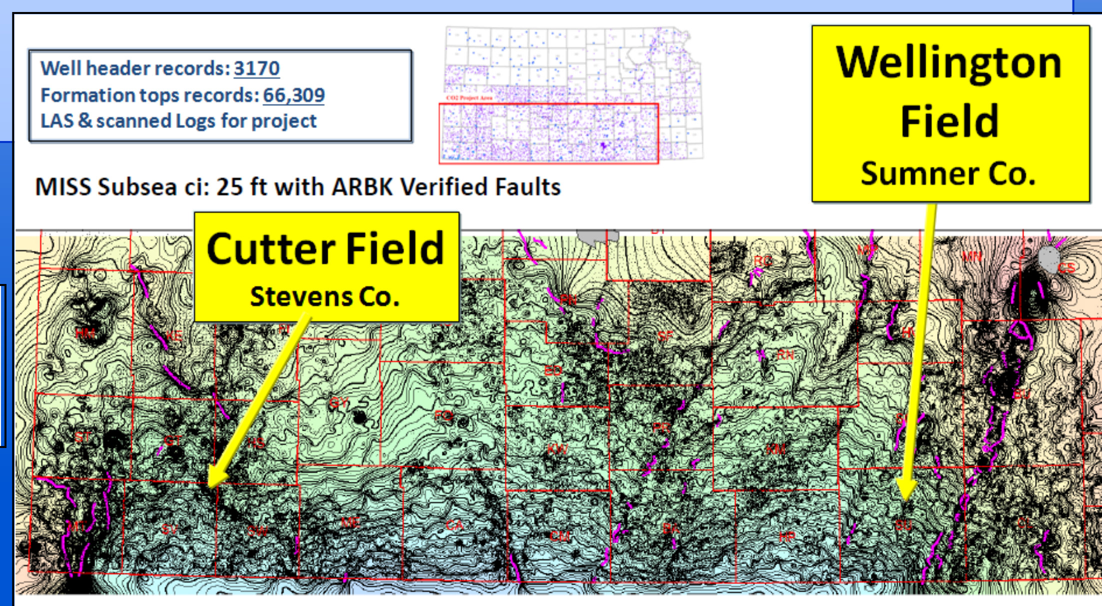
Sedimentologic and Stratigraphic Effects of Episodic Structural Activity During the Phanerozoic in the Hugoton Embayment, Kansas USA

W. Lynn Watney[1], John Youle[2], Dennis Hedke[3], Paul Gerlach[4], Raymond Sorenson[5], Martin Dubois[6], Larry Nicholson[7], Thomas Hansen[10], David Koger[8], Ralph Baker[9], Jennifer Raney[1]

[1]Kansas Geological Survey, The University of Kansas, Lawrence, KS.
[2]Sunflower LLC, Longmont, CO. [3]Hedke-Saenger Geoscience, Ltd., Wichita, KS.
[4]Charter Consulting, Miramar, FL. [5]Consultant, Tulsa, OK. [6]Improved Hydrocarbon Recovery, LLC, Lawrence, KS. [7]Western Frontier Inc., Hanover, KS. [8]Koger Remote Sensing, Ft. Worth, TX. [9]Consultant, Houston, TX. [10]Bittersweet Energy, Inc., Wichita, KS.

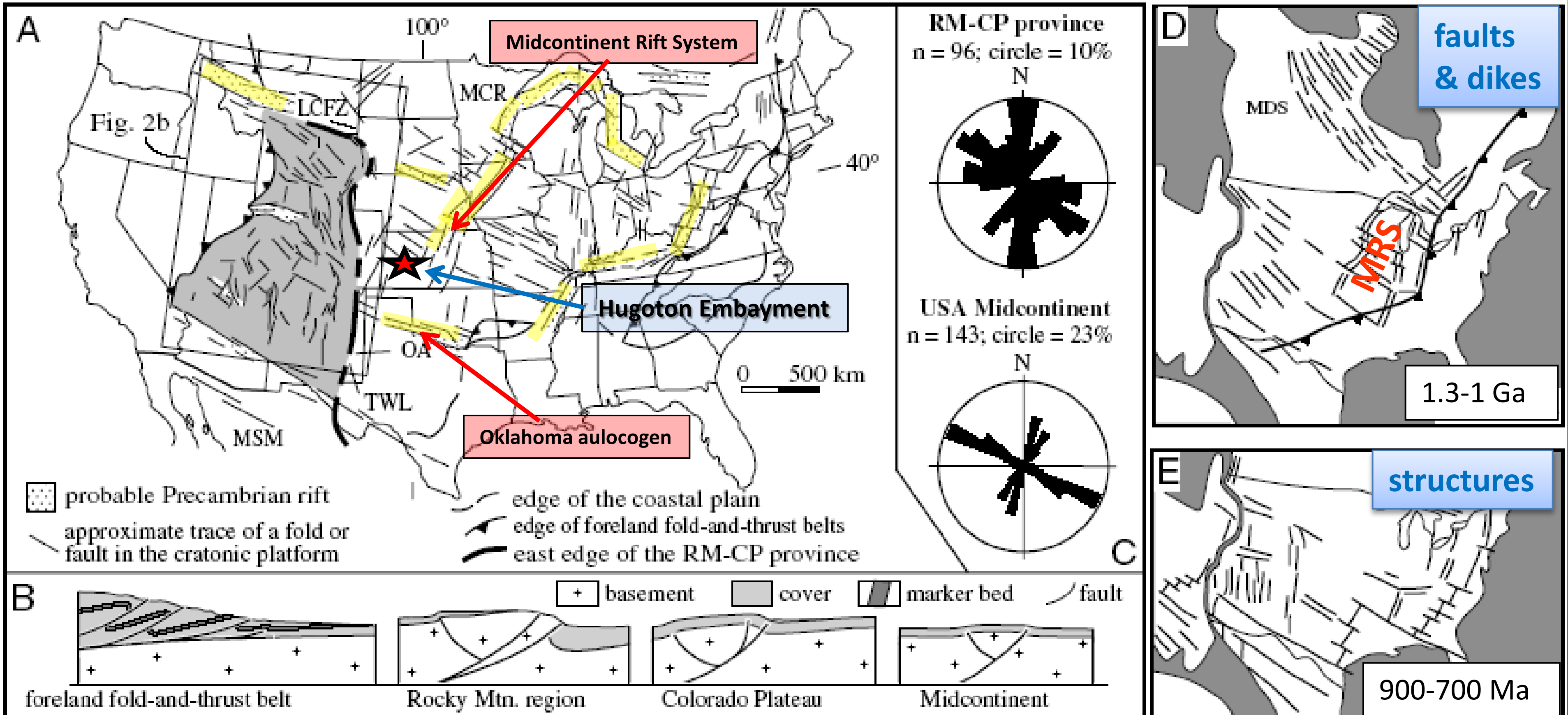
Outline

- **Anadarko Basin** – Proterozoic extension to Phanerozoic compression
- **Hugoton Embayment (HE)** – 10,000 km^2 Anadarko Basin extension
- **Major HE structures–** reactivation along basement lineaments
- **Episodic movement** – Phanerozoic sedimentation/stratigraphy
- **Pattern of deformation** – basement weaknesses (the template) and evolving stress field
- **Summary**



Cratonic platform - Proterozoic

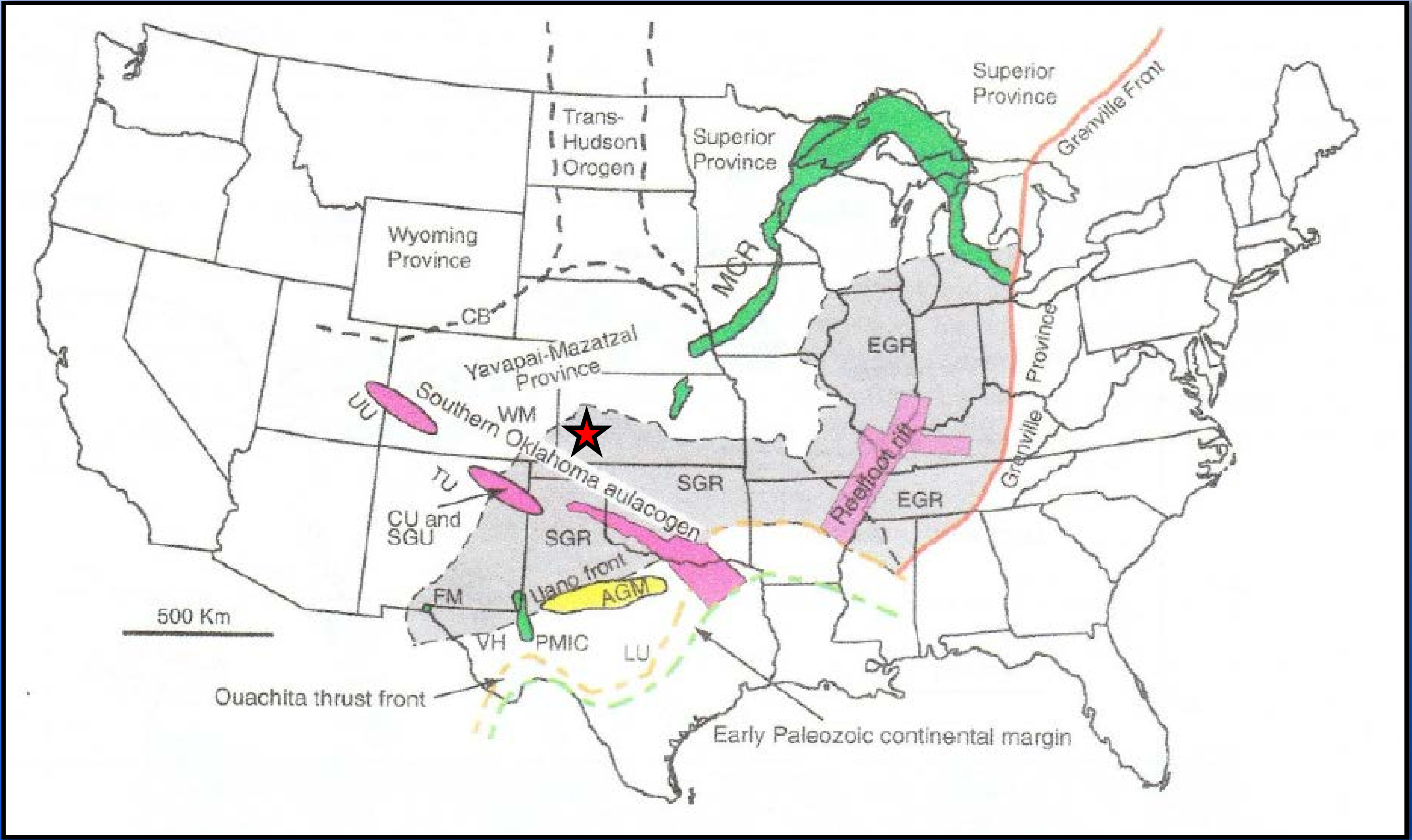
Extensional faults and folds



- Two dominant directions of extensional structures in Proterozoic
- Faults reactivated during Phanerozoic compressional orogenies (Kluth and Coney, 1981)
- Inversion of once normal faults leading to *reverse & oblique-slip*

Marshak, Karlstrom, and Timmons (2000)

Proterozoic Basement Terrains

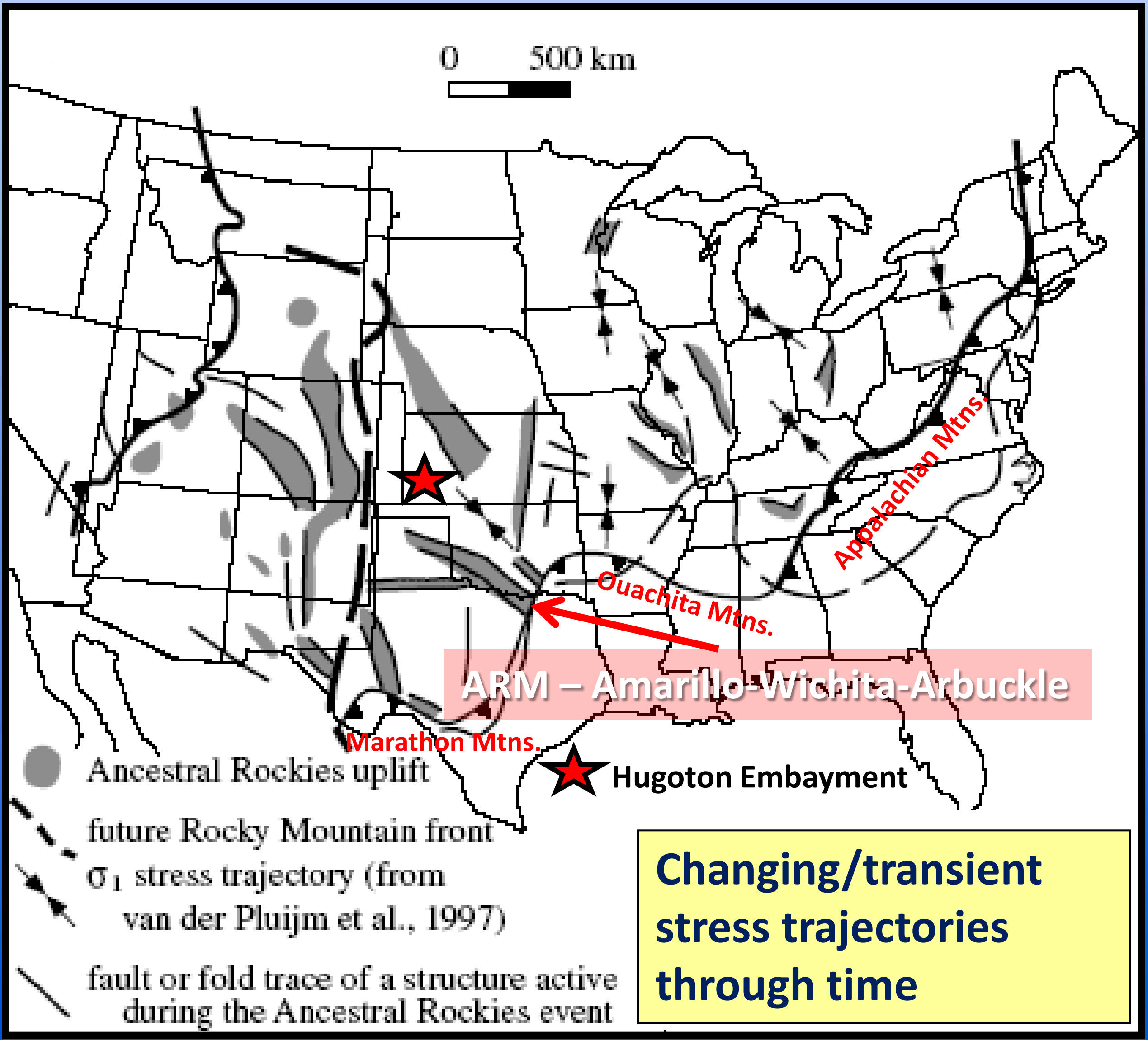


Kansas has three distinct basement terrains

Keller and Stephenson (2007)

Structures - Ancestral Rockies

Early Chesterian - Late Leonardian deformation

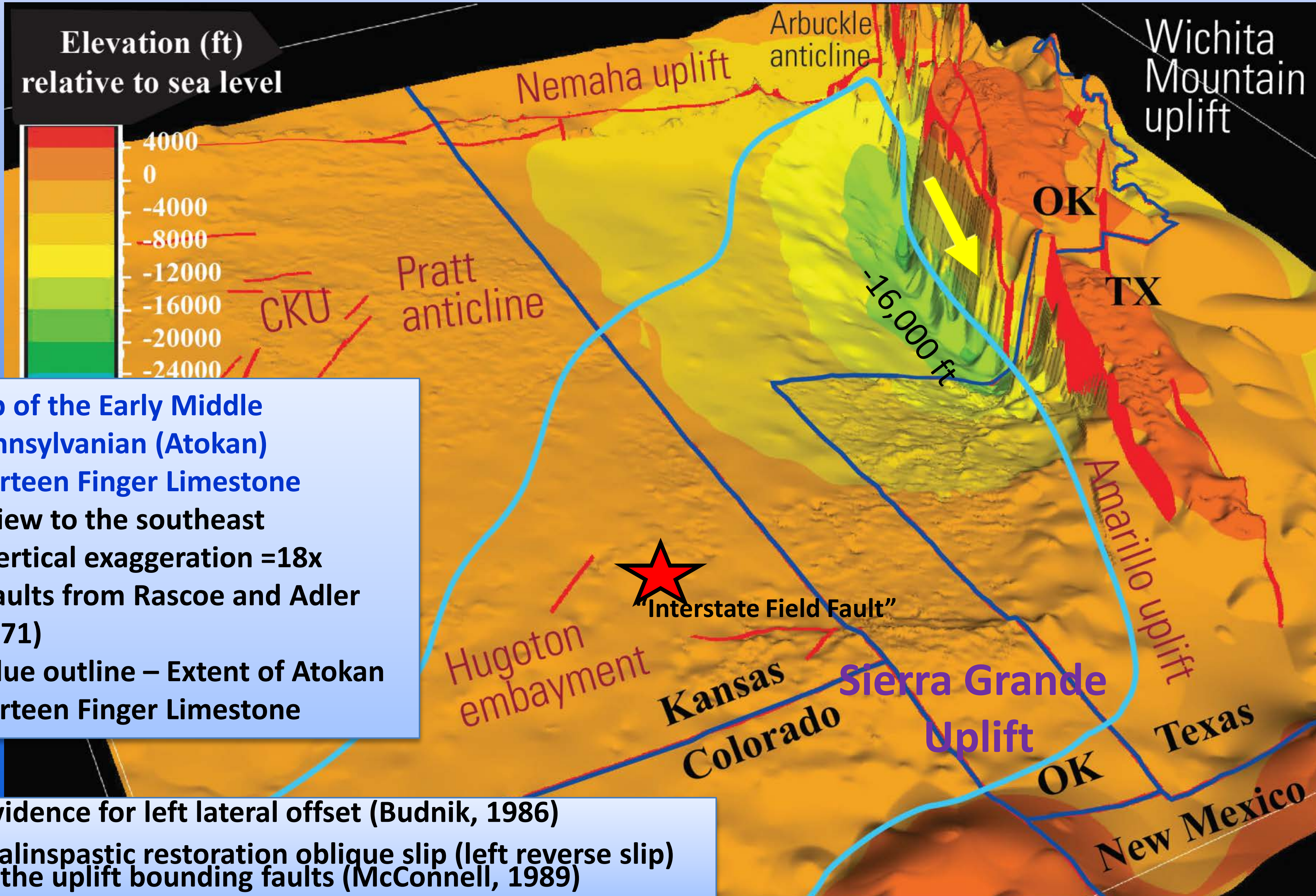


Changing/transient stress trajectories through time

Marshak, Karlstrom, and Timmons (2000)
Ages from Dickinson and Lawton (2003)

Intraplate fault reactivation is mainly dependent on orientation of (weak) fault zones relative to plate margin… deformation in interior can be represented by simple rheological models
(van der Pluijm et al., 1997)

Peak Late Paleozoic Tectonism during Morrowan and Atokan



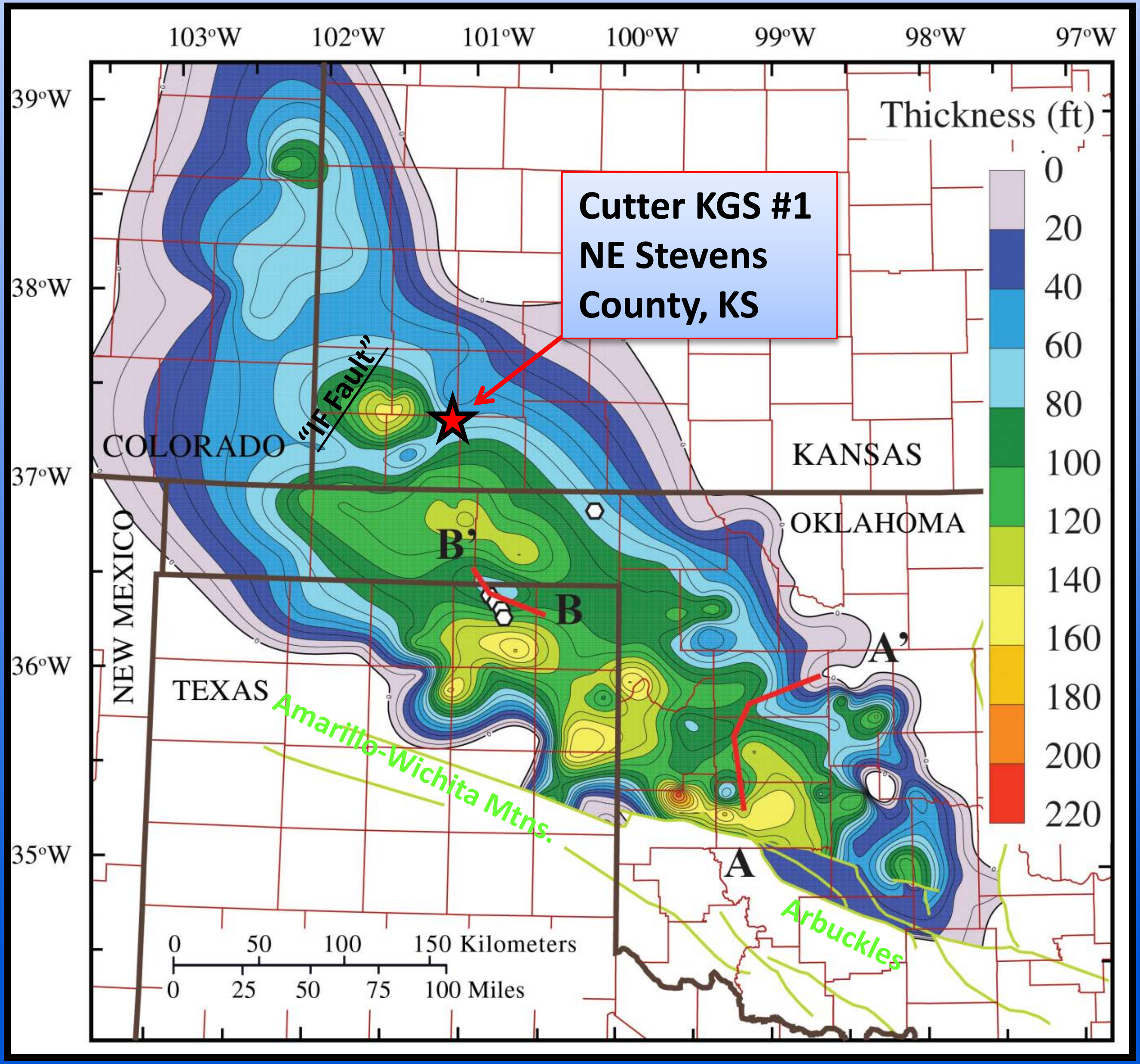
Top of the Early Middle Pennsylvanian (Atokan) Thirteen Finger Limestone

- View to the southeast
- Vertical exaggeration =18x
- Faults from Rascoe and Adler (1971)
- Blue outline – Extent of Atokan Thirteen Finger Limestone

- Evidence for left lateral offset (Budnik, 1986)
- Palinspastic restoration oblique slip (left reverse slip) on the uplift bounding faults (McConnell, 1989)

(Higley, 2011)

Isopach - Top Thirteen Finger Limestone to Top of Morrow Shale



(Higley, 2011)

Organic analyses from Berexco Cutter KGS #1 core

Atokan sample at 5233.5 ft is organic rich (3.77% TOC) and TTI of 443 indicates sample is in the oil generating window

Client ID	Depth (ft)	Sample Type	Sample Prep		Leco	SRA			Tmax		Meas.	HI	OI	S2/S3	S1/TOC*	PI	Notes		Lab ID
	Top			*	TOC	S1	S2	S3	(°C)	**	% Ro				100		Checks	Pyrogram	
1-1TOC	5233.5	Chunk	NOPR		3.77	0.80	12.68	0.41	443			337	11	31	21	0.06	SRA TOC	n	101065946
1-1-1TOC	5233.7	Chunk	NOPR		1.83	0.20	0.80	0.22	445			44	12	4	11	0.20	TOC	n:lts2sh:hts2sh	101065948
1-5TOC	5237.4	Chunk	NOPR		0.24	0.07	0.30	0.22	440	**		127	93	1	30	0.19	TOC	n	101065950
1-8TOC	5240.5	Chunk	NOPR		1.55	0.32	1.20	0.34	445			77	22	4	21	0.21	SRA TOC	n:hts2sh	101065952
1-12TOC	5244.1	Chunk	NOPR		0.48	0.08	0.17	0.37	443	**		35	76	0	17	0.32	TOC	n:lts2sh:hts2sh	101065954
2-38TOC	5289.5	Chunk	NOPR		0.56	0.07	0.19	0.55	445	**		34	99	0	13	0.27	TOC	n:lts2sh:hts2sh	101065956
3-15TOC	5414.6	Chunk	NOPR		0.90	0.11	0.59	0.41	445			66	46	1	12	0.16	SRA TOC	n:lts2sh:hts2sh	101065958
5-53TOC	5535.5	Chunk	NOPR		0.16	0.04	0.07	0.42	440	**		45	256	0	27	0.37	TOC	n:lts2sh:hts2sh	101065960
6-47TOC	5589.15	Chunk	NOPR		0.53	0.11	0.46	0.36	442	**		86	68	1	21	0.19	TOC	n	101065962
12-47TOC	6486.2	Chunk	NOPR		0.18	0.03	0.12	0.41	442	**		68	233	0	17	0.20	SRA TOC	n:lts2sh	101065964
12-47-1TOC	6486.4	Chunk	NOPR		0.22	0.03	0.29	0.29	441	**		131	131	1	14	0.09	TOC	n:lts2sh	101065966

Notes:

"-1" = not measured or invalid value
TOC - Total Organic Carbon, wt. %
S1 - volatile hydrocarbon (HC) content, mg HC/ g rock
S2 - remaining HC generative potential, mg HC/ g rock
S3 - carbon dioxide content, mg CO_2/ g rock

* - Sample contaminated
** - low S2, Tmax is unreliable
Meas. %Ro - measured vitrinite reflectance
HI - Hydrogen index = S2 x 100 / TOC, mg HC/ g TOC
OI - Oxygen Index = S3 x 100 / TOC, mg CO_2/ g TOC
PI - Production Index = S1 / (S1+S2)

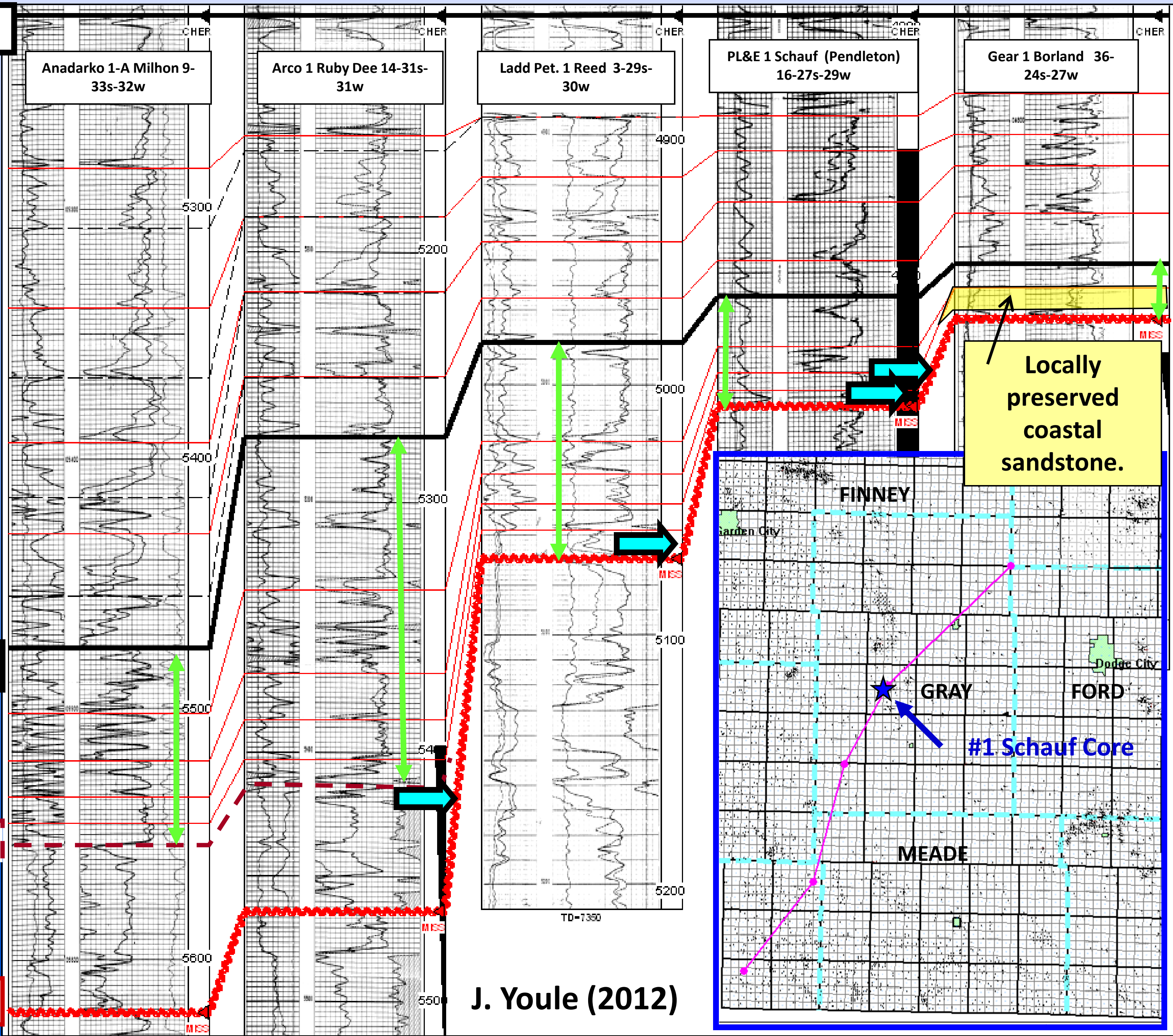
Pyrogram:
f - flat S2 peak
n - normal
ltS2sh - low temperature S2 shoulder
ltS2p - low temperature S2 peak
htS2p - high temperature S2 peak

LECO - TOC on LECO Instrument
SRA - Programmed Pyrolysis on SRA instrument
RE - Programmed Pyrolysis on Rock-Eval instrument
EXT - Extracted Rock
NOPR - Normal Preparation

Weatherford Lab

Correlation of sequence boundaries illustrates retrogradation of Atokan units in Kansas.

