PS Development of a Static Reservoir Models for Niagara Reefs, Michigan Basin, USA*

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Abstract

Silurian-age Niagaran "pinnacle reefs" of the Michigan Basin 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. Many of these fields are approaching, or have already passed, economic viability of primary production, but the high degree of compartmentalization makes them a potential target for CO_2 enhanced oil recovery, as well as natural gas storage. The primary objective of this study was to produce geologically precise 3D static models of Niagara-Lower Salina Reef Complexes, which could be used as fundamental inputs for dynamic fluid-flow modeling. A robust depositional model was first built for the Columbus III field, which has a high density of data with 32 cored wells at ~300m well spacing over 3 km^2. The new model resulted in the observation that Niagara-Lower Salina Reef complexes are highly asymmetrical with predictable internal facies distributions that are strongly influenced by an east-northeast paleo-wind direction. Application of the new asymmetrical reef model to reefs throughout the basin shows remarkable consistency with respect to the overall asymmetry and facies distribution patterns. This new asymmetrical reef model was then used to identify lateral facies distributions where little core data exists, and used in combination with observed diagenetic overprint to define reservoir flow units. Rock properties within the 3D static reservoir were populated using porosity-permeability data obtained from conventional whole core analysis. For the Columbus III field, the validity of the modeled HC volume estimates, which were calculated from porosity, fluid saturations, and fluid contacts, was confirmed by a near exact match with pressure-derived estimates provided by the field's operator. This study highlights the importance of using sequence stratigraphy and rock typing to define reservoir flow units for static reservoir models.

Reference Cited

Briggs, L.I., D.Z. Briggs, R.E. Elmore and D. Gill, 1978, Stratigraphic facies of carbonate platform and basinal deposits, late Middle Silurian, Michigan Basin, *in* R.V. Kesling, editor, The North-Central Section of the Geological Society of America, field excursions: GSA, p. 117-131.

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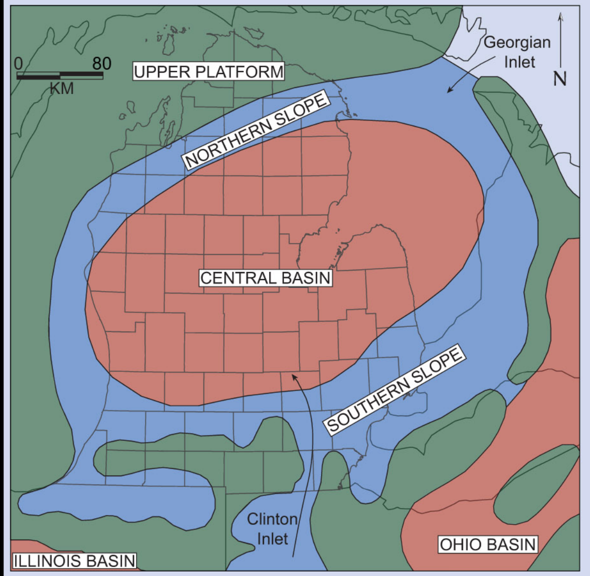
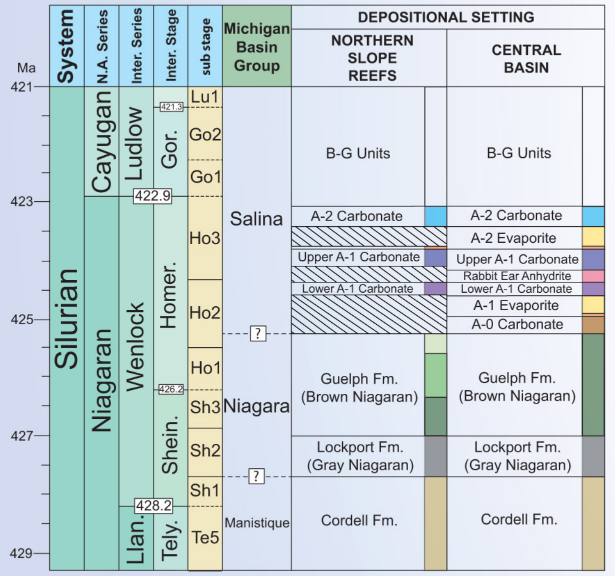
ABSTRACT

