

EVALUATING STRUCTURAL CONTROLS AND THEIR ROLE IN FORECASTING PROPERTIES OF PHANEROZOIC ROCKS IN THE NORTHERN MIDCONTINENT, U.S.A. – ANCIENT EXAMPLES AND MODERN ANALOGS

***W. Lynn Watney, Evan K. Franseen¹, Alan P. Byrnes,
Susan E. Nissen***

***Energy Research and ¹Stratigraphic Research Sections,
Kansas Geological Survey, The University of Kansas
1930 Constant Avenue - Campus West, Lawrence, Kansas 66047
and***

Sihuang Xu

***Department of Petroleum Engineering, Faculty of Resources,
China University of Geosciences, Wuhan, PRC***

KGS Open-File Report 2006-19



Integrated Tectono-Stratigraphic Analysis

- **Ancestral Rocky Mountain and Laramide tectonism were far reaching and systematically deformed shelves and shelf margins of the upper Midcontinent.**
- **Precambrian faults served as templates for later deformation, crustal segmentation.**
- **Resultant segmentation of shelves and shelf margins via reactivation of basement faults -- complex, but predictable.**
- **Forecasting rock properties: Quantify segmentation of shelf and associated subsidence & tilting in context of deposition and diagenesis.**
 - **Kinematic analysis of structures analogous to current research in neotectonics:**
 - **Global Positioning Systems (GPS)**
 - **Interferometric Synthetic Aperture Radar (InSAR)**
 - **High-resolution regional stratigraphy**
 - **3-D seismic attribute analysis**
 - **Delineate locations and “activity” (relative timing) of faults, folds, and deformation zones and motion of structural blocks.**

Key Points

- 1. True stratigraphic traps of economically producible hydrocarbons are probably fewer than believed.
- 2. The relative roles of processes including deposition, diagenesis, and structure probably need to be re-evaluated to improve modeling of remaining fields.
- 3. Geologic models and concepts will continue to be refined & quantified with new technologies – 3D seismic imaging, high resolution potential fields, surface and satellite-based techniques.

Stratigraphic intervals reviewed

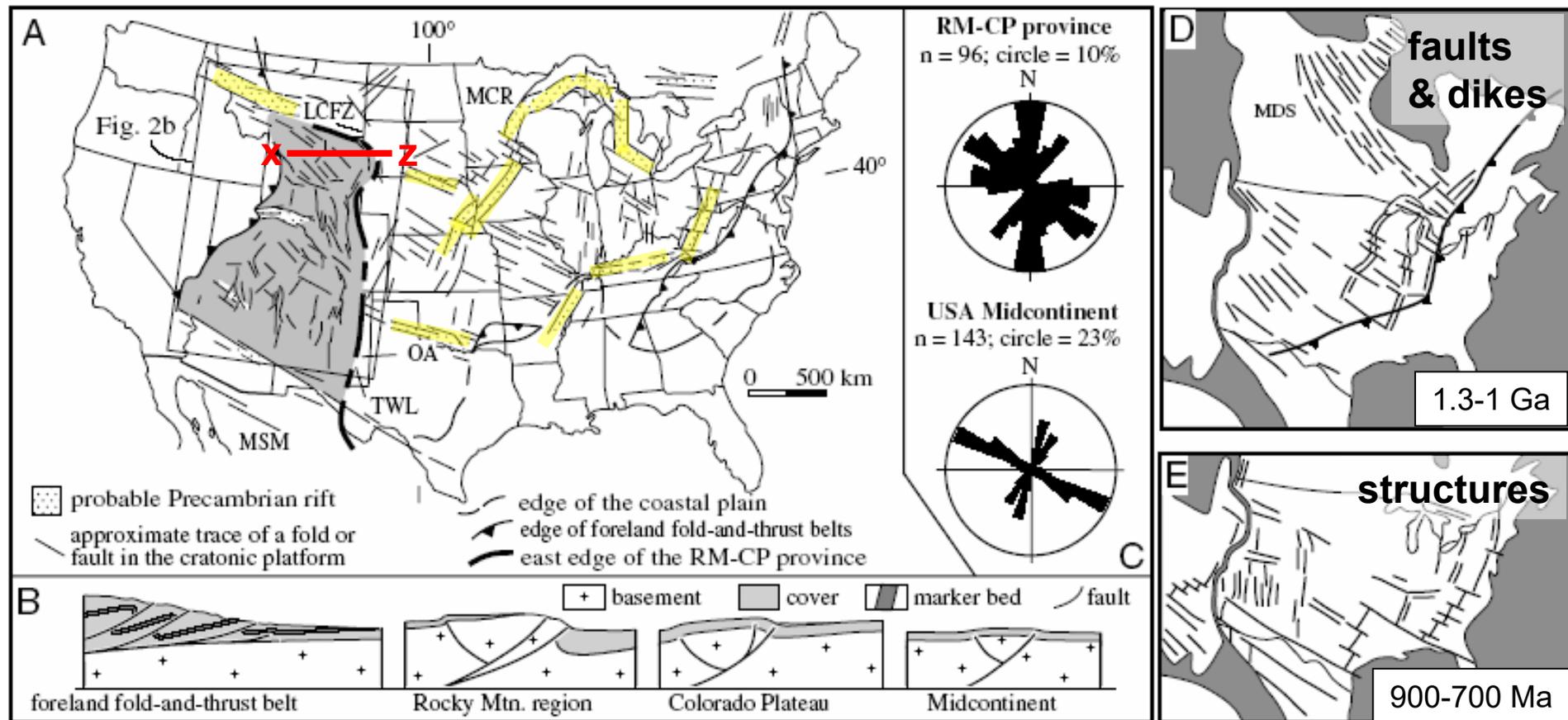
- Emphasis on structural controls as added element in prediction and quantification of reservoir properties

SYSTEM	LITHOLOGY	SERIES	GROUP	SIGNIFICANT FORMATIONS	
QUATERNARY		PLEISTOCENE			
TERTIARY		PLIOCENE		OGALLALA	
CRETACEOUS		UPPER	MONTANA COLORADO	NIOBARRA	
		LOWER		DAKOTA	
JURASSIC		UPPER		MORRISON	
PERMIAN		GUADALUPIAN			
		LEONARDIAN	NIPPEWALLA SUMNER	STONE CORRAL	
		WOLFCAMPIAN	CHASE COUNCIL GROVE ADMIRE	WINFIELD	
PENNSYLVANIAN		VIRGILIAN	WABAUNSEE SHAWNEE DOUGLAS		
		MISSOURIAN	LANSING KANSAS CITY PLEASANTON		
		DESMOINESIAN	MARMATON CHEROKEE		
		ATOKAN			
MISSISSIPPIAN		Morrowan			
		CHESTERIAN		CHESTER STE. GENEVIEVE ST. LOUIS SALEM WARSAW	
		MERAMECIAN			
		OSAGIAN			
ORDOVICIAN		KINDERHOOKIAN		GILMORE CITY VIOLA	
		MIDDLE	SIMPSON		
CAMBRIAN		LOWER	ARBUCKLE		
		UPPER		BONNETERRE DOL.? REAGAN SS.	
PRECAMBRIAN	IGNEOUS AND METAMORPHIC BASEMENT ROCKS				

**Greater Ancestral Rocky
Mountain (Ouachita-Marathon)
and Laramide tectonism were far
reaching and systematically
deformed shelves and shelf
margins of the upper
Midcontinent**

- Compressional stress regime continues today within craton

Two dominant orientations of Precambrian faults and folds in cratonic platform

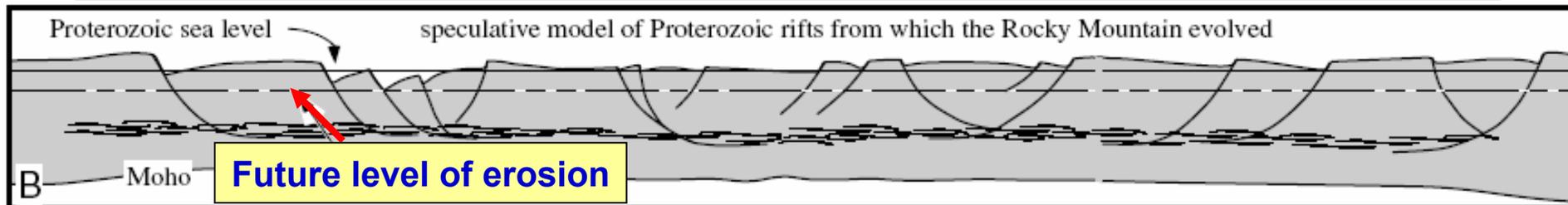
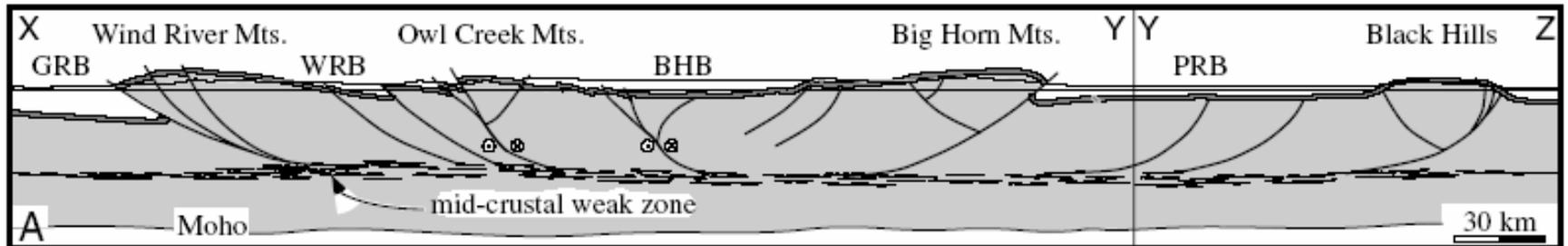


- Proterozoic rifting (extensional faults)
- Faults continue to be reactivated during Phanerozoic compressional orogenies (Kluth and Coney, 1981)
- Inversion of normal faults (*reverse & oblique-slip*)

Marshak, Karlstrom,
and Timmons (2000)

Reactivation of Precambrian extensional fault throughout the craton

X Y Z

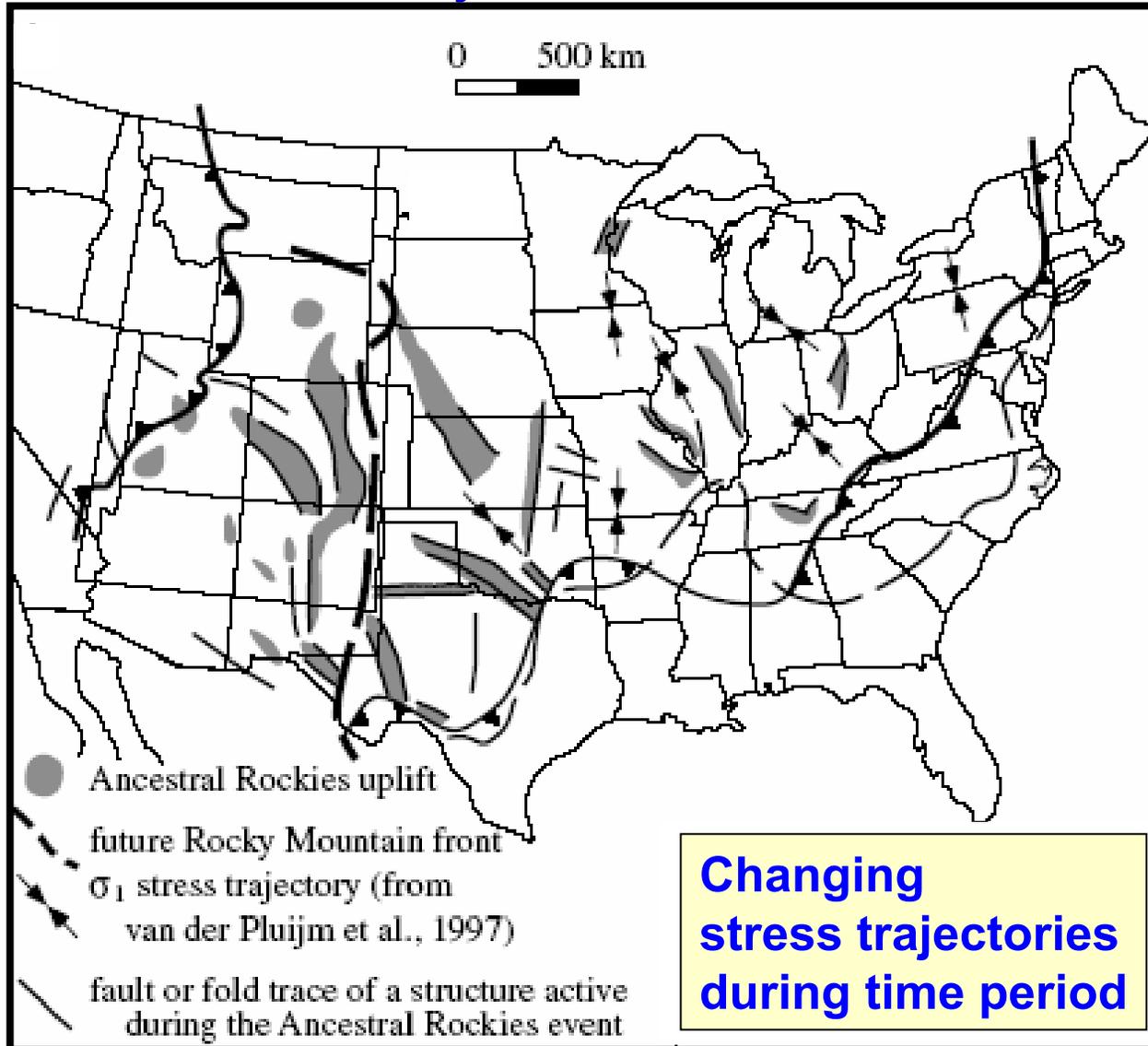


A) Schematic cross section of Rocky Mountains

B) Hypothetical east-west cross section of Proterozoic structure for same traverse as cross section A)

Ancestral Rockies Structures

-- Early Chesterian - Late Leonardian



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)

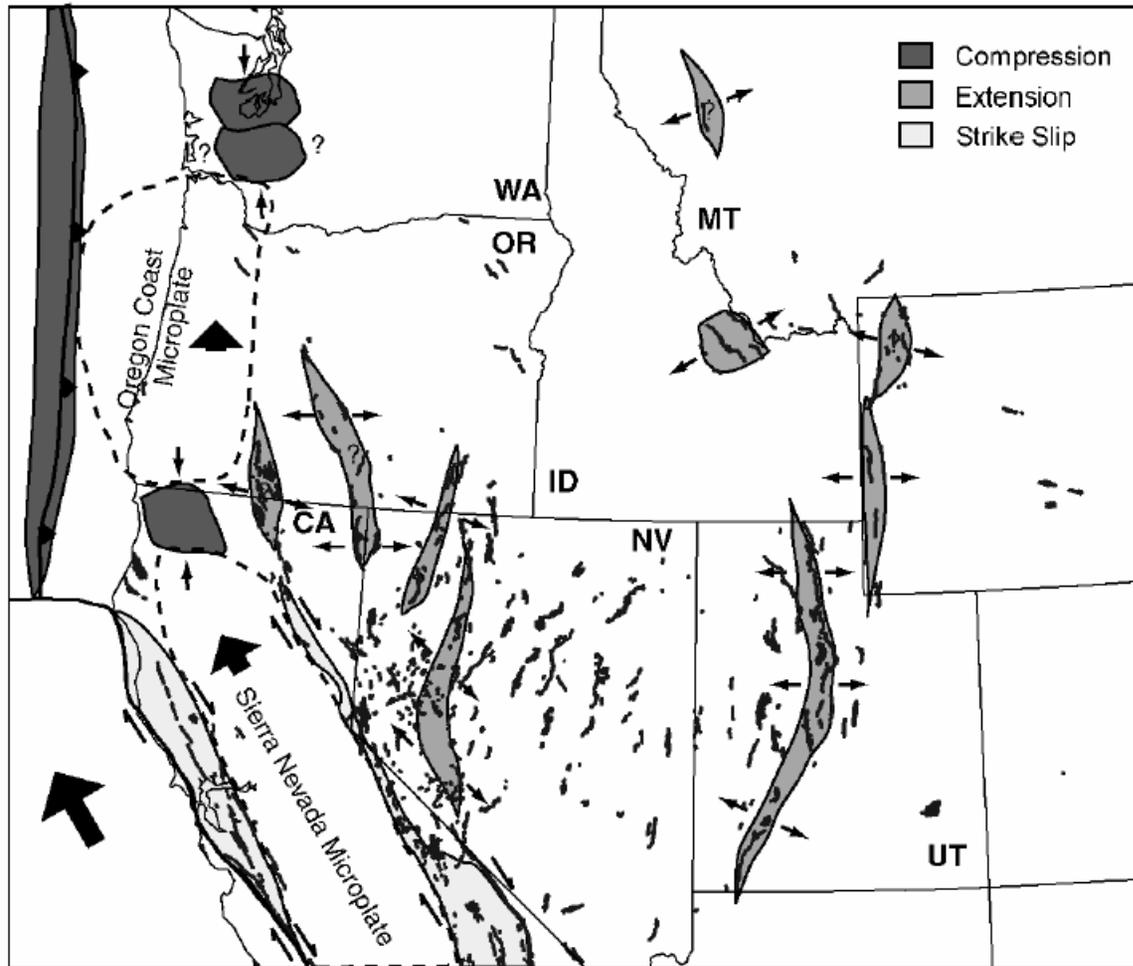
Marshak, Karlstrom, and Timmons (2000)

Ages from Dickinson and Lawton (2003)

Resultant segmentation of shelves and shelf margins via reactivation of basement faults -- complex, but can be further characterized in temporal-spatial framework for prediction

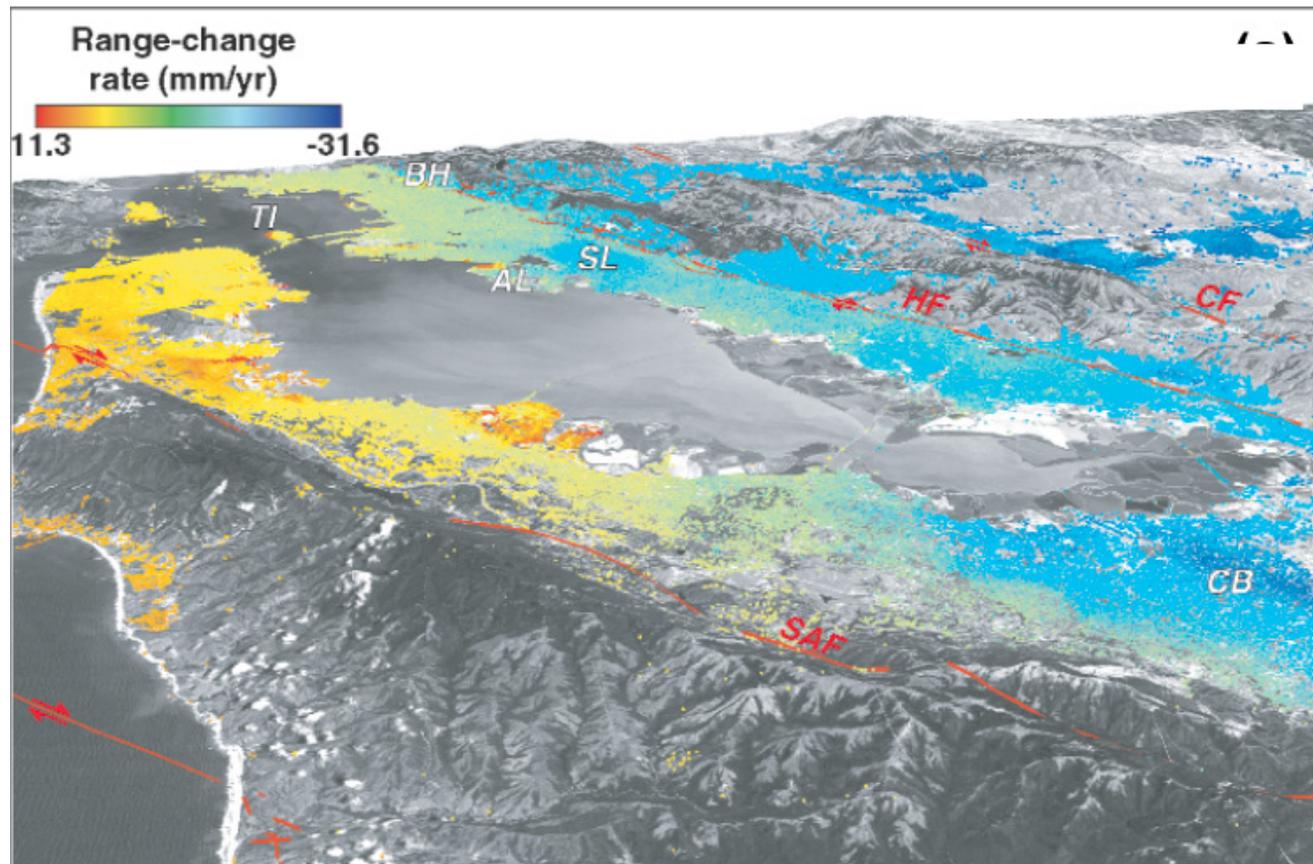
Examples from Neotectonism

Schematic mapping of zones of localized deformation in the western U.S. suggested from recent GPS survey results, Holocene faults, and seismicity.



Thatcher (2003)

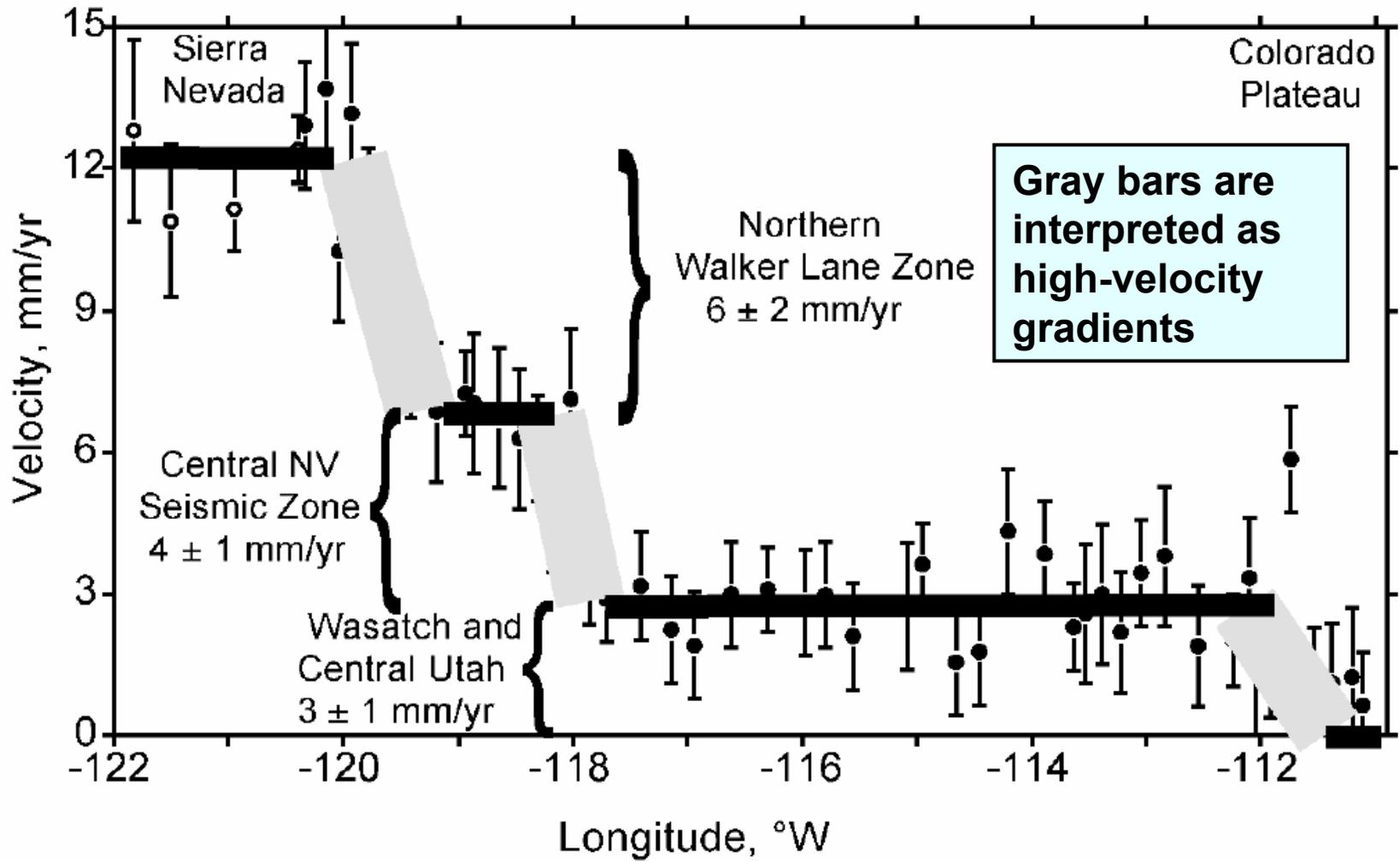
Synthetic Aperture Radar Interferometry (InSAR)



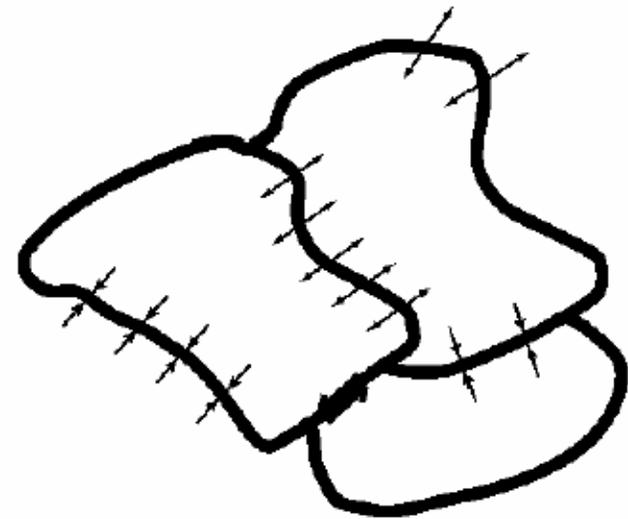
PS analysis of the Bay Area, consists of 115,487 PS data points InSAR. The color of each point indicates its measured velocity toward or away from the ERS SAR satellite. Range change rates gradually vary across the region due to elastic strain accumulation about the major plate-bounding faults. Large subsidence rates due to settling are observed alongside San Francisco Bay such as on Treasure Island and in Alameda. (After Ferretti et al., 2004).

**San Francisco Bay Area
-- roughly 30 miles across**

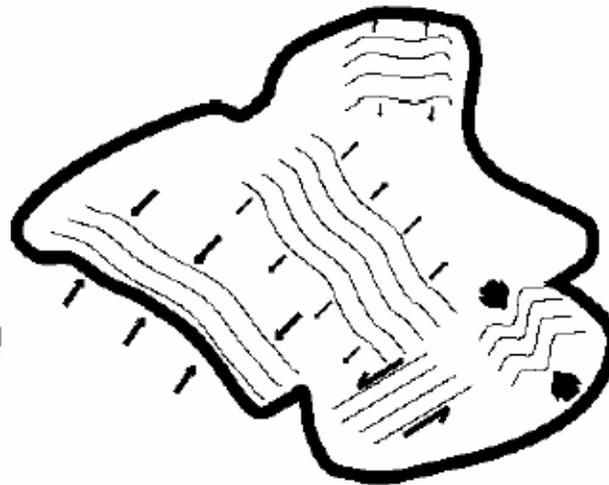
Magnitude of GPS velocity with respect to stable North America plotted on west-to-east profile versus longitude from Sierra Nevada to Colorado Plateau



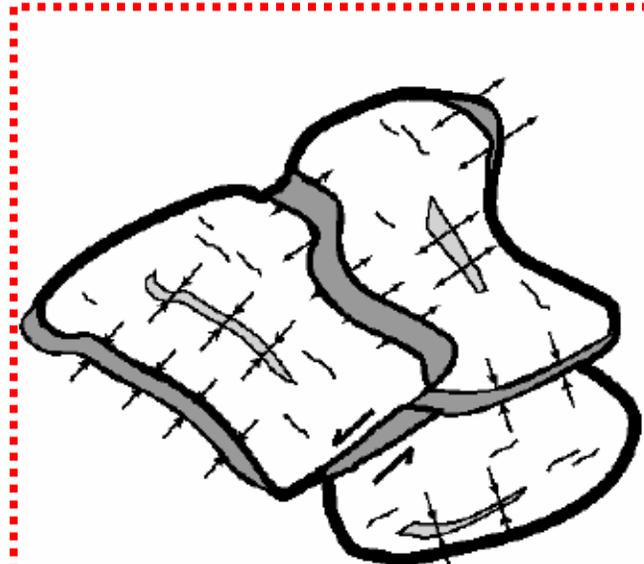
Schematic diagrams showing alternative kinematic descriptions of continental deformation



A. Plate-like



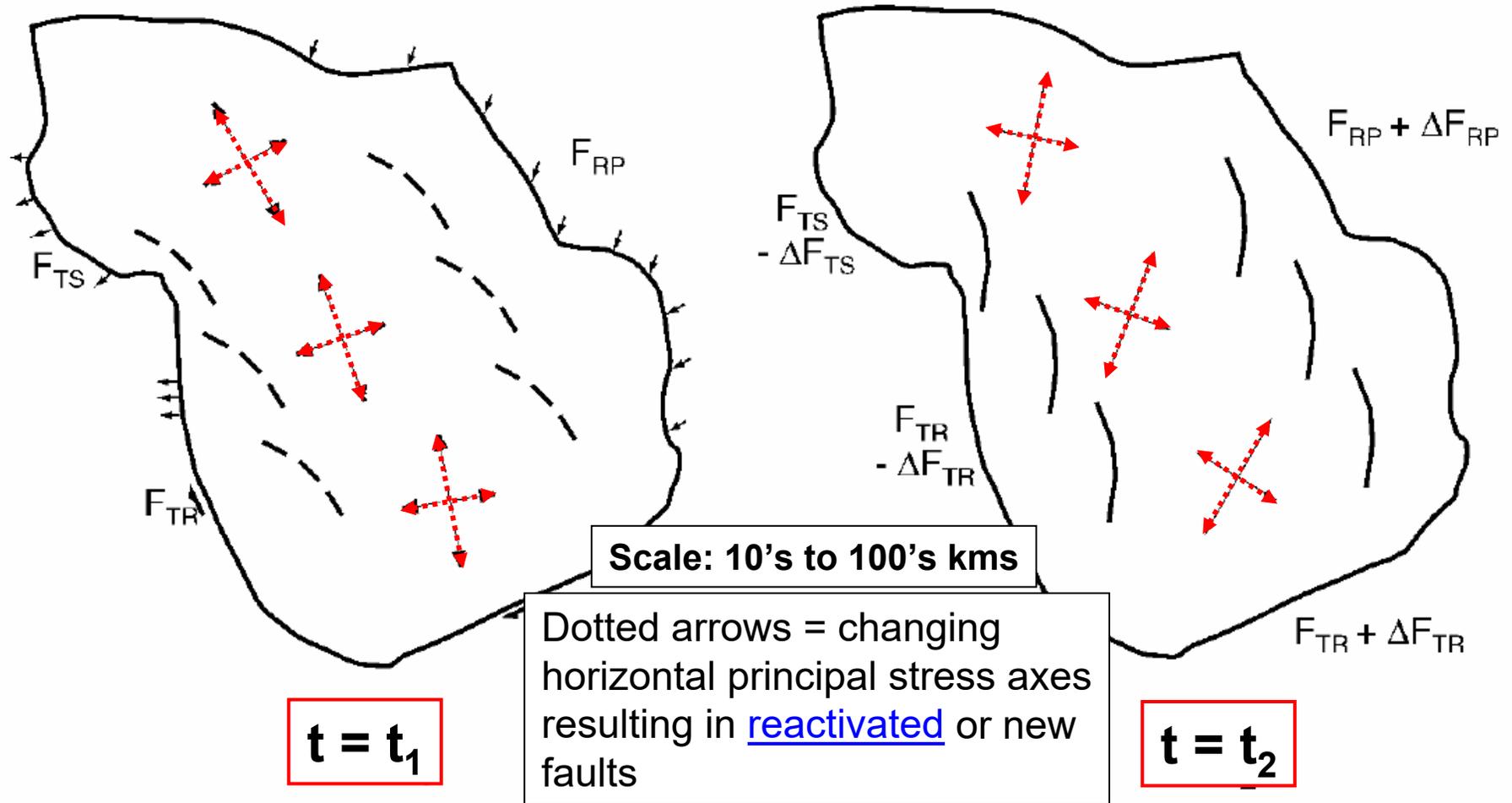
B. Continuum sea



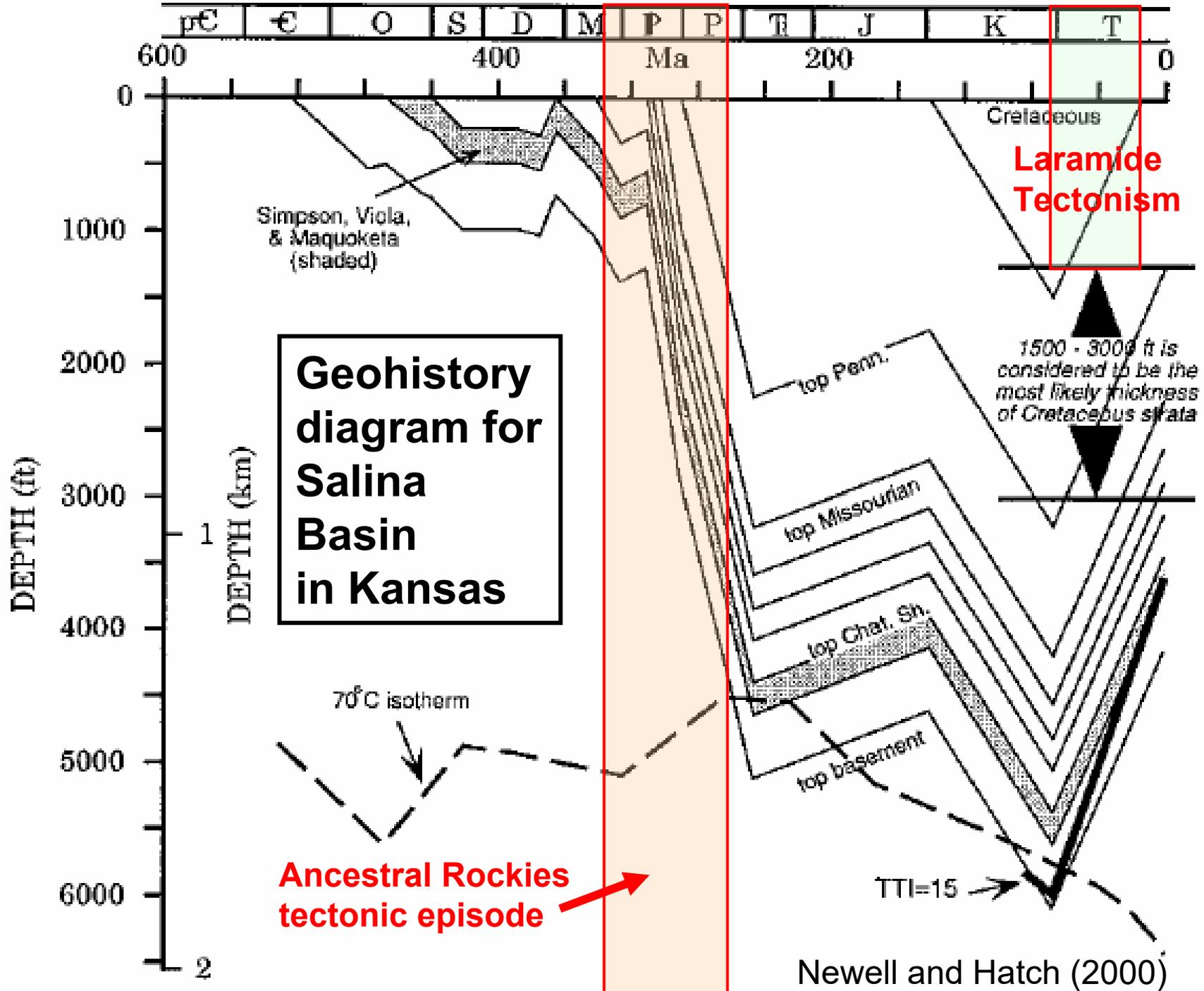
C. Narrow zones

- Deformation focused in narrow zones, several km, separating blocks that are 10s to 100s km across.
- Rigid block motions successfully describe continental tectonics.
- Framework from **GPS studies** can be confidently applied to **quantify seismic hazard assessment -- ancient equivalent, paleoseismicity.**

Conceptual diagram - Effect of changing plate boundary forces on intraplate stress field and fault patterns



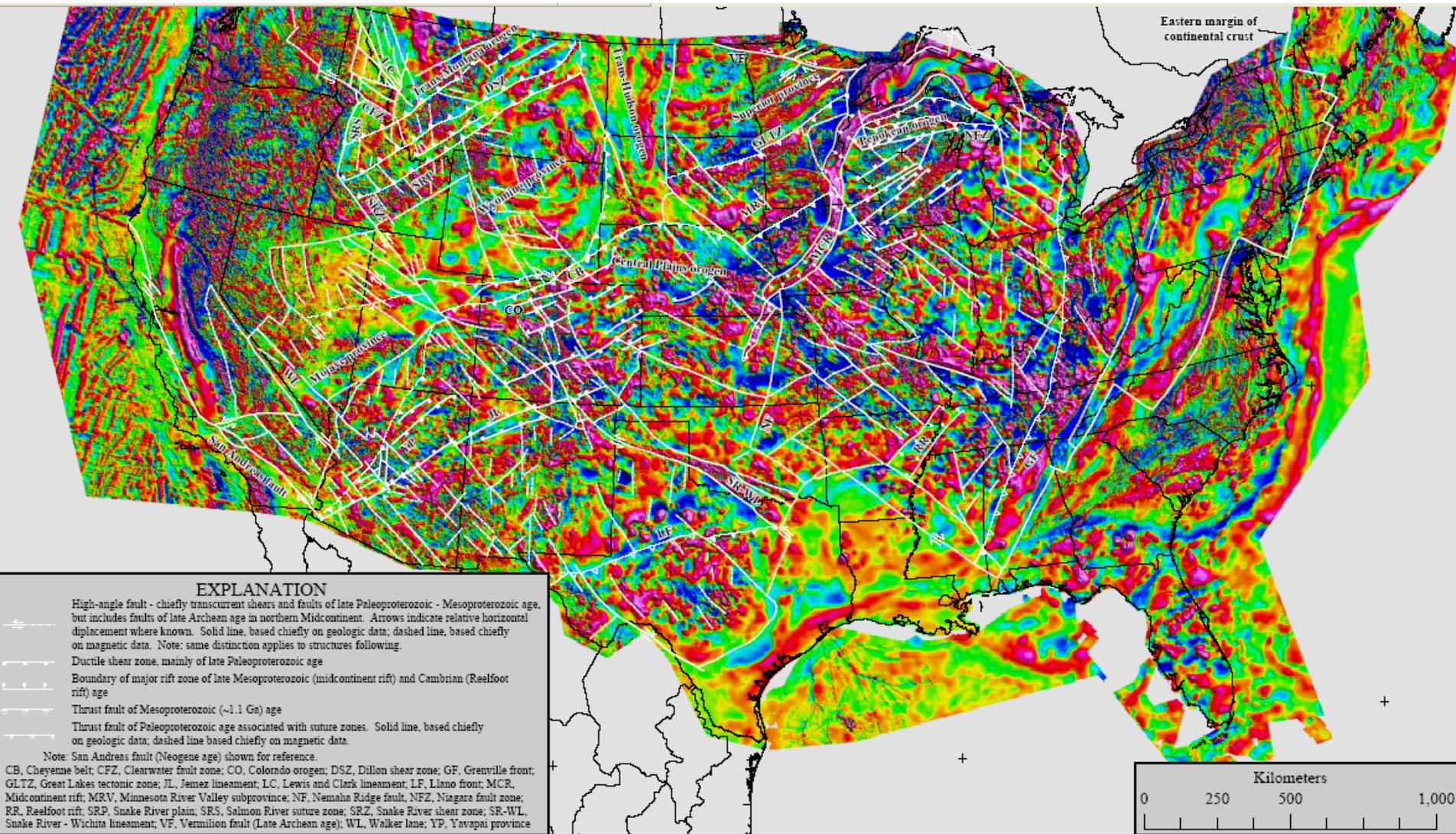
From Thatcher (2003), GPS constraints on the kinematics of current continental deformation. Examples in paper include deformation linking “real time” Modern faulting and microplate formation along --
San Andres Fault - Basin & Range - Colorado Plateau system.



**Precambrian faults serve as
templates for later
deformation and crustal
segmentation**

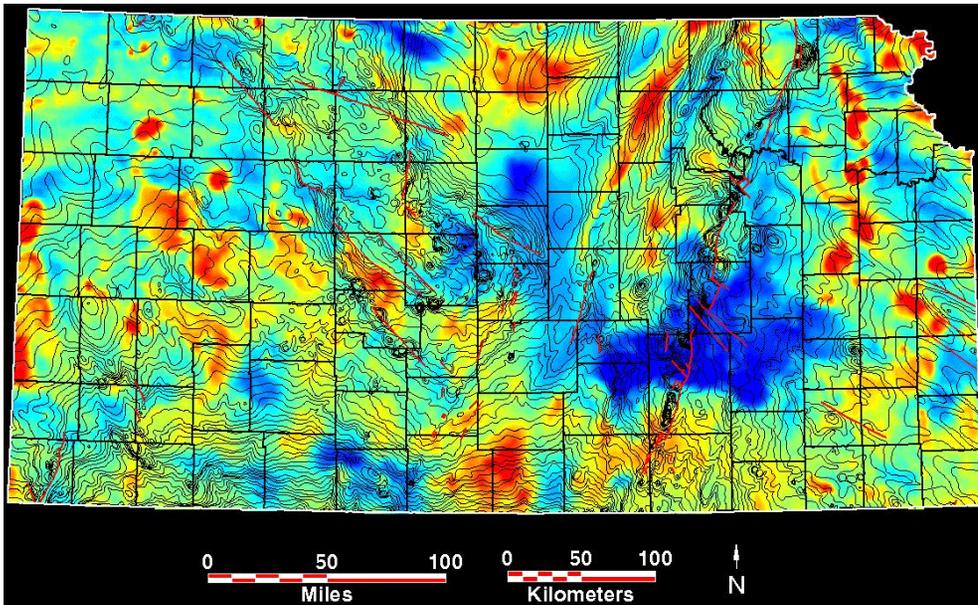
Preliminary Precambrian Basement Structure Map of Continental U.S.

-- An interpretation of Geologic and Aeromagnetic Data



Sims, Saltus, and Anderson (2005)

Total Magnetic Field Intensity

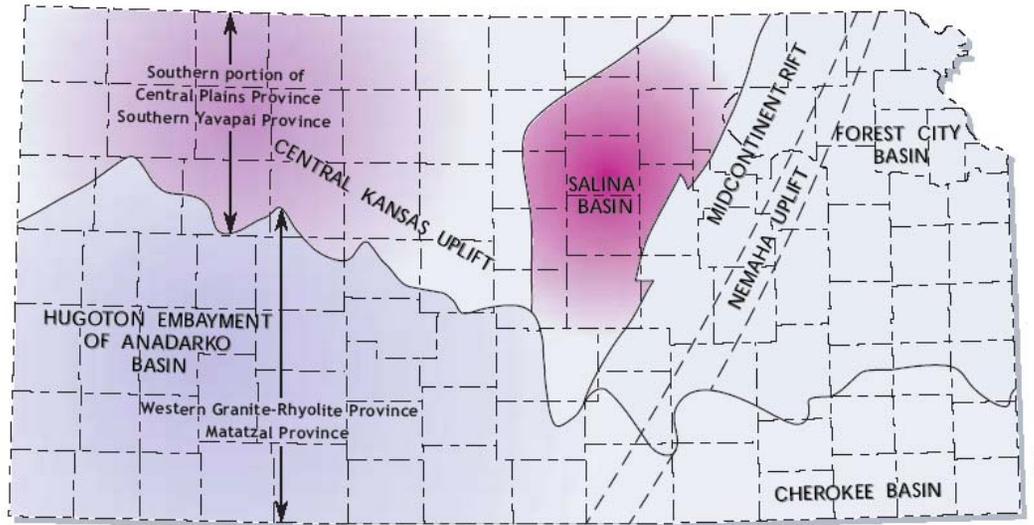


Kruger (1997)

Contours = Precambrian surface isochores

Red = high mag.
Blue = low mag.

