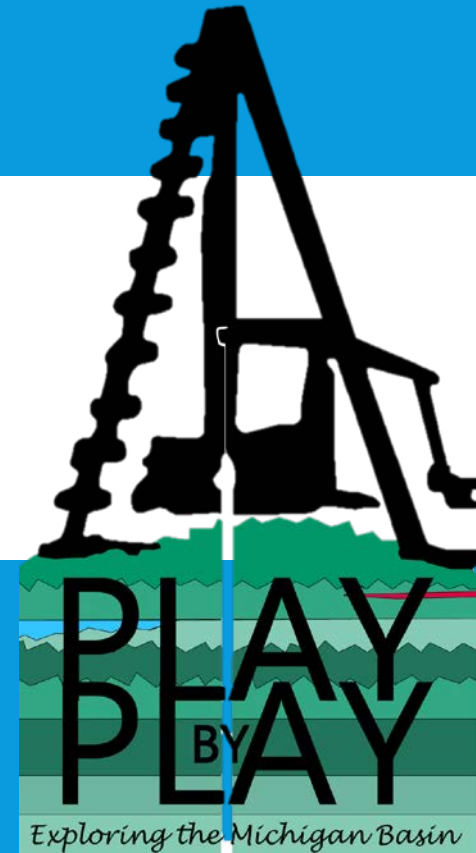


DEVONIAN OIL AND GAS PLAYS OF THE MICHIGAN BASIN

William B. Harrison, III

Michigan Geological Repository for Research and Education
(MGRRE)

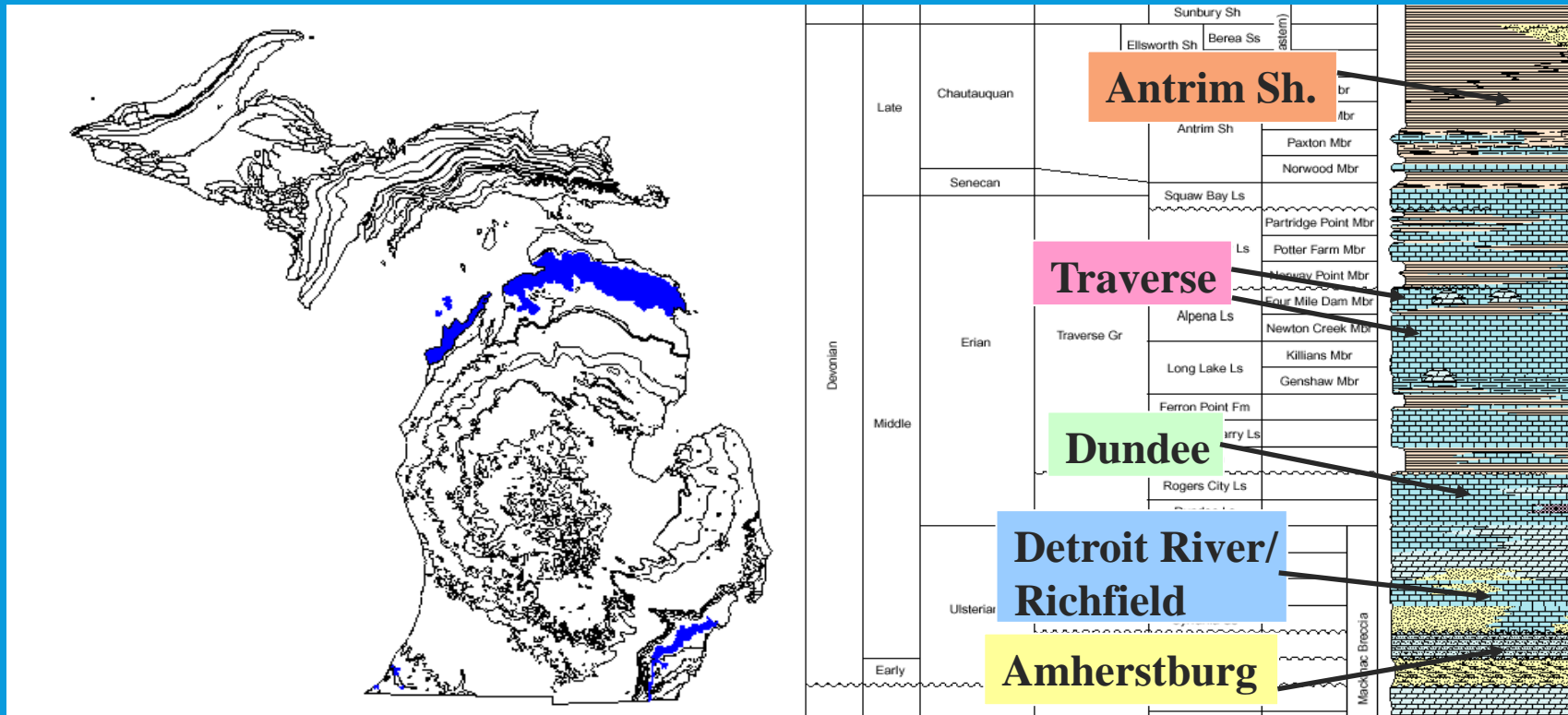
Western Michigan University-Michigan Geological Survey



Devonian Hydrocarbon Production in Michigan

- Commercial development began in the 1920's with Traverse and Dundee Oil
- Detroit River Group oil and gas production began in the mid-1930's
- Antrim Shale and Amherstburg production took off in the 1980's
- Antrim Shale fields are defined as "continuous" and named by their County - over 12,000 wells have been drilled in the Antrim Shale play – all are gas producers. Currently around 9000 wells are producing.
- Traverse Lime reservoirs are found in 265 classified fields – 96 are Gas fields, 169 are oil fields
- Dundee producing fields include those with production in the Dundee, Rogers City and Reed City units. There are 171 classified fields – 42 are Gas, 128 are oil and 1 is Gas Storage
- Detroit River Group production comes from the "Detroit River *sour zone*" in the Horner Member of the Lucas Fm. and the Richfield Member of the Lucas Fm. There are 114 classified fields in this interval.
- Amherstburg production comes from 5 known fields

Hydrocarbon Producing Devonian Rocks in Michigan



Antrim Sh.

