PS 3-D Reservoir Characterization of the South Buckeye Field, Dundee Formation (Devonian), Michigan Basin, USA*

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Abstract

Middle Devonian Dundee carbonates are prolific hydrocarbon reservoirs throughout the Michigan Basin that have produced in excess of 375 million barrels of oil from more than 100 fields. Carbonate systems are driven by dynamic processes that vary in time and space at nearly all scales, from the pore network to the regional sequence stratigraphic architecture. The internal variability and detailed facies geometry of the Dundee are not well understood. This high resolution reservoir characterization study defines the complex internal heterogeneities of the South Buckeye field by tying reservoir quality (i.e., porosity and permeability from whole core analyses) directly to seven primary depositional facies.

The fundamental goal of this study is to evaluate if the geographic distribution of patch reefs can be accurately modeled in Petrel based on core and log data without a tie to 3-D seismic by utilizing the application of geometrical data from multiple depositional analogs. Paleotopographic highs provided nucleation sites for the stromatoporoid patch reefs to grow, but within each of these reefs reservoir quality varies significantly. The internal architecture of the South Buckeye field and the distribution of patch reefs were defined through the integration of petrophysical and petrographic analyses from high density subsurface core data.

Based upon core and wireline log analysis, three end member interpretations to define the distribution and scale of the patch reef reservoirs in South Buckeye field are possible. These end-member interpretations vary on the size and continuity of the patch reefs, with models ranging from single well reefs below seismic scale, multiple well reefs with horizontal/multi-lateral potential, and two large reef bodies concluded from previous research. These end member interpretations will be modeled geostatistically in Petrel to compare 3-D visualizations of the reef complexes with known production histories from the field. As with many carbonate reservoirs, a three- dimensional static reservoir model is a critical step in the workflow for efficient hydrocarbon extraction, natural gas storage, and CO_2 sequestration, and will provide insight into the Michigan Basin Dundee patch reefs as well as possibly other Devonian carbonates and patch reef trends around the world.

Selected References

Gardner, W.C., 1974, Middle Devonian Stratigraphy and Depositional Environments in the Michigan Basin: Michigan Basin Geological Society, Special Papers, No. 1, 138 p.

Gischler, E., and A.J. Lomando, 1999, Recent sedimentary facies of isolated carbonate platforms, Belize-Yucatan system, Central America: Journal of Sedimentary Research, v. 69, p. 747-763.

Website

Blakely, R., PaleoMap Project: Website accessed 21 October 2011, 2006 http://www2.nau.edu/rcb7/

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Middle Devonian Dundee carbonates are prolific hydrocarbon reservoirs throughout the Michigan Basin that have produced in excess of 375 million barrels of oil from more than 100 fields. Carbonate systems are driven by dynamic processes that vary in time and space at nearly all scales, from the pore network to the regional sequence stratigraphic architecture. The internal variability and detailed facies geometry of the Dundee are not well understood. This high resolution reservoir characterization study defines the complex internal heterogeneities of the South Buckeye field by tying reservoir quality (i.e., porosity and permeability from whole core analyses) directly to seven primary depositional facies.

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Based upon core and wireline log analysis, three end member interpretations to define the distribution and scale of the patch reef reservoirs in South Buckeye field are possible. These end-member interpretations vary on the size and continuity of the patch reefs, with models ranging from single well reefs below seismic scale, multiple well reefs with horizontal/multi-lateral potential, and two large reef bodies concluded from previous research. These end member interpretations are modeled geostatistically in Petrel to compare 3-D visualizations of the reef complexes with known production histories from the field. As with many carbonate reservoirs, a three-dimensional static reservoir model is a critical step in the workflow for efficient hydrocarbon extraction, natural gas storage, and CO_2 sequestration, and will provide insight into the Michigan Basin Dundee patch reefs as well as possibly other Devonian carbonates and patch reef trends around the world.

Fundamental Questions

1. What is the geographic distribution of reservoir quality within the field and is the distribution related to facies variability?
2. Are the primary reservoir facies patch reefs, and can the geometry/scale of the buildups be determined from closely-spaced core data (≤ 40 acre spacing)?
3. What causes the heterogeneity of porosity and permeability values within the patch reef facies?
4. Can the patch reefs be accurately modeled in Petrel using core and log data without a tie to 3-D seismic?

