Reservoir Characterization and Modeling of a Chester Incised Valley Fill Reservoir, Pleasant Prairie South Field, Haskell County, Kansas

Martin K. Dubois, Peter R. Senior,
Eugene Williams, Dennis E. Hedke

Presented at the Geophysical Society of Oklahoma City
2012 Continuing Education Seminar

IHR Improved Hydrocarbon Recovery LLC
Ihr-llc.com

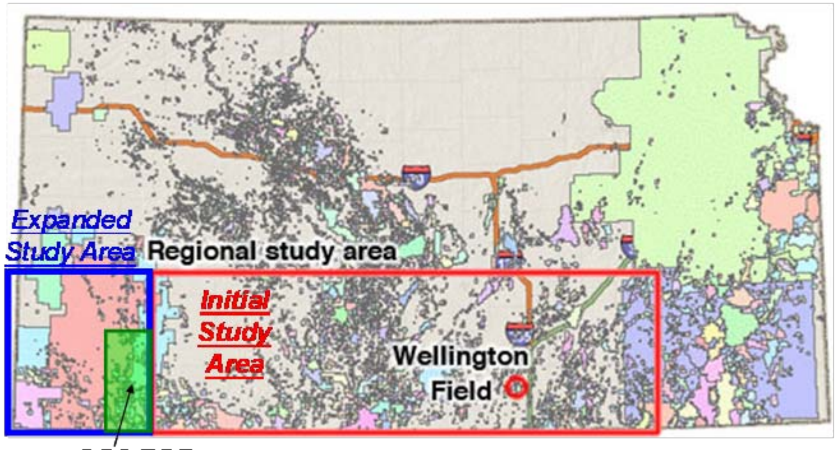
KU Kansas Geological Survey The University of Kansas

Williams Petroleum Consulting

Hedke-Saenger Geoscience, Ltd

Southwest Kansas CO2 EOR Initiative Chester and Morrow Reservoirs

Western Annex to Regional CO2 Sequestration Project (DE-FE0002056) run by the Kansas Geological Survey



Six Industry partners:

- Anadarko Petroleum Corp.
- Berexco LLC
- Cimarex Energy Company
- Glori Oil Limited
- Elm III, LLC
- Merit Energy Company

Support by:

Sunflower Electric Power Corp.

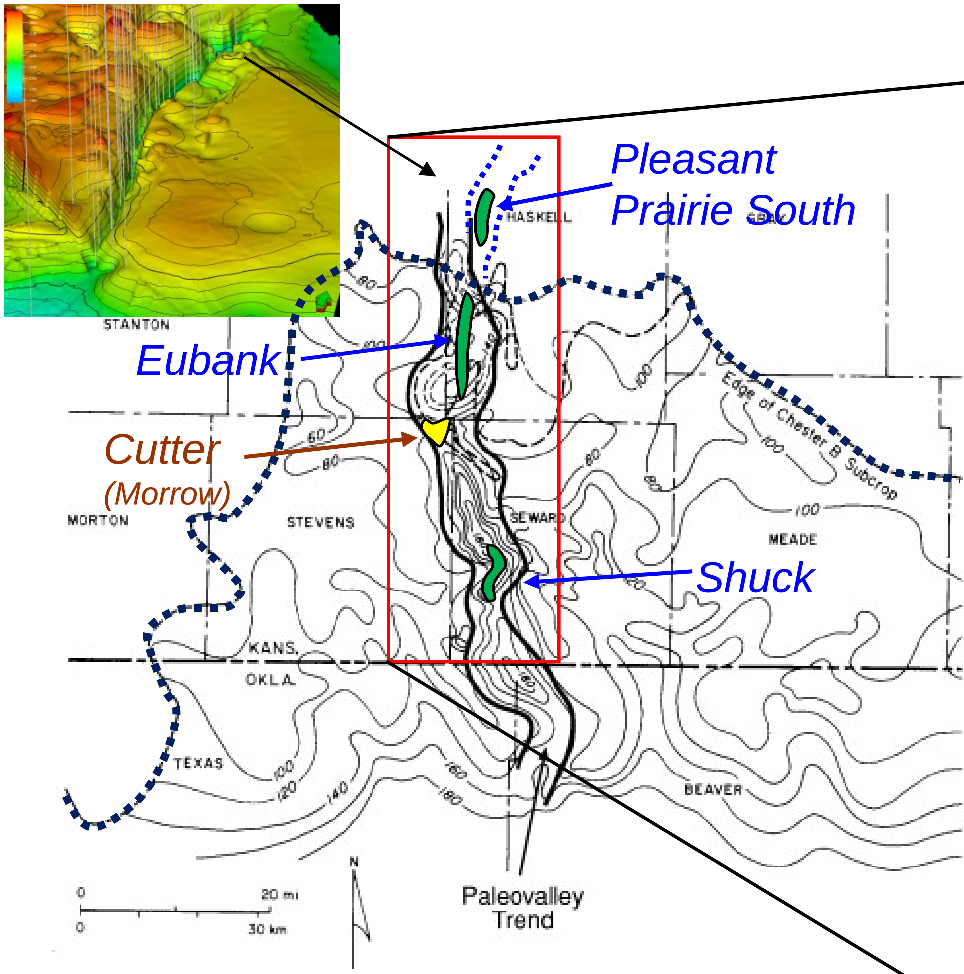
The SW Kansas part of project

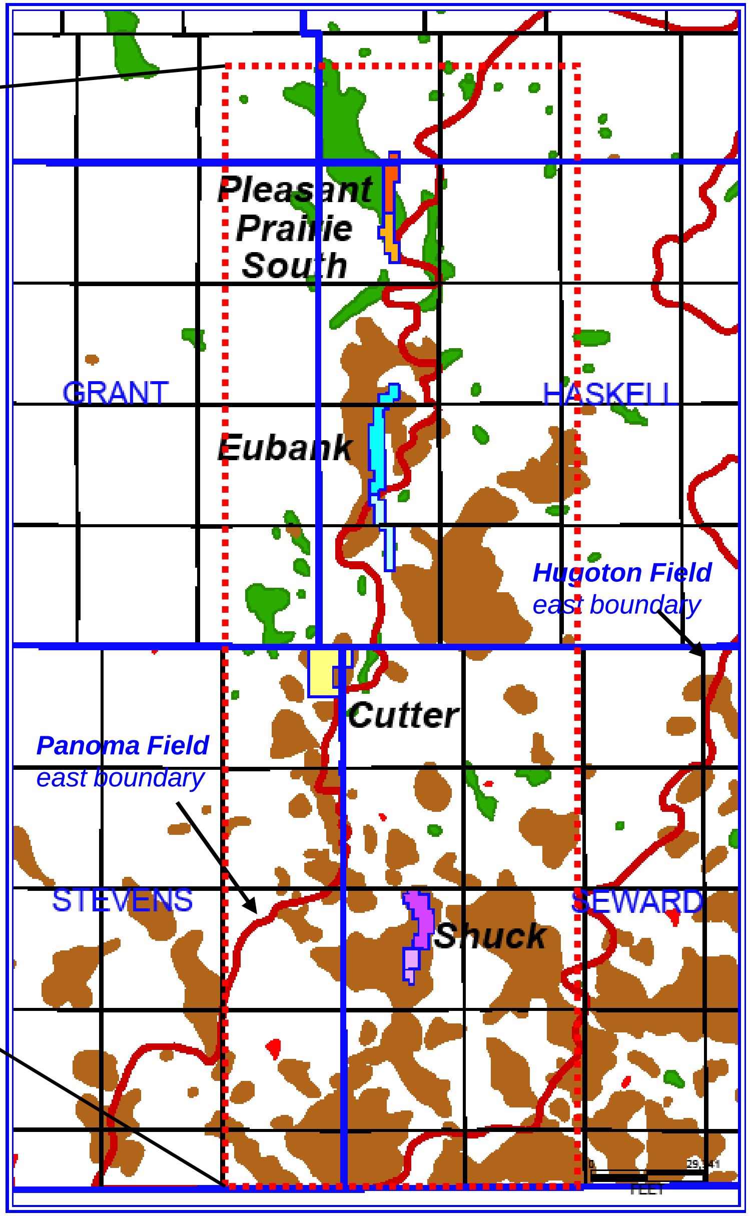
- CO2 EOR technical feasibility study – Chester IVF and Morrow
- Part of larger KGS-industry CCS and EOR study
- Will not inject CO2 – paper study only
- Get fields in study "CO2-ready"

Technical Team:

	Project Role	Company
Martin Dubois	Team Lead, geo-model	Consultant - IHR LLC
John Youle	Core & depo-models	Consultant - Sunflower
Ray Sorenson	Data sleuth & advisor	Consultant
Eugene Williams	Reservoir engineering	Williams Petrol. Consultants
Dennis Hedke	3D Seismic	Consultant - Hedke & Sanger
Peter Senior	Reservoir modeling	MS student
Ken Stalder	Geotech	IHR, LLC
Susan Nissen	3D Seismic	Consultant
Lynn Watney	Project PI	KGS
Jason Rush	Project PI	KGS
John Doveton	Log Petrophysics	KGS
Paul Gerlach	Data support	Consultant - Charter

Fields in study in relation to Chester Incised Valley





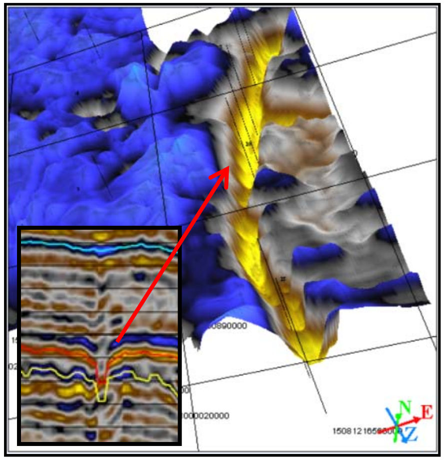
(Above) Regional isopach of lowermost Chesterian incised valley fill (*Montgomery & Morrison, 2008)*

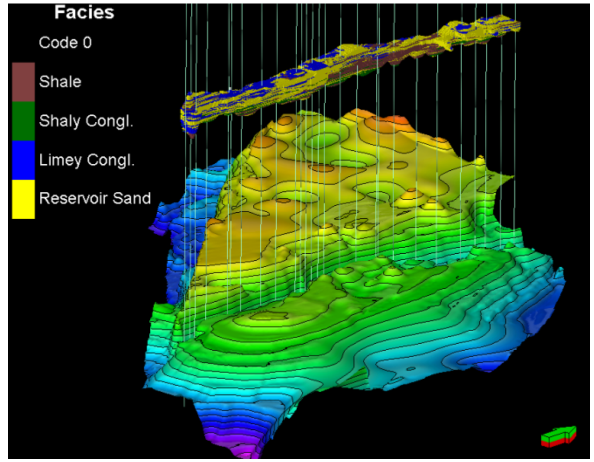
(Right) Four fields in study. Green – Oil; Brown – Oil and Gas. Grid is Township-scale (6 mi.).

Integrated Multi-Discipline Project

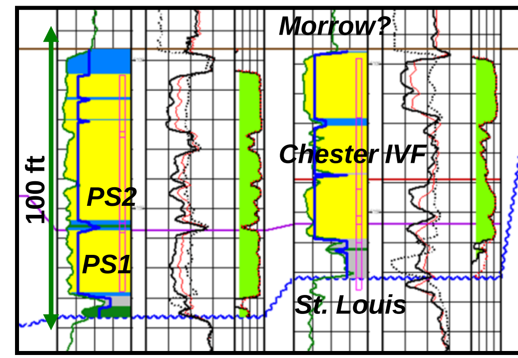
Static Model

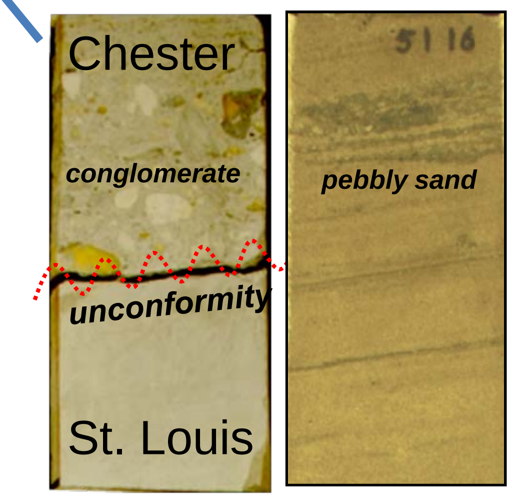
Geophysics:
structure, attributes, faults



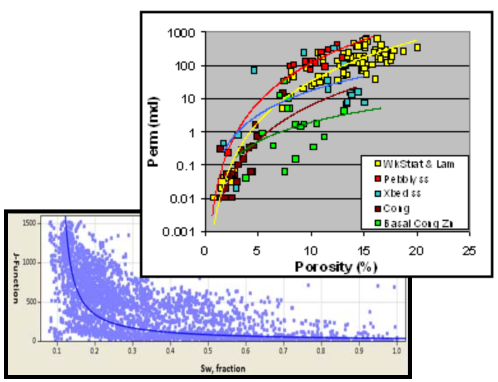


Geology:
Formation tops, sequence stratigraphy, core lithofacies, lithofacies prediction (NNet)



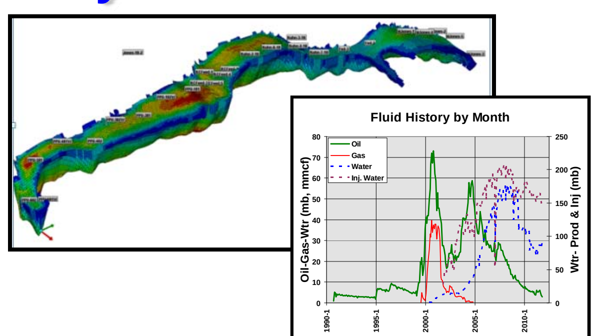


Petrophysics:
Core K-Phi, corrected porosity, free water level, J-function



Engineering:
PVT and fluid analysis, recurrent histories, dynamic modeling

Dynamic Model



Basic Workflow

Inputs

Framework data:
- Formation tops
- Sequence stratigraphy
- Depth-converted seismic structural surfaces
- Seismic attributes

Well-scale data
- Lithofacies (by NNet)
- Core data
- Porosity (corrected)
- Water saturation (Archies)

Sw solution
- Oil/water contacts and free water level
- Sw by Leverett J-function

Static Model

Structural wire frame model
- Incised valley by seismic and well tops
- Two parasequences
- 0-249 layers
- Cells: XY=55 ft, Z=2ft
- 700,000 active cells

Fine- grid cellular property model
- Lithofacies
- Porosity
- Permeability (XY)
- Water saturation
- OOIP

