Little Cedar Creek Field: Reservoir Characterization to Simulation. A Geological and Engineering Case Study of an Upper Jurassic Microbial Carbonate Reservoir in Southwest Alabama*

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Search and Discovery Article #20228 (2013)**
Posted December 23, 2013

*Adapted from oral presentation given at Geoscience Technology Workshop, Revisiting Reservoir Quality Issues in Unconventional and Conventional Resources: Techniques, Technologies and Case Studies, Austin, Texas, November 12-13, 2013. Please refer to closely related article by the authors in AAPG Bulletin, v. 97/11, p. 2059-2083.

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Abstract

Little Cedar Creek field is a mature oil field located in southwestern Alabama, in the onshore area of the northeastern Gulf of Mexico. The main reservoirs are microbial carbonate facies and associated nearshore carbonate bank facies of the Upper Jurassic Smackover Formation that overlie conglomerate and sandstone facies of the Norphlet Formation and underlie argillaceous, anhydritic and carbonaceous facies of the Haynesville Formation. The lower reservoir is comprised of subtidal thrombolitic boundstone associated with microbial buildups oriented in a southwest to northeast direction over an area that encompasses 83 square kilometers (32 square miles). These buildups attained thicknesses of 13 meters (43 feet) and developed in clusters in the western, central and northern parts of the field. The inter-buildup areas of microbialites are 2-3 meters (7-9 feet) in thickness and are overlain by a thick section of non-reservoir microbially influenced lime mudstone and wackestone. These beds are potential barriers or baffles to flow and serve to separate the microbial boundstone flow units recognized in the western, central and northern parts of the field. Porosity in the microbial reservoirs includes depositional constructed void (intraframe) and diagenetic solution-enhanced void and vuggy pore types. This pore system provides for high permeability and connectivity in the reservoir beds and high productivity. Permeability ranges up to 7953 md and porosity up to 20%. The upper reservoir consists of a series of progradational ooid and peloid sand bodies in a carbonate bank setting. The carbonate bank complex extends from the western part of the field to the central part in a southwest to northeast direction. These marine carbonate sand belt buildups consist of up to six wackestone-packstone grainstone sequences and attain thicknesses of 8 m (26 ft). In inter-buildup areas associated with the carbonate sand bodies have a thickness of 1-2 m (4-8 ft) and are underlain by a thick section of wackestone. Porosity consists of primary interparticle and secondary solution-enhanced interparticle, intraparticle, vuggy and grain moldic pore types and ranges 0- 33%. Permeability is critical to the low productivity of this reservoir and ranges 0-452. Carbonate sand belt buildup areas serve as potential heterogeneous hydrocarbon flow units and the inter-buildup areas containing a thick section of low permeability to non-reservoir rock serve as potential baffles or barriers or baffles to flow. The petroleum trap in the field is stratigraphic being controlled primarily by changes in depositional facies. The trapped hydrocarbons are sourced from Smackover basinal beds

rich in amorphous and microbial kerogen. The objective of this article is to present the results from an integrated geologic-petroleum engineering field case study of the microbial carbonate and associated reservoirs at Little Cedar Creek Field to further the understanding of the spatial distribution of the sedimentary characteristics of microbial carbonate facies, the petrophysical properties of microbial reservoirs, and the variability in the heterogeneity and productivity of microbial reservoirs. The study provides a sound framework in the establishment of a field/reservoir-wide development plan for optimal primary and enhanced recovery for these reservoirs. Moreover, and with the recent discovery of microbial carbonate reservoirs in the South Atlantic, such a reservoir-wide development plan has broad applications to other fields producing from microbial carbonate reservoirs, particularly in the ability to model trends in microbial reservoir heterogeneity and to simulate their hydrocarbon productivity.

References Cited

Al Haddad, S.S., 2012, Reservoir characterization, formation evaluation, and 3D geologic modeling of the Upper Jurassic Smackover microbial carbonate reservoir and associated reservoir facies at Little Cedar Creek field, northeastern Gulf of Mexico: M.S. thesis, Texas A&M University, College Station, Texas, 97 p.

Al Haddad, S.S., and E.A. Mancini, 2013, Reservoir characterization, modeling, and evaluation of Upper Jurassic Smackover microbial carbonate and associated facies in Little Cedar Creek field, southwest Alabama, eastern Gulf coastal plain of the United States: AAPG Bulletin, v. 97/11, p. 2059-2083.

Mancini, E.A., 2008, E. A., W. C. Parcell, W. M. Ahr, V. O. Ramirez, J. C. Llinas, and M. Cameron, 2008, Upper Jurassic updip stratigraphic trap and associated Smackover microbial and nearshore carbonate facies, eastern Gulf coastal plain: AAPG Bulletin, v. 88, p. 409–434.

Ridgway, J.G., 2010, Upper Jurassic (Oxfordian) Smackover facies characterization at Little Cedar Creek field, Conecuh County, Alabama: M.S., University of Alabama, Tuscaloosa, Alabama, 128 p.

Little Cedar Creek Field: Reservoir Characterization to Simulation. A Geological and Engineering Case Study of an Upper Jurassic Microbial Carbonate Reservoir in Southwest Alabama

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AAPG GTW 2013

November 13th, 2013

Objectives- Little cedar Creek Study

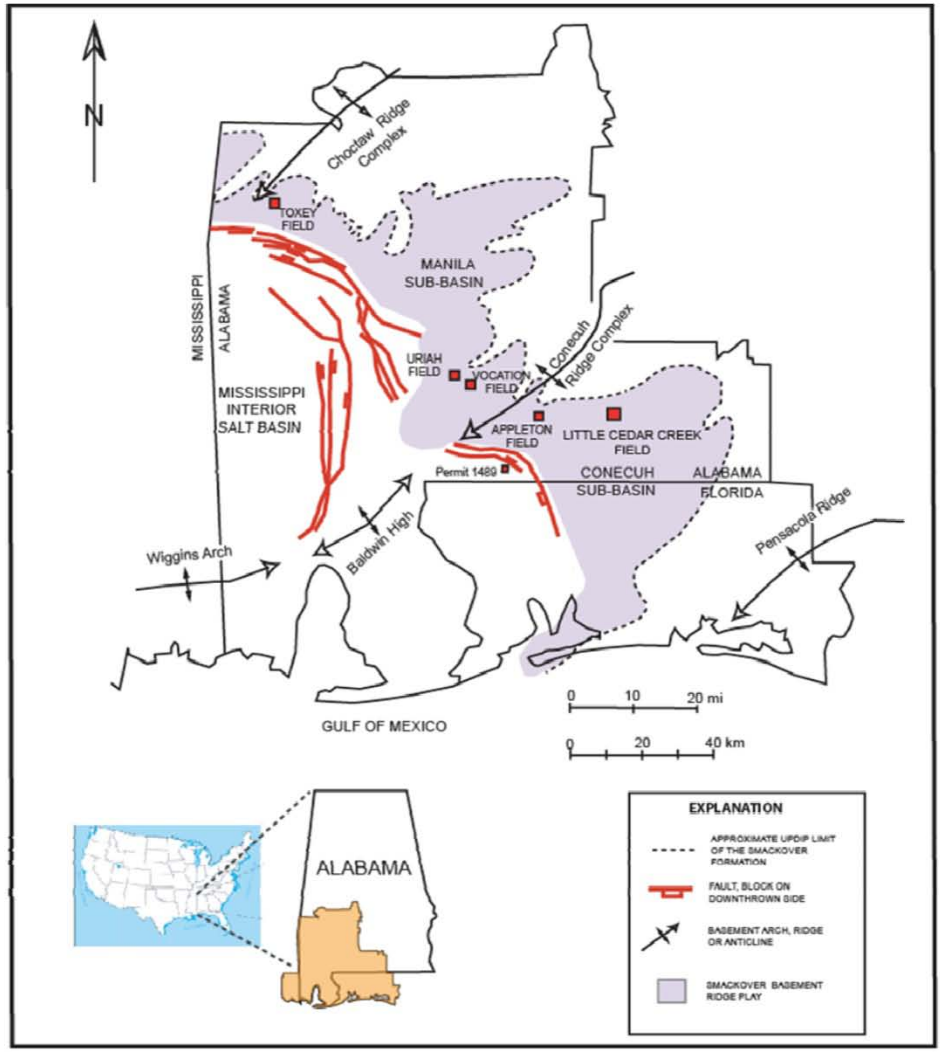
- A scientific integration of reservoir characterization, formation evaluation, and 3D geologic modeling that provides a sound framework in the establishment of the field/reservoir-wide development plan

- Understand the ***reservoir heterogeneities***, the spatial distribution of ***flow units***, and the identification of ***baffles and barriers*** to flow in the Little Cedar Creek field and enhance exploration and development strategies in the field and similar microbial carbonate reservoir fields in the Gulf of Mexico.

- Utilize the 3D static reservoir model in dynamic simulation and history matching.

