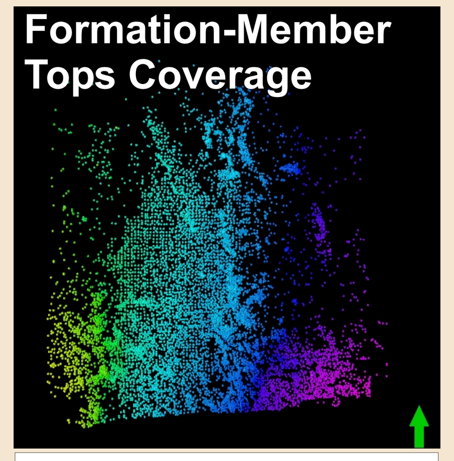
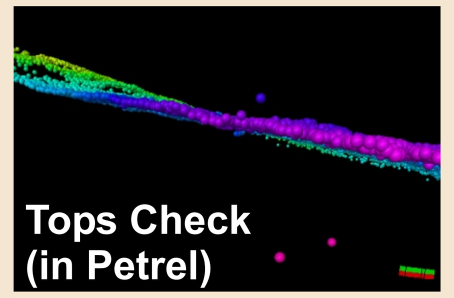
Panoma (Council Grove) Geomodel

Data



11000+ wells, formation level tops



Data busts readily apparent (rotated view looking north).

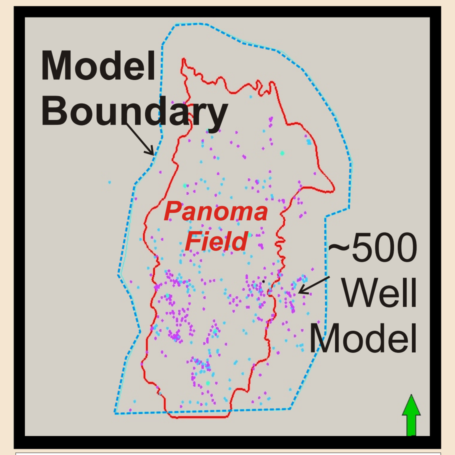
Data Management:

Tops data set

24,879 Total wells in initial PETRA project, including regions outside of model
12,097 Wells having at least Council Grove top pick by KGS geologist
11,367 Wells in initial structure model.
10,836 After screening for tops busts. Further screening reduced the well count to10,700.

Digital well log data set

1,103 Sufficient Council Grove penetration
536 After removing wells with bad curves, data gaps or other problems
469 Final count after further screening



500 wells with proper log suite for facies and petrophysical modeling

Model Architecture

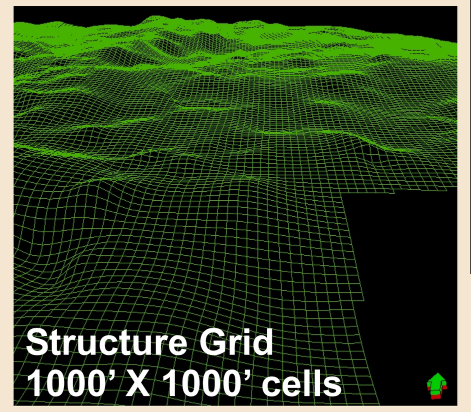
Slice and Dice

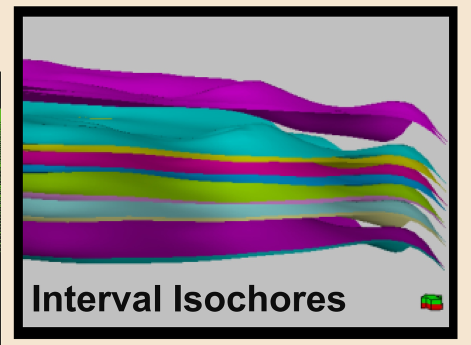
Seven cycles modeled
For efficiency while maintaining fine heterogeneity, reservoir model was divided into 7 marine-nonmarine cycles (A1-C) for lithofacies, porosity and permeability modeling. The 7 perm models were then joined for simulation.

