Statistically-based Lithofacies Predictions for 3-D Reservoir Modeling:
Example from the Panoma (Council Grove) Field, Hugoton Embayment, Southwest Kansas

Martin K. Dubois[1], Alan P. Byrnes[1], Geoffrey C. Bohling[1], Shane C. Seals[2], and John H. Doveton[1]

(1) Kansas Geological Survey, University of Kansas,(2) Pioneer Natural Resources USA, Inc.

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Purpose

To construct a geologic and petrophysical model of the Panoma Field in sufficient detail to accurately represent the fine-scale vertical and lateral heterogeneities for accurate reservoir modeling of the entire field.

Abstract

The Panoma (Council Grove) Field in southwest Kansas lies stratigraphically subjacent to the more prolific Hugoton (Chase) Field, and has recovered 2.8 TCF of gas from approximately 2,600 wells across 1.7 million acres since its discovery in the early 1960's. Field-wide upscaling of lithofacies distribution for reservoir characterization has proven problematic in large heterogeneous reservoirs like the Panoma Field, but prediction tools, neural networks and the Excel add-in Kipling.xla, a non-parametric discriminant analysis tool, provide solutions to the facies prediction dilemma.

Panoma produces gas from the upper seven fourth-order sequences of the Permian Council Grove Group containing 50% nonmarine siliciclastics and 50% marine carbonates and siliciclastics. Lithofacies controlled petrophysical properties dictate gas saturations and discrimination of lithofacies reduces standard error in permeability prediction in marine carbonate facies by a factor of twelve. Nonmarine siliciclastic facies error was reduced by a factor of three. At low gas column heights, lithofacies discrimination can result in predicted saturation differences of 20-40% while differences at high gas column heights, near “irreducible”, are less than 10%.

Both a neural network and Kipling.xla were “trained” on data from eight wells including half-foot digital wireline log data and descriptions of two thousand feet of core utilizing a digital rock classification scheme. Both models were then used to predict lithofacies in non-cored wells based on their log attributes. Techniques employed in this study could be applied to other large and complex reservoirs where accurate representations of lithofacies heterogeneity in the 3D volume are key to realistic reservoir analysis.

Kansas Hugoton Project

The Hugoton Project (http://www.kgs.ku.edu/Hugoton/index.html) is an Industry, University and Governmental funded consortium whose purpose is to develop technology and information to better understand the oil and gas resources of the Hugoton Embayment in Southwest Kansas. This paper is one of the outcomes of the five year project.

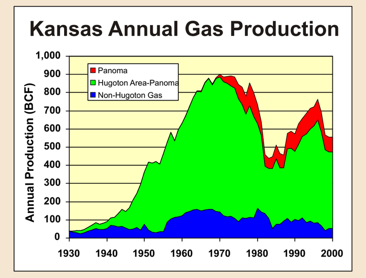
We wish to acknowledge members of the Hugoton Consortium that contributed data including Pioneer Natural Resources USA, Inc., BP, OXY USA, Inc., and Anadarko Petroleum Corp. We are grateful to those who served as technical advisors including Kevin Schepel, Louis Goldstein, and Randy Offenberger, Pioneer, and those that provided technical support including Bob Perry, Bill Tulp Jenna Anaya and Susan Leigh, Pioneer, Tim McGinnley, McGinnley and Associates, David Hamilton and Jeff Kiester, SCM, Inc., and Ken Dean and Mike Maroney, Kansas Geological Survey.