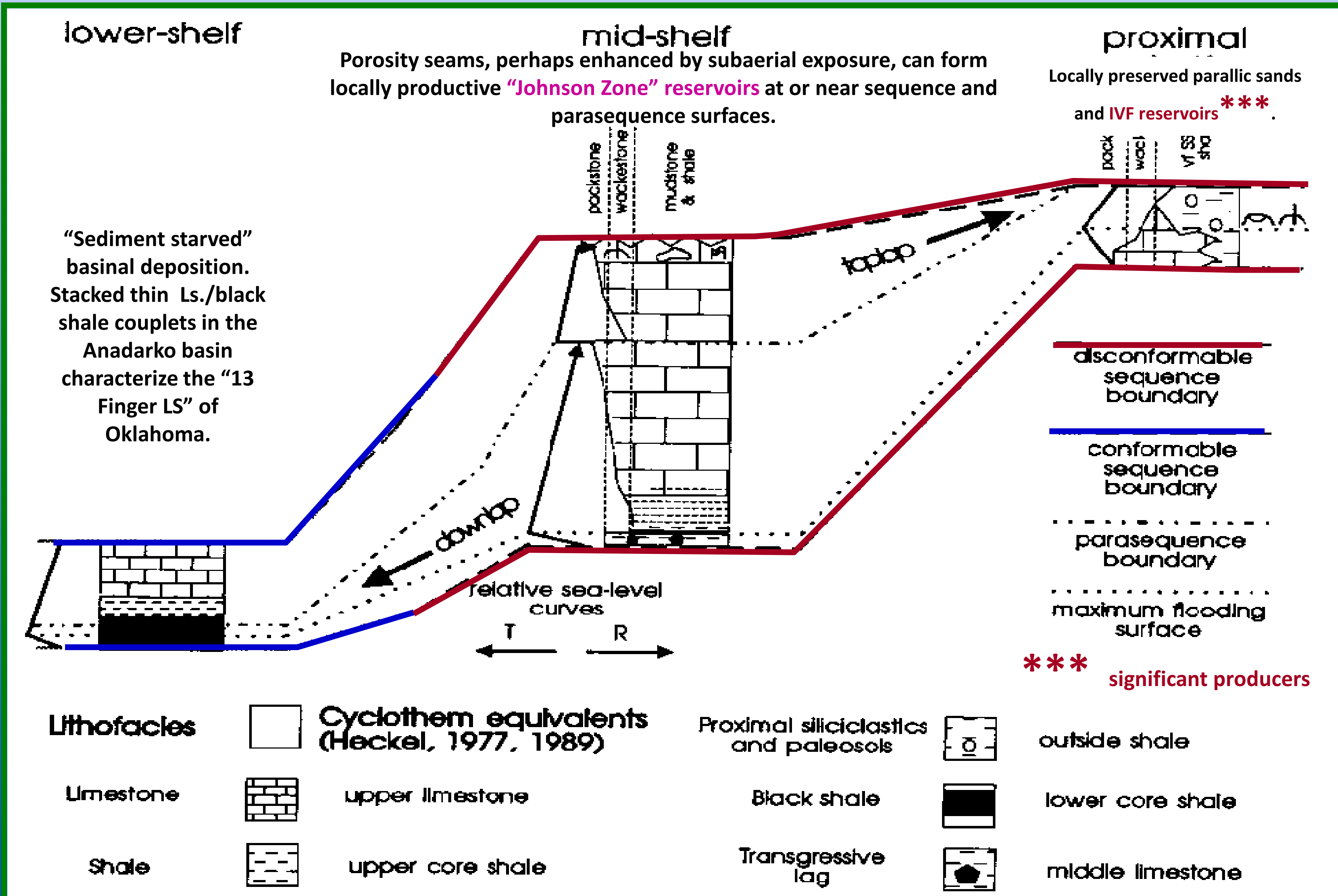
Blue arrows show units that onlap the Miss.. Atokan carbonates grade into shoreline SS.s near the point of onlap of each sequence.



Facies changes in an ideal Atokan "cycle" across Kansas.

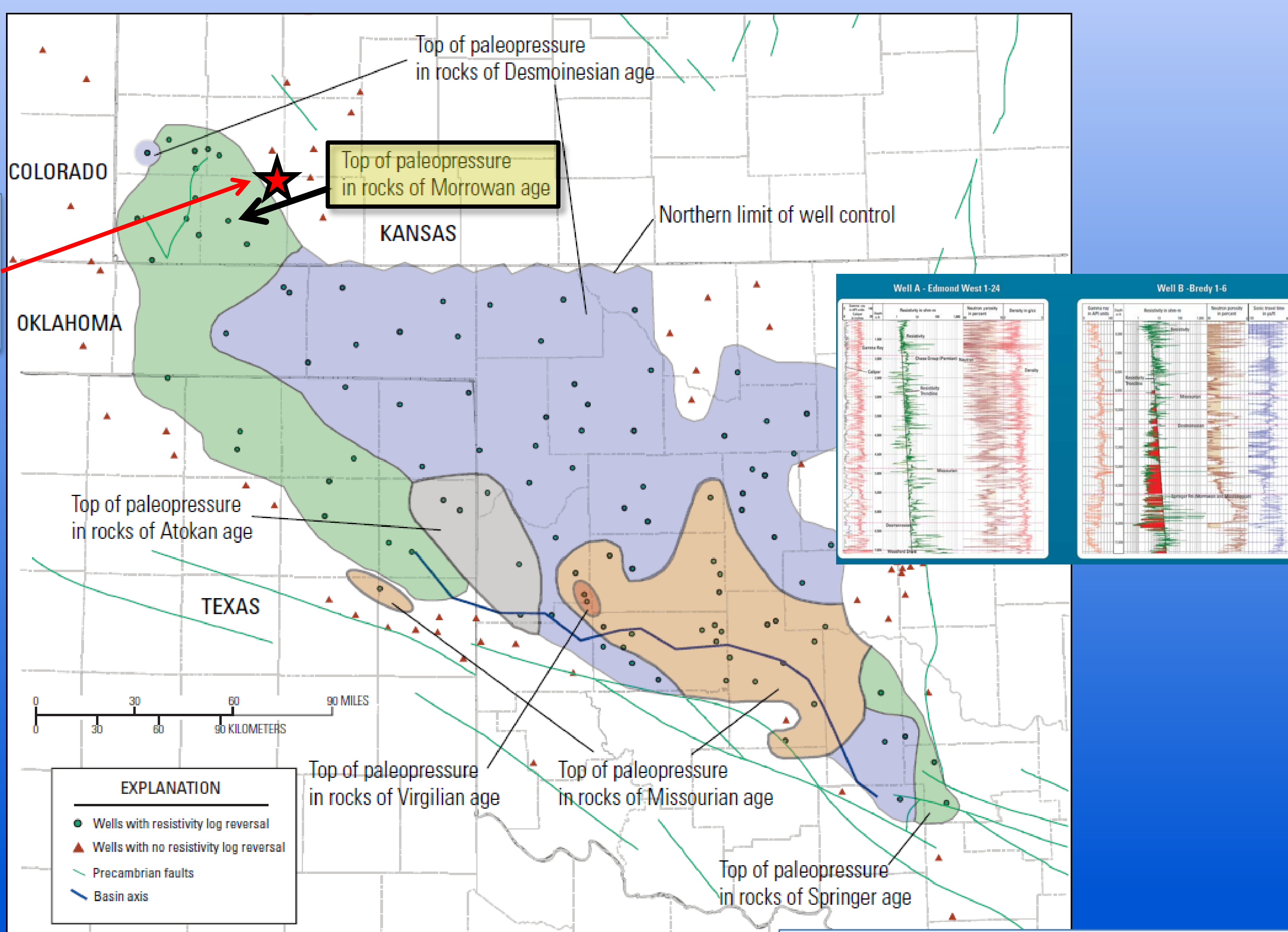
J. Youle (2012)

Anadarko basin → towards the Central Kansas uplift



Top Paleopressure – Morrowan Shale Resistivity

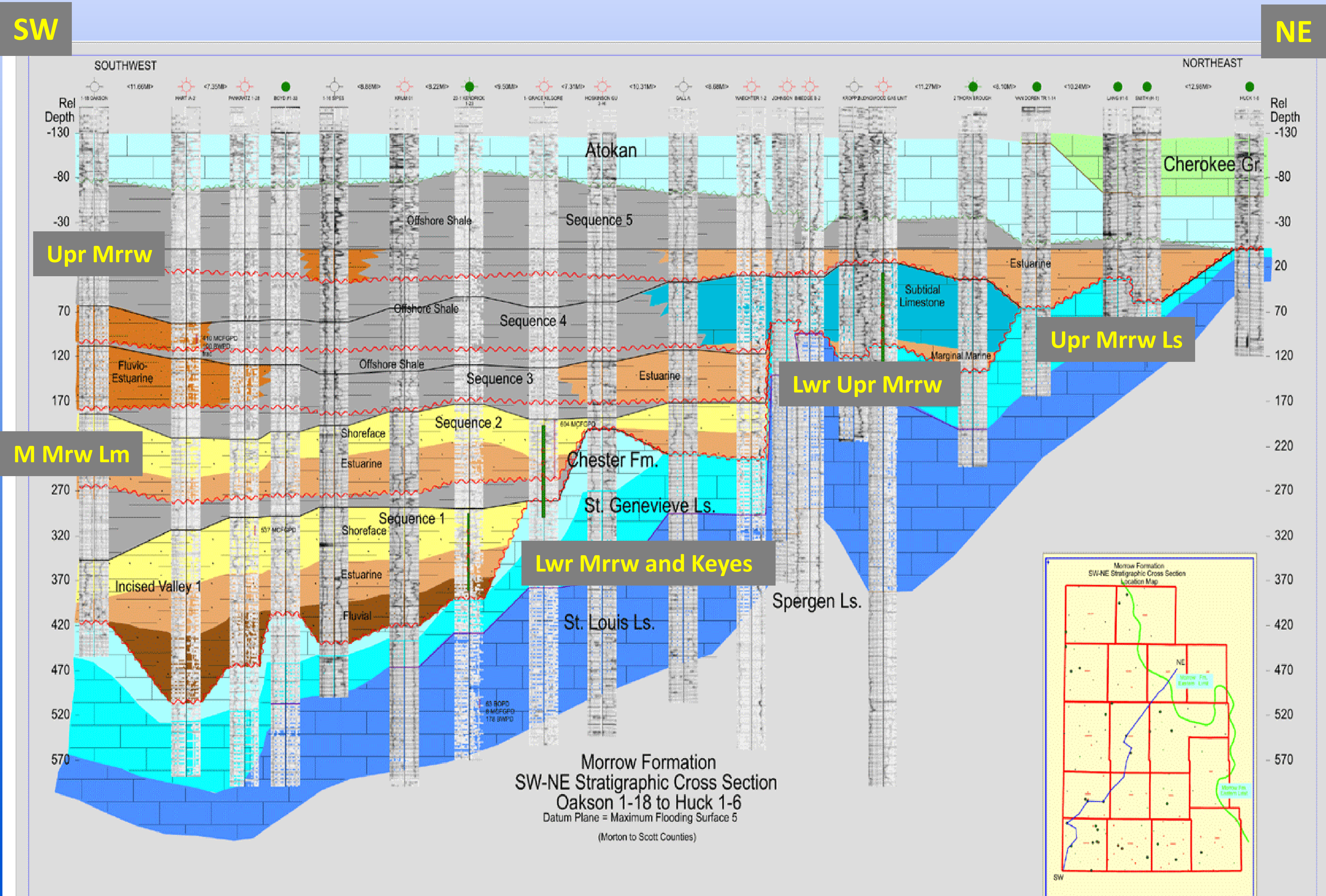
Cutter Field NE Stevens County, KS



Nelson and Gianoutsos (2011)

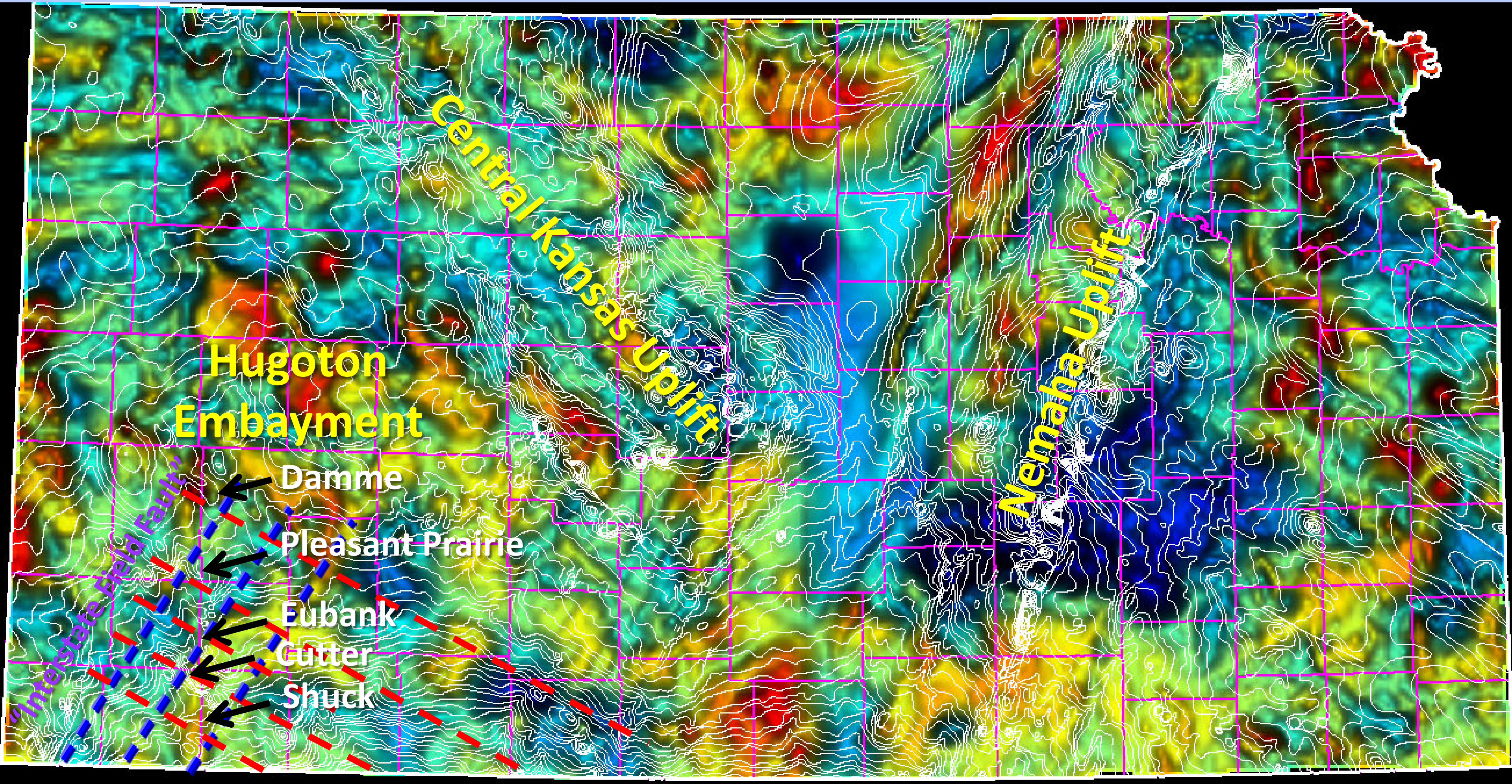
Morrowan Depositional Systems Actual

Regional Cross Section SW to NE



Salcedo, 2004 as prepared by P. Gerlach

Proterozoic correlations – Magnetic Field and Phanerozoic Structures

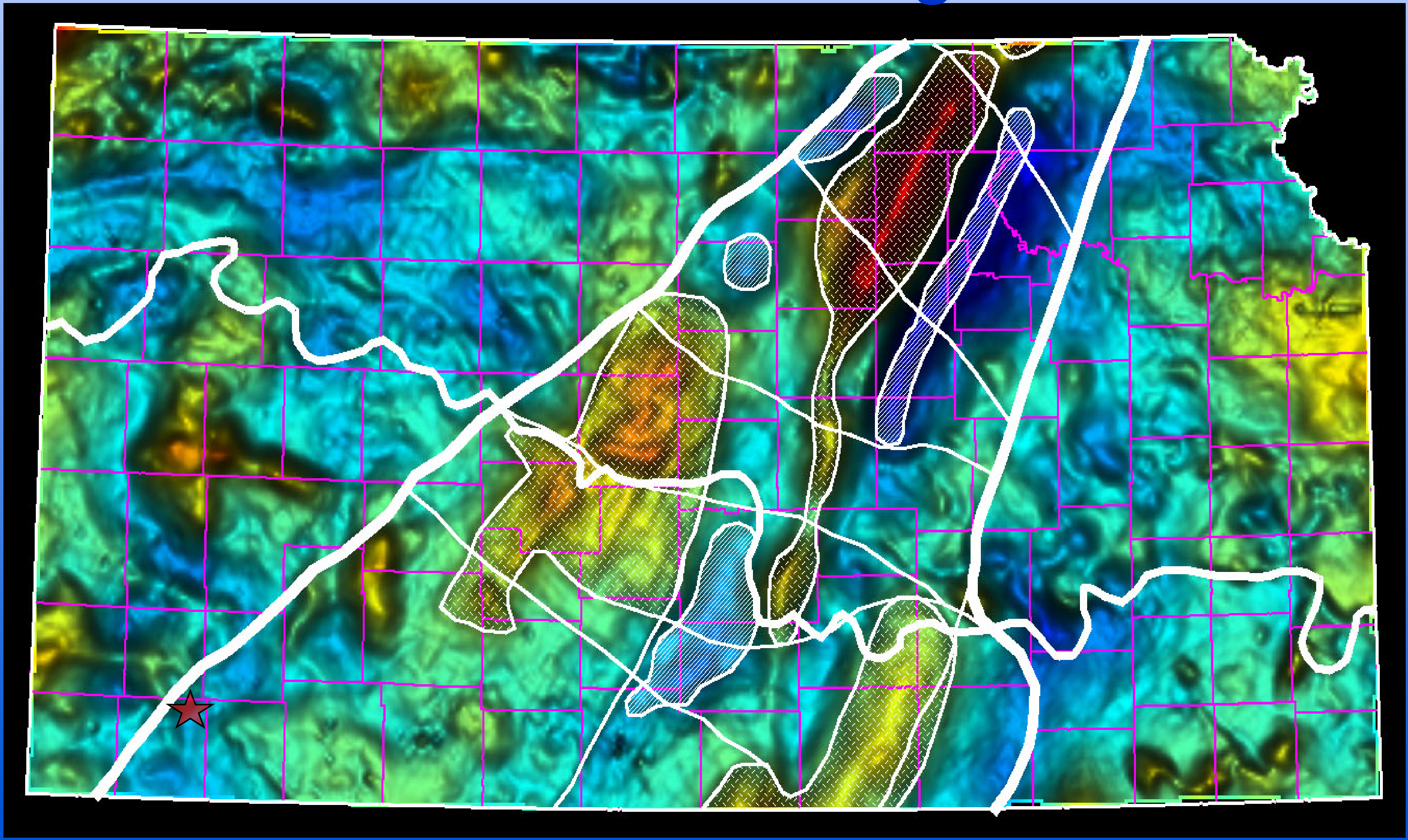


Total Intensity of Magnetic Field Reduced to Pole overlain with configuration of Precambrian surface

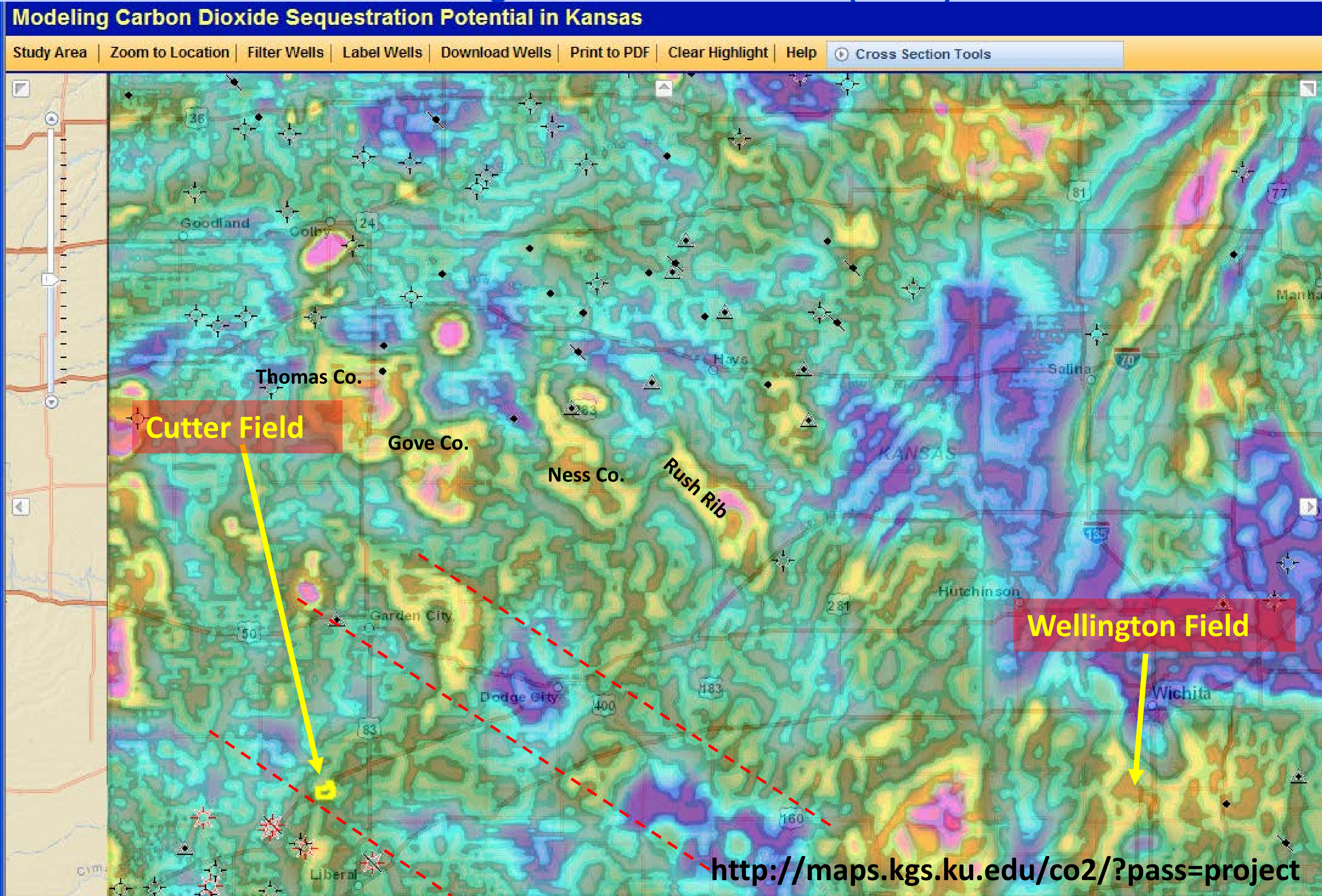
- Correspondence of Phanerozoic structures to magnetic anomalies
- Local and subregional changes in strike and dip appear to closely correlate to magnetic map
- Major influence on lithofacies distribution and sequence characteristics

(Cole, 1976; Kruger, 1999)

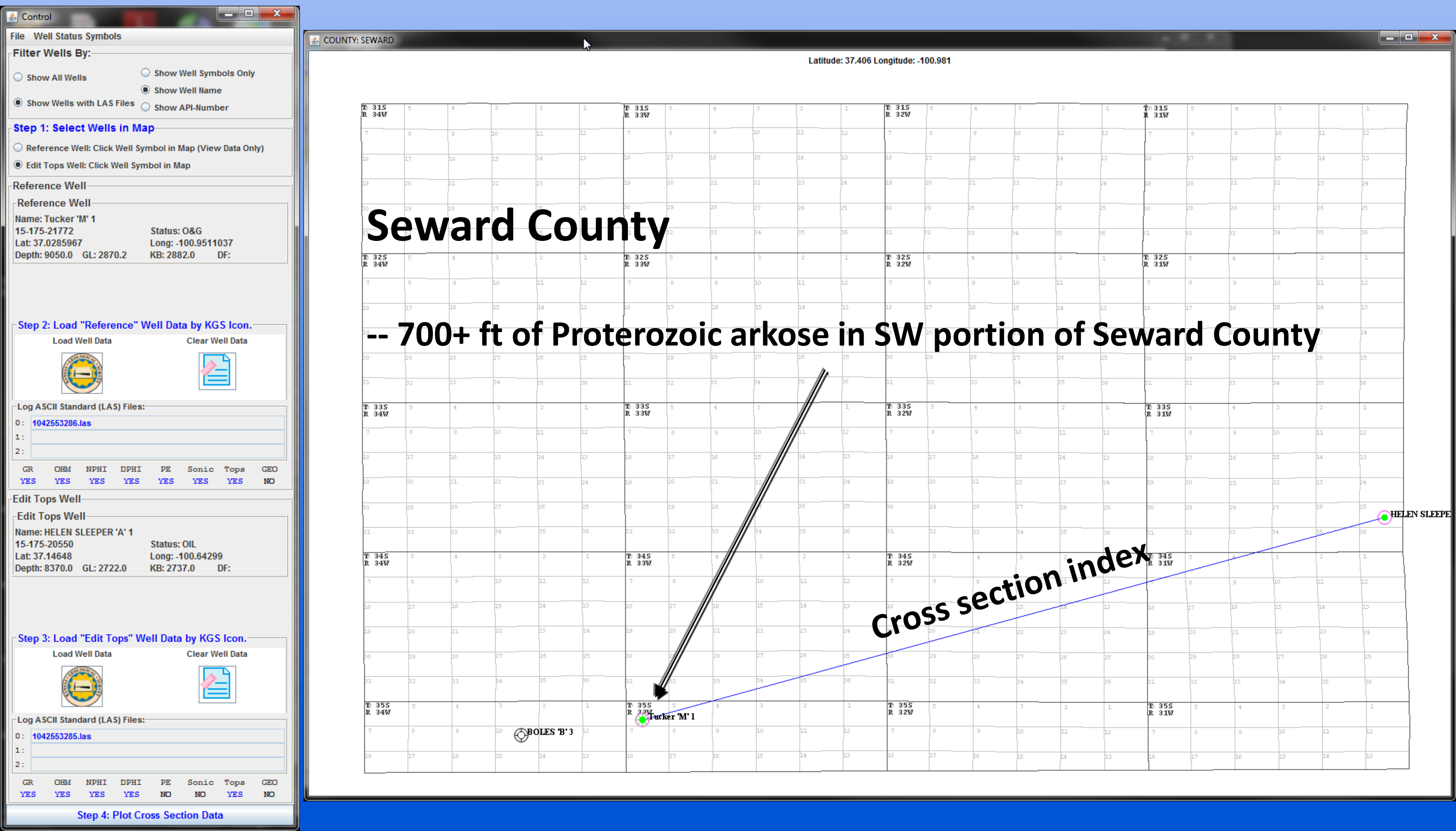
Gravity map - Precambrian Terrane Boundaries including MRS