Methodology

- Detailed analysis of 27 cores (facies and depositional environment)
- Interpretation of wireline log data for porosity/permeability; tie to core
- Construct 3-D geostatistical models of porosity, permeability, and facies (Petrel)
- Comparison of reservoir property model to well production histories

Michigan Basin in the Devonian

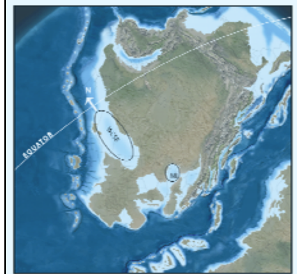
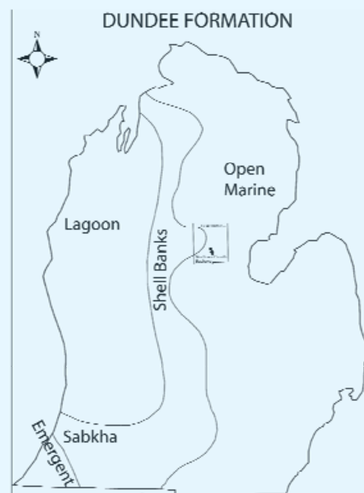


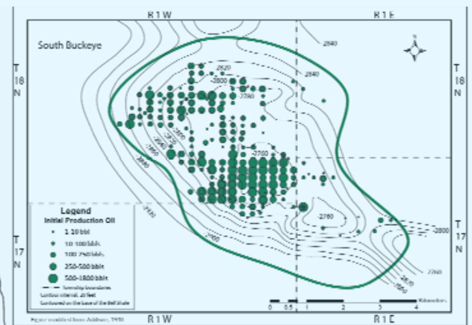
Figure from Blakely (2006)

- The Michigan Basin was located in sub-tropical latitudes (30 degrees south)
- Shallow intracratonic sea
- Abundant shallow water carbonate sedimentation, little to no siliciclastic input (Dundee Fm.)

Location of South Buckeye Field



Modified from Gardner (1974)



Bubble map of initial production shows reservoir is loosely constrained by topographic highs. Original field development on 10 acre spacing, currently 40 acre "classic five-spot" configuration under water flood.

- Average well IP = 271 BO
- Primary production = 5.5 MMBO
- Secondary production = 2 MMBO

South Buckeye field discovered in 1936
- 2,490 acre oil field
- Produced >7.5 MMBO (primary + secondary)
- 39 API gravity

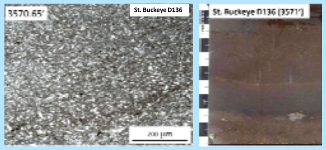
- Previous work focused on generalized regional deposition of facies from "shell bank" (shelf) to open marine as illustrated in figure above.
- Current study is focused on details of depositional system and reservoir architecture.

Dundee Characteristics

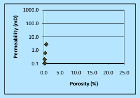
- Two carbonate members have been identified and interchangeably used as the Dundee
  - The upper Rogers City limestone and the lower Dundee limestone
- Reservoir rock is a stromatoporoid boundstone facies located in the Dundee limestone

Primary Depositional Facies

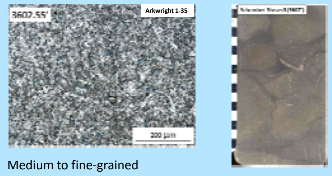
Facies 1 — Restricted Lagoon



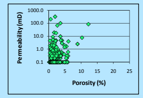
Fine-grained laminated Mudstone-Wackestone with wispy stylolite swarms, nodular bedding caused by differential compaction/ burrows. Little to no porosity.



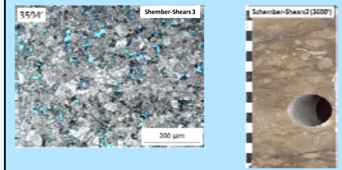
Facies 2 — Open Marine Ramp



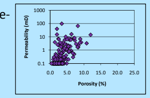
Medium to fine-grained Mudstone-Wackestone with wispy stylolite swarms, nodular bedding caused from differential compaction/ burrows, and localized fracture porosity.



