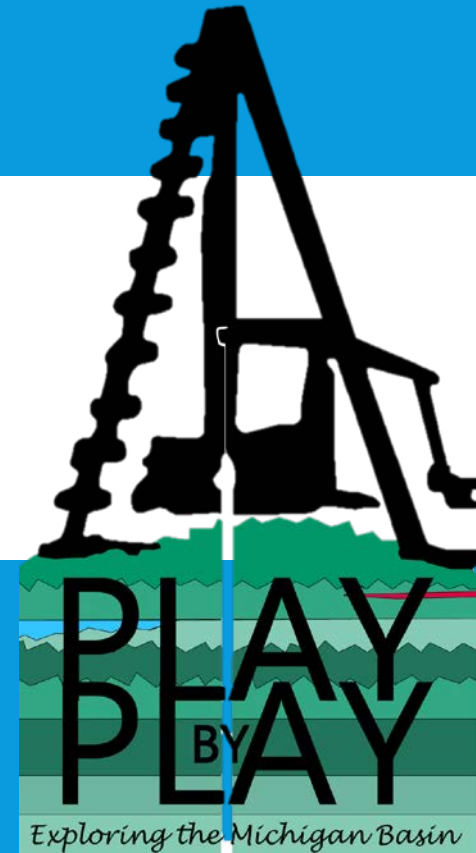


HISTORY AND DEVELOPMENT OF OIL AND GAS PLAYS OF THE MICHIGAN BASIN

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Michigan Geological Repository for Research and Education
(MGRRE)

Western Michigan University-Michigan Geological Survey



EARLY HISTORY OF MICHIGAN OIL AND GAS EXPLORATION

- Some wildcatting as early as 1861, no significant finds
- First commercial wells near Port Huron in 1886-1887, 21 wells by 1910 producing up to 10 barrels per day
- Smith, 1912 reported over 100 wells that had been drilled in southeastern Michigan had natural gas and was being used for domestic heating, mostly from Antrim Shale or Traverse Limestone
- By 1920, five wells in the Deerfield Field were producing oil from the Trenton Formation
- The Saginaw Field was discovered in the Berea Sandstone in 1925 and had 320 oil wells, 3 gas wells and 62 dry holes by the end of 1927
- Oil and Gas Permitting began in 1927
- The Muskegon Field in 1927 (Traverse Lime) and the Mt. Pleasant Field in 1928 (Dundee) established that oil production was possible throughout Michigan

