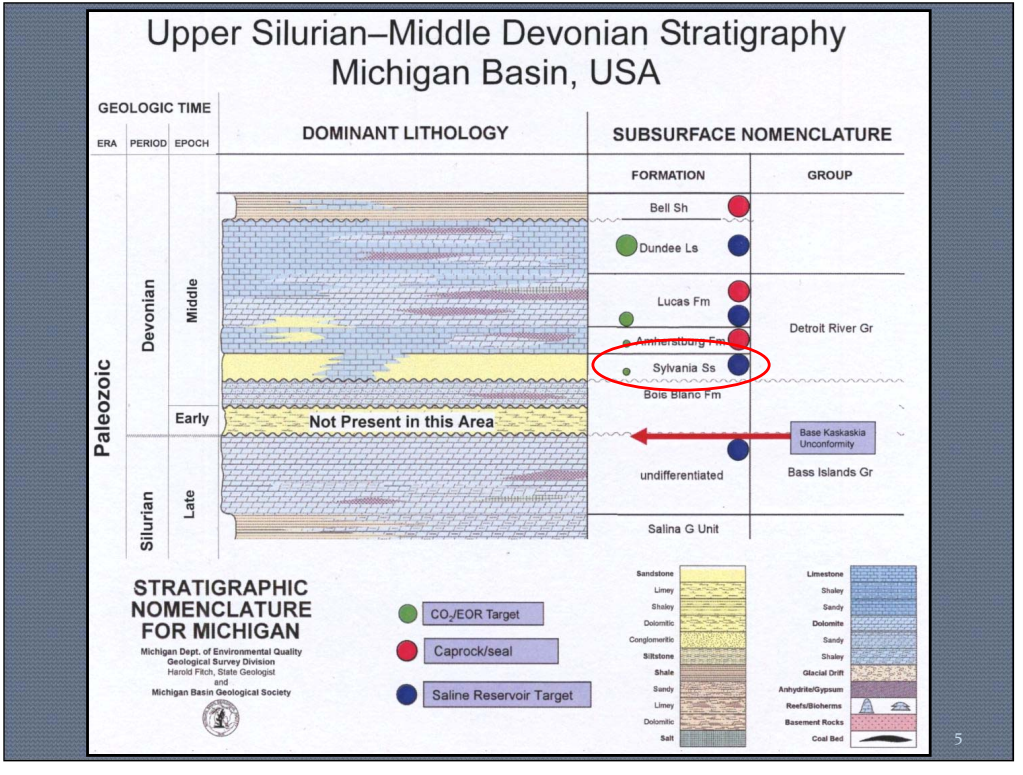
The larger map shows real bore hole penetrations extruded downwards into the St Peter Sandstone formation. These subsurface depth data are the basis for the maps. The deeper the formation the fewer the data points.

CO_2 Sources in Michigan



From:
DOE-NETL
Carbon Sequestration Atlas II

Presenter's Notes:
Michigan sources large (>100Kt/yr); CO_2 point source (~43).
Need to match sources and sinks, especially in the central basin.



Presenter's Notes:

•Middle Paleozoic: U. Silurian –Middle Devonian Strat;

Presenter's Notes:

•Several significant Reservoirs and seal systems.

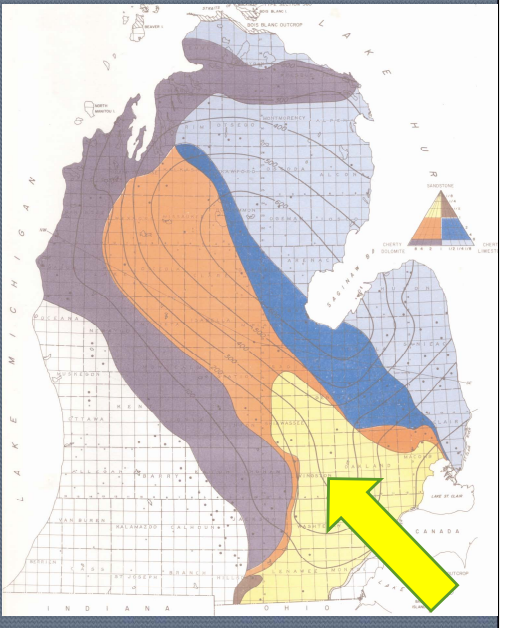
•Substantial O&G production (~400MMBBL oil equivalent).