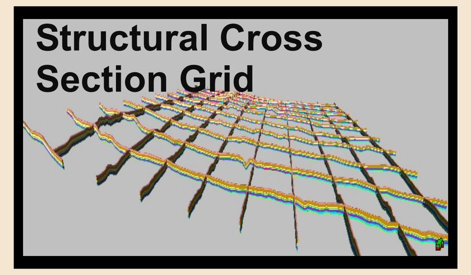
Proportional layering in cycles
Layer (N) proportional to interval thickness (h). Nm (marine) = (mean h + sd) and Nnm (nonmarine) = mean h. "Dummy" layers hold places of other cycles in each model (12 per model)

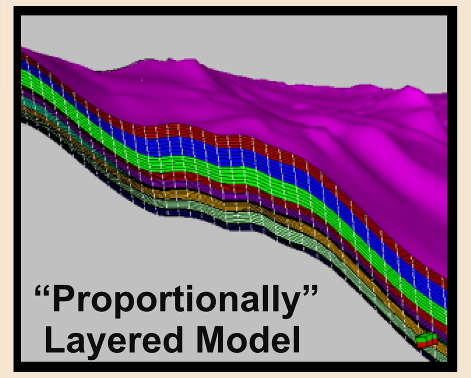
Define Framework

1. Create a "skeleton grid"
2. Construct top horizon for Council Grove Group (top A1_SH)
3. Create isochores for subjacent zones (2/cycle) and "hang" on top horizon
4. Proportionally layer the zones
5. QC structural framework by sectioning









Cells in model
XY = 1000 X 1000 feet
5,200 square mile model
Average model 8.6 million
Maximum15 million (C cycle)
Minimum 5.7 million (B2 cycle)

Layers per Model

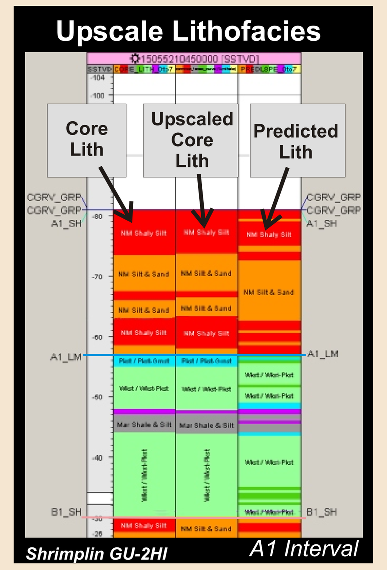
	SH	LM	"Dummy"	Total
A1	23	41	12	76
B1	19	16	12	47
B2	12	15	12	39
B3	20	15	12	47
B4	17	18	12	47
B5	8	34	12	54
C	28	61	12	101

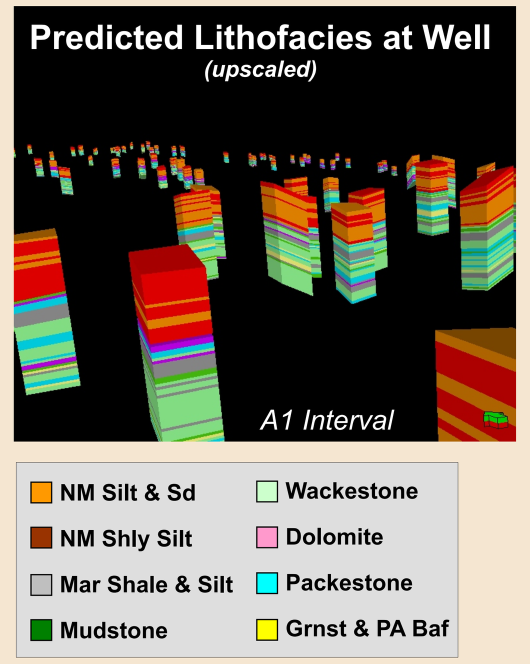
Lithofacies Model

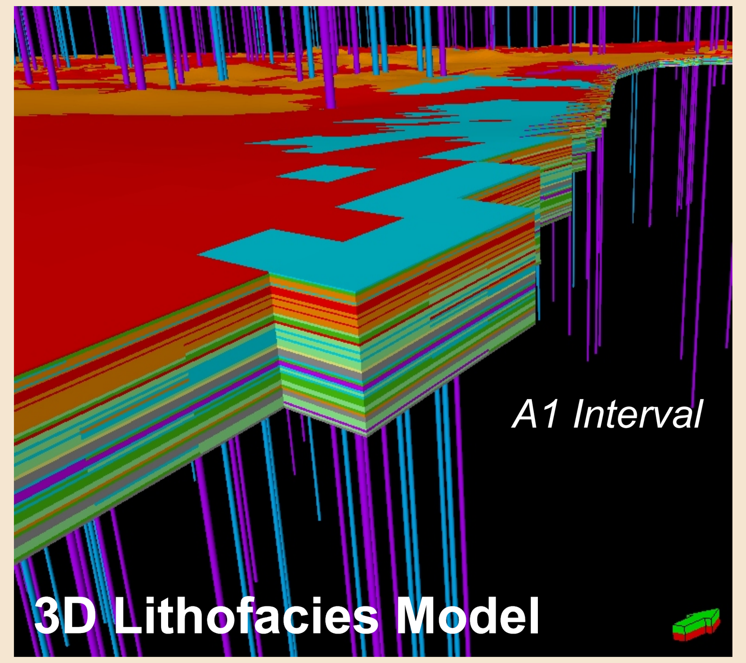
(1) Upscale lithcode curves wells having facies predicted by NNets.

