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

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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

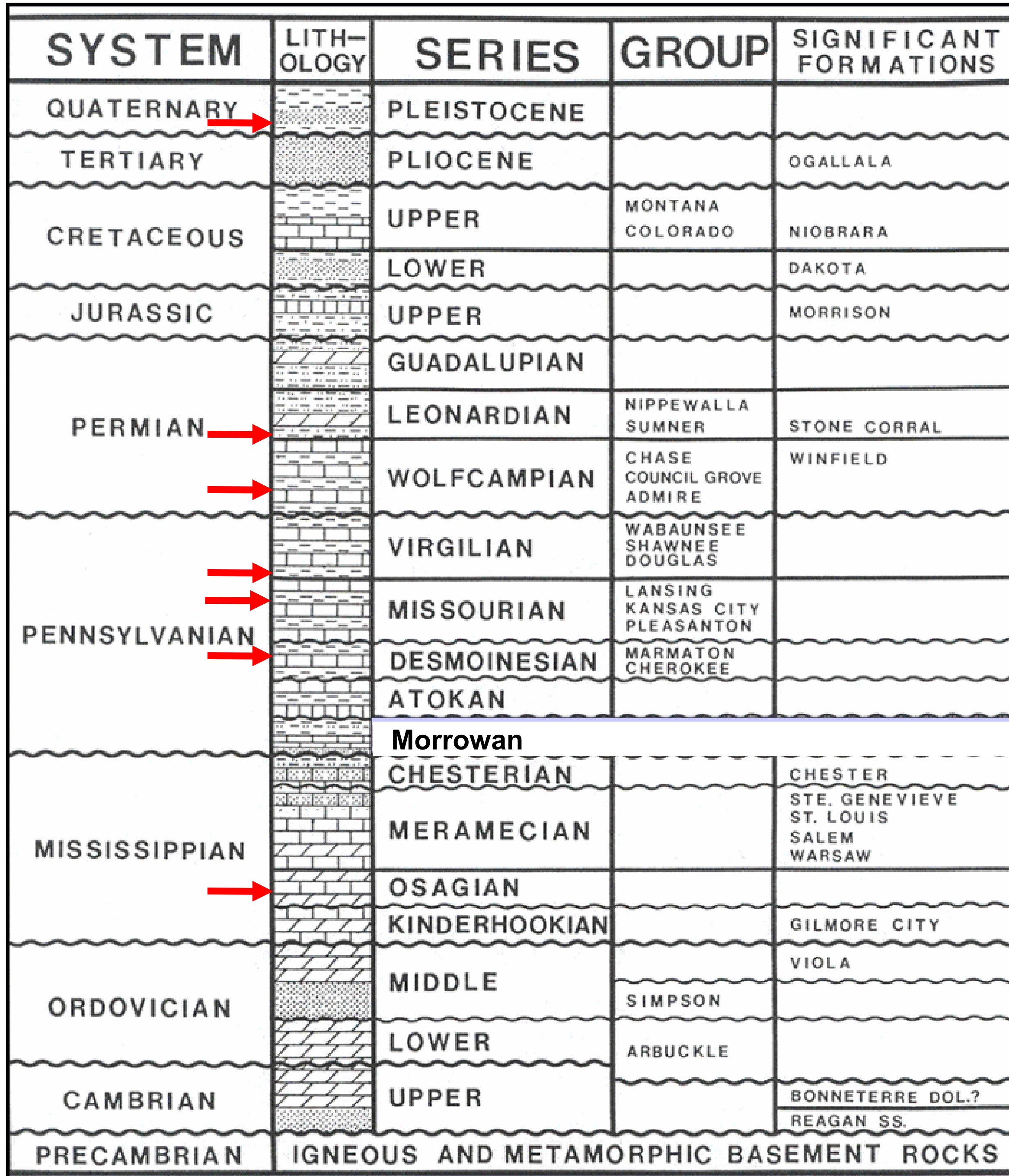
- 1. True stratigraphic traps of economically producible hydrocarbons are probably fewer than believed.

- 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

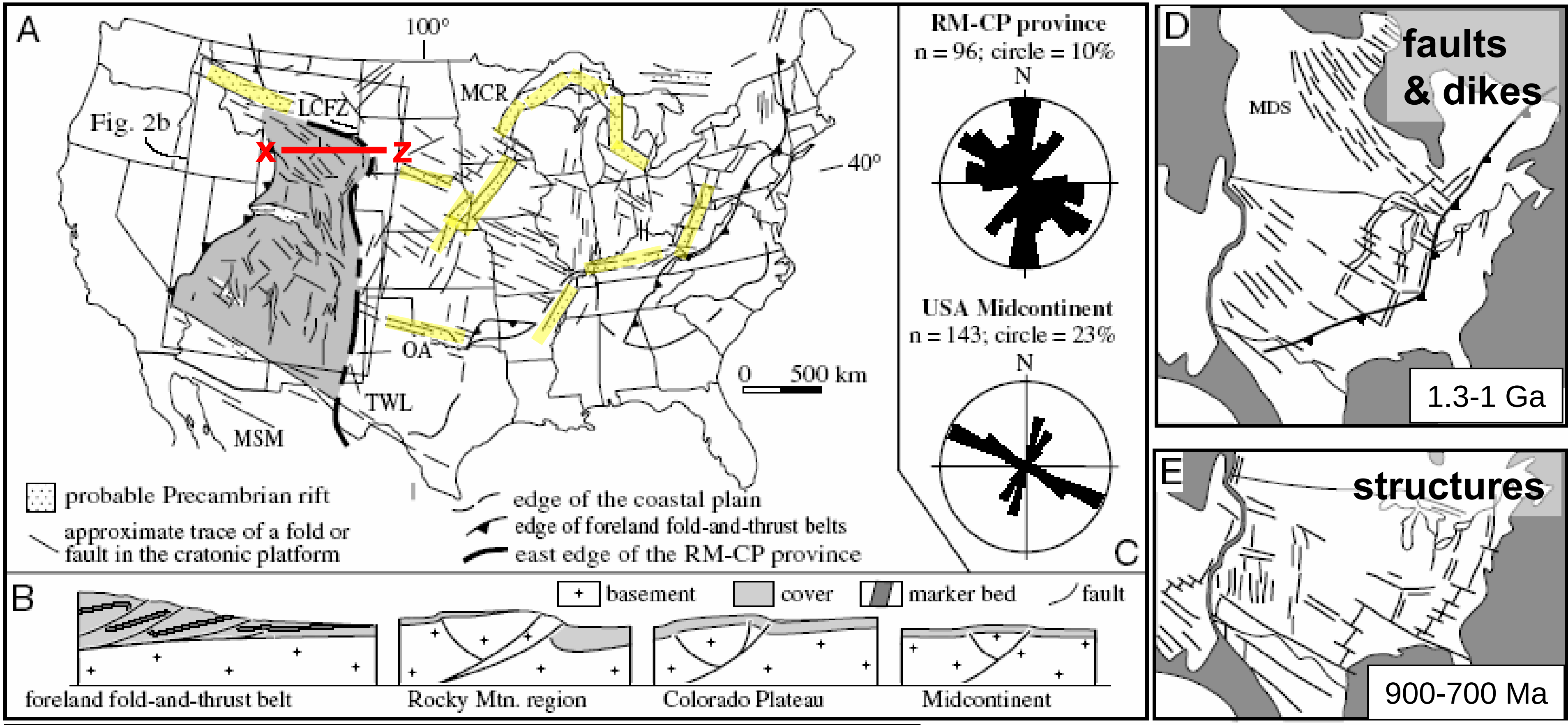
- Emphasis on structural controls as added element in prediction and quantification of reservoir properties



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

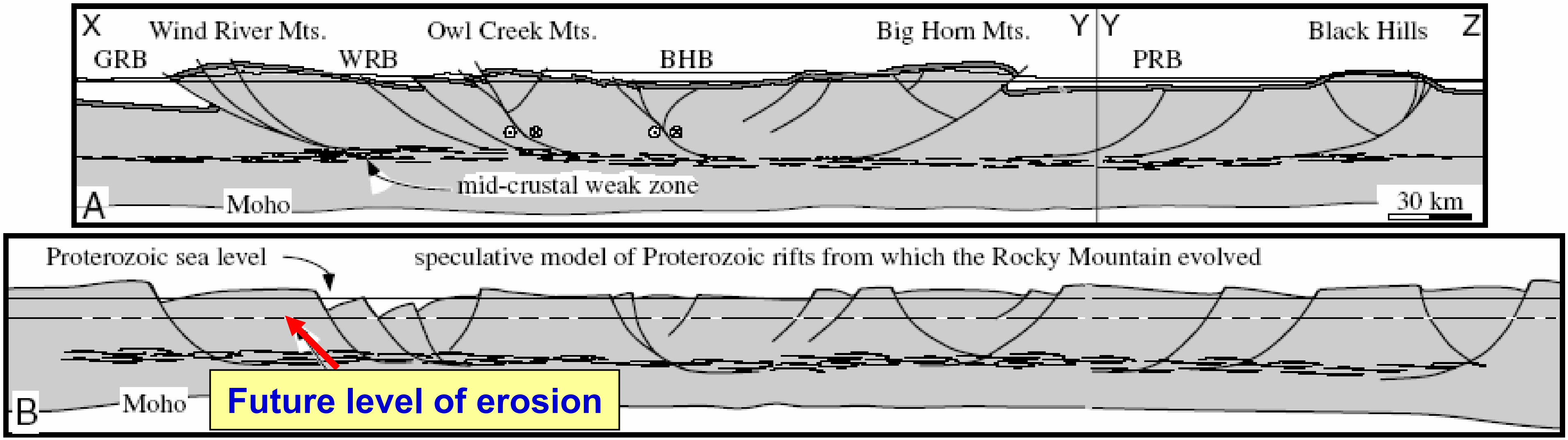


- Proterozoic rifting (extensional faults)
- Faults continue to be reactivated during Phanerozoic compressional orogenies (Kluth and Coney, 1981)
- Inversion of normal faults (*reverse & oblique-slip*)

Marshak, Karlstrom, and Timmons (2000)

Reactivation of Precambrian extensional fault throughout the craton

X Y Z



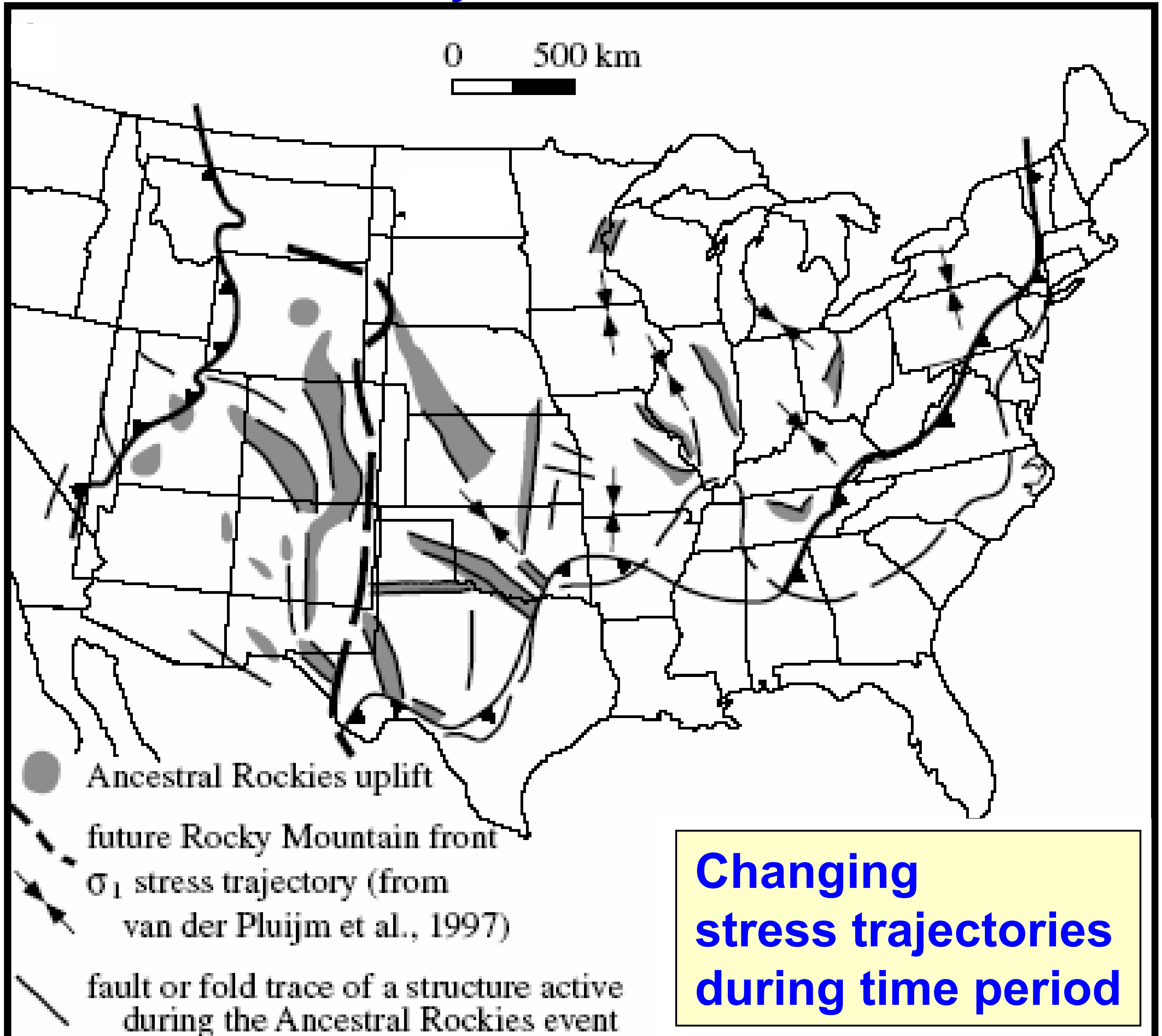
A) Schematic cross section of Rocky Mountains

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

Marshak, Karlstrom, and Timmons (2000)

Ancestral Rockies Structures

-- Early Chesterian - Late Leonardian



Changing stress trajectories during time period

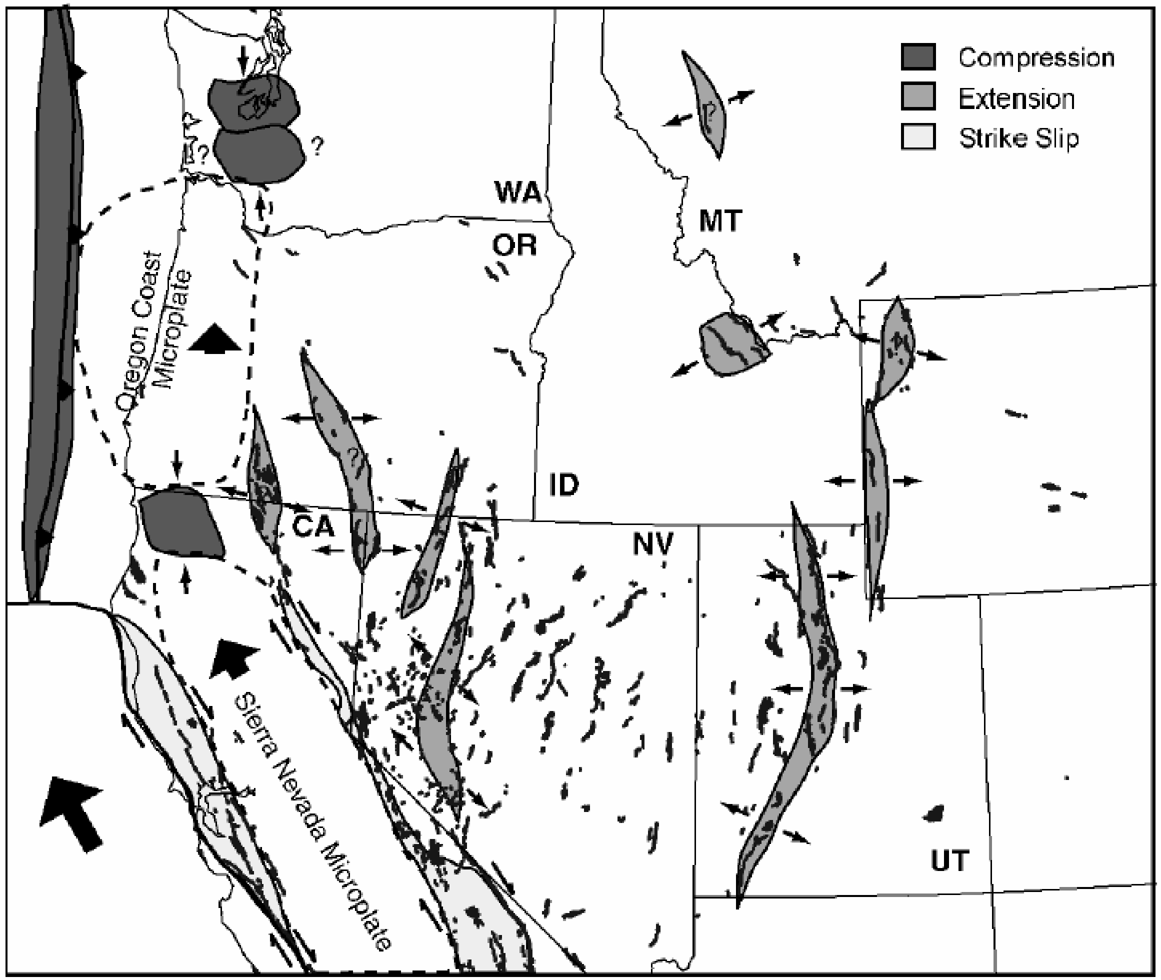
Intraplate fault reactivation is mainly dependent on orientation of (weak) fault zones relative to plate margin… deformation in interior can be represented by simple rheological models (van der Pluijm et al., 1997)

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

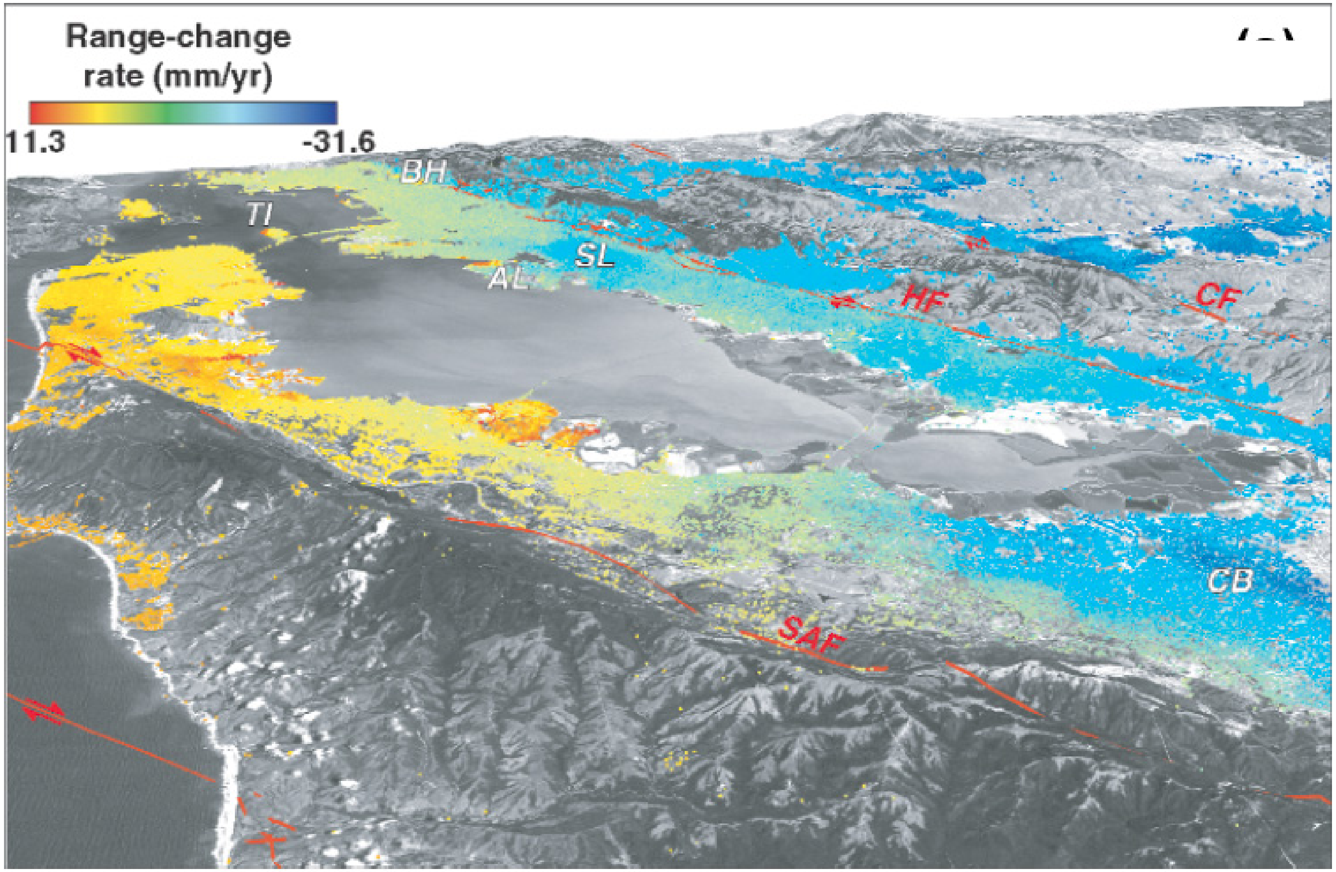
Examples from Neotectonism

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



Thatcher (2003)

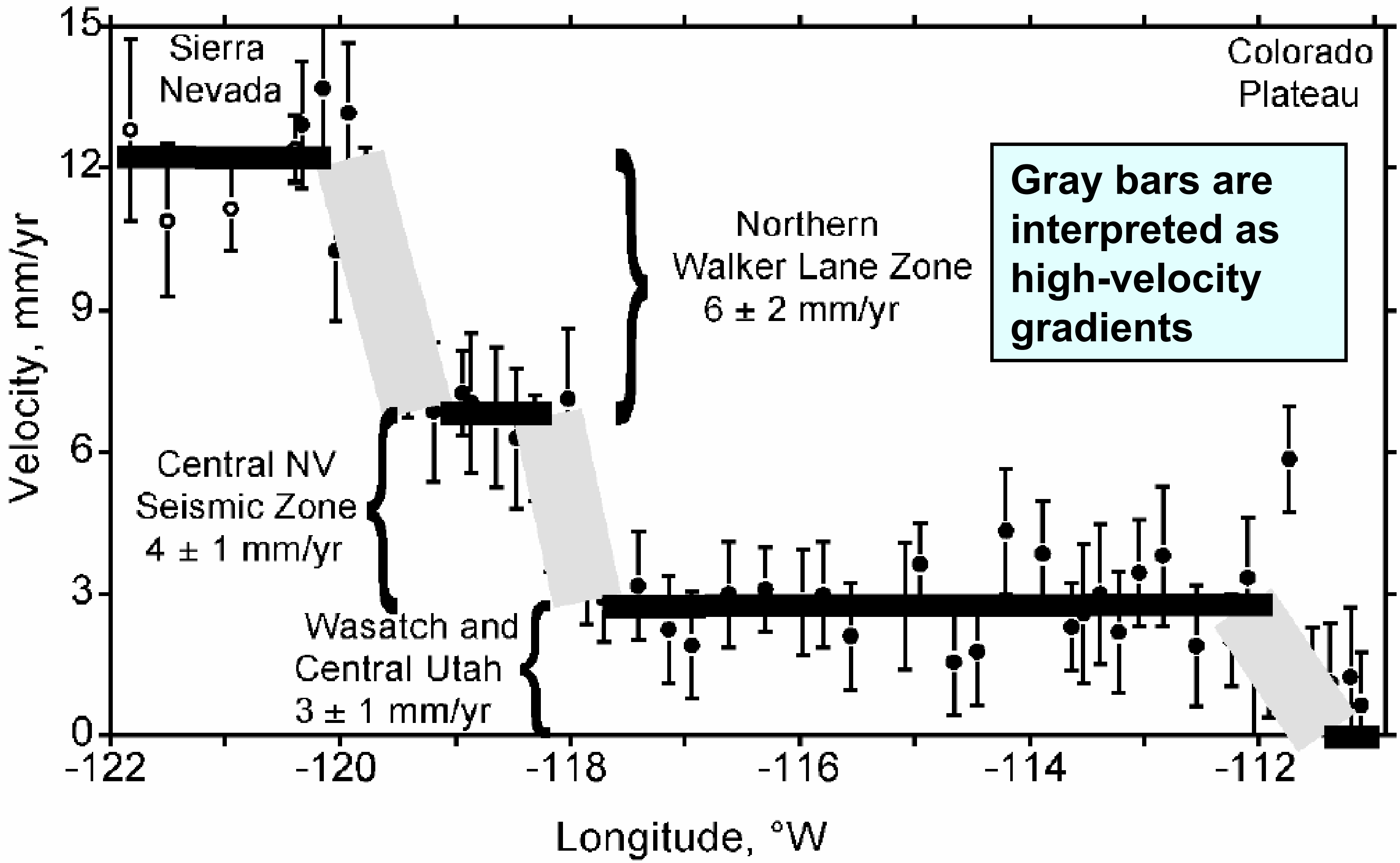
Synthetic Aperture Radar Interferometry (InSAR)



*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*).*

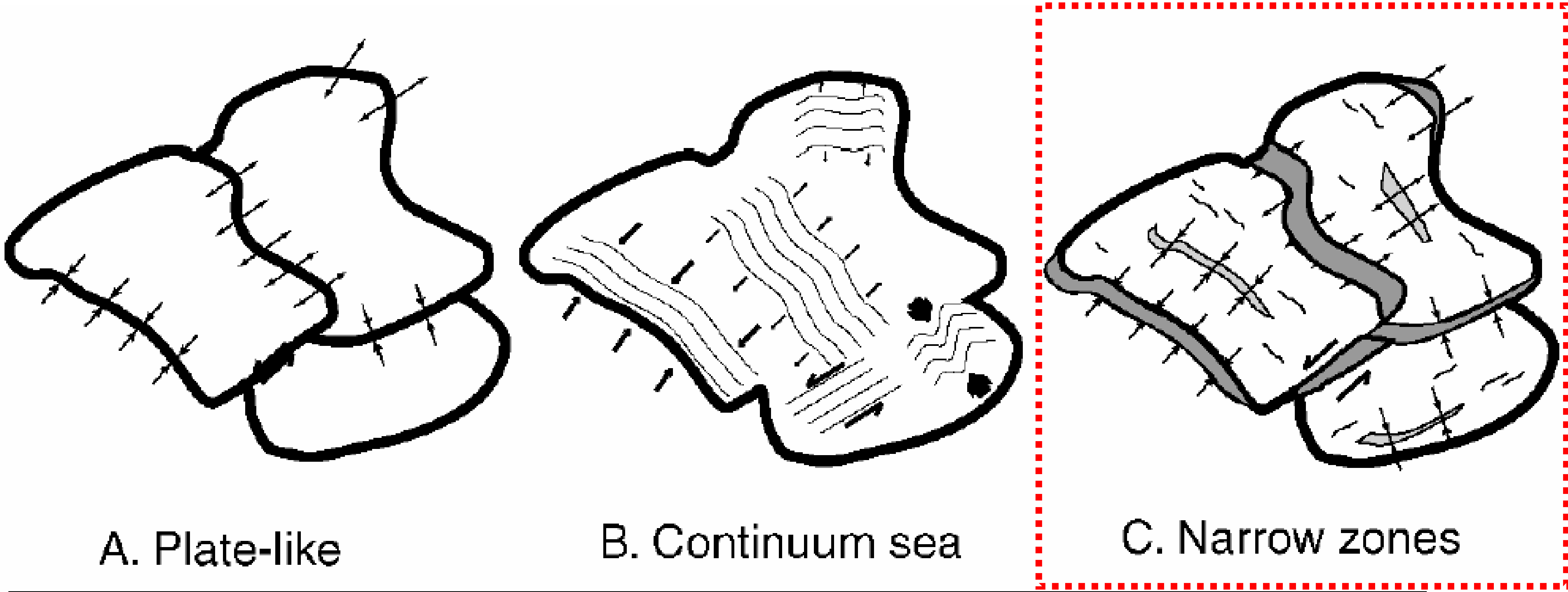
San Francisco Bay Area
-- roughly 30 miles across