Basement Structures and Terranes



granitic and metamorphic rocks

approximately 1.6 billion years old

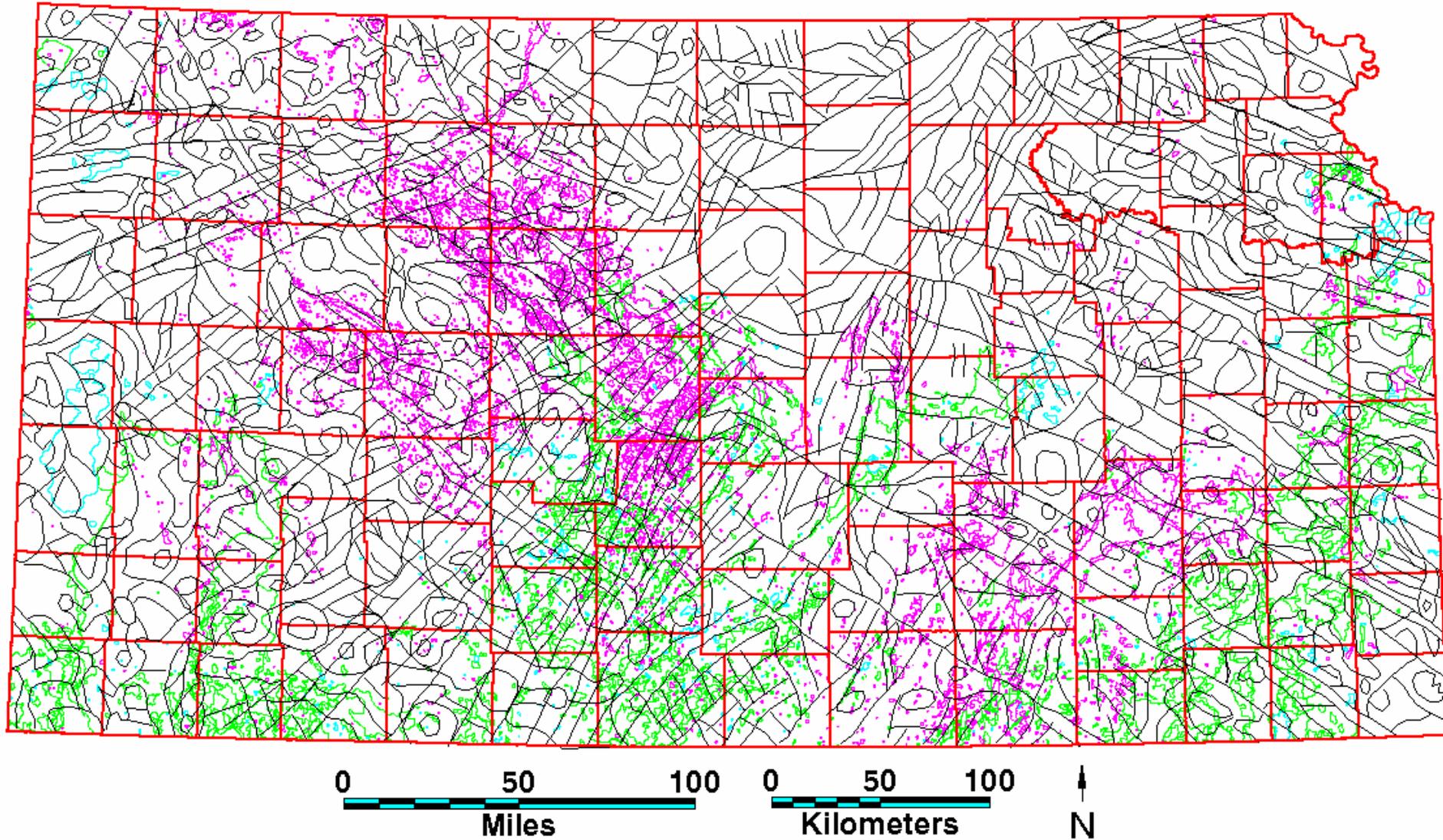
approximately 1.4 billion years old

Central North American rift approximately 1.1 billion years old

0 50 miles
0 50 kilometers

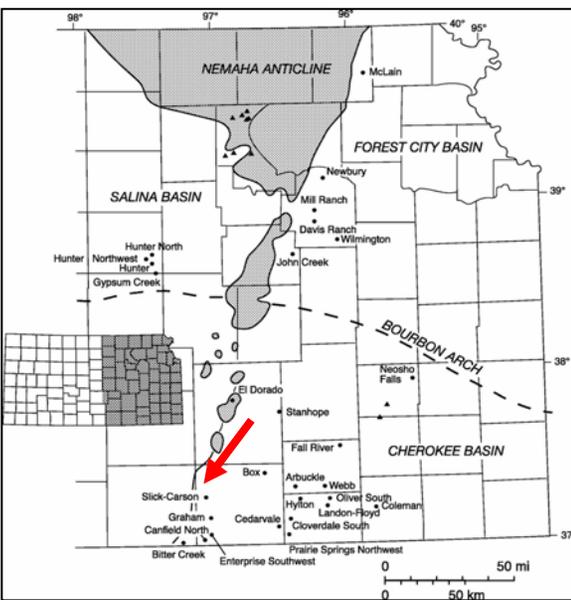
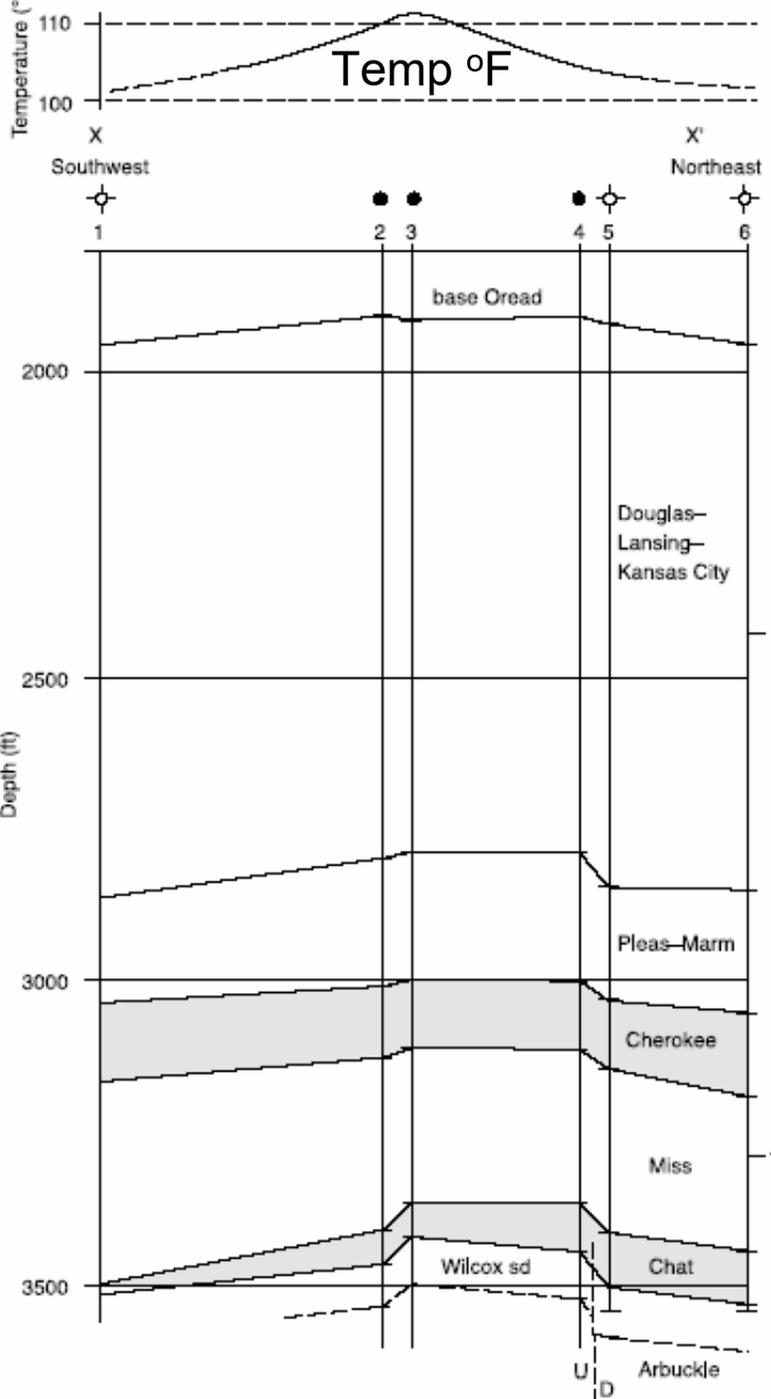
Gerhard (2004)

Local magnetic lineations from total magnetic field intensity Overlain with oil and gas fields (Kruger, 1997)



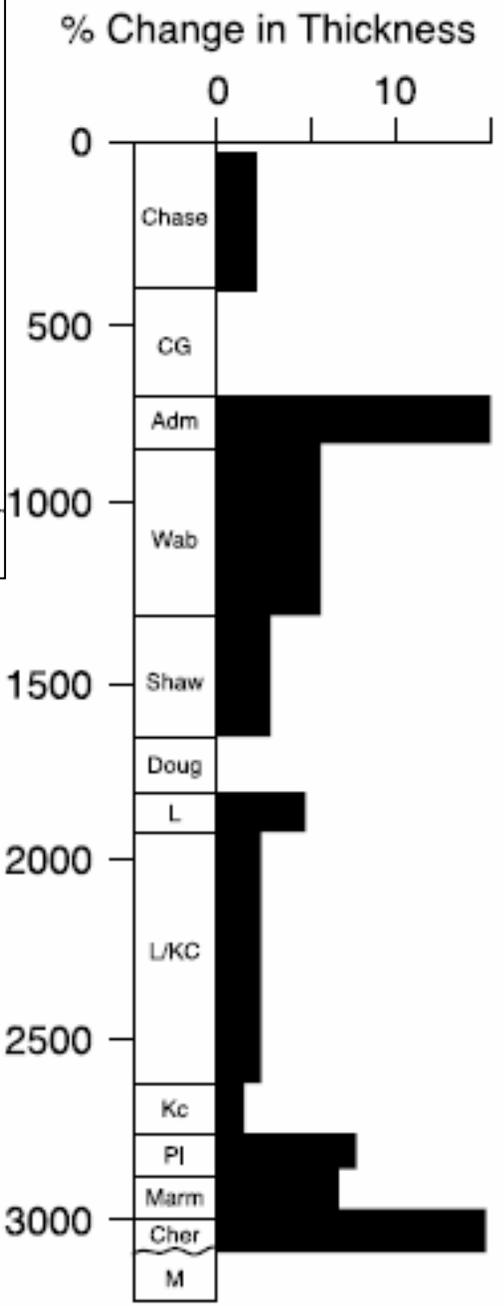
Mosaic of NW and NE trending lineaments

-- Applied to oil and gas exploration -- Kruger et al. 1999

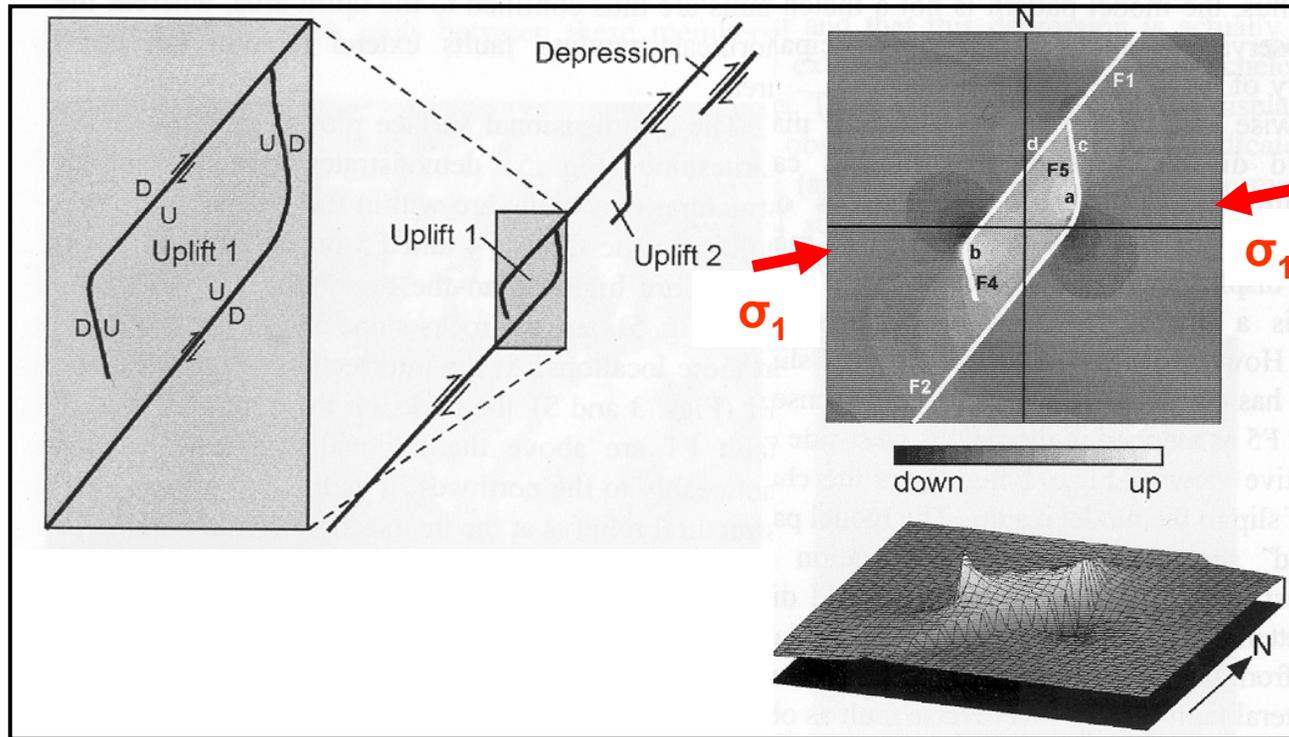
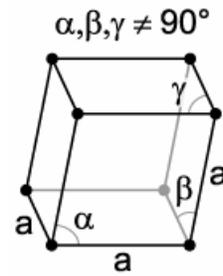


Origin and development of plains-type folds

Merriam (2005)

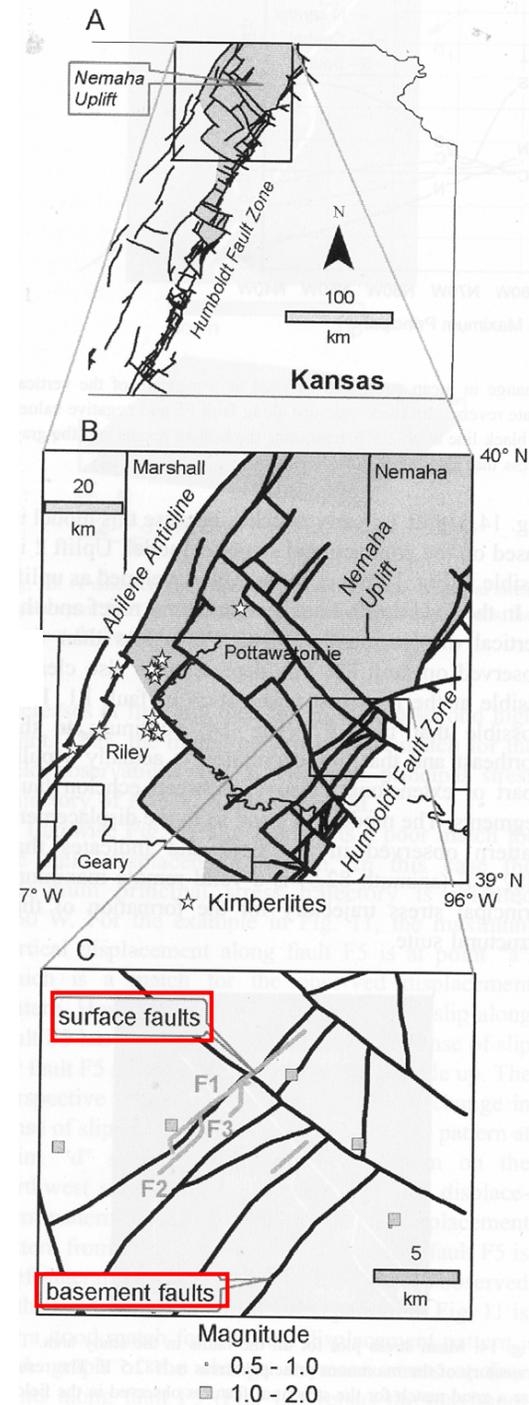


Kinematic model and simulation for fault-bounded rhombohedral blocks (*contractional stepover*) along Nemaha Uplift related to right lateral motion on NE-SW trending fault system and σ_1 trending at N82.5°E.

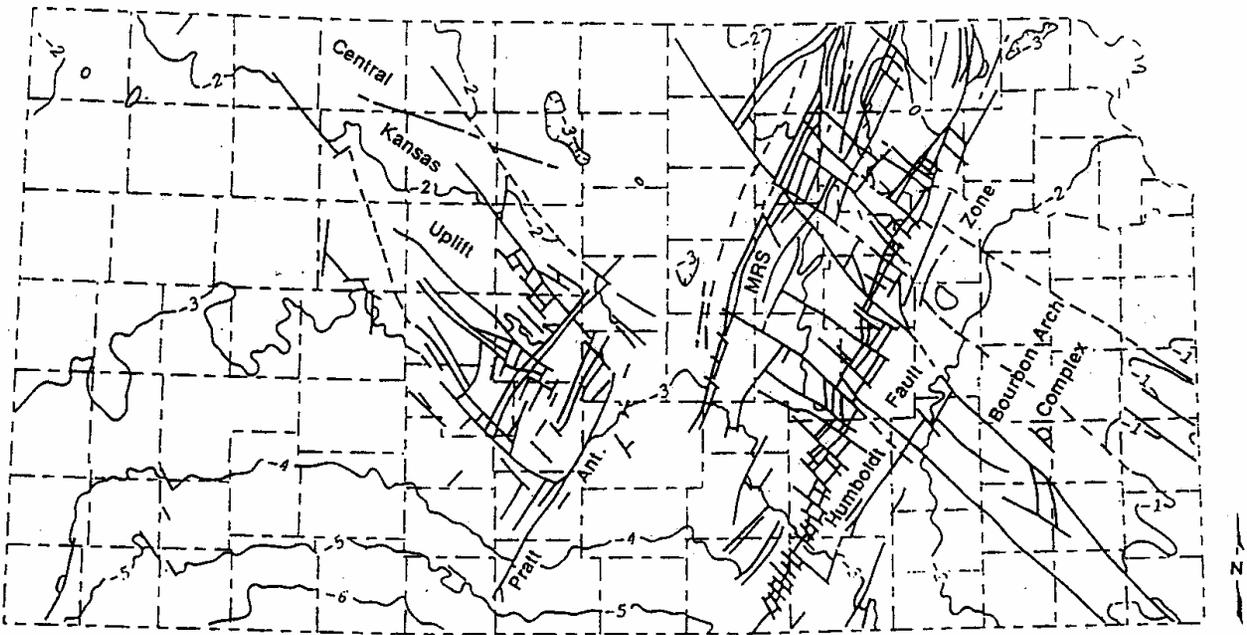


Laramide reactivation of basement faults in Pottawattamie County with N82.5°E σ_1

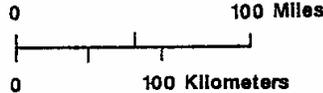
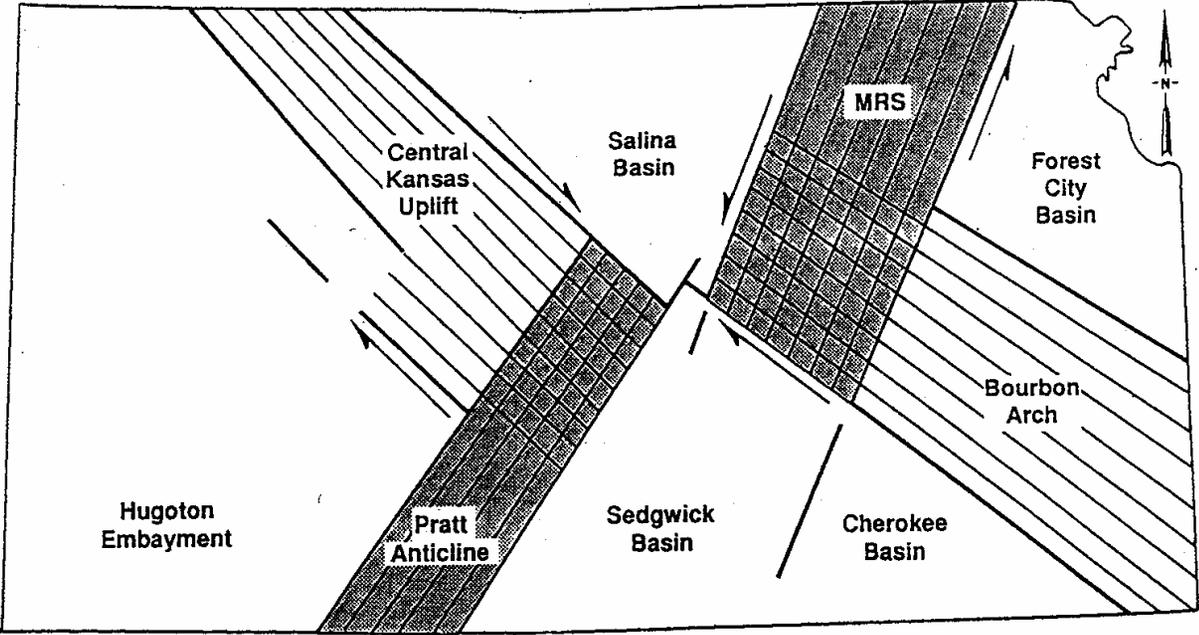
Ohlmacher and Berendsen (2005)



**Configuration
of the
Precambrian
Surface
(well based)**



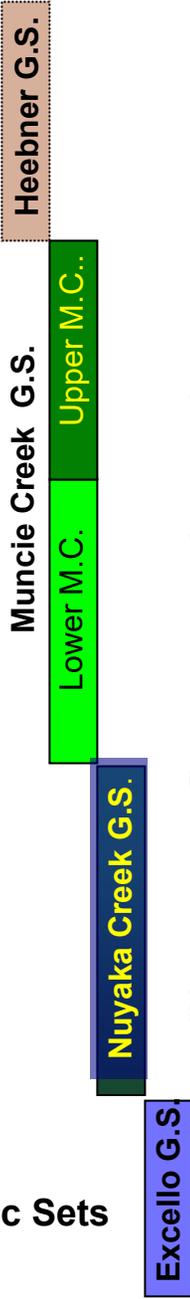
**Precambrian
structural
domains
and strain
behavior –
wrench
faulting?**



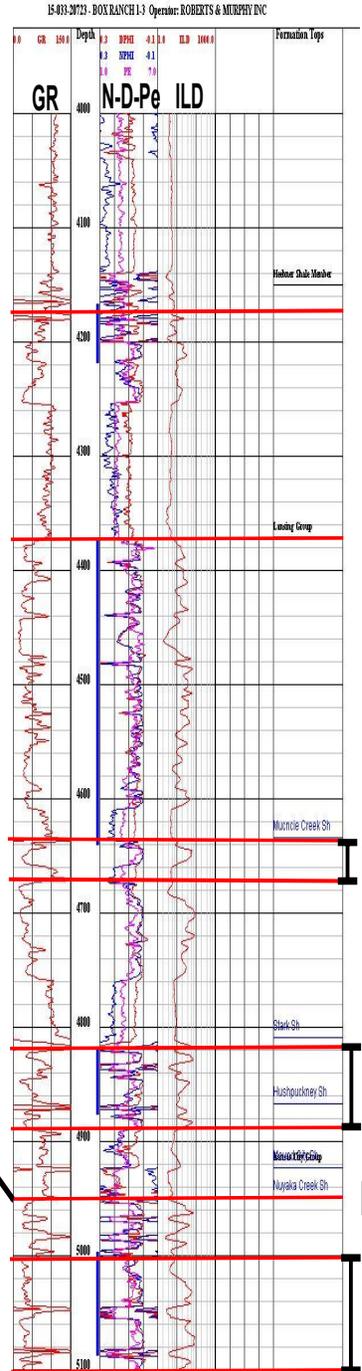
Forecasting rock properties -- Quantify segmentation of shelf and corresponding subsidence & tilting in context of deposition and diagenesis

- **Kinematic structural analysis –
(rates, magnitude, duration of
movement)**
- **Integrate with play and field
characterization**

G.S. = Genetic Sets



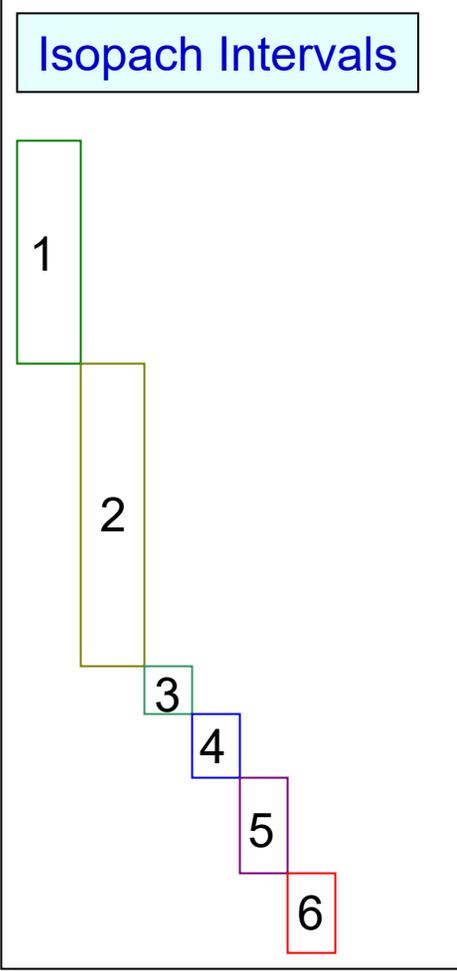
Upper Pennsylvanian



Heebner Shale
Lansing Group
Dewey Limestone
Swope Limestone
Marmaton Group
Ft. Scott Limestone

Well: Roberts & Murphy
Box Ranch #1-3
se se Sec. 3-35S-20W
Comanche Co., KS
- (southern shelf)

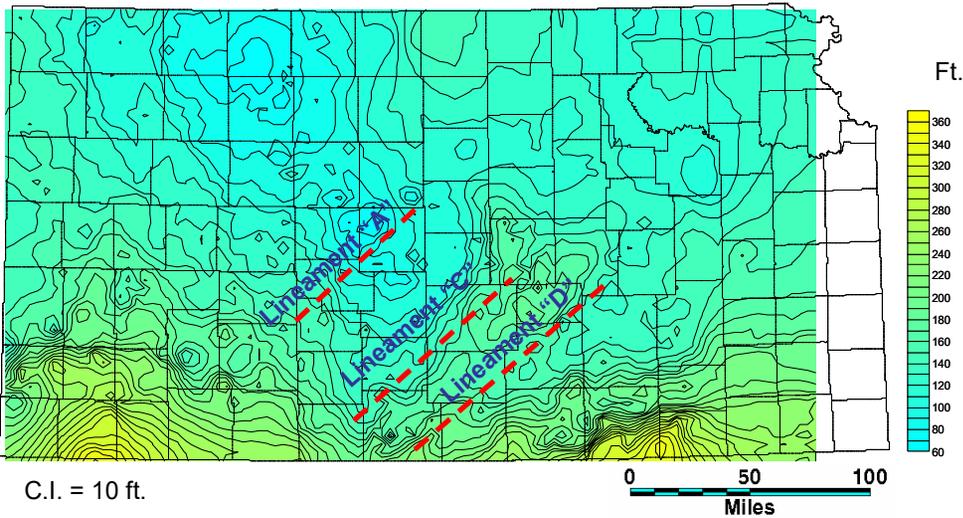
Recognizing Temporally Distinct Structural Reactivation - Map Comparison



100 ft.

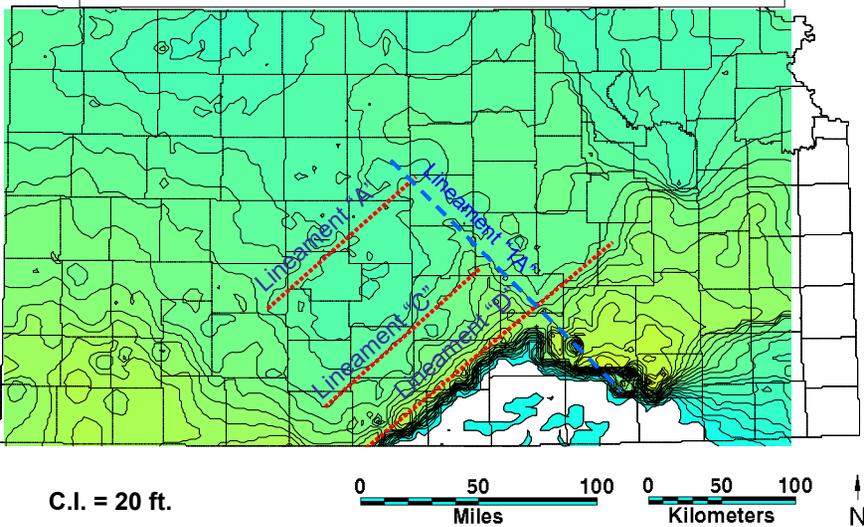
Statistical Regionalized Analysis Using 6 Upper Pennsylvanian Isopachous Intervals in Kansas (circa 1997)

Most of Nuyaka Creek 3rd-order Genetic Set

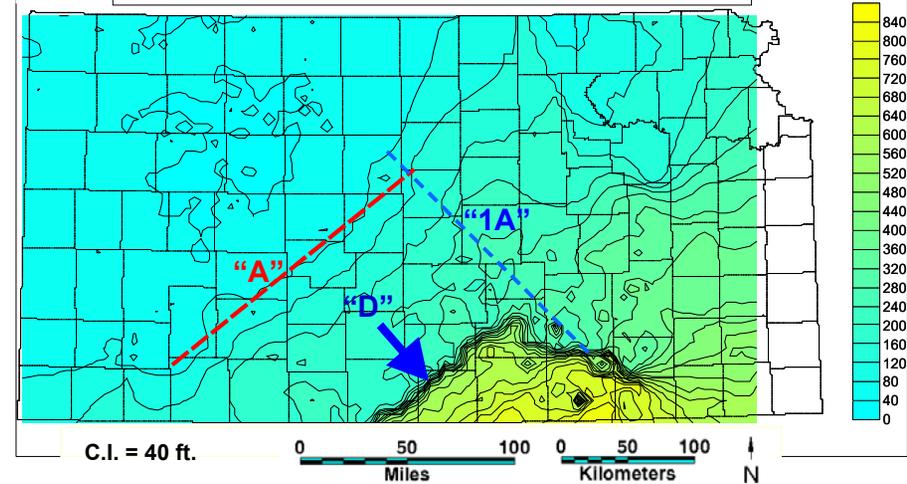


Lineaments on isopachs of 3rd order depositional sequences reflect differential subsidence and tilting toward Anadarko & Arkoma foreland basins

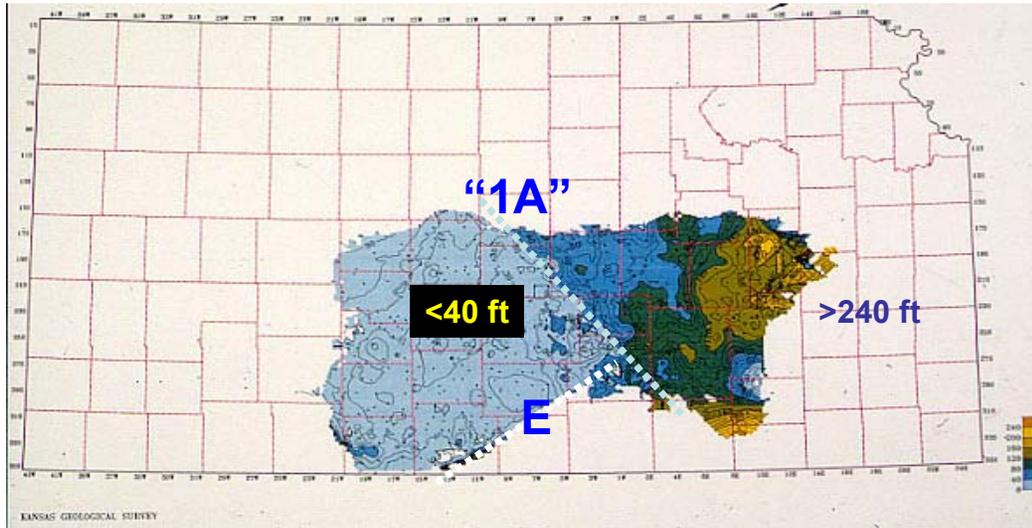
Lower Portion of Muncie Creek 3rd-order Genetic Set



Upper Portion of Muncie Creek 3rd-order Genetic Set



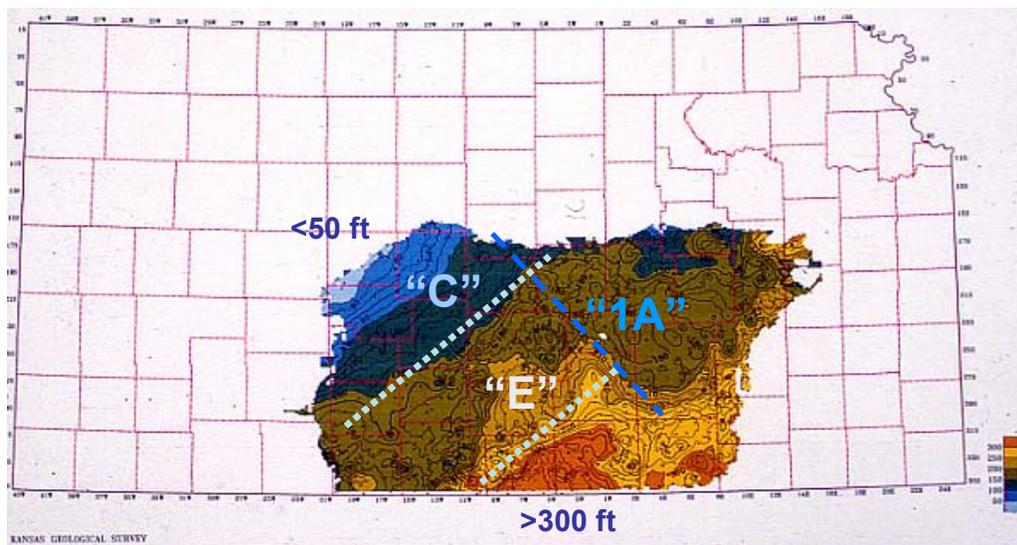
Isopach map of Top of Lansing Group to Top of Haskell Limestone



Watney et al (1995)

- Apparent differential subsidence between two structural blocks along light blue dashed line, "1A". Lansing bank margin is line "E".
- Eastern block of thick strata in lower Douglas and Pedee Groups contain Tonganoxie paleovalley developed in eastern Kansas

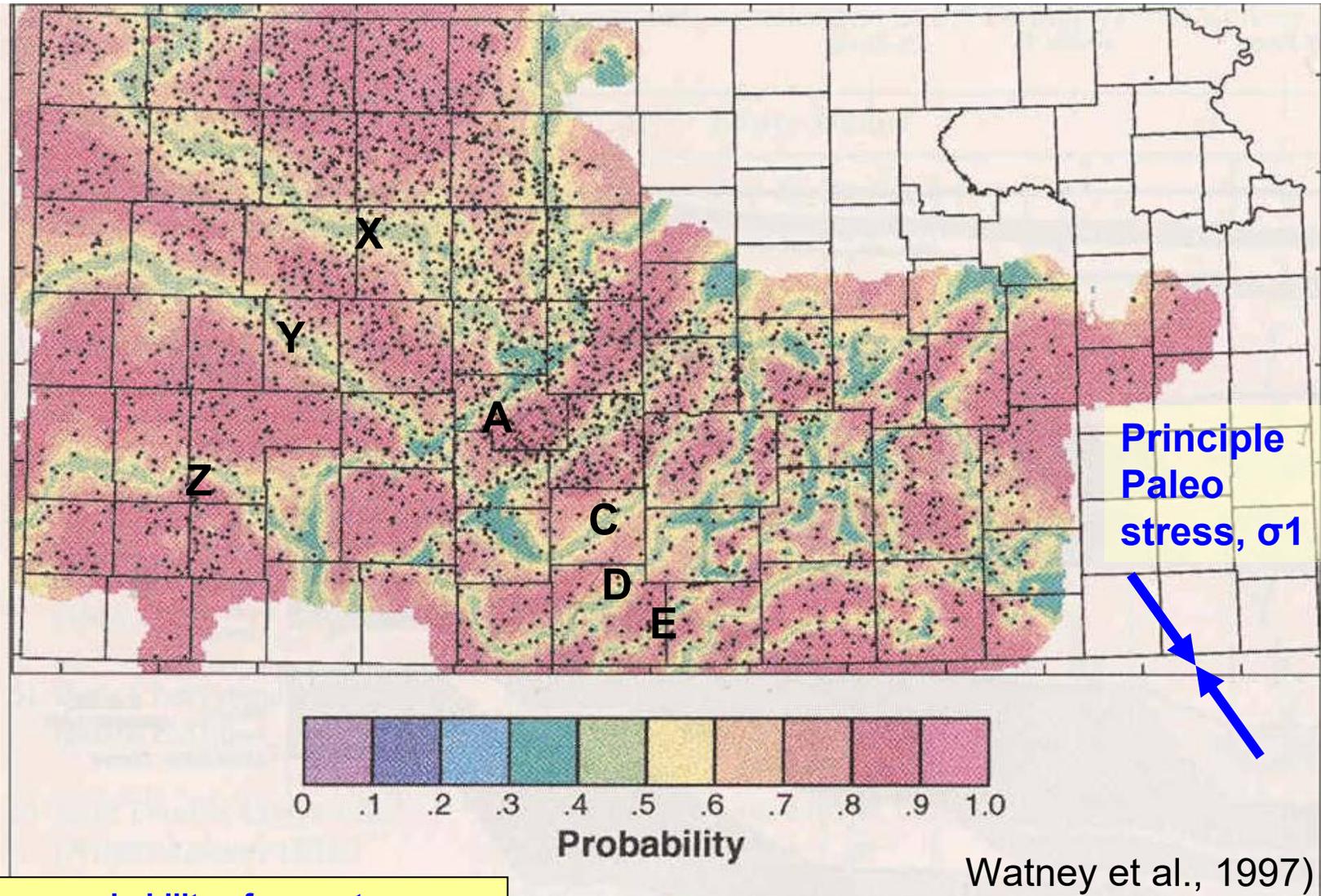
Isopach map of base of Haskell Limestone to base of Heebner Shale



Watney et al (1995)

- Dramatic change in thickness/sediment accommodation patterns from underlying interval
- Infer northeast-trending structural breaks on lineaments "C" and "E" and subdued "1A".

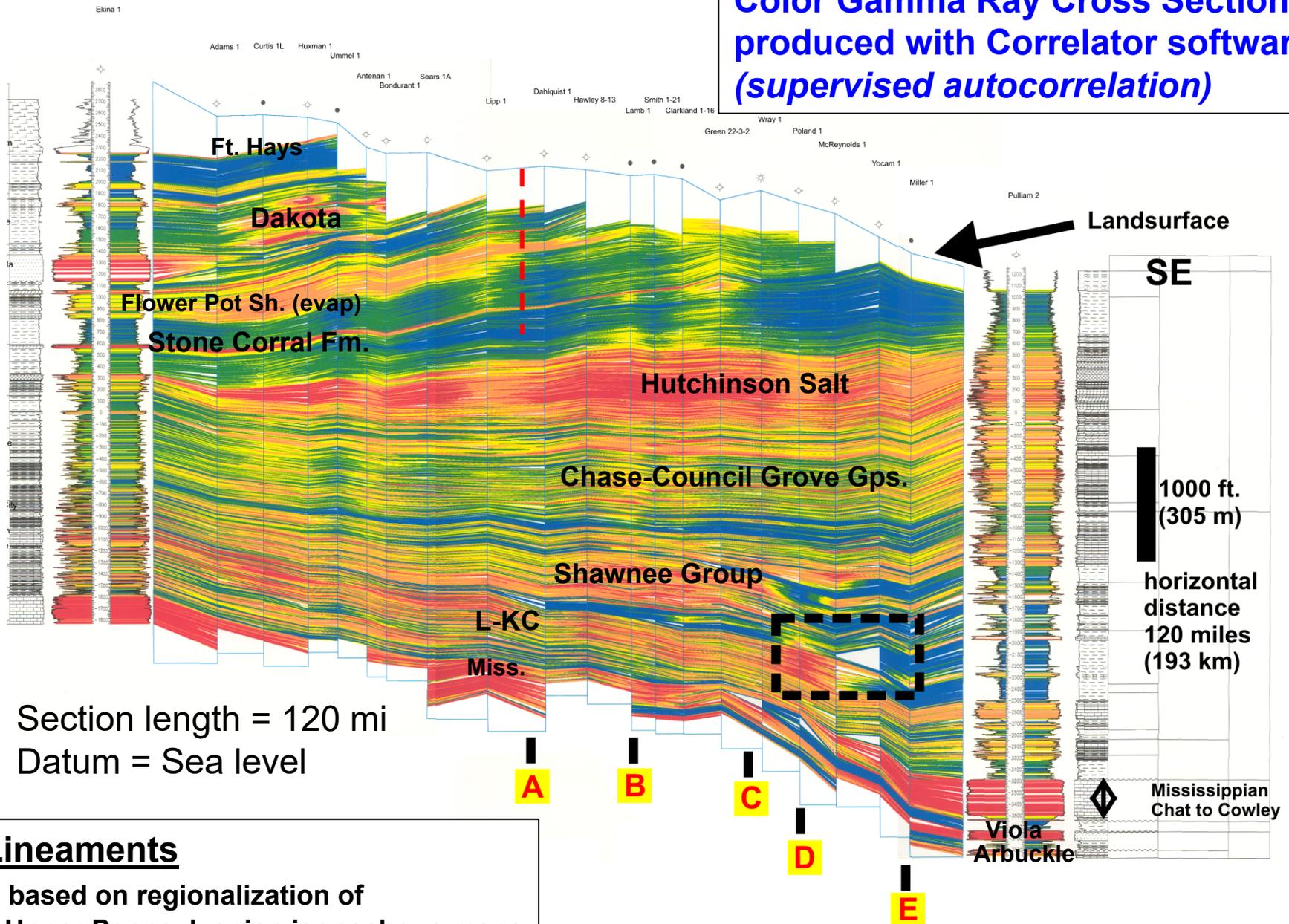
Areas of similar **Upper Pennsylvanian cycle** thicknesses separated by narrow structural transition zones



Maximum probability of correct classification in the assigned group, for 15 regions. Contour interval is $p = 0.10$



Color Gamma Ray Cross Section produced with Correlator software (supervised autocorrelation)



Section length = 120 mi
Datum = Sea level

Lineaments

- based on regionalization of
Upper Pennsylvanian isopachous maps

Watney et al. (1999)

Reds & Yellows = Carbonates, Evaporites, Sandstones
Blue = Shales

Vertical exaggeration: 500X
Shale content, fraction 0-1

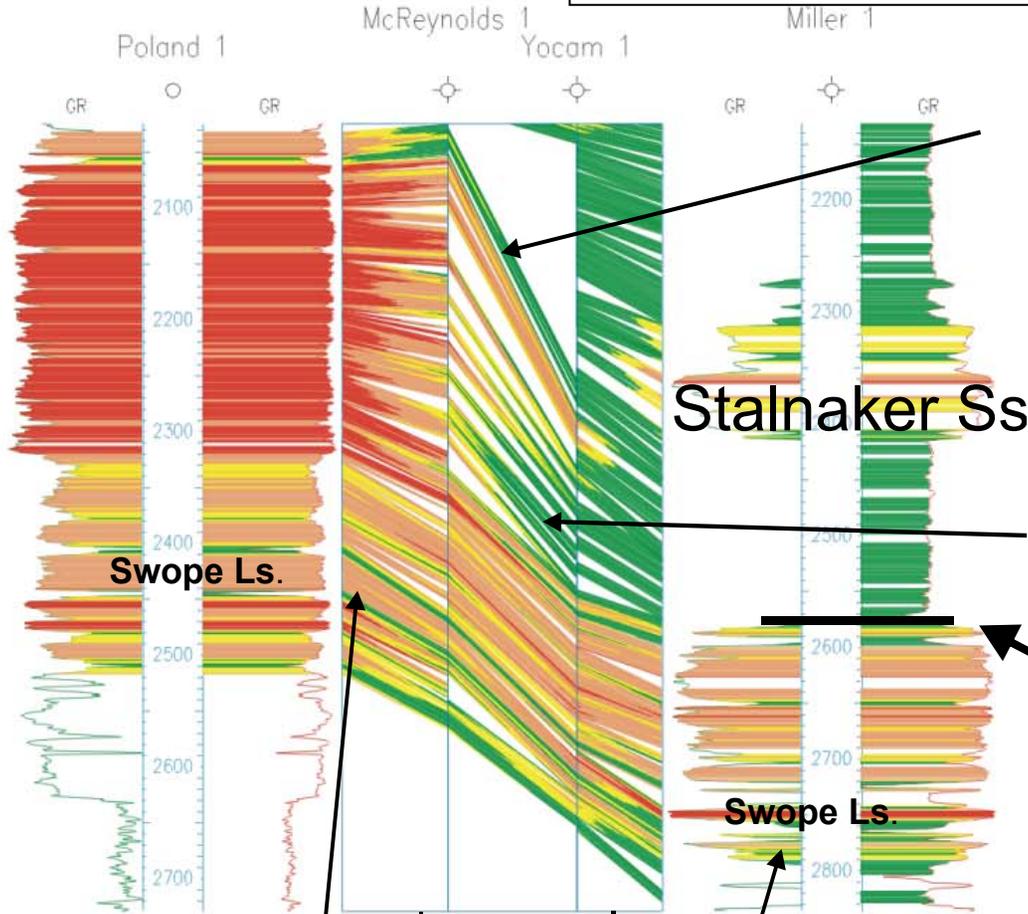
Pennsylvanian

Color Gamma Ray Cross Section using Correlator software (Olea, 1989)
Datum: sea level

Set T	Genetic Unit
Muncie Creek Genetic Set	Douglas
	Springhill
	Merriam _n
	Farley _y
	Argentine
Nuyaka Creek Genetic Set	Iola
	Quivira _l
	Wea _l
	Stark _l
	Hushpuckney _K
	Mound City _L
	Nuyaka Creek

Mapped

Mapped



Stalnaker Ss

Swope Ls.

