Depositional Controls on Reservoir Quality in the Dundee-Rogers City Interval: Lithofacies and Production Characteristics*

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Abstract

The Dundee-Rogers City interval has been a prolific producer of hydrocarbons since the 1920's in the Michigan Basin with cumulative production of more than 360 million barrels of oil. Three general categories of reservoirs are found in the Dundee-Rogers City: 1.) primary and intercrystalline porosity in dolomites sealed by anhydrites (western central Lower Peninsula), 2.) vuggy and intercrystalline porosity in hydrothermal dolomite reservoirs (central Lower Peninsula), and 3.) primary porosity in limestone reservoirs (eastern Lower Peninsula). In the central and eastern basin, the Dundee-Rogers City reservoirs are sealed by a combination of tight limestone (Dundee-Rogers City) or shale (Bell Shale). The Dundee Formation consists of a paralic to open shelf carbonate deposits. The Dundee exhibits a trend of deeper water deposits to the east, with dominantly tidal flat, sabkha, and shallow lagoon deposits in the west, followed by sand shoals, patch reefs, and open shelf deposits in the central and eastern Lower Peninsula. The overlying Rogers City Formation represents a flooding event with deeper water outer shelf deposits laid on top of the Dundee. Grain-rich beach deposits bear both intergranular and open fenestral porosity. In the eastern basin, primary porosity includes intraskeletal (patch reefs), intergranular (shoals), and vugs. Dolomitization in the western Dundee was early and preserved primary depositional fabrics. In the central basin, primary porosity provided pathways for dolomitizing fluids to invade fractured Dundee-Rogers City limestones. Dolomitization enhanced the porosity generating both intercrystalline and vuggy porosity. This phase of dolomitization is not fabric preserving. Fracturing and fluid migration are linked to reactivation of basement structures during the Acadian and Alleghenian orogenies. Limestone and Dolomite Reservoirs

in the Dundee-Rogers City interval behave differently during production. Dolomite reservoirs maintain near virgin reservoir pressure throughout their production history. Strong bottom water drive pushes the oil-water contact up during production and produced water increases throughout the lifetime of wells in the dolomite reservoirs. Conversely, the limestone Dundee reservoirs tend to exhibit overall decrease in reservoir pressure during production. Water production is much lower in the limestone reservoirs. The limestone reservoirs are more productive during secondary production operations.

References Cited

Catacosinos, P.A., W.B. Harrison III, R.F. Reynolds, D.B. Westjohn, and M.S. Wollensak, 2001, Stratigraphic Lexicon for Michigan: Bulletin, Geological Survey Division, Department of Environmental Quality and Michigan Basin Geological Society, Lansing, MI, v. 8, 56 p.

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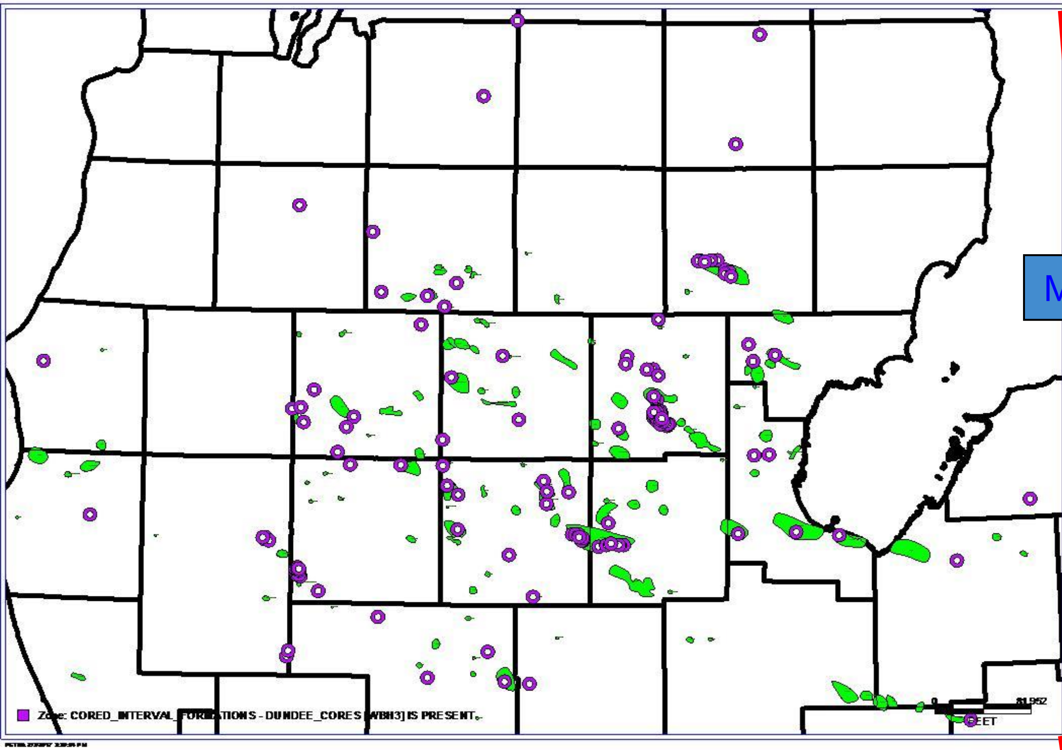
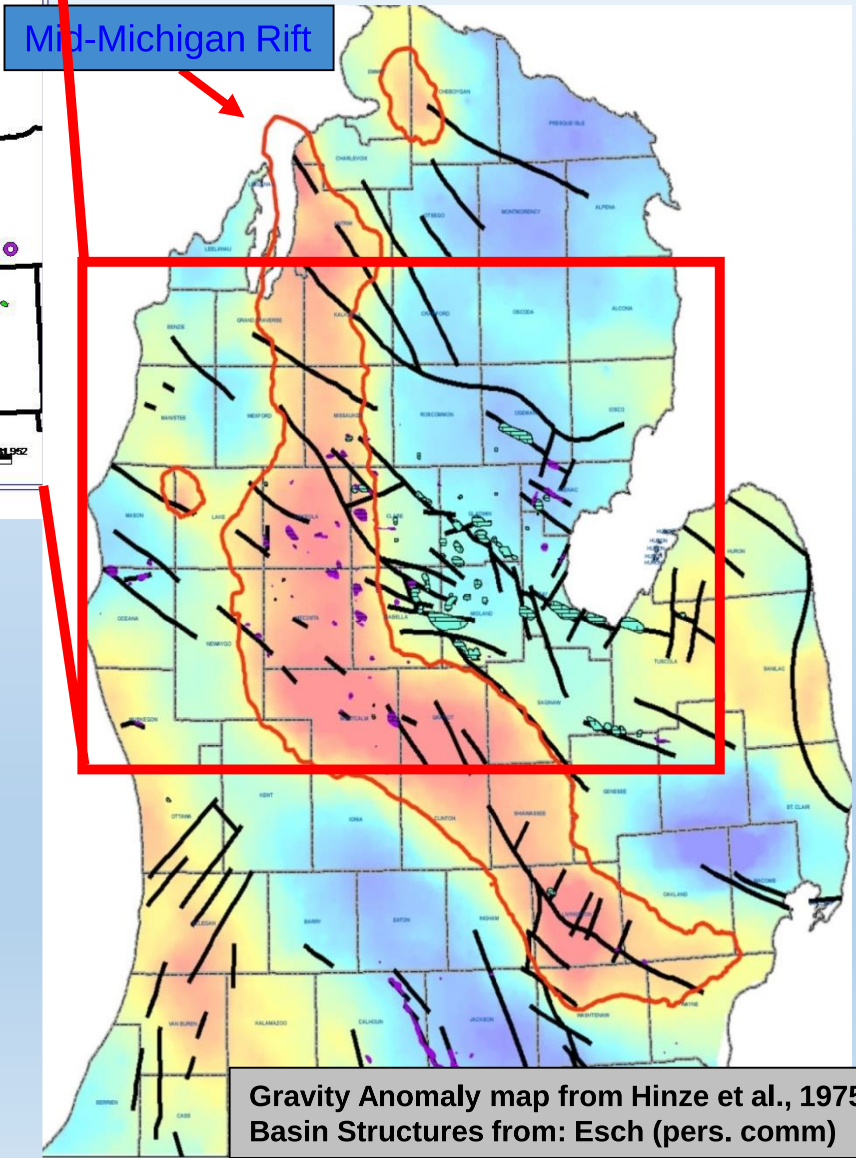