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



Thatcher (2003)

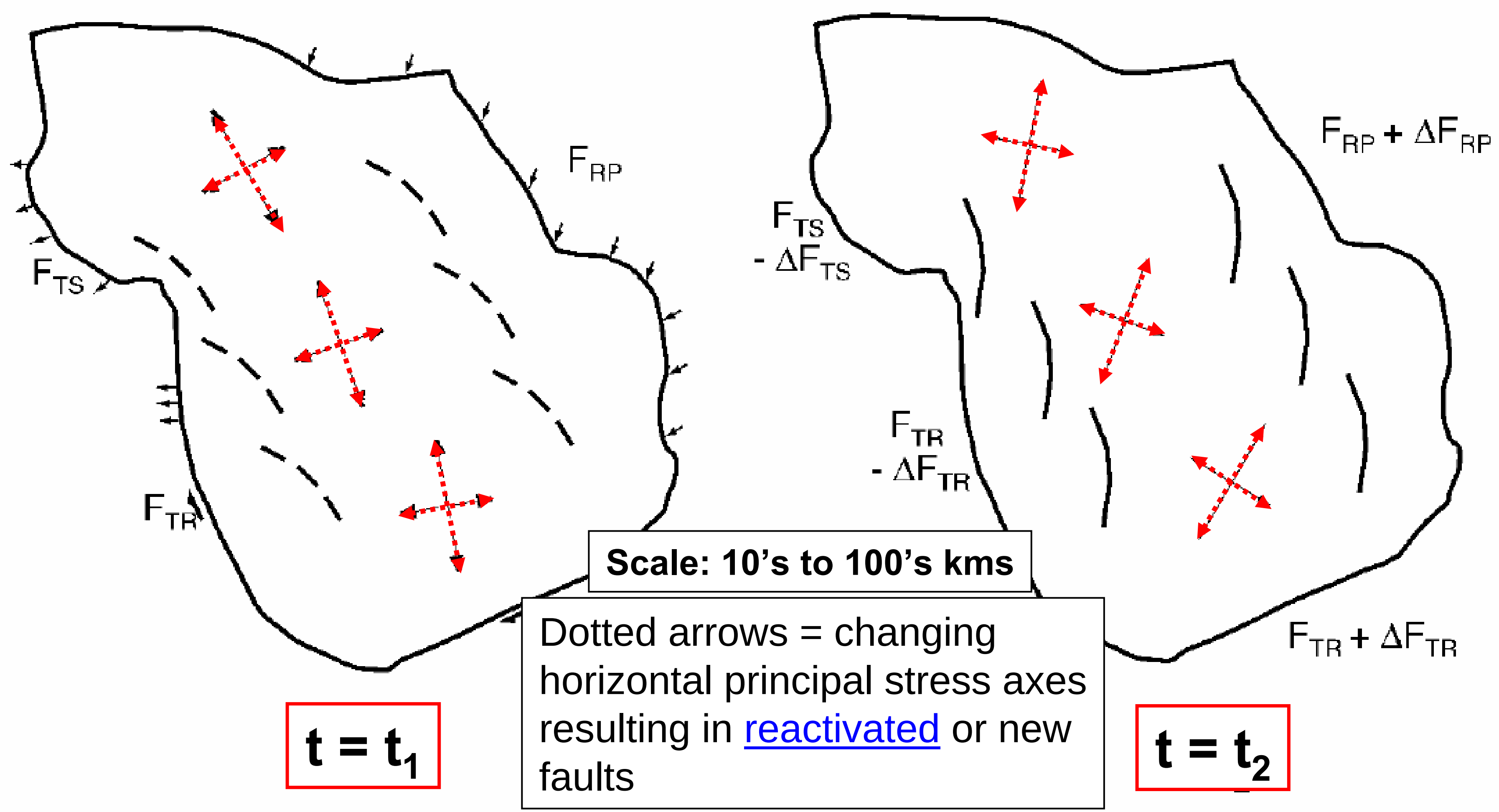
Schematic diagrams showing alternative kinematic descriptions of continental deformation



- 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***.

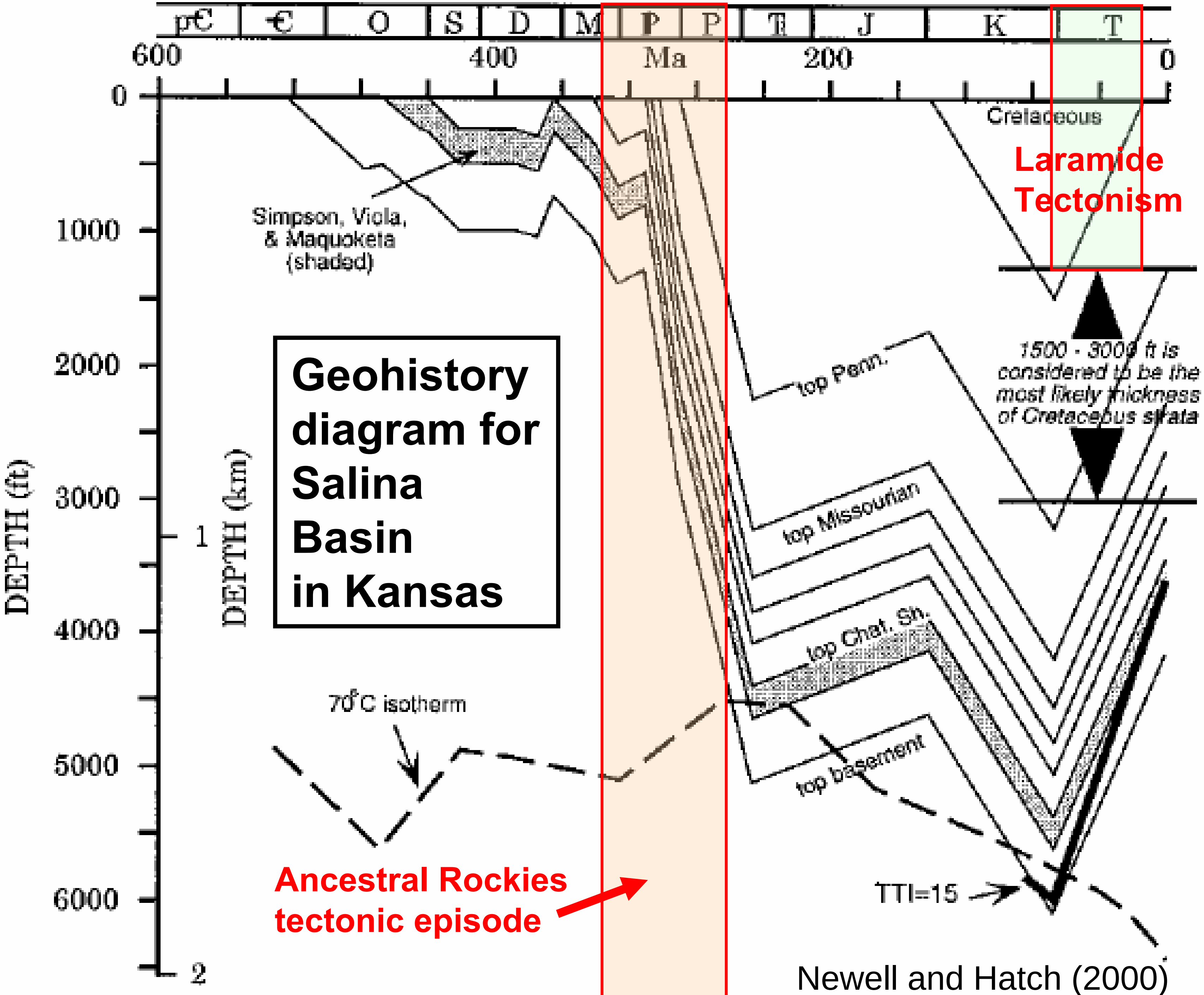
Thatcher (2003)

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 --

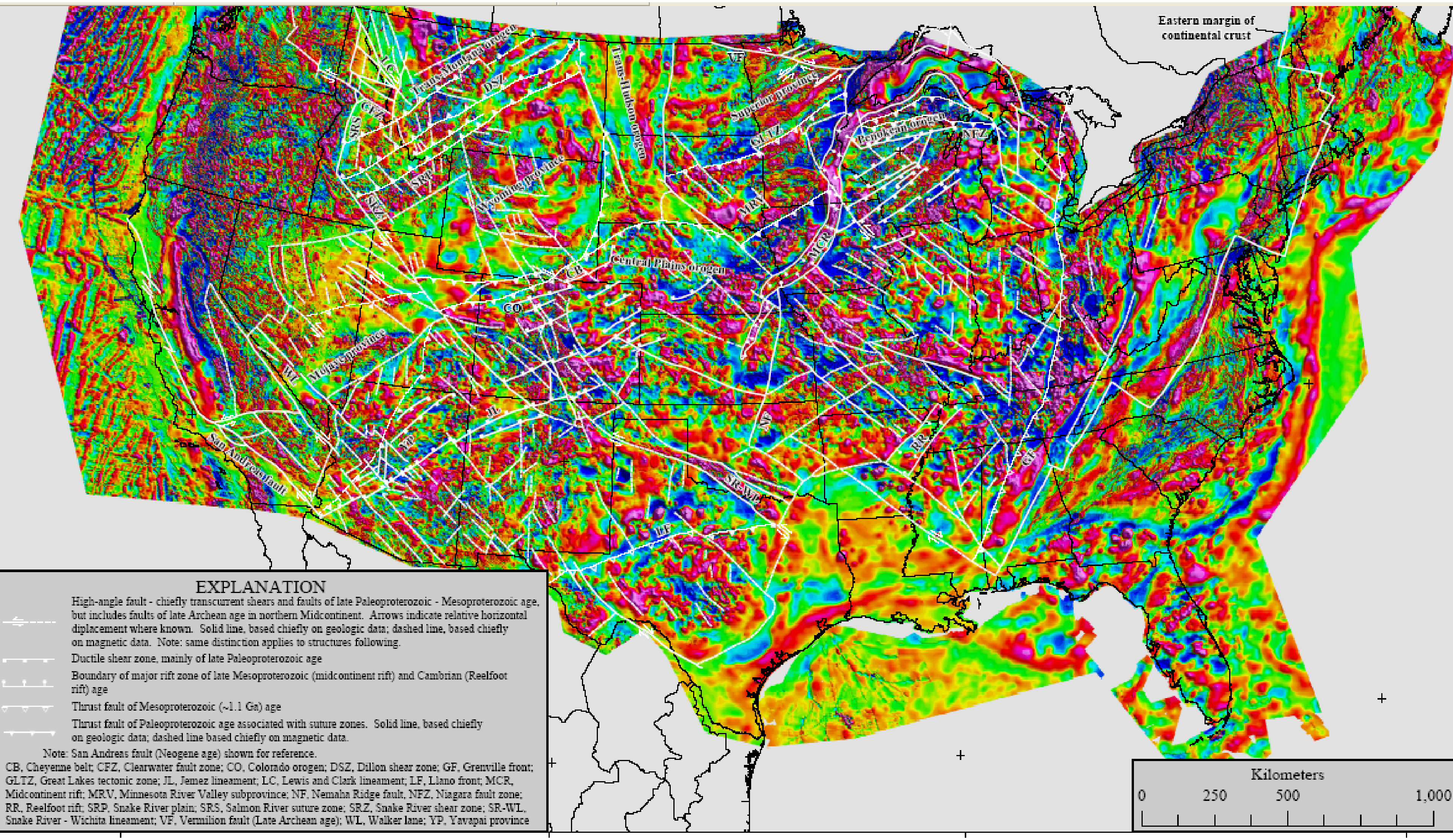
San Andres Fault - Basin & Range - Colorado Plateau system.



Newell and Hatch (2000)

Precambrian faults serve as templates for later deformation and crustal segmentation

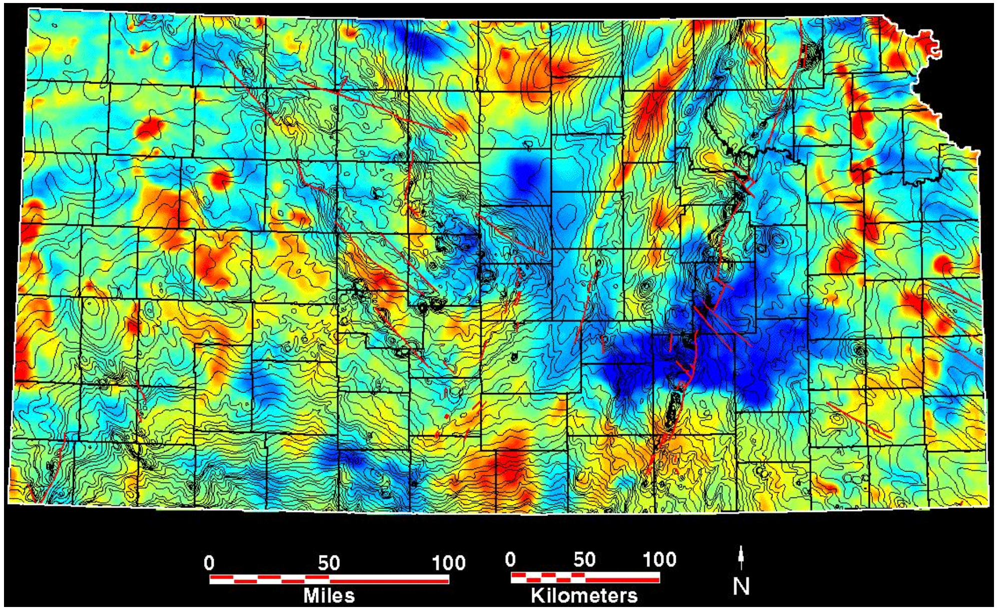
Preliminary Precambrian Basement Structure Map of Continental U.S. -- An interpretation of Geologic and Aeromagnetic Data



Sims, Saltus, and Anderson (2005)

Basement Structures and Terranes

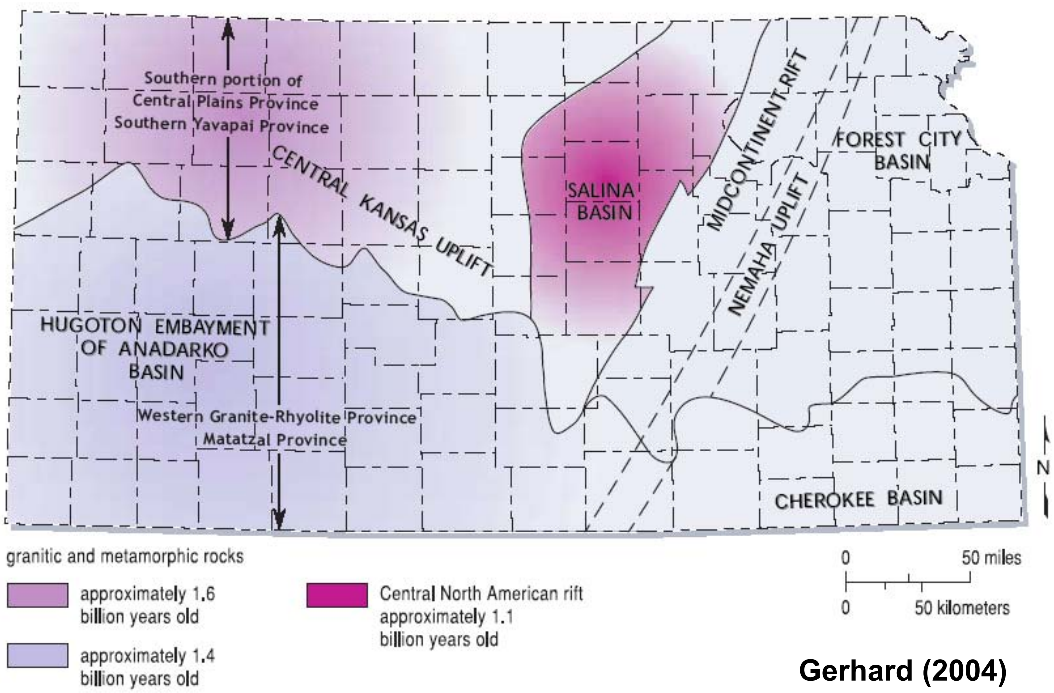
Total Magnetic Field Intensity



Kruger (1997)

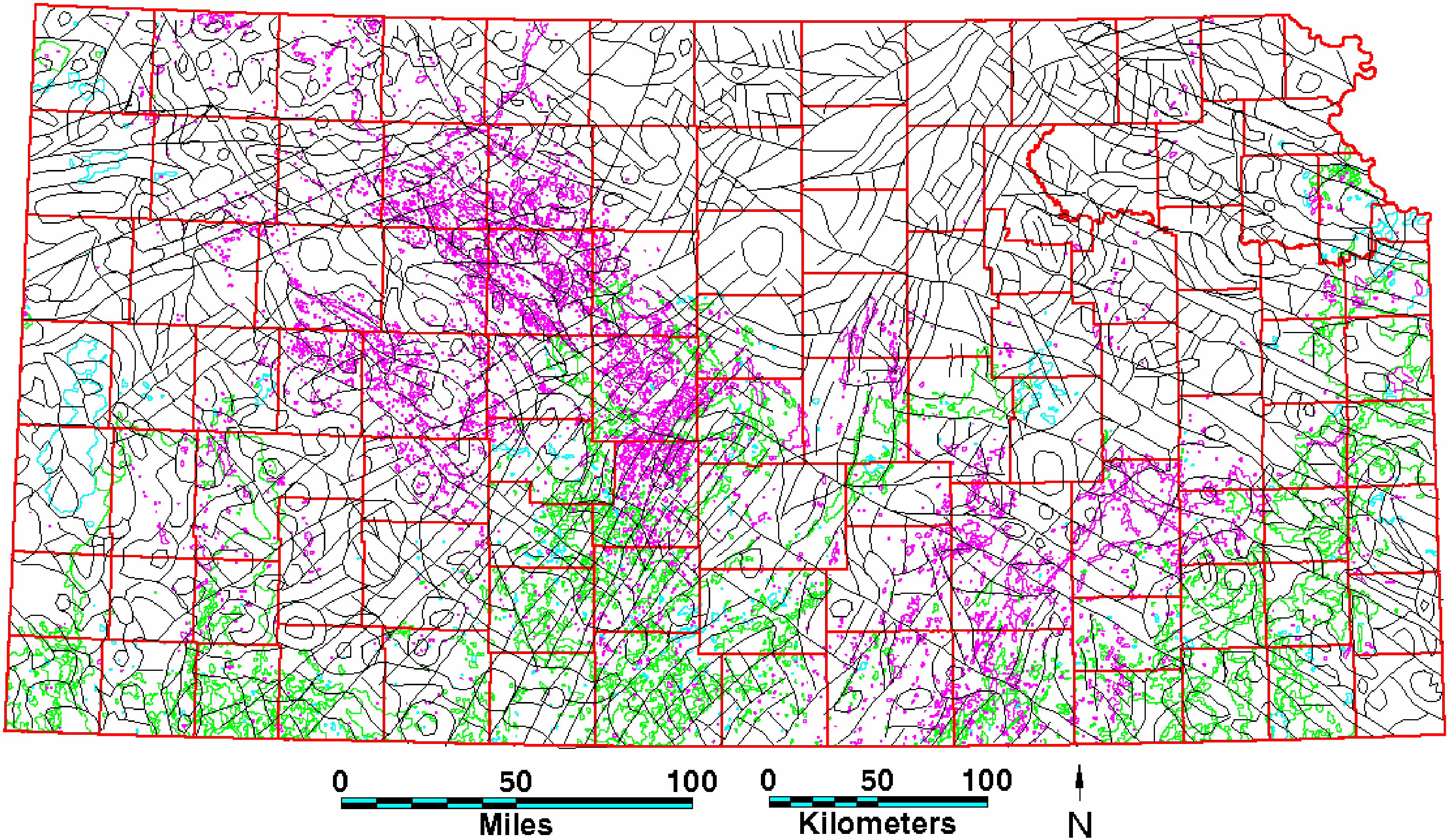
Contours = Precambrian surface isochores

Red = high mag.
Blue = low mag.



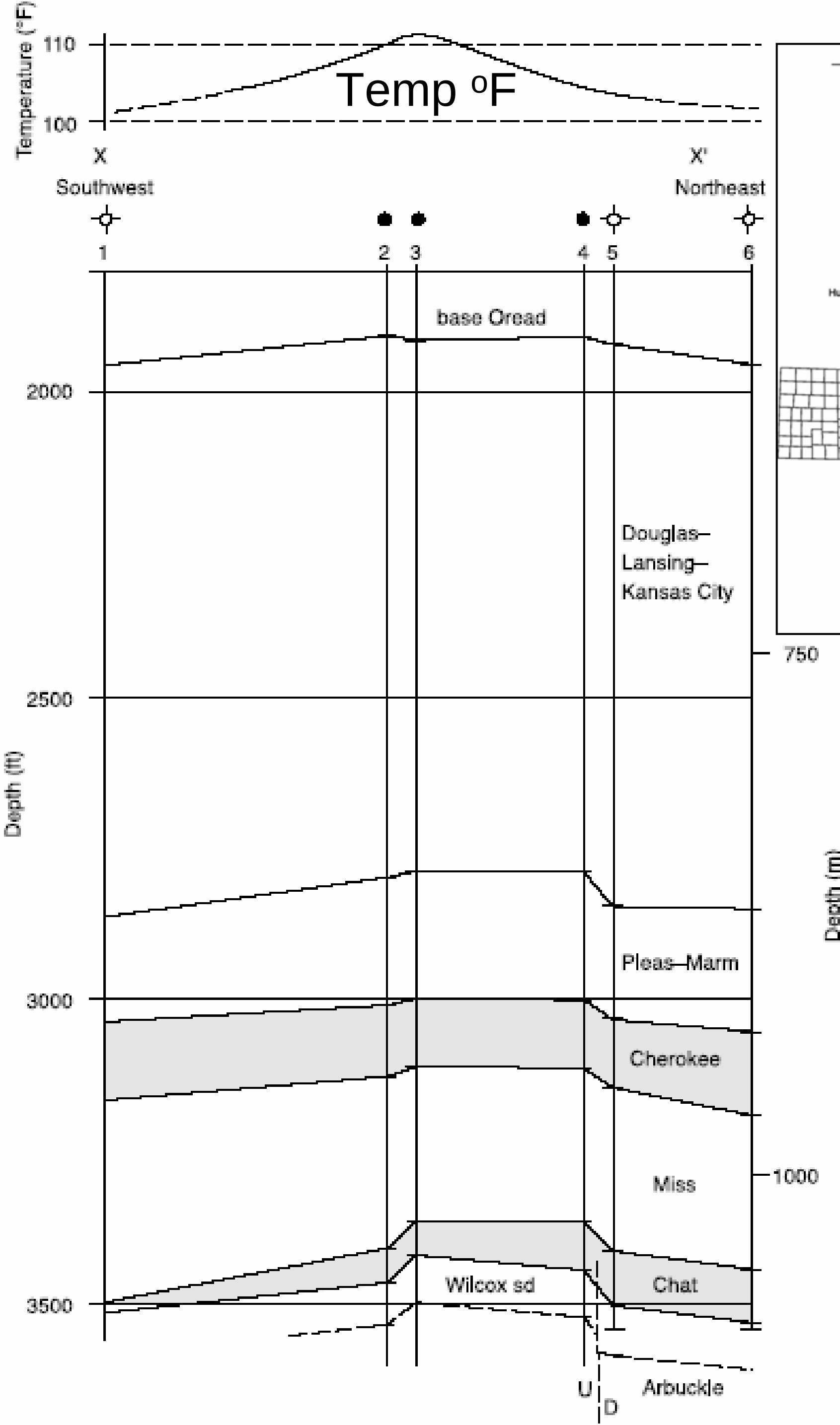
Gerhard (2004)

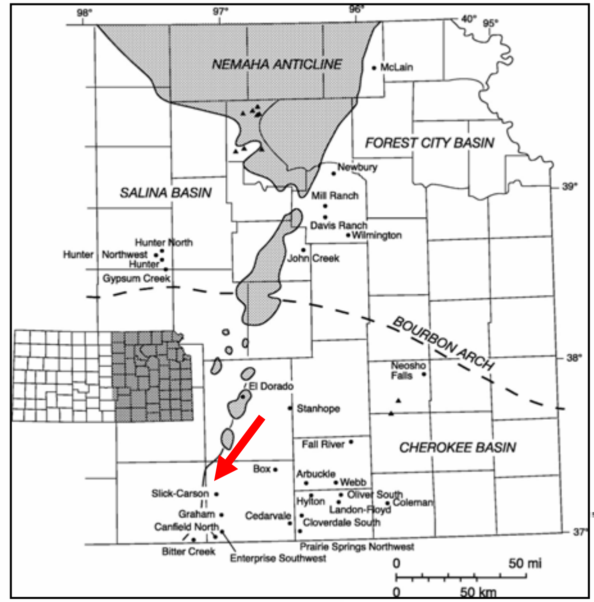
Local magnetic lineations from total magnetic field intensity Overlain with oil and gas fields (Kruger, 1997)

