The Role of Moldic Porosity in Paleozoic Kansas Reservoirs and the Association of Original Depositional Facies and Early Diagenesis With Reservoir Properties

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Stratigraphic column of

and Upper Missourian

Upper Middle Desmoinesian

Mudelone and Shale

Unrestone (Mainly Waskestone ond Muddy Packetone)

Limetions (Mainly Cottle Germanne Minor Sequence and well-waihed Pockstone) Boundary

Purpose

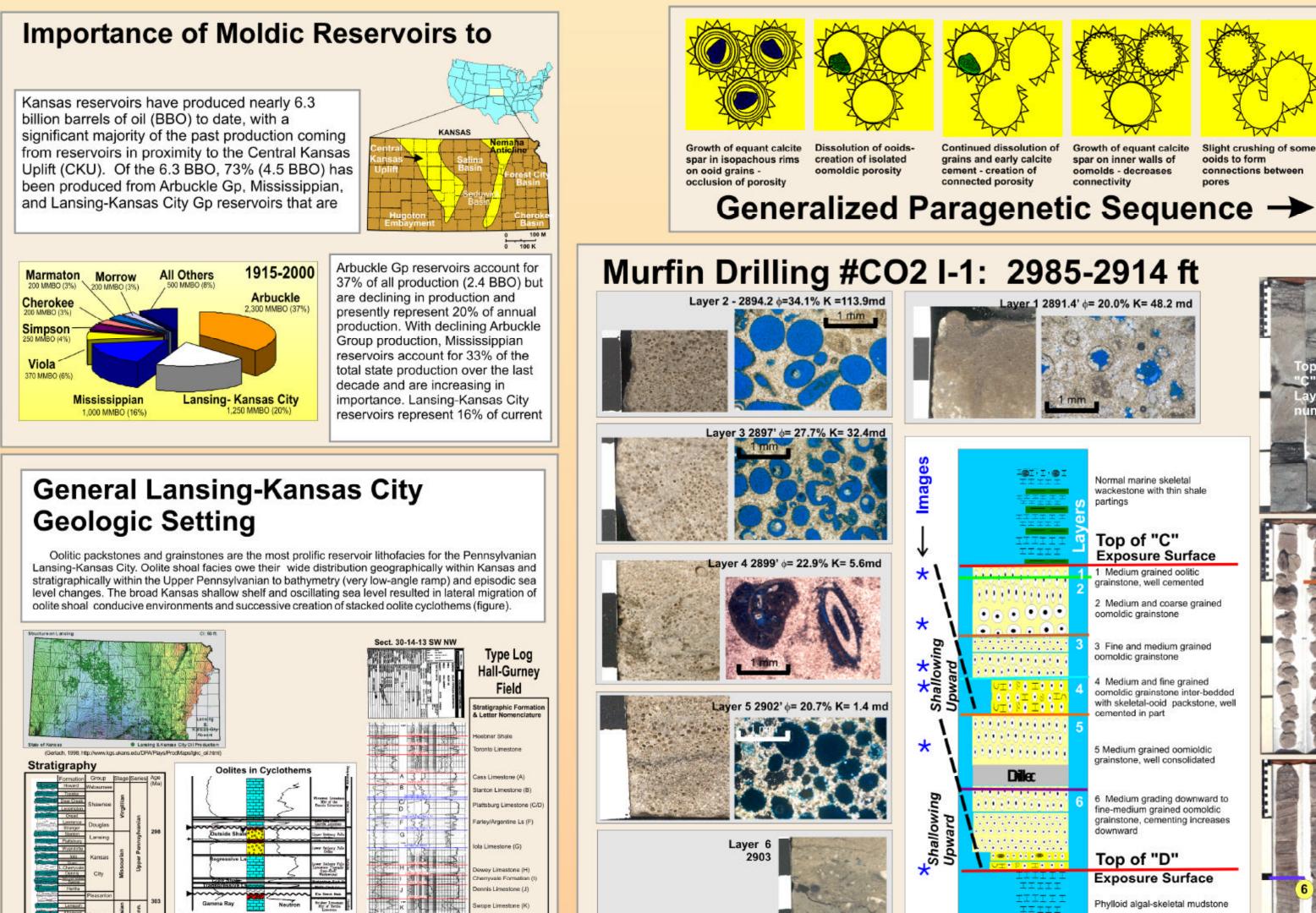
The multiple goals of this work include:

- To better understand the nature and distribution of moldic porosity in the shallow shelf carbonate systems. To understand the role of original depositional facies and early
- diagenesis on subsequent rock geologic and petrophysical
- To enhance modeling relating moldic porosity, and more broadly pore architecture, to petrophysical properties.
- To compare and contrast the effects of different kinds of
- To improve prediction of reservoir quality in these systems (or better define the limits of prediction).
- To improve reservoir properties models for reservoir evaluation, characterization, and simulation.