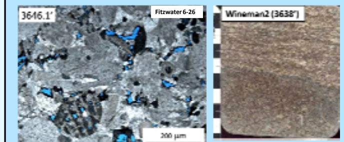
Facies 3 — Open Marine Ramp



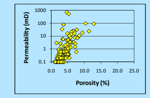
Bioturbated mud-rich Wackestone-Packstone, fossiliferous with peloids, pellets, suture stylolites. Moldic and interparticle porosity.



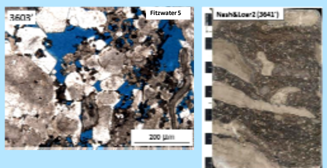
Facies 4 — Crinoidal/Skeletal Shoal



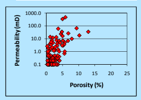
Coarse-grained crinoidal/ skeletal Grainstone with cross-bedding, suture stylolites. Intercrystalline, fracture and moldic porosity.



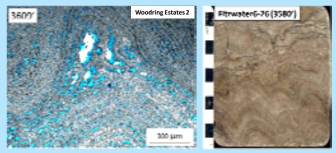
Facies 5 — Reef Flank



Medium-grained Floatstone-Rudstone, burrow/mottled with stylolite swarms and ripped up stromatoporoids. Isolated moldic and intercrystalline porosity.

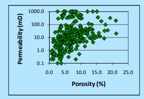


Facies 6 — Patch Reef

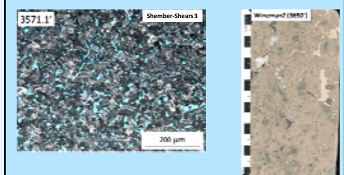


Primary Reservoir

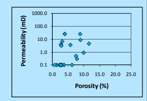
Stromatoporoid Framestone-Boundstone with peloids and pellets. Intraparticle, moldic, Fracture, and intercrystalline porosity common.



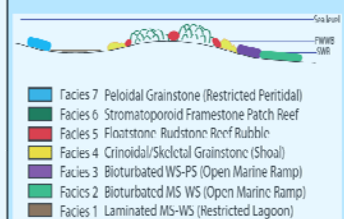
Facies 7 — Restricted Peritidal



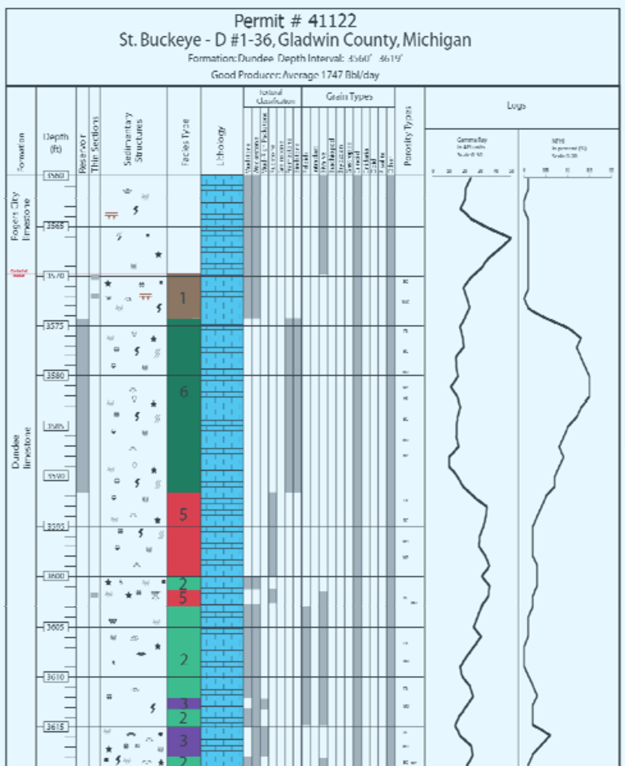
Fine-grained Peloidal Grainstone with dolomite cement, suture stylolites. Vuggy, moldic, inter-crystalline, intraparticle, and fracture porosity common.