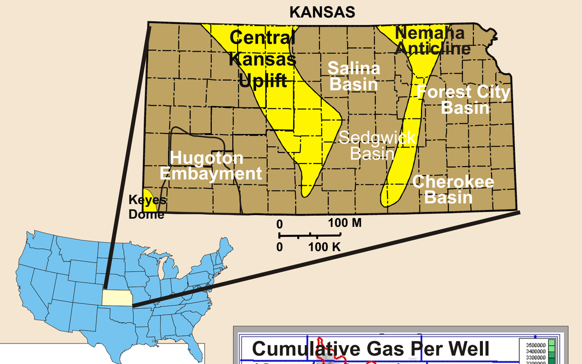
Setting and History

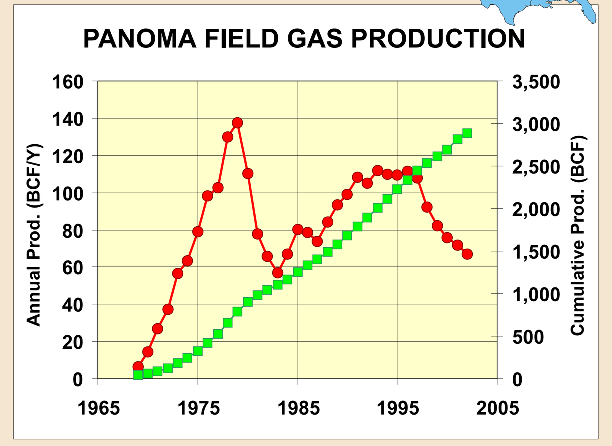
The Panoma Field (2.9 TCF gas) produces from Permian Council Grove Group marine carbonates and nonmarine silicilastics in the Hugoton embayment of the Anadarko Basin. It and the Hugoton Field, which has produced from the Chase Group since 1928, the top of which is 300 feet shallower have combined to produce 27 TCF gas, making it the largest gas producing area in North America. Both fields are stratigraphic traps with their updip west and northwest limits nearly coincident. Maximum recoveries in the Panoma are attained west of center of the field. Deeper production includes oil and gas from Pennsylvanian Lansing-Kansas City, Marmaton, and Morrow and the Mississippian.

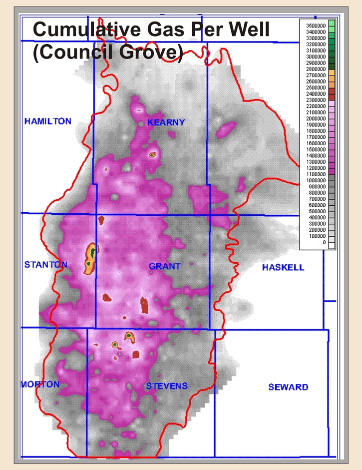
Statistics

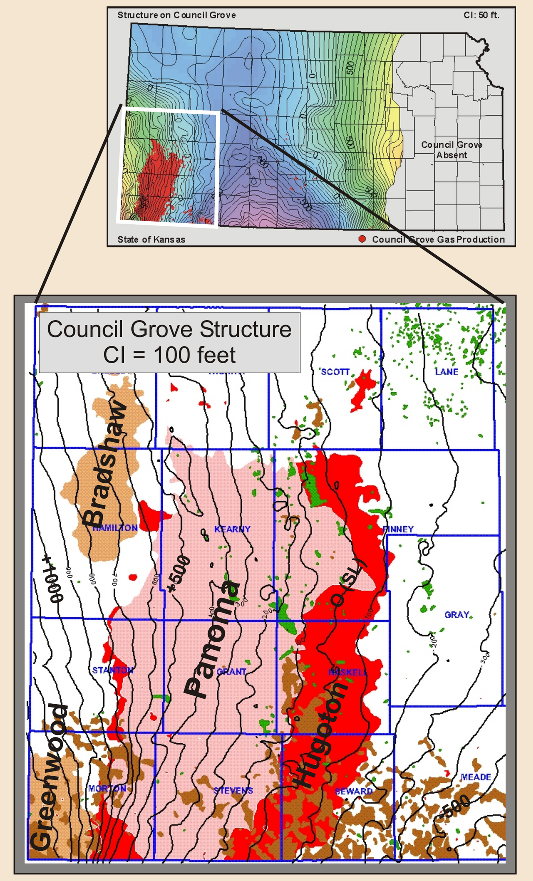
IInitial Prod	1968
2002 Prod	67 BCF
Cum. Prod	2.88 TCF gas
Well count	2600
Per well avg.	1.1 BCF to date
Area	1.7 million acres (1 well per sect)
Top of pay	2500-3200 feet (+800 to 100)
Current SIP	~60#
OriginaSIPI	~480#