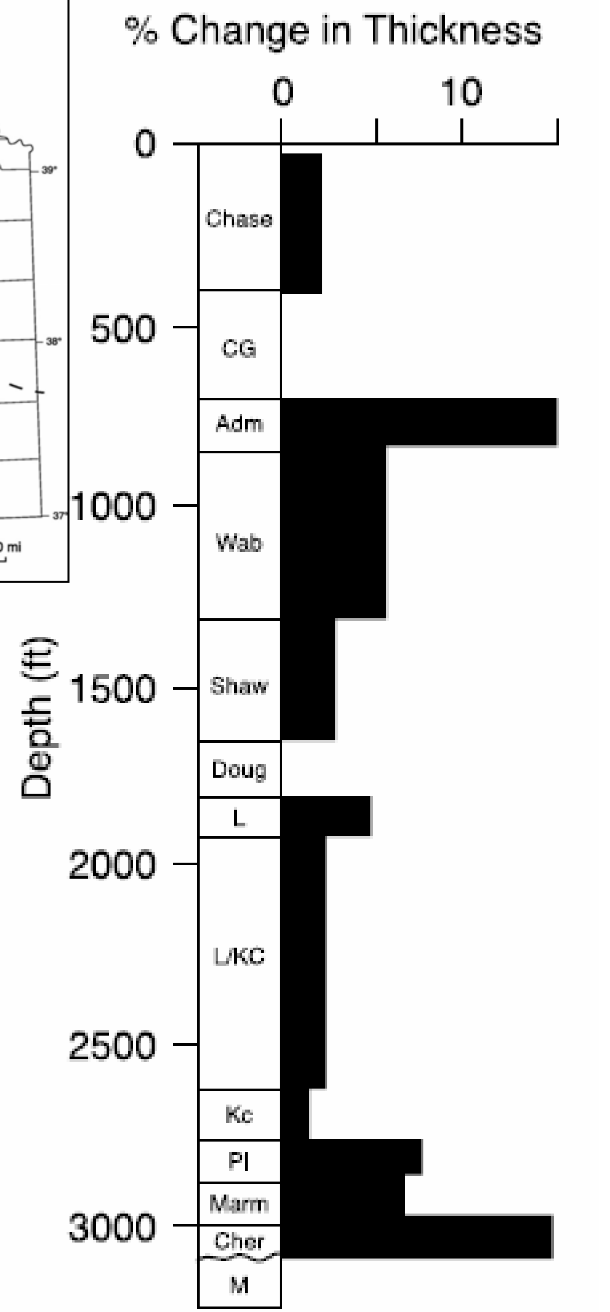


Mosaic of NW and NE trending lineaments

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



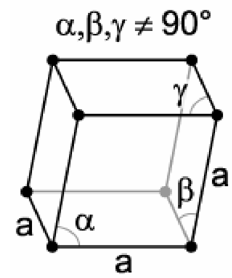


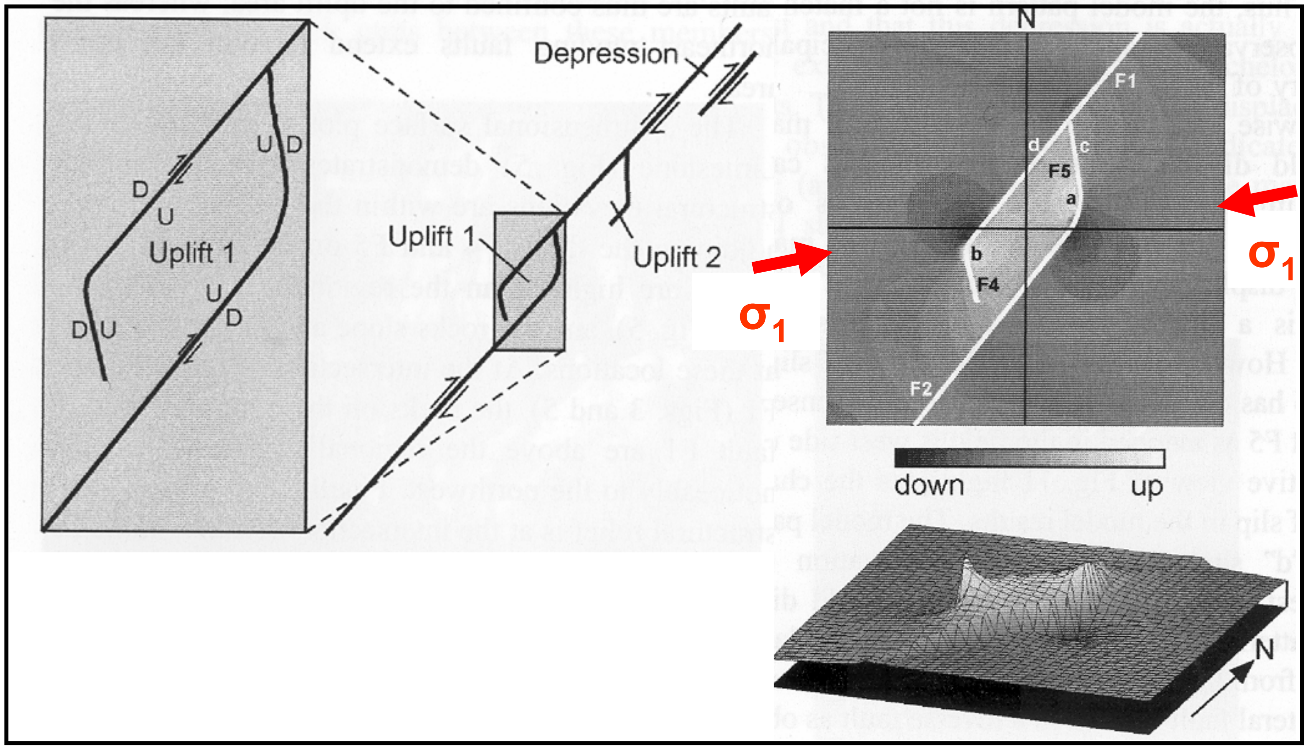


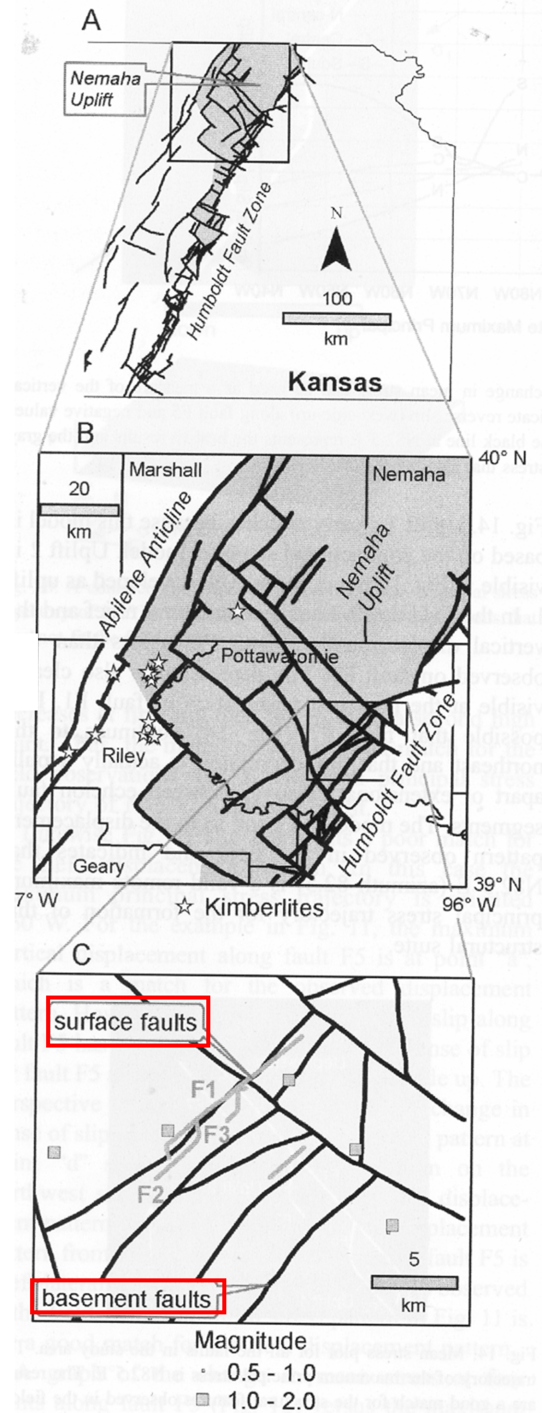
Origin and development of plains-type folds

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.

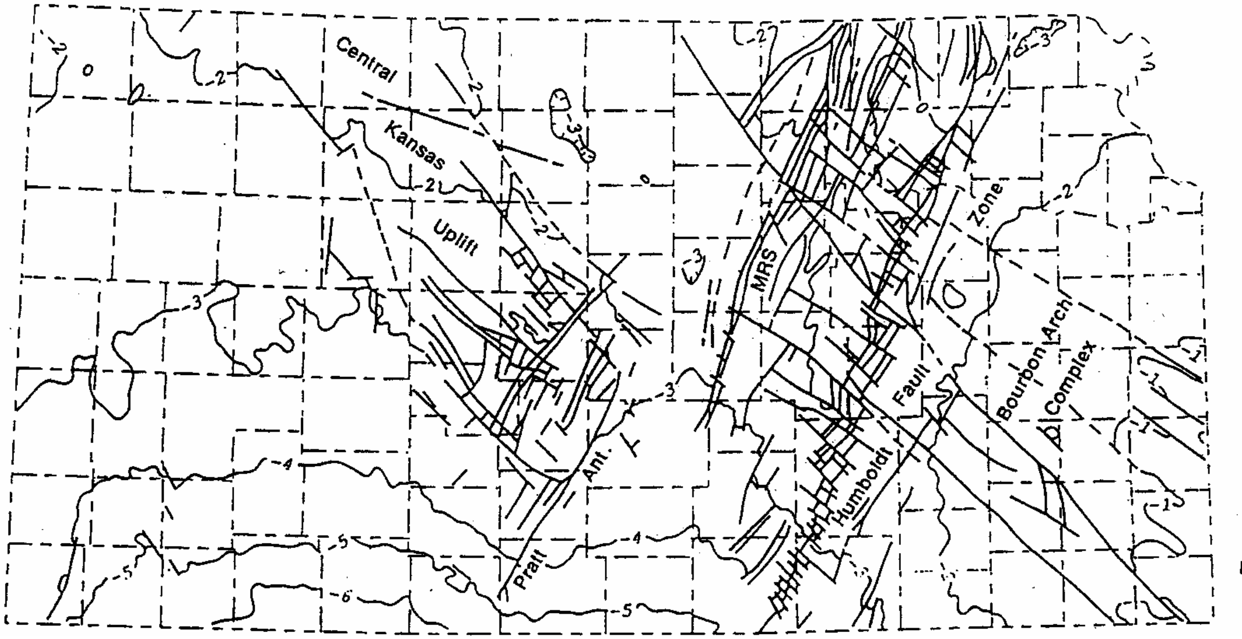




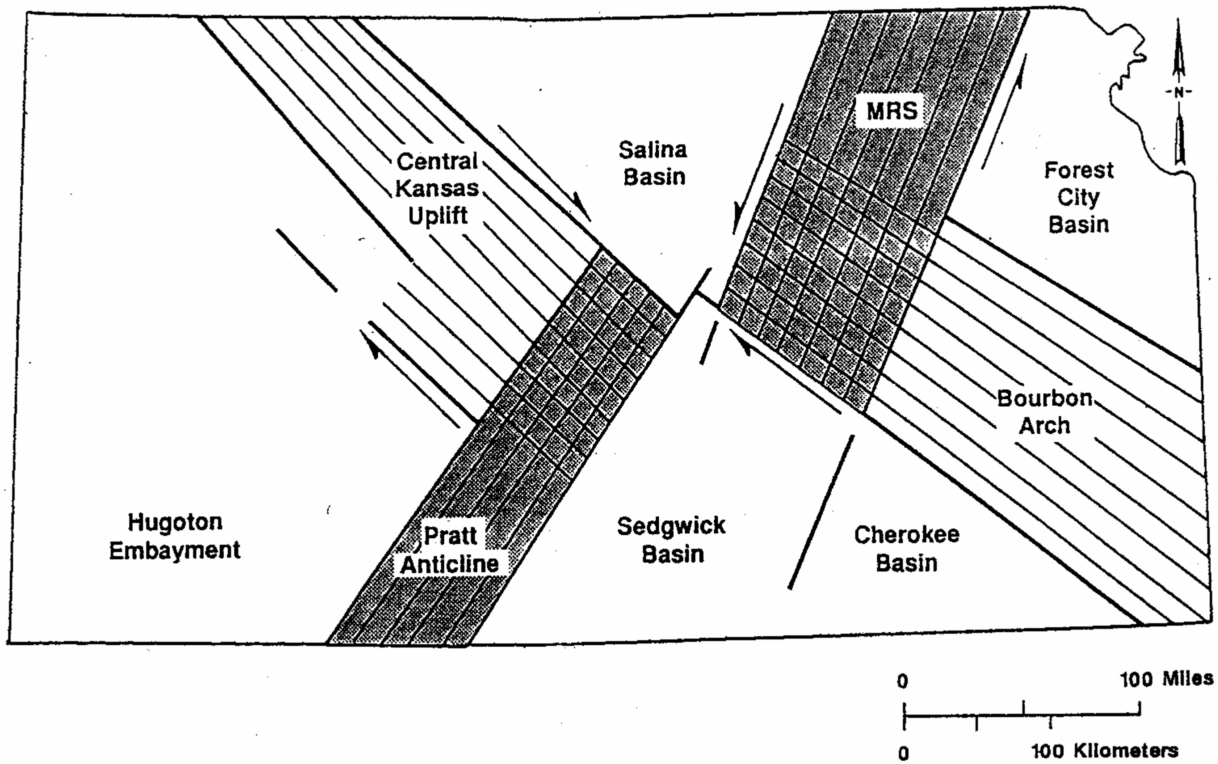


Laramide reactivation of basement faults in Pottawattamie County with N82.5°E σ_1

Ohlmacher and Berendsen (2005)



Configuration of the Precambrian Surface (*well based*)



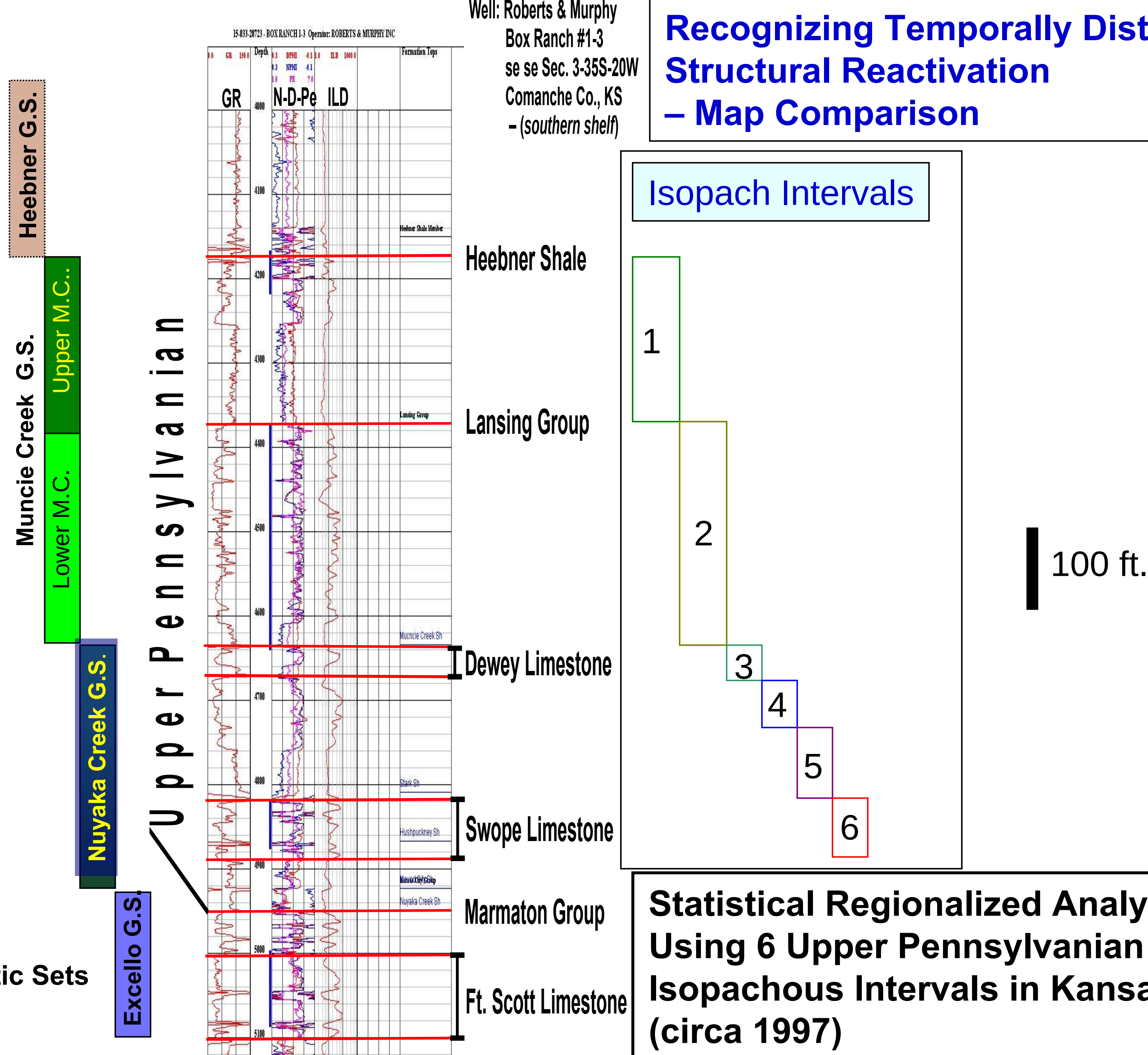
Precambrian structural domains and strain behavior – wrench faulting?

Baars and Watney (1991)

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**

Recognizing Temporally Distinct Structural Reactivation – Map Comparison

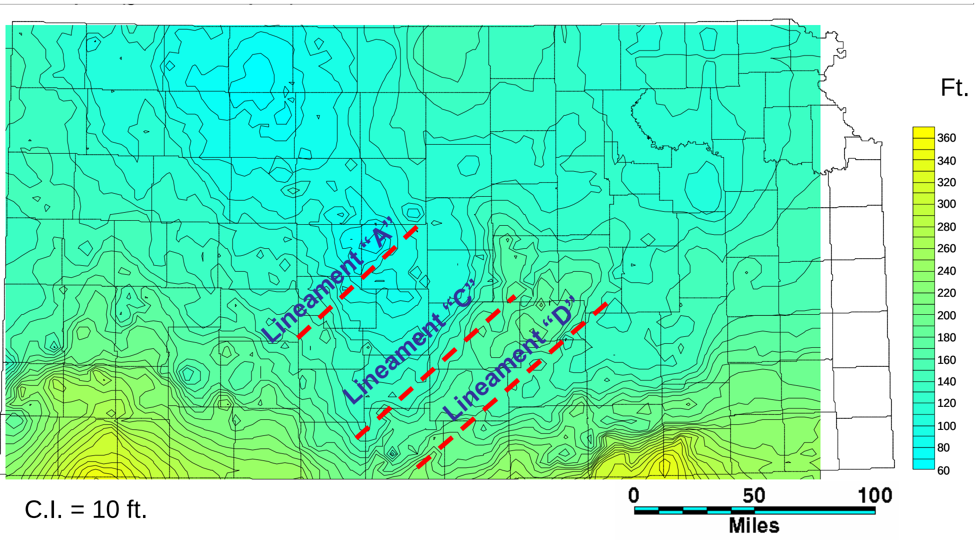


G.S. = Genetic Sets

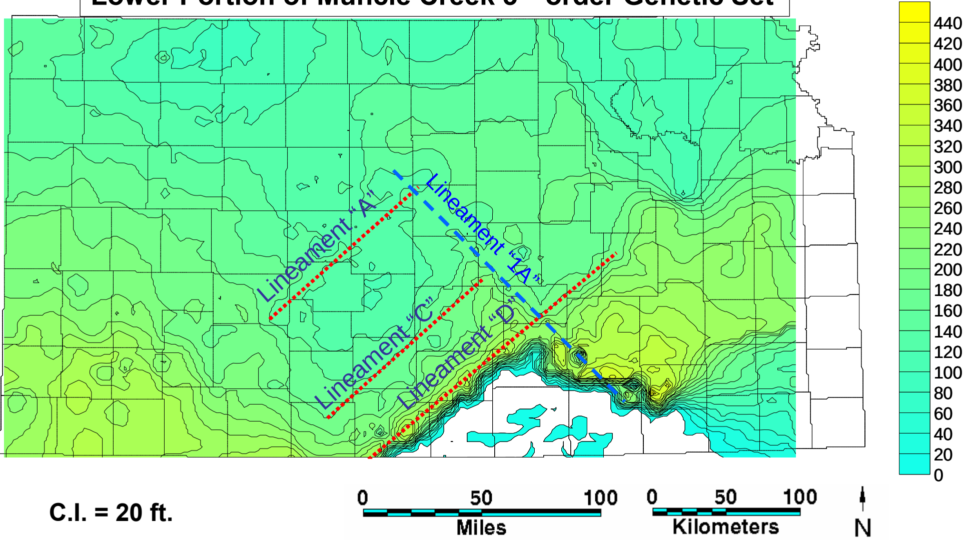
Statistical Regionalized Analysis Using 6 Upper Pennsylvanian Isopachous Intervals in Kansas (circa 1997)

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

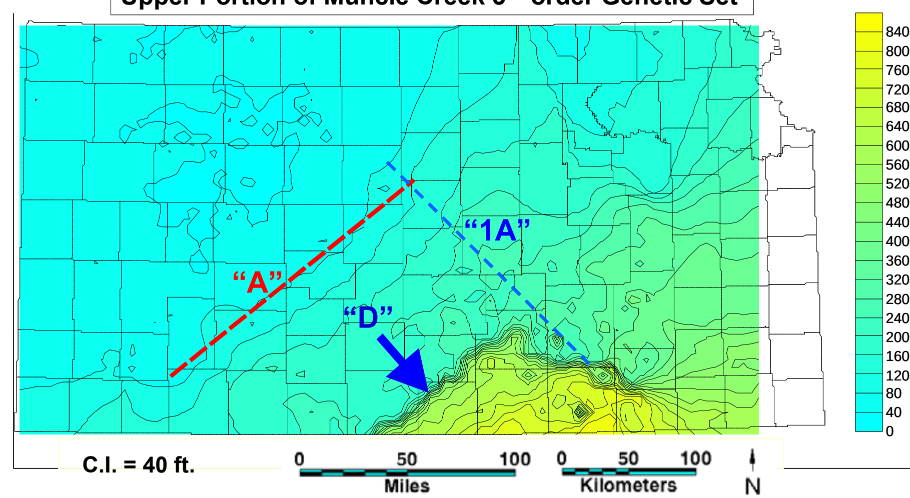
Most of Nuyaka Creek 3rd-order Genetic Set



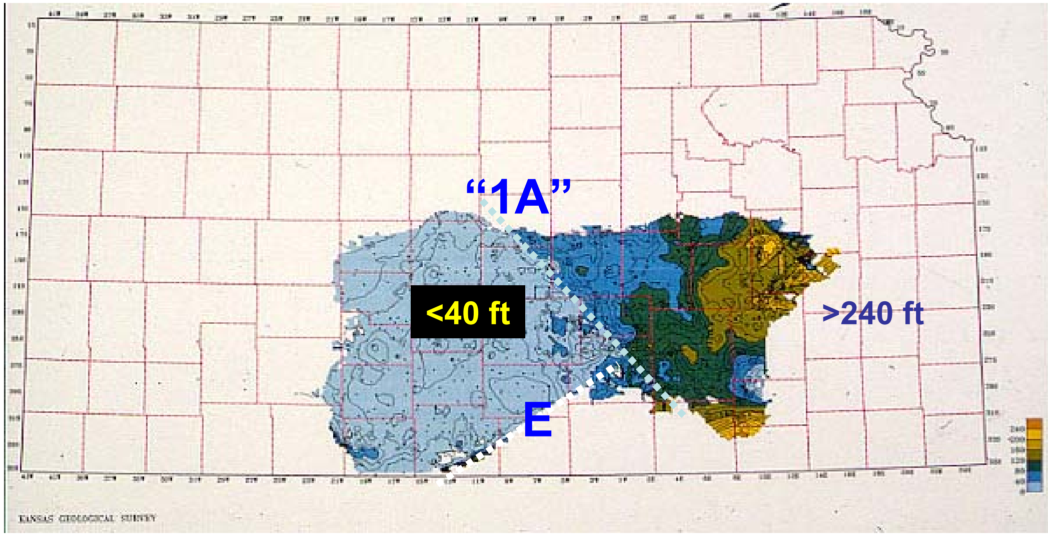
Lower Portion of Muncie Creek 3rd-order Genetic Set



Upper Portion of Muncie Creek 3rd-order Genetic Set



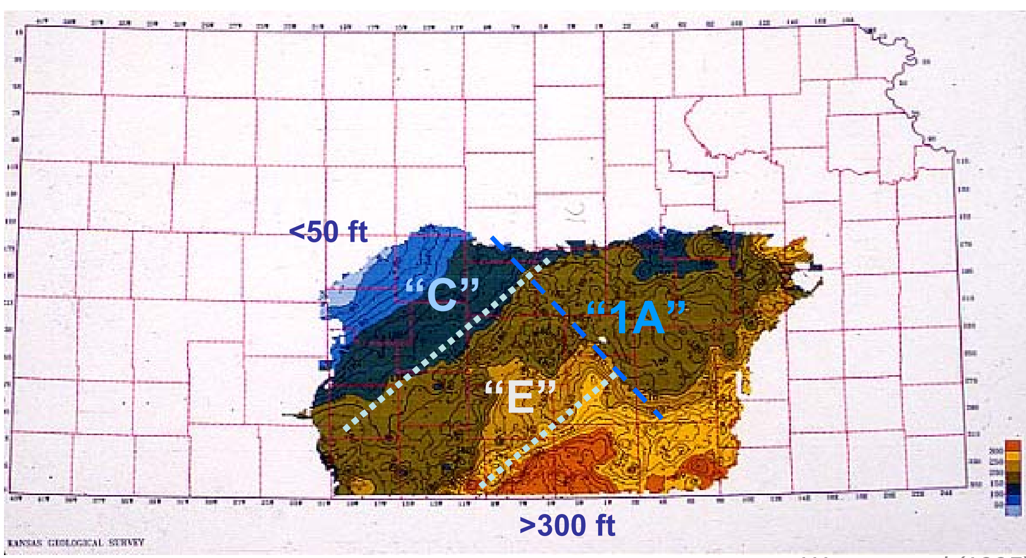
Isopach map of Top of Lansing Group to Top of Haskell Limestone



Watney et al (1995)

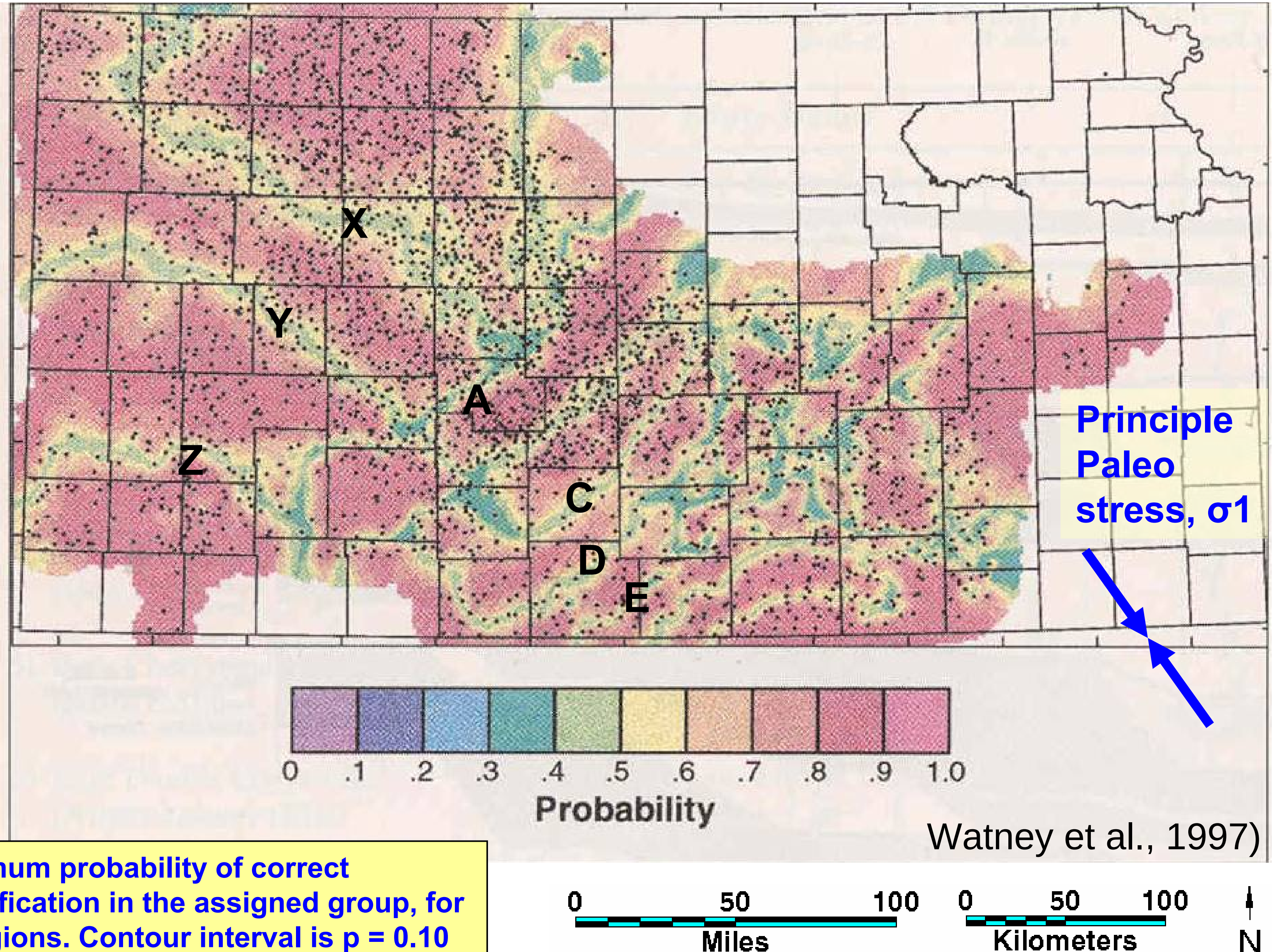
- Apparent differential subsidence between two structural blocks along light blue dashed line, "1A". Lansing bank margin is line "E".
- Eastern block of thick strata in lower Douglas and Pedee Groups contain Tonganoxie paleovalley developed in eastern Kansas

