Characterization and Simulation of the Panoma Field (Wolfcampian);

a Tight, Thin-Bedded Carbonate Reservoir System Southwest Kansas

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Cimarex Energy Co.
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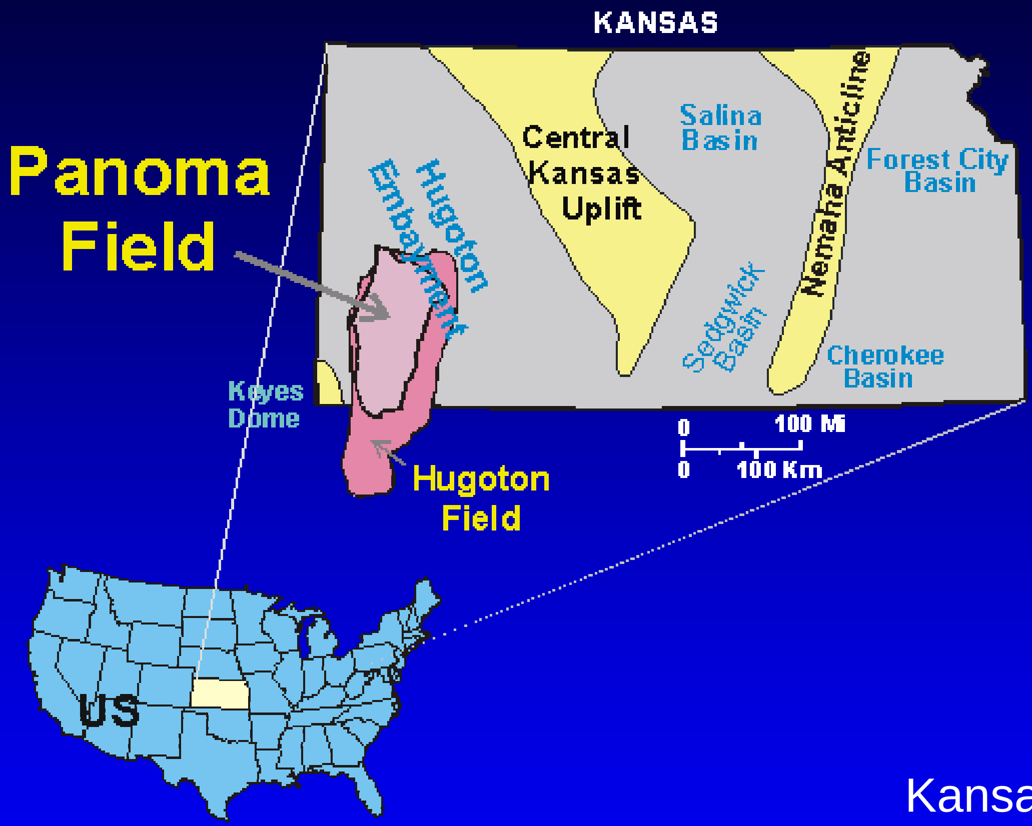
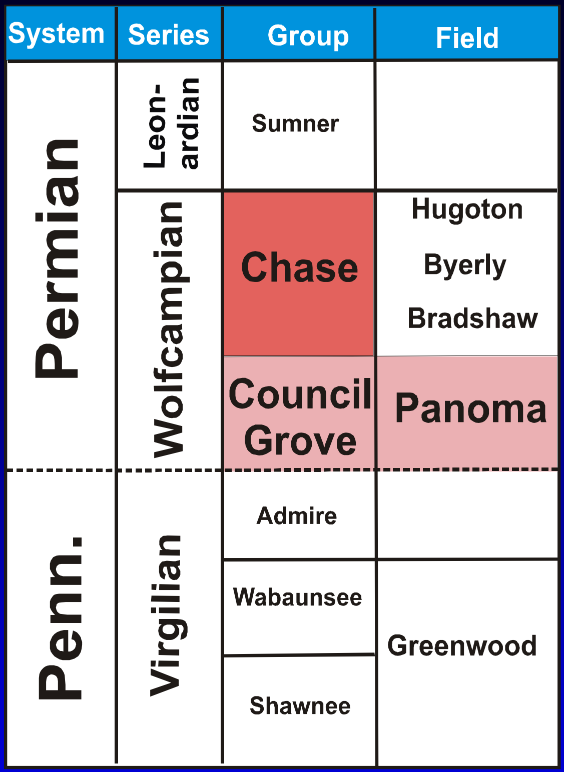
Presentation Outline

- Overview, unique problems and lithofacies (Marty)
- Petrophysical properties and relationships (Alan)
- 3D cellular model (Shane)
- Initial simulations (Randy)
- What's next

Setting





System	Series	Group	Field
Permian	Leon-ardian	Sumner	
	Wolfcampian	Chase	Hugoton Byerly Bradshaw
		Council Grove	Panoma
Penn.	Virgilian	Admire	
		Wabaunsee	Greenwood
		Shawnee	

Giant stratigraphic trap(s)
Kansas Panoma 2.8 TCF
Kansas Hugoton 24 TCF

Kansas Hugoton (Olson, etal, 1996)	EUR 35-38 TCF
Panoma	EUR ???

Challenges and Key Points

Challenges:

Data volume (5200 sq miles, 2600 producers, 10,000+ wells) ***Automate & upscale***

Direct measurements of Sw by logs is problematic (must use property-based OGIP)

Free water level varies and not documented ***Automate***

Facies representation in model is critical ***Automate***

Volumetric OGIP

Automate

Some key points:

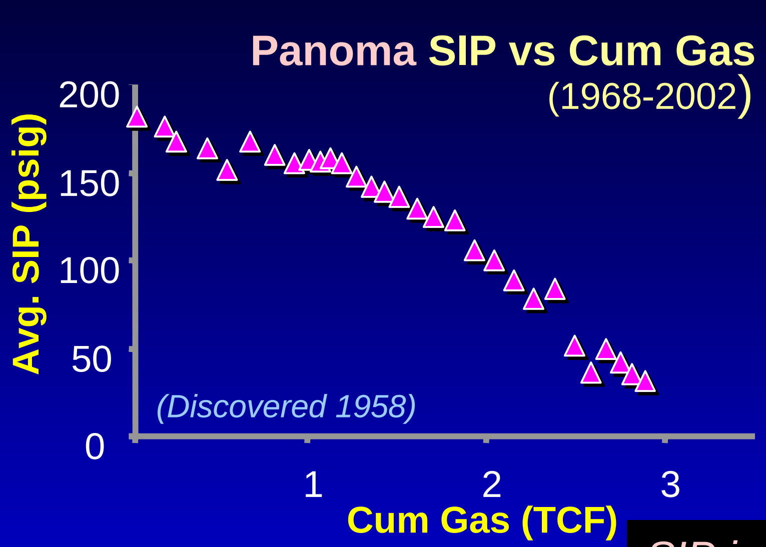
1. **Thinly layered reservoir**, moderate to **low-crossflow between zones (**pressure data indicates differential depletion)
2. **Matrix properties drive the system** and thin high perm layers may control flow

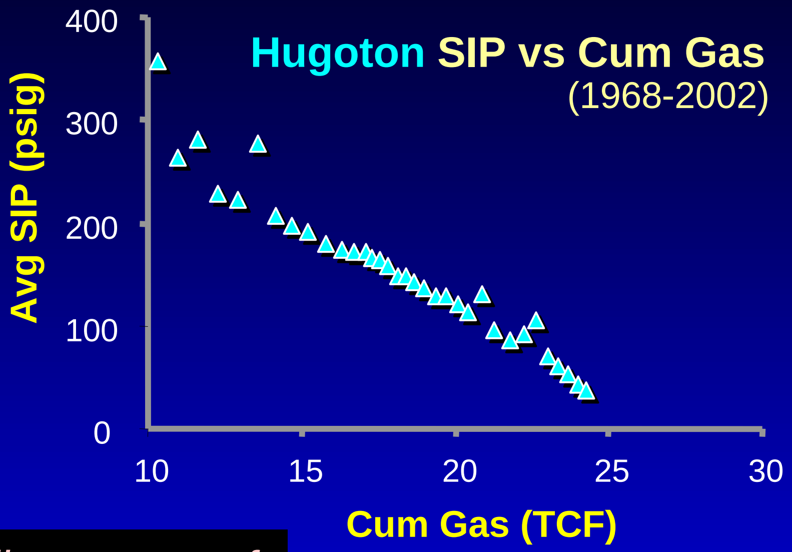
And one more challenge:

Material balance GIP is problematic due to lack good pressure data by zone.

SIP for commingled production is available, but this represents the lowest possible SIP of the most permeable of the commingled zones.

Why Model These Mature Reservoirs?



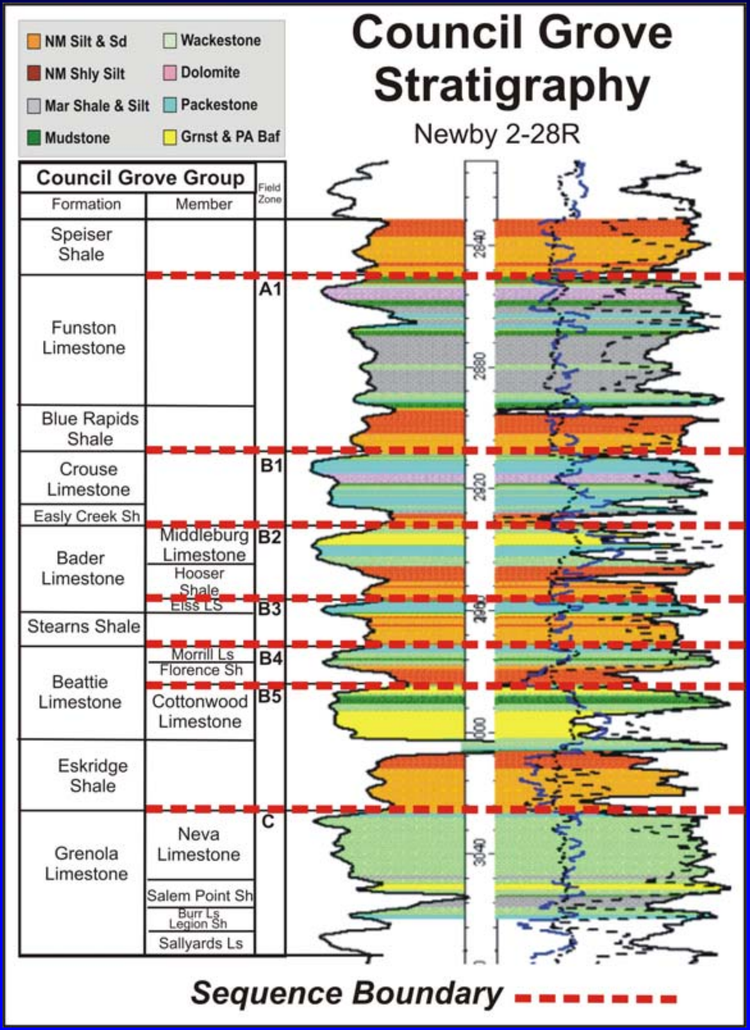


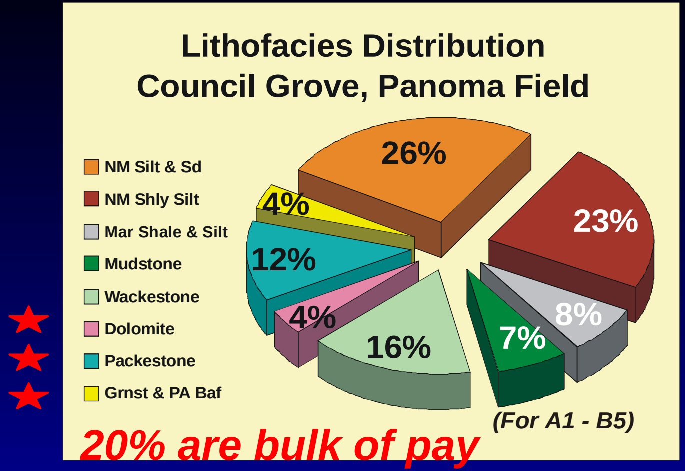
SIP is actually pressure of highest perm zone in commingled production

Goals:

1. Functional comprehensive geologic and engineering models for simulation and reservoir management
2. Resolve zonal differential depletion questions
3. Resolve question of continuity between two reservoir systems that are regulated separately