Swope Ls.

backstepping and forward stepping 4th-order cycles

backstepping surface – base of sequence set

D

E

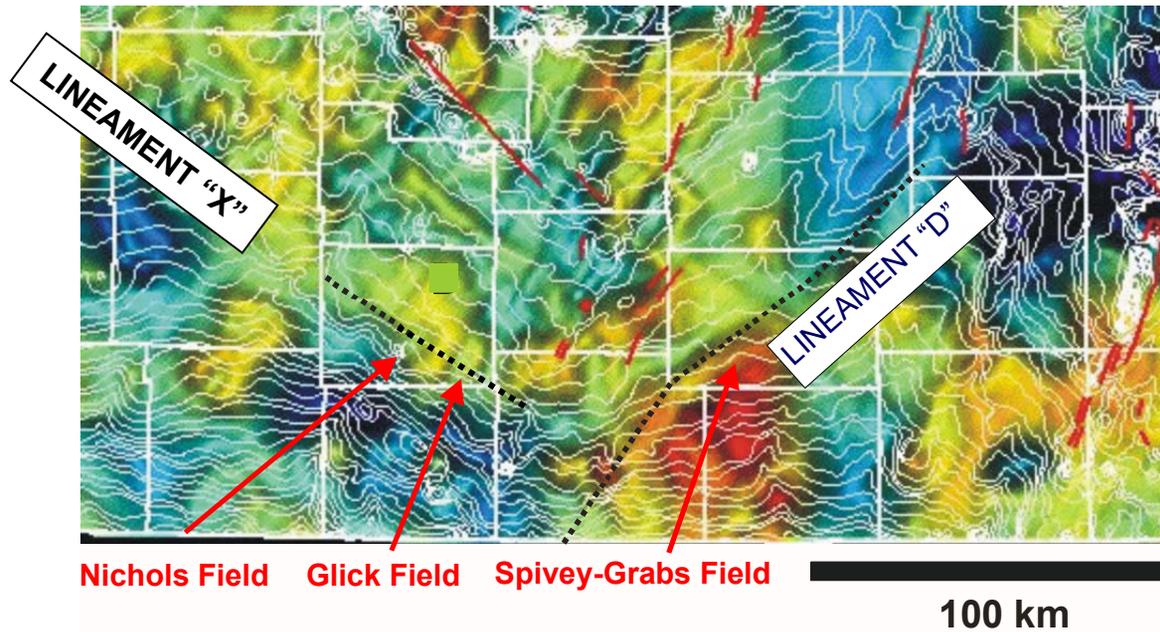
Lineament “D” defines shelf margin during Upper Pennsylvanian Muncie Creek Genetic Set

Swope Ls. undergoes distinct condensation southward across “D” lineament

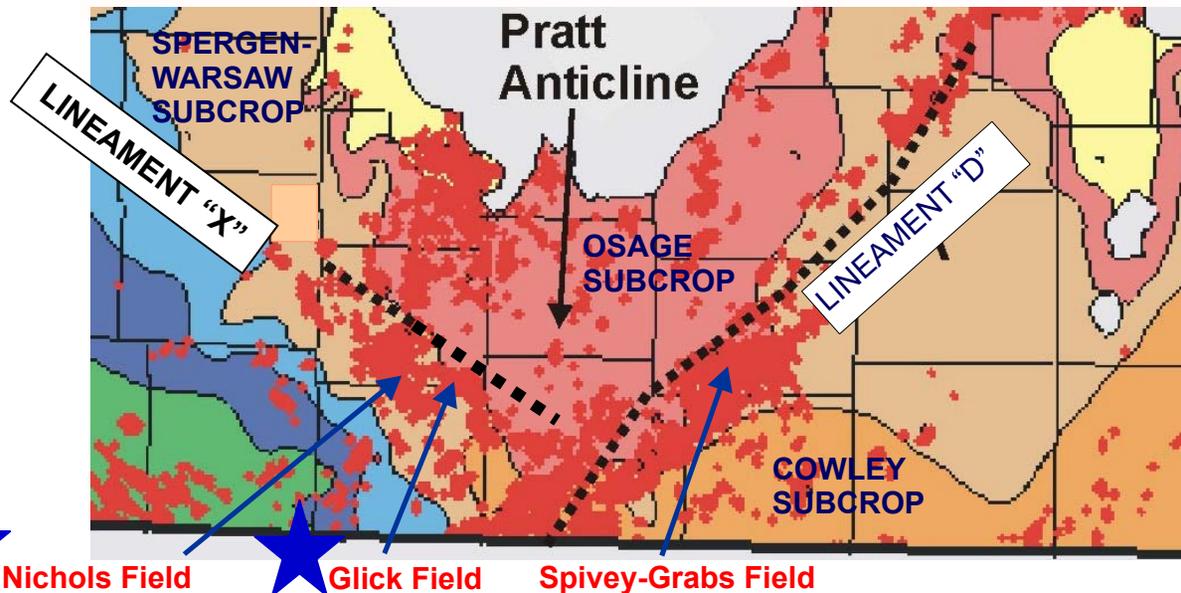
200 ft

5 miles

Total Magnetic Field Intensity

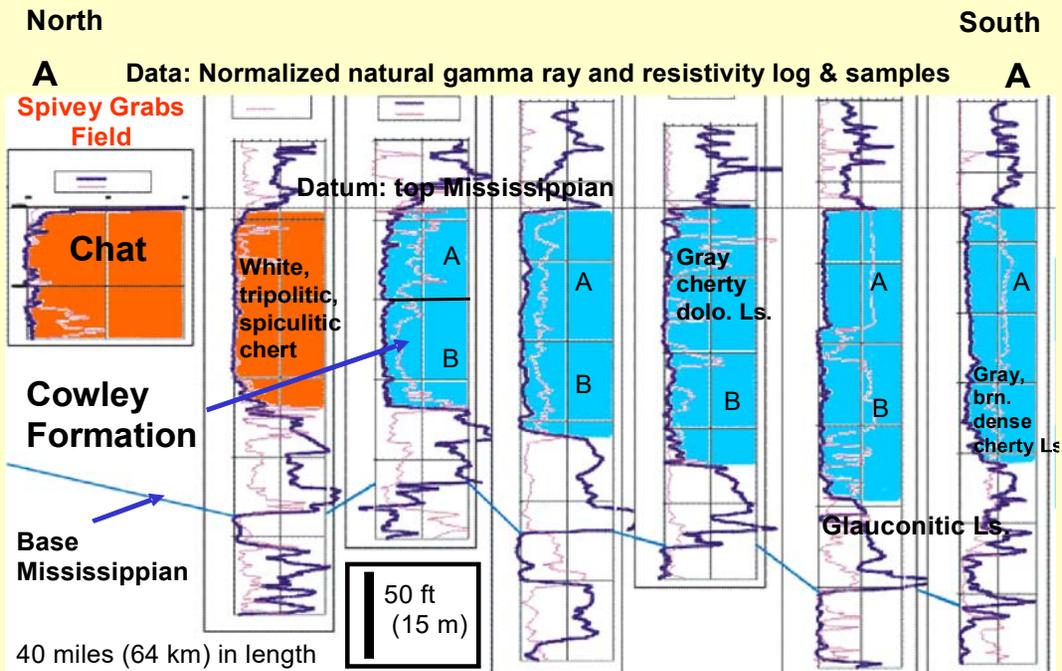


Basal Pennsylvanian Subcrop



Examples

Pennsylvanian shelf edge and Mississippian shelf flexure In South-Central Kansas coincide with lineament “D”



Chat= low gamma ray & resistivity

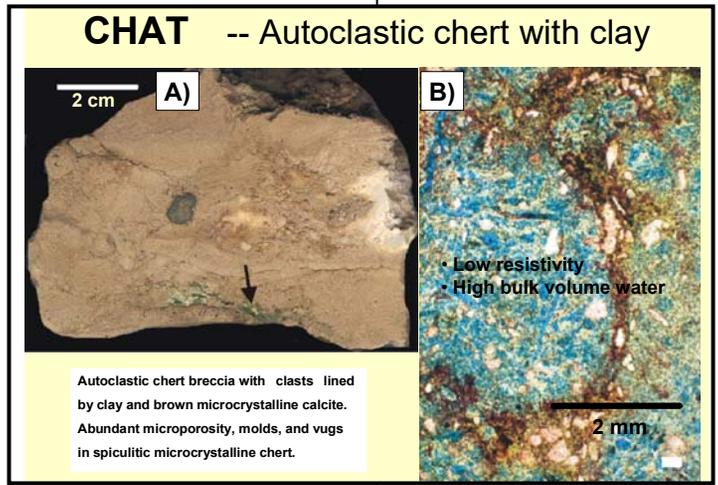
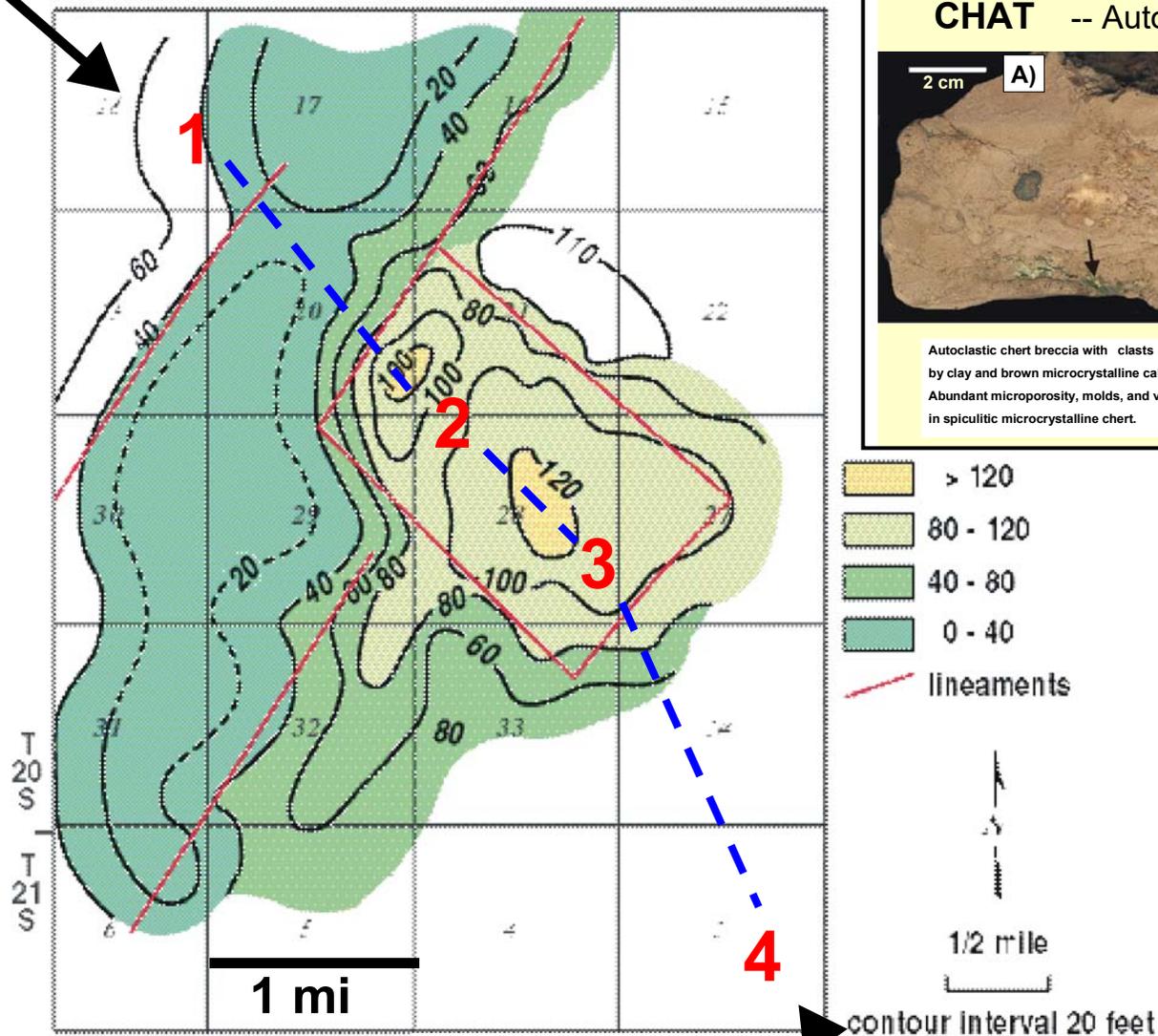
Cowley = low to moderate GR
moderate resistivity



Lineament “D” = landward limit of shelf margin, updip transition from Cowley Fm. to weathered “Chat”

line of section

Nichols Field - Residual Chert Thickness



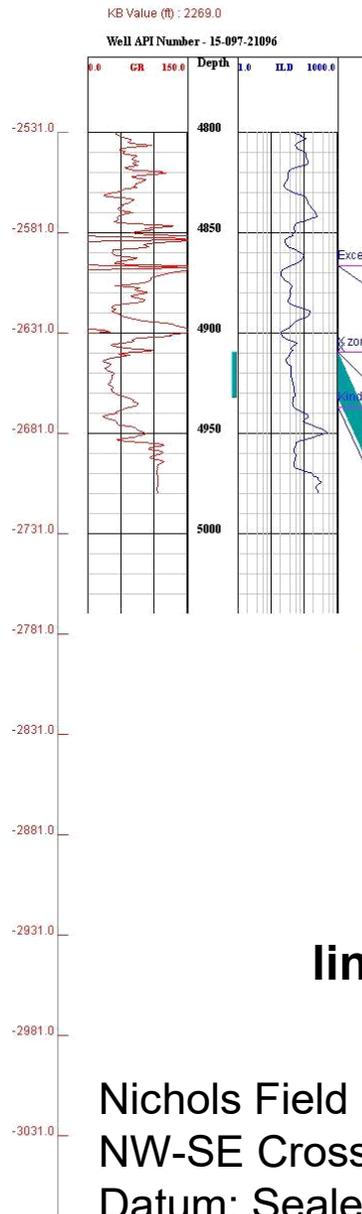
Modified from Zajic (1956)

line of section

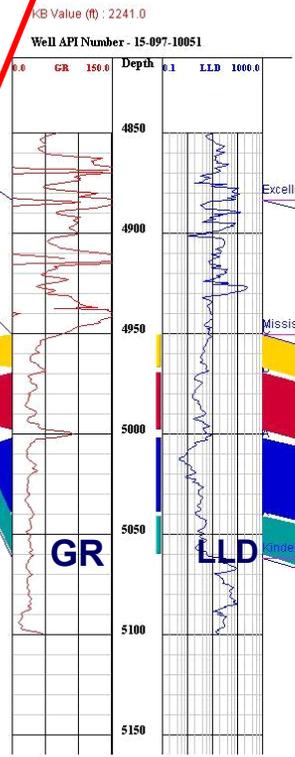
NW

1

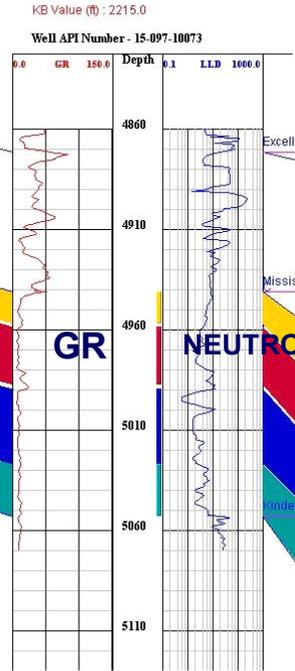
Erosional Truncation of Chat at PBU



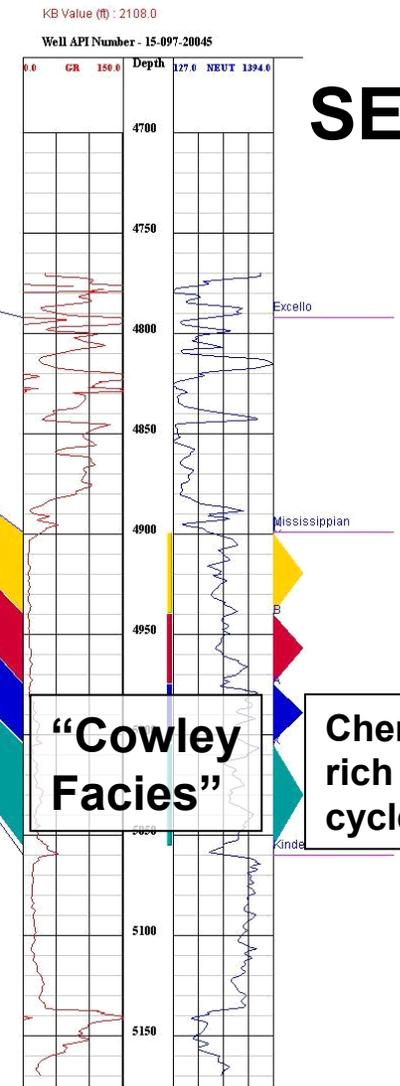
2



3



4



SE

lineament

lineament

“Chat” facies

“Cowley Facies”

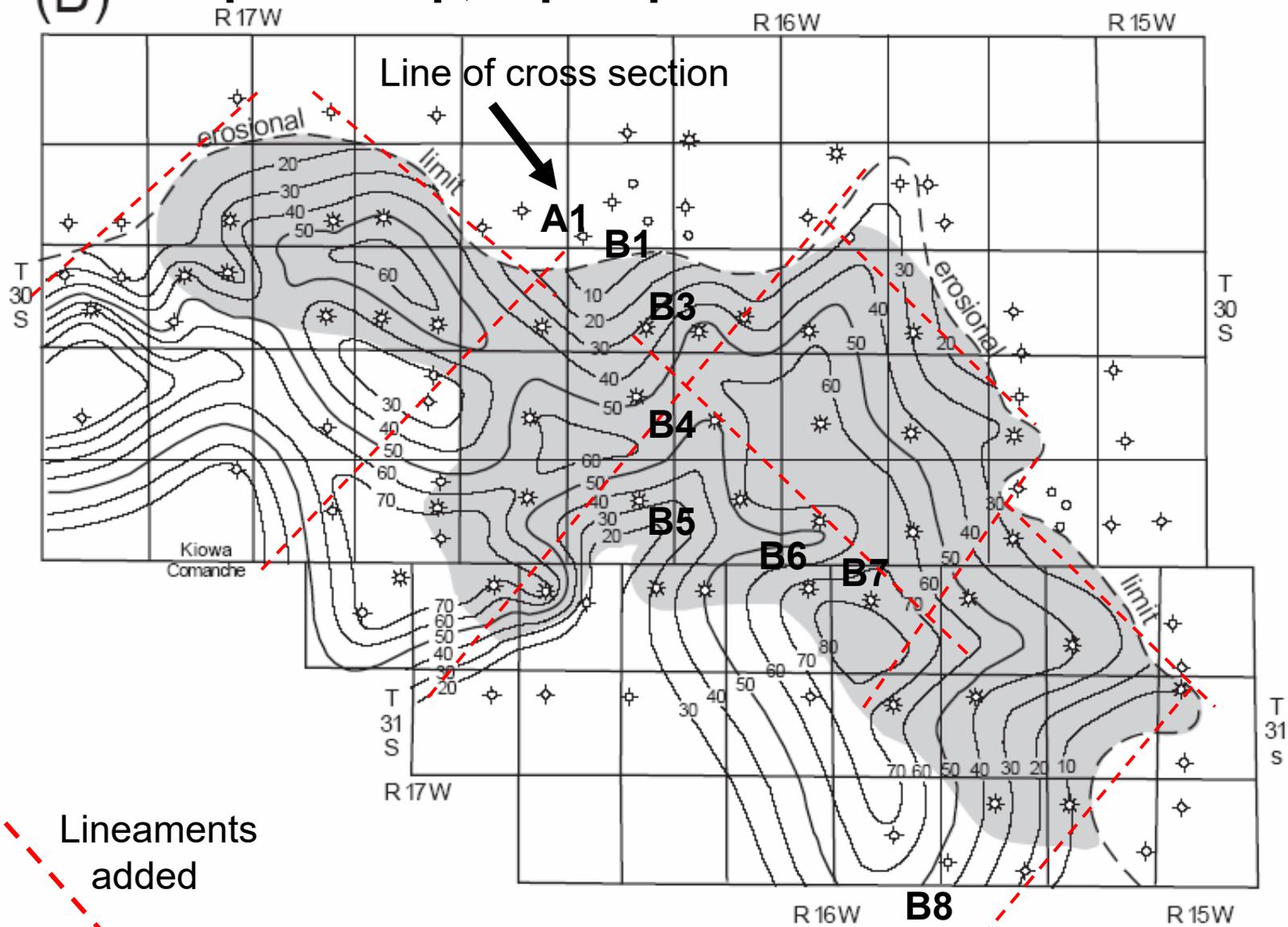
Chert-rich cycles

- X
- D
- C
- B
- A

Nichols Field
NW-SE Cross Section
Datum: Sealevel
Section length: ~5 mi.

Glick Field

(B) Isopach map, top of productive chat reservoir



Montgomery et al. (1998),
After Rogers et al. (1995)

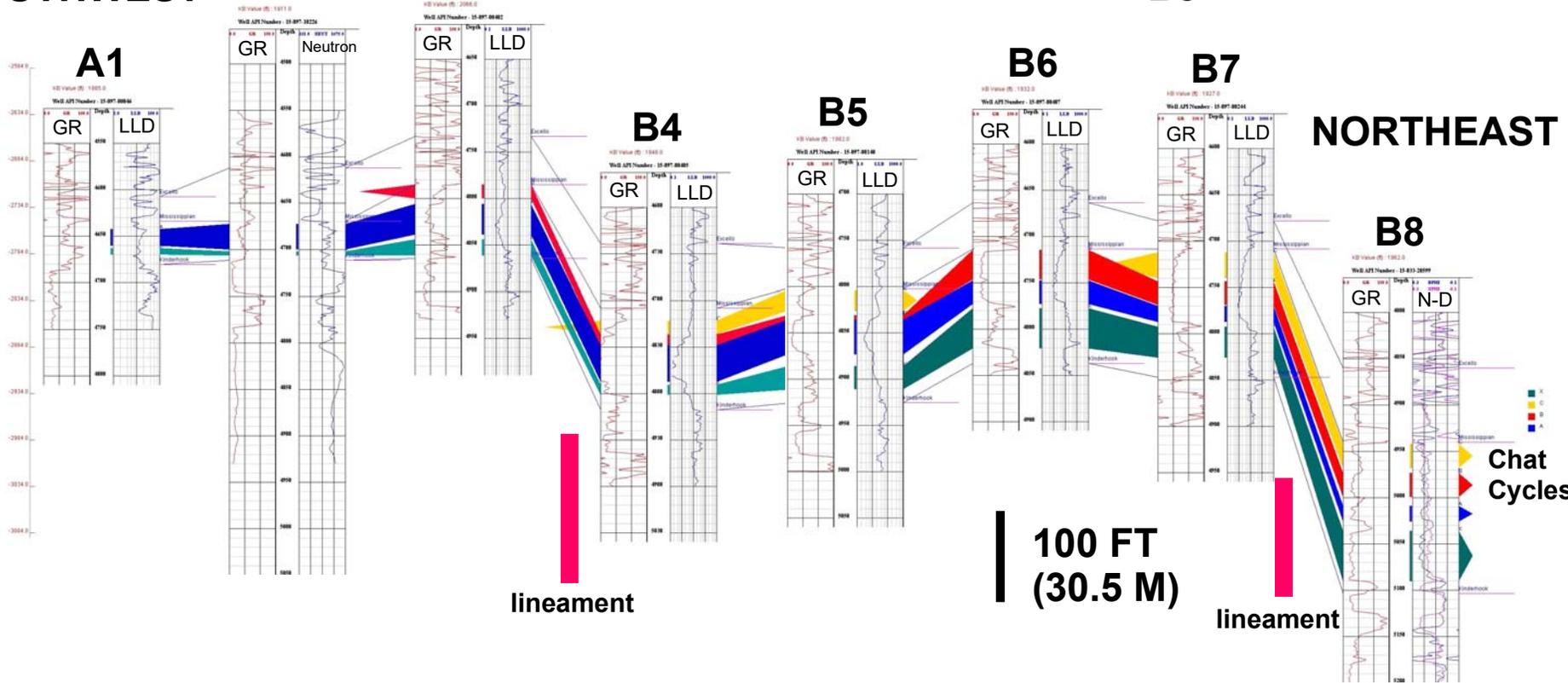
Structural cross section through chat Reservoir in Glick Field

SOUTHWEST

B1

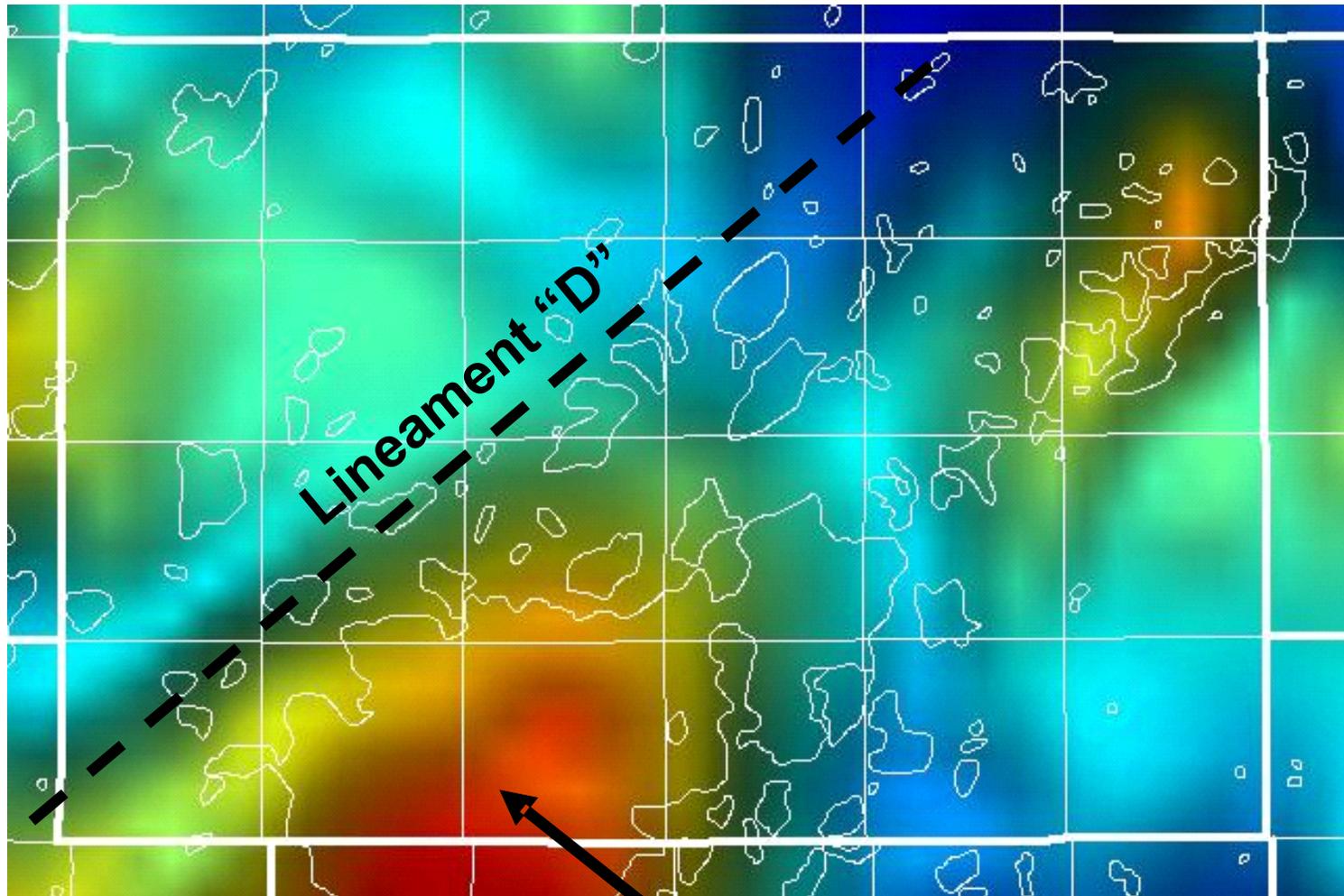
B3

B8



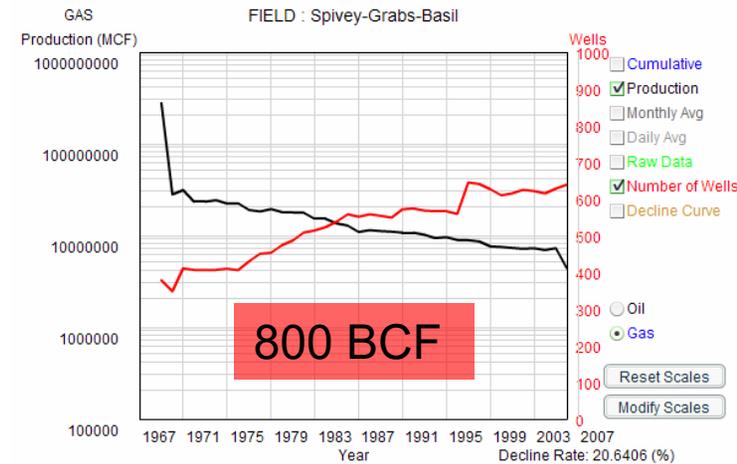
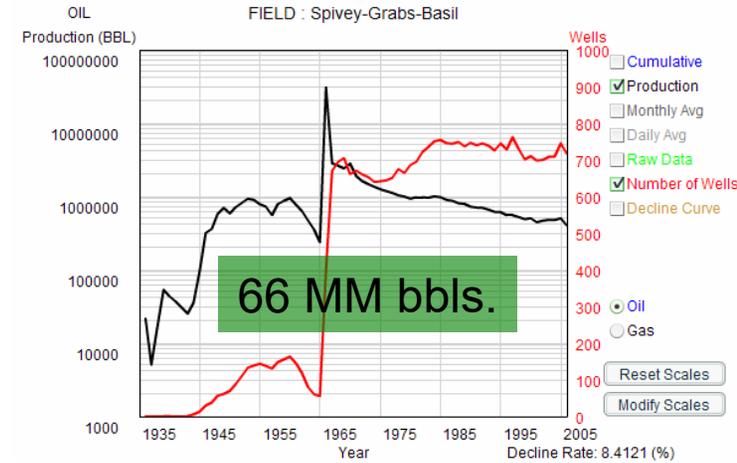
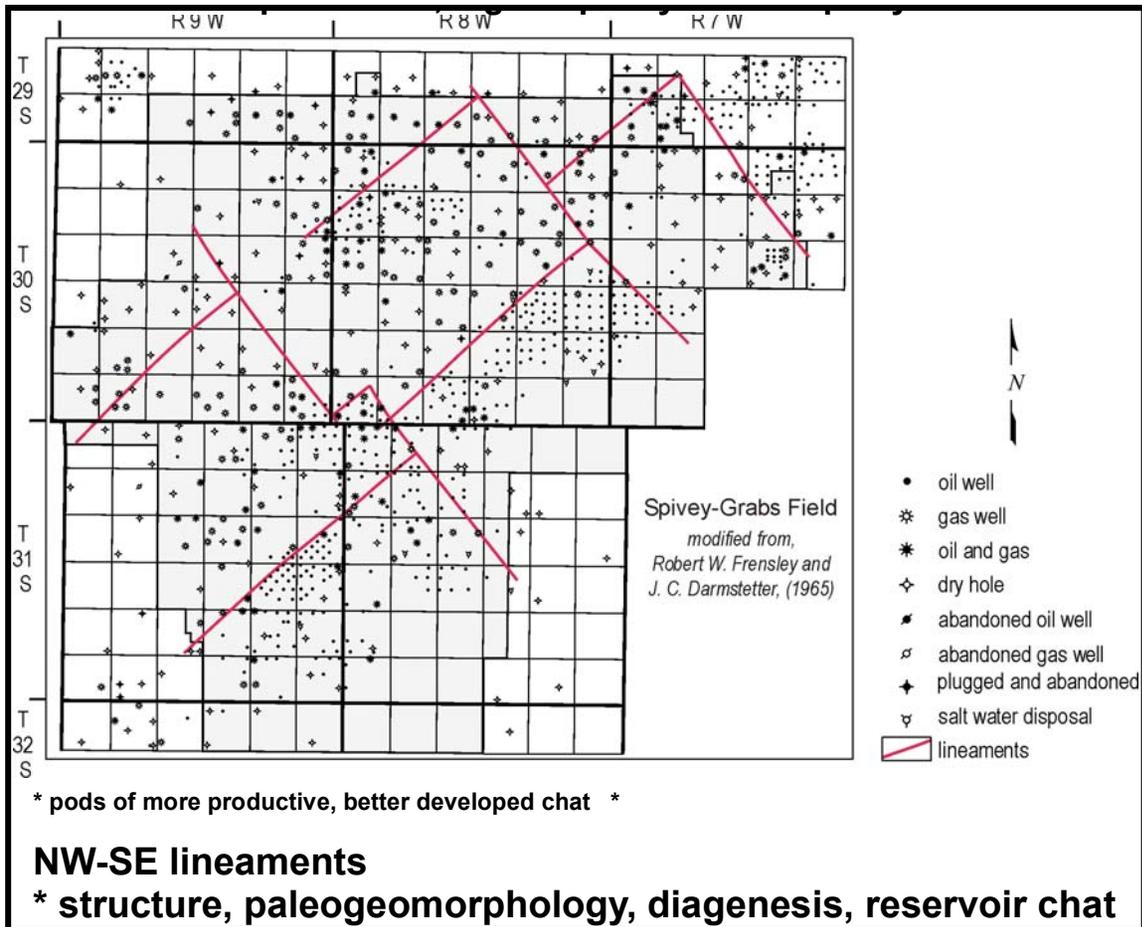
No horizontal scale, section length ~9 mi
Equidistant wells

Magnetic Map, Kingman County

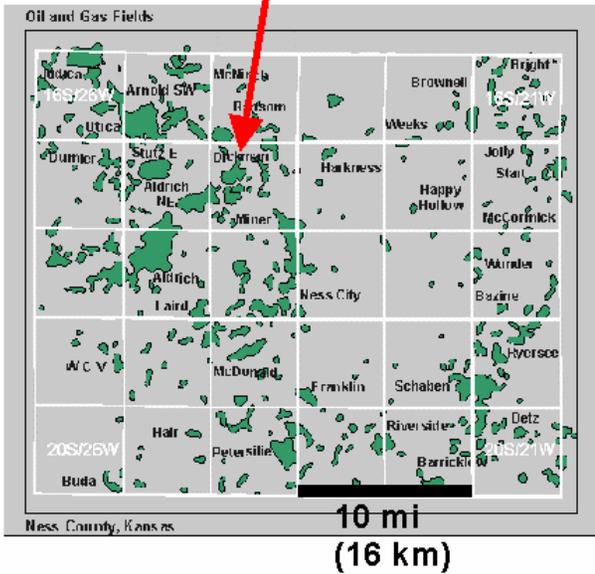
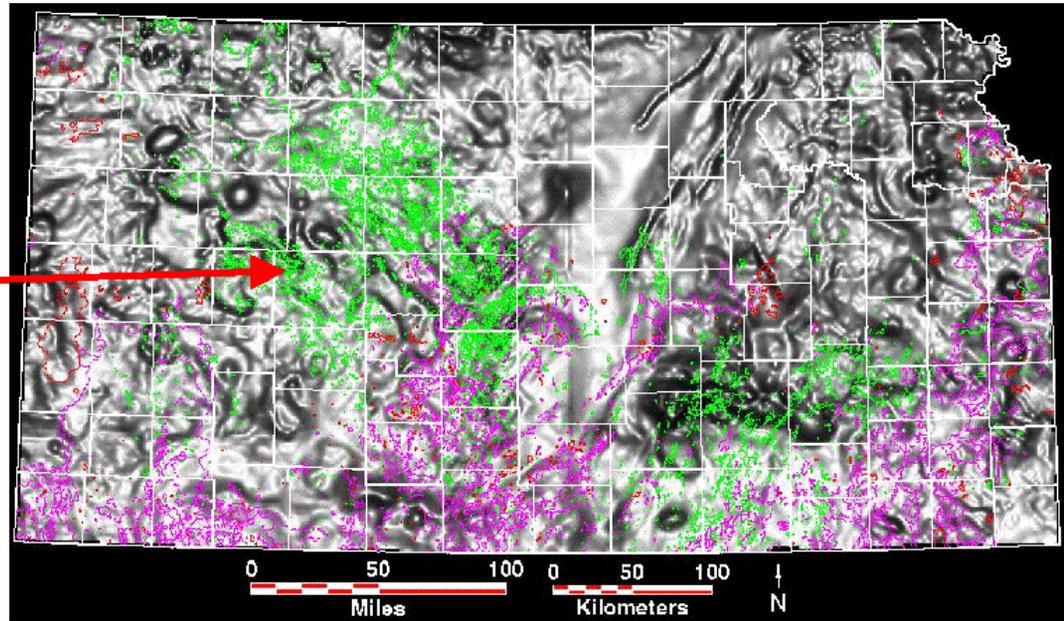
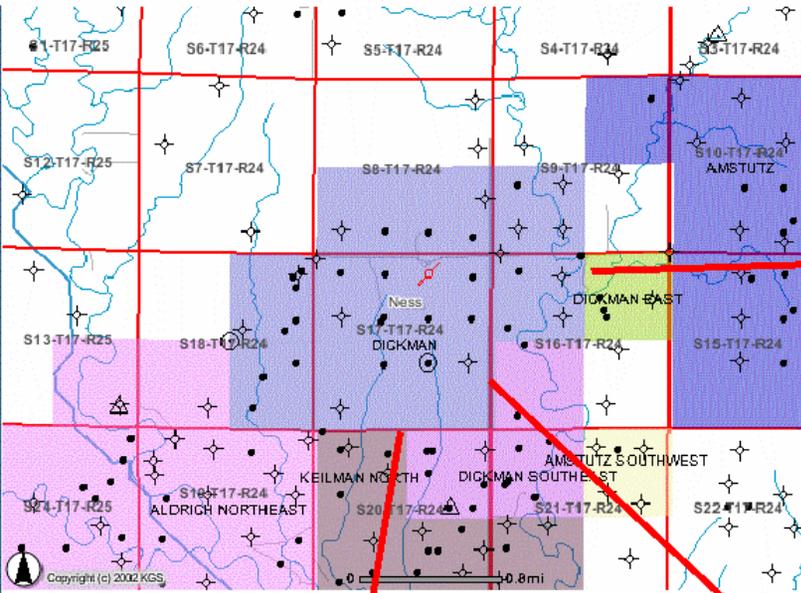


Spivey Grabs Field

Compartments of more highly productive chat In Spivey-Grabs-Basil Field Barber, Harper, and Kingman counties Kansas

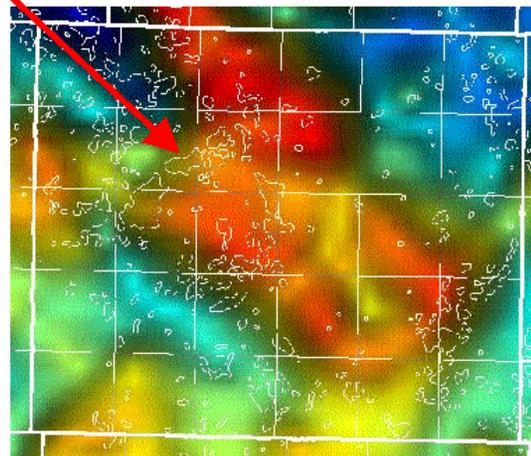


Dickman Field – Contemporaneous structural control on secondary pay in Ft. Scott Ls. (Desmoinesian oomoldic CO₃)

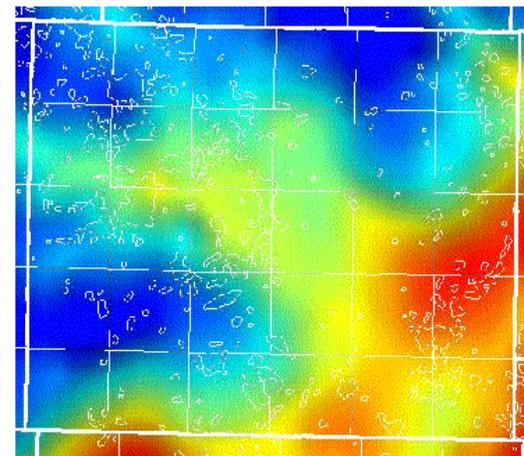


Magnetic Map, Ness County

Gravity Map, Ness County

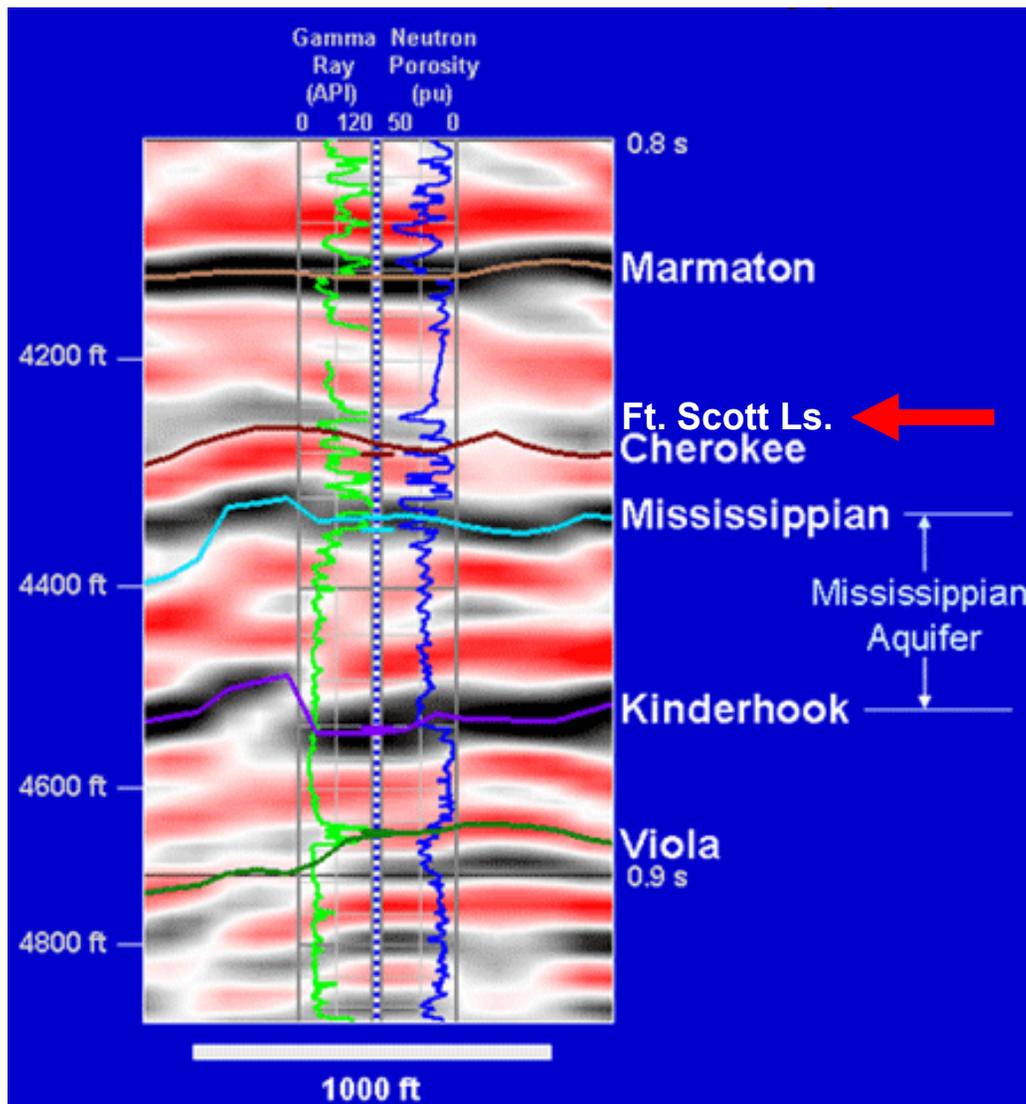


Strong NW-SE lineaments



10 mi
(16 km)

3-D seismic analysis of Mississippian and Middle Pennsylvanian reservoirs at Dickman Field, Ness County, Kansas



The top of the **Mississippian System (Warsaw Dolomite)** is a positive seismic reflection (black), corresponding to the boundary between Cherokee shales and Mississippian dolomite seen on the gamma ray log.

