

# A New Model for Niagaran “Pinnacle” Reef Complexes of the Michigan Basin\*

**Matthew Rine<sup>1</sup>, Jon Garrett<sup>1</sup>, Stephen Kaczmarek<sup>1</sup>, David Barnes<sup>1</sup>, and William Harrison III<sup>1</sup>**

Search and Discovery Article #51319 (2016)\*\*

Posted November 7, 2016

\*Adapted from oral presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 16-22, 2016. Please refer to related article by these authors, [Search and Discovery Article #51318 \(2016\)](#).

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## Abstract

Hydrocarbon reservoirs in the Niagara-Lower Salina Reef Complex in the Michigan Basin have been extensively studied since the early 1960's. These reservoirs host an immense hydrocarbon resource, existing as closely spaced, highly compartmentalized reservoirs that have produced >500 million barrels of oil and 2.9 trillion cubic feet of natural gas. Previous studies depict these “pinnacle reefs” as tall, symmetrical towers with a random distribution of facies. This study utilizes abundant core data (32 cores, 20-acre spacing), thin-section petrography, and petrophysical wireline logs to reconstruct the geometry, facies distributions, depositional history, and sequence stratigraphy of the Columbus III Reef Complex within the Southern Niagaran-Lower Salina Reef Trend. Our analysis indicates that there are three depositional sequences, which include a lower bioherm complex, the middle Niagaran reef complex, and the uppermost Lower Salina A-1 Carbonate. These sequences are highly influenced by relative sea level fluctuations within the Michigan Basin and can be correlated to global seal level changes. The bioherm complex is relatively homogenous and acts as a topographic high upon which the reef complex nucleates. Within the Niagaran reef sequence, there are five major depositional facies, each with its own characteristic shallowing-upward trend. These facies include: reef core, reef talus, proximal reef apron, distal reef apron, and flank. The overall geometry of the reef complex and the vertical and horizontal facies distributions within the reef are highly asymmetrical, and are dominated by a northeast paleo-wind direction. Lateral facies distributions in the Lower Salina A-1 Carbonate are highly influenced by the underlying topography set-up by the Niagaran reef sequence. This new stratigraphic model allows for better predictability within the Michigan Basin, particularly in reefs without abundant well control. The high-resolution model also permits more accurate

correlations between the Lower Salina shallow-water carbonate factory and the surrounding inter-reef and basin-center carbonates, which represent a potential unconventional resource.

### **References Cited**

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- Huh, J.M.S., 1973, Geology and Diagenesis of the Niagaran Pinnacle Reefs in the Northern Shelf of the Michigan Basin: Ph.D. dissertation, University of Michigan, 268 p.
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- Sarg, J.F., 1987, Off-reef Salina deposition (Silurian). southern Michigan basin: SEPM Special Publication, Depositional and Diagenetic Spectra of Evaporites (CW3), p. 354-384.
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<http://www.scotese.com/newpage2.htm>.
- Sears, S.O., and F.J. Lucia, 1979, Reef growth model for Silurian pinnacle reefs northern Michigan reef trend: Geology, v. 7, p. 299-302.
- Sears, S.O., and F.J. Lucia, 1980, Dolomitization of northern Michigan Niagara reefs by brine refluxion and freshwater/seawater mixing: SEPM Special Publication no. 28, p. 215-235.

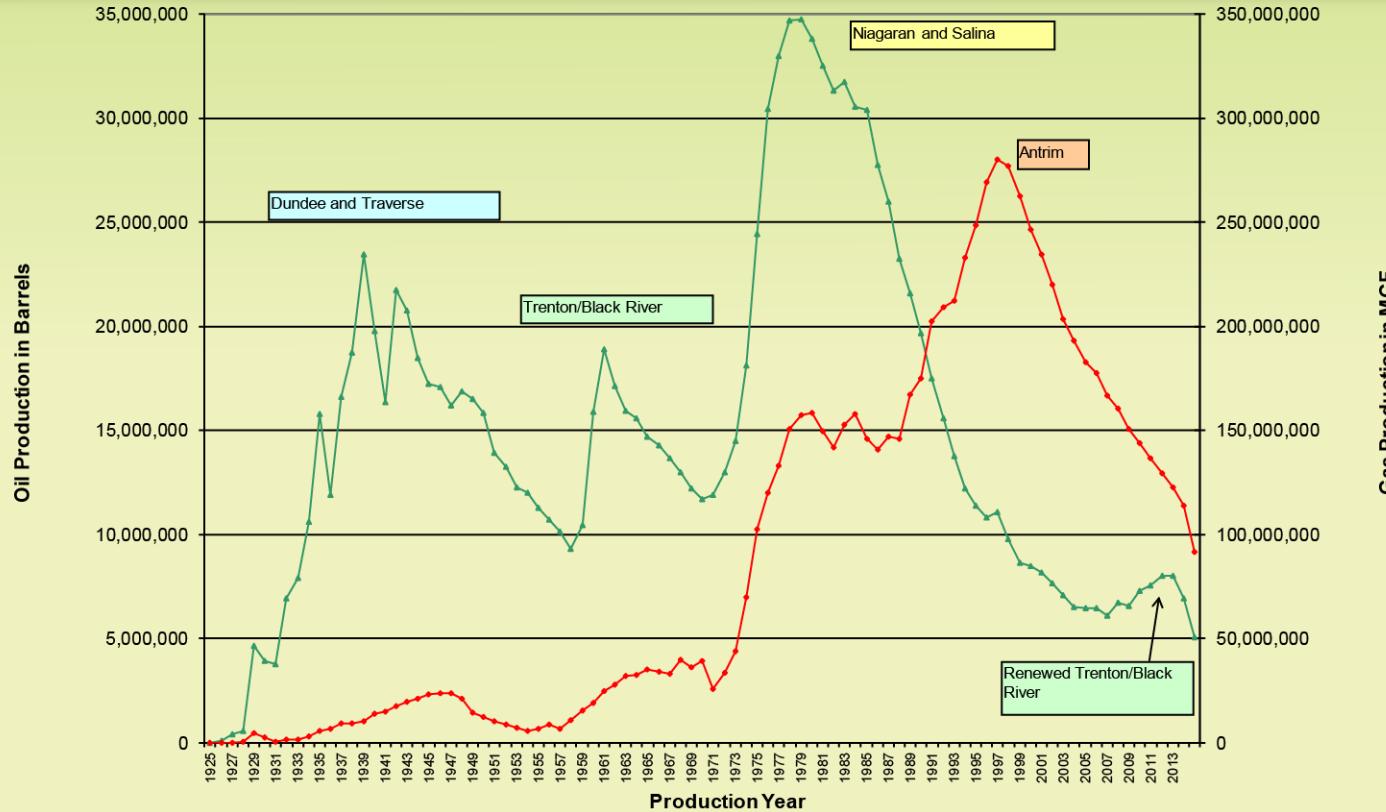
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June 20, 2016



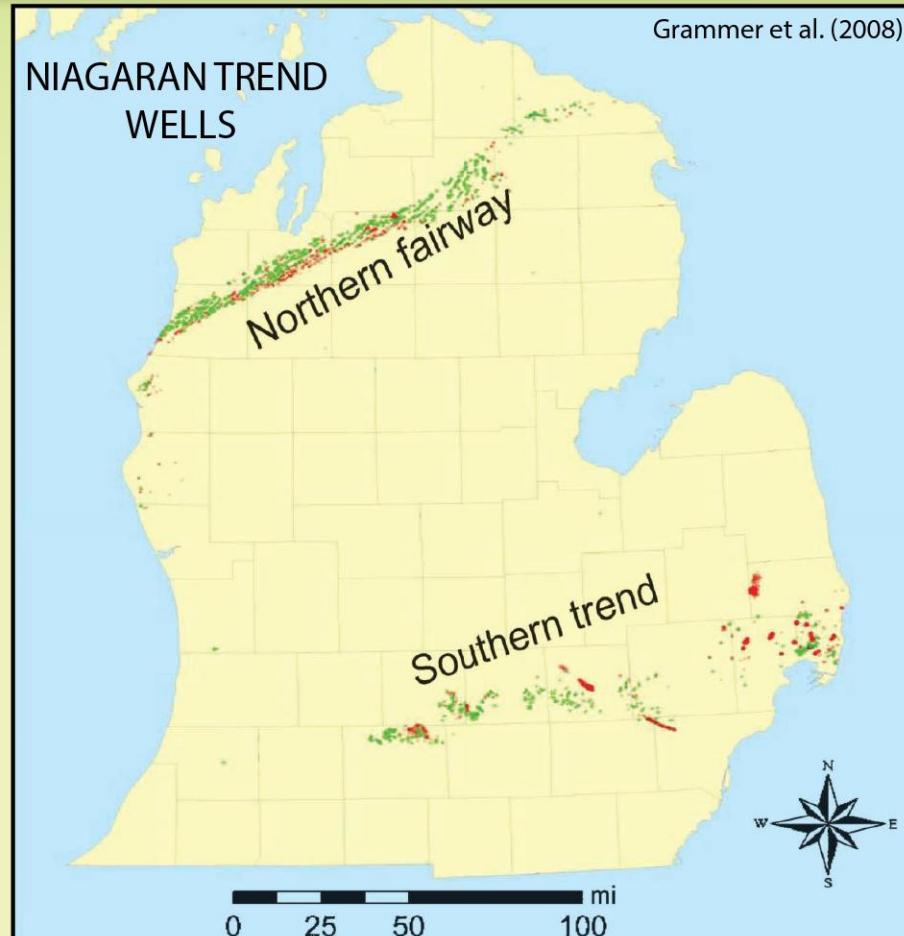
# Niagaran Reef Play



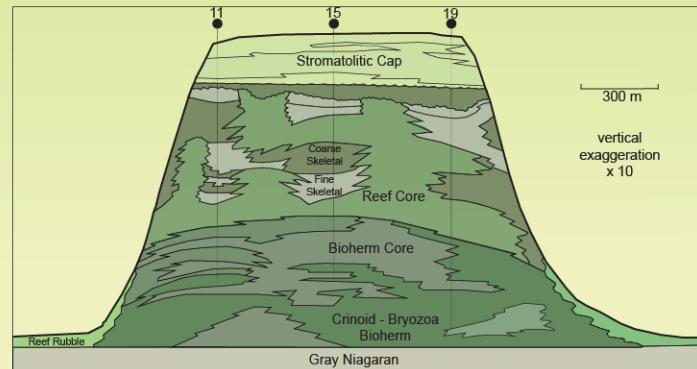
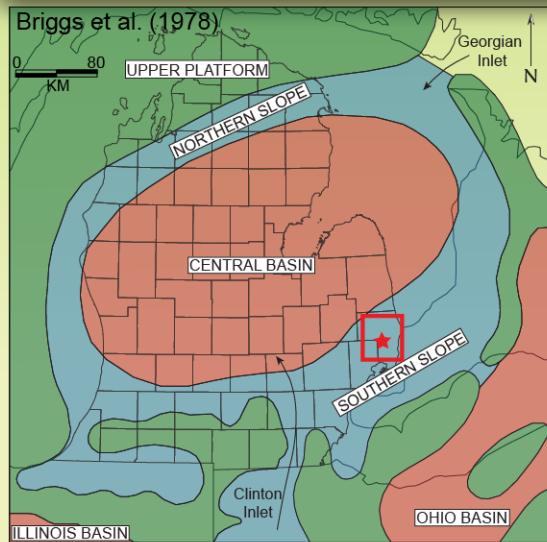
**Niagaran Cumulative Production:** ~500 Million bbls Oil; ~2.9 TCF Natural Gas  
1,200 fields – 3,200 wells

# Niagaran Reef Play

1. **1952** - Discovery of Southern Trend reefs using gravity techniques
2. **1969** – use of seismic reflection launched exploration along Northern fairway
3. **1971** – Oil & Gas consortium funded “*The Northern Michigan Project*”, a research program at the University of Michigan formed to address stratigraphic concerns
4. **1970s to present** – numerous geologic studies published on Niagaran reef stratigraphy