•Sylvania Sandstone: Brine mining for halides including Br, I, & Cl.

•BILD target injection zone for successful MRCSP Phase II Demo 2009; 60,000mt injected).

Early Work: Sylvania & Bois Blanc

- Middle Devonian SLVN – BBLC onlap Base Kaskaskia (U. Silurian – M. Devonian) unconformity
- Complex, generally marine transgressive depositional system comprising heterolithic sandstone, chert, and carbonate facies
- SLVN Ss is the quartz-sand-dominated lithofacies
- Quartz sand derived from the Findley arch (Northern Ohio);
- Shallow depositional trough with northwest paleotransport towards subsiding, shallow marine basin to the north and northeast;
- Intracratonic Michigan basin margin to the west and northwest



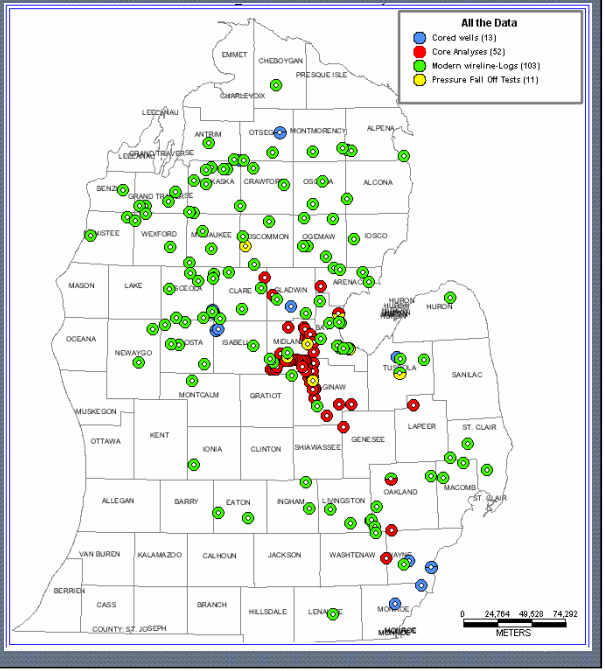
Gardner, 1974

Presenter's Notes:

•Middle Devonian SLVN – BBLC onlap Base Kaskaskia (U. Silurian – M. Devonian) unconformity.
•Complex, generally transgressive depositional system comprising heterolithic sandstone, chert, and carbonate facies.
•SLVN Ss is the quartz-sand-dominated lithofacies

Sylvania Ss Reservoir Characterization: Available Data

- Cores (little)
- Core analysis (core generally unavailable)
- Modern WLL
- Pump test data



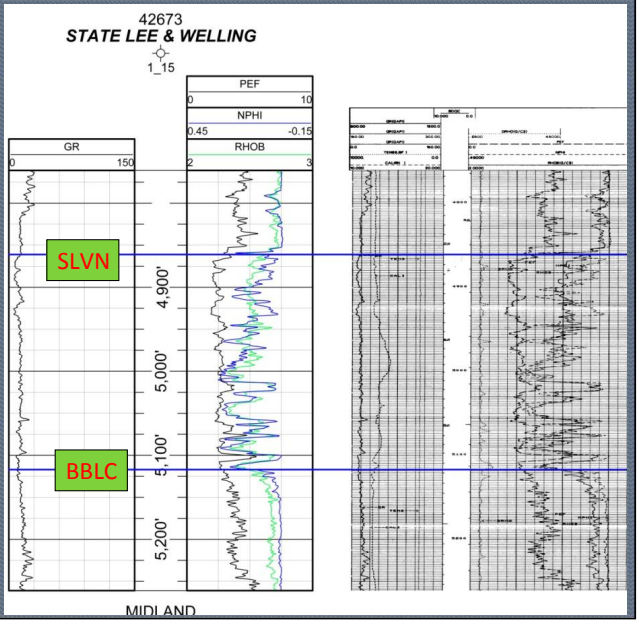
Presenter's Notes:

•Abundant and widely distributed subsurface data.