Upscale model
- Phi, K, Sw
- 0-25 layers
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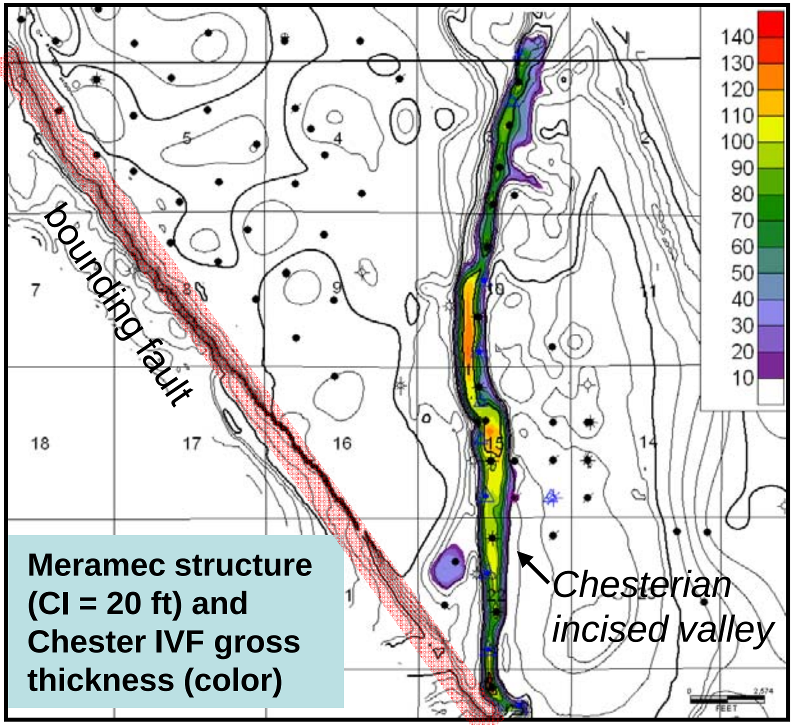
Dynamic Model

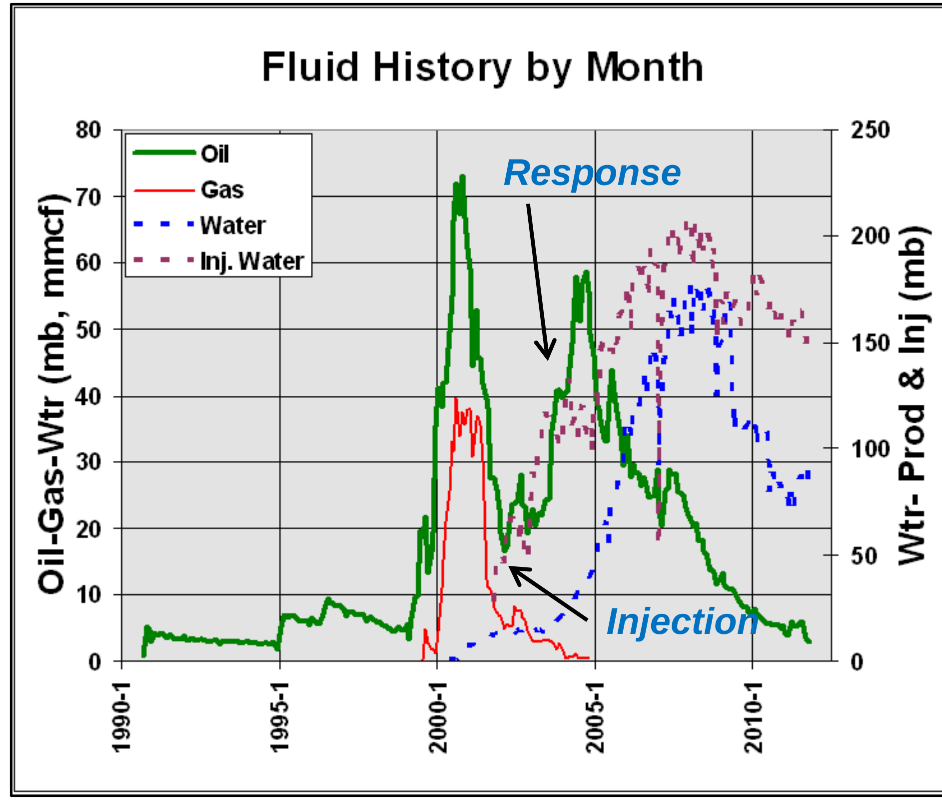
- ✓ **History matched primary and secondary** black oil simulation
- ✓ **Forecast CO2 EOR** compositional simulation

Equation of State from PVT and fluid composition

Recurrent well history
- Mechanical
- Fluids produced and injected

Field Summary

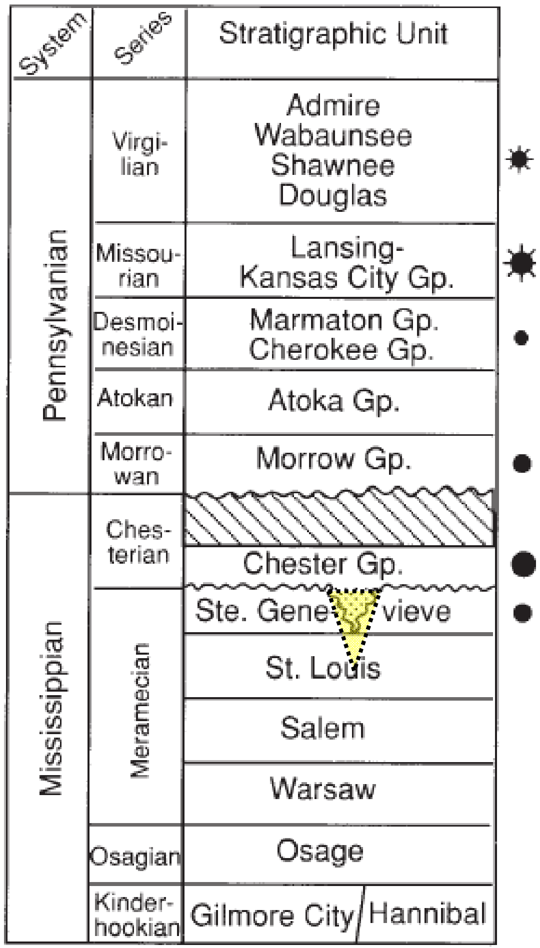




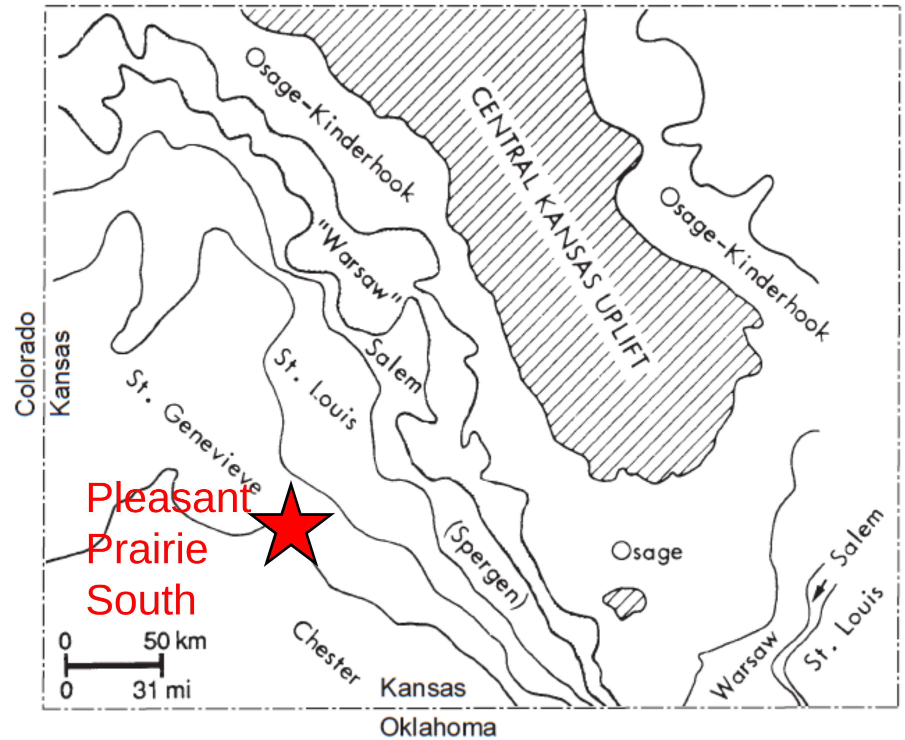
Chester IV (Pleasant Prairie South) cuts through Pleasant Prairie, a faulted anticline producing from the St. Louis (34 mmbo).

Producing zone	Miss. Chester	**WF recovery**	Appx 50% of cum.
Discovered	1990	**Oil wells total**	18*
Waterflood	2002	**Current oil wells**	13
Cumulative Oil	4.4 mmbo	**Current wtr inj wells**	9
Cumulative Gas	0.7 BCF		**5 oil converted to injectors*

Stratigraphic setting



Generalized stratigraphic column (Montgomery and Morrison, 1999).

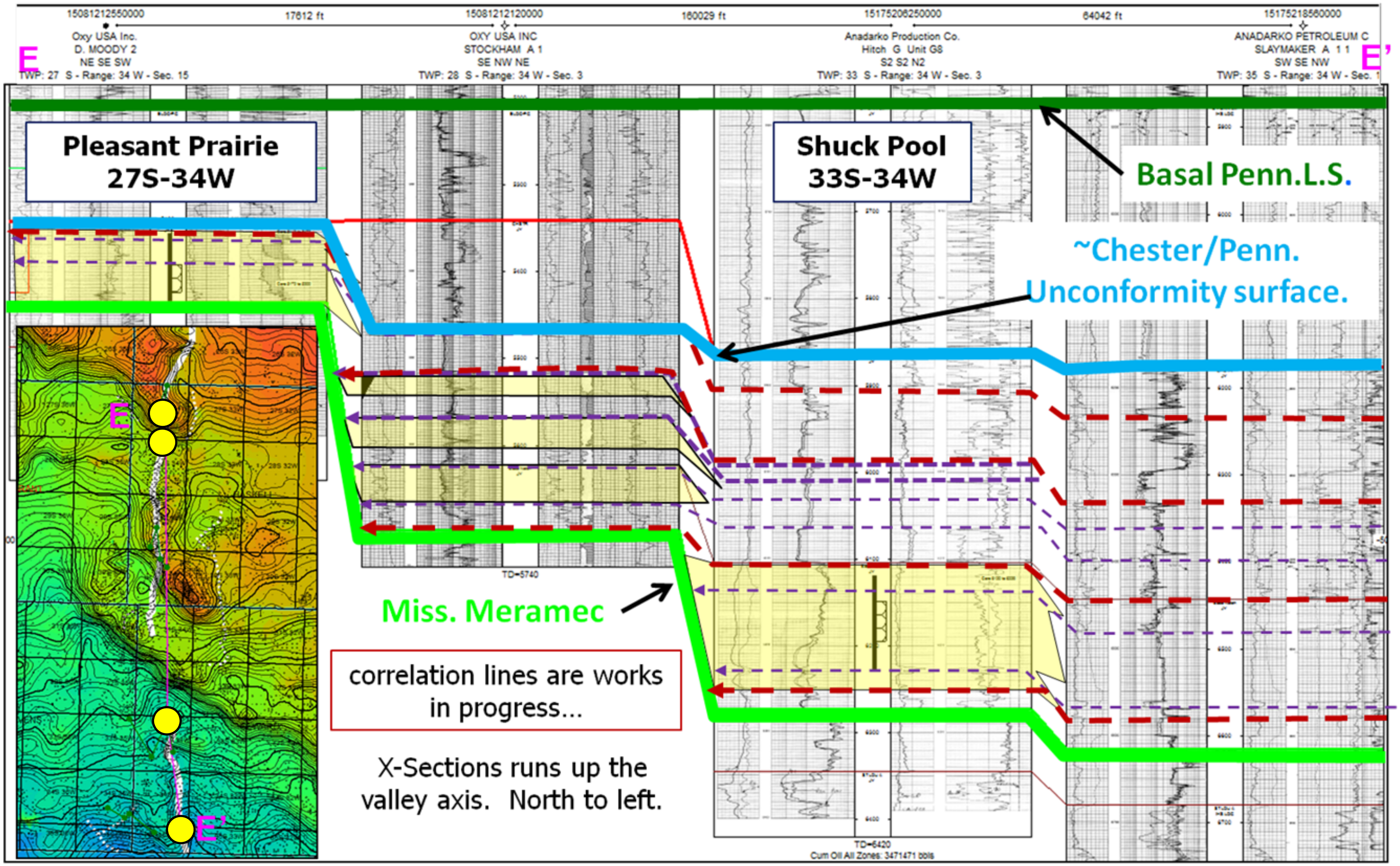


Subcrop pattern for Mississippian strata, western Kansas (Ebanks, 1991).

Valley incision took place during exposure of the Meramecian. Subsequent Chesterian transgression, punctuated by still-stands filled the narrow, nearly linear valley with fine-grained reservoir sand.

Chester Sequence Stratigraphy

work by John Youle



The cyclic retrogradational nature of Chester shoreline advances into Kansas are interpreted to have filled incised valleys with a series of 'back-stepping' stacked estuarine sandstone reservoirs. Red dashed lines are postulated sequence boundaries, and purple lines are possible parasequences.

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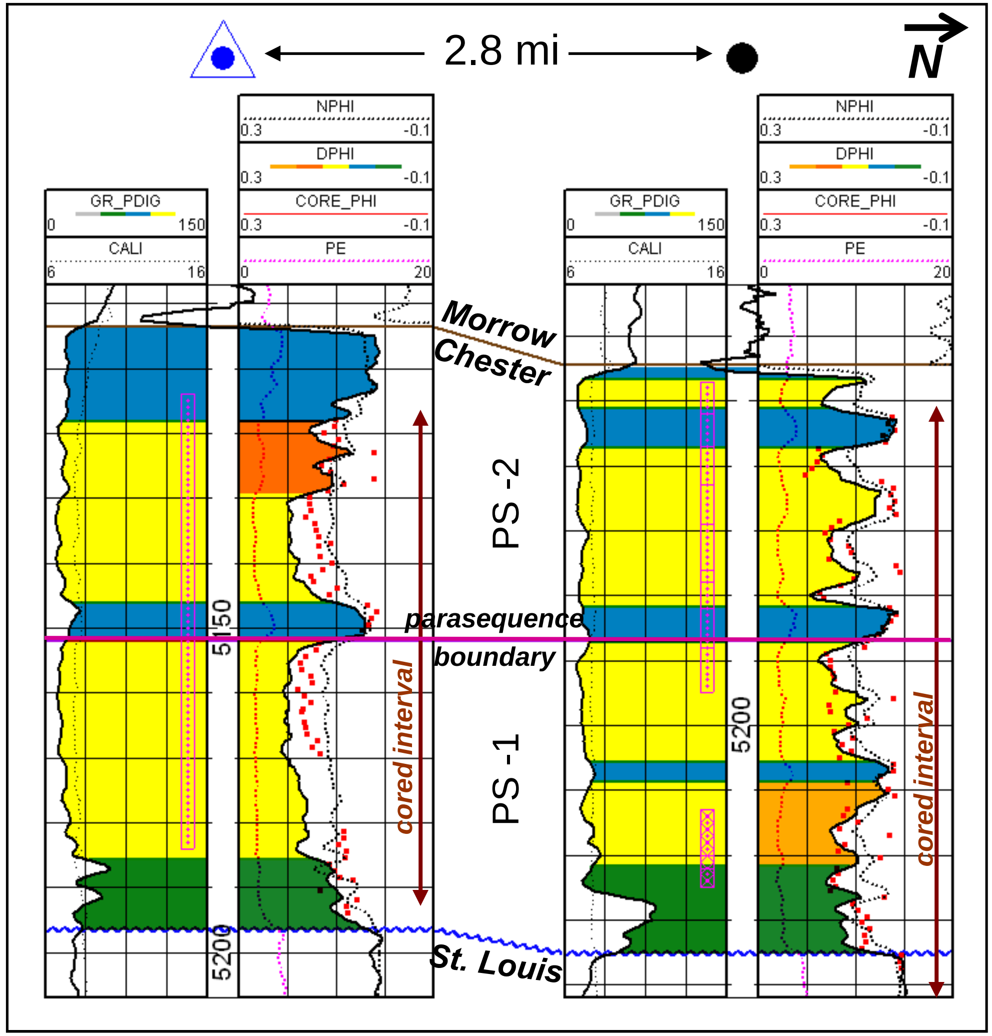
Lithofacies in core and wireline logs