Silurian-age Niagaran "pinnacle reefs" of the Michigan Basin 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. Many of these fields are approaching or have already passed economic viability of primary production, but the high degree of compartmentalization makes them a potential target for CO_2 enhanced oil recovery, as well as natural gas storage. The primary objective of this study was to produce geologically precise 3D static models of Niagara-Lower Salina Reef Complexes, which could be used as fundamental inputs for dynamic fluid-flow modeling. A robust depositional model was first built for the Columbus III field which has a high density of data with 32 cored wells at ~300 m well spacing over 3 km^2. The new model resulted in the observation that Niagara-Lower Salina Reef Complexes are highly asymmetrical with predictable internal facies distributions that are strongly influenced by an east-northeast paleo-wind direction. Application of the new asymmetrical reef model to reefs throughout the basin shows remarkable consistency with respect to the overall asymmetry and facies distribution patterns. This new asymmetrical reef model was then used to identify lateral facies distributions where little core data exists, and used in combination with observed diagenetic overprint to define reservoir flow units. Rock properties within the 3D static reservoir were populated using porosity-permeability data obtained from conventional whole core analysis. For the Columbus III field, the validity of the modeled HC volume estimates, which were calculated from porosity, fluid saturations, and fluid contacts, was confirmed by a near exact match with pressure-derived estimates provided by the field's operator. This study highlights the importance of using sequence stratigraphy and rock typing to define reservoir flow units for static reservoir models.

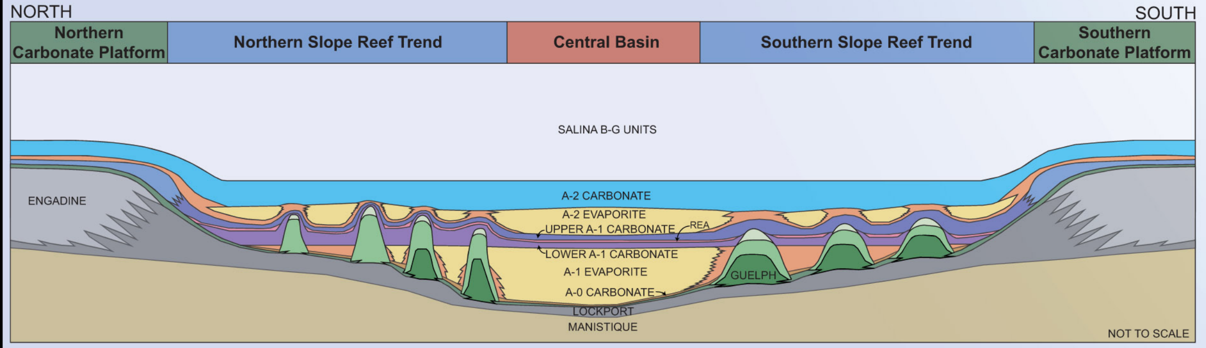
GEOLOGIC BACKGROUND



Generalized depositional environments of the Michigan Basin in the Silurian during Niagaran deposition (modified from Briggs et al. 1978).

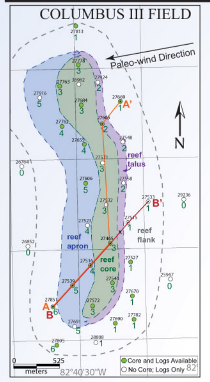


Chronostratigraphic chart for the Silurian (Niagaran-Cayugan) with corresponding depositional settings.

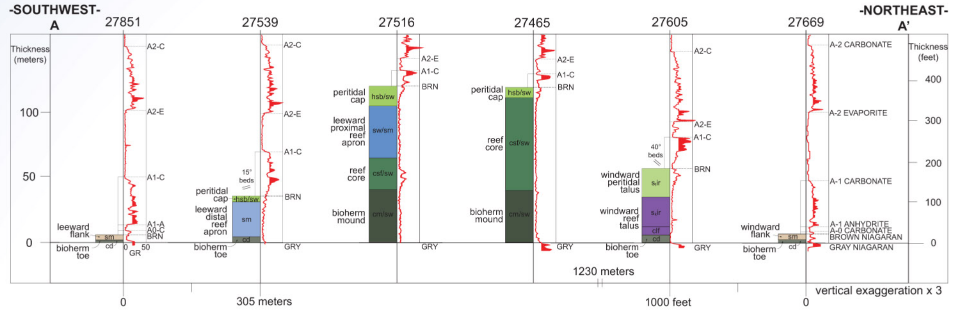


Schematic structural cross-section (not to scale) of the Silurian (Niagaran-Cayugan) units in the Michigan Basin from the northern carbonate platform, across the center of the basin, to the southern carbonate platform.