•Little/no overlap of data sets--Cores (little), Core analysis (cores are generally unavailable), Modern WLL, Pump test data

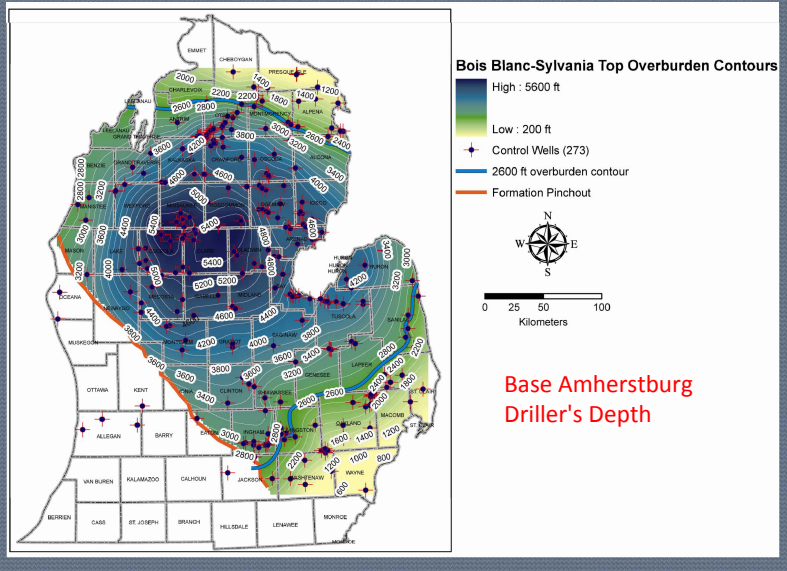
SLVN-BBLC Type Log Data

- Typical WLL picks for top SLVN (base AMBG)
- Top BBLC
- Complex, mixed WLL signature



Presenter's Notes:
Typical WLL picks for top SLVN (base AMBG) and Top BBLC
Complex, mixed lithology WLL signature.

Overburden Thickness: Combined SLVN-BBLC



Presenter's Notes:

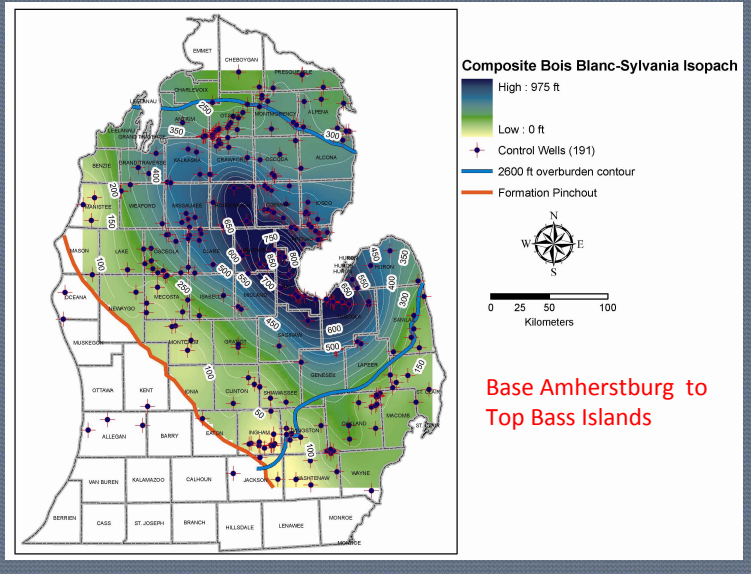
Drillers depth (overburden thickness) of combined SLVN & BBLC

•Depositional pinch-out (red)

•Minimum overburden thickness for GCS

Basin-centered subsidence pattern and central basin area of prospective GCS.