Little Cedar Creek Field- Location Map

- Located 10 miles southeast of Evergreen, in Conecuh County, Alabama.
- 1994, Hunt Oil Company drilled the first discovery well.
- 120+ wells drilled to date.
- 17.2 MMBLS of oil and 18.8 MMCF of natural gas



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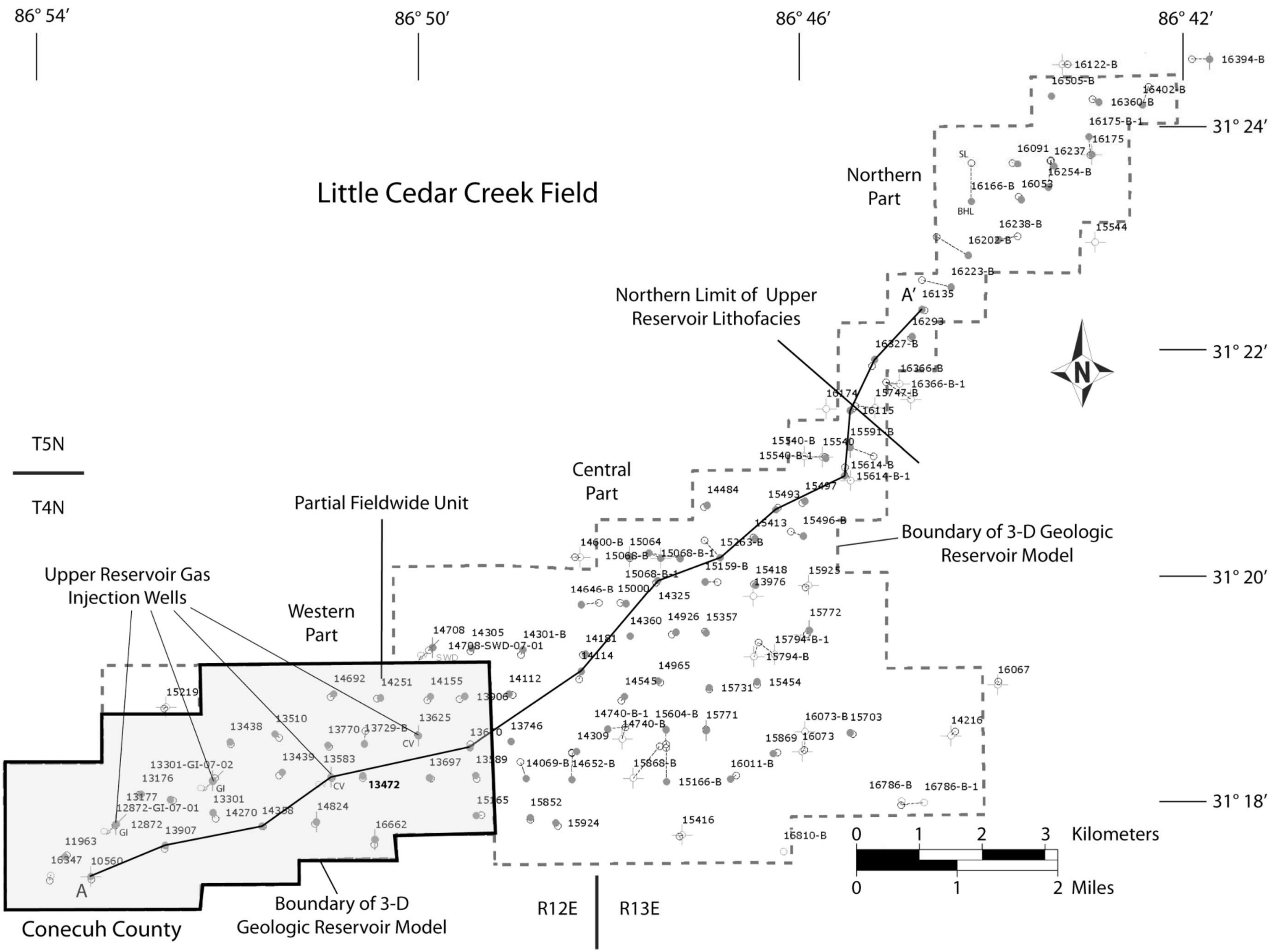
Presenter's notes: Updip Smackover play. Most significant field in past 20 years. 1994: Discovery well. 1995 (GOR=934): Established. 2000 – present: Field development. Unitized in part in 2005. Gas injection started in 2007.
Field area of 32 square miles. 120+ wells drilled; 92 producing wells. Production of 17.2 million barrels of oil and 18.8 mmcf of gas.

Little Cedar Creek Field



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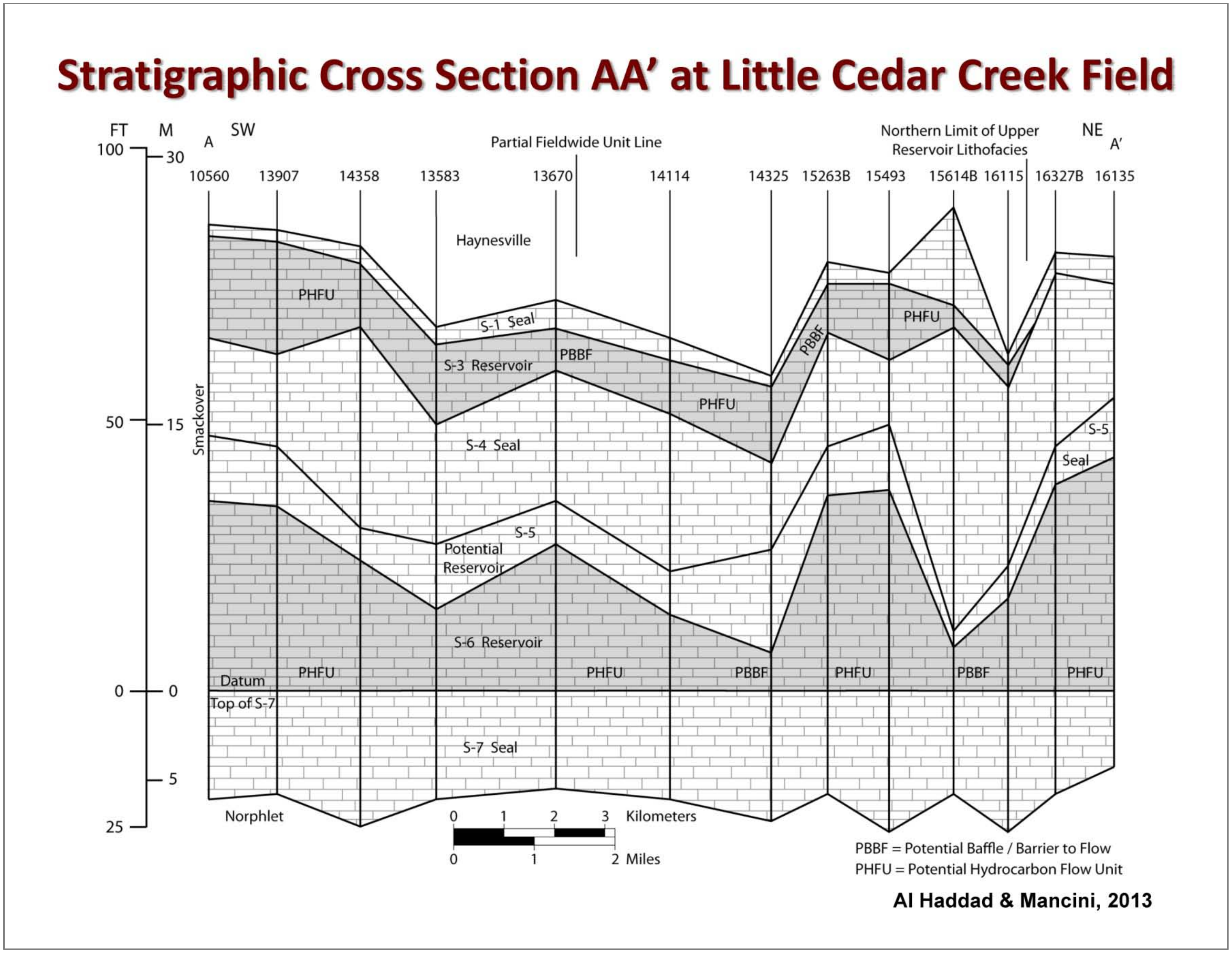
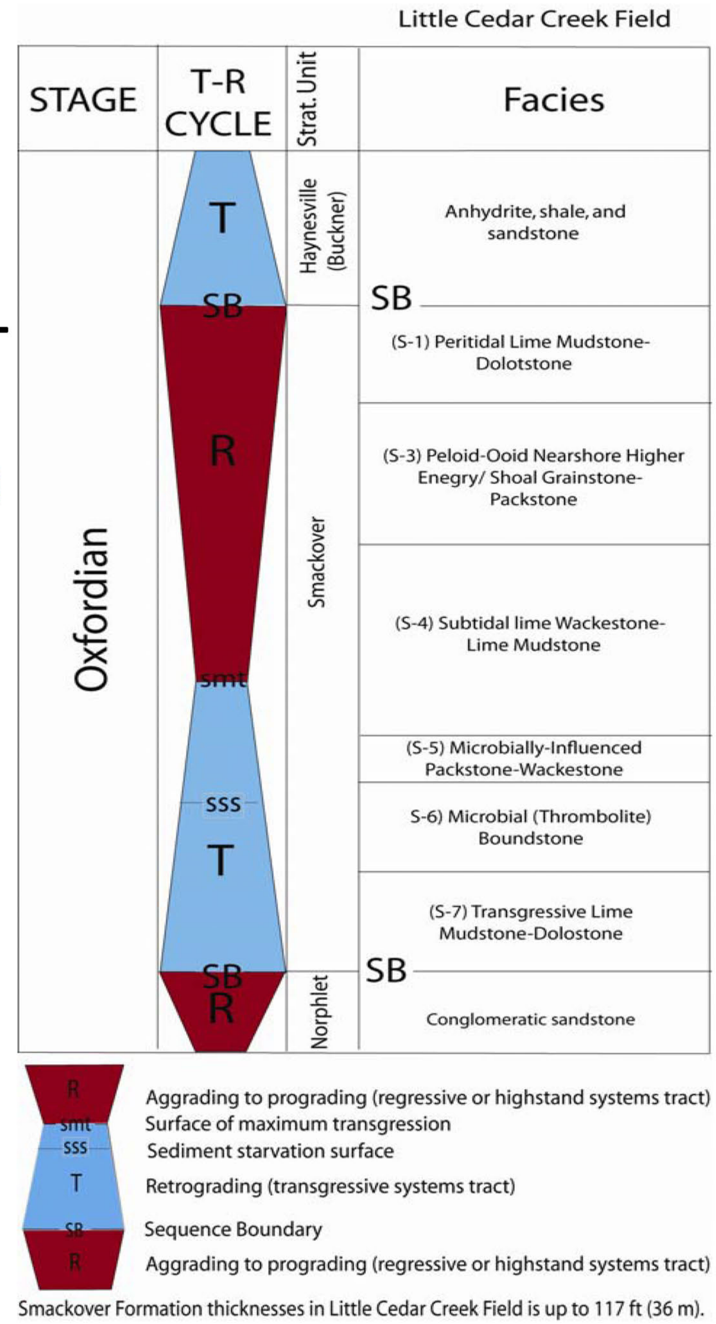