The top of the **Ft. Scott Limestone** is a small positive seismic reflection immediately above the Cherokee.

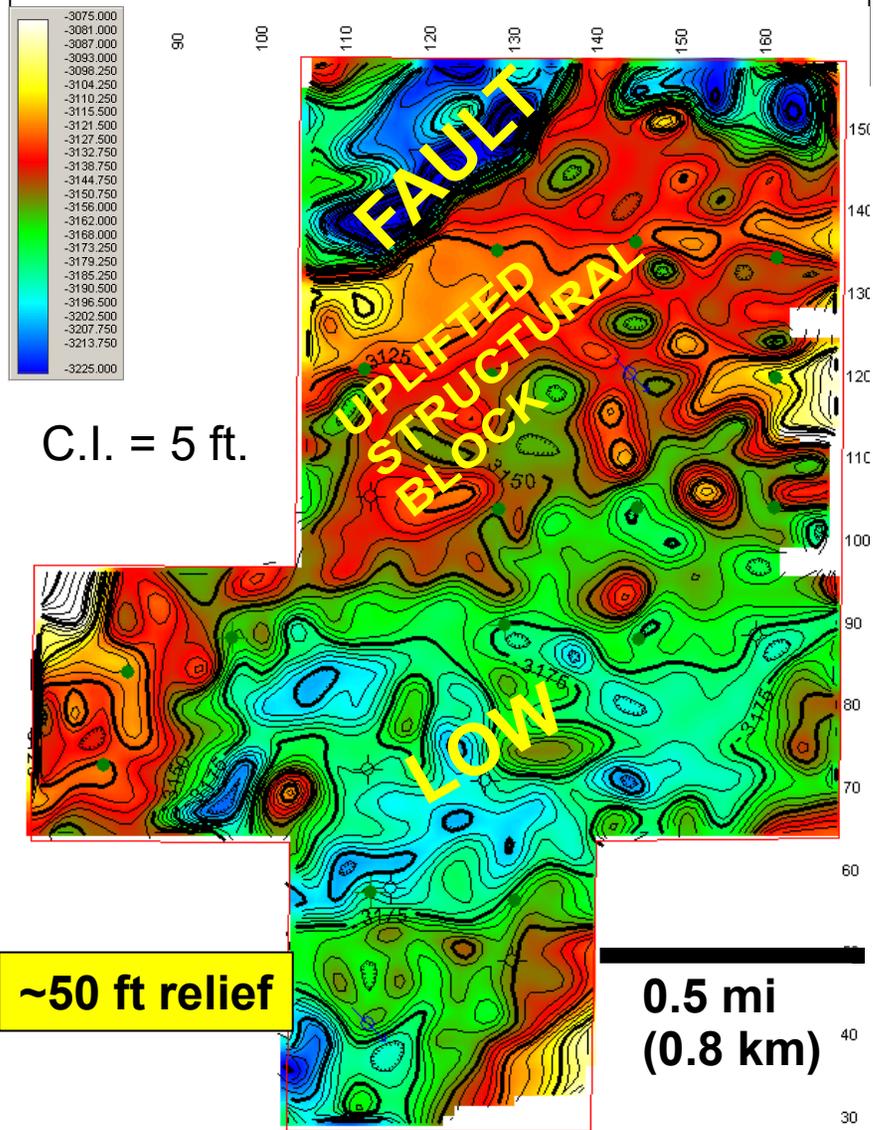
Nissen et al. (2005)

<http://www.kgs.ku.edu/PRS/publication/2004/2004-56/index.html>

Seismic data provided by
Grand Mesa Operating Co.

Basement Subsea Depth

(Estimated using 19,000 ft/s velocity below Top Miss)

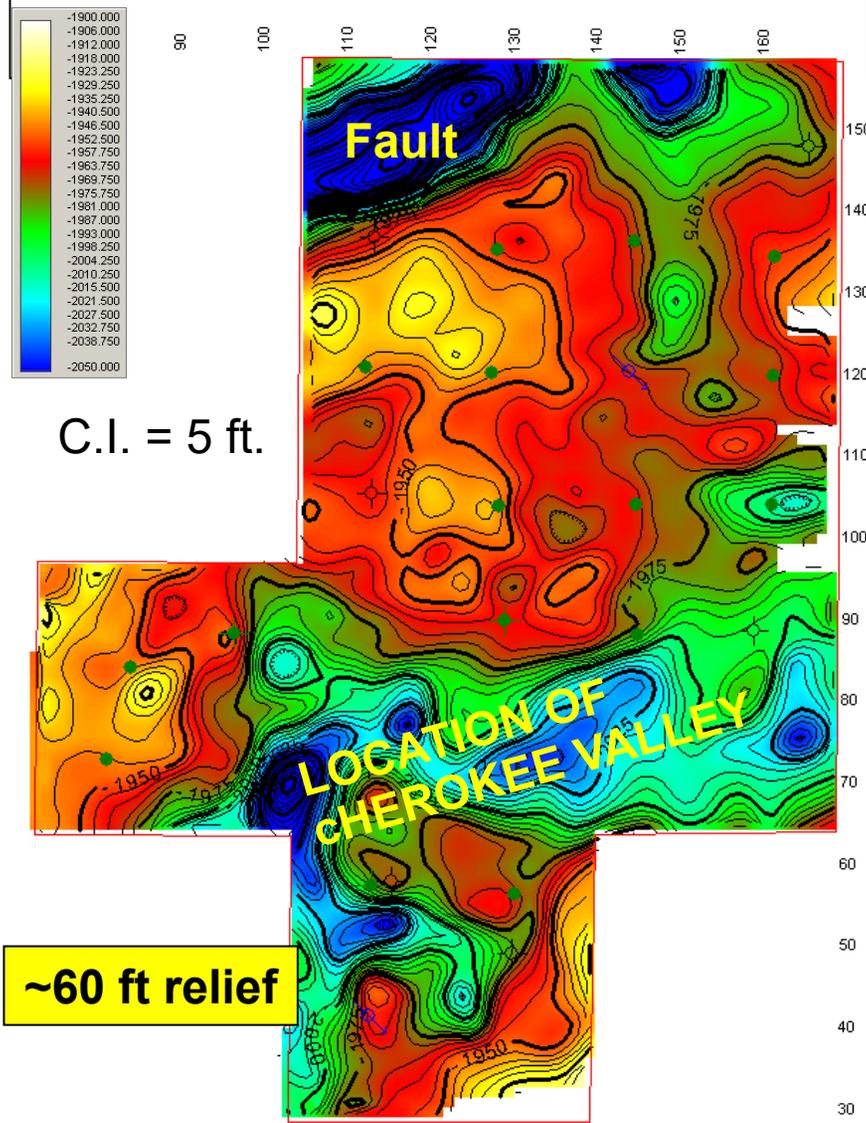


C.I. = 5 ft.

~50 ft relief

0.5 mi
(0.8 km)

Mississippian Subsea Depth

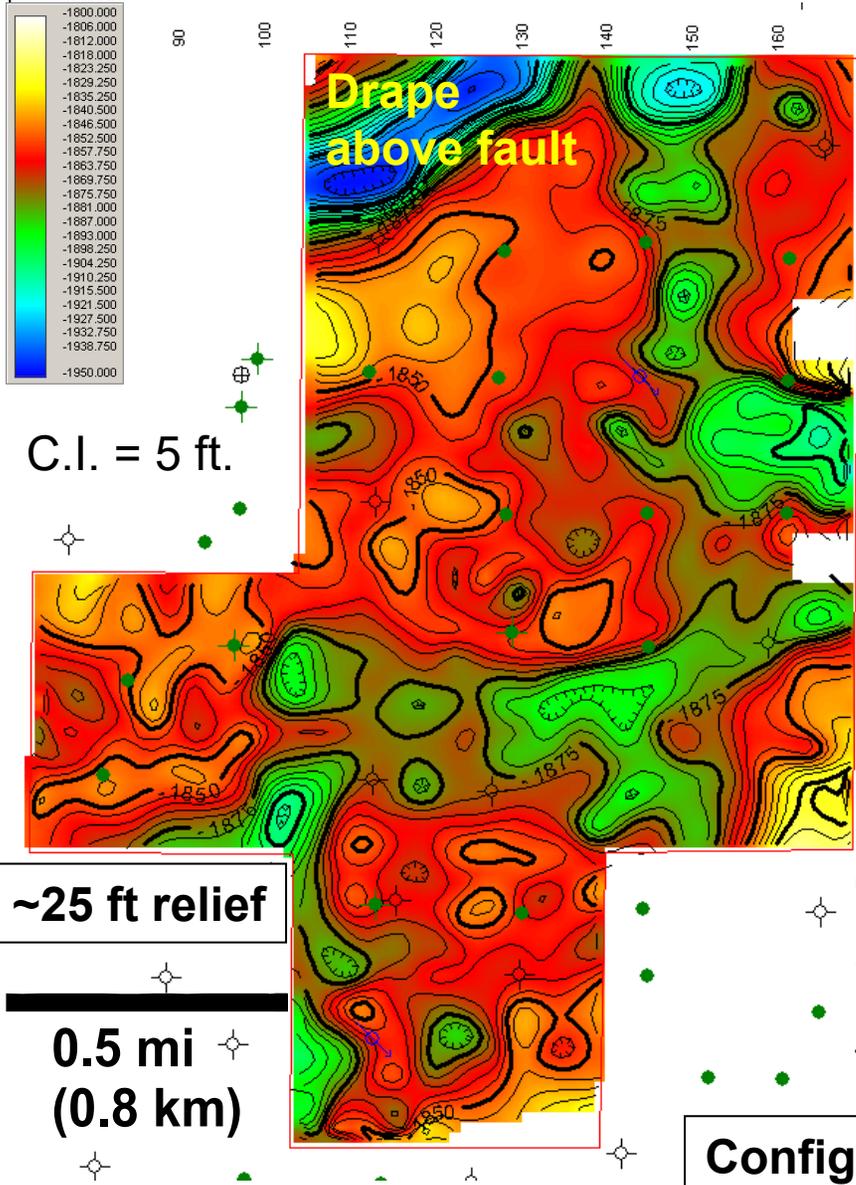


C.I. = 5 ft.

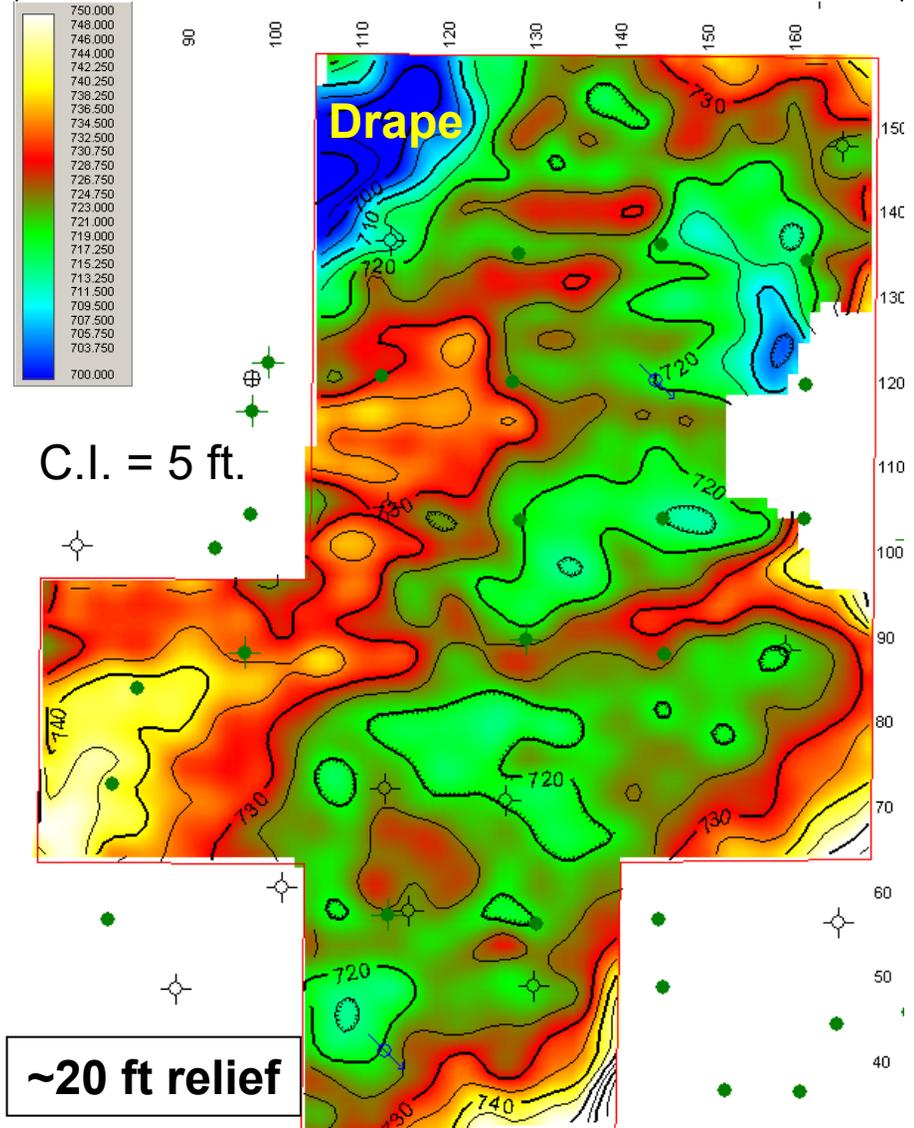
~60 ft relief

Cherokee paleovalley coincides with structural low on Precambrian surface

Fort Scott Subsea Depth

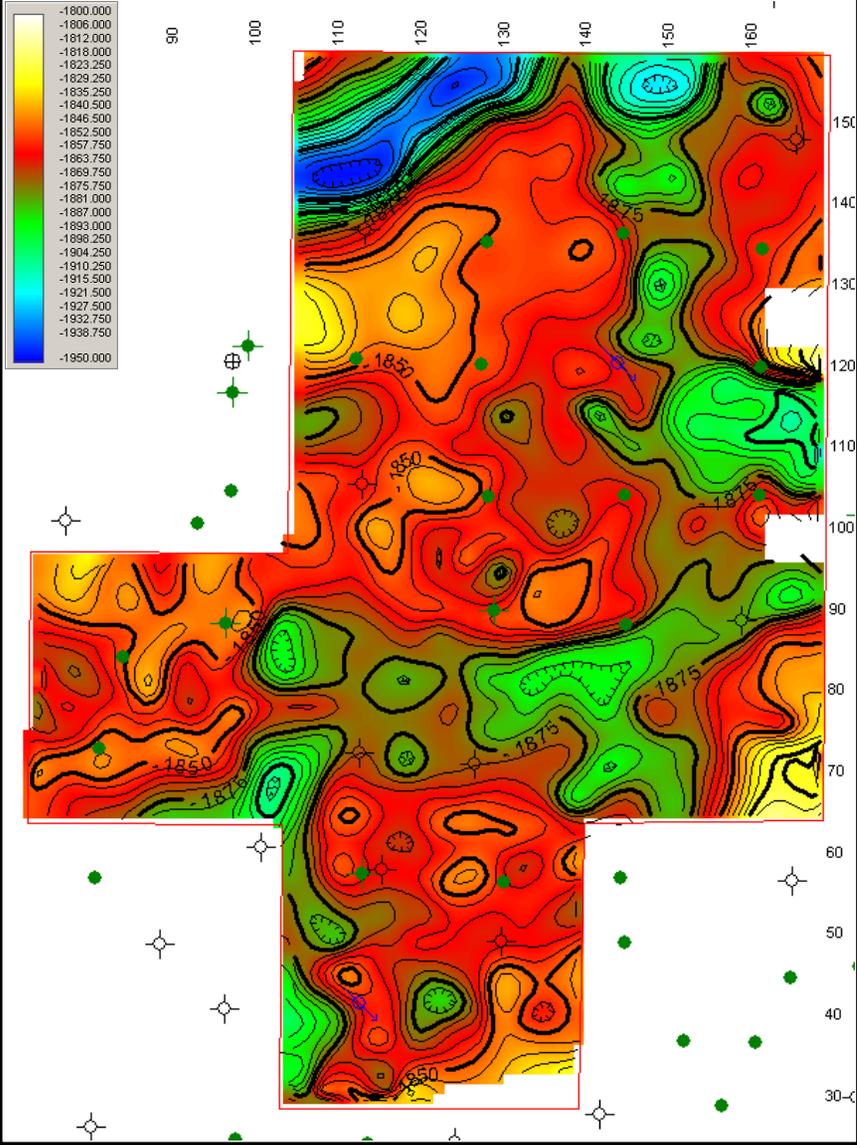


Stone Corral Subsea Depth

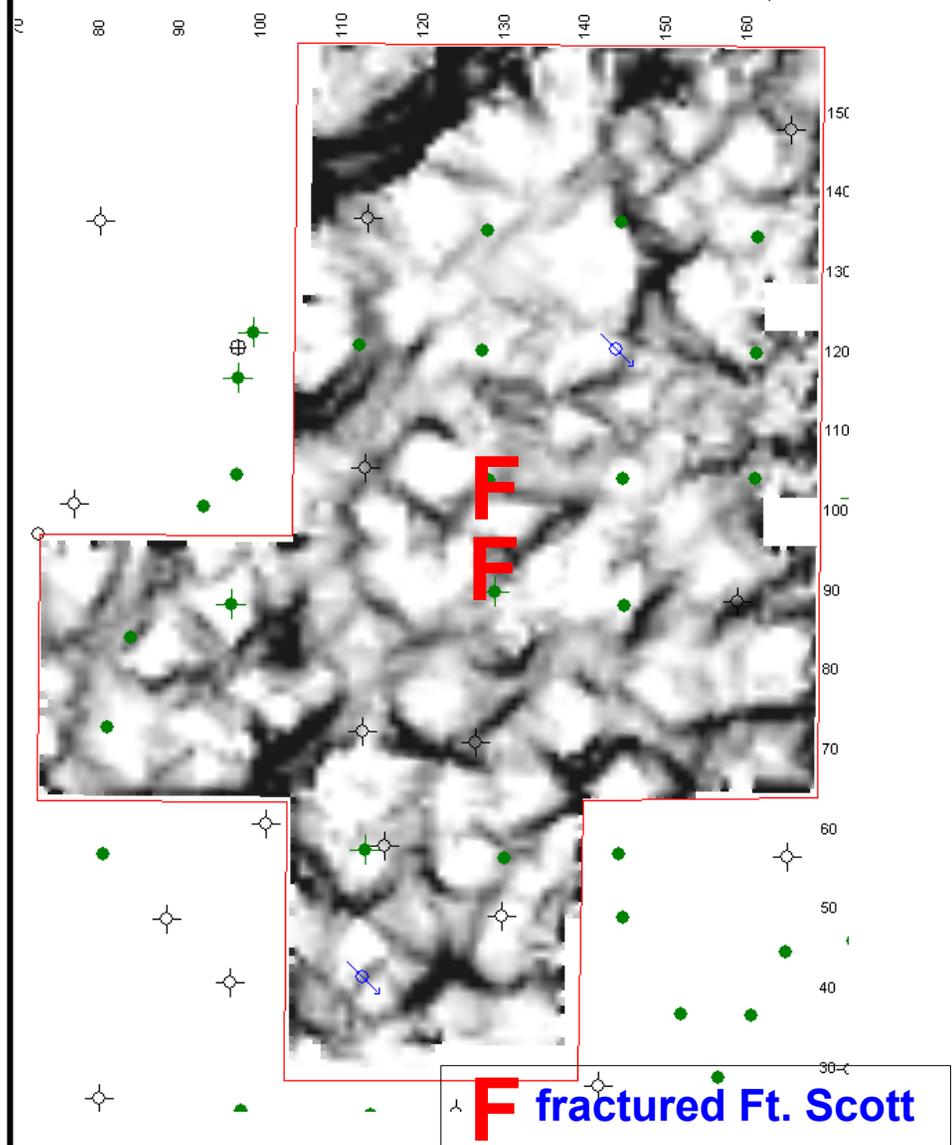


Configuration of L. Permian Stone Corral surface resembles Middle Pennsylvanian surface (1/2 mi lower in section)

Fort Scott Subsea Depth

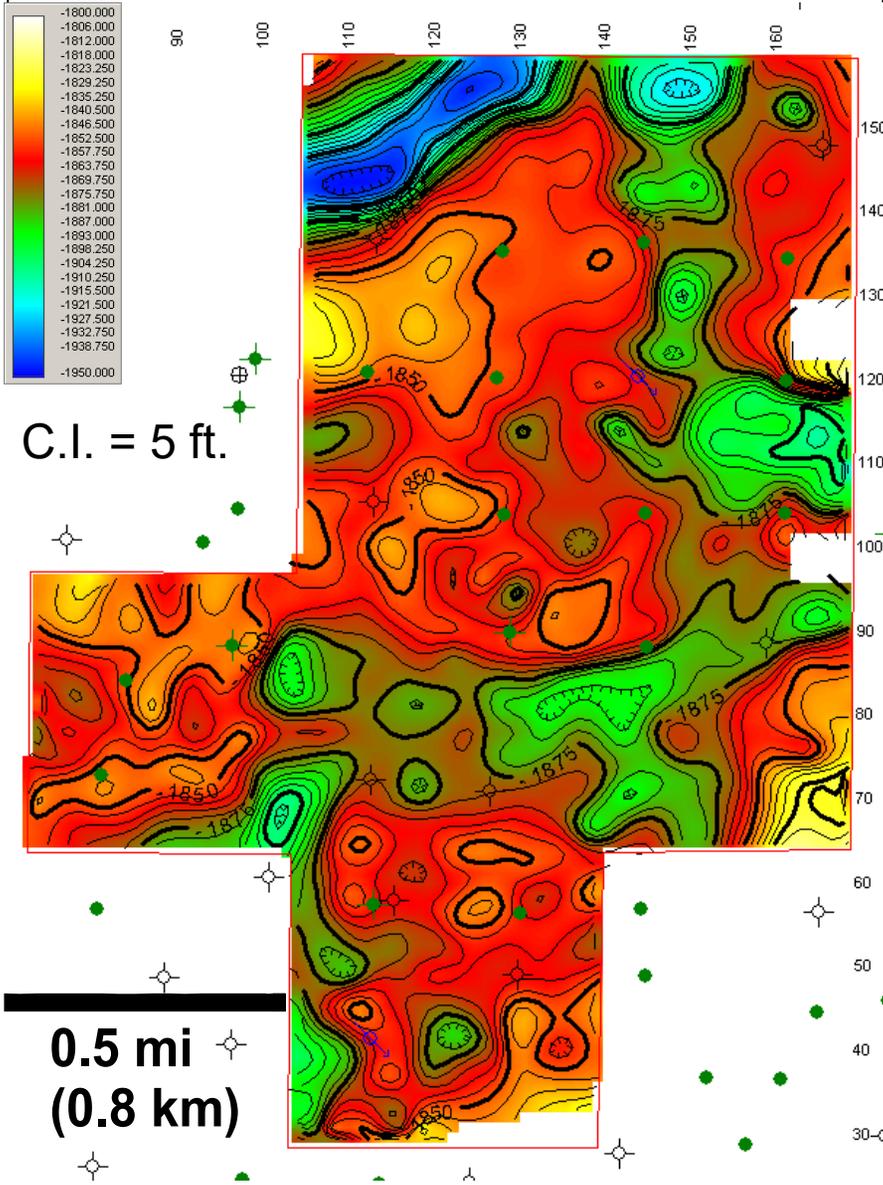


Fort Scott Volumetric Curvature

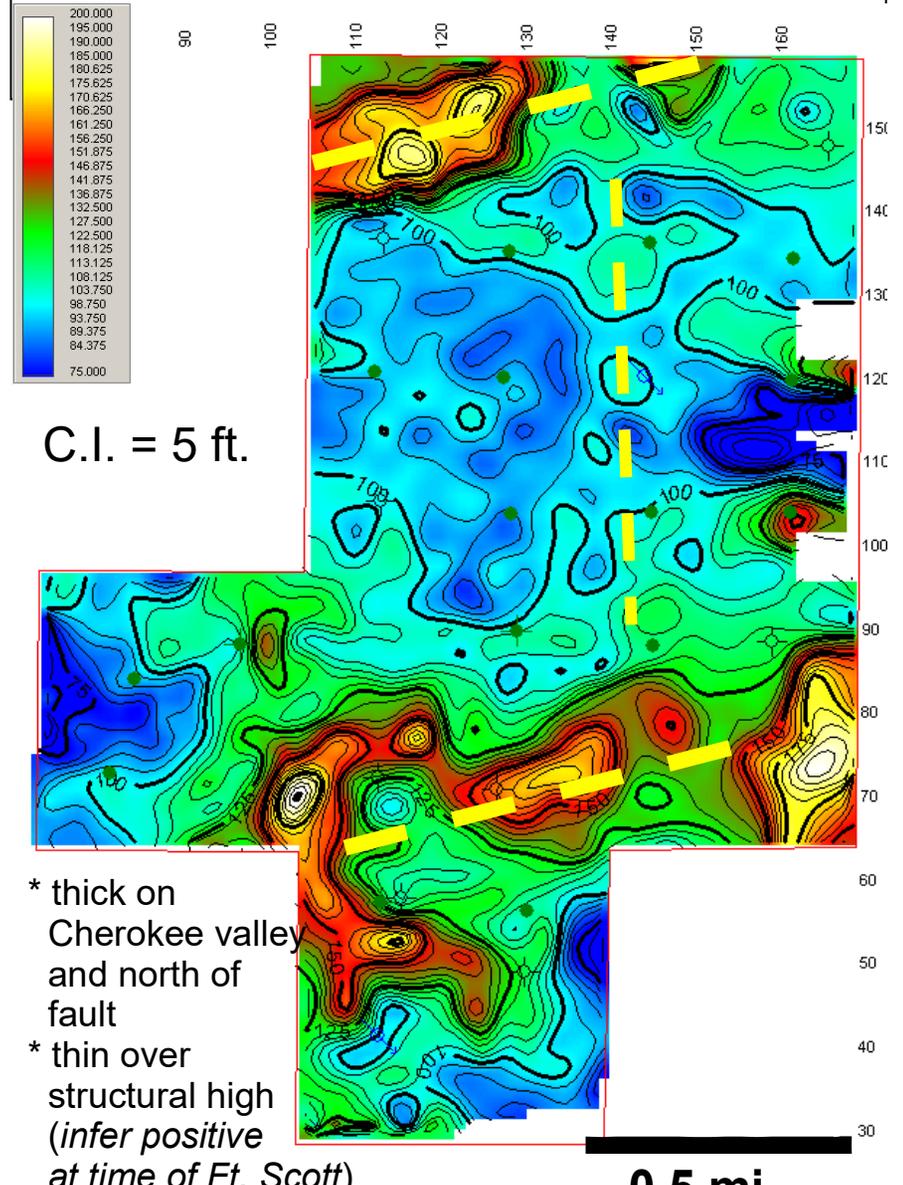


F fractured Ft. Scott

Fort Scott Subsea Depth



Fort Scott to Mississippian Isopach

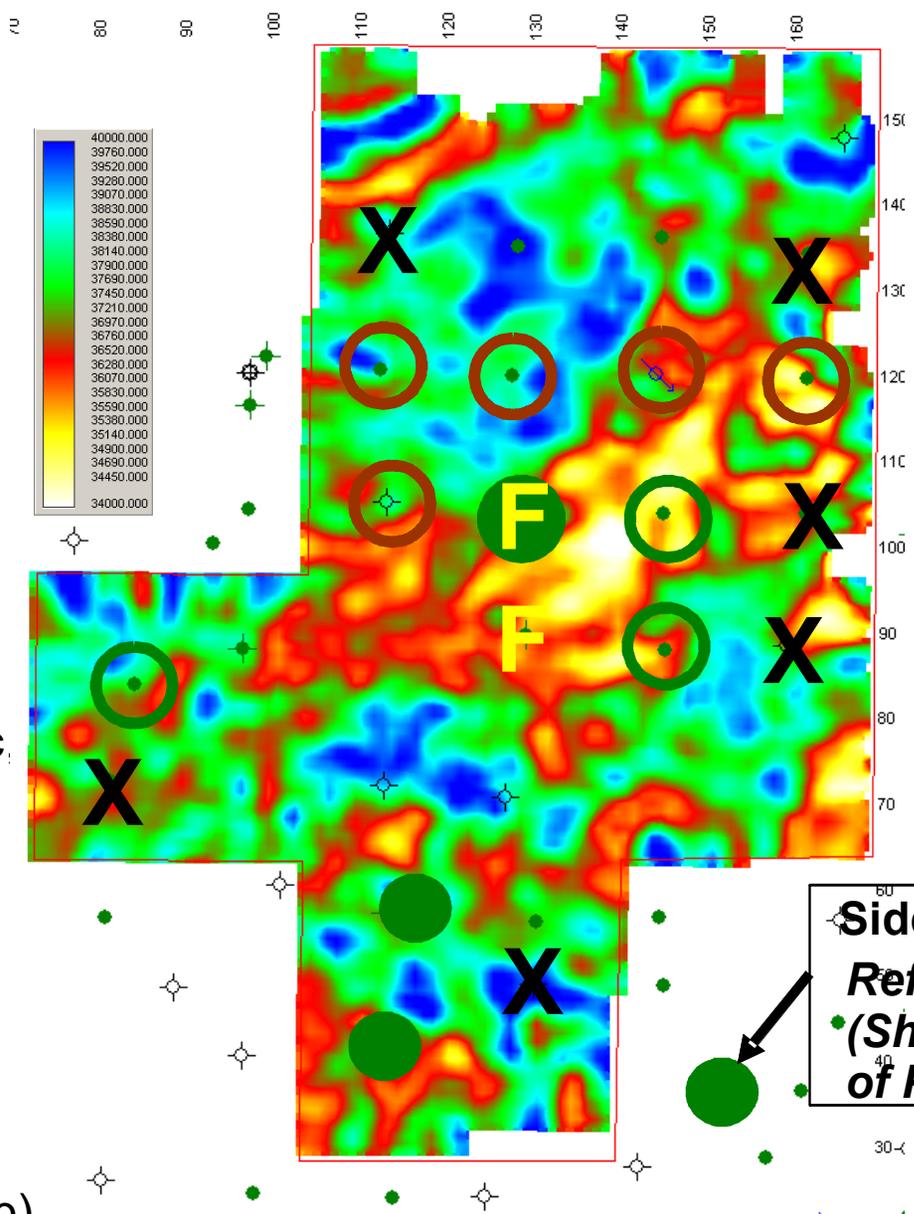


Fort Scott Impedance

Yellow=low velocity/porous; Blue=high velocity/tight

Infer fractured, vuggy, oomoldic carbonate pay in Ft. Scott Ls. developed along southern portion of structurally positive and paleotopographic high block

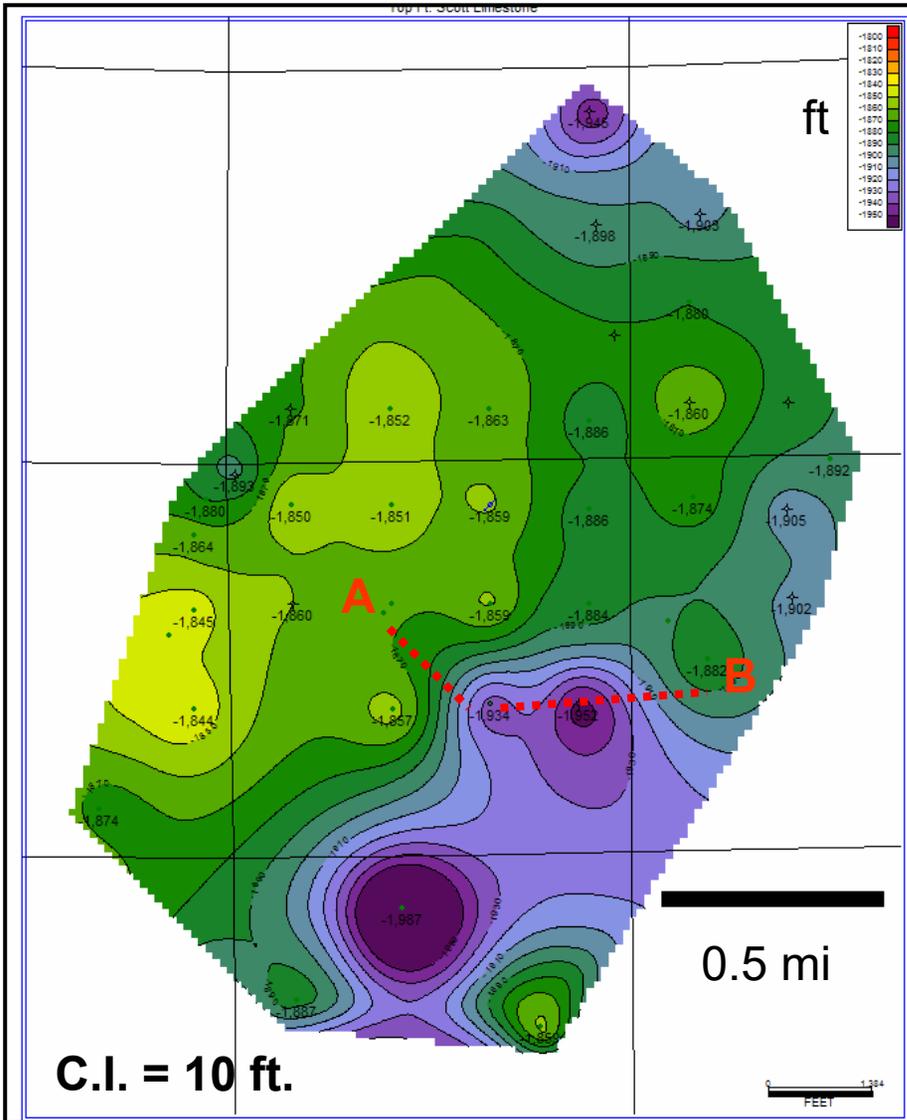
-  Low-poor P&P
-  Good P&P, oomoldic fossil mold, vuggy good DST and HC shows
-  Very good P&P, oomoldic, vuggy, PERFORATED
-  Fractures described from cores
-  Tight Limestone



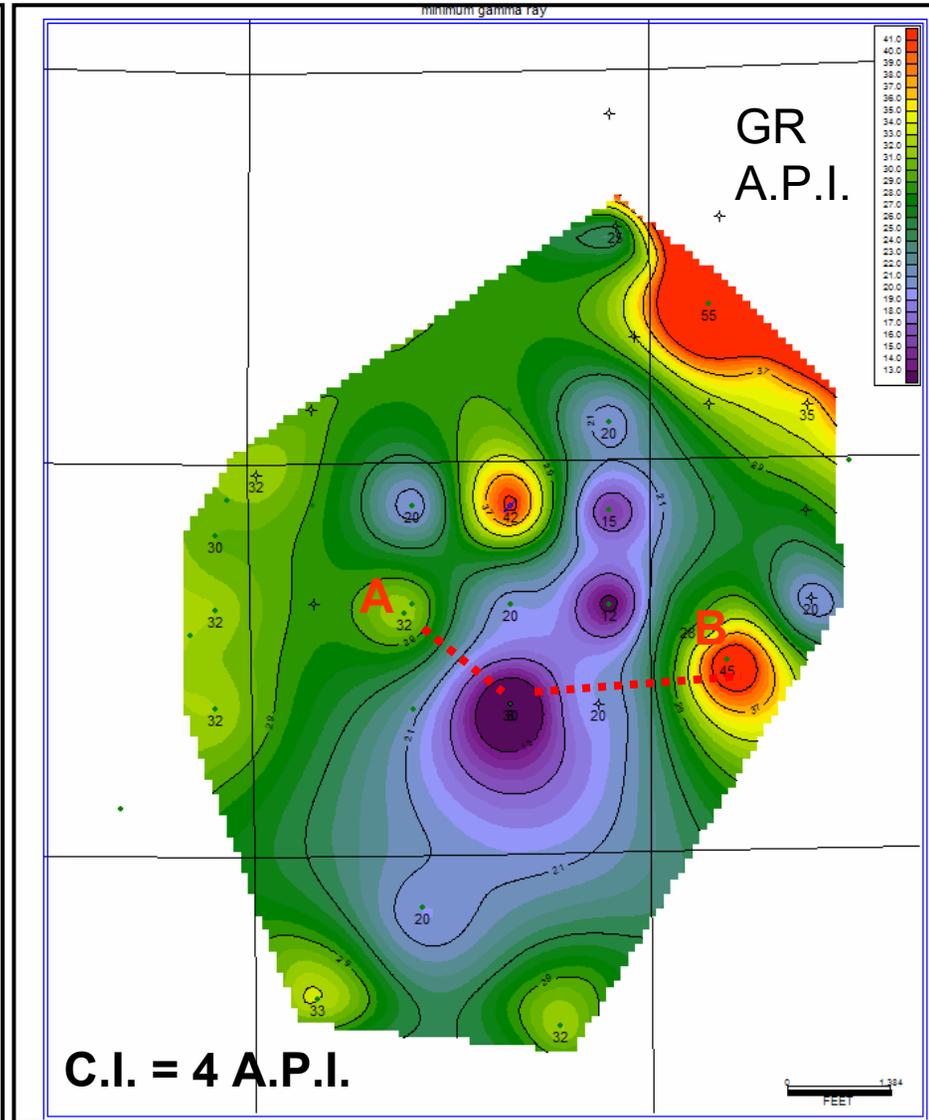
Sidebottom #6
Reference Log
 (Shown at top of Panel)

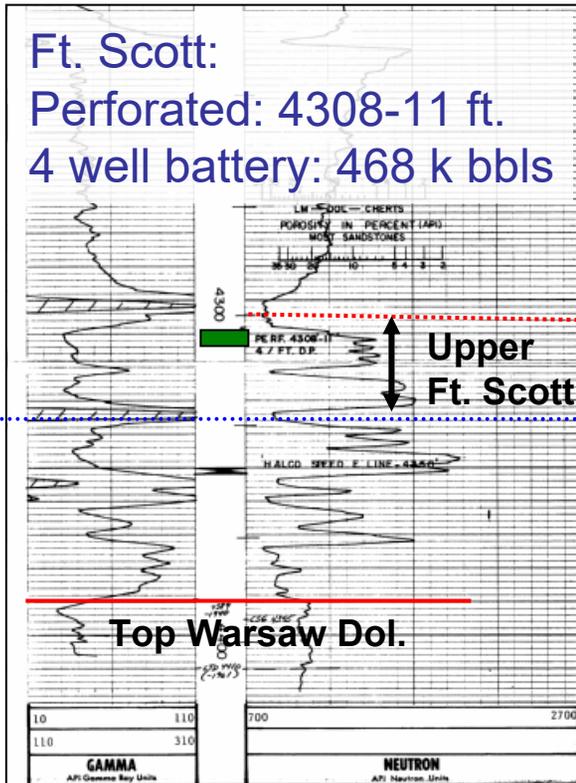
(based on sample and core descriptions of Don Beauchamp)

Top Ft. Scott Limestone Dickman Field using Well Control

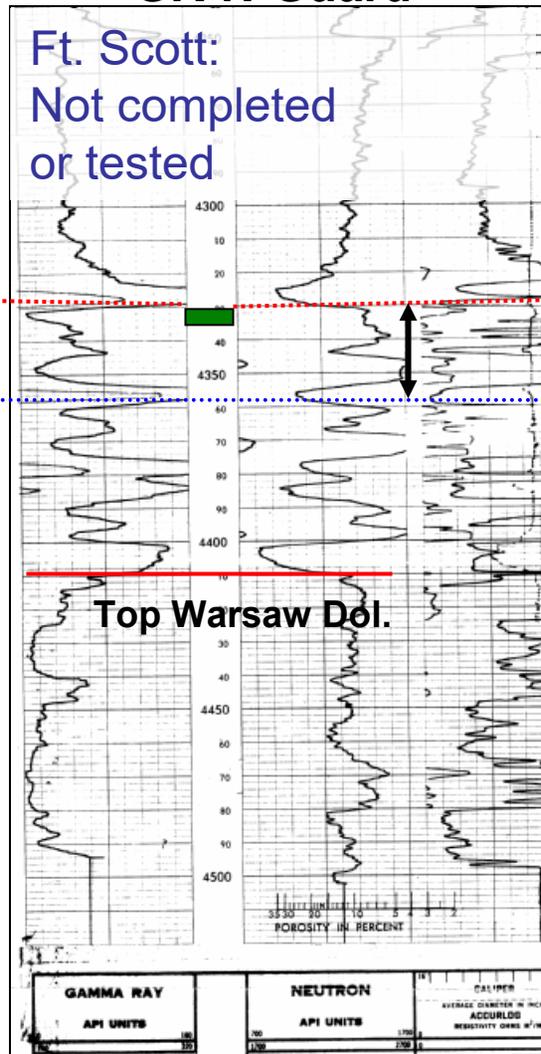


Minimum Gamma Ray Top Ft. Scott Pay

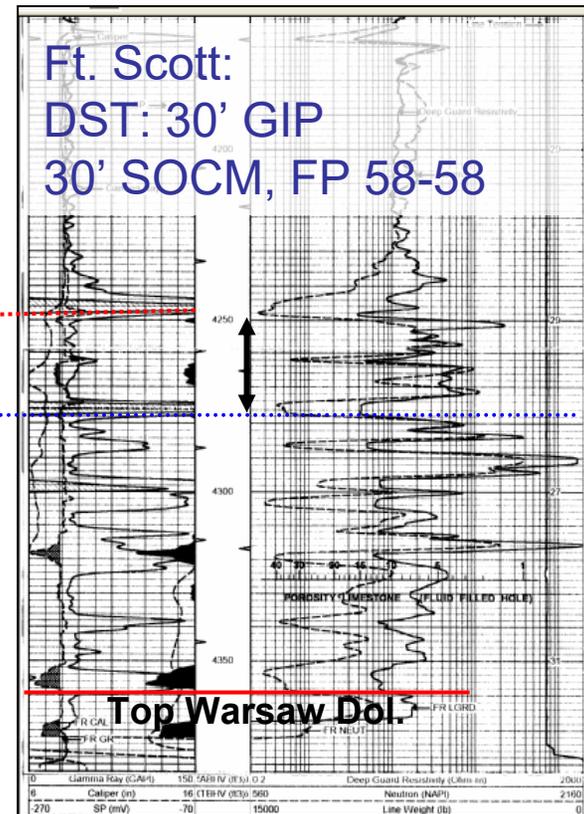


NW**Dickman #3****GR-N**

- Samples: Peloidal to oolitic, tightly cemented
- Core description: fractured, vuggy, some oomoldic ls.
- Elevated gamma ray (not as clean CO3)
- Southern edge of structure (fracture prone?)
- Low seismic impedance = porous area