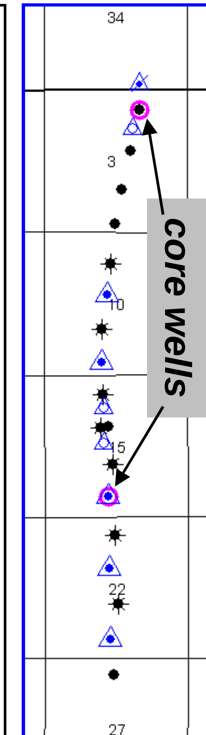
Two cores of nearly entire Chester IVF

- Lithofacies
- Petrophysics

Main Lithofacies

Model	Core
limey congl	limey congl
reservoir ss	wkly strat/lam ss
	pebbly ss
	x-bedded ss
shale	shale
basal congl	basal congl



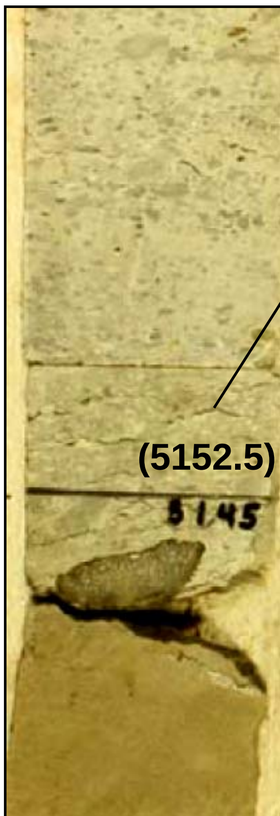


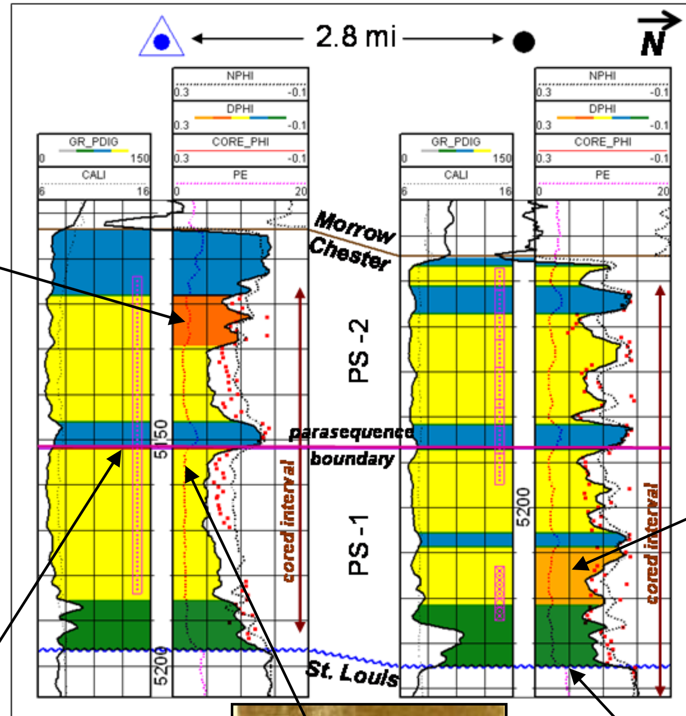
Lithofacies in core and wireline logs

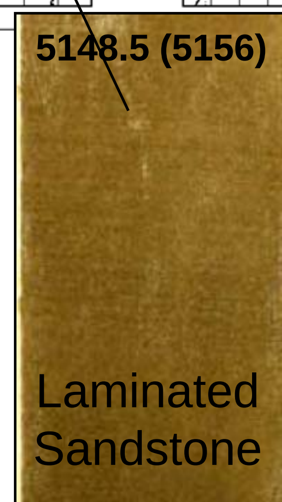
(log depth)

Pebbly Sandstone

Limey Congl.



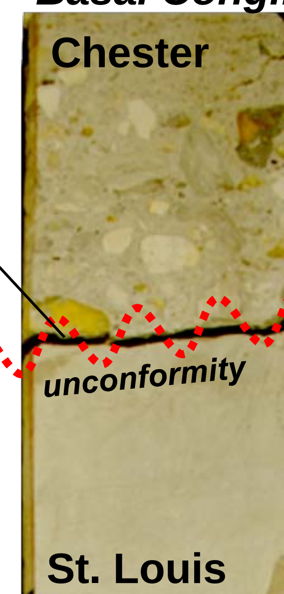




5218.5 (5213.5)

X-bedded Sandstone

Basal Congl.



5240.5 (5235.5)

Main Lithofacies

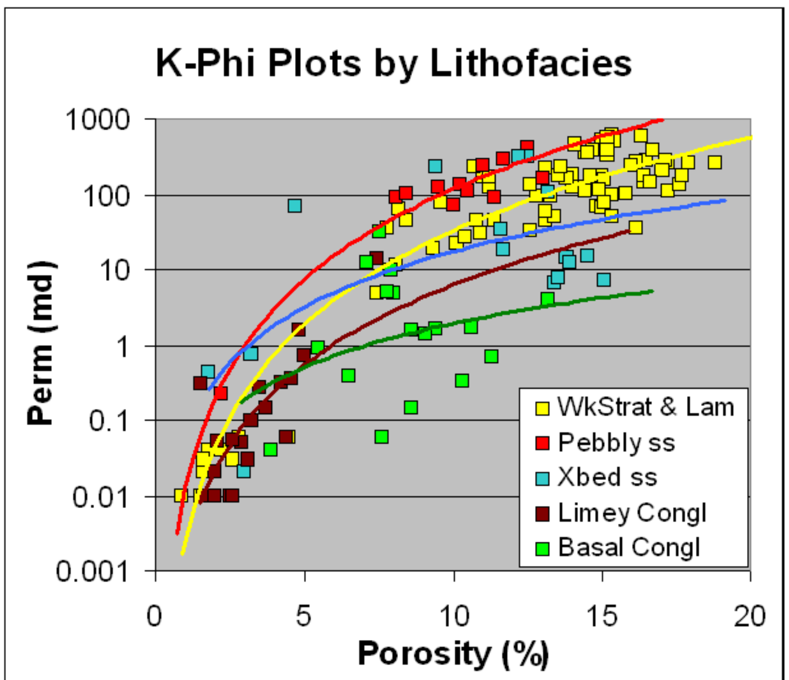
Model	Core
limey congl	limey congl
reservoir ss	wkly strat/lam ss
	pebbly ss
	x-bedded ss
shale	shale
basal congl	basal congl

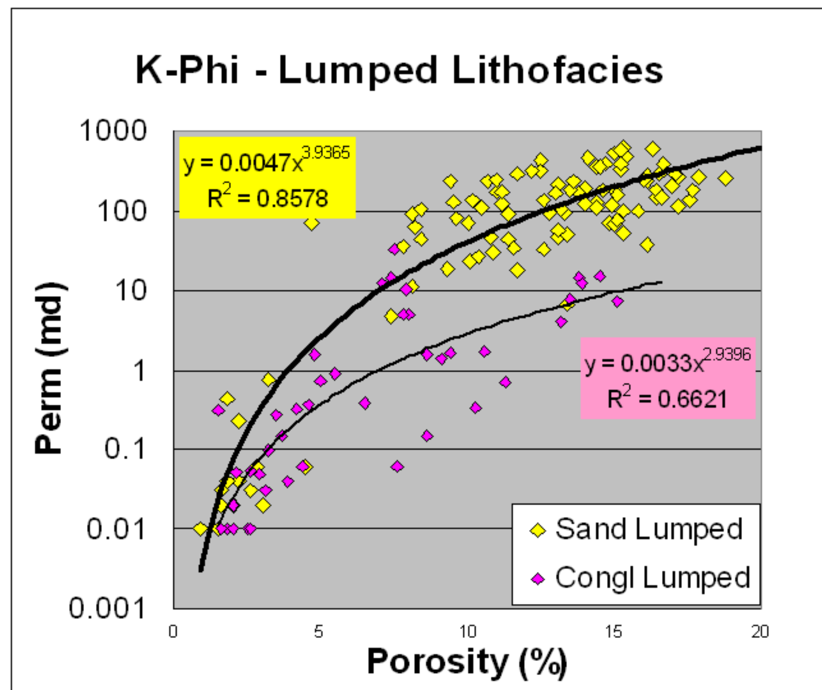
Define lithofacies in wells without core

Questions to be answered

1. Do lithofacies make a difference?
2. Can they be defined in wells without core?
3. Lumping and splitting decision process
   - What can be defined?
   - What makes sense petrophysically?

- They do make a difference
- Decided to lump



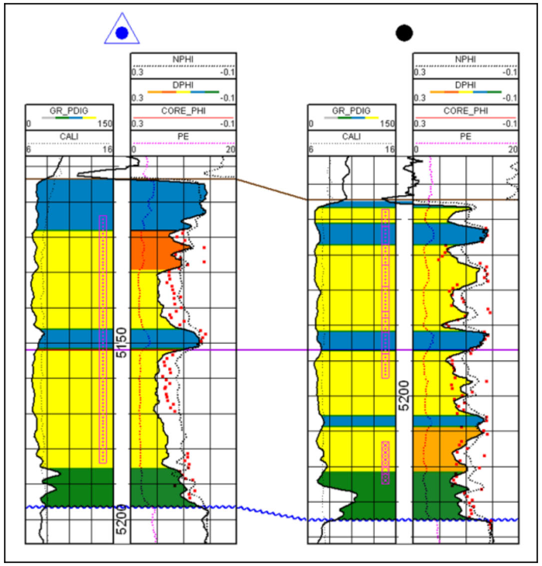


Lithofacies estimated by Neural Network

- Train Nnet on core lithofacies
- Use modified jacknife approach in training
- Could not differentiate 3 reservoir lithofacies
- Very high success rate (>90%) with four lithofacies

Predictor variables:

- Gamma Ray
- Nphi-Dphi Xplot
- Nphi-Dphi difference
- Log10 ResDeep
- PE
- Relative position curve



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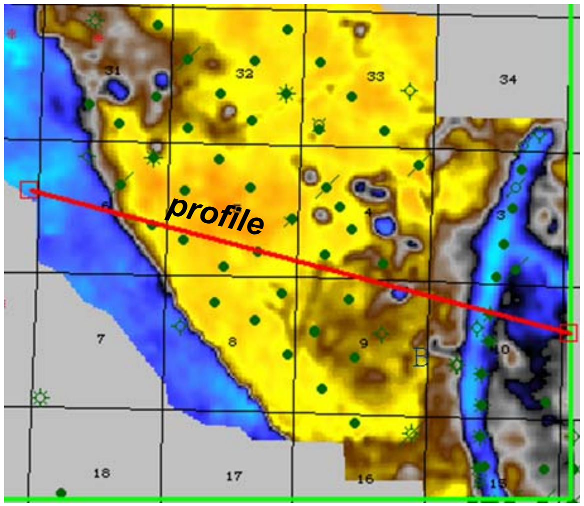
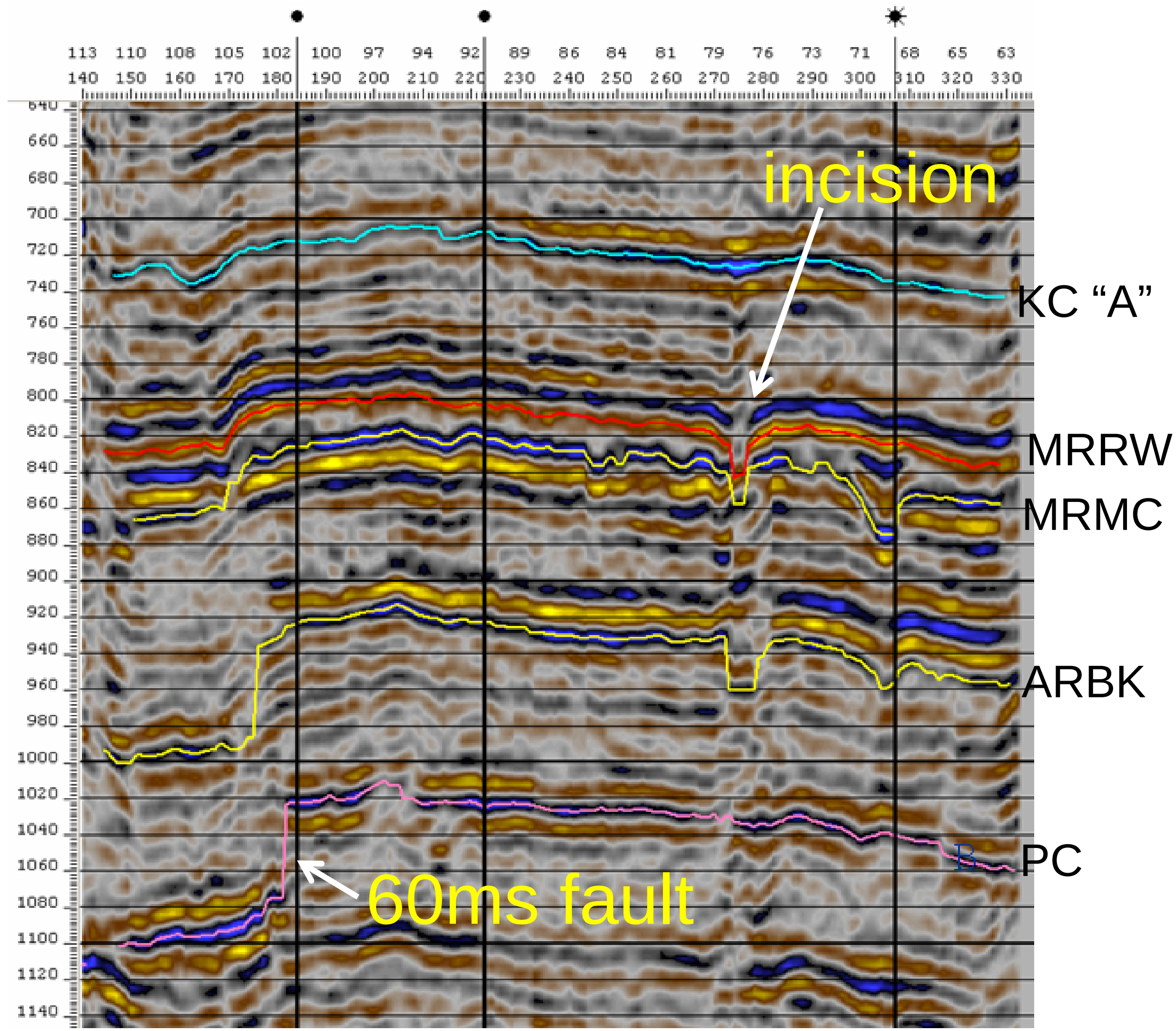
3D Seismic Pleasant Prairie