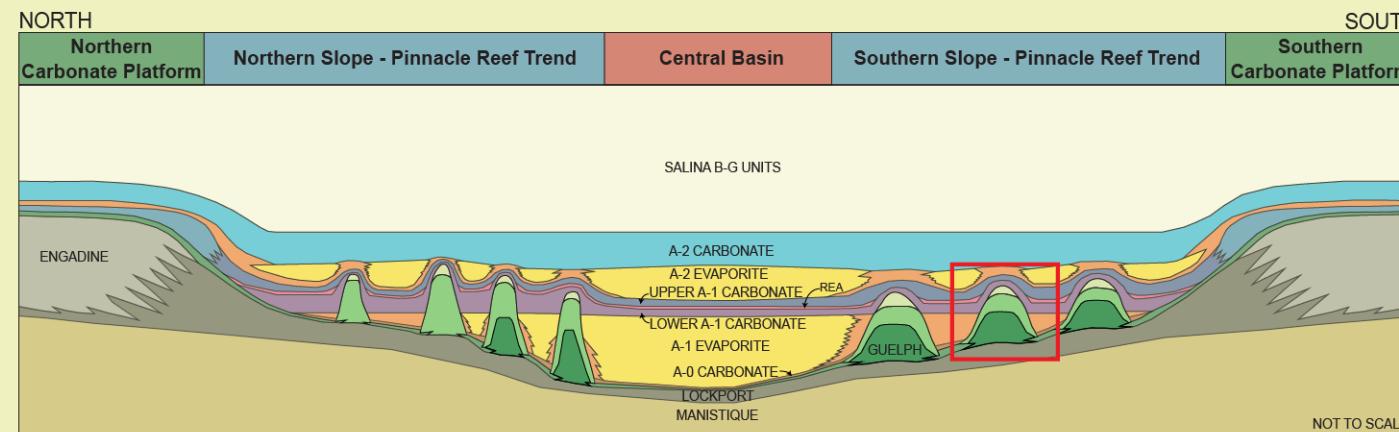
# Seminal Reef Studies



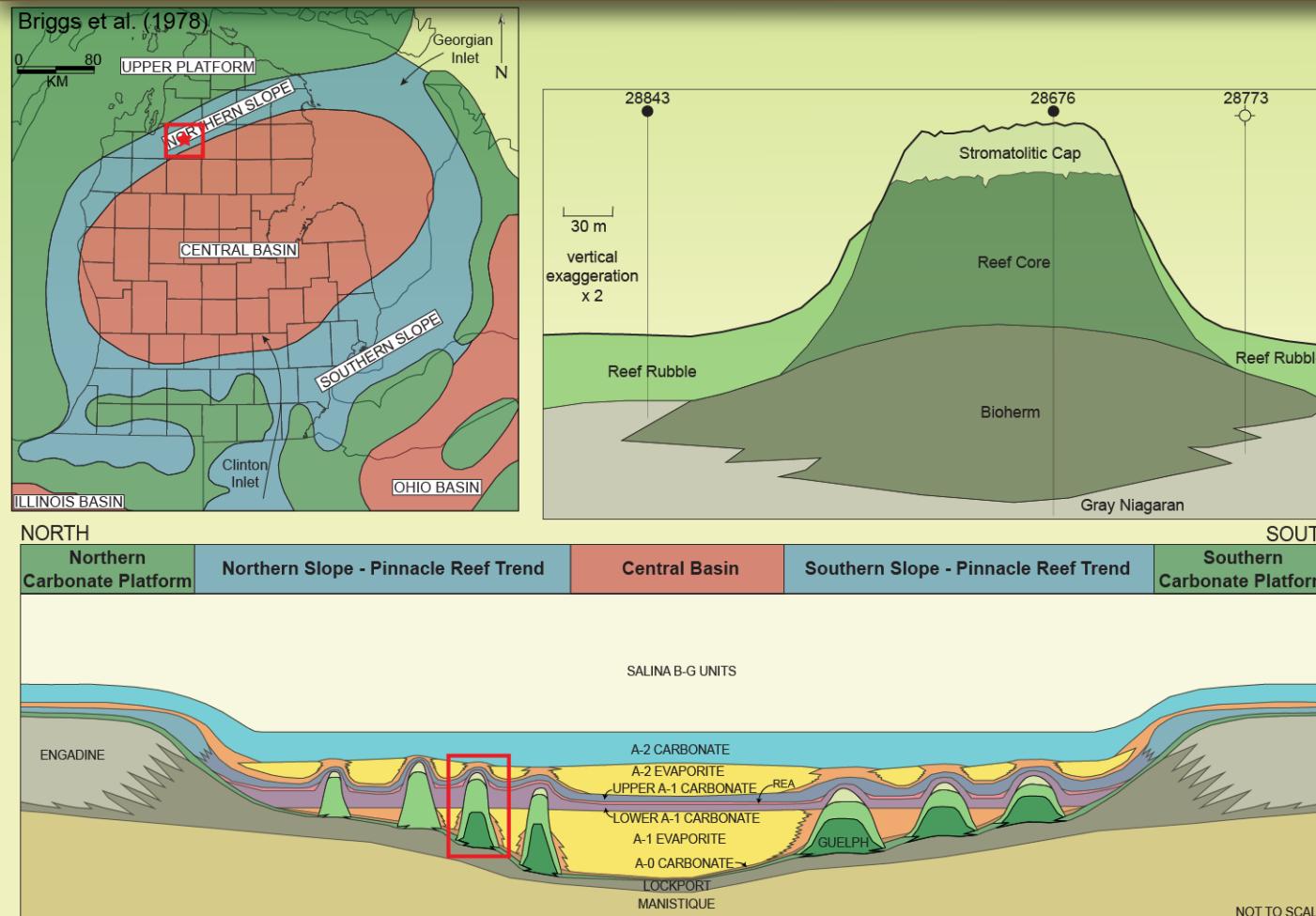
## 1) Gill (1973) – Southern Trend, Belle River Mills Field

- Model built on 31 cored wells (most data-rich study)

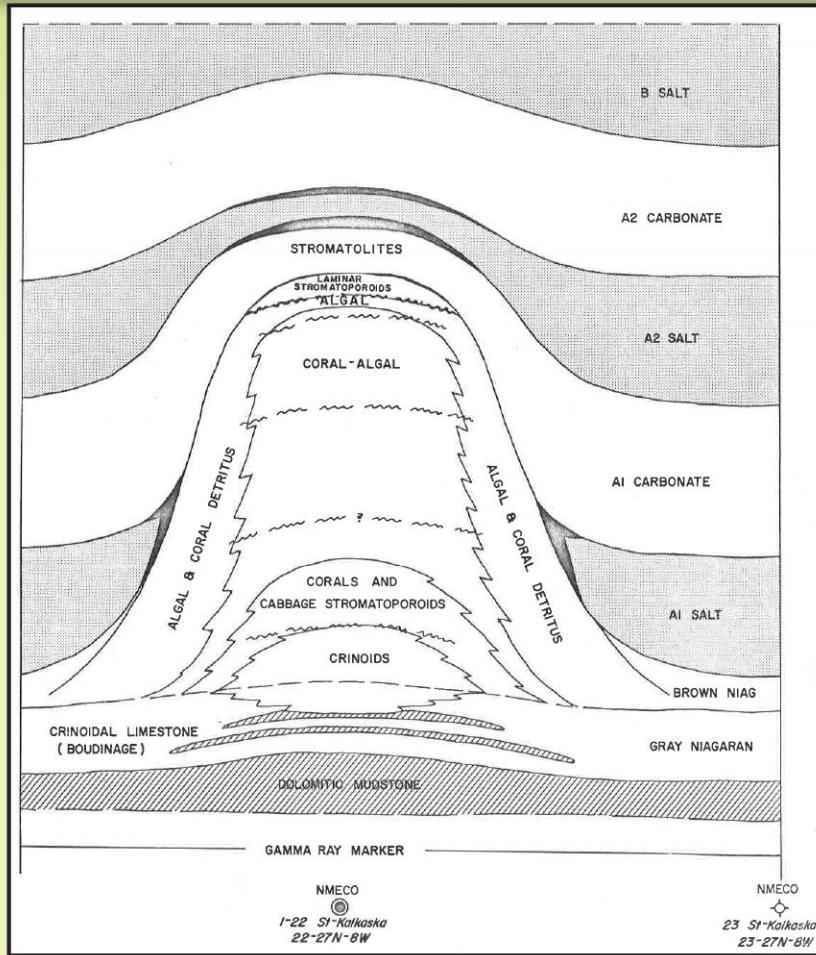
**Gill's (1973) model widely accepted, propagated through time**



# Seminal Reef Studies



# Symmetrical Reef Models

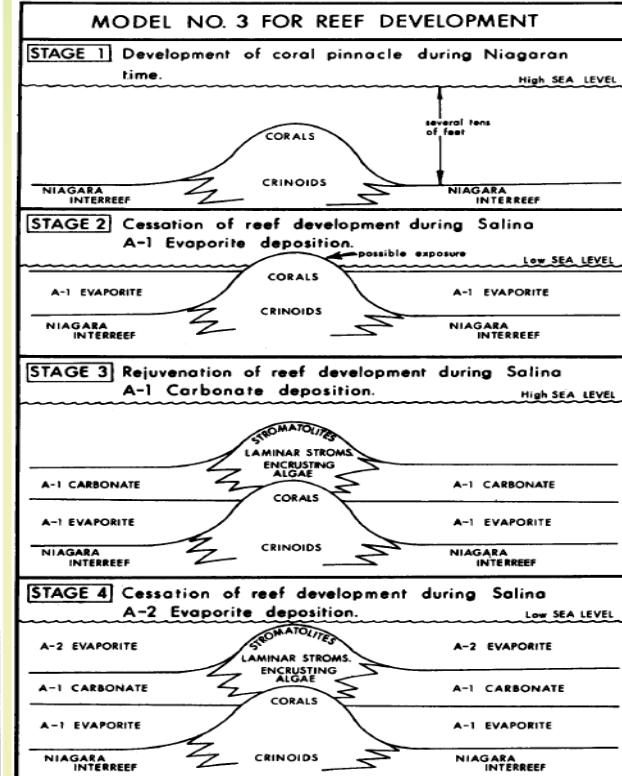
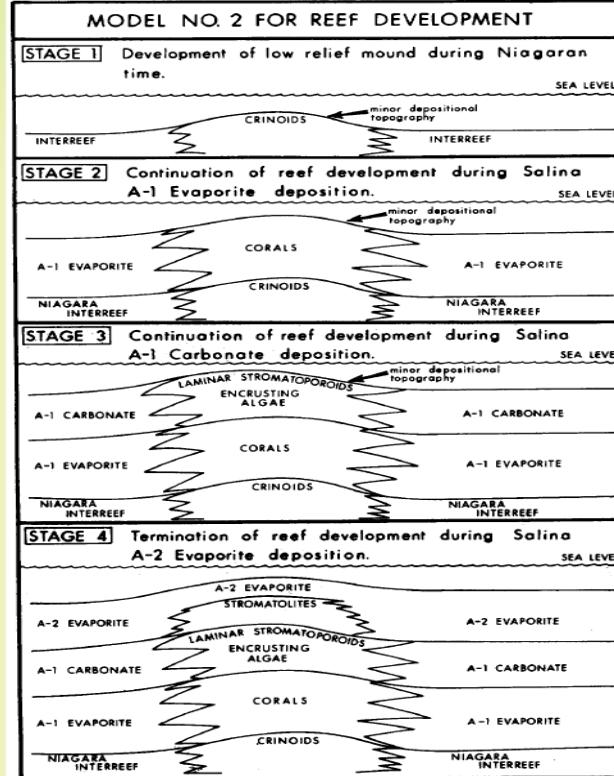
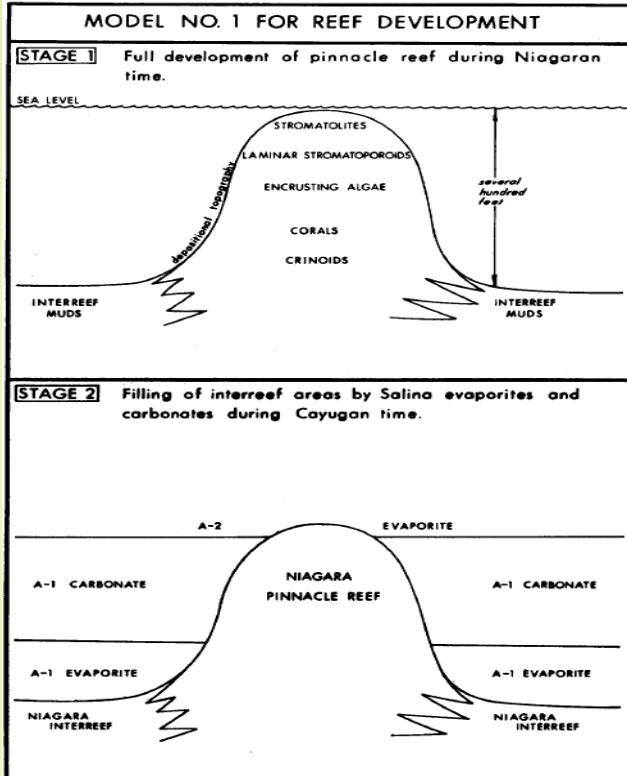


