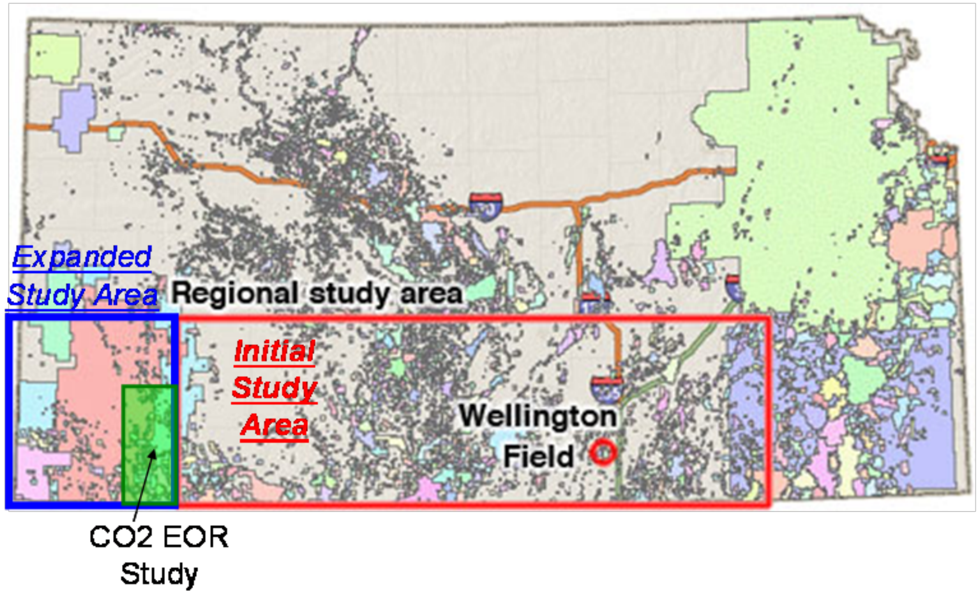
Southwest Kansas CO2 EOR Initiative
Chester and Morrow Reservoirs

Western Annex to Regional CO2 Sequestration Project

DE-FE0002056

Martin K. Dubois. Improved Hydrocarbon Recovery, LLC
John C. Youle, Sunflower Energy, LLC



What this is all about

The project

- CO_2 EOR technical feasibility study – Chester IVF and Morrow
- Five industry partners (operators of fields)
- Part of larger KGS-industry CCS and EOR study
- Will not inject CO_2 – paper study only
- Get fields in study "CO_2-ready"

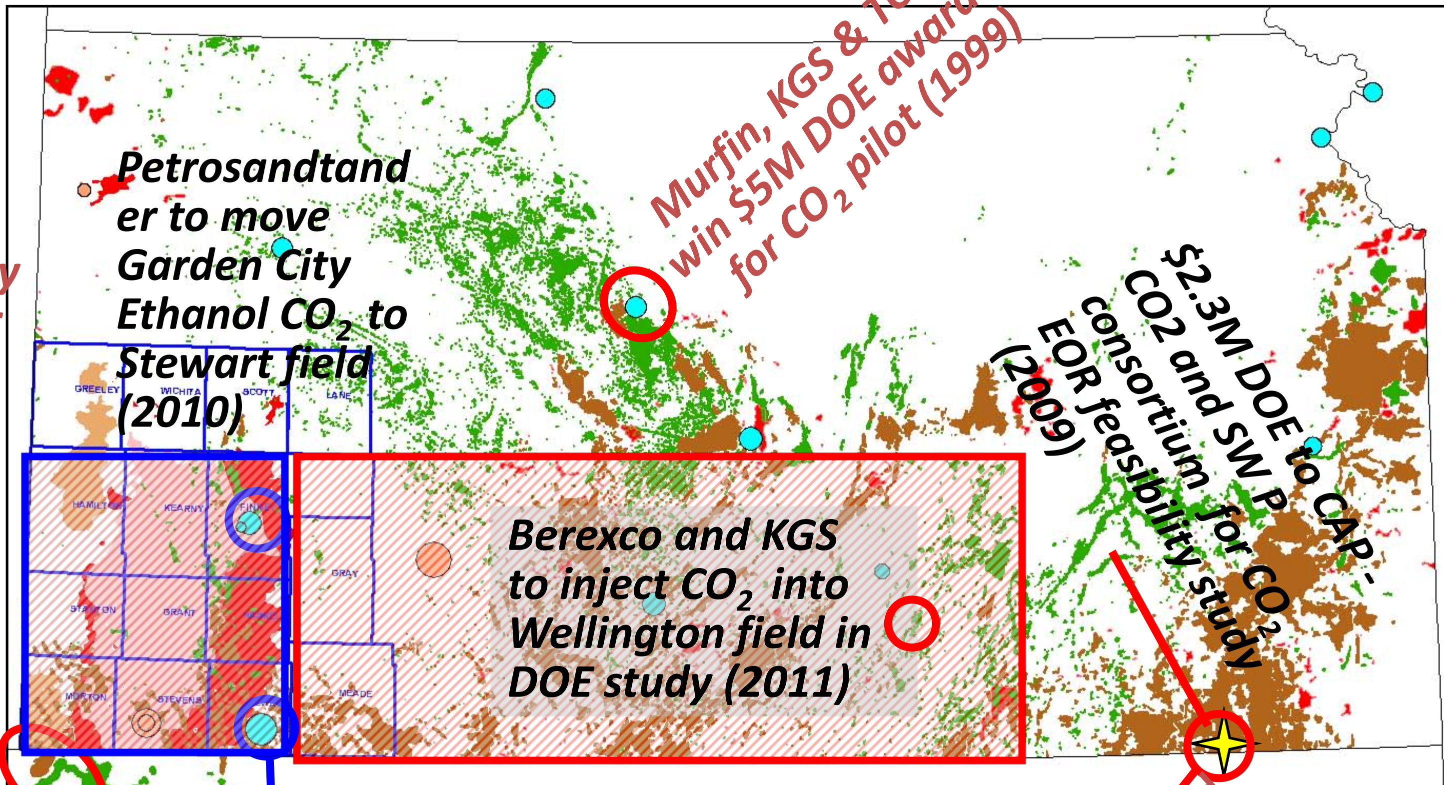
Discussed today

- CO_2 EOR highlights in Kansas
- Project description
- Initial reservoir depositional model (by Youle)

CO2 EOR and CCS in Kansas

Kansas Ethanol Plants (2008)

Blue – active, Tan - planned



KGS and five industry partners expand CCS and EOR study with another $5M DOE grant (2010)

Petrosandtander to move Garden City Ethanol CO_2 to Stewart field (2010)

Murfin, KGS & TORP win $5M DOE award: for CO_2 pilot (1999)

$2.3M DOE to CAP - CO2 and SW P consortium for CO_2 EOR feasibility study (2009)

Berexco and KGS to inject CO_2 into Wellington field in DOE study (2011)

Transpetco builds CO_2 pipeline from Denver City to Postle Field (1997)

Chapparal buys Liberal Ethanol CO_2 for Okla. EOR (2009)

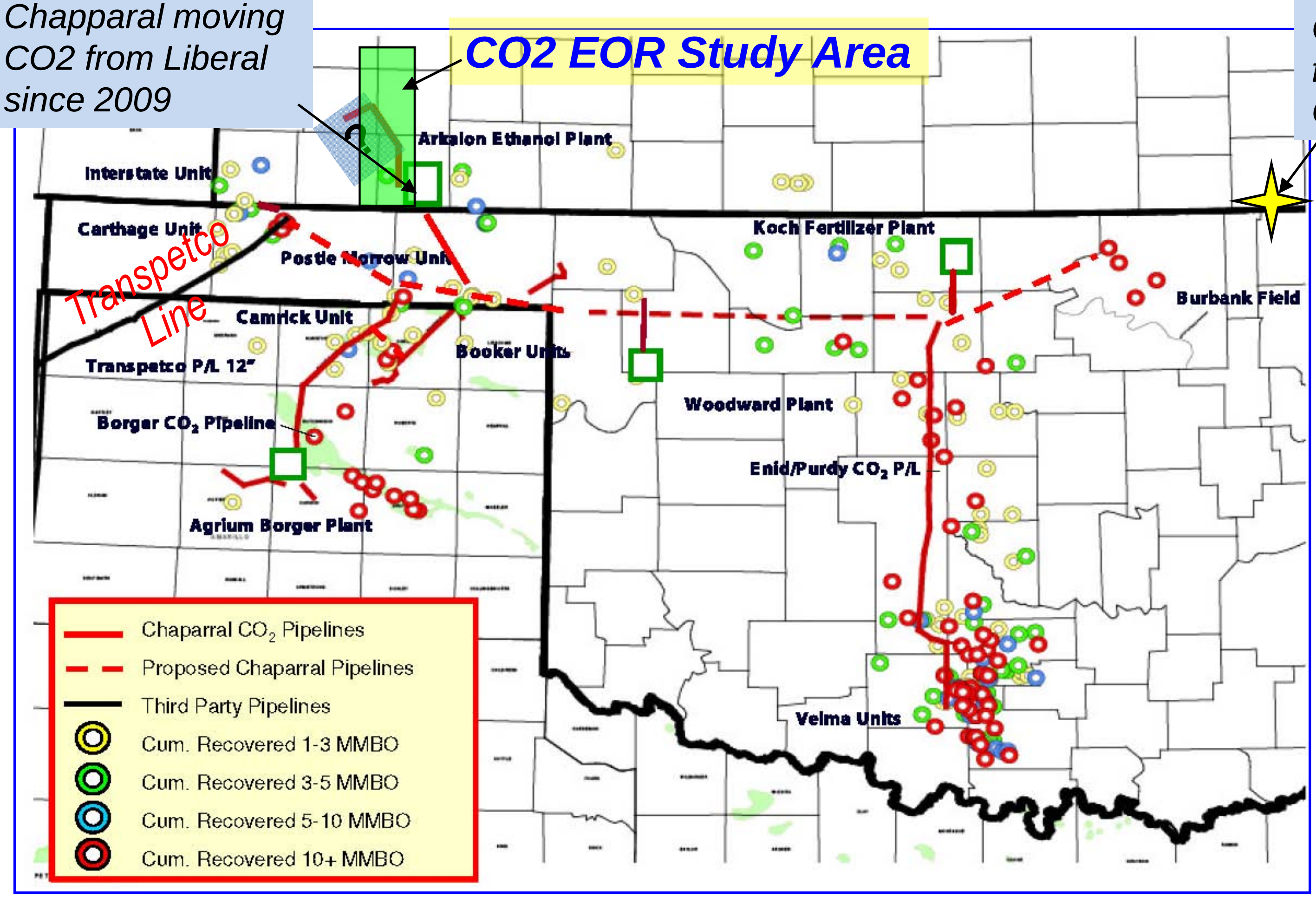
Berexco and KGS to study Arbuckle CO_2 storage potential with $5M DOE grant (2009)

Chapparal and CVR ink deal for fertilizer CO_2 for EOR (2011)

Infrastructure is gradually building: Oklahoma CO2 Infrastructure

Chapparal moving CO2 from Liberal since 2009

3/29/2011 Chapparal contract for 2000 tons/day CO2 from CVR

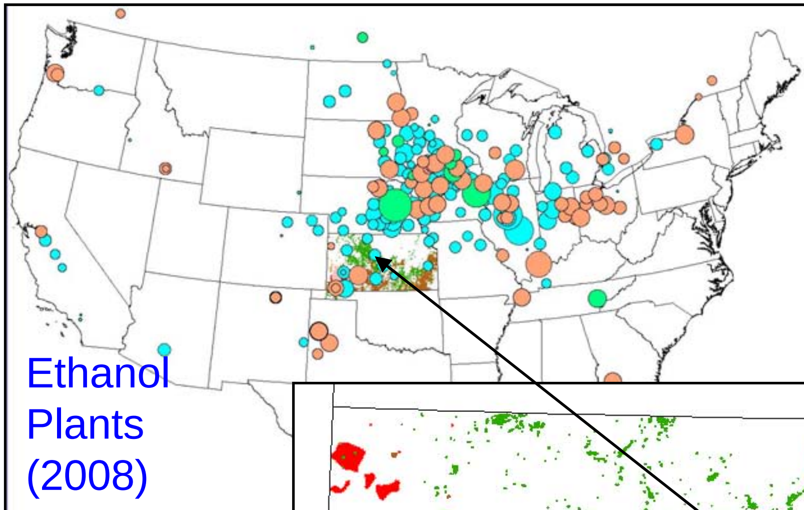


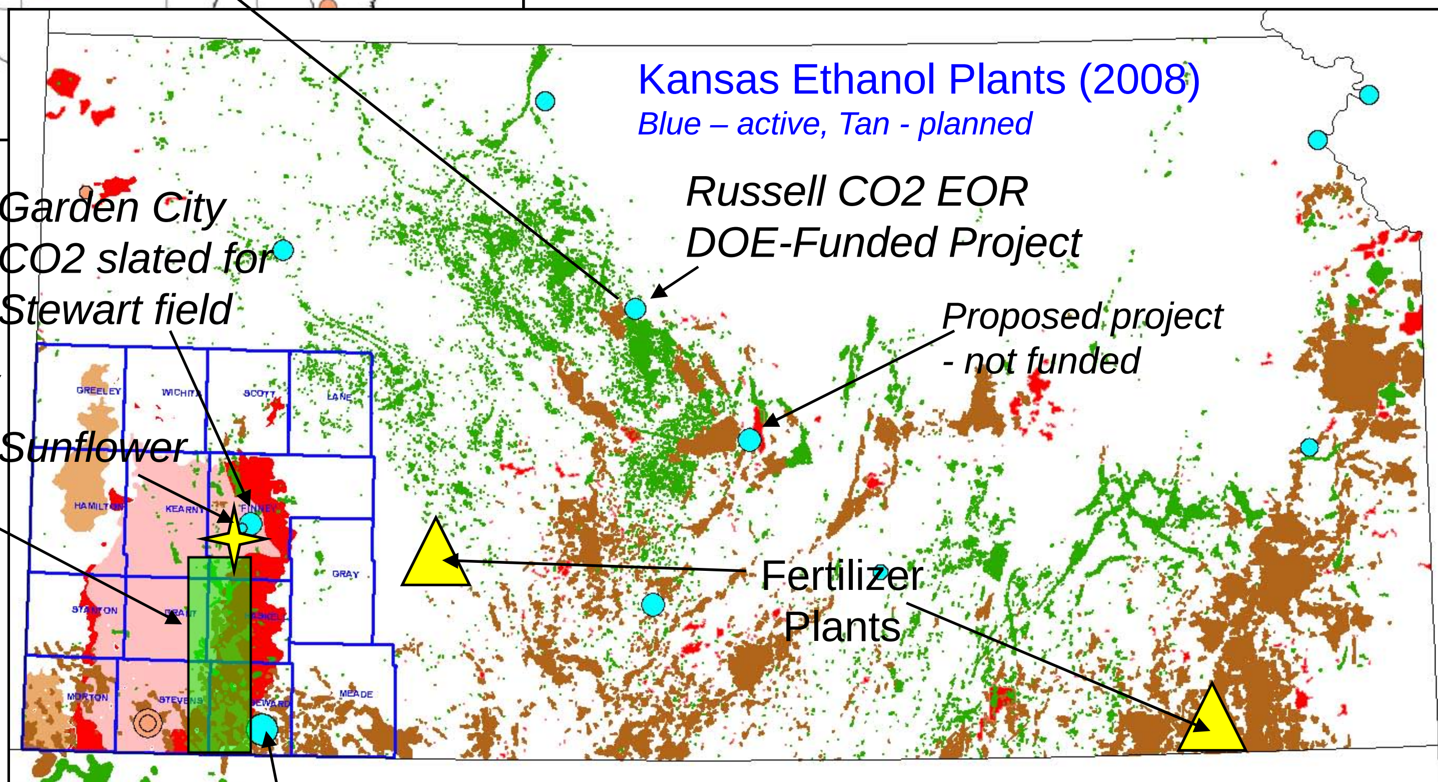
Red solid lines currently deliver CO2 from ethanol and fertilizer plants to oil fields

Modified From: Chaparral Energy presentation at JP Morgan conference (March 2010)
http://www.chaparralenergy.com/pressreleases/JP%20Morgan%20HY%20Conf%20March%202010.pdf

Activity related to ethanol plants

- Ethanol plants in Midwest produce 1.2 BCF CO2/day, on par with “new” CO2 injected in West Texas
- Challenge 1: getting it to the oil fields
- Challenge 2: reliability risk