Seven Sequences,
Eight Lithofacies

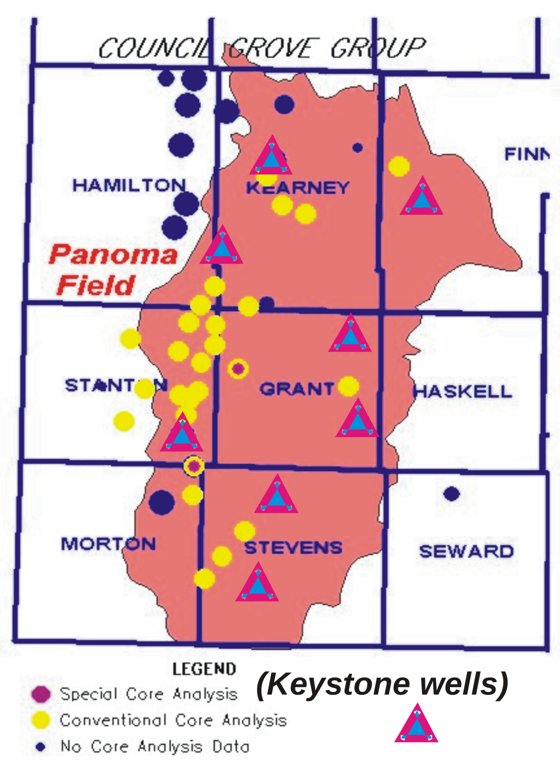




~ 50% Marine, ~ 50% Nonmarine

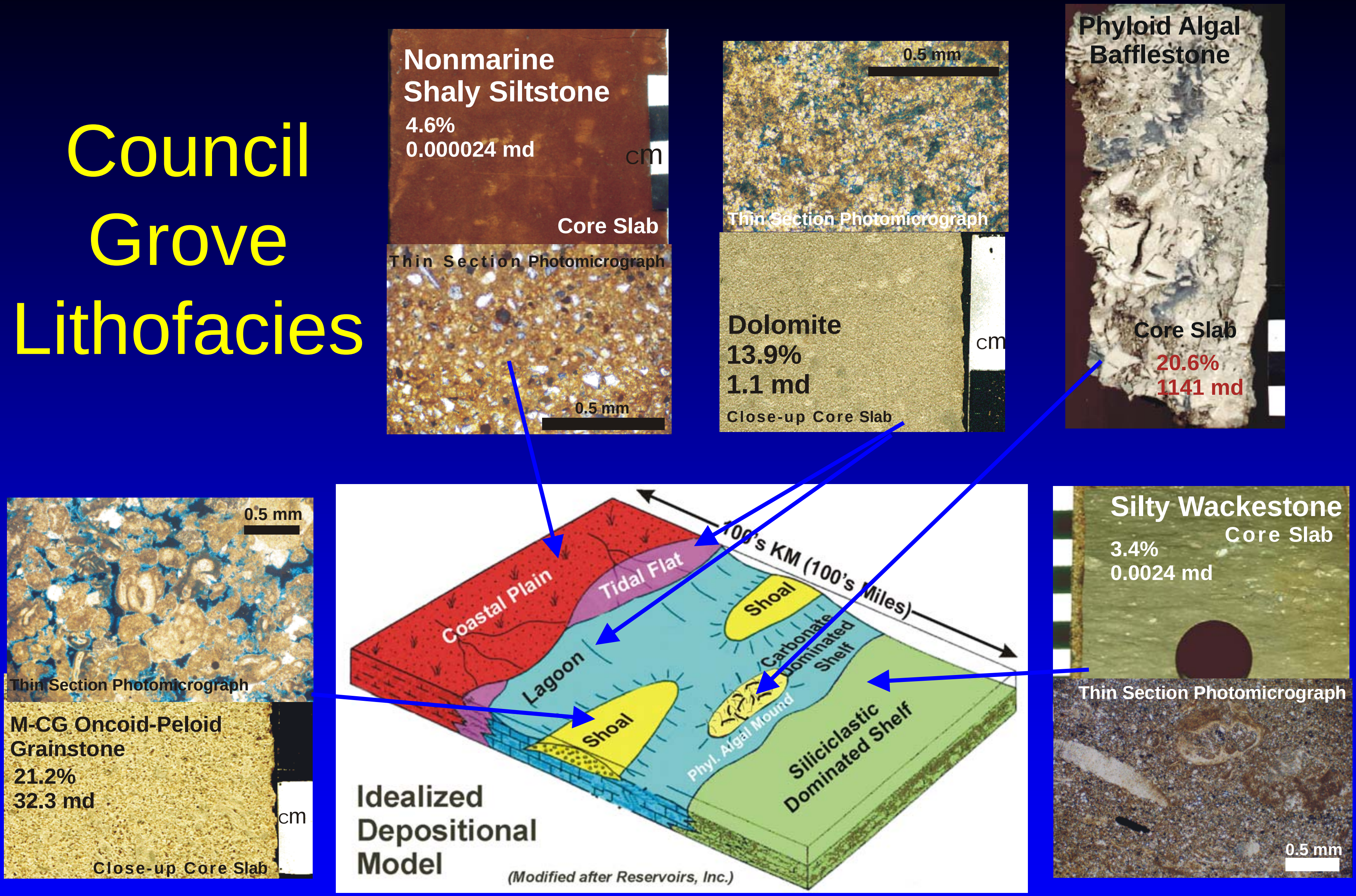
Gas production from upper seven marine-nonmarine sequences of Council Grove

- Depth (top) 2400-2800'
- 300 feet below Chase



(Keystone wells)

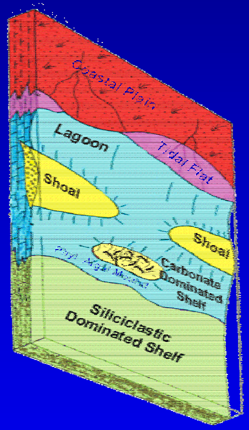
Council Grove Lithofacies

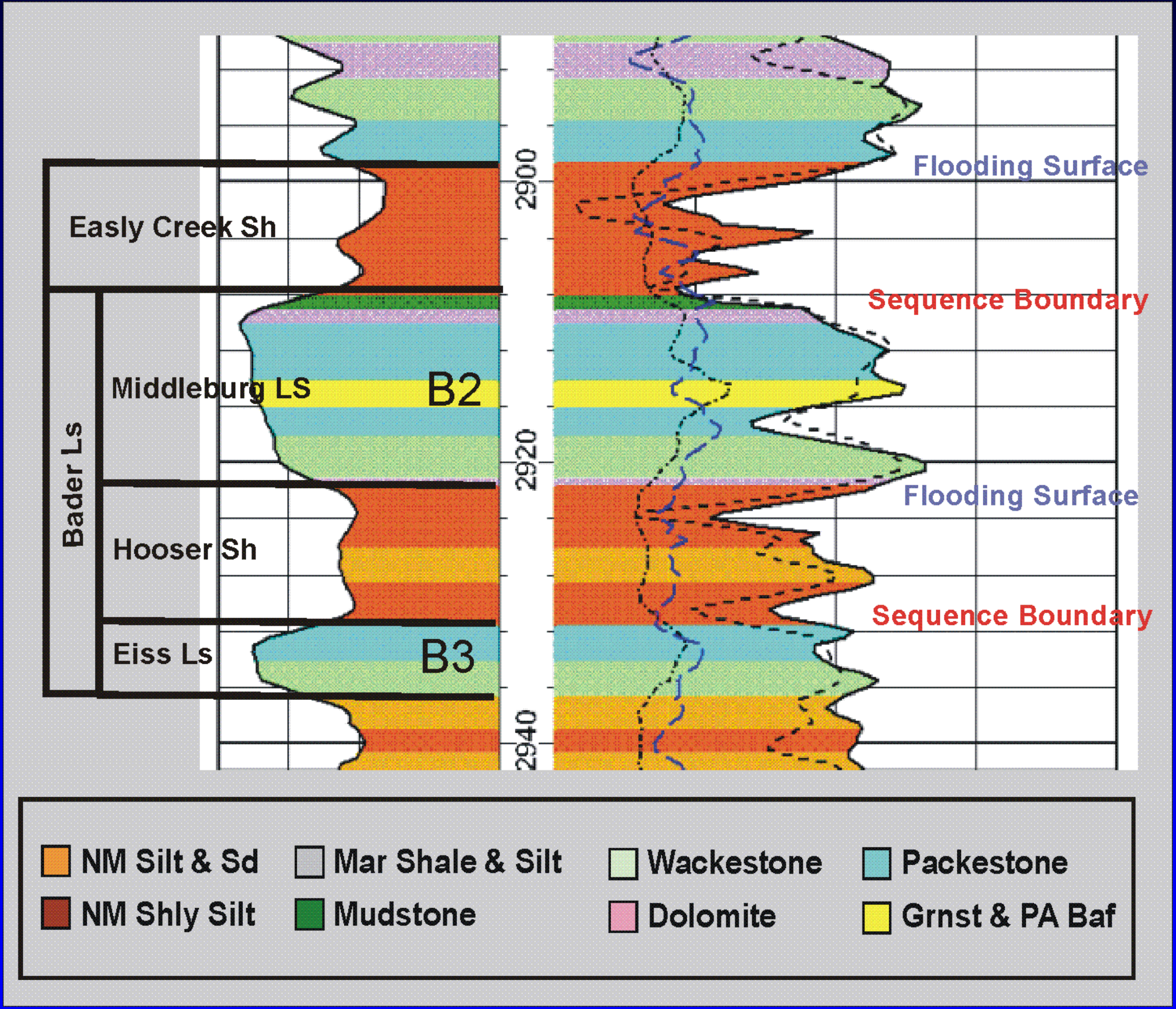


Lithofacies classes and their depositional environment

Facies Stacking Patterns

- Migrating facies belts response to rapid glacial-eustatic SL fluctuation
- Facies vertically stacked in predictable manner
- Sequences bounded by exposure surfaces

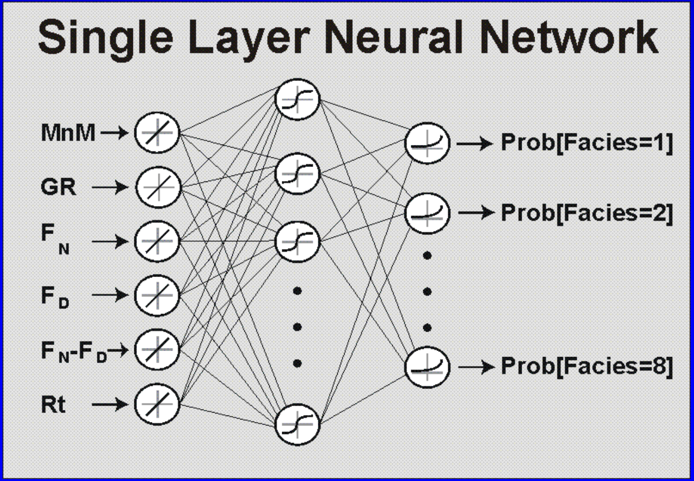


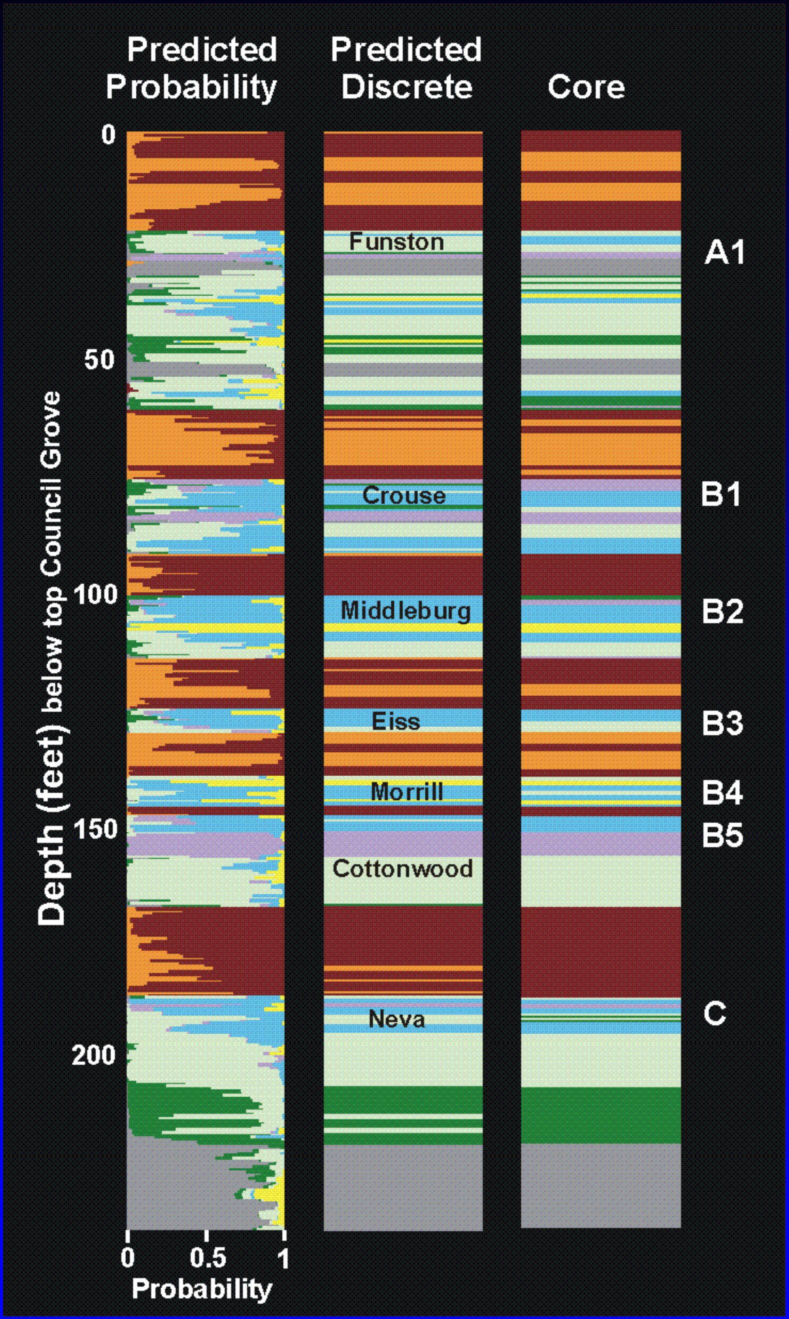


- Facies log response predictable
- M-NM and Rel-Pos Geologic Constraining Variables helpful