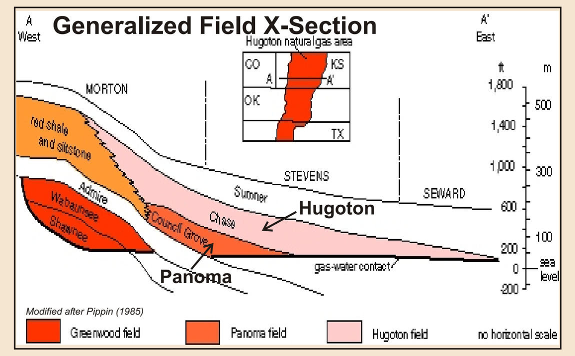








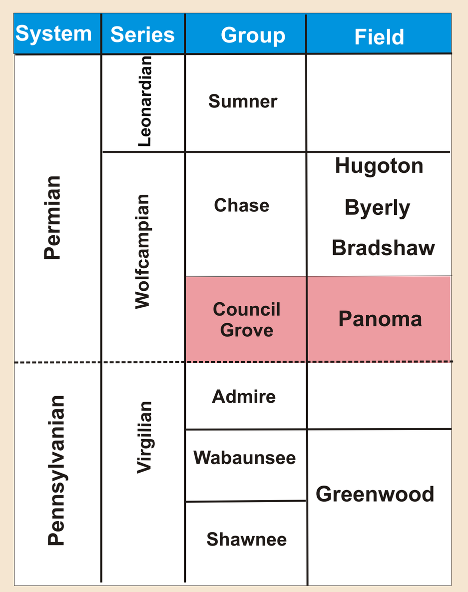


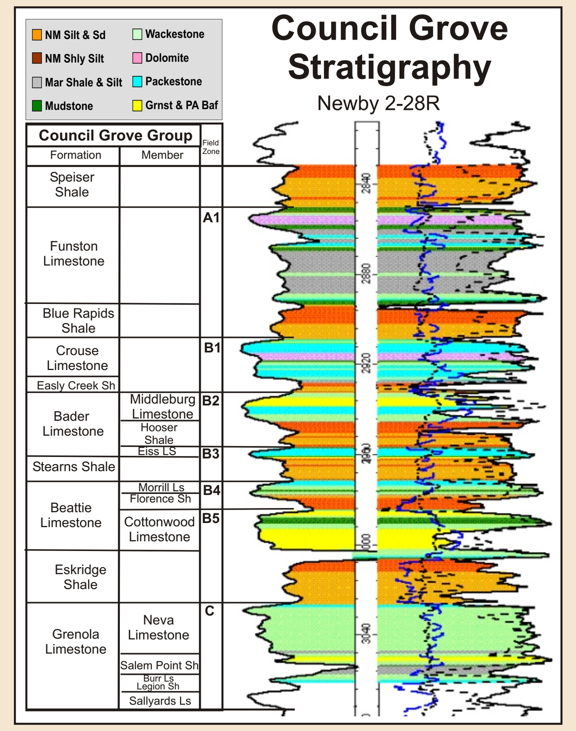


Seven Sequences

The Council Grove Group is comprised of seven fourth-order marine-nonmarine sequences bounded by unconformities on exposed carbonate surfaces. A typical vertical succession, beginning at the exposed carbonate surface, are primarily wind blown silts, very fine sands and clay rich silts with paleosols. Above a flooding surface are generally thin, shallow water carbonates with grain-supported textures deposited during the initial, shallow water portion of the flooding event. These are overlain by deeper water dark marine siltstones and silty carbonate mud- and wackestones which are, in turn, overlain by “cleaner” mud- and wackestones deposited in shallower water. With progressive shallowing these are overlain by either packstones and grainstones, interpreted to indicate increased wave or tidal agitation; quiet water, lagoonal, mudstones and wackestones; or silty dolomites and dolomites, where there was little or no wave agitation. Fenestral and laminated tidal flat carbonates are also common near the top of the carbonate interval. Exposure is evidenced by well-developed calcretes, root molds, and other indicators. Higher frequency cycles are evident in the Funston and Neva, in particular.