Meramec Time Structure

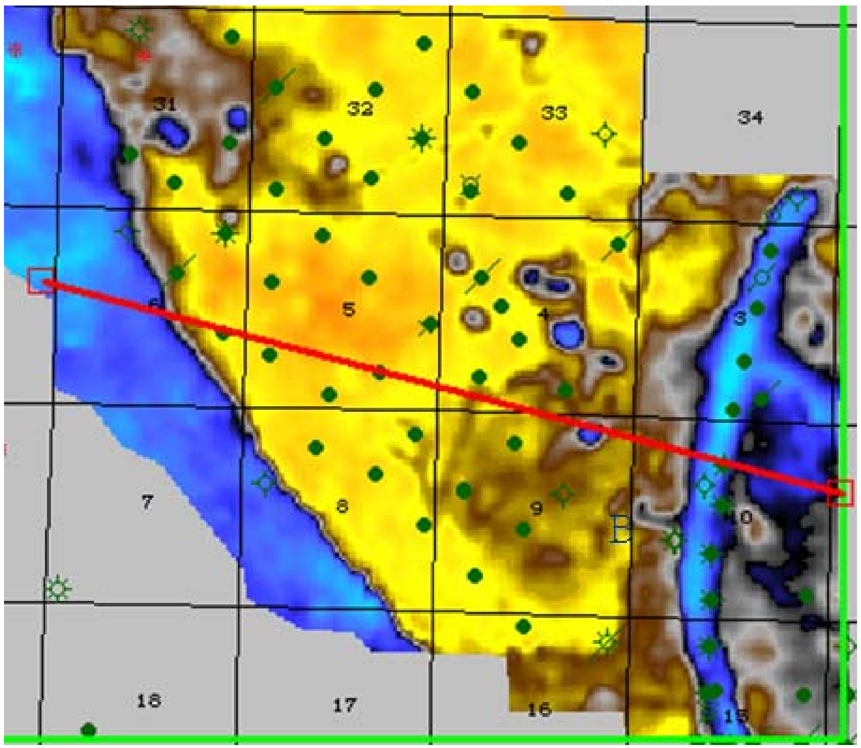
- Down to west bounding fault
- Chester IV cuts Pleasant Prairie anticline
- IV may be associated with deeper karst in Arbuckle
- Karsted Meramec surface evident in time structure



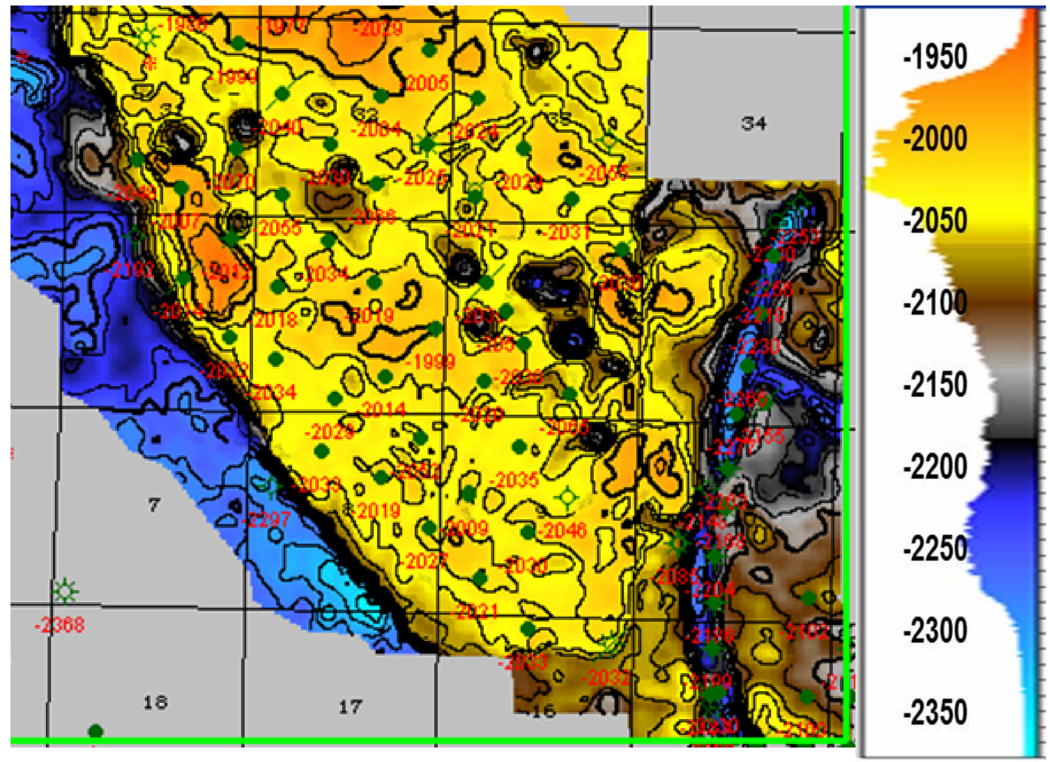
Interpretation work by Dennis Hedke

Meramec structure in time and depth

Meramec Time Structure CI = 2ms

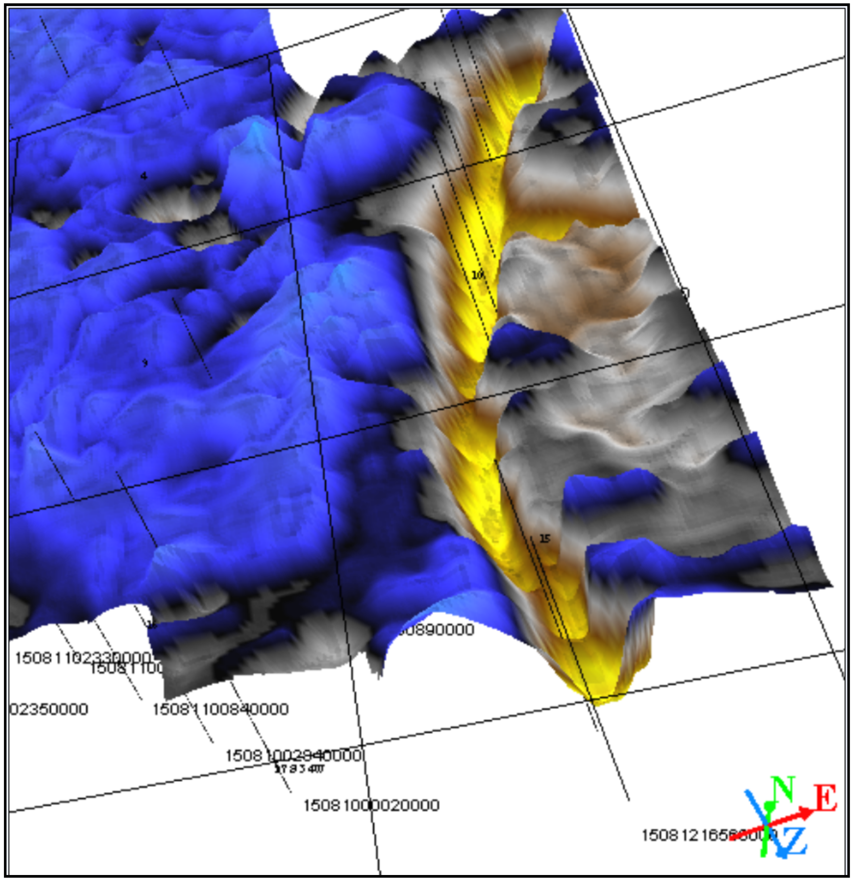


Meramec Seismic Depth Structure CI = 25 ft

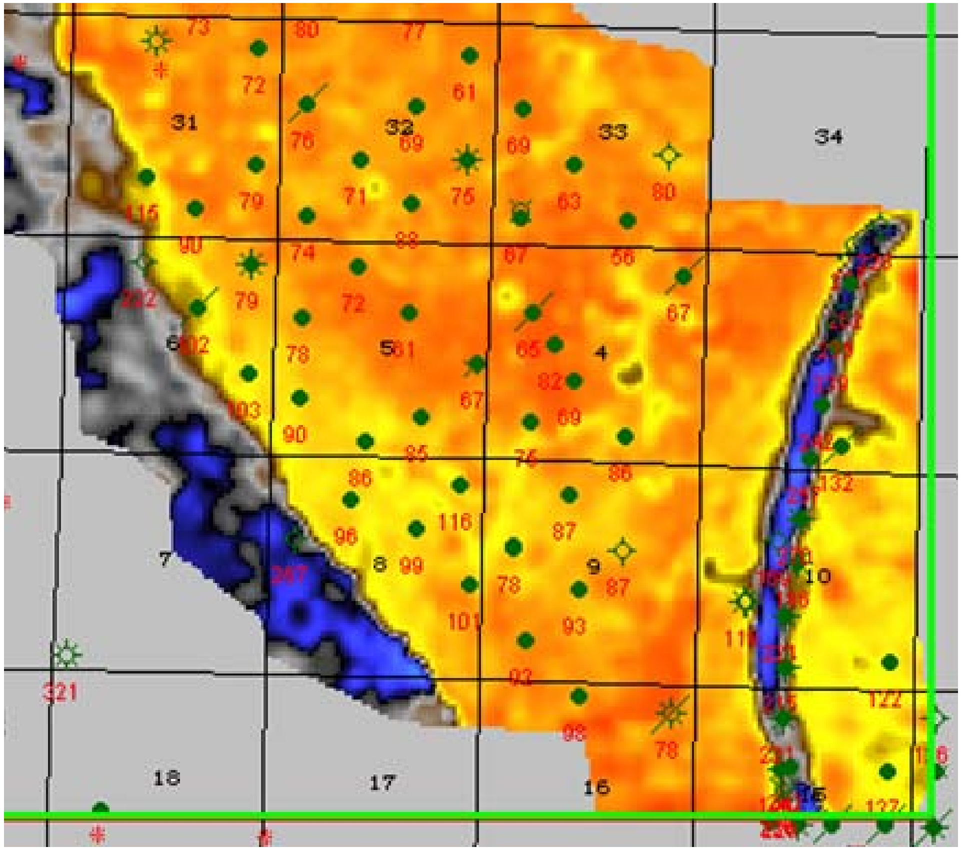


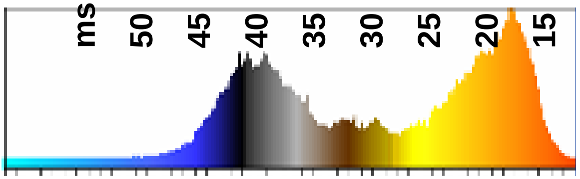
More views

Meramec seismic depth

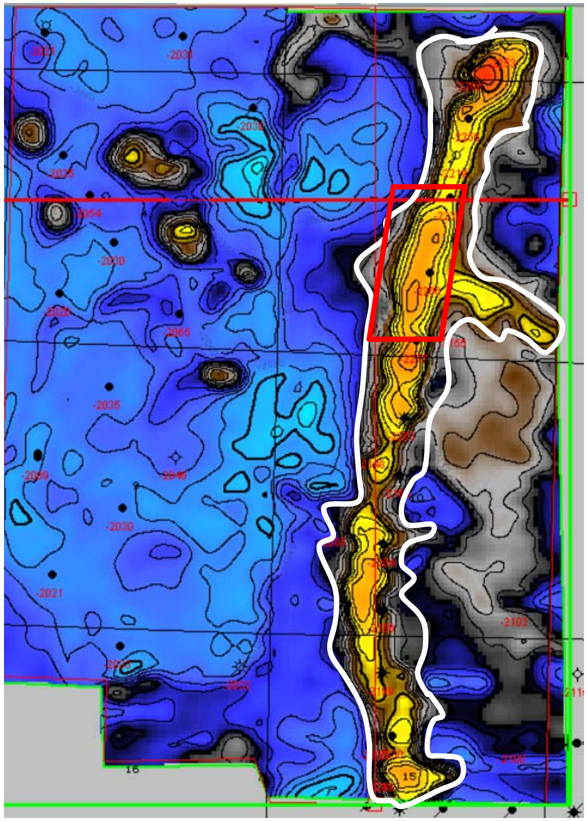


Morrow - Meramec Isochron

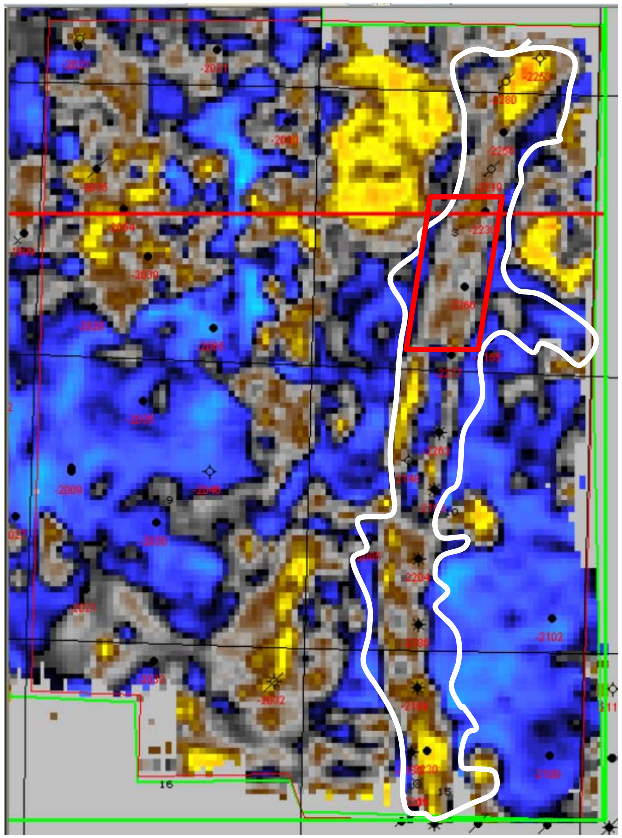




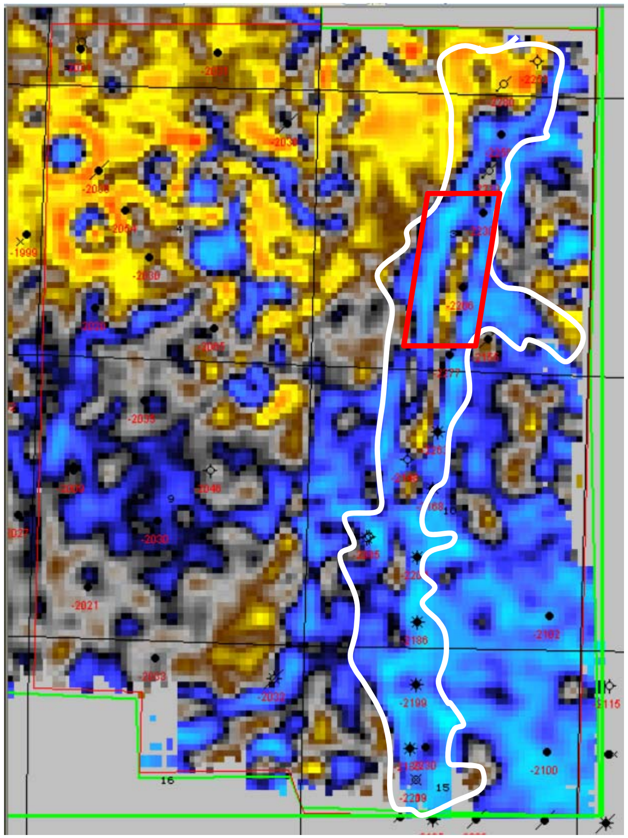
Early view of some basic attributes



Meramec seismic depth



Mean amplitude
0-15ms above MRMC

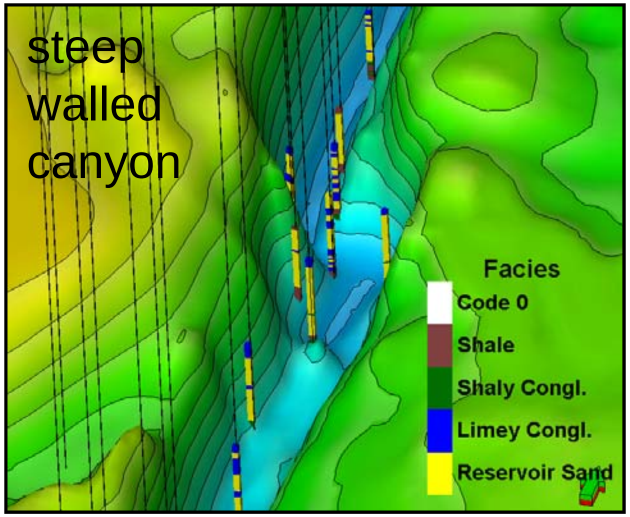


Mean “sweetness”
0-15ms above MRMC

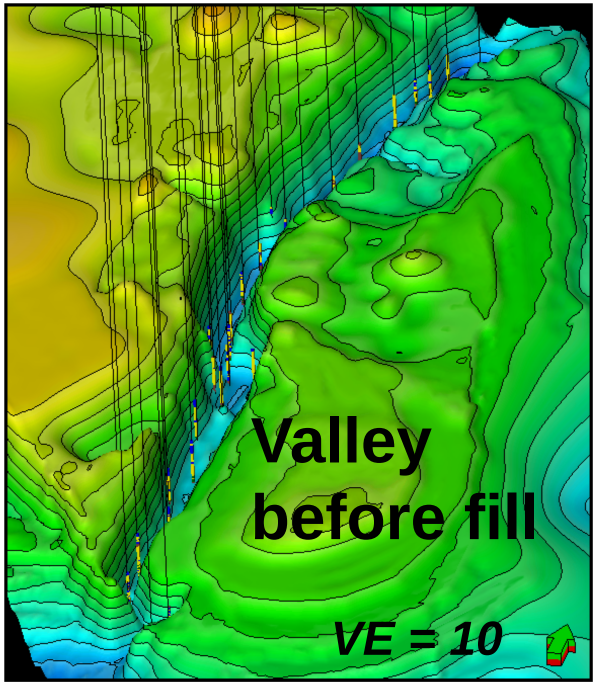
Isolated compartment yet to be resolved by seismic