Predict lithofacies at well scale with Neural networks

- Select e-log predictor variables and develop **geologic constraining variables**
- Train N-Nets on core lithofacies
- Run N-Net models on 500 wells and output facies curves in LAS format (automated, batch process)
- Import lithofacies curves files into geologic applications



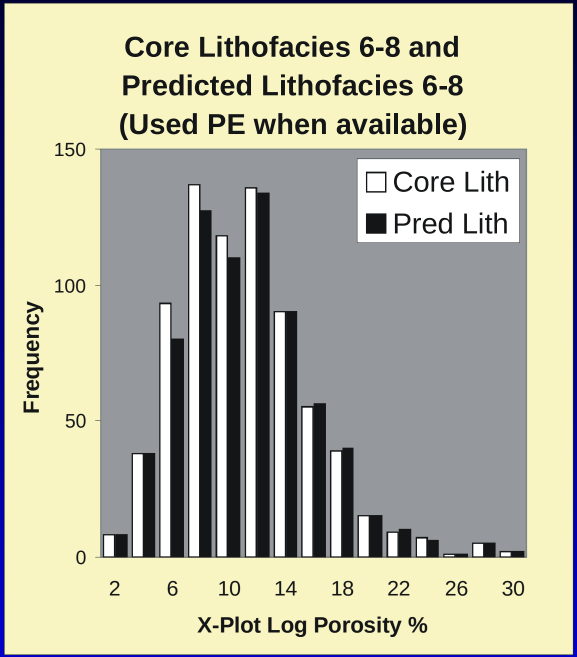


Measuring error in test set predictions

Effectiveness Metrics

- ✓ Absolute accuracy
- ✓ Accuracy within one facies
- ✓ Proportional representation
- ✓ Porosity (and perm) distribution in facies populations

Porosity Distribution in Pay Lithofacies



Core Lithofacies 6-8 and
Predicted Lithofacies 6-8
(Used PE when available)

Predicted Lithofacies "Scorecard" (Counts)

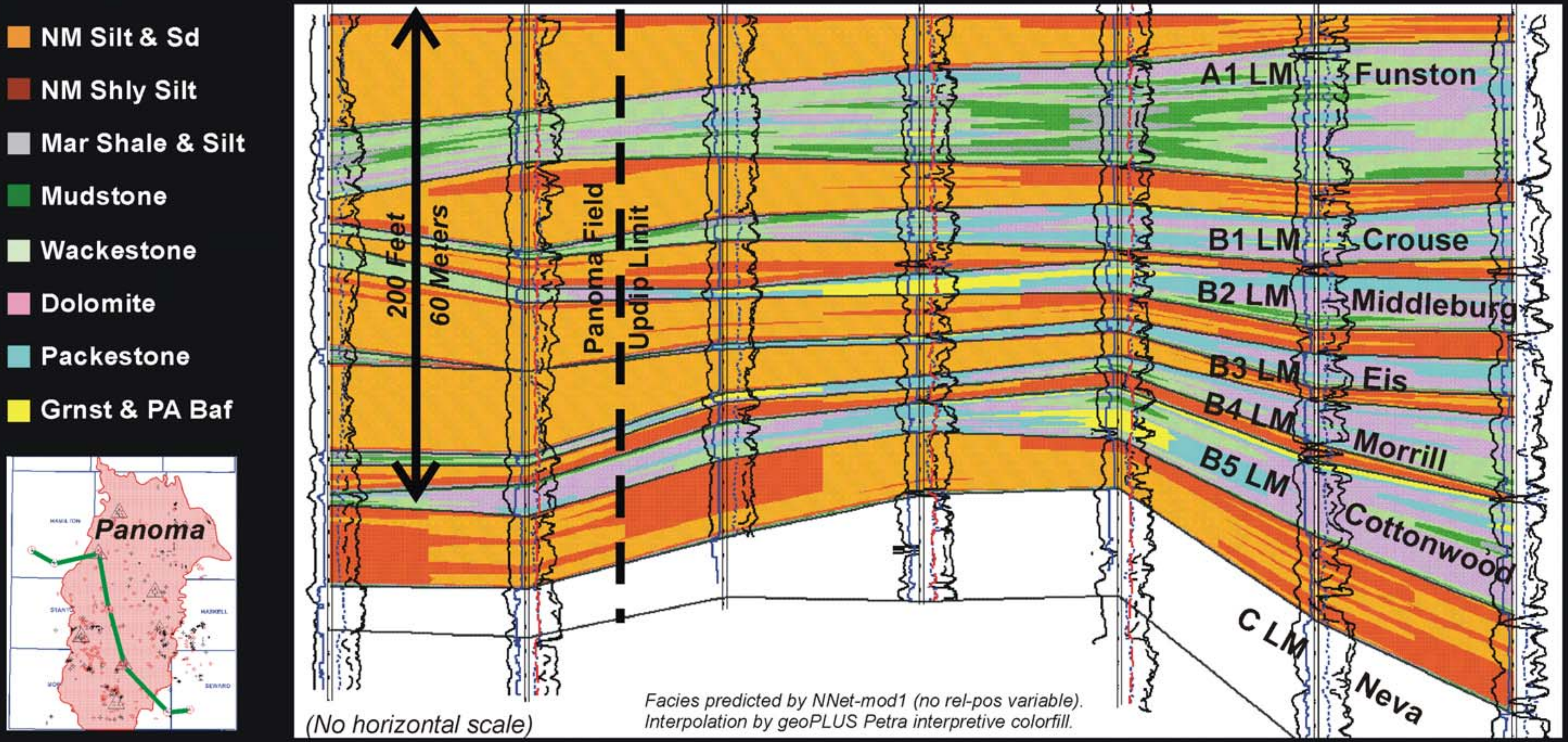
(Nnet mod1, no RelPos, w/ PE)

Core Lithofacies (Actual) — *Predicted Lithofacies* (rows)

Facies	1	2	3	4	5	6	7	8	Total	Within 1 Facies
1	**465**	89							554	100%
2	71	**523**							594	100%
3			**149**	5	11	1	4		170	91%
4			12	**101**	26	4	7	2	152	91%
5			9	20	**353**	3	34	4	423	89%
6			1	3	6	**69**	8		87	95%
7			4	9	36	3	**204**	8	264	95%
8			2	2	8	5	7	**72**	96	88%
Total	536	612	177	140	440	85	264	86	2340	
Pred/Actual	**97%**	**103%**	**104%**	**92%**	**104%**	**98%**	**100%**	**90%**		

97.3% of actual predicted for L6,7,8

Panoma Stratigraphic X-Sec



Neural network predicted lithofacies, 5 log variables, 1 geologic constraining variable

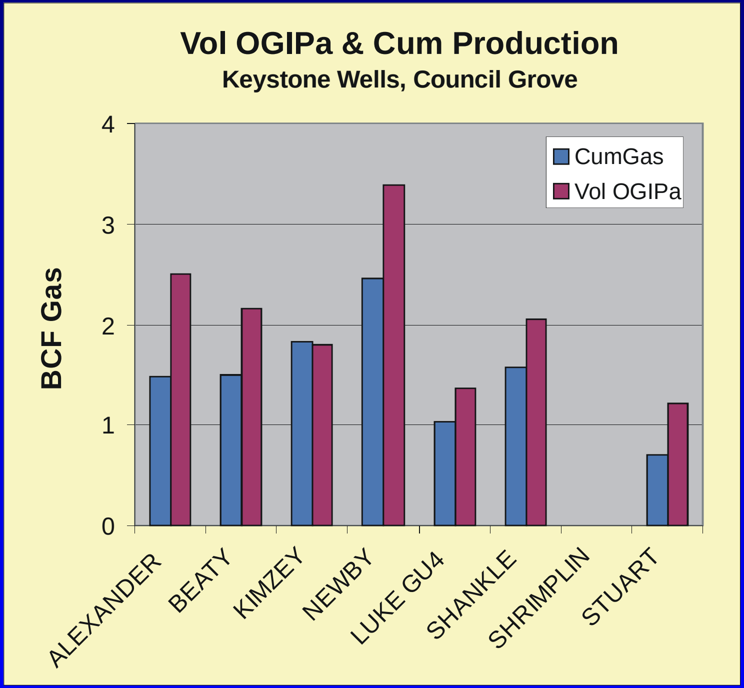
Property-based OGIP

OGIP (property-based) is good early test of facies predicition, k-phi-Sw transforms and Phi correction.

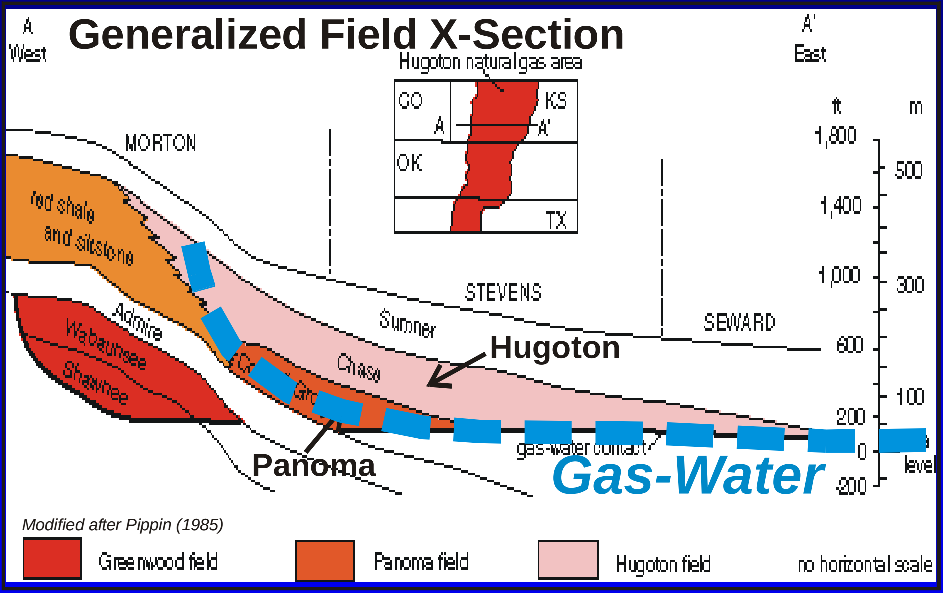
Sw = *f* (facies unique properties, Phi, FWL)

OGIP = *f* (Sw,P, T, Z, Phi)

Automated; generate OGIP well curve in LAS format



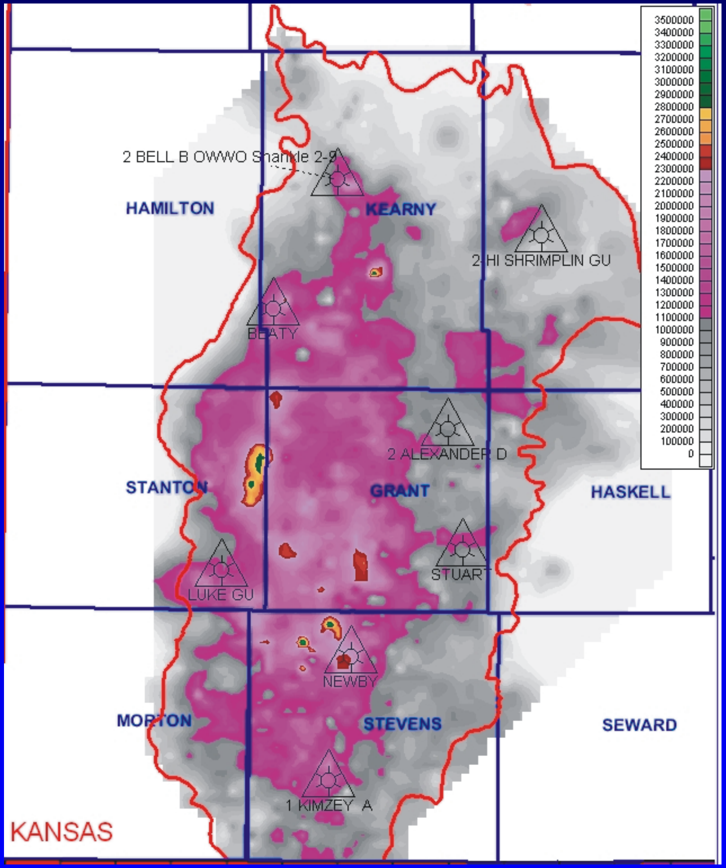
Using "best guess" FWL based on anecdotal data (perforations, tests, lowest producing perfs) and Pippin (1985). Cum gas is ~ 80% ERU.