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



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

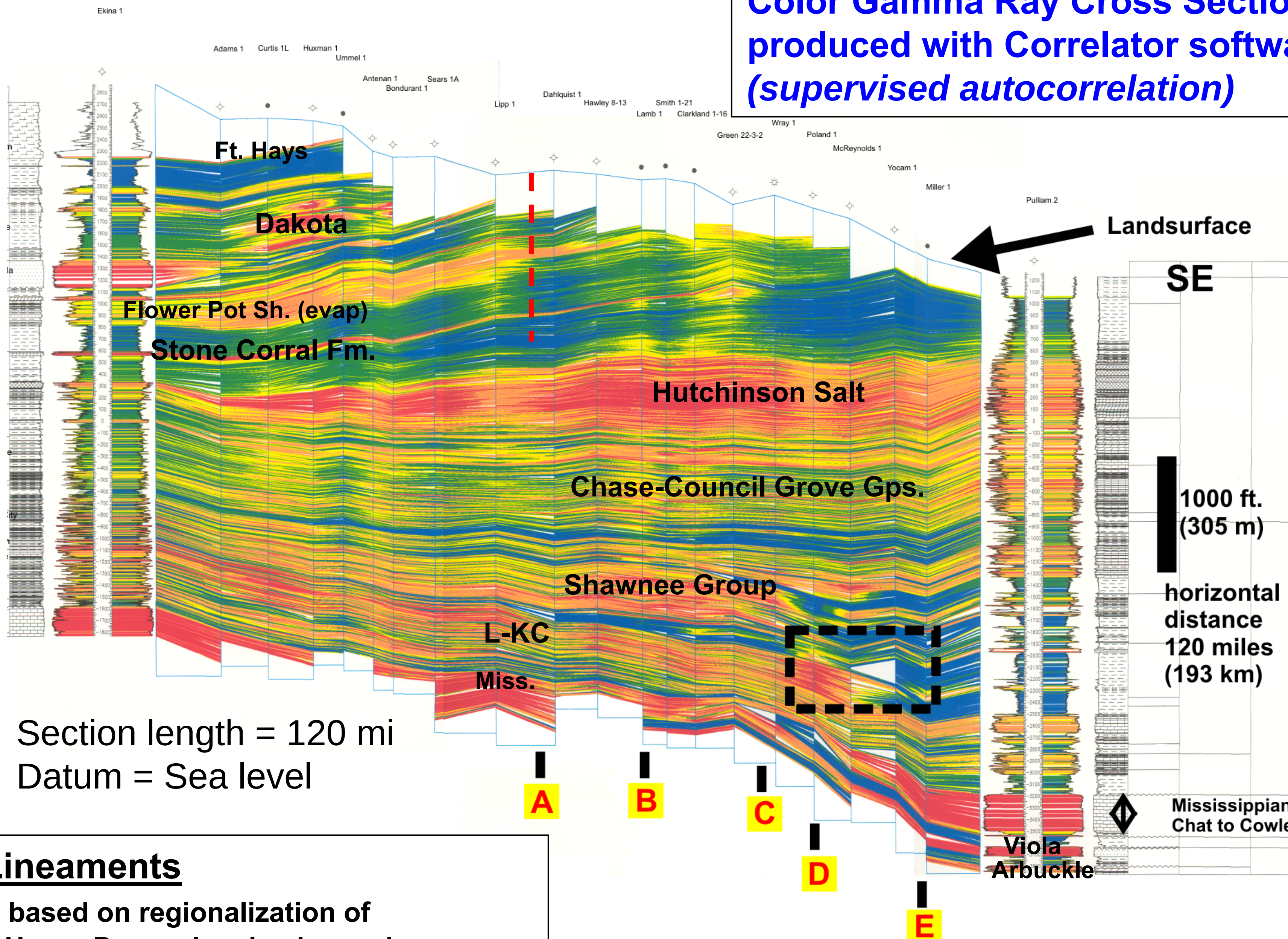
Areas of similar Upper Pennsylvanian cycle thicknesses separated by narrow structural transition zones



Watney et al., 1997)

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)*



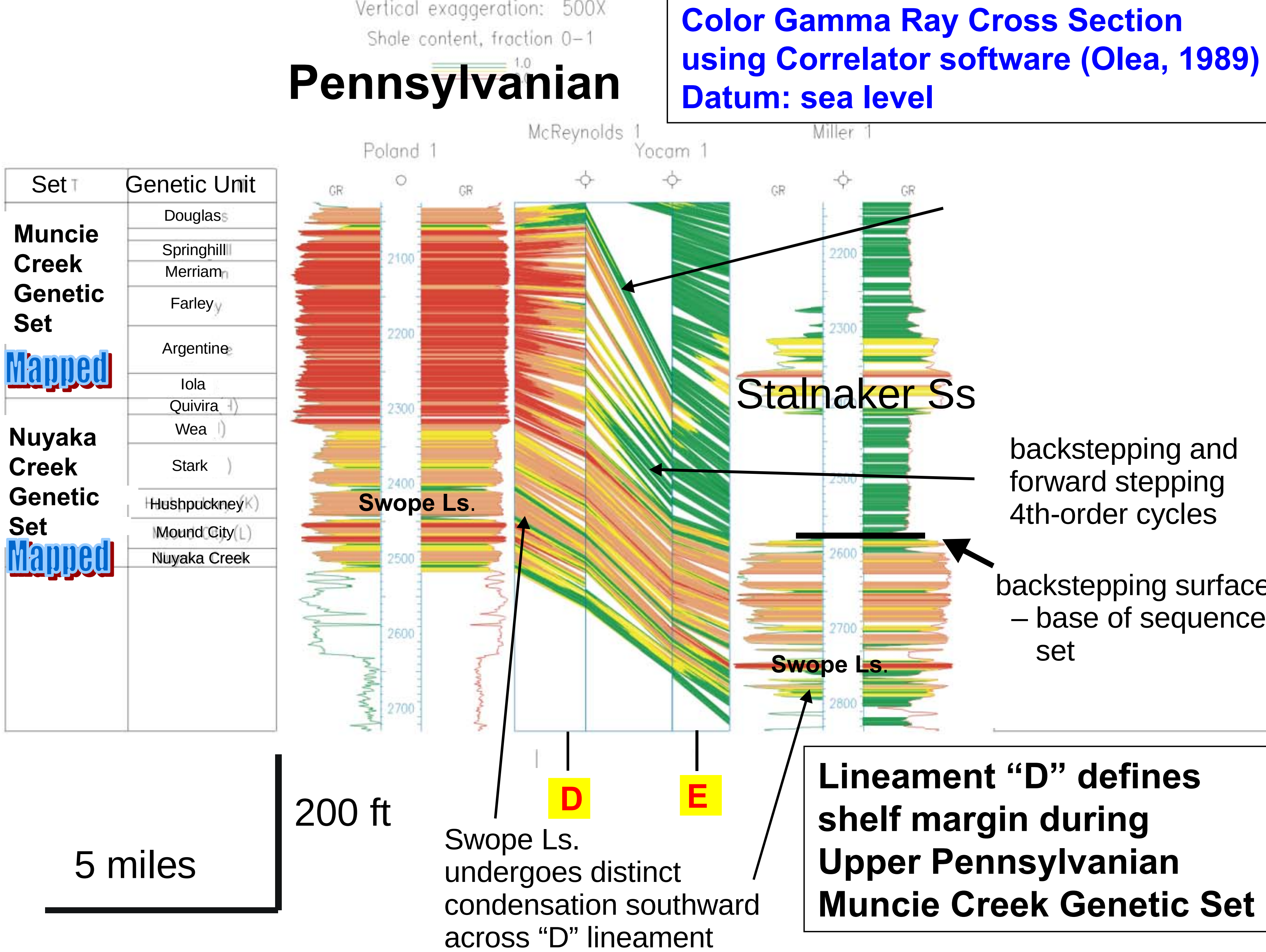
Section length = 120 mi
Datum = Sea level

Lineaments

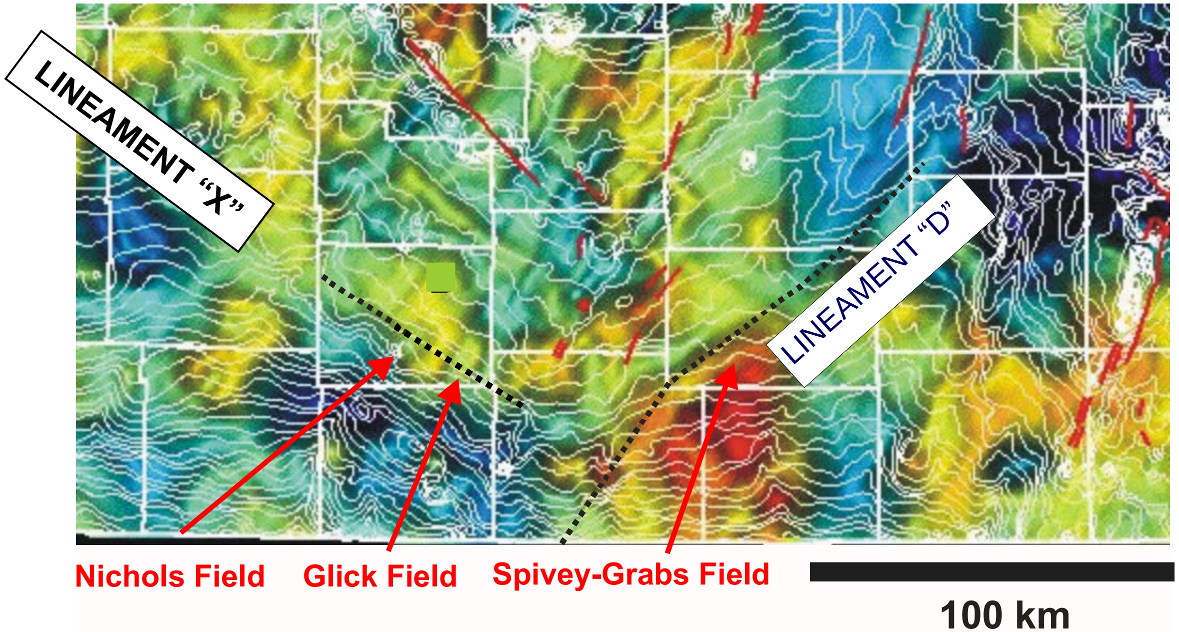
- **based on regionalization of Upper Pennsylvanian isopachous maps**

Watney et al. (1999)

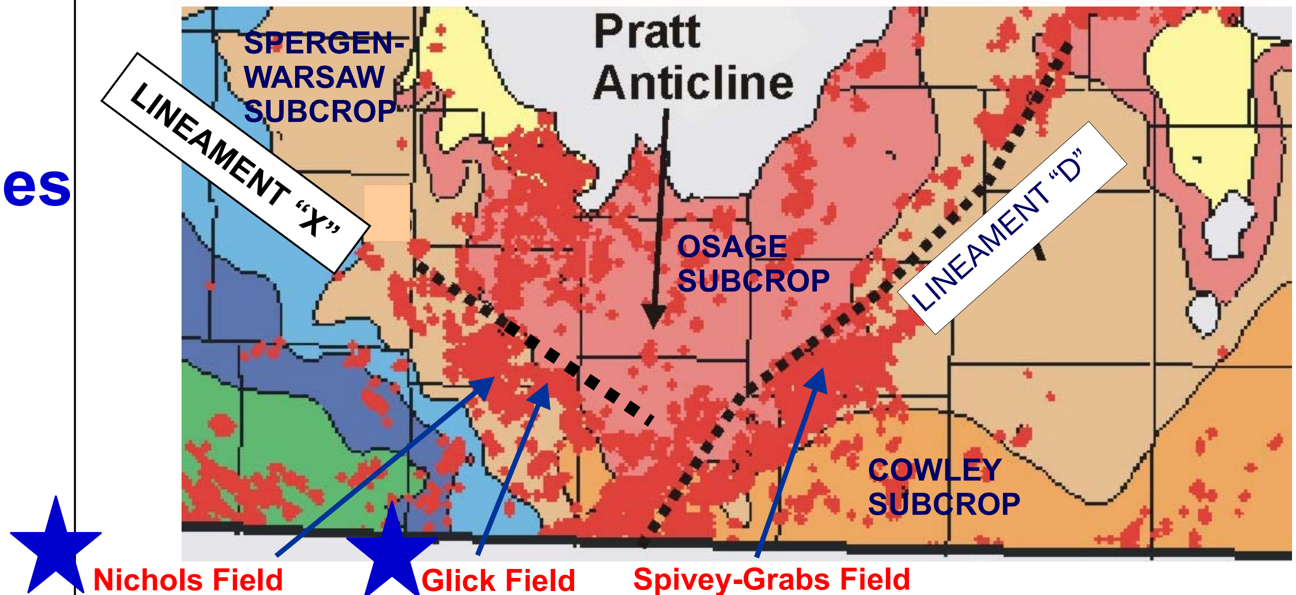
Reds & Yellows = Carbonates, Evaporites, Sandstones
Blue = Shales


Vertical exaggeration: 500X
Shale content, fraction 0–1
1.0
Pennsylvanian
Color Gamma Ray Cross Section
using Correlator software (Olea, 1989)
Datum: sea level
Poland 1
McReynolds 1
Yocam 1
Miller 1
GR
Set
Genetic Unit
Muncie Creek Genetic Set
Mapped
Douglas
Springhill
Merriam
Farley
Argentine
Iola
Quivira
Wea
Nuyaka Creek Genetic Set
Mapped
Stark
Hushpuckney
Mound City
Nuyaka Creek
2100
2200
2300
2400
2500
2600
2700
2800
Swope Ls.
Stalnaker Ss
backstepping and forward stepping 4th-order cycles
backstepping surface – base of sequence set
Swope Ls.
D
E
200 ft
5 miles
Swope Ls. undergoes distinct condensation southward across "D" lineament
Lineament "D" defines shelf margin during Upper Pennsylvanian Muncie Creek Genetic Set

Total Magnetic Field Intensity

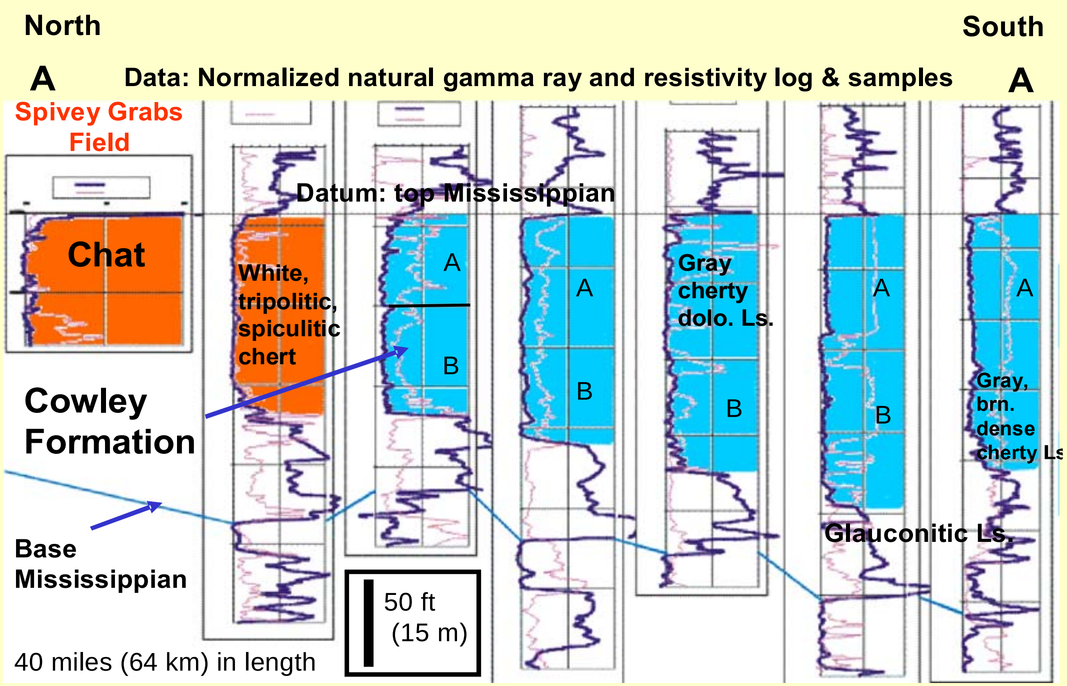


Basal Pennsylvanian Subcrop



Examples

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

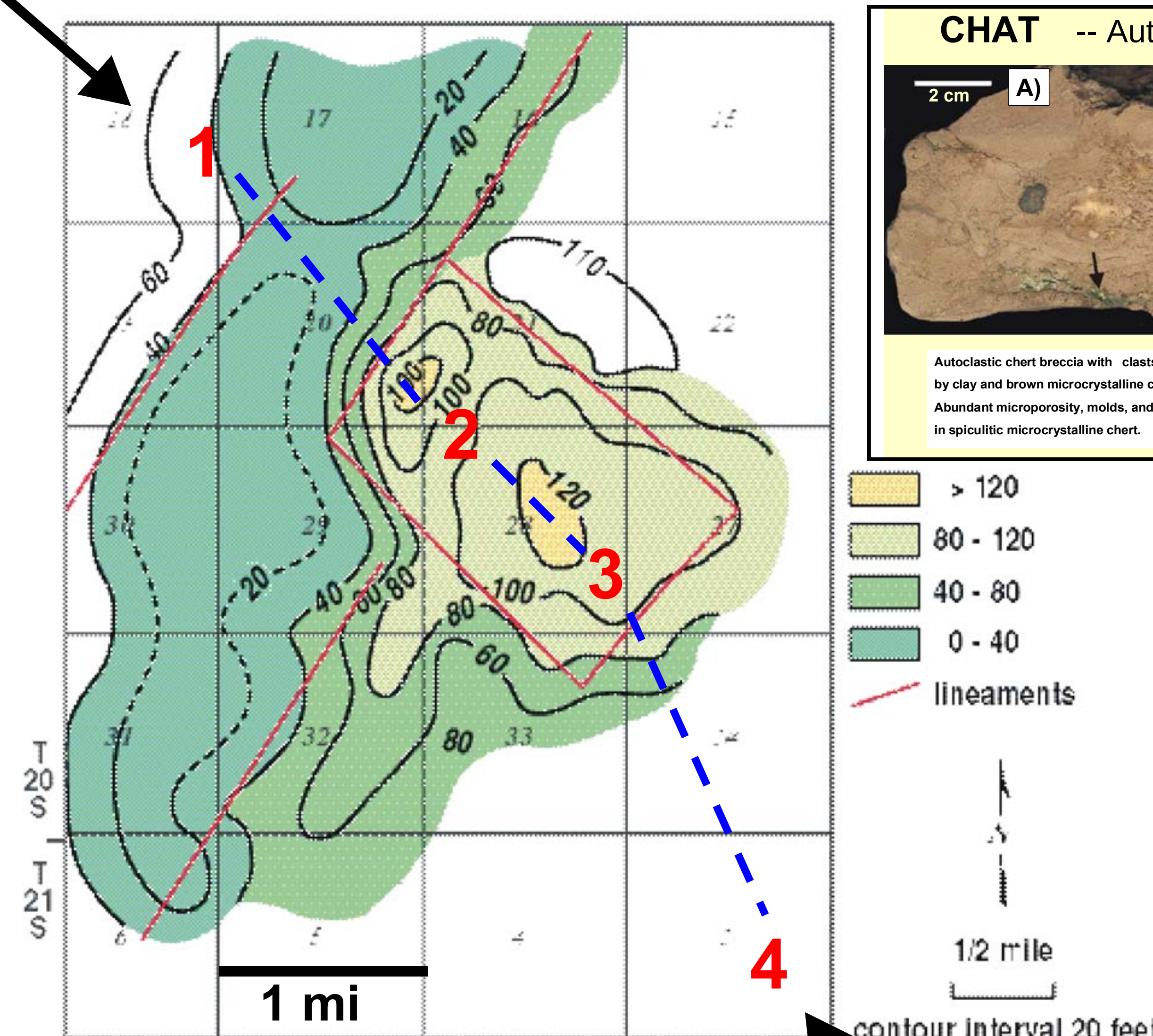


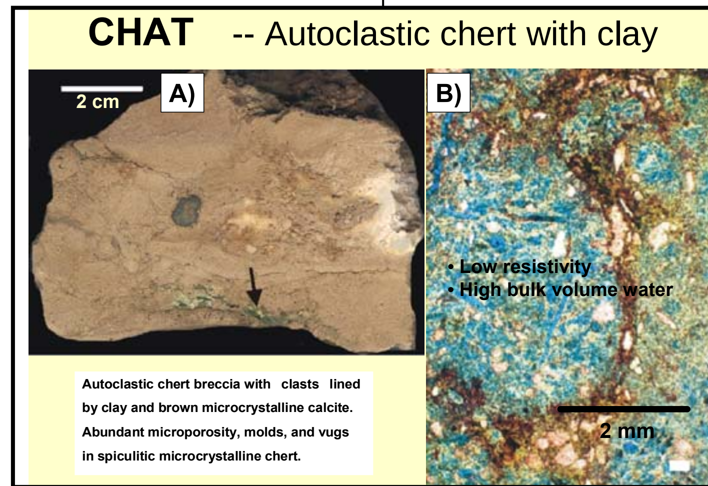
Chat= low gamma ray & resistivity

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

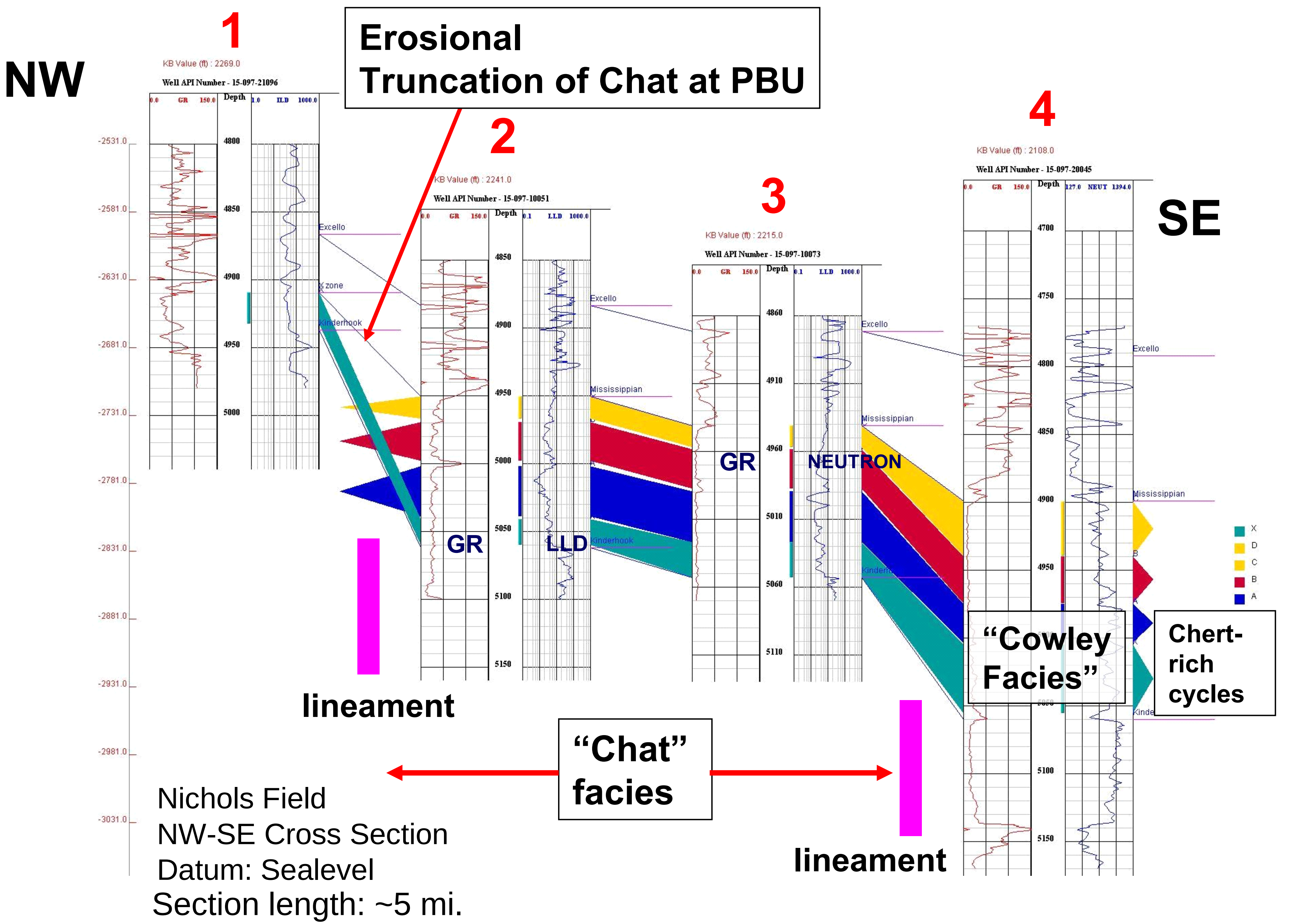
Nichols Field - Residual Chert Thickness