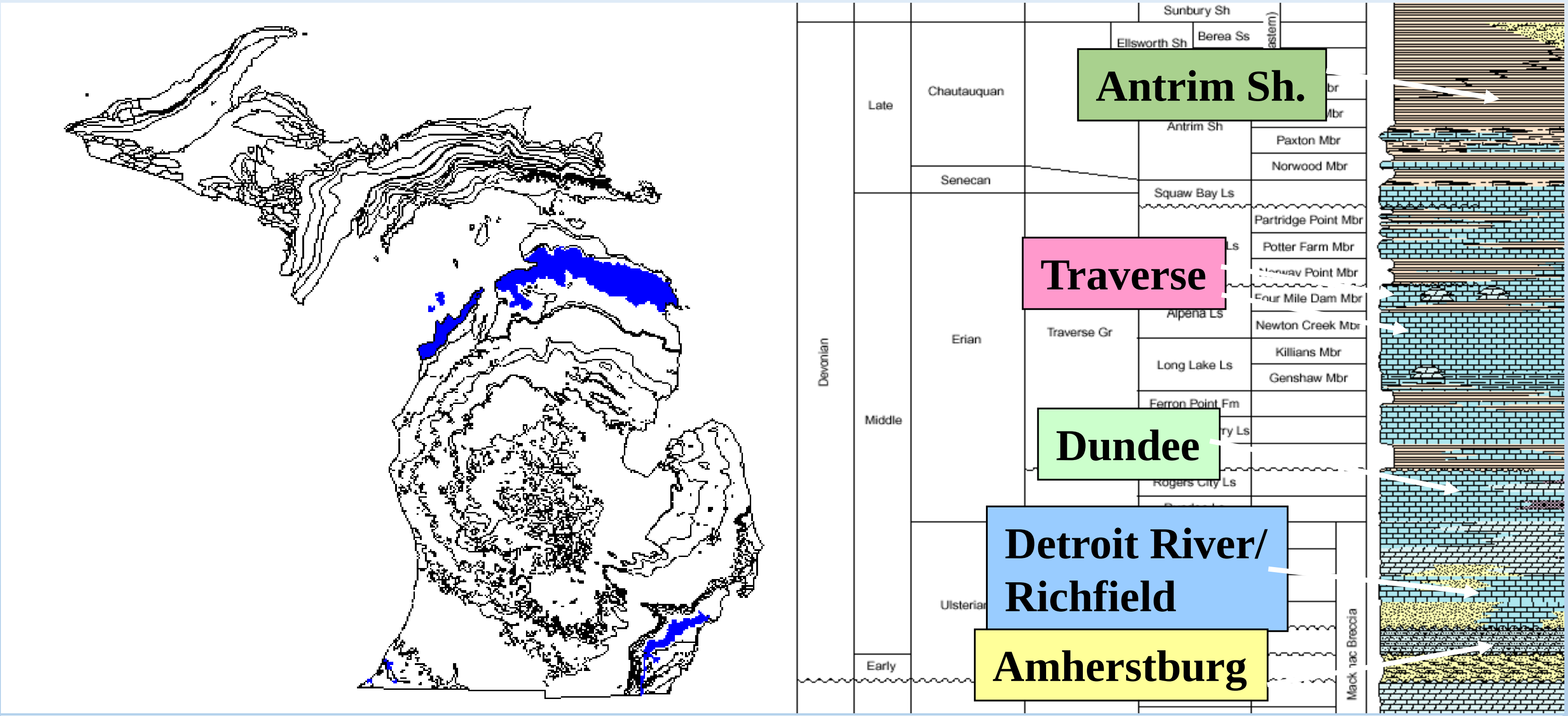
134 Cores in our collection – Dundee-Rogers City Interval!



Gravity Anomaly map from Hinze et al., 1975; Basin Structures from: Esch (pers. comm)

Field Maps courtesy of Dave Barnes

Hydrocarbon Producing Devonian Rocks in Michigan



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

Regional Stratigraphy

Western Michigan | **Eastern Michigan**

Bell Shale, Traverse Group

Sequence Boundary

Rogers City Formation

Rogers City Formation

Maximum Flooding Surface

"Reed City Anhydrite"

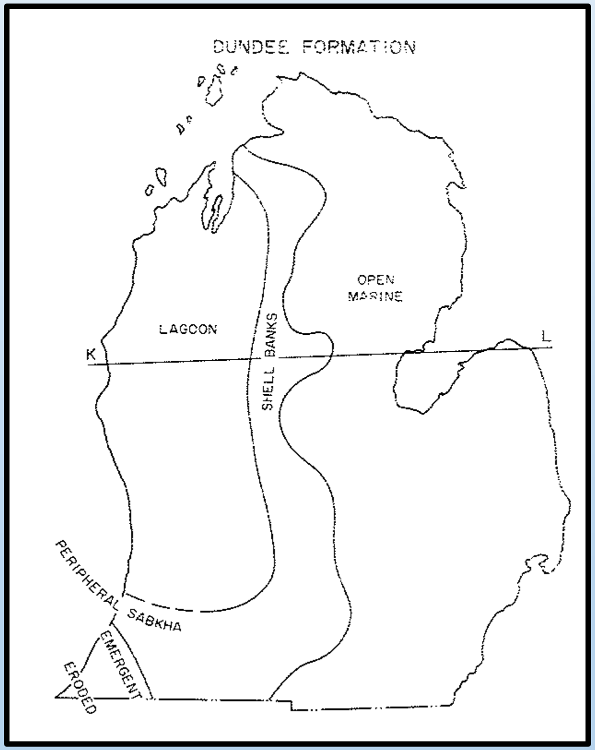
Dundee Limestone

"Reed City Dolomite"