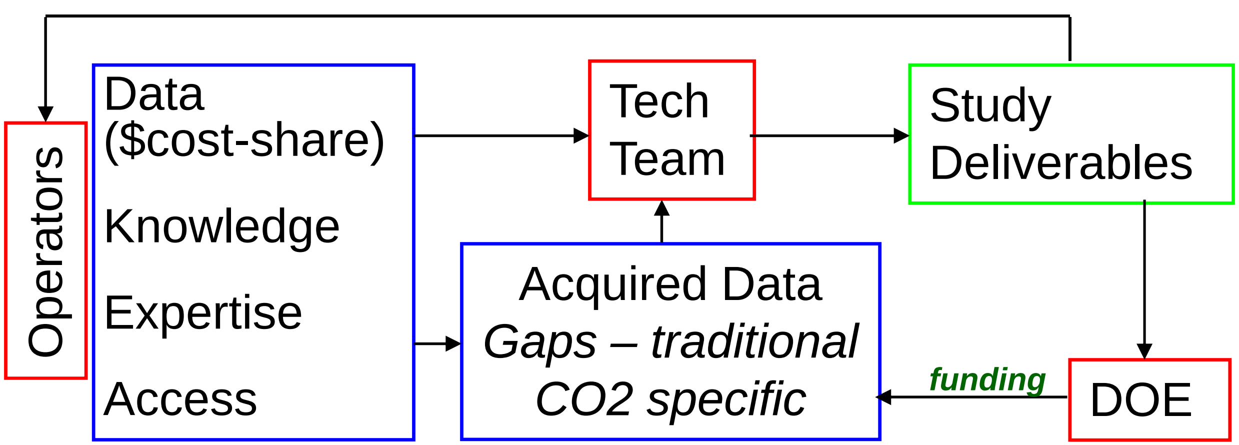


Circumstances and Opportunity

Circumstances make sense for consortium-based study

- Chester and Morrow reservoirs are **good waterfloods**, and likely to be **good CO2 EOR candidates**
- **No single field** is large enough to justify the capital required for CO2 infrastructure alone
- **No single operator** has oil resource base to justify capital costs
- **$5M DOE** opportunity for CO2 EOR and sequestration studies
- **CO2 EOR could happen with Cooperation and/or Aggregation**

Consortium-based study structure



Tech Team:
✓KGS staff
✓Skilled consultants
plus
✓Operator steering committee

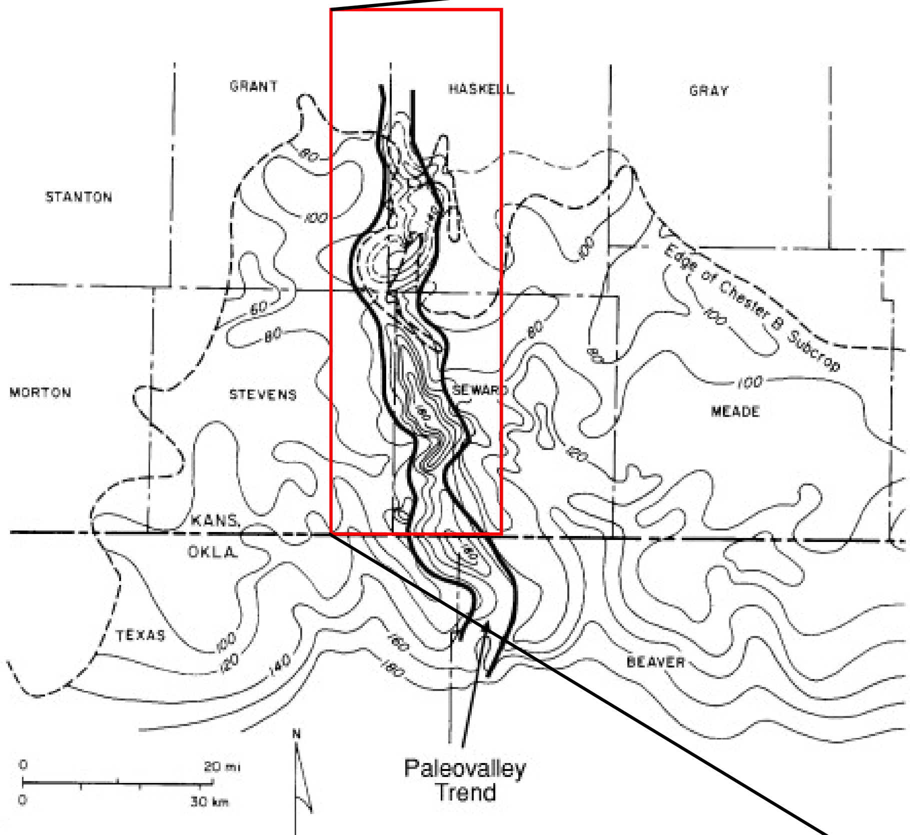
Strong Operator Support and Deep Technical Bench

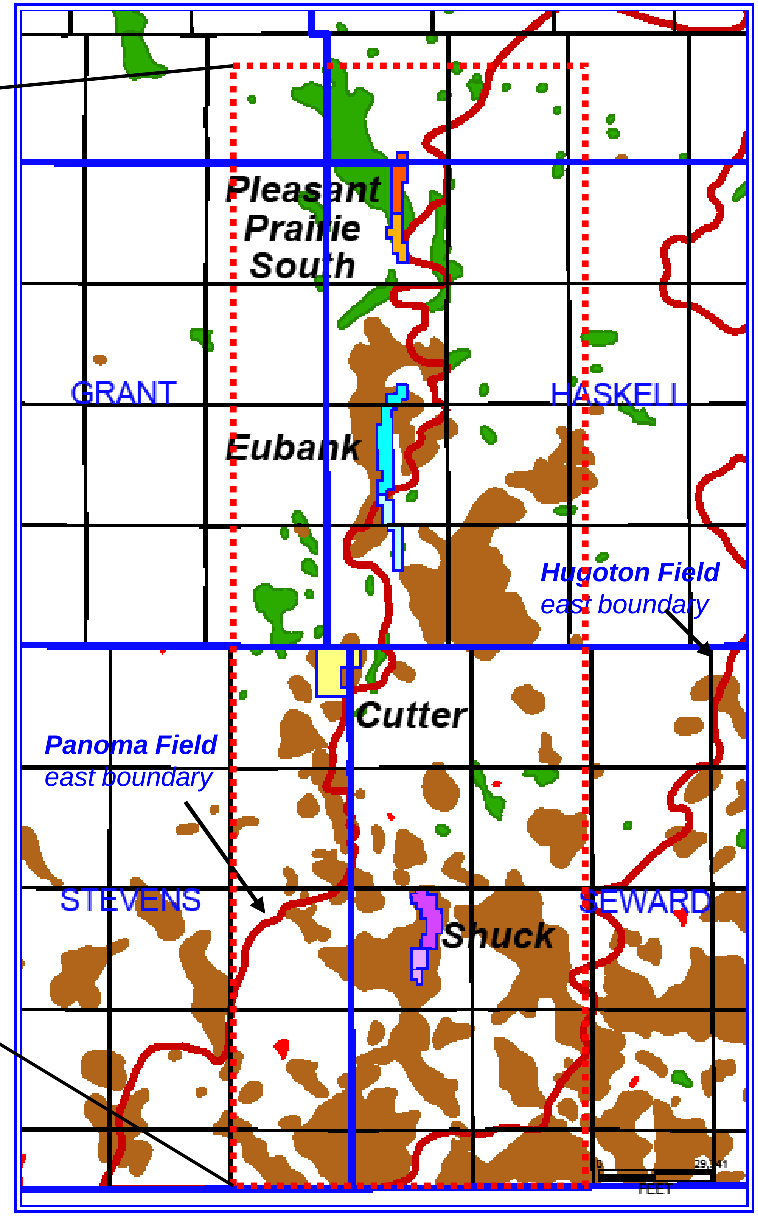
Industry partners:
- Anadarko Petroleum Corp.
- Berexco LLC
- Cimarex Energy Company
- Glori Oil Limited
- Merit Energy Company

Support by:
Sunflower Electric Power Corp.

	Project Role	Company	Education	Exper-ience
Martin Dubois	Team Lead, geo-model	Consultant - IHR LLC	PhD Geology	35
John Youle	Core and depo-models	Consultant - Sunflower Energy	MS Geology	30
Ray Sorenson	Data sleuth and advisor	Consultant	MS Geology	35
Eugene Williams	Reservoir engineering	Williams Petrol. Consultants	BS Mech.Eng. MBA	30
Dennis Hedke	3D Seismic	Consultant - Hedke & Sanger	BS Geophysics MS Mat. Sci.	35
Susan Nissen	3D Seismic	Consultant	PhD Geophysics	25
Lynn Watney	Project PI	KGS	PhD Geology	40
Jason Rush	Project PI	KGS	MS Geology	10
John Doveton	Log Petrophysics	KGS	PhD Geology	40
Paul Gerlach	Data support	Consultant - Charter	MS Geology	35

Fields in study in relation to Chester IVF

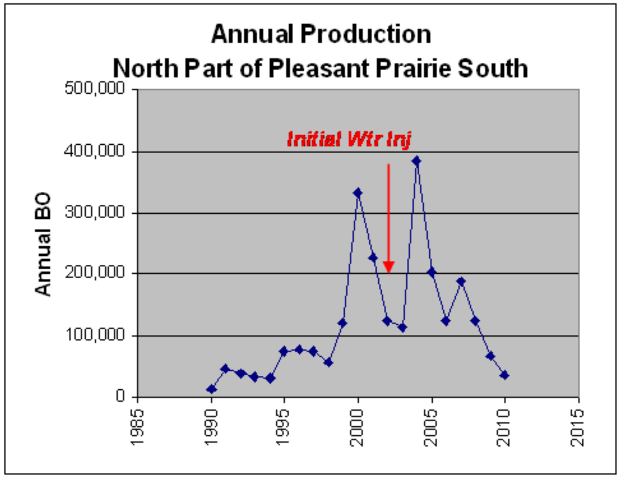


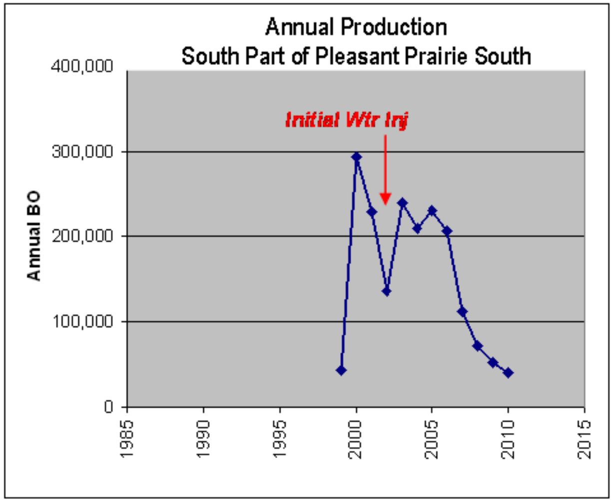


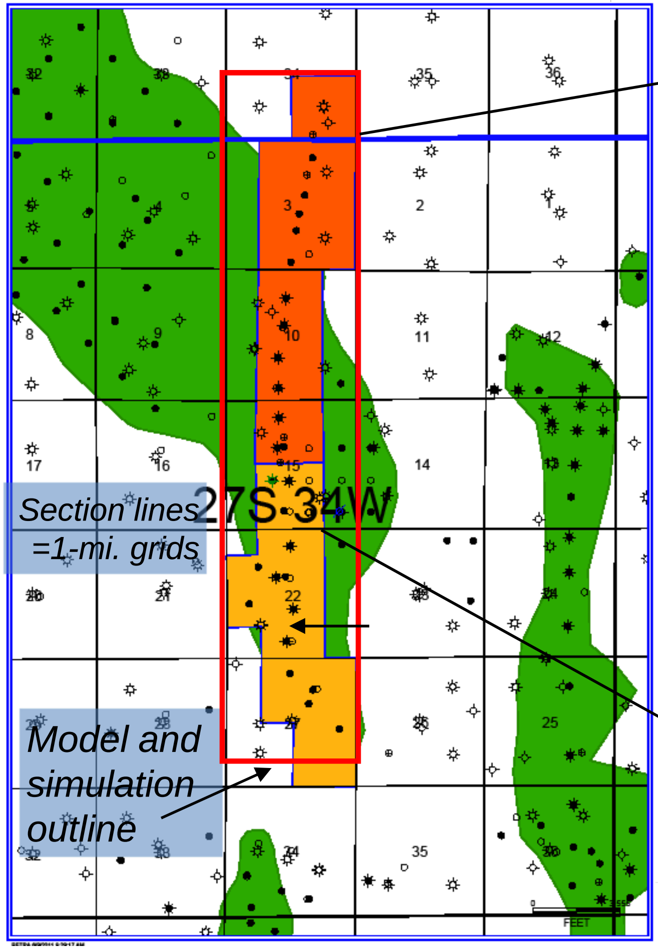
(Above) Regional isopach of lowermost Chesterian incised valley fill (*Montgomery & Morrison, 2008)*

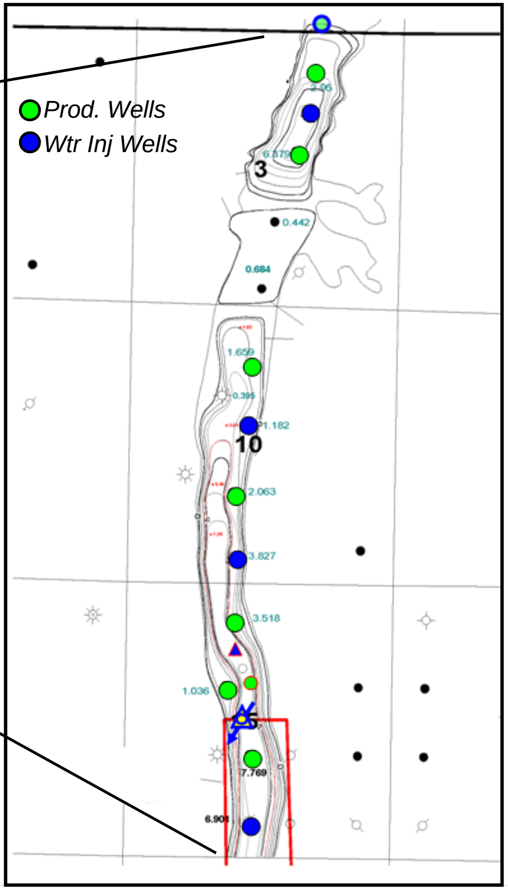
(Right) Four fields in study. Green – Oil; Brown – Oil and Gas. Grid is Township-scale (6 mi.).

Pleasant Prairie South







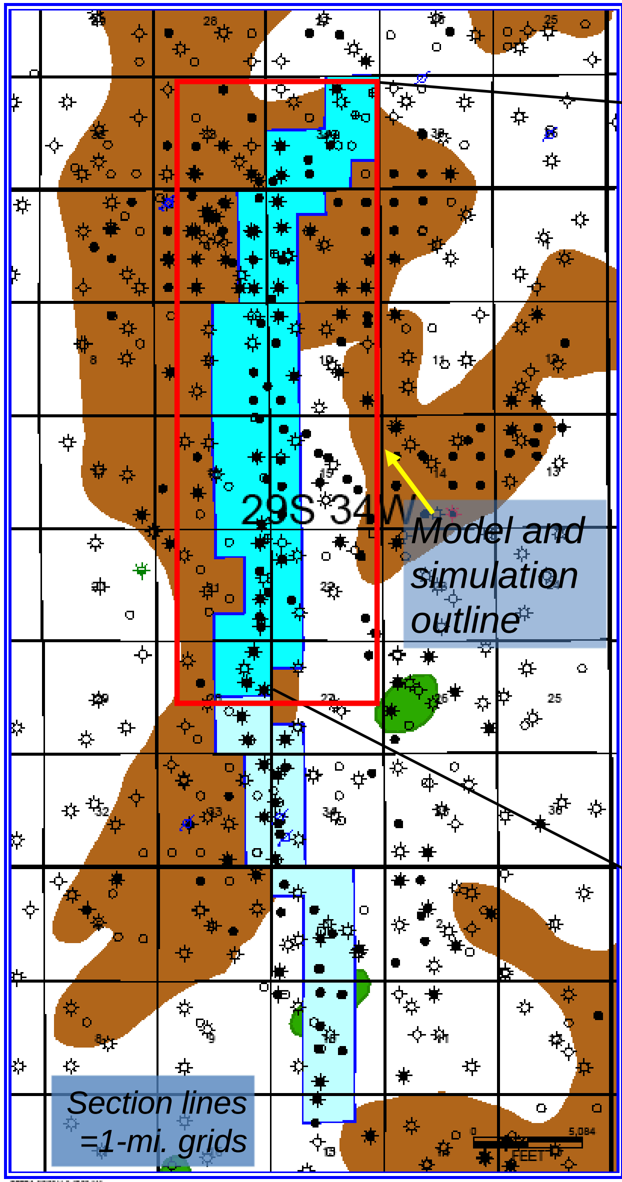


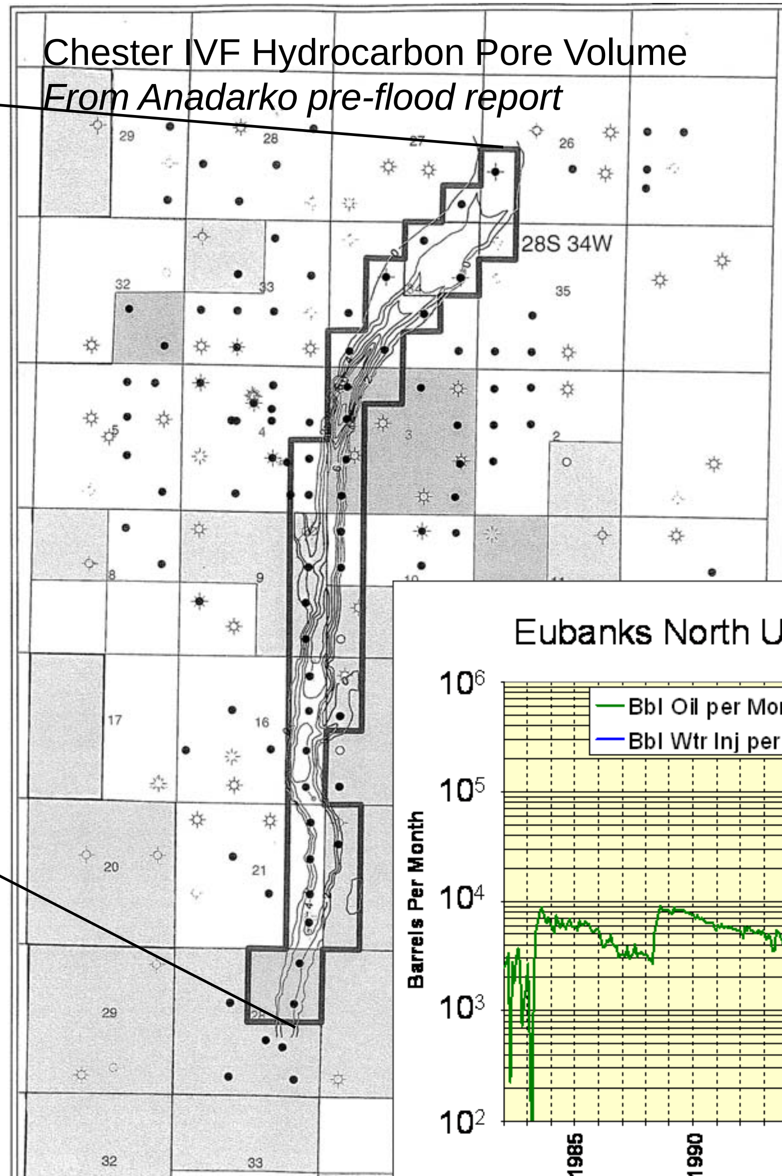
Chester IVF general geometry

Pleasant Prairie South

Discovered:	1990
Waterflood:	2002
Pre-WF:	1.76 mmbo
Since WF:	2.61 mmbo
Cumulative:	4.36 mmbo

