PART 5. SUMMARY

Summary

Fundamental Model Properties

- **Basic Architecture**
  - Structural Top
  - Thickness
  - Facies Architecture
  - Connectivity (transmissibility)
  - # Layers – Gridcell dimensions

- **Reservoir Rock Properties**
  - Porosity
    - Compressibility
  - Permeability
    - Absolute
    - Relative Permeabilities (krw,krg)
  - Saturations
    - Wireline log parameters
    - Capillary Pressure
    - Free Water Level
    - History

- **Fluid Properties**
  - Density (=f(P,T))
  - Viscosity (=f(T))
  - Expansion Factor (E_g=f(P,T))
Integrated Approaches to Modeling Late Paleozoic Petroleum Reservoirs in the Greater Midcontinent

Who Should Attend:
- Geologists and engineers who are characterizing late Paleozoic reservoirs to optimize oil and gas recovery.
- Geoscientists exploring for new fields and extensions in the greater Midcontinent.

Objectives:
- Describe oil and gas plays and reservoir characterization in the context of tectonic/structural framework, sequence stratigraphy, and lithofacies distribution.
- Illustrate integrated geomodel development using core descriptions and analyses, wireline log analysis techniques, well tests, 3D seismic, and production histories.
- Effectively integrate recent analogs and surface exposures to define and model reservoir heterogeneity and design appropriate recovery technologies.
- Highlight case studies of carbonate, sandstone, and chert reservoirs ranging from Mississippian (Lower Carboniferous) through Lower Permian age.
- Integrate reservoir characterization in the context of reservoir systems and hydrocarbon accumulation – re-exploration and exploitation.
- Provide tools and insights for efficient prospecting and development for remaining oil and gas resources.

Content:
- Regional structural/tectonic framework during the late Paleozoic.
- Variations in sequence stratigraphy and reservoir architecture of late Paleozoic strata in the Midcontinent.
- Common reservoir lithofacies and their Recent analogs.
- Petrofacies and pore typing approach to quantitative reservoir analysis and modeling petroleum reservoirs, roles of diagenesis.
- Case studies based on integrated geo-engineering modeling of Mississippian, Pennsylvanian, and Permian reservoirs:
  - carbonate ooid and grainstone shoals
  - phylloid algal mounds and related lithofacies
  - incised valley and estuarine sandstones
  - Low resistivity, often low permeability spiculitic bioclastic buildups that comprise shelf and shelf margin environments.
Take Home Points of Short Course

- Basement structures and tectonic events affecting them are important in defining location and properties of reservoirs.
- Process-based field, outcrop, and Recent analogs provide more appropriate, accurate interpolation of reservoir properties.
- Late Paleozoic reservoirs are dominated by depositional fabric selective diagenesis.
- Establishing petrofacies and pore types is essential to accurate calculations of water saturations, volumetrics, ROIP, establishing permeability correlations and predicting fluid flow.
- Infill locations and new pays within oil and gas fields remain significant targets for IOR in mature regions; requires comprehensive, integrated approach.
- Re-exploration and exploitation of mature producing areas can be substantially benefited by access to and mining of large data sets – digital and electronic data – logs, production, core/samples and descriptions, in an integrated and quantitative manner.

Oil and Natural Gas Production in the United States
(Derived from Mast, et al, 1998)
Kansas’ version of Geoengineering modeling – web-based tools – “doing simple reservoir modeling versus none at all”

- Well Level Analysis Applets
- Field Level Analysis Applets
- Gemini User/Project Module
- Volumetrics Module
- Cross Section Module
- Material Balance Module
- PVT Module
- Synthetic Seismic Module
- Rock Catalog
- Rock & Fluid Characteristics Tables and Applets

- KGS Server
- apache - jserv
- Java Servlets
- KGS Database & Files

- PIEFFER Module
- DST Module
- Synthetic Seismic Module
- KHAN
  
- 284,772 lines Java code
- 908 files
- Level 2 compliant code and documentation

- Rock Catalog
- Fluid Catalog

- * 284,772 lines Java code
  * 908 files
  * Level 2 compliant code and documentation

Ancestral Rocky Mountain, Ouachita-Marathon, and Laramide tectonism were far reaching and systematically deformed shelves and shelf margins of the Midcontinent U.S.

Baars et al. (1995) recognized continental-scale orthogonal patterns and basic similarity of structures to the San Andreas fault system.

Contractional reactivation of basement extensional faults

Schematic diagram of the creation of a listric normal fault (top) that is later reactivated in compression (bottom), creating a footwall shortcut. Pre-extensional rocks are shown in dark gray.

Tri-shear faults are generated during reactivation.

Upper strata may be simply draped over deeper fault.