Depositional Model



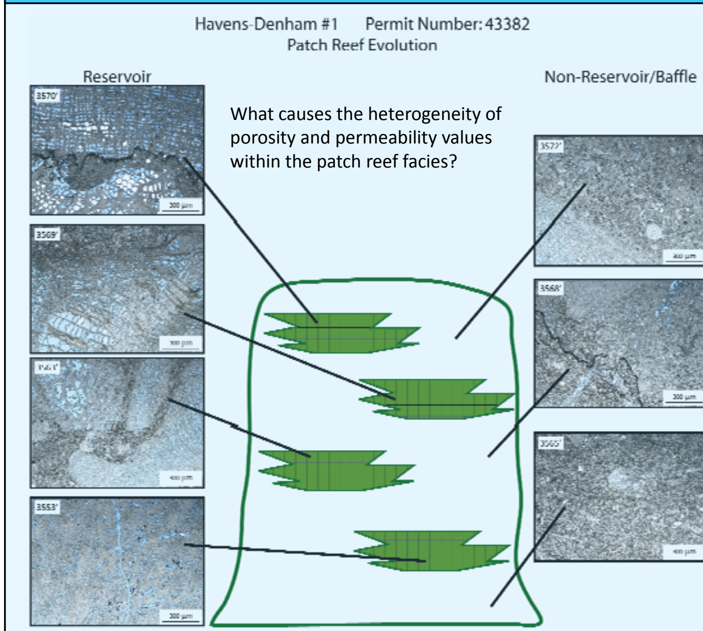
Vertical Core Description

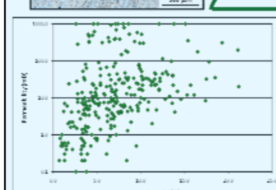


Idealized Facies Succession

Seven depositional facies were observed within core from which an idealized facies stacking pattern was established representing a shoaling upwards package (below).

Internal Heterogeneity of Patch Reefs





Conceptual cartoon model based on core data

Average patch reef thickness = 11ft

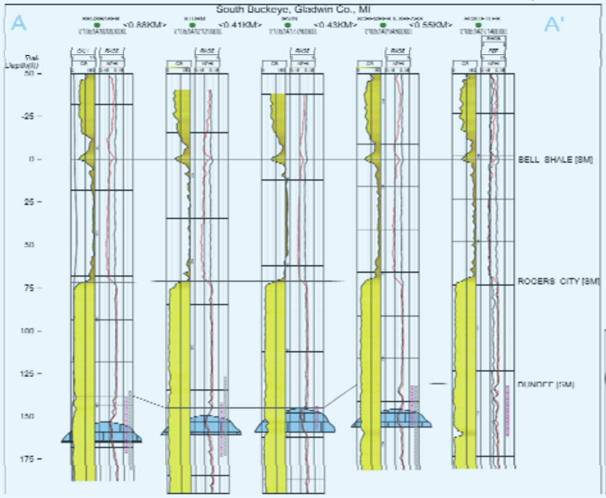
Total thickness across cored intervals = 0 – 21ft

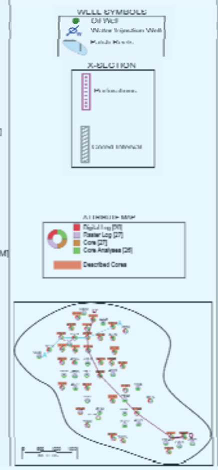
Reservoir compartmentalization caused by variability due to internal growth of patch reefs

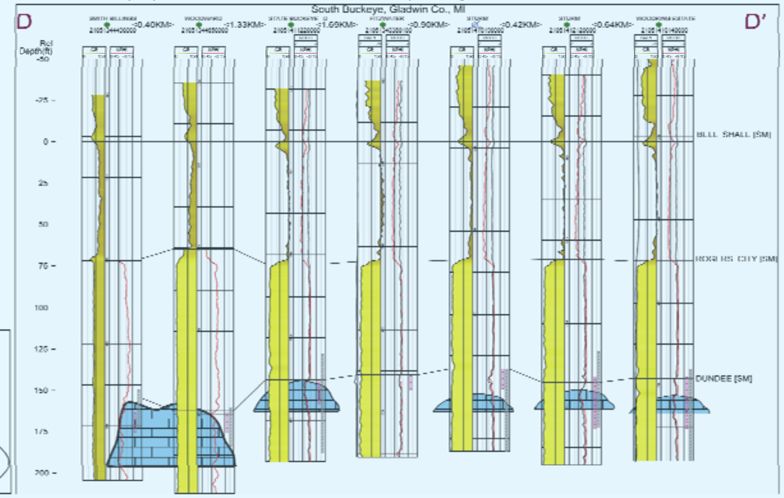
Cross-Sections Showing Patch Reef Distribution

What is the geographic distribution of reservoir quality within the field and is the distribution related to facies variability?