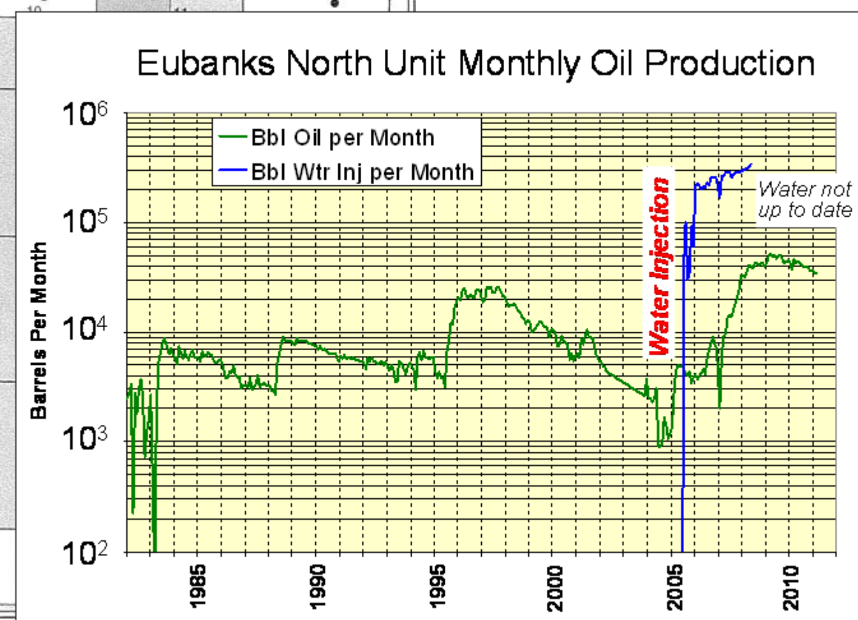
Eubanks North Unit





Eubanks North Unit

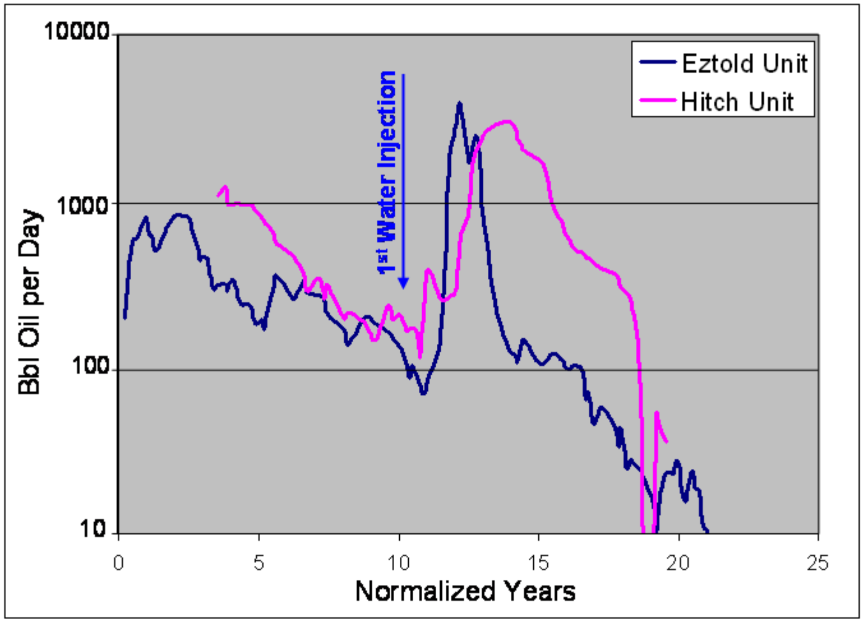
Discovered:	1982
Waterflood:	2005
Pre-WF:	2.09 mmbo
Since WF:	1.89 mmbo
Cumulative:	3.97 mmbo



Shuck Field, Hitch and Etzold Units

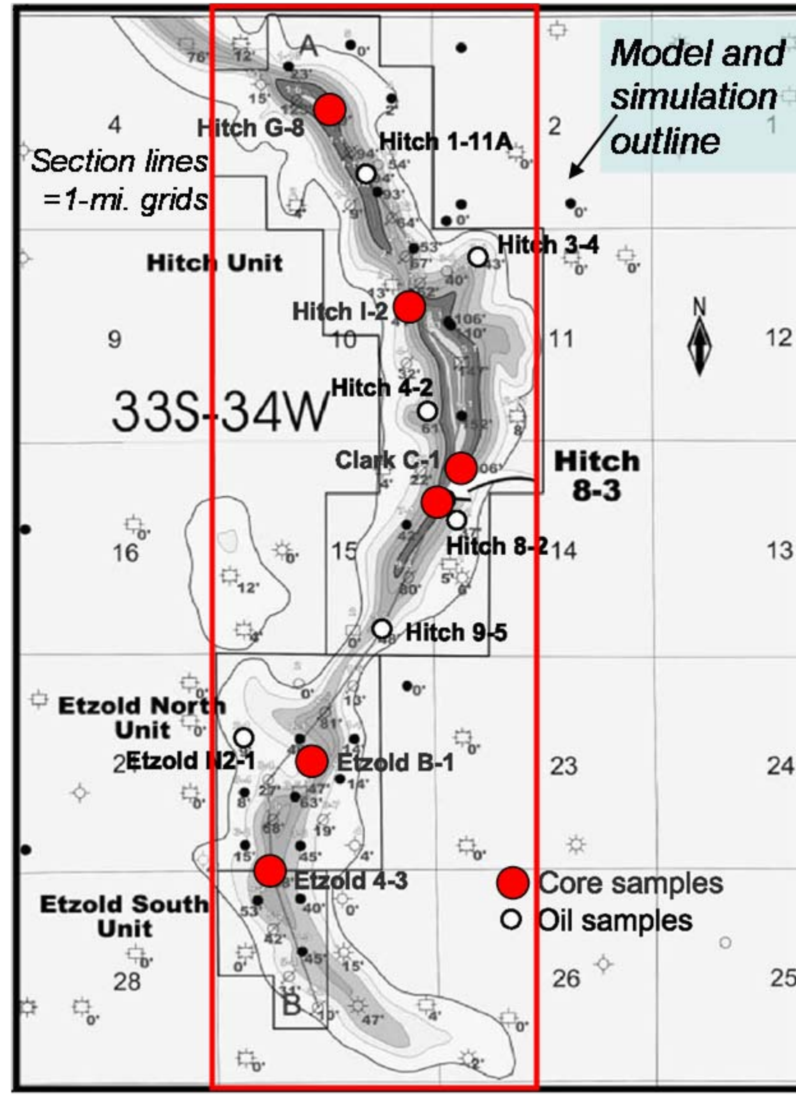
<u>Shuck Waterflood Units Unit</u>

Discovered:	1978
Waterflood:	1989
Pre-WF:	3.53 mmbo
Since WF:	4.28 mmbo
Cumulative:	7.81 mmbo



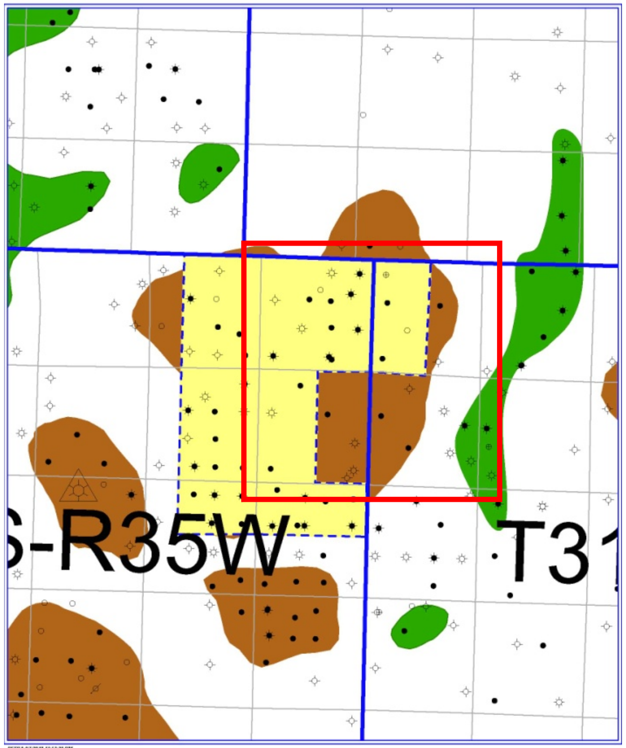
(Above) Production plots for Hitch and Etzold waterflood units in Shuck Field, normalized to waterflood initiation.

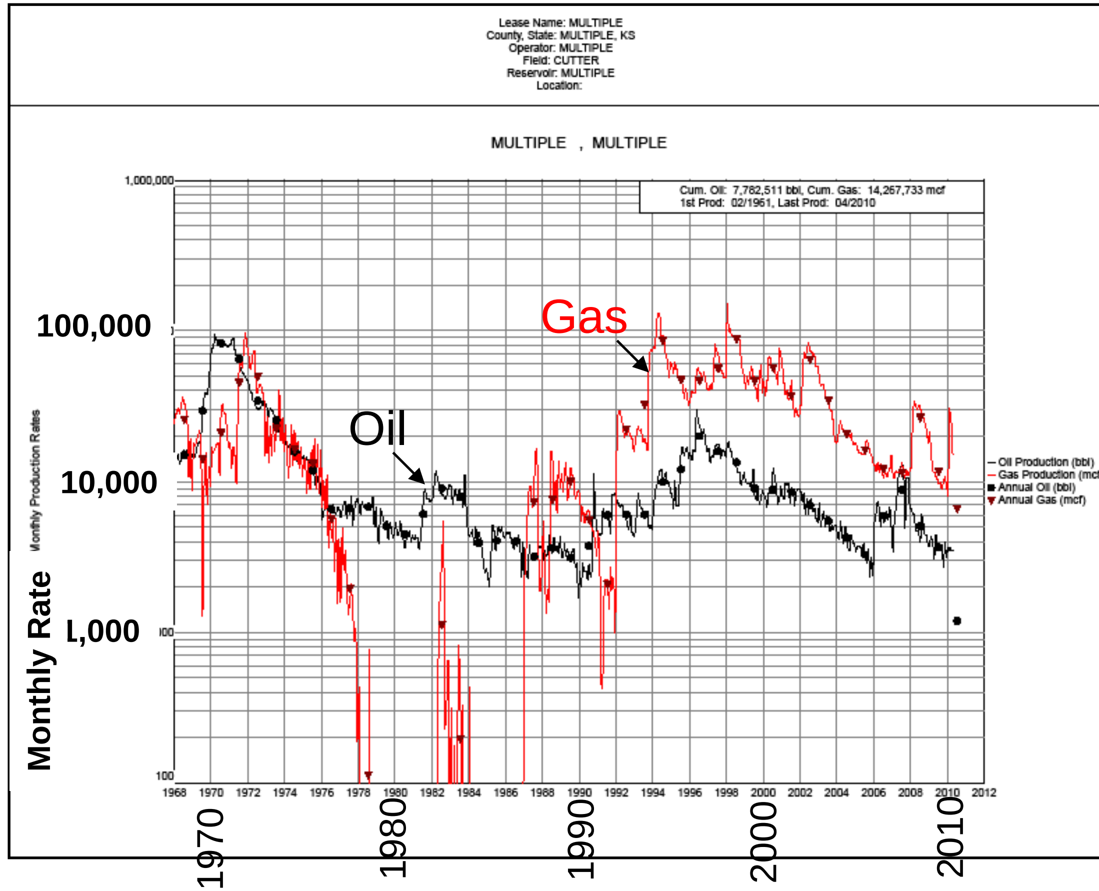
(Right) Isopach map of the net basal Chester sandstone, >8% porosity, contour interval 20 ft.



(from Kim, Philip, and Sorenson, 2010).

Cutter waterfloods (Morrow)





- Cutter field produces primarily from Morrow but also from Chester (not IVF)
- Much of the Morrow has been waterflooded in an older Mobil waterflood.
- Production allocation in later years is yet to be updated. Mobil records indicated that the Morrow waterflood unit cumulative was 3.2 mmbo in 1982.
- Cumulative for the field in 2011 is 6.46 mmbo.

Workflow and Timeline

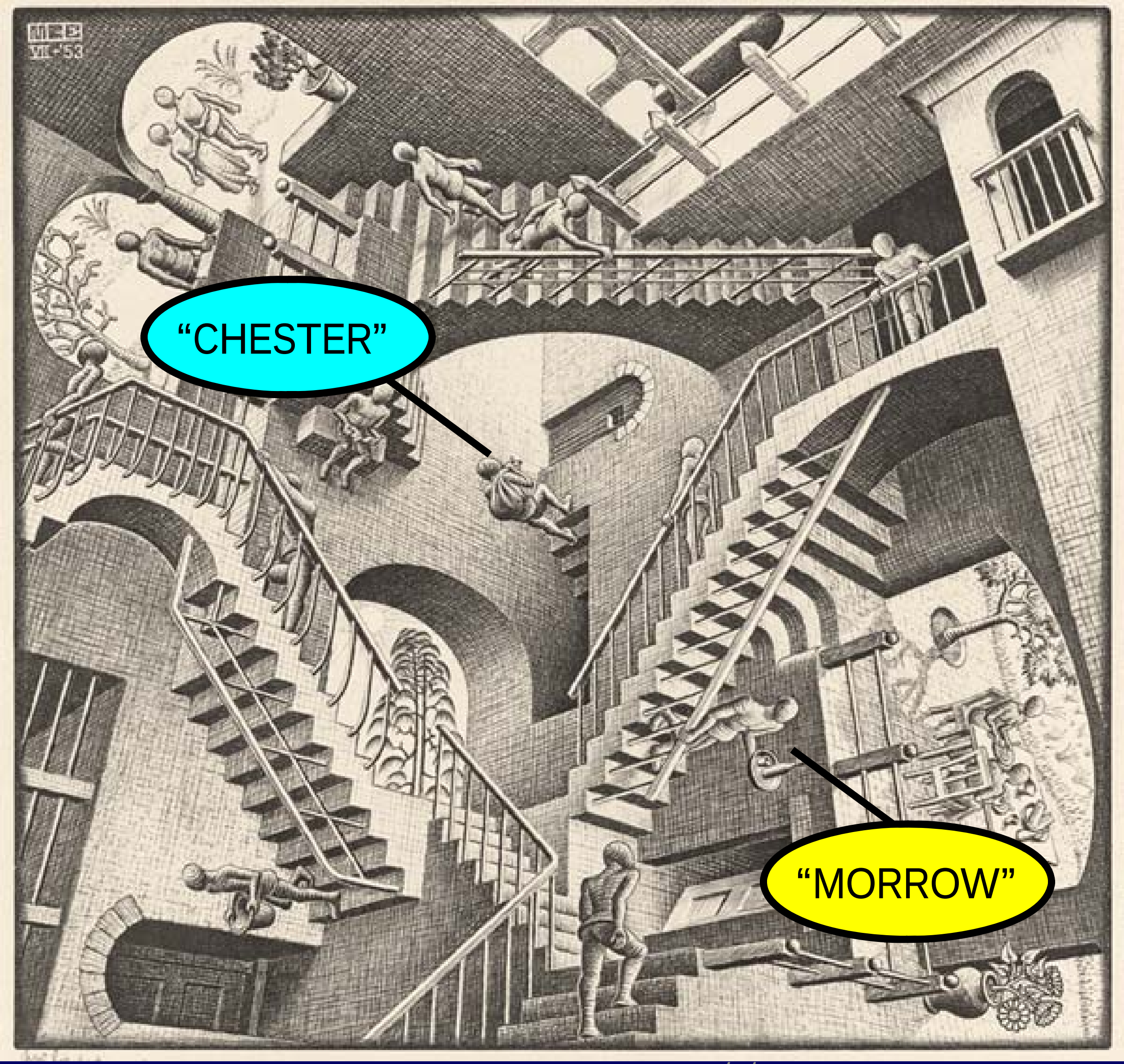
Workflow

Data Gather	Characterization	Modeling	Simulation
Well logs	Core depo- & lithofacies	3D cellular geomod	Black oil
Completion & tests	Geologic (2D)	Integrate 3D seismic	History-match primary & secondary
Core analysis	Integrate 3D seismic	3D property	Compositional - CO2
Mapping database	Core-log-properties	Fluid EOS	Forecast and optimization
Fluid histories	Reservoir properties		
PVT	Fluid properties		

Timeline

	2011						2012												2013							
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	J	F	M	A	M	J	J	A
	Field 1				Field 2				Field 3				Field 4													
Well database	1	1			2	2			3	3			4	4												
Core work	1	1			2	2			3	3			4	4												
Detailed 2D		1	1			2	2			3	3			4	4											
3D seismic	1	1	1		2	2	2		3	3	3		4	4	4											
3D modeling			1	1	1		2	2	2		3	3	3		4	4	4									
Well histories			1	1	1		2	2	2		3	3	3		4	4	4									
Fluid characterization				1	1			2	2			3	3			4	4									
Simulation					1	1			2	2			3	3			4	4								

THE BIG DITCH OF THE HUGOTON:
AND IT'S VALLEY FILL RESERVOIRS



Preliminary Observations and Musings.