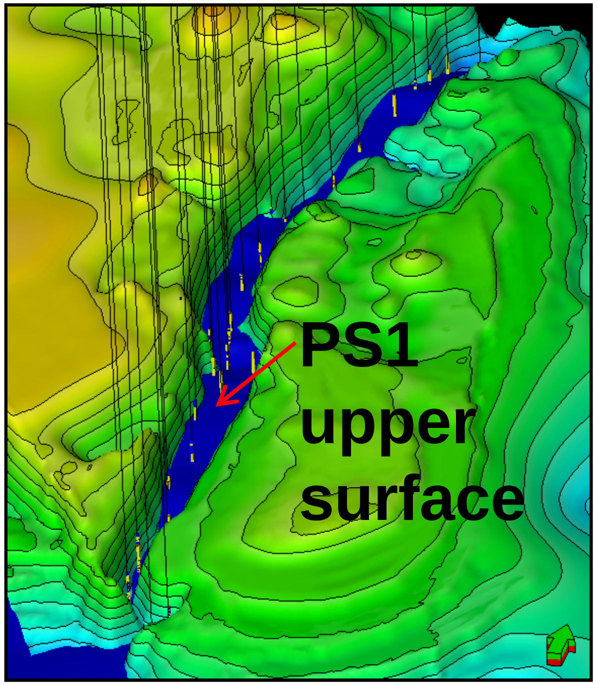
Model framework

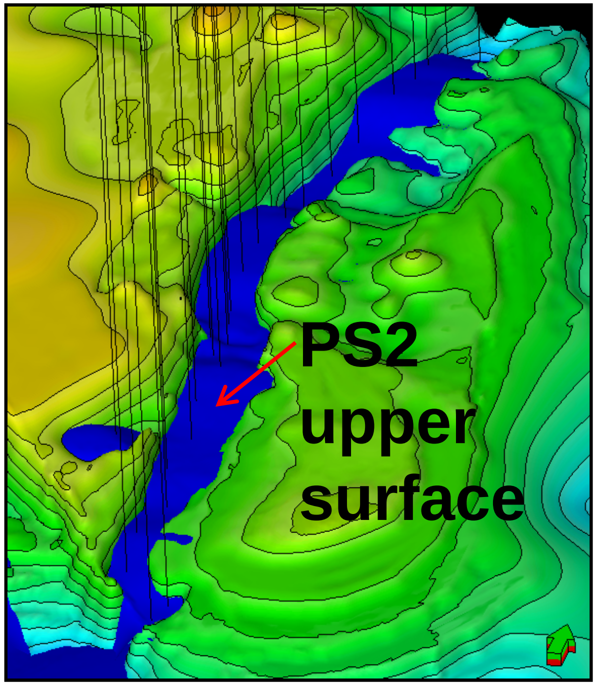
1. Build Meramec surface with 3D tied to wells
2. Define PS1 and PS2 tops in 25 wells in valley and build surfaces
3. Define PS1 volume (Base IV to PS1 surface)
4. Define PS2 volume (Top PS1 to PS2 surface, bounded by IV walls)
5. Layer PS2 volume: layers follow base
6. Layer PS1 volume: layers follow top
7. Cell dimensions: XY=55’, Z ~2 ft



Initial modeling work by Peter Senior. Geomod2 by Dubois.







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Equation of State from PVT and fluid composition

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Static Model Properties

Inputs: 25 valley wells with ***Phi**, **Lithofacies** and **Sw***

Import LAS curves at half-foot sample rate

Upscale to layer scale (2-ft)

Model Lithofacies

- Data analysis and variograms
- Sequential indicator simulation

Model Porosity

- Data analysis and variograms by lithofacies
- Sequential Gaussian simulation by lithofacies

Calculate Kxy by lithofacies

Sandstone	K(md)= 0.0047*PHI^3.9365
Conglomerate	K(md)= 0.0033*PHI^2.9396
Shale	K(md)= 0.01

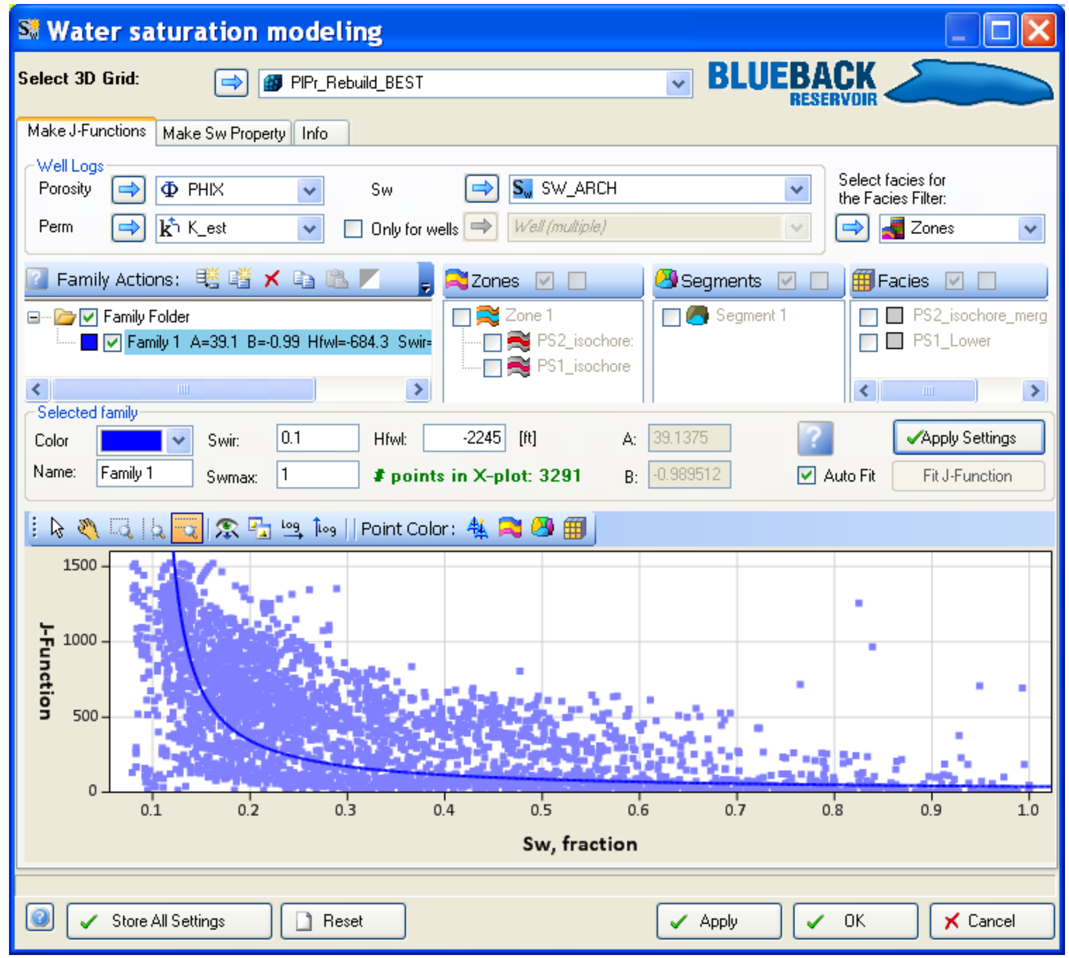
Estimate Sw by J-Function

Sw by Leverett J-Function

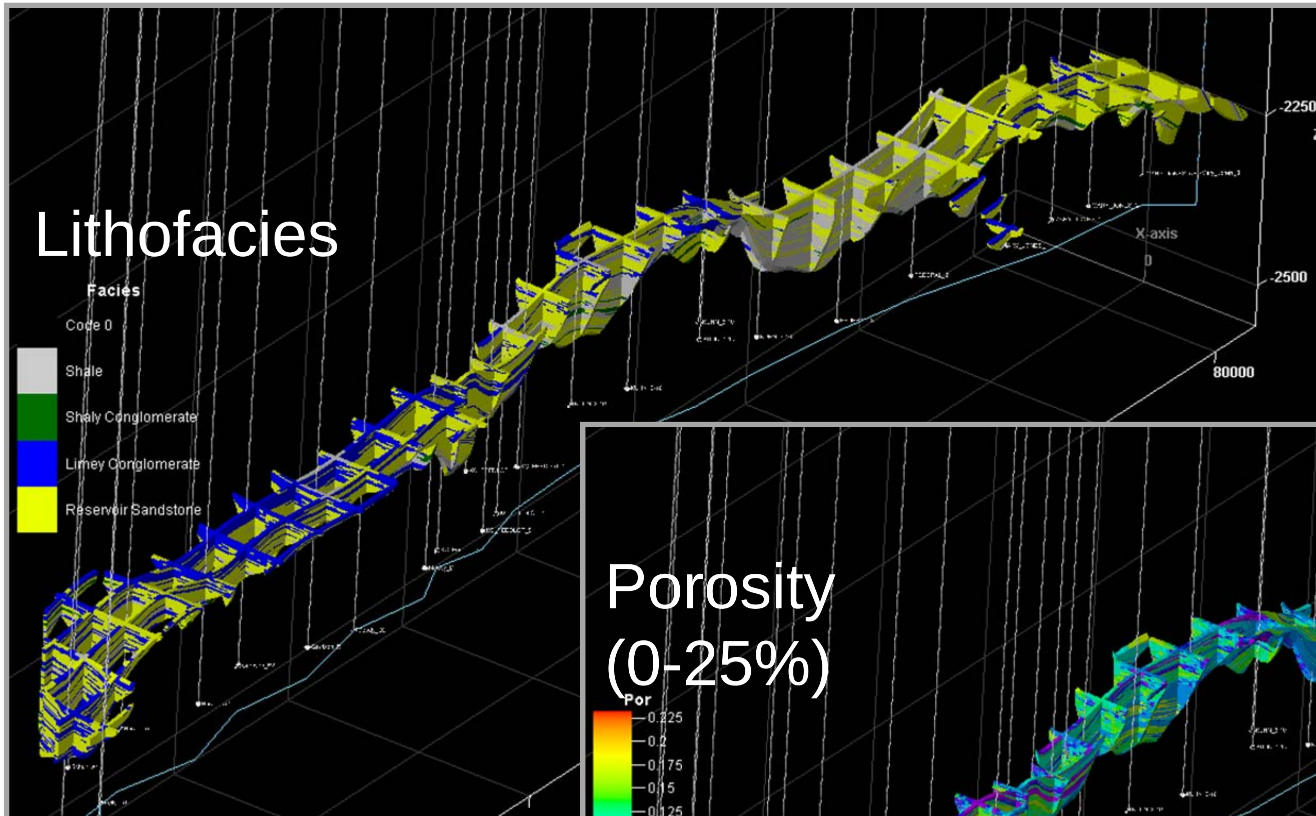
1. **O/W contact** estimated -2235. by operator confirmed Assume FWL~10ft below O/W contact (-2245)

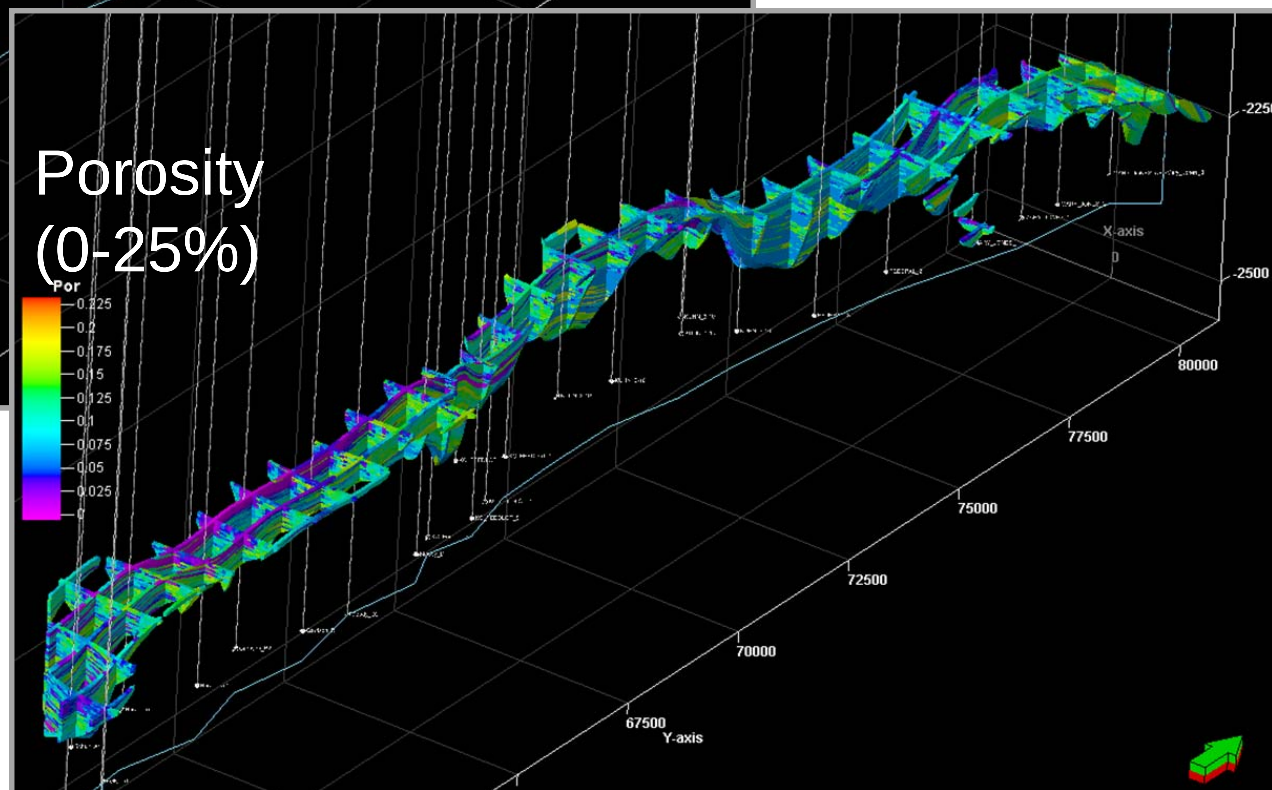
2. **E-Log inputs** for J-Function:
   - **PhiX** - Corrected porosity from core-log phi algorithm
   - **Kest** - from empirically derived K-phi transform equations
   - **Sw_Arch** – calculated Sw using standard Archies equation (m,n = 2, Rw=0.04)