Mantek (1973)  
Northern Michigan Exploration

# Symmetrical Reef Models

Mesolella et al. (1974) – Amoco Production

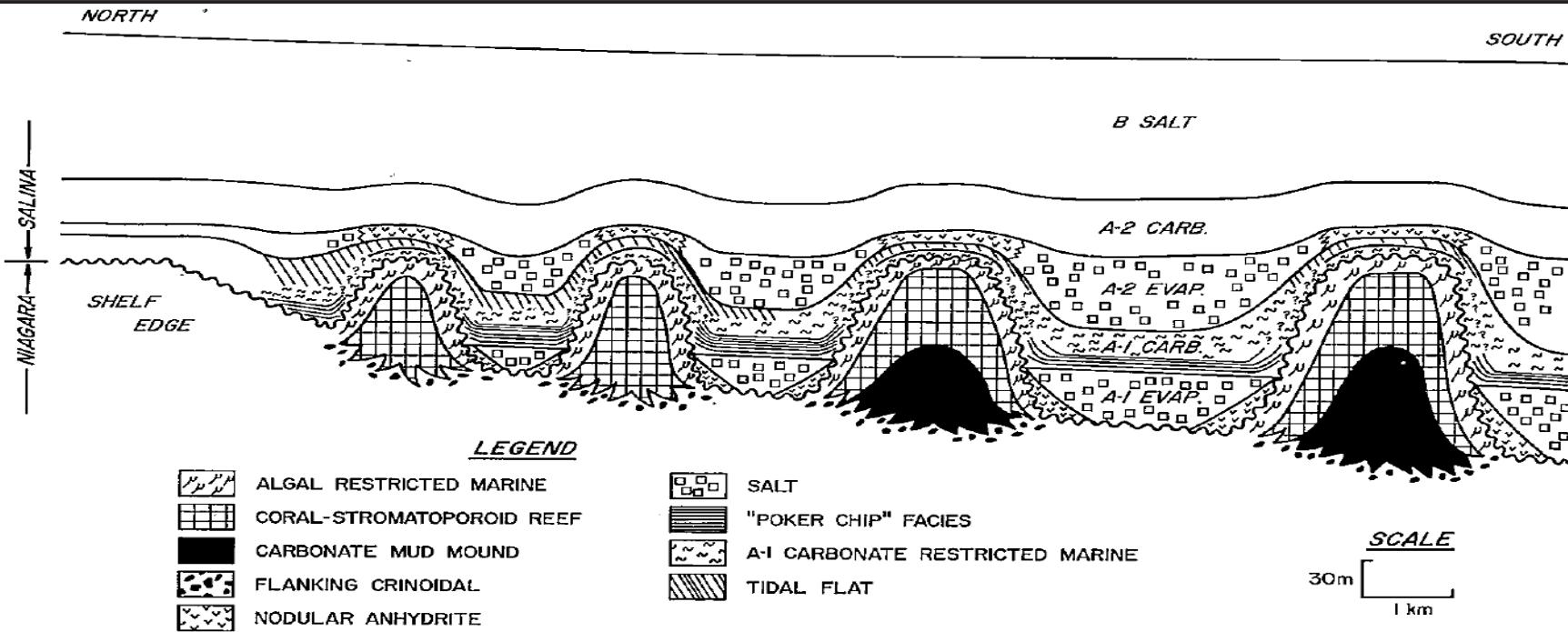
## Sequence Stratigraphic Models



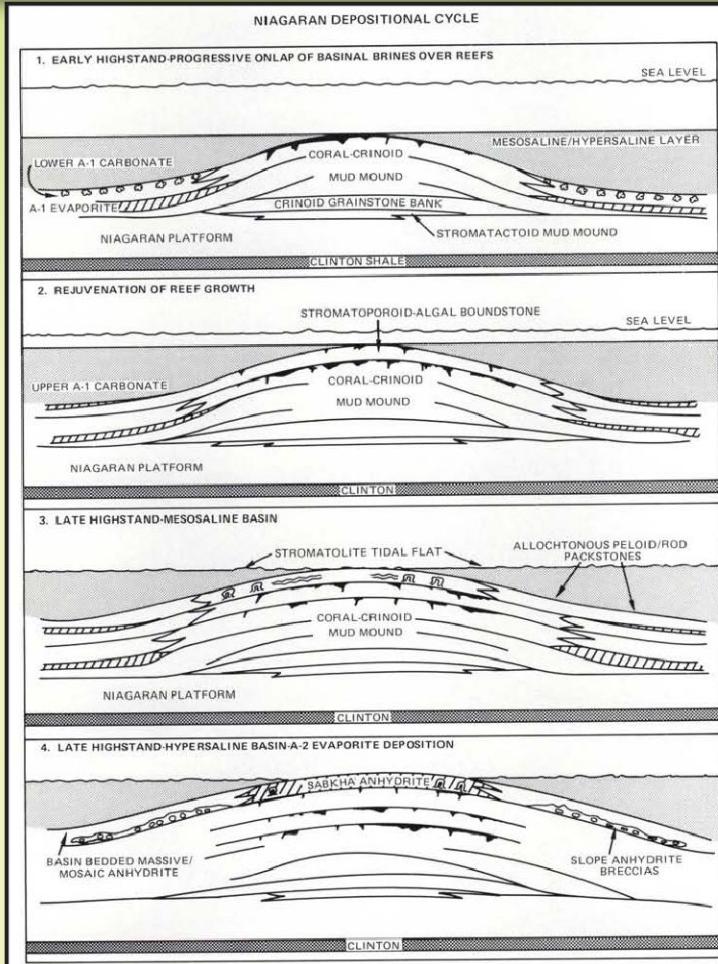
# Symmetrical Reef Models

Sears and Lucia (1979; 1980) – Shell Development

Reef Growth Timing & Diagenetic History



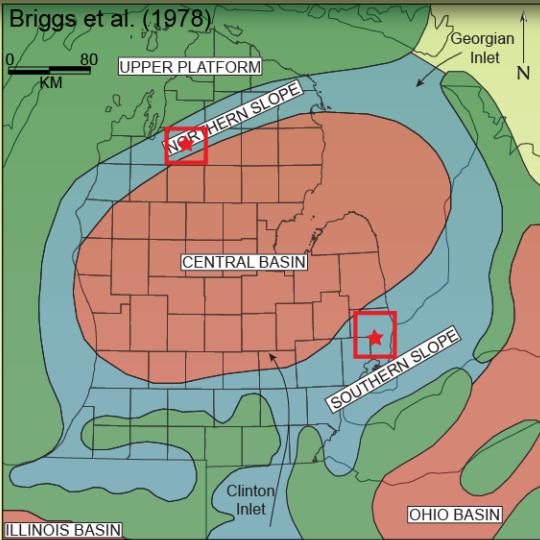
# Symmetrical Reef Models



**Sarg (1987)**  
Exxon Production Research

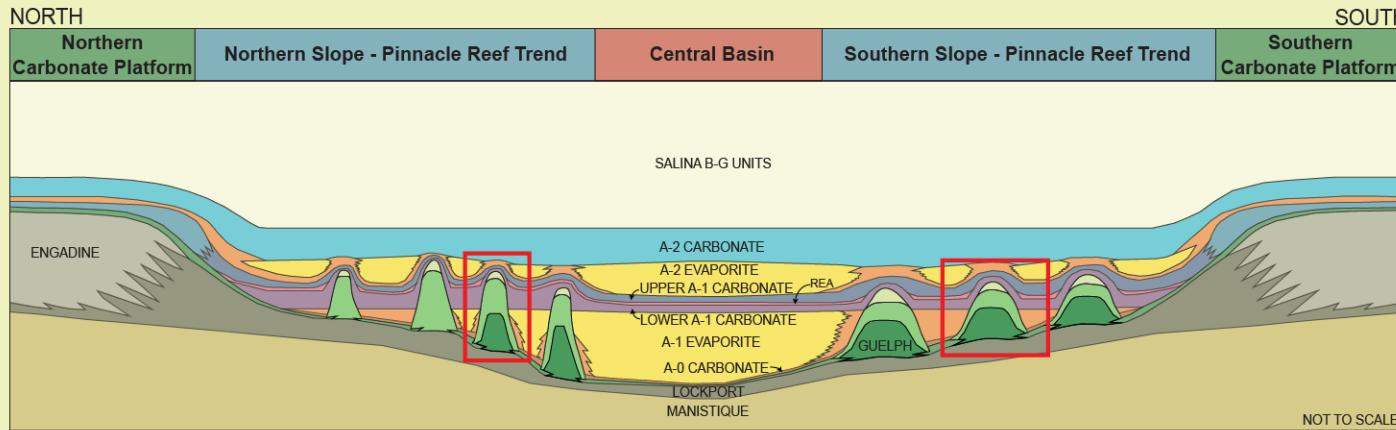
Contemporaneous Reef Growth &  
Salina Evaporite Model

# Reefs in this study



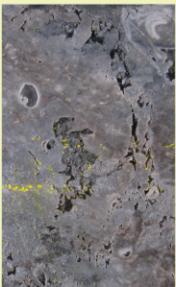
## This Study:

1. **3 Southern Trend fields - 2 New; re-examine Belle River Mills (Gill 1973)**
2. **1 Northern Trend field – re-examine Kalkaska 21 (Huh 1973)**



# Study Workflow

## CORE DESCRIPTIONS



## FACIES ANALYSIS/ DEPOSITIONAL ENVIRONMENTS

Lithofacies	Lithologic Attributes
<i>hemispheroid stromatolitic bindstone</i>	Dark brown, laterally-linked hemispheroid stromatolites
<i>skeletal wackestone</i>	Skeletal fragments composed of reef core organisms (tabulate corals, brachiopods, bryozoan); abundant cements
<i>stromatolitic intraclastic rudstone</i>	Large (pebble to cobble), tightly packed stromatolite clasts ( <i>flat pebble conglomerate</i> ) ; poorly sorted
<i>stromatolitic intraclastic floatstone</i>	Small (granule to pebble), infrequent stromatolite clasts in a micrite matrix
<i>skeletal mudstone</i>	Minor skeletal fragments in a micrite matrix; anhydrite-filled vugs; <10 m thick
<i>skeletal mudstone</i>	Minor skeletal fragments; abundance of drusy calcite spar cement lining vuggy porosity; >10 m thick
<i>skeletal mudstone</i>	Minor skeletal fragments; abundance of drusy calcite spar cement lining vuggy porosity
<i>skeletal wackestone</i>	Disarticulated fossils (tabulate corals, brachiopods, bryozoans, crinoids) in a micrite matrix
<i>coral/stromatoporoid framestone</i>	Frame-building organisms (tabulate corals, stromatoporoids)
<i>skeletal wackestone</i>	Intra-reef faunal assemblages (bryozoans, brachiopods, crinoids, rugose corals); 50-75% micrite matrix
<i>coarse lithoclastic floatstone</i>	Large, dark gray angular clasts in light gray micrite matrix; abundant crinoids
<i>skeletal intraclastic rudstone</i>	Large clasts composed of tabulate corals, brachiopods, and crinoids; moldic porosity
<i>skeletal mudstone</i>	Occasional skeletal fragments and small (pebble), angular clasts in a micrite matrix; anhydrite-filled vugs
<i>crinoidal mudstone</i>	Mottled gray and white; abundant crinoids in a micrite matrix; abundant stromatactis
<i>skeletal wackestone</i>	Mottled gray and white; bryozoans, tabulate corals, rugose corals and crinoids in a micrite matrix; abundant stromatactis
<i>crystalline dolomite</i>	Devoid of fossils; composed of dolomite rhombs; intercrystalline porosity

## GR SIGNATURES

## DEPOSITIONAL MODEL

# Study Workflow

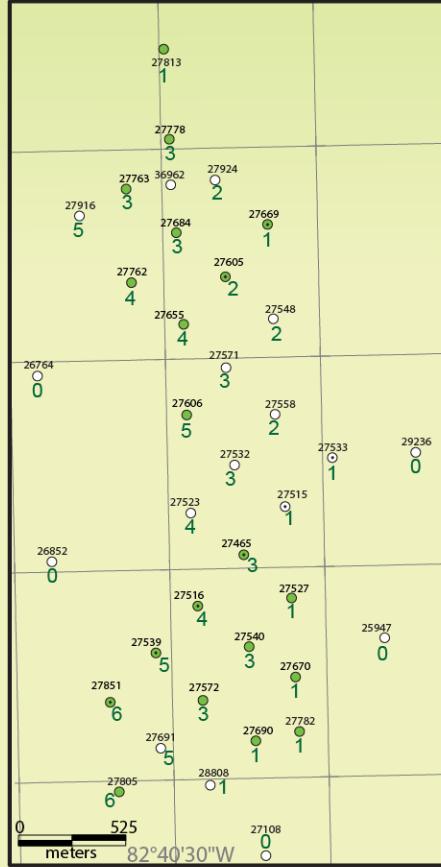
## CORE DESCRIPTIONS

## FACIES ANALYSIS/ DEPOSITIONAL ENVIRONMENTS

## GR SIGNATURES

## DEPOSITIONAL MODEL

Reef Growth Stage	Depositional Environment	Lithofacies	Lithologic Attributes
3 Stromatolitic Cap	Peritidal Cap	<i>hemispheroid stromatolitic bindstone</i> <i>skeletal wackestone</i>	Dark brown, laterally-linked hemispheroid stromatolites Skeletal fragments composed of reef core organisms (tabulate corals, brachiopods, bryozoan); abundant cements
	Windward Peritidal Talus	<i>stromatolitic intraclastic rudstone</i>	Large (pebble to cobble), tightly packed stromatolite clasts ( <i>flat pebble conglomerate</i> ); poorly sorted
	Windward Peritidal Flank	<i>stromatolitic intraclastic floatstone</i>	Small (granule to pebble), infrequent stromatolite clasts in a micrite matrix
2 Reef Complex	Leeward Flank	<i>skeletal mudstone</i>	Minor skeletal fragments in a micrite matrix; anhydrite-filled vugs; <10 m thick
	Leeward Distal Reef Apron	<i>skeletal mudstone</i>	Minor skeletal fragments; abundance of drusy calcite spar cement lining vuggy porosity; >10 m thick
	Leeward Proximal Reef Apron	<i>skeletal mudstone</i> <i>skeletal wackestone</i>	Minor skeletal fragments; abundance of drusy calcite spar cement lining vuggy porosity Disarticulated fossils (tabulate corals, brachiopods, bryozoans, crinoids) in a micrite matrix
	Reef Core	<i>coral/stromatoporoid framestone</i> <i>skeletal wackestone</i>	Frame-building organisms (tabulate corals, stromatoporoids) Intra-reef faunal assemblages (bryozoans, brachiopods, crinoids, rugose corals); 50-75% micrite matrix
	Windward Reef Talus	<i>coarse lithoclastic floatstone</i> <i>skeletal intraclastic rudstone</i>	Large, dark gray angular clasts in light gray micrite matrix; abundant crinoids Large clasts composed of tabulate corals, brachiopods, and crinoids; moldic porosity
	Windward Flank	<i>skeletal mudstone</i>	Occasional skeletal fragments and small (pebble), angular clasts in a micrite matrix; anhydrite-filled vugs
	Bioherm Mound	<i>crinoidal mudstone</i> <i>skeletal wackestone</i>	Mottled gray and white; abundant crinoids in a micrite matrix; abundant stromatactis Mottled gray and white; bryozoans, tabulate corals, rugose corals and crinoids in a micrite matrix; abundant stromatactis
1 Biohermal Complex	Bioherm Toe	<i>crystalline dolomite</i>	Devoid of fossils; composed of dolomite rhombs; intercrystalline porosity