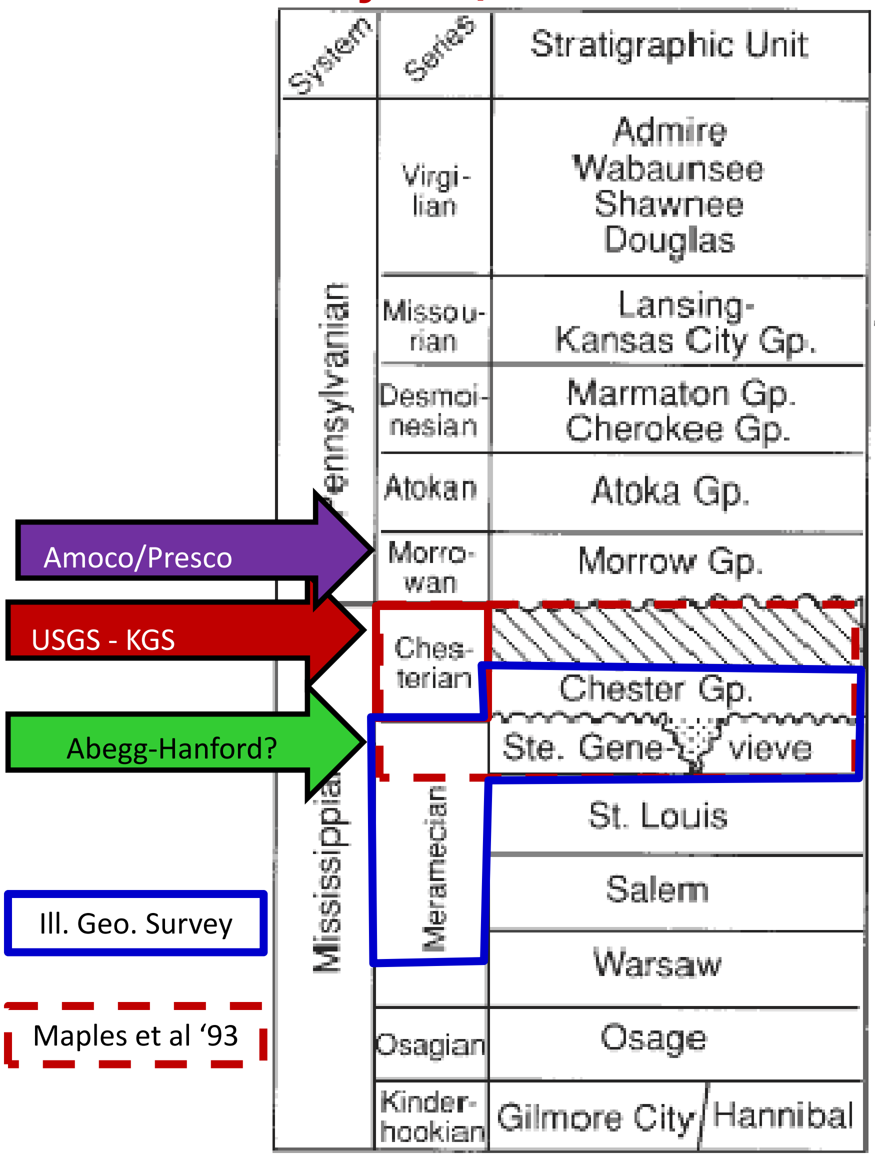
John Youle Sunflower Energy LLC

KSN 2011 Talk Outline

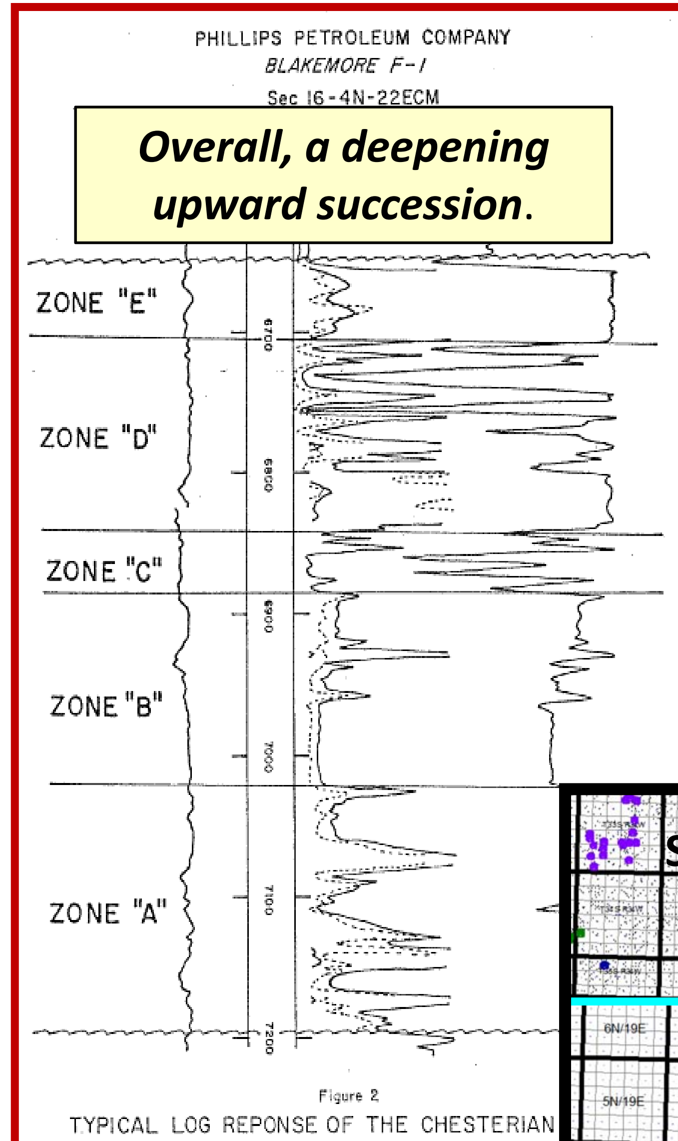
- Overview:
  - Stratigraphy
    - IVF Chester Vs. Meramec Vs. Morrow
      -Goebel- Severy –Abegg/Hanford/Maples - Cirilo/Ill. - Amoco
  - Characteristics of Valley & IVF reservoirs
    - Valley length
    - Changes if width
    - Changes in thickness of SS IVF reservoir facies.
    - Sandstone fabric changes.
- Compartmentalization (Not Leaks!)
  - Stratigraphic
    - Large scale – Sequence Stratigraphy
    - Small Scale – Parasequence /Event beds
    - Small Scale – Tidal Bars
  - Structural
    - Fault seals? Cutter/Cutter South.
    - Karst trap north side of Shuck.
  - Diagenetic
    - Tar Mats
    - Lime cementation.

STRATIGRAPHY OF INCISED VALLEY AND FILL:

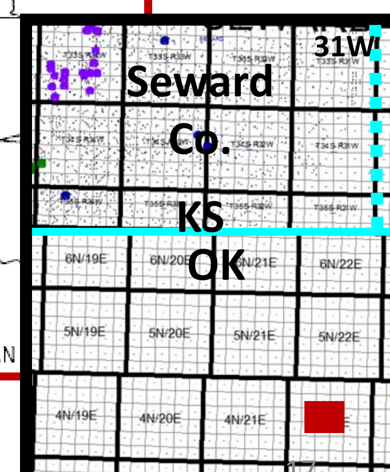
When was valley cut, and when was it filled.....



Montgomery & Morrison, 1999



Severy, 1975



“Chester” Incised Valley Axis in White.

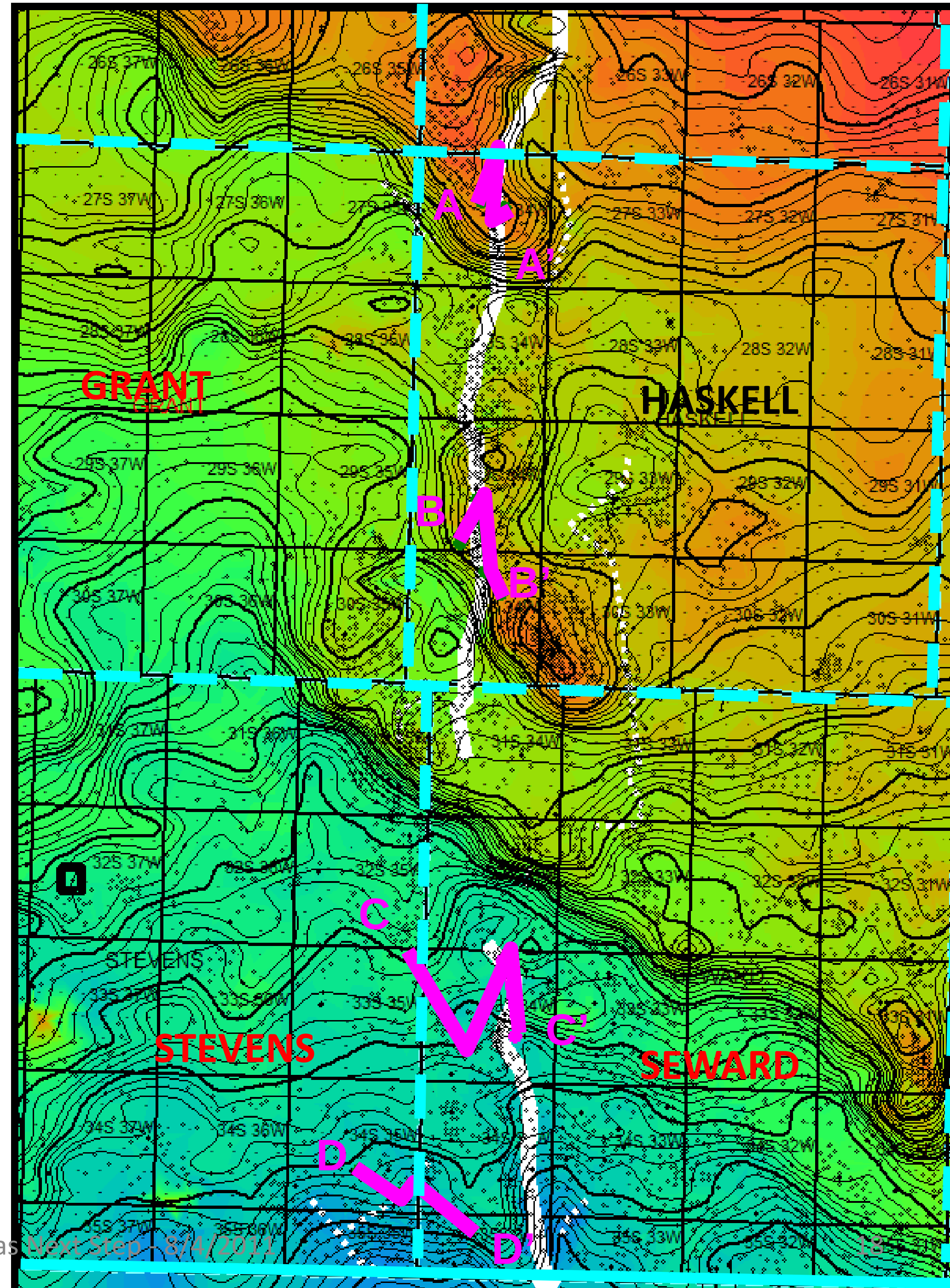
Map suggests that Chester valley incision predates and was not influenced by Late Miss/Pennsylvanian structural events or features.

MAP LEGEND

Computer generated contour lines show subsea structure on top of Miss. Meramec (Ste. Gen. in most of the area). 25’ C.I. (smoothed)

Computer generated color fill represents thickness from the basal Pennsylvanian limestone to the top of the Miss. Meramec (Ste.Gen. in most of the area). (smoothed)

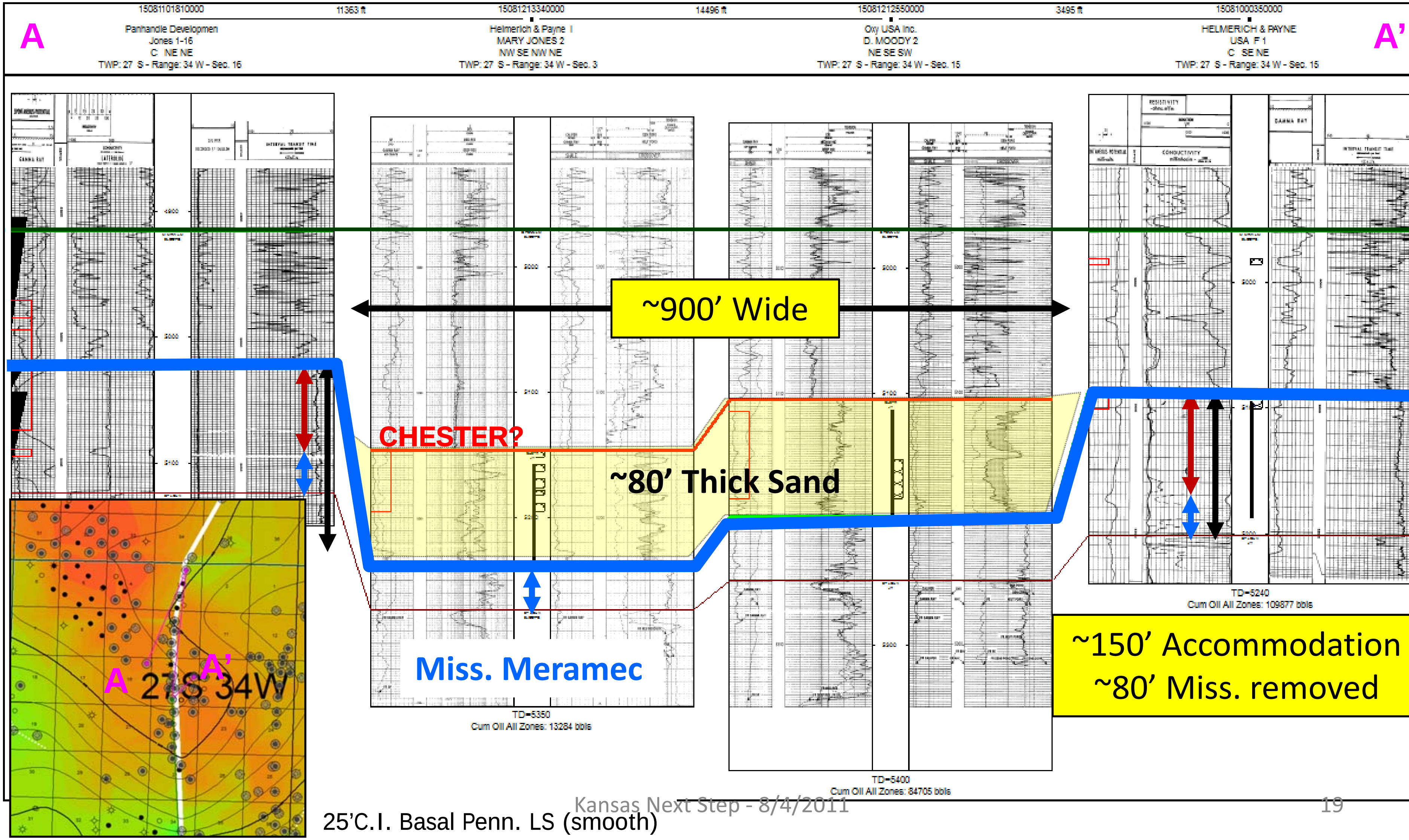
Cross Sections displaying valley morphology over the next few slides are shown as purple lines.