Phelps #1**(60 ft low to Dickman #3)****GR-N-Guard**

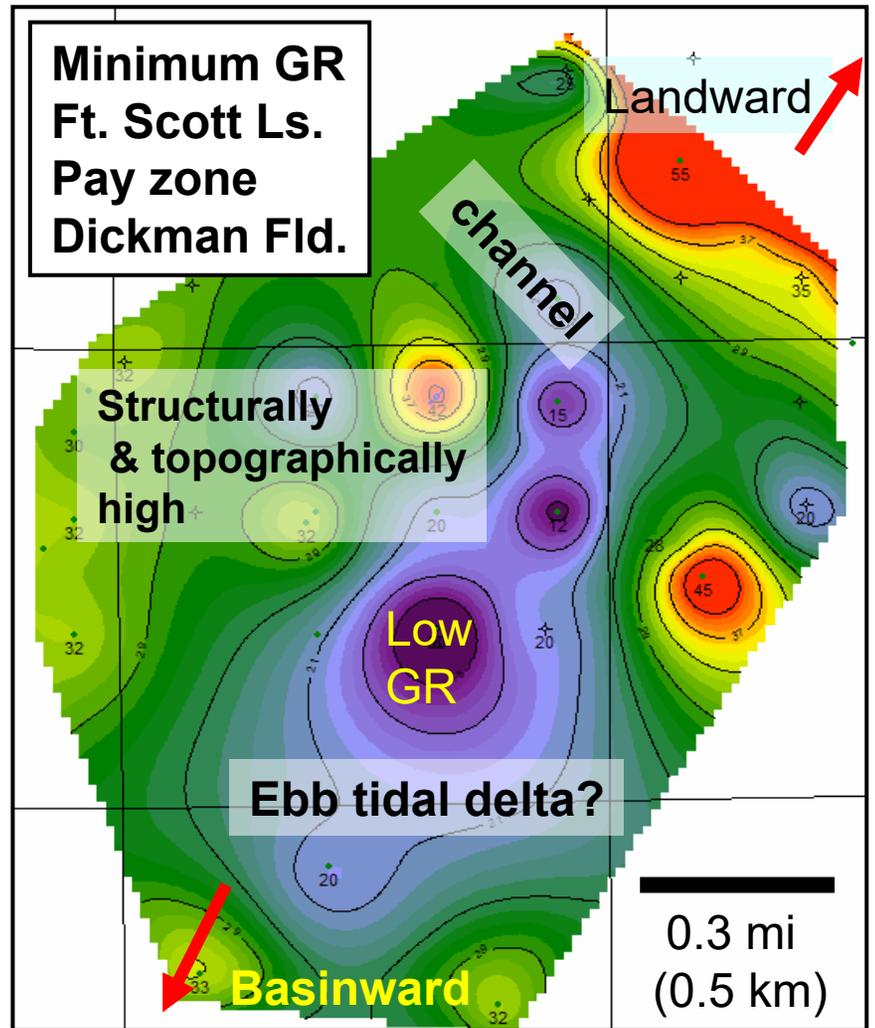
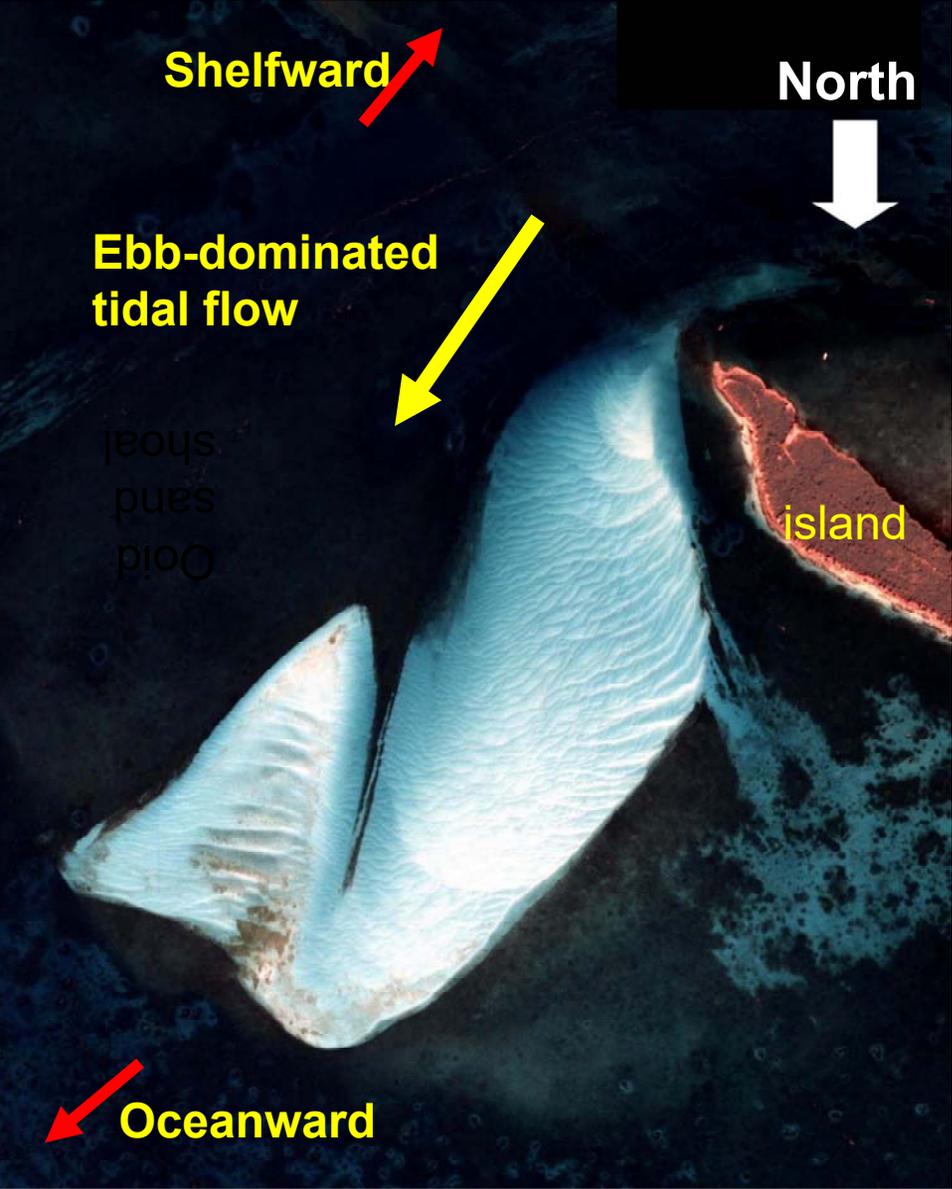
- Logs: est. 4.5 ft pay, low GR
- Samples: oomoldic, vuggy sucrosic & micrxln. cement

Keilman-Noll #1**GR-N-Guard****East**

- Sample description: fossil mold, some sucrosic

50 Feet

**Datum: Base U. Ft. Scott
(Little Osage Sh.)**



Interpretive patterns of flow in an ebb-dominated oolitic tidal bar. S. Reeder and G. Rankey (2005) *DigitalGlobe*[©]

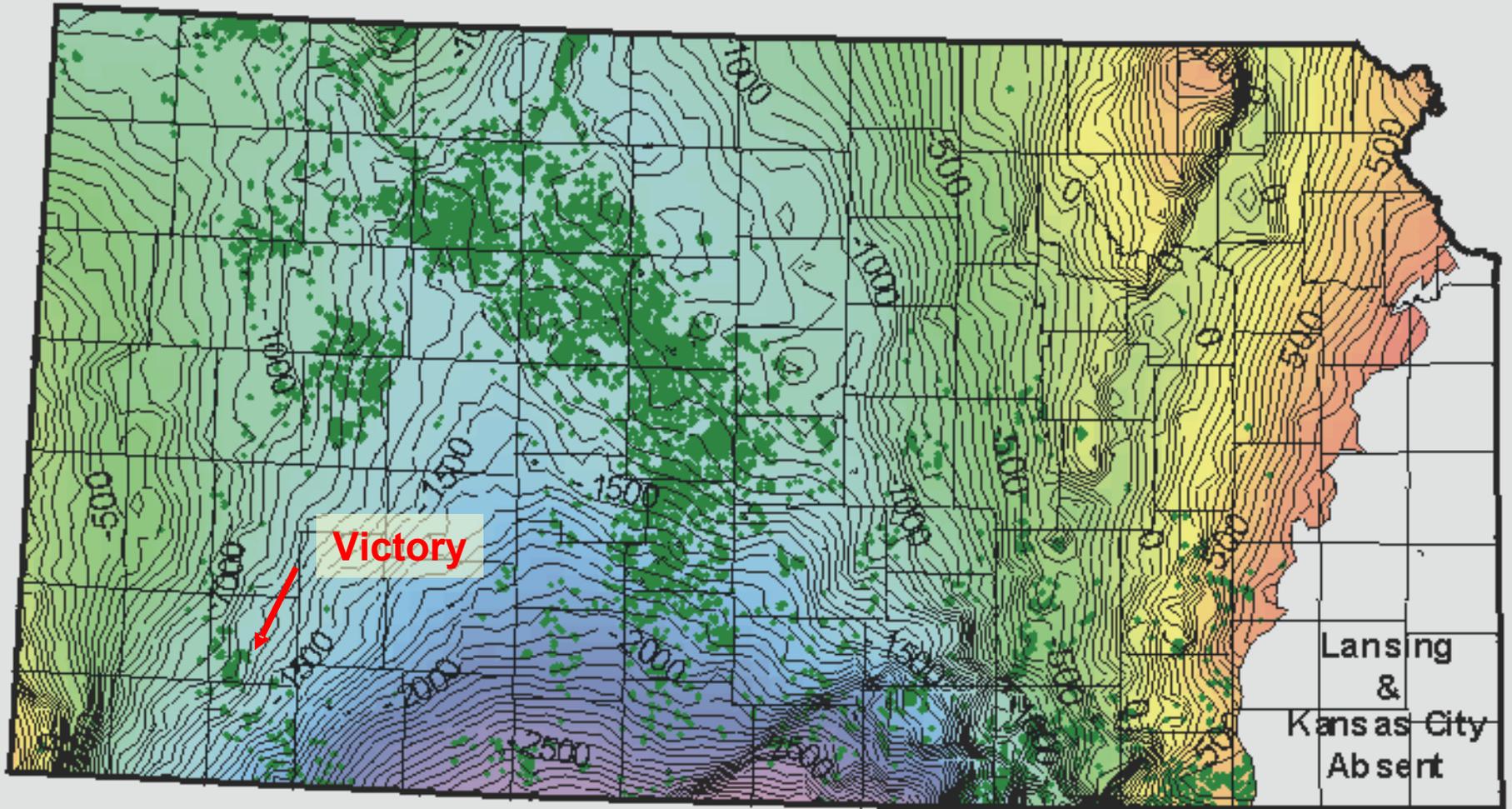
Victory Field, Haskell County

Lansing-Kansas City

Oomoldic grainstone

Structure on Lansing

CI: 50 ft.

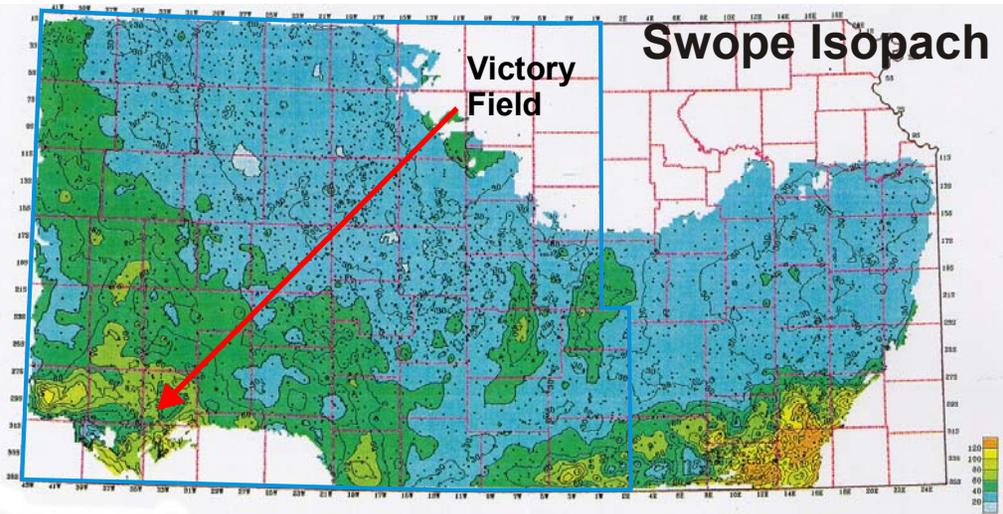


State of Kansas

● Lansing & Kansas City Oil Production

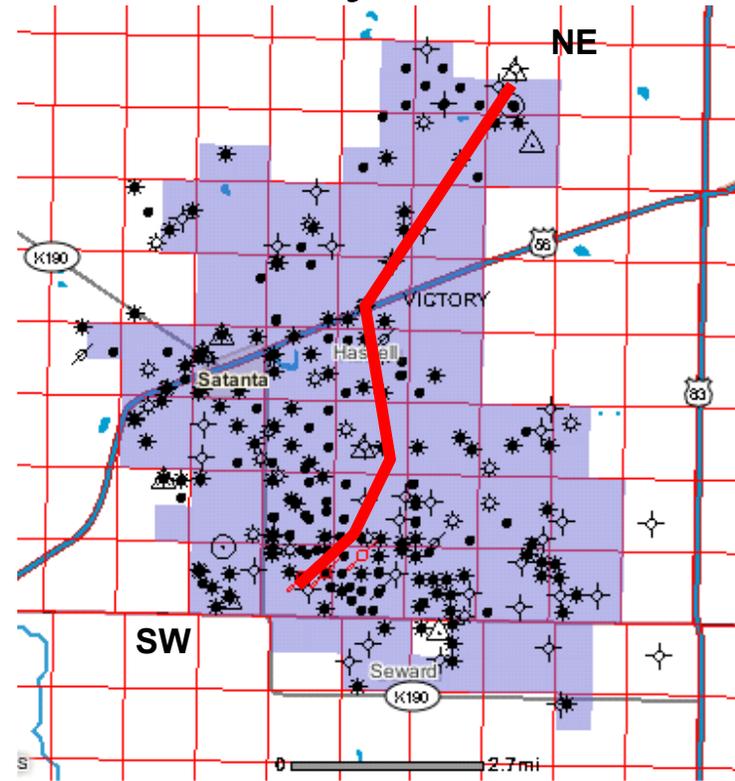
http://www.kgs.ku.edu/DPA/Plays/ProdMaps/lgkc_oil.html

Victory Field



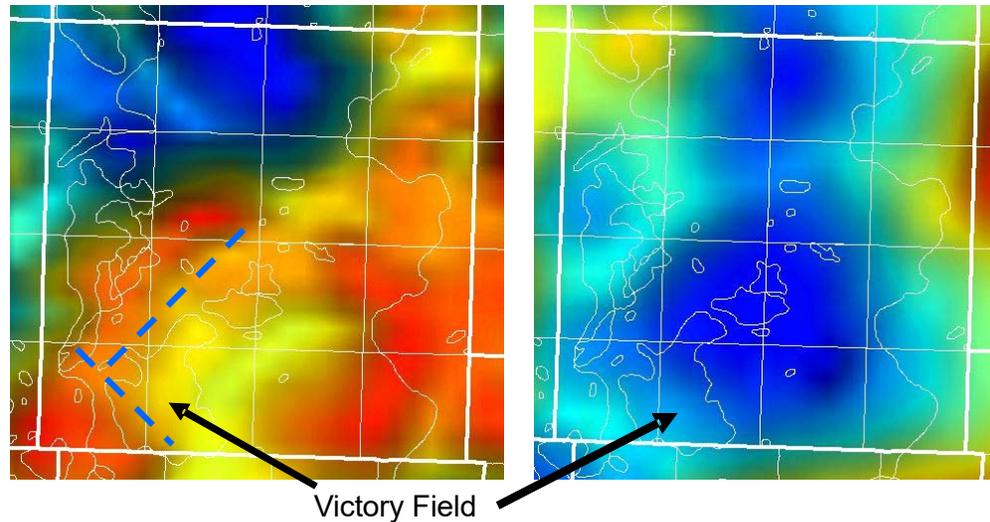
Magnetic Map, Haskell County

Gravity Map, Haskell County



5 miles (8 km)

Victory Field is a large oil and gas field having produced over 54 BCF gas and 12.5 MBO. A considerable amount of oil may still be behind pipe, making fields like this lucrative to further exploit.

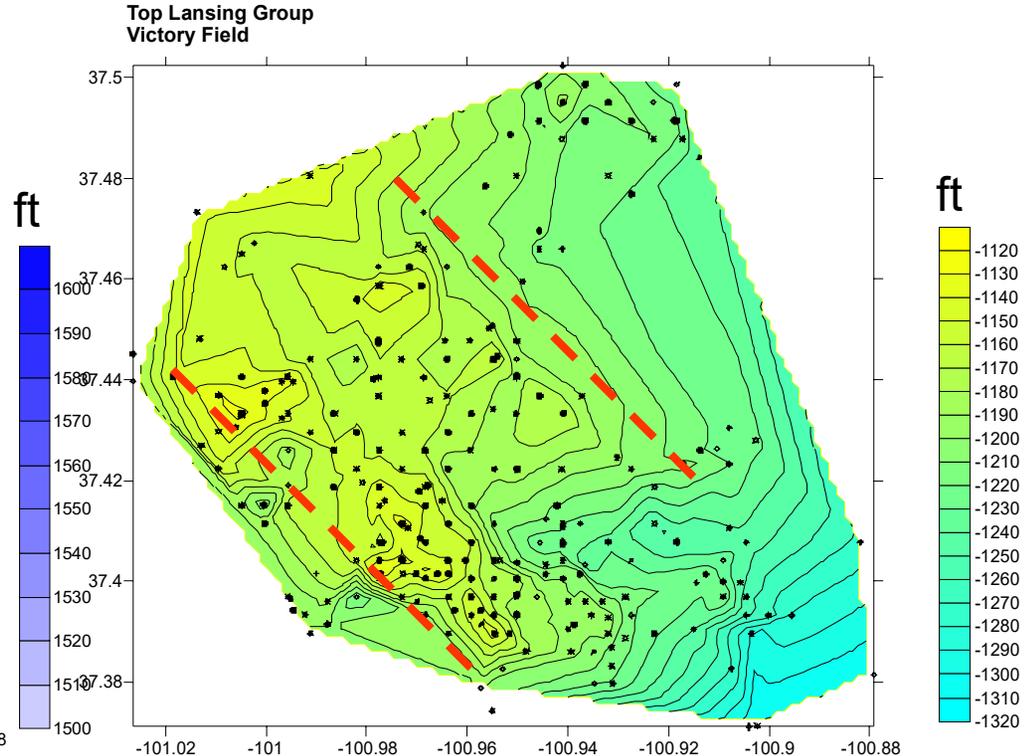
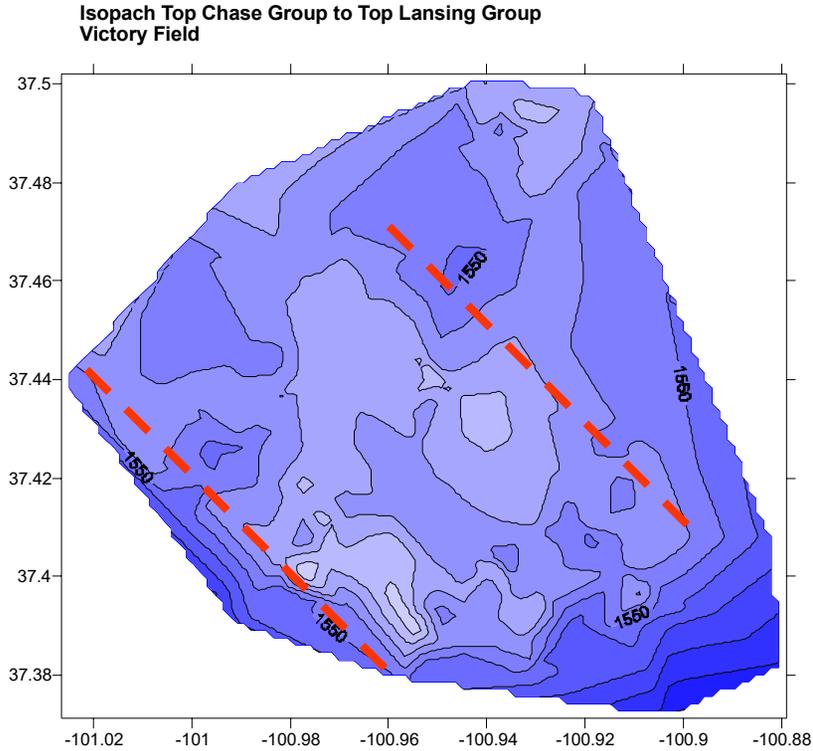


Victory Field

Structure maps of the tops of the Lansing and Chase Groups

L. Permian Chase to Upper Penn. Lansing isopachous map closely follows Top Lansing structure

Top Lansing structure



5 MILES

Rhombohedral NW & NE-trending pattern?

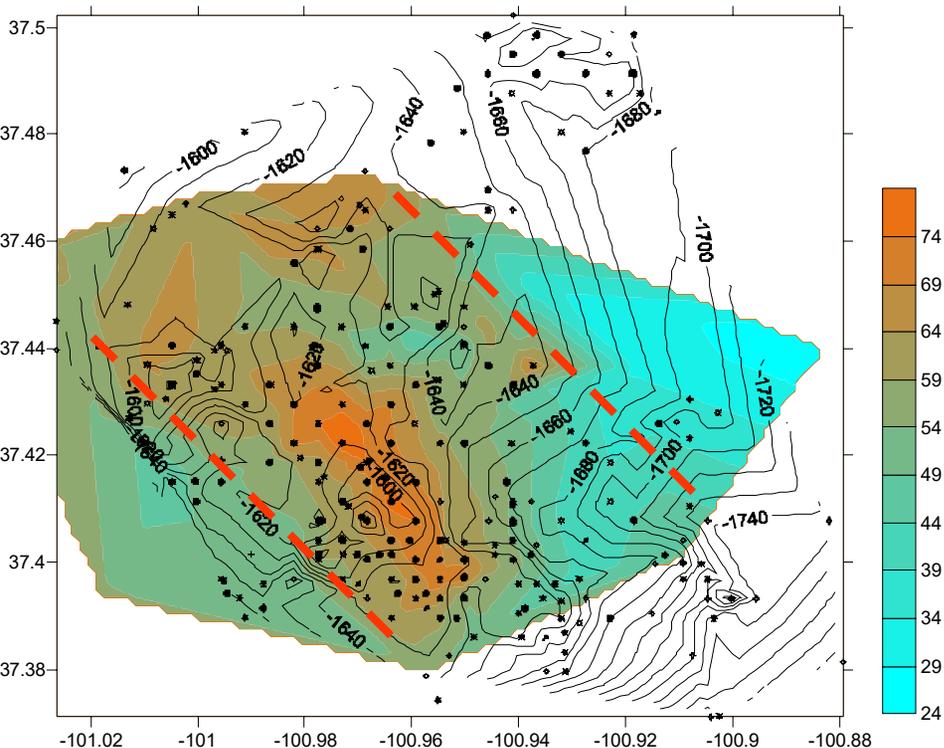
Structure = contours

Gross isopach (RIGHT color overlay) -- light blue to brown

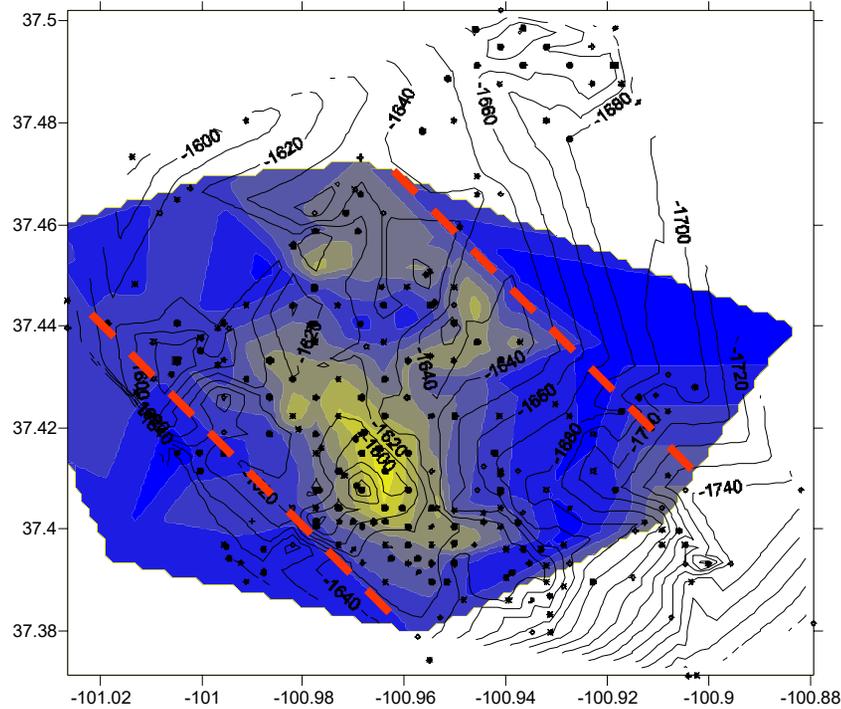
Thickness of porous carbonate (LEFT) -- dark blue to yellow

SWOPE LIMESTONE

Top Swope Formation (lines) &
Thickness of Swope Formation (color)
Victory Field

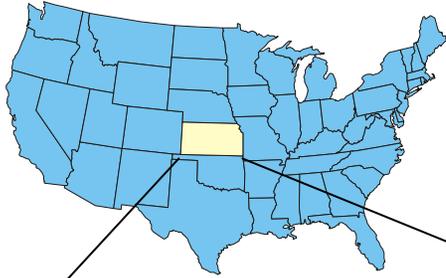


Top Swope Formation (contours)
Thickness of porous carbonate (>8%) (color)
Victory Field

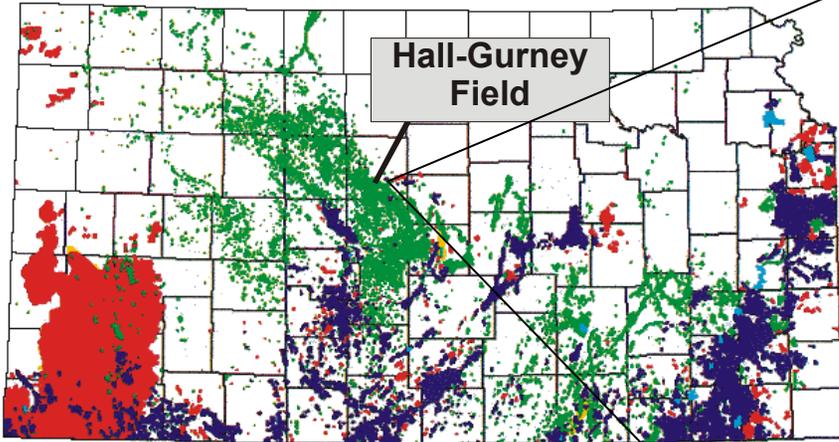


Thickening on top of structure

Hall-Gurney CO2 Field Demonstration Project

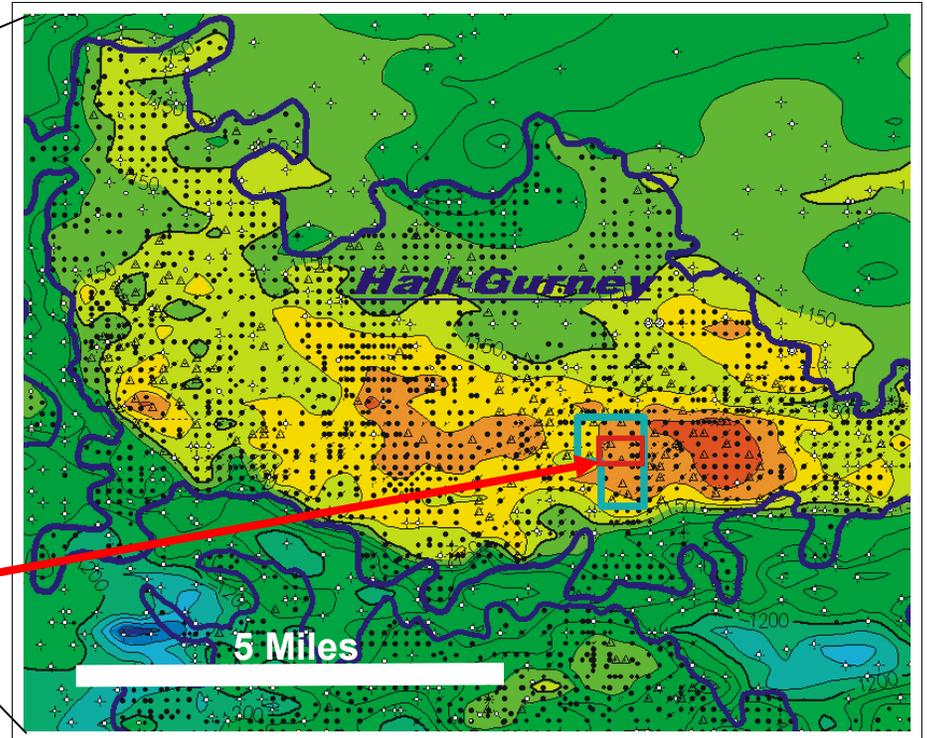
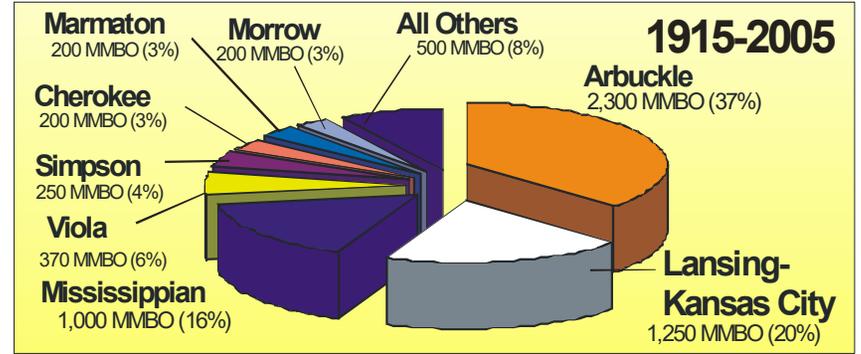


Oil and Gas Fields in Kansas



0 50 mi

CO2 Pilot Study Area

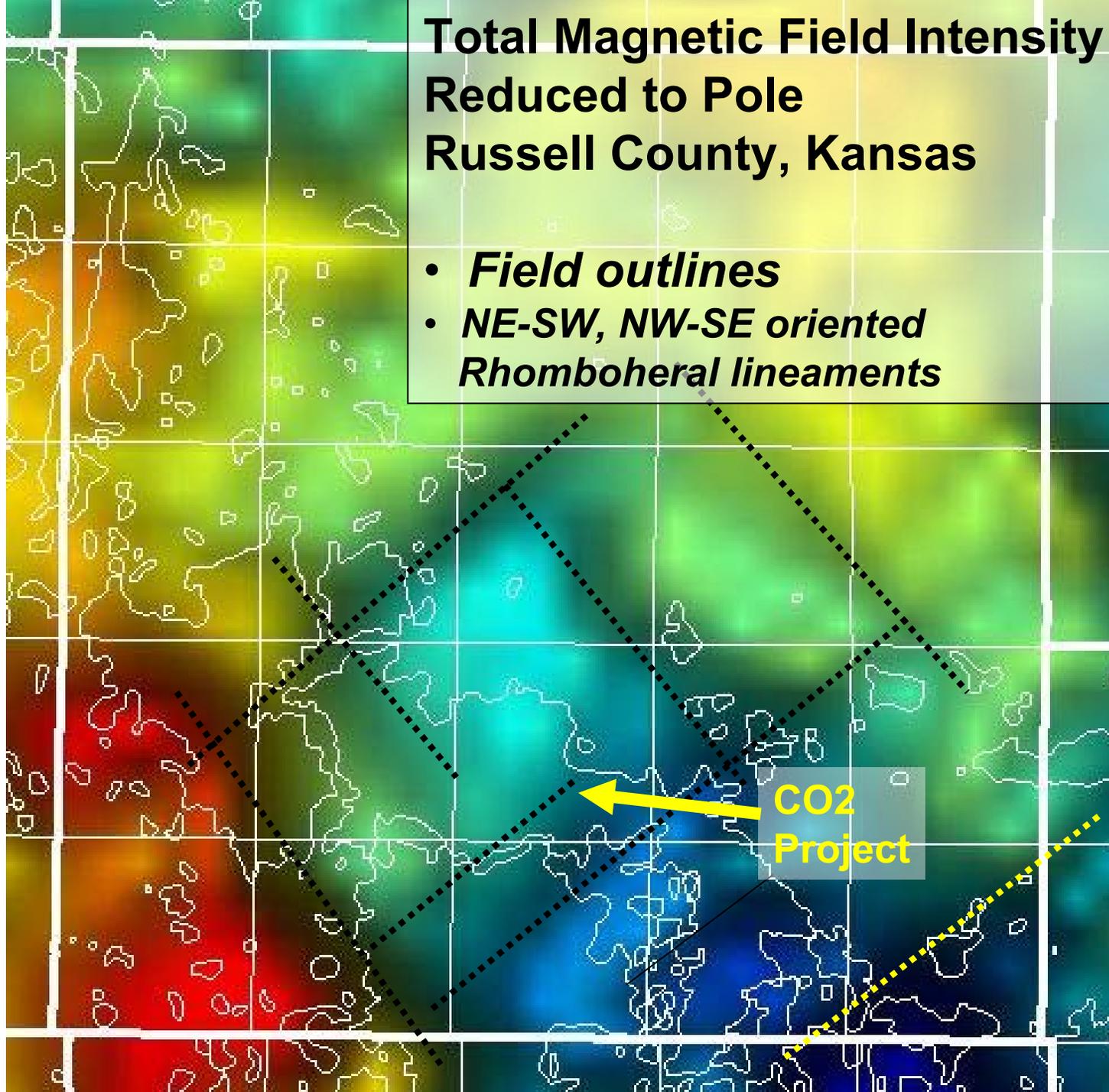


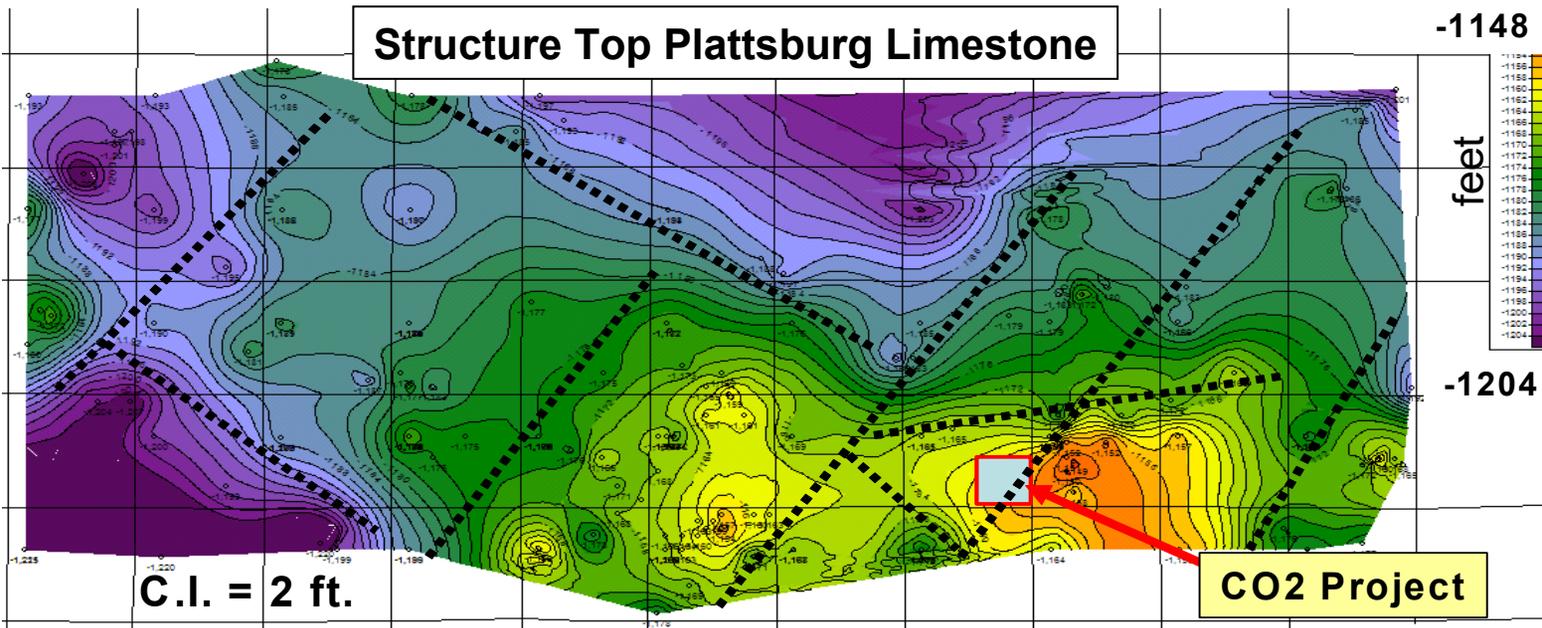
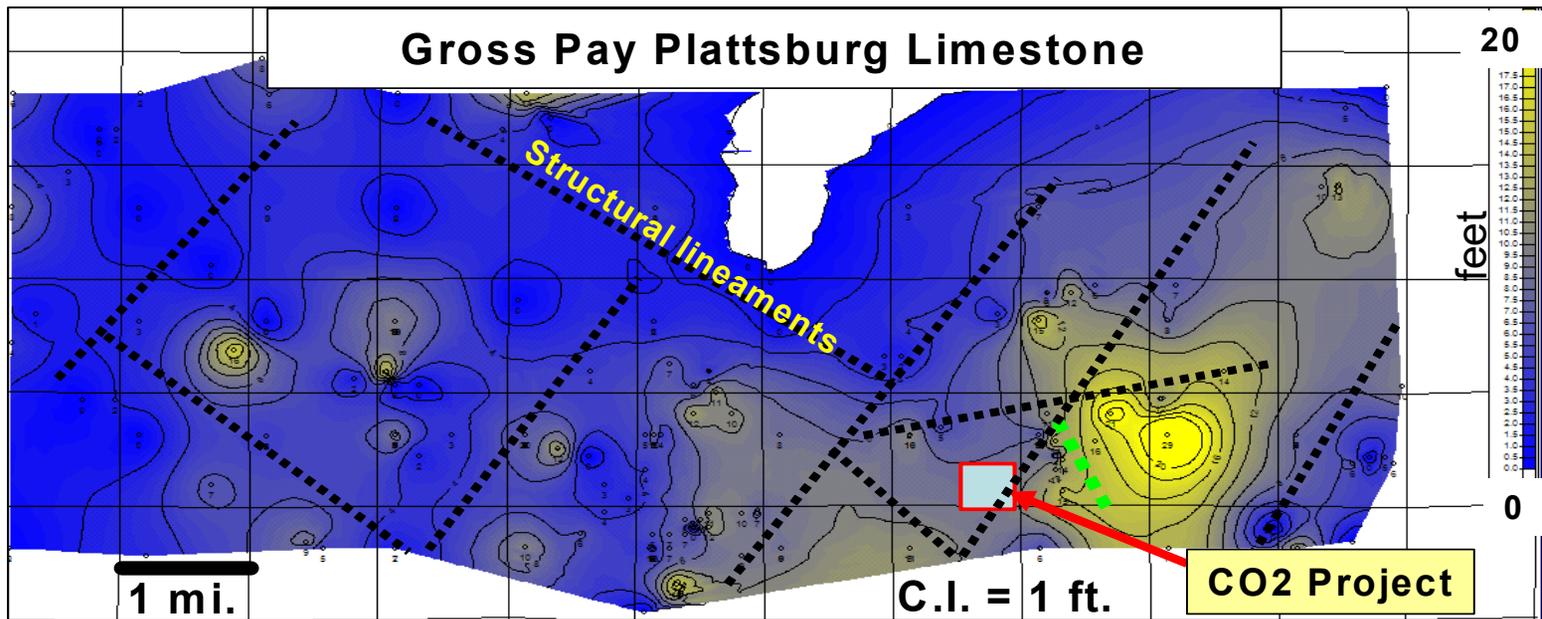
5 Miles

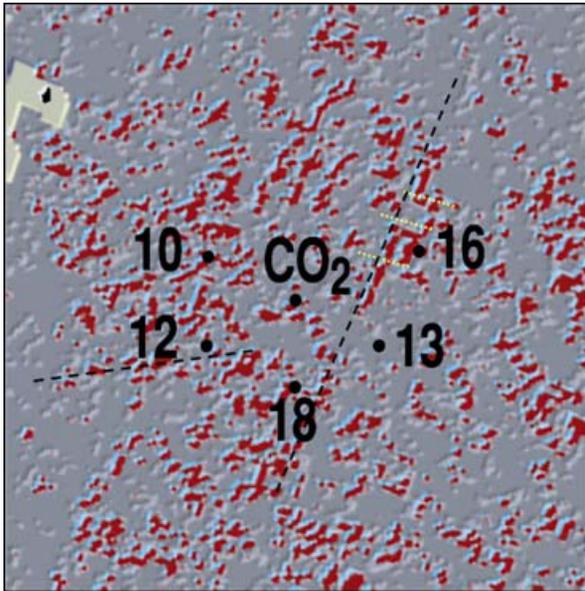
Murfin Drilling. Co., operator

Total Magnetic Field Intensity Reduced to Pole Russell County, Kansas

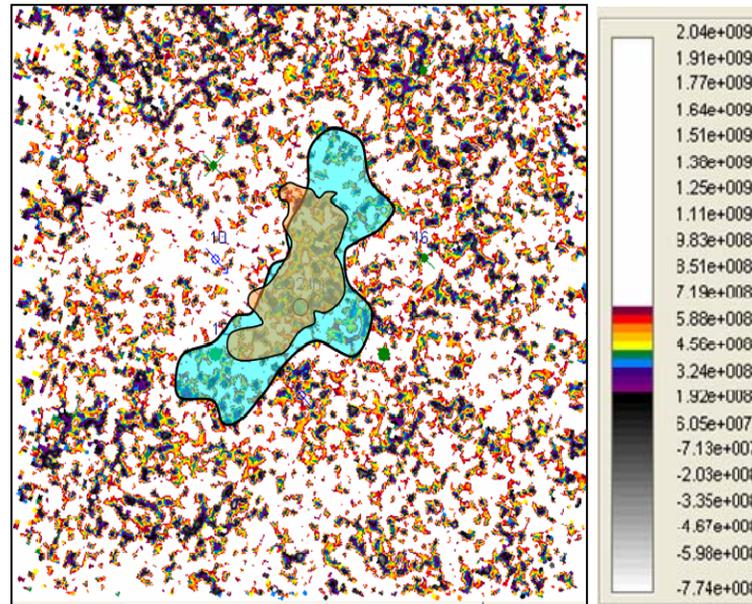
- *Field outlines*
- *NE-SW, NW-SE oriented
Rhomboheral lineaments*







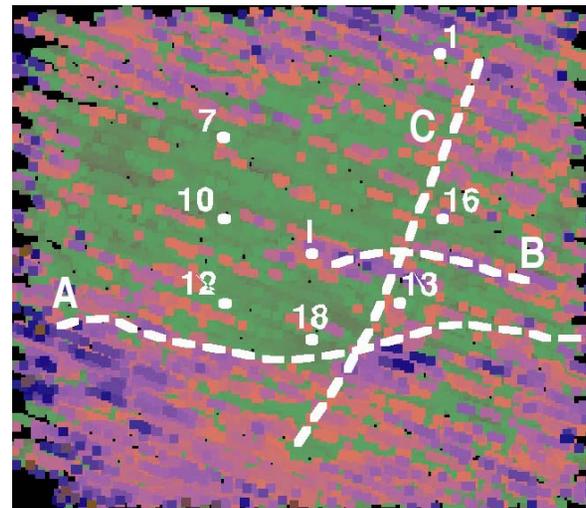
Lineament attribute baseline data (prior to CO₂ injection)



Parallel progressive blanking of amplitude envelope, April 2004 and June 2005 showing 2 stages of CO₂ plume

A strong correlation exists between the preferential movement of the CO₂ through this reservoir and features evident on the lineaments attribute map

It appears lithology, especially rock properties, are preferentially influencing fluid movement through this reservoir