3. **Generate J-Function** and apply at model cell scale
   - Model cell inputs: **Phi, K, HaFwl**
   - **K is lithofacies** sensitive, so facies is taken into account

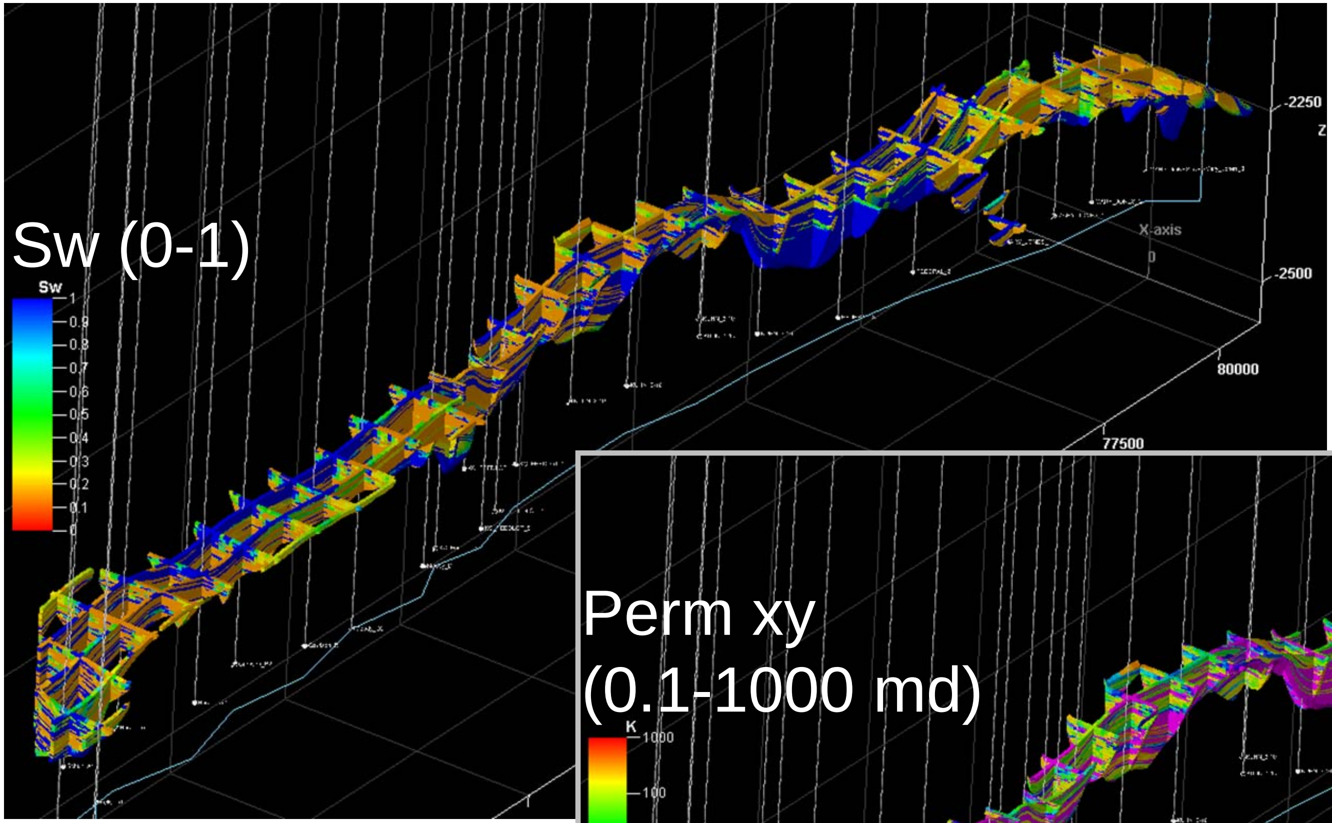


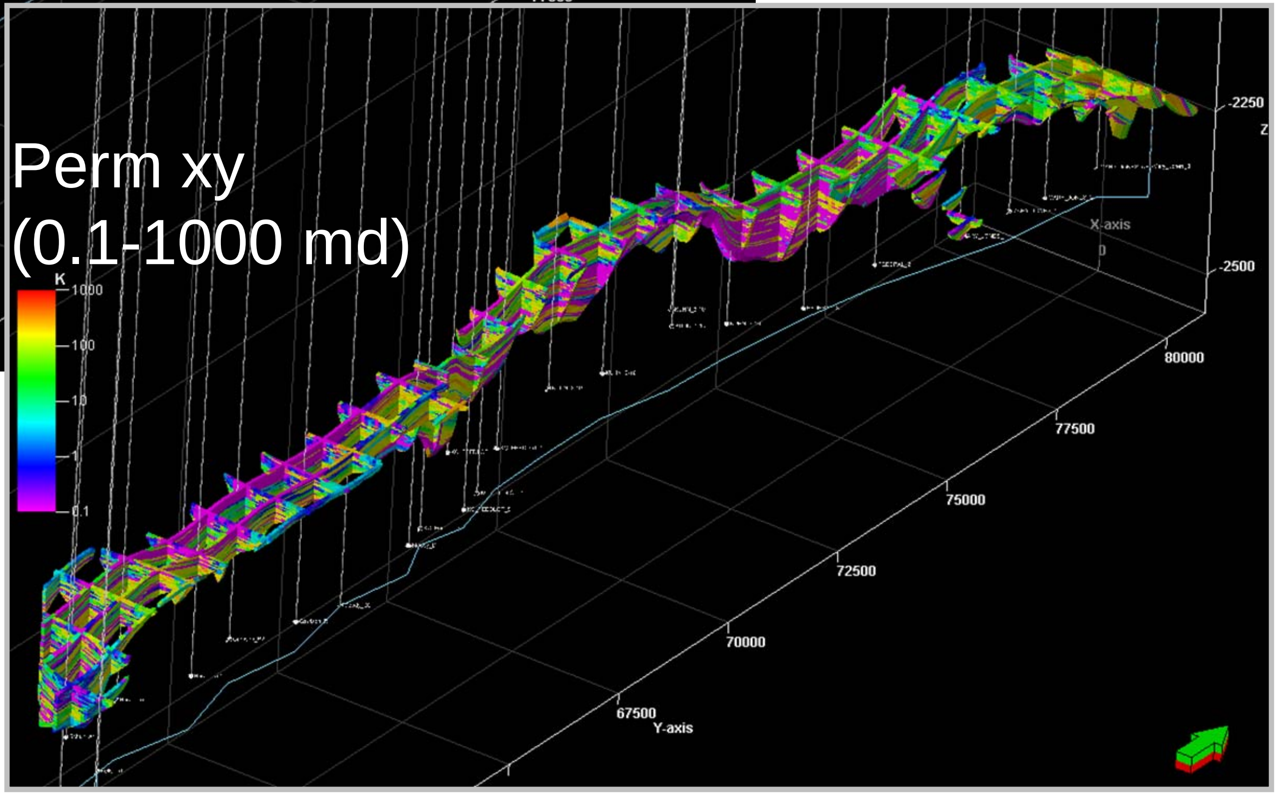
Lithofacies and Porosity





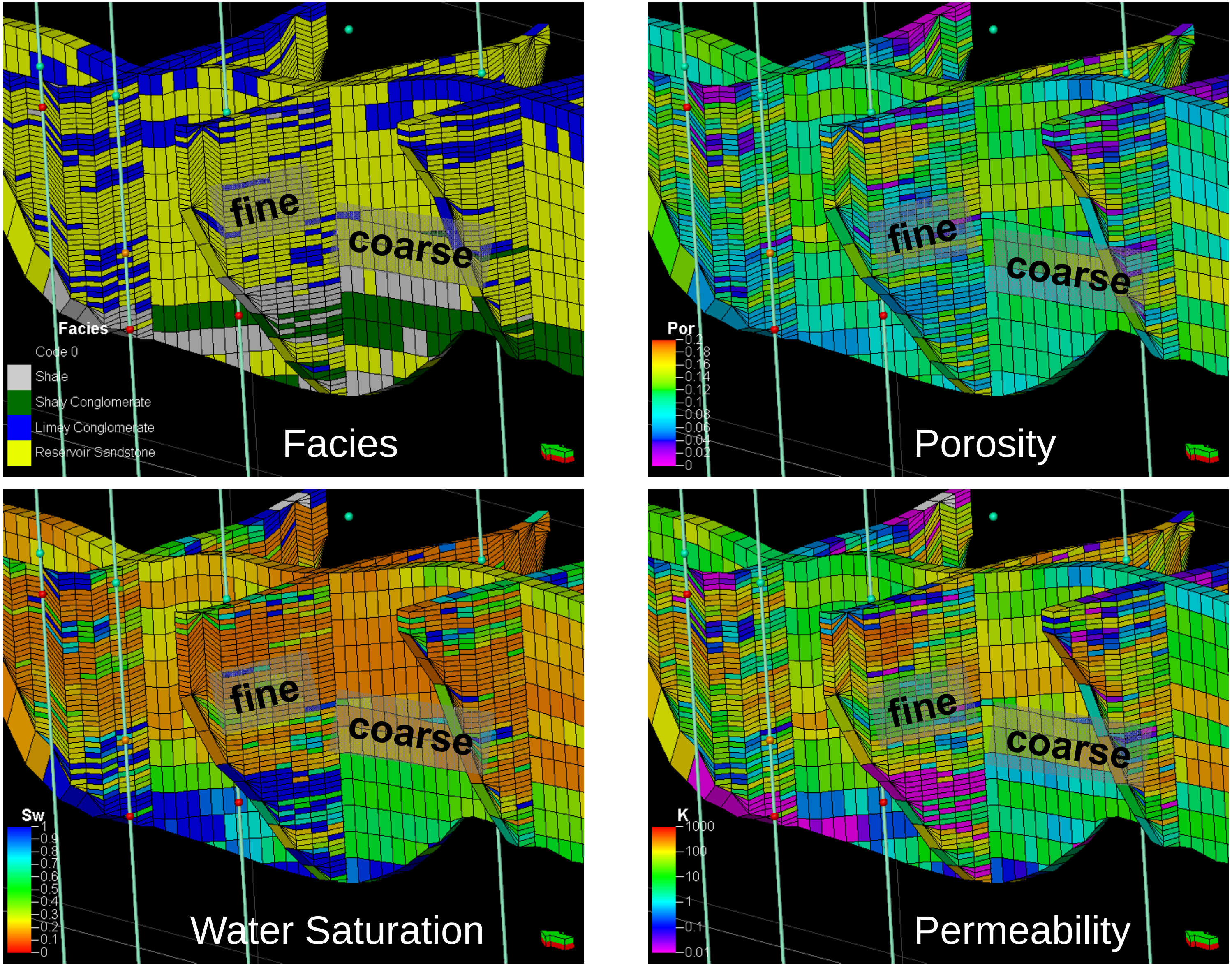
Water Saturation and Permeability





Upscale to coarse grid and export for simulation

Fine-grid static model 2-ft *h* cells were upscaled to 10-ft *h* cells for simulation.



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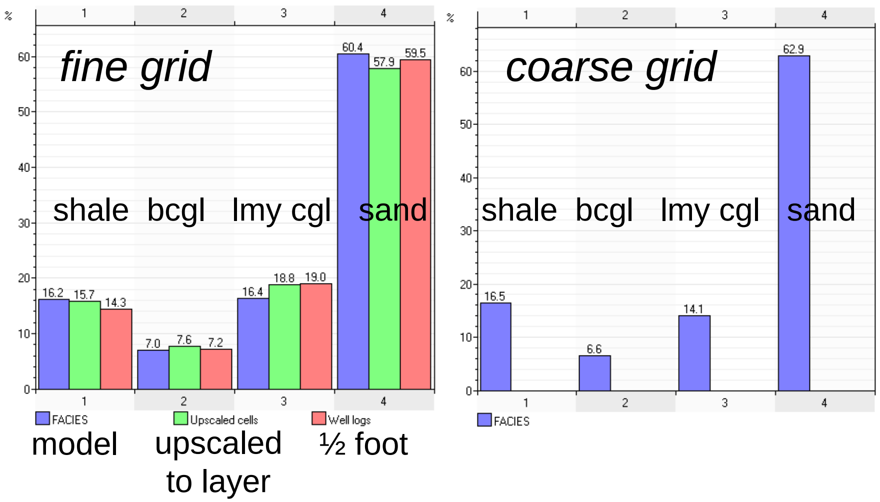
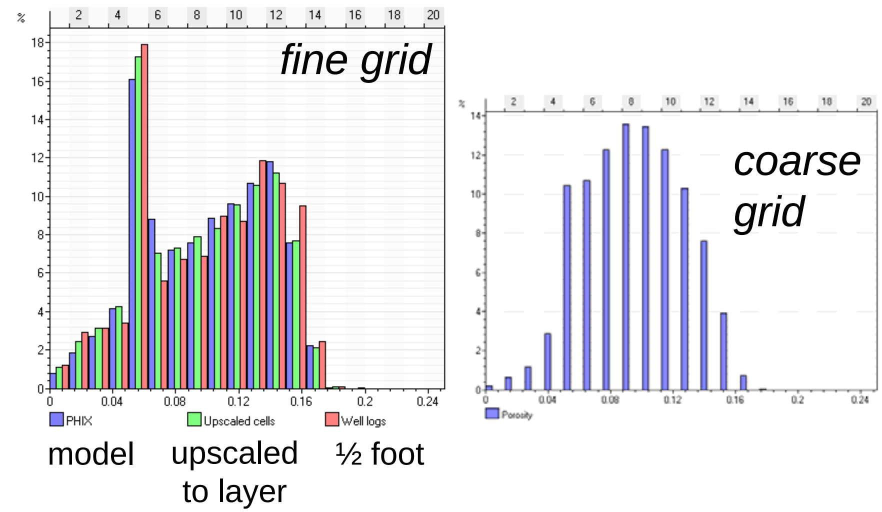
Properties at varying scales