Presenter's notes: The petroleum trap in this field is an updip (near the depositional limit of Smackover carbonates) stratigraphic trap consisting of a change in lithofacies from subtidal microbial boundstone and carbonate bank grainstone and packstone to bay and lagoonal lime mudstone and wackestone toward the northeastern end of the field, near the Smackover shoreline. Dual Smackover carbonate reservoirs. Haynesville and Smackover seal rocks. Smackover lime mudstone source beds.

Reservoir Characterization

Smackover Facies at LCCF

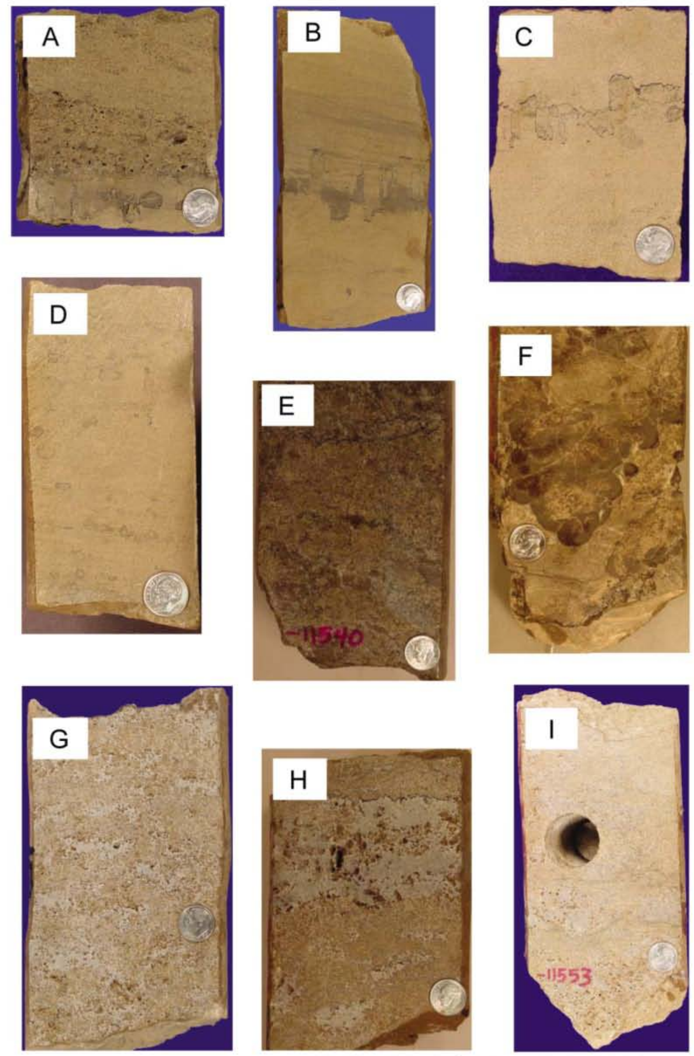
- **S-1: Peritidal Lime Mudstone-Dolomudstone to Wackstone (Seal)**
- **S-3: Nearshore Higher Energy/ Shoal Grainstone-Packstone (Reservoir)**
- **S-4: Subtidal Wackestone- Lime Mudstone (Seal)**
- **S-5: Microbially Influenced Packstone-Wackestone (Lower Reservoir and probable Seal to the Northeast)**
- **S-6: Microbial (Thrombolite) Boundstone (Reservoir)**
- **S-7: Transgressive Lime Mudstone-Dolomudstone (Seal)**



Mancini et al., 2008; Ridgway, 2010

Reservoir Characterization

(A) S-3 leached grainstone, upper/middle facies of a carbonate sand belt buildup, well permit #14181, depth 11,238 ft;
(B) S-3 cross bedded grainstone, upper/middle facies of a buildup, well permit #14181, depth 11,237 ft;
(C) S-3 ooid grainstone, upper/middle facies of a buildup, well permit #13472, depth 11,495 ft;
(D) S-3 peloidal packstone, lower margin facies of a buildup, well permit #13472, depth 11,512 ft;
(E) S-5 microbially influenced packstone, bioturbated disturbed facies overlying a microbial buildup, well permit #13472, depth 11,540 ft;
(F) S-6 thrombolitic boundstone, microbial buildup facies, well permit #14181, depth 11,282 ft;
(G) S-6 leached boundstone, microbial buildup facies, well permit #12872, depth 11,881;
(H) S-6 highly leached boundstone, microbial buildup facies, well permit #12872, depth 11,880; and
(I) S-6 leached and pelodial boundstone, microbial buildup facies, well permit #13472, depth 11,553 ft.



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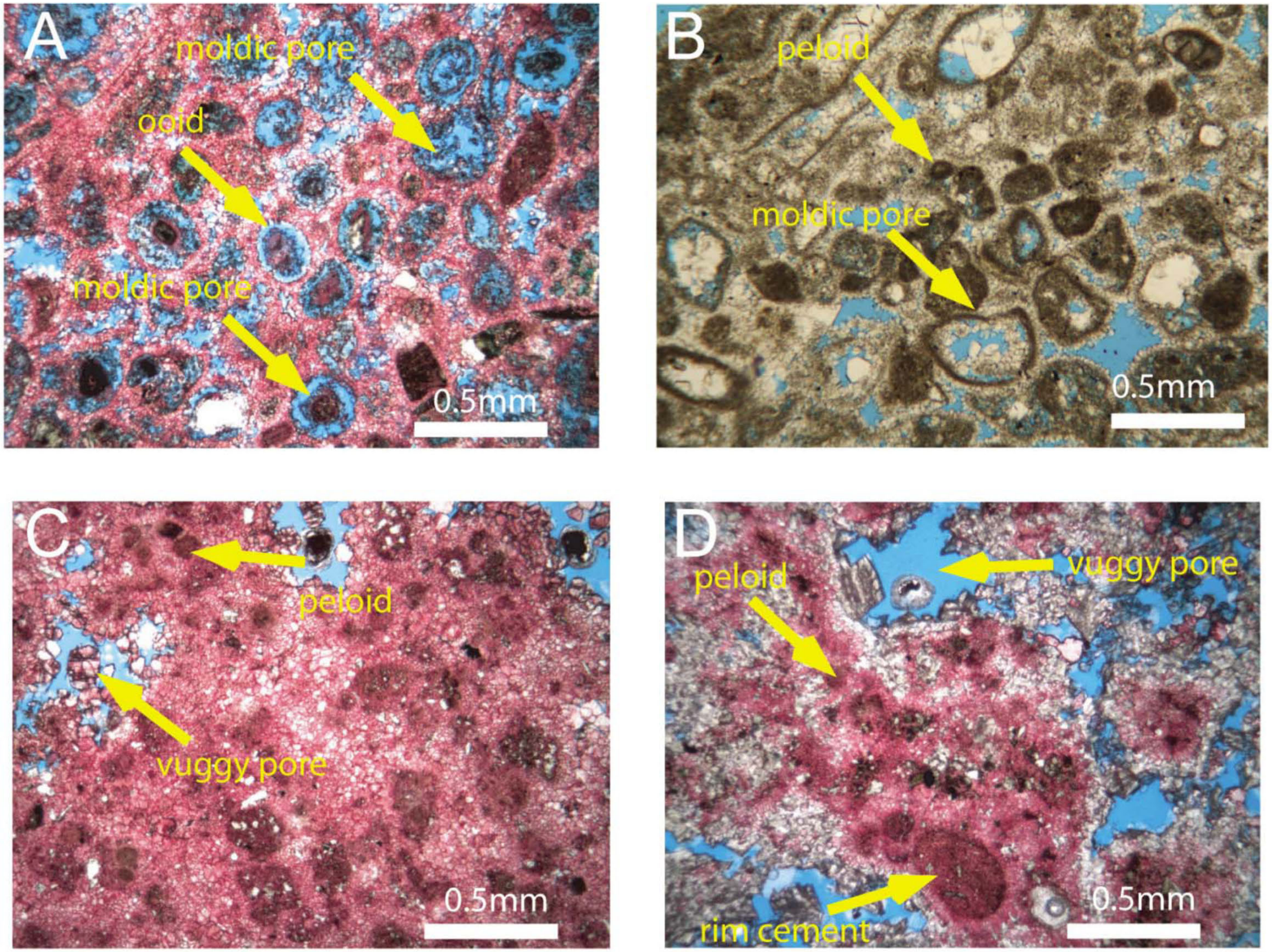
Presenter’s notes: These marine carbonate sand belt buildups comprise as much as six wackestone-packstone grainstone sequences. These features are characterized by an upper to middle buildup facies of ooid and peloidal grainstone to packstone, a lower margin buildup facies of peloidal packstone, and an inter-buildup facies of wackestone.