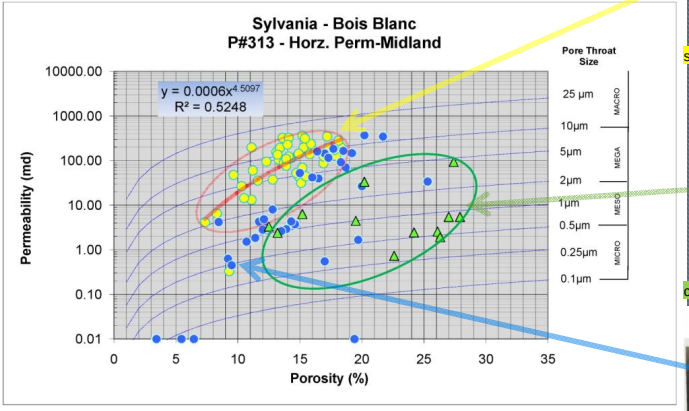
Combined Isopach: SLVN-BBLC

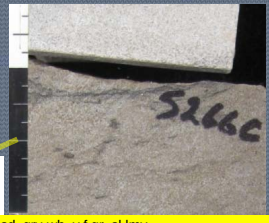


Presenter's Notes:

NW-SE oriented isopach of combined SLVN – BBLC; Combined thickness to 800'.

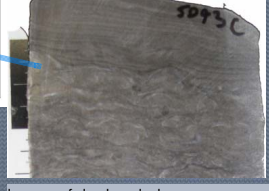
SLVN-BBLC Core Analysis and Lithology





sd, gry-wh, v f gr, sl lmy

chert, weathered, gry-wh



lm, gry, v f xln, dse, sl sdy

Sandstone Lithofacies (reservoir): Good/moderate porosity and good/excellent permeability

Tripolitic Chert (Questionable reservoir quality): High porosity; low/moderate permeability

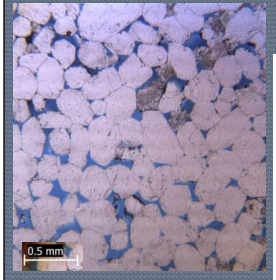
Limestone Lithofacies (non-reservoir) : Low/moderate porosity and low permeability

Presenter's Notes:

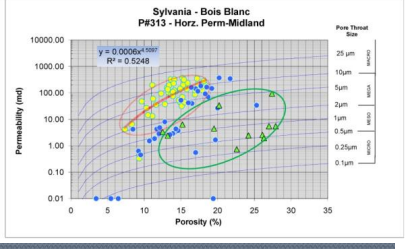
Core analysis and lithologic descriptions--Sst reservoir, Tripolitic chert possible/low quality reservoir, Carbonate non-reservoir.

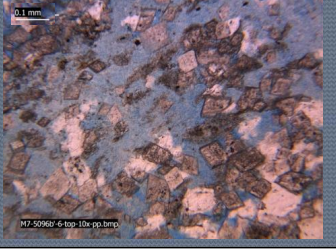
Lithology/Petrophysics

Core poro cut off: > 0.2 (20%) [Orange]
Core perm cut off: < 5 md [Green]

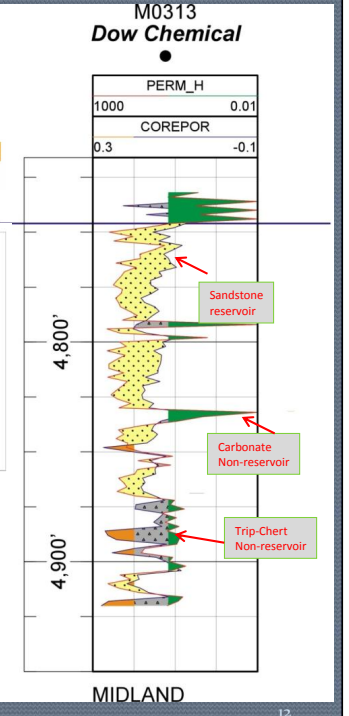


Reservoir
Sandstone



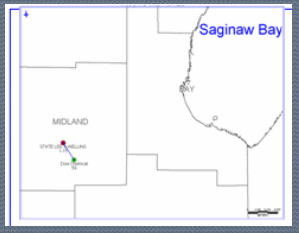


Non-Reservoir
Calcareous chert



Presenter's Notes:
Stratigraphic distribution of reservoir and non-reservoir facies and poroperm properties.