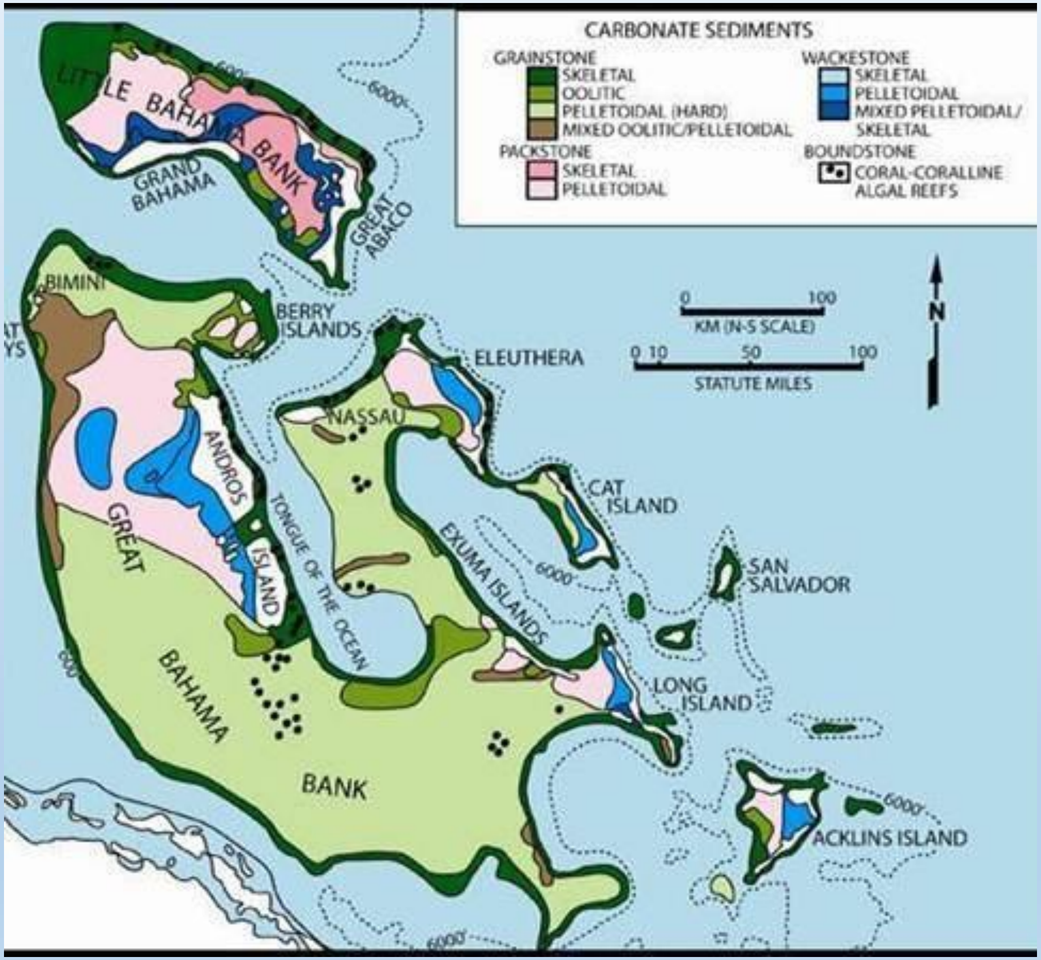
Dundee Formation

Lucas Formation, Detroit River Group

Great Bahama Bank and Michigan at the same scale

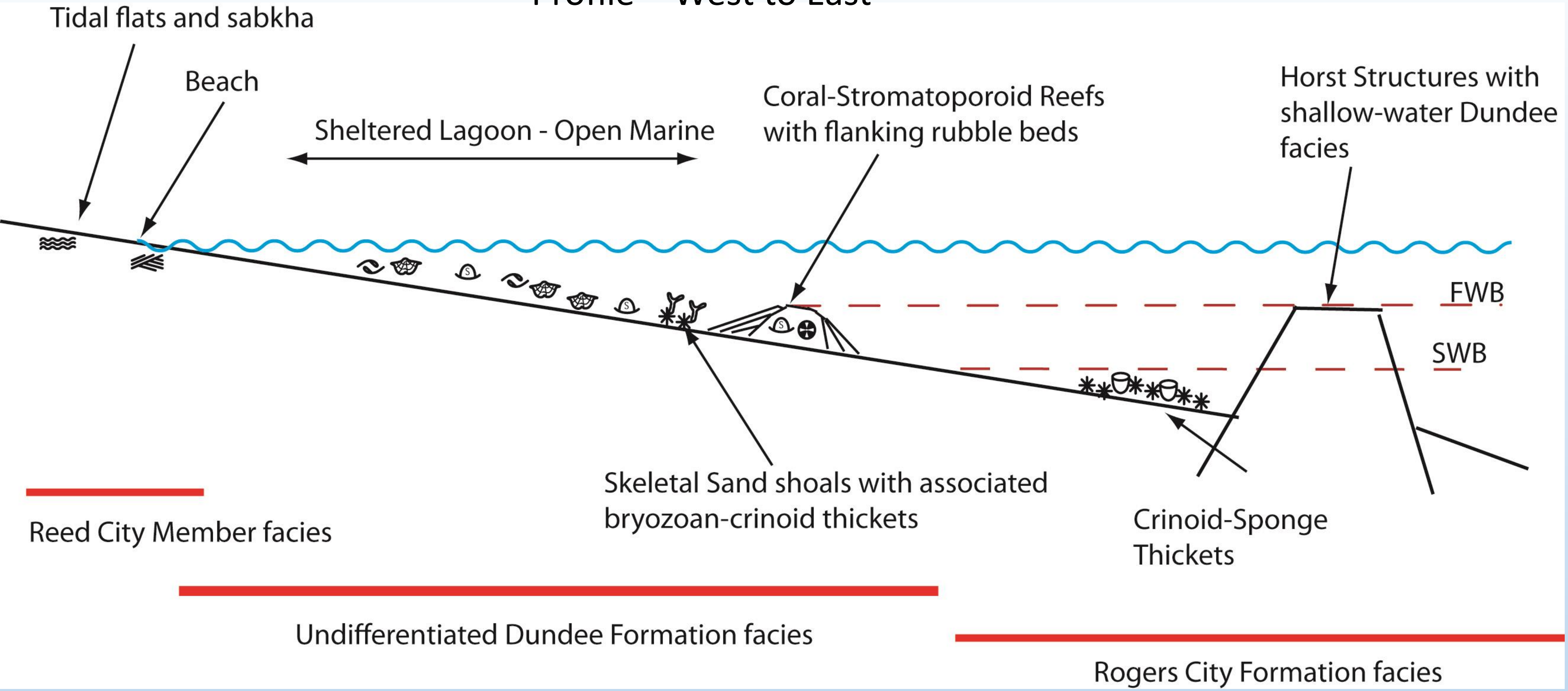


Gardner, 1974



Enos and Perkins, 1976

Profile – West to East



Muddy carbonates ± Gypsum, Locally grainy

Grainy carbonates

Mud-dominated Carbonates

Carbonate facies Mosaic – controlled by:

1. Bathymetric gradient – shallower water facies to west, deeper to east
2. Structural controls on bathymetry – shallower-water facies on pre-existing topography due to structures

Seals – low ϕ and K!

Algal-laminated mudstone
Associated sedimentary structures:

1. Mud cracks
2. Imbricated Rip-up intraclasts (storms, tides)
3. Soft-sediment deformation
4. Mottled Paleosols
5. Associated Anhydrites – bedded and nodular

"Reed City Anhydrite"

Nodular anhydrite in dolomudstone matrix – started out as gypsum.

MCGC LR83-2, 3545 ft., Osceola Co. (PN: 29261)

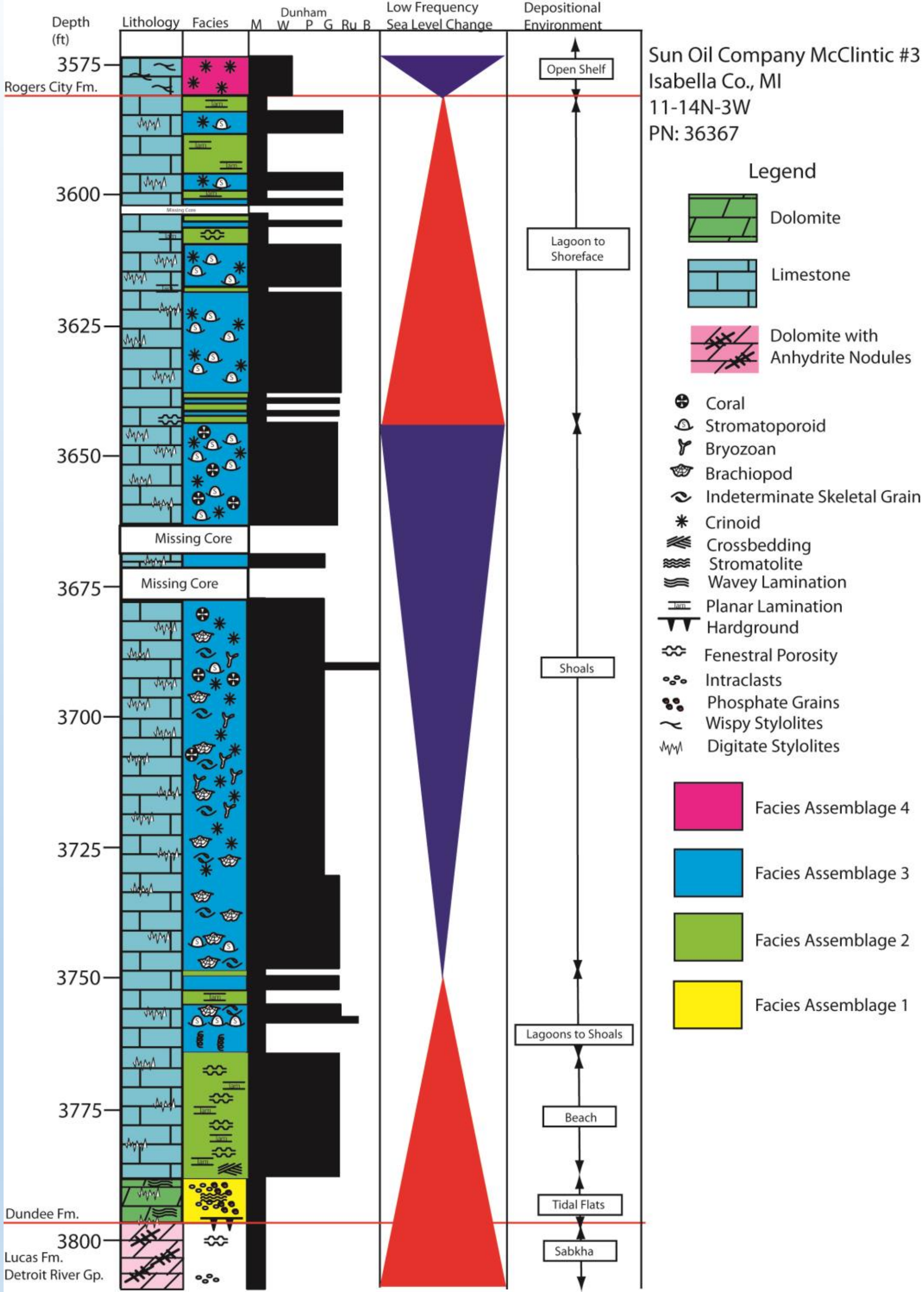
Peninsular Oil Connover Lake Trust #1-13
Newaygo Co. PN: 37265
Reed City Dolomite- Reed City Anhydrite Contact