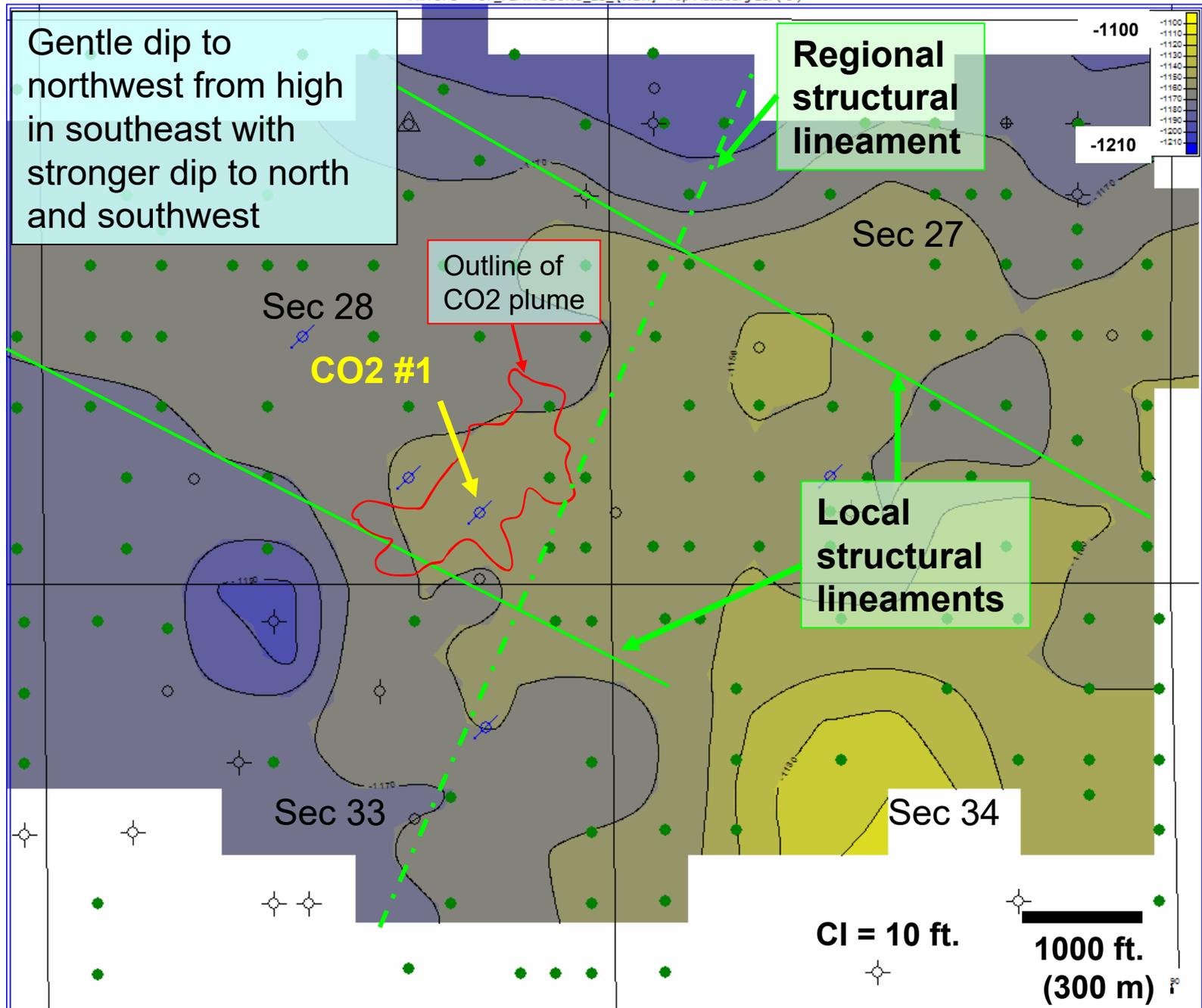
Instantaneous frequency at 560 msec with lineaments



North

0.25 mi (0.4 km)

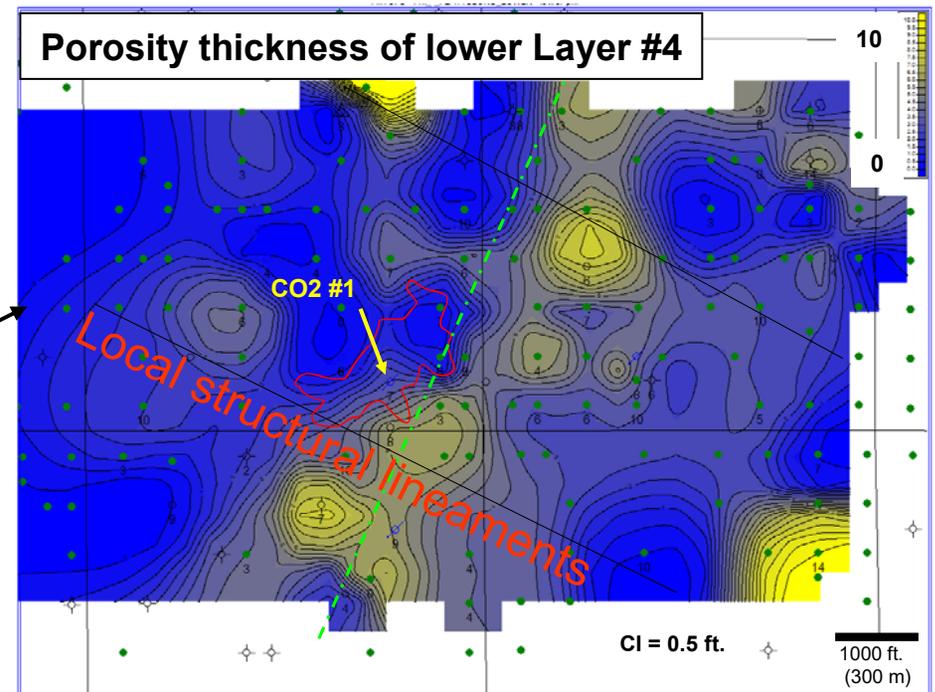
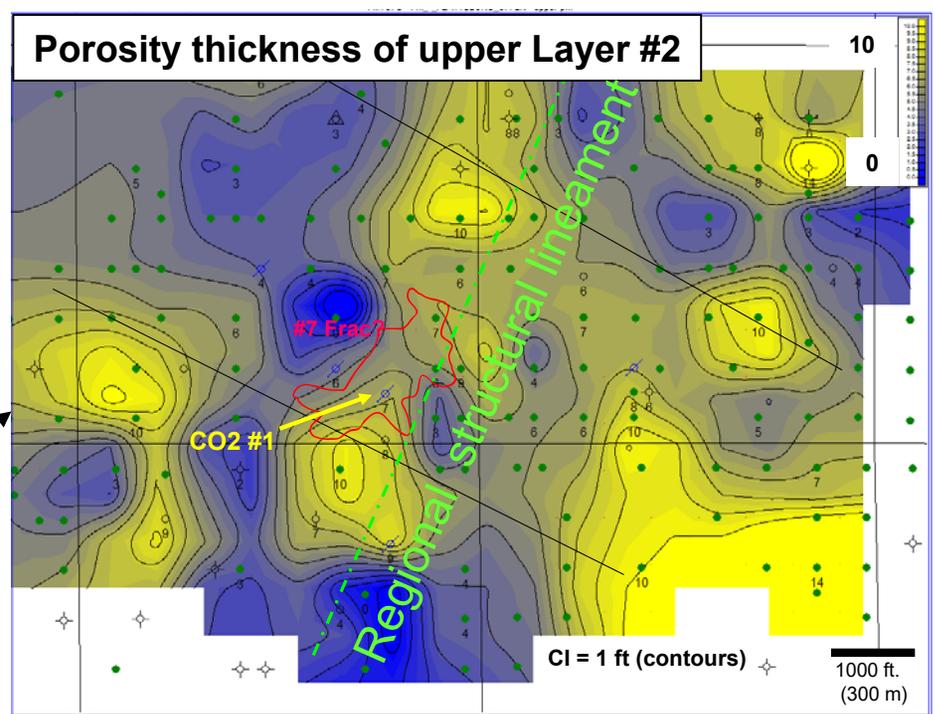
Structure Contour Map, Top Plattsburg Limestone

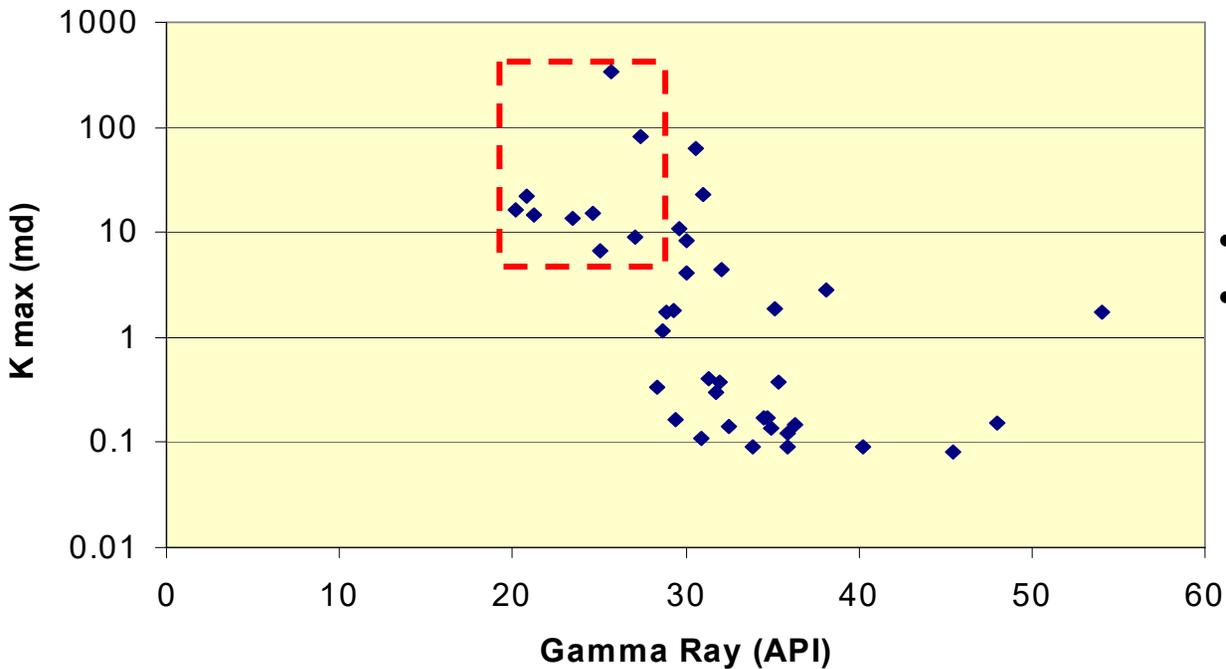


Comparison of two stacked, high-frequency cycles

- Possible polygenic parabolic-shaped ooid shoals
- Roughly orthogonal trends paralleling structure lineaments
- Location of #2 shoal is offset to west of underlying layer #4
- CO₂ movement along porous layer #2

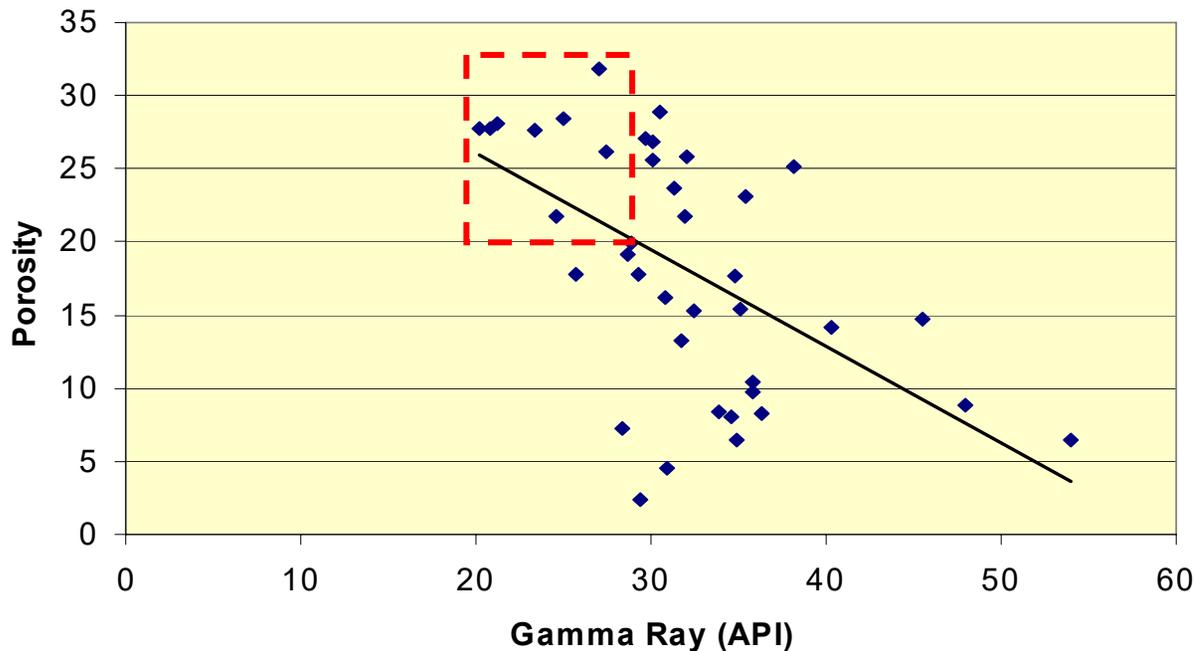
- Isolated elongate ooid shoal developed sub-parallel to regional structural lineament
- No CO₂ movement in lower layer #4





**Clean (lower gamma ray),
better-sorted oolite/
oomoldic**

- Higher permeability, >10 md
- Correlation with:
better sorting, packing,
and interconnected oomolds
(microvugs & associated
high Archie cementation
exponent)



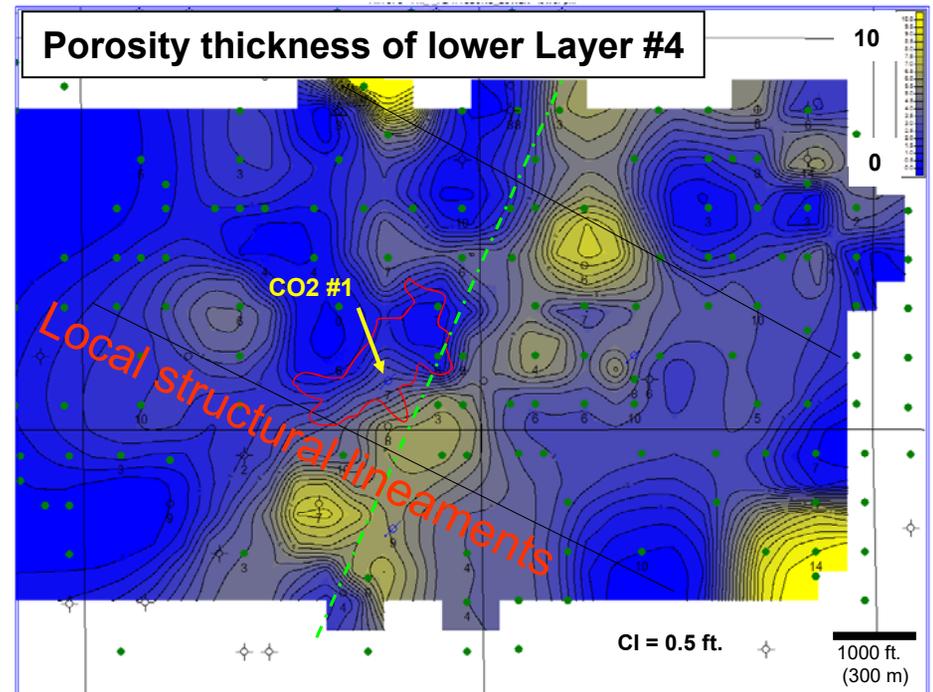
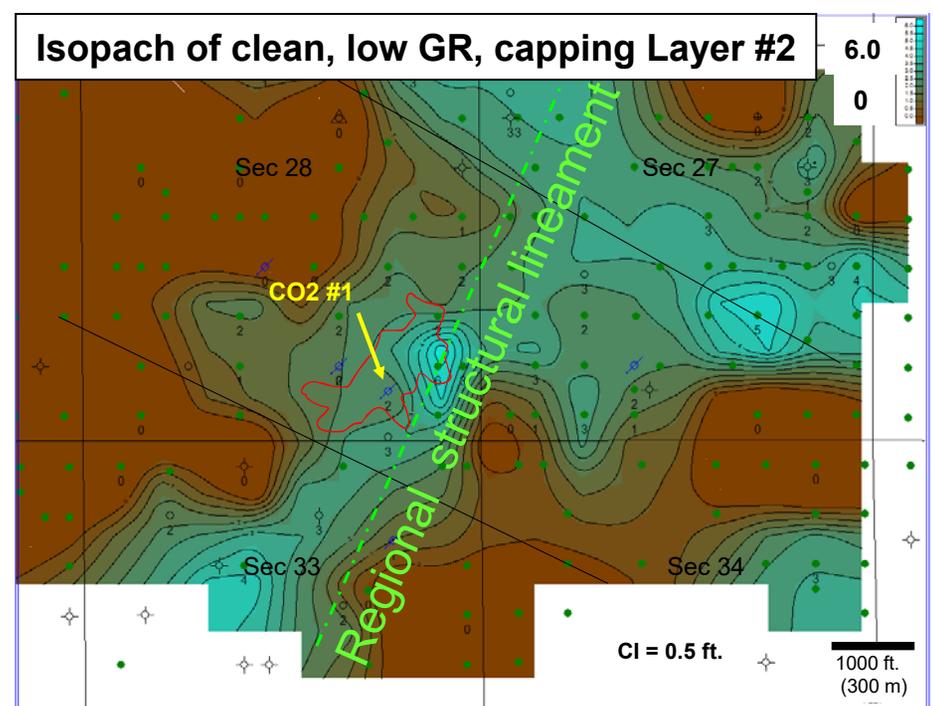
**Clean, better-sorted
higher porosity in
cycle caps,
porosity highest near
top of shallowing
upward succession**

- **Better-sorted bar crests
in Modern ooid shoals**

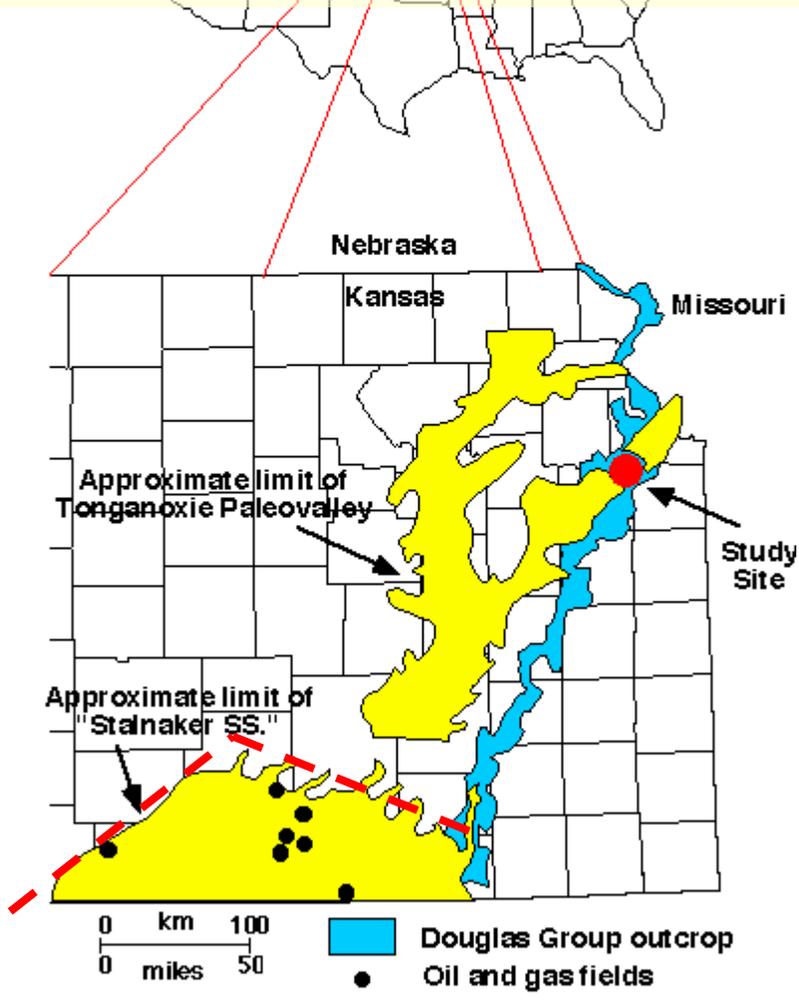
Colliver #16 core data

Comparison of porosity thickness of lower Layer #4 and thickness of clean, low gamma ray interval capping Layer #2

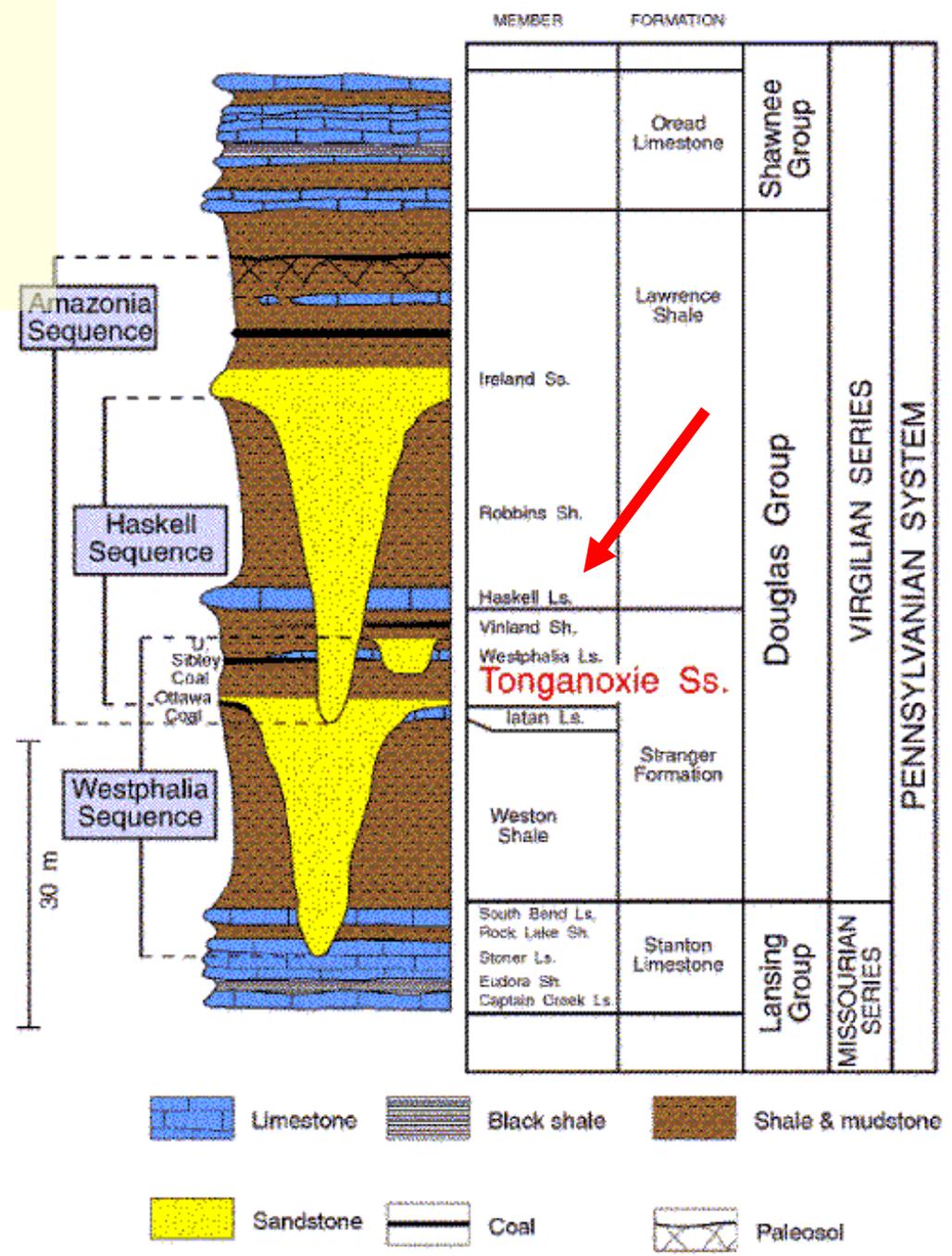
- Close correspondence of location and NE-trend of low gamma interval of upper layer #2 and thick porous interval of lower layer #4
- NW-trend of clean GR in layer #2 not reflected in #4
- Both trends closely parallel regional and local structural lineaments
- Also, possible inherited topography from buildup of #4 affecting #2



Proposed basement structural controls on incised valley development – Tonganoxie Sandstone (Lower Virgilian, U. Pennsylvanian)

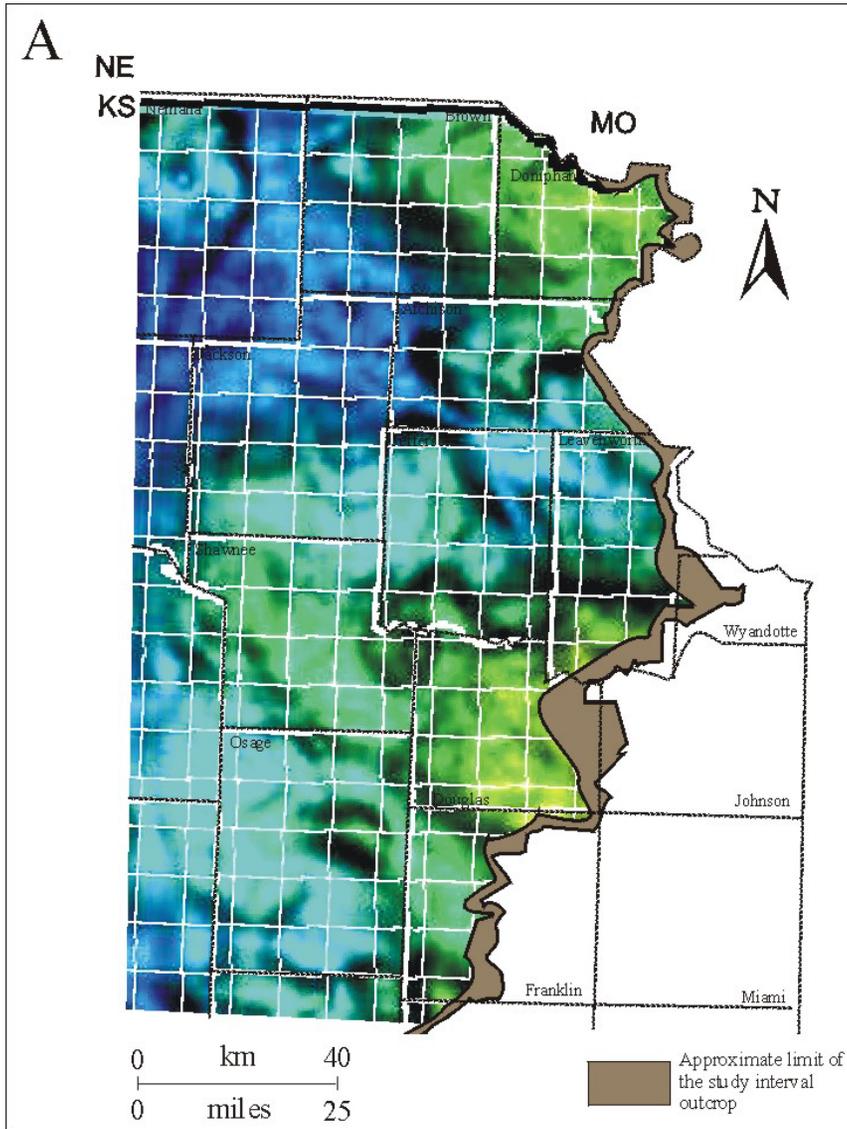


(modified from Feldman et. al. 1995)

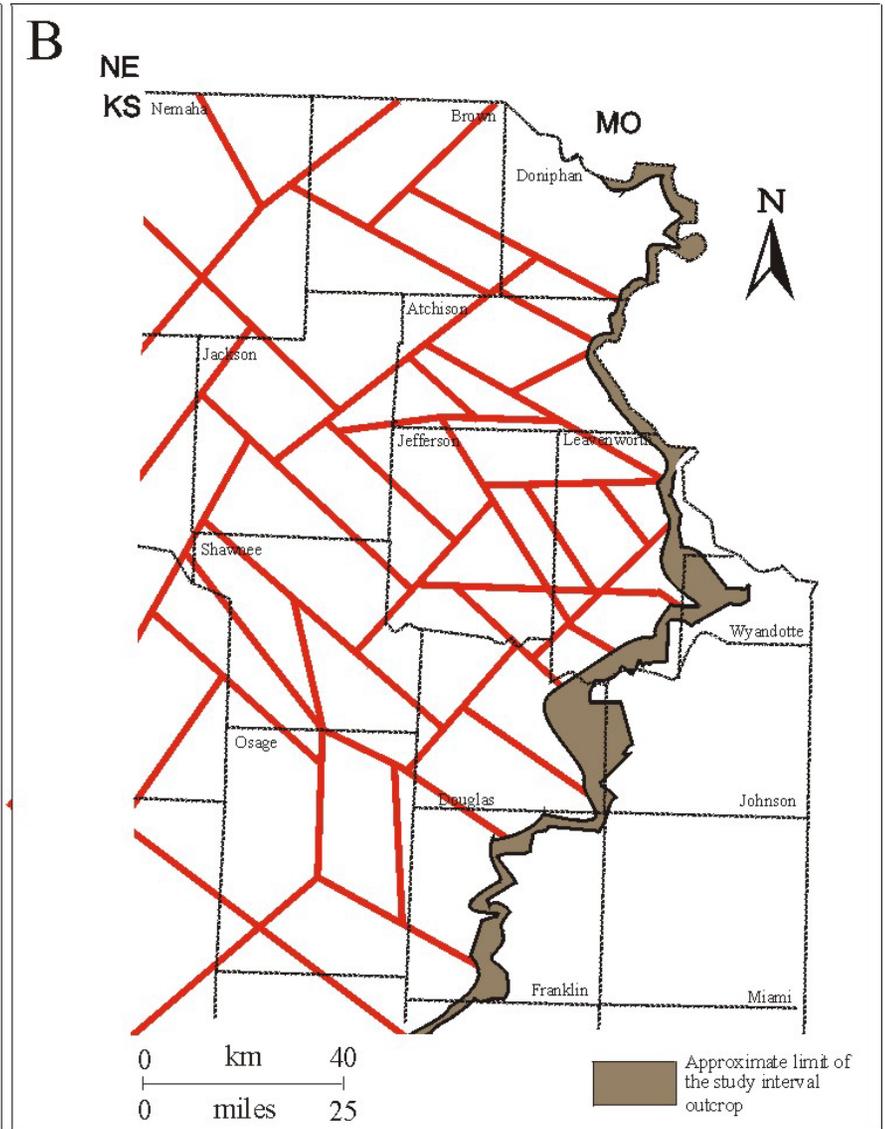


(Modified from Feldman, et. al., 1995)

2nd-order residual gravity

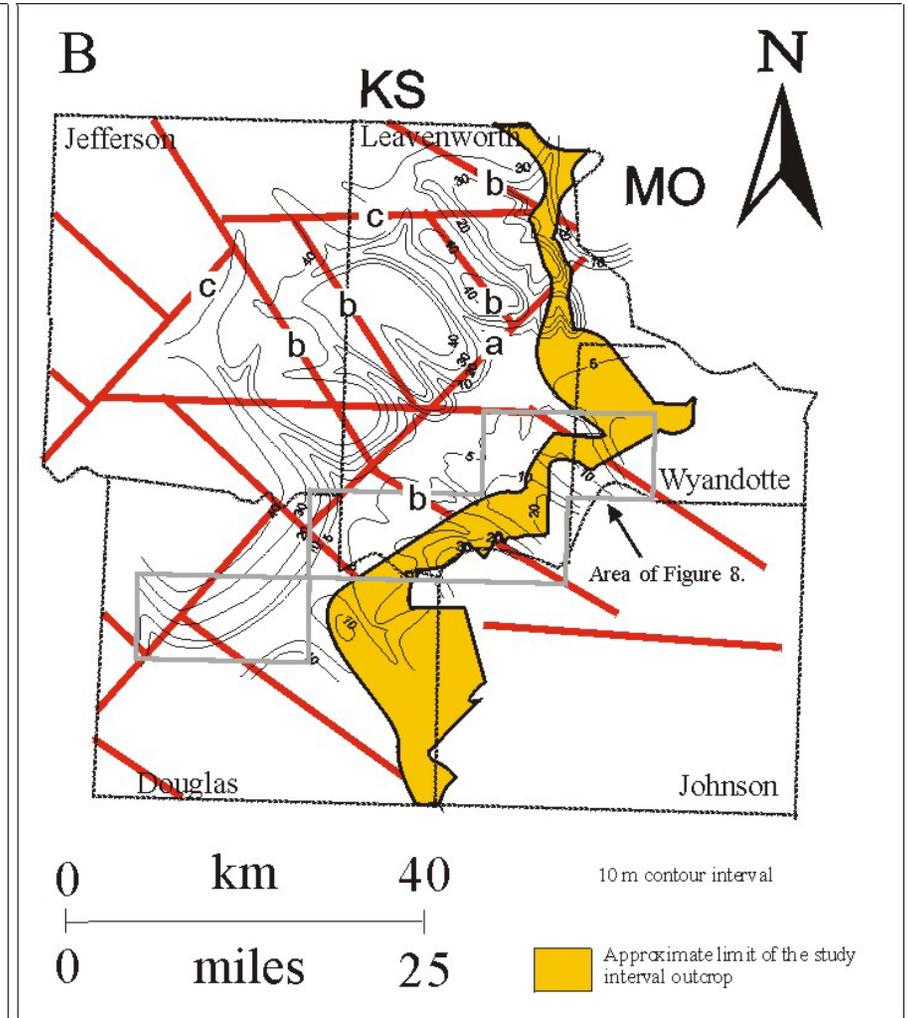
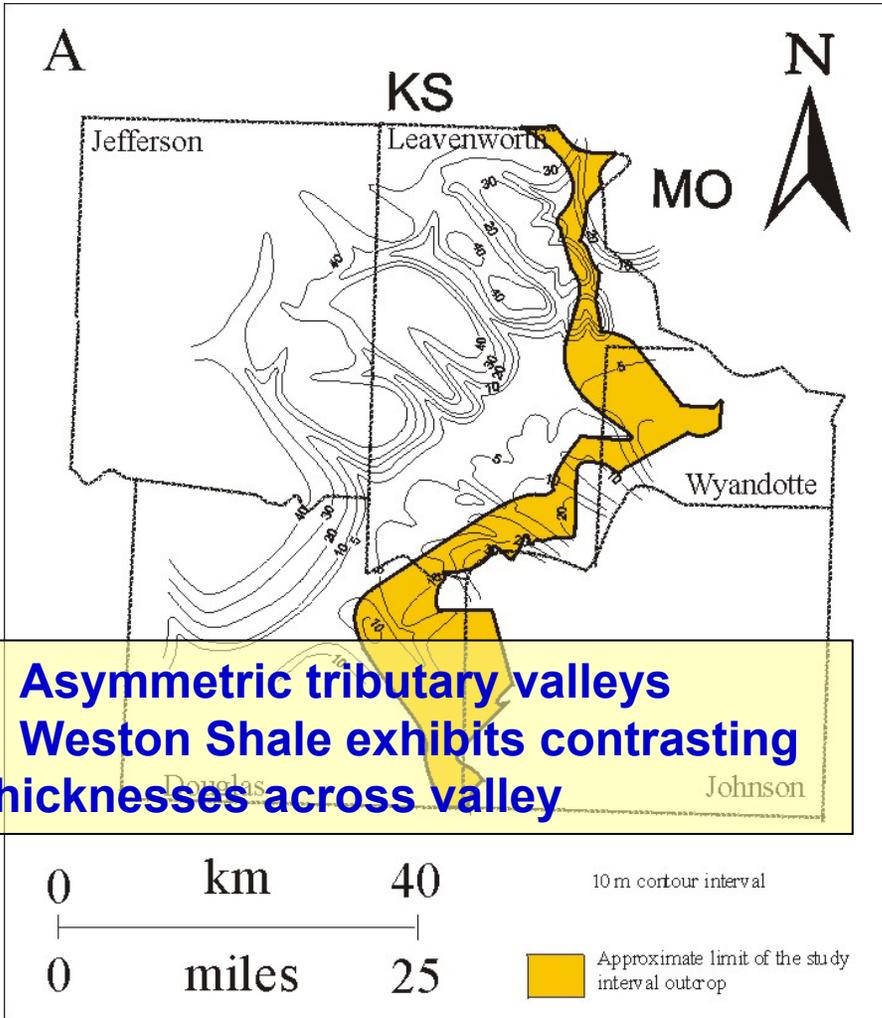


Lineaments inferred from gravity map



- Dominant NW-trending gravity lineaments
- Lineaments parallel predominant basement structure

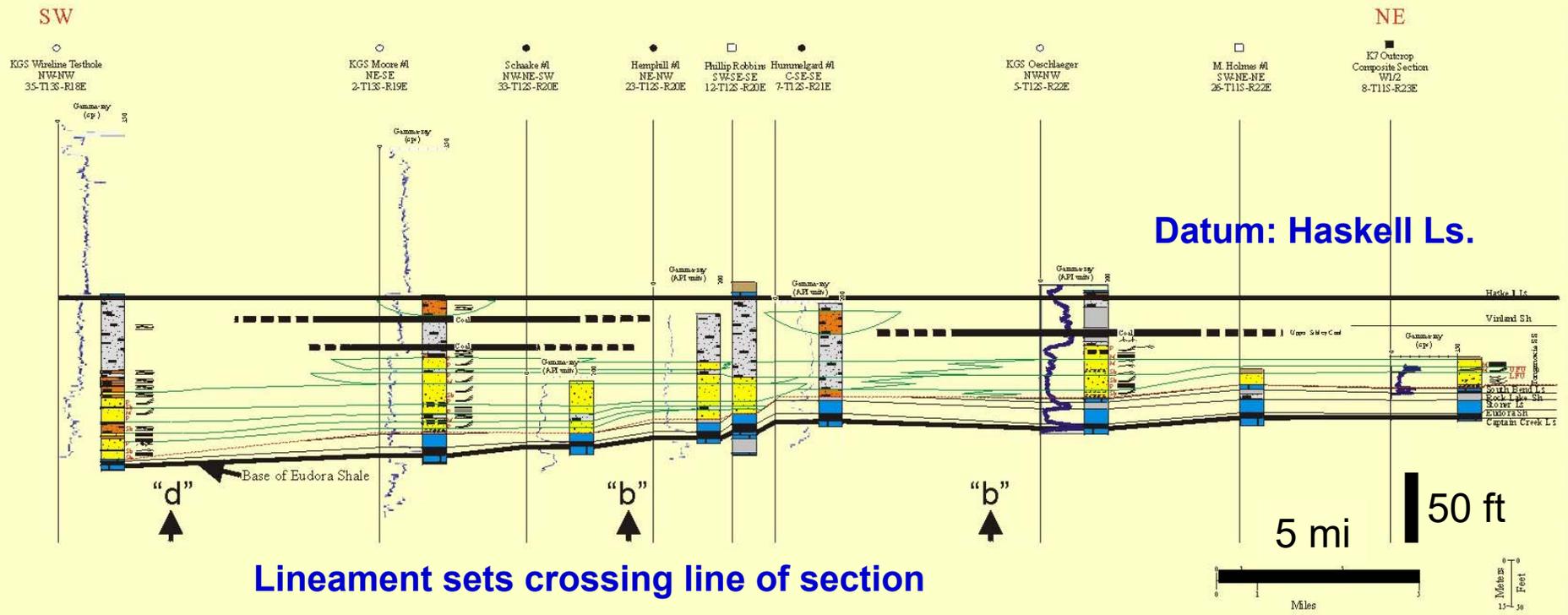
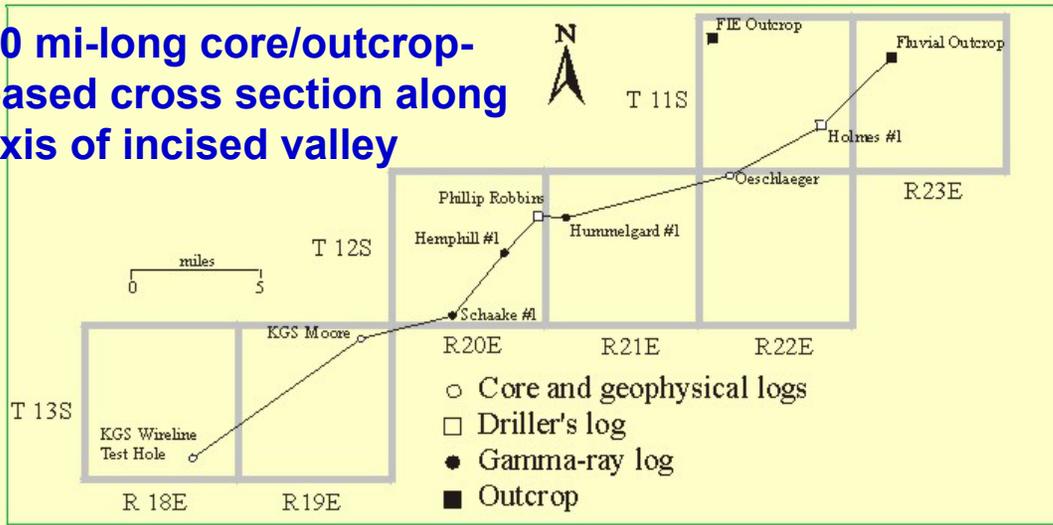
Isopach map of the base of Eudora Shale to the lower sequence boundary of the the Tonganoxie IVF modified from Feldman et al (1995) with gravity lineaments



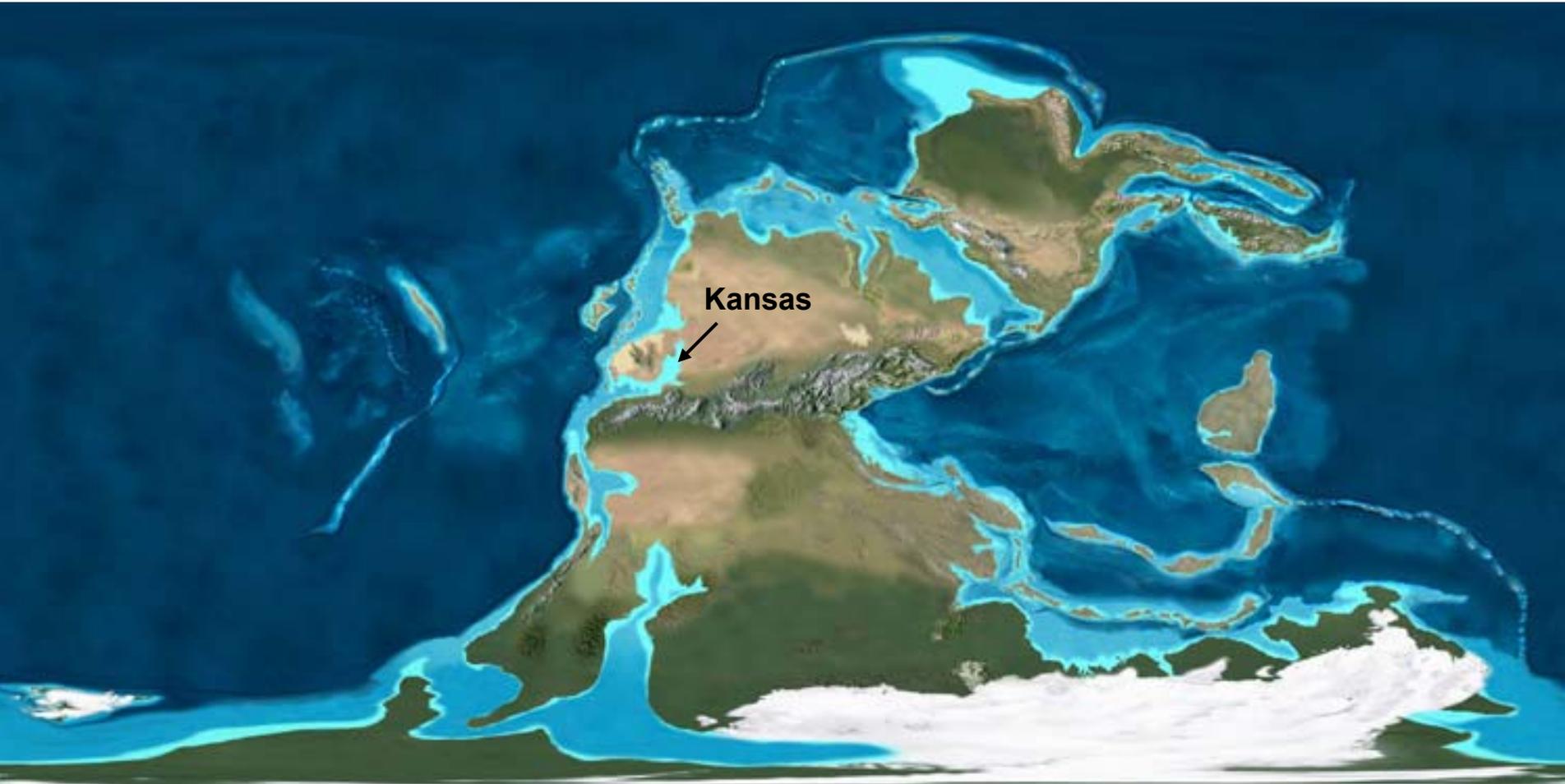
Beaty et al. (1999)

- Incised valley system along and near rhombohedral basement lineaments
- Northeastern Kansas