Reservoir Characterization- Well Permit # 13472



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(A) S-3 leached ooid grainstone showing grain moldic pores, depth 11,495 ft
(B) S-3 leached peloid packstone showing grain moldic pores, depth 11,512 ft
(C) S-5 microbially influenced packstone showing peloids and vuggy pores, depth 11,542 ft and
(D) S-6 leached thrombolitic boundstone showing vuggy pores, depth 11,533 ft.

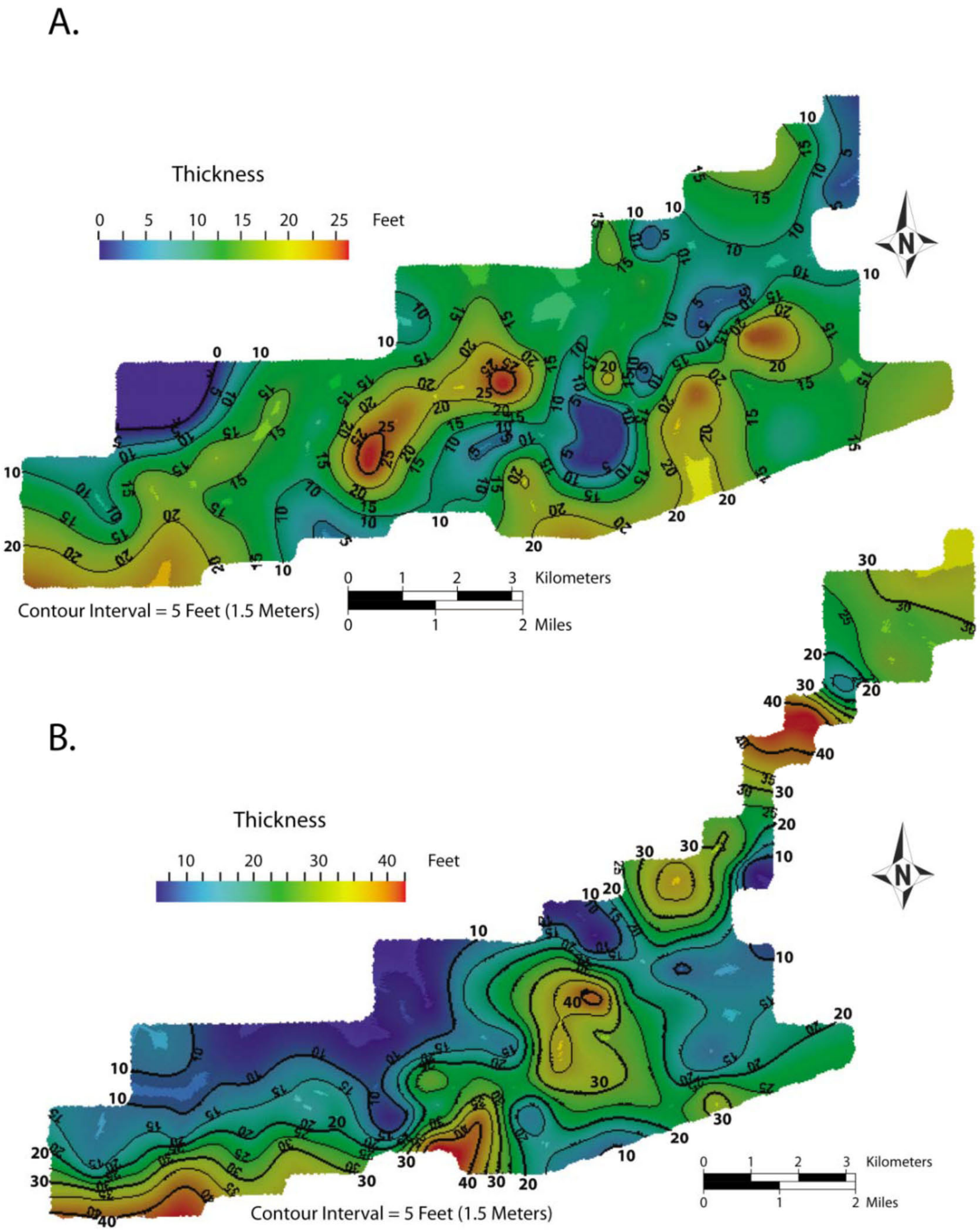
Isopach Maps of Top (S3) and Lower Reservoirs (S6)

S3 Reservoir

- Depositional environment of progradational sand bodies in a carbonate bank setting
- Sand belt buildups attain 26 ft in thickness
- Inter-buildup areas are 4-8 ft in thickness

S6 Reservoir

- Depositional environment of subtidal thrombolite
- Microbial buildups attain 43 ft in thickness
- Inter-buildup areas are 7-9 ft in thickness



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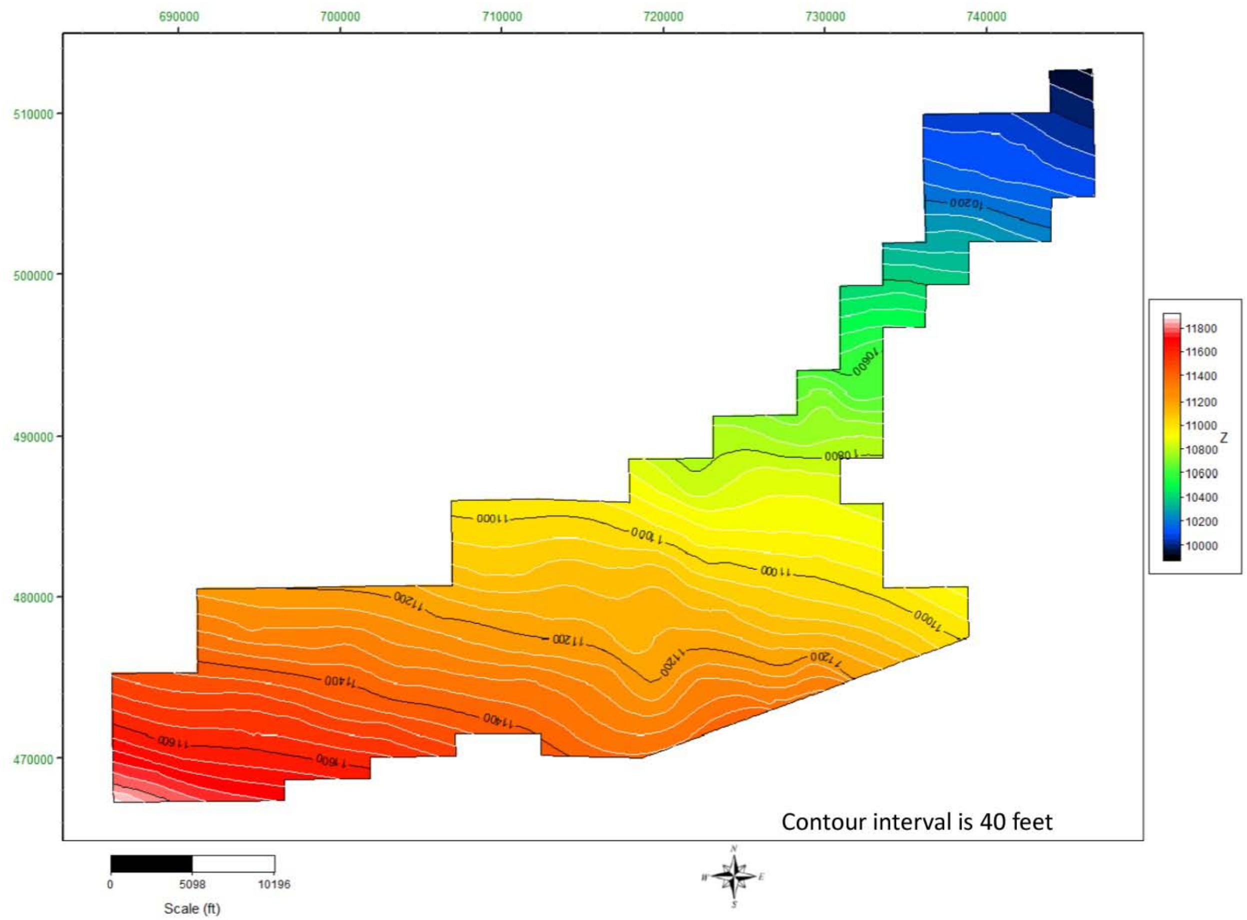
Structure Map- Norphlet