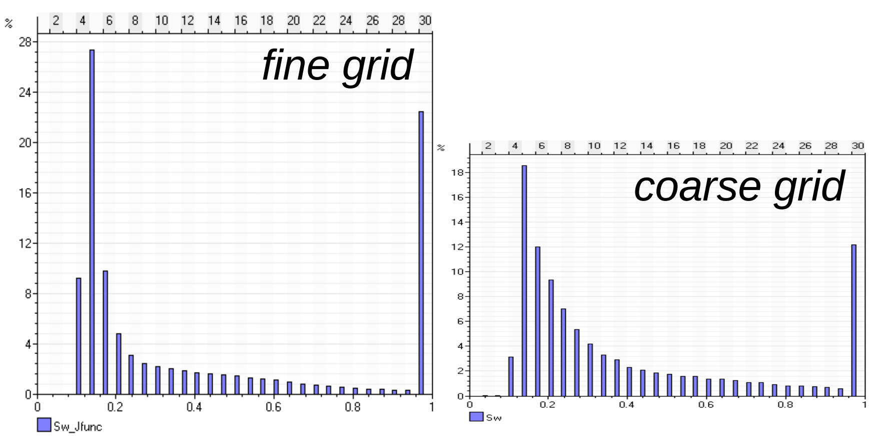
Lithofacies



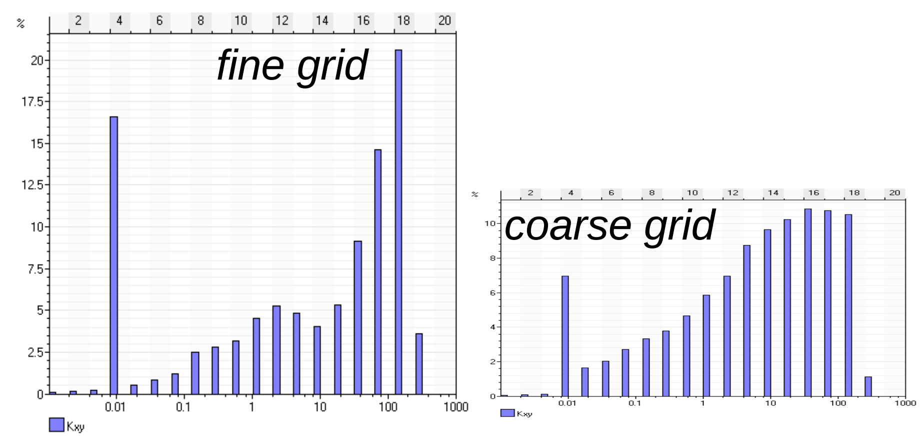
Porosity



Sw by J-function

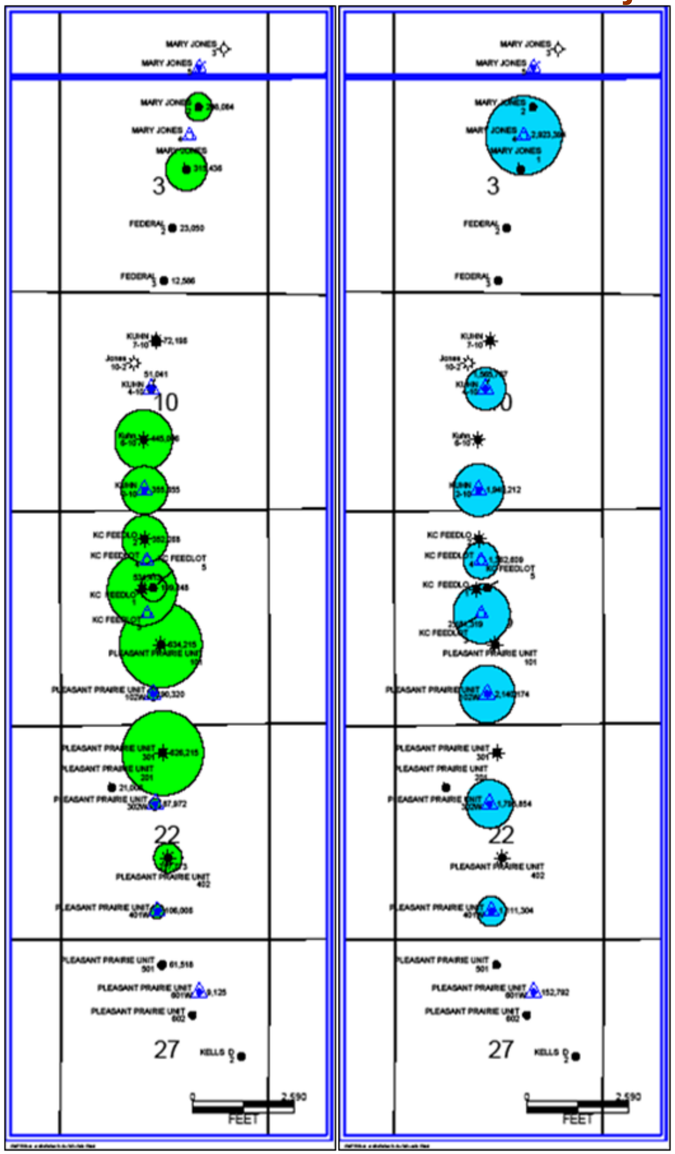


Permeability XY



Static Model Volumetrics

Cum. Oil Cum. Wtr Inj



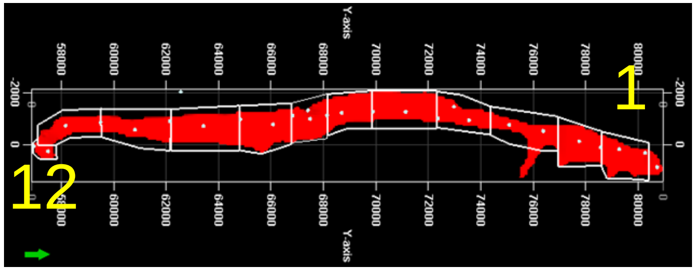
Geomod Build 2

Parameters

FVF	1.18
Swir	0.1
Phi cut-off	0.06
FWL	-2245

Region	BV [*10^3 RB]	PV [*10^3 RB]	HCPV [*10^3 RB]	STOIP [*10^3 STB]	Cum Prod [*10^3	RF
Polygon1	14,258	1,529	990	840	208	24.8%
Polygon2	15,742	1,639	1,184	1,004	315	31.4%
Polygon3	11,531	1,132	547	464	36	7.7%
Polygon4	9,396	915	515	437	98	22.4%
Polygon5	24,363	2,757	1,915	1,623	648	39.9%
Polygon6	19,645	2,193	1,640	1,390	530	38.1%
Polygon7	22,854	2,618	1,955	1,656	734	44.3%
Polygon8	29,898	3,732	2,958	2,506	715	28.5%
Polygon9	28,098	3,334	2,603	2,206	752	34.1%
Polygon10	16,751	1,870	1,462	1,239	331	26.7%
Polygon11	15,600	1,849	1,385	1,173	125	10.7%
Polygon12	1,788	183	122	103	7	6.9%
	209,924	**23,751**	**17,276**	**14,641**	**4,500**	**30.7%**

twelve patterns



Basic Workflow

Inputs

Framework data:

- Formation tops
- Sequence stratigraphy
- Depth-converted seismic structural surfaces
- Seismic attributes

Well-scale data

- Lithofacies (by NNet)
- Core data
- Porosity (corrected)
- Water saturation (Archies)

Sw solution

- Oil/water contacts and free water level
- Sw by Leverett J-function

Static Model

Structural wire frame model

- Incised valley by seismic and well tops
- Two parasequences
- 0-249 layers
- Cells: XY=55 ft, Z=2ft
- 700,000 active cells

Fine- grid cellular property model

- Lithofacies
- Porosity
- Permeability (XY)
- Water saturation
- OOIP

Upscale model

- Phi, K, Sw
- 0-25 layers
- Cells: XY=55 ft, Z=10 ft
- 65,000 active cells

Dynamic Model

✓ **History matched primary and secondary** black oil simulation

✓ **Forecast CO2 EOR** compositional simulation

Equation of State from PVT and fluid composition

Recurrent well history

- Mechanical
- Fluids produced and injected

Simulation modeling

- ✓ **Petrel export (RESCUE format) for simulation**
- ✓ **PVT EOS** in WINPROP : Chester PVT reports and CO_2 swelling tests at Wellington
  - **IMEX Black Oil PVT** for Black-Oil history match stage
- ✓ **Saturation functions:** Gravity Stable (VE) and Corey functions.
  - **Capillary pressure** based on RESCUE initial water saturations
- ✓ **Initialization** using WOC -2245 ft SS, Pressure 1389 psia at WOC
- ✓ **Well production and injection data** from operator records (1990-2011)

- ✓ **Initial history matching using black oil simulation** (IMEX) and CMOST
  - Check sensitivities to matching modifications
  - Refine well (Oil prod) matches
  - Resolve Pressure Match
- ❑ Convert history matched model to **EOS simulation (GEM)**
  - Working through convergence issues with GEM
- ❑ **Prediction cases** using GEM
  - NFA
  - CO_2 Injection Cases

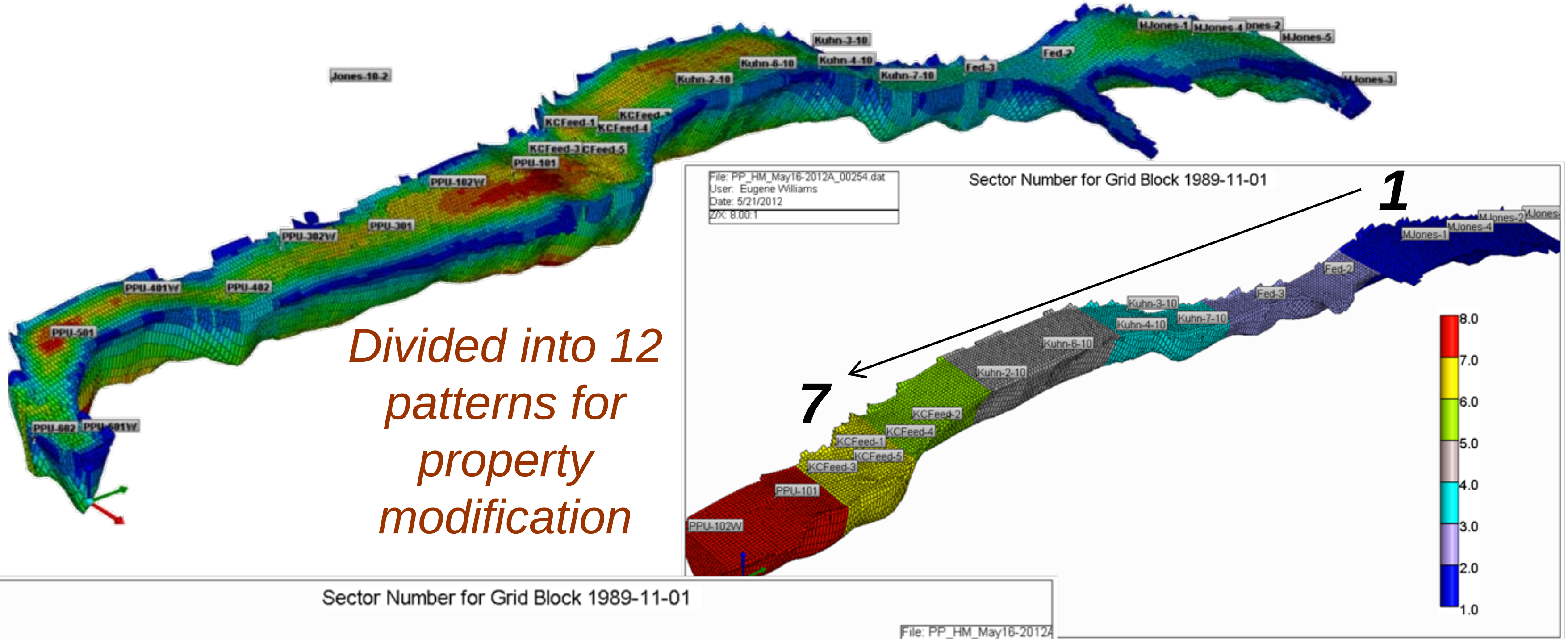
Black Oil Simulation

Reservoir simulation work by Eugene Williams

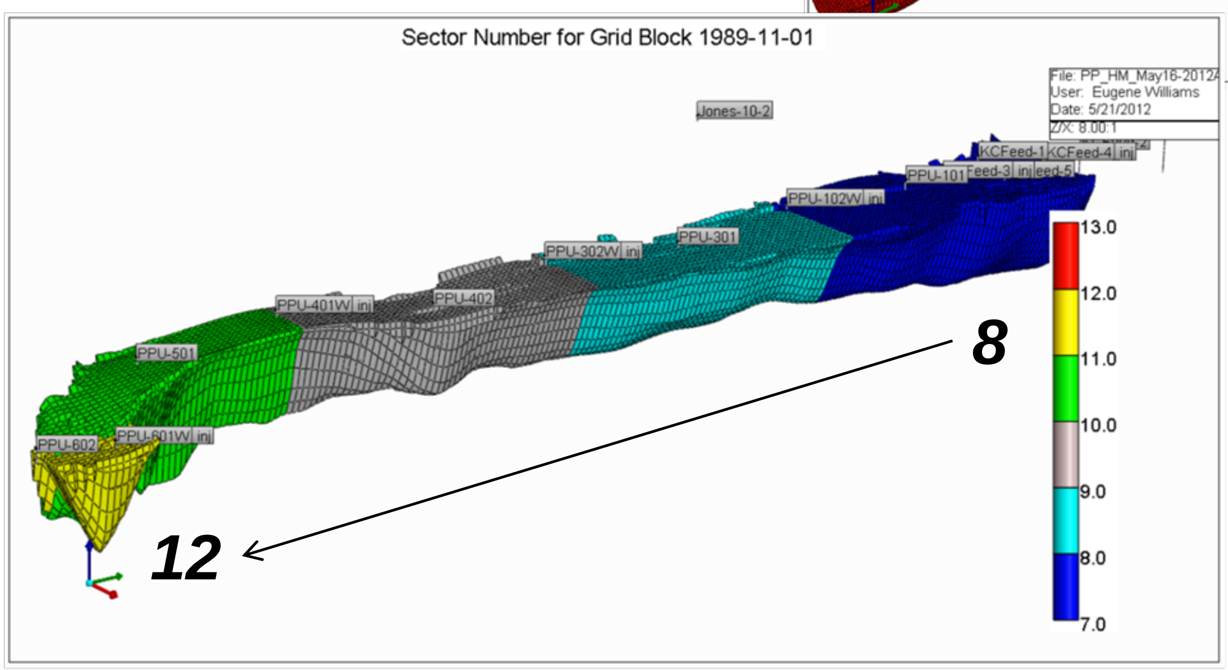
General workflow

1. Match fluid & pressure histories (1990-2011)
2. Define 12 patterns (polygons)
3. Modify properties to attain match
    - Pore volume modifiers by polygon
    - I-Permeability modifiers by polygon
    - I and J Transmissibility modifiers (by polygon)
    - Relative permeability
        - Psuedo-functions – Rocktype, VE, Stratified – by polygon
        - End points (SWCR, SOWR, KRW) by region
4. CMOST automation to run hundreds of iterations to get close
5. QC and manual inputs for final