Traverse

Dundee

**Detroit River/
Richfield**

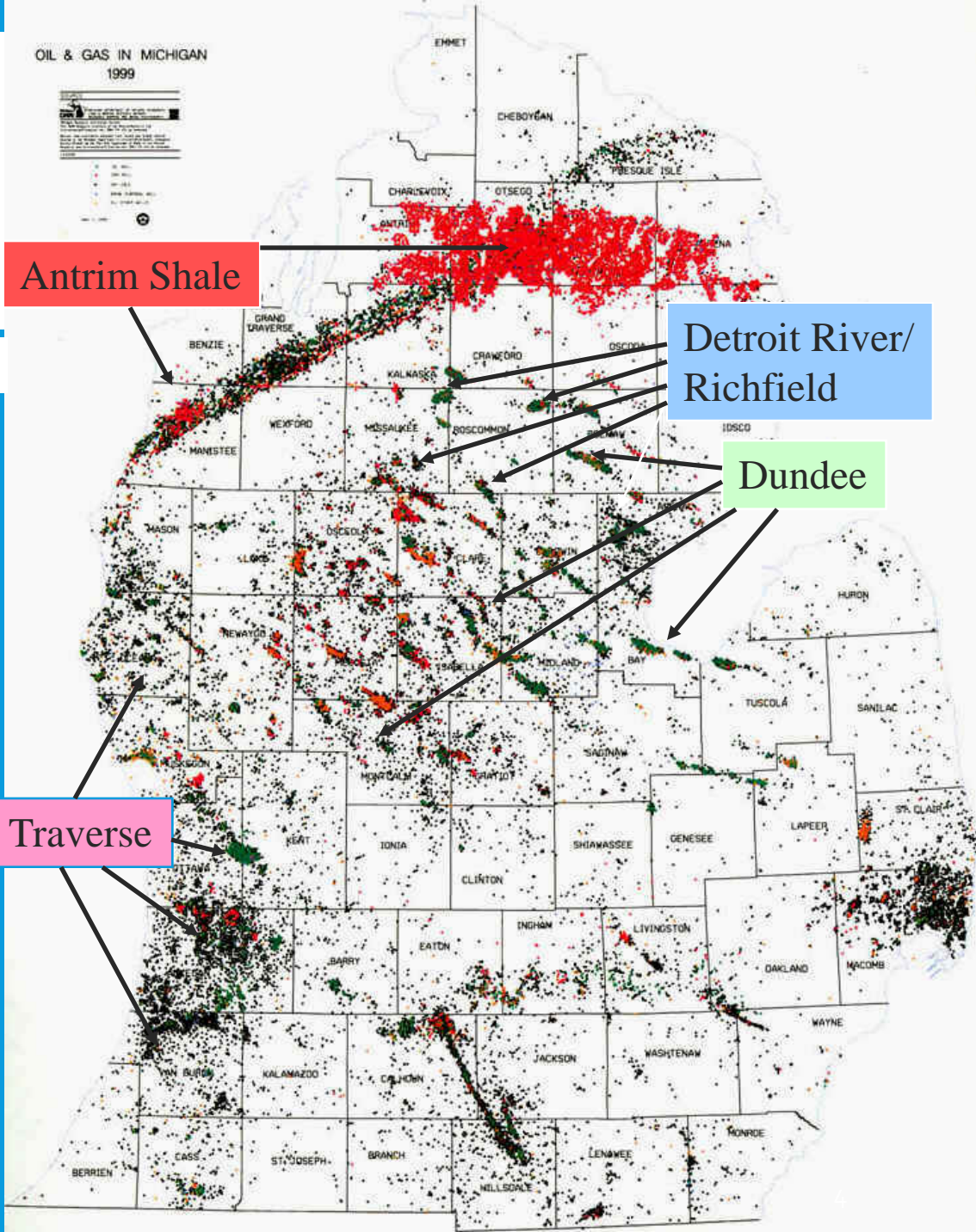
Amherstburg

Modified from Michigan Geological Survey Presentation—"The Rock Cycle"

Devonian reservoirs include Antrim Shale, Traverse Limestone, Dundee Formation, Detroit River Group and Amherstburg Fm. Outcrop and Subcrop of these rocks shown in blue.

MAP OF OIL AND GAS WELLS FOR MICHIGAN'S DEVONIAN RESERVOIR PLAYS

From State of Michigan Geological Survey, 2003



Antrim Shale

Detroit River/
Richfield

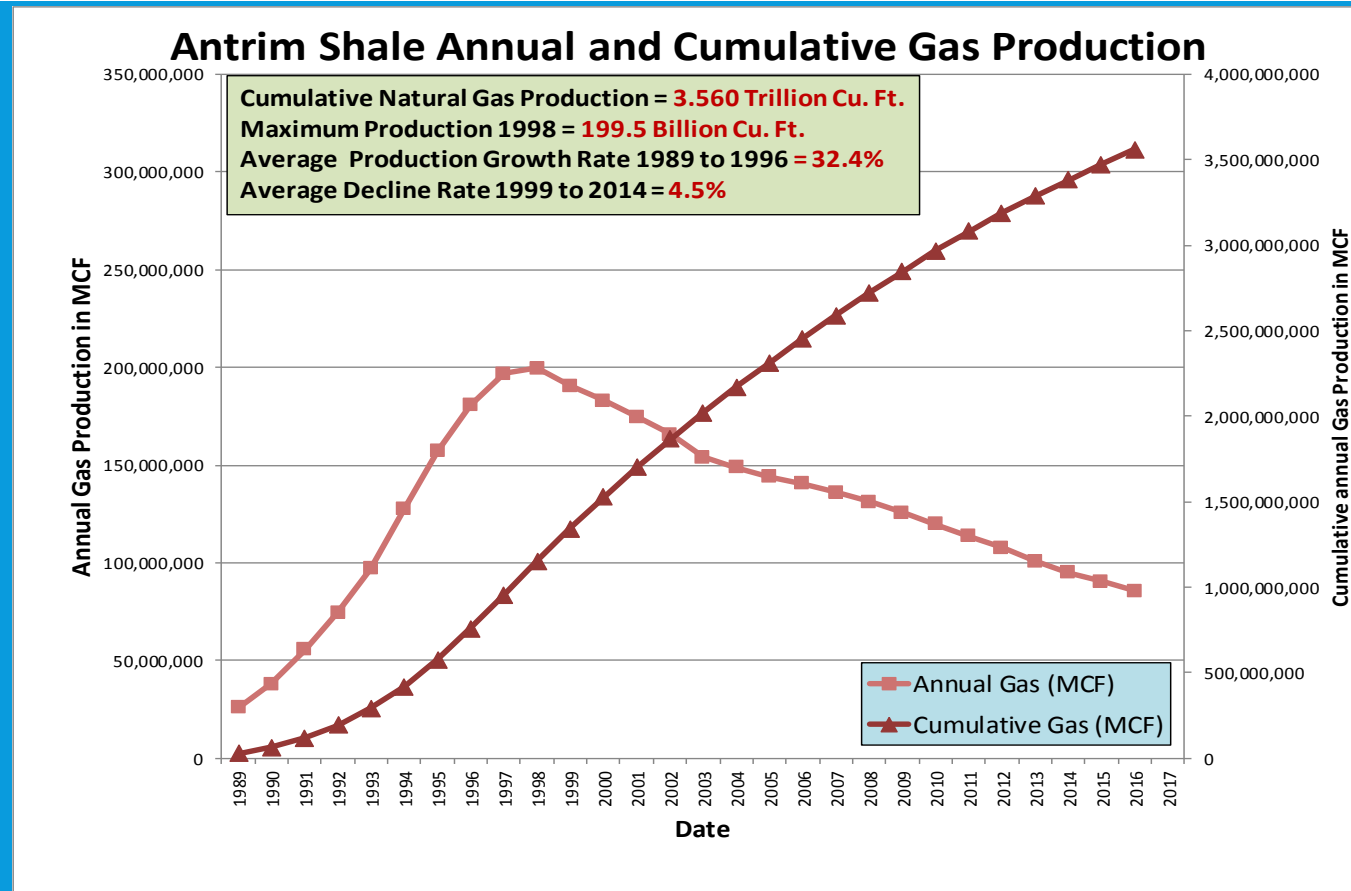
Dundee

Traverse



Antrim Shale Production in Michigan

- Antrim Shale production began in the 1940's, but large-scale, commercial began in the 1980's
- Production peaked in 1998
- Cumulative production through 2016 is 3,560,645,741 MCF of natural gas.
- Two wells in 2015 produced 1115 bbls oil from central basin



ANTRIM SHALE – LACHINE MEMBER

Welch-St. Chester 18, Otsego County



- The Antrim Shale is an organic-rich (up to 25% TOC)
- There is moderate clay content and high silica content
- Extensive fracturing may be present from a combination of glacial unloading and rebound and deeper tectonic structures
- Fresh water recharge into the fractures facilitates methanogenic bacteria

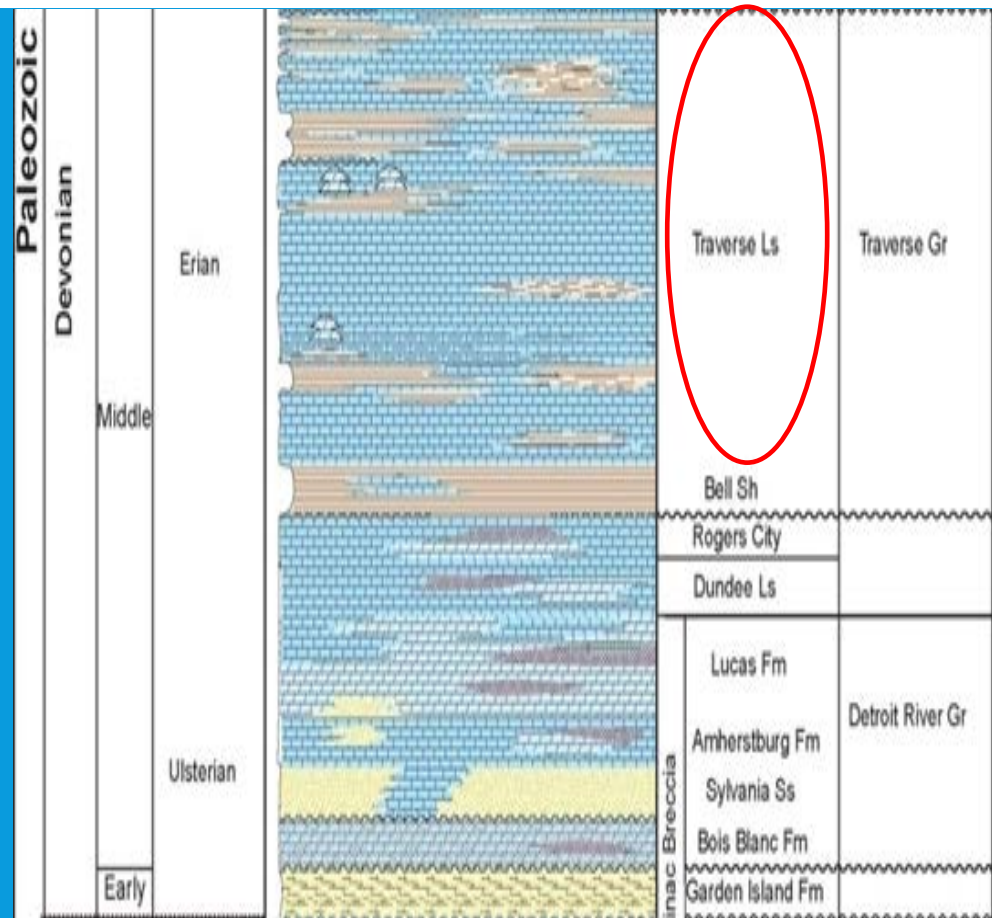
Michigan Basin during Middle Devonian Time