(2) Populate cells at these wells with upscaled facies.

(3) Model cells between wells for lithofacies (Sequential Gaussian). A constant average curve was fitted creating a constant distribution (from "lith-code" curves) equal to the average probability of that facies.

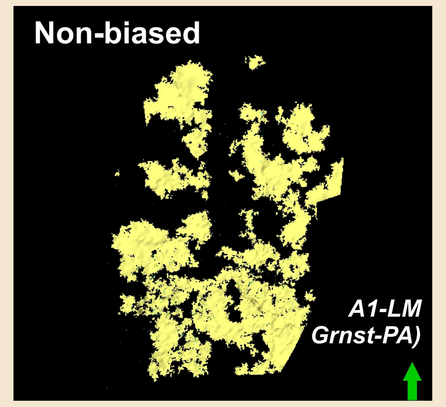


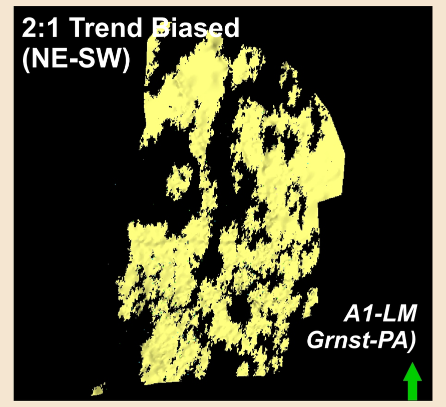


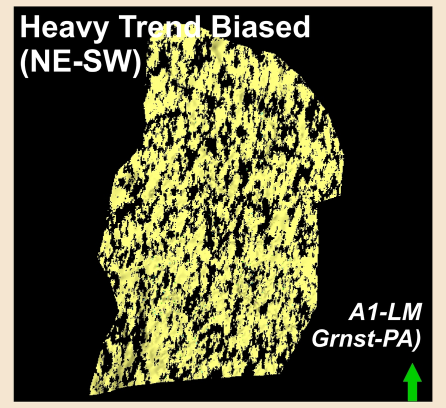


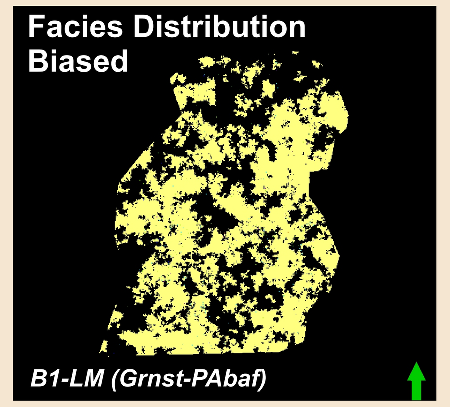
Biasing Lithofacies Geometry

Model facies using different biasing parameters based on geologic understanding. Examples include "non-biased" using a spherical range of 100,000' x 100,000', slightly biased (2:1 ratio to NE-SW), heavily biased to NE-SW, and bias based on mapped regional facies distribution patterns.