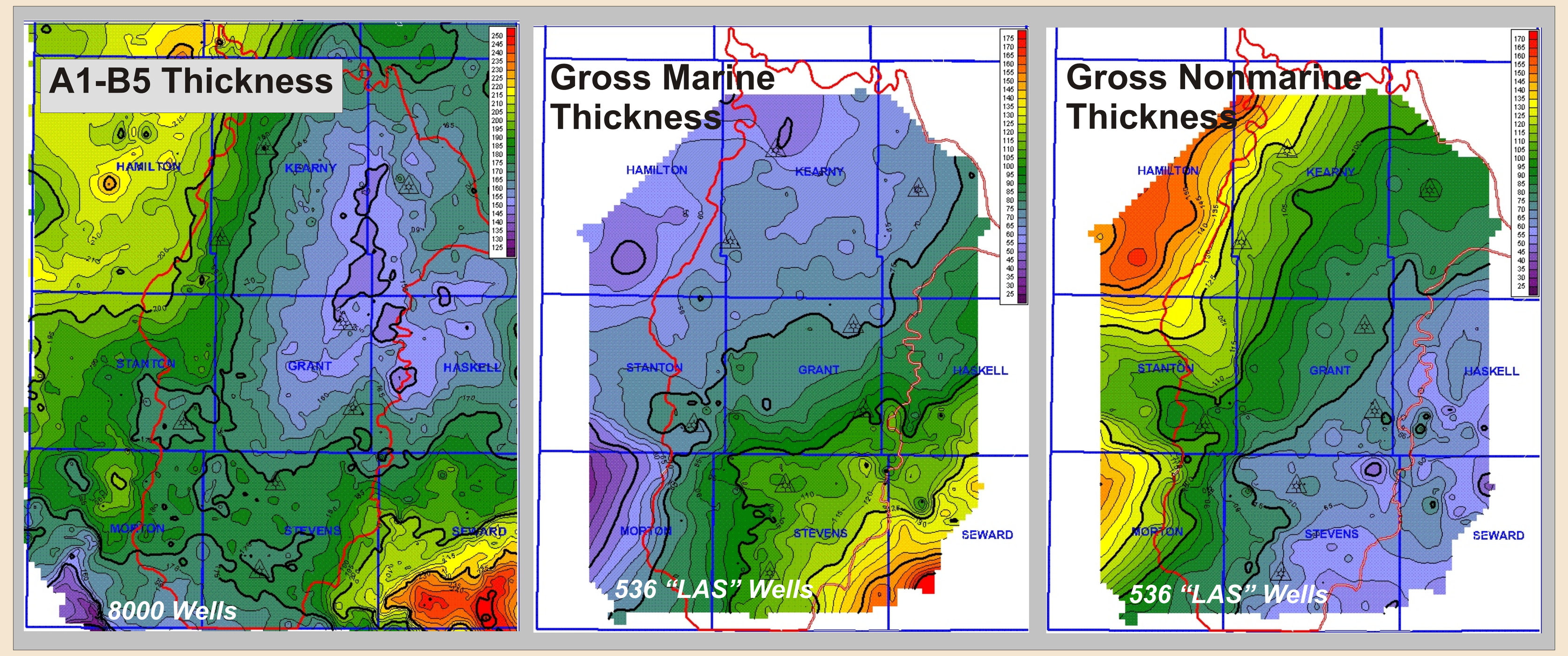
Stratigraphy



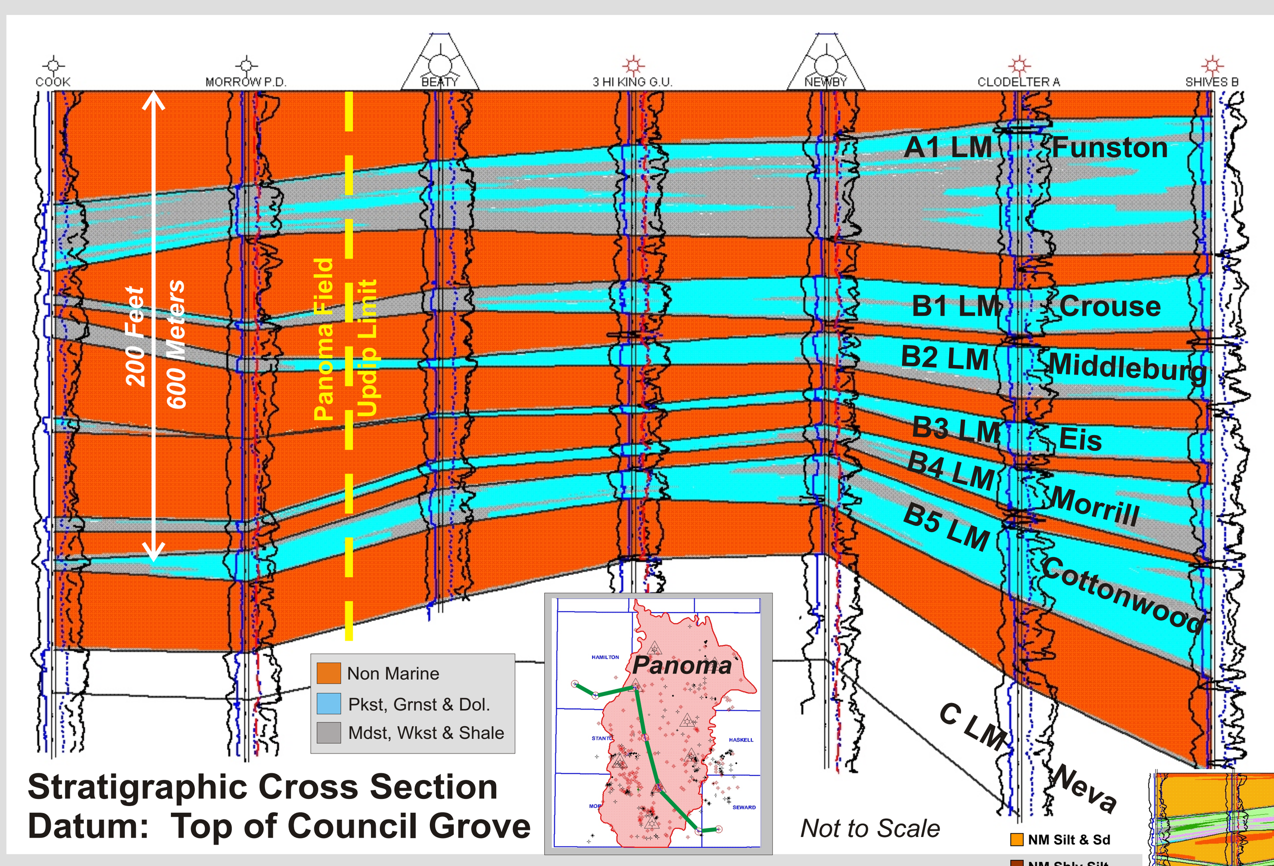


General Geology Panoma Field

The most striking large-scale geometry feature of the Panoma reservoir is the reciprocal relationship between nonmarine and marine interval thickness. Though the total thickness of the Council Grove (A1-B5) in most of the study area varies less than 50 feet (from 200-250 feet), the summed nonmarine and marine intervals each vary 120 feet (from 50-170 feet) and their respective summed thicknesses are reciprocal. Thick nonmarine shale and silt dominates the northwest side of the study area while marine carbonates dominate to the southeast.



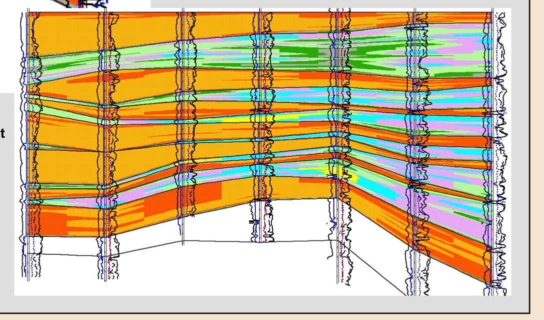