# Study Workflow

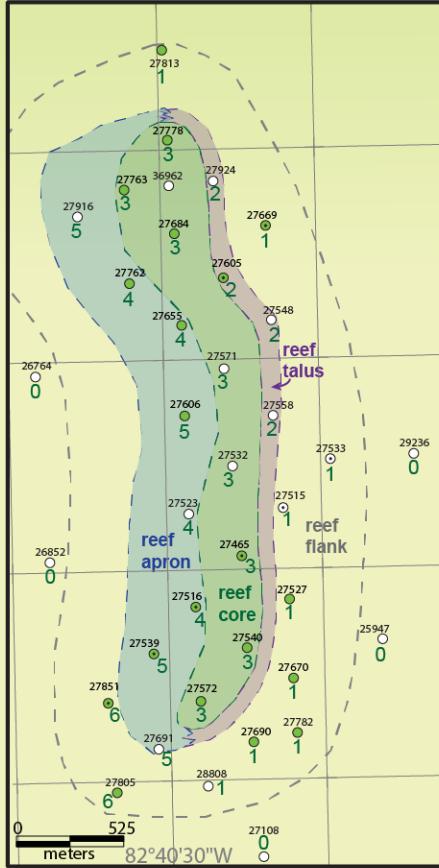
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	Windward Flank	<i>skeletal mudstone</i>	Occasional skeletal fragments and small (pebble), angular clasts in a micrite matrix; anhydrite-filled vugs
1 Biohermal Complex	Bioherm Mound	<i>crinoidal mudstone</i> <i>skeletal wackestone</i>	Mottled gray and white; abundant crinoids in a micrite matrix; abundant stromatoliths Mottled gray and white; bryozoans, tabulate corals, rugose corals and crinoids in a micrite matrix; abundant stromatoliths
	Bioherm Toe	<i>crystalline dolomite</i>	Devoid of fossils; composed of dolomite rhombs; intercrystalline porosity



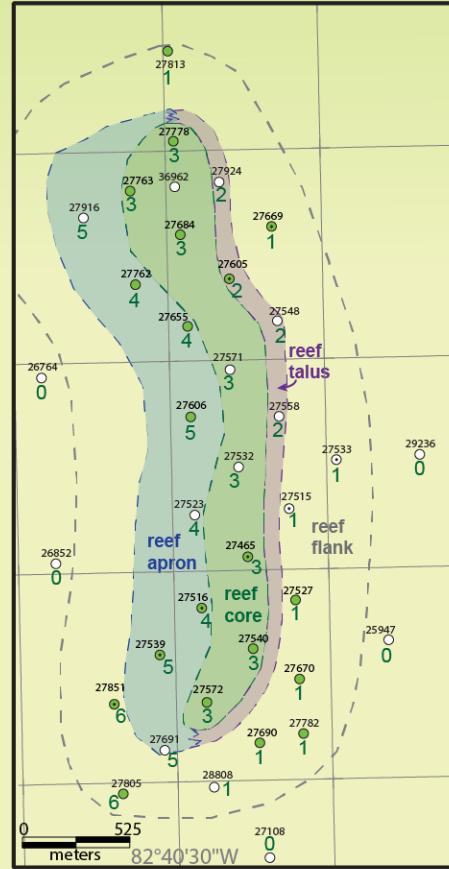
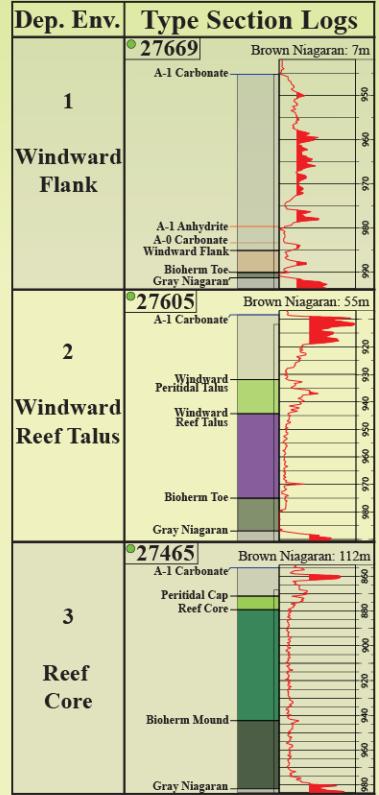
# Study Workflow

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## GR SIGNATURES

## DEPOSITIONAL MODEL



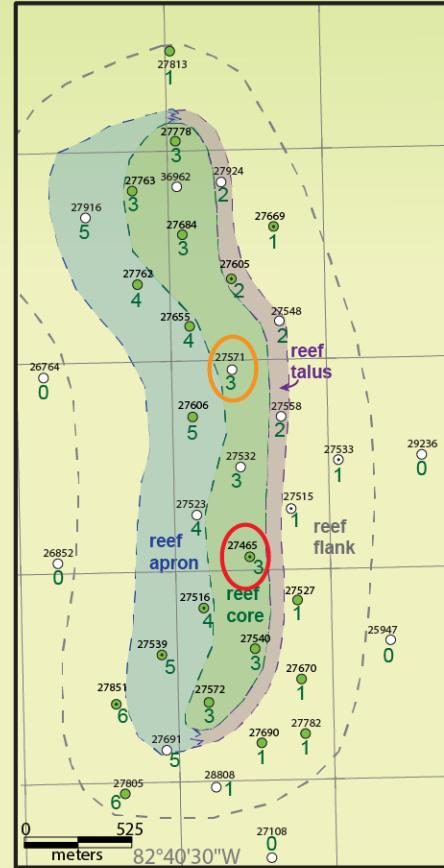
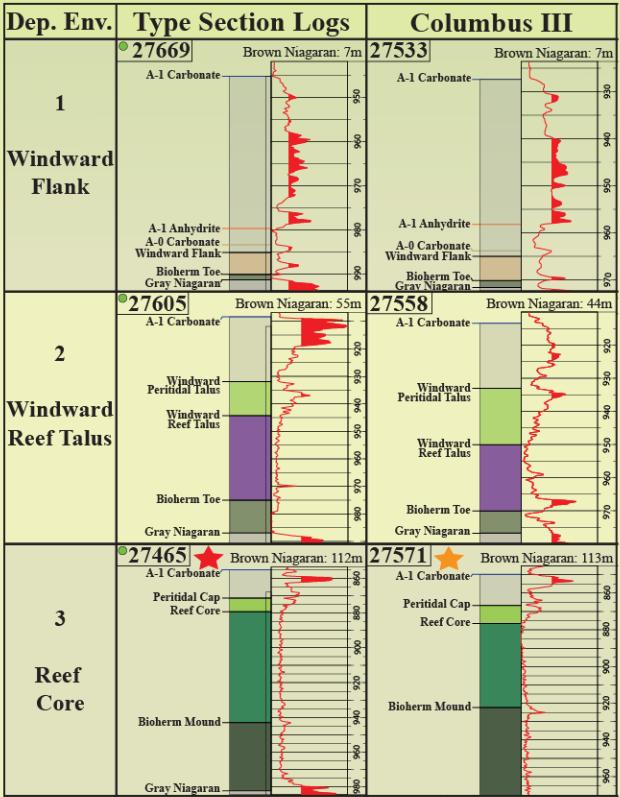
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# **DEPOSITIONAL MODEL**



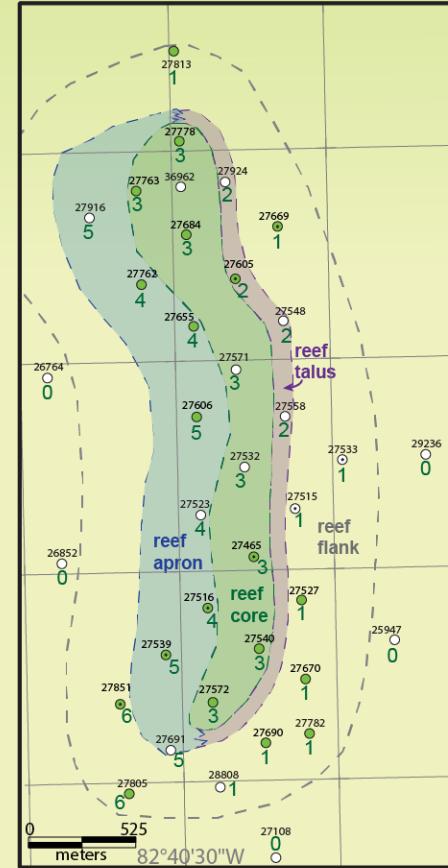
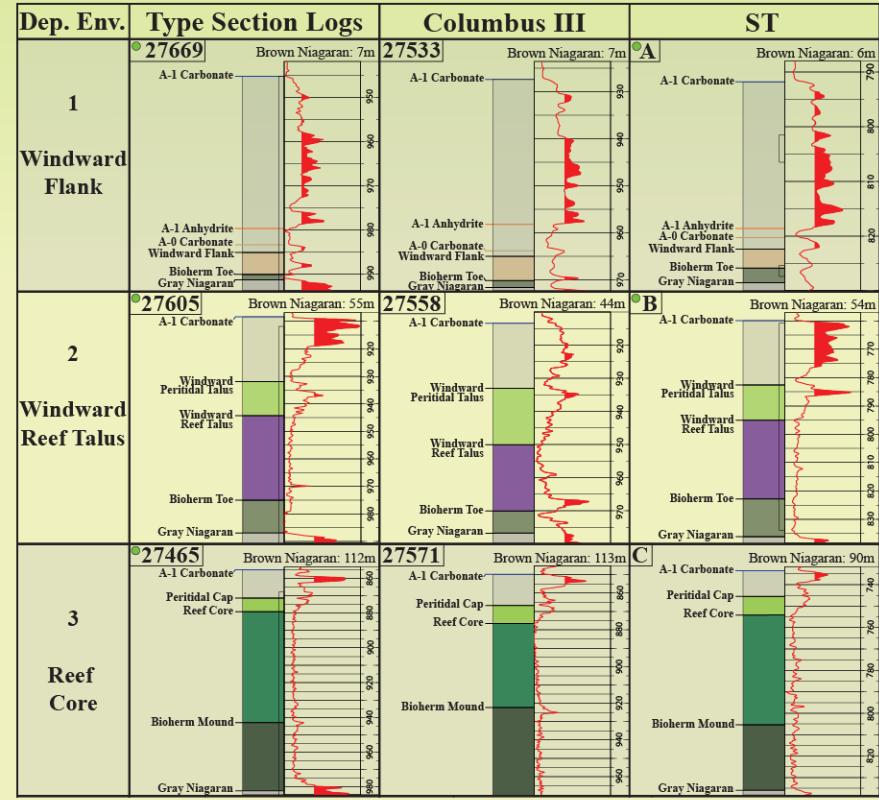
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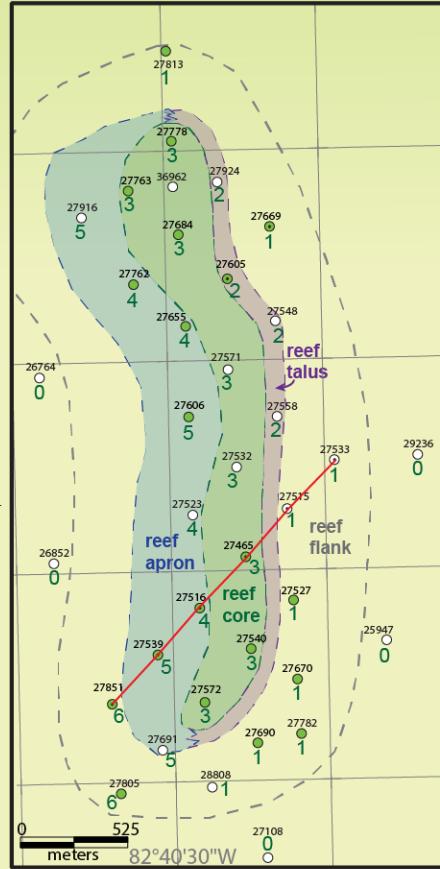
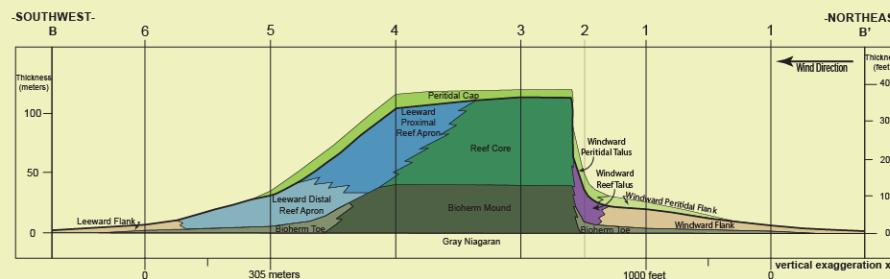
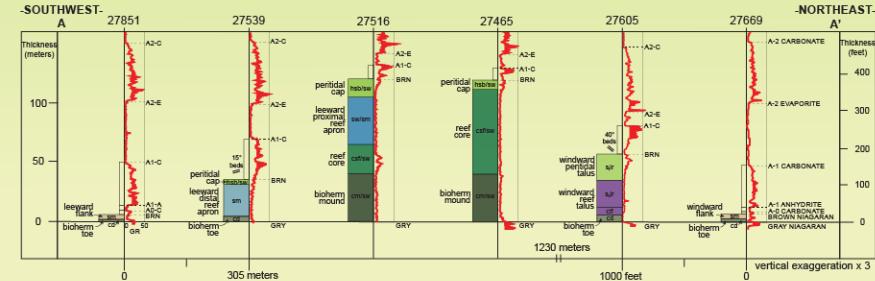
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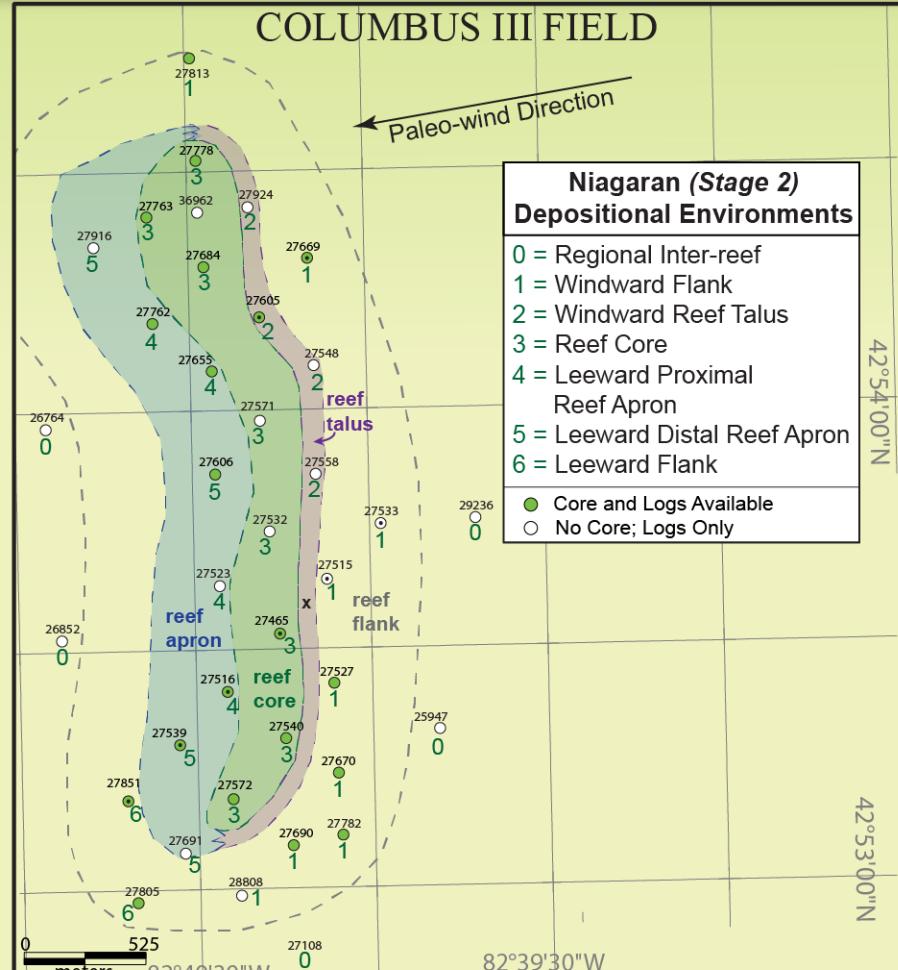
# OBSERVATIONS / INTERPRETATIONS