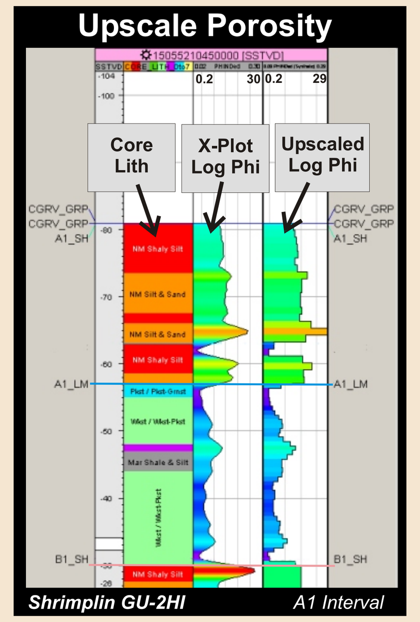








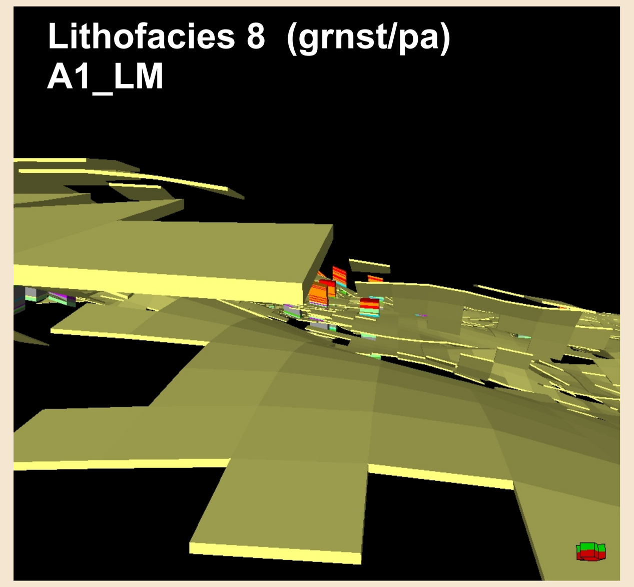
Petrophysical Model



Raw log data was quality checked and aliased. During the processing a cross-plot porosity curve was generated using the Neutron and Density Porosity curves. No shale correction was made in the first models. Similar to facies modeling, porosity curves were "upscaled" at the wells for modeling porosity in cells between the wells (Sequential Gaussian).

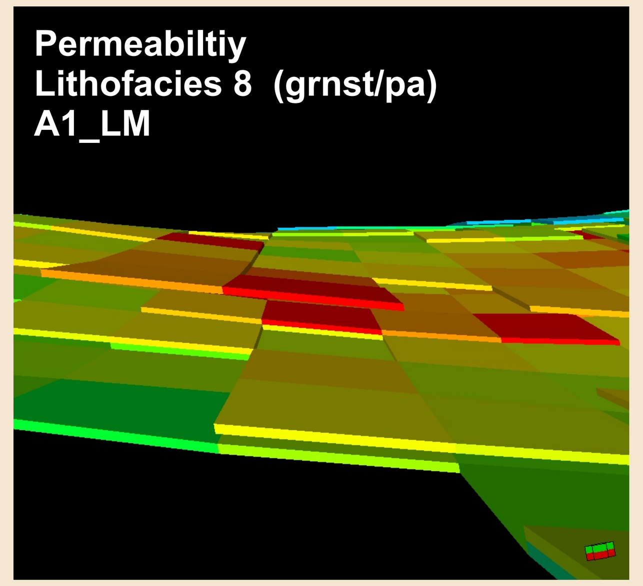
3D view of Facies 8 (Grnst/PAbaff)

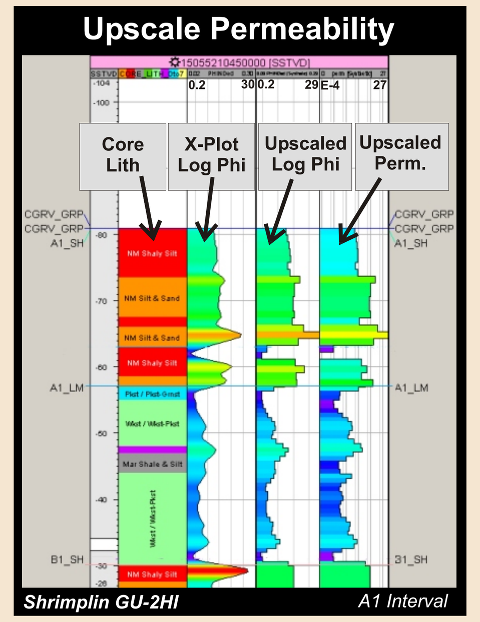
This view of the occurrences of Facies 8 illustrates the discontinuous nature of this particular facies in 3D. Discontinuity, to different degrees, is the norm for all facies.



3D view of Permeabilty

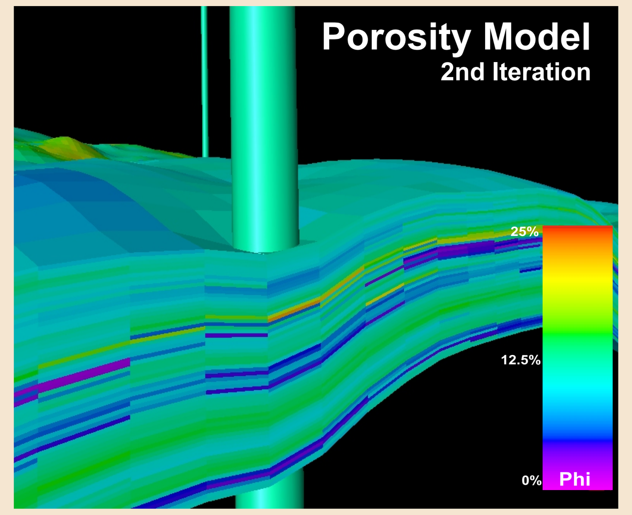
(Facies 8) A view of a portion of the adjacent slide illustrates the permeability distribution with of Facies 8.