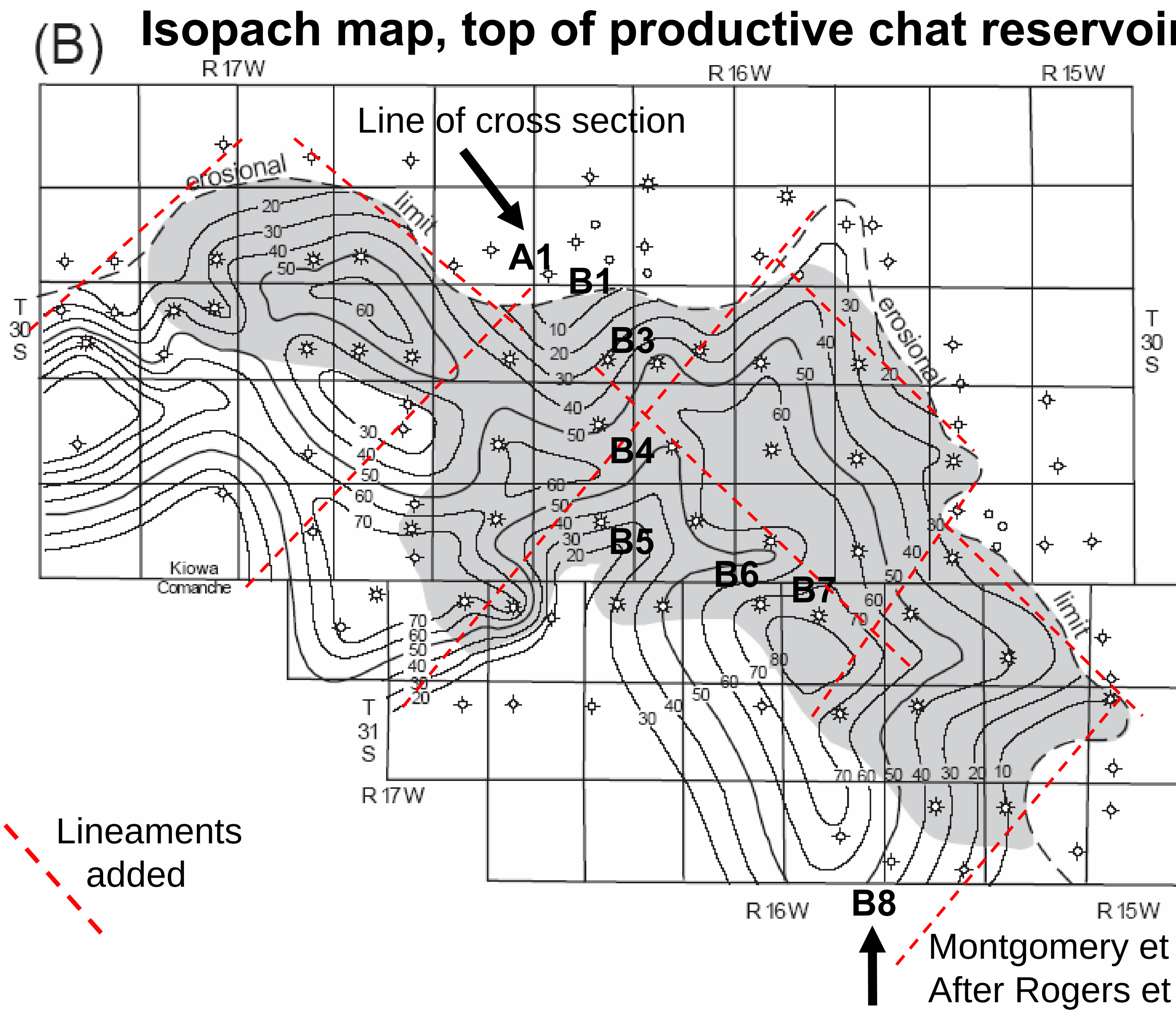
Modified from Zajic (1956)

line of section



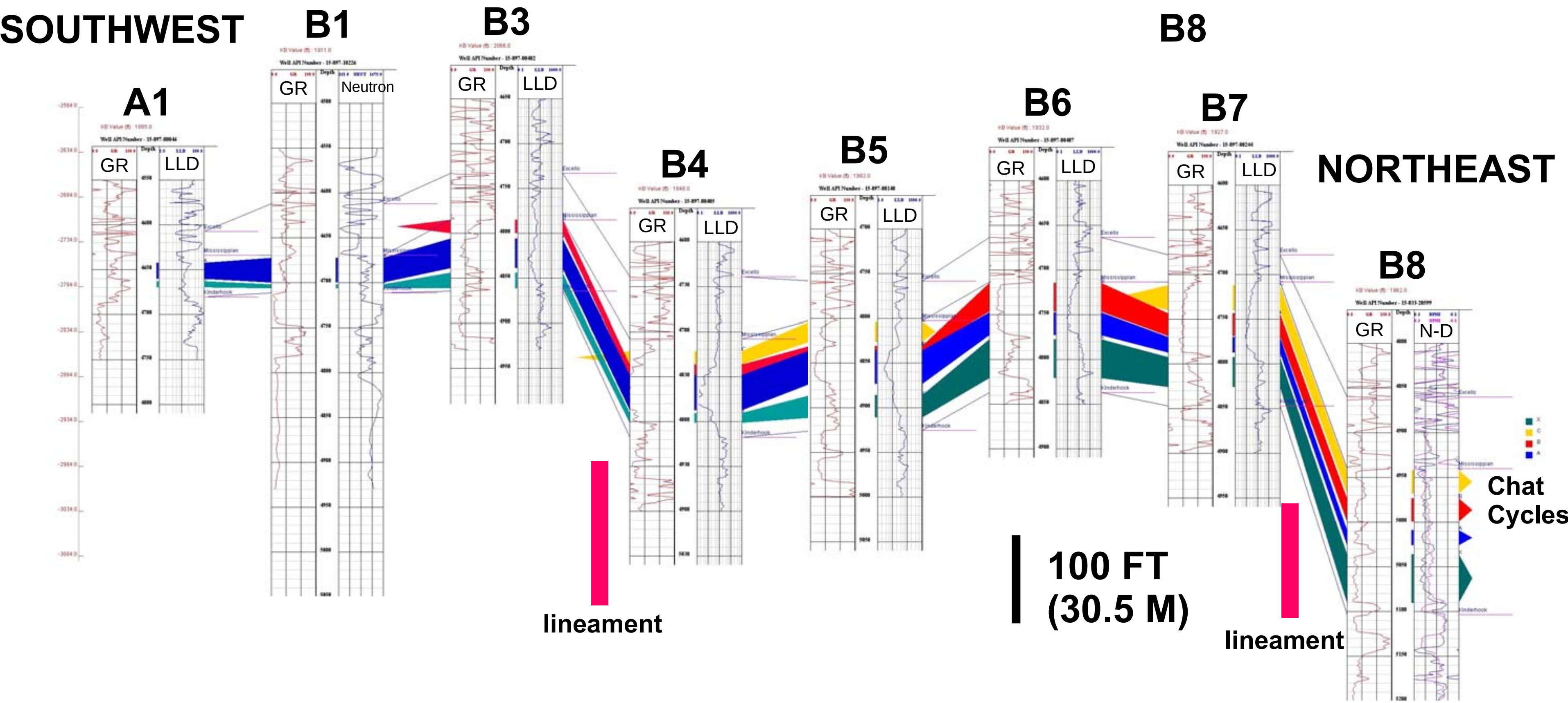
NW
SE
1
2
3
4
Erosional Truncation of Chat at PBU
KB Value (ft) : 2269.0
Well API Number - 15-097-21096
KB Value (ft) : 2241.0
Well API Number - 15-097-10051
KB Value (ft) : 2215.0
Well API Number - 15-097-10073
KB Value (ft) : 2108.0
Well API Number - 15-097-20045
Excello
X zone
Kinderhook
Mississippian
GR
LLD
NEUTRON
"Cowley Facies"
Chert-rich cycles
X
D
C
B
A
lineament
"Chat" facies
lineament
Nichols Field
NW-SE Cross Section
Datum: Sealevel
Section length: ~5 mi.

Glick Field
Isopach map, top of productive chat reservoir



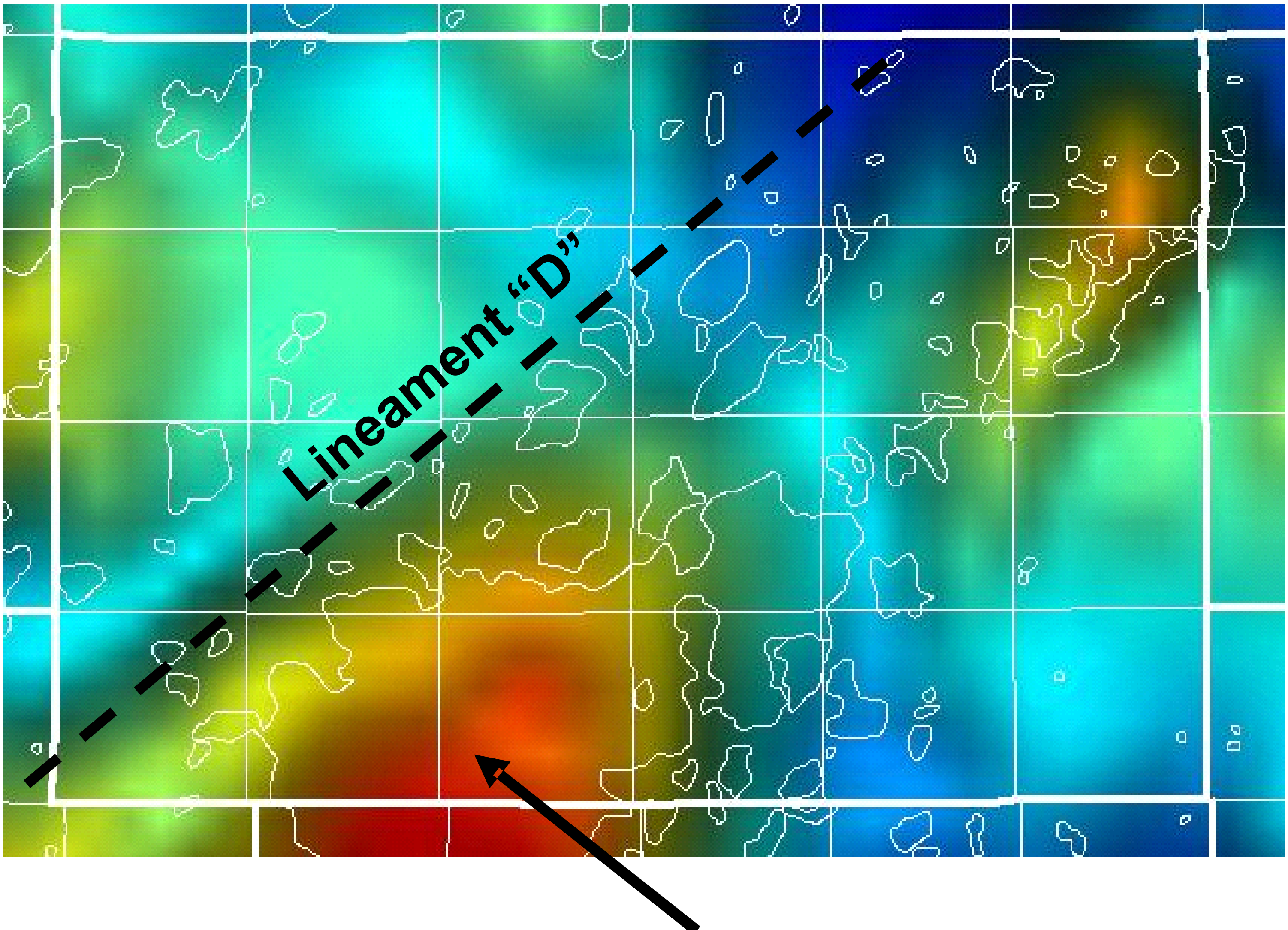
Montgomery et al. (1998), After Rogers et al. (1995)

Structural cross section through chat Reservoir in Glick Field

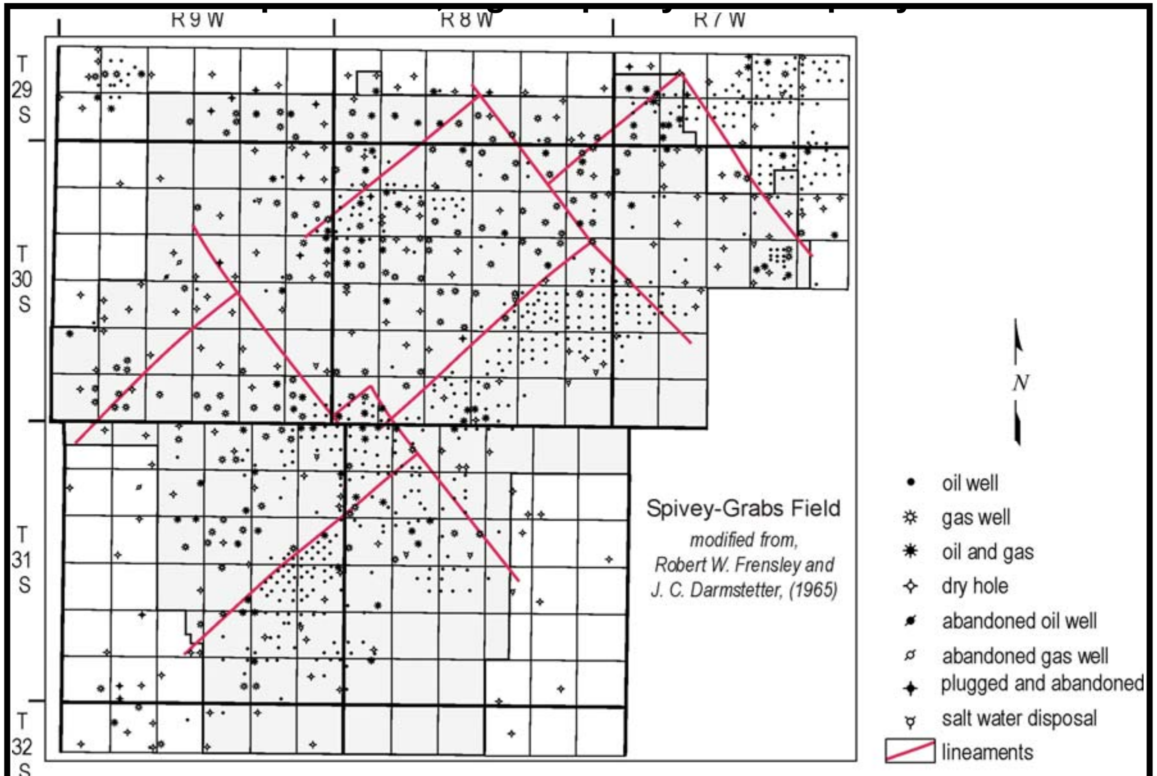


No horizontal scale, section length ~9 mi
Equidistant wells

Magnetic Map, Kingman County



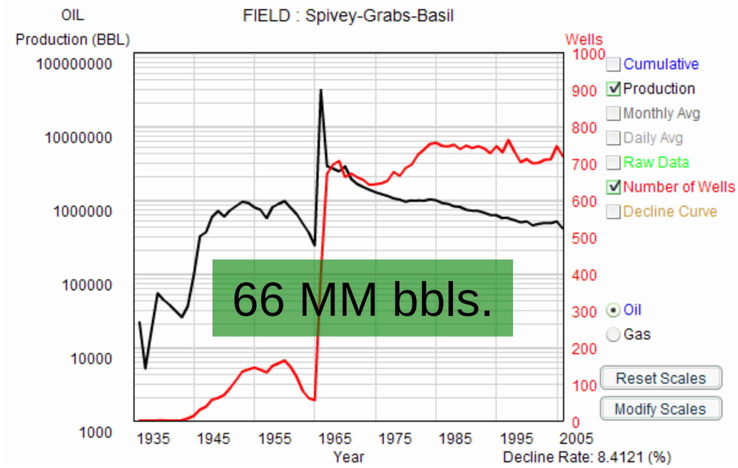
Compartments of more highly productive chat
In Spivey-Grabs-Basil Field
Barber, Harper, and Kingman counties Kansas

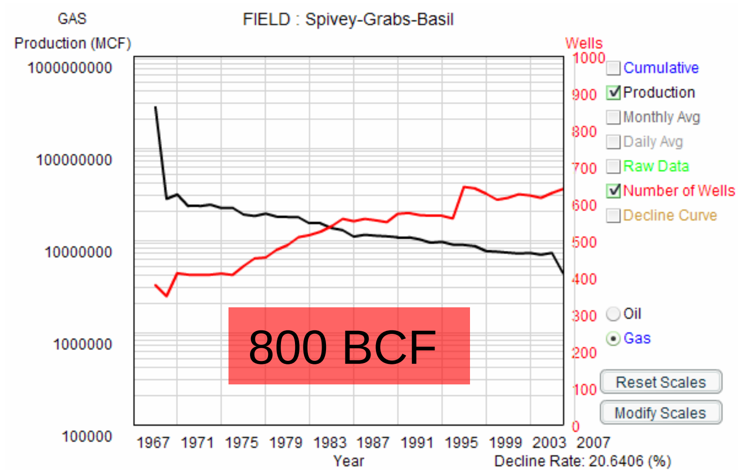


* pods of more productive, better developed chat *

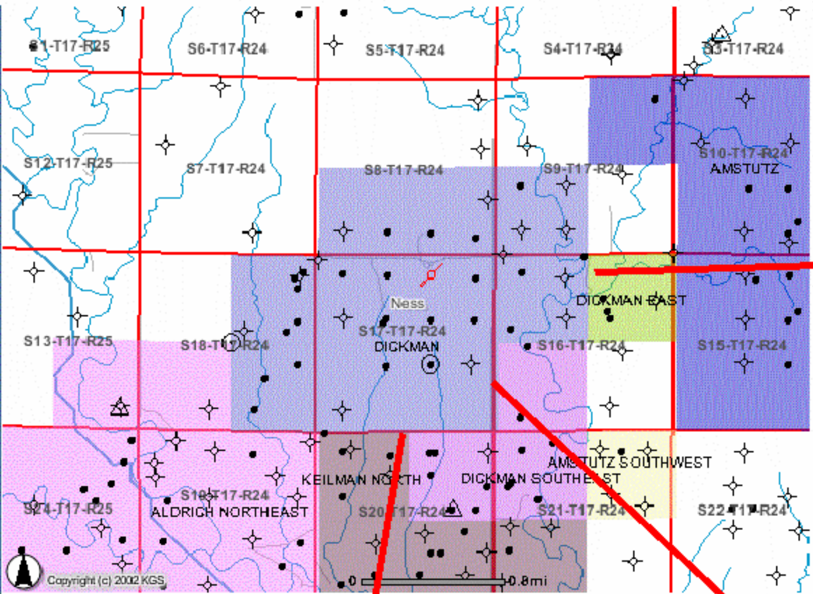
NW-SE lineaments

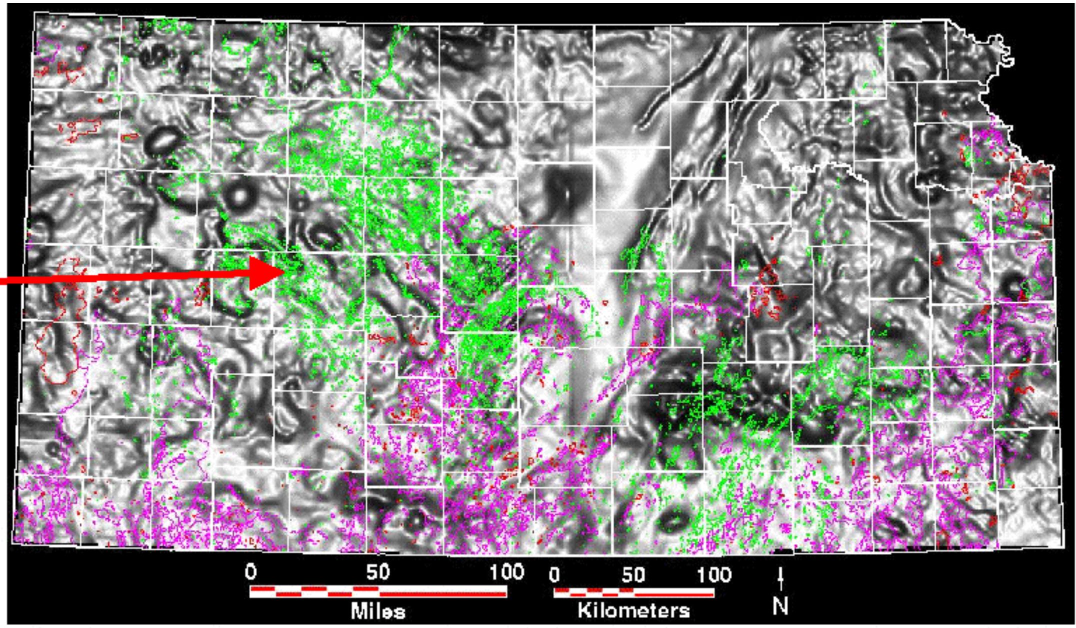
*** structure, paleogeomorphology, diagenesis, reservoir chat**

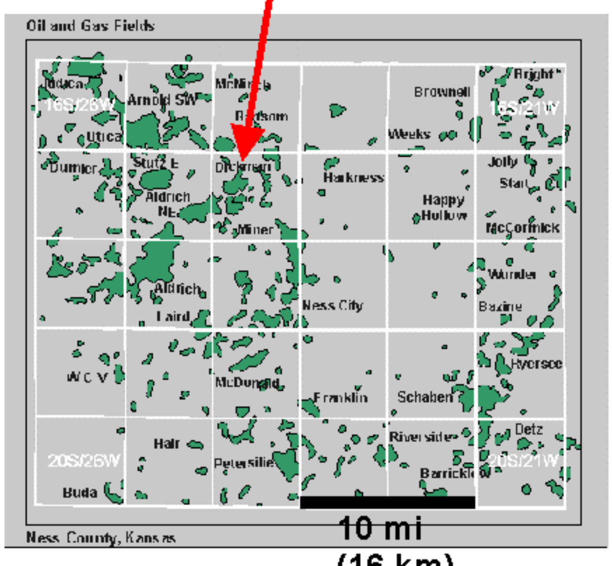




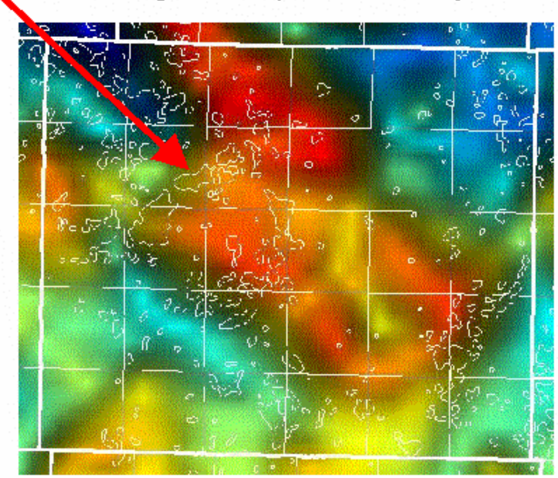
Dickman Field – Contemporaneous structural control on secondary pay in Ft. Scott Ls. (Desmoinesian oomoldic CO3)



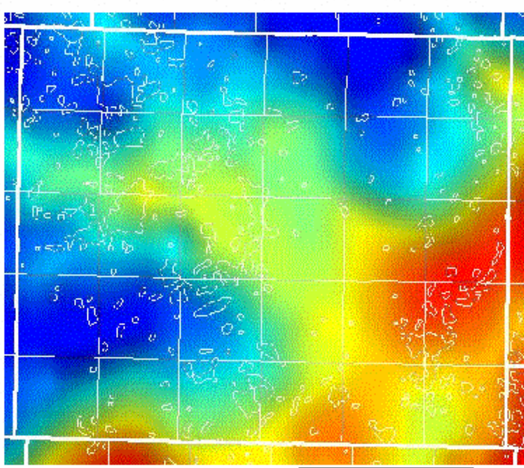




Magnetic Map, Ness County



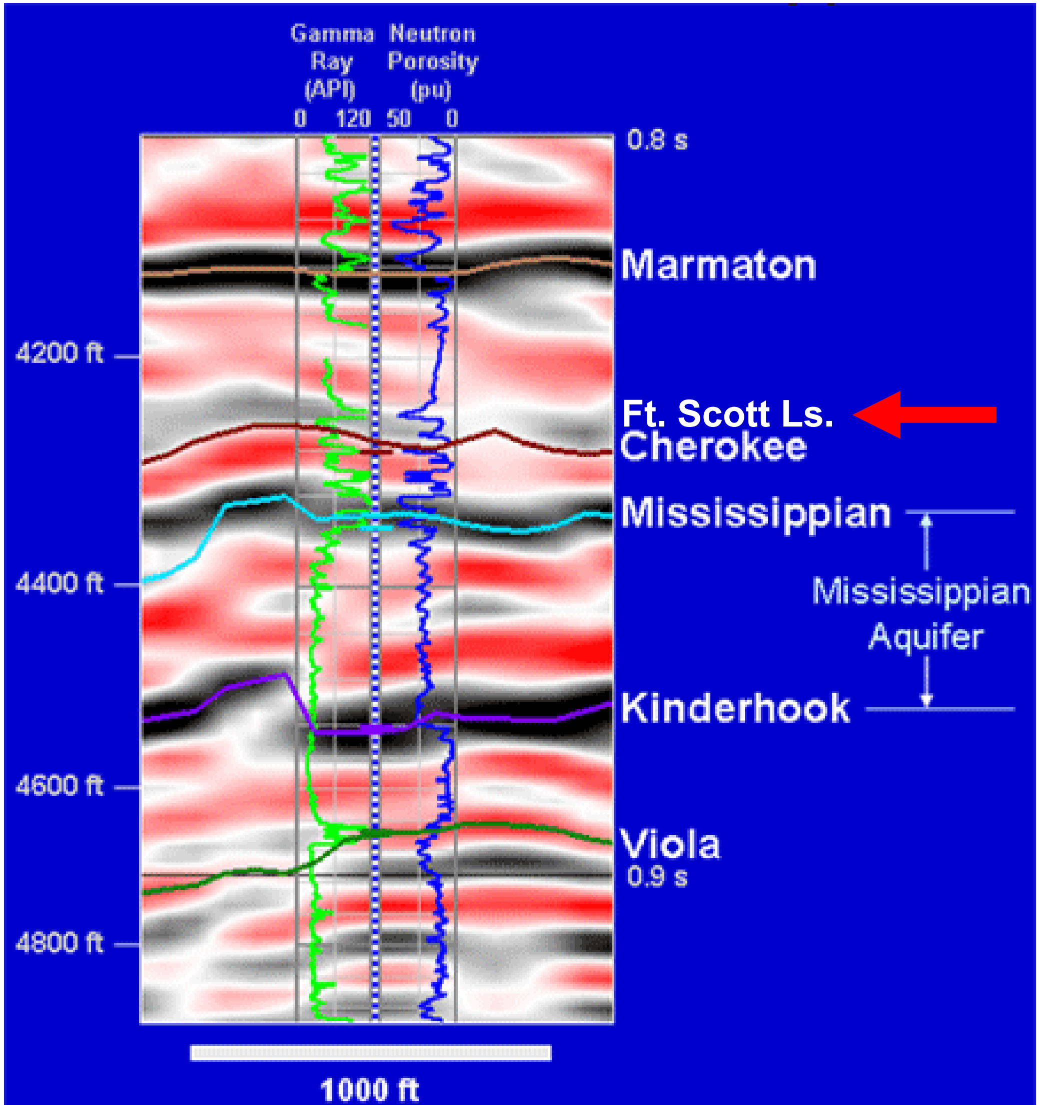
Gravity Map,Ness County



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.

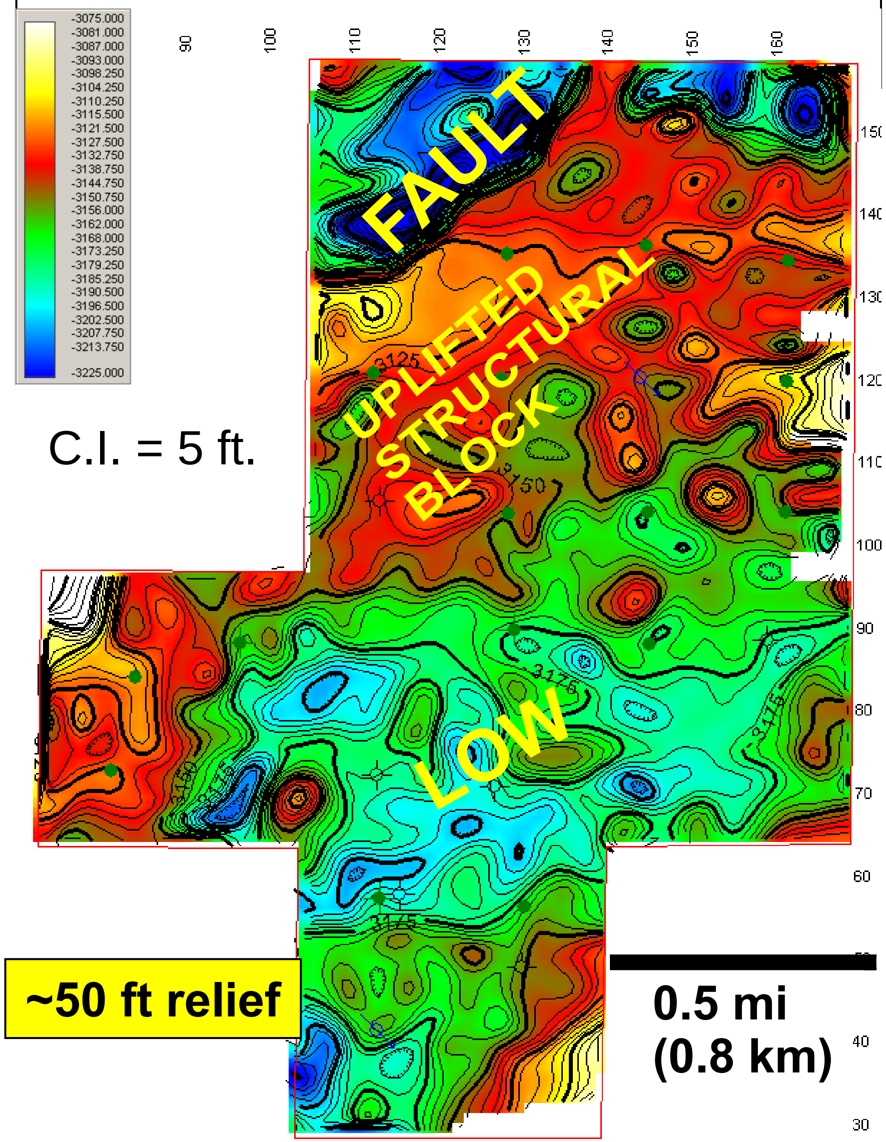
The top of the **Ft. Scott Limestone** is a small positive seismic reflection immediately above the Cherokee.