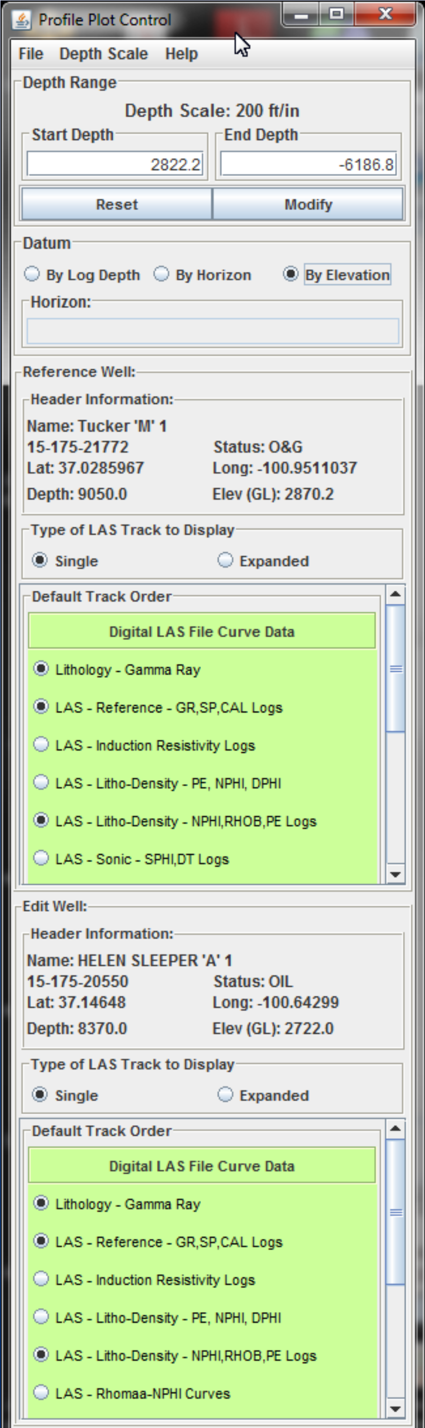
Reprocessed Kansas Magnetics -- Tilt Angle, Total Magnetic 2-10 mi + Total Magnetic Reduced to Pole (910m)

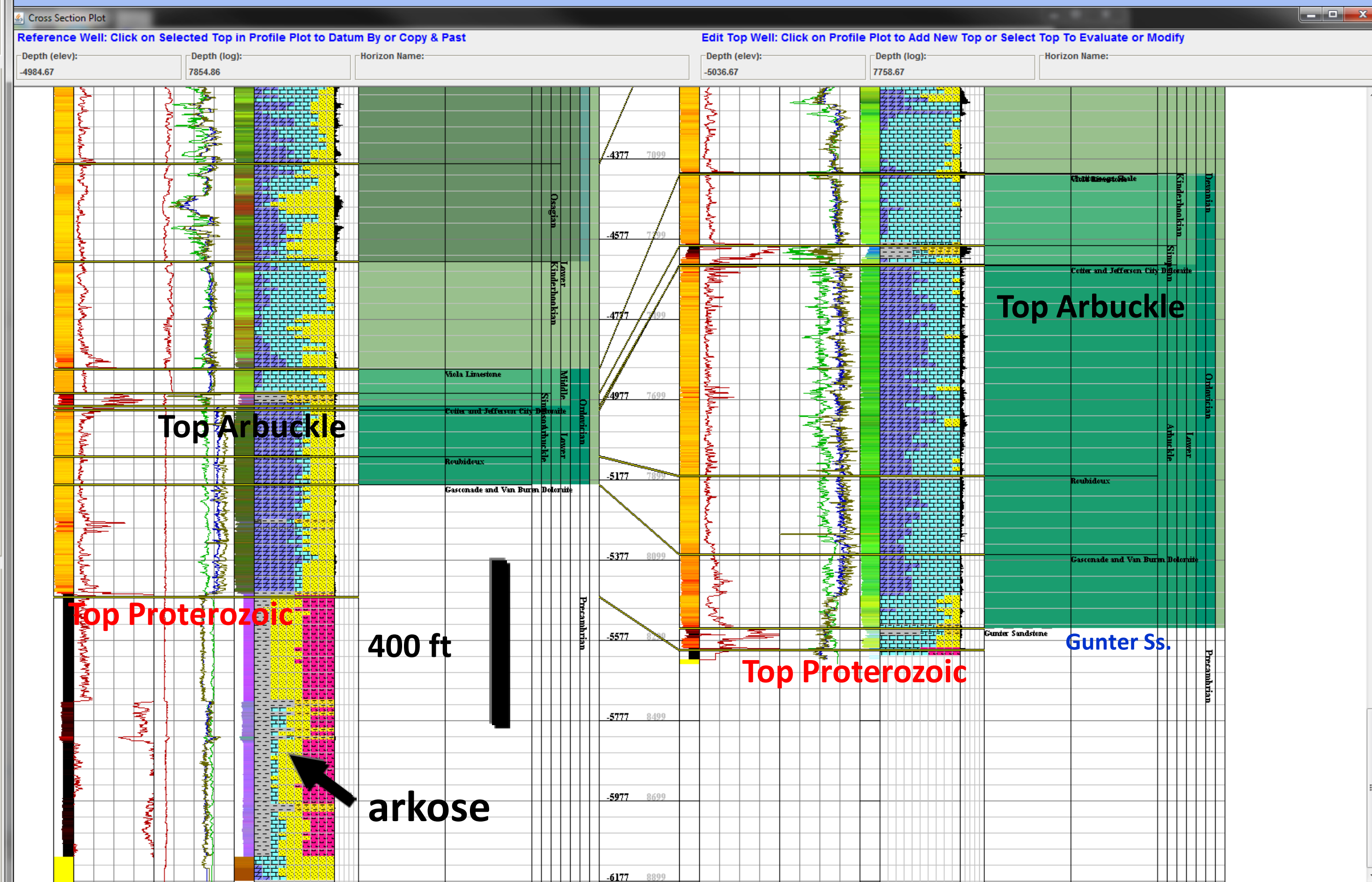


Interactive map to compare control well with well to be classified



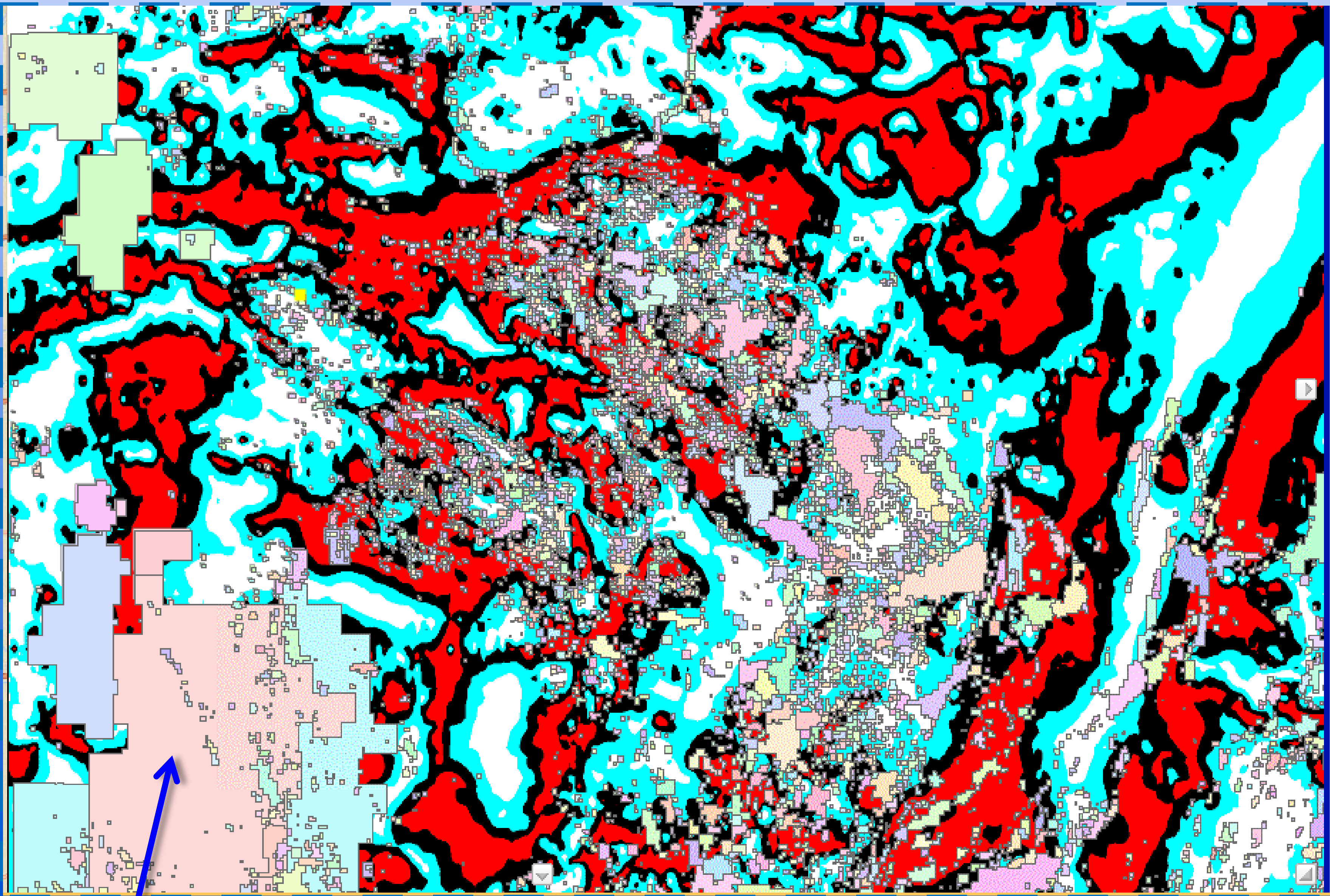
SW-NE Structural Cross Section of Lower Paleozoic in Seward County





Bob Slamal Kansas Type Log Web Application

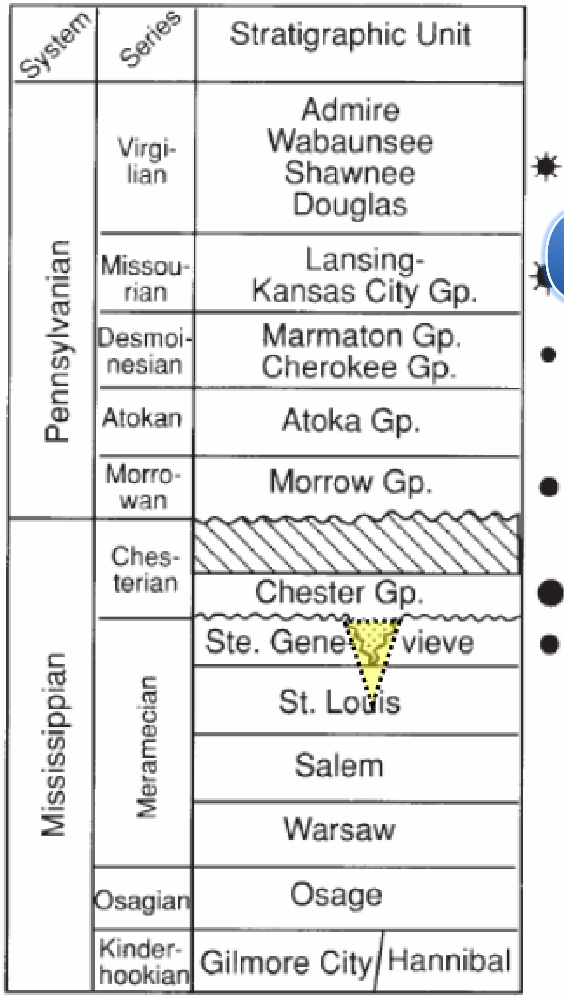
Tilt Angle Total Magnetic Reduce to Pole



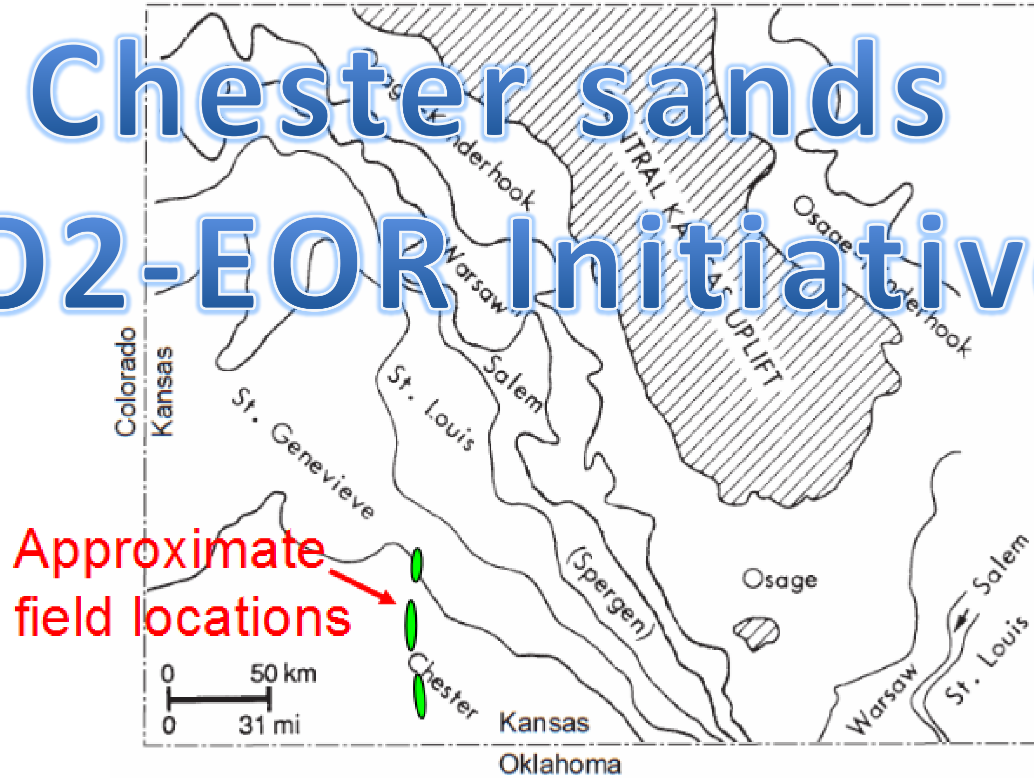
Oil fields in western 2/3rd of Kansas

http://maps.kgs.ku.edu/co2/?pass=project

Stratigraphic setting



Generalized stratigraphic column (Montgomery and Morrison, 1999).

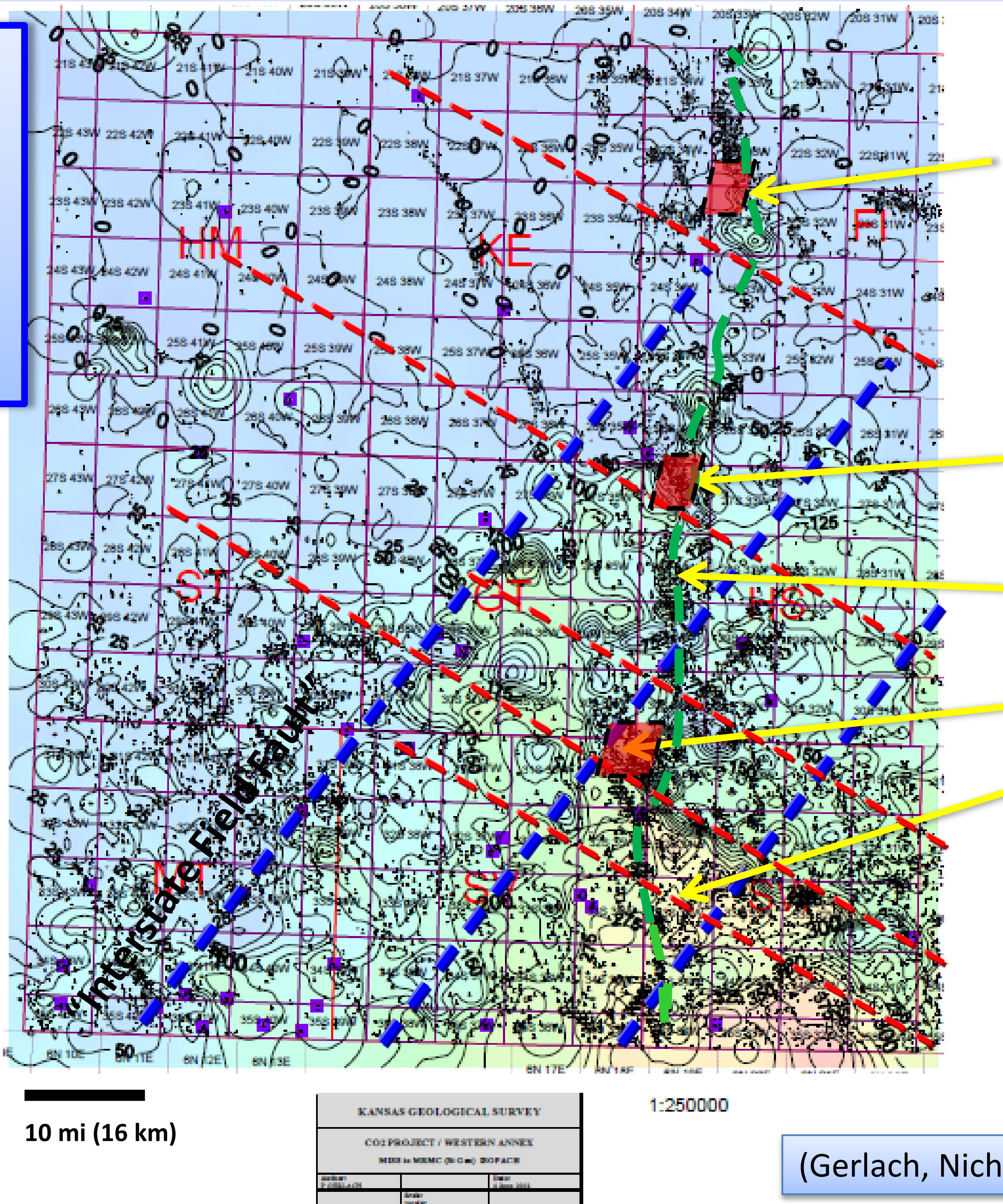


Subcrop pattern for Mississippian strata, western Kansas (Ebanks, 1991).

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 Isopach delimiting *incised valley system*

(~100 miles long)



Damme

Pleasant Prairie

Eubank Field

Cutter Field

Shuck Field

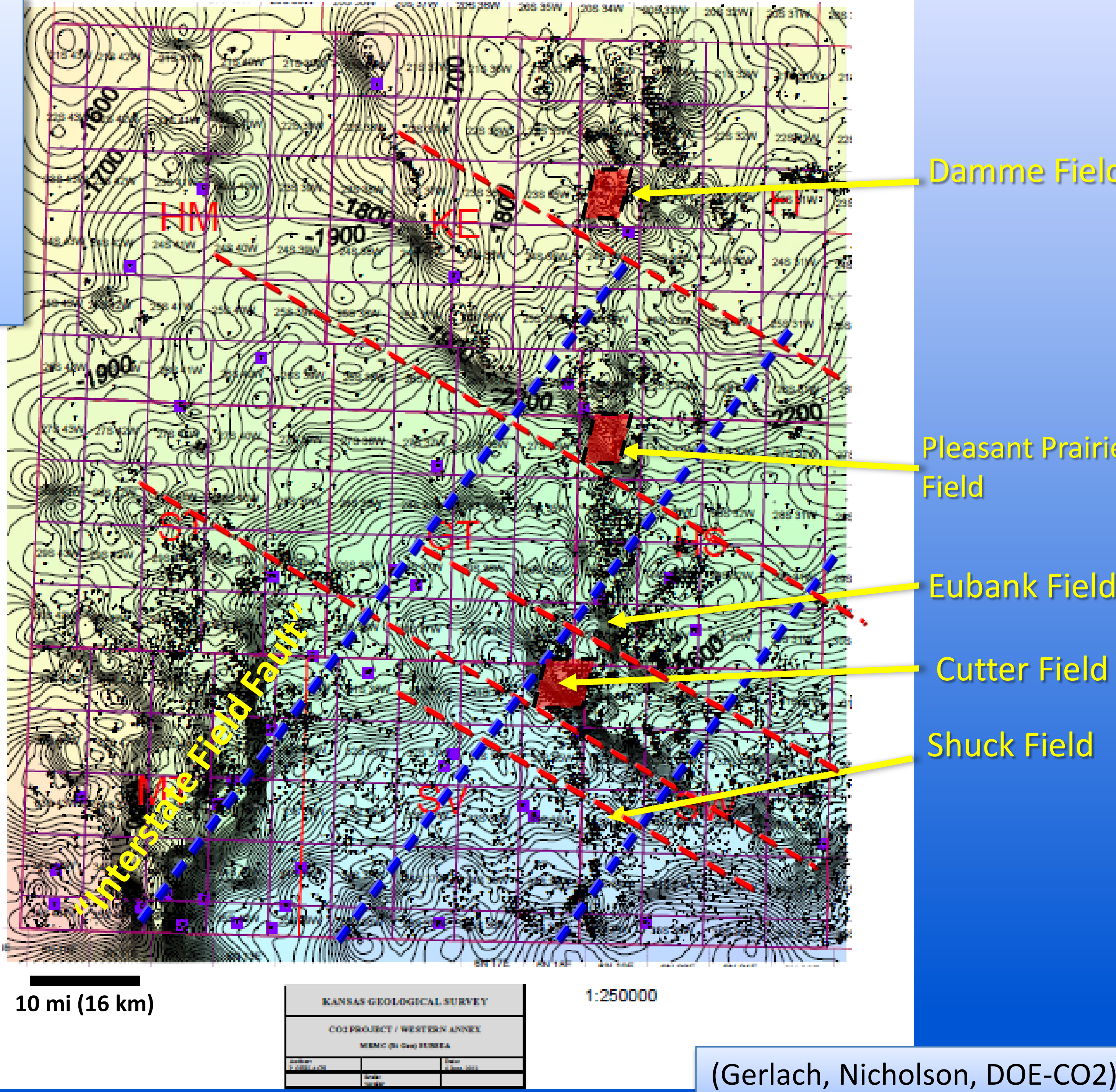
Rhombic horst blocks (reverse faults on south and west flanks)

Incised valley

(Gerlach, Nicholson, DOE-CO2)

Structure Top Meramec Mississippian

Horst with faulted southwest and west flanks



(Gerlach, Nicholson, DOE-CO2)

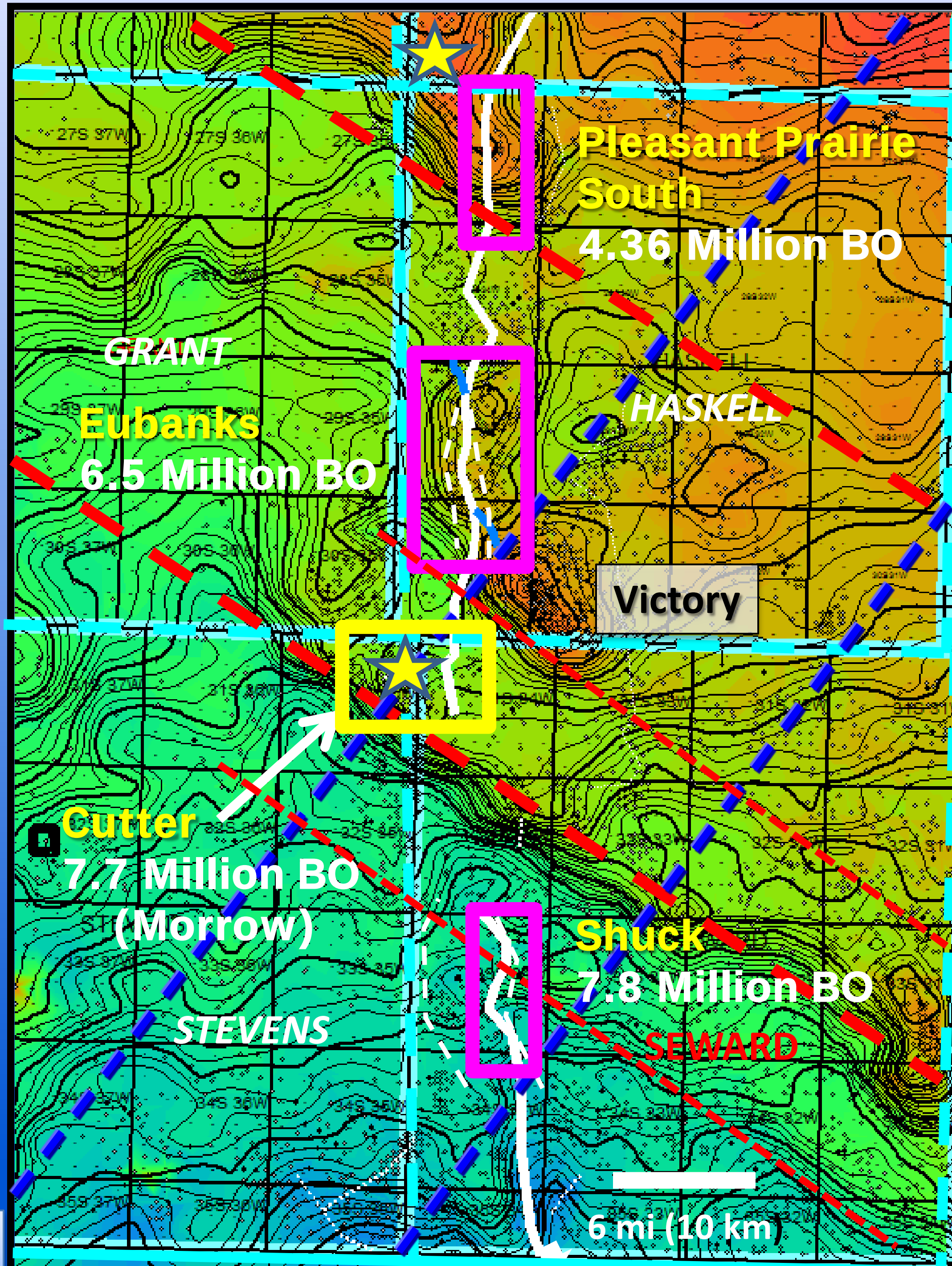
Chester valley incision and fill predated post-Mississippian – pre-Middle Pennsylvanian Ouachita related structural events

- Traps in valley fill sand pools sprung by Ouachita events
- No channel deflection around features.
- Ubiquitous fractures in Chester IVF cores.
- Antecendent paleogeomorphology

Subsea structure on top of Mississippian Meramec

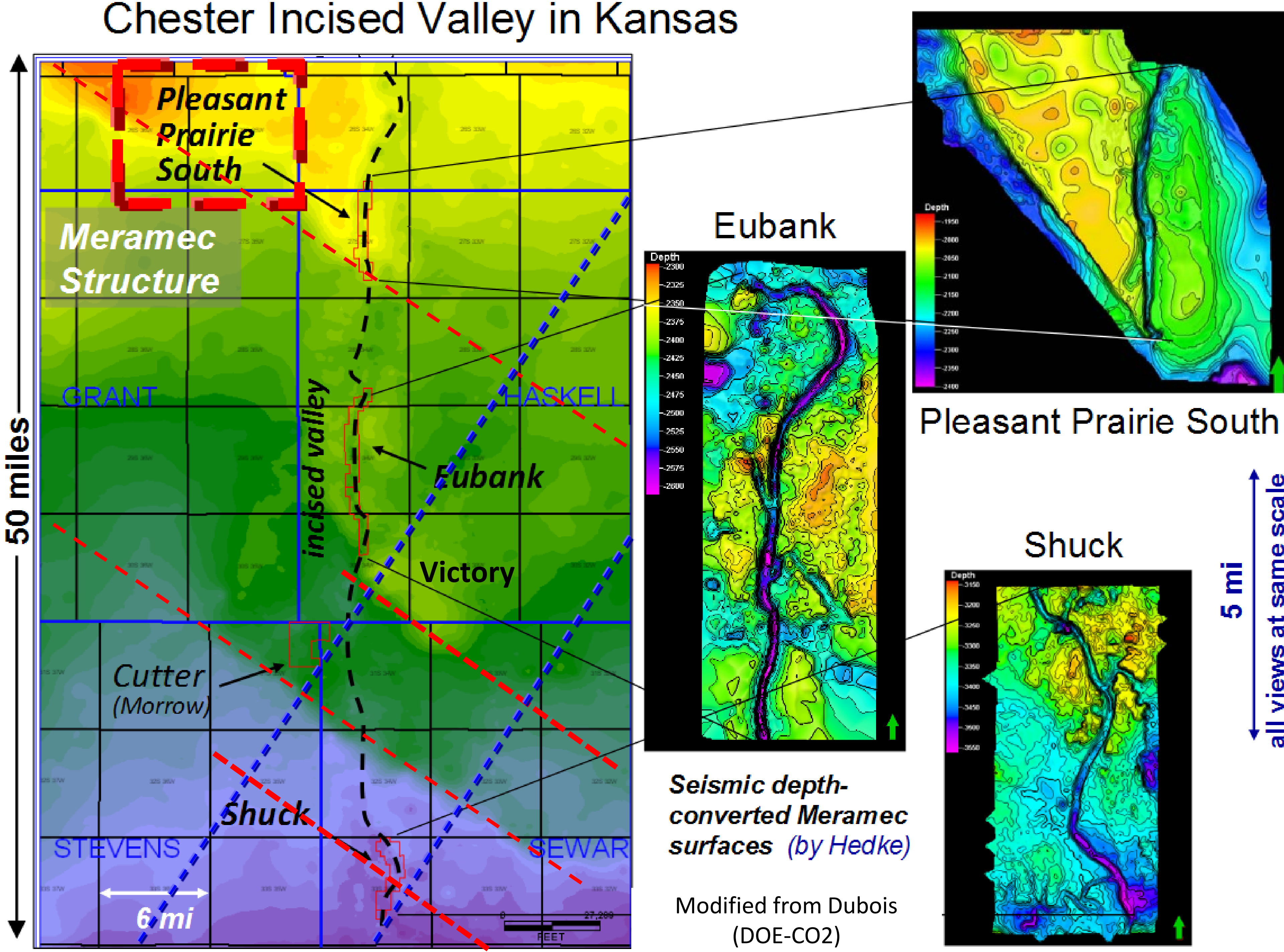
(mostly Ste. Gen.)