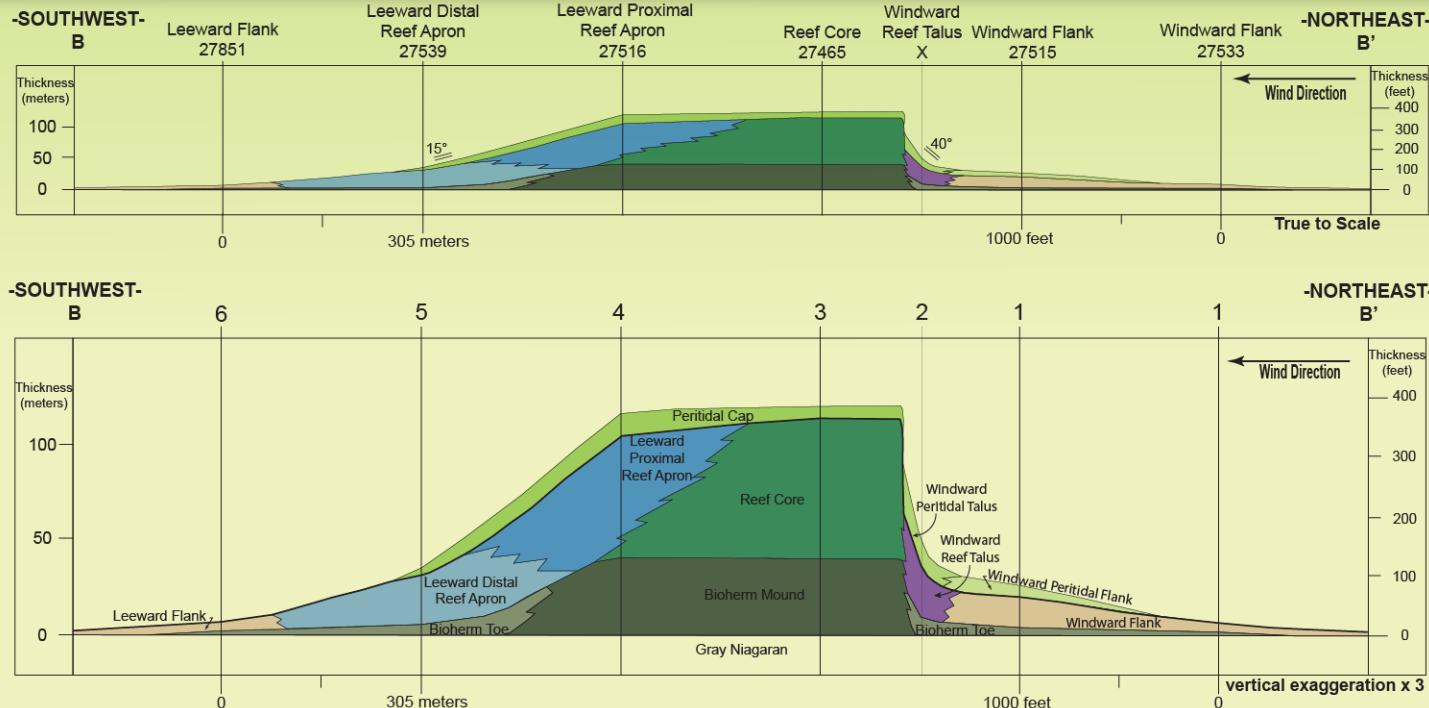
# RESULT: DEPOSITIONAL MODEL

# Southern Trend – Columbus III

- Most **data-rich** field in Michigan Basin (previously unstudied)
- **32 cored wells** (20 available for study) over 2 km<sup>2</sup>; average well spacing ~300m
- **Key Observations:**
  1. Reef Core strikes N-S
  2. Lithofacies variations from E-W
  3. Laterally thin reef talus to east with steep beds (>40°)
  4. Laterally wide reef apron to west with shallow dips (<15°)



# Columbus III X-Section



## Reef Core

- framestone to wackestone
- tabulate corals, stromatoporoids, bryozoans, brachiopods, crinoids, rugose corals

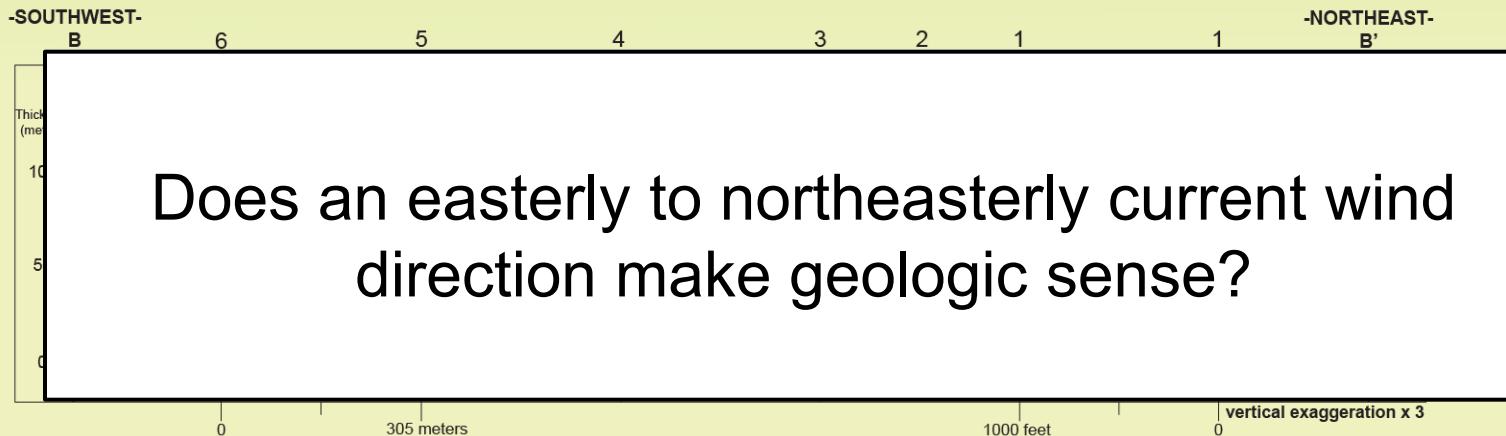
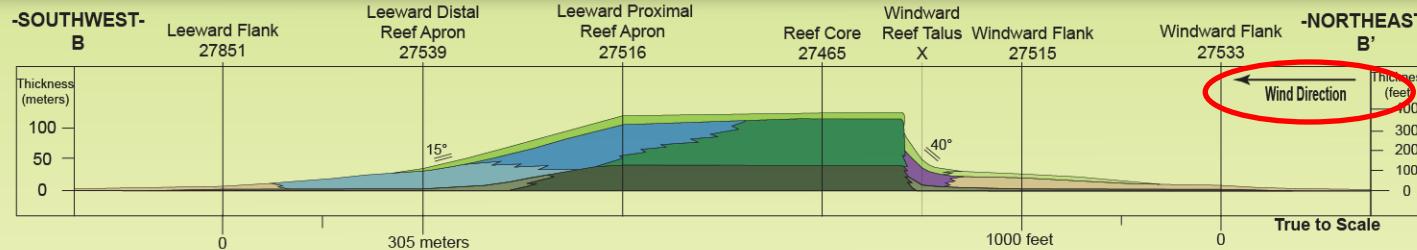
## Leeward

- wackestone to mudstone
- fines and thins away from Reef Core

## Windward

- stratified, coarse intraclastic rudstone
- fines and thins away from Reef Core

# Columbus III X-Section



## Leeward

- wackestone to mudstone
- fines and thins away from Reef Core

## Reef Core

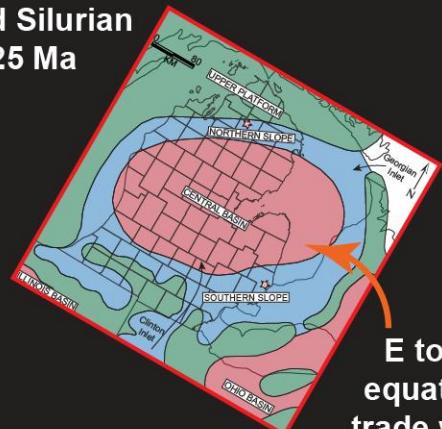
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- tabulate corals, stromatoporoids, bryozoans, brachiopods, crinoids, rugose corals