- No localized elevated features



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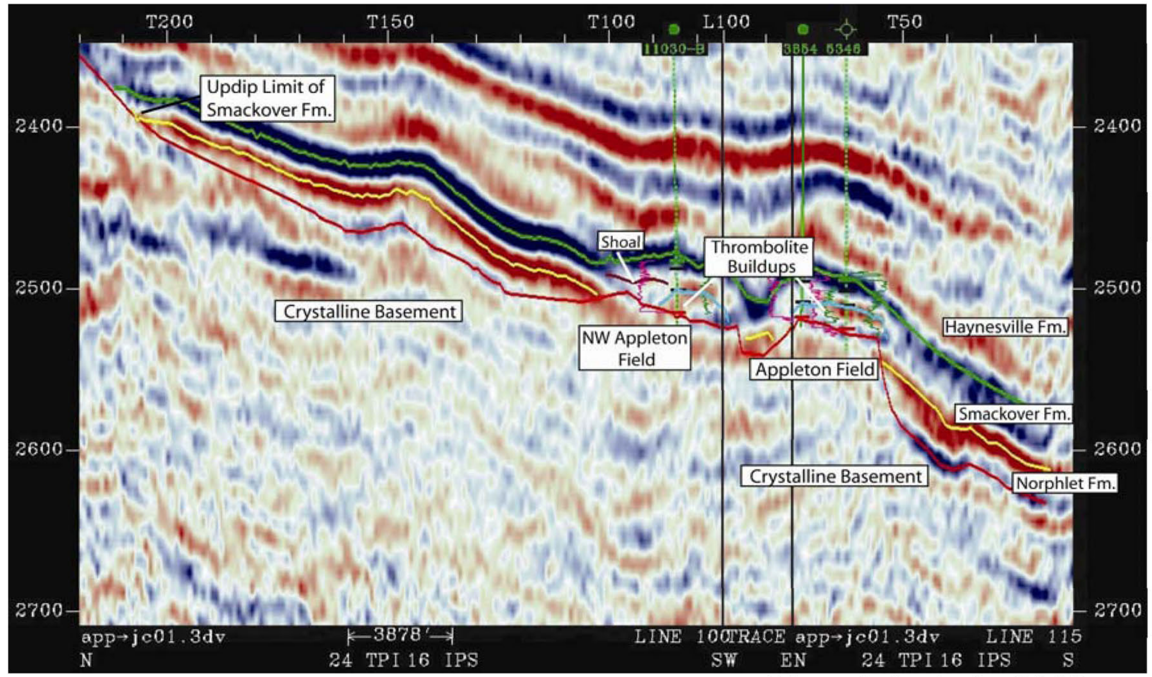
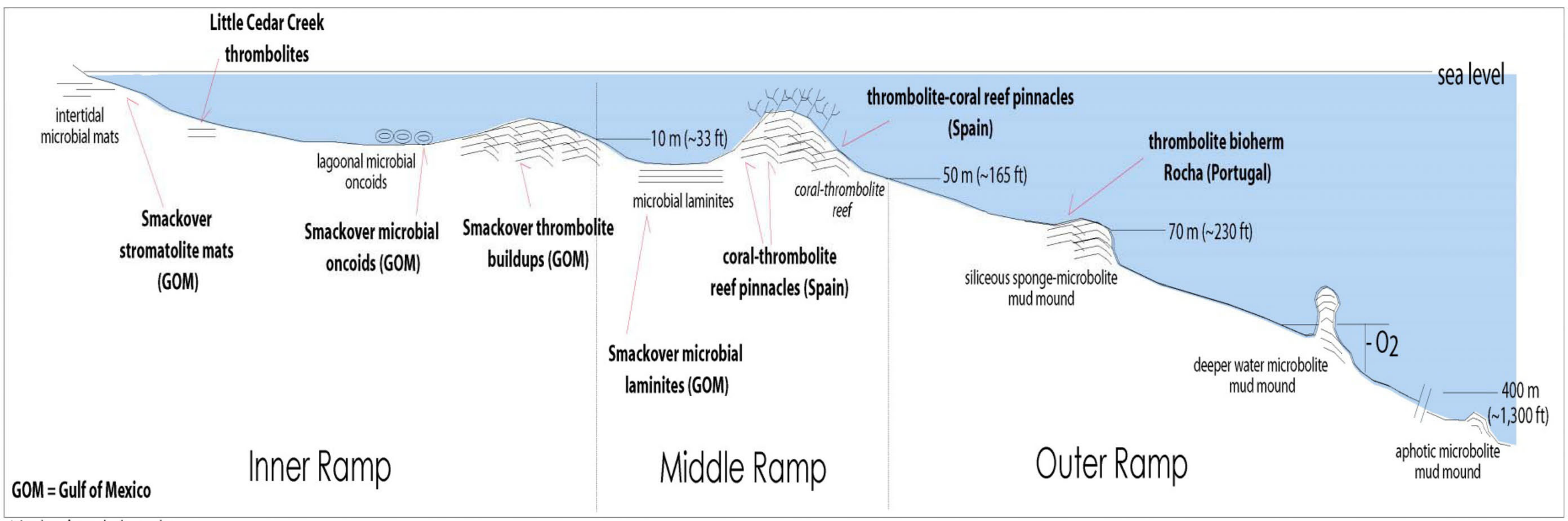
Presenter's notes: Structural maps drawn on top of the Smackover and Norphlet formations show uniform dip to the southwest at a rate of 150–200 ft/mi (28–38 m/km). To date, no faulting, structural closure, or localized paleotopographic highs have been observed in Little Cedar Creek field, meaning that no paleohighs similar to Appleton or Vocation fields.

Depositional Environment

- The facies were deposited near the updip limit of the Smackover Formation and indicate a shallow-water, inner ramp setting (Mancini et al., 2008).