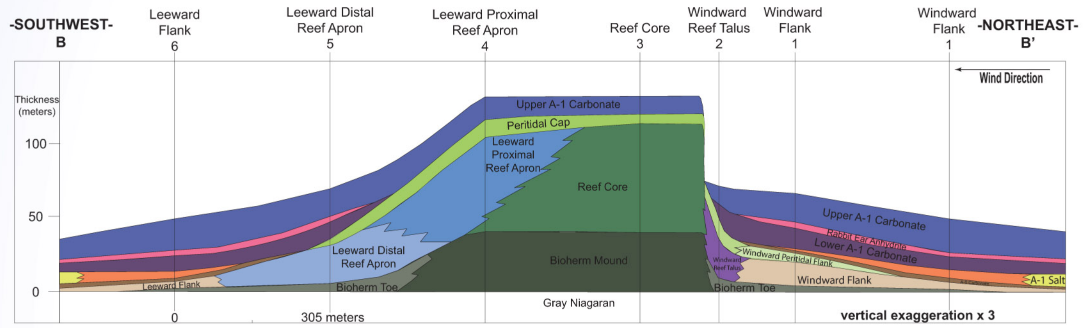
1. BUILD THE GEOLOGIC MODEL



Niagaran Reef Complex Depositional Environments

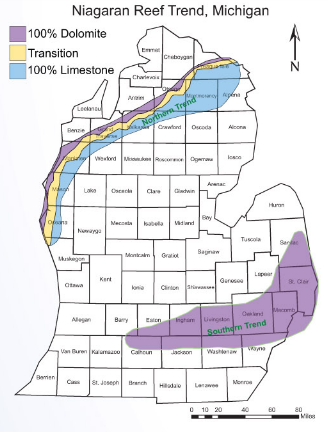


Stratigraphic cross-section of the Columbus III reef complex illustrating the observed distribution of lithofacies, associated depositional environments, GR log signatures, and vertical stacking in the 6 type section cores.

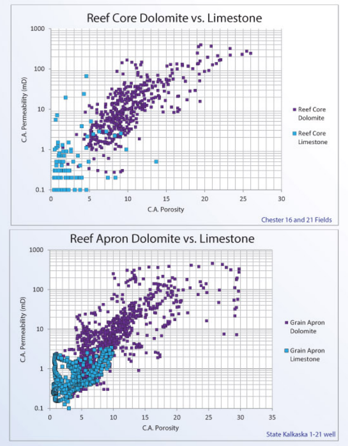


3 to 1 vertically exaggerated stratigraphic cross-section of the Columbus III reef complex.

2. ADDRESS DIAGENETIC OVERPRINT



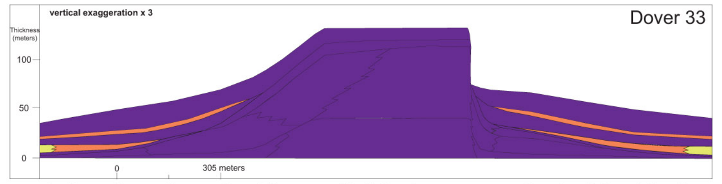
Regional-Scale Diagenetic Trends



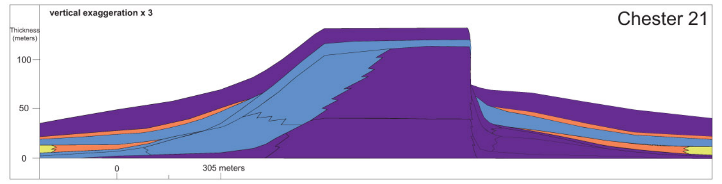
Core-Scale Diagenetic Trends

Field-Scale Diagenetic Scenarios

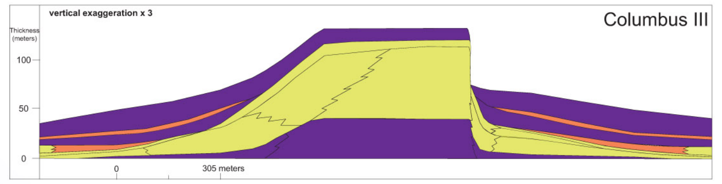
Dolomite / Anhydrite / Limestone / Halite