- 25’ C.I. (smoothed)
- White line: Chester incised valley axis
- Pink rectangles: Chester valley fill fields
- **Horst blocks** at Cutter, Victory, Eubank, and Pleasant Prairie are faulted on south and west flanks
- **Horst blocks** on north sides of regional NW-trending lineaments



Youle (DOE-CO2)

Chester Incised Valley in Kansas

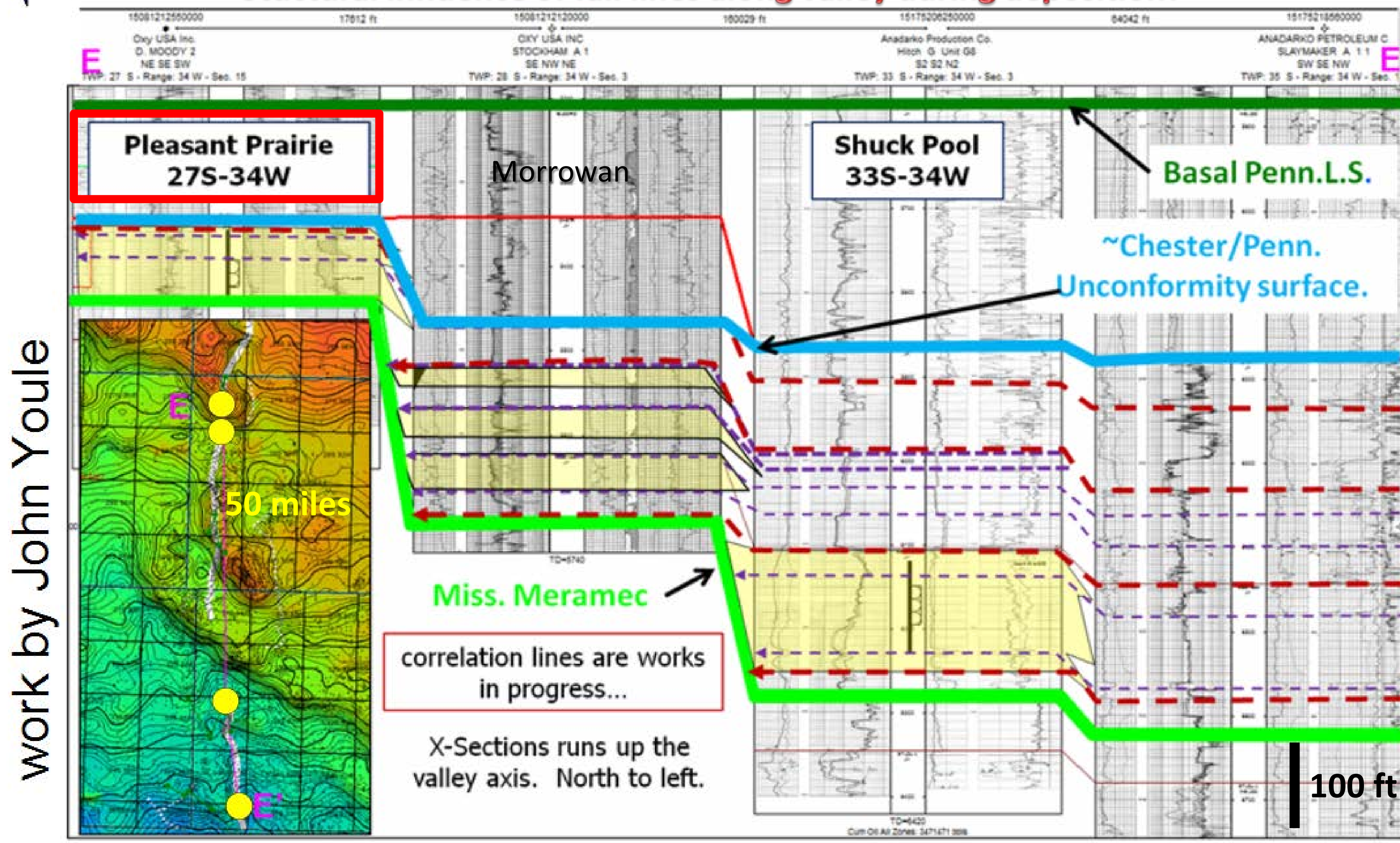


Modified from Dubois (DOE-CO2)

Chester Sequence Stratigraphy

North

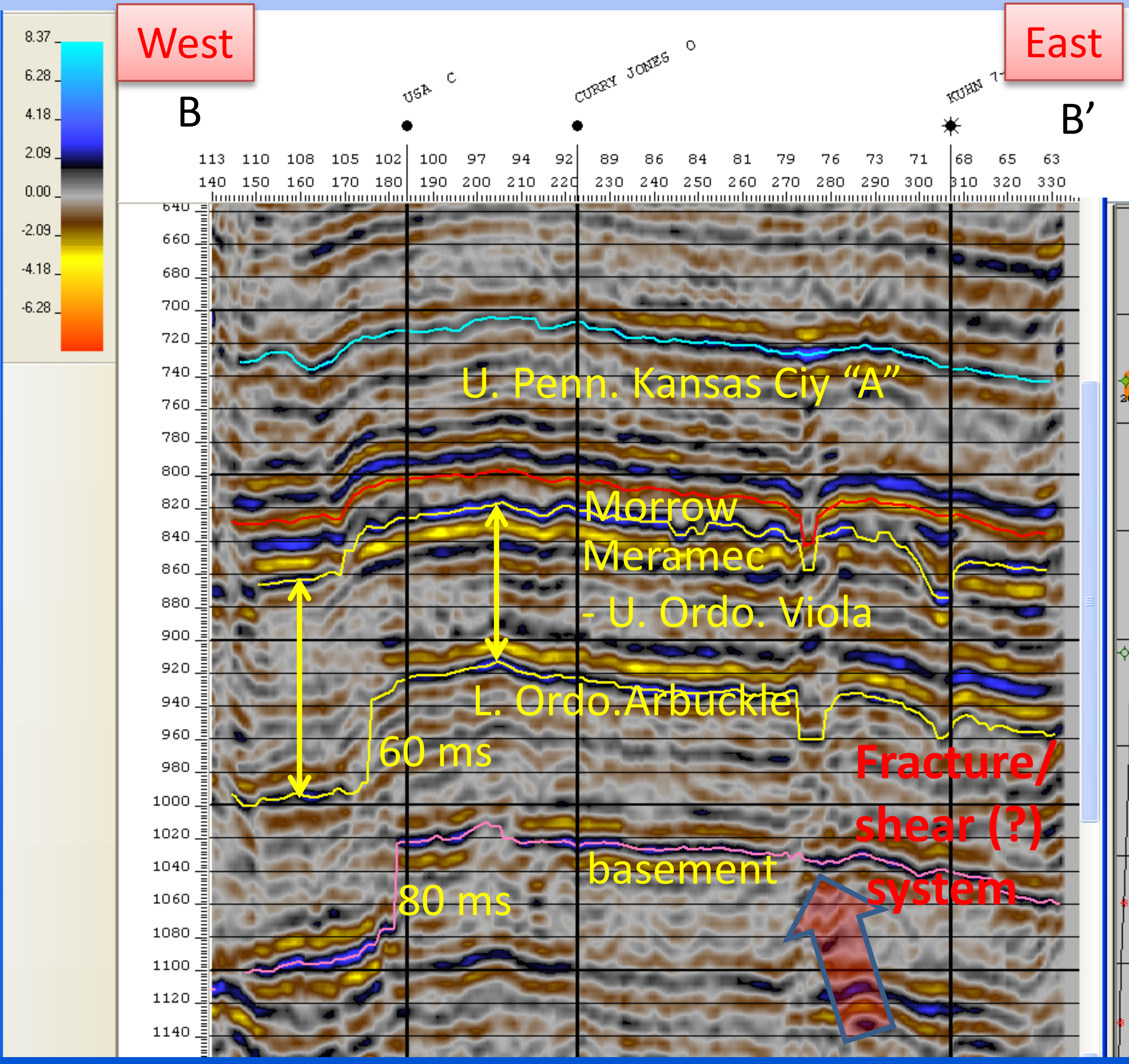
Stuctural influence of fall lines along valley during deposition?



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. *(Youle)*

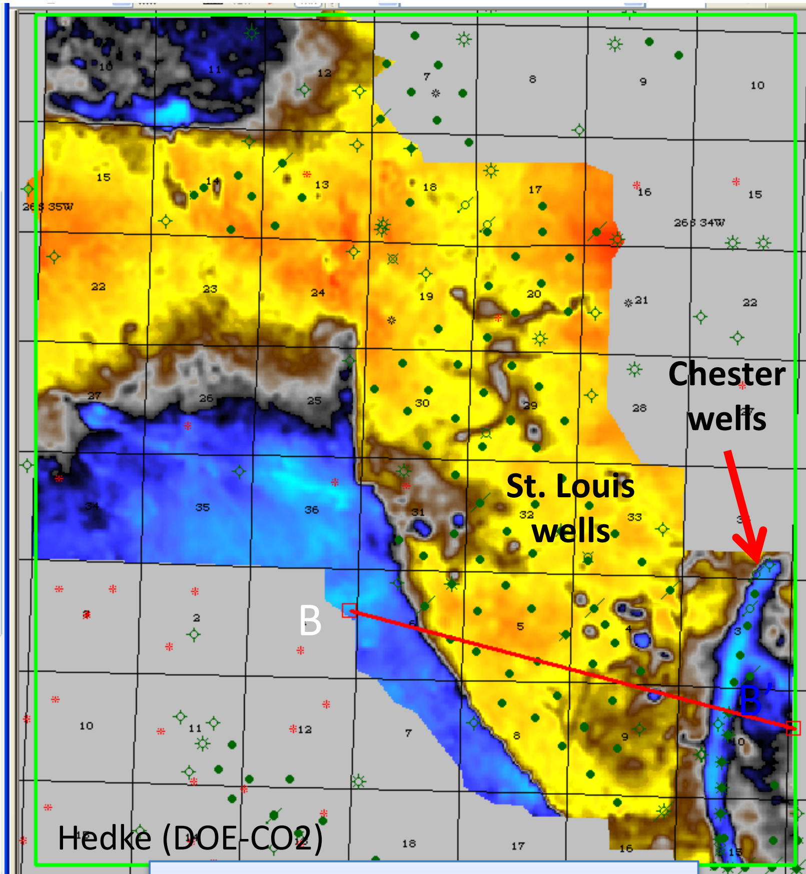
Mississippian-U. Orodovician Expansion

Chester incised valley & fracture set



Arbitrary Time Profile B-B', W – E

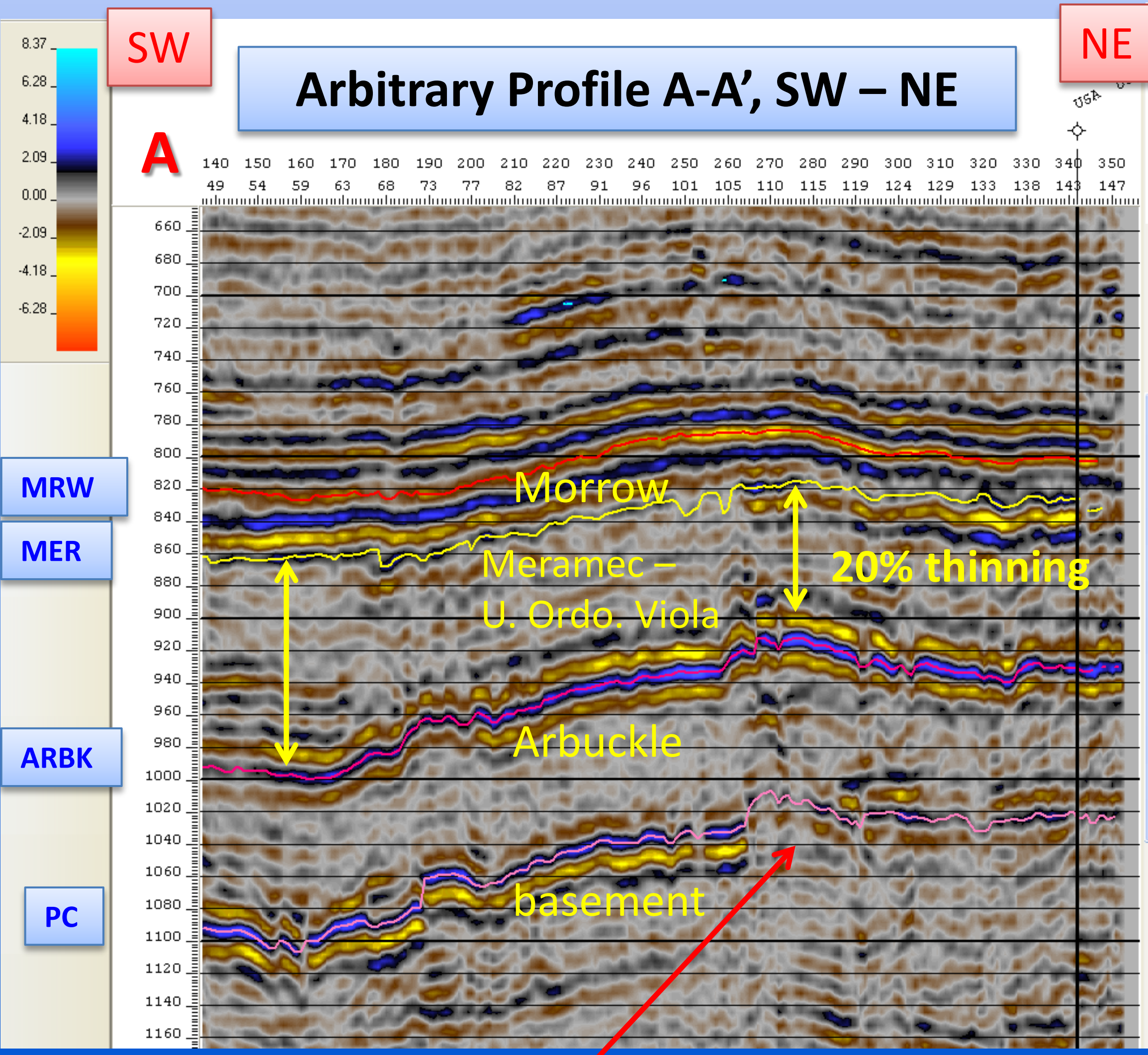
Disrupted beds within the St. Louis interval that are suggestive of karst collapse.



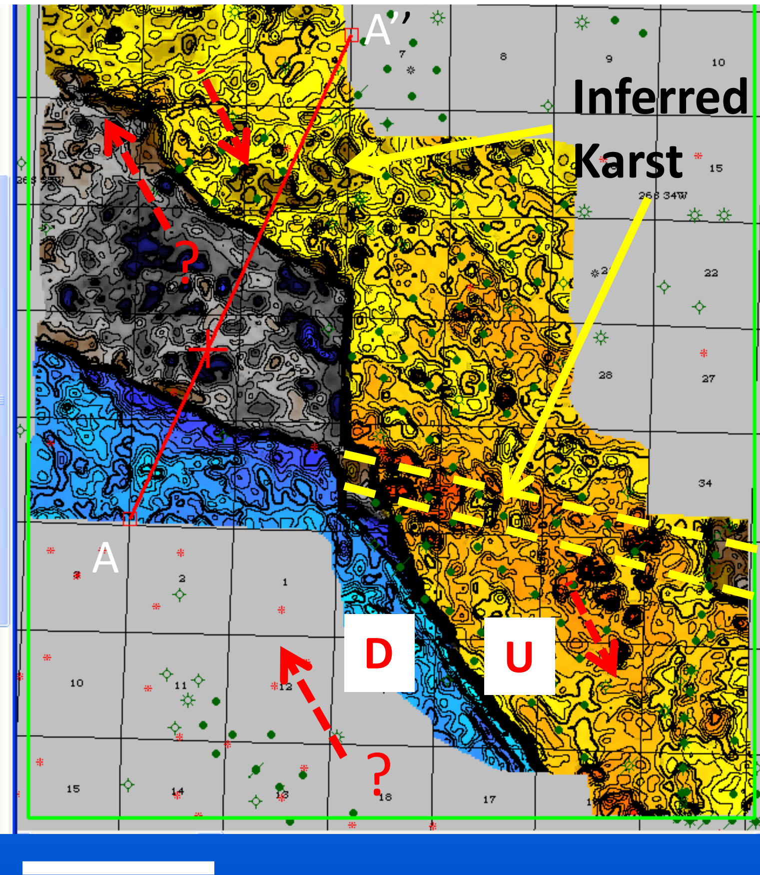
Meramec Time Structure
Pleasant Prairie Field

Pleasant Prairie structural block

Fault orientation-right lateral component along restraining bend



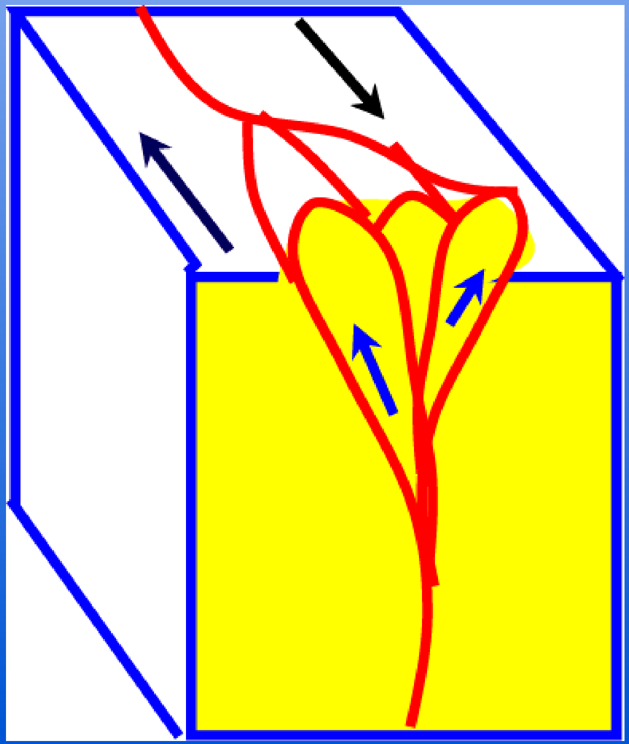
Flower structure
Right lateral fault?



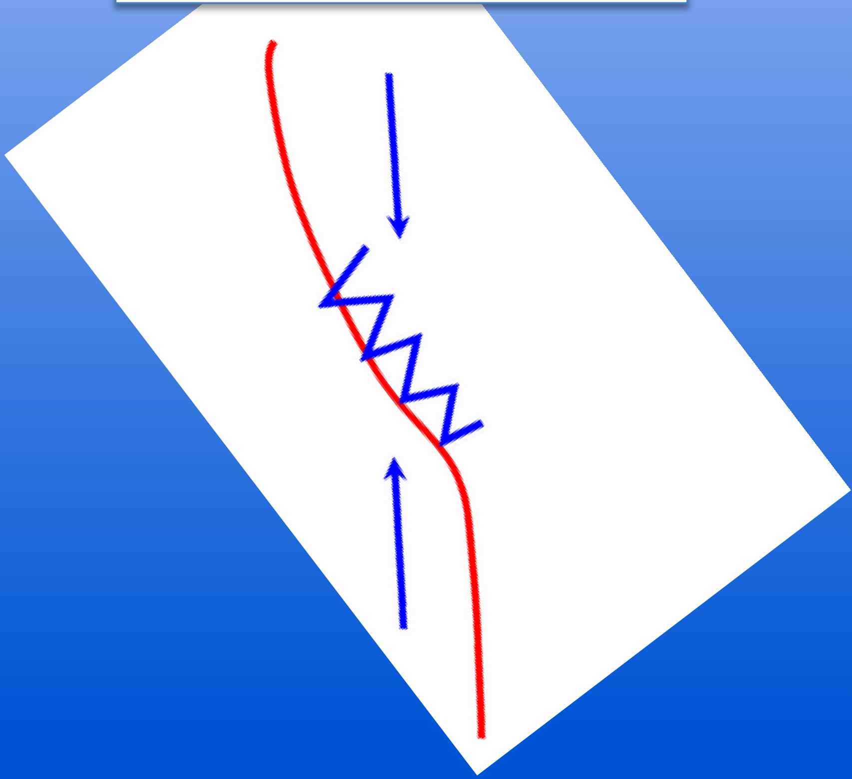
Hedke (DOE-CO2)

Strike-Slip Faults
– flower structures & restraining bends

Flower Structures
Positive (Palm Tree) → Transpression
Right lateral



Restraining Bends-
transpressional zones
occurring at fault bends
Push Up Ridges



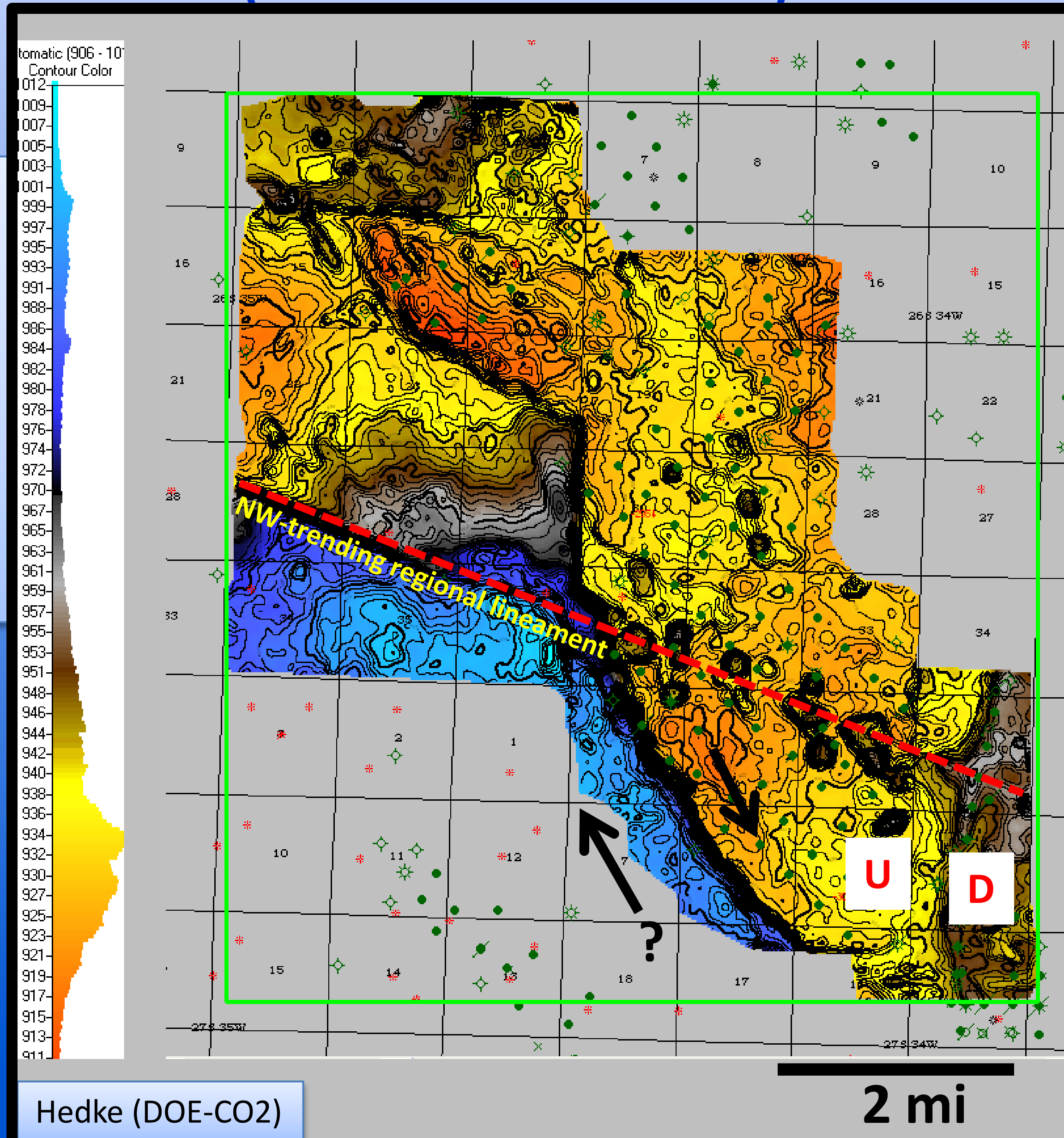
Modified from http://www4.uwsp.edu/geo/faculty/hefferan/geol320/strikeslip.html