Mancini et al., 2008



No horizontal scale

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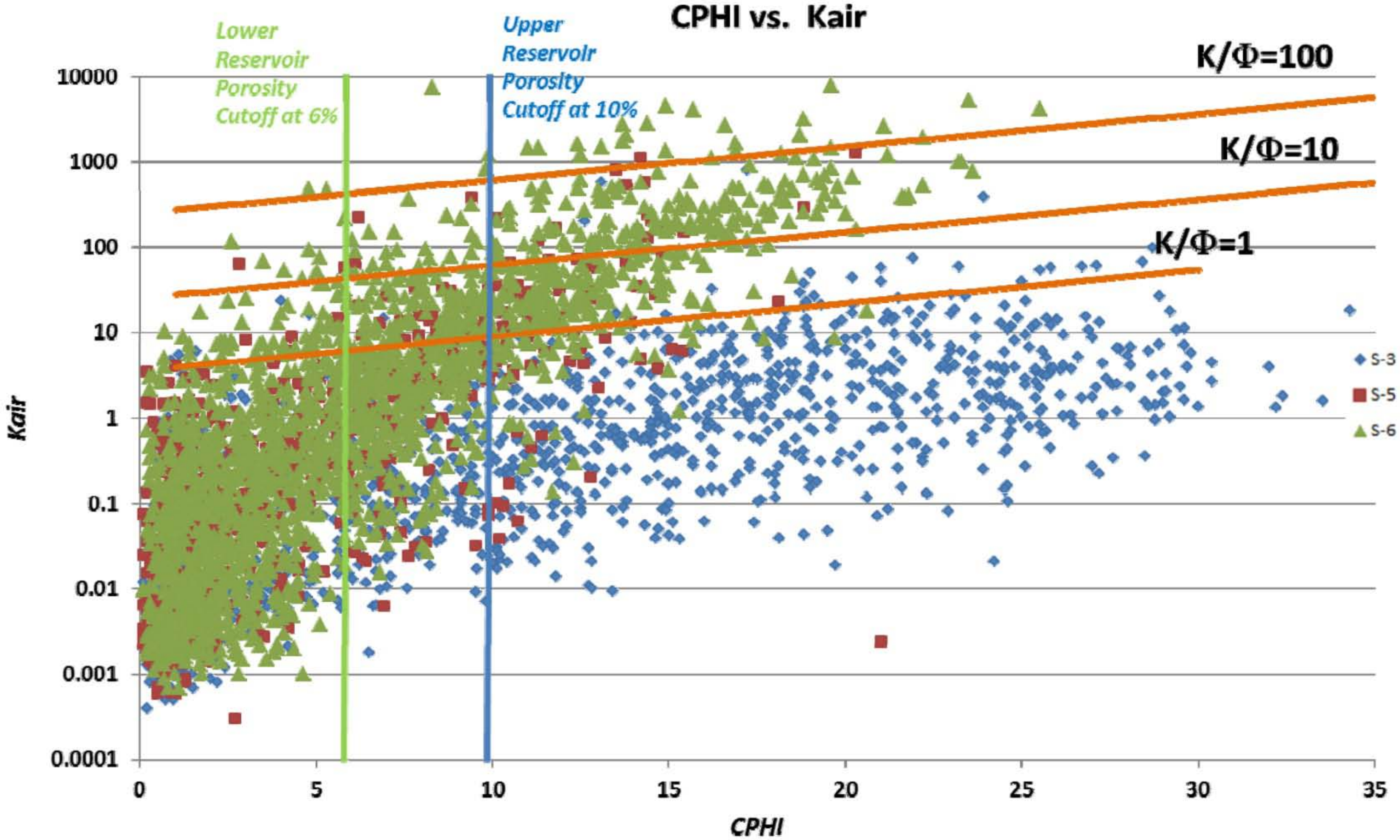
Porosity vs. Permeability

- Linear regression techniques fail to represent any relationship between porosity and permeability in Little Cedar Creek Field

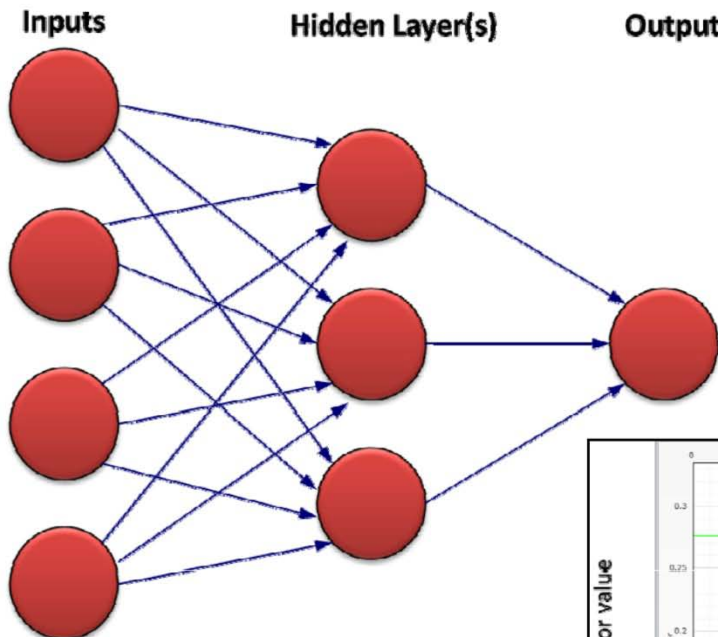


Al Haddad, 2012

Presenter's notes: The limestone reservoirs in the Little Cedar Creek field were not pervasively dolomitized and/or cemented thus preserving various amounts of the original depositional porosity.

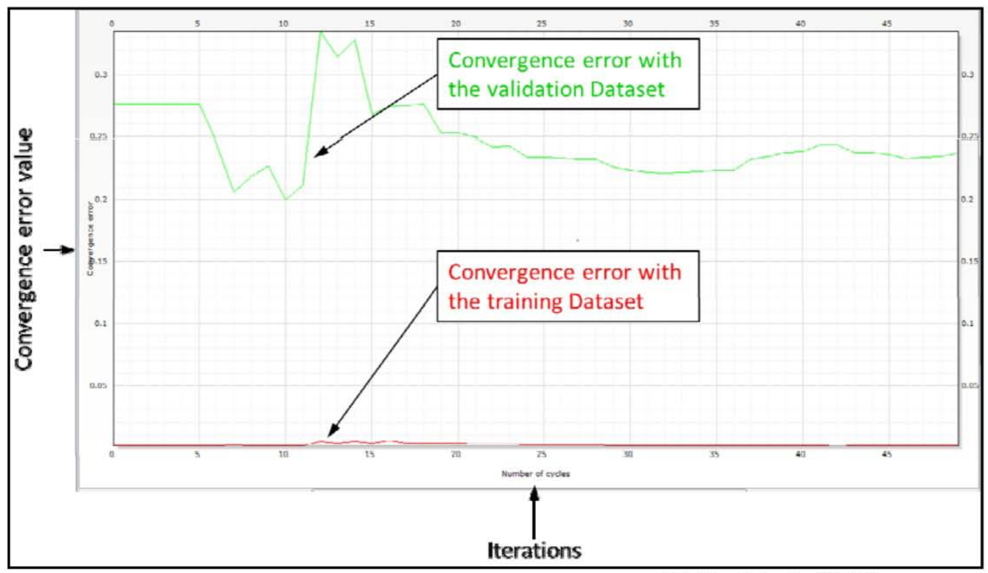
Formation Evaluation

- Permeability and water saturation prediction using artificial neural networks



The operation consists of an input layer, an internal layer of hidden neurons and an output layer.
The network is provided with training and validation datasets of known inputs and outputs.

We use multilayer perception (MLP) networks (a variety of BPANN)



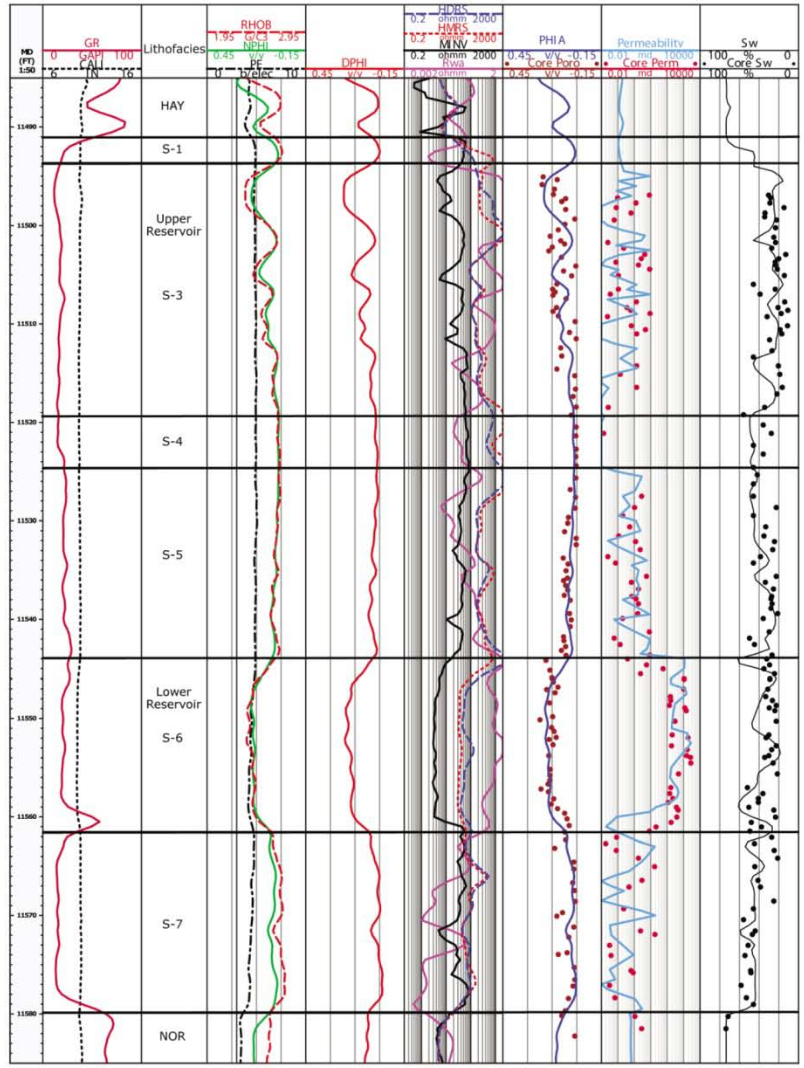
Al Haddad, 2012

Presenter's notes: In the learning phase, random weights are applied to the input variables in the hidden layer, and the network is adjusted to minimize the convergence error (root mean square error) with the validation dataset and the convergence error with the training dataset.