VALLEY MORPHOLOGY: North End of Study Area

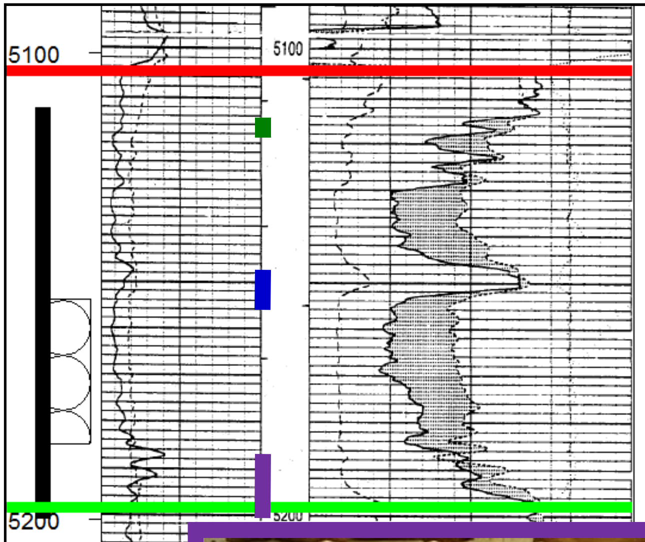
Pleasant Prairie South Field 4.36MBO

Valley Incised through the SE end of Pleasant Prairie anticline.



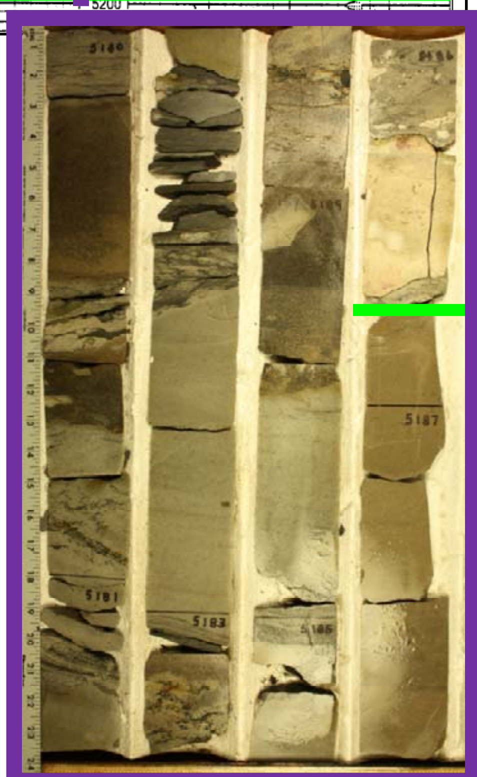
25'C.I. Basal Penn. LS (smooth)

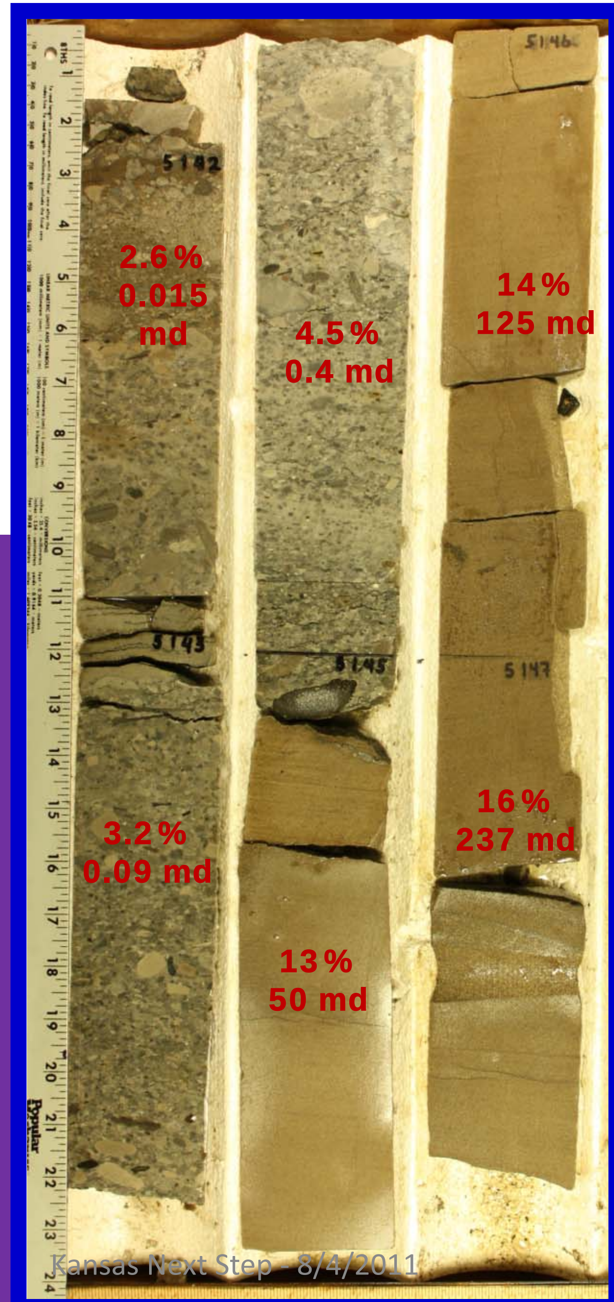
Valley Fill Facies: Pleasant Prairie Pool Oxy Moody 2 15-27s-34w

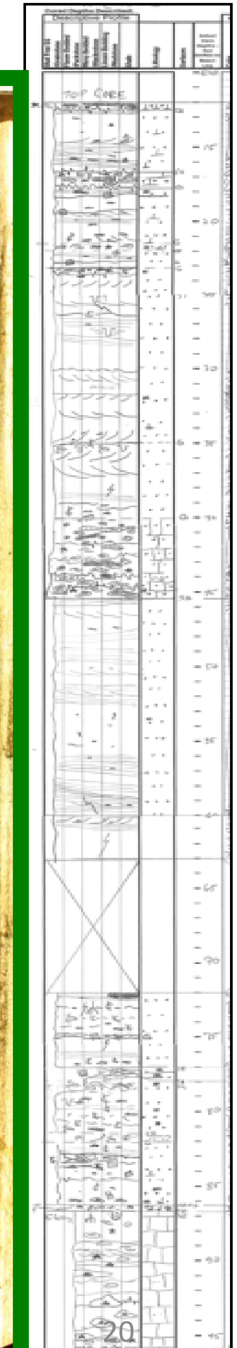


Best Producting facies:

Mostly fgr to vfgr, tr md gr, low angle to trough X-bedded SS. Locally common shale pebbles and organic debris.



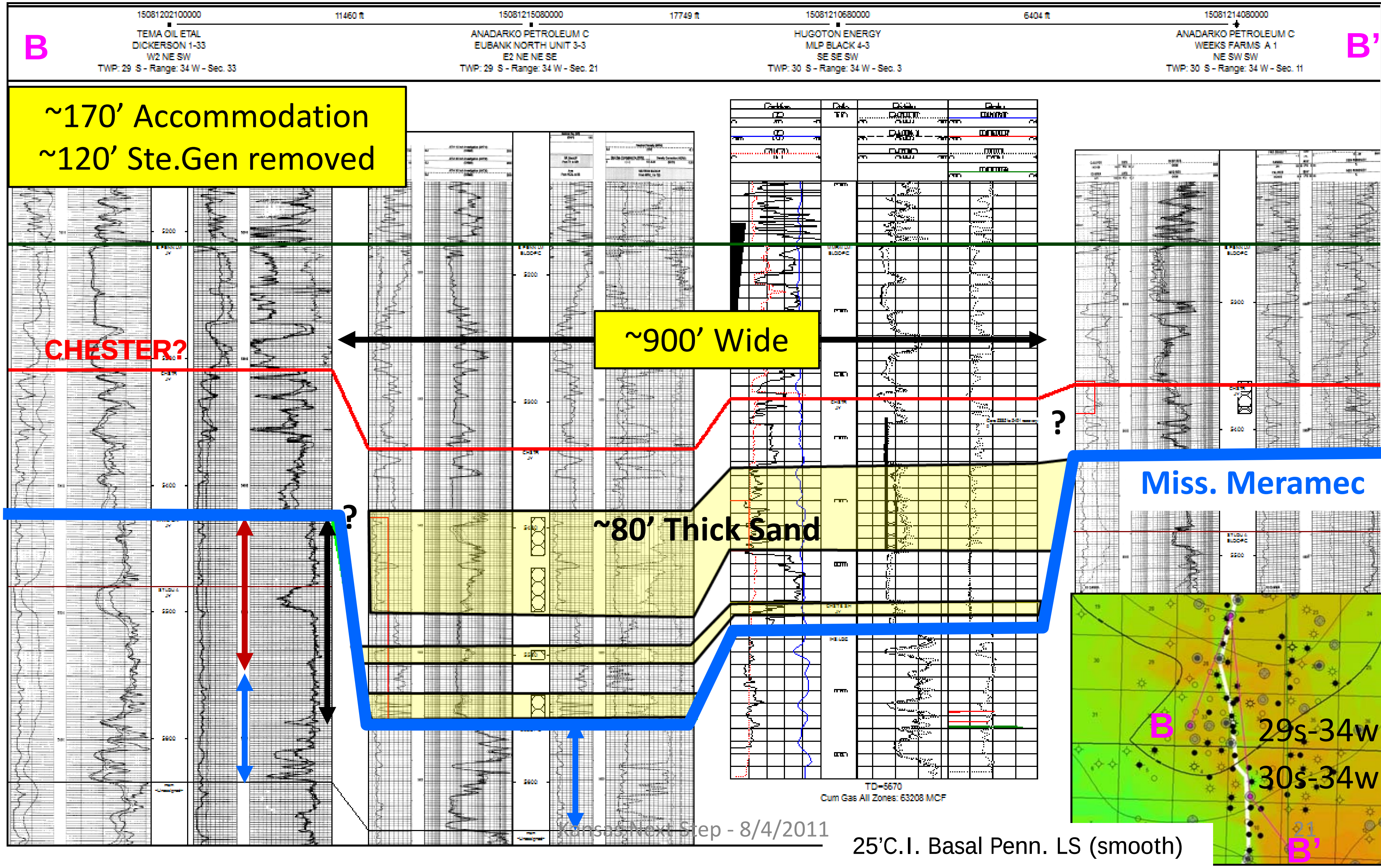




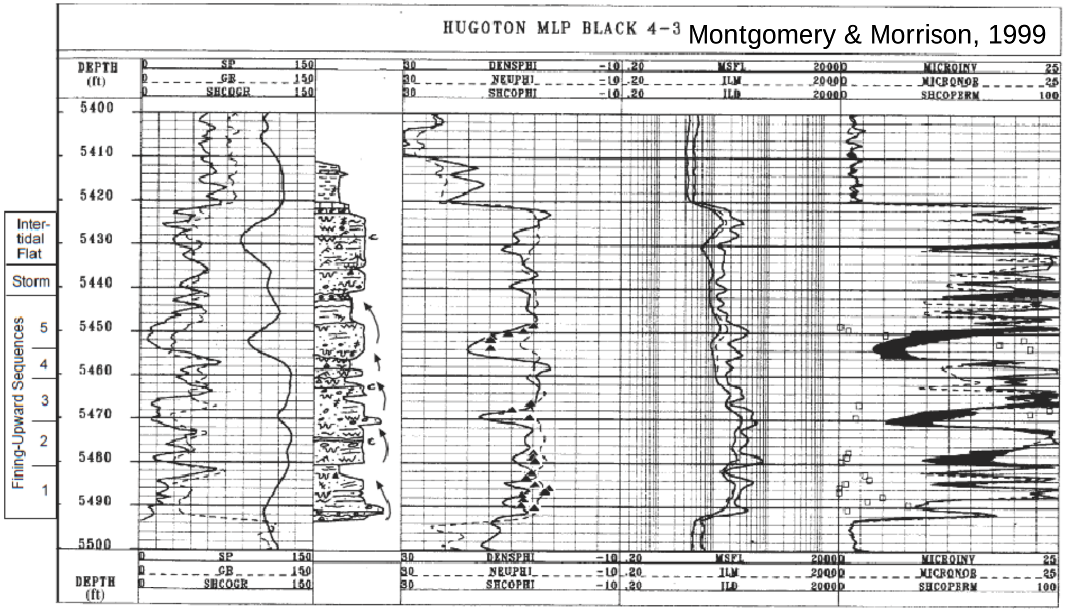
VALLEY MORPHOLOGY: Center of Study Area

Eubanks Field
~6.5MBO

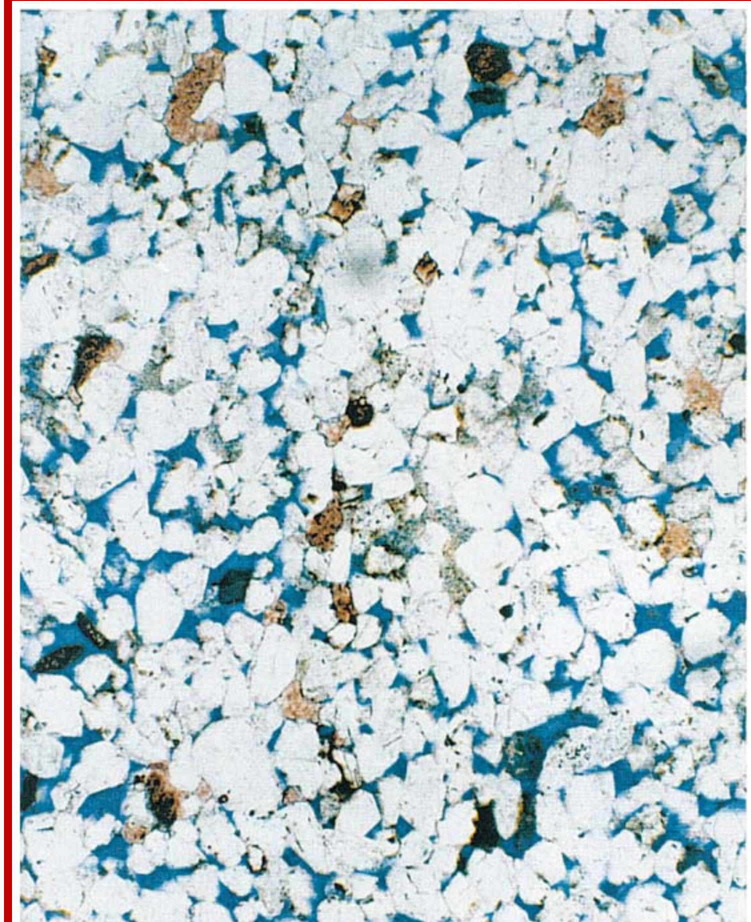
In the Eubanks Field area the depth of valley incision can vary by up to 100' (Morrison & Montgomery, 1998).



Valley Fill Facies: Eubanks Pool, Hugoton Energy MLP Black 4-3.



Best Producting facies:
Vf to fg gr low-angle X-bedded SS. Locally structureless, and commonly contains shale pebbles, carbonate grains, and organic debris. Frac.s



5451' fgr wsort SS with carbonate grains (red)
Best Foot in Core: Phi 13%, K 84md.

VALLEY FILL FACIES

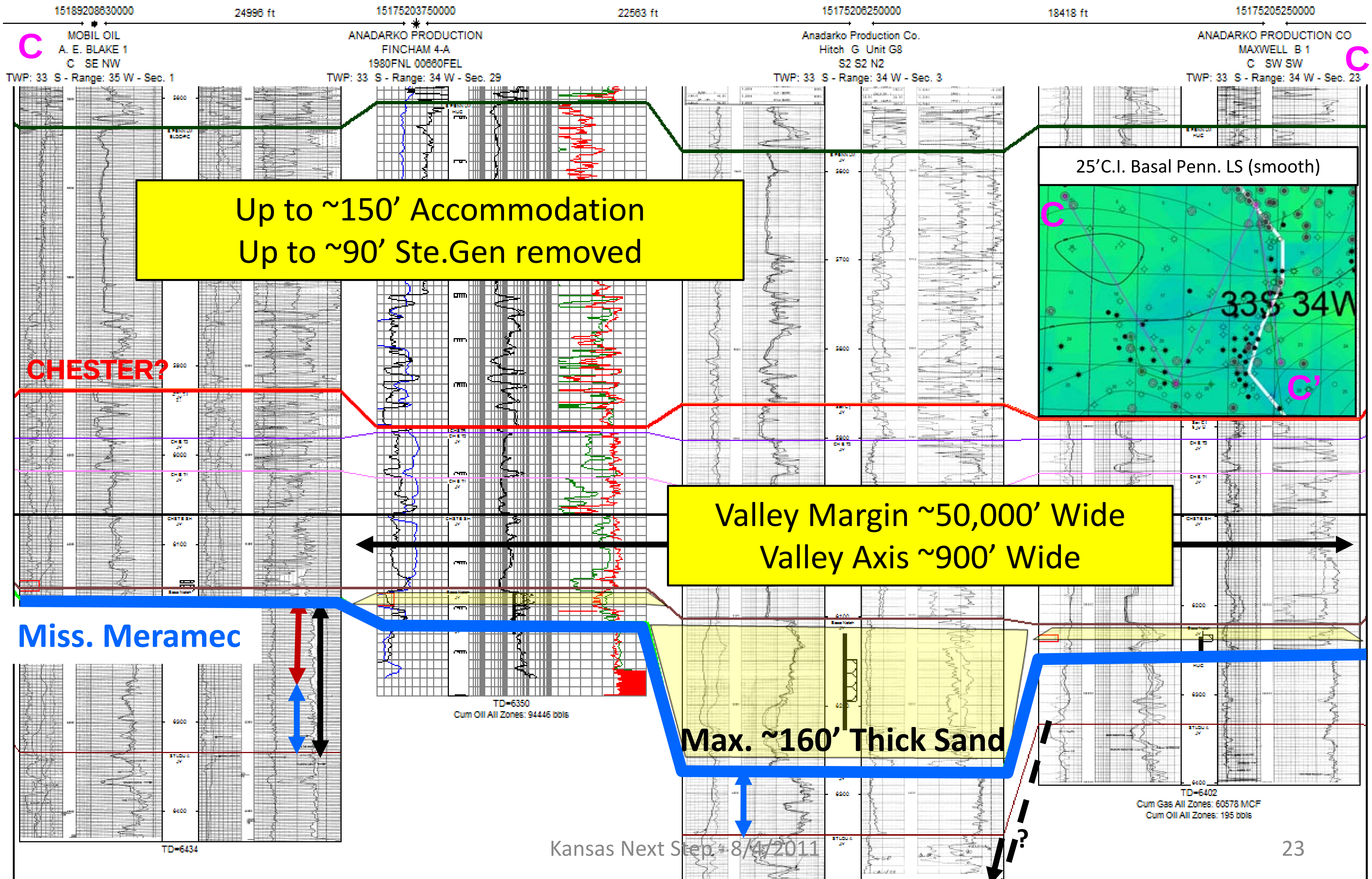
Marine Influence: common crinoid and brachiopod fragments, coated grains and poikolitic limestone cements.
Tidal Influence: neap spring cyclicity, reactivation surfaces, double mud drapes.
Fluvial Influences: abundant carbonaceous debris throughout, and woody frag.s common at base of section.