Pseudo-Core to Log Correlation



Core poro cut off: > 0.2 (20%) [Orange]
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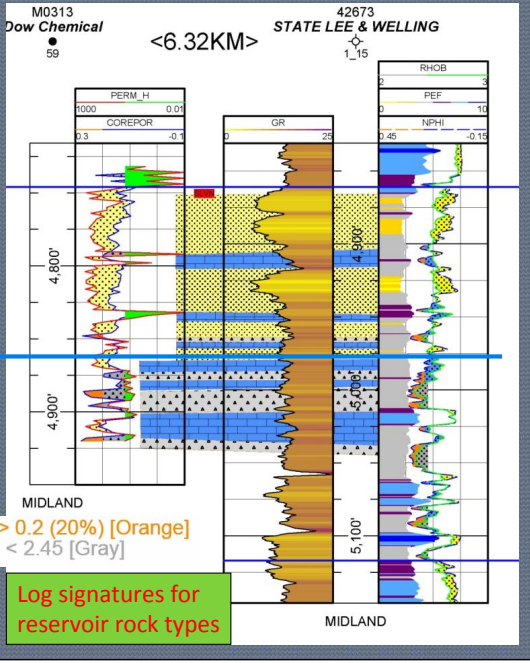


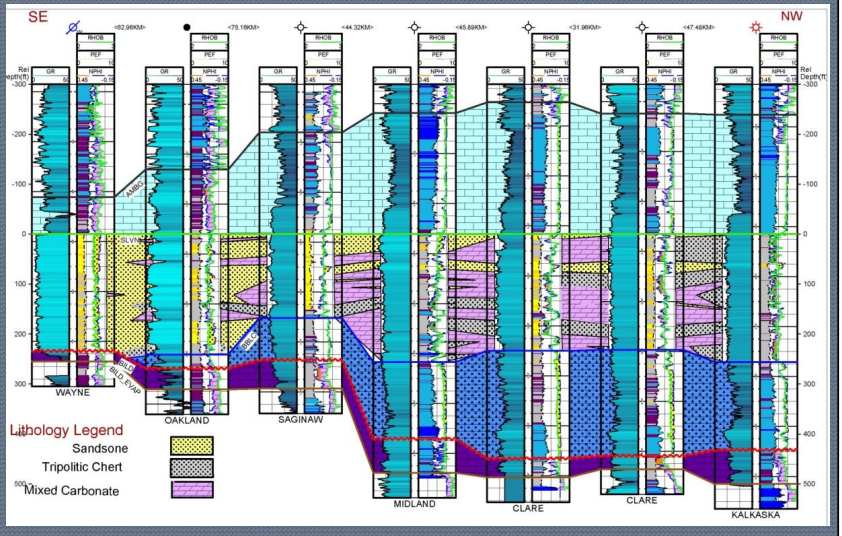
NPHI cut off: > 0.2 (20%) [Orange]
RHOB cut off: < 2.45 [Gray]