Formation Evaluation

Type Log- Well Permit #13472

- Modeled (output) permeability and water saturation
- The output matches the core data very well



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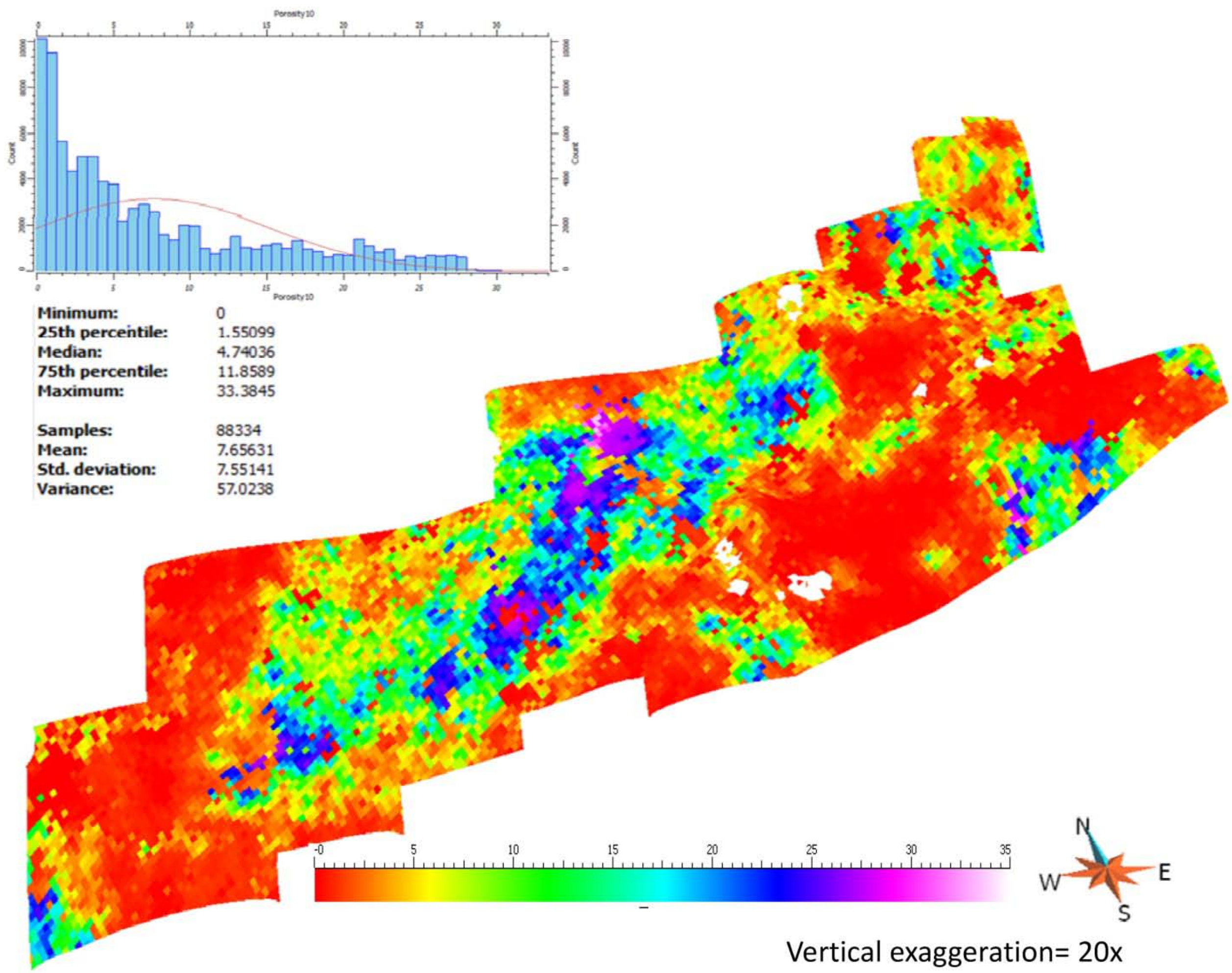
Presenter's notes: In total, 80 wells were found to have a high level of confidence in predicting permeability using an ANN approach.

3D Modeling- Porosity Model

- Porosity distribution on top of the upper reservoir S-3



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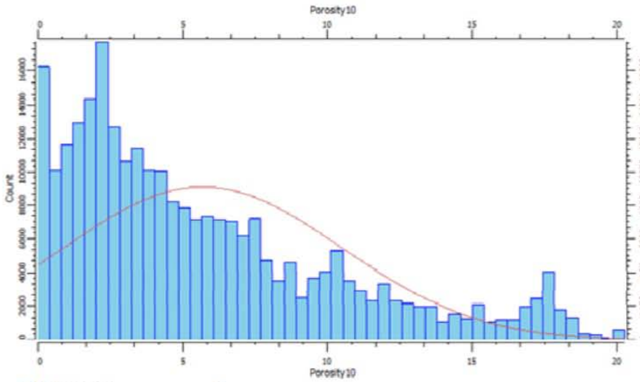
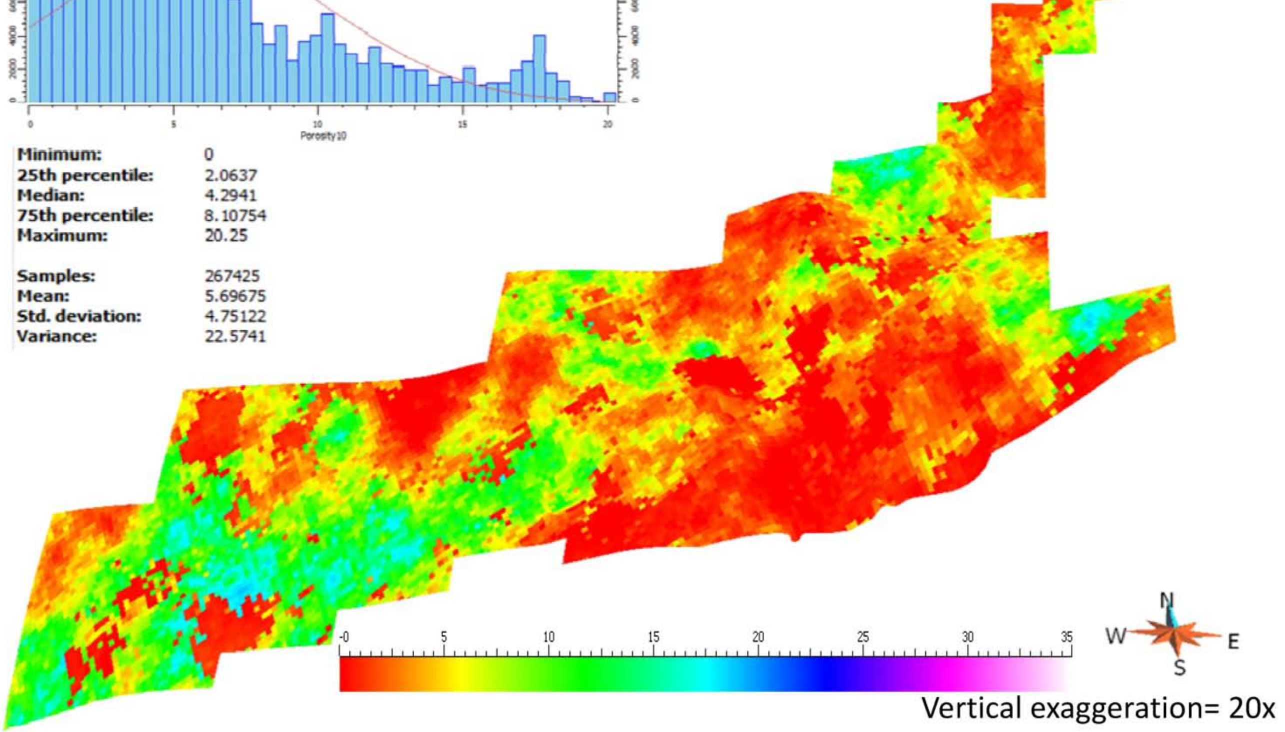
Presenter's notes: Mean porosity of 7.6% and ranges up to 33%. Porosity consists of primary interparticle and secondary solution-enhanced interparticle, intraparticle, vuggy and grain moldic pore type.