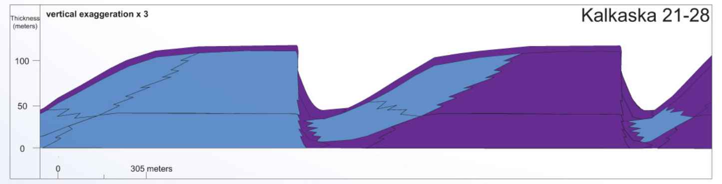
1: Best Case Scenario - Niagaran/A-1 Carbonate completely dolomitized



2: Partial Dolomitization - Facies Selective; abundant early-marine cements

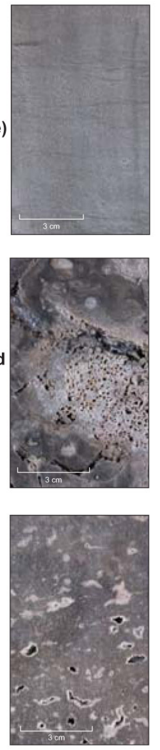


3: Salt Plugging - Top Down Salt Plugging of the Brown Niagaran



4: Coalescing Reef Complexes - Partial Dolomitization

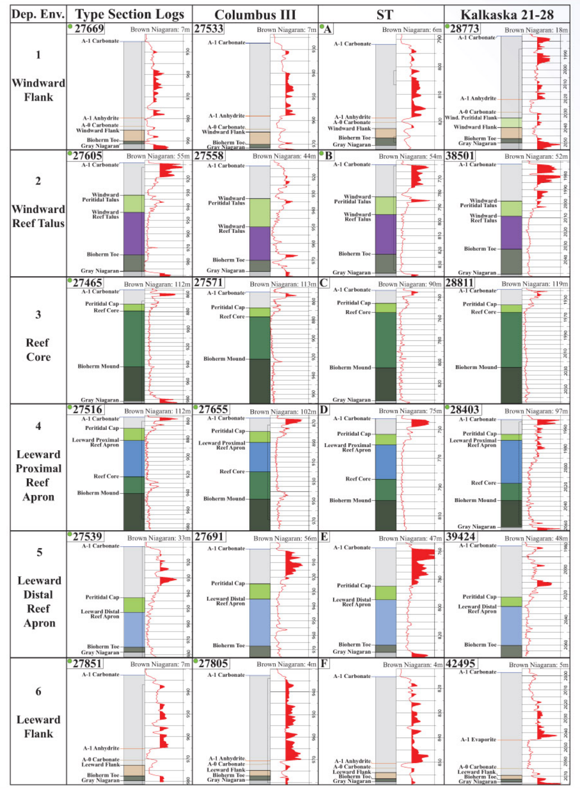
3. CORE-TO-LOG CORRELATION



crystalline dolomite (bioherm toe)

coral/ stromatoporoid framestone (reef core)

skeletal mudstone (leeward distal reef apron)



coarse lithoclastic floatstone (windward reef talus)

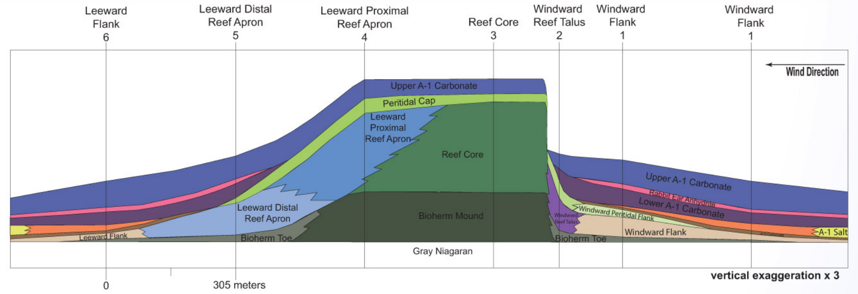
skeletal wackestone (bioherm mound)

hemispheroid stromatolitic bindstone (peritidal cap)