Midwest Oil Productions Thelma Rousseau #1-12, 3949 ft., Mecosta Co. (PN: 35426)

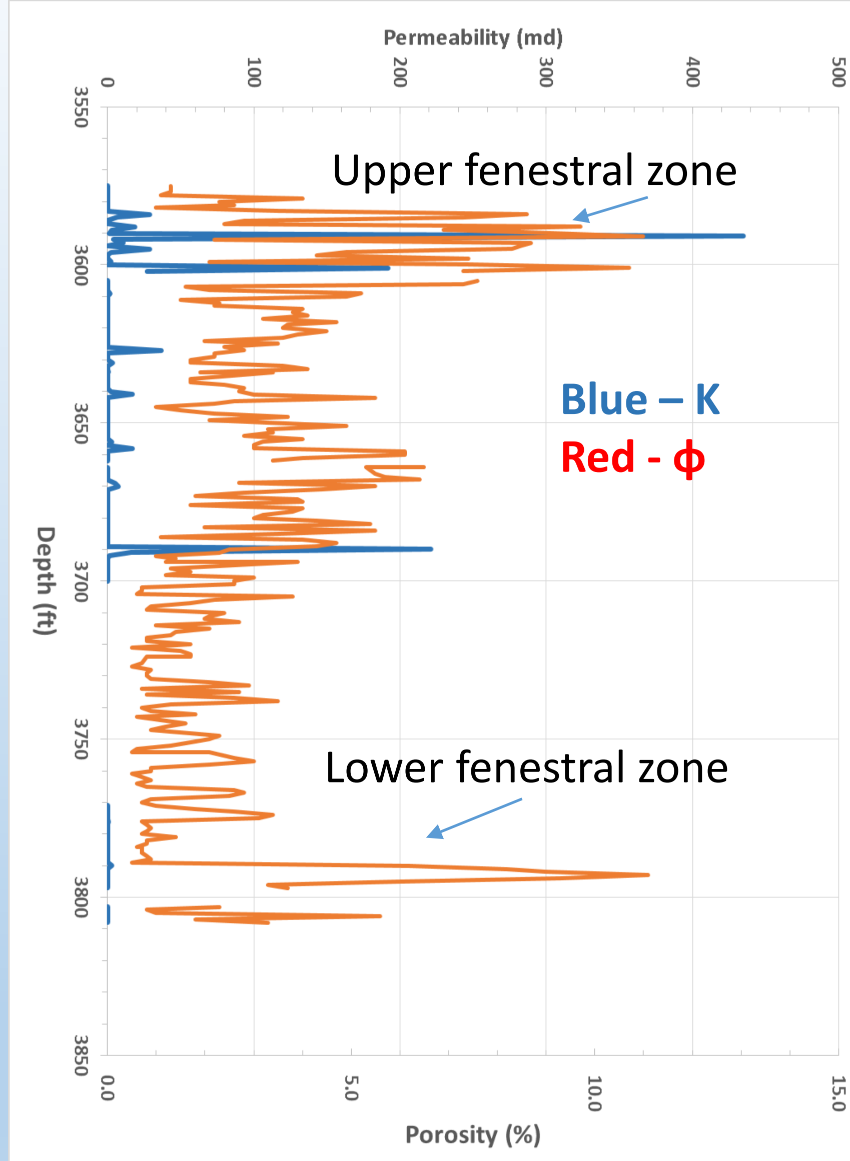
Fenestal Carbonates – highly porous, grainy carbonates – beach deposits

Reservoir: When not cemented – decent ϕ, low to moderate K

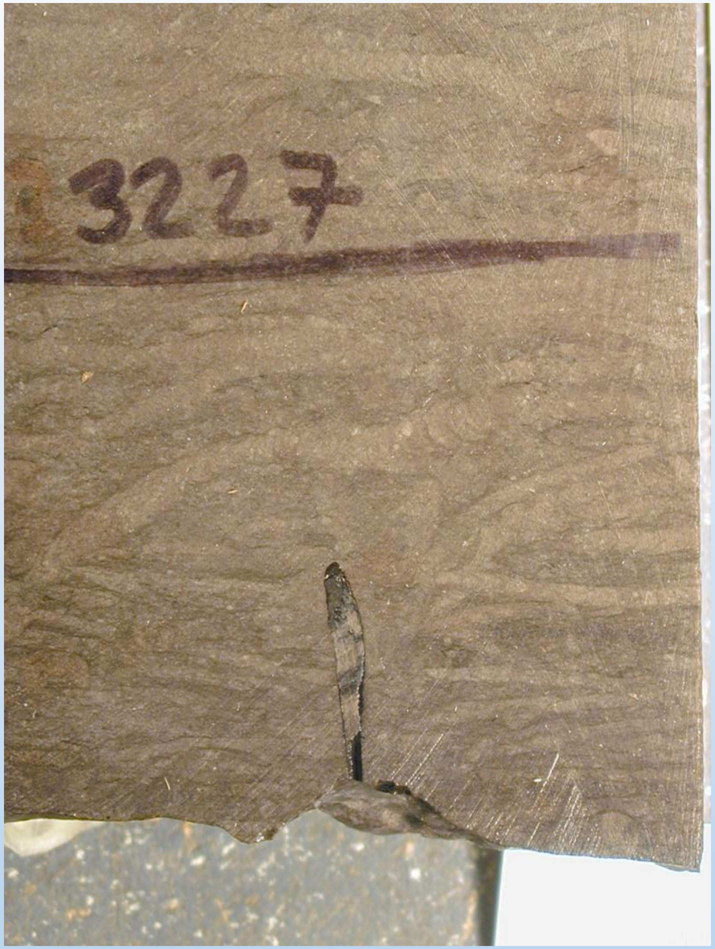
MCGC LR83-2, 3570 ft., Osceola Co. (PN: 29261)



Depth (ft)
Lithology
Facies
Dunham
M W P G Ru B
Low Frequency Sea Level Change
Depositional Environment
3575
Rogers City Fm.
3600
Missing Core
3625
3650
Missing Core
Missing Core
3675
3700
3725
3750
3775
Dundee Fm.
3800
Lucas Fm.
Detroit River Gp.
Open Shelf
Lagoon to Shoreface
Shoals
Lagoons to Shoals
Beach
Tidal Flats
Sabkha
Sun Oil Company McClintic #3
Isabella Co., MI
11-14N-3W
PN: 36367
Legend
Dolomite
Limestone
Dolomite with Anhydrite Nodules
Coral
Stromatoporoid
Bryozoan
Brachiopod
Indeterminate Skeletal Grain
Crinoid
Crossbedding
Stromatolite
Wavey Lamination
Planar Lamination
Hardground
Fenestral Porosity
Intraclasts
Phosphate Grains
Wispy Stylolites
Digitate Stylolites
Facies Assemblage 4
Facies Assemblage 3
Facies Assemblage 2
Facies Assemblage 1



Permeability (md)
0
100
200
300
400
500
Depth (ft)
3550
3600
3650
3700
3750
3800
3850
Porosity (%)
0.0
5.0
10.0
15.0
Upper fenestral zone
Blue – K
Red - ϕ
Lower fenestral zone



Peninsular Oil McDonald #1-12
Newaygo Co. PN: 38437

Cronus Development Tow 1-3-HD-1
Montcalm Co, PN: 50047

Lagoonal carbonates – intensely bioturbated
Muddy and Pelletal
Skeletal grains – float in matrix – locally leached out

Moderate ϕ, but low K

Wiser Oil Sturm #4-0
Gladwin Co., PN: 41212
Footage: 3598 ft

Sand shoals

Near fairweather wave base

Mix of:
1. Oolitic grains
2. Skeletal material from nearby thickets (bryozoans, crinoids)
3. Debris shed from local patch reefs

High energy environment – winnows away fines

Can be good reservoir quality if not cemented up!