Arbuckle Time Structure
(Pleasant Prairie Field)

Fault bounded orthogonal structural block:

-Regional NW-trending lineament

-Paleo Arbuckle karst (Ordovician)



- **Meramec age karst define partly define location of Chester incised valley**
- **Intersecting with NW-trending Arbuckle karst trend with north-trending fault corresponding with location of Chester IVF**

Subsea structure on top of Mississippian Meramec

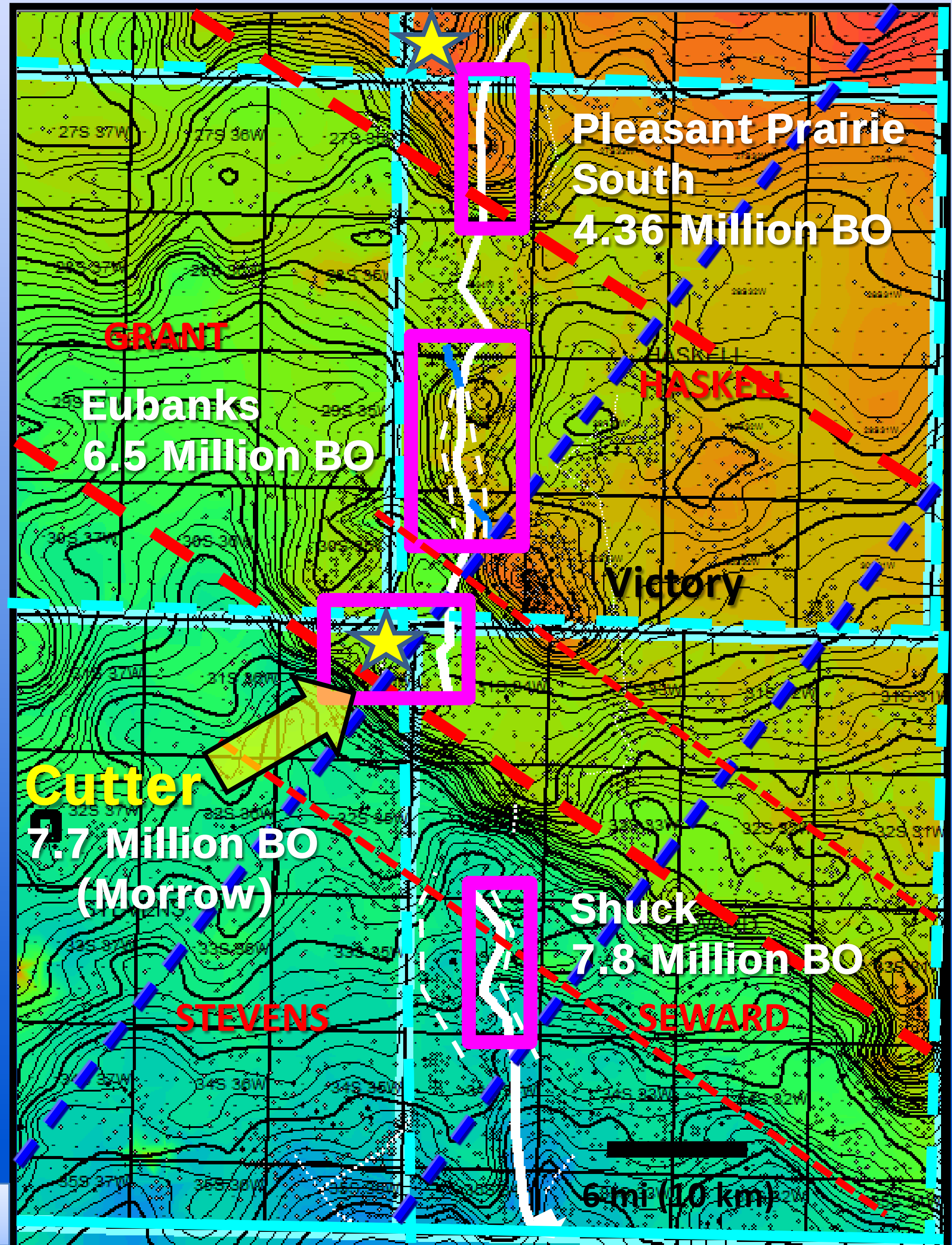
(mostly Ste. Gen.)

Chester valley incision and fill predated post-Mississippian – pre-Middle Pennsylvanian Ouachita related structural events

- However, traps in valley fill sand pools were sprung by Ouachita events.
- No channel deflection around features.
- Ubiquitous fractures in Chester IVF cores.
- Antecendent paleogeomorphology – stepwise subsidence and slope to south controlled regional drainage

- *Horst blocks* : Cutter, Victory-Eubank and Pleasant Prairie (faulted on south and west flanks)
- *Horst blocks :* north sides of regional NW-trending lineaments
- *Contour Interval:* 25' (smoothed)
- *White line:* Chester incised valley axis
- *Pink Rectangles:* Chester valley fill fields (DOE investigated)

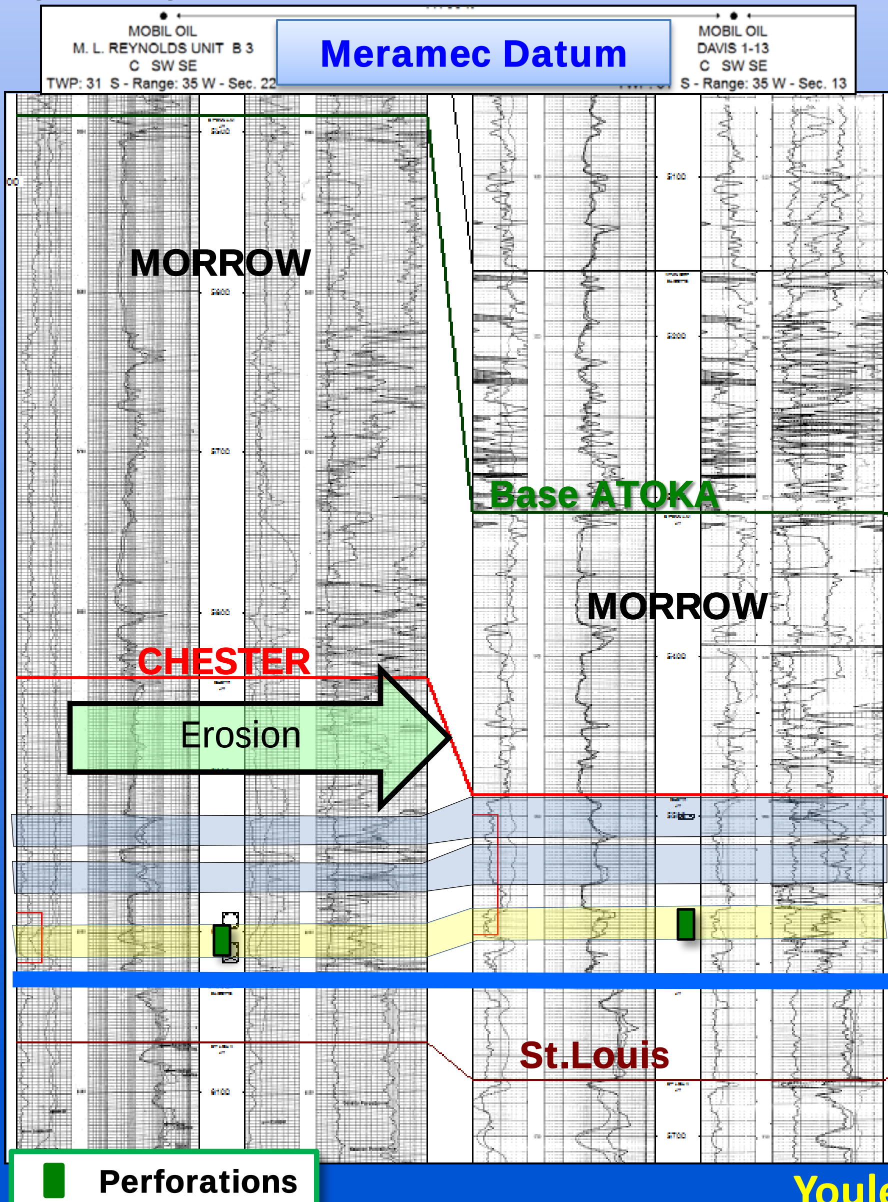
Youle (DOE-CO2)

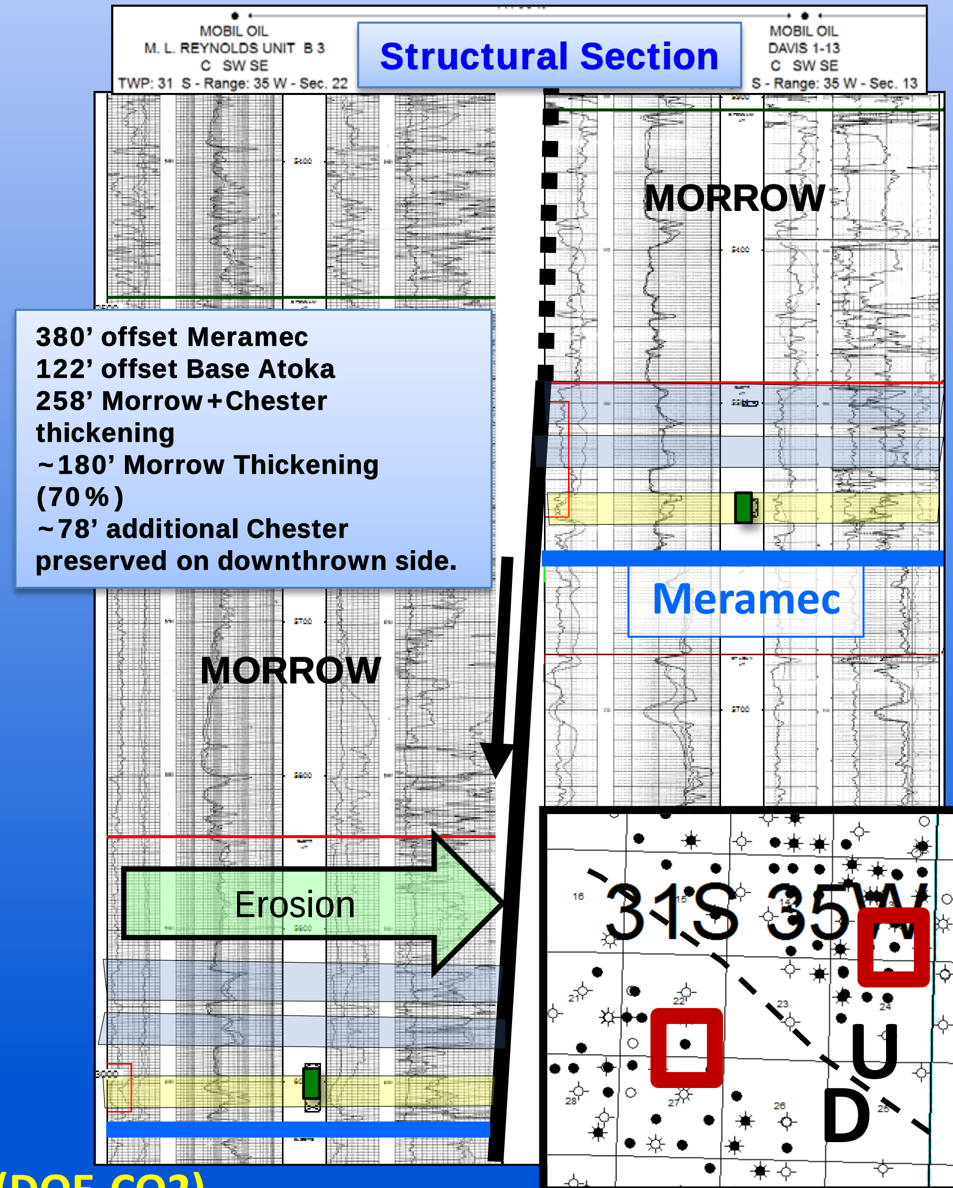


COMPARTMENTALIZATION:
Structural Compartments: Post Chester Fault Seals?

Cutter & Cutter South Field Areas

Could Chester sands be locally sealed on the downthrown side of NW-SE trending faults?....if juxtaposed against tight Meramec Limestones?



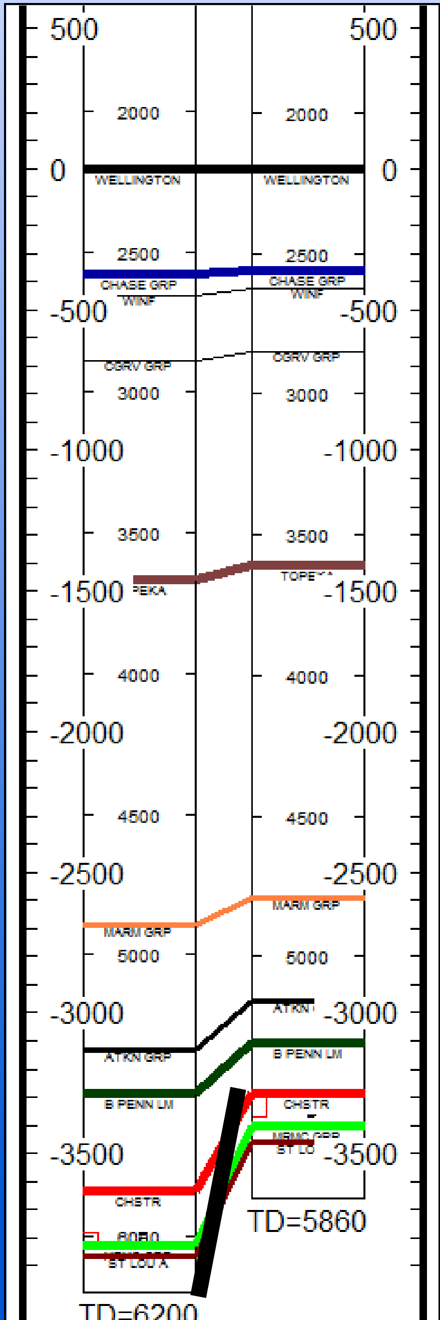


Youle (DOE-CO2)

Datum:
Lower Permian Wellington

Cutter & Cutter South Field Areas

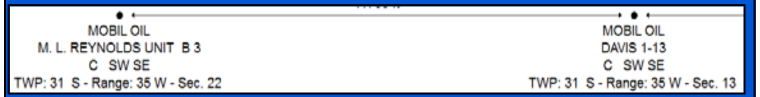
Structural Section

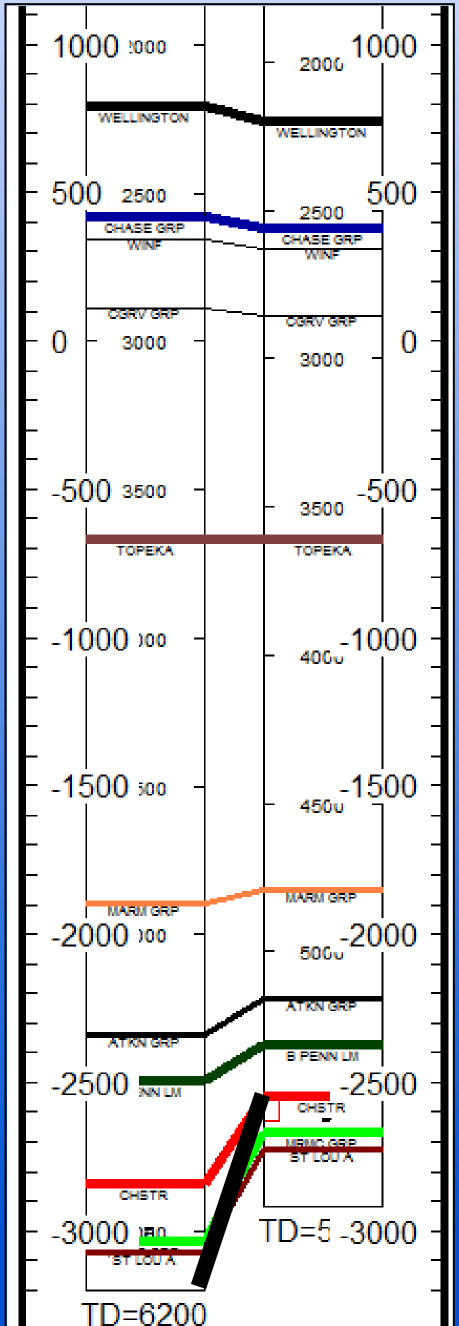


Up to at least Wellington time, subsidence continued on downthrown side of fault. However, amount of downthrown subsidence appears to have decreased over time at close to a constant rate.

Since Wellington time Laramide tectonic events impacting the Keyes Dome, Sierra Grande Uplift, and Las Animas Arch resulted in 55' of uplift and dip reversal on the downthrown well.

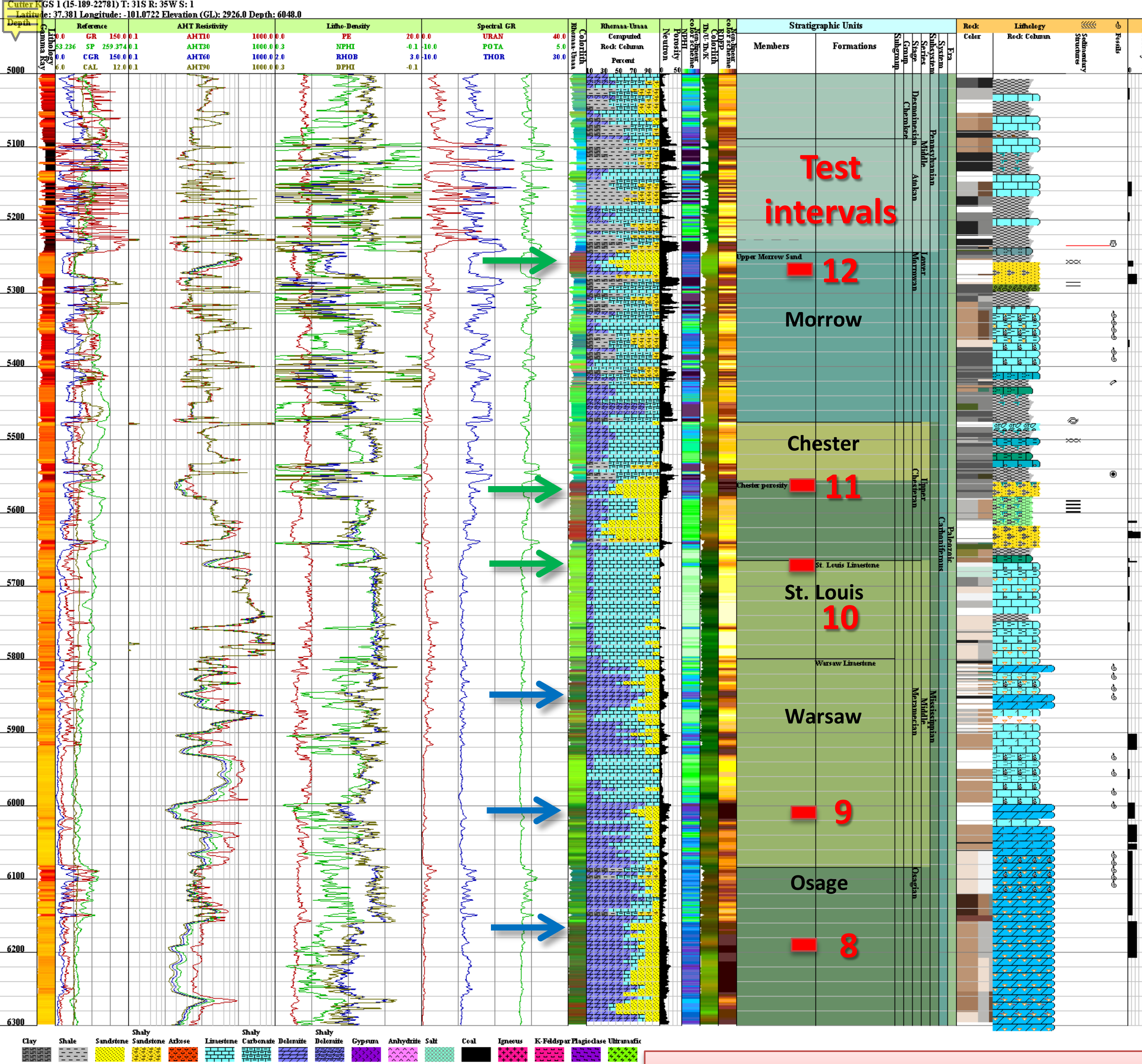
Youle (DOE-CO2)





Berexco *Cutter* KGS #1 Cutter Field

Multiple pay & shows



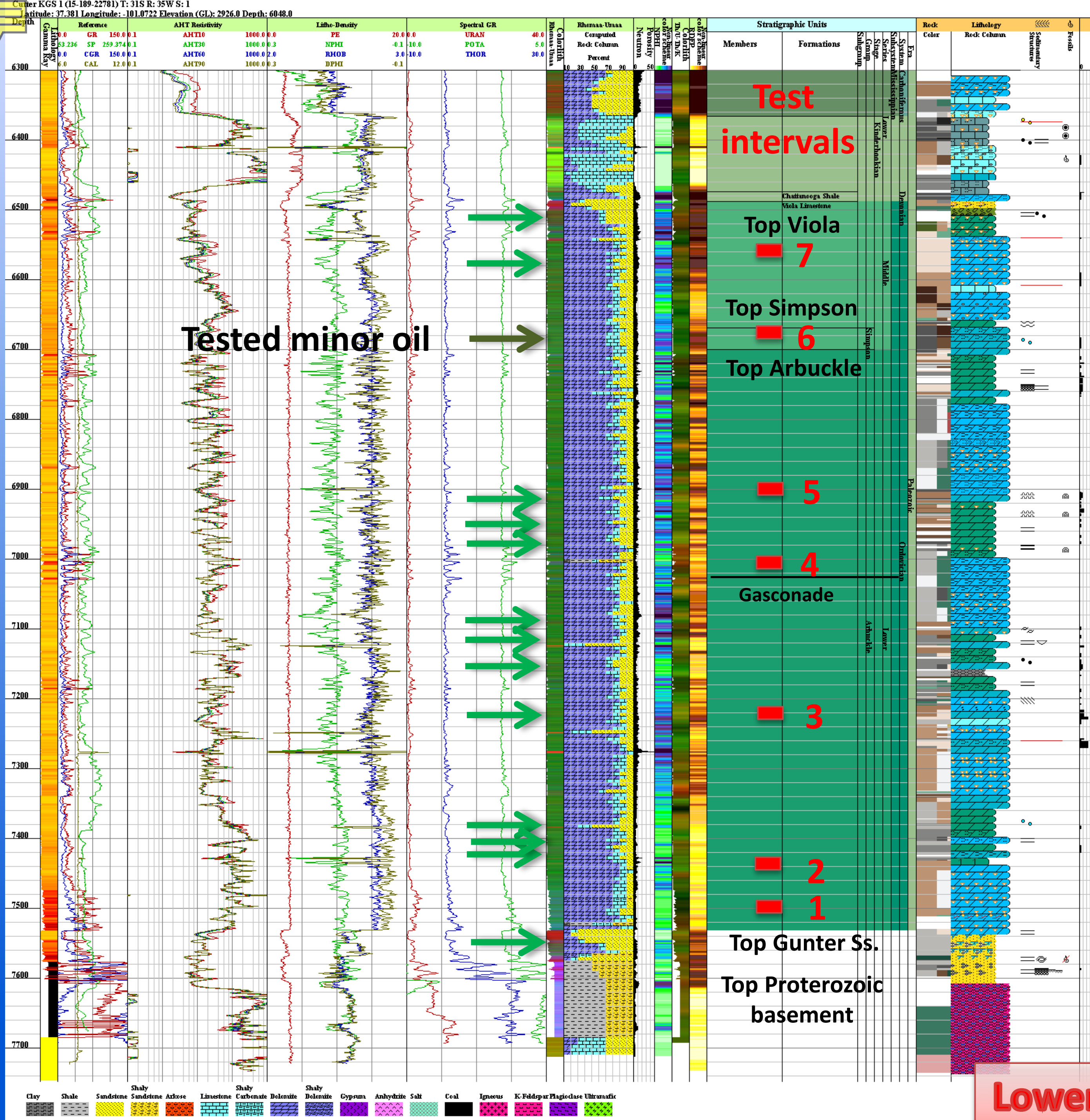
Upper half of cored interval

oil show

no show

200 ft

Berexco *Cutter* KGS #1 Cutter Field



- Extended oil shows (fluorescence) in lower Paleozoic
- Upthrown structural block near regional fault
- Prior work: Chester oil in Hitch Field has Ordovician source (Kim et al., 2010)

oil show →
No oil on perf and swab

200 ft

Lower half of cored interval

Subsea structure on top of Mississippian Meramec

(mostly Ste. Gen.)