Nissen et al. (2005)

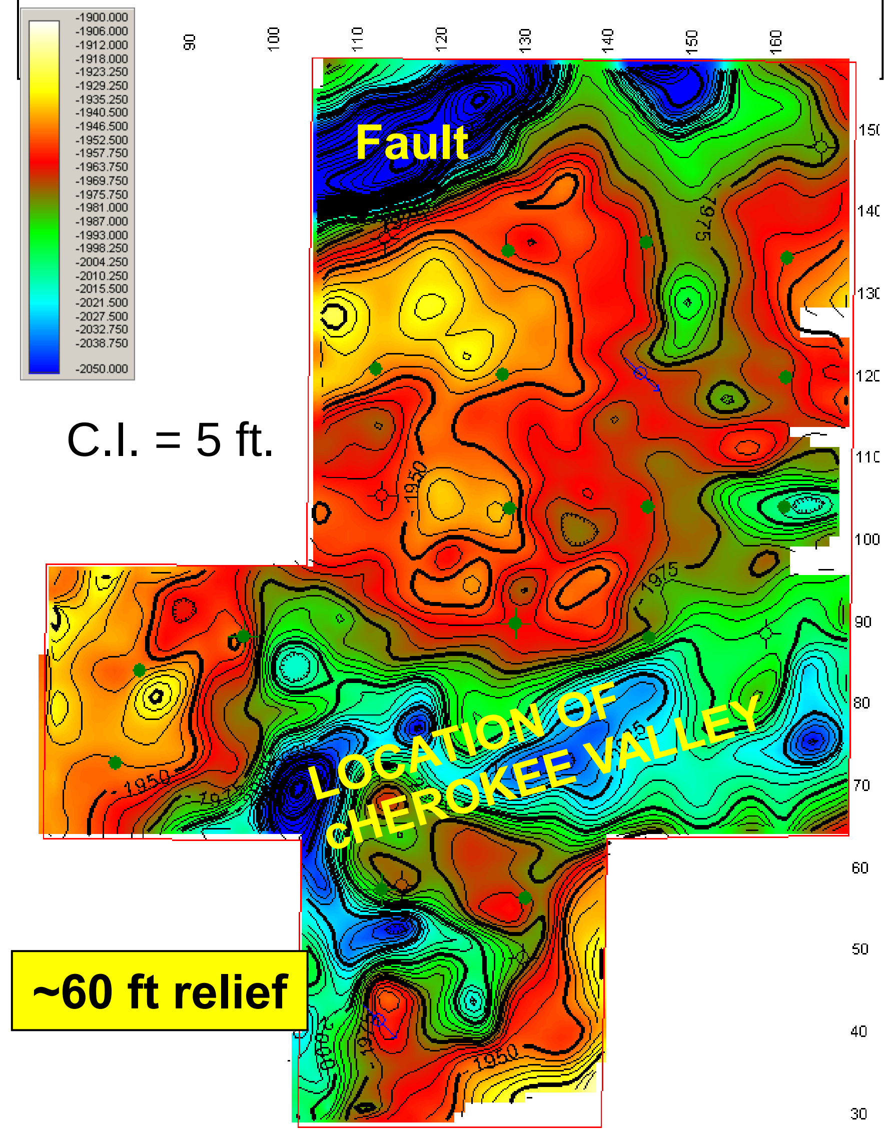
http://www.kgs.ku.edu/PRS/publication/2004/2004-56/index.html

Seismic data provided by Grand Mesa Operating Co.

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

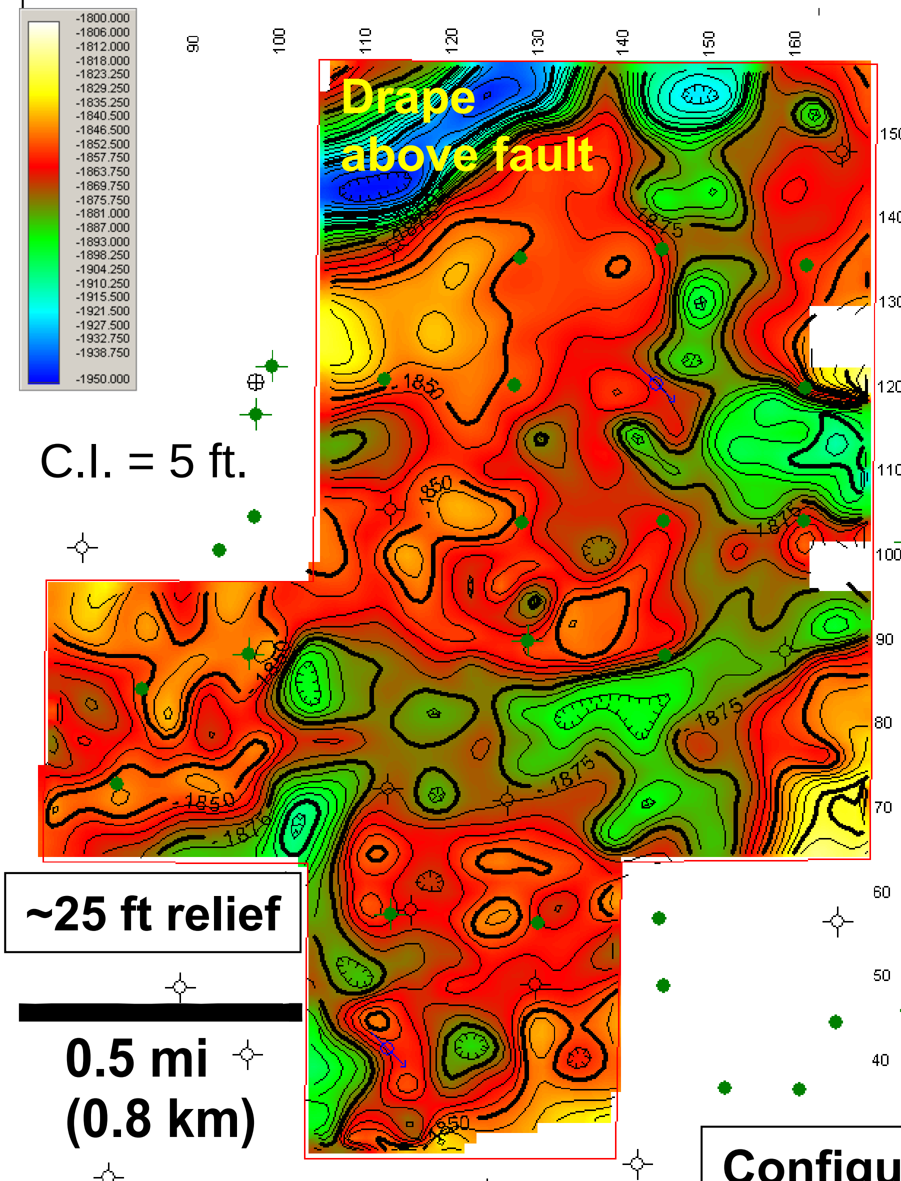


Mississippian Subsea Depth

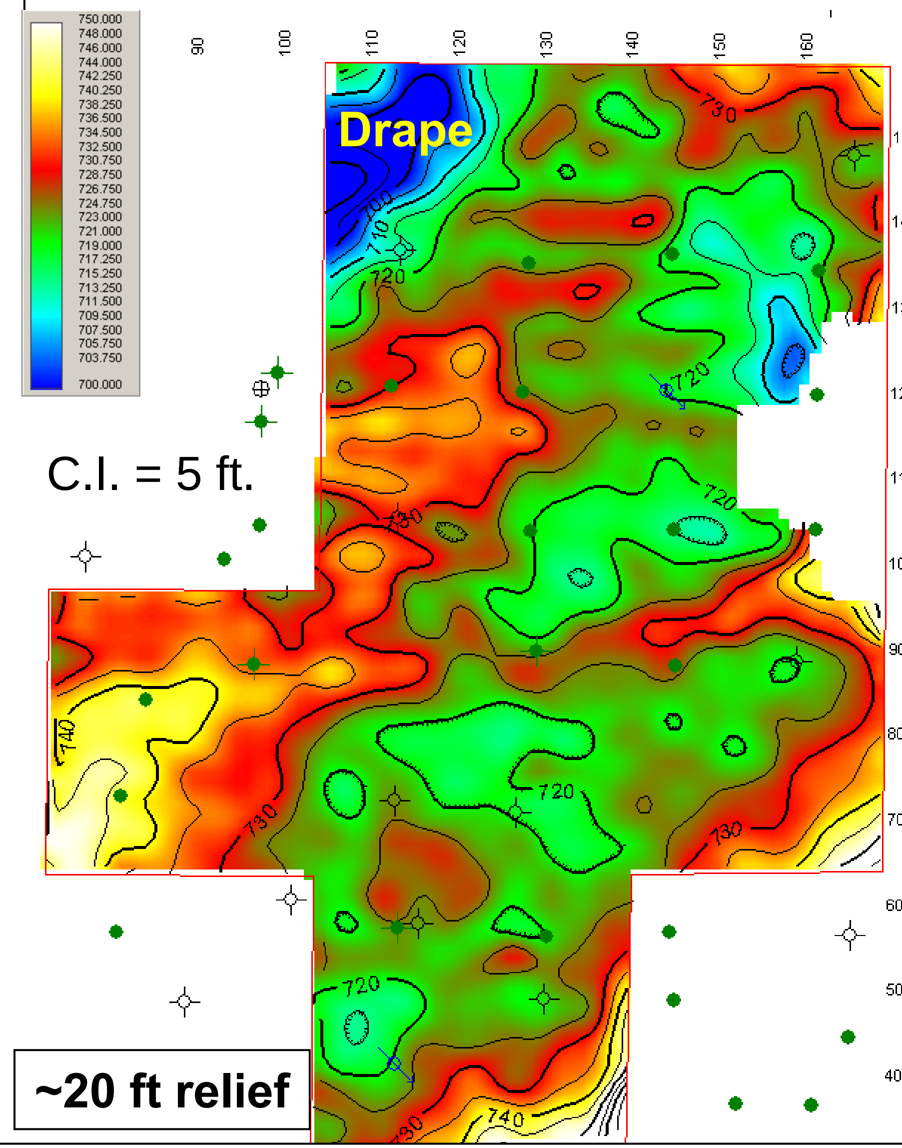


Cherokee paleovalley coincides with structural low on Precambrian surface

Fort Scott Subsea Depth

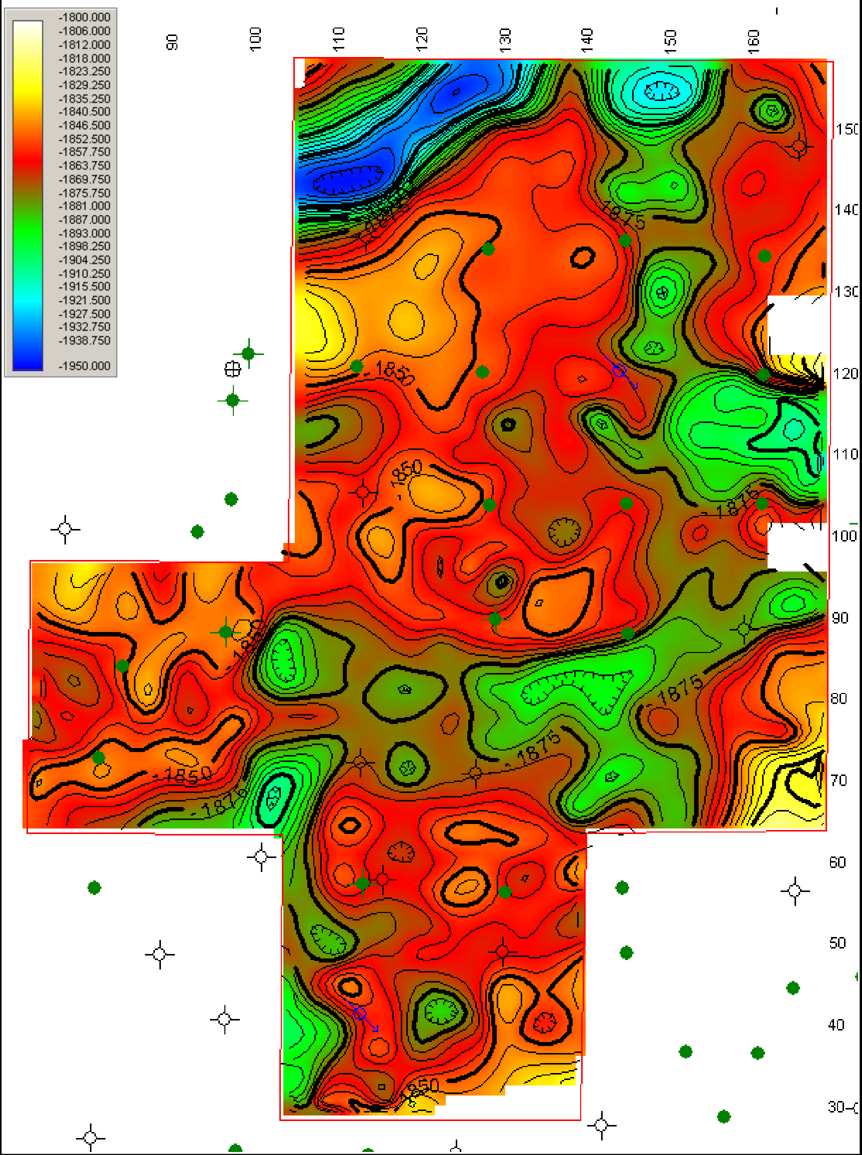


Stone Corral Subsea Depth

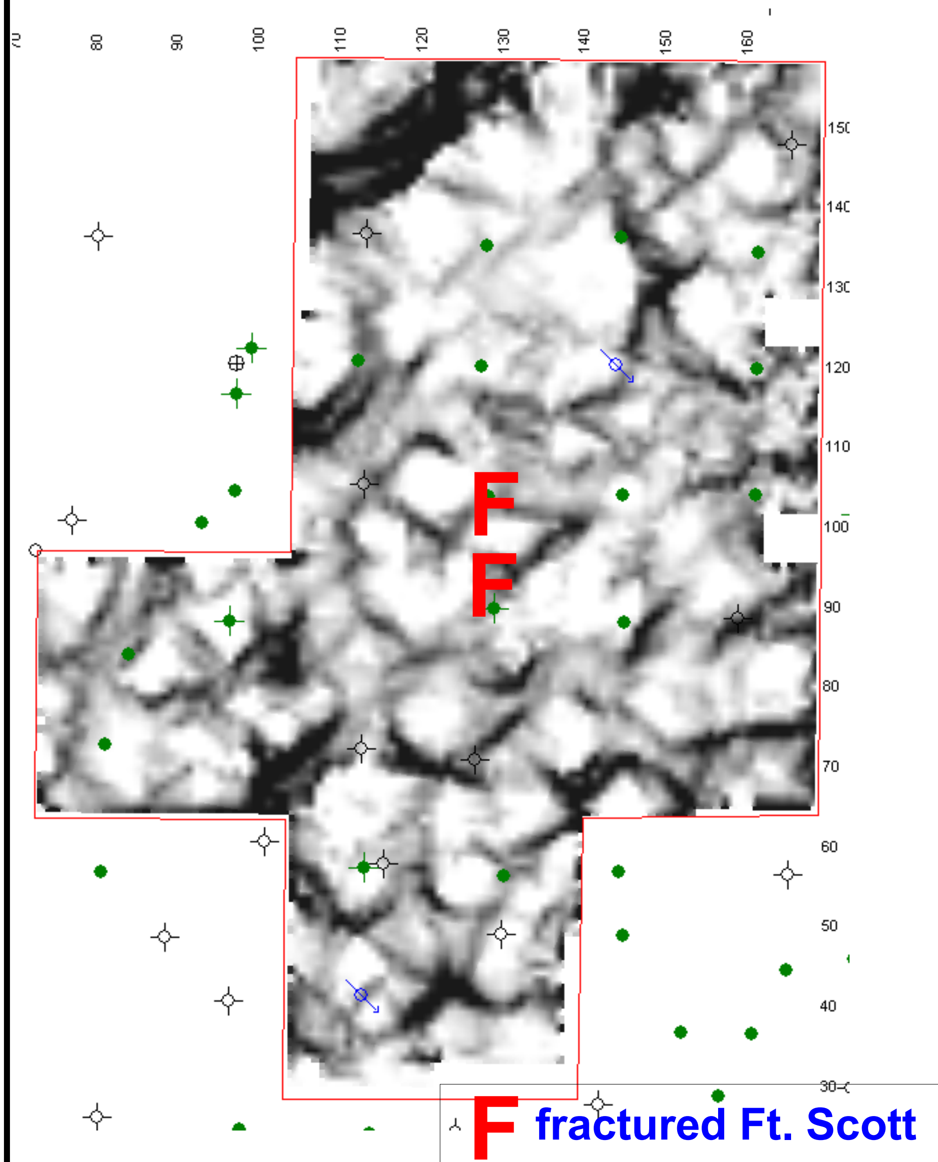


Configuration of L. Permian Stone Corral surface resembles Middle Pennsylvanian surface (1/2 mi lower in section)

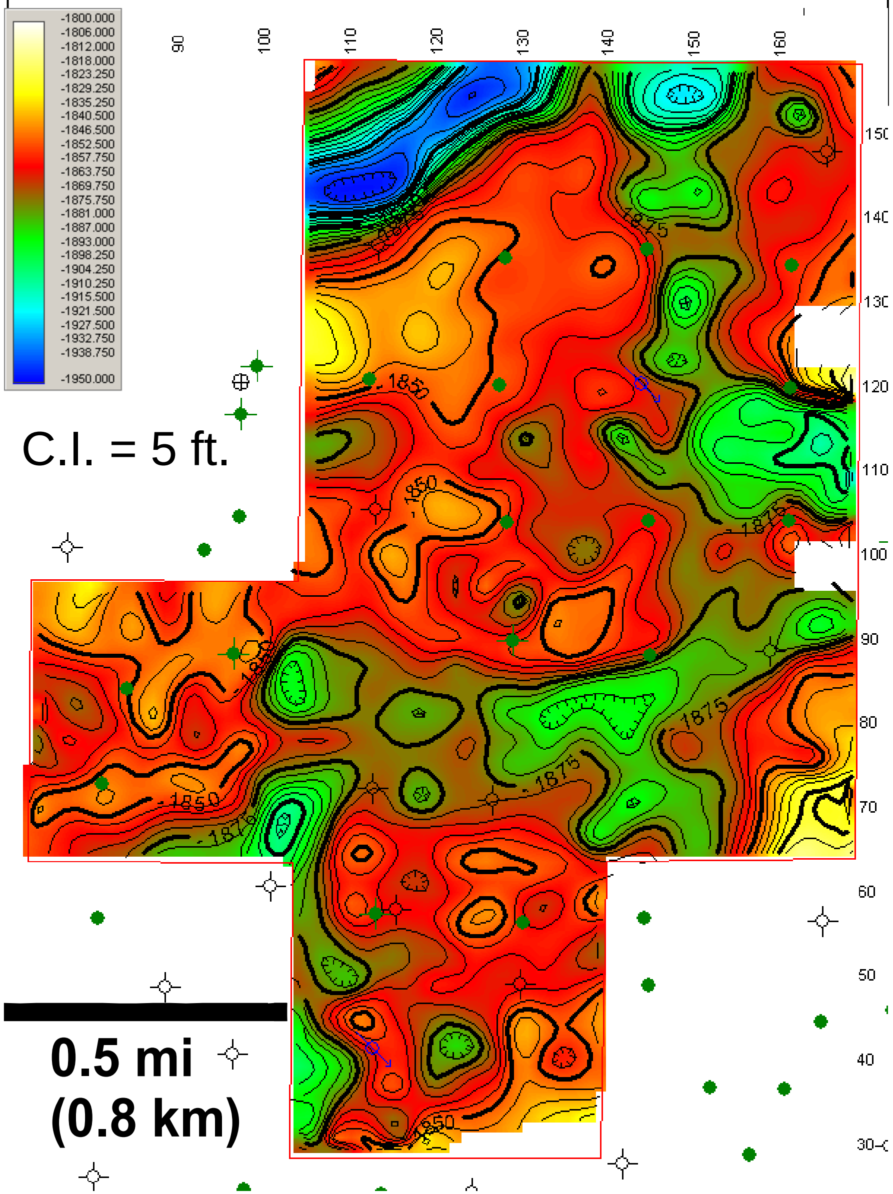
Fort Scott Subsea Depth



Fort Scott Volumetric Curvature

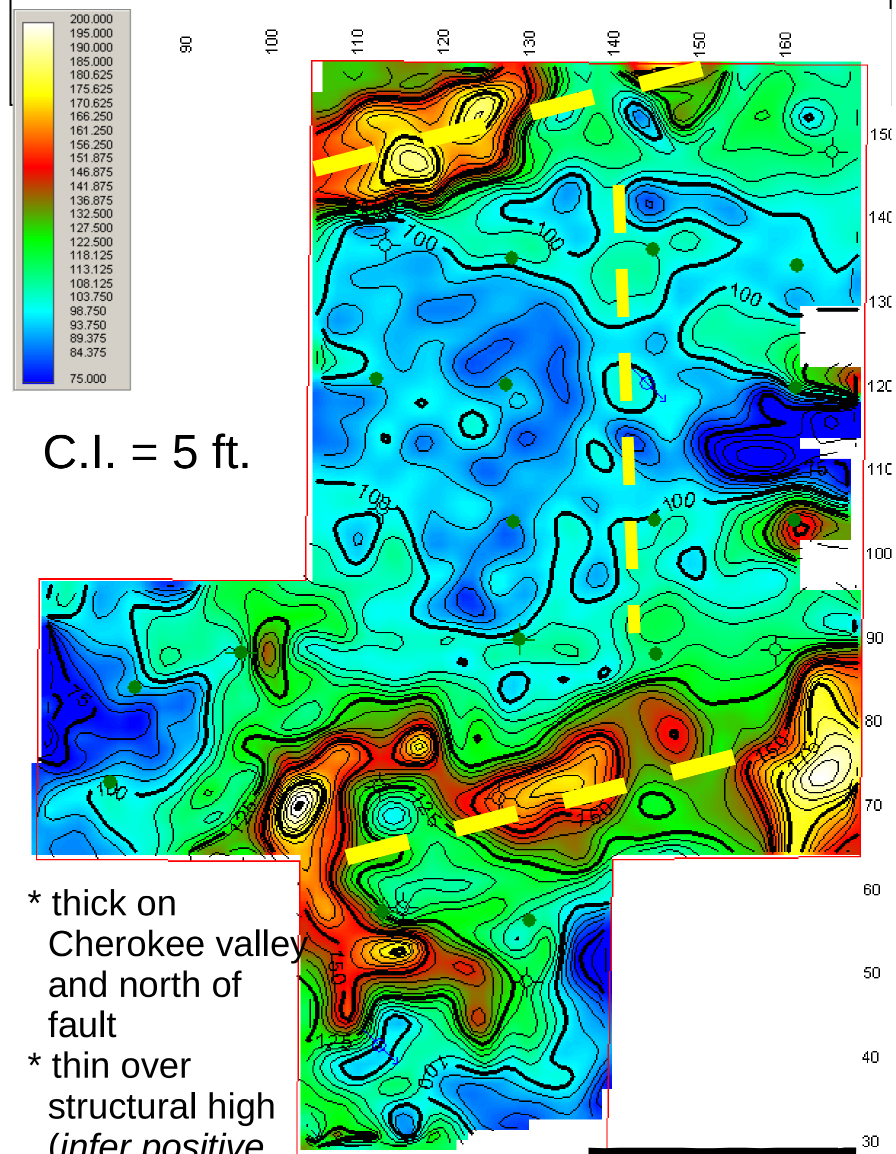


Fort Scott Subsea Depth



~60 ft relief

Fort Scott to Mississippian Isopach



* thick on Cherokee valley and north of fault
* thin over structural high (*infer positive at time of Ft. Scott*)