Locations of Oil and Gas wells drilled throughout Michigan

57,441 boreholes drilled as of 3/28/2017

Red – Natural Gas

Green – Oil

Black – Dry hole

1,205 – Brine Disposal Wells

22,459 – Dry Holes

13,480 – Gas or Cond. Wells

3,026 – Gas Storage Wells

885 – Gas/other OBS Wells

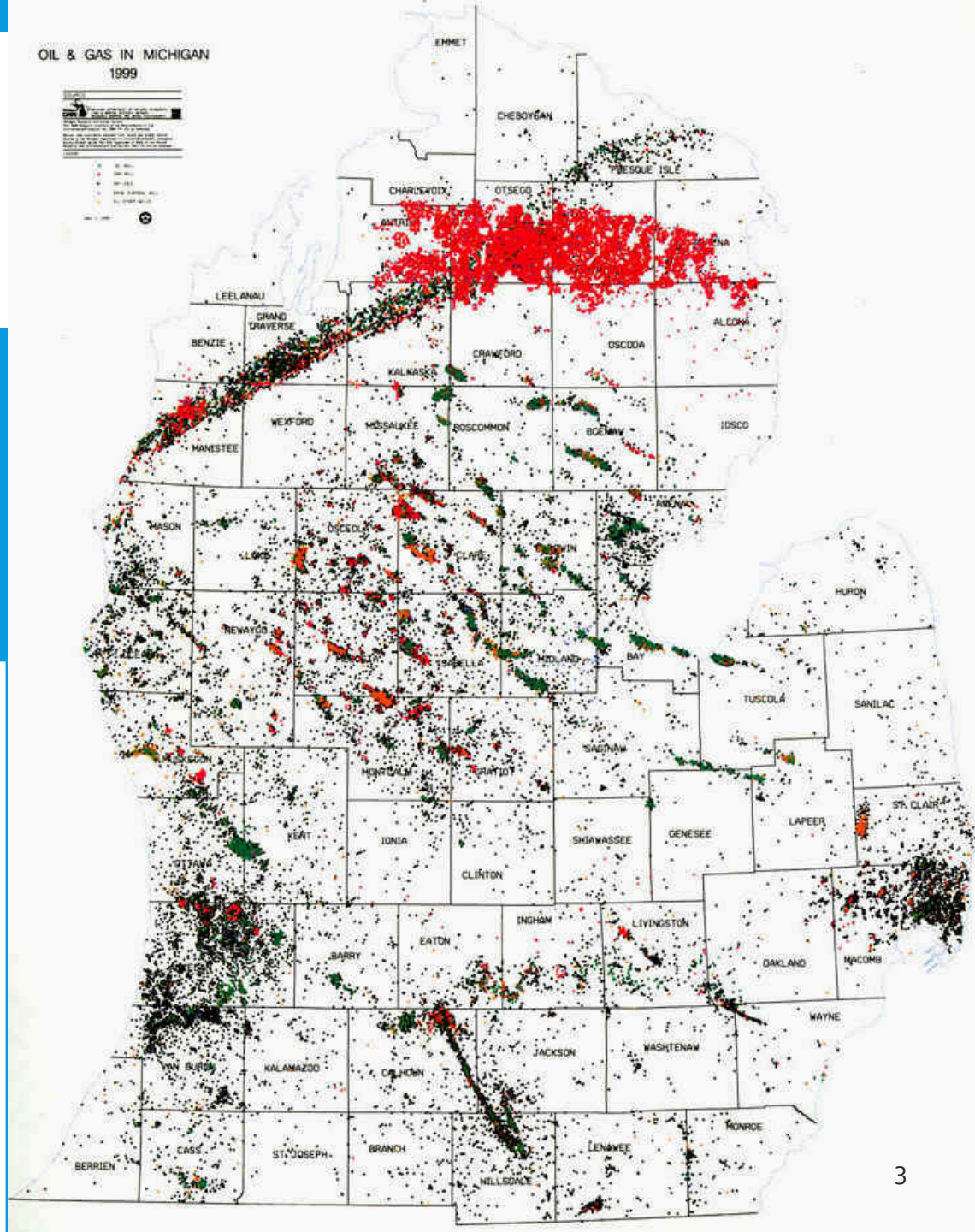
106 – Type Unknown

59 – LPG Wells

506 – Mineral Wells

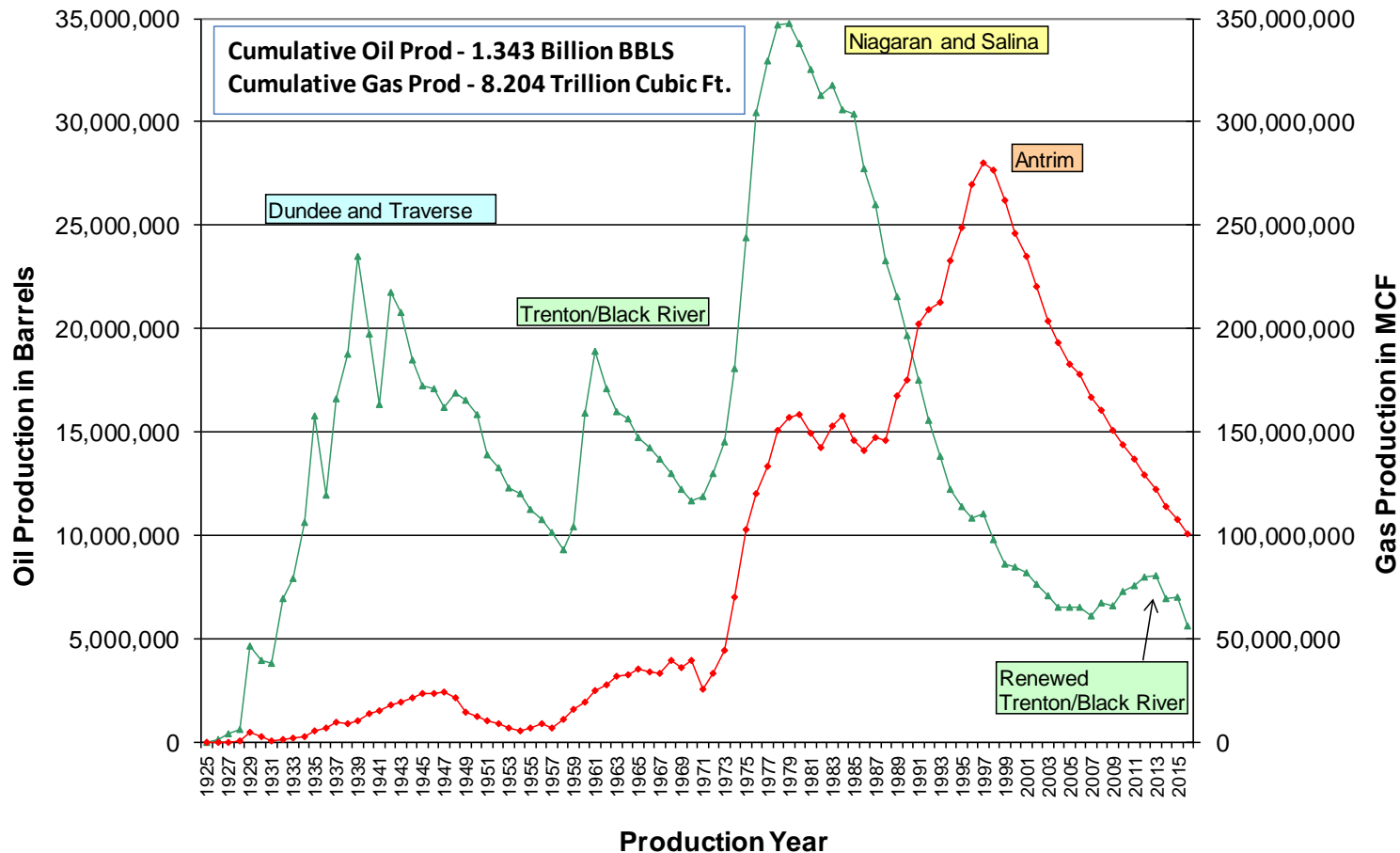
14,817 – Oil Wells

886 – Injection Wells



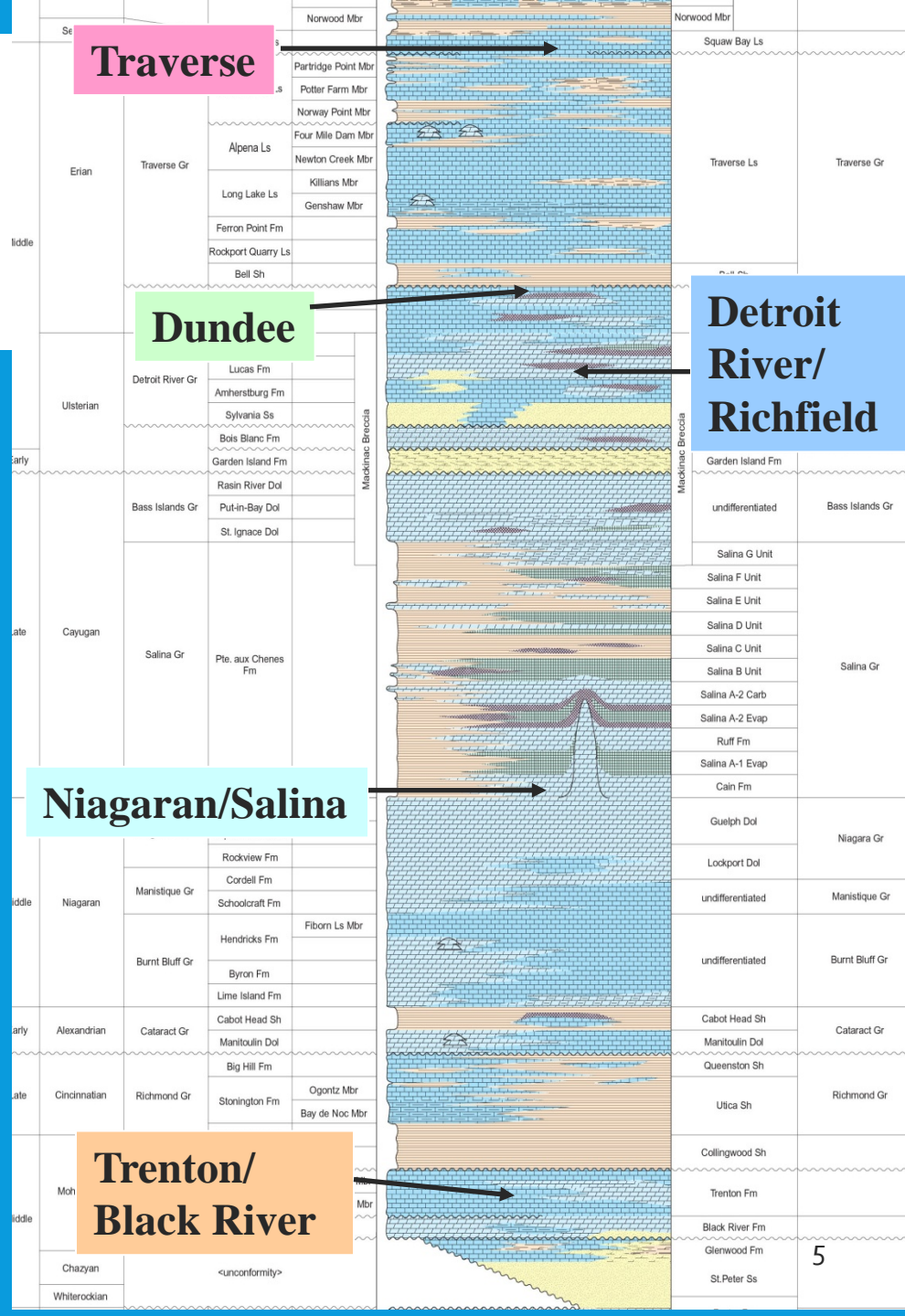
MICHIGAN OIL AND GAS ANNUAL PRODUCTION THROUGH DEC, 2016

Michigan Oil and Gas Annual Production through Dec. 2016



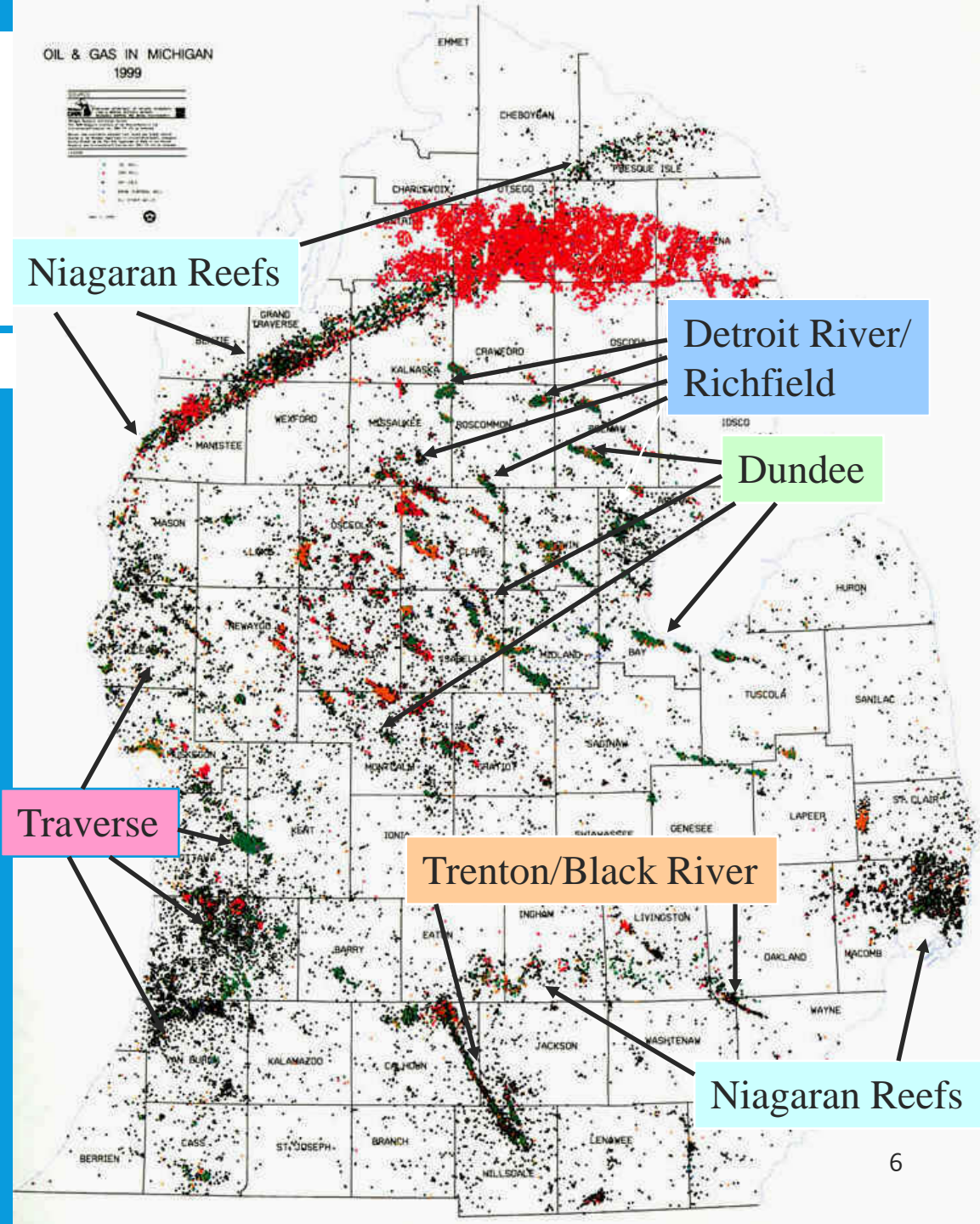
Major Carbonate Reservoir Intervals in Michigan Basin