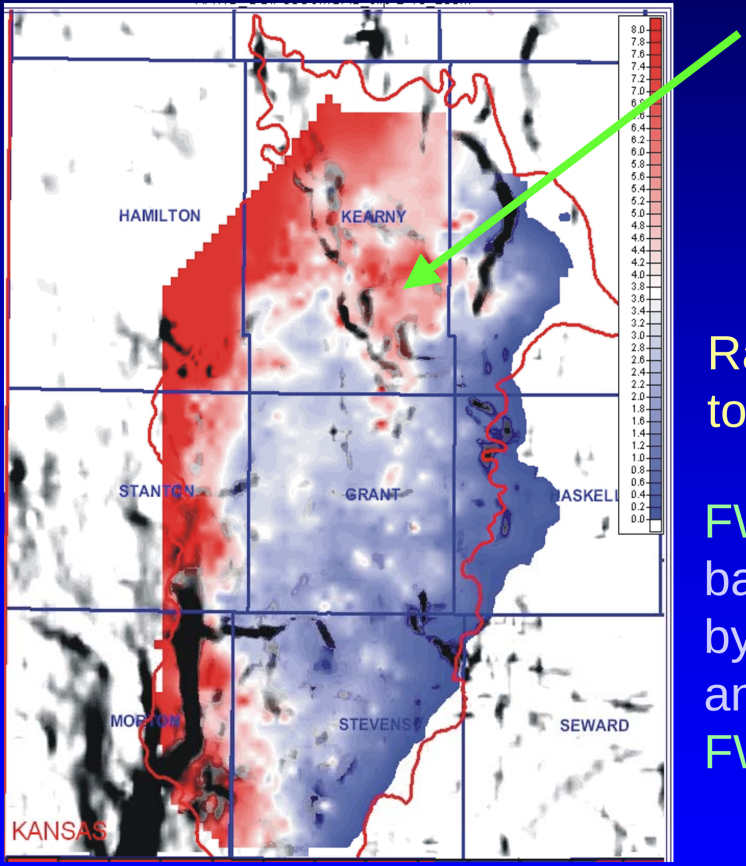
Modified after Pippin (1985)

Variable Free Water Level

Estimating free water level



Cum Gas by Section 2002



Related to minor faulting?

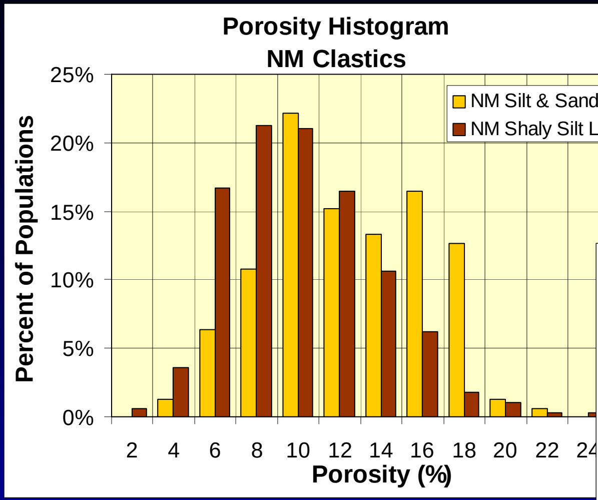
Ratio OGIP$_{50}$ / Cum Gas
“Fault” map overlay

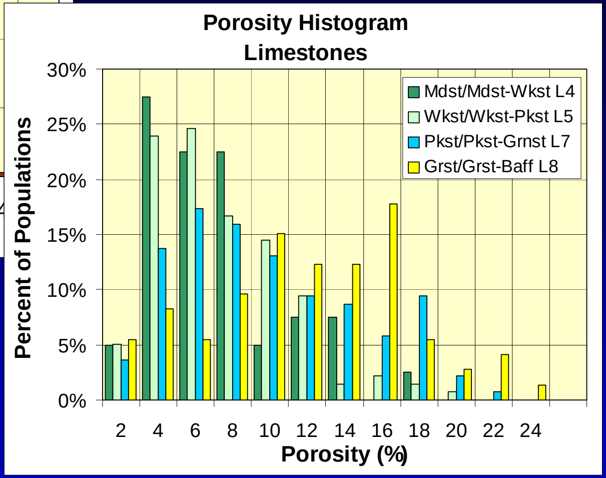
Ratio is relative to FWL

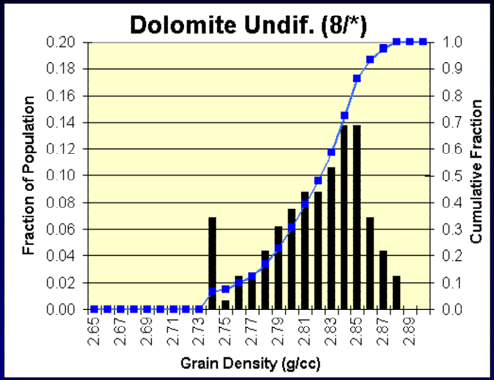
FWL can be back-calculated by est. OGIPmb and solving for FWL.