Maps of the A1SH (top Council Grove) through the B5LM (base Cottonwood)



Stratigraphic Cross Section
Datum: Top of Council Grove

Strat X-Sections

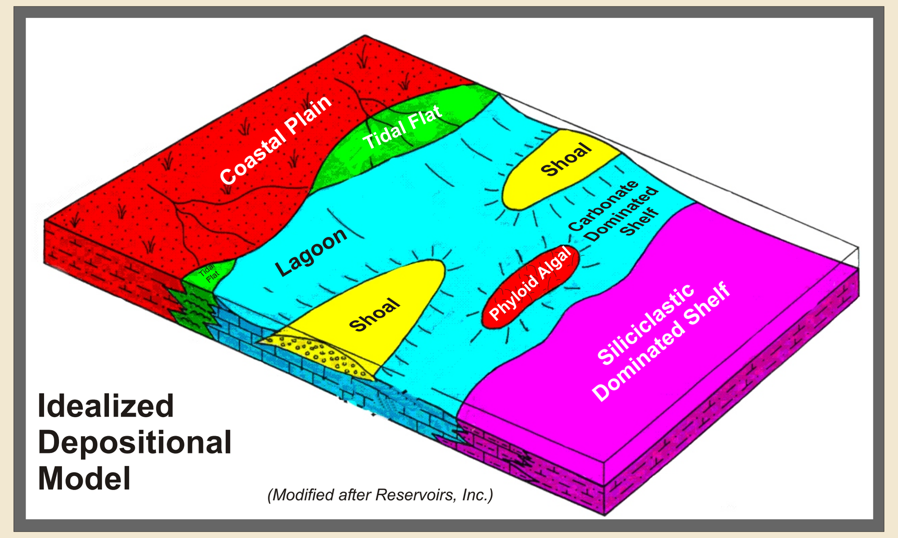
Northwest to southeast cross sections illustrate the large-scale lithofacies and depositional relationships in the Panoma Field. The updip limit to the Panoma coincides with thinned marine carbonate intervals and their reciprocally thicker nonmarine silts and shaly silts. The smaller scale cross section of the same wells shows the 8 lithofacies using Petrel's interpretive colorfill. It illustrates some major lateral and vertical facies relationships but is not to be considered a true representation of the finer geometries.