From State of Michigan Geological Survey, 2000



MAP OF OIL AND GAS WELLS FOR MICHIGAN'S LOWER PENINSULA CARBONATE RESERVOIR PLAYS

From State of Michigan Geological Survey, 2003

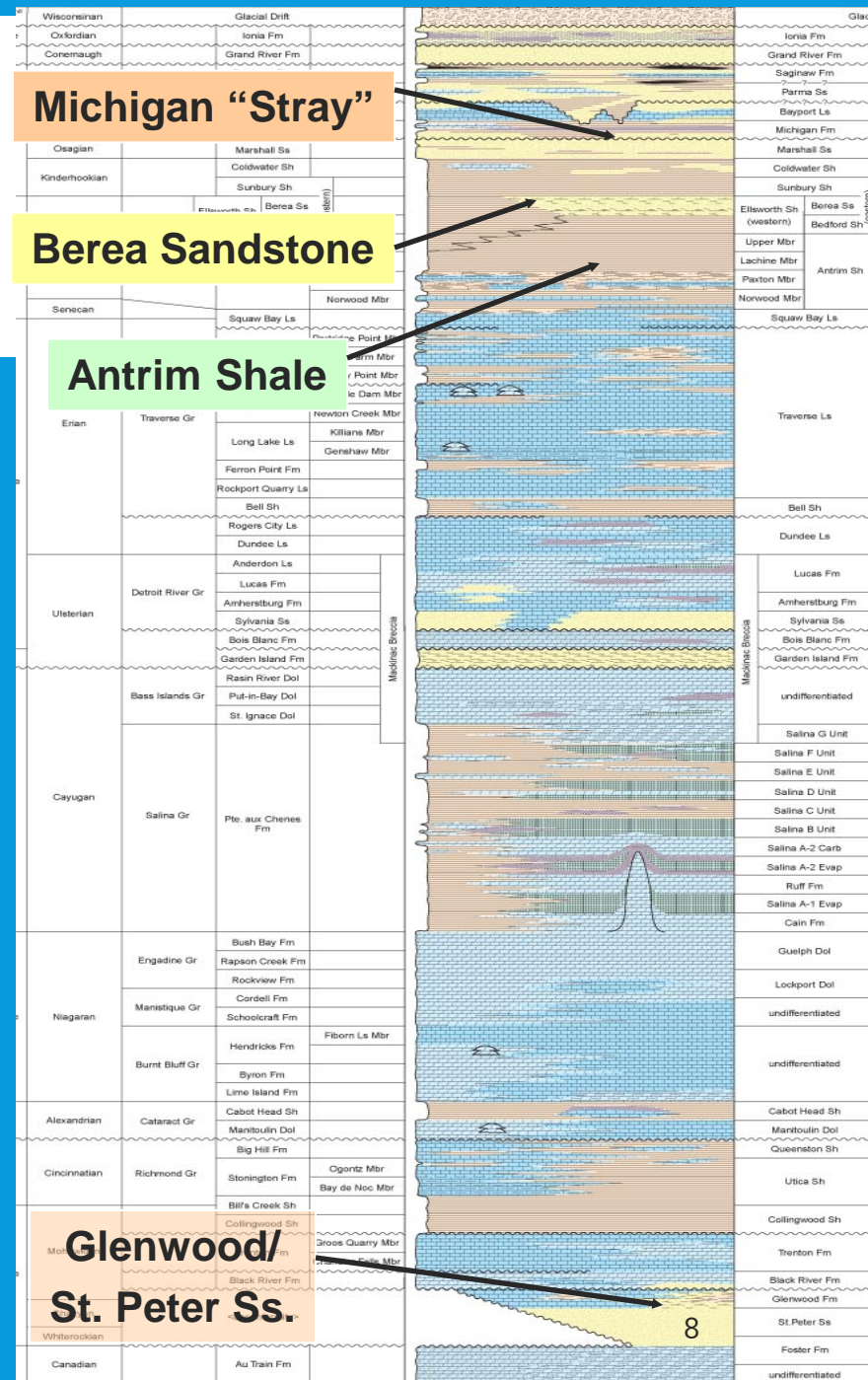


OIL AND GAS FIELDS PRODUCTION HISTORY - MICHIGAN CARBONATE RESERVOIRS

<u>Formation</u>	<u>Number of Fields Reporting Production</u>	<u>Cumulative Oil Produced</u>	<u>Cumulative Gas Produced</u>	<u>Average Depth and Depth Range</u>
Traverse	260	110 Million BBLS	13 BCF	2000 600 to 3400
Dundee	144	352 Million BBLS	42 BCF	3400 2200 to 4100
Detroit River/ Richfield	92	100 Million BBLS	120 BCF	4000 2000 to 5100
Niagaran	1187	450 Million BBLS	2500 BCF	5400 2300 to 7400
Trenton/Black River	19	140 Million BBLS	250 BCF	3900 2500 to 4700