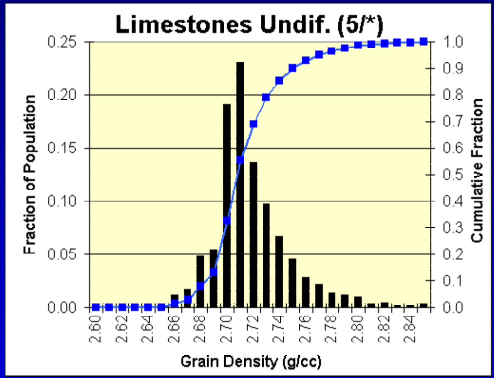
Porosity

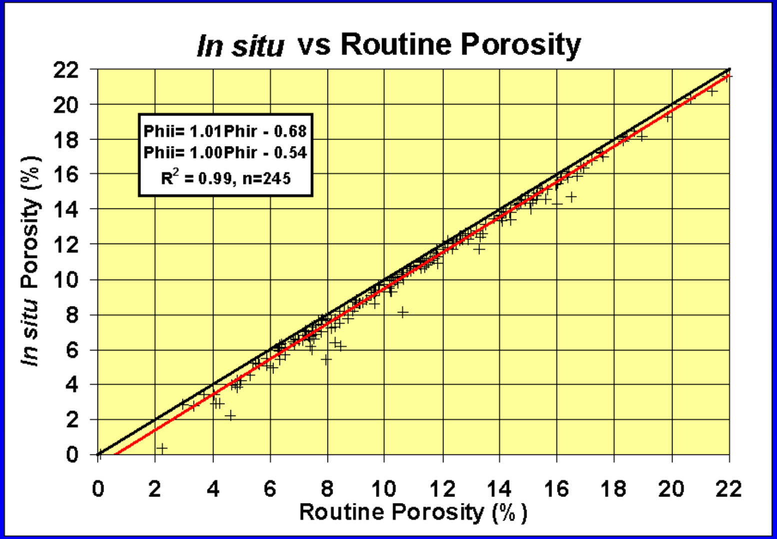
Density log calibration

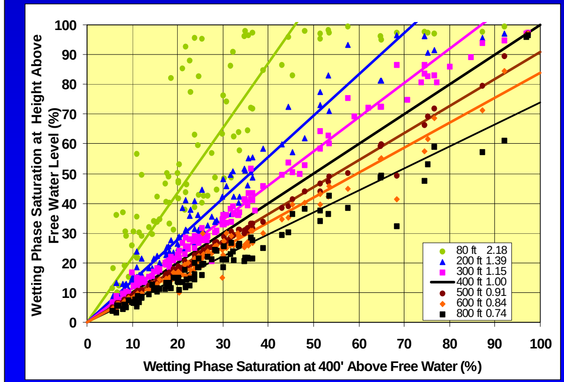


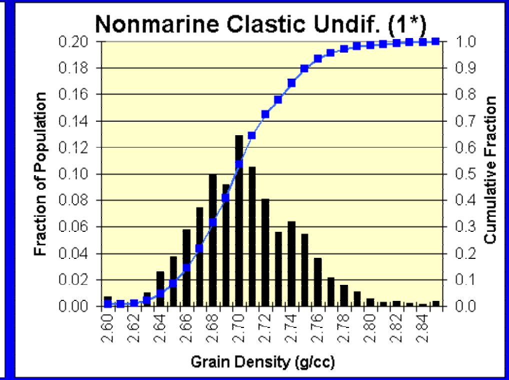




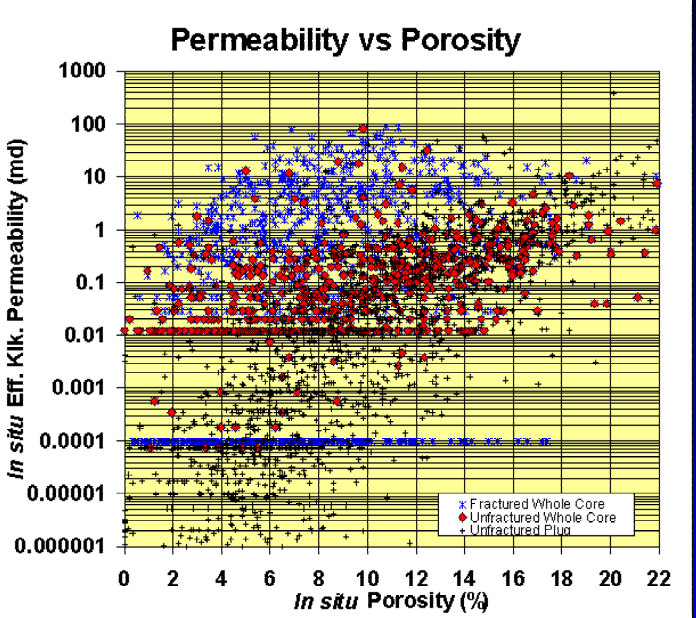


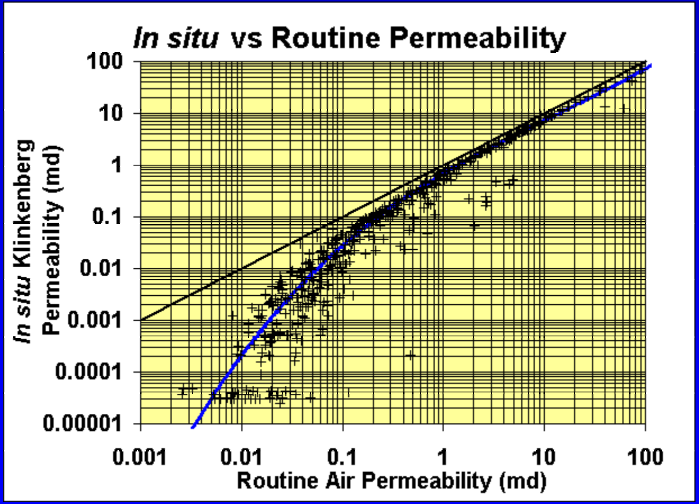






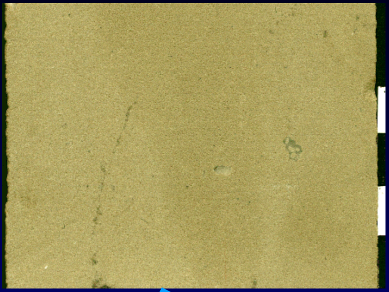
Permeability



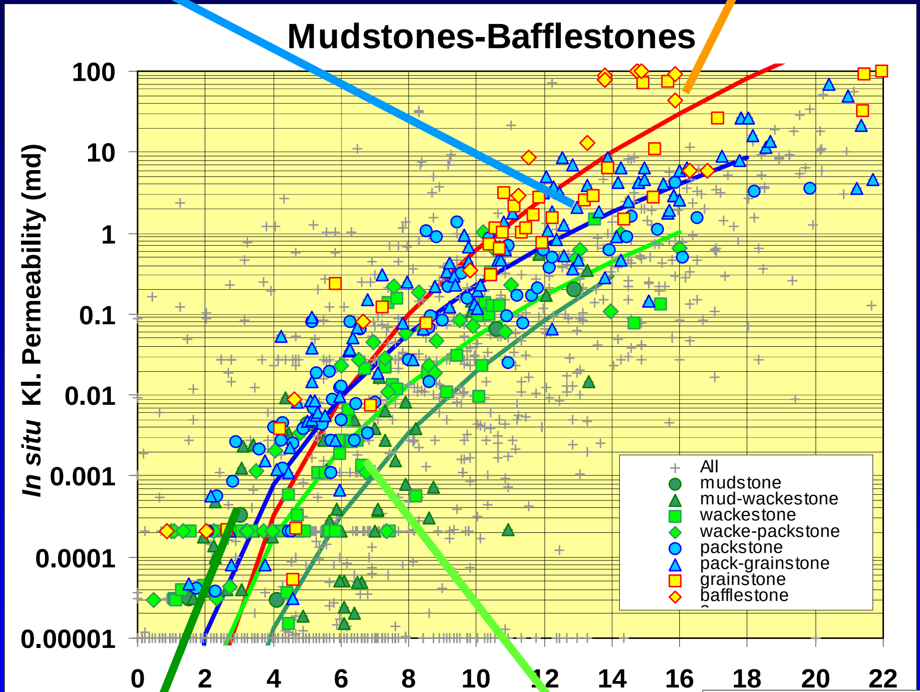


$\log ki=0.0588 \log ka^{3}-0.187 \log ka^{2}+1.154 \log ka-0.159$

Packstone

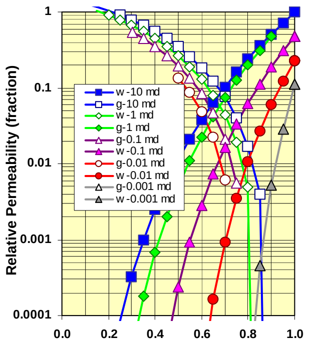


Bafflestone



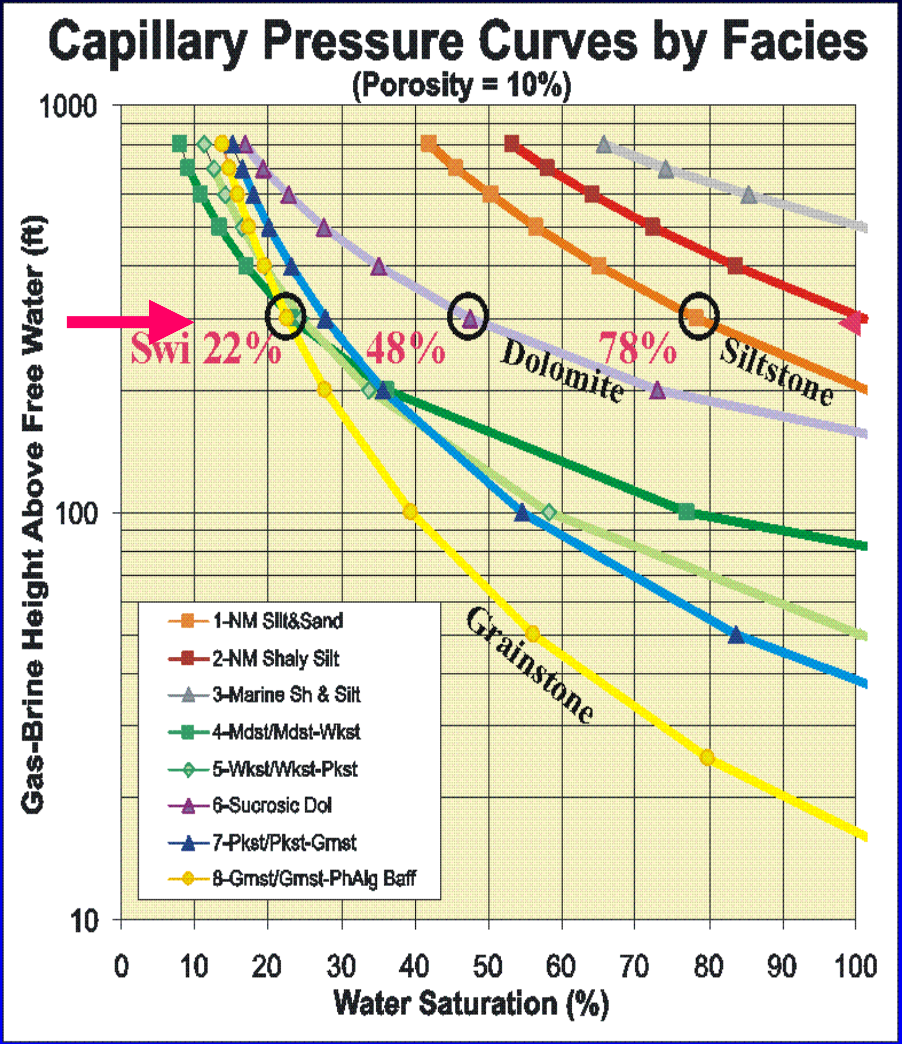
Mudstone-Wackestone

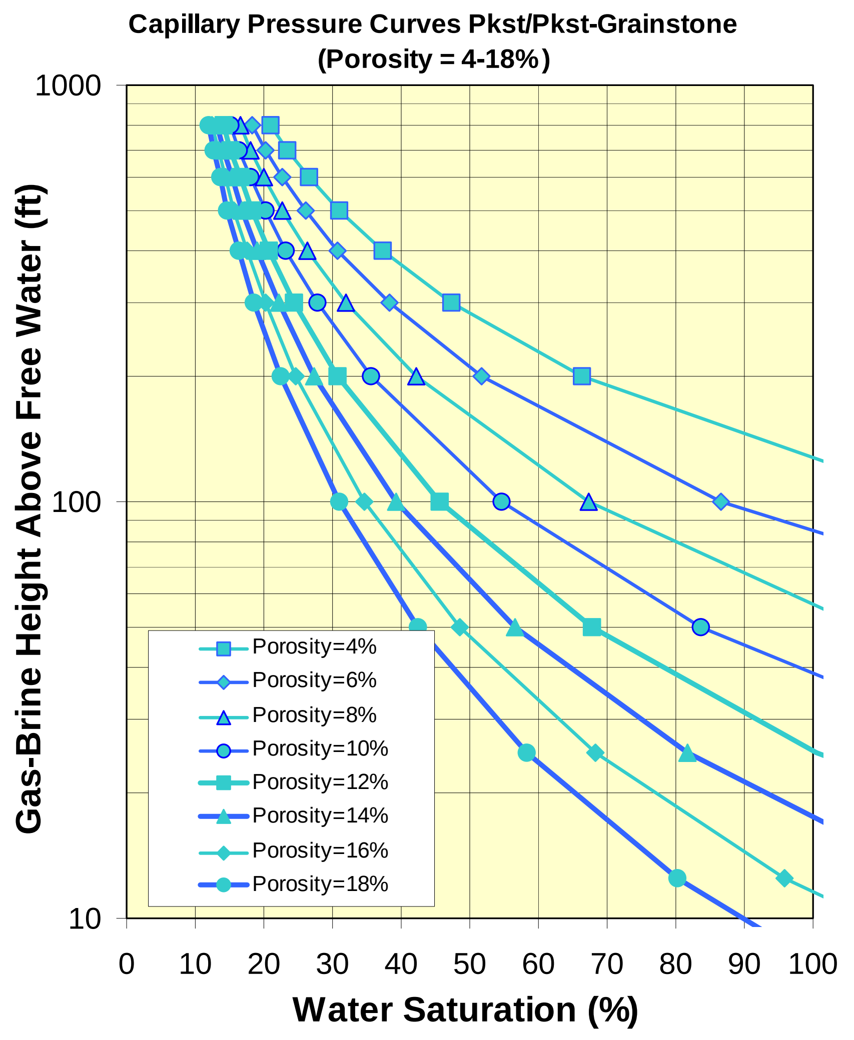
Wackestor



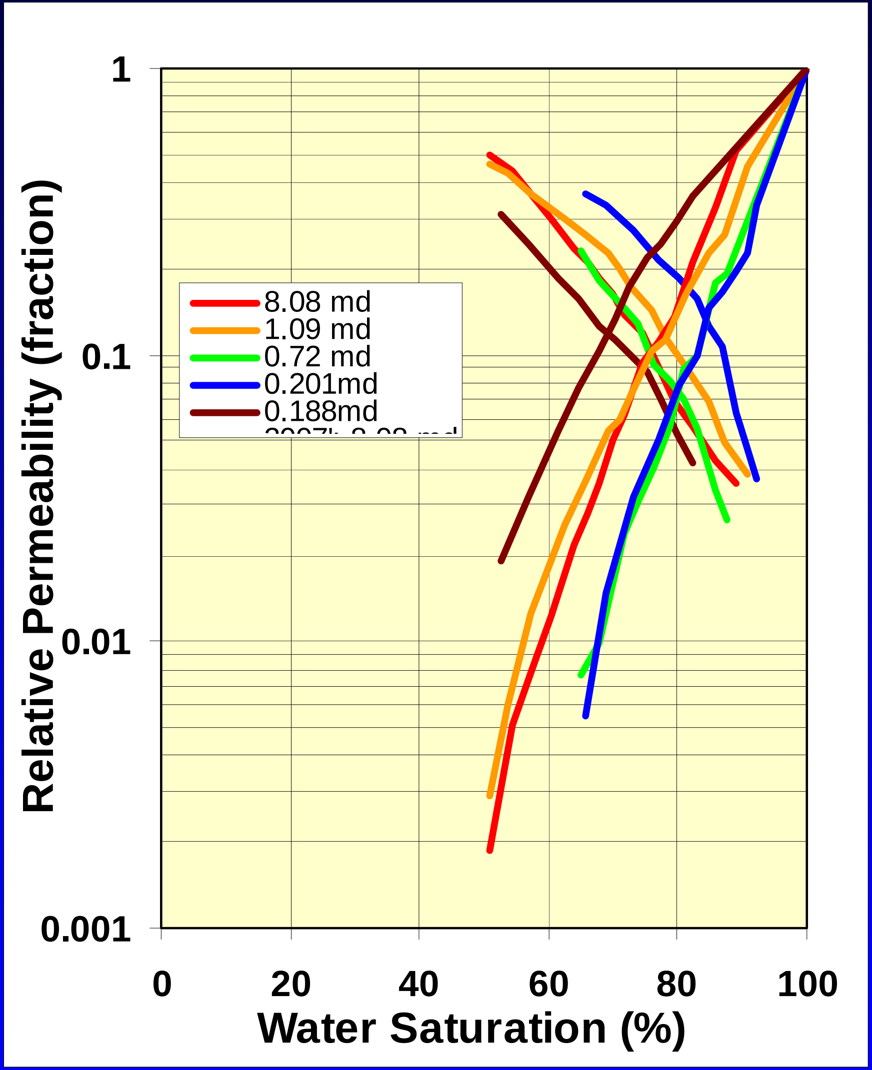
300’ Above Free Water

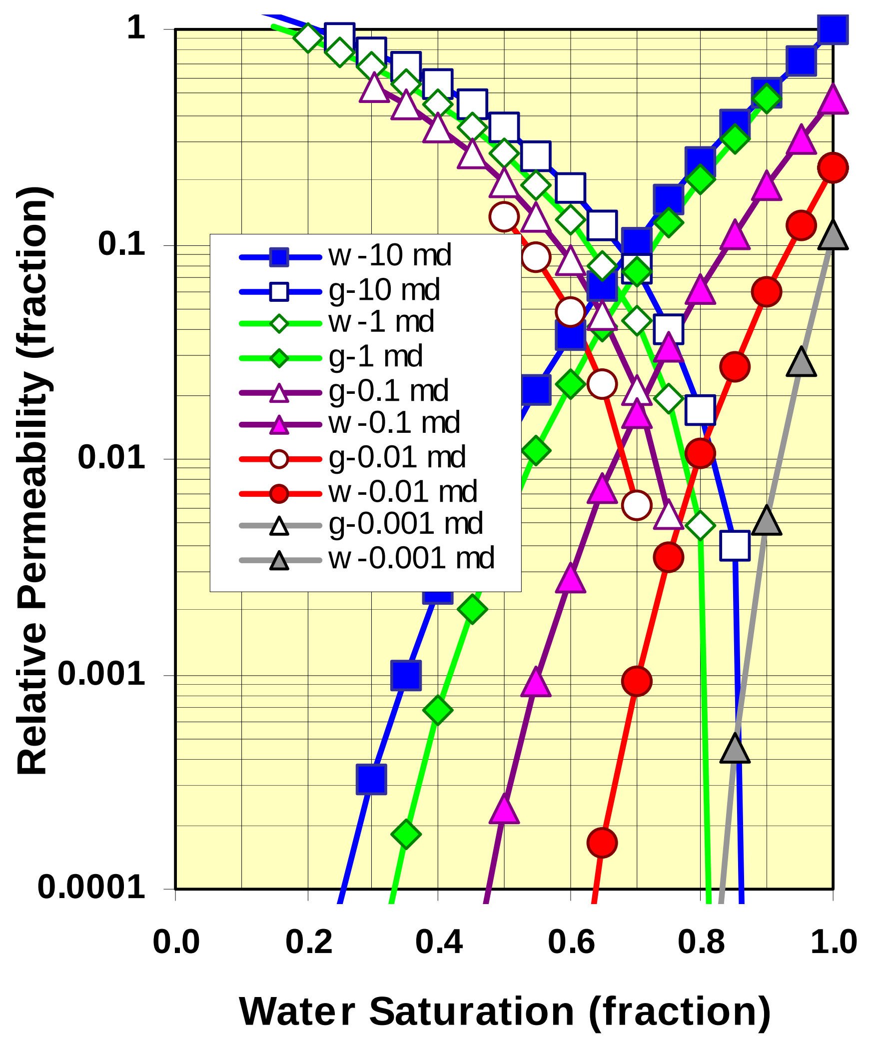
Capillary Pressure





Gas and Water Relative Permeability





Building the Structural Framework

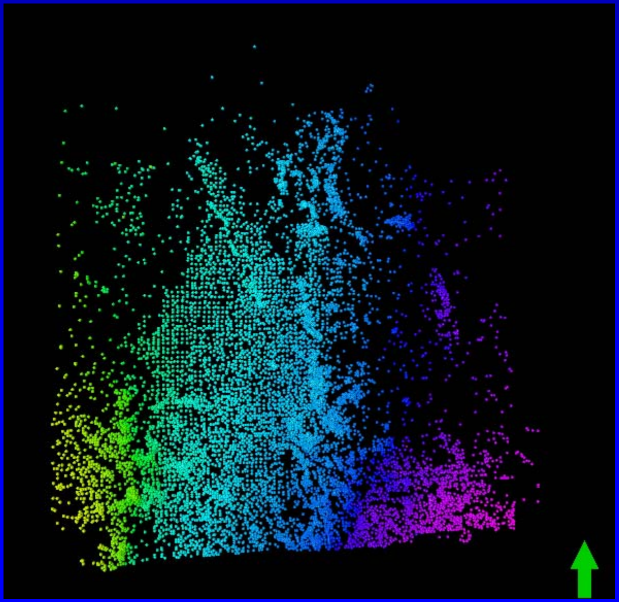
Import wells with tops and logs

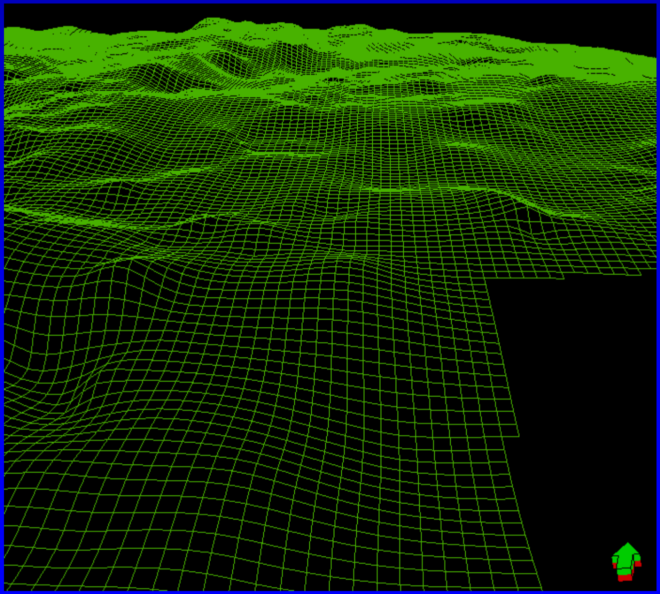
- *11,367 total wells, 527 of which contain log data*
- *10,840 wells with tops only (no logs)*
- *527 wells with tops, predicted facies curves, “probability” curves, and porosity curves*

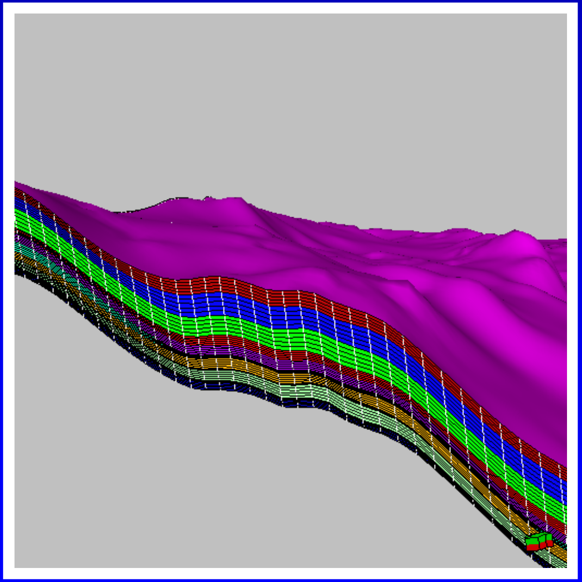
(Facies from two Nnet models, 352 with PE and 175 without PE)