5431' showing reactivation surfaces.

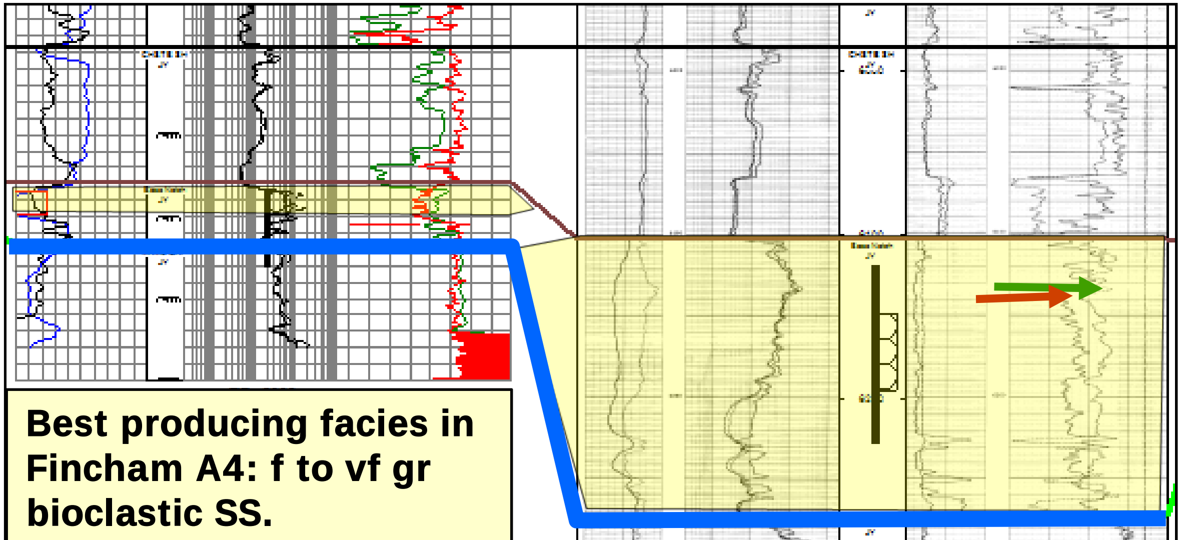
VALLEY MORPHOLOGY: South end of Study Area

Shuck Field
7.81MBO

Valley Morphology at Shuck Fld. Narrow valley axis flanked by broad valley terraces.



Valley Fill Facies: Shuck Field, Anadarko Hitch G-8 (valley axis) & Fincham A4 (valley margin).

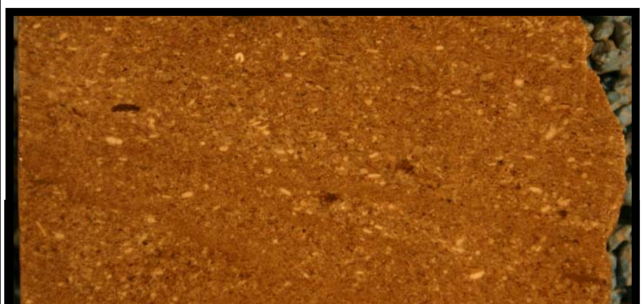


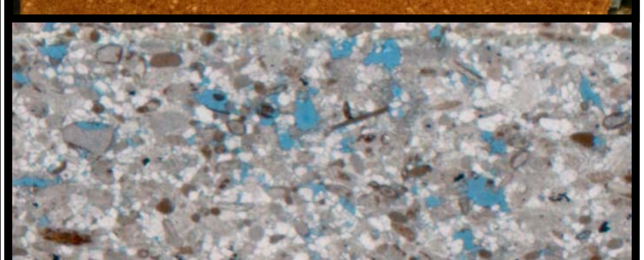
Best producing facies in Fincham A4: f to vf gr bioclastic SS.

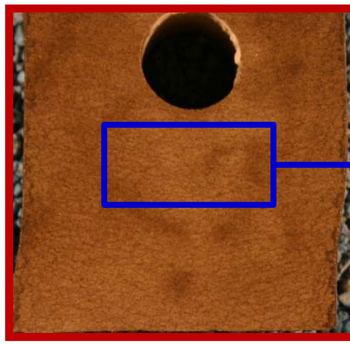
Best producing facies in valley axis from Hitch G-8 (Avg.~25md & 10%):

f to vfg gr structureless SS with carbonaceous debris. Fossil fragments and shale pebbles are common. Locally this facies contains low-angle and trough cross bedding, cryptobioturbation, and patchy limestone cemented intervals.

Fincham A4 @ 6235'. "unconfined" tidal bar producing facies.
Bioclastic sandstone showing large oversized pores due to dissolution of carbonate grains.





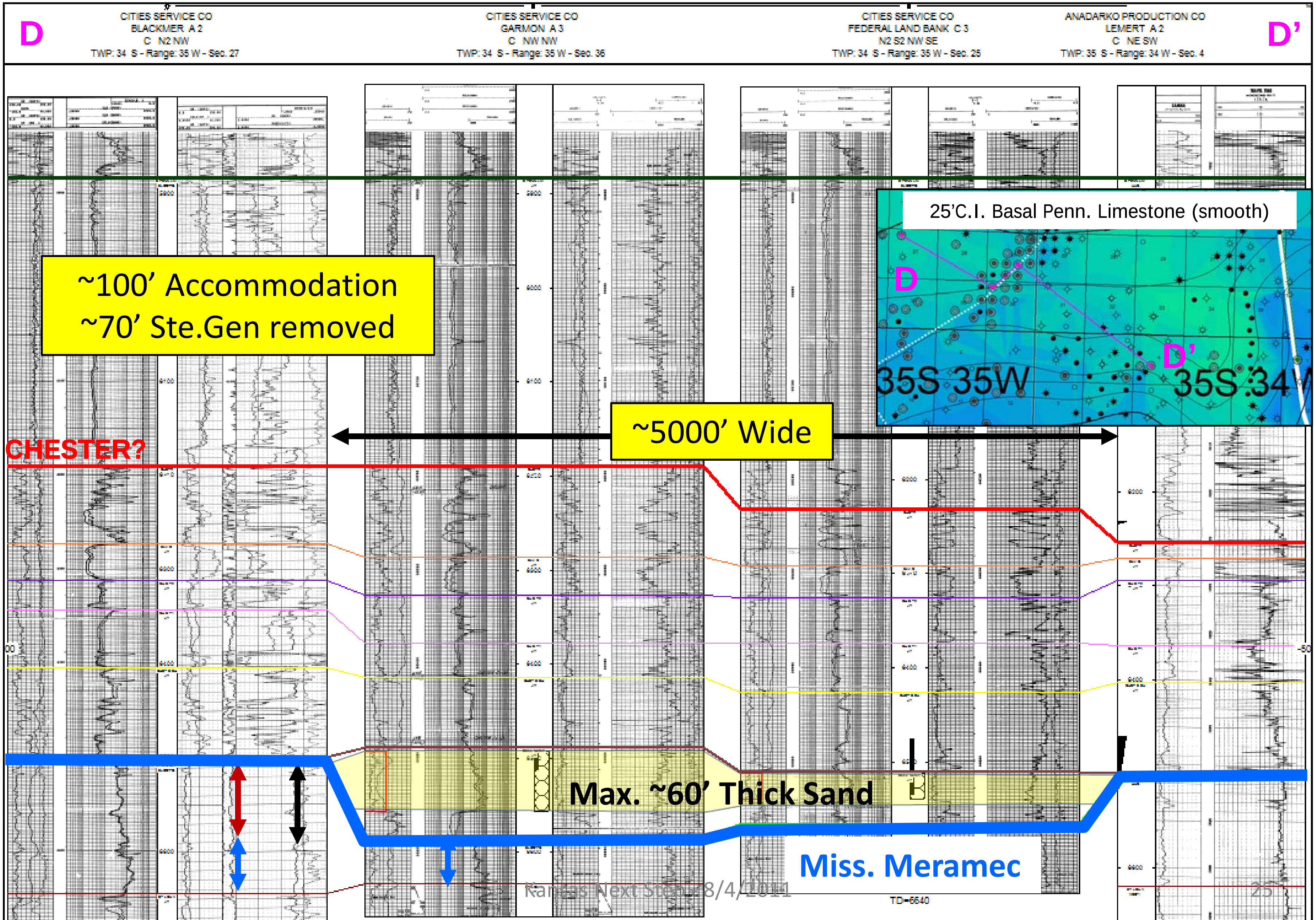


6143' vfgr SS showing probable meiofauna bioturbation of *Macaronichnus*.

6142' bioclastic conglomerate with sharp stylolitic contact sharply above best producing facies.

VALLEY MORPHOLOGY: Southwest of Study Area. *Wide Awake Field*

Not part of major IVF. Smaller broad valley linked directly to Chester coast.



Valley Fill Facies: in a smaller valley linked directly to Chester coast. Not related to 'da big ditch' incised valley system.

Wide Awake Field
Stratigraphic Equivalent to Shuck

Best producing facies:

f to mgr gr structureless to low-angle cross bedded SS with fine bioclastic debris common. Phi ~8-10%, K ~15md

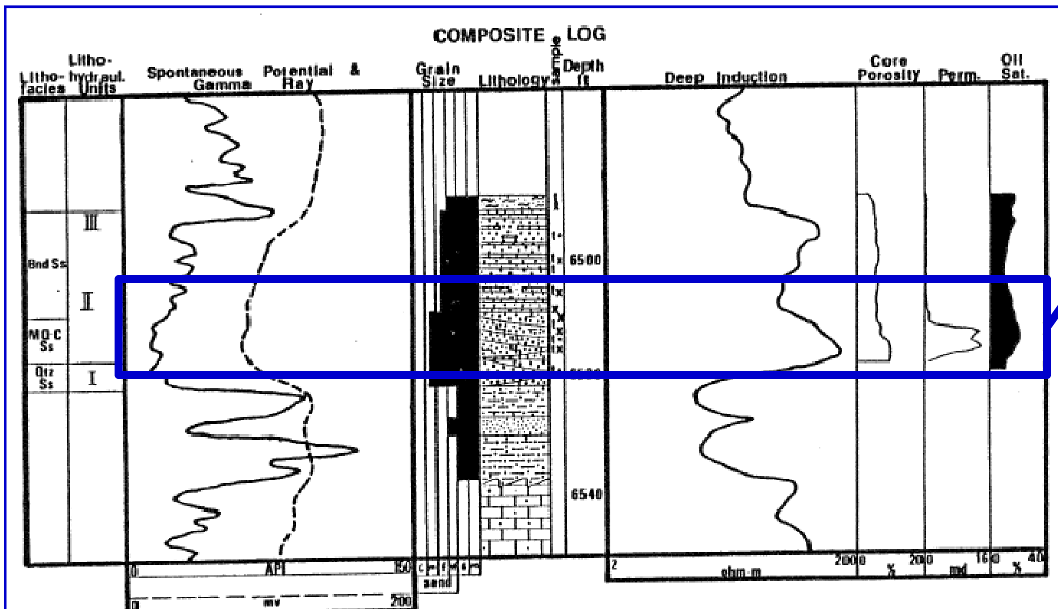


Figure 32. Composite log of Federal Land Bank C-1 well (25 T34S R35W, C-SW-SE). Refer to Figure 22 for explanation of lithologic and sedimentary structure symbols. T = thin-section sample; X = XRD sample; * = SEM sample

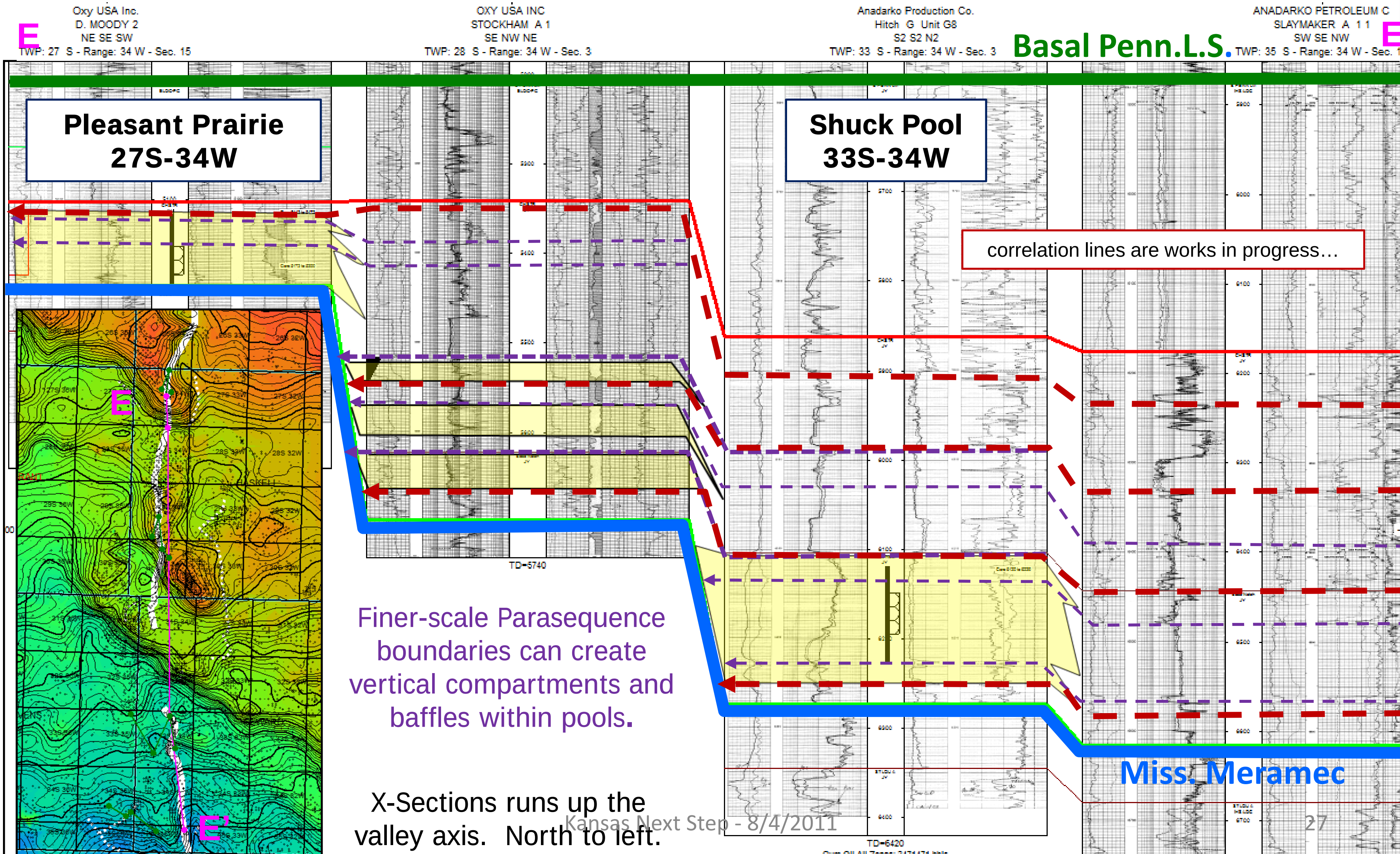
Shonfelt, '85

Cities Service Federal Land Bank C1 25-34s-35w

COMPARTMENTALIZATION WITHIN VALLEY AXIS:

Regional-Scale Stratigraphic Compartments.

Red dashed lines (sequence boundaries?) partition IVF rocks into large-scale compartments that may have formed in response to a series of cyclic back-stepping transgressions.