Are the primary reservoir facies patch reefs, and can the geometry/scale of the buildups be accurately modeled in Petrel from closely-spaced core data (≤ 40 acre spacing) without a tie to 3-D seismic?



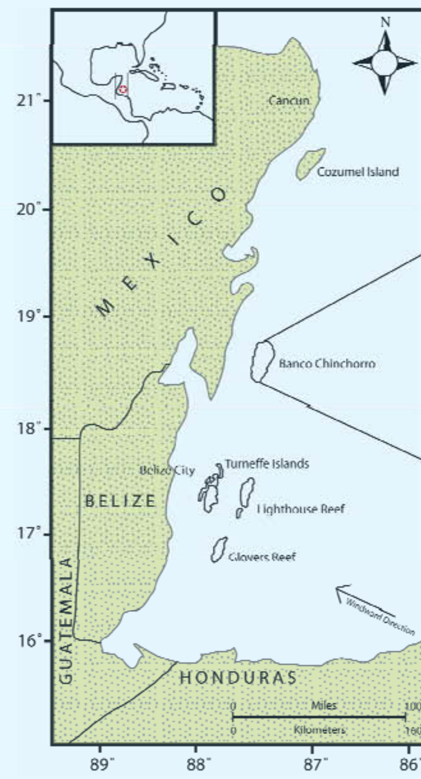




The above cross-sections show discontinuous patch reef distribution across the South Buckeye field. Patch reef thicknesses range from 0 - 21 feet and average thickness when present is 11 feet. One core description captures a stacked patch reef, all other cores show patch reef growth at different structural depths across the field. This is significant when trying to understand heterogeneity on a field scale. Distance between individual patch reefs (based on core descriptions and best fit Petrel model) are approximately 500 meters. Core data control is approximately 400 meters (40 acre-spacing).

Modern Analog (Belize Patch Reefs)

Distribution of modern patch reefs show significant variability within 40 acres (1320 ft) and may explain the heterogeneous oil production. Figure on right further captures how much a patch reef environment can vary with respect to the Dunham Classification system. Banco Chinchorro is an isolated platform with similar depositional environments (e.g., Patch reefs, restricted lagoons, sand shoals, and reef rubble) and facies as South Buckeye.

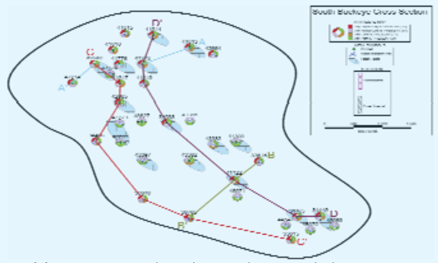


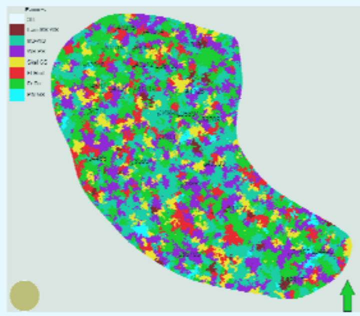
Map above captures the texture of surface sediments at Banco Chinchorro. This may explain the geographic distribution of reservoir quality across the South Buckeye field and how it relates to facies variability.

Reservoir Characterization – End Member Interpretations

I. Single well reefs – Below seismic scale

500 foot variogram

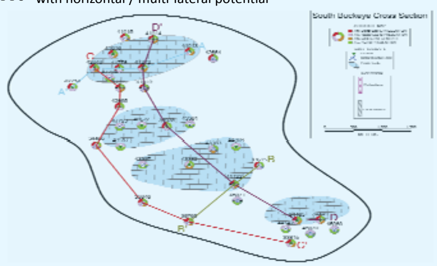


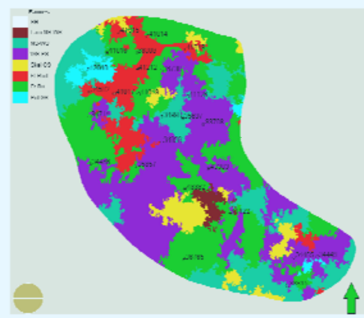


Model I. captures random chaos and excessively heterogeneous variability across the field with no tie to petrophysical models, this is interpreted as unreasonable for the South Buckeye field.