30 mi-long core/outcrop-based cross section along axis of incised valley



Early Permian Paleogeography

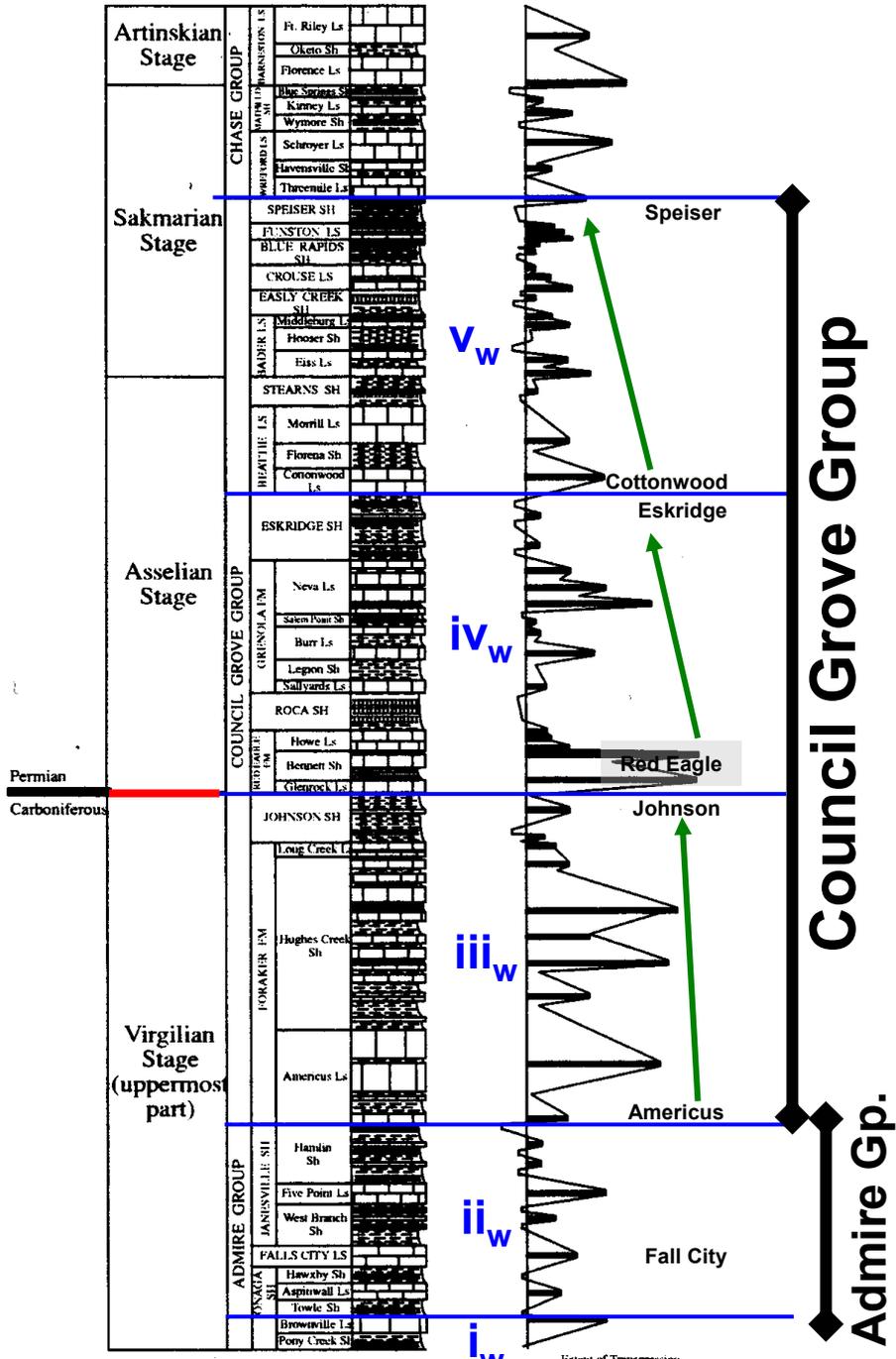


Factors impacting stratigraphy and lithofacies in the U.S. Midcontinent:

- Clastic sedimentation and structural deformation associated with waning stages of two related orogenies: *Ouachita/Marathon* & *Ancestral Rocky Mountain*
- Drier climate and glacio-eustacy with continued southern Pangea continental glaciation

Possible 3rd order depositional sequences

Virgilian and Lowermost Permian Sea-Level Curve and Cyclothems (after Boardman, 1999)



Permian Subsystem

Carboniferous

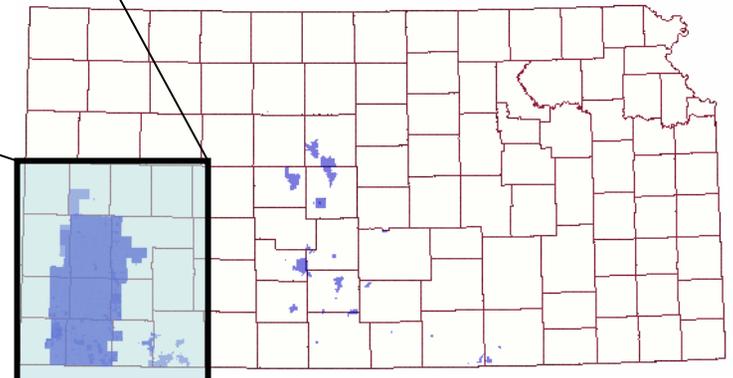
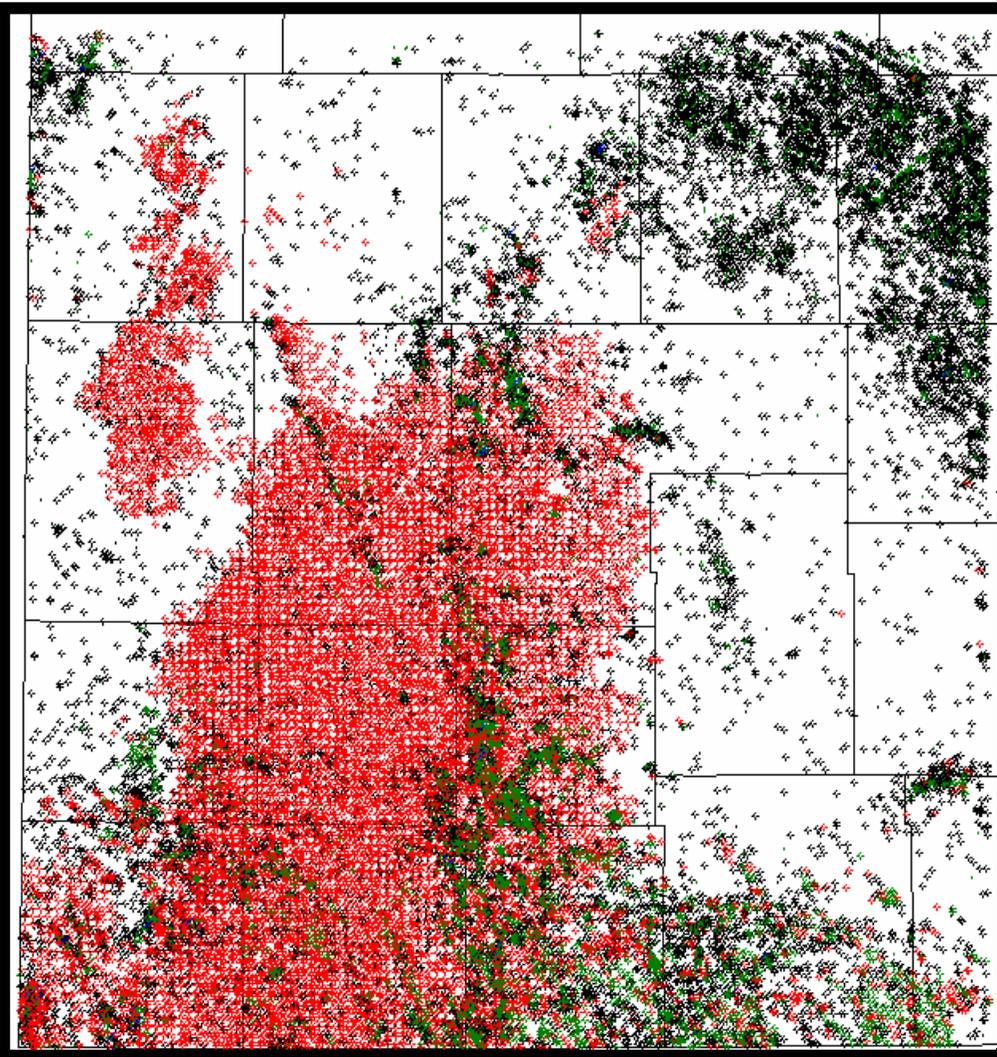


Council Grove Group

Late-stage tectonism of Ancestral Rockies

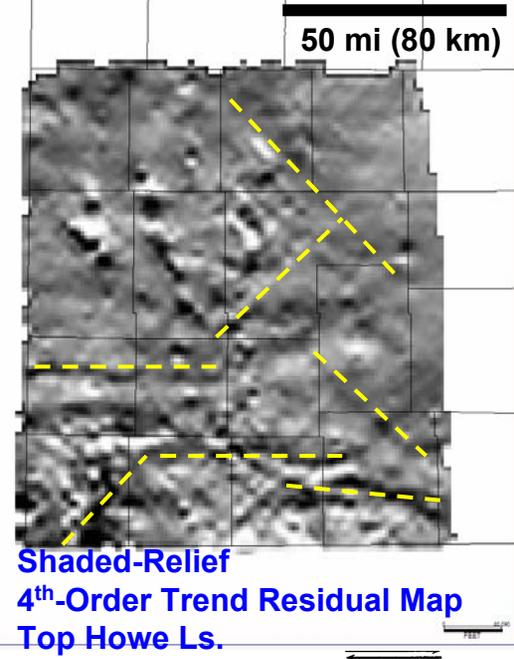
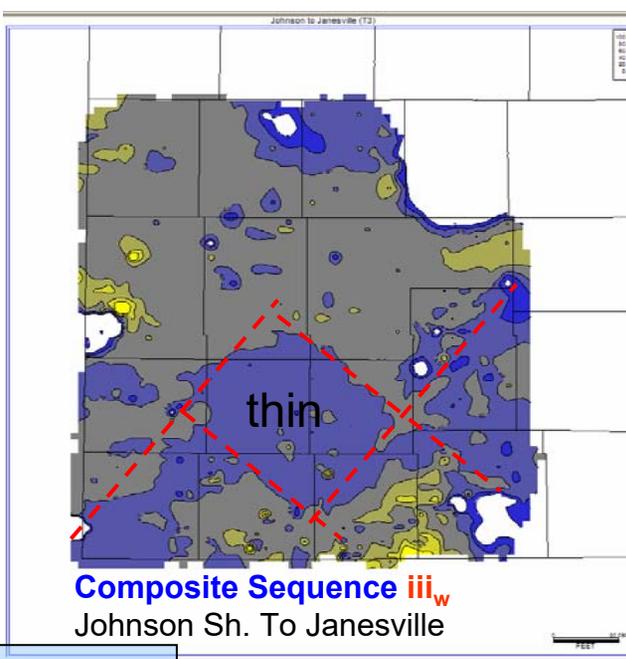
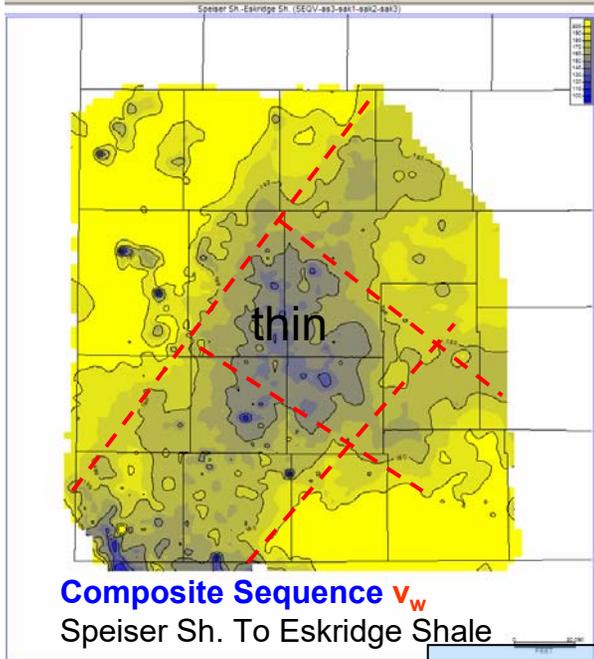
Well control in Southwest Kansas

- Average 12,000 wells per stratigraphic datum
- All data are available on website via ARC-IMS map server

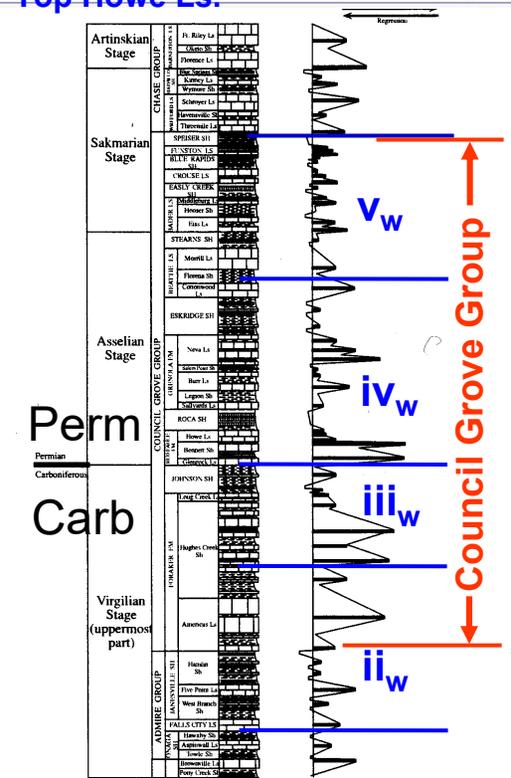
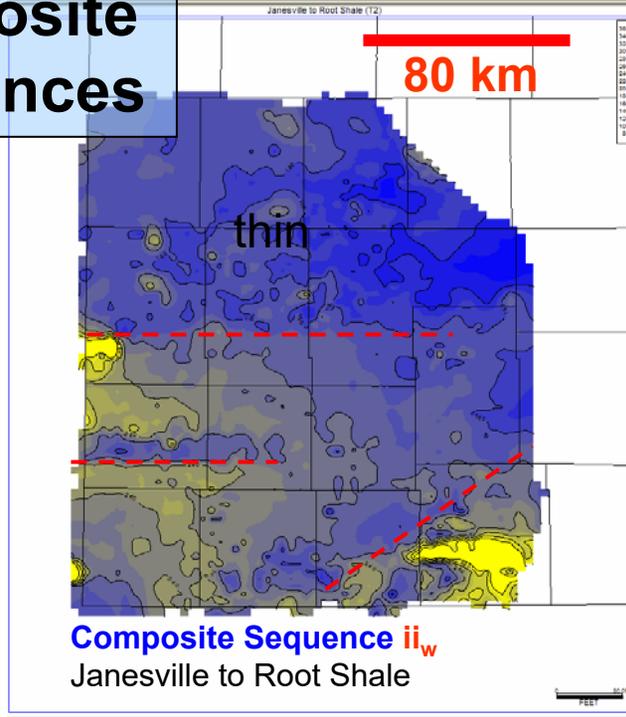
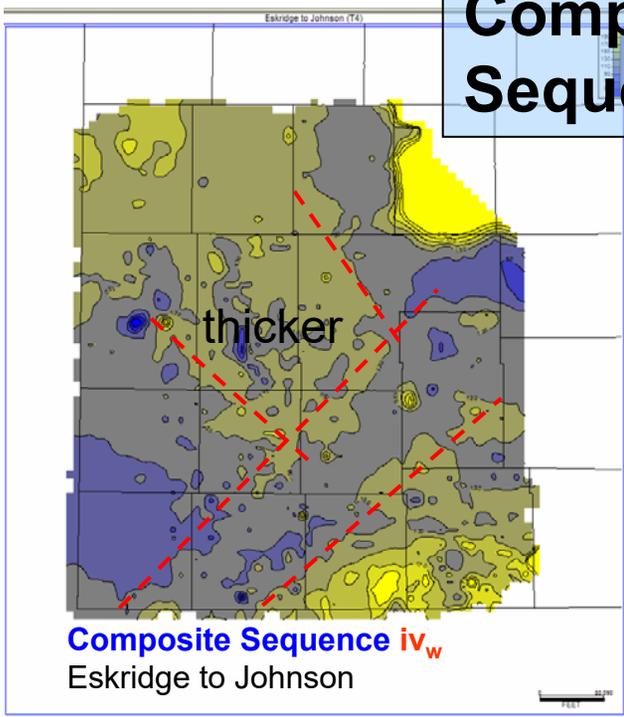


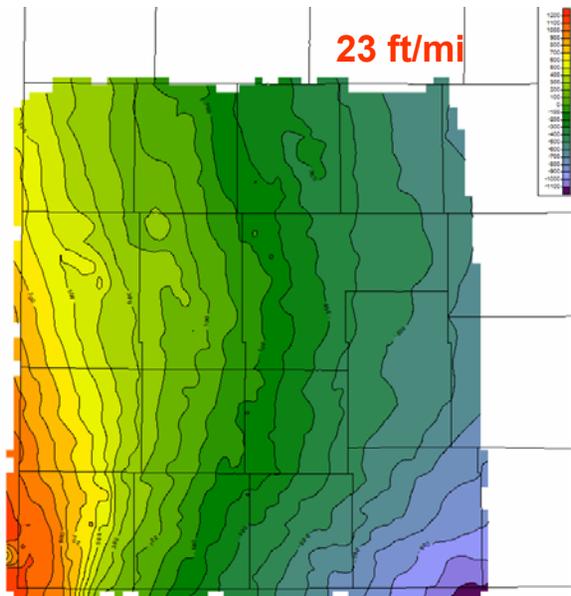
Gas production from Council Grove Group In Kansas

50 miles (80 km)

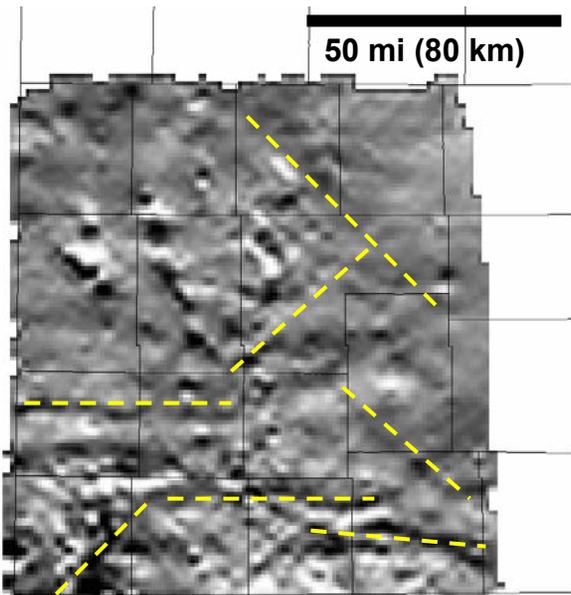


Composite Sequences



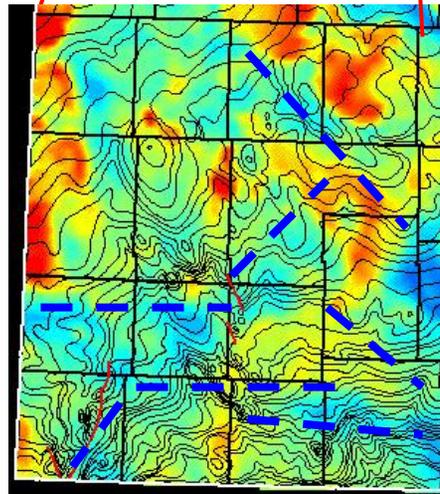
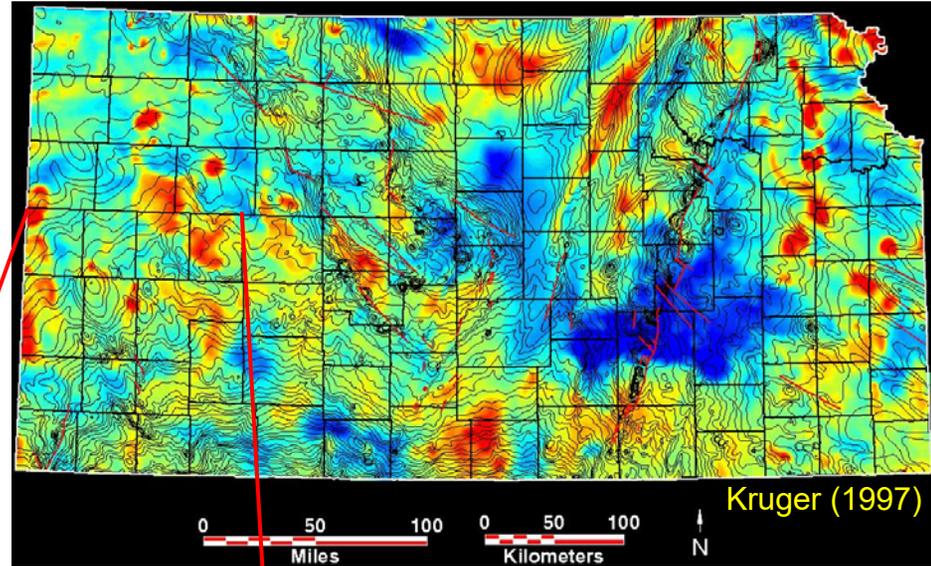


Structural Contour Map
Top Howe Ls.

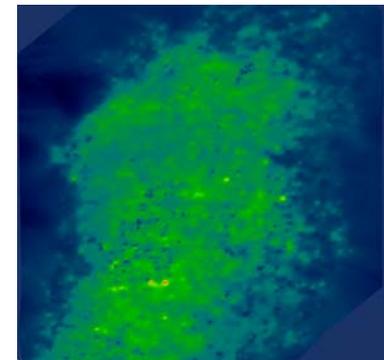


Shaded-Relief
4th-Order Trend Residual Map
Top Howe Ls.

Total Magnetic Field intensity with Precambrian basement contours

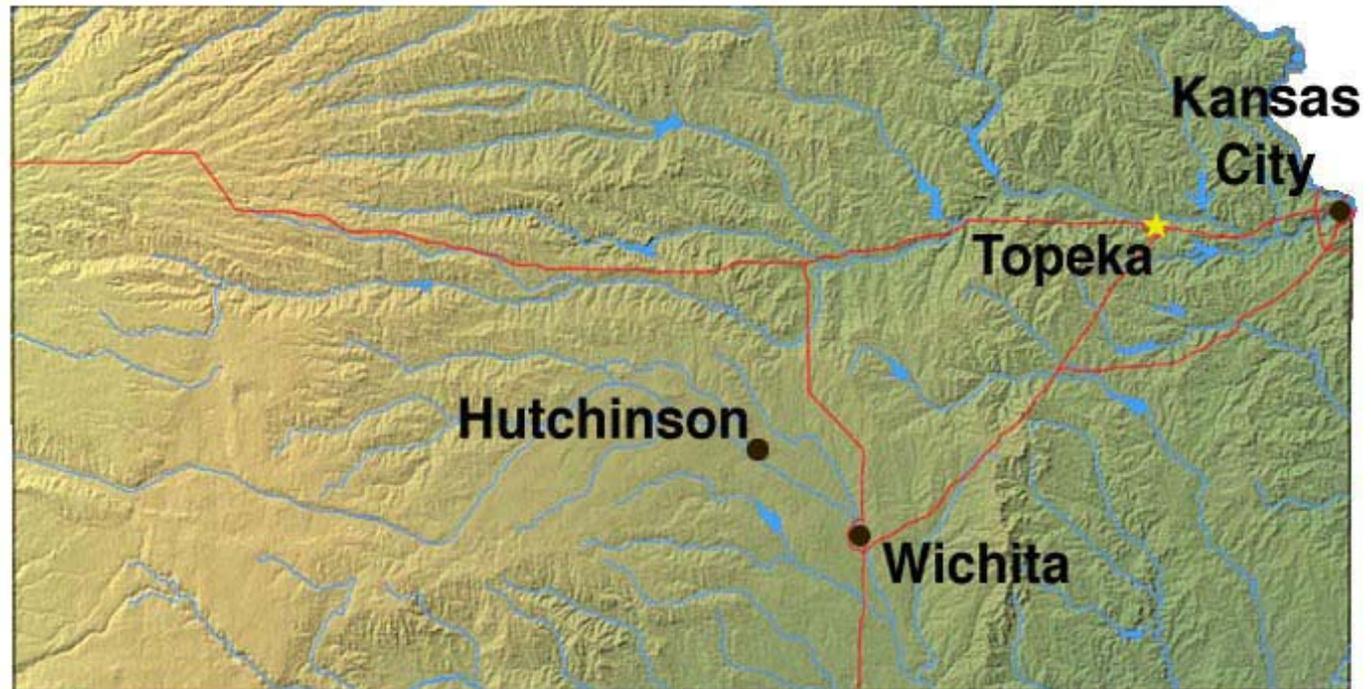


- Laramide structural overprint on Howe Ls.
- NW, NE, and E-W trends

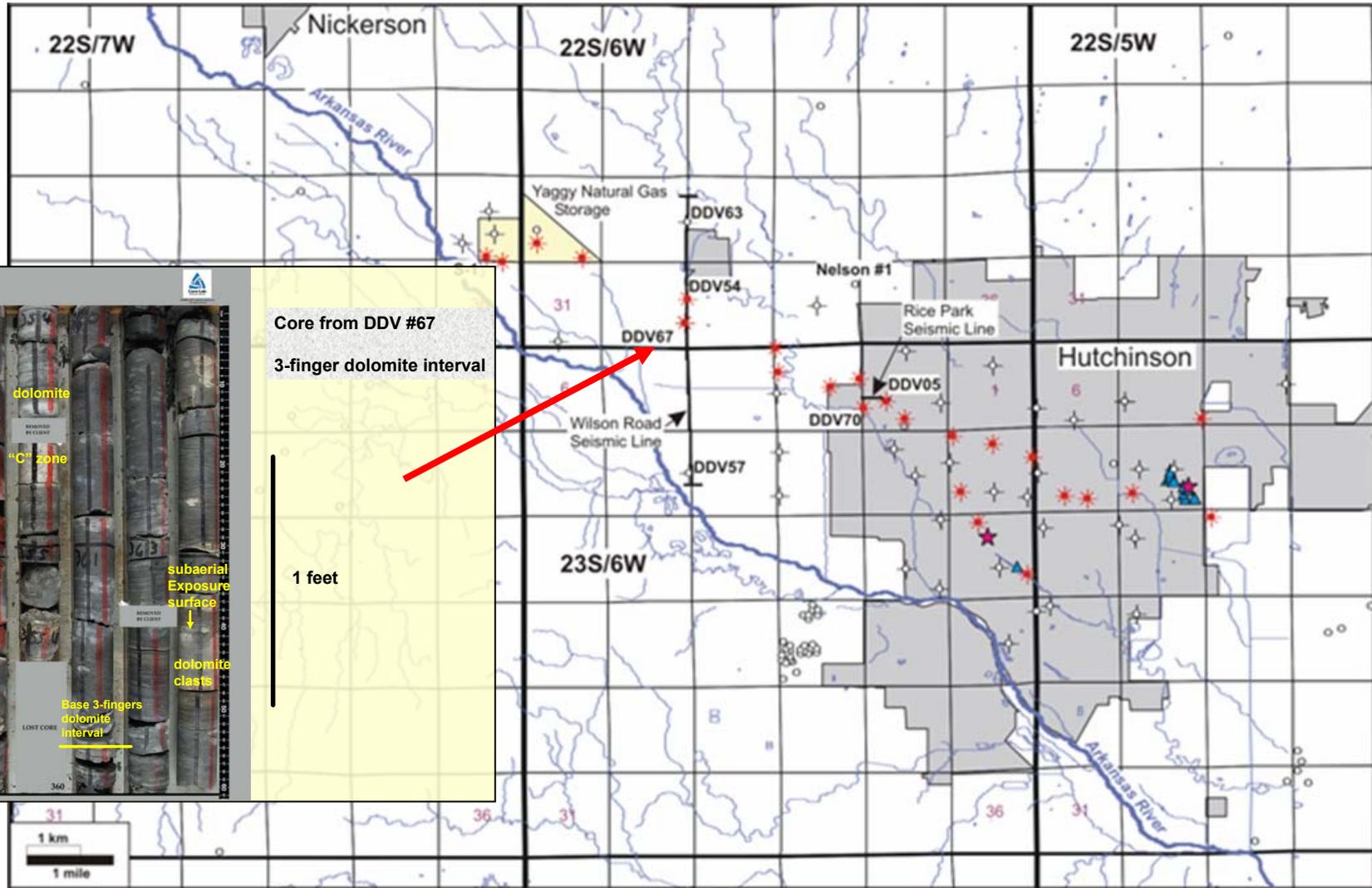


Cumulative CH₄ Production
(brighter = more gas)
Hugoton Gas Area
Southwest 3x4 counties

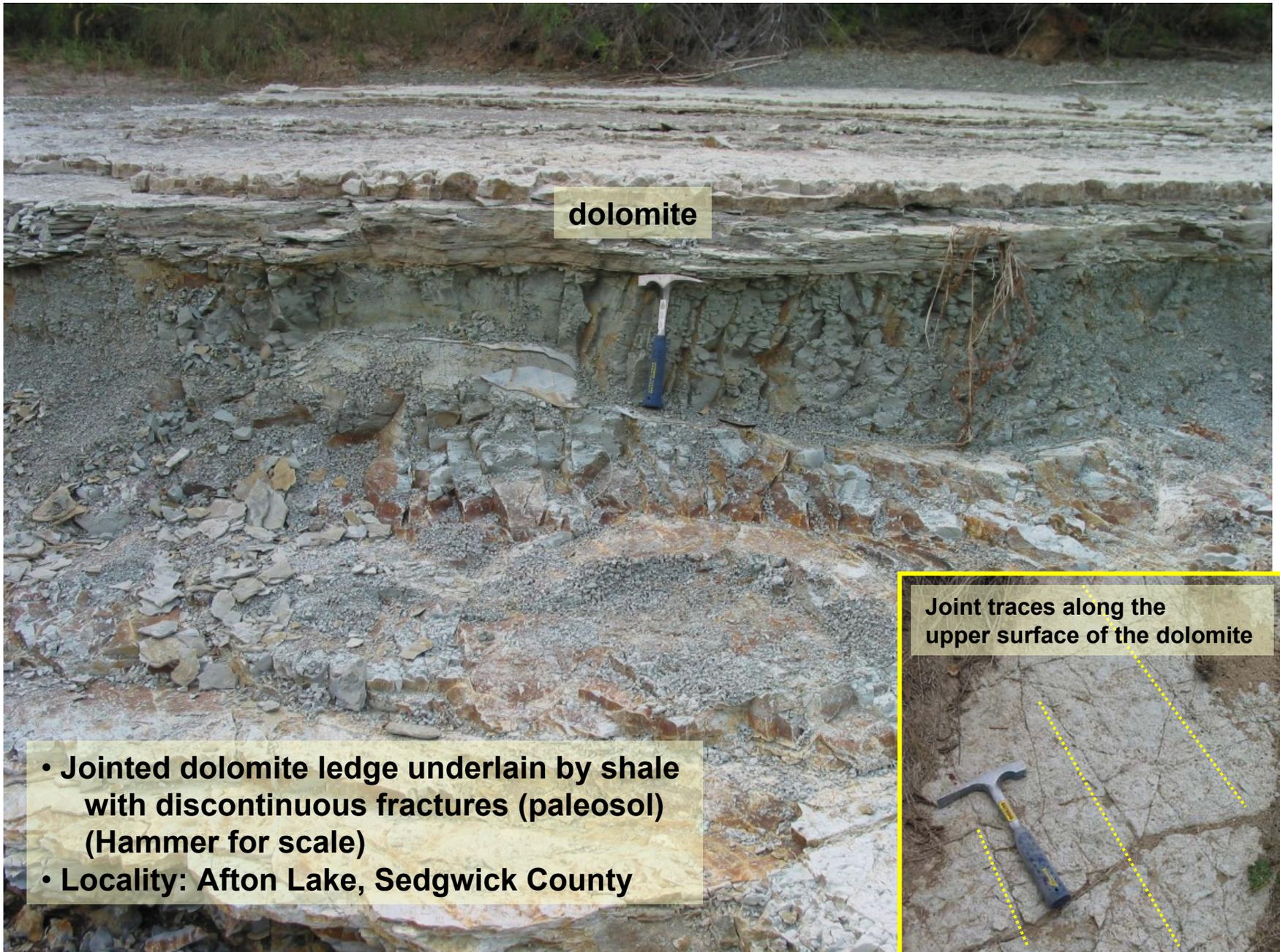
Fracturing and Evaporite Dissolution in Permian Strata



Hutchinson Gas Leaks

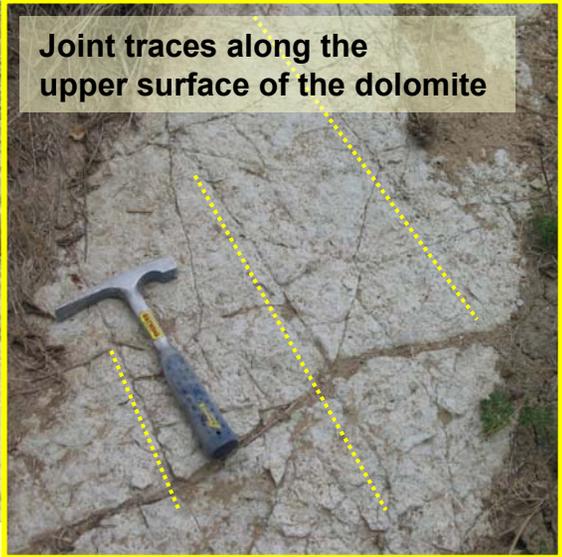


Sub-regional fracturing of a thin Upper Wellington dolomite bed above the Hutchinson Salt.



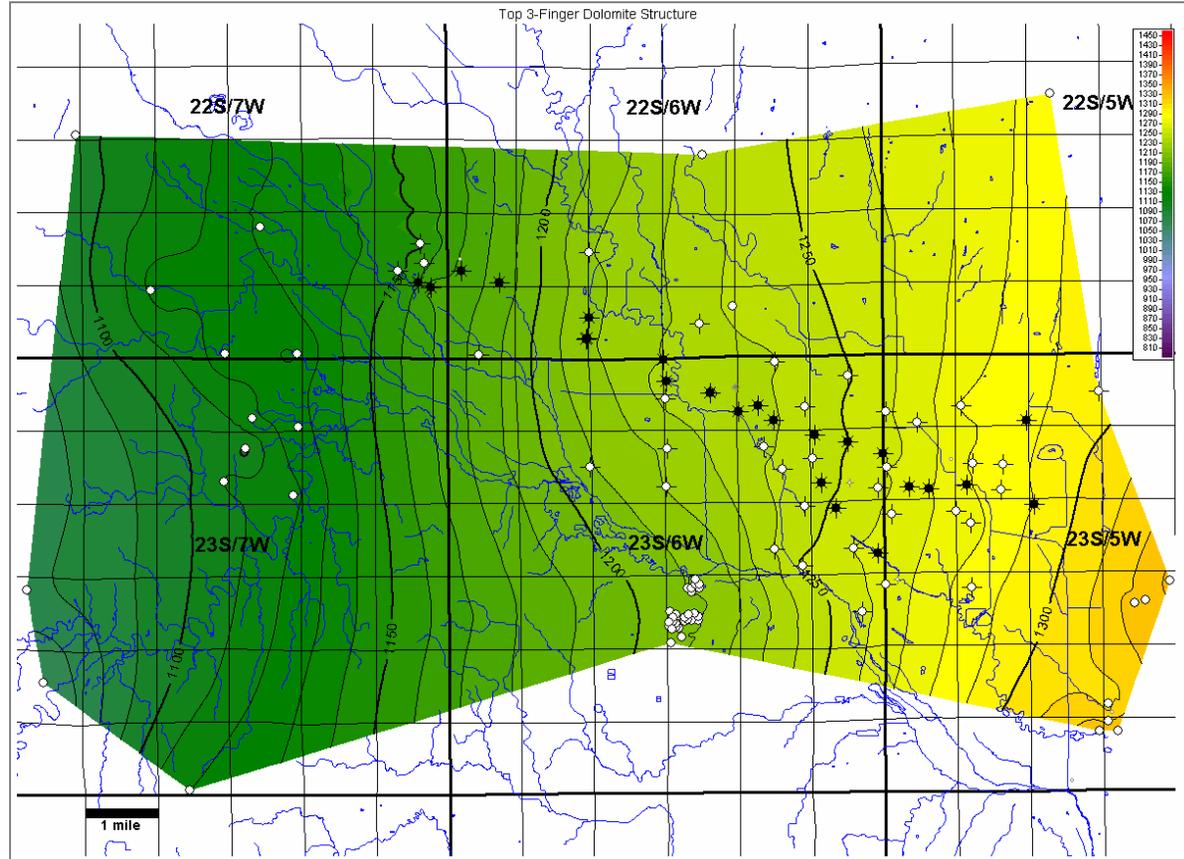
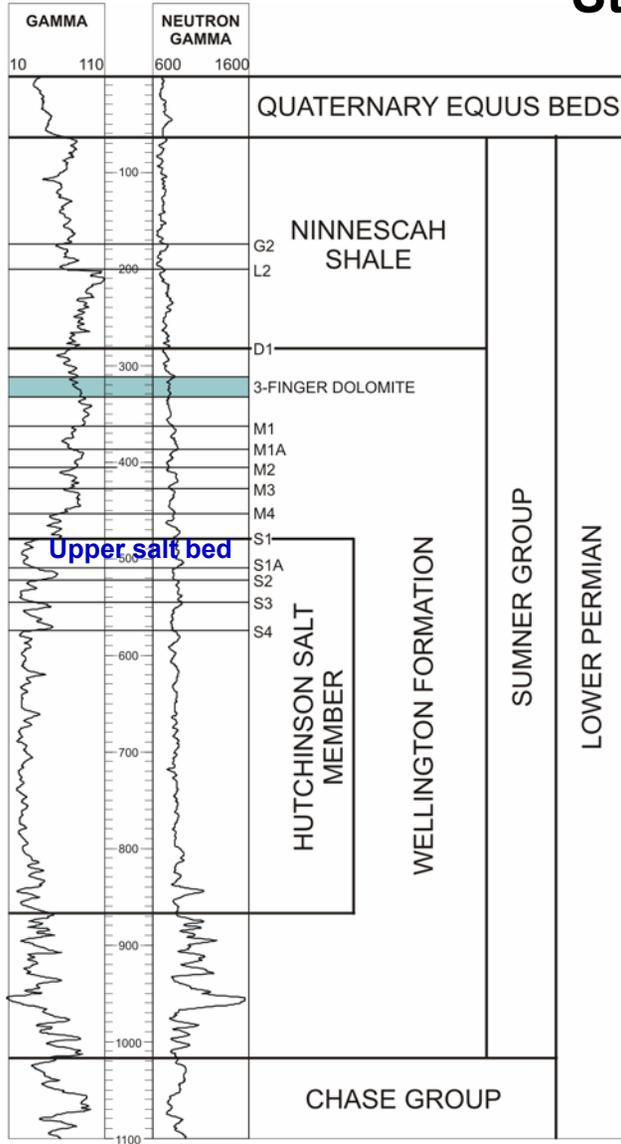
dolomite

- **Jointed dolomite ledge underlain by shale with discontinuous fractures (paleosol) (Hammer for scale)**
- **Locality: Afton Lake, Sedgwick County**



Joint traces along the upper surface of the dolomite

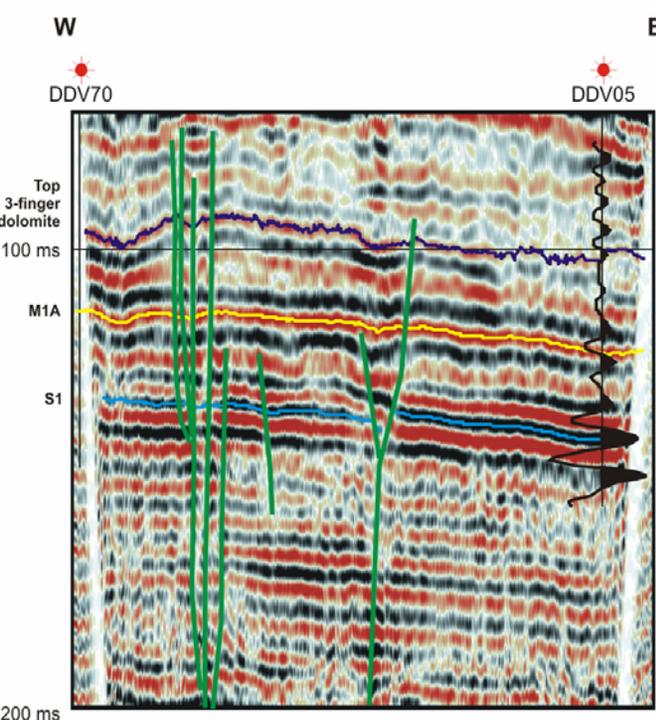
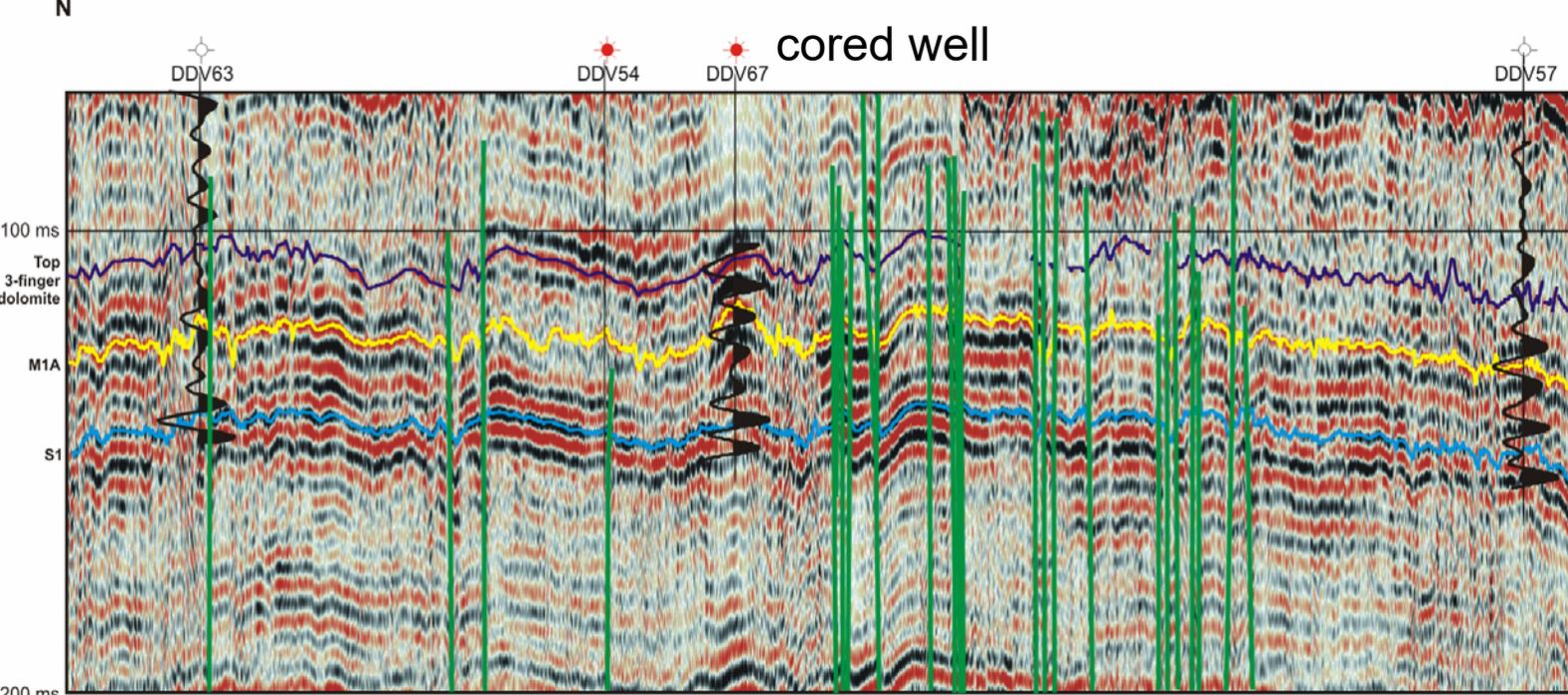
Structural contour map on top of 3-Finger dolomite



Type log Hutchinson Area

Watney et al. (2003)

- **Monoclinial dip**
- **High-resolution stratigraphic mapping of intervals above Hutchinson Salt reveal episodic dissolution of upper Hutchinson Salt**
- **Upper salt bed locally missing**



Wilson Road (Top) and Rice Park (Bottom) seismic lines

Seismic peaks are black, troughs are red.