Patch Reefs

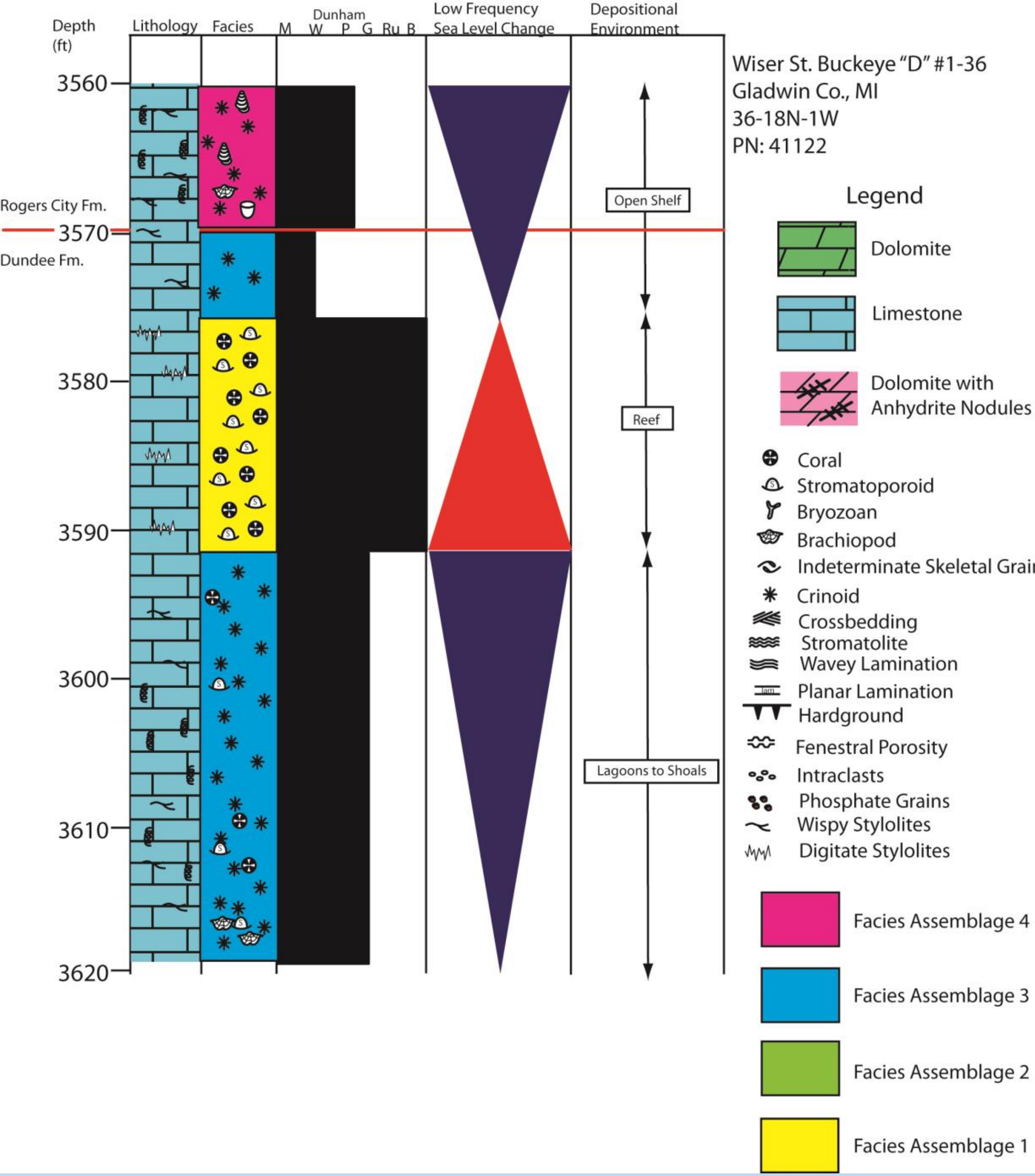
Jordan Energy St. Buckeye “D” #1-36
Gladwin Co., PN: 41122
Depth: 3588 ft

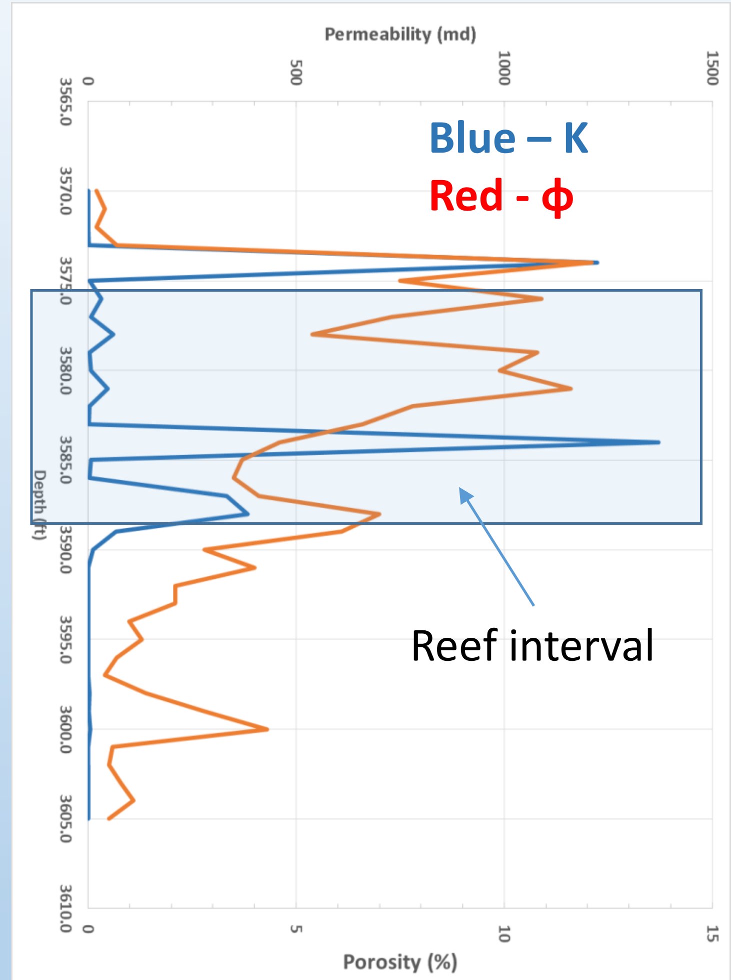
Stromatoporoid – hydrocarbons plugging **intraskeletal porosity**

Tabulate Coral – Dundee Formation, Rogers City Quarry

Both photos - Jordan Energy St. Buckeye “D” #1-36
Gladwin Co., PN: 41122 (3594 and 3599 ft)

Reef debris – Stromatoporoids, colonial rugose corals (*Hexagonaria*), variety of tabulate corals