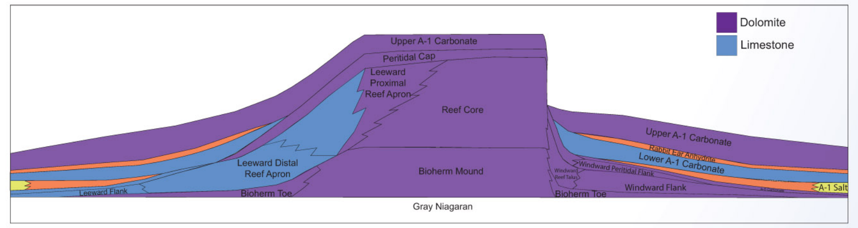
4. DEFINE FLOW ZONES

STEPS

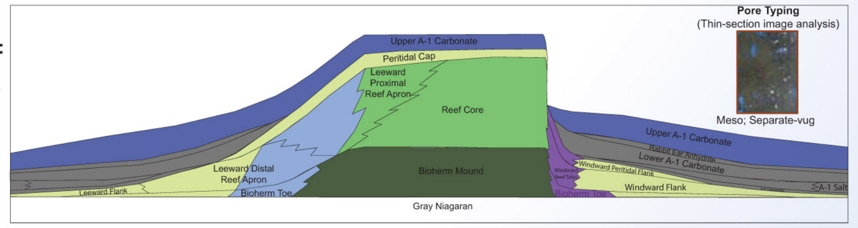
1. Depositional Facies Distribution: predict vertical & lateral facies distributions using conceptual geologic model and all available data (cores, logs, seismic)



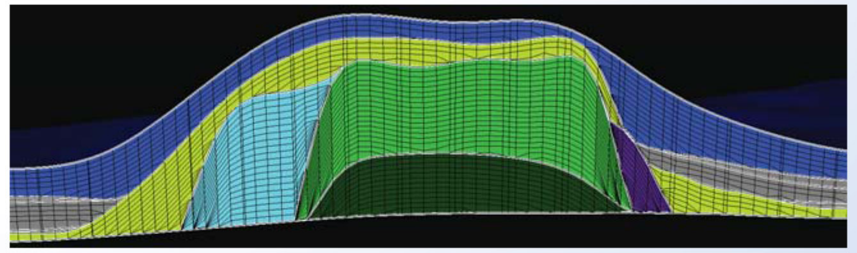
2. Diagenetic Overprint: predict vertical & lateral diagenetic overprint from regional trends and available data



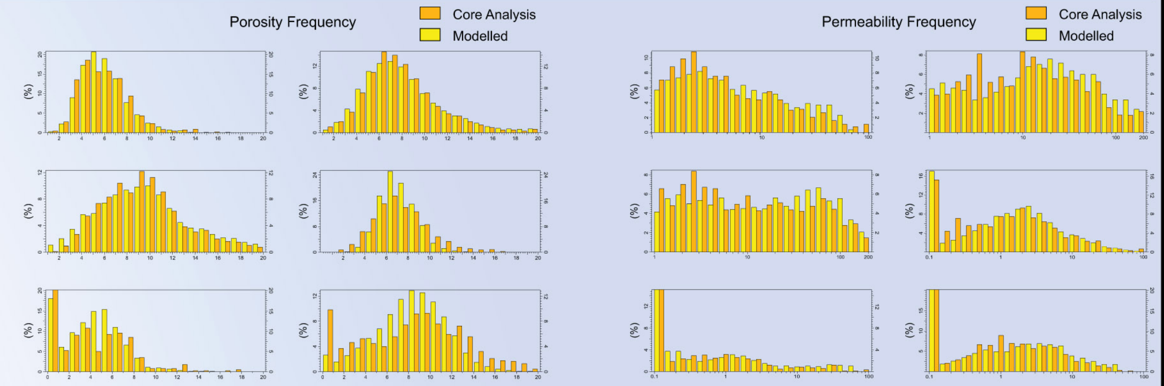
3. Flow Zone Designation: delineate flow zones (geo-bodies) with similar pore types & sizes (pore typing); requires combination of depositional and diagenetic understanding