- Located about 25 degrees south of the Equator in the tropical trade winds belt
- Shallow marine and peritidal depositional environments
- Predominately carbonate systems with low clastic input most of the time

TRAVERSE LIME STRATIGRAPHY

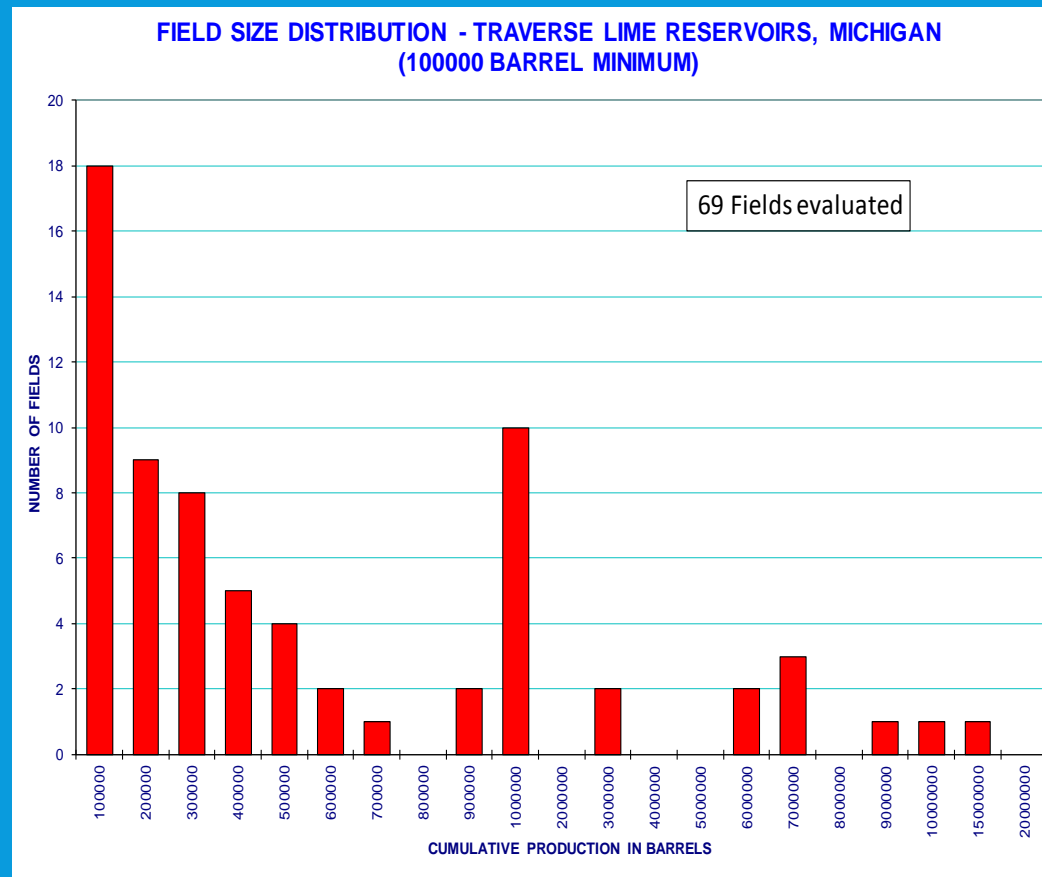
- Traverse Limestone is defined from outcrops and in Quarries in northern Lower Michigan
- “Traverse Lime” is general subsurface name for entire carbonate strata between Base of the Antrim Shale and the top of the Dundee/Rogers City
- Many formations and members have been named in outcrop, but are not distinguished in subsurface
- Production is near the top of the package



(modified from
Catacosinos et al., 1990)

Traverse Lime Production in Michigan

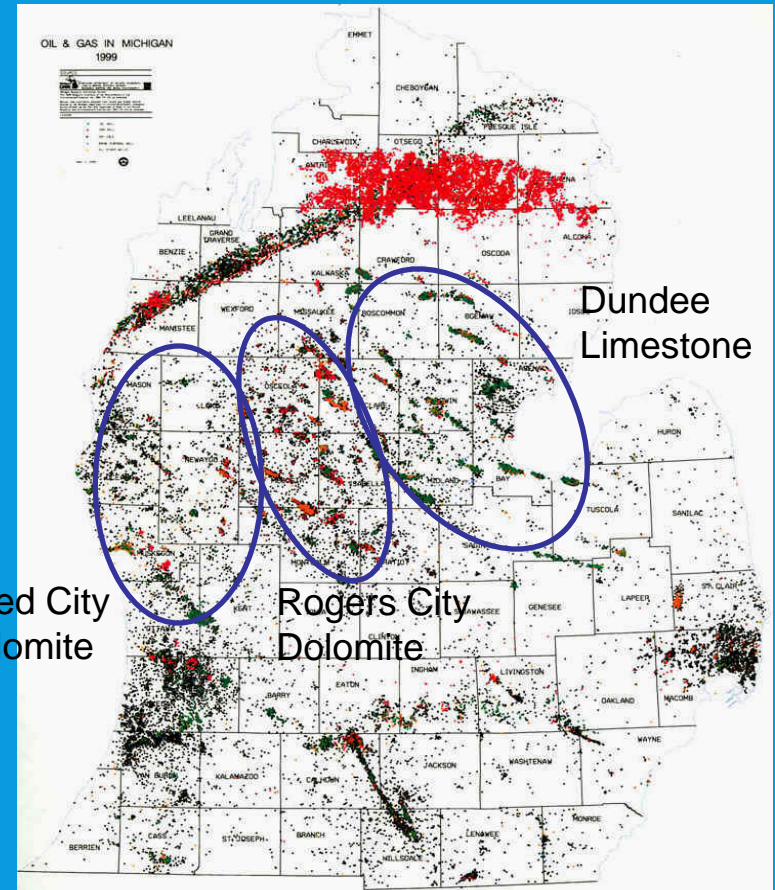
- Production from individual Devonian carbonate reservoirs cannot be precisely documented because historically production totals have been comingled from the Traverse, Dundee and Detroit River Groups in some fields. Additionally, no publicly available production data exists from 1986 to 1997. That 10 year period can only be estimated from decline curves.
- Traverse Lime has produced since the mid-1920's, but many field discoveries were made in the 1930's and 1940's. Cumulative production from the Traverse Lime play exceeds 110 million barrels of oil