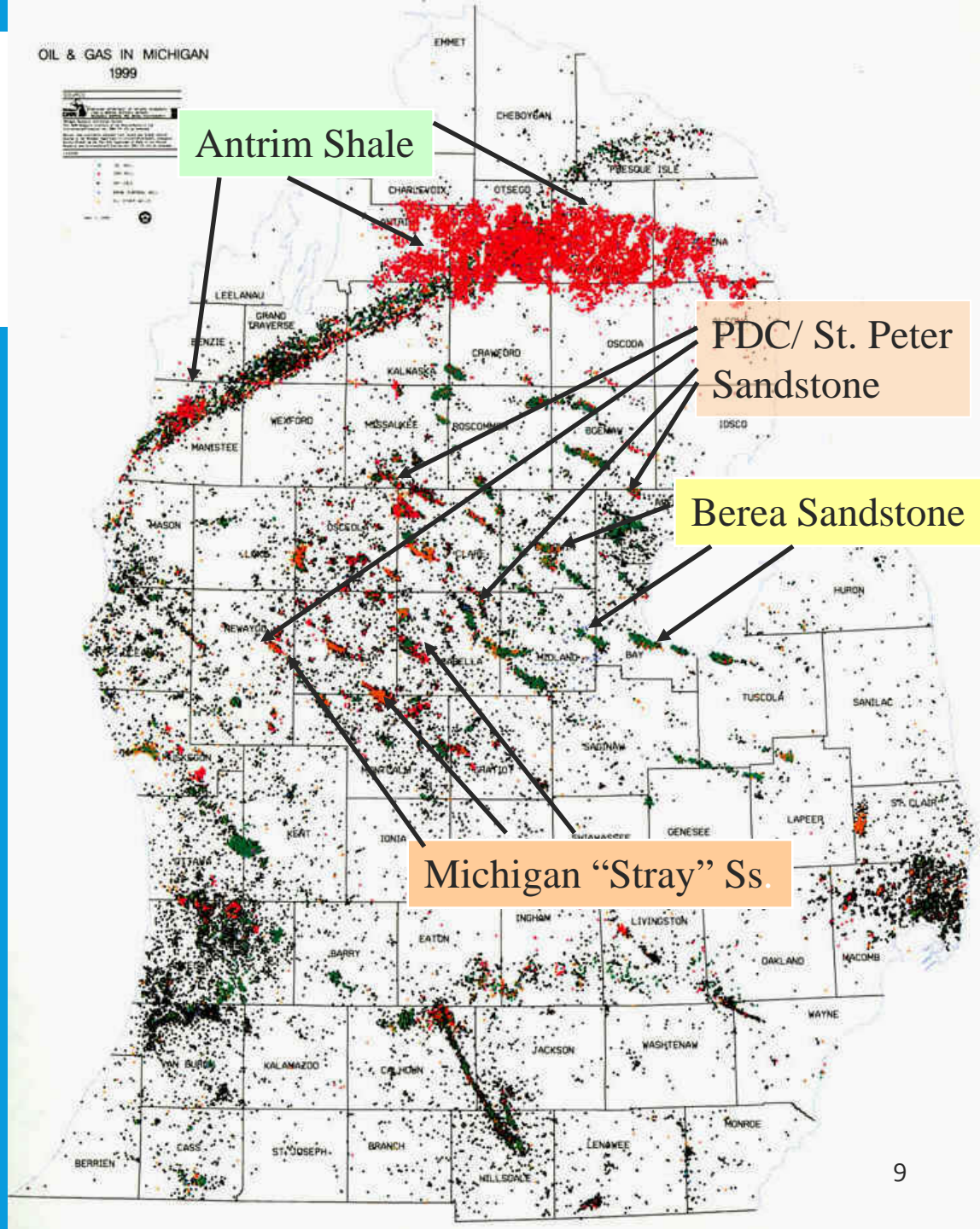
MAJOR SILICLASTIC RESERVOIR INTERVALS IN MICHIGAN BASIN

From State of Michigan Geological Survey, 2000



MAP OF OIL AND GAS WELLS FOR MICHIGAN'S LOWER PENINSULA SILICLASTIC RESERVOIR PLAYS

From State of Michigan Geological Survey, 2003



OIL AND GAS FIELDS PRODUCTION HISTORY

MICHIGAN CLASTIC RESERVOIRS

<u>Formation</u>	<u>Number of Fields Reporting Production</u>	<u>Cumulative Oil Produced</u>	<u>Cumulative Gas Produced</u>	<u>Average Depth and Depth Range</u>
Michigan "Stray"	82	5 Million BBLS	215 BCF	1200 900 to 1800
Berea Ss.	53	8 Million BBLS	16 BCF	1500 800 to 2400
Antrim Shale	36	none	3335 BCF	1300 500 to 2600
St. Peter/ PDC	70	15 Million BBLS	600 BCF	9500 7000 to 12000

USGS PETROLEUM SYSTEMS CLASSIFICATION

- Based on source rock formation
- May have multiple reservoir formations for same source rock
- May have multiple seals for the different reservoir units
- TPS 1 – PreCambrian Nonesuch – no commercial production
- TPS 2 – Ordovician Foster
- TPS 3 – Ordovician to Devonian Composite
- TPS 4 – Silurian Niagaran/Salina
- TPS 5 – Devonian Antrim Shale
- TPS 6 – Pennsylvanian Saginaw – trivial commercial production

TPS 2 – ORDOVICIAN FOSTER

- Ordovician Sandstones and Carbonates AU
- Source – Foster Formation
- Reservoir – St. Peter Ss. (aka. PDC) and thin sandstone beds within the upper Foster Fm.
- Seal – Shales in the Glenwood Fm., Tight Limestones of Black River Group
- Trap – Structural anticlines on basement structures