3D Modeling- Porosity Model

- Porosity distribution on top of the lower reservoir S-6



Minimum:	0
25th percentile:	2.0637
Median:	4.2941
75th percentile:	8.10754
Maximum:	20.25
Samples:	267425
Mean:	5.69675
Std. deviation:	4.75122
Variance:	22.5741



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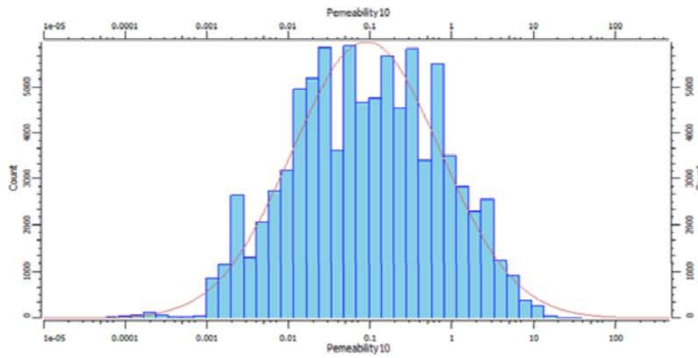
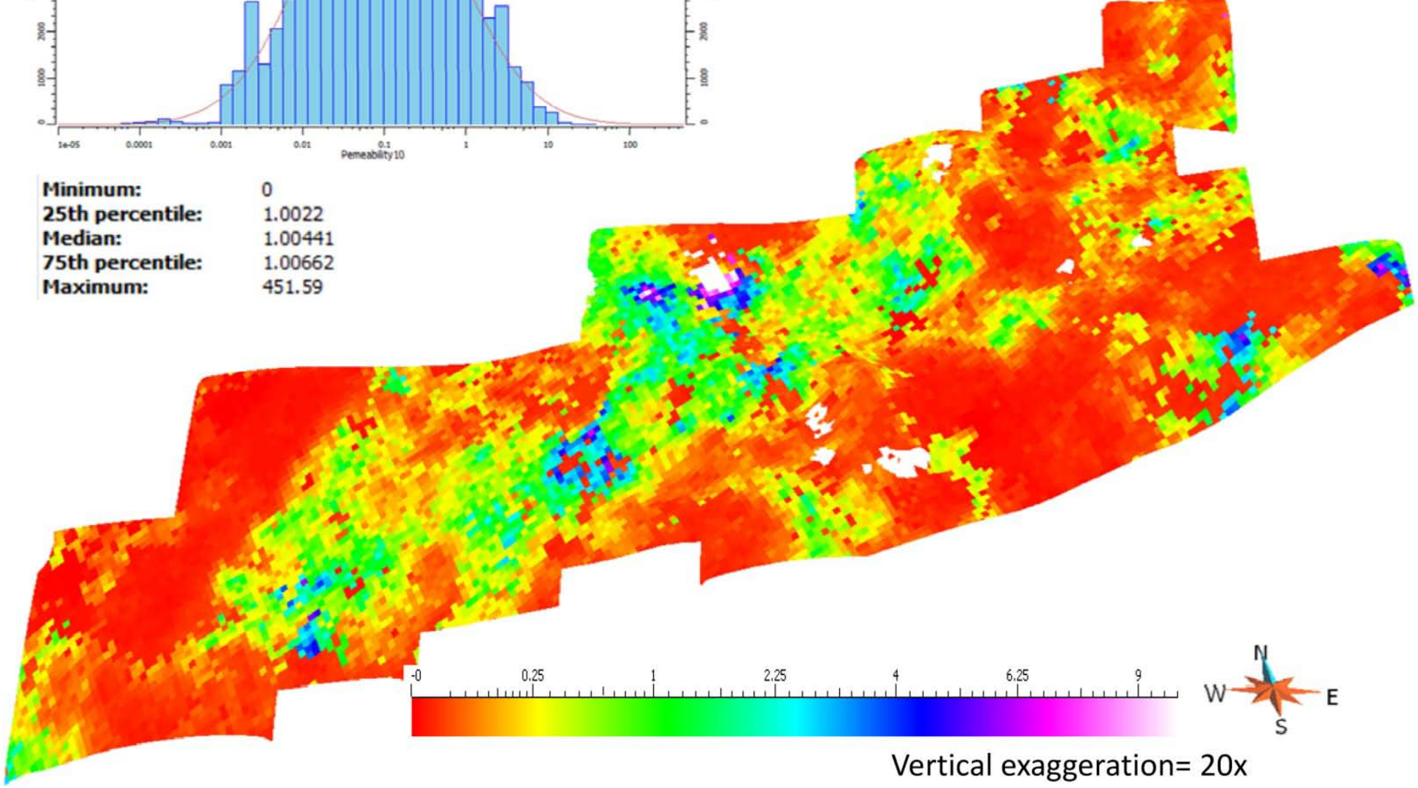
Presenter's notes: Mean porosity of 5.7% and ranges up to 20%. Porosity consists of primary constructed void (intraframe) and secondary solution-enhanced void and vuggy pore types.

3D Modeling- Permeability Model

- Permeability distribution on top of the upper reservoir S-3



Minimum:	0
25th percentile:	1.0022
Median:	1.00441
75th percentile:	1.00662
Maximum:	451.59



Vertical exaggeration= 20x

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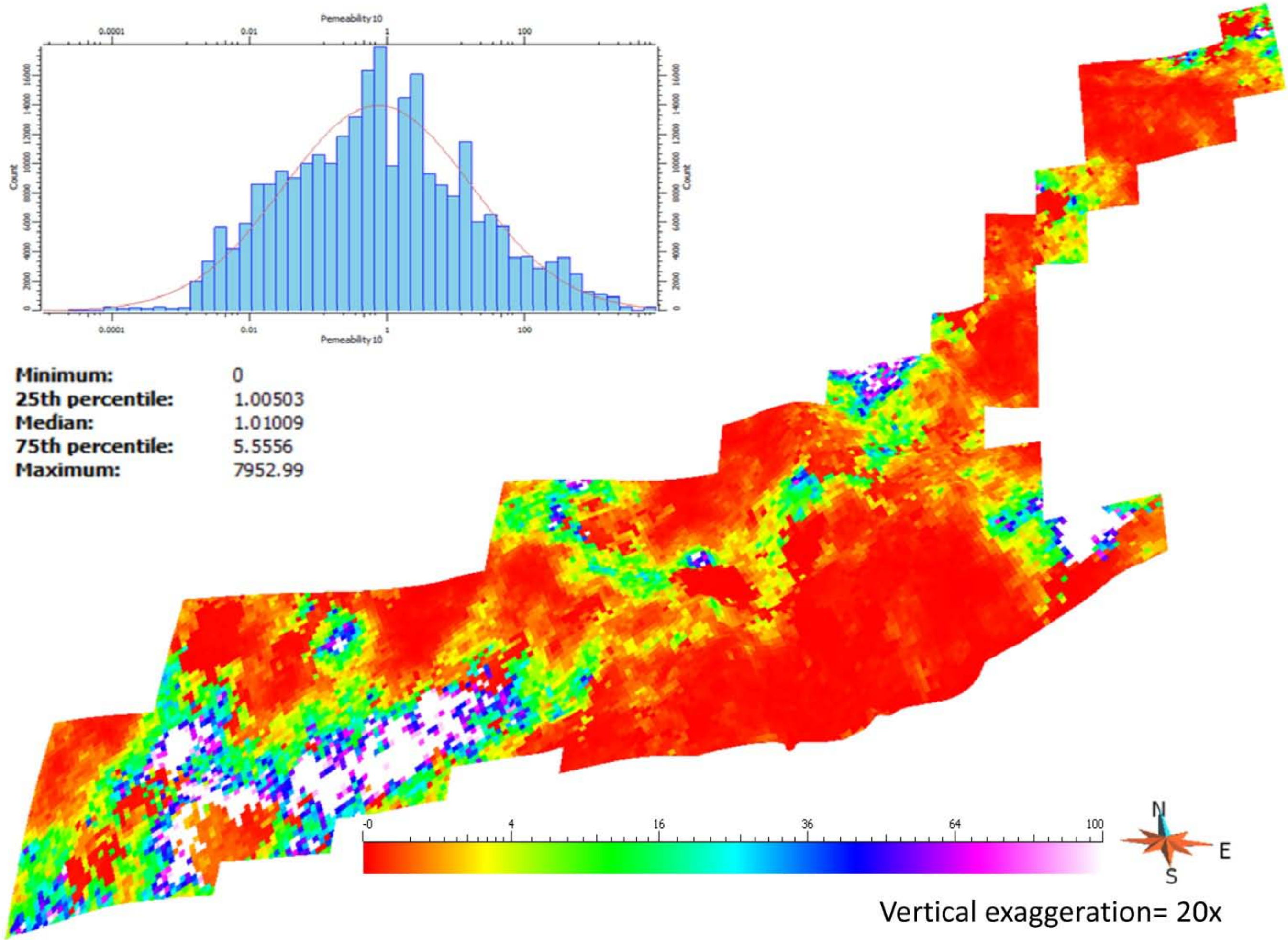
Presenter’s notes: Mean permeability of 1 md and ranges up to 452 md.

3D Modeling- Permeability Model

- Permeability distribution on top of the lower reservoir S-6



Al Haddad & Mancini, 2013

Presenter's notes: Mean permeability of 1 md and ranges up to 7953 md.

Conclusions

- An integrated geoscience and engineering study of the microbial carbonate and associated reservoirs at Little Cedar Creek field in southwest Alabama, Eastern Gulf Coastal Plain of the United States provides information to further the understanding of the spatial distribution of the sedimentary, petrophysical and productivity trends in microbial reservoirs

- The results from the Little Cedar Creek field case study have direct application to the design of an improved development strategy for other fields producing from microbial carbonate reservoirs