Chester valley incision and fill predated post-Mississippian – pre-Middle Pennsylvanian Ouachita related structural events

- However, traps in valley fill sand pools were sprung by Ouachita events.
- No channel deflection around features.
- Ubiquitous fractures in Chester IVF cores.
- Antecendent paleogeomorphology controlling valley location is discussed in context of more subtle structural deformation

- ***Horst blocks*** : Cutter, Victory-Eubank and Pleasant Prairie (faulted on south and west flanks)
- ***Horst blocks :*** north sides of regional NW-trending lineaments
- *Contour Interval:* 25' (smoothed)
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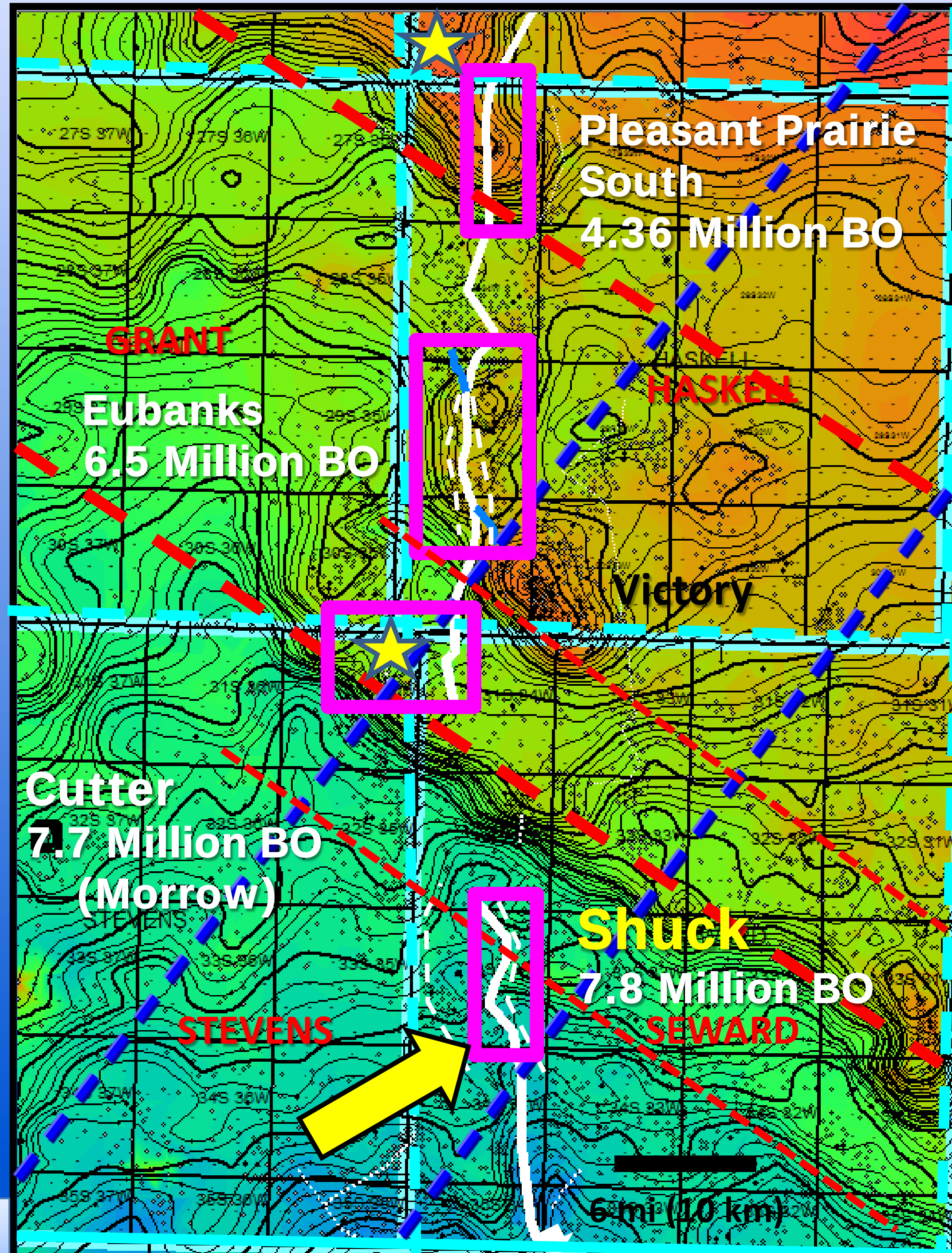
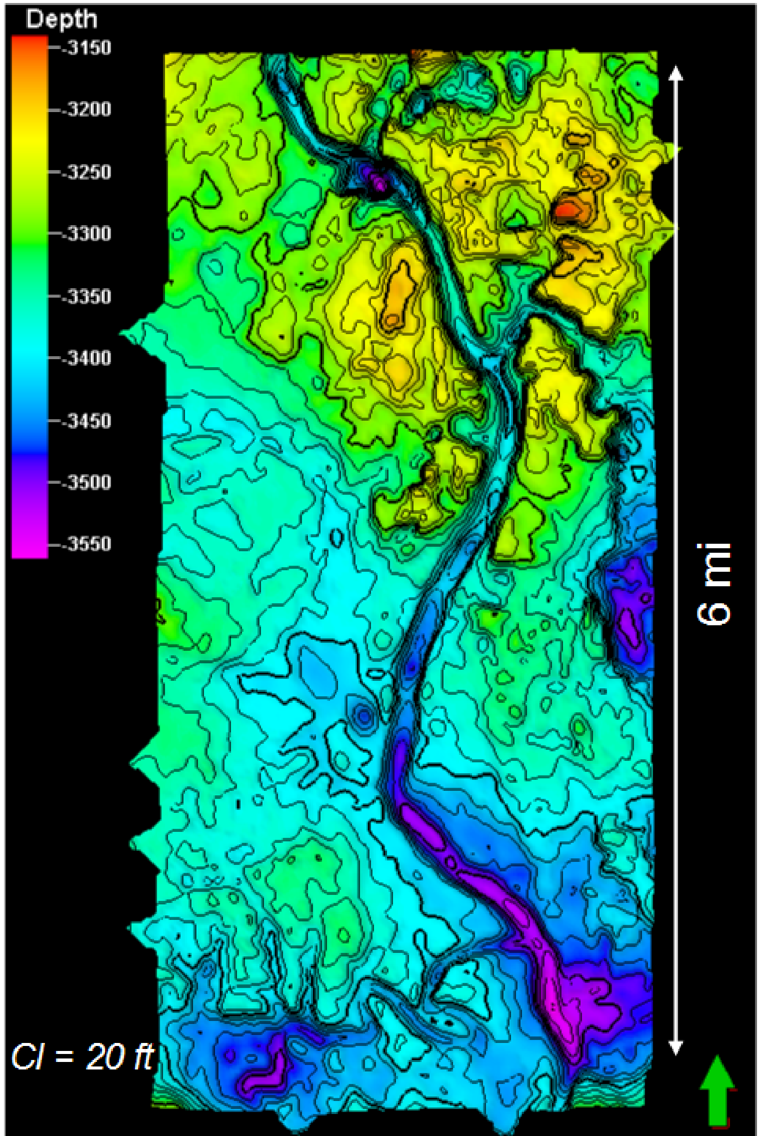
Youle (DOE-CO2)



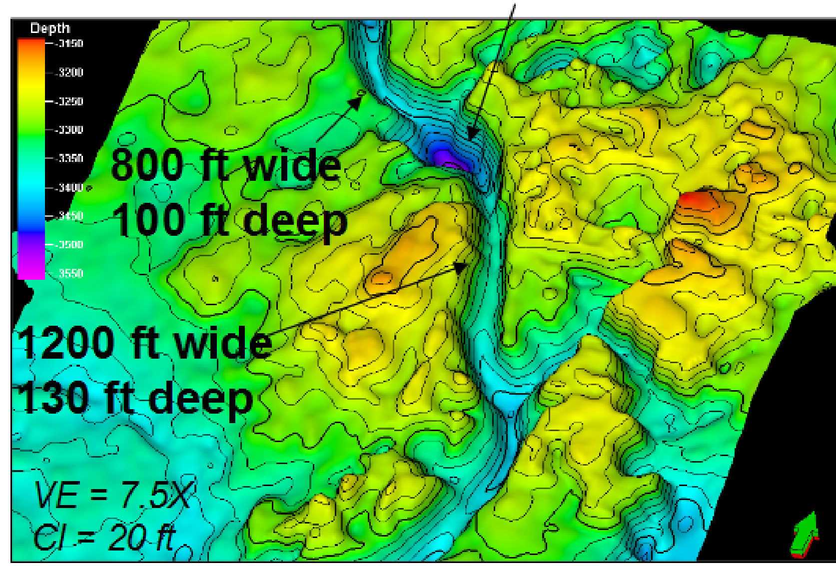
Shuck

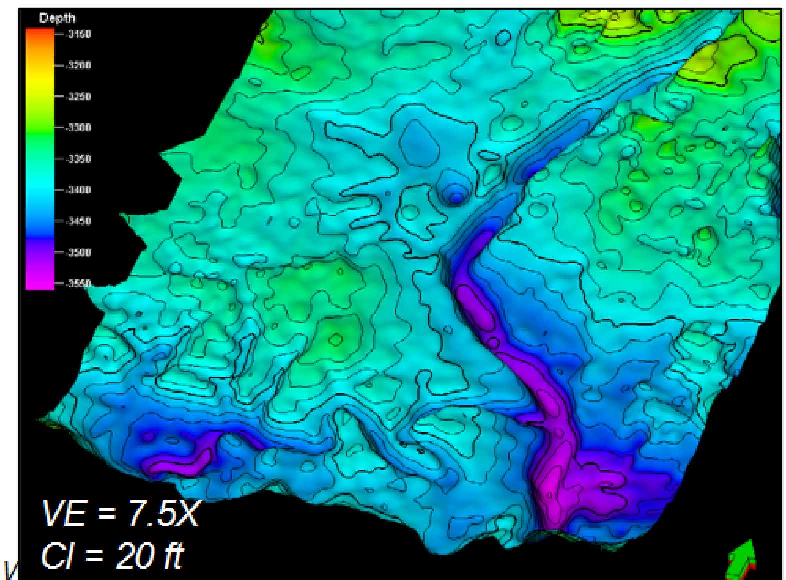
Seismic depth-converted Meramec surface

Seismic interpretation by Hedke



Post-Chester sinkhole forms trap

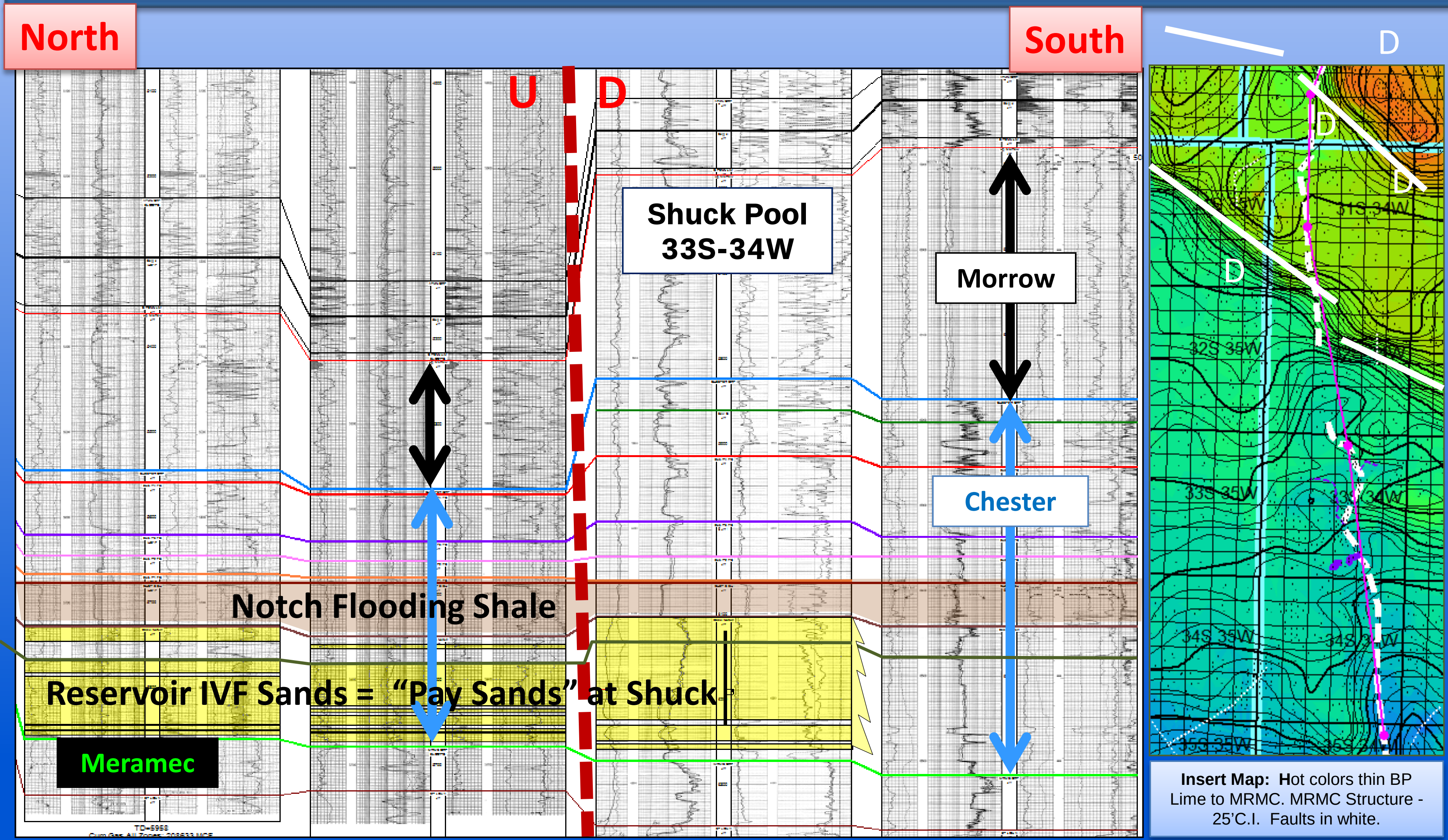




KGS, V

Chester IVF deposition not influenced by Ouachita Faulting and structuring

- Sandy estuarine parasequences into unconfined (regional) clay-rich lime mudstones in the Shuck area.
- Identical facies change seen from Shuck to south
- Northern fault influenced Chester IVF deposition, not southern
- Chester constant across southern fault; but over 100’ removed on footwall
- Morrow thickens in headwall
- Southern fault occurred post Chester; north fault may have moved before Chester valley filled



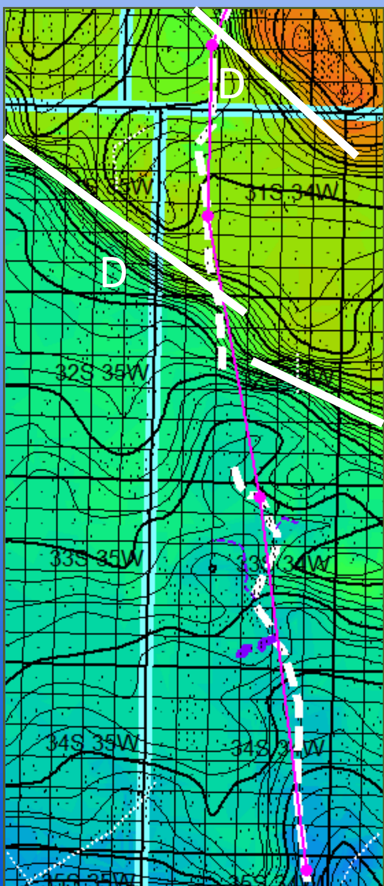
Insert Map: Hot colors thin BP Lime to MRMC. MRMC Structure - 25’C.I. Faults in white.

Chester Valley Cross Section: timing of fault movement

A. Datum on top of Notch Shale. No indication of major pre-Chester valley fill movement on fault.

B. Datum on Atoka Limestone marker. ~ 100' of Chester eroded from up thrown side of fault (section shaded green has been removed). Also, ~100' of Morrow thickening on downthrown side of fault. Ouachita orogeny dated as starting post Chester & pre-Morrow.

C. Present day structural section. 300' of post Atokan movement on fault shows most offset on fault occurred <u>post Atokan</u>. IVF sands shaded yellow.



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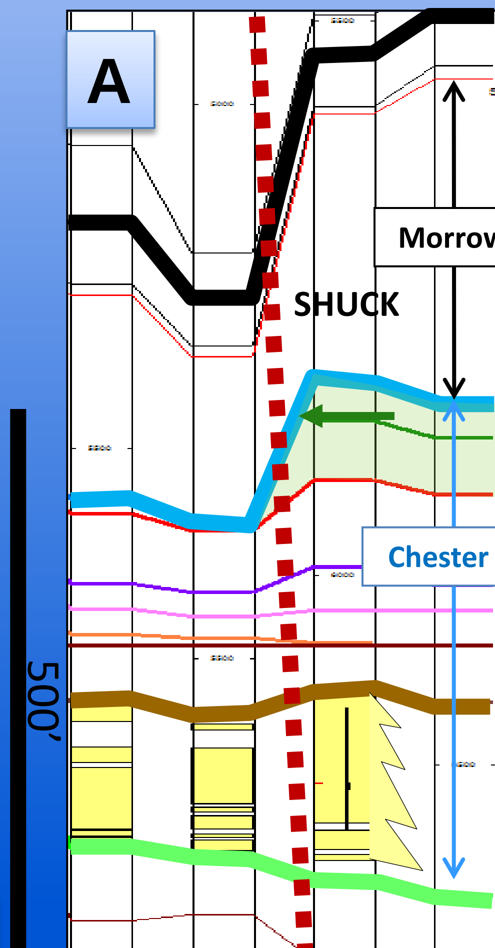
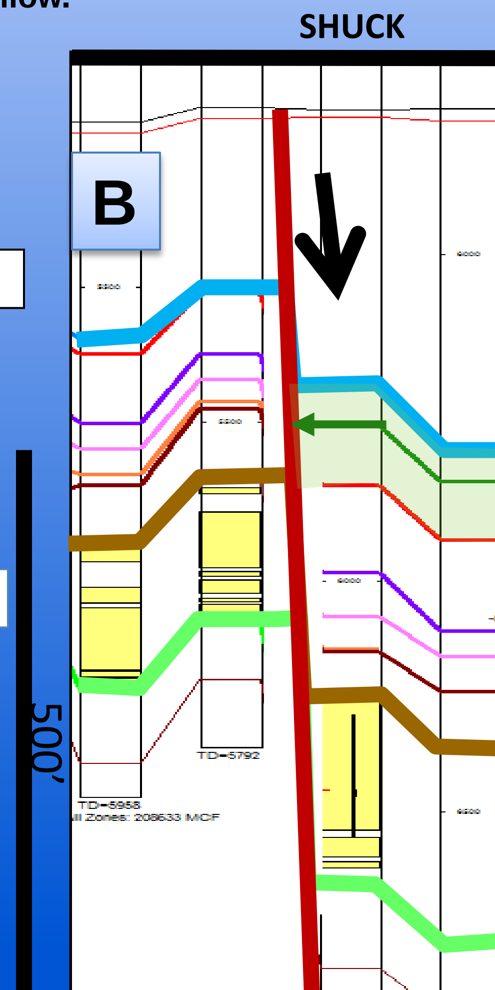
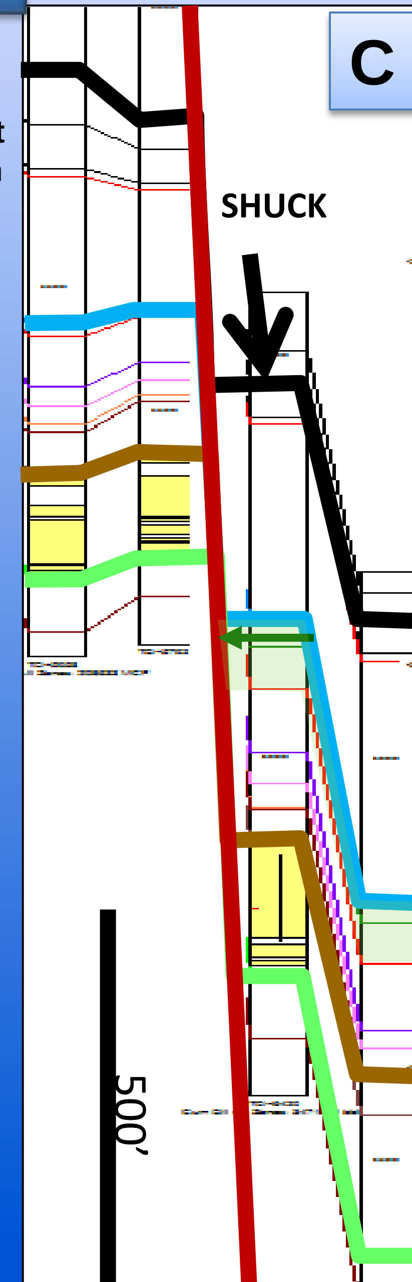


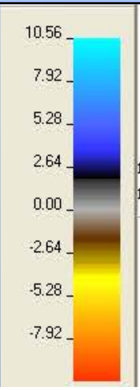


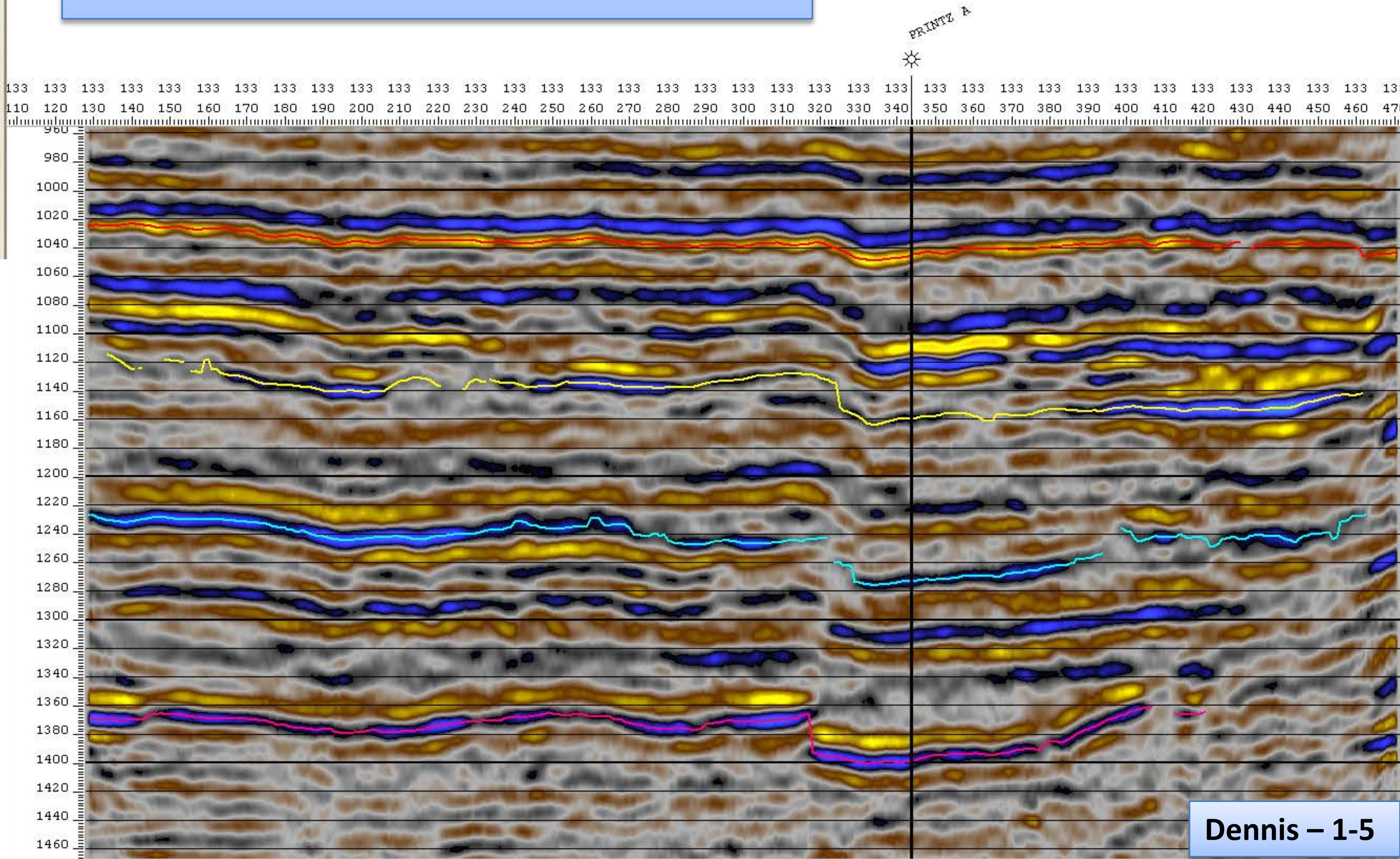


Horizons: Black – Atoka L.S., Red - Morrow, Blue - Chester, Brown – Notch, Green – Meramec.

East-west profile, Seward County

- Near southern end of Adamson 3D
- Provides more evidence of reverse faulting
- Vertical offset in Meramec is ~200 ft

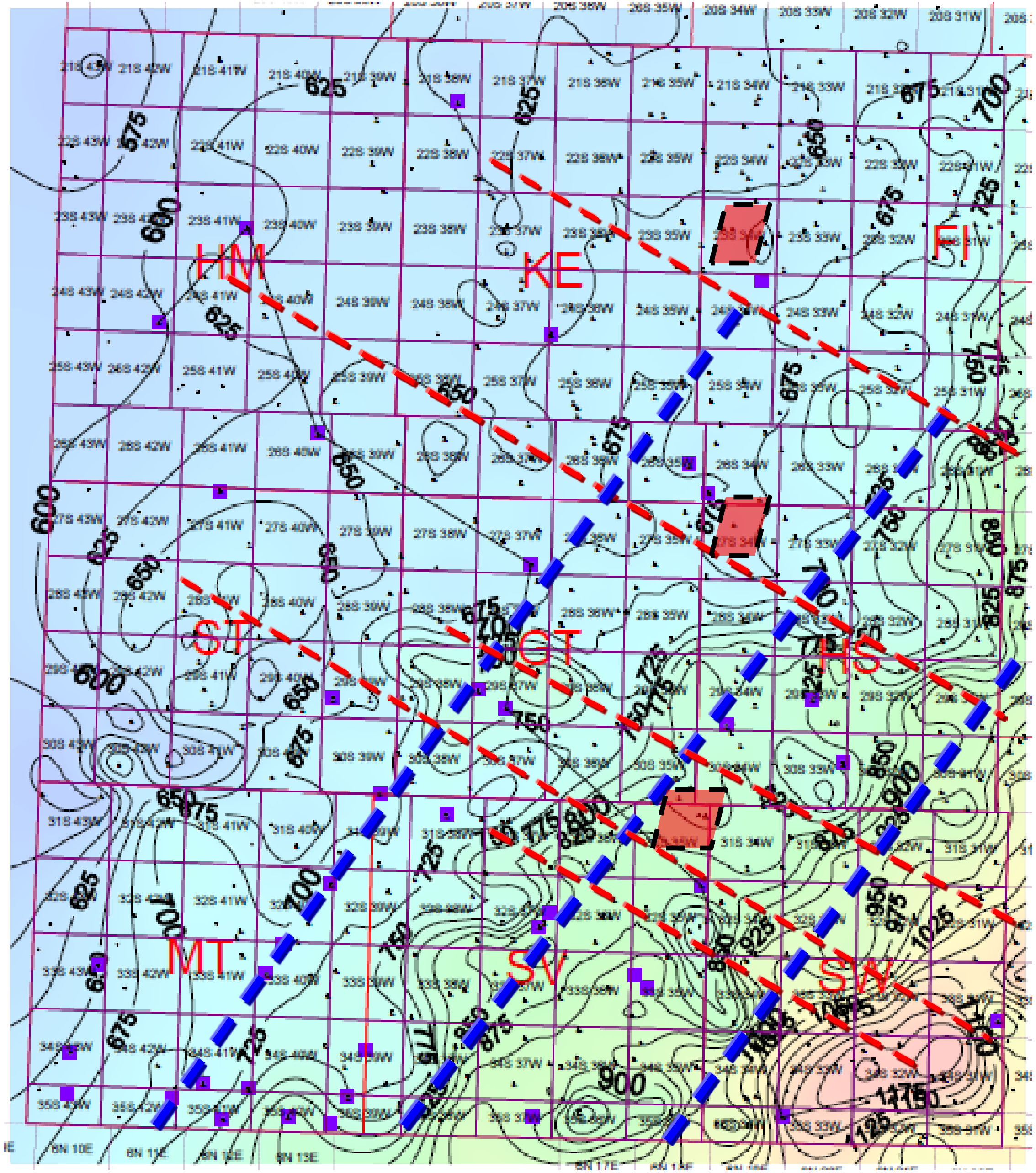




Dennis – 1-5

Isopach Lower Permian Hutchinson Salt to Neva Ls.