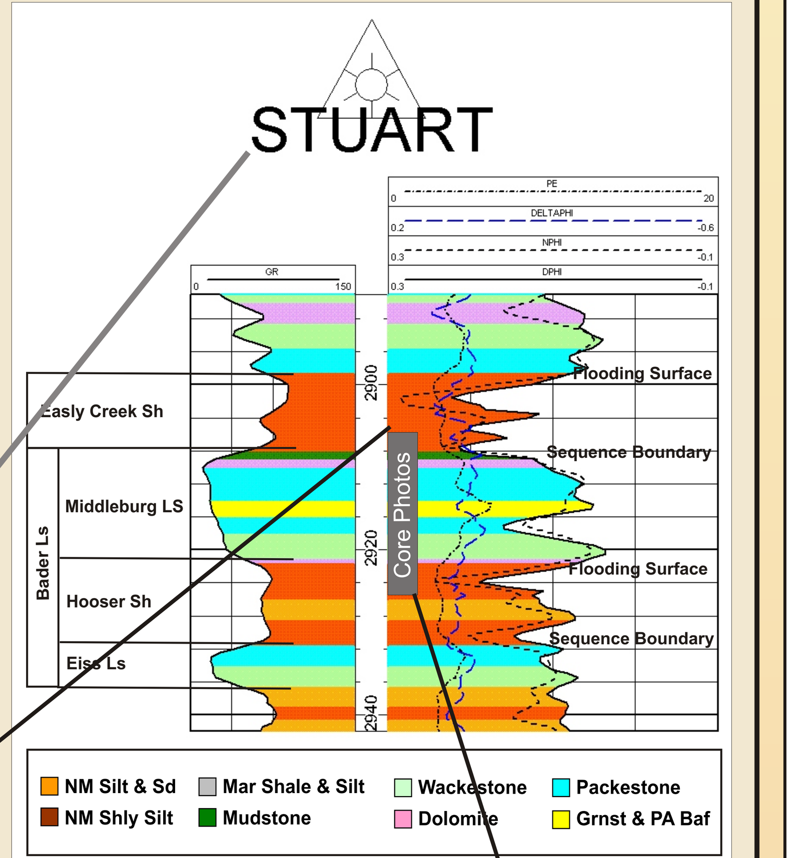


Lithofacies are those predicted by neural net models (see Panel 3) in wells without triangles around the well symbols. Lithofacies by core description are shown in wells with triangles which are two of the eight ‘keystone wells.”

Maps and cross sections in this panel were created In geoPLUS Petra with an academic license.

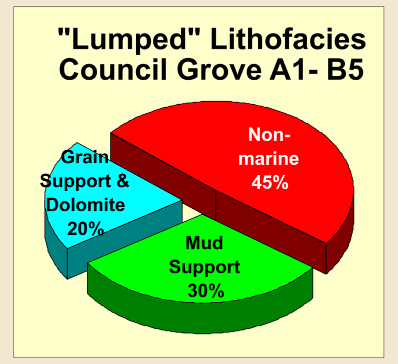
Lithofacies, Sequences, Depositional Environments