~50 ft thinning

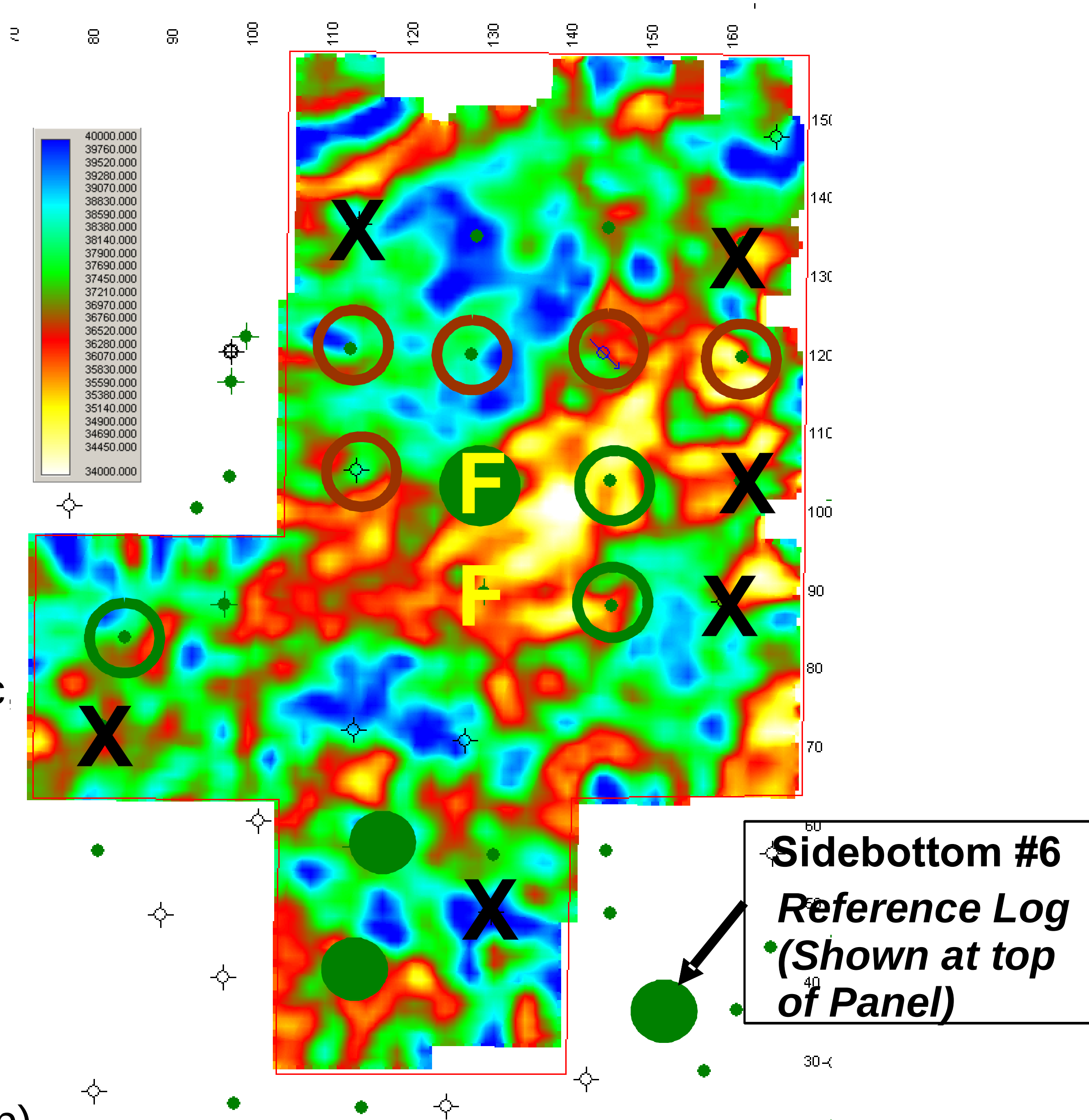
Fort Scott Impedance

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 paleotopgraphic high block

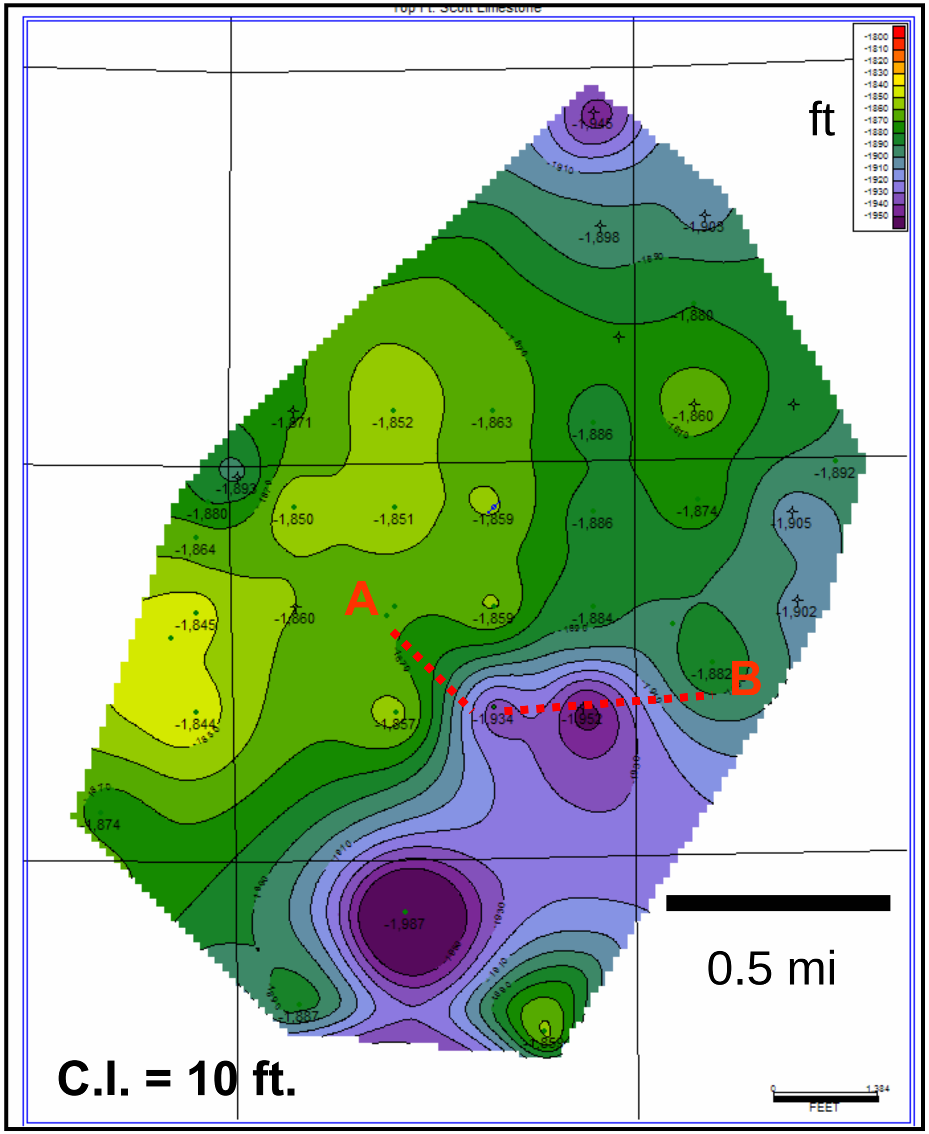
- Low-poor P&P
- Good P&P, oomoldic fossil mold, vuggy good DST and HC shows
- Very good P&P, oomoldic, vuggy, <u>PERFORATED</u>
- F Fractures described from cores
- X Tight Limestone

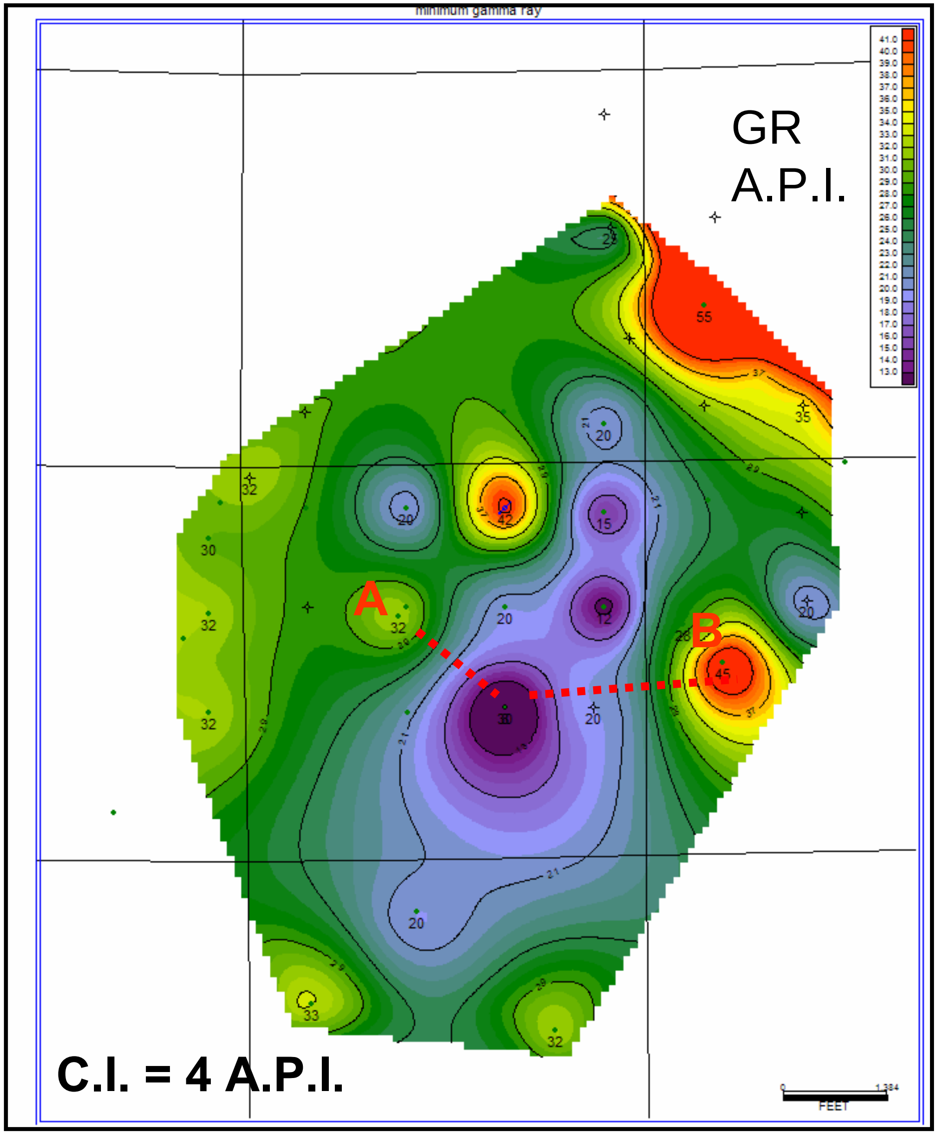
(based on sample and core descriptions of Don Beauchamp)



Top Ft. Scott Limestone Dickman Field using Well Control

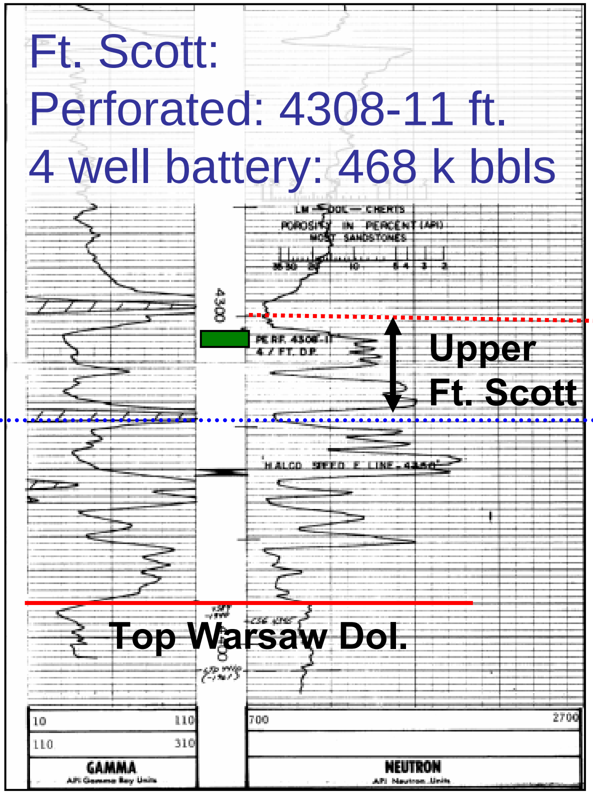
Minimum Gamma Ray Top Ft. Scott Pay





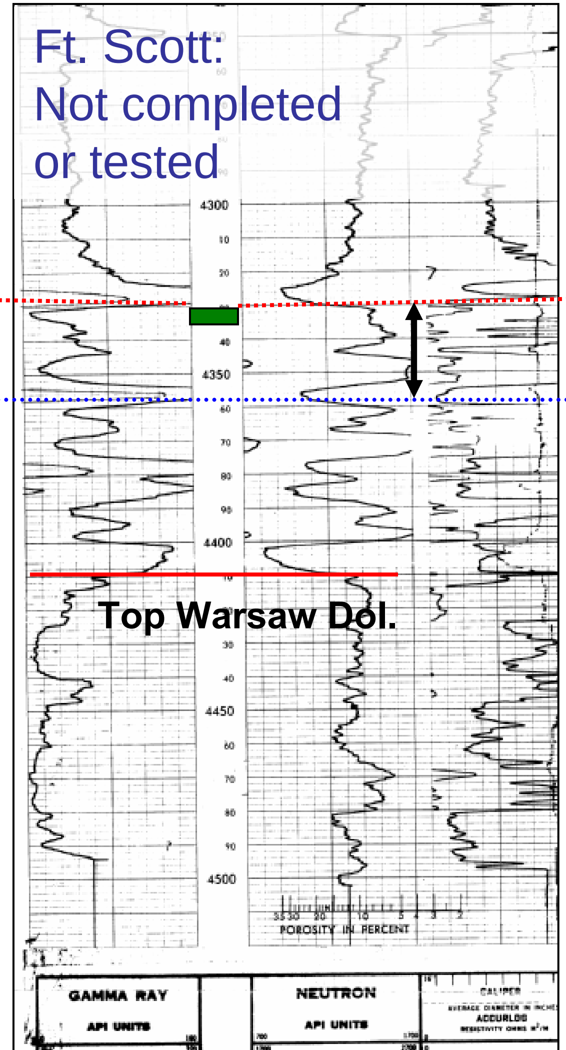
NW

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*

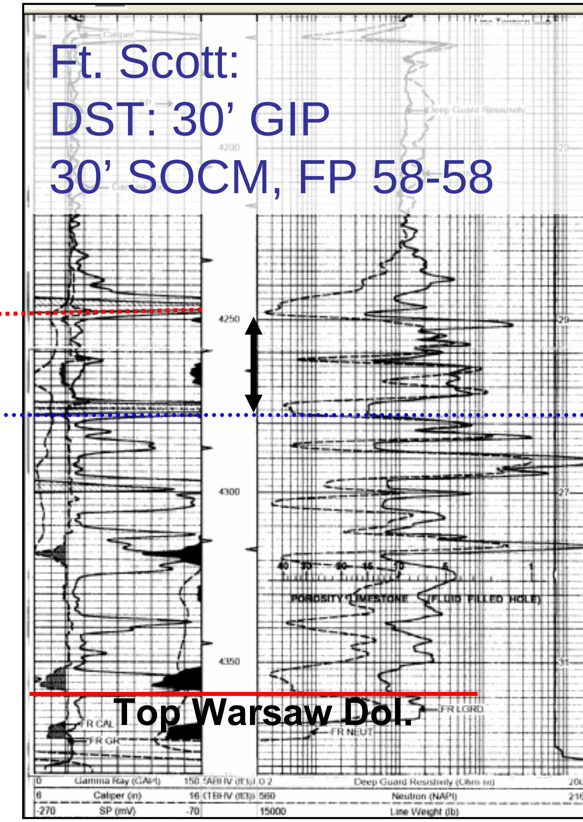
Phelps #1
(60 ft low to Dickman #3)
GR-N-Guard



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

Keilman-Noll #1
GR-N-Guard

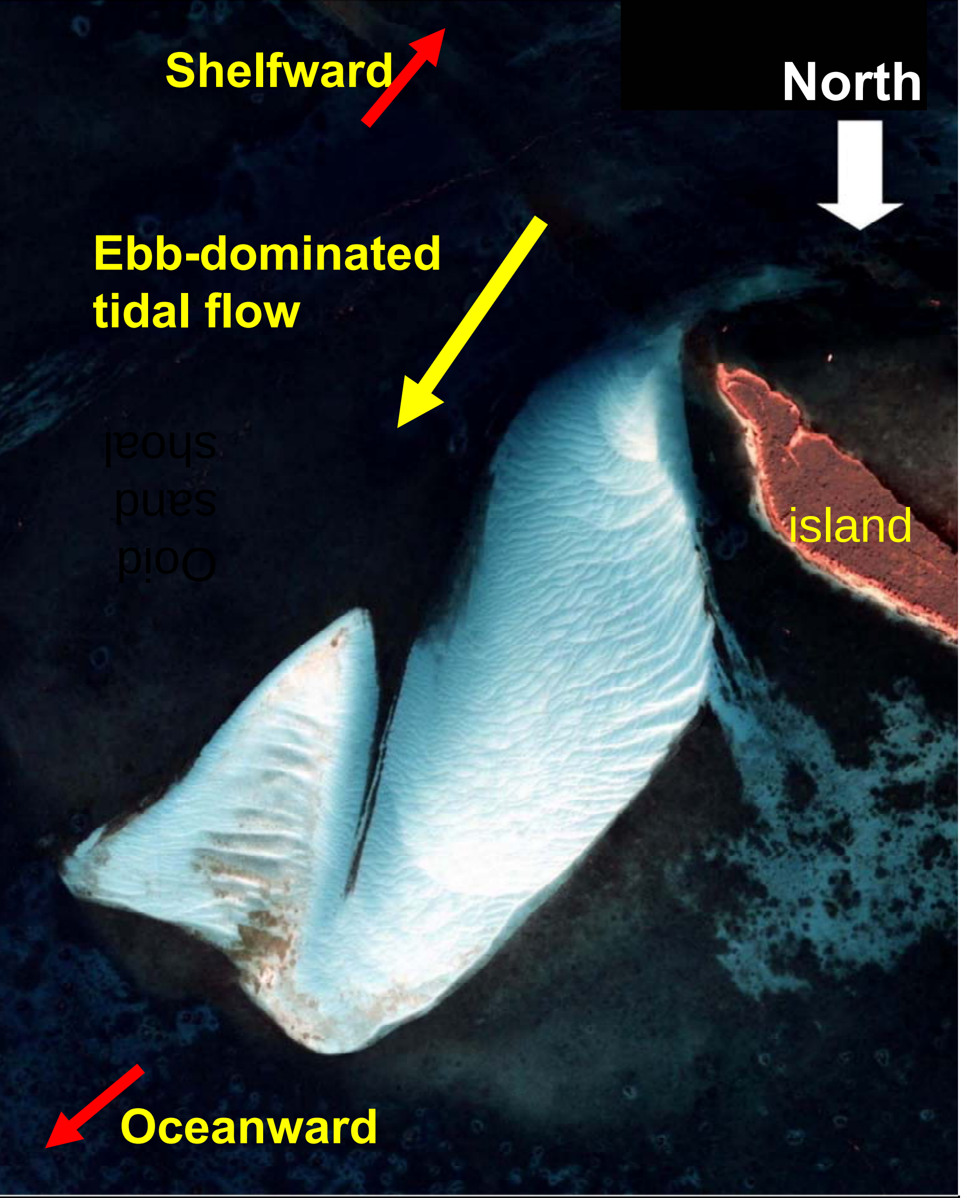
East

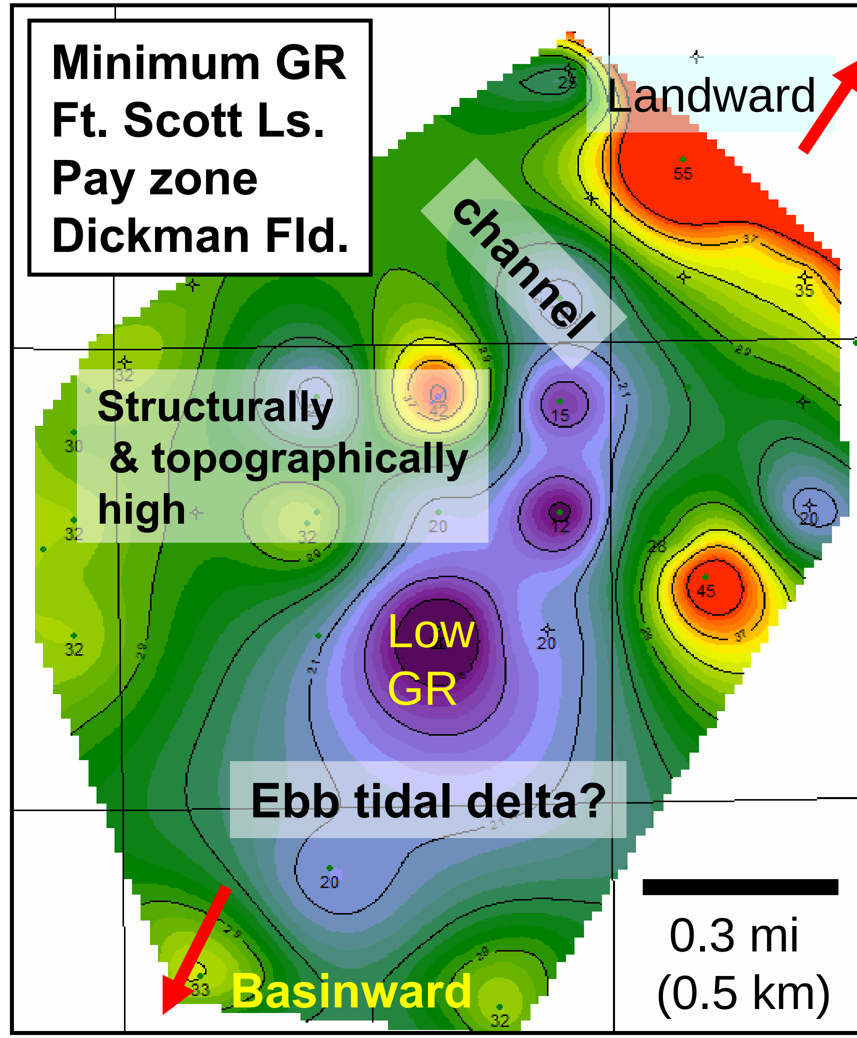


- Sample description: fossil mold, some sucrosic

50 Feet

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



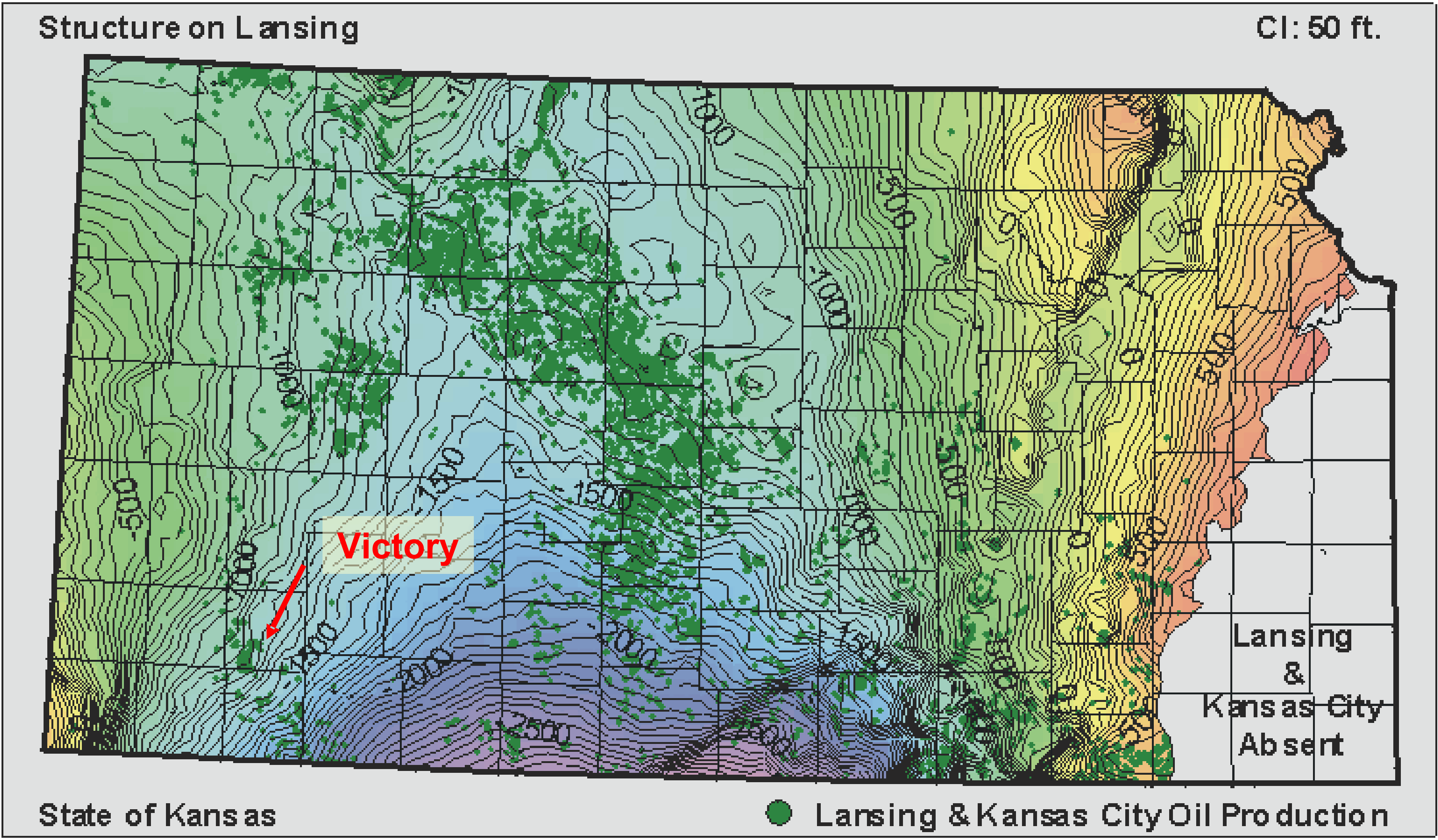


Interpretive patterns of flow in an ebb-dominated oolitic tidal bar. S. Reeder and G. Rankey (2005)
DigitalGlobe^c