(top Pennsylvanian)



25 mi (40 km)

KANSAS GEOLOGICAL SURVEY

1:250000

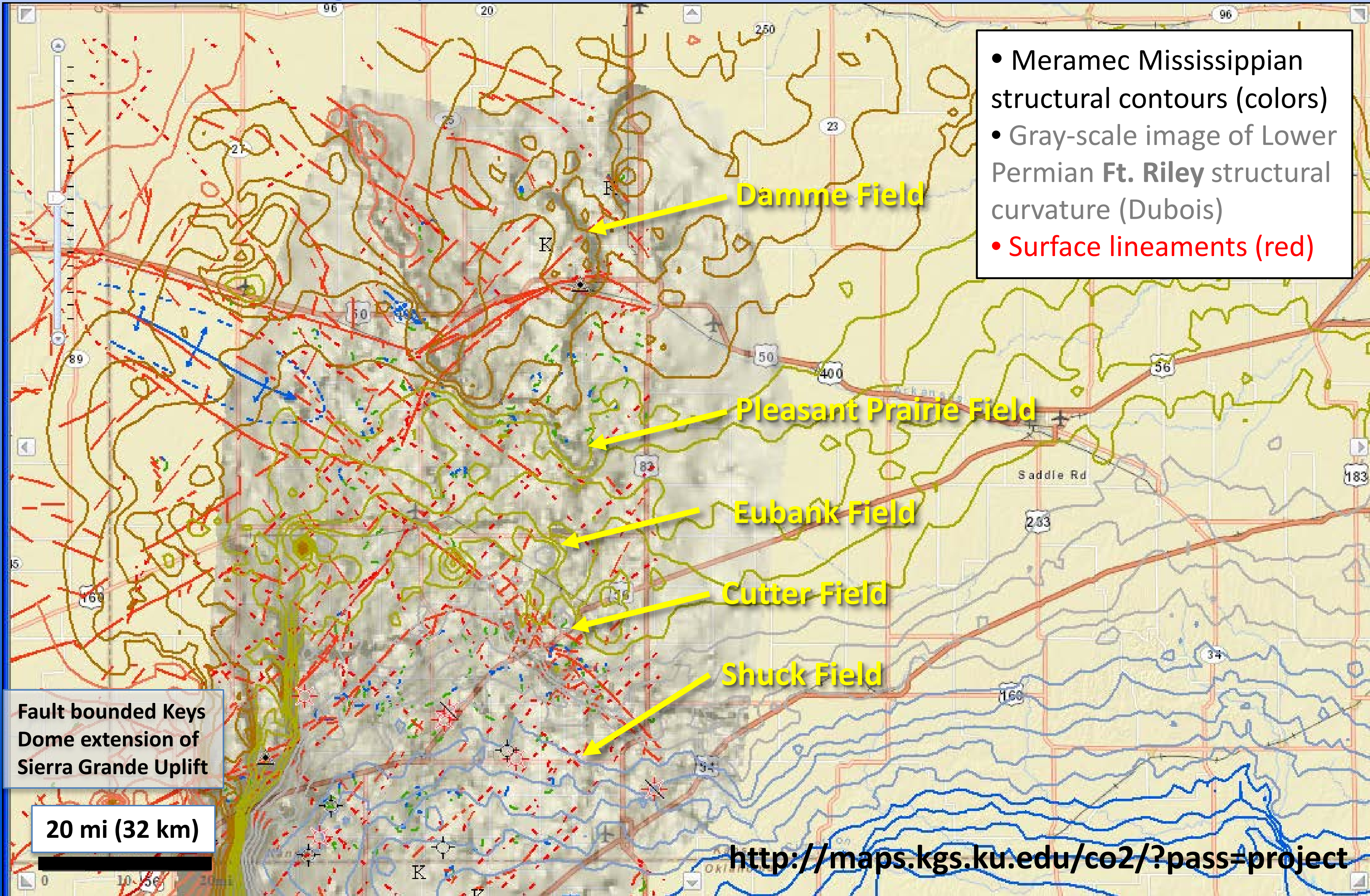
NE-trending regional lineaments controlling lower Permian deposition in SW Kansas (more northerly paleo σ_1?)

(Gerlach, Nicholson, DOE-CO2)

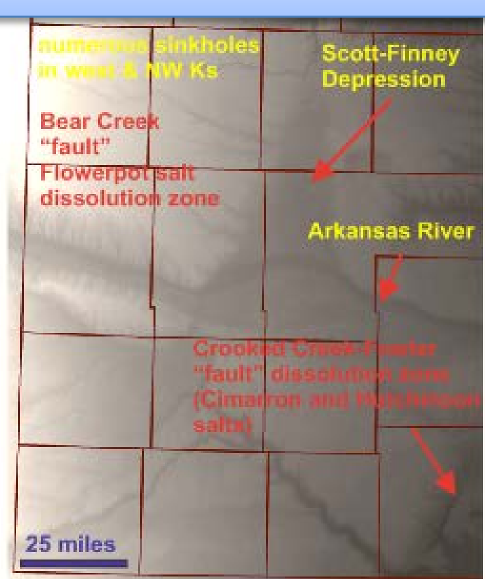
Shallower structures and surface lineaments

Movement along N-S Chester IVF

NW- and NE-trending deep-seated structures

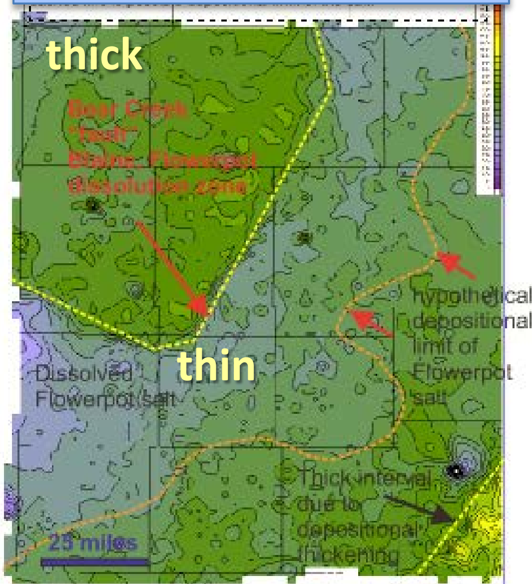


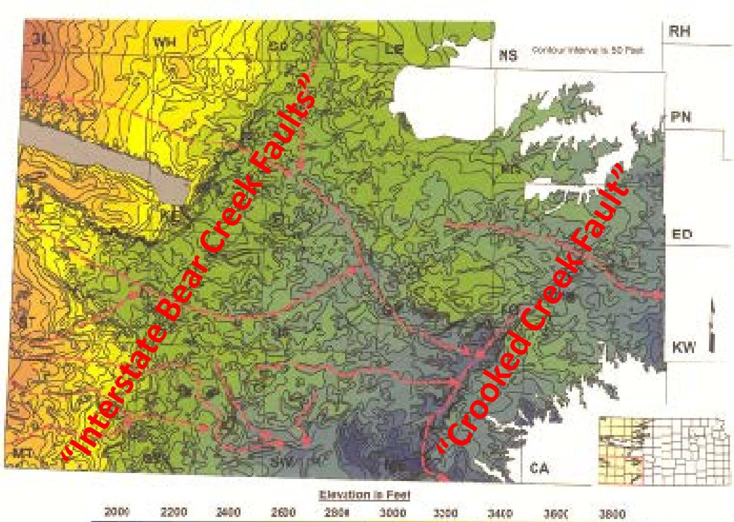
Gray scale DEM of SW KS
Postive above thicker Blaine halite



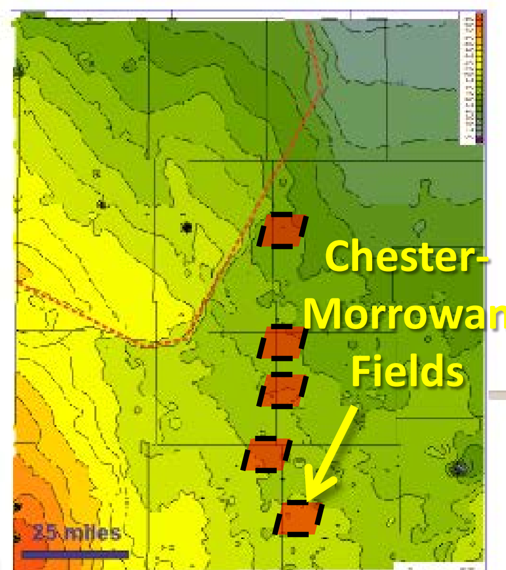
Surface elevation, gray scale (light = higher). Central portion of mapped area is topographically low.

Isopach of halite-bearing
Lower Permian Blaine Fm.





Bedrock elevation at base
Pliocene Ogallala formation
Macfarlane and Wilson (2006)



Structure top of Blaine
Formation

- Lower Permian evaporite dissolution (~1000-2000 ft below surface)
- Accomodation Space for High Plains aquifer

- **Influence of NW- & NE-trending basement structures**

- **Timing of dissolution to regional uplift and tilting of Rocky Mountains and Great Plains during mid Miocene** (McMillian et al., 2006; Goes and van der Lee, 2002)

- **Timing similar to emplacement of gas into Hugoton Field** (Sorenson, 2005)

Accommodation space for High Plains Aquifer
- major influence by contemporaneous dissolution of underlying Permian evaporites

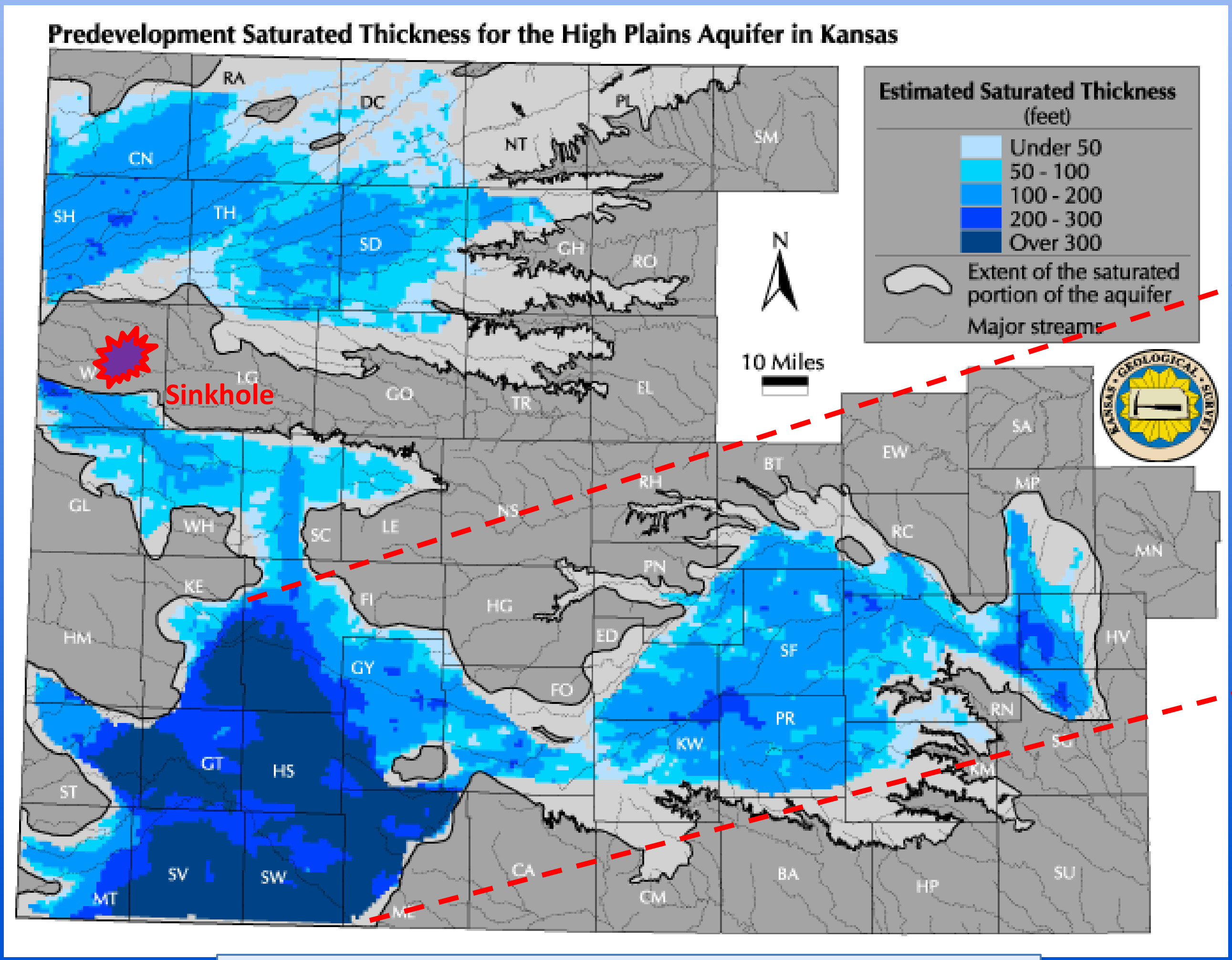
Structural reactivation along fractures provide template linear edges of dissolution and drainage

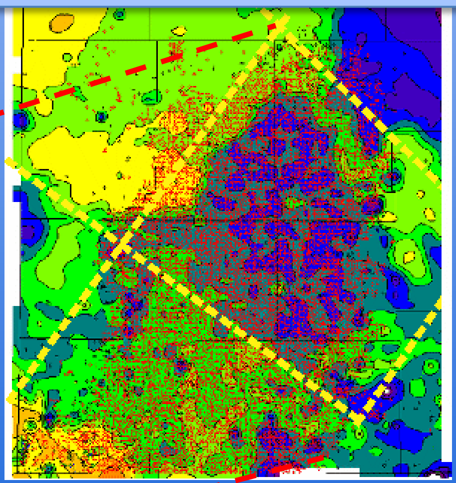
Isopach of Blaine Fm.

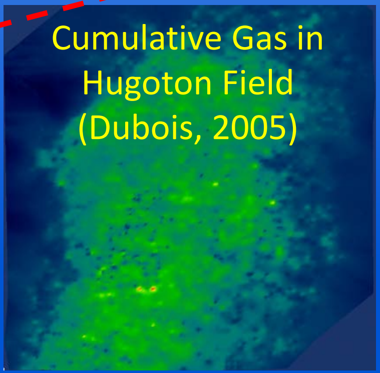
-Green/yellow thicker evaporite

Red dots – wells in Hugoton Field

- note coincidence of dissolution of salt and location of gas field
- gas migrated into Hugoton conciding regional uplift Sorenson (2005) and evaporite dissolution

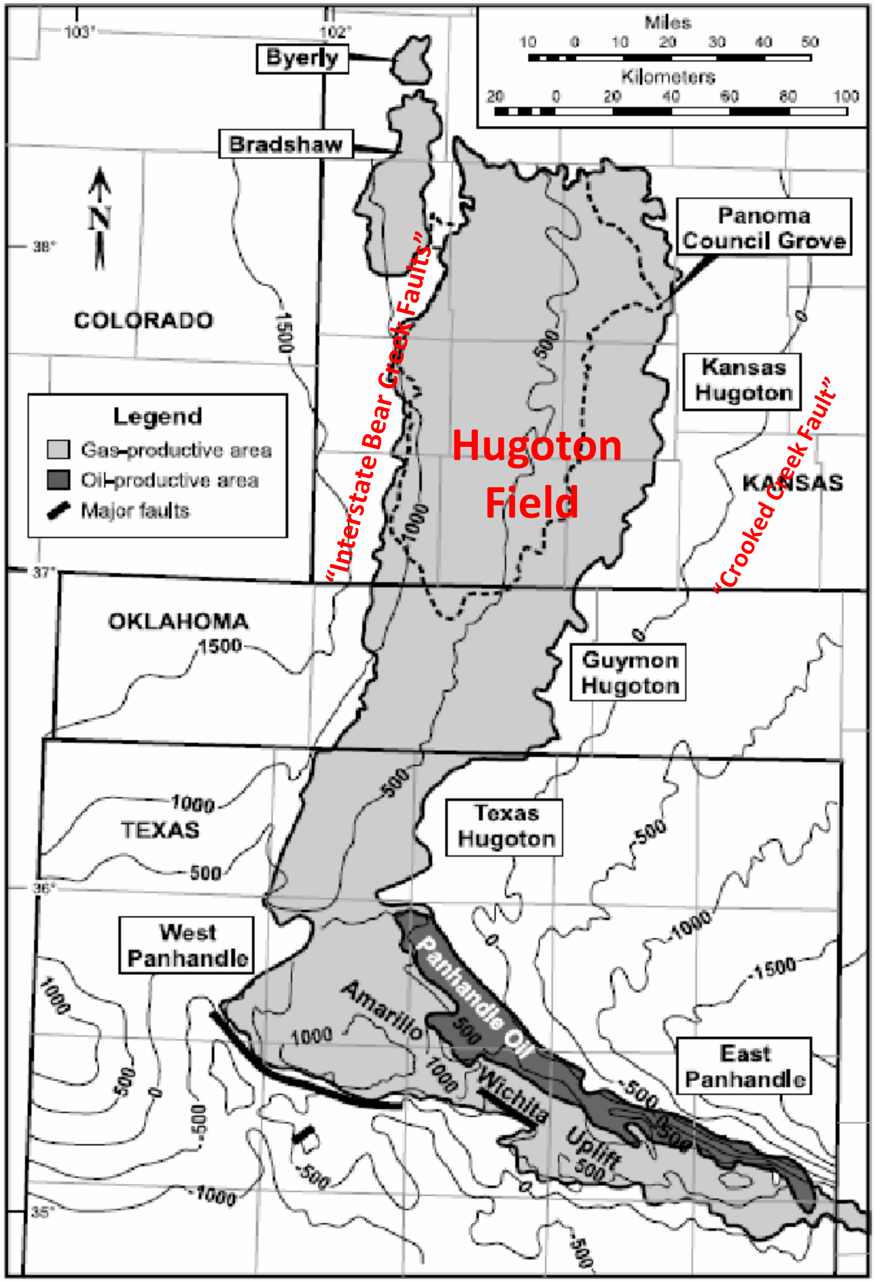






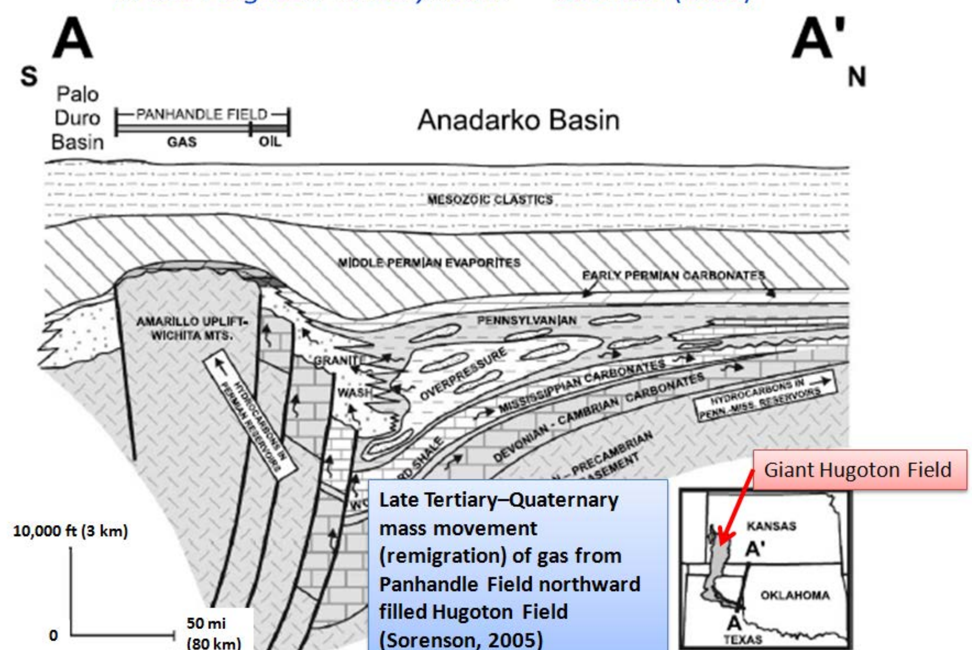
http://www.kgs.ku.edu/HighPlains/atlas/index.html#Atlas_Directory

Gas migration from Amarillo-Wichita to create Hugoton Gas Area post-Laramide (Late Tertiary) during regional uplift and tectonic adjustment closely corresponding to timing of salt dissolution

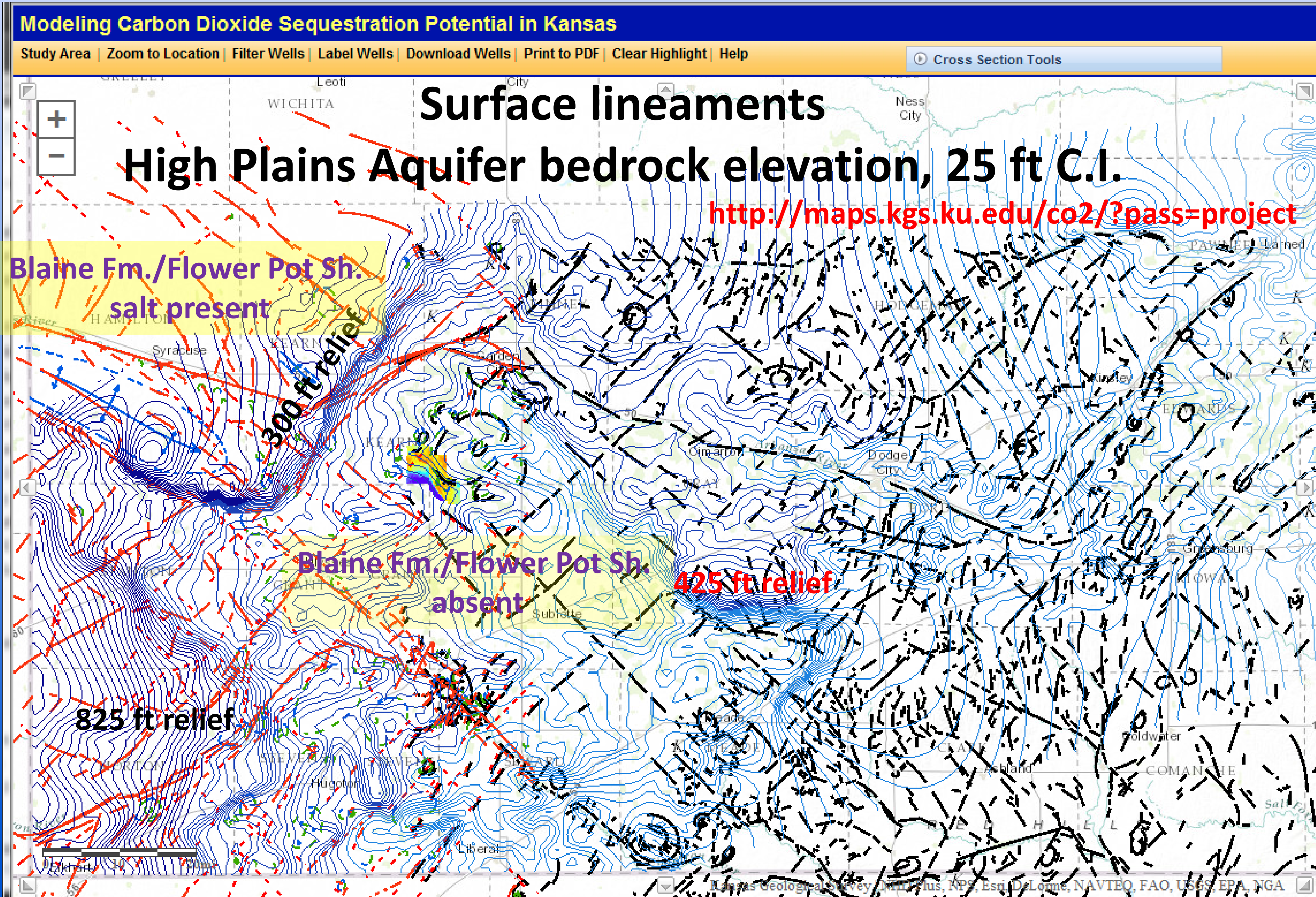


Panhandle-Hugoton field, with regulatory divisions. Wolfcampian structure, in feet, after Pippin (1970). from Sorenson (2005)

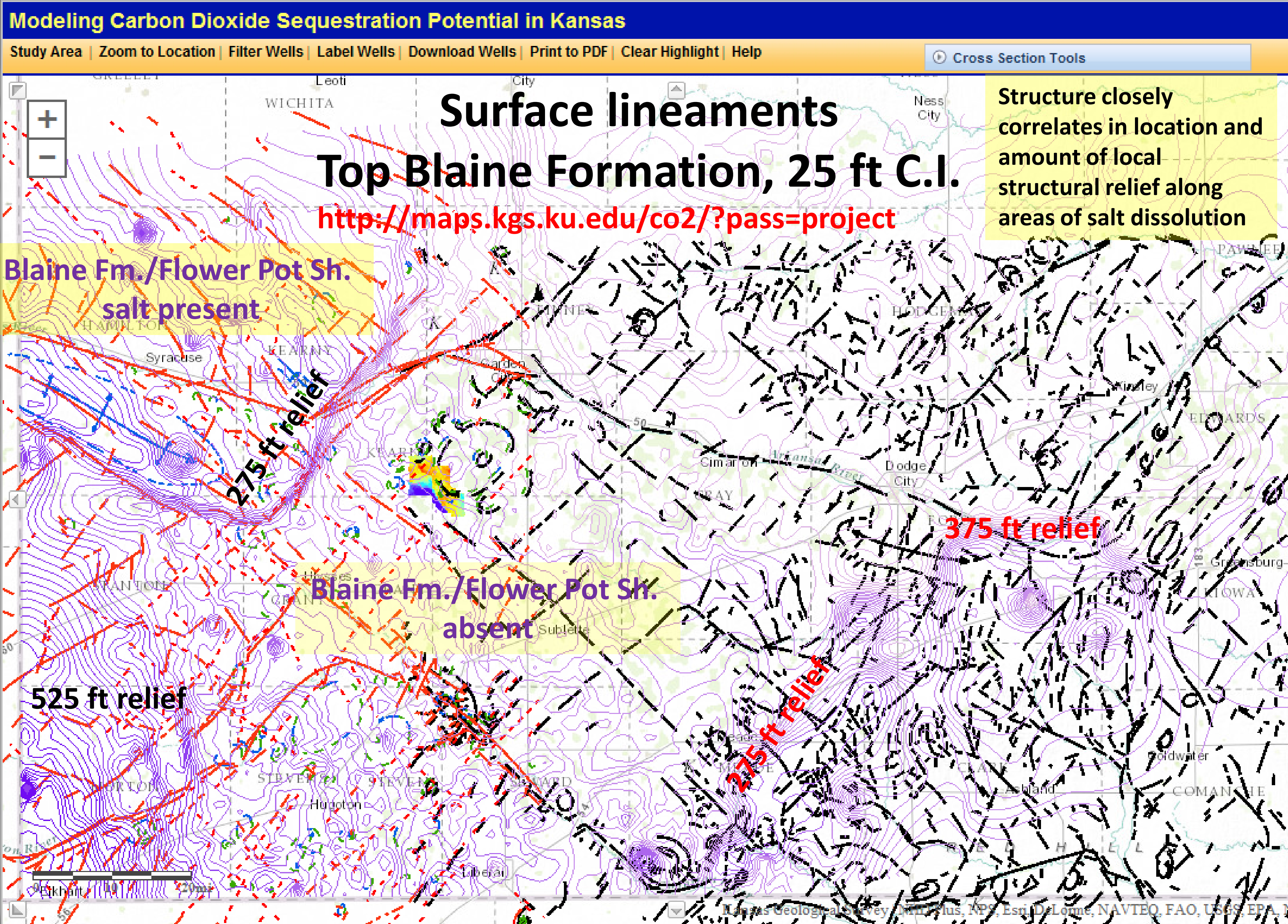
"Northward migration up the Anadarko shelf yielded most of the oil and gas in Pennsylvanian and Mississippian reservoirs in the Hugoton embayment" – Sorenson (2005)