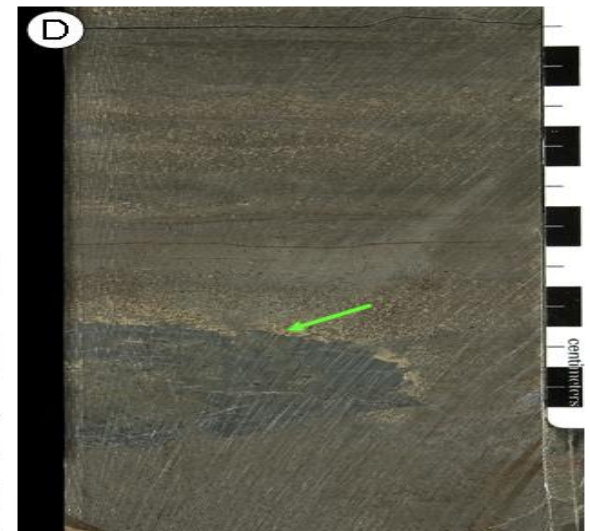
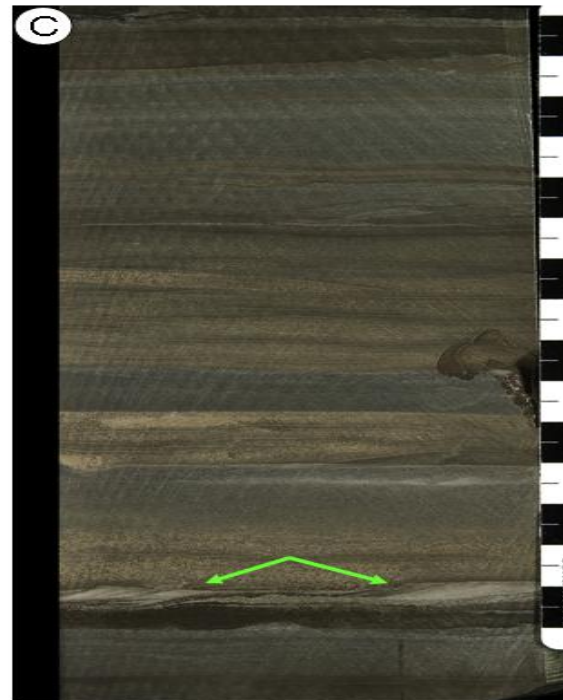
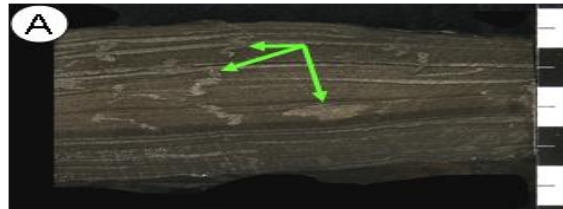
FOSTER FORMATION – BRAZOS-ST. FOSTER CORE – OGEMAW COUNTY

A) Black laminated mudstone with isolated burrows (arrows) 11,959 feet.

B) Laminated mudstone (dark) intercalated with laminar anhydrite 12,398 feet

C) Laminated dolomicrite (dark) with intercalated laminar anhydrite (light). Localized very fine sandstone with ripple cross laminae (arrows) 12,544 feet.

D) Laminated dolomicrite, cyanobacterial mats and anhydrite. Nodules of displacive anhydrite (arrow). 11,731 feet.



ST. PETER (AKA PRAIRIE DU CHIEN) SANDSTONE - RESERVOIR

Cross-bedded and burrowed,
Moderately sorted sandstone



TPS 3 – ORDOVICIAN TO DEVONIAN COMPOSITE SYSTEM

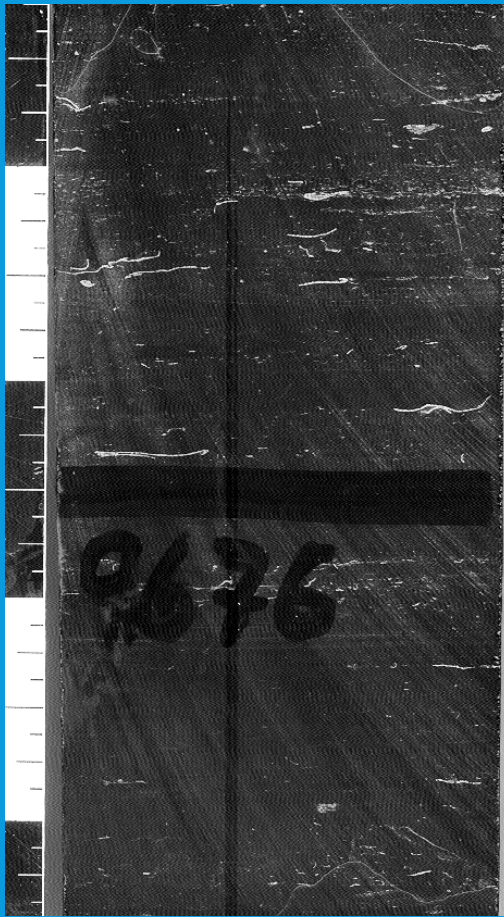
- Ordovician Trenton/Black River AU
- Ordovician Collingwood Shale Gas AU
- Silurian Burnt Bluff AU
- Middle Devonian Carbonates AU
- Devonian Antrim Continuous Oil AU
- Devonian to Mississippian Berea/Michigan Sandstone AU

TPS 3 – ORDOVICIAN TO DEVONIAN COMPOSITE - ORDOVICIAN TRENTON/BLACK RIVER AU

- Source – Shale beds within the Trenton/Black River, Collingwood Fm., Utica Shale
- Reservoir – Fractured, vuggy and intercrystalline dolomite in T-BR
- Seal – Utica Shale or tight limestone of the Trenton/Black River
- Trap – Stratigraphic occurrence of porous Dolomite surrounded by tight Limestone