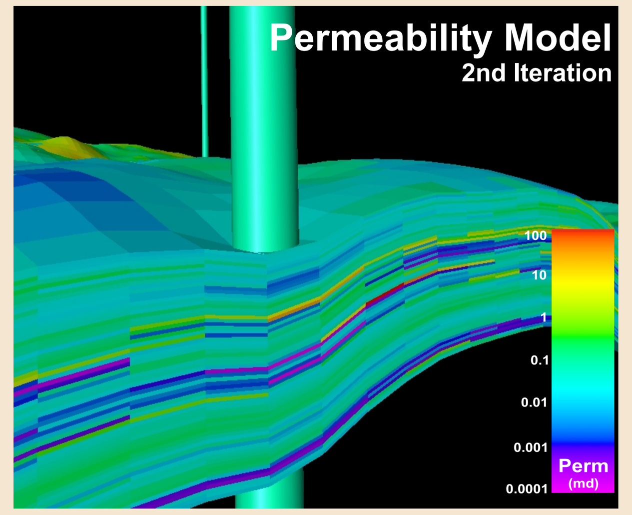




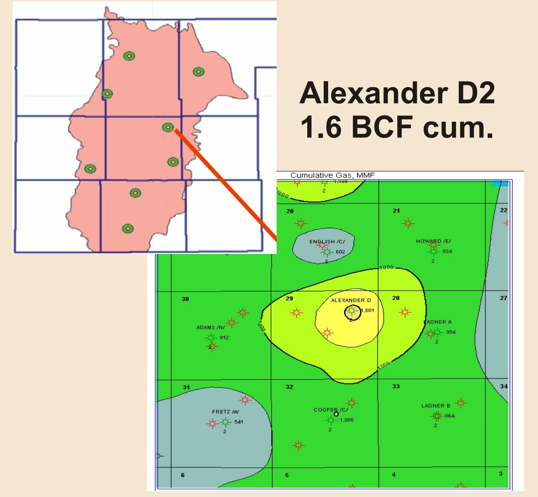
3D views of Porosity and Permeability

Porosity was extrapolated in three dimensions from the wells having upscaled facies and porosity using Sequential Gaussian Simulation. This yielded a cellular model with facies and porosity at each cell. Permeability was then calculated at each cell by using Byrnes lithofacies specific porosity-permeability transform equations that are based on empirical data and absolute permeability.





Initial Simulations (Single Well)

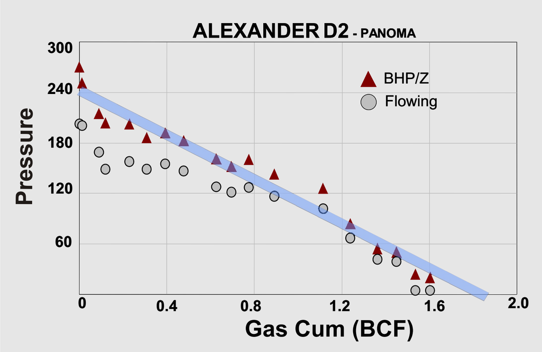


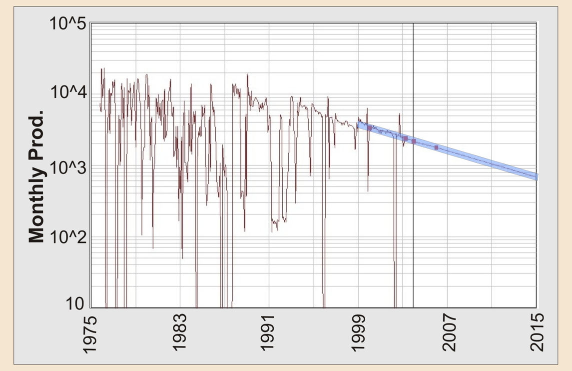
Three Runs

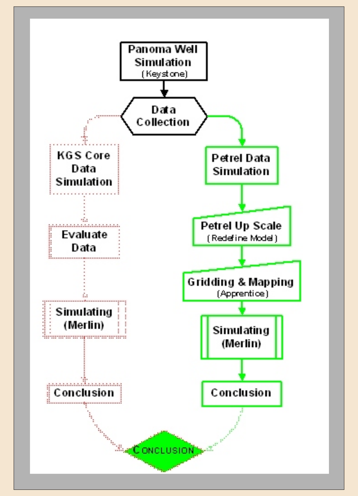
1. Upscaled from well
2. GeoModel, Rate Specified
3. Geomodel, Pressure Specified