TRAVERSE LIMESTONE RESERVOIRS



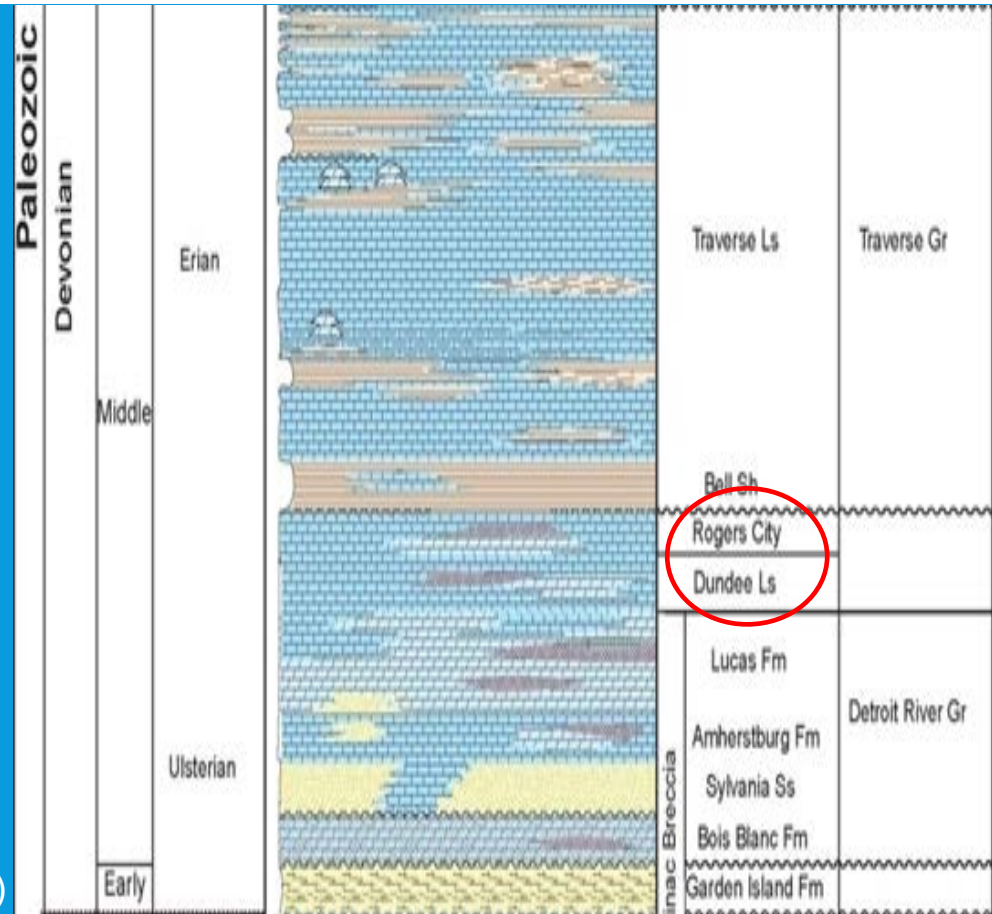
Scale of Michigan compared to Modern Bahama Platform (Same Scale on Both)



DUNDEE AND ROGERS CITY STRATIGRAPHY

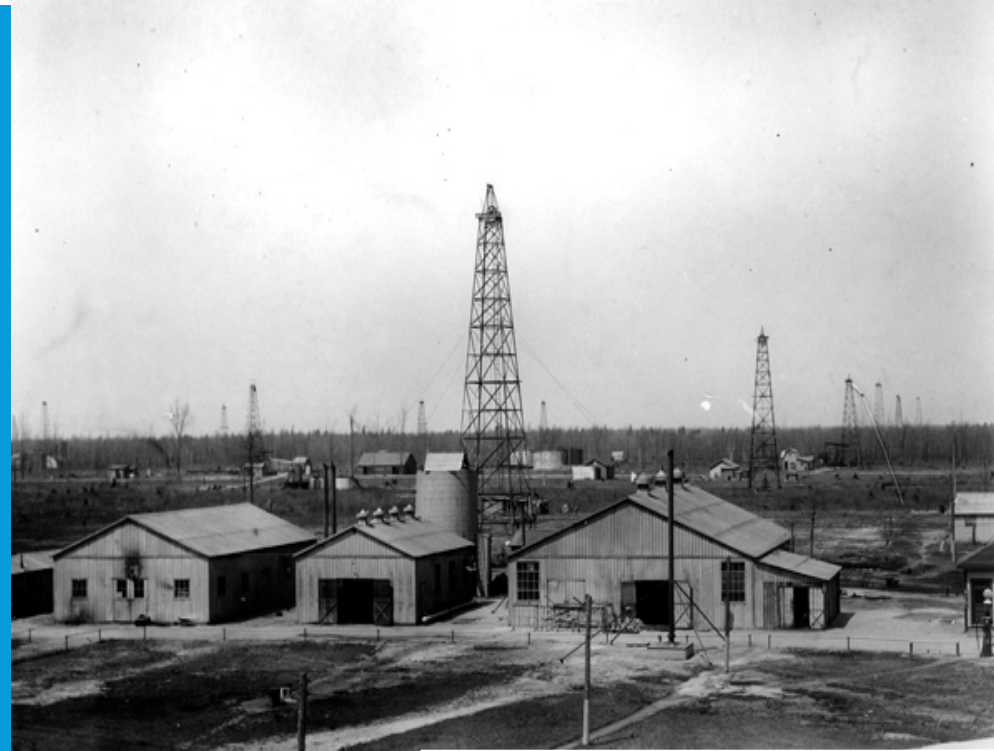
- Rogers City and Dundee Formations are defined from exposures in Quarries in Presque Isle Co.
- “Dundee” is general subsurface name for entire carbonate strata between Lucas Fm. and Bell Shale
- Both can be distinguished in subsurface

(modified from Catacosinos et al., 1990)