COLLINGWOOD FM. SOURCE ROCK AND UTICA SHALE SOURCE ROCK & SEAL

JEM- Bruggers #3-7 Core
Missaukee Co., MI



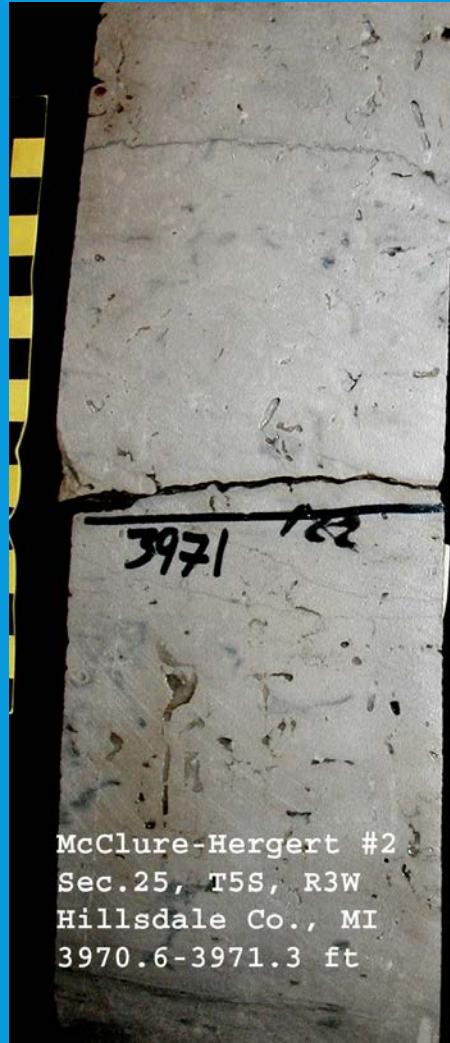
Collingwood

Petoskey Exploration – State Pioneer
#1-3 Missaukee County

Utica Shale



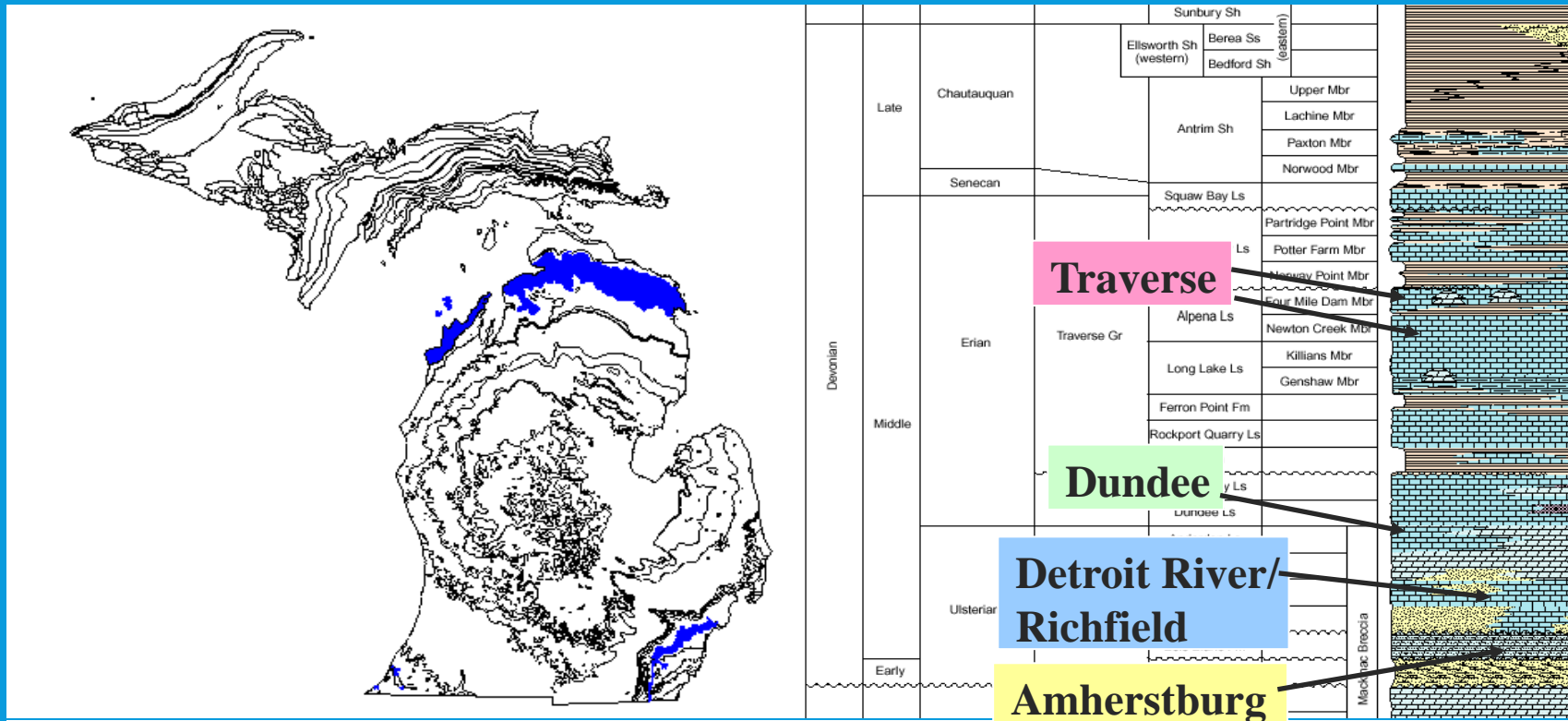
TRENTON-BLACK RIVER RESERVOIR



TPS 3 – ORDOVICIAN TO DEVONIAN COMPOSITE - MIDDLE DEVONIAN CARBONATES AU

- Source – Amherstburg and Lucas Fms.
- Reservoir – Open marine shelf carbonates of the Traverse, Dundee and Amherstburg Limestones, Fractured and vuggy dolomite in the Traverse and Dundee and restricted carbonate facies in the Detroit River Group
- Seal – Bell Shale, Squaw Bay Fm., Antrim Sh., Tight Limestone, Anhydrite and Halite in the Lucas and Anhydrite in the Reed City
- Trap - Structural anticlines on basement structures, Porous Limestone from original depositional facies, porous dolomite from hydrothermal alteration, sucrosic dolomite from evaporative reflux

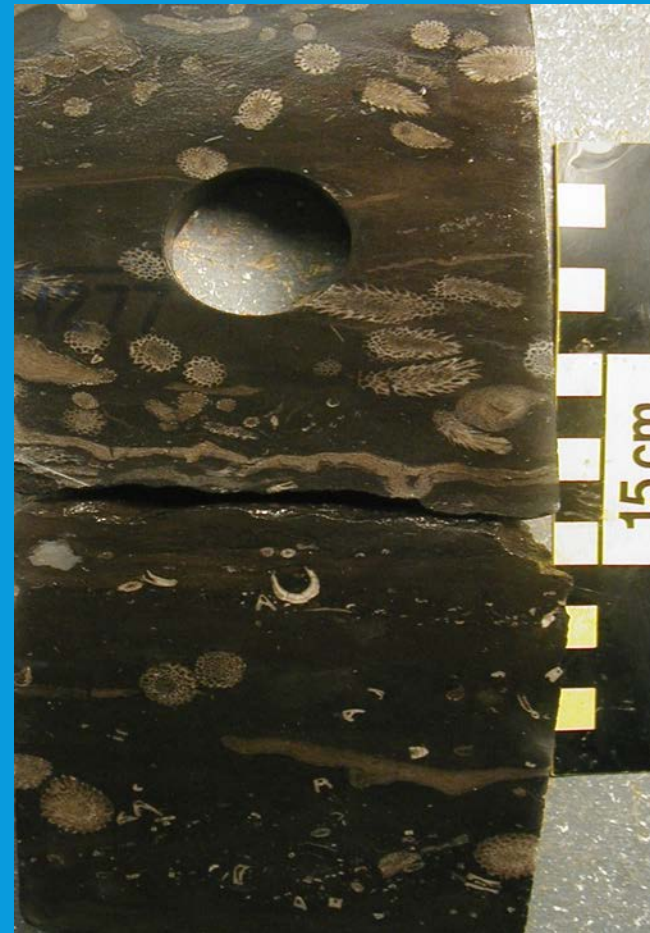
HYDROCARBON PRODUCING MIDDLE DEVONIAN ROCKS IN MICHIGAN



Middle Devonian

Traverse Lime, Dundee Fm., Detroit River Group and Amherstburg Fm. Outcrop and Subcrop of these rocks shown in blue.

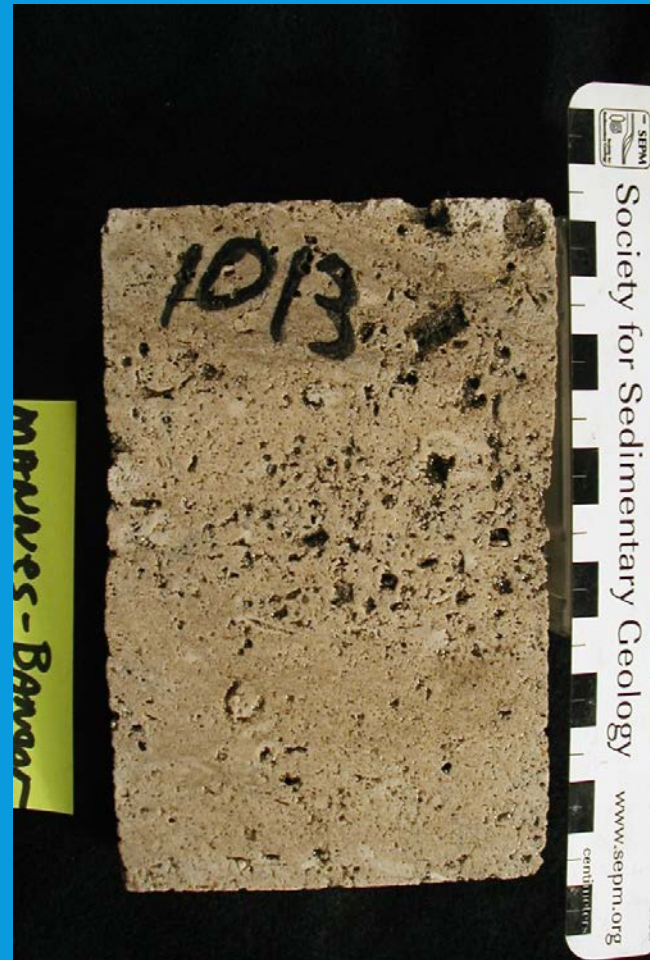
AMHERSTBURG FM. – SOURCE ROCK AND RESERVOIR



Core Energy-St Charlton #4-30, Otsego Co.