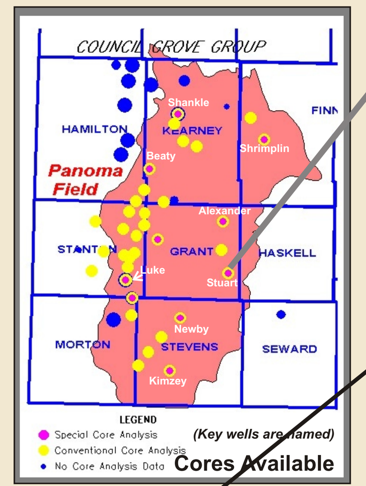


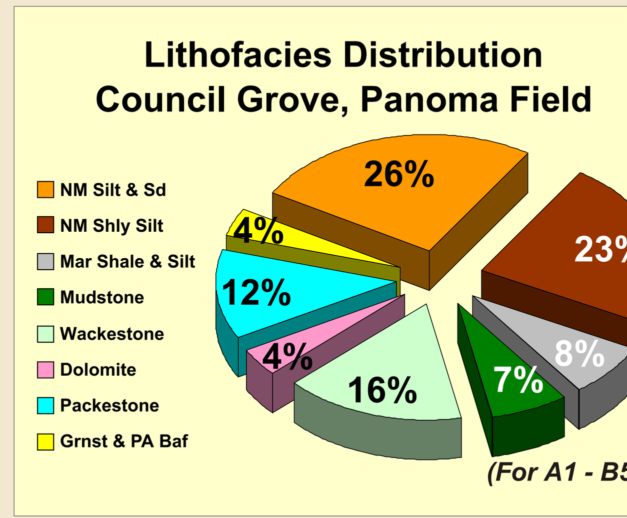
Lithofacies and Depositional Environments

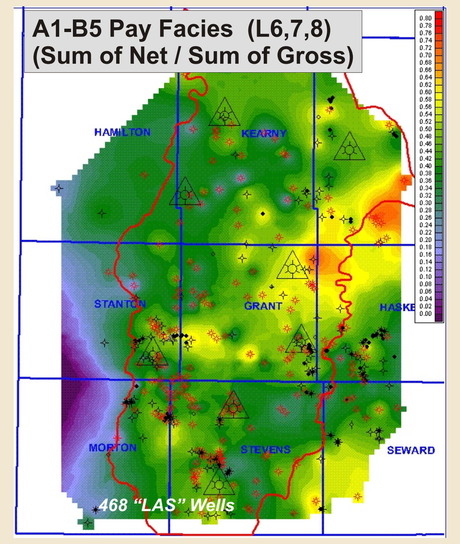
In the Panoma Field of southwest Kansas the Council Grove Group comprises seven fourth-order marine-nonmarine sequences. Through the detailed study of ten widely distributed and lengthy cores eight major lithofacies were identified and characterized (see Panel 2).

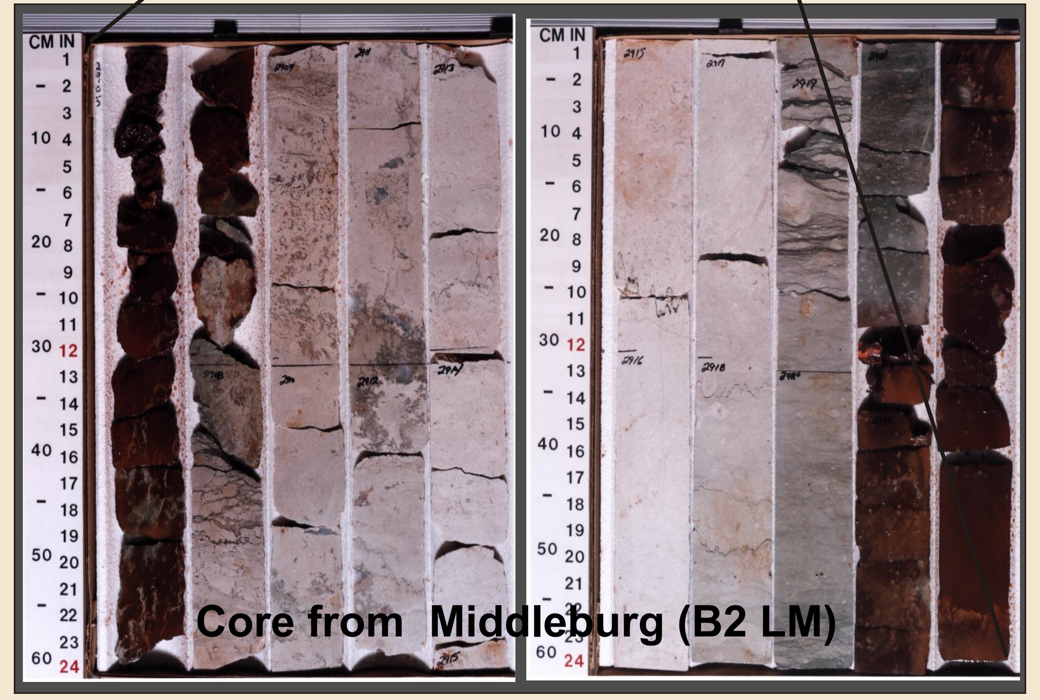


During Council Grove deposition, the Panoma Field area was situated on a broad shallow shelf or ramp that dipped gently southward into the Anadarko basin in Oklahoma. The geometry of the shelf was conducive for broad, parallel depositional environments and associated lithofacies belts. In response to cyclical sea level fluctuations, lithofacies belts migrated across the shelf resulting in a predictable vertical succession of the eight major lithofacies.