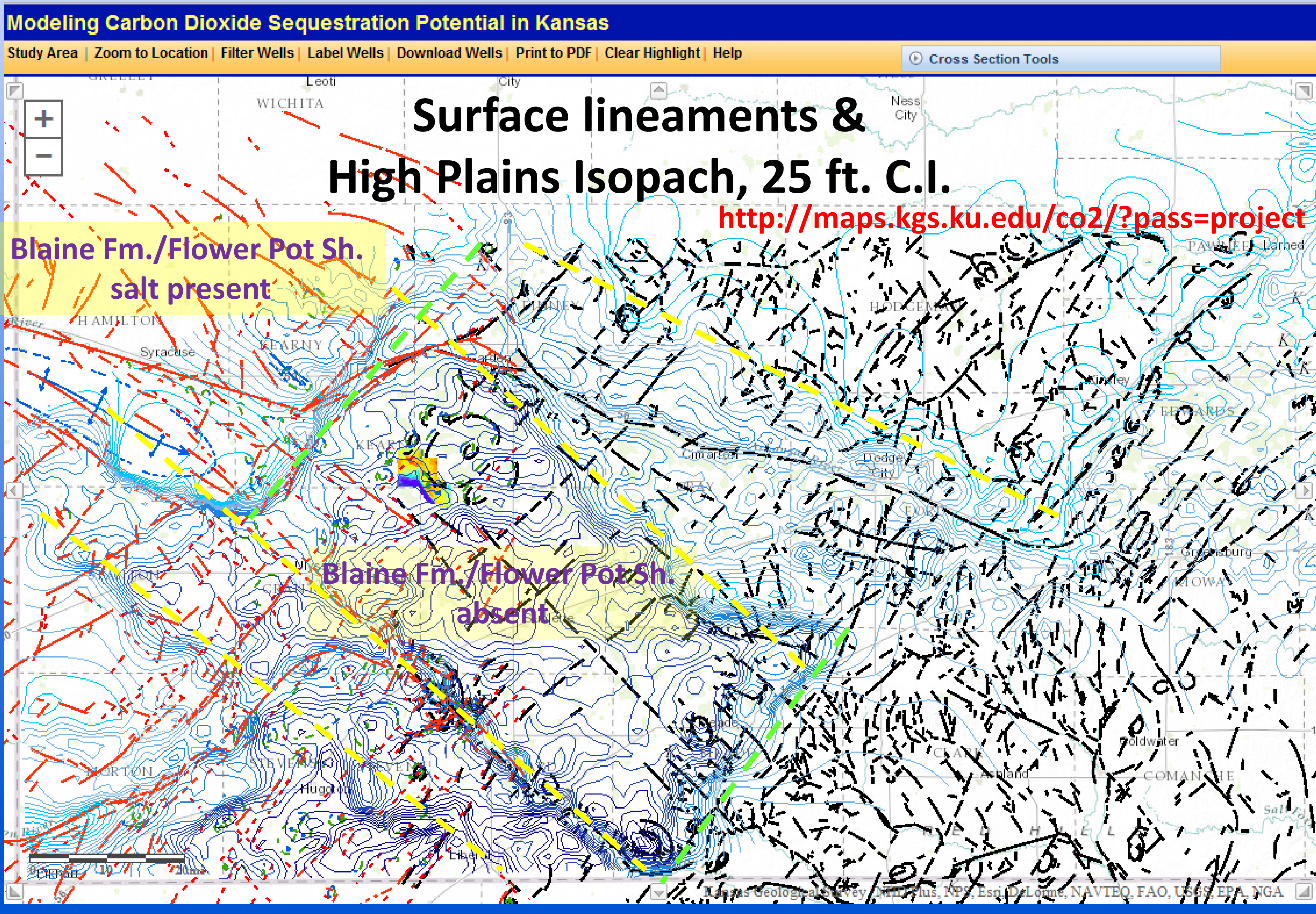
Notable correlation between surface lineaments and base of High Plains Aquifer Elevation



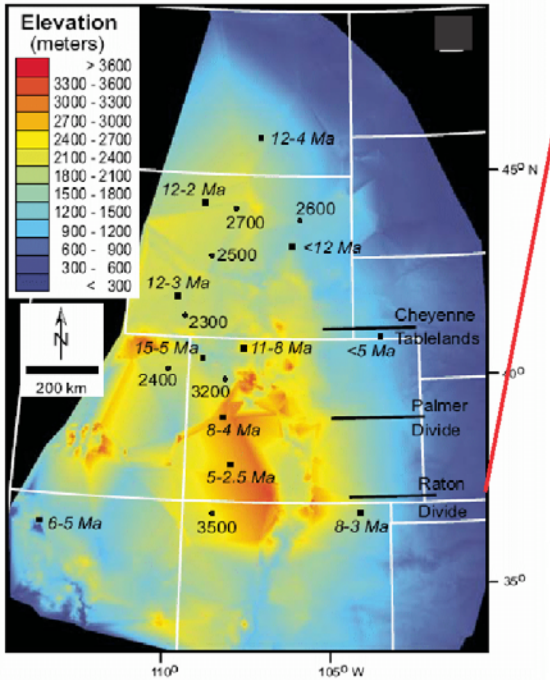
Notable correlation between surface lineaments and elevation of top of the Blaine Formation



Notable correlation between surface lineaments and High Plains Isopach



Significant post Laramide uplift in western Kansas during and after deposition of the High Plains Aquifer



Color-shaded map of reconstructed basin fill surface relative to modern topography (from McMillian et al., 2006)

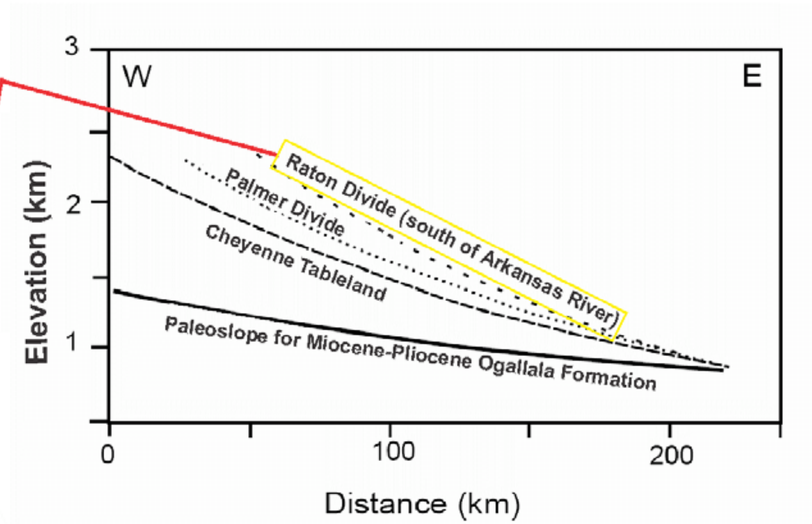
– Black east-west transect lines located are along the interfluves between the North and South Platte Rivers (Cheyenne Tablelands), the South Platte and Arkansas Rivers (Palmer Divide), and the Arkansas and Canadian Rivers (Raton Divide). Transects are shown above and right.

– Black circles are elevations of fill top over now-eroded basins reconstructed from indirect indicators of former topography.

– Black squares are compiled age constraints of turnaround from degradation in late to incision. The first value is before incision began and the second value after incision was initiated in Ma, millions of years before present.

– A major regional uplift and incision event occurred late during Ogallala deposition and extended to the Recent.

McMillian et al., 2006)



Gradients of major interfluves in the western Great Plains. Raton Divide separates Arkansas and Canadian River Drainages.

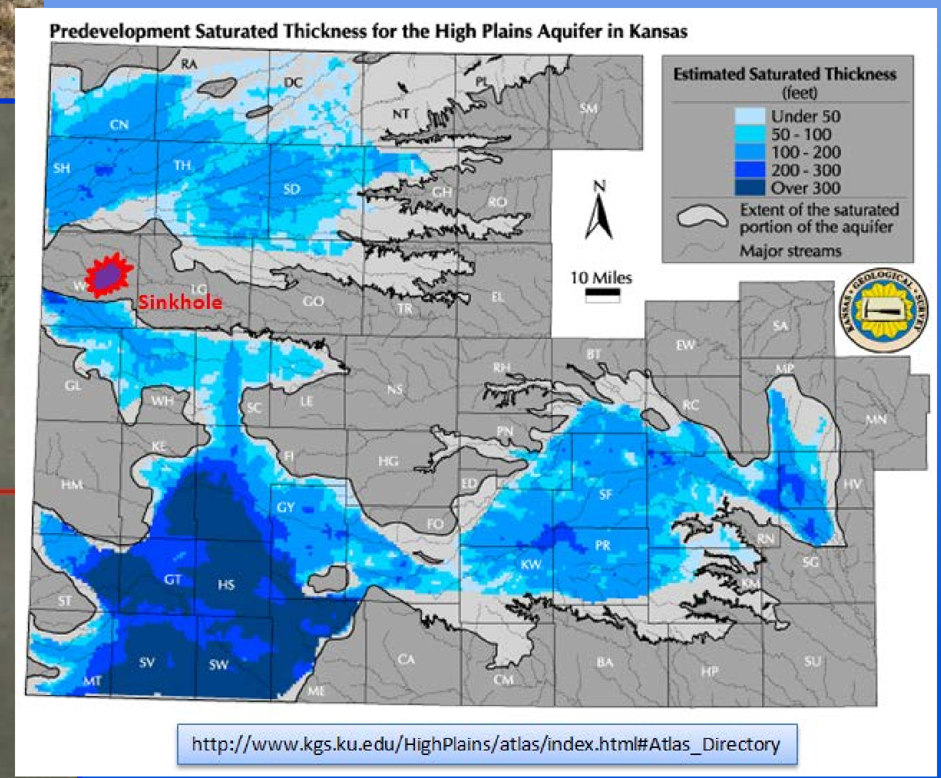
"Modern gradients are up to an order of magnitude greater than the paleoslope calculated from preserved gravels in the Miocene-Pliocene Ogallala Formation in the Cheyenne Tablelands" (McMillan et al., 2006)

Relatively recent uplift in the western Great Plains has been significant and could have initiated or at least renewed evaporite dissolution, SW Kansas Arkansas River evaporite dissolution basin.

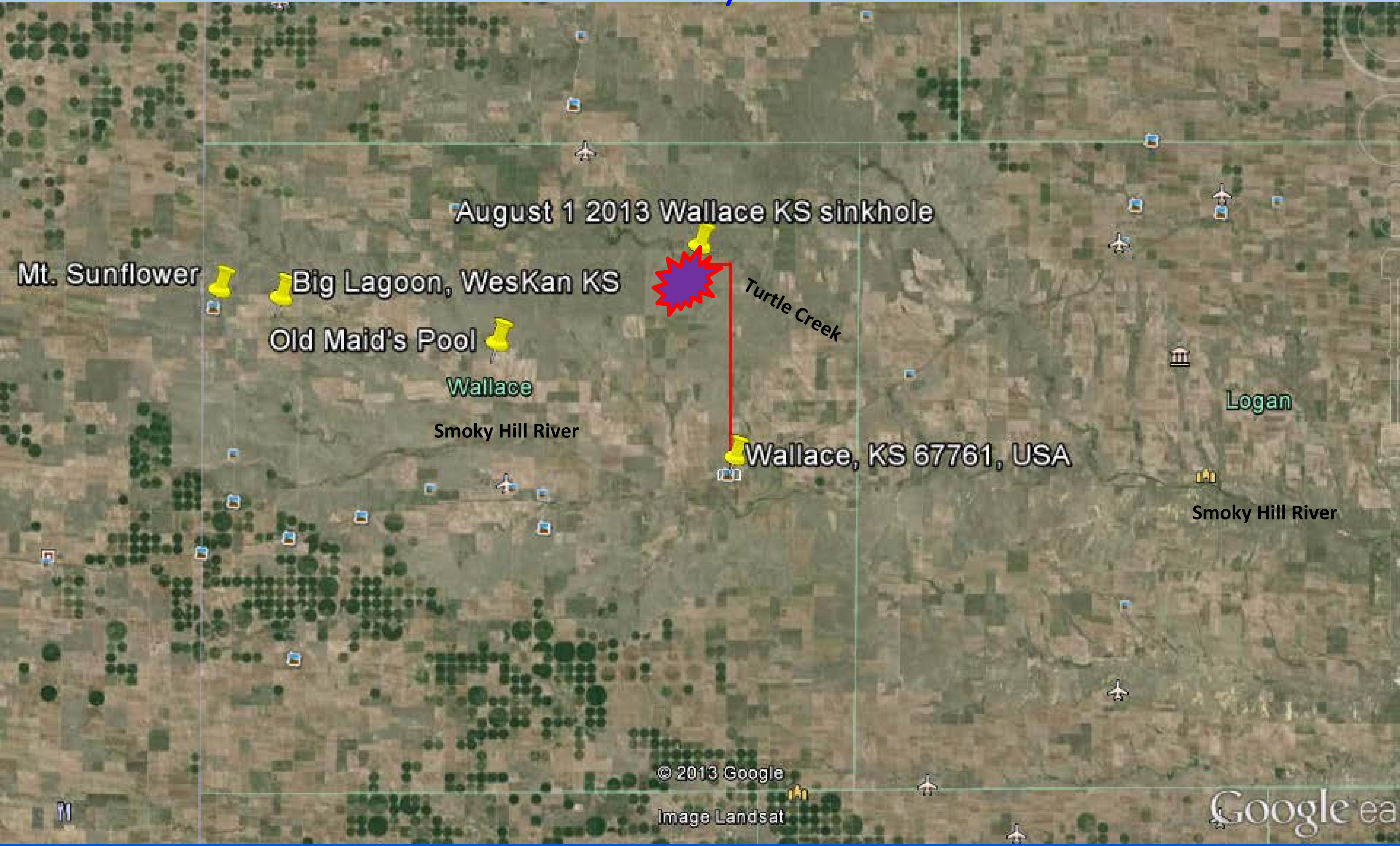
Timing of dissolution fronts for Permian evaporites in western Kansas appear to be late Miocene and younger. Lithofacies and thickness patterns in Ogallala and cofiguration of the bedrock and surface all support late evaporite dissolution.

A sinkhole, which is 200 to 300 feet wide, was discovered last week in a pasture ~ 8.5 mi N & 1.5 mi W of Wallace, Wallace County, Kansas

Read more here: http://www.kansas.com/2013/08/06/2928066/large-sinkhole-draws-curious-to.html#storylink=cpy

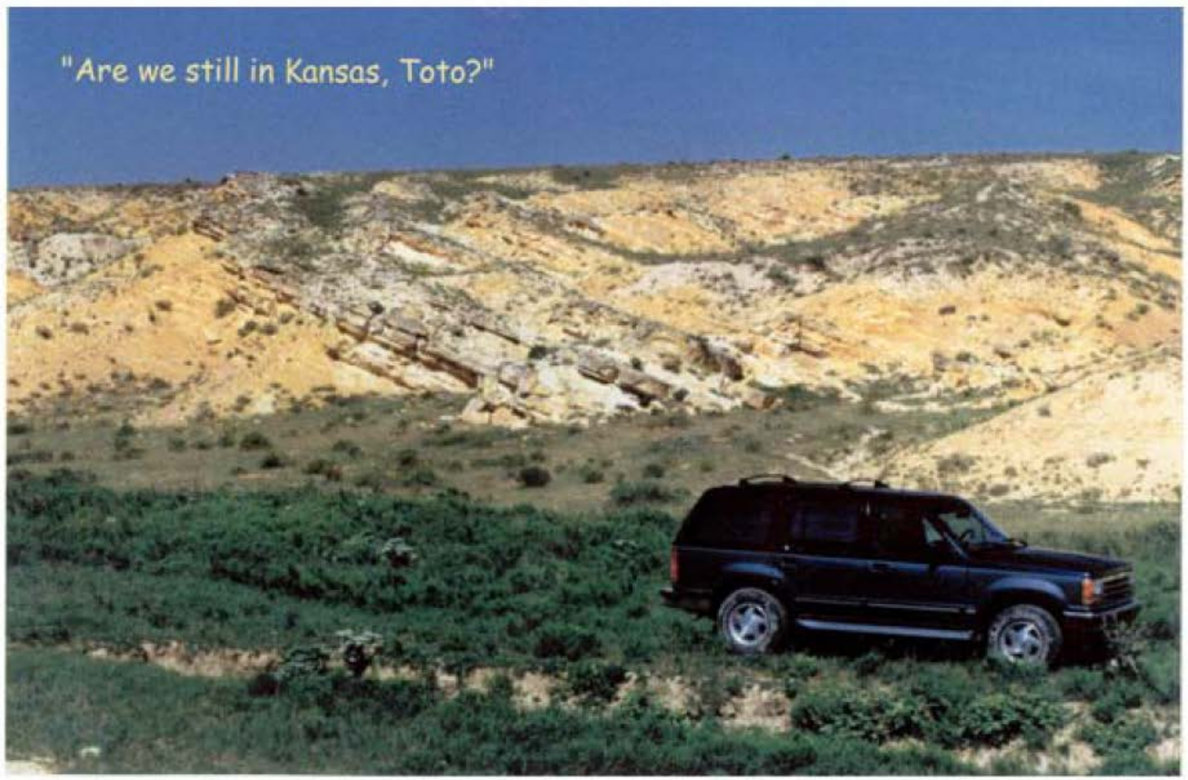


August 2013 Wallace County Sinkhole near other prominent sinkholes along headwaters of the Smoky Hill River

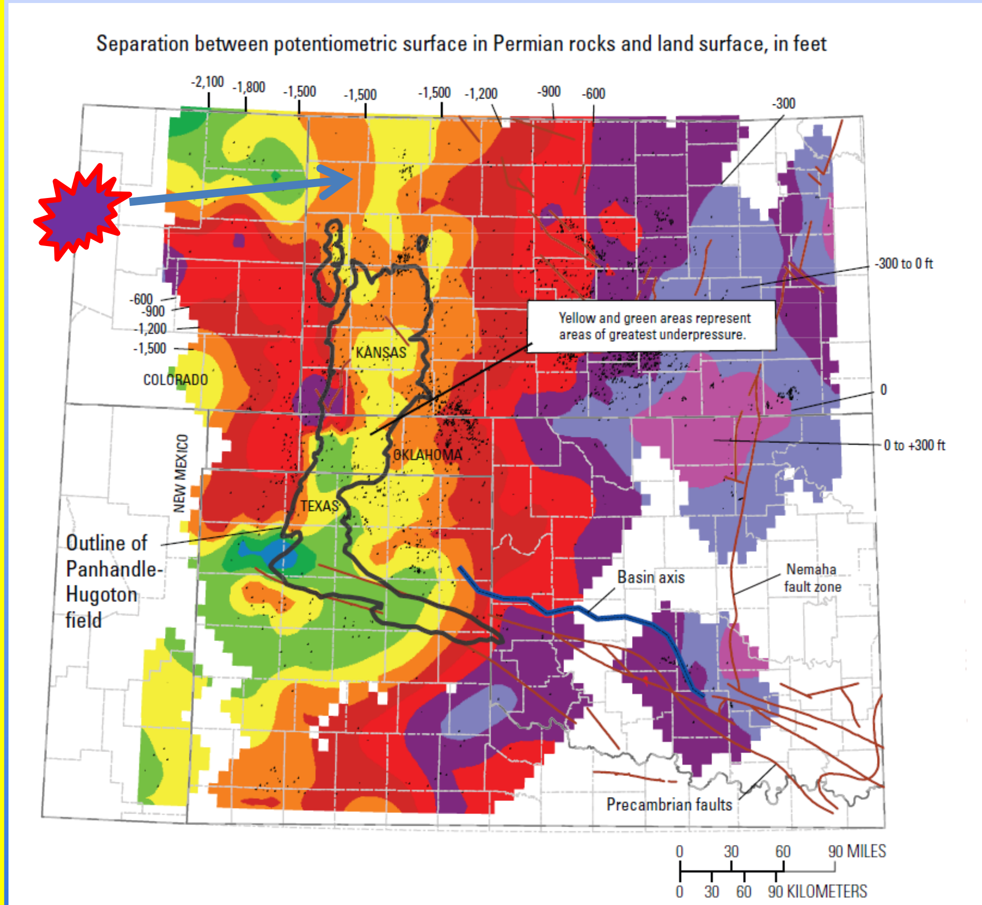


Rotated blocks of Niobrara Chalk are common along exposures along Smoky Hill River in Logan and Thomas counties

Extensive Faulting and Block Rotation in the Outcrops
Of the Smoky Hill Chalk Member in West Central Kansas



Courtesy of M. Dubois



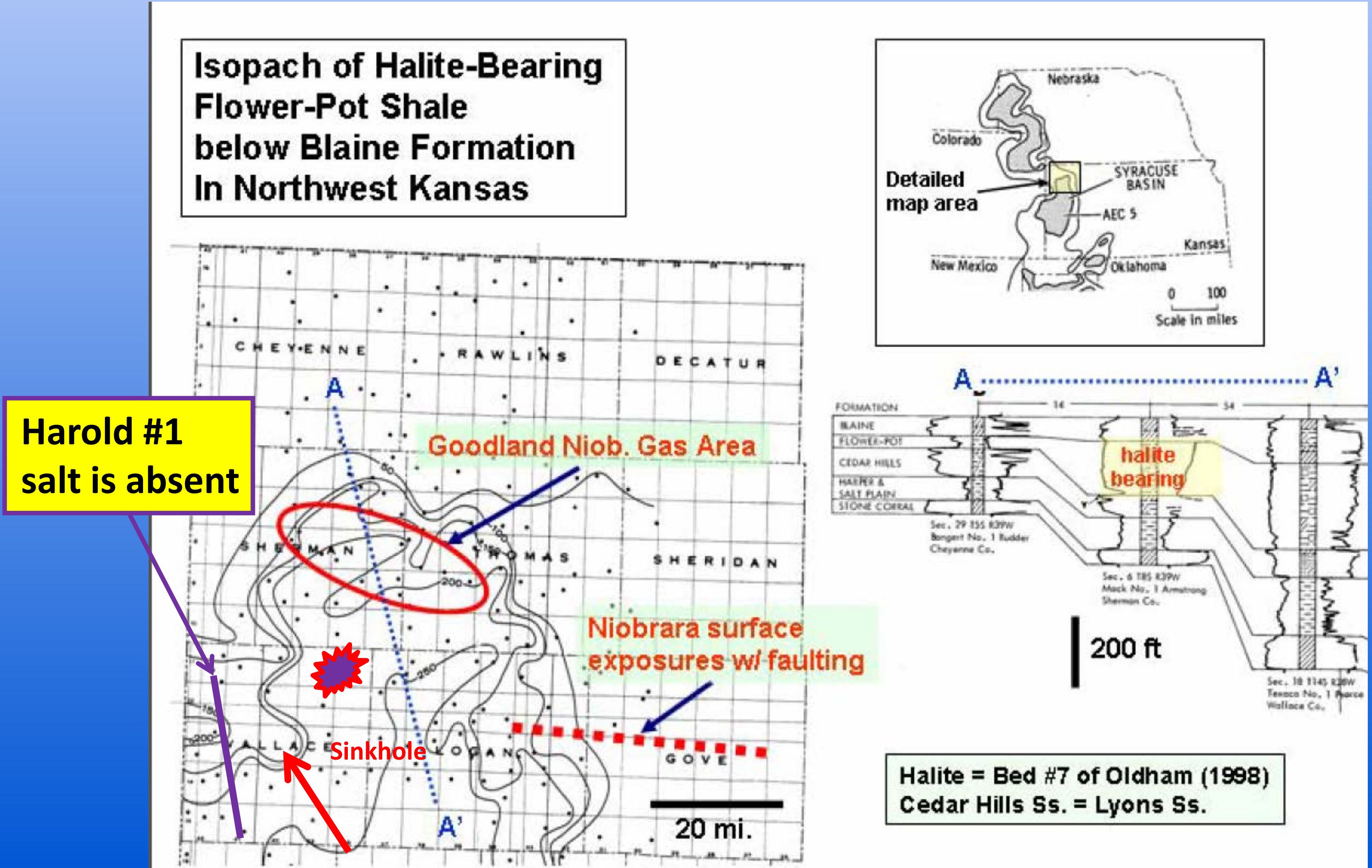
Potentiometric surface of brine in Permian strata is ~1650 ft below the land surface in the vicinity of the sinkhole.

100 mi

from Nelson and Gianoutsos, 2011, USGS OFR 2011-1245

- Difference between the potentiometric surface of fluids in the Permian and the shallow aquifers **provides a potential for downward flow**, if communication is established.
- Extensional fractures during regional post Laramide (Late Tertiary) uplift is believed to have led to extensive dissolution of Permian halite beds in western Kansas .
- Headwaters of the Smokey Hill River appear to be site of incipient dissolution of Flower Pot/Blaine salt
- Paleocavity collapse & paleo-disturbed bedding and rotated blocks of Niobrara Chalk along river.

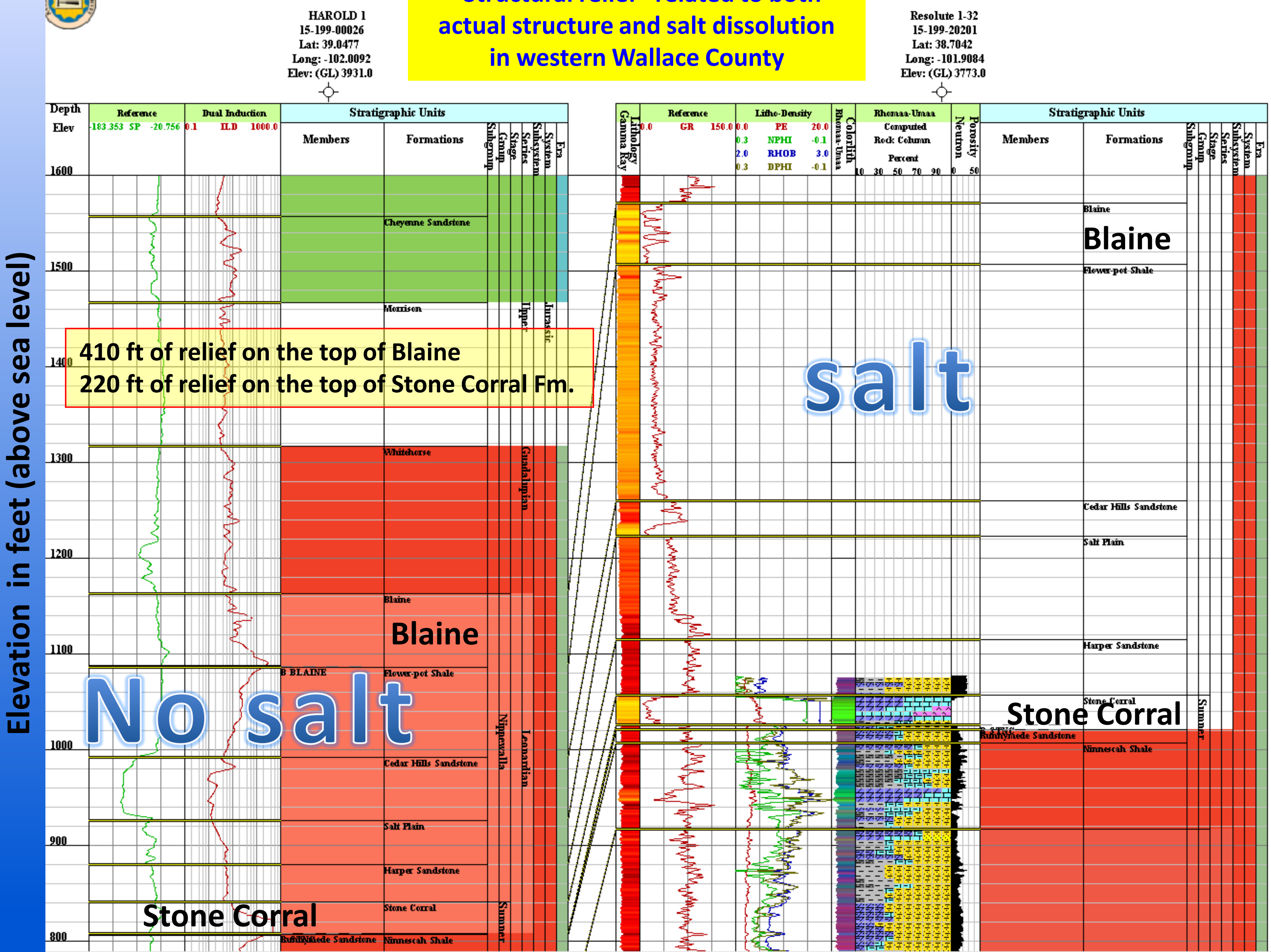
Blaine/Flowerpot halite isopach suggests dissolution of salt on the west side in Wallace County



Thinning of Blaine salt in Wallace county

after Holdaway (1978)

"Structural relief" related to both actual structure and salt dissolution in western Wallace County



Summary & Conclusions

- **Anadarko Basin** –Proterozoic extension to Phanerozoic compression from rift basins to horst & graben system
- **Hugoton Embayment (HE)** – 10,000 km^2 northern extension of Anadarko Basin and structurally integrated
- **Major structures in the HE –** prominent evidence of coupled and complex compressional events from far field stresses including diagnostic features such as flower structures and restraining bends developed along reactivated basement lineaments
- **Episodic structural movement** – post tectonic movement affecting sedimentation/stratigraphy throughout Phanerozoic including High Plains Aquifer and surface lineaments and topography
- **Pattern of deformation** – strongly influenced by prominent basement weaknesses (the template) revealed by potential fields and lineament analysis interacting with an evolving stress field

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