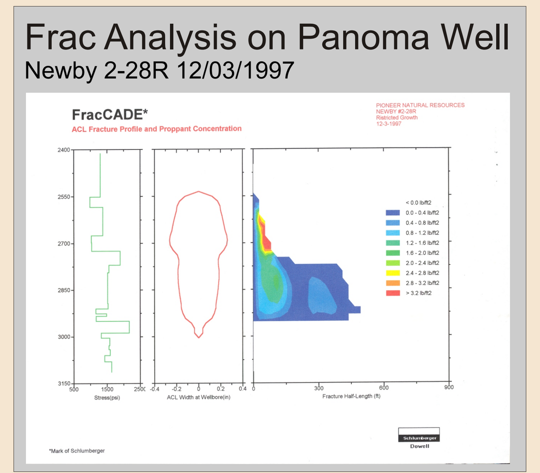
Parameters

- 640 Acre Section
- Cell Size: 390' X 415'
- Layers: Upscale Well – 6
  Geomodel -- 41
- Well Location: Center
- .6' X 315' Fracture
- 100 Year Run
- Sw_{ic} 30 %
- BHP_i 260 psia









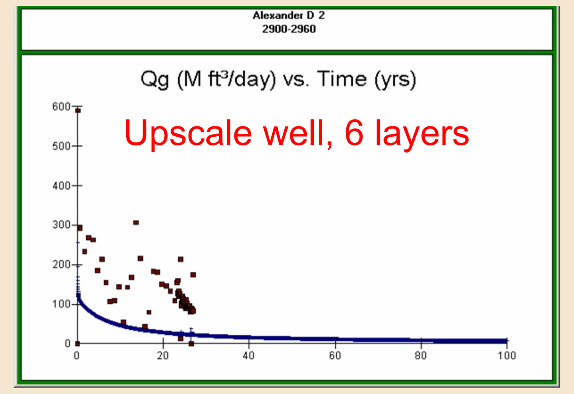
Upscaled from Well Model

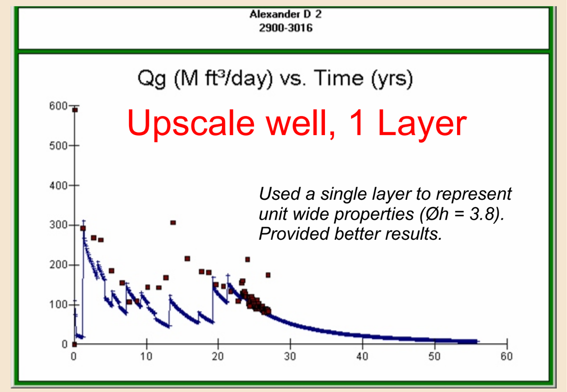
Core Properties
- Tied to Lithofacies
- Corrected for Klinkenberg
- Filter Data> *.1 Perm,>.01 Perm*

Lithofacies Layering
- Used 6 Layers to capture different facies & zones
- Simulation under performed actual

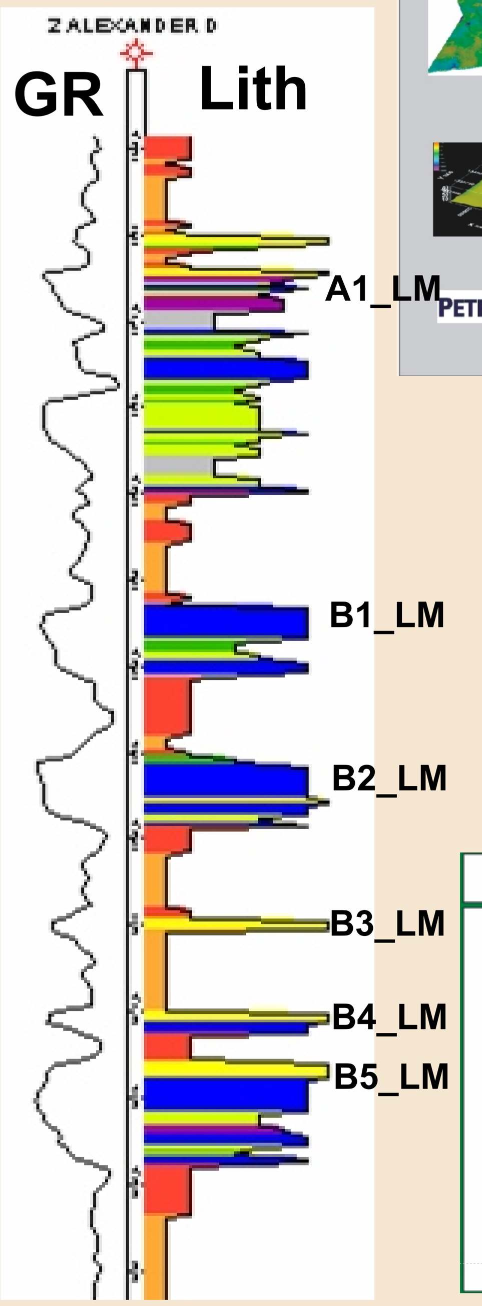
Layer	Porosity	Perm	Top	Bottom	Gross	Net
1	8.679	5.864239	2900.5	2905.5	5	5
2	8.475	0.107800	2906.5	2920.5	14	11.5
3	8.391	0.221282	2921.5	2936.5	15	12.5
4	5.530	0.009621	2937.5	2958.5	21	6
5	4.956	0.006298	2959	2961.5	2.5	2.5
6	6.722	0.276967	2962	3015.5	53	20