The seismic reflections:

- top of 3-finger dolomite (purple)
- M1A marker (yellow)
- top Hutchinson Salt Member (S1) (blue)

Heavy green lines are interpreted faults.

NORTH

SOUTH

#63

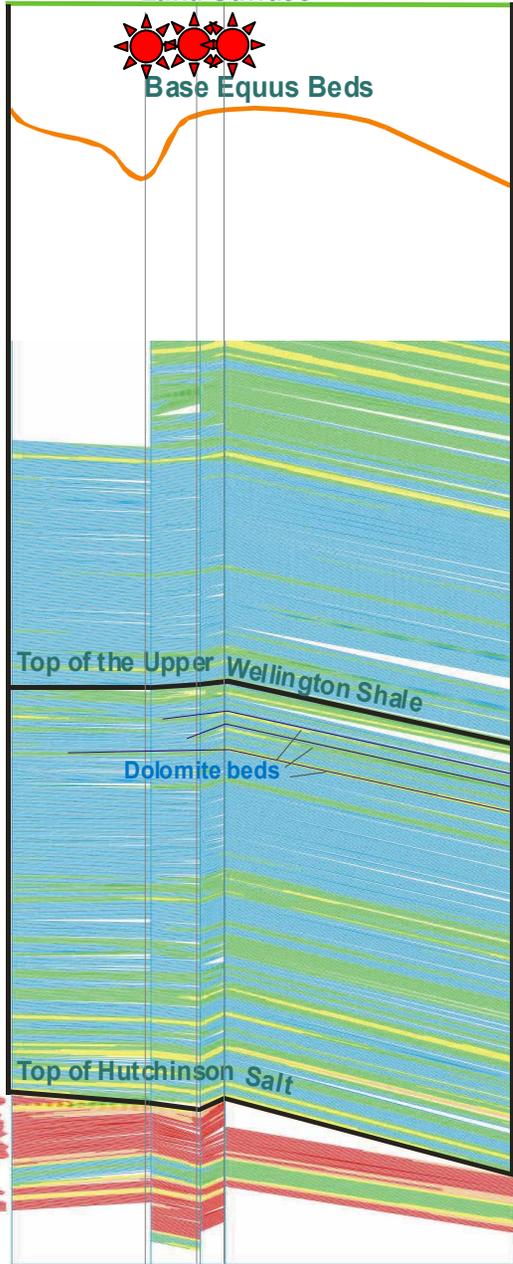
#54 #53 #67

#57

Land Surface



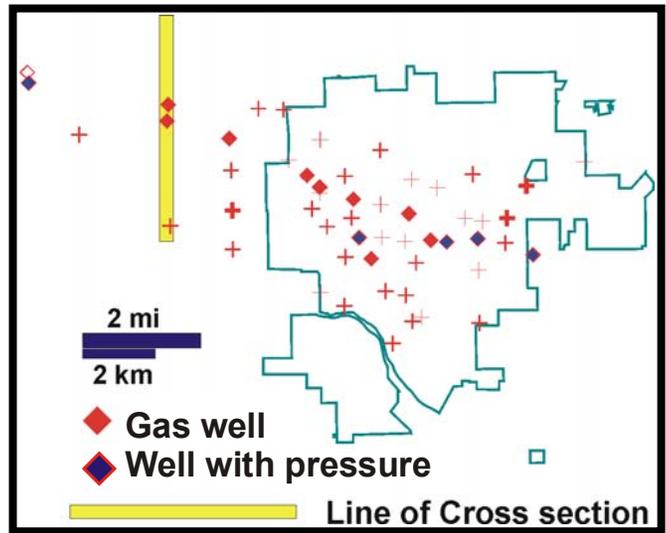
Base Equus Beds



100 ft

1 MILE

34X EXAGGERATION



2 mi

2 km

◆ Gas well

◆ Well with pressure

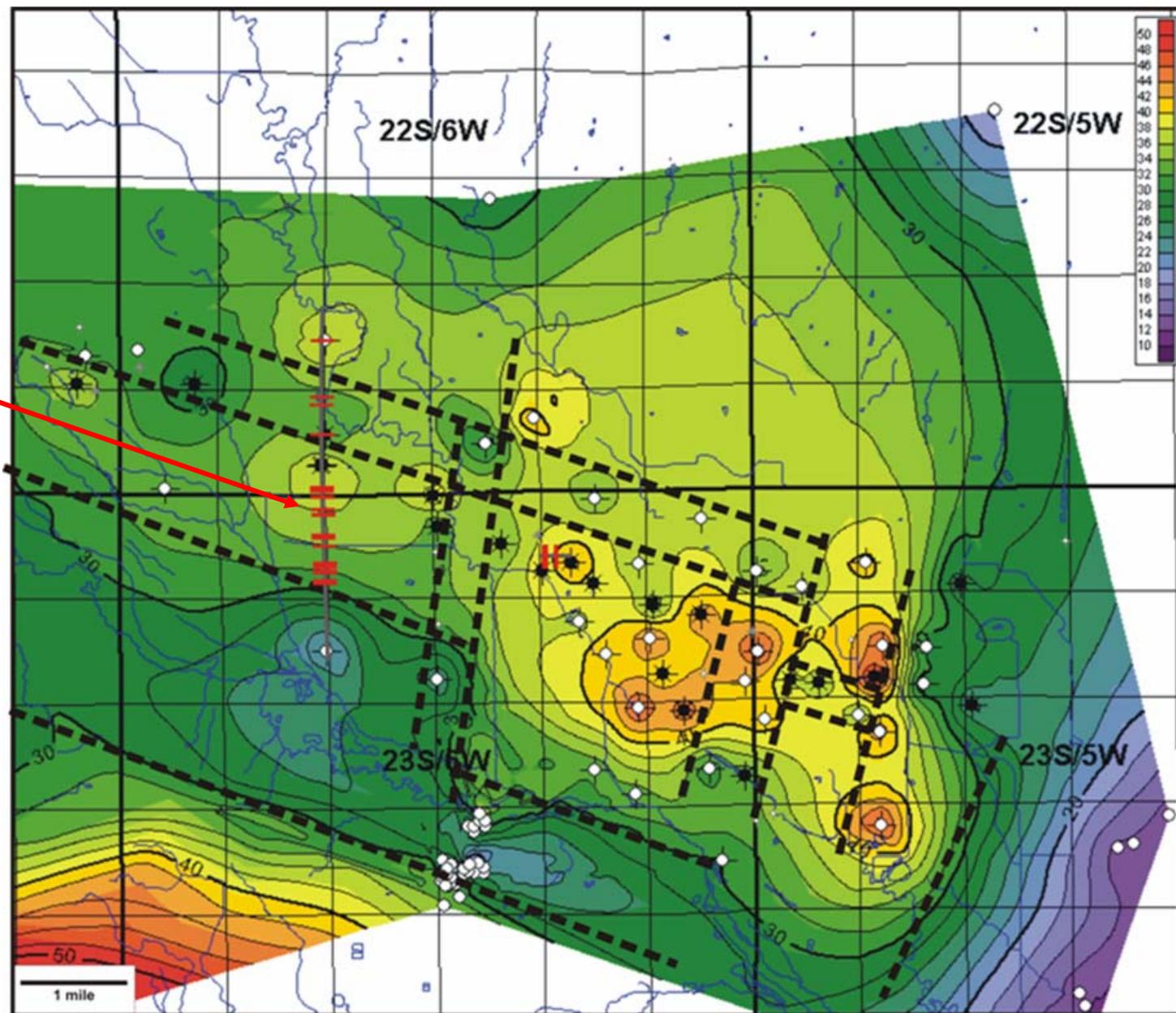
Line of Cross section

Structural cross section along Wilson Road

- Natural gamma ray
- Autocorrelated for interval above Hutchinson salt
- Upper bed Hutchinson Salt (red) markedly thins
- Dolomite beds in yellow
- Northward thinning of 3-finger dolomite
- Wells #54 & #53 = gas at seismic anomalies

S2-S1 (upper salt bed) isopach map for Yaggy- Hutchinson area, with interpreted structural lineaments

Fractures interpreted from seismic



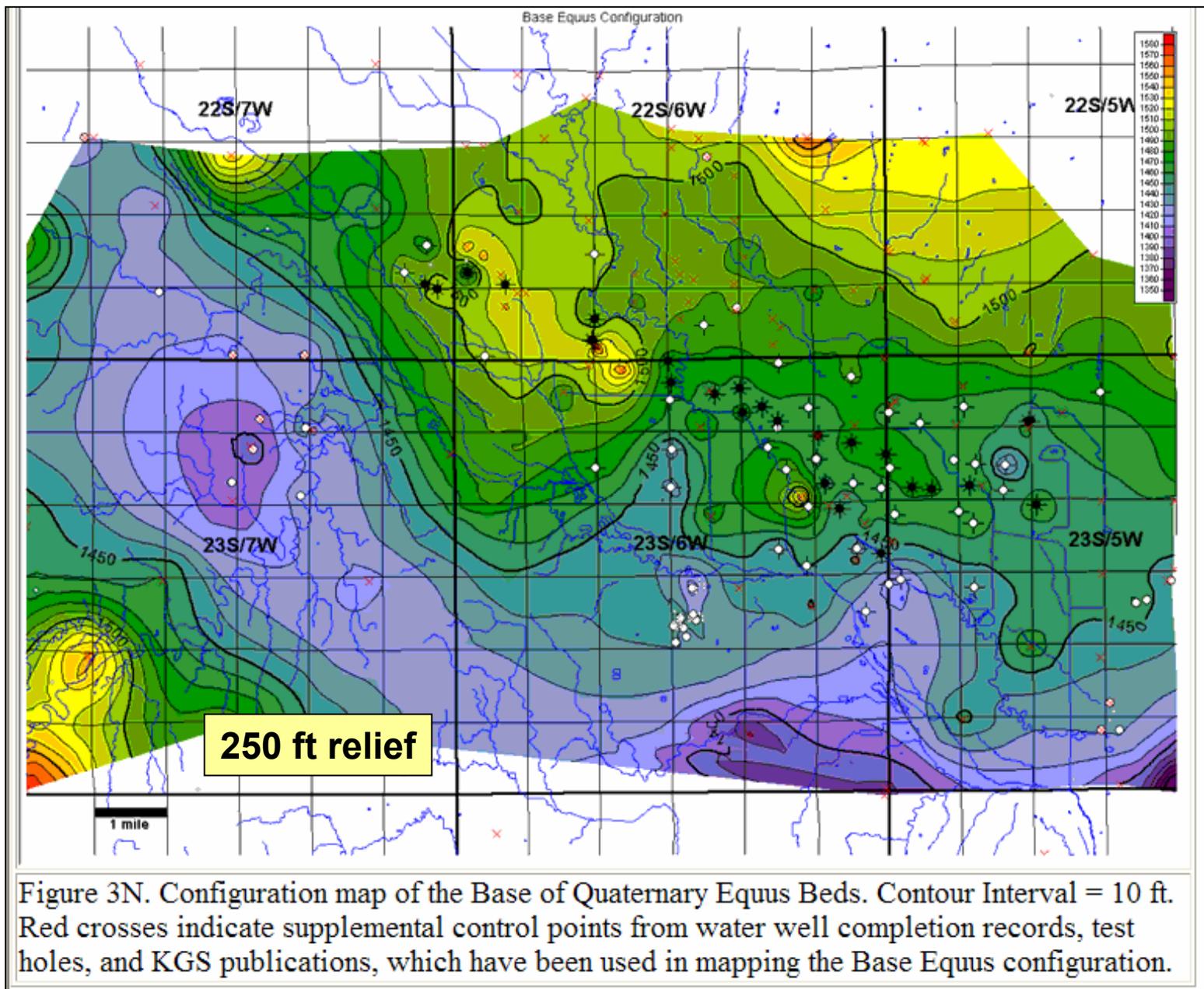
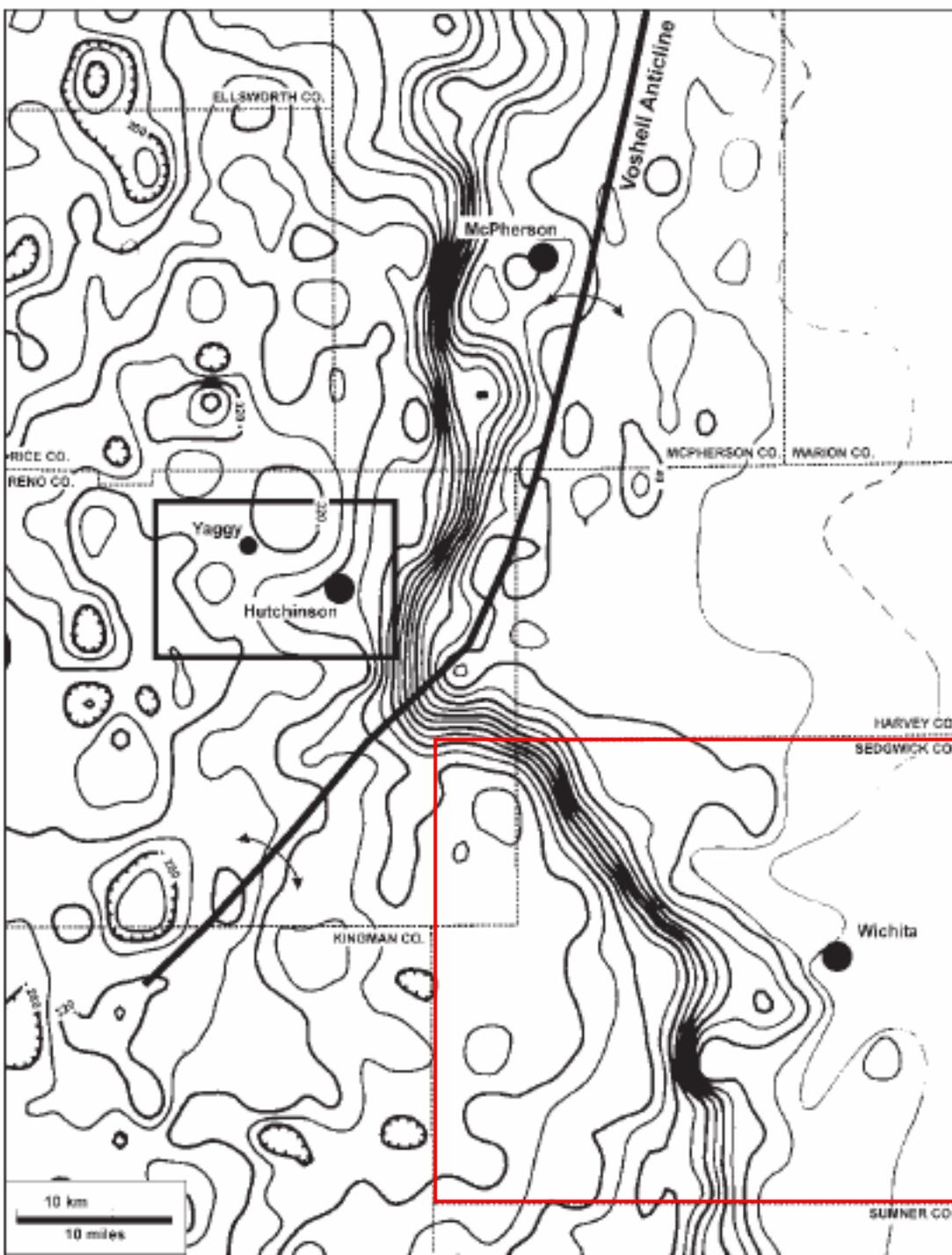


Figure 3N. Configuration map of the Base of Quaternary Equus Beds. Contour Interval = 10 ft. Red crosses indicate supplemental control points from water well completion records, test holes, and KGS publications, which have been used in mapping the Base Equus configuration.

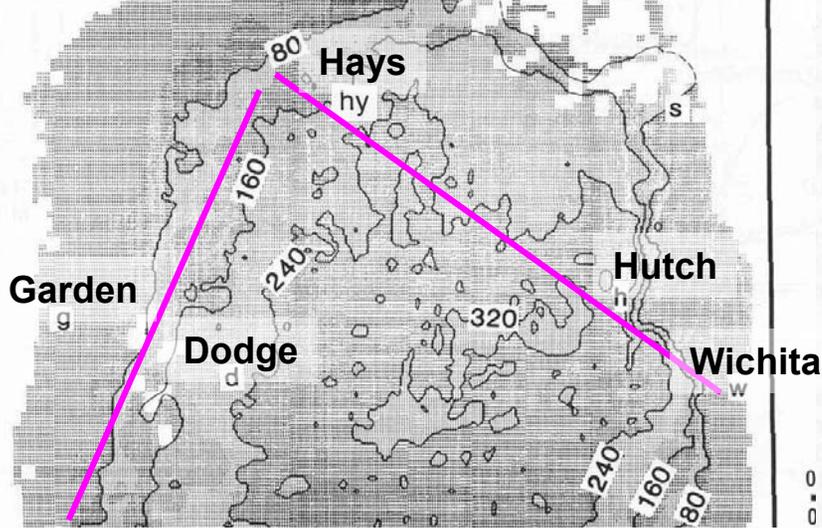
Nissen and Watney (2003)

Net Halite Isopach For Hutchinson Salt (Watney & Paul, 1980)



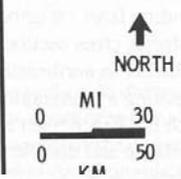
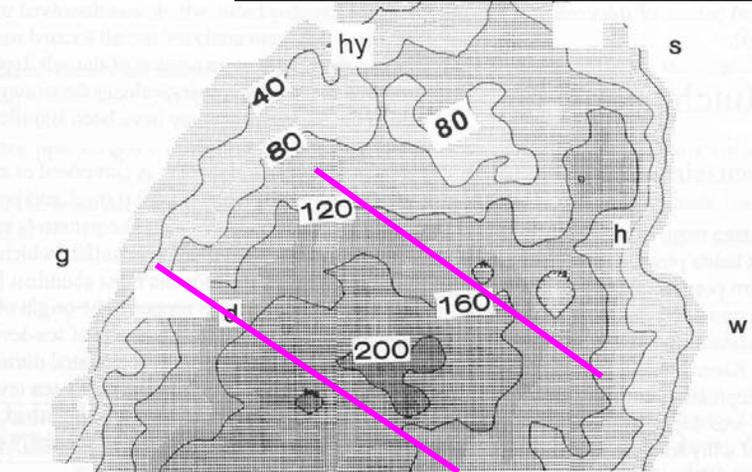
- Structural control on dissolution front of Hutchinson Salt –Voshell-Abilene Anticline (MRS)
- Dissolution front bends along Arkansas River between Hutchinson and Wichita

**Total Net Halite
Hutchinson Salt
Watney et al. (1988)**

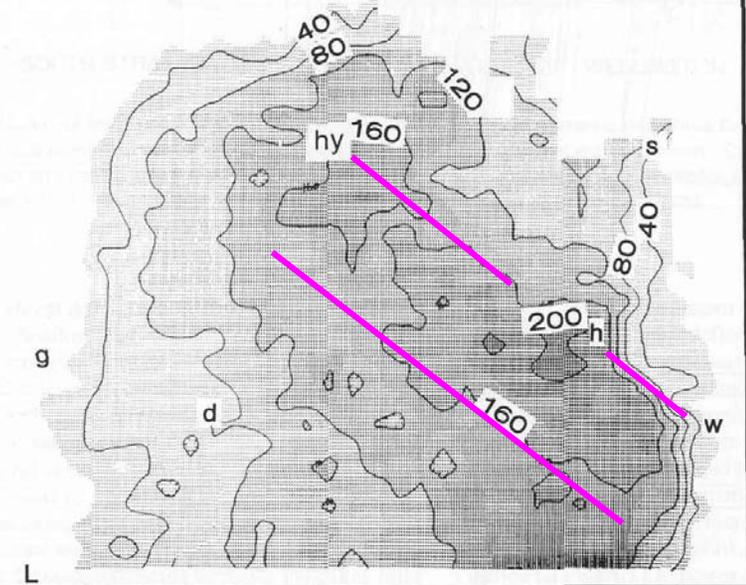


**Net Halite
Upper
Hutchinson
Salt**

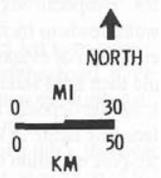
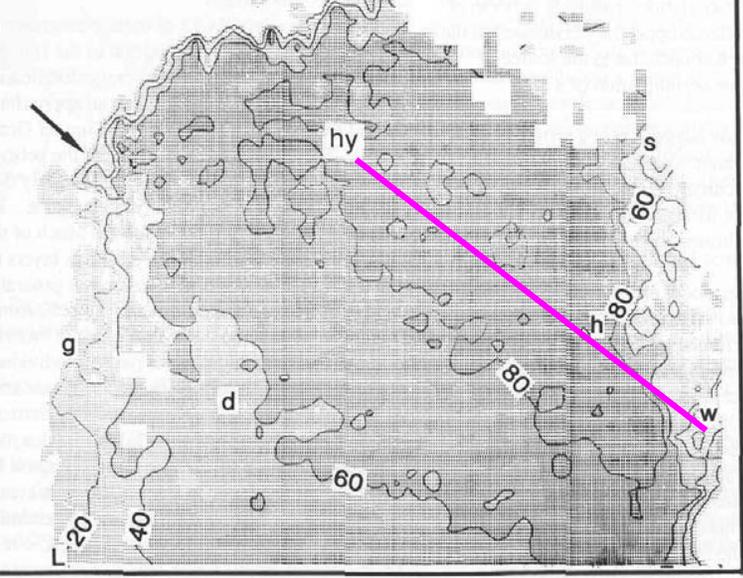
**Persistent lineaments expressed during
deposition of Hutchinson Salt
corresponding to
Precambrian terrane boundary
and potential field lineaments**



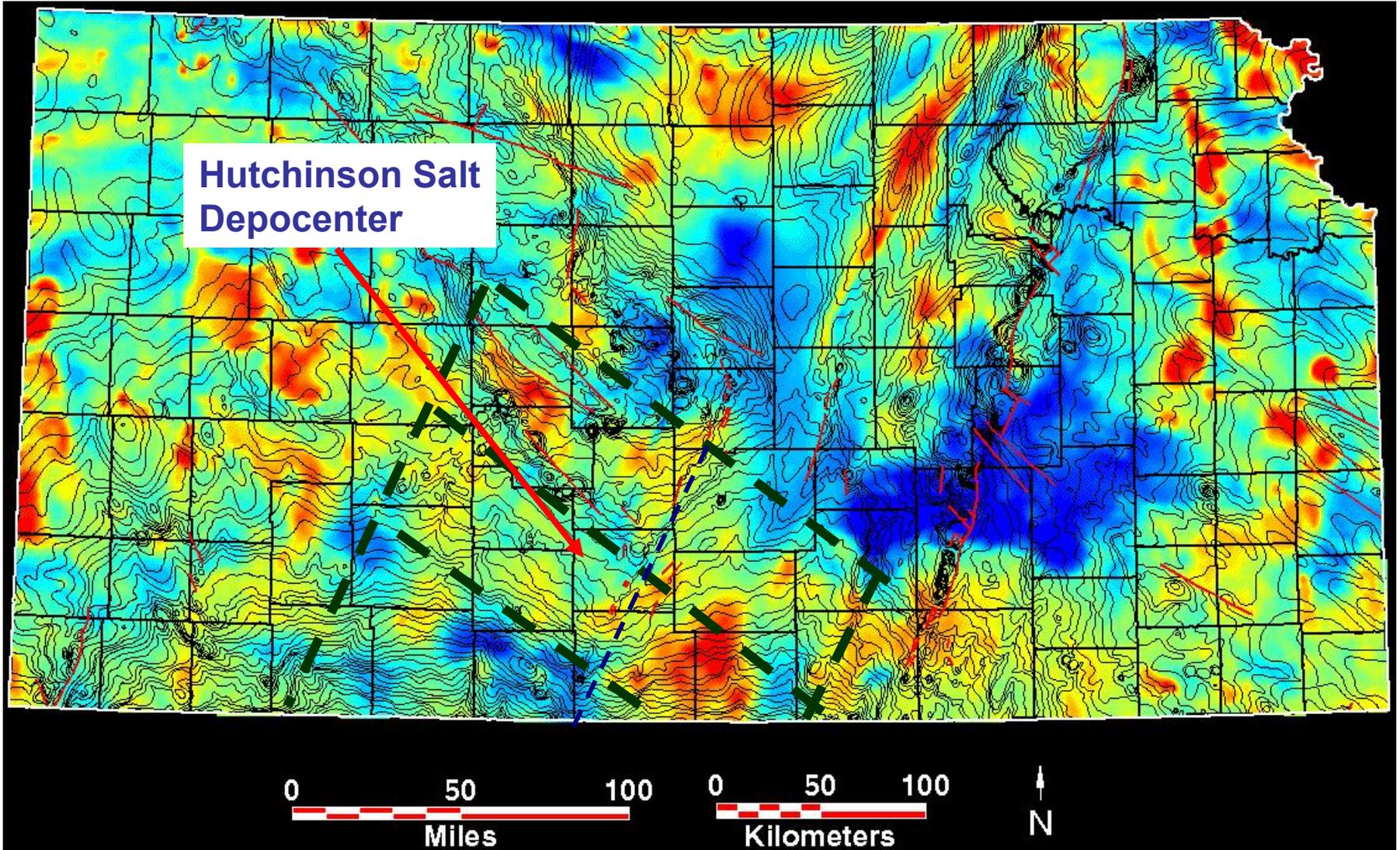
**Net Halite
Lower Hutchinson Salt**



**Percent Halite
Hutchinson Salt**



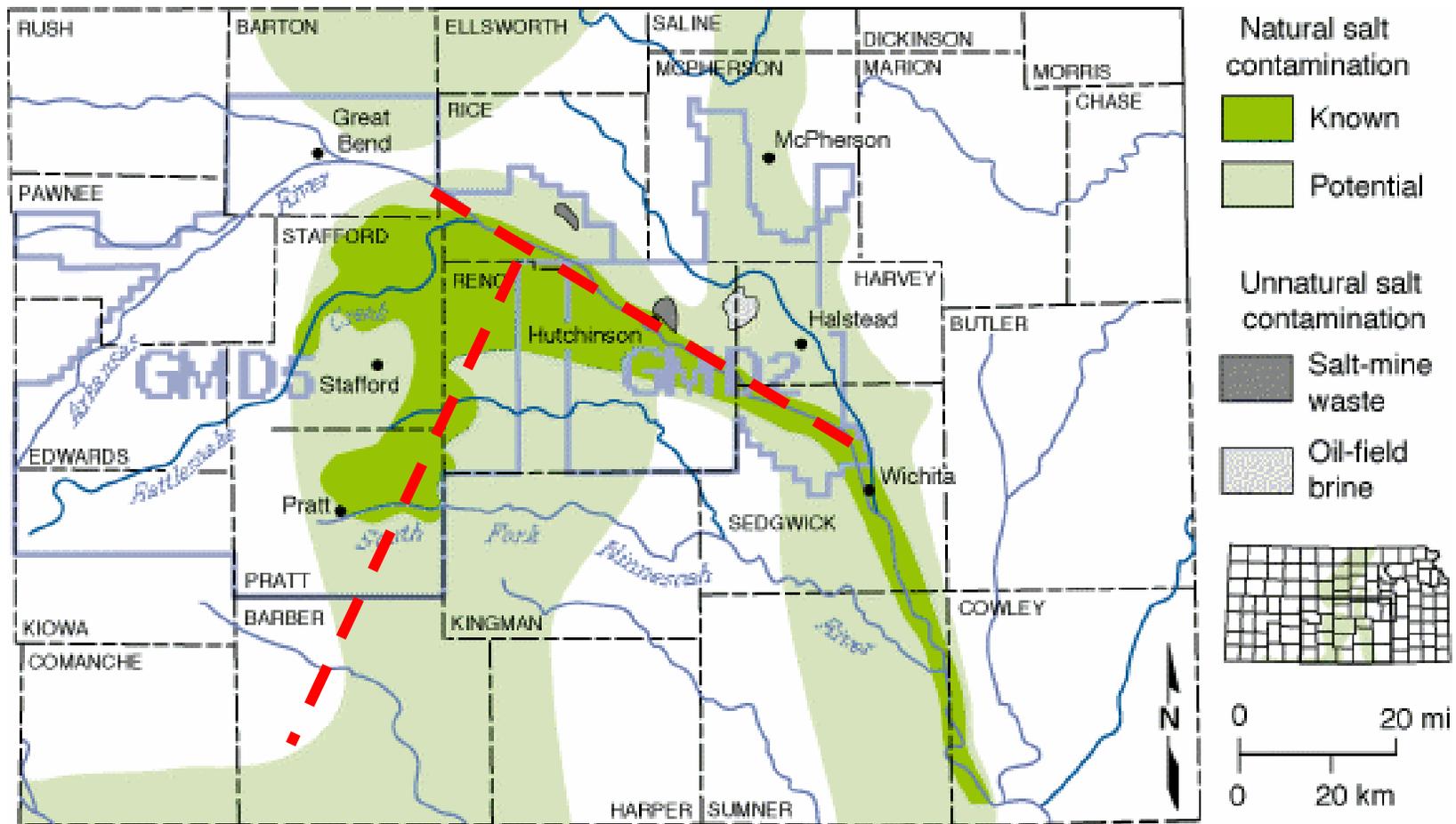
Total Magnetic Field Intensity



Lineaments shown are edges of thick salt and internal trends

Red = high mag.
Blue = low mag.

Contours = Precambrian surface isochores



Final Summary and Data Report: The Equus Beds Mineral Intrusion Project

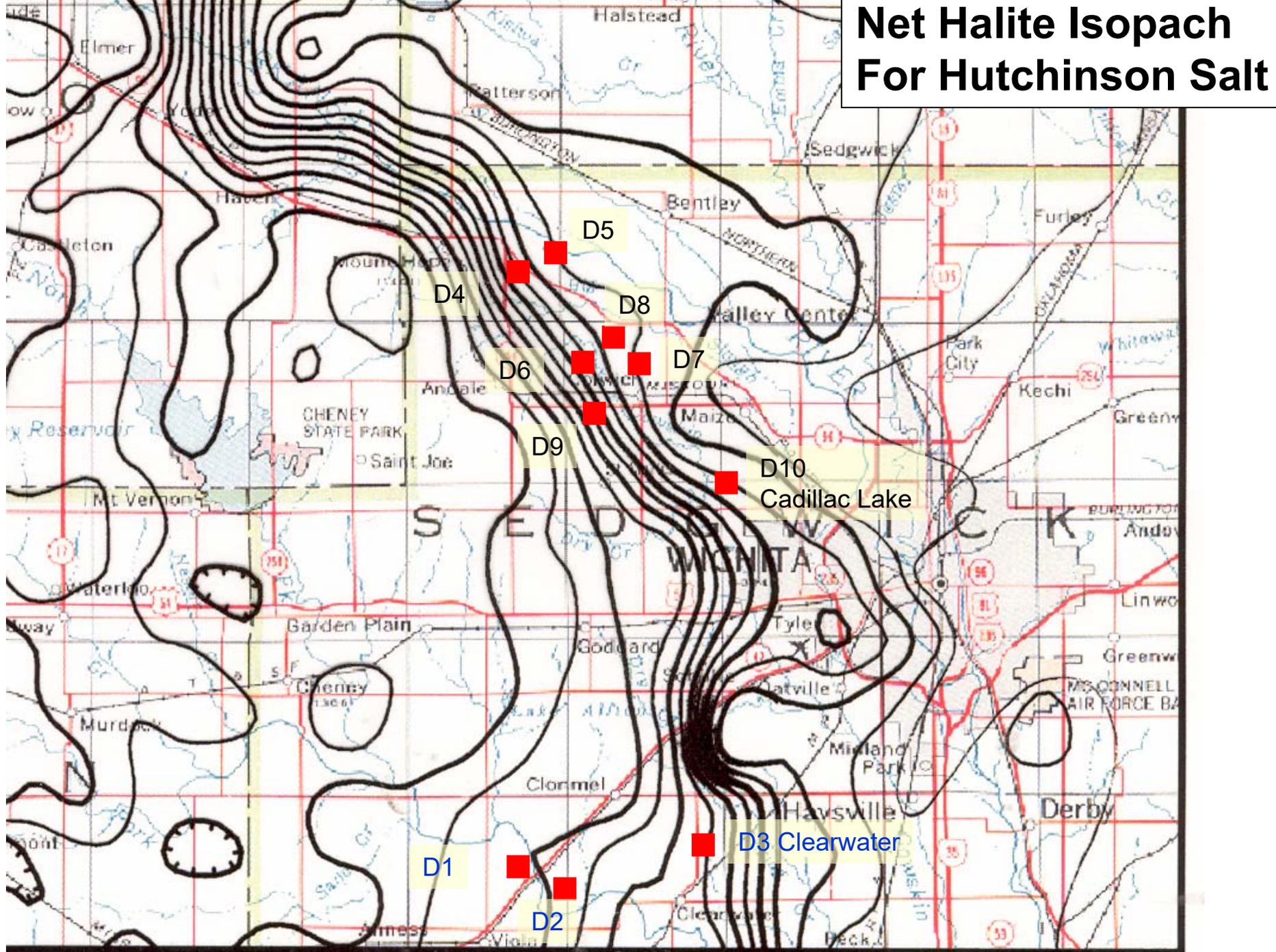
by D. P. Young, R. W. Buddemeier, D. O. Whittemore, and H. Rubin

Kansas Geological Survey, University of Kansas

KGS Open File Report 2000-30

March, 2001

Net Halite Isopach For Hutchinson Salt



Surface
Subsidence
(Clearwater)

Salt dissolution
solution front



Pointer 37°34'00.58" N 97°29'13.34" W

© 2006 Navteq
Image © 2006 MDA EarthSat
Image © 2006 DigitalGlobe

© 2005 Google

Streaming ||||| 100%

Eye alt 22220 ft

Conclusions

- Shelf margin and inner shelf carbonate settings were affected by subtle, but important block faulting at scales of 10's to 100's of km (rhombohedral-shaped blocks)
- Preferred reactivation of basement faults influenced locations of shelf edges, caused segmentation of the ramp/shelf profiles, and influenced deposition & diagenesis.
- Large- to small-scale kinematic (3D structural time-series) analysis accomplished through 3-D seismic & regional high-resolution stratigraphic analysis will aid in refined reservoir and play prediction.
- Sea level, climate, depositional setting, and local paleotopography affected by contemporaneous structural movements led to site-specific conditions favoring reservoir development.

Reevaluate Role of Midcontinent Structures in Play, Field, and Reservoir Characterization

- **Dominant role of Precambrian faults**
- **Segmented shelf bounded by narrow deformation zones**
- **Localized structural blocks active during sedimentation**
 - Affecting paleotopography and sedimentation
 - Controlling drainage pathways for streams and valley incision
 - Localized currents and waves affecting carbonate shoal or topography for carbonate/siliceous buildups
- **Episodic reactivation of preferred structures through time**
 - Influence diagenesis, evaporite dissolution, and fluid migration.
- **Changing structural patterns through time:**
 - Changing stress field
 - Pre-existing faults with orientations favoring episodic reactivation
 - Variations in local composition/density of crust affecting strain behavior
 - Modeled by relatively simple mechanical simulations
- **Couple structure history with sea level, diagenesis, HC migration = Prediction**
- **Opportunities**
 - Unparalleled resolution of subsurface volumes with 3D seismic imaging
 - High-density acquisition of potential fields data and basement modeling
 - Incorporation of improved mechanical models in reservoir characterization

Acknowledgements

- Grand Mesa Operating Company for providing seismic and well data for Dickman Field & Don Beauchamp for excellent sample & core descriptions
- Murfin Drilling Co. for operation of Hall-Gurney Field CO2 field demonstration
- Seismic Micro-Technology, Inc. for access to *The KINGDOM Suite+* software
- GeoPLUS Corporation for access to the PETRA software
- US Department of Energy for support on Dickman Field, Hall-Gurney, Penn. Modeling, GEMINI web-based software development.,

References

Baars, D.L., and Watney, W.L., 1991, Paleotectonic control of reservoir facies: in Franseen, E.K., Watney, W.L., Kendall, C.G.St.C., and Ross, W., Sedimentary Modeling: Computer Simulations and methods for improved parameter definition: Kansas Geological Survey Bulletin, 233, p. 253-262.

Beaty, S. Watney, W.L.; and Martinez, A., 1999, Analysis of structural controls on the development of the Upper Pennsylvanian Tonganoxie incised paleovalley system of northeastern Kansas, pp. 141-151, In, Merriam, D.F., (ed.); Geoscience for the 21st century, transactions of the 1999 American Association of Petroleum Geologists, Midcontinent Section Meeting: Kansas Geological Survey, Open-file Report, no. 99-28.

Blakey, R., accessed 2005, Early Permian Paleogeography, Mollenwide Plate Tectonics Maps, <http://jan.ucc.nau.edu/~rcb7/280moll.jpg>.

Byrnes, A.P. Franseen, E.K., Watney, W.L., Dubois, M.K., 2003, The Role of Moldic Porosity in Paleozoic Kansas Reservoirs and the Association of Original Depositional Facies and Early Diagenesis With Reservoir Properties: Kansas Geological Survey, Open-File Report 2003-32, <http://www.kgs.ku.edu/PRS/publication/2003/ofr2003-32/index.html>.

Dickinson, W.R., and Lawton, T.F., 2003, Sequential intercontinental suturing as the ultimate control for Pennsylvanian Ancestral Rocky Mountain deformation: Geology, v. 31, no. 7, p. 609-612.

Dubois, M.K., Byrnes, A.P., Watney, W.L., 2001, Field Development and Renewed Reservoir Characterization for CO2 Flooding of the Hall-Gurney Field, Central Kansas, by Martin K. Dubois, Alan P. Byrnes, and W. Lynn Watney Kansas Geological Survey, Open-File Report, 2001-38, <http://www.kgs.ku.edu/PRS/publication/OFR2001-38/toc1.html>.

Feldman, H.R., Gibling, M.R., Archer, A.W., Wightman, W.G., and Lanier, W.P., 1995, Stratigraphic architecture of the Tonganoxie Paleovalley Fill (Lower Virgilian) in Northeastern Kansas. American Association of Petroleum Geologists Bulletin, 79, p. 1019-1043.

Ferretti, A., Novali, F., Bürgmann, R., Hilley, G., Prati, C., 2004, Analysis Reveals Ups and Downs in San Francisco Bay Area: EOS Transactions, AGU, Volume 85, Issue 34, p. 317-324.

Gerhard, L.C., 2004, A new look at an old petroleum province: Kansas Geological Survey, Current Research in Earth Sciences, Bulletin, no. 250, pt. 1, <http://www.kgs.ku.edu/Current/2004/Gerhard/index.html>

Kluth, C.F., and Coney, P.J., 1981, Plate tectonics of the Ancestral Rocky Mountains: *Geology*, v. 9, p. 10-15.

Kruger, J.M., 1996, On-line gravity and magnetic maps of Kansas: Kansas Geological Survey, Open-file Report, no. 96-51, <http://www.kgs.ku.edu/PRS/PotenFld/potential.html>

Kruger, J.M., Watney, W.L., and Olea, R.A., 1999, Use of gravity and magnetics for low-cost exploration and development in mature areas such as Kansas, in, Merriam, D.F., ed., *Geoscience for the 21st century*, transactions of the 1999 American Association of Petroleum Geologists, Midcontinent Section Meeting: Kansas Geological Survey, Open-file Report No. 99-28, p. 51

Longman, M.W., and Sonnenfeld, M.D., 1996, Introduction and overview, *in* Longman, M.W., and Sonnenfeld eds., *Paleozoic Systems of the Rocky Mountain Region*: Rock Mountain Section SEPM, p. 1-10.

Marshak, S., Karlstrom, K., and Timmons, J.M., 2000, Inversion of Proterozoic extensional faults: An explanation for the patterns of Laramide and Ancestral Rockies intracratonic deformation: *Geology*, v. 28, p. 735-738.

Merriam, D.F., 2005, Origin and development of plains-type folds in the mid-continent (United States) during the late Paleozoic: *AAPG Bulletin*, v. 89, no. 1, p. 101-118.

Montgomery, S. L., Mullarkey, J.C., Longman, M.W., Colleary, W.M., and Rogers, J.P., 1998, Mississippian "chat" reservoirs, south Kansas: low-resistivity pay in a complex chert reservoir: *AAPG Bulletin*, v. 82, p. 187-205.

Nissen, S.E.; and Watney, W.L., 2003, Detailed mapping of the Upper Hutchinson Salt and overlying Permian strata beneath Hutchinson, Kansas: Kansas Geological Survey, Open-file Report, no. 2003-66, <http://www.kgs.ku.edu/PRS/publication/2003/ofr2003-66/index.html>.

Nissen, S.E., Watney, W.L., and Xia, J., 2004, High-resolution seismic detection of shallow natural gas beneath Hutchinson, Kansas: *Environmental Geosciences*; September 2004; v. 11; no. 3; p. 129-142.

Nissen, S.E., Marfurt, K.J., and Carr, 2005, Identifying Subtle Fracture Trends in the Mississippian Saline Aquifer Unit Using New 3-D Seismic Attributes: KGS Open-File Report 2004-56, <http://www.kgs.ku.edu/PRS/publication/2004/2004-56/index.html>.

Ohlmacher, G.C., and Berendsen, P., 2005, Kinematics, mechanics, and potential earthquake hazards for faults in Pottawatomie County, Kansas, USA: *Tectonophysics*, v. 396, p. 227-244.

Reeder S. , and Rankey, G., 2005, Stop 2-2 -- Ebb-tide dominated ooid shoal, in *Processes and Patterns in Ooid Shoals, Abaco Island Chain, Bahamas*, Guidebook, Comparative Sedimentology Laboratory, University of Miami, p. 15-16.

Rogers, J. P., Longman, M.W., and Lloyd, R.M., 1995, Spiculitic chert reservoir in Glick field, south-central Kansas: *The Mountain Geologist*, v. 32, p. 1-22.

Sims, P.K., Saltus, R.W., and Anderson, E.D., 2005, Preliminary Precambrian basement structure map of the continental United States – An interpretation of geologic and aeromagnetic data: U.S.G.S. Open-File Report 2005-1029, 31 p. (text) + Plate. <http://pubs.usgs.gov/of/2005/1029/pdf/OFR-1029.pdf>.

Thatcher, W., 2003, GPS constraints on the kinematics of continental deformation: *International Geological Review*: v. 45, no. 3, p. 191-212.

van der Pluijm, B.A., Craddock, J.P., Graham, B.R., Harris, J.H., 1997, Paleostress in cratonic North America: implications for deformation of continental interiors: *Science*, v. 277, no. 5327, p. 794-796.

Watney, W.L., Berg, J.A., and Paul, S.[E.], 1988, Origin and distribution of the Hutchinson Salt (lower Leonardian) in Kansas, pp. 113-135, in: Morgan, W.A.; and Babcock, J.A., eds., *Permian Rocks of the Midcontinent*, Society of Economic Paleontologists and Mineralogists, Midcontinent Section, Special Publication, no. 1, 224 pages.

Watney, W.L., Davis, J.C., Olea, R. A., Harff, J., and Bohling, G.C., 1997, Modeling of sediment accommodation realms by regionalized classification: *Die Geowissenschaften*, v. 15, p. 28-33.

Watney, W.L., Kruger, Davis, J.C., Harff, J., Olea, R.A., and Bohling, G.C., 1999, Validation of Sediment Accumulation Regions in Kansas, U.S.A.: *Proceedings of Symposium, Computerized Modeling of Sedimentary Systems*, Harff, ed., *Computerized Basin Analysis*, Springer, p. 341-360.

Watney, W.L., Nissen, S.E., Bhattacharya, S., Young, D., 2003, Evaluation of the role of evaporite karst in the Hutchinson, Kansas, Gas Explosions, January 17 and 18, 2001: Oklahoma Geological Survey Circular 109, p. 120-147.

Watney, W.L., Franseen, E.K., Byrnes, A.P., and Nissen, S.E., 2005, Contrasting styles and common controls on Middle Mississippian and Upper Pennsylvanian carbonate Platforms in the Northern Midcontinent, U.S.A.: 2005 West Texas Fall Symposium, West Texas Geological Society Publication No. 05-115, Midland, Tx., p. 221-253.

Watney, W.L., Callighan, N., Callaghan, Bartley, J., Xu, Sihuang, 2006, Applying Visual Techniques on Geological Formations Using Modeling Techniques and 3-D Visualization: ESRI Petroleum User's Group Annual Meeting, Houston.

Young, D.P., Buddemeier, R.W., Whittemore, D.O., and Rubin, H., 2000. Final summary and data report: the Equus Beds Mineral Intrusion project: Kansas Geological Survey, Open-File Report 2000-30 (Version 2.0): http://www.kgs.ku.edu/Hydro/Equus/OFR00_30/index.htm.