Characterization of Seismically-Imaged Pennsylvanian Ooid Shoal Geometries and Comparison with Modern

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Overview

- Thin (~4 m) Penn. 16 km x 3 km ooid shoal complex that encompasses two prominent stacked, high-frequency shoaling-upward cycles.

- 4-D seismic (CO2 movement) suggests:
  - Sinuous to linear, isolated pods, possible parabolic forms,
  - Oomoldic pore system and bed geometry variations appear to relate to amplitude patterns.
  - Structural lineaments that may have influenced the location of depositional and diagenetic lithofacies.

- Guided by seismic data, finer scale examination and integration of core, wireline log, and CO2 flood data are refining geomodel.

- The resultant higher resolution subsurface picture of oolitic reservoir strata have geometries and facies distributions similar to individual oolitic shoal complexes in the Modern.
Lansing-Kansas City Oil Production
Hall-Gurney Field Area
Lansing Structure Map
Contour Interval = 10 Feet

Dubois et al. (2003)
Lansing-Kansas City

Hall-Gurney Type Curve

4th Order Sequences

Heebner
- Toronto Ls
- Cass Ls (A)
- Stanton Ls (B)
- Plattsburg Ls (C)
- Farley/Argentine Ls (D)

Iola Ls (G)
- Dewey Ls (H)
- Cherryvale Fm (I)
- Dennis Ls (J)
- Swope Ls (K)
- Sniabar LS (L)

2-3 stacked 5th order parasequences

3rd-order Sequence Set

Thickness: 3-30 ft
Porosity: 0-35%
Permeability: 0.001-300md
2894.2 ft, Layer 2
clean well sorted, cm-scale bedding, oomoldic Ø

φ = 34.1%
k = 113.9 md
low gamma ray

Dubois et al. (2003)
Synthetic Seismic Trace

- Base of Lansing & top of Kansas City Plattsburg LS
  - 900 m
  - 548 ms
- Porous zone
  - 5 m thick

Klauder 20-100 Hz Wavelet

Heebner Shale
Plattsburg Ls
A strong correlation exists between the preferential movement of the CO\textsubscript{2} through this reservoir and features evident on the lineaments attribute map. It appears lithology, especially rock properties, are preferentially influencing fluid movement through this reservoir.
Attribute Analysis on Baseline Data

- Time structural map (red highs)
- Similarity “seismic facies” map white poorer reservoir properties
- NE-SW trend of more favorable reservoir properties
- Patterns of more favorable reservoir is lobate-shaped like porosity-ft map (Dubois et al., 2003)
Murfin CO2-Colliver #16

- Deepen, re-perforated
- Drilled April 2003
- **Pay zone** cored with full suite of wireline logs
- Upward increase in porosity
- **Super Pickett** – pay zone clearly identified as low gamma ray zone with highest porosity and lowest water saturation
- Archie equation parameters:
  
  - $a = 1$, $n = 2$, $m = 3.15$
Colliver #16 core: Bedsets, grain size range

**Bedset #2:**
- 3-finling up, well sorted
- 1-coarsening up, well sorted
- 1-finling up, less well sorted

**Bedset #3:**
- Top-coarse, well sorted
- Lower-poorly sorted w/bioclasts

**Bedset #4:**
- Cap- well sorted
- Lower-Poorly sorted

**Bedset #5:**
- Top– 3 cm thick beds w/biocl.caps
- Lower-micritic clasts, bioclasts, superficial oolite

**Bedset #6:**
- Poorly sorted, biocl., to marine wackest.

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**Better sorted capping strata on bedsets**

**Largest to smallest grain size**
Colliver #16 core: Upward increasing in oomoldic content

Bed #

Dip Angle

% Moldic

VC  c-m  f-vf  mud

Better sorted

Largest-smallest grain size
Colliver #16 Core/Log: Notably higher permeability toward top of Plattsburg Ls. and in cycle caps; relates to upward increase in porosity and Archie cementation exponent, m (more oomoldic and “micro-vugs”).