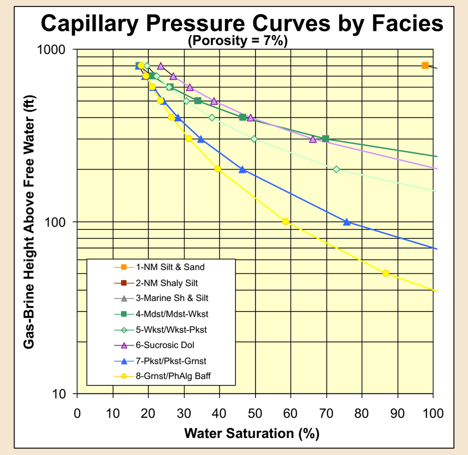


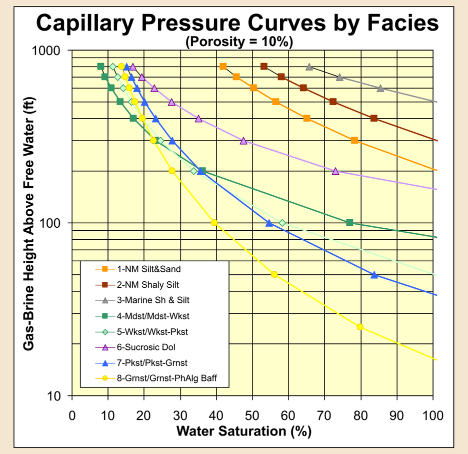
Statement of Problem:

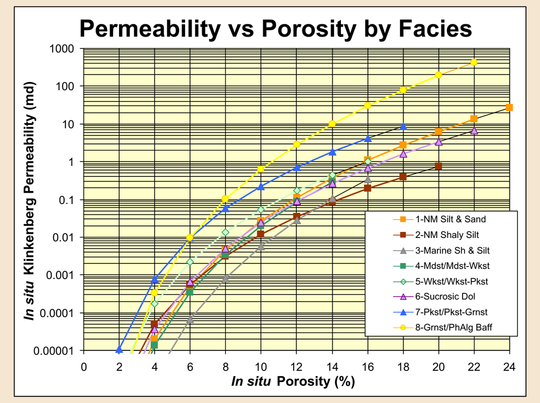
1. No comprehensive geologic model for the Council Grove available.
2. Accurate reservoir model is critical for most efficient management of remaining resources in this large asset.
3. Lithofacies controlled petrophysical properties dictate gas saturations.
4. Accurate discrimination of lithofacies reduces error in predicted permeability and gas volume.
5. The Council Grove is a large, complex heterogeneous reservoir.
6. Field-wide upscaling of lithofacies distribution for reservoir characterize -ation and analysis of large heterogeneous reservoirs like the Panoma Field is impractical by traditional methods.

Solution: Use artificial intelligence to predict lithofacies in 500 wells and fill a 3D volume with lithofacies constrained porosity, permeability and gas saturations.

1. Identify and characterize key lithofacies and tie to core petrophysical properties.
2. Predict lithofacies for wells without cores using a neural net and electric log curves and marine-nonmarine indicator curve as predictor variables. Generate predicted lithofacies and probability curves.
3. Fill 3-D cellular volume with lithofacies and porosity using Petrel.
4. Add lithofacies-constrained permeability and gas saturations to cell properties with transform formulas and height above free water.
5. Export cellular model with porosity, permeability, and initial gas saturations to a reservoir simulator.







Council Grove facies identification is important to reservoir characterization because petrophysical properties vary between facies. At porosities > 6% permeability in grainstone/bafflestones can be 30X greater than mudstones and >100X greater than marine siltstones of similar porosity. Differences in permeabilities between nonmarine silt/sand-stones and shaly siltstones range from 3.3X at 12% porosity to 7X at 18%.

Capillary pressures and corresponding water saturations also vary between facies. For example, at 7% porosity (which represents >50% of all Mstn/Wkstn) at 200 ft above free water Mudstones are 100% water saturated while grainstones exhibit water saturations of ~40%. Differences in water saturations between facies increase with decreasing porosity and decreasing height above free water.