Log signatures for reservoir rock types

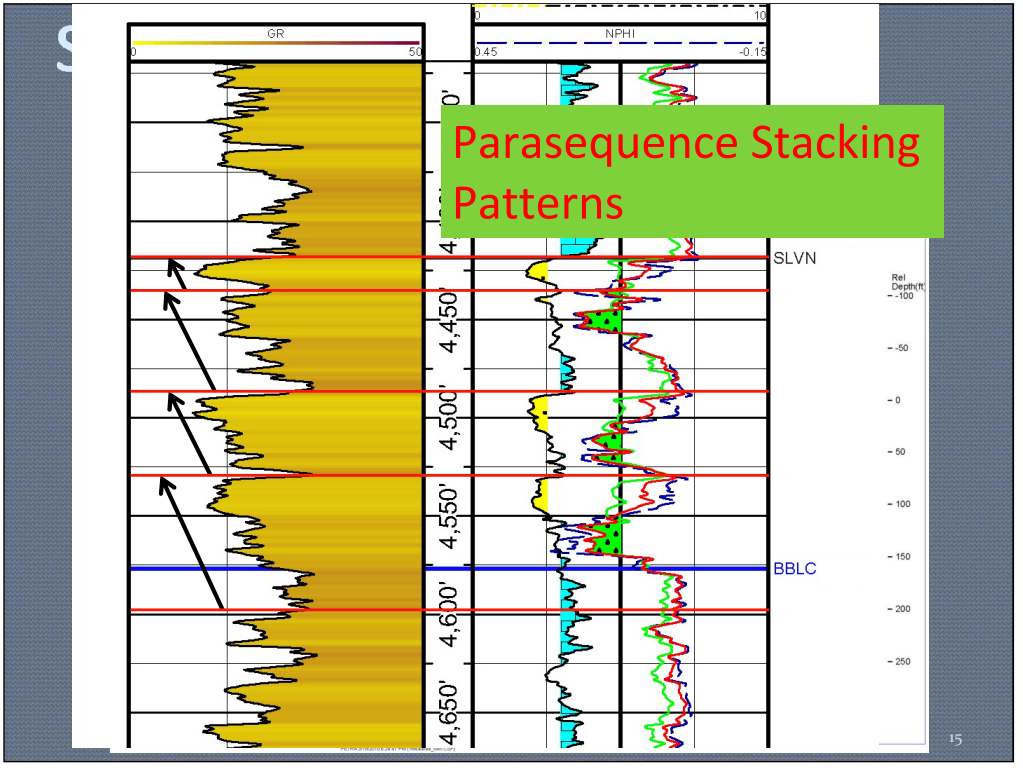
Presenter's Notes:

Petrophysical identification of: Reservoir ss: moderate porosity and density with RHOB left of NPHI (for LS matrix) vs. Non-reservoir trip. chert: high porosity – low density; NPHI left of RHOB.

Gross Lithostratigraphy



Presenter's Notes:
Gross lithostratigaphy; SE to NW decrease in SLVN lithofacies.



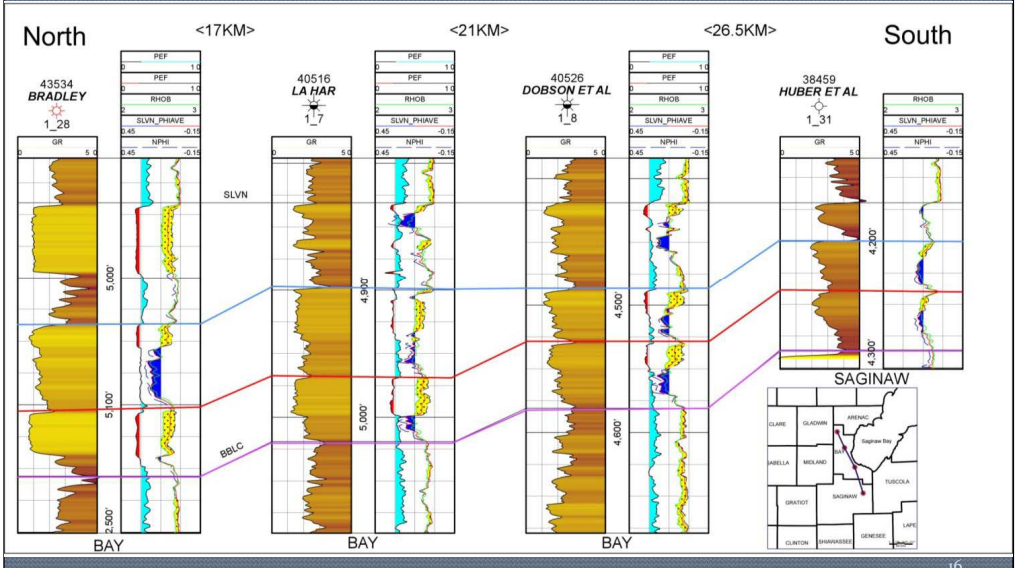
Presenter's Notes:

Log-defined lithofacies stacking patterns.

Flooding-surface bounded, shoaling-upward parasequences:

Offshore muddy carbonate, to more proximal chert, shoaling upwards to littoral sandstone.

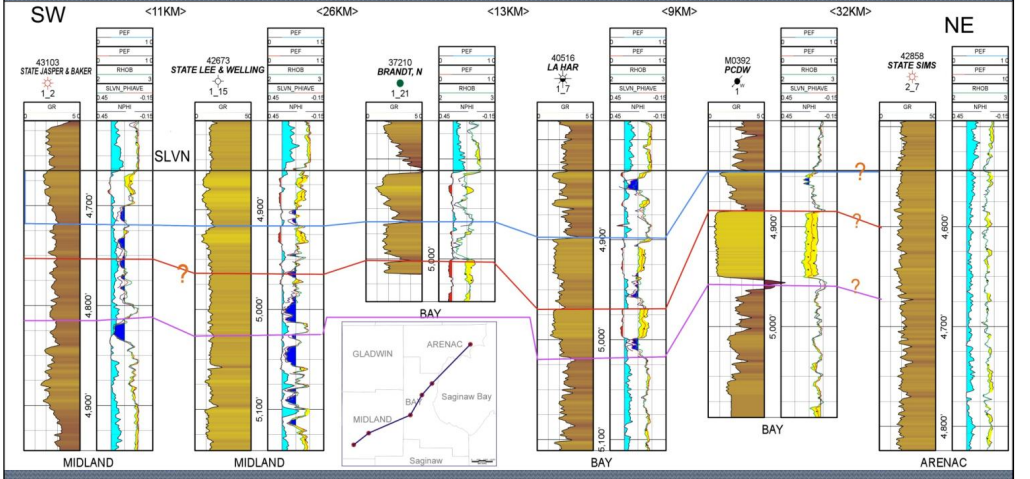
Vertical Reservoir Compartmentalization by Parasequences Along Depositional Trend



Presenter's Notes:

Correlating electrofacies to lithofacies allowed us to recognize three shallowing-upward parasequences and confidently correlate them along depositional strike. The ideal parasequence starts with the limestone lithofacies at the base and grades into tripolitic chert, which is topped by the sandstone lithofacies. These parasequences compartmentalize the reservoir vertically into a series of sandstone reservoirs overlain by generally impermeable limestone and chert confining layers.

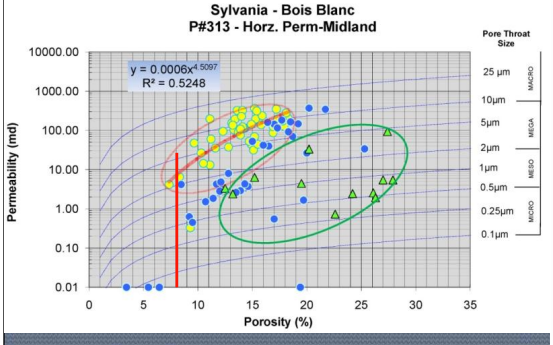
Lateral Reservoir Compartmentalization by Facies Tract Across Depositional Trend