Results and Implications

- Core examples from Upper Cambrian- Lower Ordovician Arbuckle, Mississippian & Pennsylvanian shallow-shelf carbonates in Kansas indicate that moldic porosity is abundant in each system, & reservoir properties, including porosity/permeability, are strongly correlated with original depositional
- Despite the nature of the molds varying through time, reflecting changes in primary carbonate grains, reservoir quality is similar in each system & increases from mudstone through grainstone.
- . Despite significant diagenetic overprinting in many of the rocks. & even some complete reversal of original solid & pore space, final moldic textures exhibit petrophysical-lithofacies trends that parallel those of original primary porosity carbonates.
- Correlation of permeability and pore throat size in moldic-porosity rocks is similar to that of intergranular- porosity rocks. This can be interpreted to indicate that despite, in some rocks, very high moldic porosity, permeability is primarily controlled by matrix properties.
- Moldic rocks play an enormous role in Kansas oil and gas production. The diverse nature of the matrix, molds and mold content with continued study is providing better understanding of the role of moldic porosity and of pore architecture to fluid flow in porous media.

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dolomite during buria

lormal marine skeletal

Top of "C"

wackestone with thin shale

Exposure Surface

Medium and coarse grained

3 Fine and medium grained

Medium and fine grained

5 Medium grained oomioldic

grainstone, well consolidated

Medium grading downward to

fine-medium grained comoldic

Exposure Surface

Phylloid algal-skeletal mudstone

Top of "D"

grainstone, cementing increases

comoldic grainstone inter-bedded with skeletal-ooid packstone, well

Medium grained oolitic

oomoldic grainstone

oomoldic grainstone

cemented in part

grainstone, well cemented

Upper Pennsylvanian Lansing-Kansas City Gp

Lansing-Kansas City oolitic reservoirs exhibit geometries and multiple stacked, or *en echelon* shoals that formed in response to sea

underwent variable degrees of early or later fracturing and crushing,

Petrophysics and Reservoir Properties

matrix crushing and fracturing. Permeability is also influenced by oomold diameter, oomold packing, and matrix properties. Increasing bioclastic constituents within and bounding onlite beds are often associated with wells exhibit porosity-permeability trends with less variance than the overall

demonstration site, permeability decreases from the top of the bottom of the limited. Sorw may increase then decrease with increasing permeability (k). LKC 'C' interval. Lower permeability with increasing depth in the reservoir

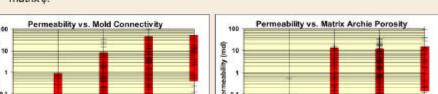
Correlations of "irreducible" water saturations (measured at pressures equivalent to 60-120 feet above free water level) indicate that Swi increases

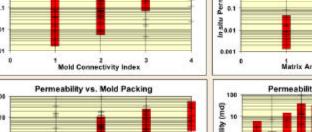
Lansing-Kansas City oomoldic limestones exhibit a near log-linear trend between wetting phase saturation and oil-brine height above free water level with capillary pressures decreasing with increasing permeability at any

Residual oil saturation to waterflood (Sorw) is a critical variable for bot waterflooding and carbon dioxide miscible flooding since this represents the target resource. Most L-KC waterfloods in Kansas have only involved 1-5 pore volumes (PV) throughput before reaching their economic limit. At 5 pore volumes throughput Sorw averages near 30%. Though sampling is

Correlation of Textural Properties with Permeability

- between oomolds as observed at 10X-20X
- Size An estimate of the average comold diameter in phi units