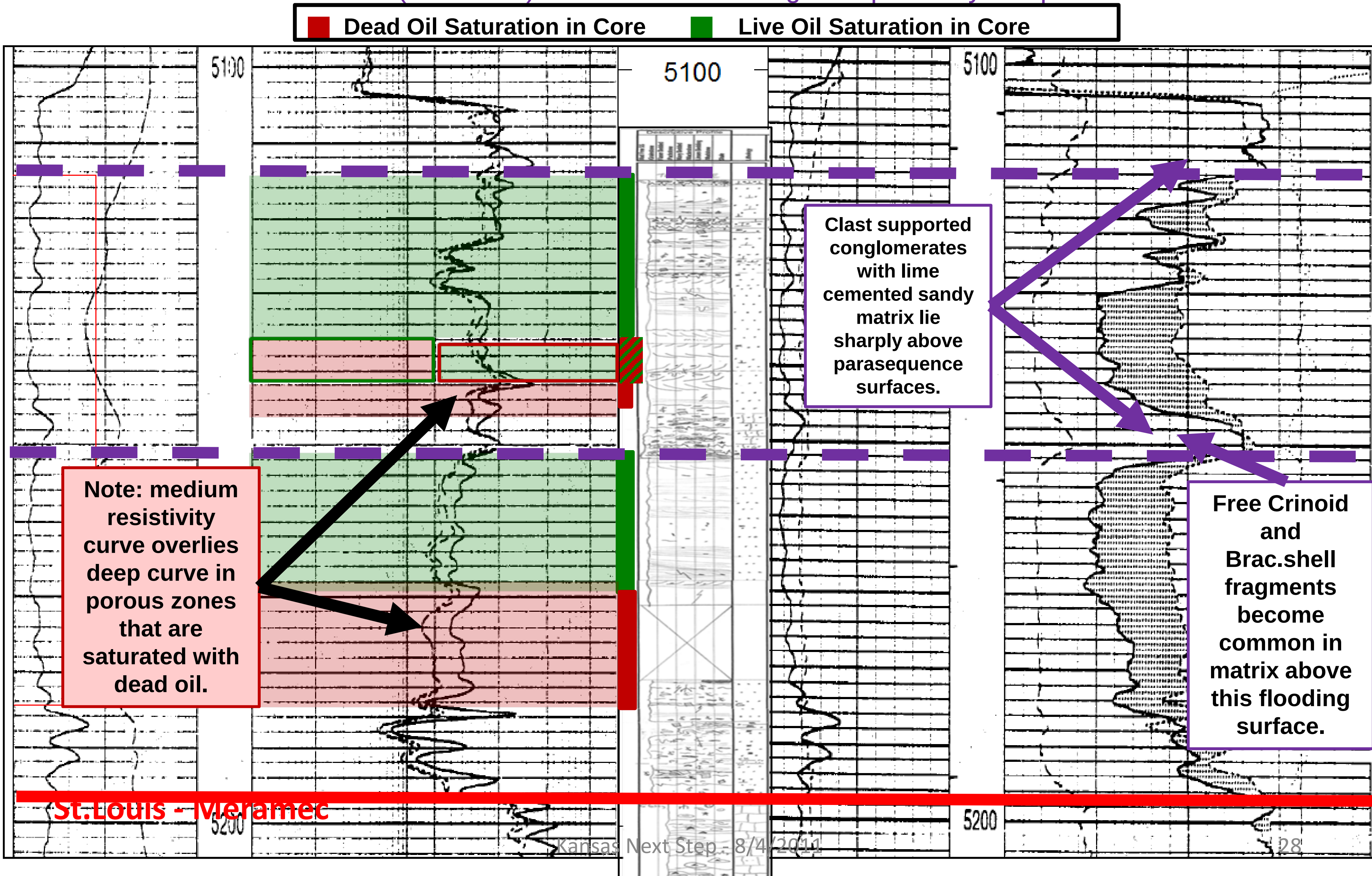


COMPARTMENTALIZATION IN THE VALLEY AXIS:

Field-Scale Stratigraphic Compartments.

Pleasant Prairie Field

Vertically stacked parasequences form separate compartments. Parasequence flooding surfaces are correlative across the Pleasant Prairie Pool (Senior '11). Oil saturation changes help identify compartments.



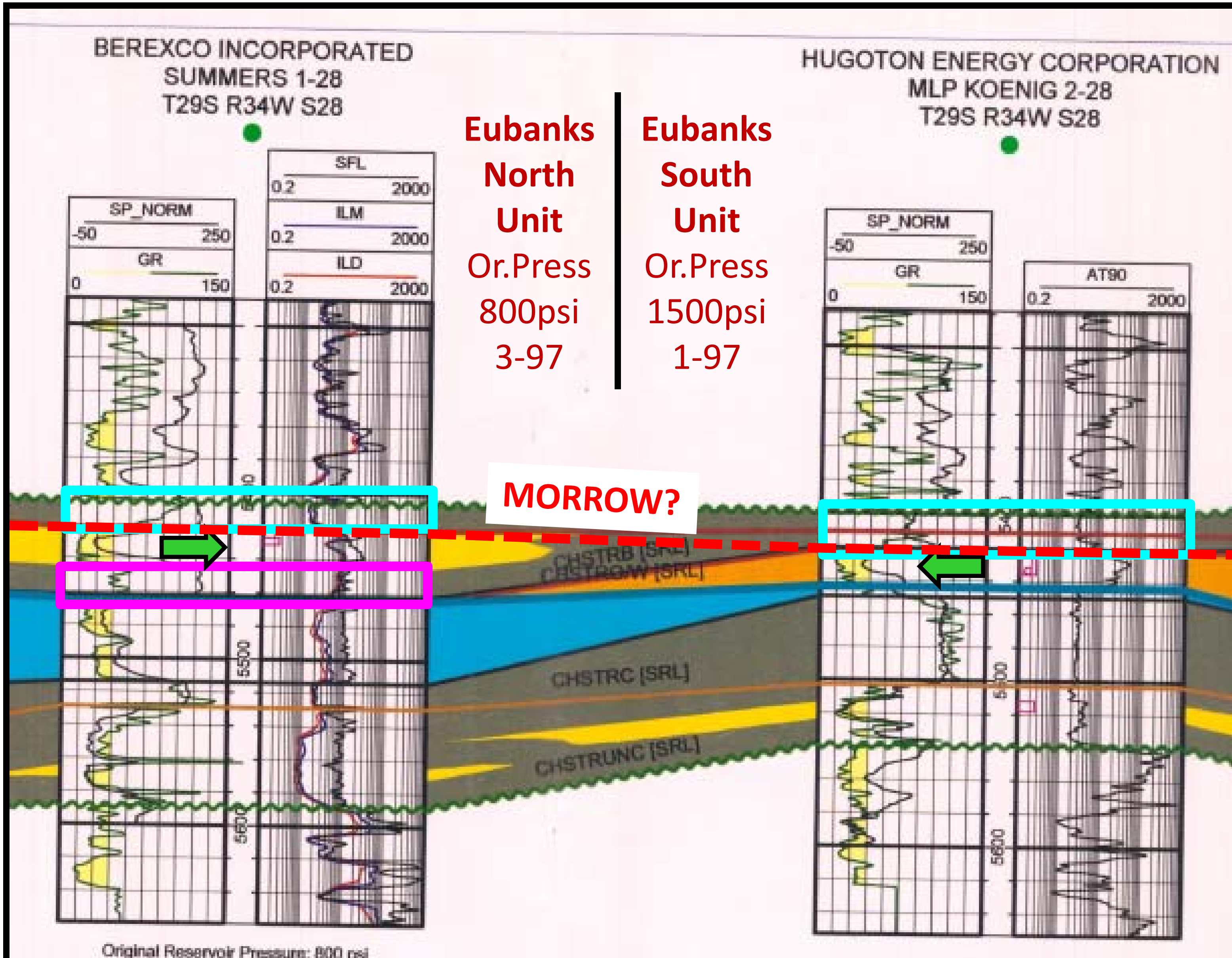
COMPARTMENTALIZATION IN THE VALLEY AXIS:
Field-Scale Stratigraphic Compartments.

Eubanks Field

Anadarko Cross Section… courtesy of Merit Energy.

Stratigraphic pinch out…

…or erosional truncation at Penn. unconformity?

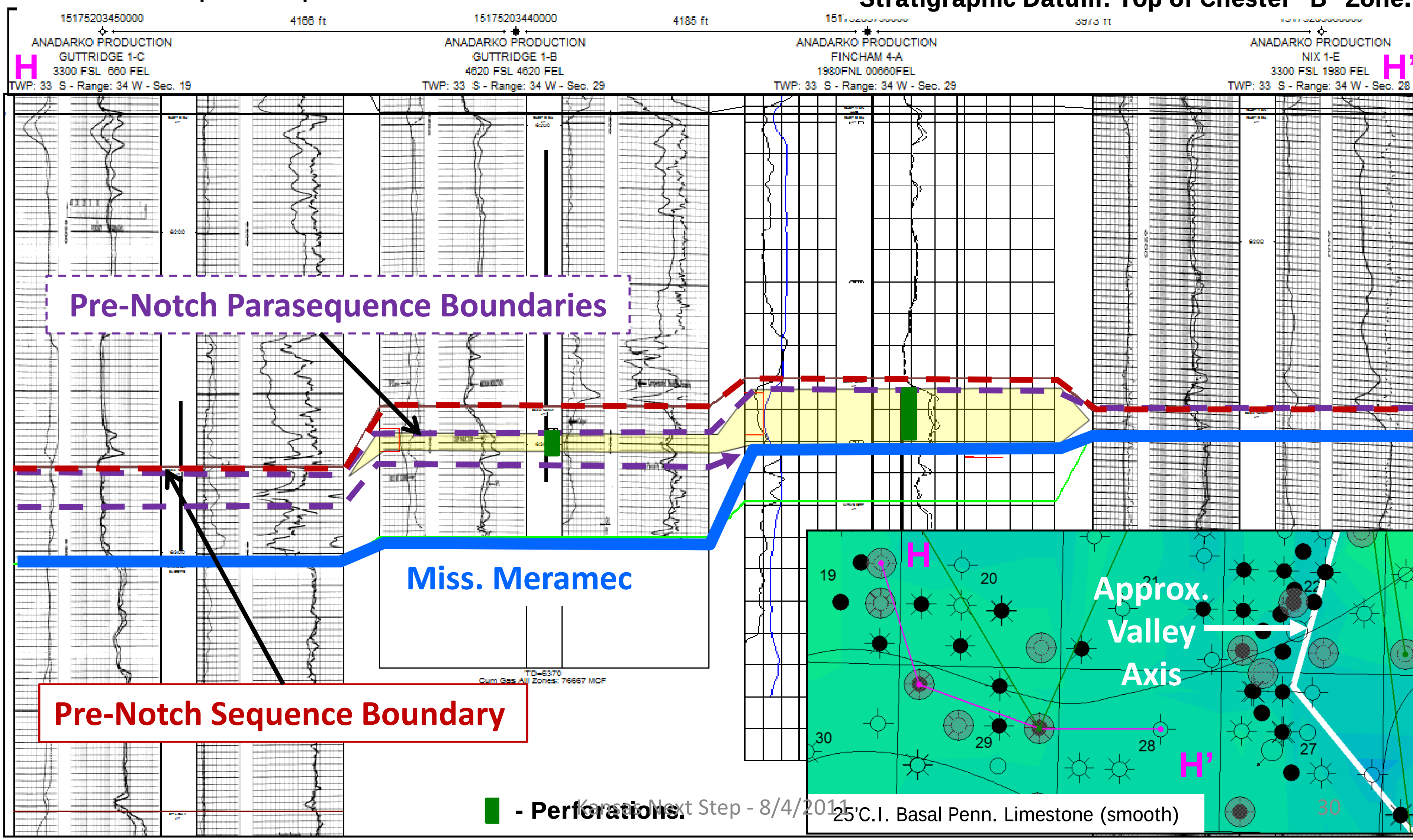


COMPARTMENTALIZATION IN THE VALLEY:
Field-Scale Stratigraphic Compartments.

Shuck Field

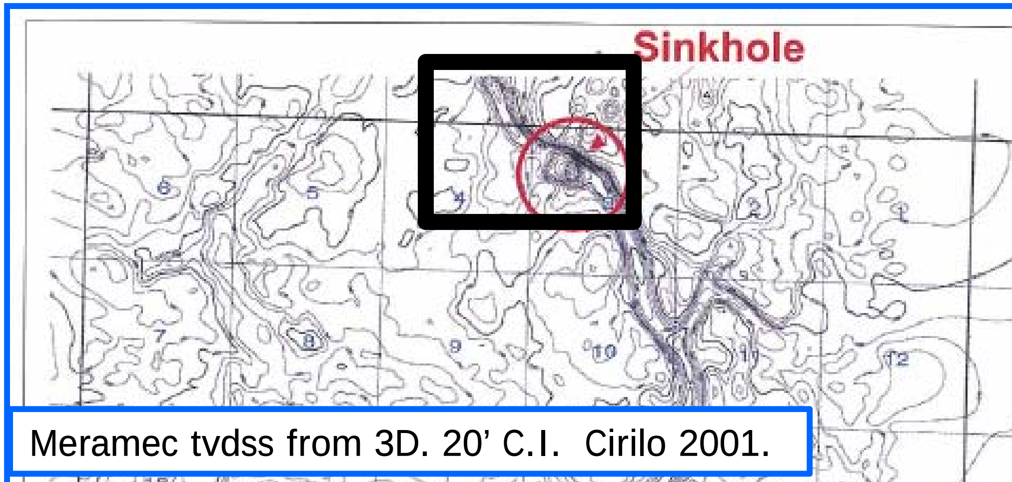
Tidal bars deposited in a lower estuary mouth environment form stratigraphic traps on broad valley terraces adjacent to the deeply incised valley axis. Bars appear to form at the parasequence scale.

Stratigraphic Datum: Top of Chester "B" Zone.

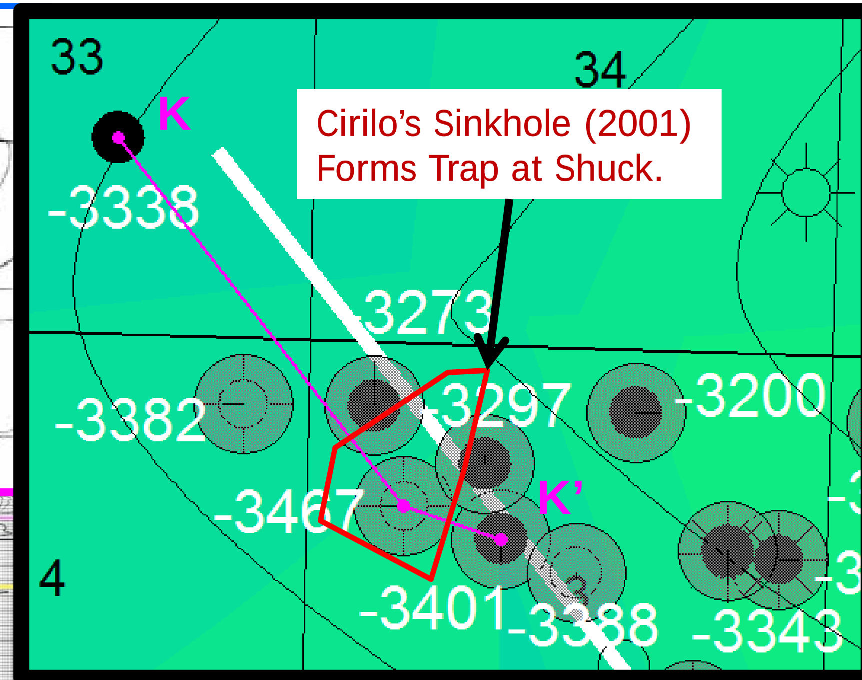


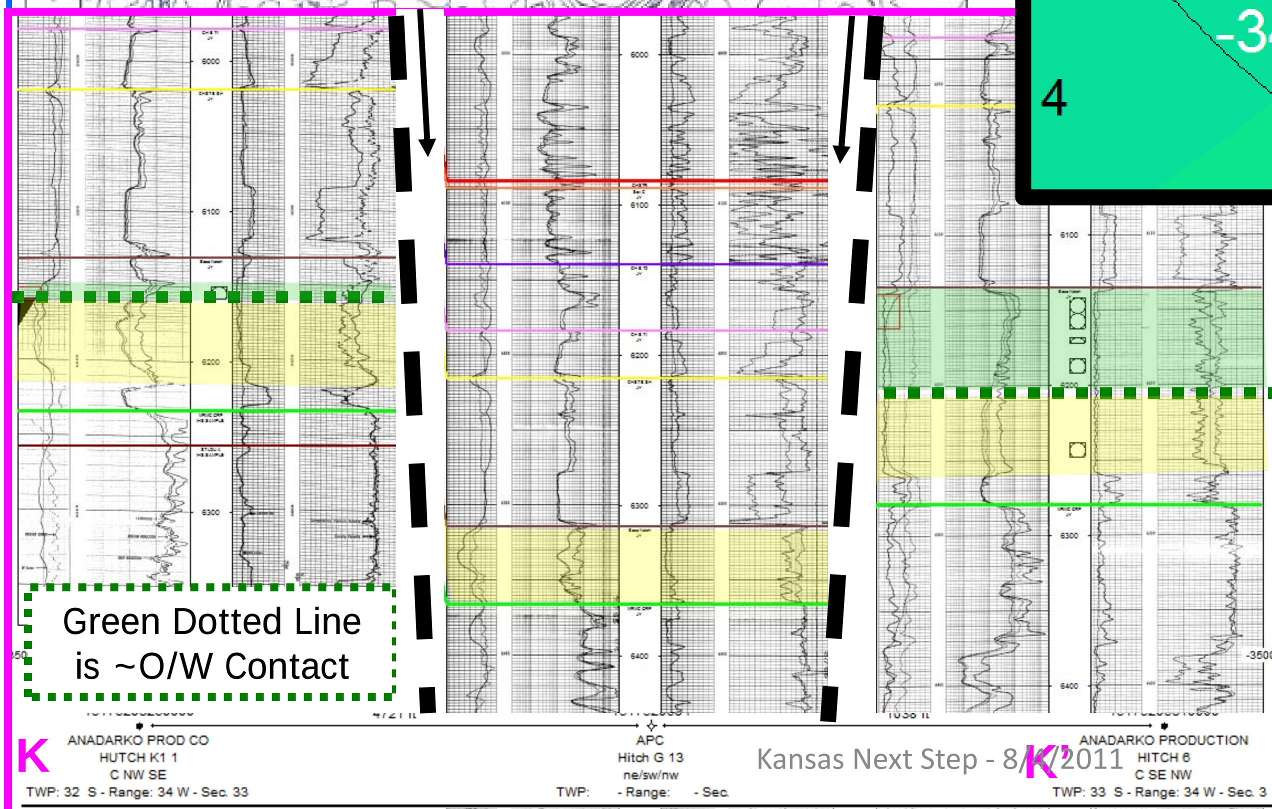
COMPARTMENTALIZATION WITHIN VALLEY AXIS:
Structural Compartments: Karst Traps?