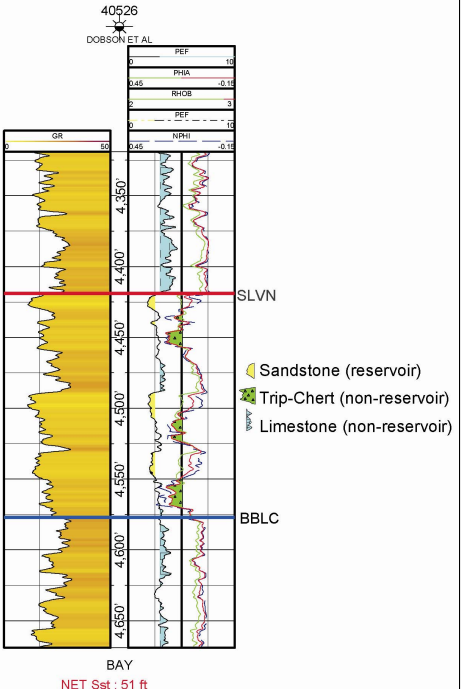
Presenter's Notes:

Correlating parasequences in the depositional dip direction was not as straightforward as in the strike direction. Lithofacies within each parasequence have higher tripolitic chert in the SW direction, and sandstone and tripolitic chert lithofacies are replaced by siliceous carbonates of the Bois Blanc Formation in the NE direction. These lithofacies change, and pinch-outs in each parasequence occur within a relatively short distance (< 10's of km) such that the Sylvania reservoir is compartmentalized laterally, in all directions, except towards the outcrop to the SE.

Porosity Cutoff & Net Porosity

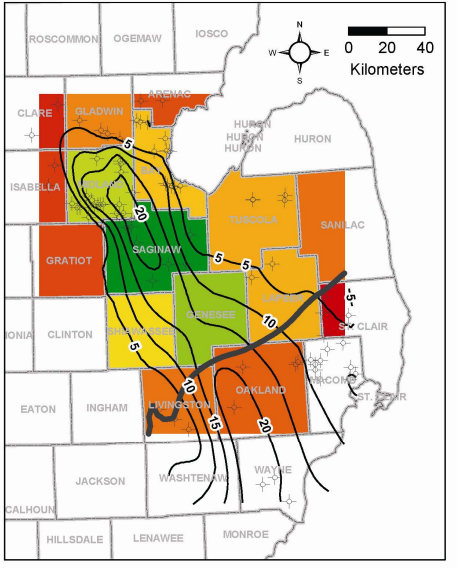


Porosity Cutoff = 8%
~6Md Permeability
Meso to Mega-intergranular Pore system
Very conservative net porosity estimates (mixed lithologies)



NET Sst : 51 ft
Net Porosity (@8%) : 6 ft
Average Reservoir Porosity : 12%

Regional CO_2 Storage Capacity



Sylvania Sandstone Storage Capacity ~731 Mmt CO2
(4% Storage Efficiency)

PHIH Control Well

Sequestration Capacity
Million metric tons

High :168.8 Mmt

Low : 0.56 Mmt

SLVN Minimum Depth

Saginaw Co. = 169 Mmt
Midland Co. = 112 Mmt
Bay Co. = 60 Mmt

341 Mmt

Presenter's Notes:
Net porosity contours and grid of storage capacity by county.
Storage efficiency of 4% and CO_2 density of 0.7 gm/cc

The Sylvania Sandstone in Michigan: Summary of Work to Date

- Detailed reservoir characterization studies indicate a conservative estimate of 730 million metric tons of Geological Carbon Sequestration Capacity in the Sylvania Sandstone in central Lower Michigan.
- This saline aquifer is geologically and stratigraphically complex, with a high degree of regional variability in reservoir quality/continuity.
- Brine withdrawal and disposal in up-hole formations may be necessary for pressure management in this laterally and stratigraphically compartmentalized saline reservoir
- Lateral and vertical geological heterogeneity will require sophisticated reservoir characterization and modeling to confidently document and safely deploy geological sequestration in the Sylvania Sandstone in Michigan

Thank You!

- **MICHCARB**

  a Geological Carbon Sequestration Research and Education Program for Michigan (Congressional Earmark/DOE-NETL)

- **Consumers Energy, Jackson MI**