## Windward

- stratified, coarse intraclastic rudstone
- fines and thins away from Reef Core

# Silurian Trade Winds

Mid Silurian  
~425 Ma

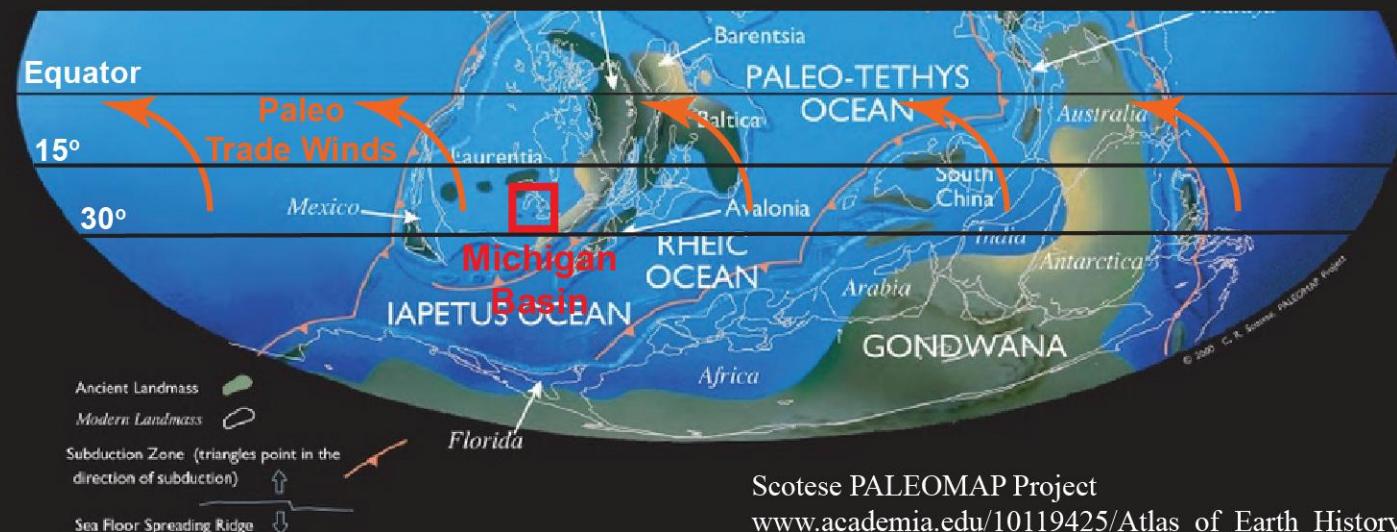


rotate 30°  
counter-clockwise  
to present day

E to SE  
equatorial  
trade winds

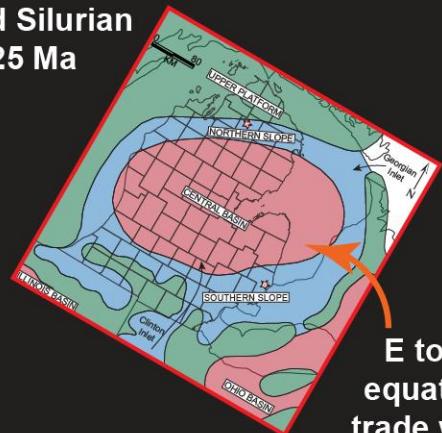


current day  
wind direction  
E to NE



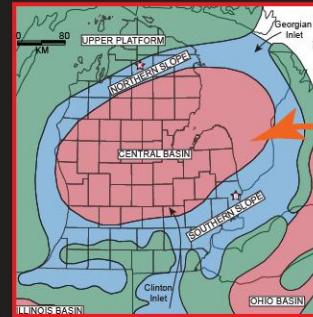
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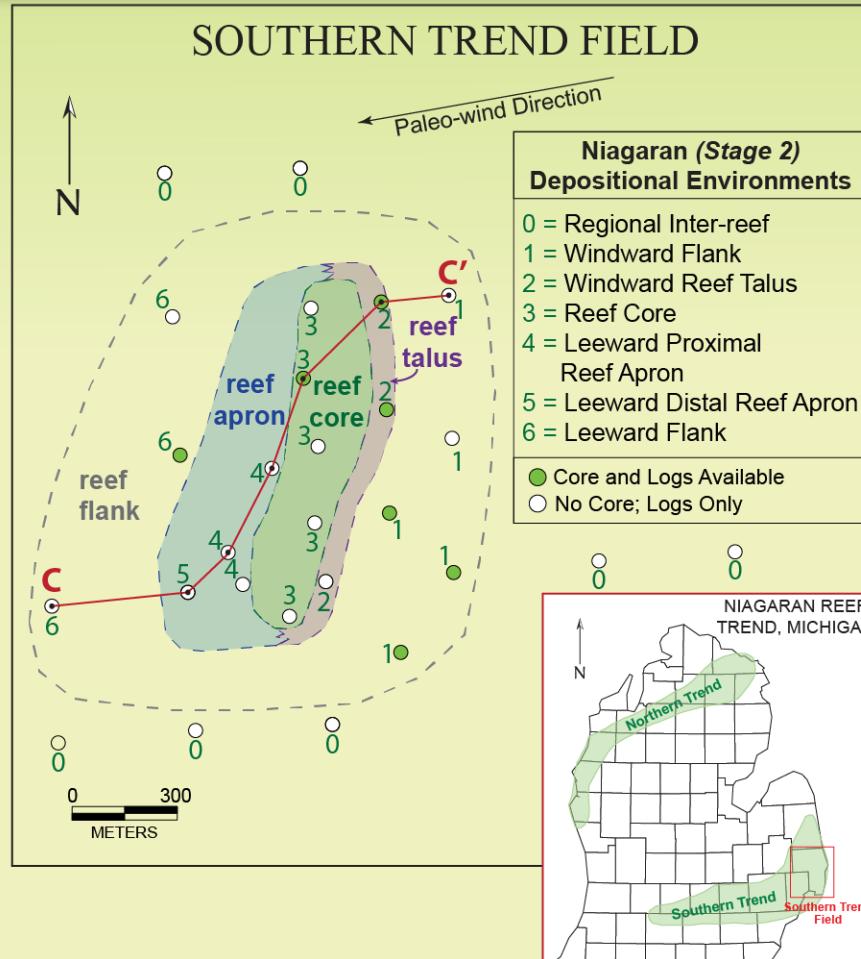
current day  
wind direction  
E to NE

Does this wind direction hold true for other  
reef complexes in the Michigan Basin?

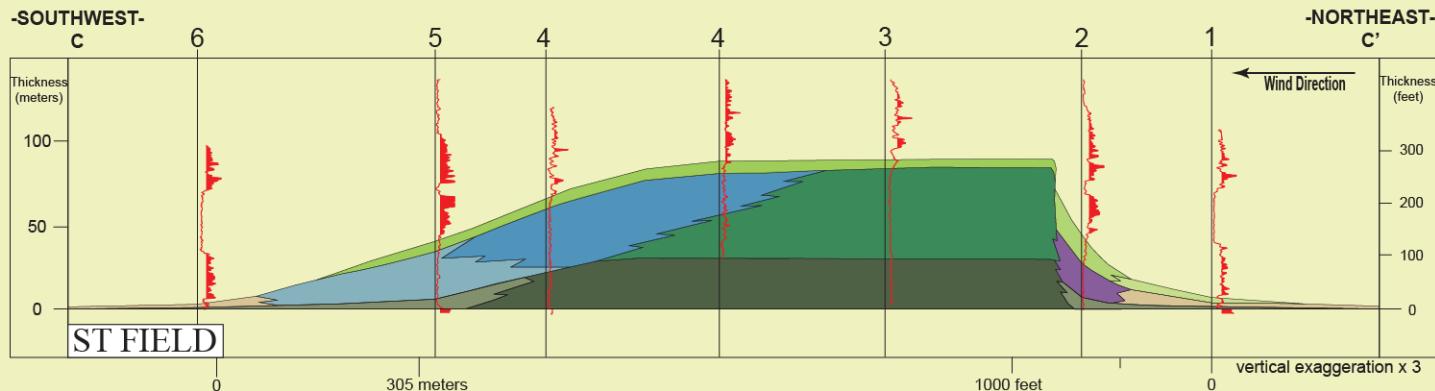
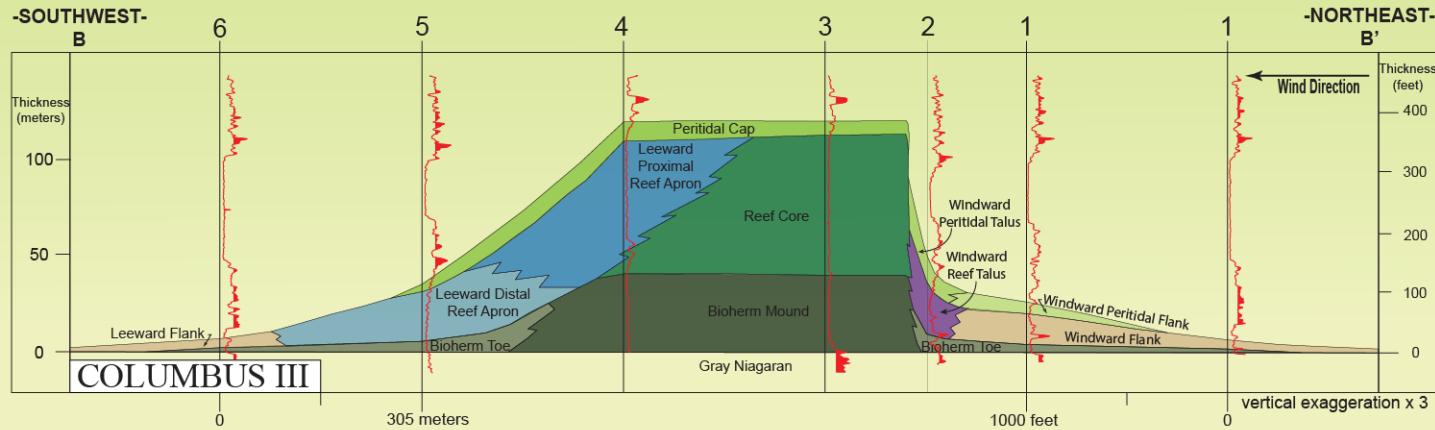


# Model Application

- 15 km south of data-rich Columbus III field
- Moderate data coverage
- 7 cored wells, 20 additional wells with logs over 1.8 km<sup>2</sup>
- Relied more heavily on **log signatures** to identify lithofacies and associated depositional environments



# Model Comparison

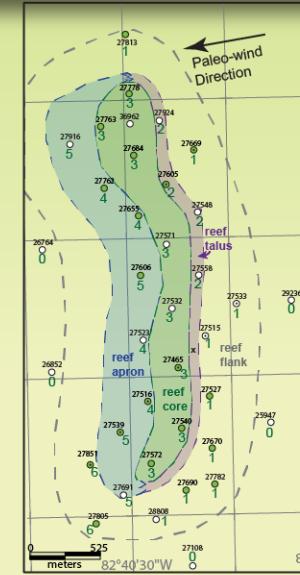
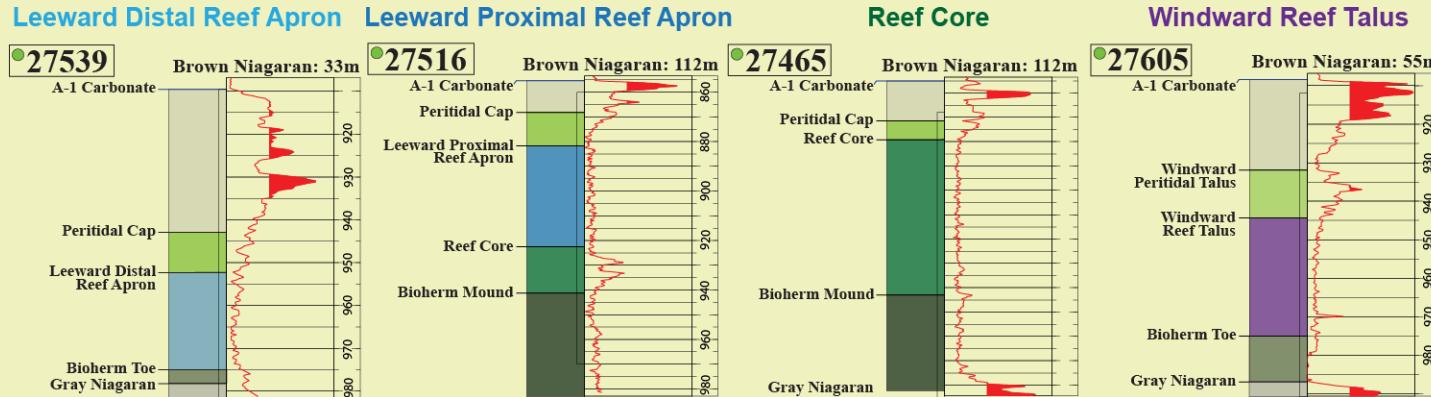


# Gamma Ray Signatures

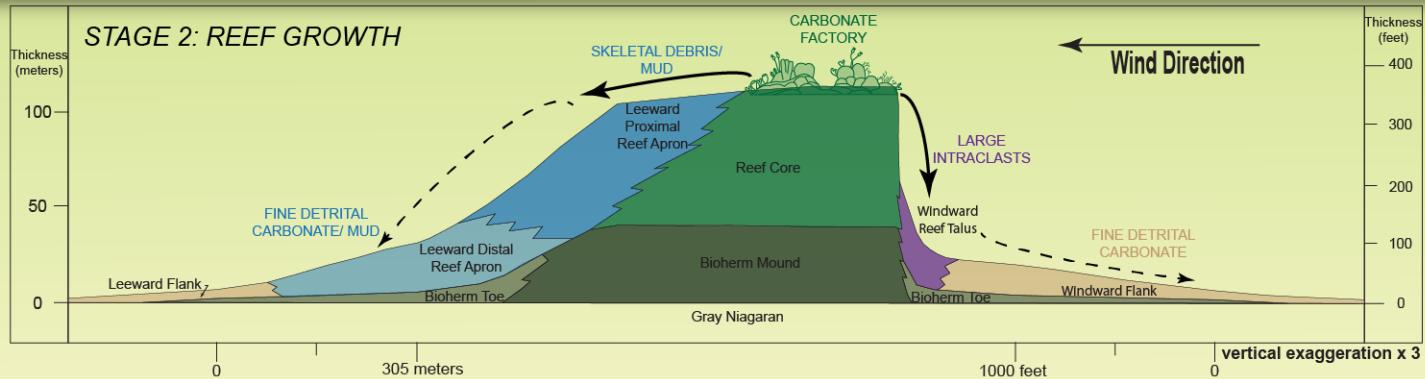
Identifying lithofacies groups from GR signatures requires:

- 1) Brown Niagaran thickness**
- 2) Well location relative to reef core**

- Similar GR signatures are expected as all sediment is genetically related, shed from same reef core. However, lithofacies are distinctly different due to different styles of sedimentation.



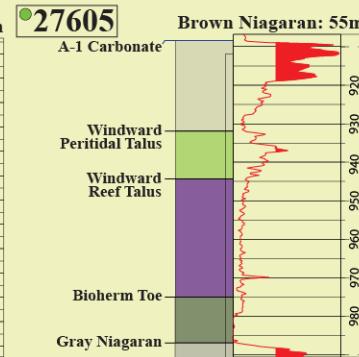
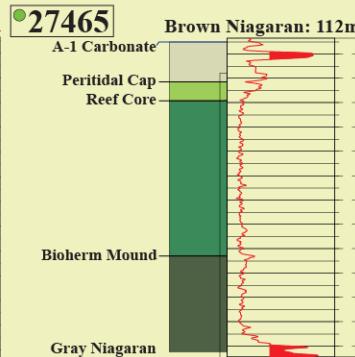
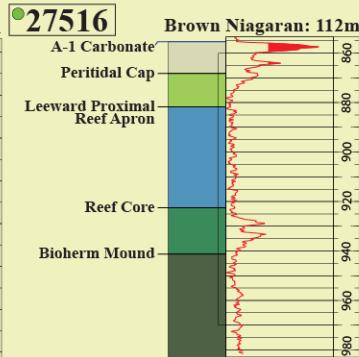
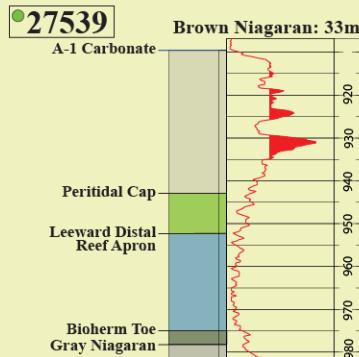
# Gamma Ray Signatures



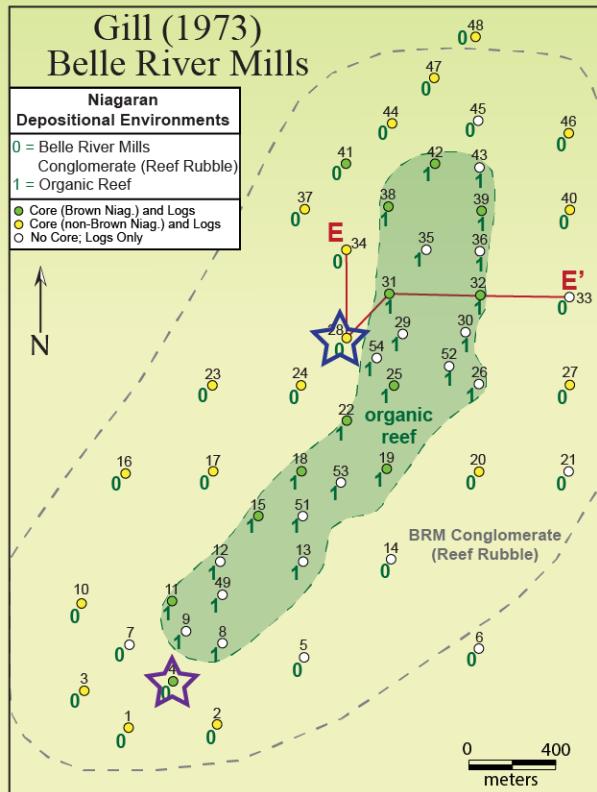
**Leeward Distal Reef Apron**      **Leeward Proximal Reef Apron**