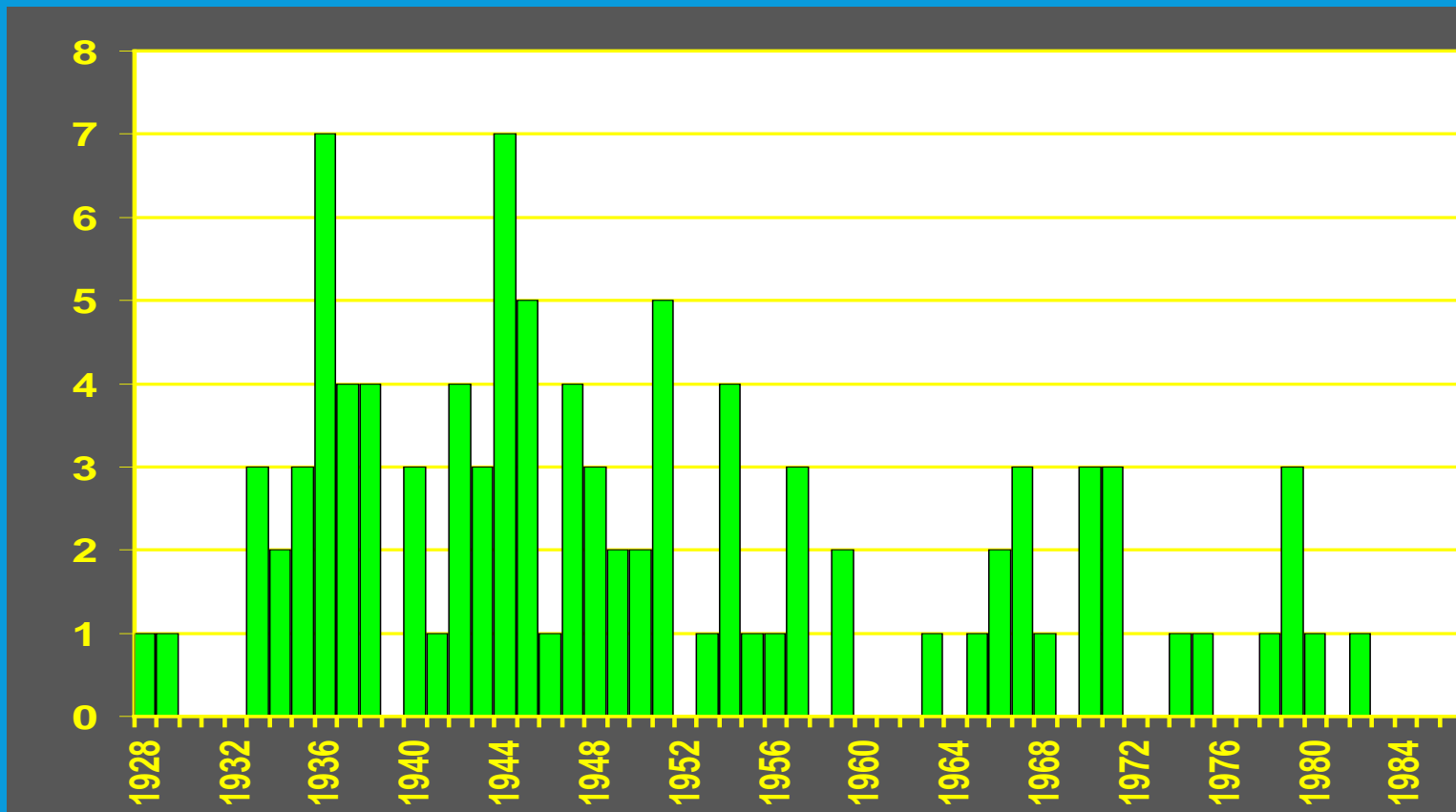
Dundee Production in Michigan

- Dundee production comes from three separate horizons in the unit. The Rogers City Fm. directly underlies the Bell Shale and is productive only when altered to Dolomite. The Reed City Member of the Dundee is a restricted dolomite unit below an Anhydrite member in the western part of the basin.
- Cumulative oil production more than 360 million Bbls from 1928-1986 and 1997-2015 (*1987 to 1996 production from the Dundee and Reed City is not reported, estimated 15-20 additional BBLs*)
- First discovery in 1928 (Mt Pleasant Field)
- Most fields discovered in 1930's and 1940's
- Reservoirs in both limestone and dolomite

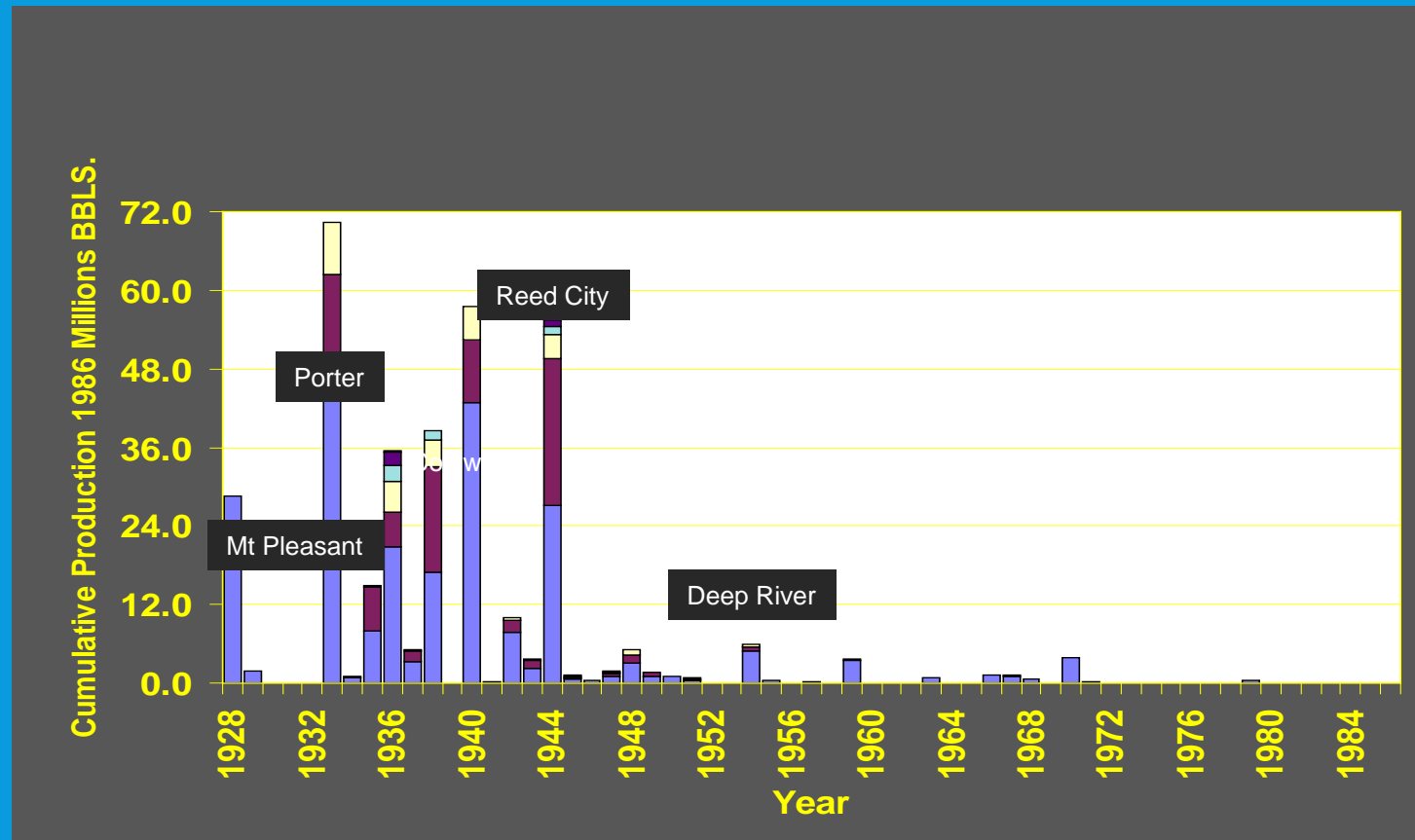


Mt Pleasant Oil Field - ca. 1930's
Courtesy of archives at Clarke
Historical Library, Central Michigan
University

NUMBER OF DUNDEE FIELDS DISCOVERED PER YEAR



DUNDEE FIELD SIZES BY DISCOVERY YEAR



DUNDEE RESERVOIR LITHOLOGIC TYPES

- Limestone - depositional fabrics
 - Grainstone shoal sand bodies
 - Fenestral peritidal packstones and wackestones
 - Stromatoporoid/coral boundstone patch reefs
- Dolomite - burial diagenetic fabrics
 - Fractured, vuggy, hydrothermal dolomite
 - Matrix, intercrystalline and vuggy dolomite
 - Sucrosic, laminated, dolomite with anhydrite

DUNDEE RESERVOIR DEPOSITIONAL FABRICS

Reed City

MichCon-LoReed #LR 83-2 Osceola Co.



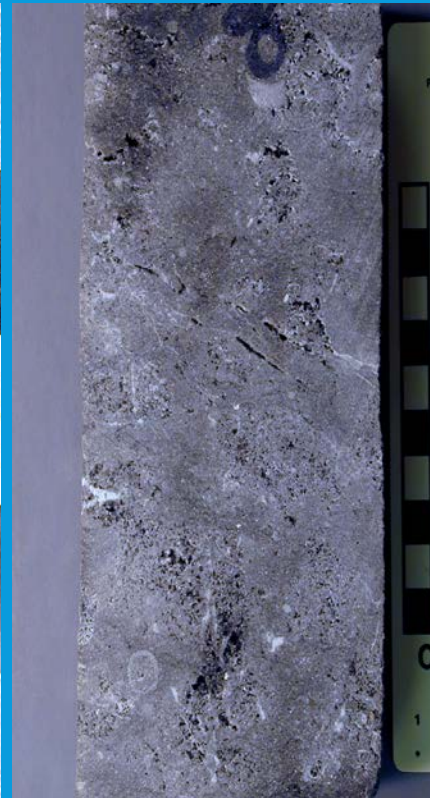
Dundee

Wiser-Sturm #4-0 Gladwin Co.



Rogers City

Thelma Rousseau #1-12 Mecosta Co.