II. Multiple well reefs – Internal heterogeneity with horizontal / multi-lateral potential

Best fit variogram

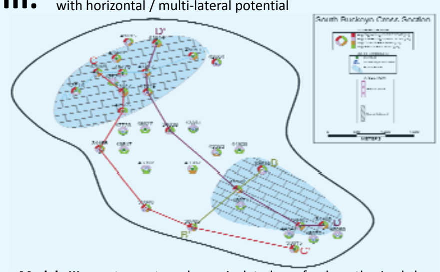


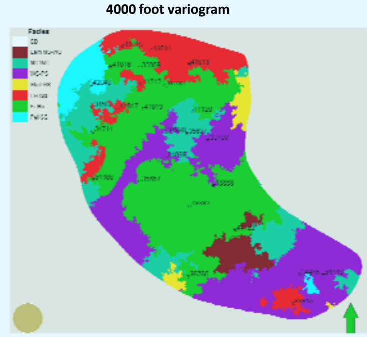


Model II. captures most representative and best realization of petrophysical properties and geologically reasonable facies distribution across the South Buckeye field.

III. Two large reefs – Internal heterogeneity with horizontal / multi-lateral potential

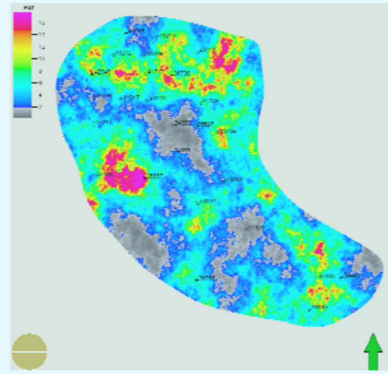
4000 foot variogram





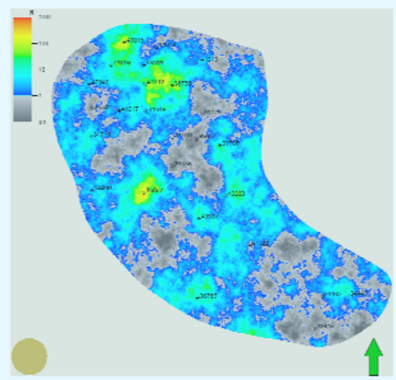
Model III. captures two large isolated reefs, hypothesized by Montgomery (1986). Facies model loosely matches permeability model but the higher degree of variability in porosity values across the South Buckeye field is not represented.

Whole Core Analysis - Porosity Model



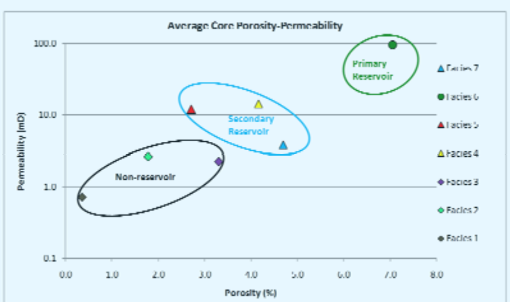
Model II. (Best fit variogram) provides the best realization for the South Buckeye field. Areas of higher porosity (>8%) capture approximate locations of patch reef (green facies) distribution across the field. This proves that patch reefs and their corresponding petrophysical (porosity) property can be accurately modeled in Petrel without shooting expensive 3-D seismic.

Whole Core Analysis - Permeability Model



Model II. (Best fit variogram) provides the best realization for the South Buckeye field. Areas of higher permeability (>3mD) capture approximate locations of patch reef (green facies) distribution across the field. This proves that patch reefs and their corresponding petrophysical (permeability) property can be accurately modeled in Petrel without shooting expensive 3-D seismic.

Porosity versus Permeability



Primary depositional facies are directly related to reservoir quality.

Conclusions

- The primary reservoir facies (i.e., patch reefs) can be accurately modeled in Petrel utilizing closely-spaced core data (≤40 acres) without a tie to 3-D seismic .
- Patch reefs are highly heterogeneous with internal baffles.
- Primary depositional facies controls both reservoir and seal distribution. Understanding of depositional architecture may enhance 3-D modeling of these reservoirs for enhanced (tertiary) recovery efforts.

Acknowledgments

Dr. William B. Harrison, III　　Dr. Dave Barnes