**Reef Core**

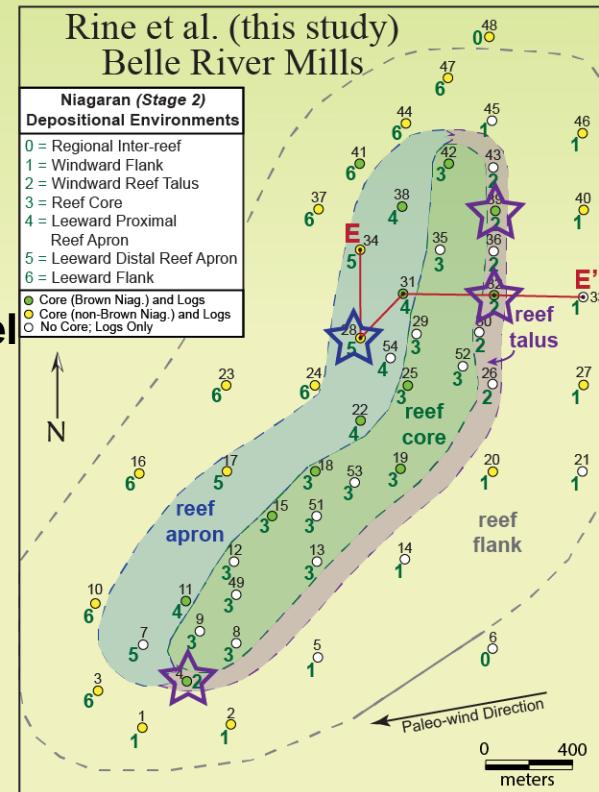
**Windward Reef Talus**



# Belle River Mills Re-examination

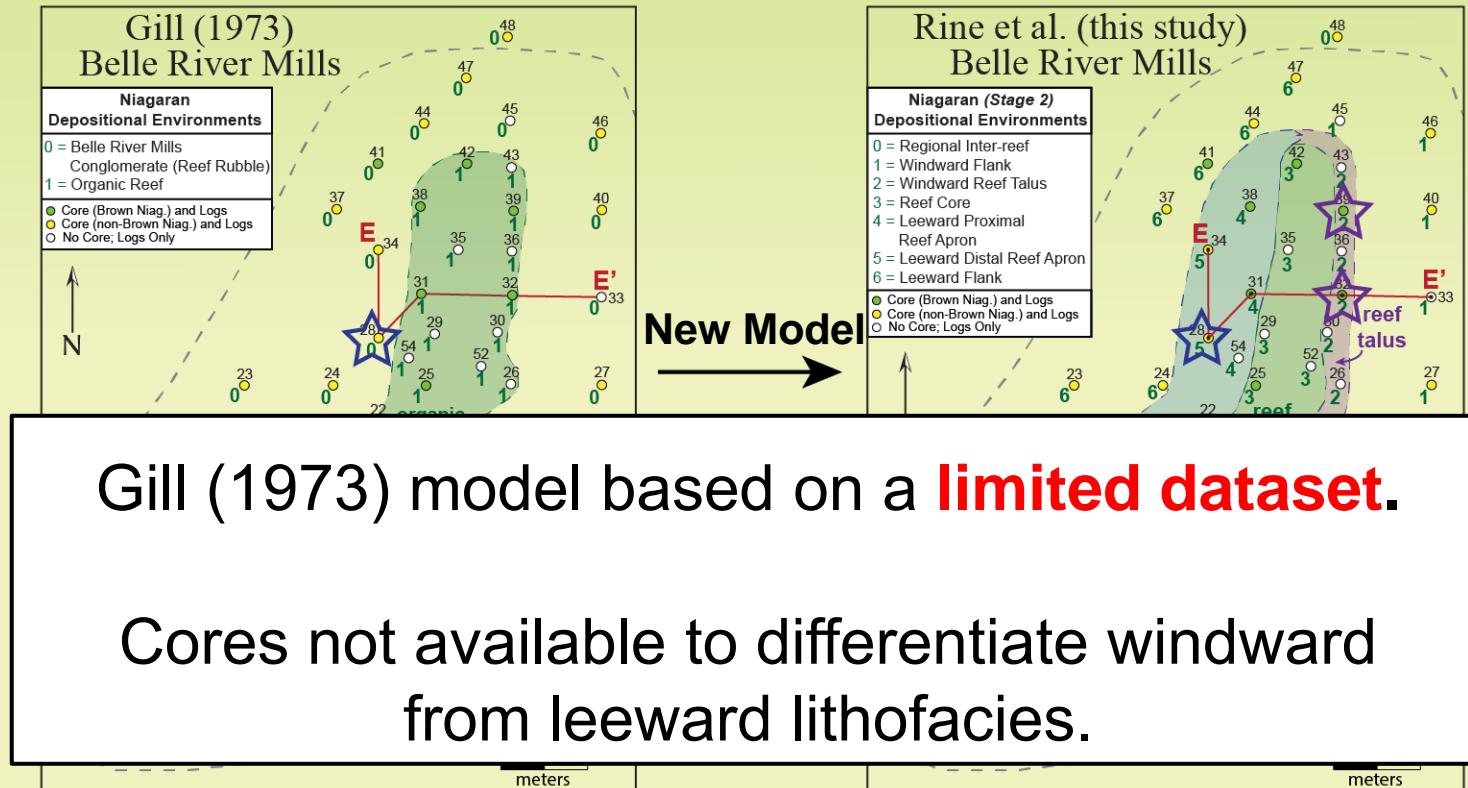


New Model



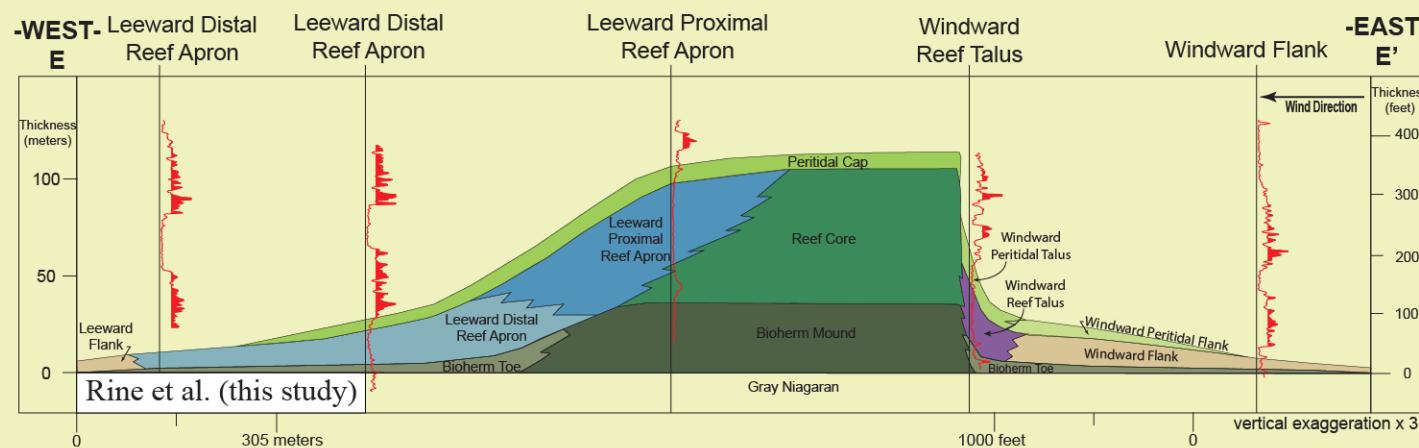
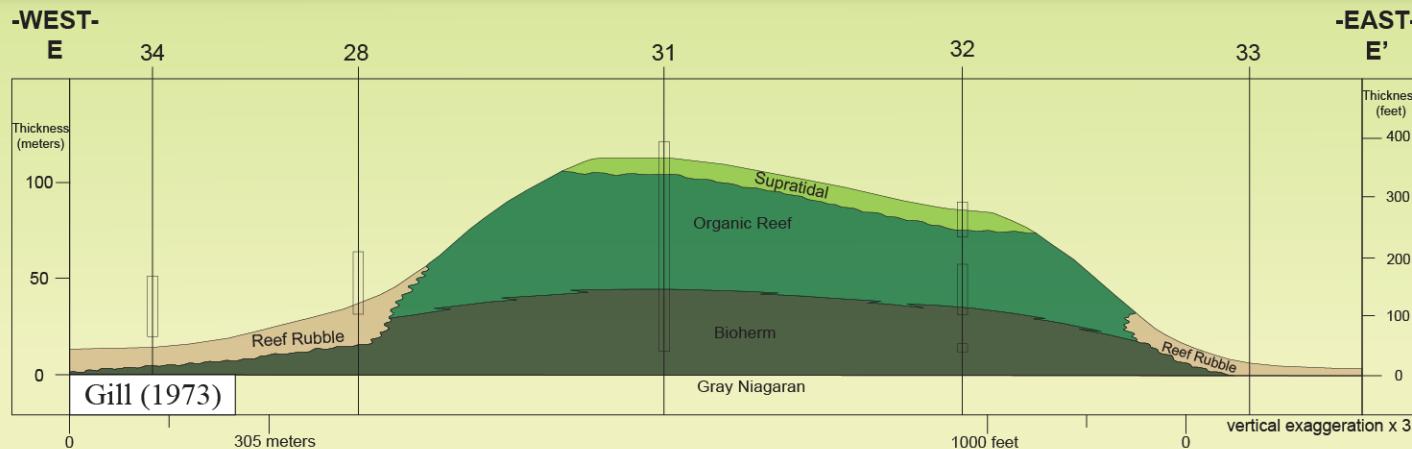
**BRM Field:** 31 total cores - 13 Brown Niagaran - 0 Distal Apron