Laminated and Fenestral
Wackestone and Mudstone

Reef and Reef
Skeletal Debris

Skeletal
Packstone

PLAY BY PLAY
EXPLORING THE MICHIGAN BASIN



LITHOLOGIC PROPERTIES IN DUNDEE LIMESTONE RESERVOIRS



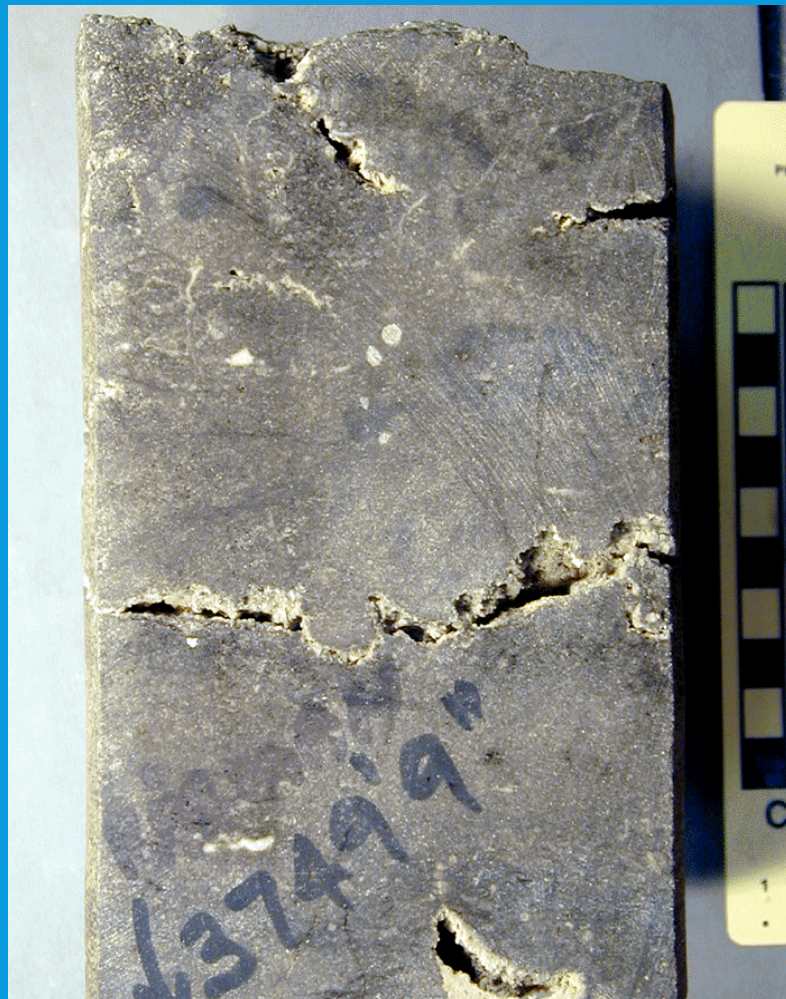
- Limestone reservoirs have significant original depositional fabrics preserved
- Porosity is primarily intergranular or intragranular
- Burial diagenesis has added some cements and produced chemical compaction (stylolites)
- Fracturing may or may not play a role

LITHOLOGIC PROPERTIES IN DUNDEE DOLOMITE RESERVOIRS

- Dolomite reservoirs have pervasive replacement of original sediment
- Some original depositional fabric is preserved and provides a template for additional diagenesis
- Solution enhanced pores and vugs are common, often with HTD cements
- Intercrystalline porosity important
- Fractures usually occur and may be abundant

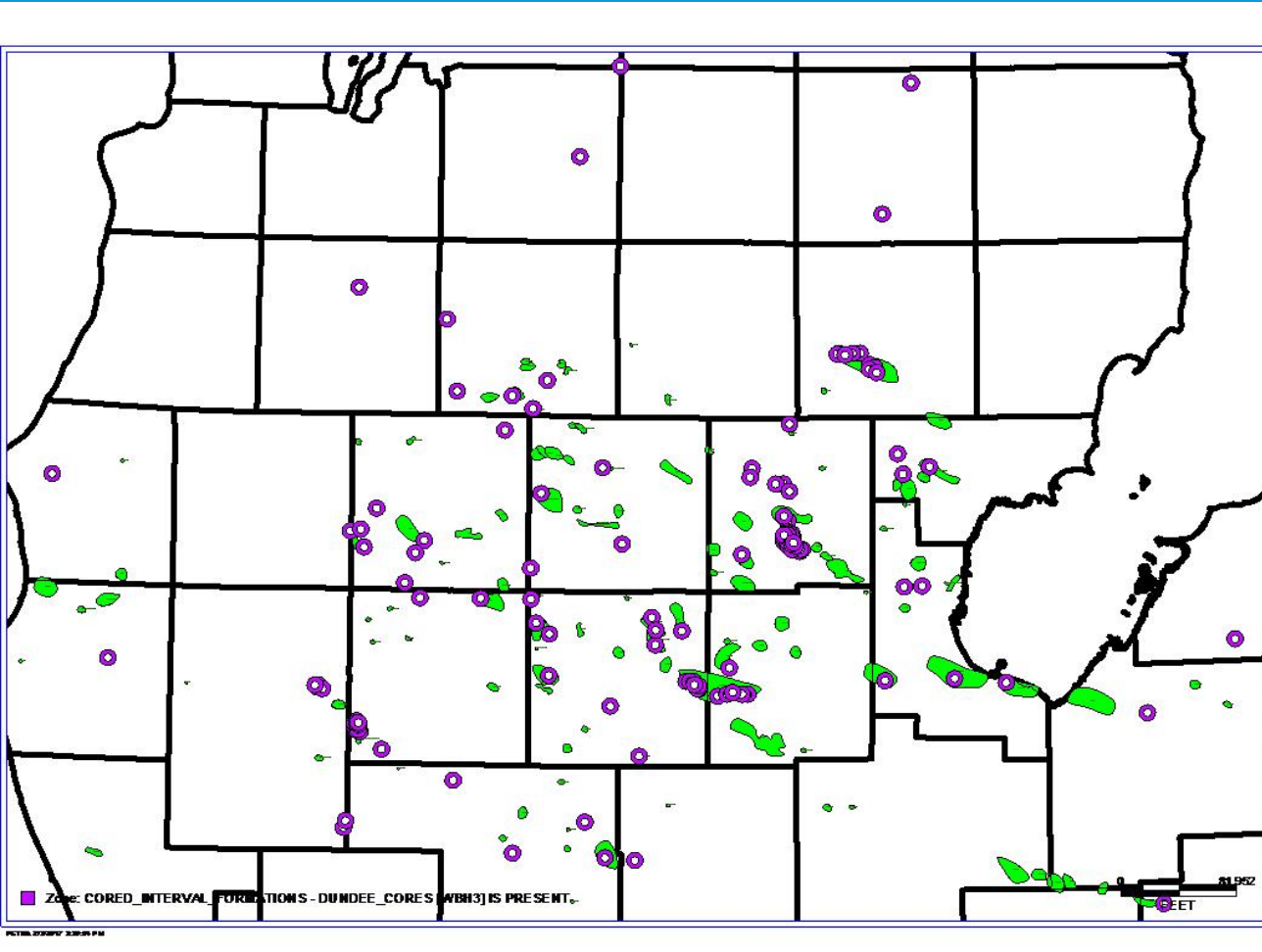
DOLOMITE-LINED SOLUTION ENLARGED VUGGY POROSITY

- Core from Reiman #1 well in Cat Creek Field, Osceola Co., MI
- White “Saddle” Dolomite lining pores
- Matrix is fine to medium crystalline planar dolomite
- Intercrystalline porosity up to 5%