Hunt-McGuire #1-22, Oscoda Co.

TRAVERSE LIMESTONE RESERVOIRS – FRACTURED AND VUGGY DOLOMITE



Mannes-Bangor Unit #1, Van Buren County

DUNDEE RESERVOIRS – LIMESTONE OR DOLOMITE

MichCon-LoReed #LR 83-2 Osceola Co.

Wiser-Sturm #4-0 Gladwin Co.

Cronus Dev. #1-3 Montcalm Co.



Laminated and Fenestral
Wackestone and Mudstone

Reef and Reef Skeletal Debris

Skeletal Grainstone

BELL SHALE SEAL



Dart-Hamming #1-22, Missaukee Co._3886-3892 feet

LUCAS FM. RESERVOIR AND SEAL



Dart-Porter Hogan #1-17, Roscommon County

TPS 3 – ORDOVICIAN TO DEVONIAN COMPOSITE - DEVONIAN TO MISSISSIPPIAN BEREA/MICHIGAN SANDSTONE AU

- Source – Antrim, Ellsworth and Sunbury Shales
- Reservoir – Berea Ss., Marshall Ss., Michigan “stray” Ss.
- Seal – Sunbury and Coldwater Shale, shales and anhydrite in the Michigan Fm.
- Trap - Structural anticlines on basement structures – mostly primary intergranular porosity, with minor cementation

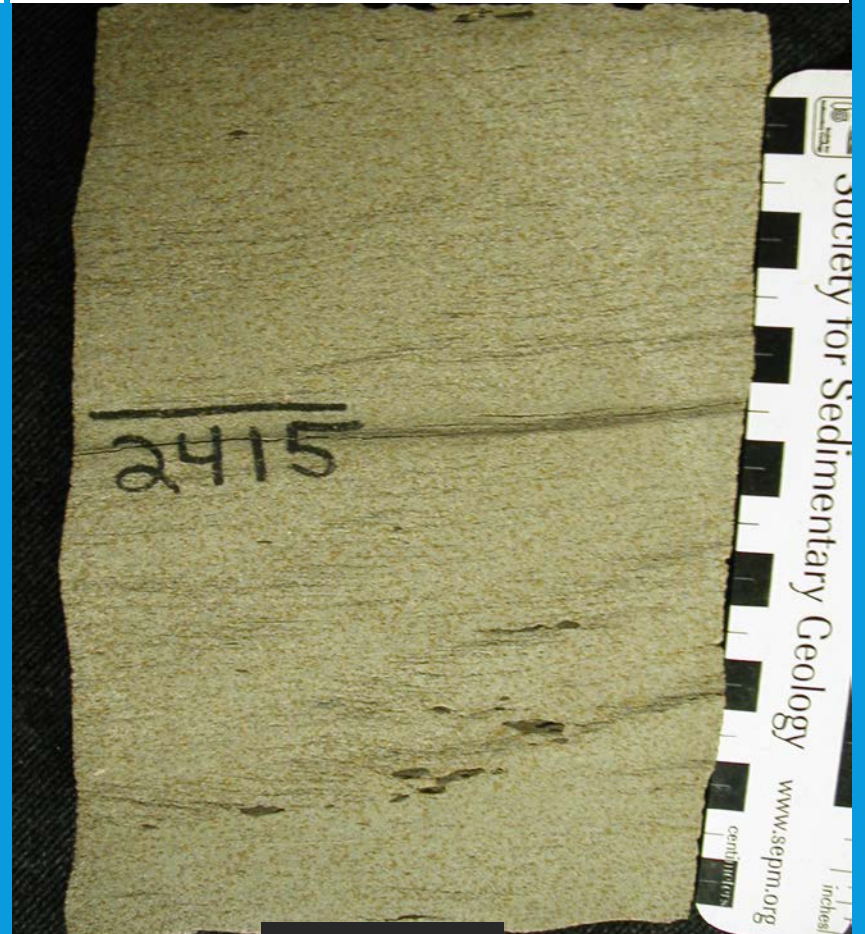
MICHIGAN "STRAY" AND BEREA SANDSTONE RESERVOIRS

MichCon SL-175-A Six Lakes Field, Montcalm, Co

Wood-Mieske #1-6 Williams Field, Bay, Co



Michigan "stray" Ss.