# Belle River Mills Re-examination

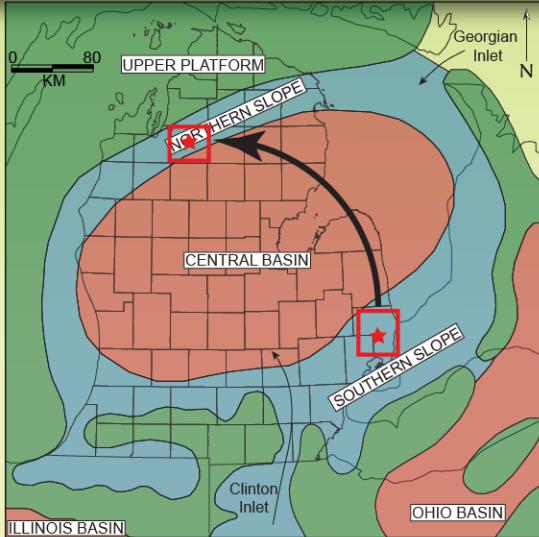


**BRM Field:** 31 total cores - 13 Brown Niagaran - 0 Distal Apron

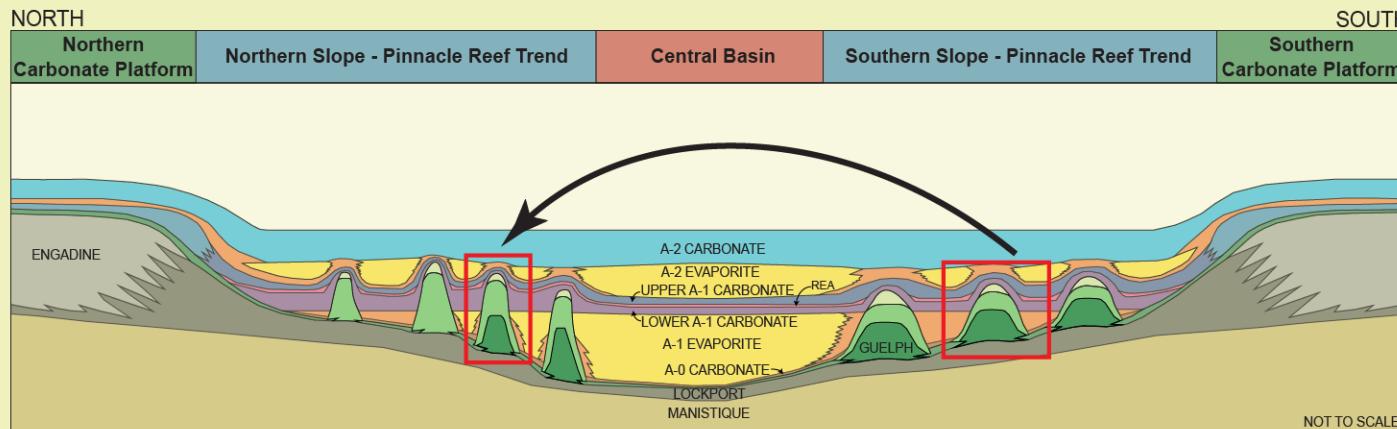
# Belle River Mills Re-examination



# Crossing Trends

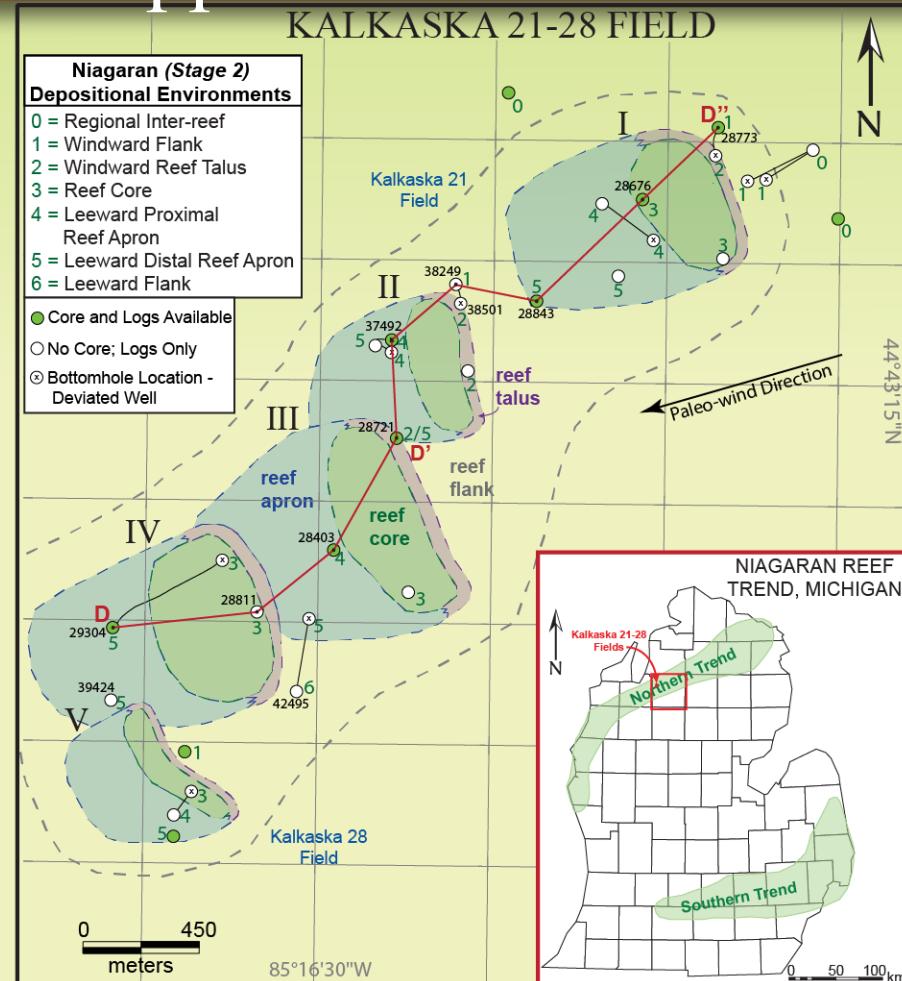


How does the  
asymmetrical reef model  
developed in the Southern  
Trend apply to the  
Northern Trend ?

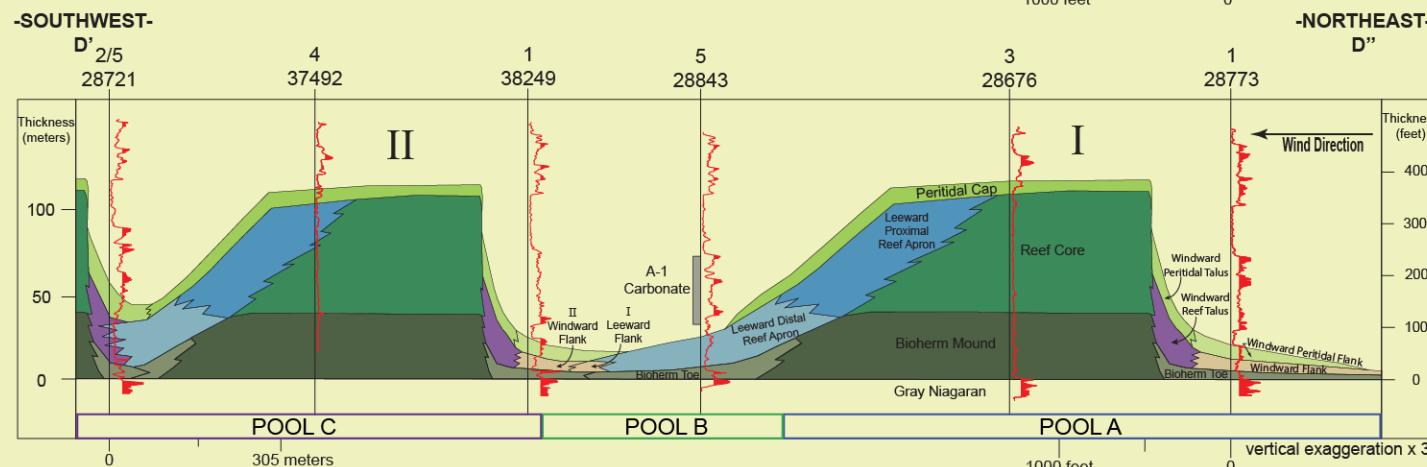
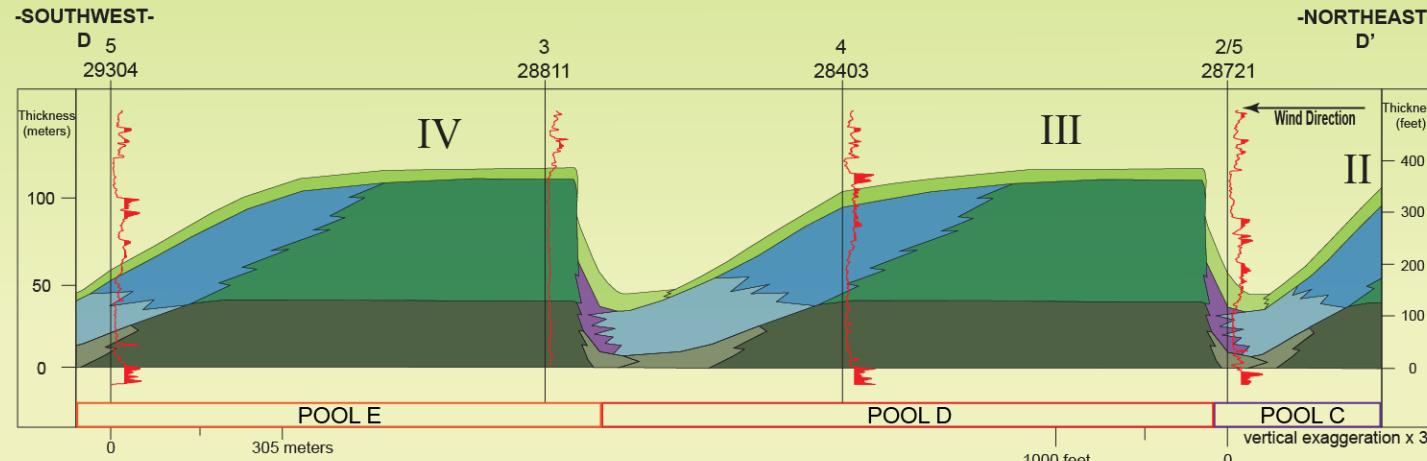


# Northern Trend Model Application

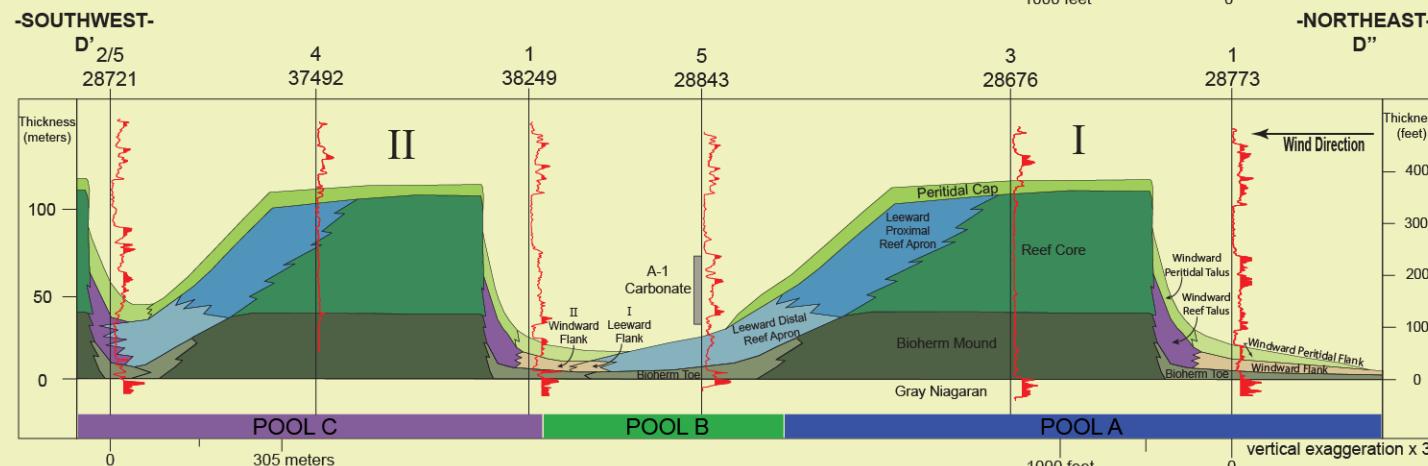
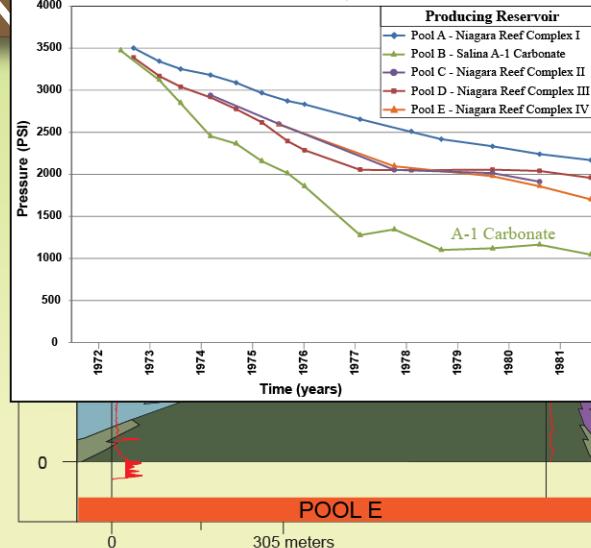
- >300 km away from southern trend fields
- Moderate data coverage
- 11 cored wells, 21 additional wells with logs over 1.2 km<sup>2</sup>
- Key Observations:
  1. Asymmetry still prevalent; Reef Cores strike NW-SE
  2. Wind direction slightly north of east
  3. Field comprised of coalescing reef complexes “string of pearls”



# Northern Trend Model Application



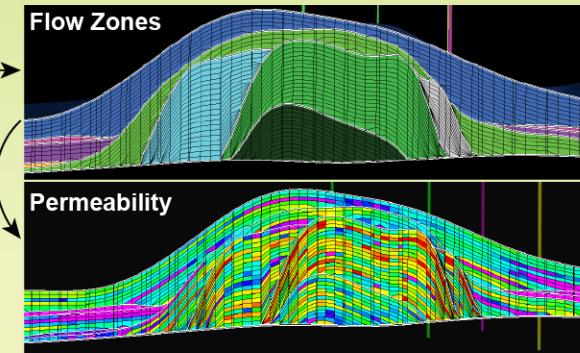
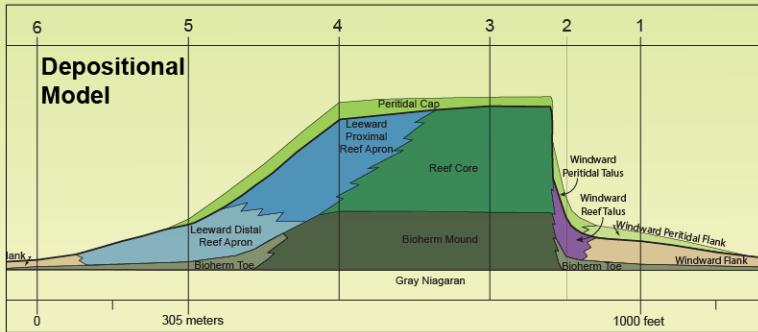
# KALKASKA 21-28 FIELD PRESSURE DECLINE HISTORY



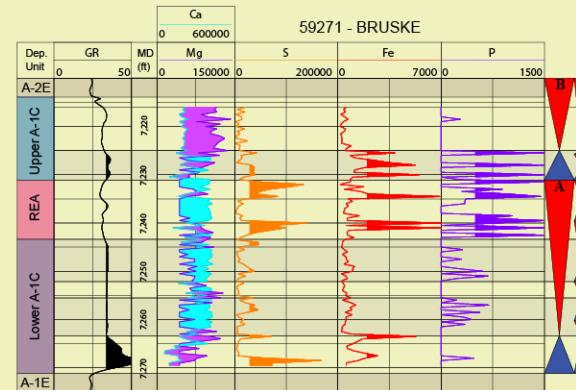
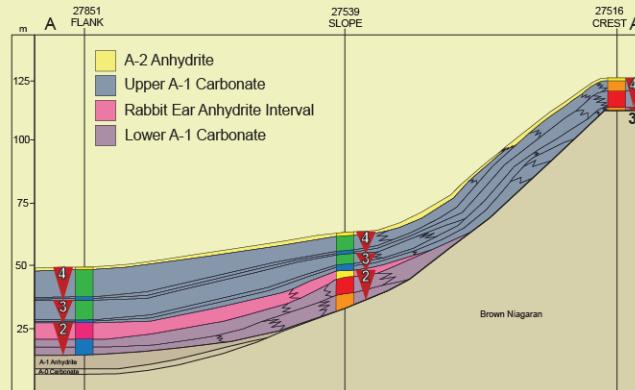
# Other ACE Presentations

## 1) Poster – Developing Static Reservoir Models for Niagaran Reefs

Search and Discovery Article #51318 (2016)



## 2) Core Conference (Jon Garrett) – Regional Chemo- and Sequence Stratigraphic Analysis of the A-1 Carbonate





# Thank You!