REIMAN #1, Osceola County, MI

DUNDEE FIELDS MAP WITH CORED WELLS

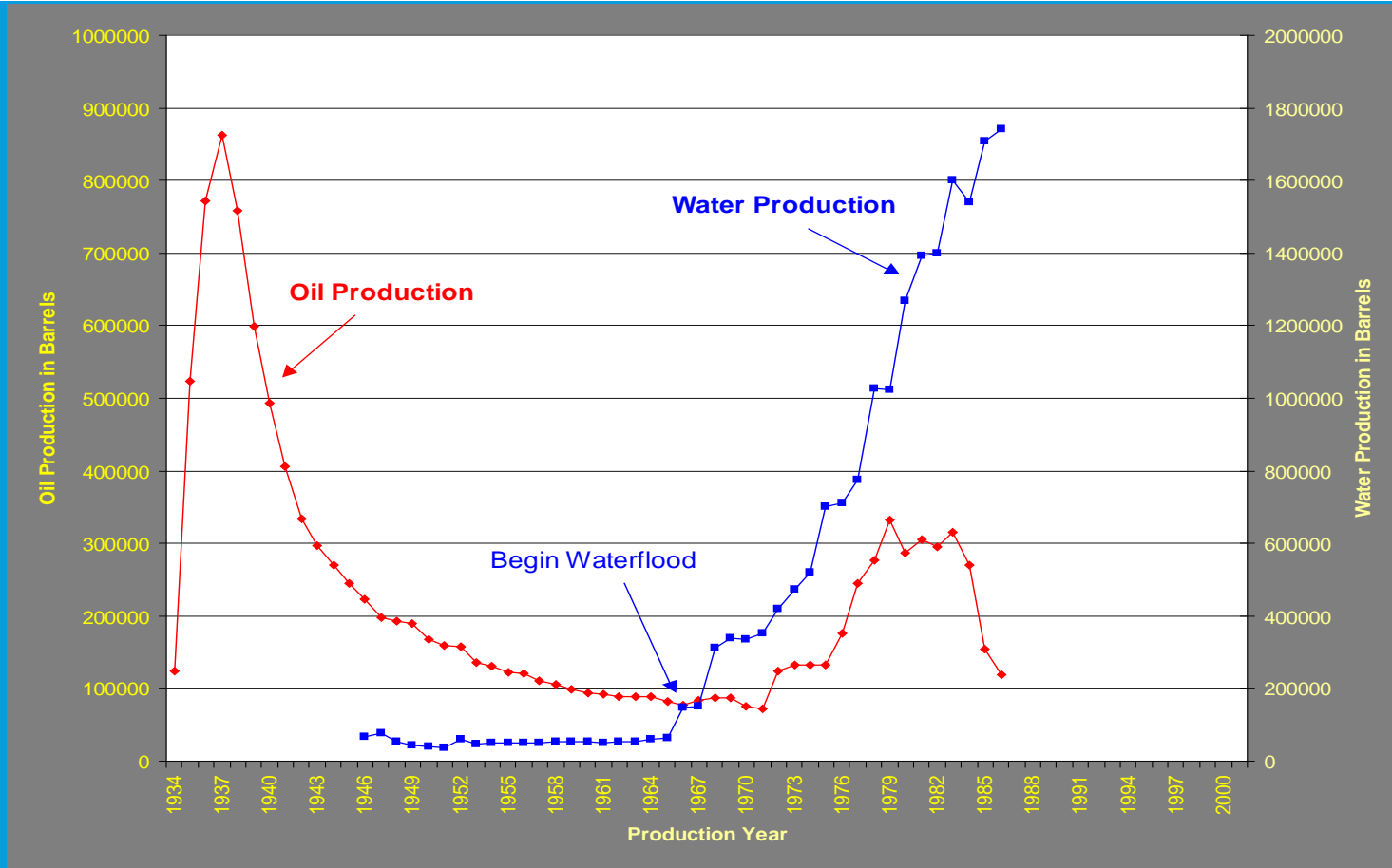


- 134 core wells in Dundee, Rogers City or Reed City intervals
- Cores represent all three zones of Dundee production
- Many are in Producing fields, but some are dry holes

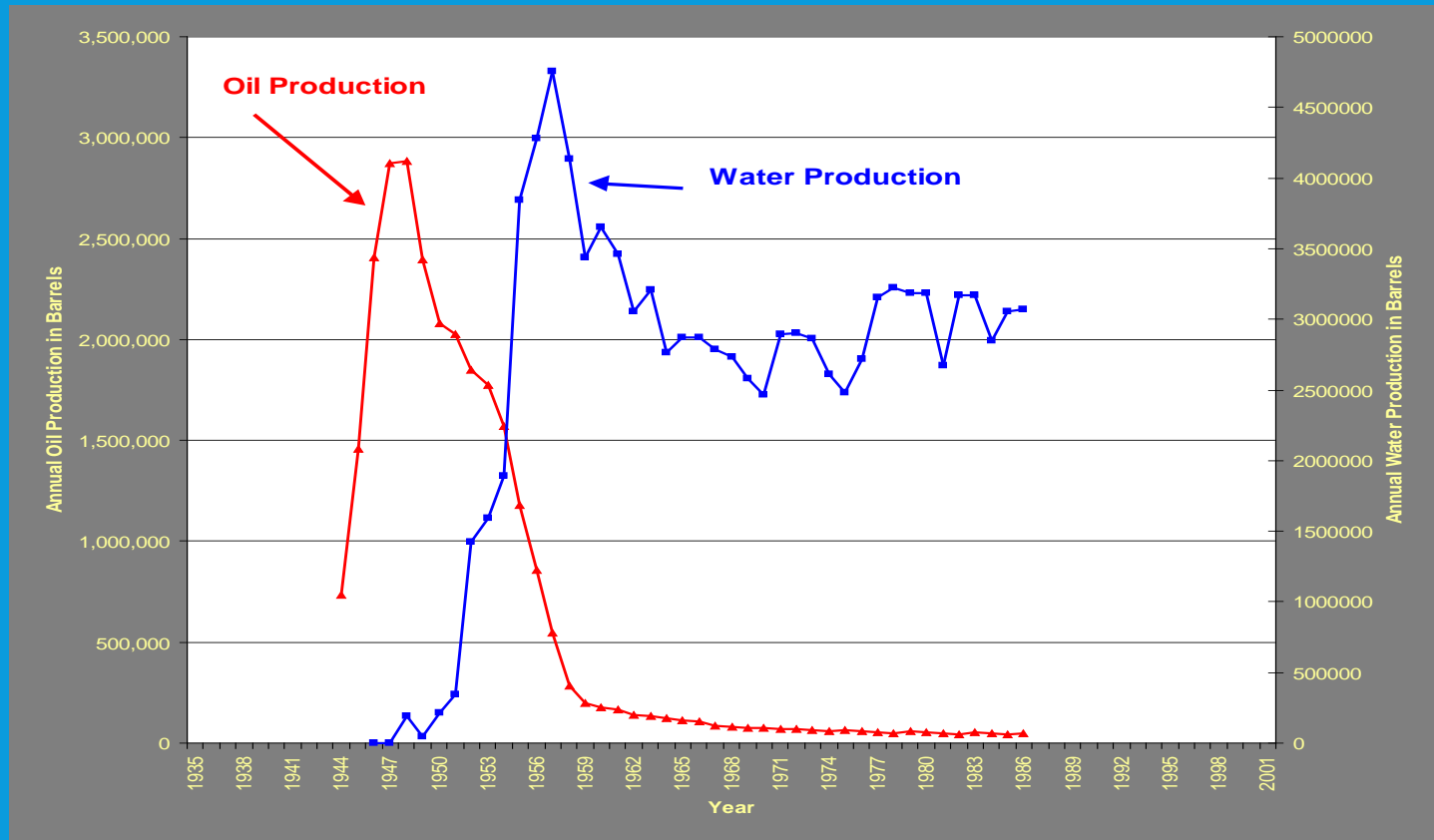
DUNDEE DRIVE MECHANISMS- PRIMARY AND SECONDARY RECOVERY FACTORS

- Limestone reservoirs have porous facies generally only on structures, relatively tight off structure – main drive is solution gas/gas expansion – as pressure in reservoir depletes, primary recovery will be low - good secondary potential
- Dolomite reservoirs have extensive porosity off structure because of regional dolomitization – main drive is bottom or lateral water drive – reservoir pressure does not deplete very much – limited secondary recovery potential