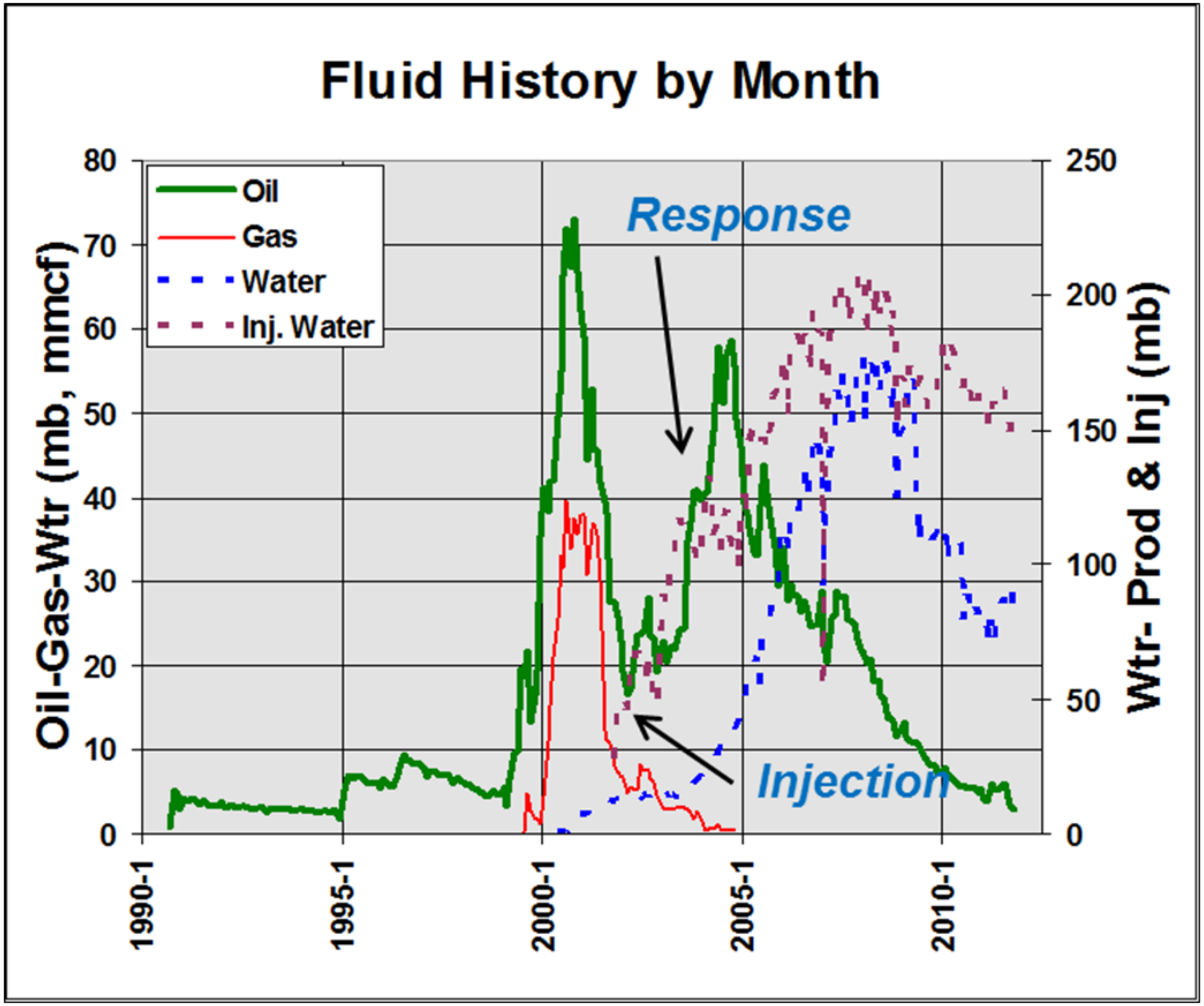
Simulation model views



Divided into 12 patterns for property modification

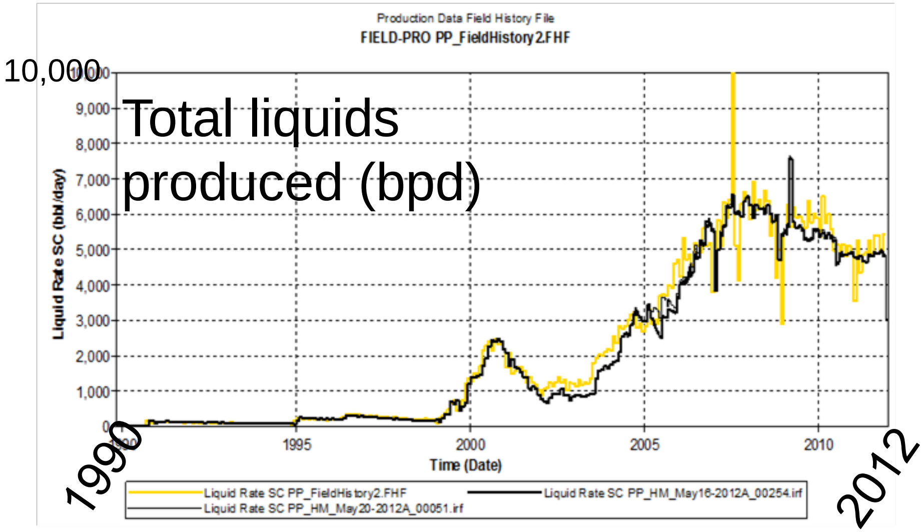


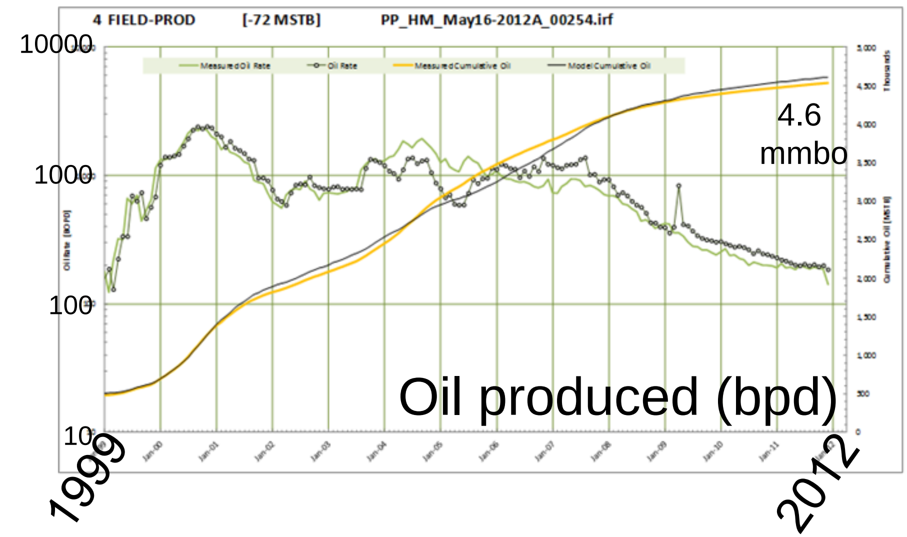
Field History - review

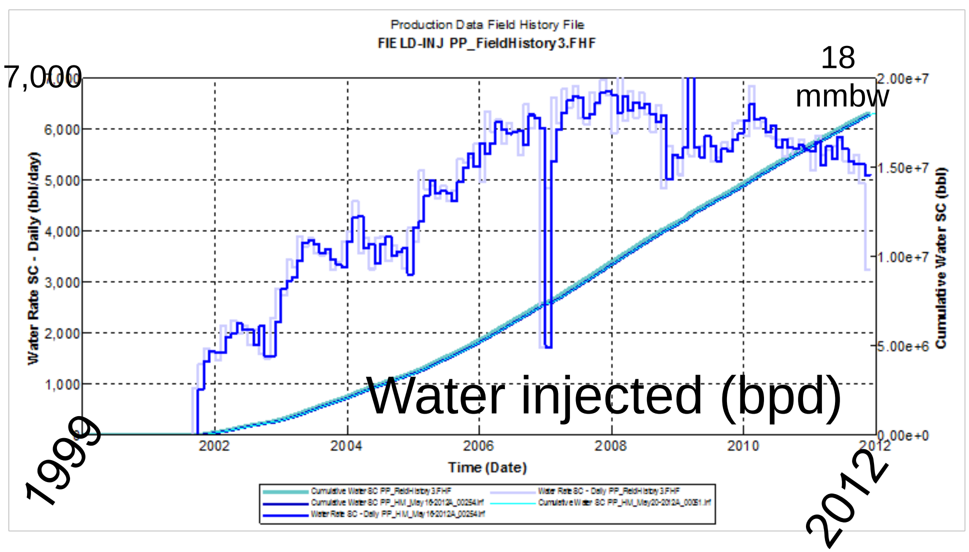


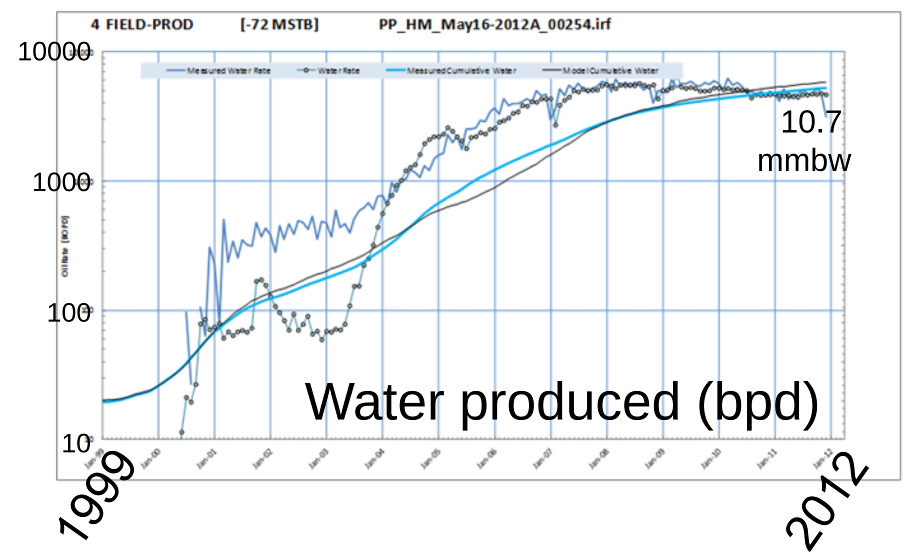
Field-scale matches

Lighter colored are actual, darker are modeled

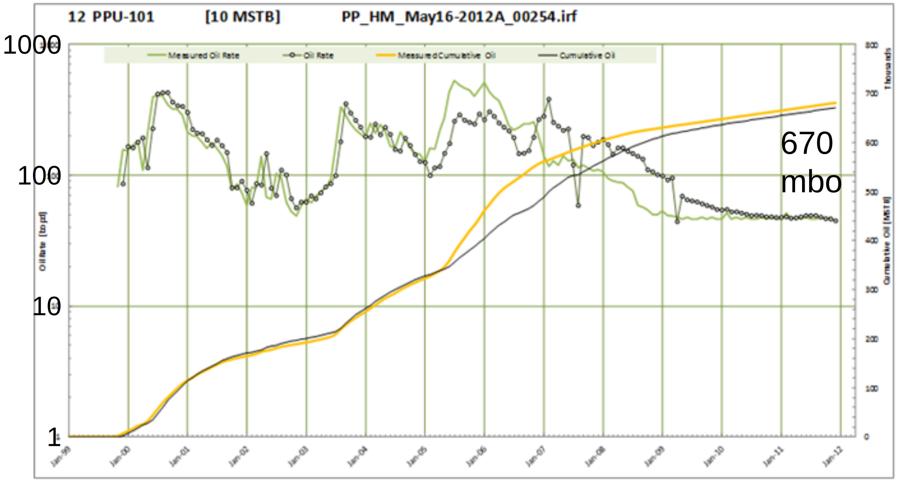


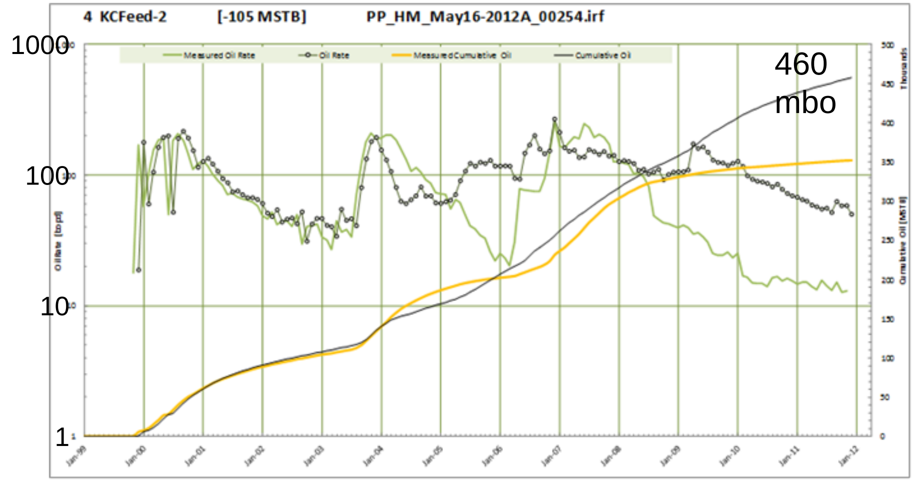


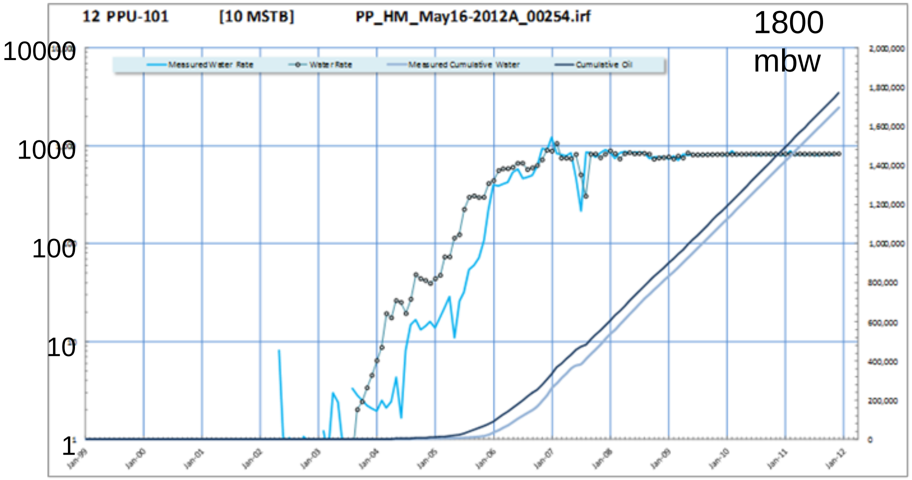


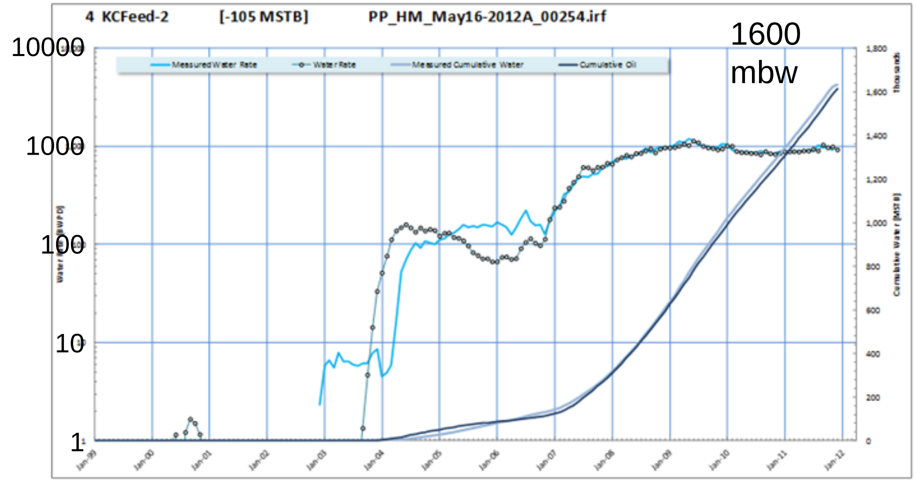


Example individual well matches









Discussion of modifications

Significant increase in permeability at low end

- Possibility of natural fractures (some noted in core)

Reduction in mobile oil by up to 30% by polygon (by reduction in pore volume)

- Static model pore volume to high (model geometry)
- Initial model Sw estimate too low
- Tortuosity not modeled (barriers or baffles not accounted for)
- Water bypass

Possibly several of above

- Static model RF is ~31% of OOIP
- Dynamic model RF is ~43% of "reduced" OOIP
- RF probably somewhere in between

Summary

- ✓ Characterization, modeling and black oil simulation is fair representation of reservoir
- ✓ Will proceed with CO_2 EOR and storage simulation

Improvements possible

1. More seismic attribute work (could require extensive reprocessing)
2. Rebuild Petrel model for better volumetrics
3. Another complete iteration

On to the next field……complete all four in 2012

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