Building the Structural Framework

- *Define grid increment and area of interest*
- *Construct top horizon for Council Grove (A1_SH) top*
- *Create isochore for each zone, and hang isochores from top horizon*
- *Generate layers (define cell thickness)*







Model Architecture

Cells in model

XY = 1000 X 1000 feet

5,200 square mile model

7 Models (one per cycle)

Average model 8.6 million

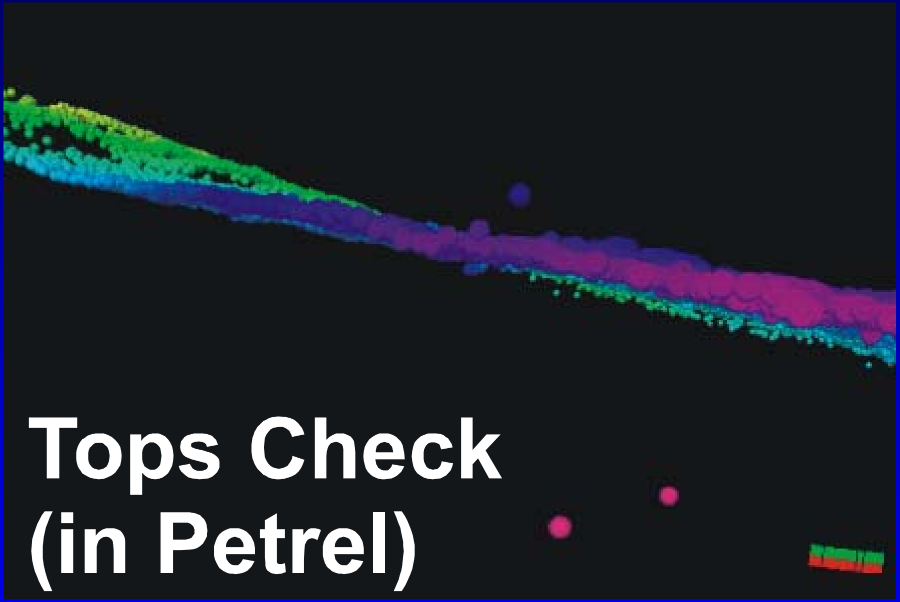
Maximum 15 million (C cycle)

Minimum 5.7 million (B2 cycle)

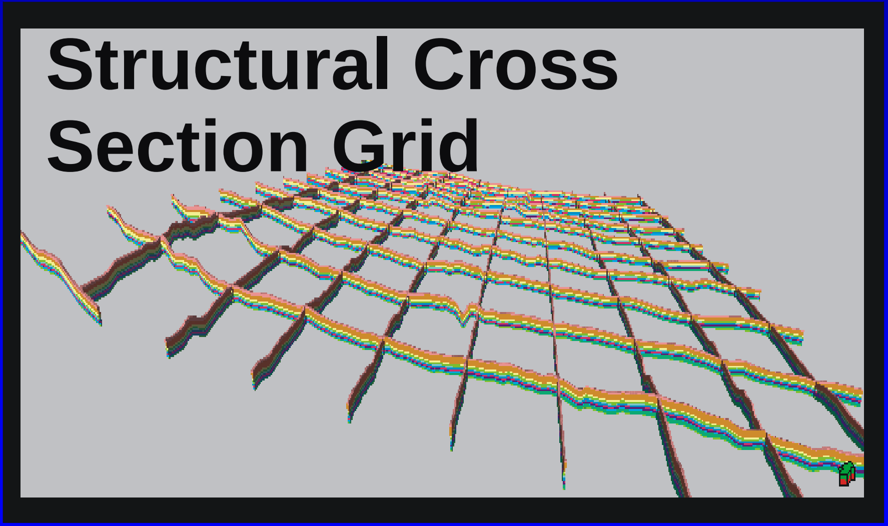
Layers per Model

	SH	LM	"Dummy"	Total
A1	23	41	12	76
B1	19	16	12	47
B2	12	15	12	39
B3	20	15	12	47
B4	17	18	12	47
B5	8	34	12	54
C	28	61	12	101

Architecture QC

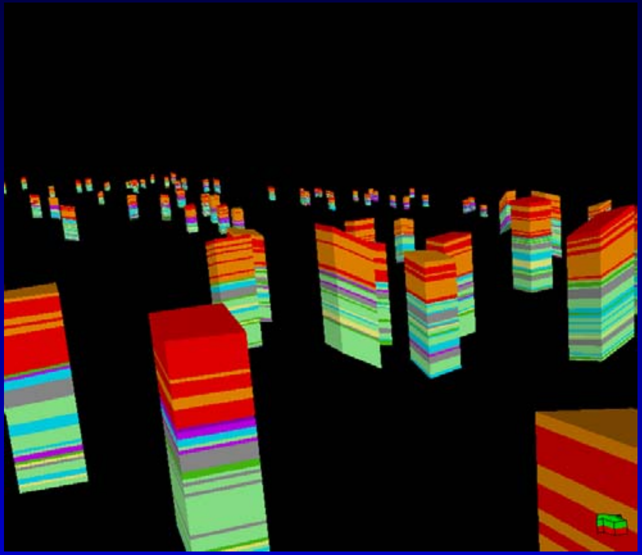


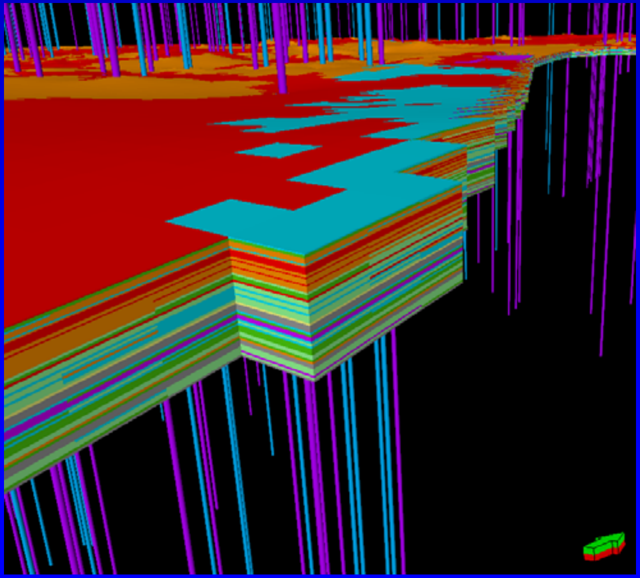
Tops Check (in Petrel)



Structural Cross Section Grid

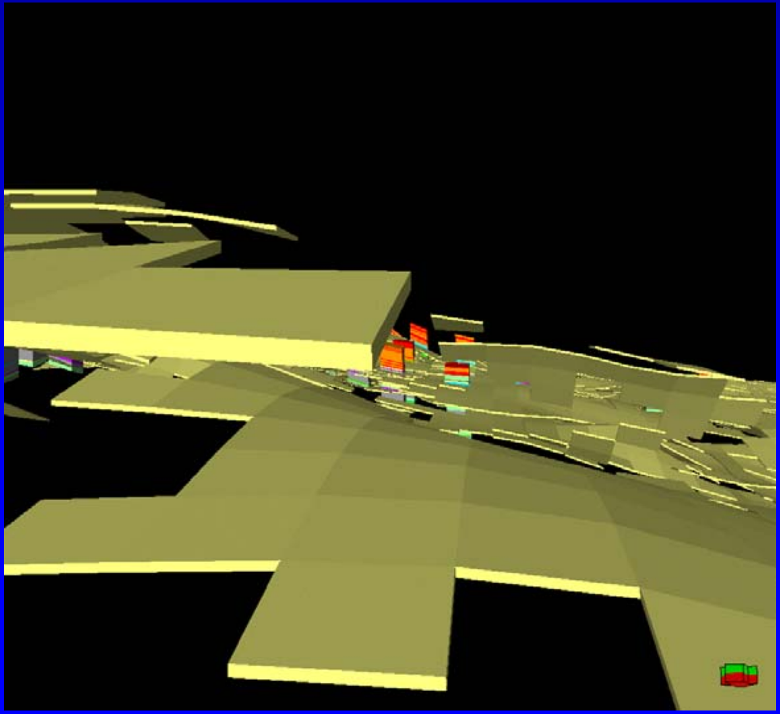
Panoma Facies Modeling



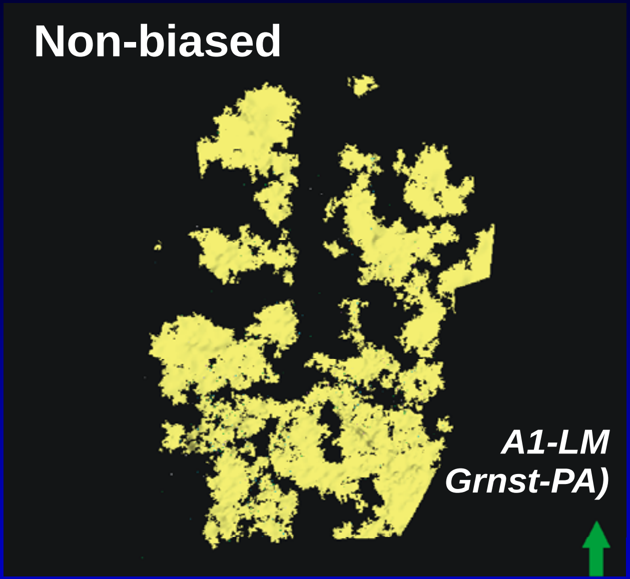


Facies Model

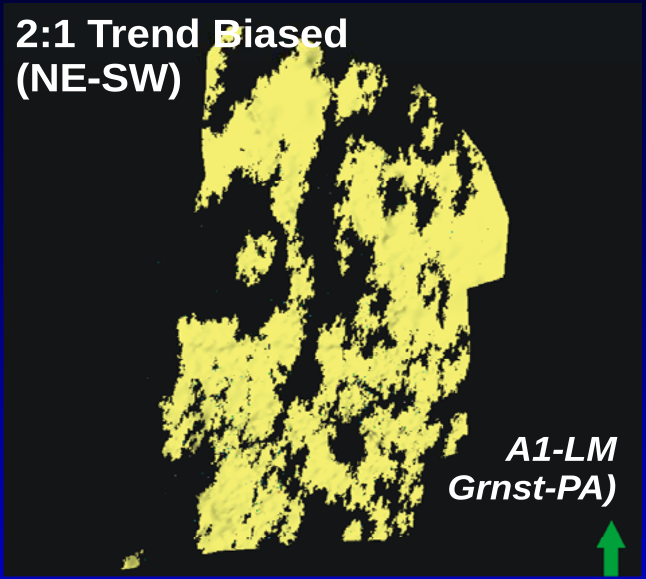
- ***Up-scaled predicted facies to fit layering***
- ***Biased facies trends based on what we know about the geology of the system***
- ***Populated cells in between wells (Sequential Gaussian Indicator)***