ANNUAL OIL AND WATER PRODUCTION WEST BRANCH FIELD - LIMESTONE - GRAINSTONE



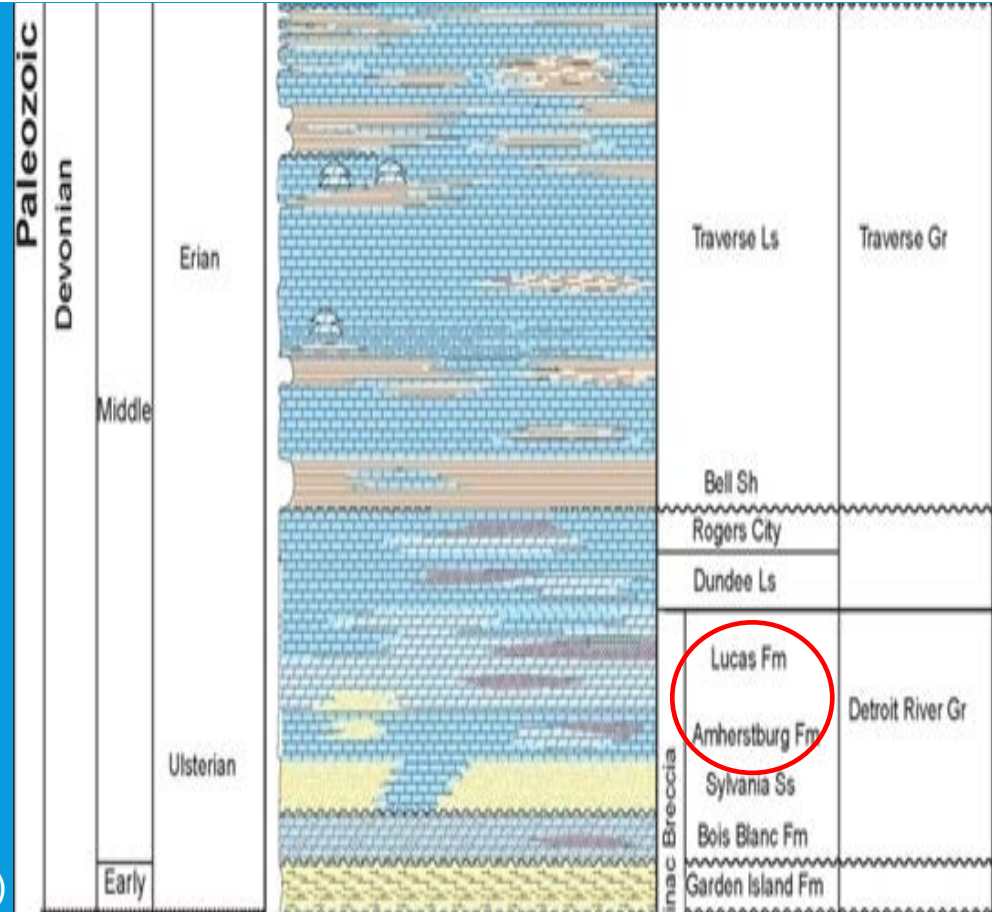
ANNUAL OIL AND WATER PRODUCTION DEEP RIVER FIELD – FRACTURED DOLOMITE



LUCAS AND AMHERSTBURG STRATIGRAPHY

- Rogers City and Dundee Formations are defined from exposures in Quarries in Presque Isle Co.
- “Dundee” is general subsurface name for entire carbonate strata between Lucas Fm. and Bell Shale
- Both can be distinguished in subsurface

(modified from Catacosinos et al., 1990)



Detroit River Group Production

- Detroit Rive Group Produces from two zones in restricted, sucrosic Dolomite, “sour Zone” in the Horner member of the Lucas Fm. and the Richfield Member of the Lucas Fm.
- 94 fields are classified as Oil fields – some fields produce from both zones, some from only one zone
- Cumulative production from the two zones is in excess of 100 million barrels of oil and 89 BCF of gas
- Waterflooding operations have been initiated in 20 of these fields, 10 in the Richfield and 10 in the Detroit River “sour zone” or in both units.
- Top 10 fields have produced 86% of the play’s oil.

Field Name	County	Total wells	Active Wells	Field Acres	Cum Oil BBLs	Cum Gas MCF
Beaver Creek	Crawford	138	84	4960	24,080,332	21,102,461
East Norwich	Missaukee	257	188	5760	17,000,000	17,000,000
Rose City	Ogemaw	134	70	5360	11,500,000	12,000,000
St Helen	Roscommon	153	101	4600	9,000,000	15,000,000
Hamilton	Clare	47	26	1870	6,000,000	3,000,000
Enterprise	Missaukee	76	55	1760	5,500,000	2,500,000
Reed City	Osceola	45	21	1800	5,000,000	4,000,000
Rich	Lapeer	58	31	2160	3,500,000	5,500,000
Headquarters	Roscommon	70	41	2320	3,000,000	2,500,000
Kawkawlin	Bay	21	20	780	2,500,000	1,500,000

RICHFIELD MEMBER OF THE LUCAS FM. RESERVOIR AND INTERNAL ANHYDRITE SEALS

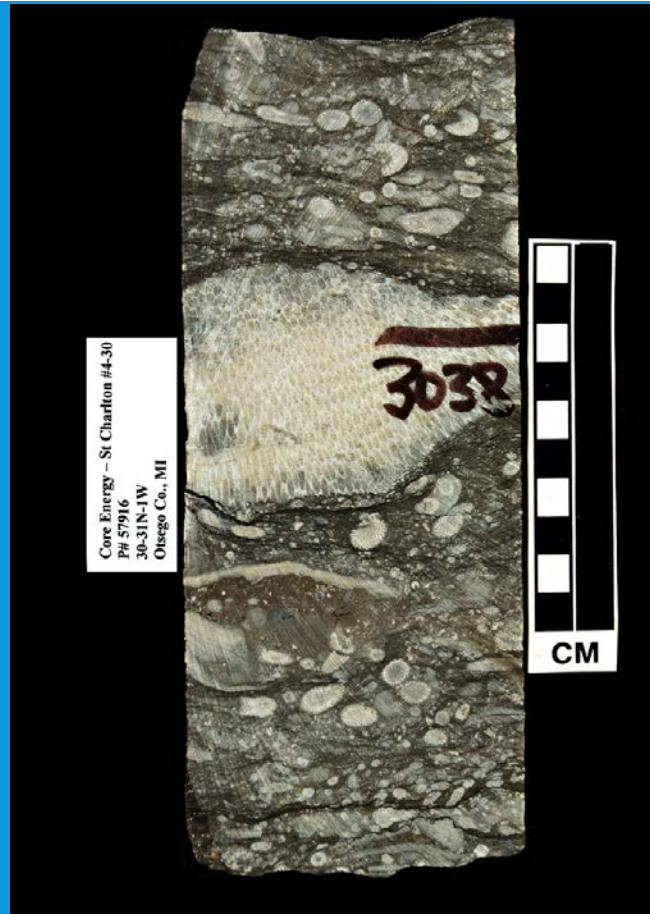


Dart-Porter Hogan #1-17, Roscommon County

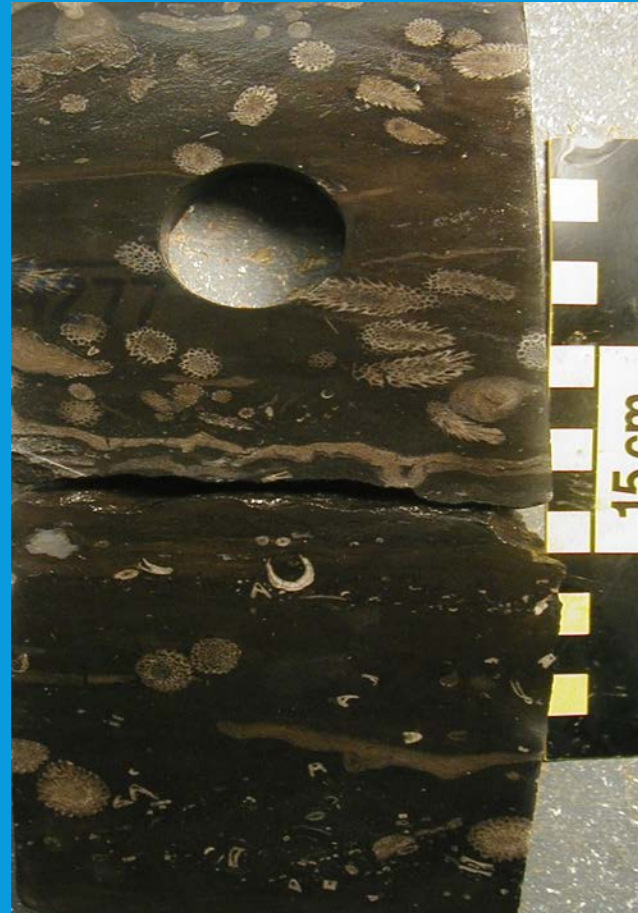
PLAY BY PLAY
EXPLORING THE MICHIGAN BASIN



Amherstburg Fm. – Source Rock and Reservoir



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



Hunt-McGuire #1-22, Oscoda Co.

Summary and Conclusions

- Devonian Reservoirs in Michigan represent about 45 % of the oil production and 50% of the natural gas production all time from the State.
- Total oil production exceeds 585 million barrels, Gas production exceeds 3.8 TCF
- Reservoirs are mostly found in Carbonate rocks, with dolomitized reservoirs generally be higher quality, but some Limestone zones maintain porosity and permeability due to specific original depositional facies
- The Antrim Shale is the only non-Carbonate producing zone in the Devonian of Michigan
- Secondary recovery has been attempted in the oil reservoirs of several plays with good results in some units and poor performance in some others