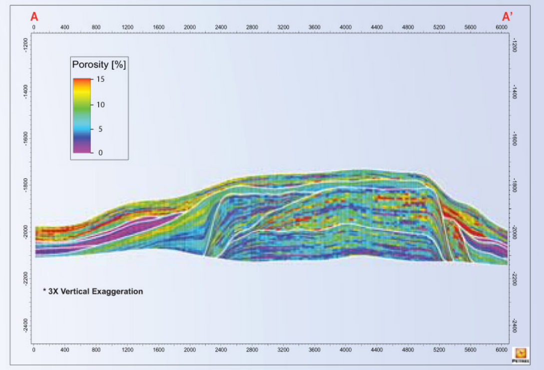


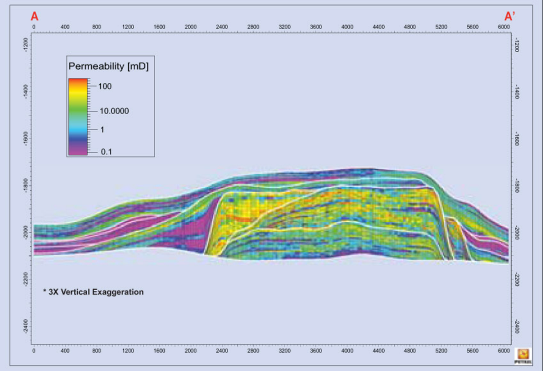
4. Model Flow Zones: hand contour flow zones to construct 3D static model that best represents geologic knowledge gained in steps 1-3



5. POPULATE FLOW ZONES

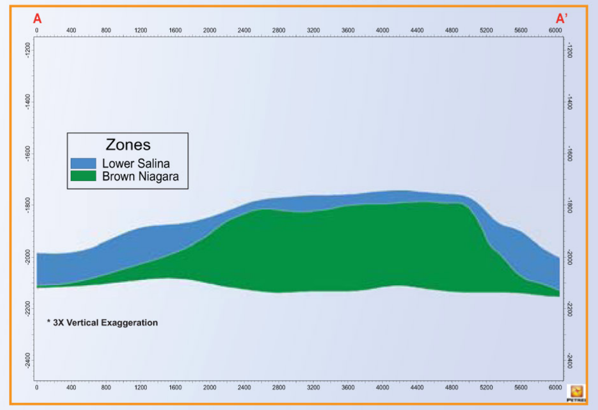




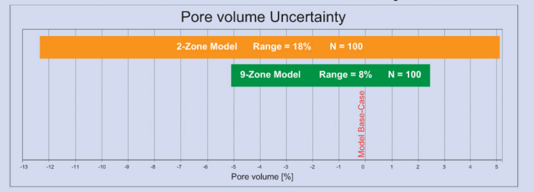


6. VALIDATE MODEL

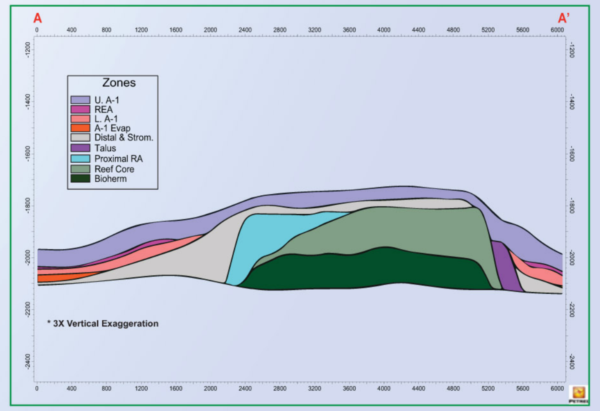
2-Zone Model



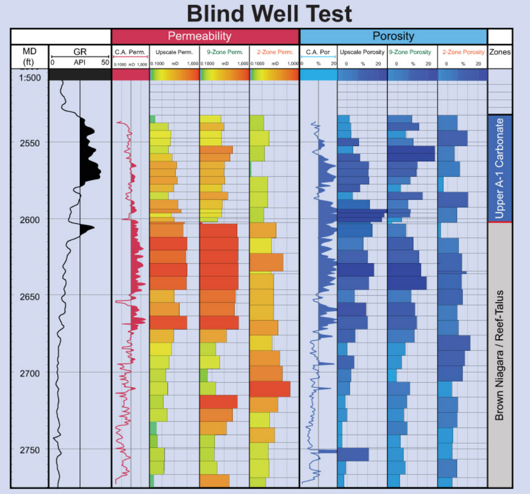
2-Zone vs. 9-Zone Model Comparison



9-Zone Model



Blind Well Test



Model Validation - Volume Comparison

	Total Pore Volume ($x10^6$ ft^3)	HCPV Oil ($x10^6$ ft^3)	HCPV Gas ($x10^6$ ft^3)	HCPV Total ($x10^6$ ft^3)
9-Zone Model	302	112	174	**286**
BWGS Estimates	--	112	175	**287**