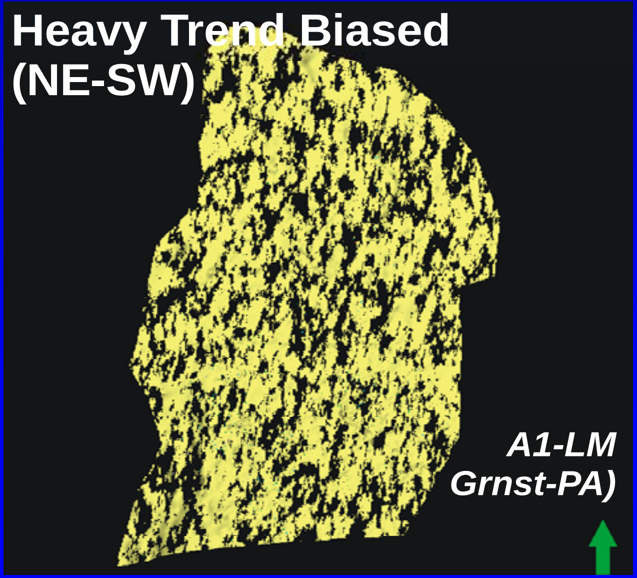
Facies “Biasing”



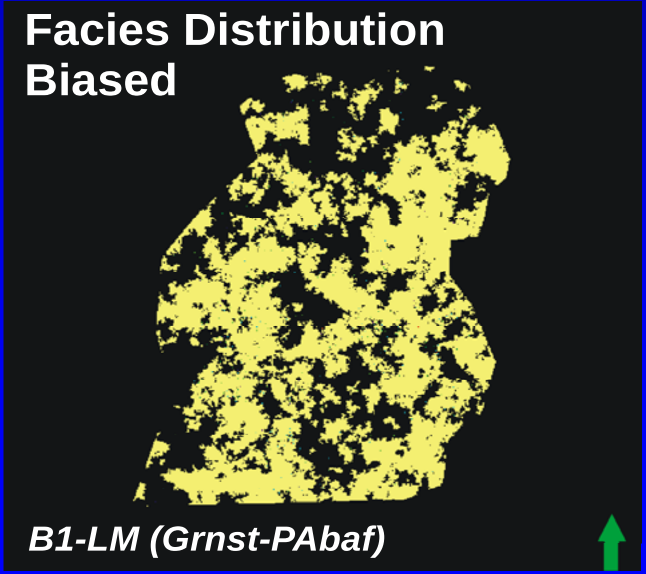
Non-biased



2:1 Trend Biased (NE-SW)

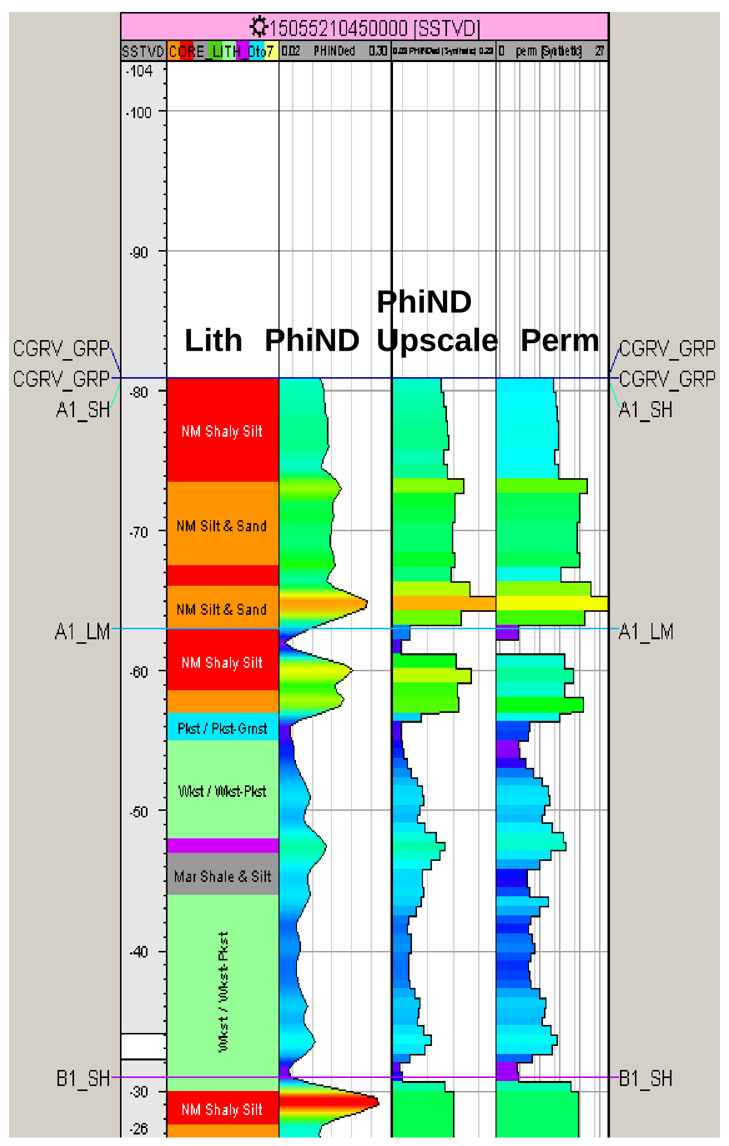


Heavy Trend Biased (NE-SW)



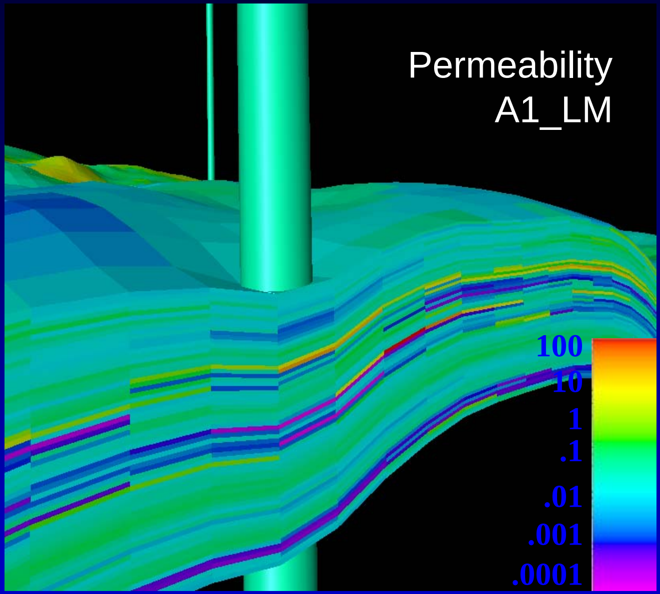
Facies Distribution Biased

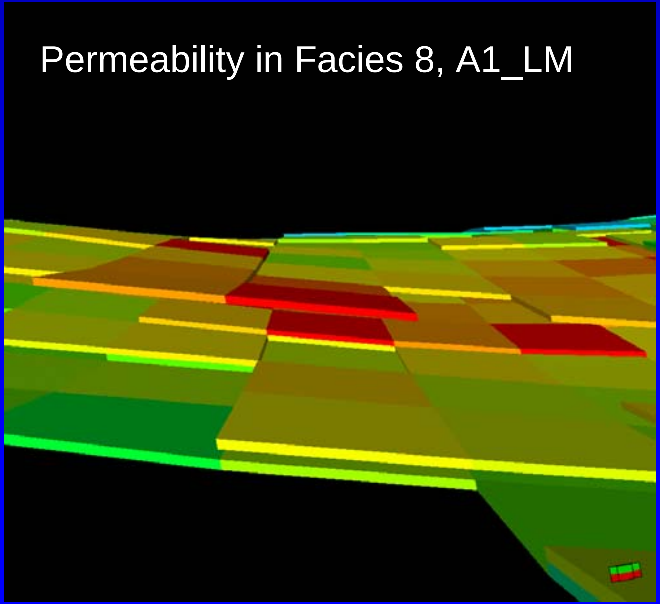
Panoma Petrophysical Modeling



Petrophysical Models

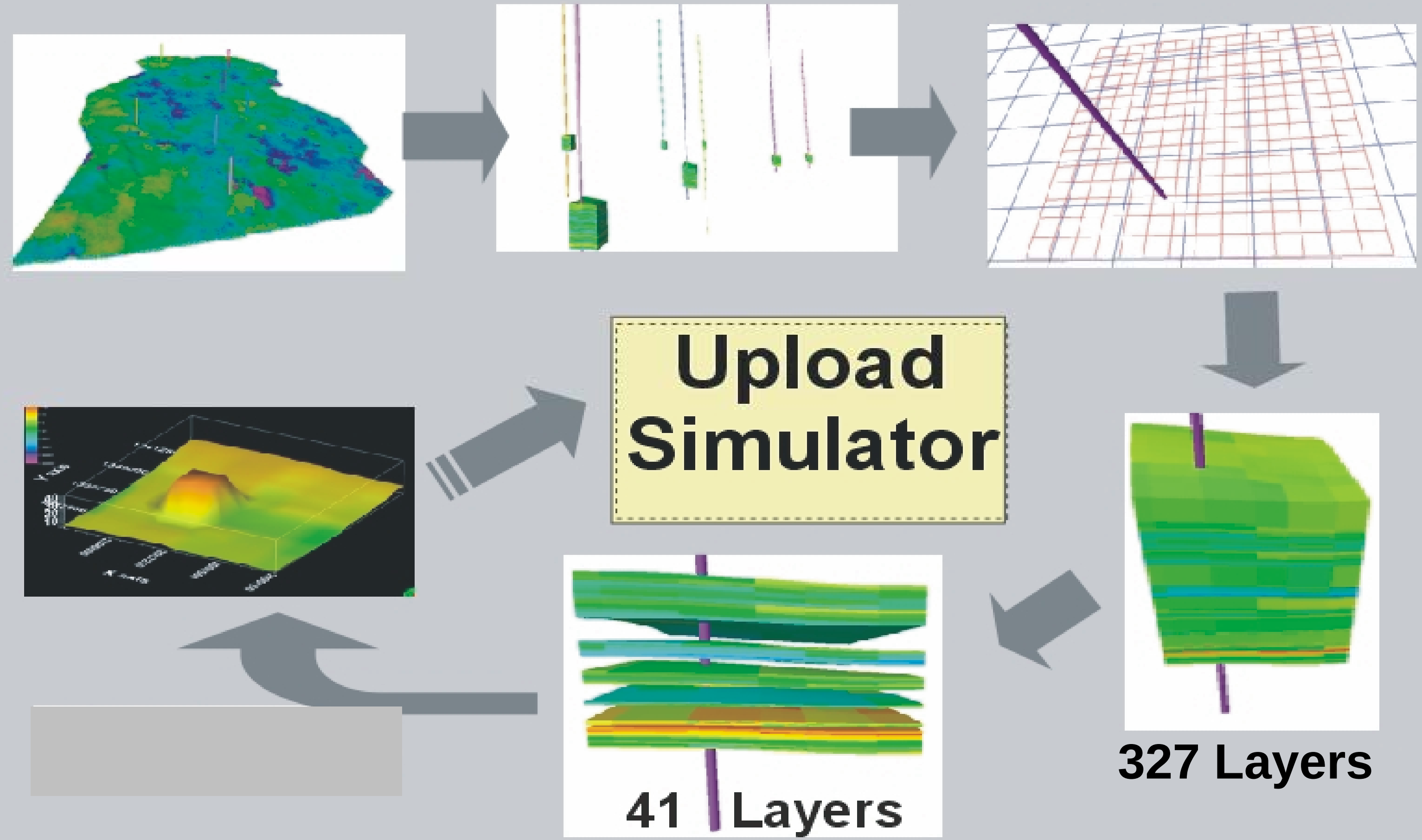
- ***Up-scaled porosity curve to fit layering and generated porosity model***