- Better sorted cycle cap (layer #2)
- Fractures
- Better sorted cycle cap (layer #4)
Clean (lower gamma ray),
better-sorted oolite/ oomoldic

- Higher permeability, >10 md
- Correlation with:
  better sorting, packing, and interconnected oomolds
  (microvugs & associated high Archie cementation exponent)

Clean, better sorted
higher porosity in cycle caps and highest near top in shallowing upward succession

- Better sorted bar crests in Modern ooid shoals,
Stratigraphic Cross Section

- North-South
- Datum: Base Plattsburg Limestone
- Crosses CO$_2$ site and porosity development to south
- Utilize color versions of uncalibrated gamma ray and neutron logs
- 0.5 Mile (0.8 km) long

Porosity*Ft Map

- 0.25 mi (0.4 km)
CO2 plume projects into cross section in upper portion of porous, **low GR** Plattsburg Limestone between wells Clvr #10 and Clvr #18.

No Horizontal scale  
Total length ~0.5 mi. (0.8 km)  
Datum: Base Plattsburg Limestone
Gentle dip to northwest from high in southeast with stronger dip to north and southwest.

Outline of CO2 plume

Regional structural lineament

Local structural lineaments

Sec 28

CO2 #1

Sec 27

Sec 28

Sec 33

Sec 34

Cl = 10 ft.
Comparison of two stacked, high-frequency cycles

- Possible polygenic parabolic-shaped ooid shoals
- Roughly orthogonal trends paralleling structure lineaments
- Offset to west of underlying layer #4
- CO2 movement along porous layer #2

- Isolated elongate ooid shoal developed sub-parallel to regional structural lineament
- No CO2 movement in lower layer #4
Comparison of porosity thickness with thickness of clean Gamma ray

- Possible polygenic, parabolic-shaped ooid shoals
- Roughly orthogonal trends paralleling structure lineaments
- CO2 movement along porous layer #2

- NW and NE trends closely paralleling structural lineaments
- Thicker, cleaner carbonate,
- Core suggest better sorted, more permeable
Comparison of porosity thickness of lower Layer #4 and thickness of clean, low gamma ray interval capping Layer #2

- Close correspondence of location and NE-trend of low gamma interval of upper layer #2 and thick porous interval of lower layer #4
- New NW-trend of clean GR in layer #2 not reflected in #4
- Both trends closely parallel regional and local structural lineaments
- Possible inherited topography from buildup of #4 affecting #2
- Isolated shoal in #4 may also reflect topography (concurrent movement) along regional structural lineament
Modern Analogs Can Help

- Similar parabolic forms (convex/concave)
- Similar scale of lobate forms
- In general terms, the best sorted sediments occur at the bar crests (as observed in analog ancient shoals in this study)
- Grain size may vary - coarsest may be in troughs or on crests

**Tidal Flood Delta (Abacos):**
Shoal crest well sorted and inner lobe less well sorted (seagrass covered area bankward of shoal crest

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Conclusions

• 4D seismic and CO2 monitoring define new heterogeneities involving apparent structure and lithofacies variations.

• Accurate and precise characterization of connected (effective) oomoldic pores is critical in IOR modeling and prediction:
  – Better sorted, cleaner (low GR), highly porous (>17%) oomoldic grainstone appear to be more permeable;
  – In Plattsburg Limestone at Hall-Gurney Field, best sorting noted in upper portion of shallowing upward high frequency (5th order) cycles and bedsets, probably delimiting separate ooid shoal development;
  – Moldic porosity increases upward in shallowing bedsets and high frequency cycles;
  – Archie cementation exponent, m, also increases upward, reflecting increased molds and microvug electrical behavior.

• Structural control likely at various scales and timing in formation of this ancient ooid shoal complex.

• Bi-directional cross stratification in stacked, shallowing upward bedsets suggest tidal influence.

• Geometries, scales, and facies distributions suggest analogs to Modern tidally influenced ooid complexes.

• Opportunity to define and predict geomorphic, granulometric, and petrophysical properties combining Modern and ancient oolitic systems.