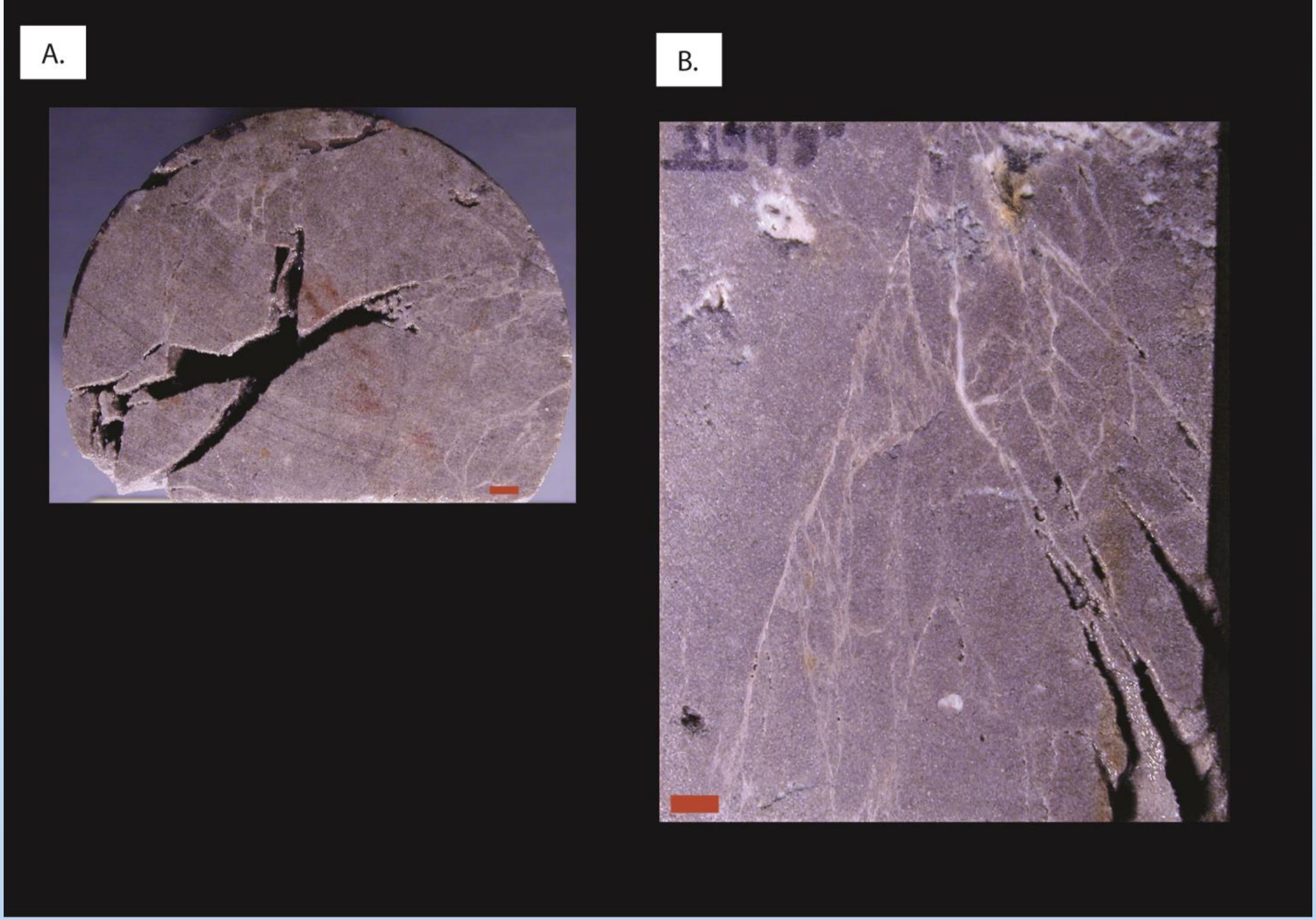

Depth (ft)
Lithology
Facies
Dunham
M W P G Ru B
Low Frequency Sea Level Change
Depositional Environment
3560
3570
3580
3590
3600
3610
3620
Rogers City Fm.
Dundee Fm.
Open Shelf
Reef
Lagoons to Shoals
Wiser St. Buckeye "D" #1-36
Gladwin Co., MI
36-18N-1W
PN: 41122
Legend
Dolomite
Limestone
Dolomite with Anhydrite Nodules
Coral
Stromatoporoid
Bryozoan
Brachiopod
Indeterminate Skeletal Grain
Crinoid
Crossbedding
Stromatolite
Wavey Lamination
Planar Lamination
Hardground
Fenestral Porosity
Intraclasts
Phosphate Grains
Wispy Stylolites
Digitate Stylolites
Facies Assemblage 4
Facies Assemblage 3
Facies Assemblage 2
Facies Assemblage 1


Permeability (md)
0
500
1000
1500
Porosity (%)
0
5
10
15
Depth (ft)
3565.0
3570.0
3575.0
3580.0
3585.0
3590.0
3595.0
3600.0
3605.0
3610.0
Blue – K
Red - ϕ
Reef interval

- Lower energy – below fairweather wave base, but above stormweather wave base
- Grainflows from higher on depositional ramp
- Background sedimentation – muddy or pelletal carbonates (± some clay)
- Fauna – lower diversity – dominated by crinoids ± brachiopods, gastropods, and sponges
- Depositional package – interlayered tempestites/grainflows with muddier background layers

Reservoir Quality – when dolomitized – vuggy, intercrystalline and fracture!
Seal when not dolomitized for underlying Dundee.

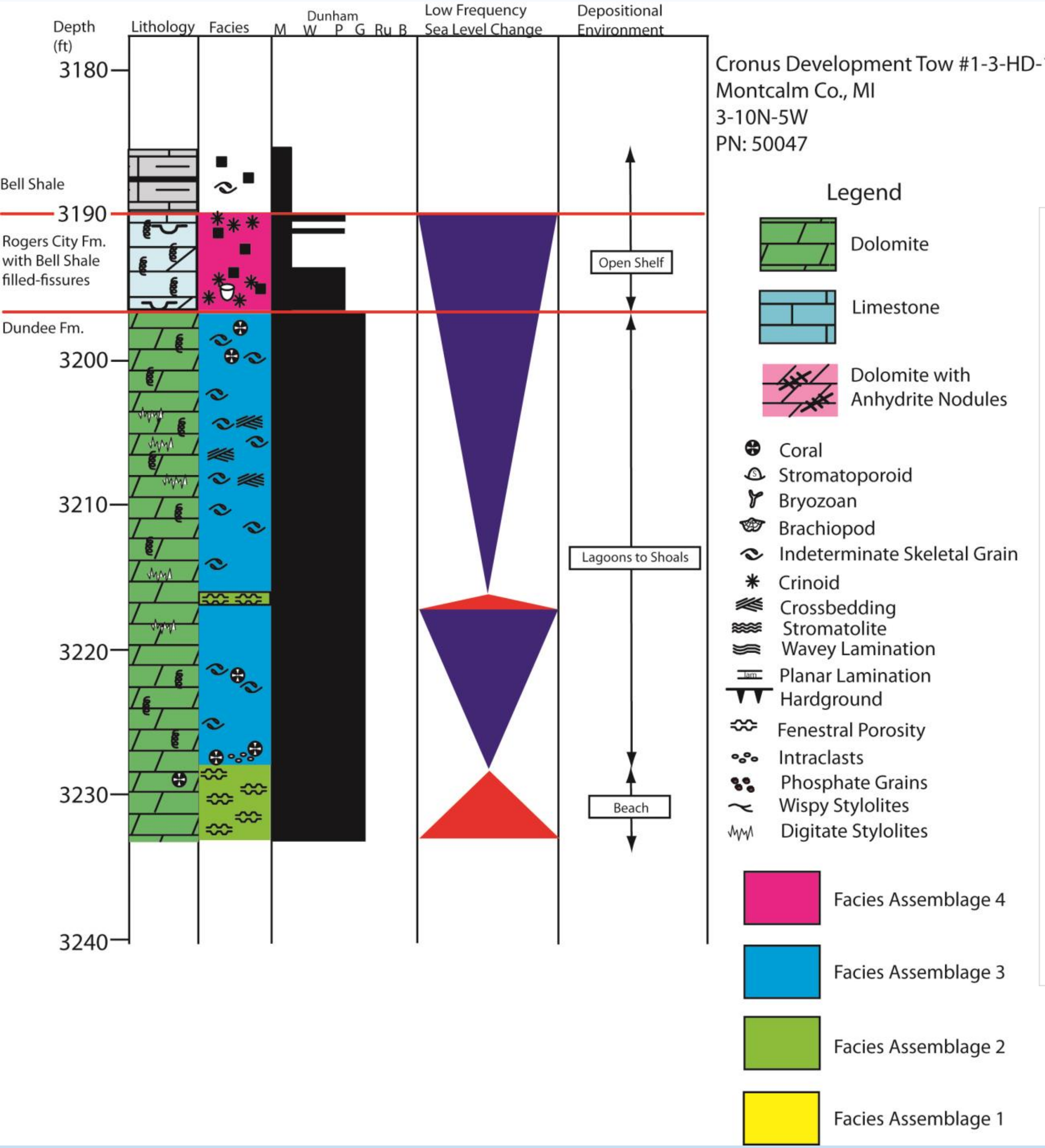
Cronus Development Tow 1-3-HD-1
Montcalm Co, PN: 50047
Depth = 3195.5 ft