Permeability
A1_LM


Permeability in Facies 8, A1_LM

- ***Used perm facies transforms and porosity values in cells to generate permeability model***

Upscale to Dynamic Model



Upload Simulator

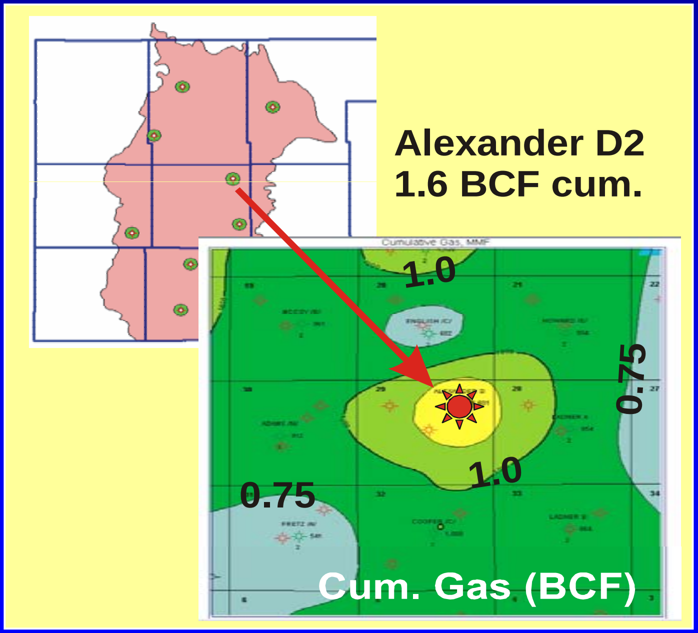
327 Layers

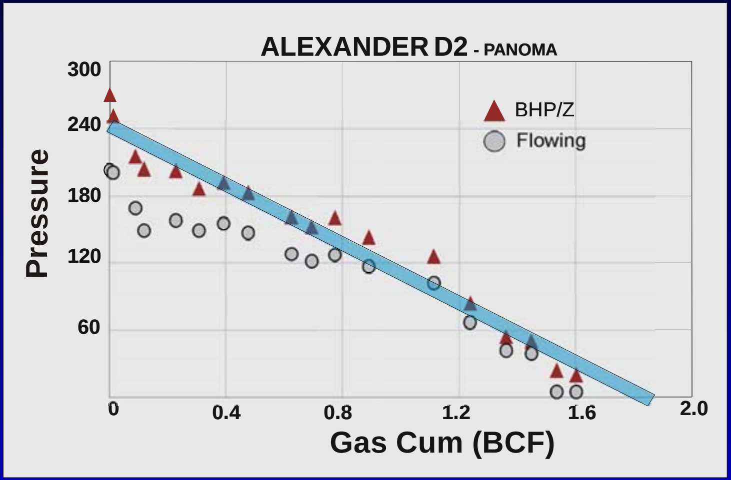
41 Layers

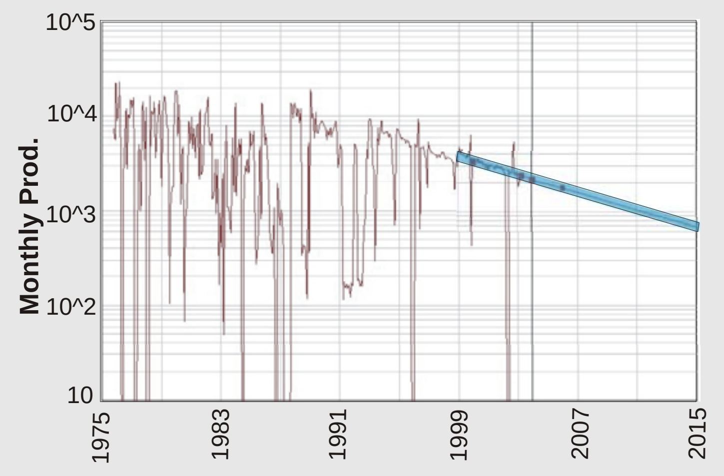
Initial Simulation; single well

We have just begun the transition from a static model to the simulator, Beginning at the single well level.

Example from one of the key wells

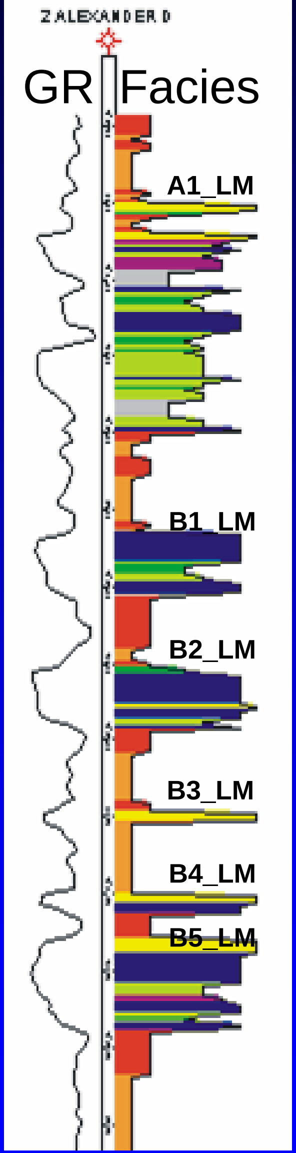






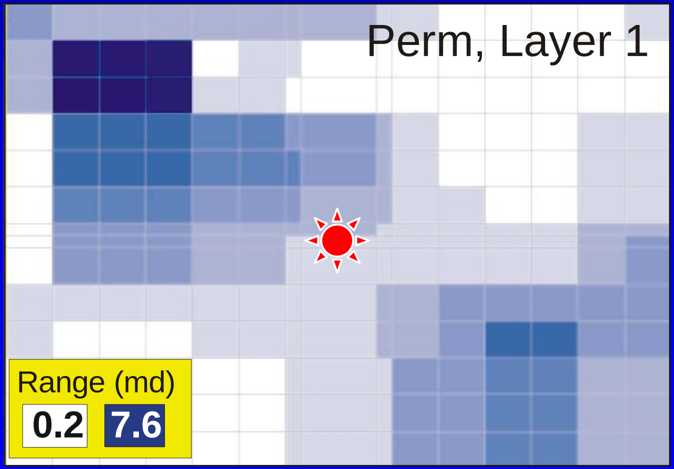
Initial dynamic models

Core facies
at single well



Three Runs

1. Upscaled from well
2. GeoModel, Rate Specified
3. Geomodel, Pressure Specified



Upscaled permeability from static model (map view layer 1)

Parameters

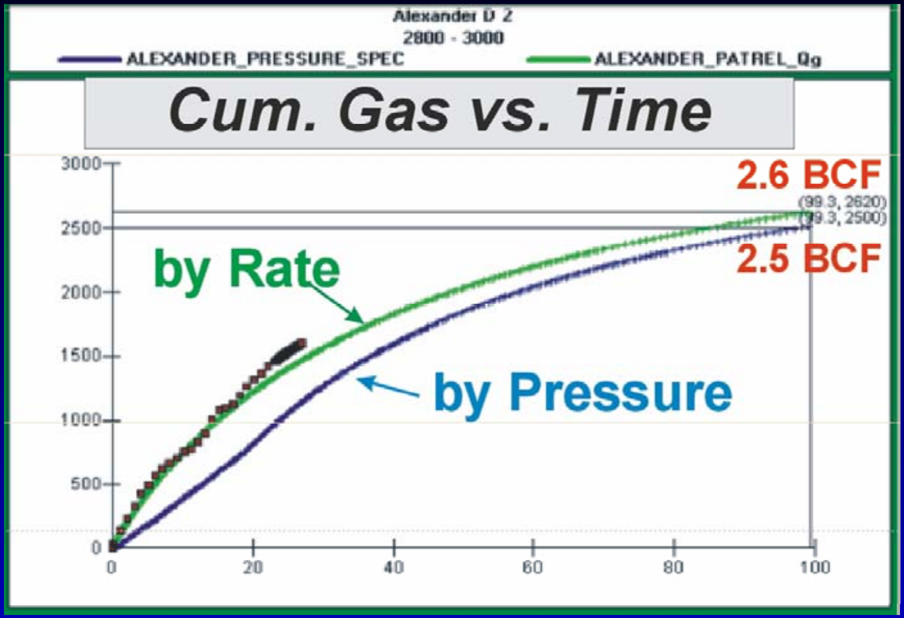
- 640 Acre Section
- Cell Size: 390’ X 415’

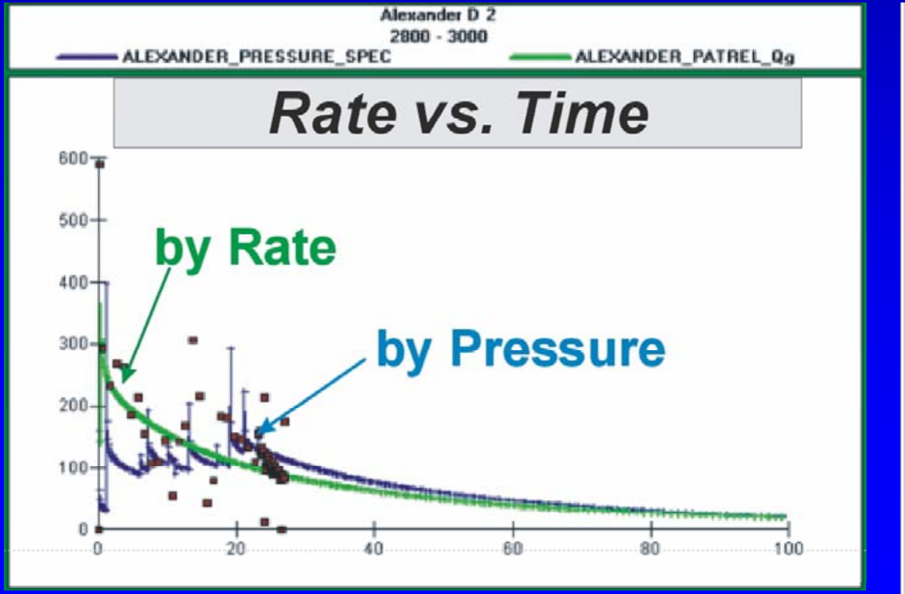
Layers:

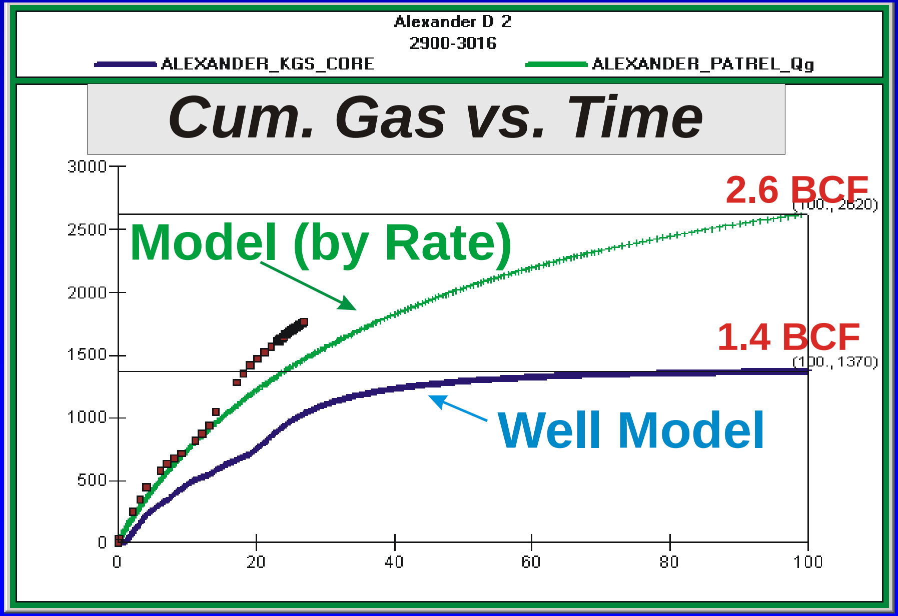
- Upscale from well – 6
- Geomodel – 41 (from 327)
- Well Location: Center
- 0.6’ X 315’ Fracture
- 100 Year Run
- Sw_c 30 %
- BHPi 260 psia

Initial Simulation Results

- Upscaled stochastic model performed better than one with upscaled well data alone
- Rate specified decline provided better match than pressure specified







Summary; What’s next?

1. Many obstacles overcome by effort and automation.
2. Upscaling to more manageable model size for larger scale simulations (9, 81 wells).
3. Devise methodology to simulate on even larger scales.
4. On to the Chase (Hugoton) and into OK Panhandle