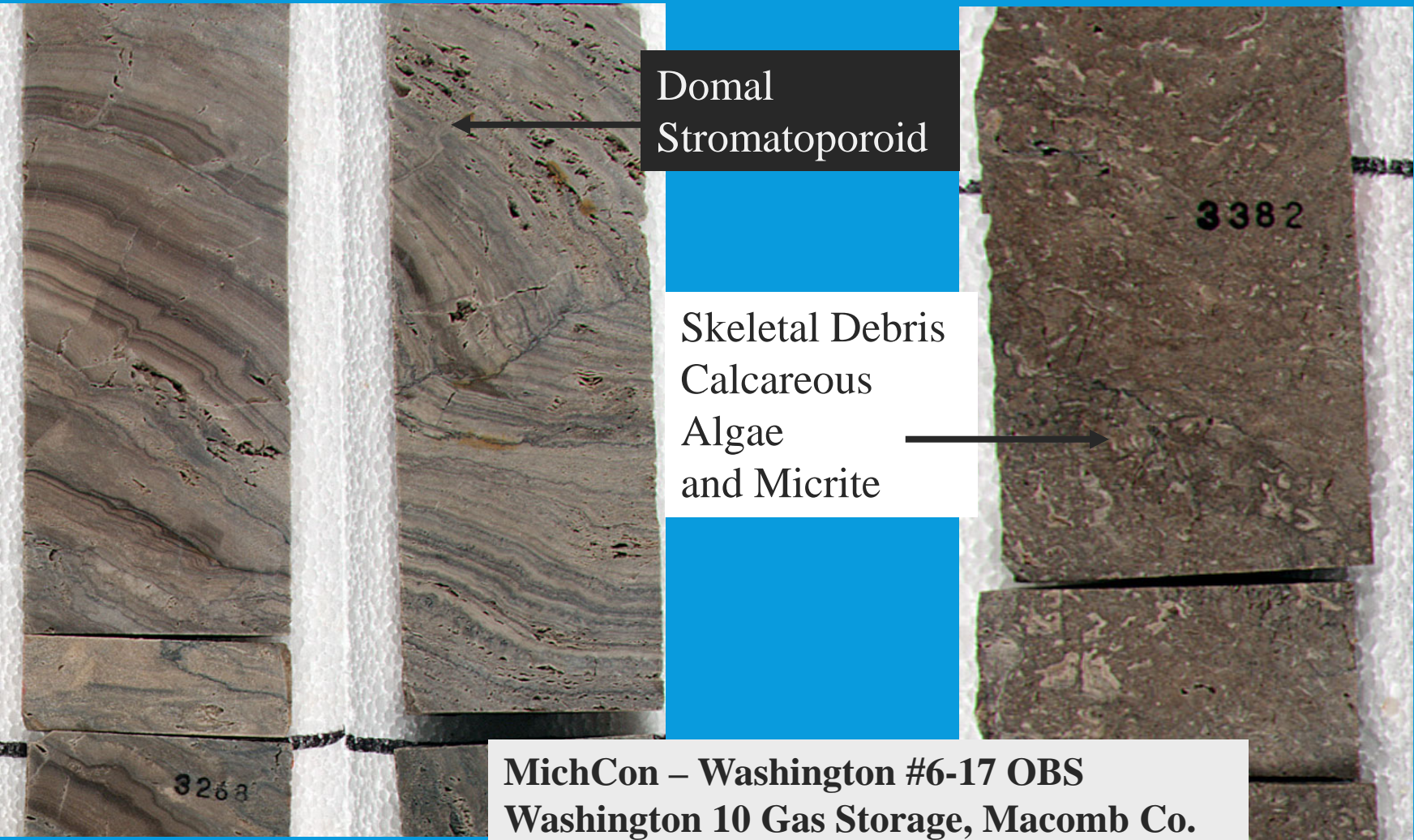


Berea Ss.

TPS 4 – SILURIAN NIAGARAN/SALINA

- Silurian Niagara AU
- Silurian A-1 and A-2 Carbonate AU
- Devonian Sylvania Sandstone AU
- No commercial production has been established in the Devonian Sylvania Ss. AU, so it was not quantitatively assessed
- Source – Salina A-1 Carbonate
- Reservoir – mostly Dolomitized Niagaran pinnacle reefs and associated facies
- Seal – Salina A-1 and A-2 Anhydrite and Halite
- Trap – Stratigraphic trap of carbonate buildups surrounded by draping evaporites. Most reservoir quality is in Dolomitized facies, minor porosity in Limestone

NIAGARAN REEF RESERVOIR

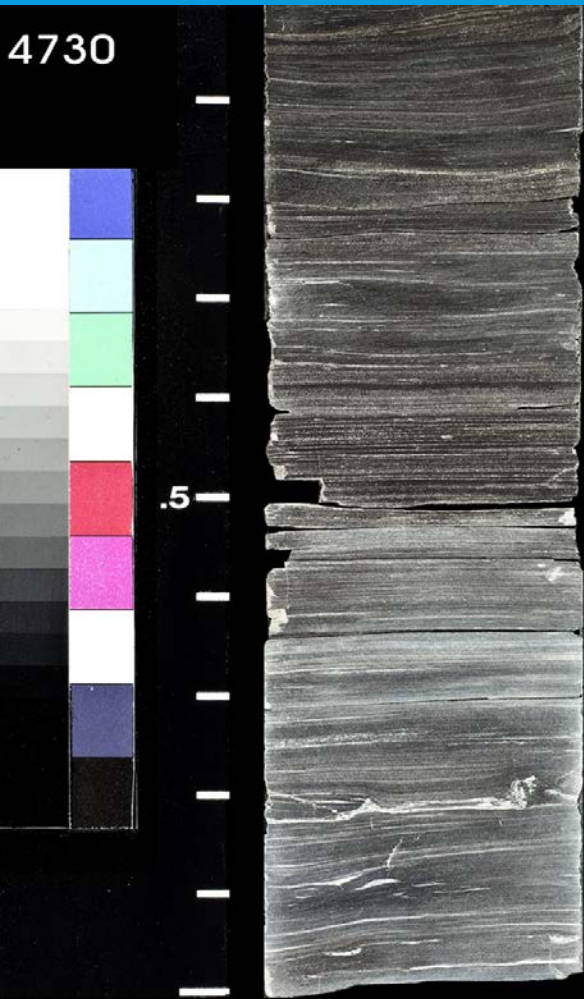


**MichCon – Washington #6-17 OBS
Washington 10 Gas Storage, Macomb Co.**

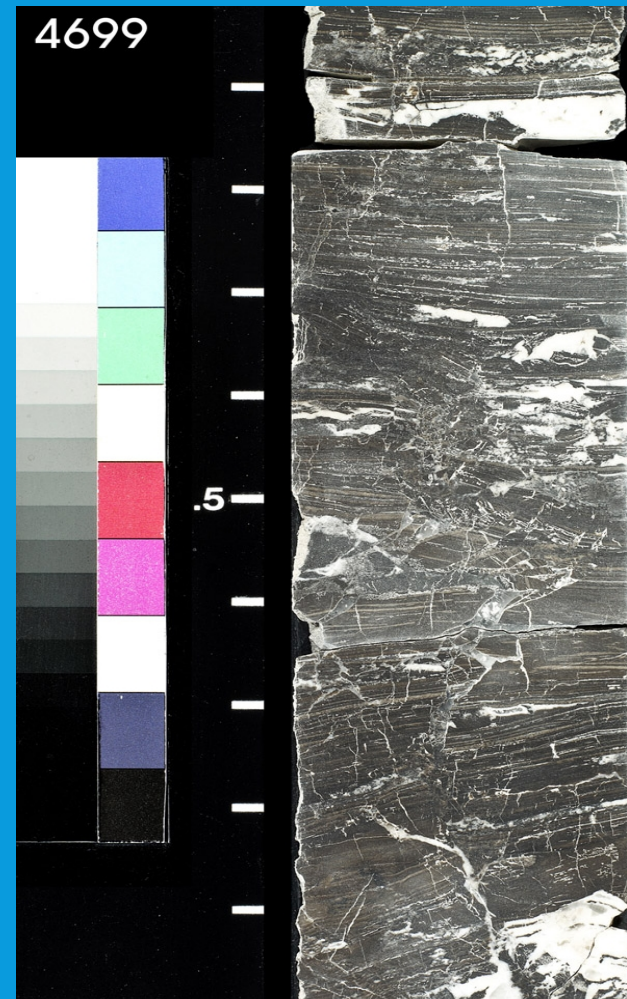
SALINA A-1 CARBONATE SOURCE/RESERVOIR

Organic-rich “poker-chip” facies Source rock

Fractured and vuggy potential Reservoir



Rosetta Resources-
Christensen #1-21P,
Ionia County



SALINA A-1 AND A-2 EVAPORITE SEAL



Chapman
Blair Brydges
Newaygo Co.
A-1 Salt
above A-0
Carbonate



AMOCO-Miller-Fox #1-11
Oceana Co.
Salina A-2 Anhydrite

TPS 5 – DEVONIAN ANTRIM SHALE

- Devonian Antrim Shale Continuous Gas AU
- Source – Antrim Shale
- Reservoir – Antrim Shale
- Seal – Antrim Shale and Ellsworth laterally and vertically
- One of the first Shale gas producing formation in the U.S.
- Trap – Hydrodynamic, Gas is adsorbed to rock and desorbs into fractures as reservoir pressure is lowered. Reservoir has leaked into the glacial drift where it subcrops and charges some of the unconsolidated sands.

ANTRIM SHALE RESERVOIR AND SOURCE

Amoco-Conn D-2,
Shiawassee County



CONCLUSIONS

- Michigan Basin Hydrocarbon exploration and production extends back to the 19th century
- Serious commercial production began in the 1920's
- Over 2200 fields are known from over 57,000 wells
- Most production is from carbonate reservoirs
- Total Michigan production is over 1.34 billion bbls oil and 8.0 TCF gas
- Michigan also leads the U.S. in underground Natural Gas storage, both working gas and total gas volumes
- Michigan reservoirs can be classified by the Total Petroleum System of source, reservoir and seal (U.S. Geological Survey)