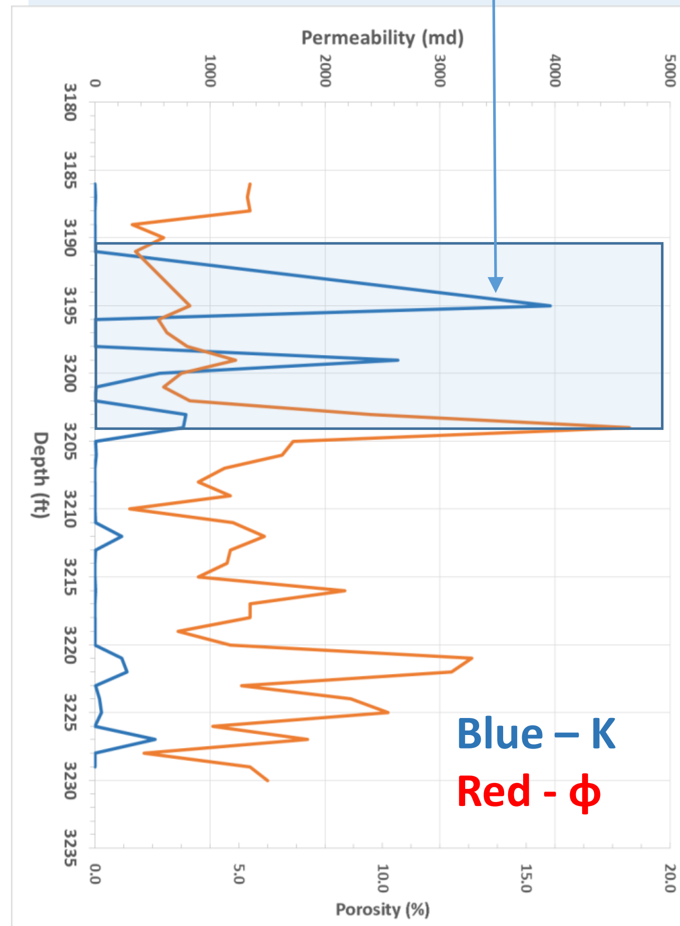


Tension fractures

Cronus Development Tow 1-3-HD-1
Montcalm Co, PN: 50047
Depth = 3199 ft

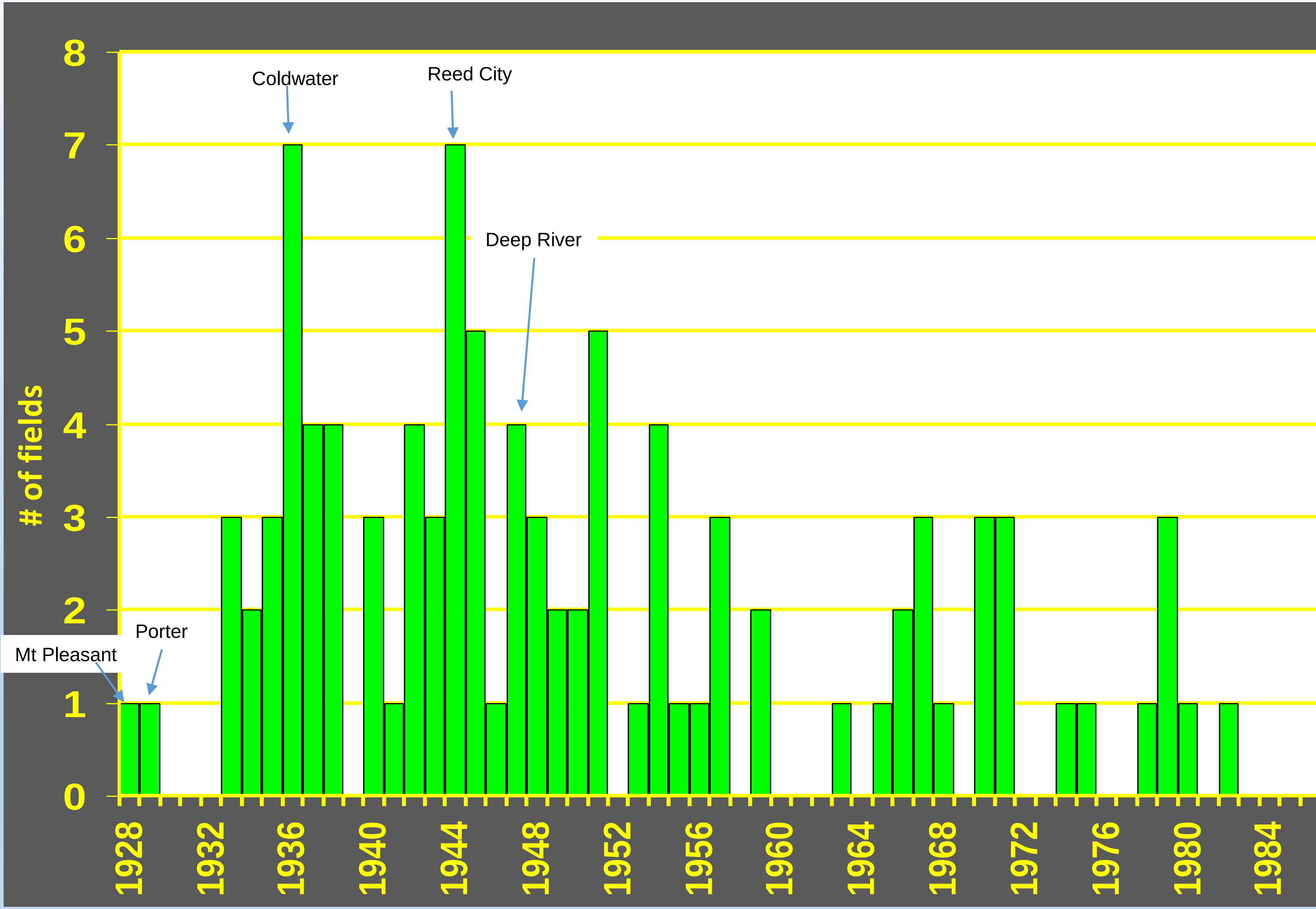
Upper Dundee-Lower Rogers City – decent K, low ϕ, overlain by Bell Shale