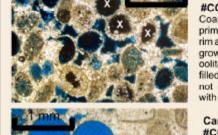
porosity are non-reservoir. Permeability (<0.001-400 md) is principally controlled by: Porosity diameter, Oomold packing, Matrix properties, Matrix fracturing. Although permeability is controlled by and correlates with several of these variables (figure below), multivariate linear

ormation concerning connectivity index, as measured on rock pieces $\log k = 0.112 \phi - 2.48$

log k = 0.090 \(\phi + 0.47 \) Connectivity Index - 3.21SE=5.53

Porosity in L-KC oomoldic limestones ranges from 0-35%. Generally rock below 15%

Important Microscopic Textures

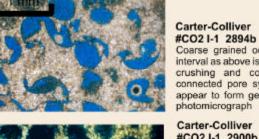


Log Density

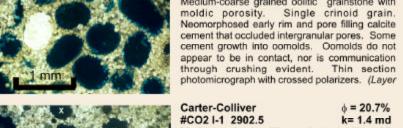
PE Curve

filled with blue epoxy (X) suggest these pores are

#CO2 I-1 2894a Coarse grained oolitic grainstone with m calcite cement that occluded intergranular pores. Notable absence of cement within comolds. No crushing evident in this view but pore connections are visible in few cases and are likely outside the plane of section. Thin section photor with plane polarized light. (Layer 2)



Coarse grained colitic grainstone from same nterval as above is very similar except extensive crushing and collapse has created well connected nore system. Fine cement shards appear to form geopedal fabric. Thin section k = 5.6 md



k= 1.4 md #CO2 I-1 2902.5 Medium grained oolitic grainstone with moldic porosity. Heavily neomorphosed early rim and tergranular pore filling calcite cement. ignificant cement growth into comolds reduced moldic porosity. No crushing of comolds evident. Lack of epoxy impregnation in nearly all oomolds (X) suggests these pores are not connected. Thin

section photomicrograph with Nichols crossed.

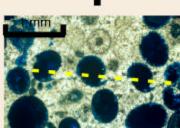
noldic porosity. Single crinoid grain.

eomorphosed early rim and pore filling calcite

ement growth into oomolds. Oomolds do not

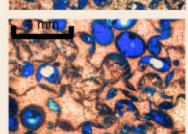
ppear to be in contact, nor is communication

rough crushing evident. Thin section

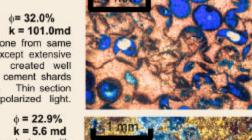


Permeability and Porosity

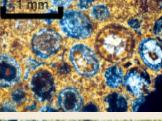
Minor crushing of comolds and slight offset is related to microfracture. Thin section otomicrograph with crossed polarizers. k = 101.0md



mework resulted in added permeability. No ement evident after collapse. Thin section otomicrograph with plane polarized light. rin red stain. (Layer 2)

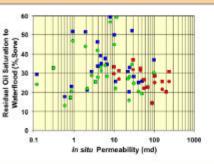


k= 46.7md oarse grained oolitic grainstone. Extensive rushing of oomolds and collapse of matrix mework resulted in slightly reduced porosity. No cement after collapse is evident. Thin section



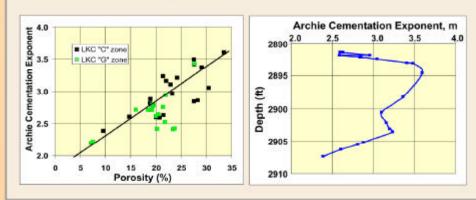
Medium-coarse grained oolitic grainstone with early silica replacement. Fabric prior to silicification, early rim and pore filling calcite cement, is well preserved. Thin section





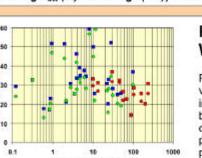
Archie Cementation Exponent

Oomoldic limestones from Kansas and globally exhibit extremely high Archie cementation exponents. This is consistent with the interpretation that the oomoldic pores are similar to nicro-yugs. Modified Archie parameters for the Carter-Colliver Lease rocks are: m=1.36. a=9.59. Conversely, if m is considered to change with porosity then m can be predicted for the the top of the 'C' and then decrease with increasing depth to the base. This is associated with the higher porosity at the top of the 'C' zone but is also influenced by pore structure changes



"Irreducible" Water Saturation

With finer pores in the matrix surrounding large oomolds it is important to understand capillary pressure relationships since high porosity may not be directly associated with effective oil porosity. Correlations of "Irreducible" water saturations indicate that Swi increases with decreasing permeability as exhibited by many rocks. Saturation increases with decreasing permeability following the relation: $\log S_{w55}$ (%) = 0.22 $\log k(md)$) - 0.43



Residual Oil Saturation to Waterflood

Residual oil saturation to waterflood (Sorw) is a critical variable. Sorw increases then decrease with increasing permeability (k). At lower k, higher Swi must be associated with lower Sorw. At high k good connectivity promotes low Sorw. Intermediate permeability rock have large pore bodies and smaller pore throats which supports oil-globule snap-off and

Insitu Permeability (md)