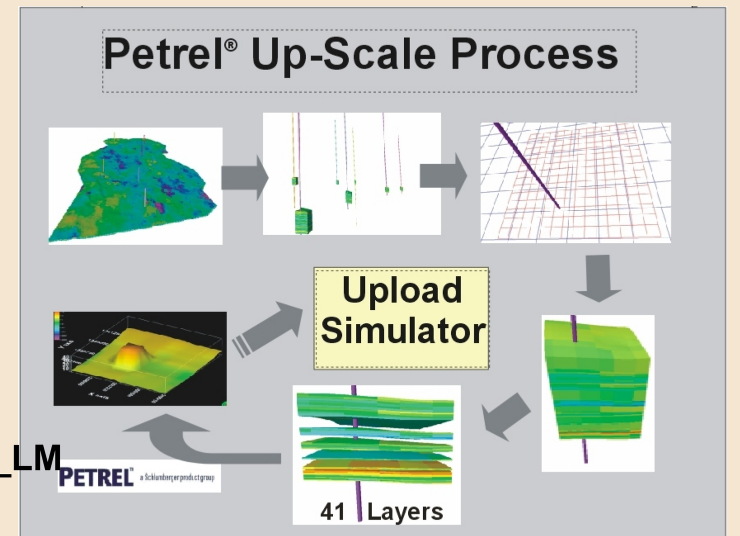
Results

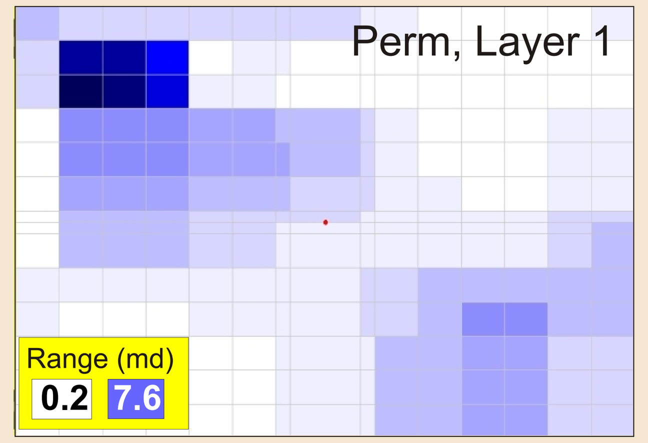


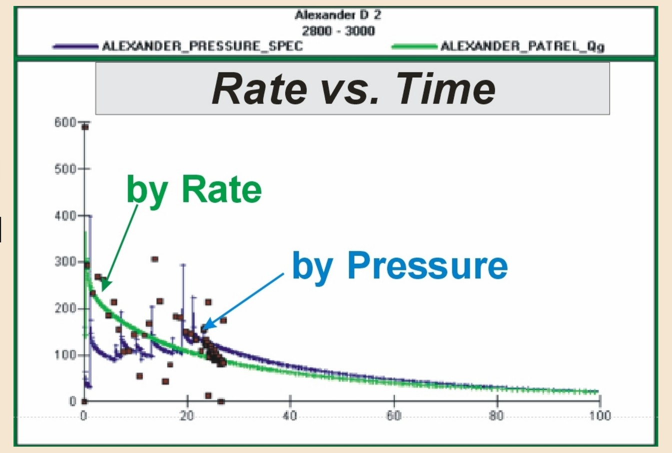


Simulations Using Geomodels







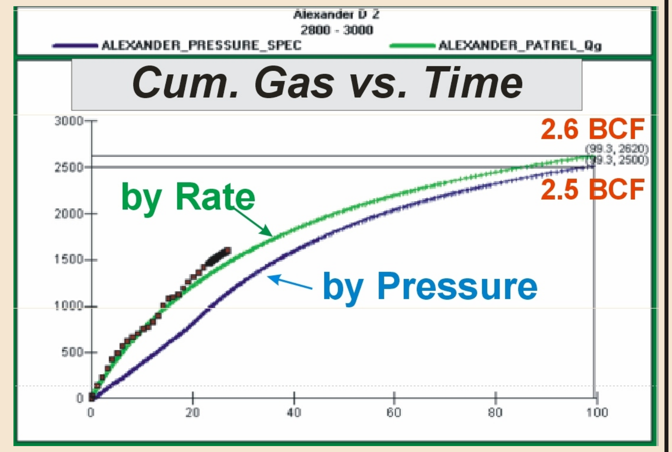


Pressure Specified Run

Step down pressure curtailment (Back Pressure Curve)
Initial Pressure: 243 Psia
Recovery 2.5 BCF

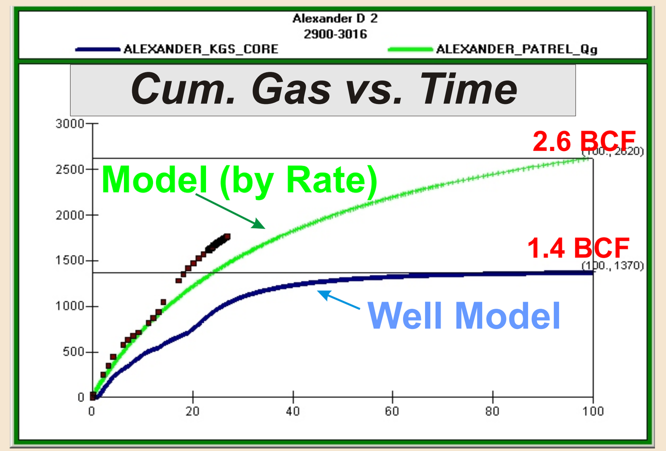
Rate Specified Run

Rate Curtailment
Initial Rate: 589 Mcf/D
Recovery 2.6 BCF



Simulation Conclusion

- Petrel model performed better than upscaled well data alone
- Rate specified decline provided better match than pressure specified



Summary

This paper is a snapshot of an ongoing effort with the ultimate goal of creating a robust three-dimensional geomodel that is suitable for accurate reservoir analysis and simulation. The work to date demonstrates:

1. **Eight lithofacies have distinct suite of petrophysical properties** and use of those properties in calculating volumetric original gas in place (OGIP) reduces error in the calculation.
2. **Neural network models accurately predict lithofacies** in non-cored wells using log curves and geologic constraining variables after training on wells with cores.
3. **The petrophysical model**, synthetic capillary pressure curves, petrophysical transform equations, facies prediction and porosity correction appear to be **validated by property-based volumetric OGIP** that matches material balance OGIP.
4. **Initial simulations** using cellular model appear to be working well.
5. **Vast detailed geomodel** is made possible by extremely large set of detailed tops, digital logs, core data and **automation** (facies prediction and OGIP calculator, for example).

FURTHER WORK:

Additional effort will be in several broad areas; 1) "ground truthing" lithofacies prediction and extrapolation, 2) increasing coverage, 3) improving the neural network model and Petrel models, and 4) expanding reservoir simulation.

1. **Test the Nnet models** by comparing core lithofacies (from undescribed, available core) with those lithofacies predicted.
2. **Test Petrel's stochastic facies modeling** by comparing its results to Nnet predictions at wells that were not used in conditioning the Petrel model.
3. **Consider alternative workflow**: populate Petrel cells with variables and use Nnet models to predict facies at cells.
4. **Increase well coverage** (wells with appropriate log curves).
5. **Improve NNet models**, if possible, by incorporating other statistically based classification techniques (e.g.: fuzzy logic and Markov chains).
6. **Explore use of Nnet facies probabilities** in Petrel facies geometry biasing.
7. Establish a detailed, **field-wide free water level**.
8. **Analyze GIP** by comparing property based volumetric with material balance OGIP and compare both with production history.
9. **Simulate at a variety of scales.**

CHALLENGES:

The primary challenge in this project is to develop single model with sufficient detail to be useful at the field, region, area and well scale. Related to the overall challenge are individual hurdles:

1. Manage vast data sets required for detailed characterization.
2. Balance upscaling against model utility.
3. Physical limitations of software and hardware.
4. Upscale simulation exercises from well to field.

Acknowledgements:

We wish to thank the following industry partners whom have supported this ongoing project financially and with data:

Pioneer Natural Resources USA, Inc.
Anadarko Petroleum Corporation
BP America Production Company
ConocoPhillips Company
Cimarex Energy Co.
E.O.G. Resources Inc.
OXY USA, Inc.
W. B. Osborn