Dundee Reservoir Lithologic Types - Summary

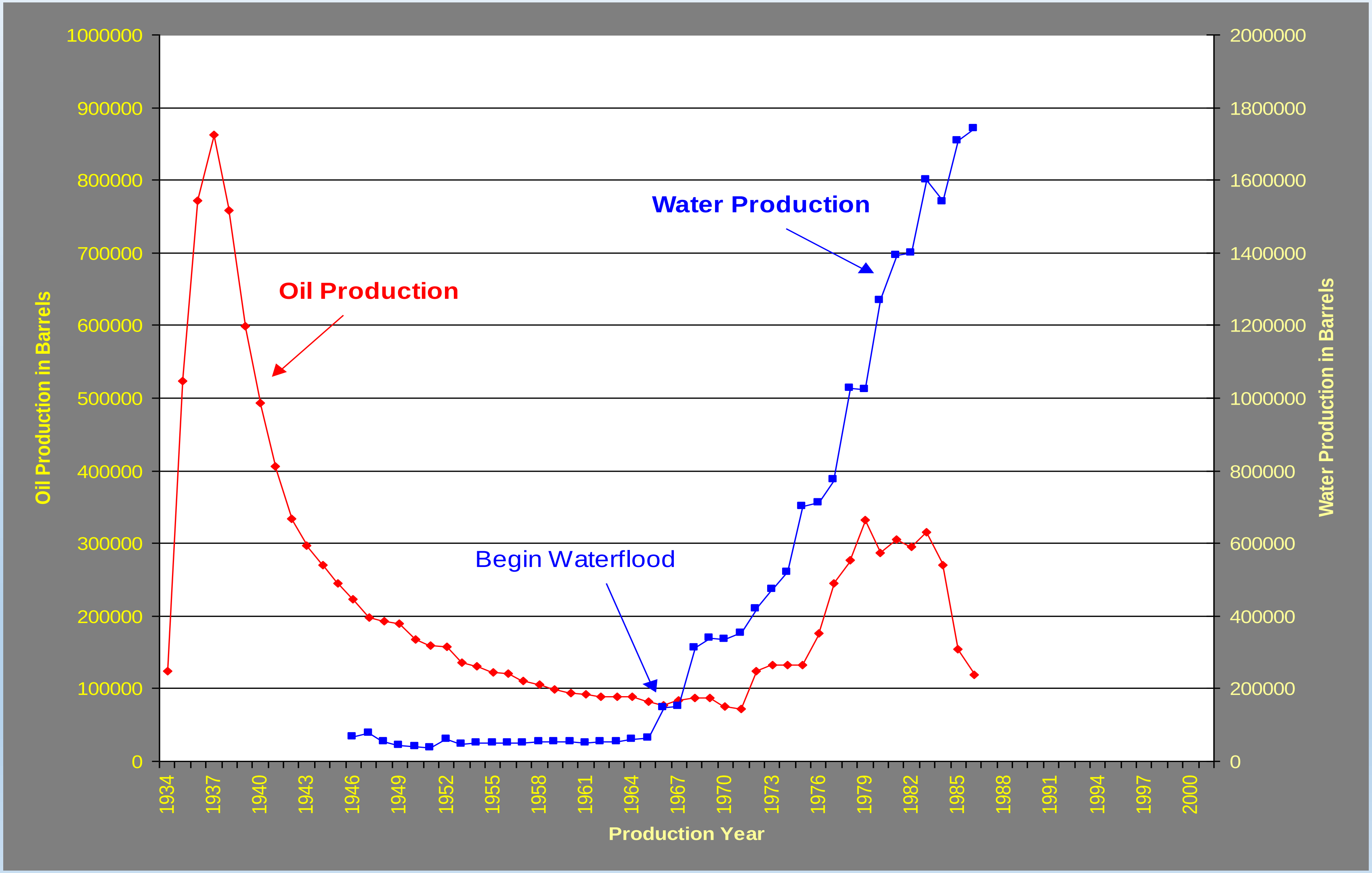
- Limestone - depositional fabrics
  - Grainstone shoal sand bodies
  - Fenestral peritidal packstones and wackestones
  - Stromatoporoid/coral boundstone patch reefs
- Dolomite - burial diagenetic fabrics
  - Fractured, vuggy, hydrothermal dolomite
  - Matrix, intercrystalline and vuggy dolomite
  -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



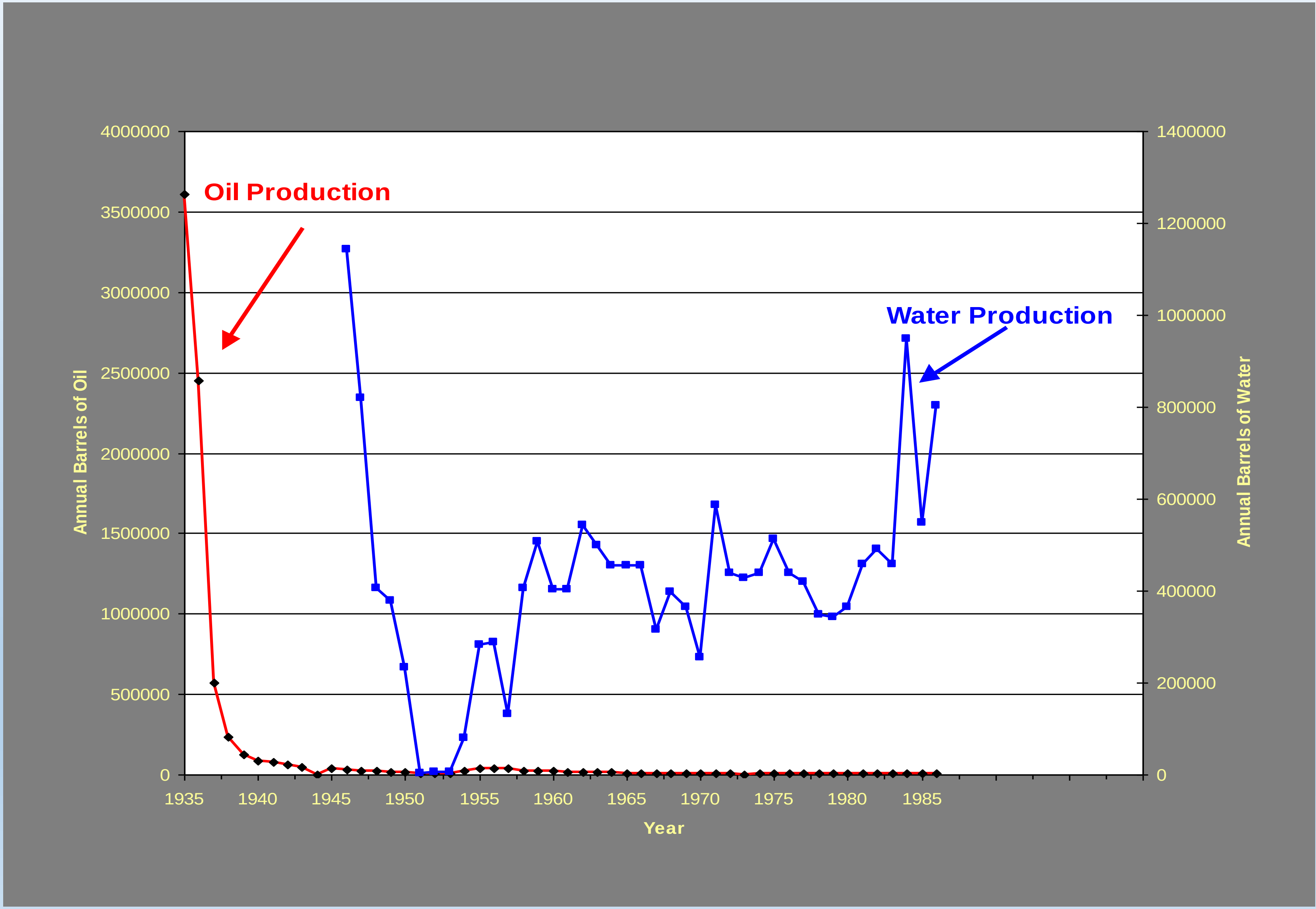
# of fields
0
1
2
3
4
5
6
7
8
Coldwater
Reed City
Deep River
Porter
Mt Pleasant
1928
1932
1936
1940
1944
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984

	Reservoir Type	
	Limestone	**Dolomite**
ϕ/K	Primary depositional control	Dolomitization-controlled – leaching and fracturing
ϕ/K and structure	Porous facies on structure, tight limestone regionally	Porous facies off structure – regional dolomitization
Initial Production	60% of wells – 250 Bbls/day	Fewer 250 Bbls/day wells – more 3000 Bbls/day wells
Pressure Drive	Solution gas/gas expansion As pressures decrease – primary recovery low, good secondary recovery potential	Bottom or lateral water drive Reservoir pressure doesn't deplete much – limited secondary recovery

Annual Oil and Water Production West Branch Field - Limestone - Grainstone



Annual Oil and Water Production Crystal Field – Fractured **Dolomite**



Dundee-Rogers City interval – Reservoir Conclusions

- Limestone Reservoirs
  - Primary fabric controlled – porosity from depositional fabrics if not cemented early; few fractures
  - Pressure depletes - decent primary production; good secondary recovery potential
- Dolomite Reservoirs
  - Templating of primary fabrics by dolomitizing fluids (K-conduits) + fracture-related dolomitization
  - Porosity off-structure from regional dolomitization
  - Little depletion of reservoirs - good early production; poor secondary recovery potential!

Voice and Harrison, 2017 References

Catacosinos, P. A., Harrison, W. B., III, Reynolds, R. F., Westjohn, D. B., and Wollensak, M. S., 2001, Stratigraphic Lexicon for Michigan, Bulletin, Geological Survey Division, Department of Environmental Quality and Michigan Basin Geological Society, Lansing, MI, v. 8, 56 p.

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