Shuck Field Area



Meramec tvdss from 3D. 20’ C.I. Cirilo 2001.





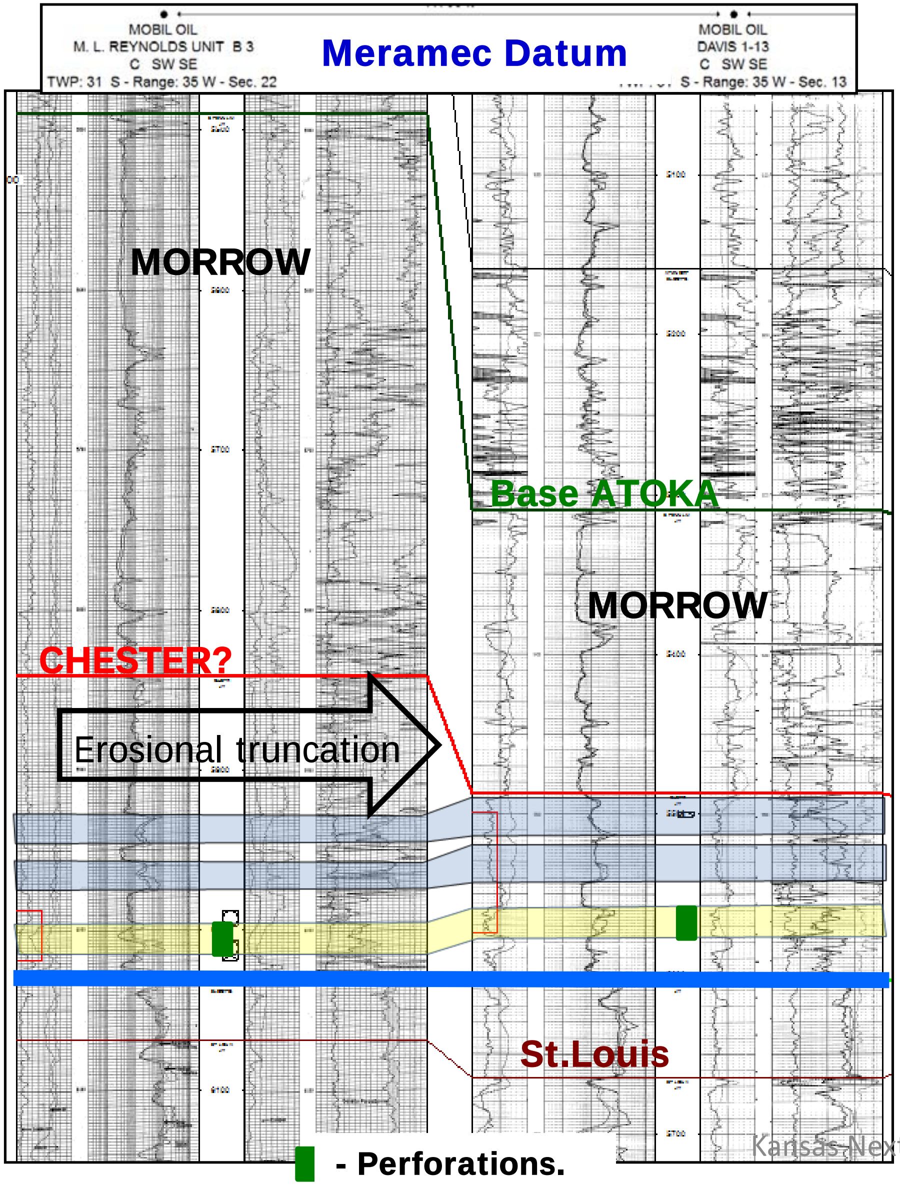
Structural X-Section displays different oil / water contacts that prove reservoir compartmentalization within valley at North end of Shuck. Cirilo (2001) interprets Shuck trap to be caused by karsting.

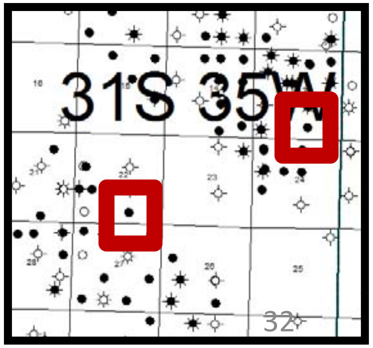
COMPARTMENTALIZATION:

Structural Compartments: Post Chester Fault Seals?

Cutter & Cutter South Field Areas

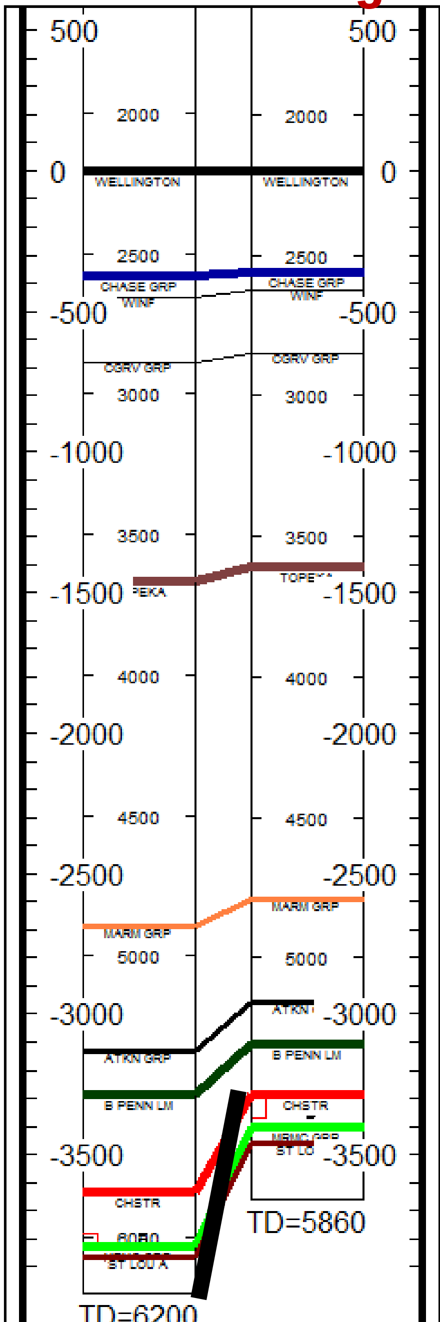
Current max. horizontal stress regime in midcontinent is NE-SW. Could Chester sands be locally sealed on the downthrown side of NW-SE trending faults?....if juxtaposed against tight Meramec Limestones?





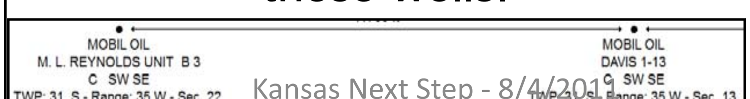
Cutter & Cutter South Field Areas

Datum: Wellngtn

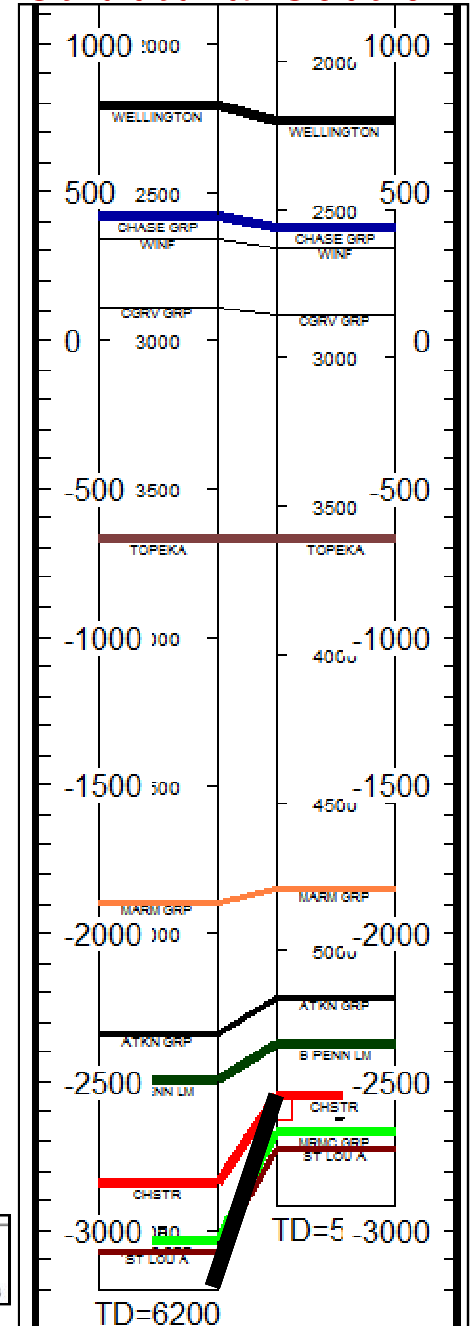


Up to at least Wellington time, subsidence continued on downthrown side of fault. However, amount of downthrown subsidence appears to have decreased over time at close to a constant rate.

Since Wellington time Laramide tectonic events impacting the Keyes Dome and Las Animas Arch resulted in 55’ of uplift and dip reversal on the Wellington in the downthrown well. Keyes dome in located SSW of these wells.

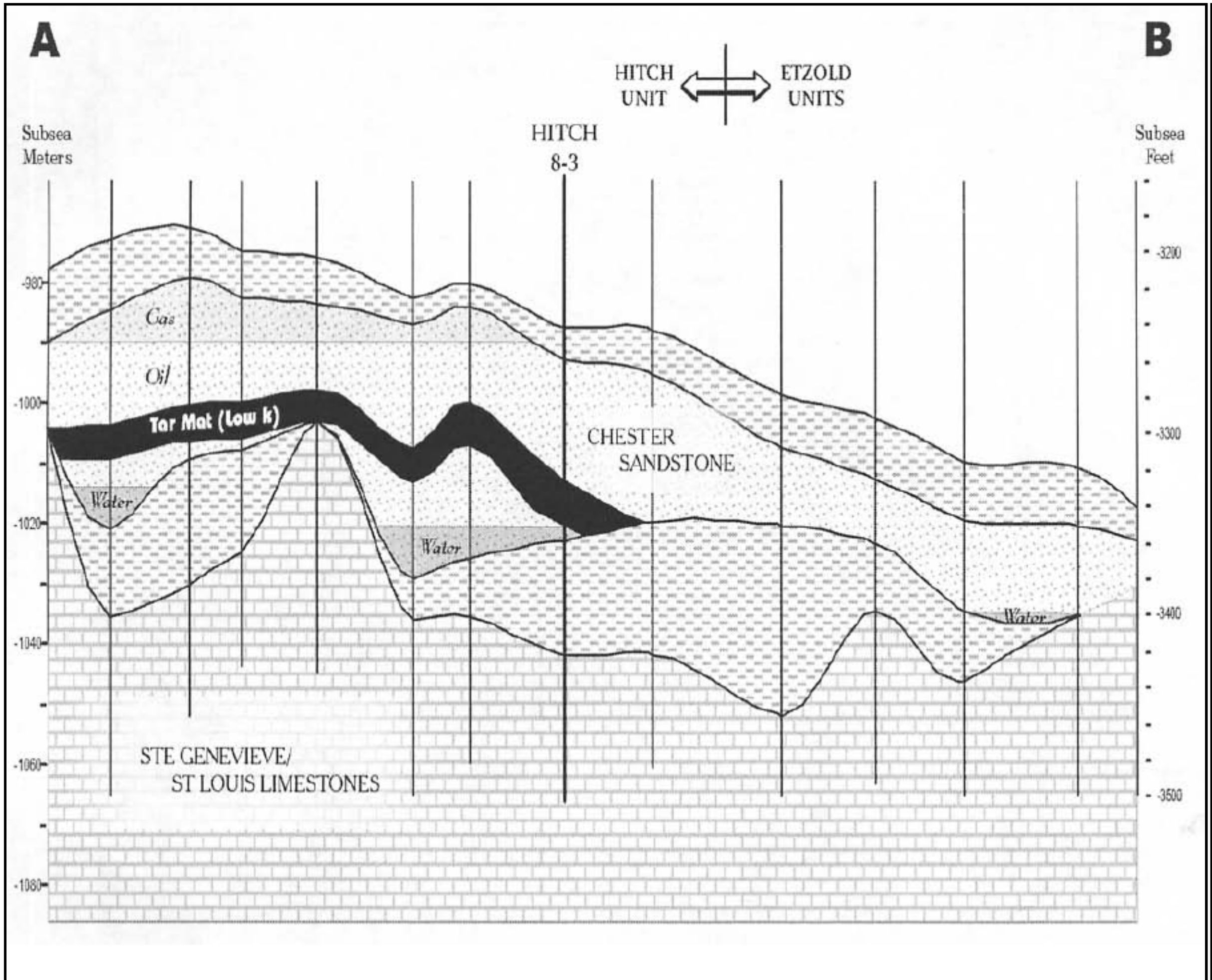


Structural Section



COMPARTMENTALIZATION:
Diagenetic Compartments.

Recent work by Sorenson (99), Kim (06), and Cirilo (01) discuss the negative impact tar mat formation has on permeability of valley filling reservoirs. Example from Shuck Pool.



IGURE 3—Structural cross section along axis of basal Chester valley. Vertical exaggeration approximately 33:1.

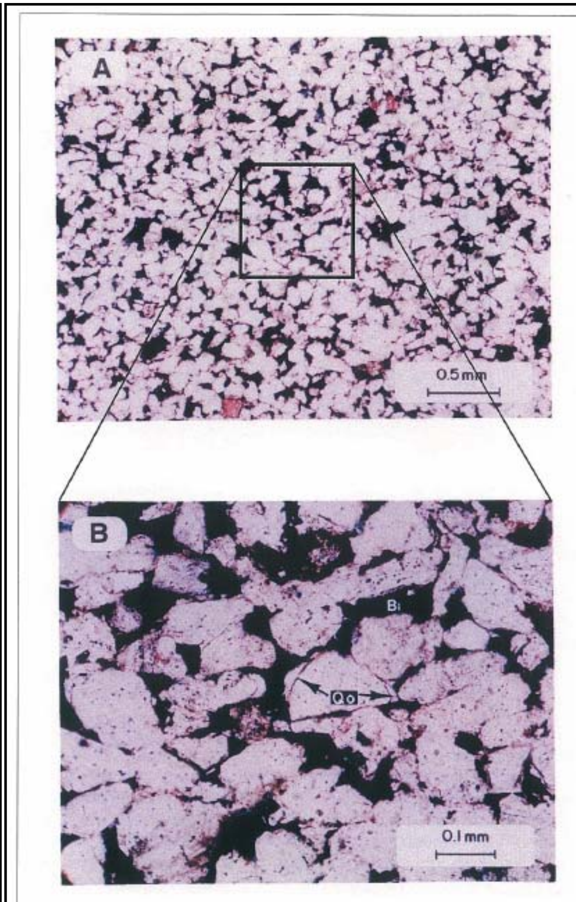


Figure 55: Photomicrographs showing complete porespace occlusion by bitumen (Bi). This diagenetic phenomenon leads to poor porosity and permeability in otherwise high-quality, reservoir rock and is often difficult to identify on electric logs. This sample is from the Hitch 8-3 well, 1896 m (6222 ft).

Sorenson et al, 1999

Cirilo, 2001

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Acknowledgments

We wish to thank the companies participating in the project:
Anadarko Petroleum Corp.
Berexco LLC
Cimarex Energy Company
Glori Oil Limited
Merit Energy Company

And Kansas Geological Survey, through the Kansas University Center for Research
and the U.S. Department of Energy

Material presented is based upon work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant Number DEFE0000002056. This project is managed and administered by the Kansas Geological Survey/KUCR, W. L. Watney, PI, and funded by DOE/NETL and cost-sharing partners.