Bump (2003)
From Thatcher (2003) –
• GPS constraints on the kinematics of current continental deformation.
• Deformation linked to “real time” Modern faulting and microplate motion.

Conceptual diagram - Effect of changing plate boundary forces on intraplate stress field and fault patterns

Dotted arrows = changing horizontal principal stress axes resulting in reactivated or new faults

Scale: 10’s to 100’s kms

From Thatcher (2003) –
• GPS constraints on the kinematics of current continental deformation.
• Deformation linked to “real time” Modern faulting and microplate motion.
Forecasting rock properties -- Characterizing fragmentation of shelf and corresponding subsidence & tilting in context of deposition and diagenesis

- Kinematic structural analysis – (rates, magnitude, duration of movement)
- Integrate with play and field characterization
- Spatial-temporal integration with other processes – sea level, climate, diagenetic events

Areas of similar Upper Pennsylvanian cycle thicknesses separated by narrow structural transition zones

Subsidence plots for early Missourian to early Virginian strata

Cluster analysis of regions interpreted as structural blocks

Watney et al. (1997)
PART 5. SUMMARY

Watney et al. (1995)

Ø ooid shoals lower shelf

Saller et al. (1994)

Ø>4%, h>1m

Soreghan (1994)

Moore (2001)
Refining parameter list and reducing assumptions through interdisciplinary studies.

2D simulation ooid lithofacies deposited during forced regression, 70 ky run

Sea level and sediment profile

White lines 30 ka timing lines

Kansas Subsidence >0.20 m/ky in Arkoma and Anadarko Basins
PART 5. SUMMARY

Thickness of Bethany Falls Limestone (shaded) overlain on isopach of Nuyaka Creek Shale to Hushpuckney Shale
- index for A-C cross section

French and Watney (1993)

Well control from wireline logs in oil and gas wells

Stacking Geometry of lower Muncie Creek sequence set along the outcrop (~150 mi east)

OKLAHOMA

KANSAS

South Bend Limestone Member
Stanton Limestone

Stoner Limestone Member

Captain Creek Limestone Mbr.

Plattsburg Limestone

Wyandotte Ls.

Iola Limestone

Dewey Limestone

Approx. 75 miles

South (basinward)

North (landward)

Forward stepping

backstepping

Algal mound

Tyro Oolite bed

Algal mound

Algal mound

Algal mound

Algal mound
Ramp Sediments

- Ebb flow over shoal
- Decreasing current velocity with distance

Ebb-Dominated Tidal Delta on Little Bahama Bank
**LKC Permeability vs Porosity**

\[
\log_{10} k_i = 0.154 \phi - 3.21 \quad \text{(SE=6X)}
\]

\[
\log_{10} k_i = 0.090 \phi + 0.47 \text{ MCI} - 3.2 \quad \text{(SE=5.5X)}
\]

**Permeability and Pore Diameter**

Pleistocene cores (*light blue*) exhibit correlation of permeability and principal pore throat diameter consistent with trend of other lithologies.

*Byrnes et al. (2006)*
Comparison of core analysis from CO2 #1 and #16: Consistent upward increase in Archie Cementation Exponent, m, which is closely related to increasing porosity.

\[ S_w = \left( \frac{R_w}{R_i} \right)^{\frac{m}{n}} \]

\[ y = 0.053x + 1.84 \]
\[ R^2 = 0.93 \]

More complex pore type in uppermost interval of CO2 #1

\[ m = f(\phi, A_{pore}) \]
\[ m = f(\phi, k) \]
\[ m = (-0.019 \log_{10} k + 0.085)\phi + 1.5 \]

Model for estimating m in oomoldic petrofacies knowing k and phi

Byrnes et al. (2007)
Marmaton B Case #1
Archie Exponents
\( m=2 \), \( n=2 \)

Well Log Cutoffs
\( \Phi = 0.15 \)
\( Sw = 0.25 \)
\( Vsh = 0.3 \)
\( BVW = 0.04 \)

9.7 MM Bbls OOIP

Marmaton B Case #2
Archie Exponents
\( m=3.5 \), \( n=2 \)

Well Log Cutoffs
\( \Phi = 0.17 \)
\( Sw = 0.55 \)
\( Vsh = 0.3 \)
\( BVW = 0.097 \)

4.2 MM Bbls OOIP
(40% less hydrocarbon than Case #1)

Pass #3 -- Adjusted Ro line to fit base of porosity using \( Rw \) now of 0.4 ohm-m, with \( m = 2.5 \)

Widely varying points at low \( \Phi \) suggest fracturing
• Significant deep-seated structural control to the northwest-trending features in the “high volume area”.
• Crosscutting north to northeast-trending features on the Devonian surface appear to have impacted porosity development in the San Andres.