Victory Field, Haskell County

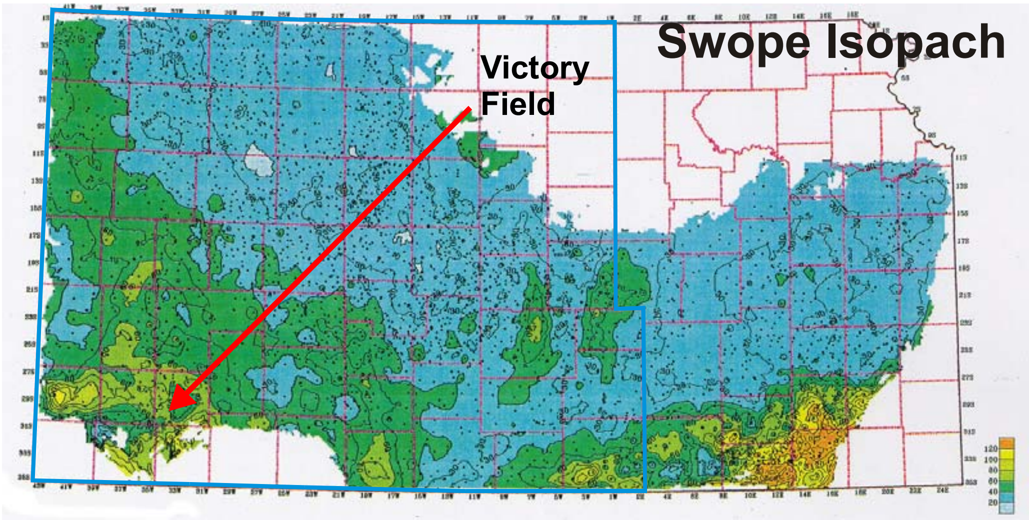
Lansing-Kansas City

Oomoldic grainstone

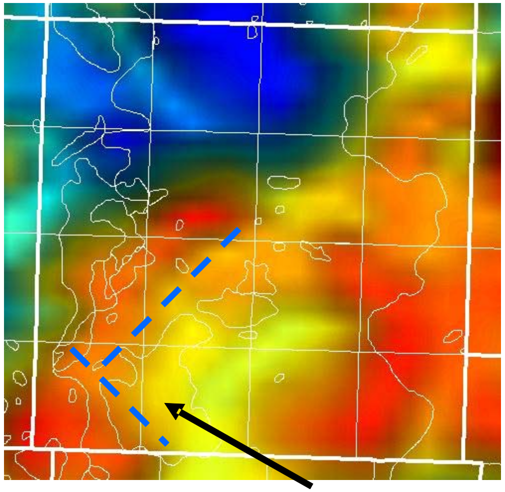


http://www.kgs.ku.edu/DPA/Plays/ProdMaps/lgkc_oil.html

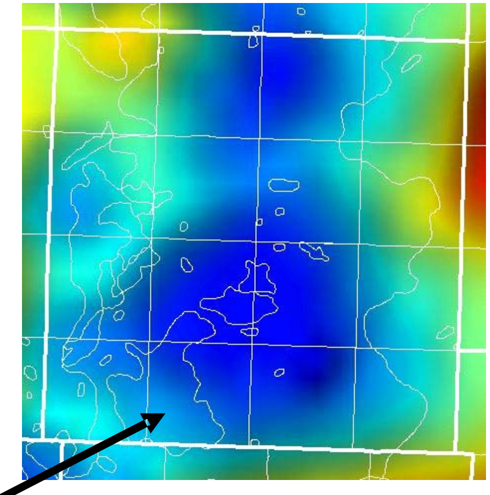
Victory Field



Magnetic Map, Haskell County

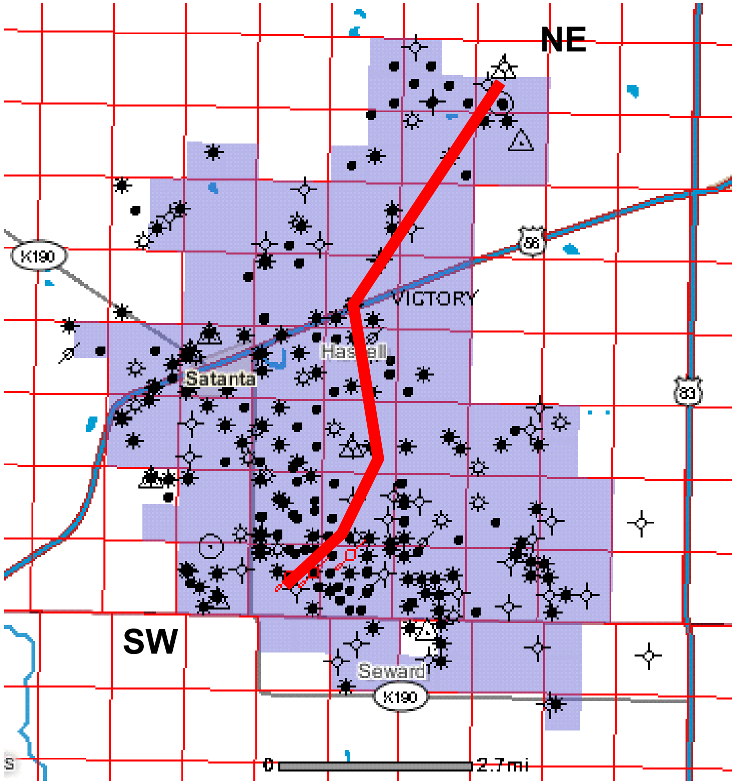


Gravity Map, Haskell County



Victory Field

Structure maps of the tops of the Lansing and Chase Groups

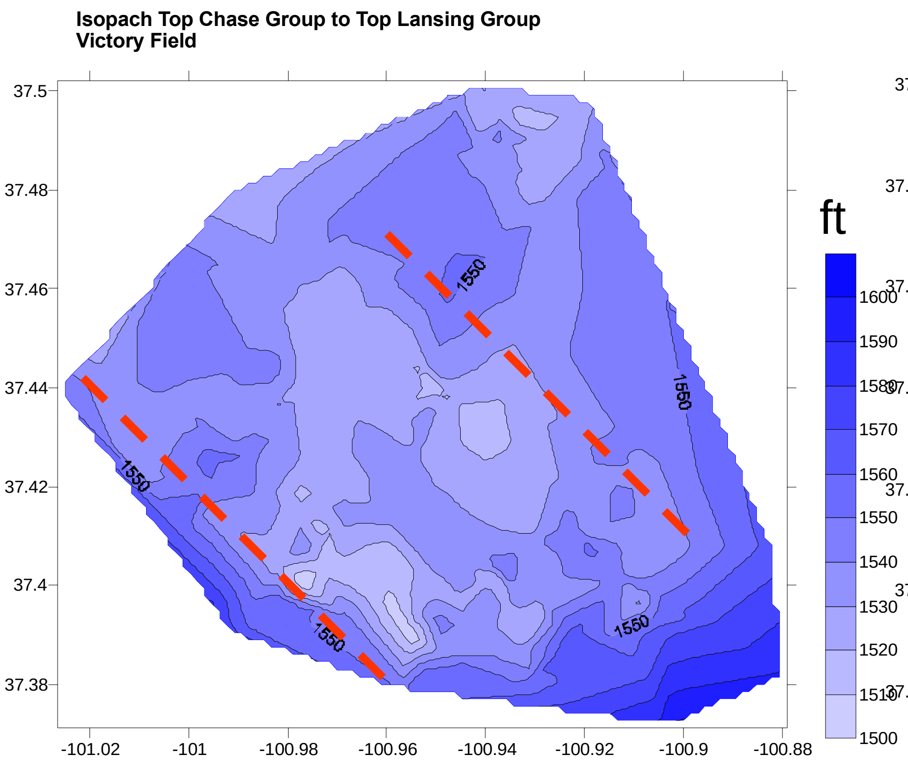


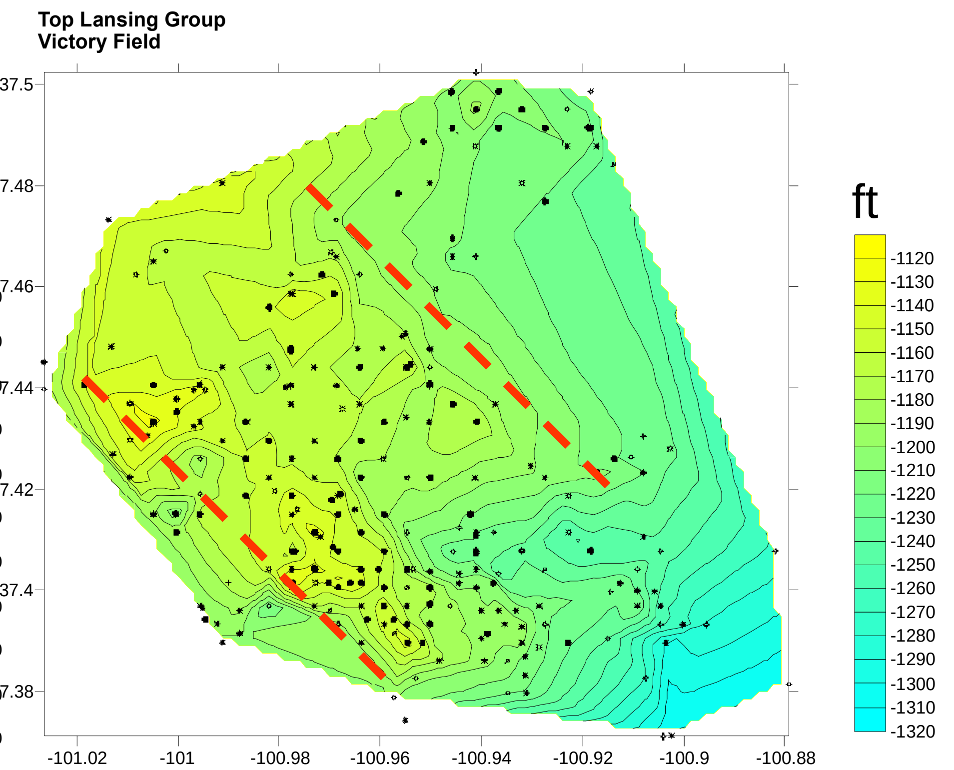
5 miles (8 km)

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.

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

Top Lansing structure





5 MILES

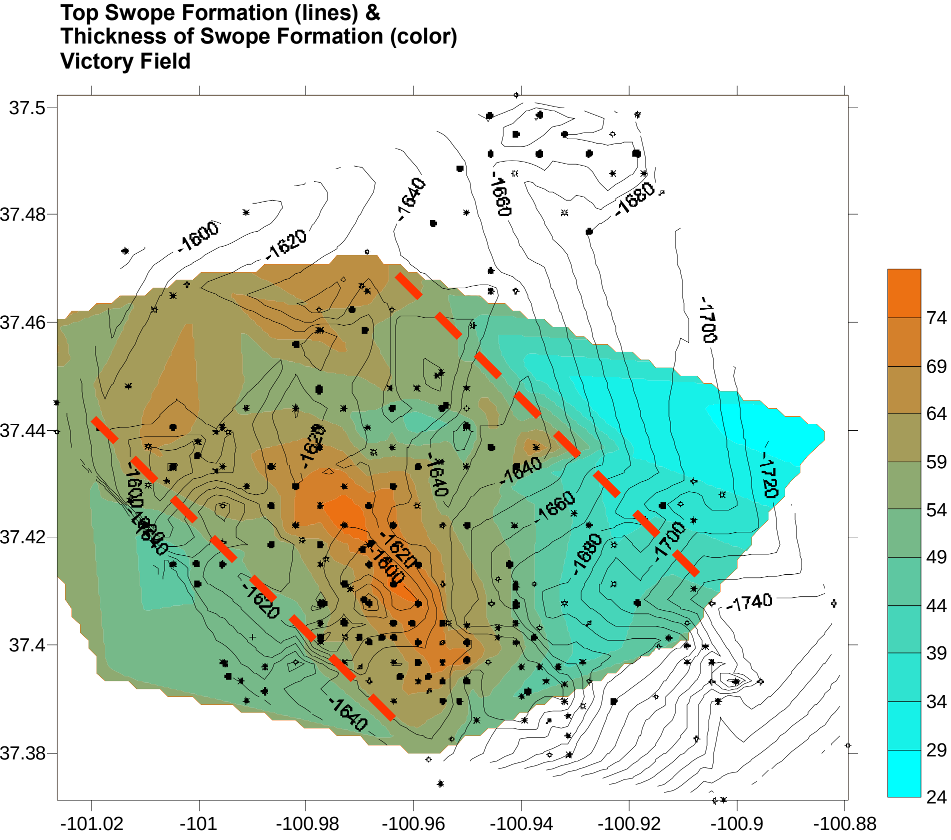
Rhombohedral NW & NE-trending pattern?

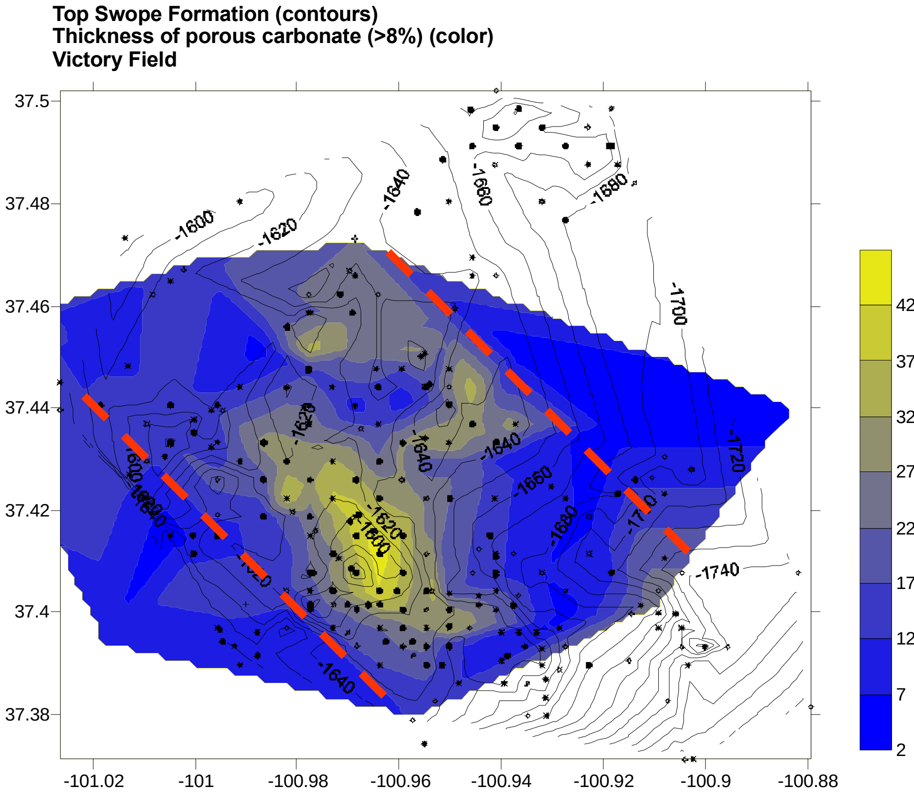
Structure = contours

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

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

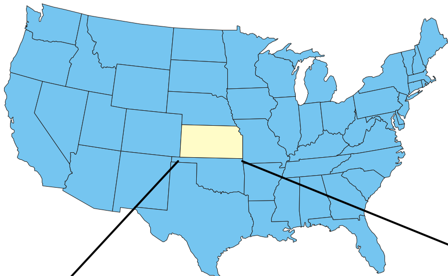
SWOPE LIMESTONE

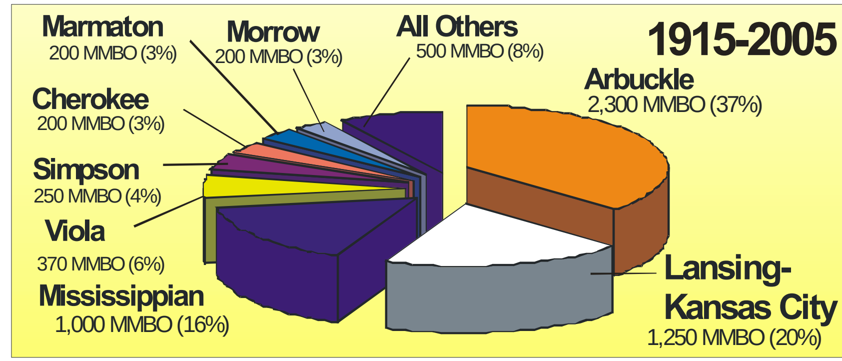


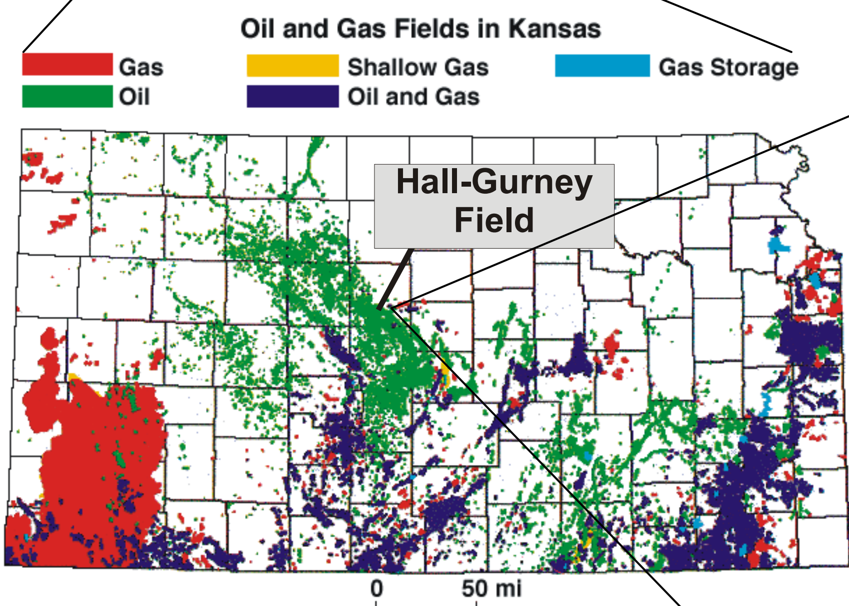


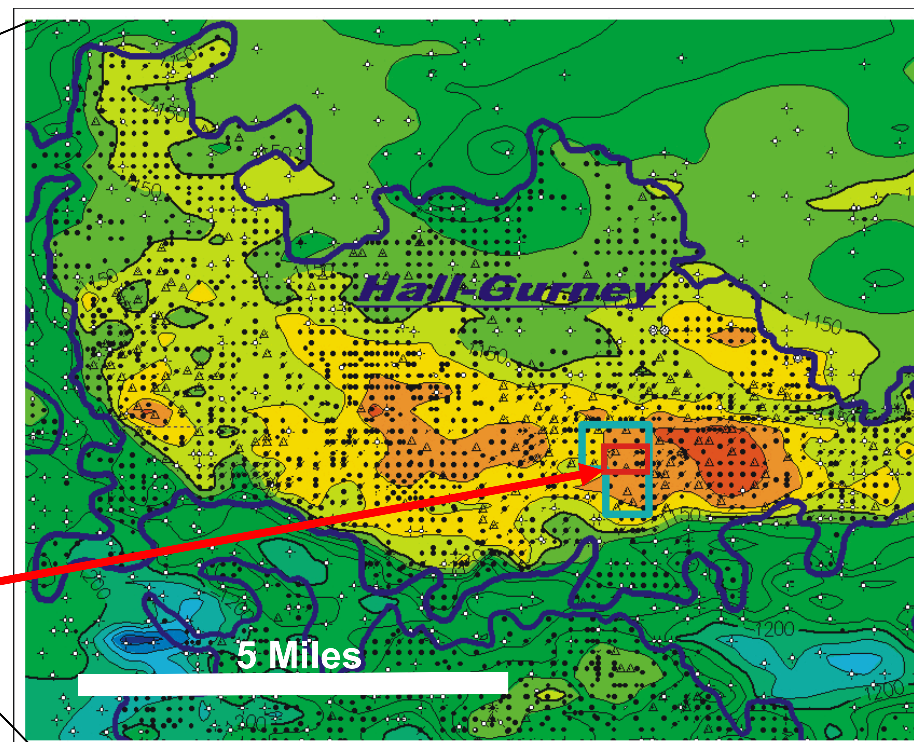
Thickening on top of structure

Hall-Gurney CO2 Field Demonstration Project







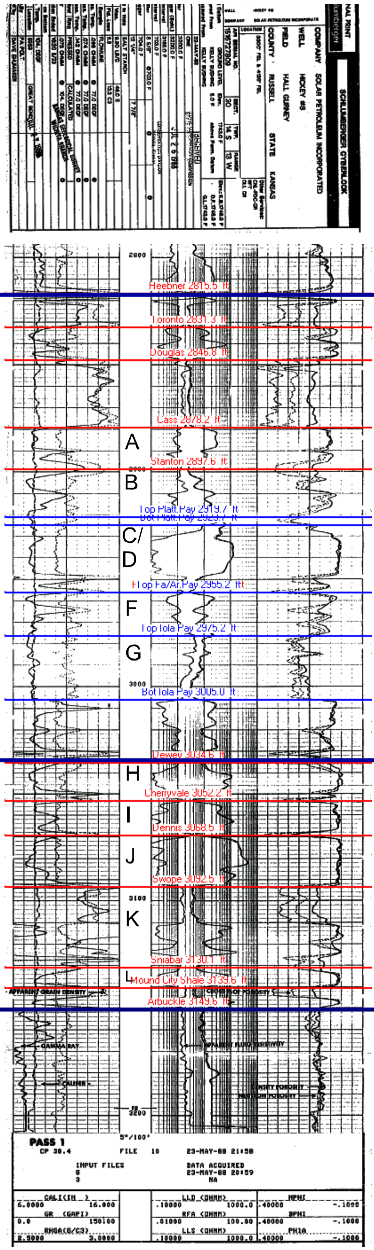


CO2 Pilot
Study Area

Murfin Drilling. Co., operator

Lansing-Kansas City

Upper Pennsylvanian (Missourian)



Hall-Gurney Type Curve

4th Order Sequences

Heebner

Toronto Ls

Cass Ls (A)

Stanton Ls (B)

Plattsburg Ls (C/D)

Farley/Argentine Ls (E/F)

Iola Ls (G)

Dewey (H)

Cherryvale Fm (I)

Dennis Ls (J)

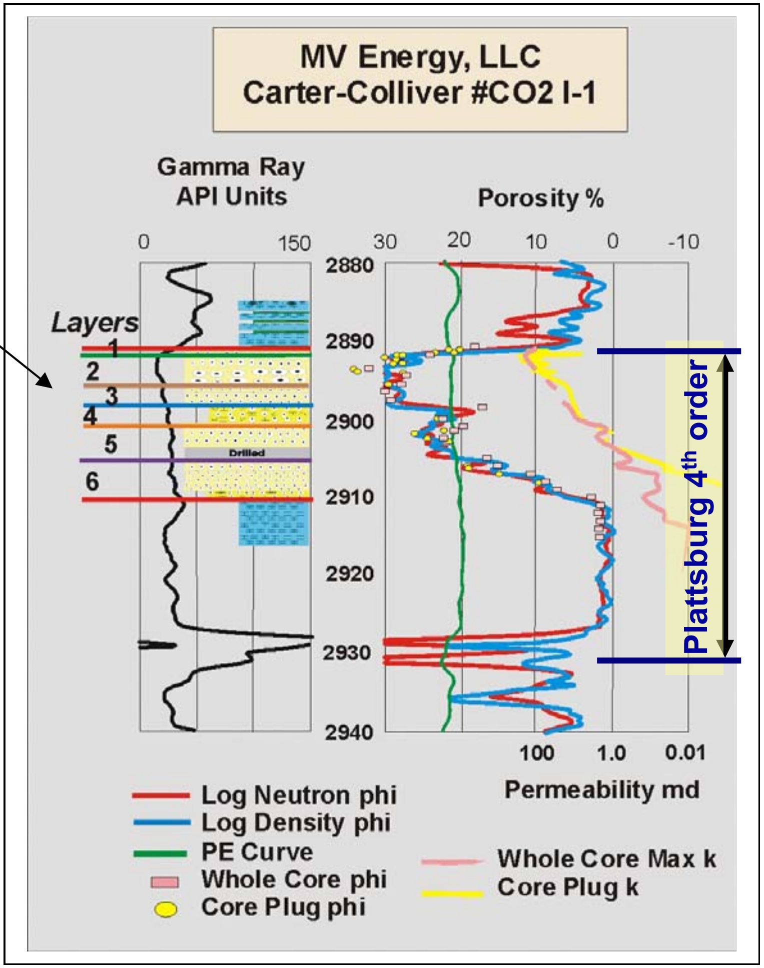
Swope Ls (K)

Sniabar LS (L)

Arbuckle Gp.

2 dominant 5th-order cycles

3rd-order Sequence Set

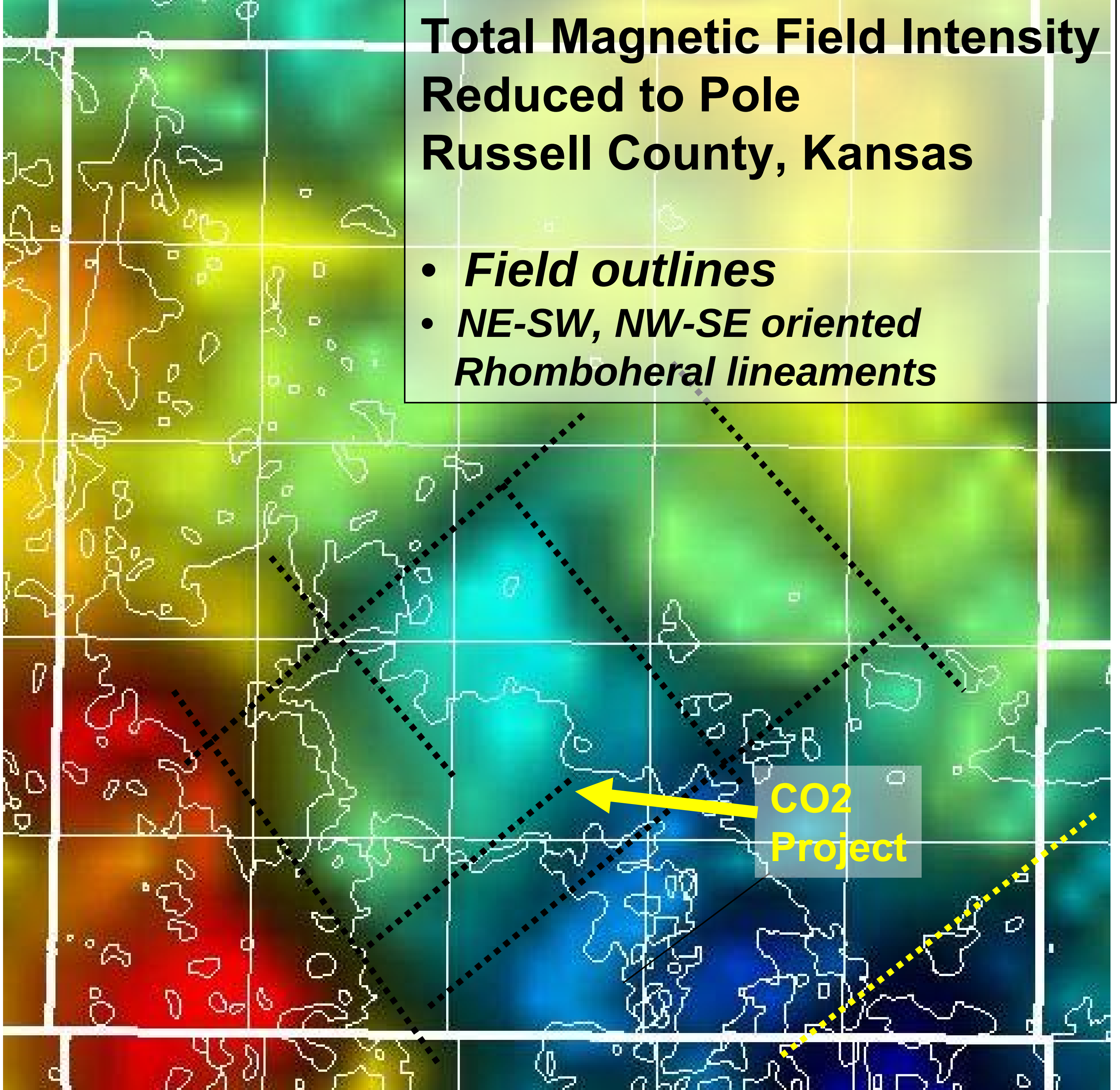


Thickness: 3-30 ft

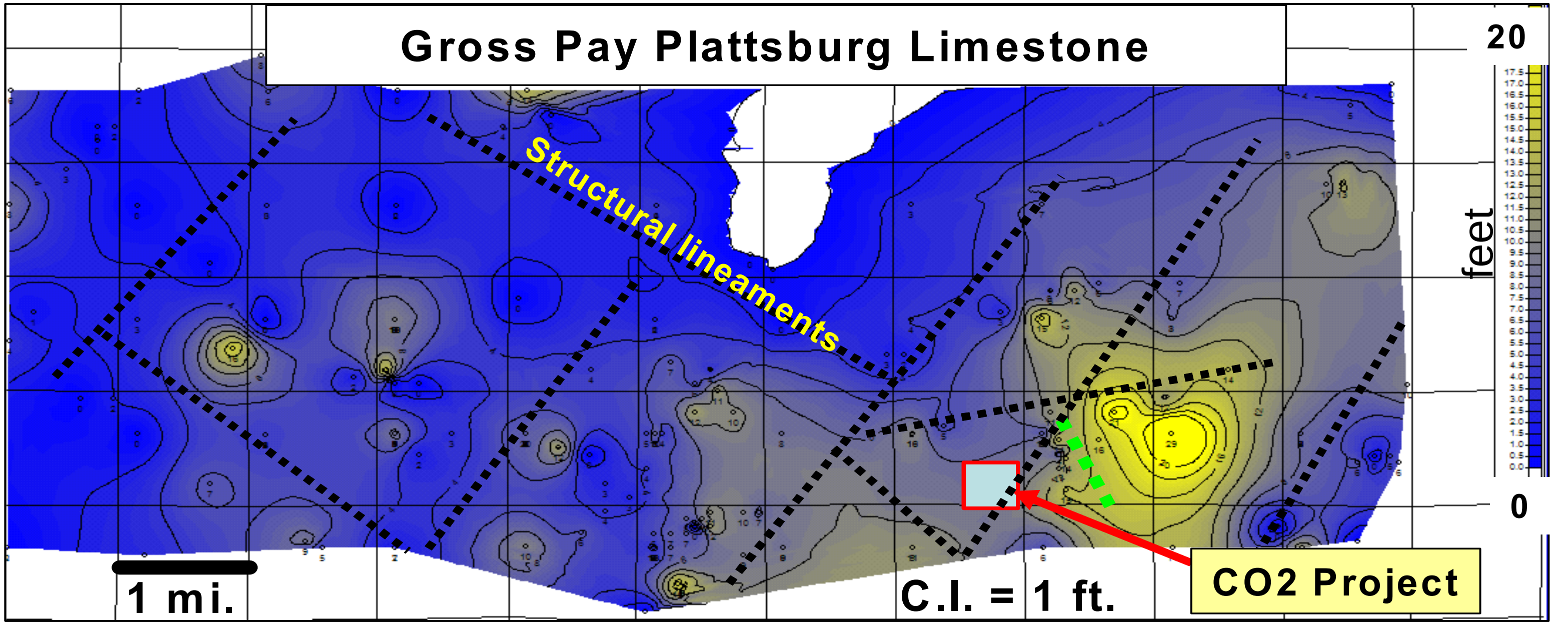
Porosity: 0-35%

Permeability: 0.001-300md

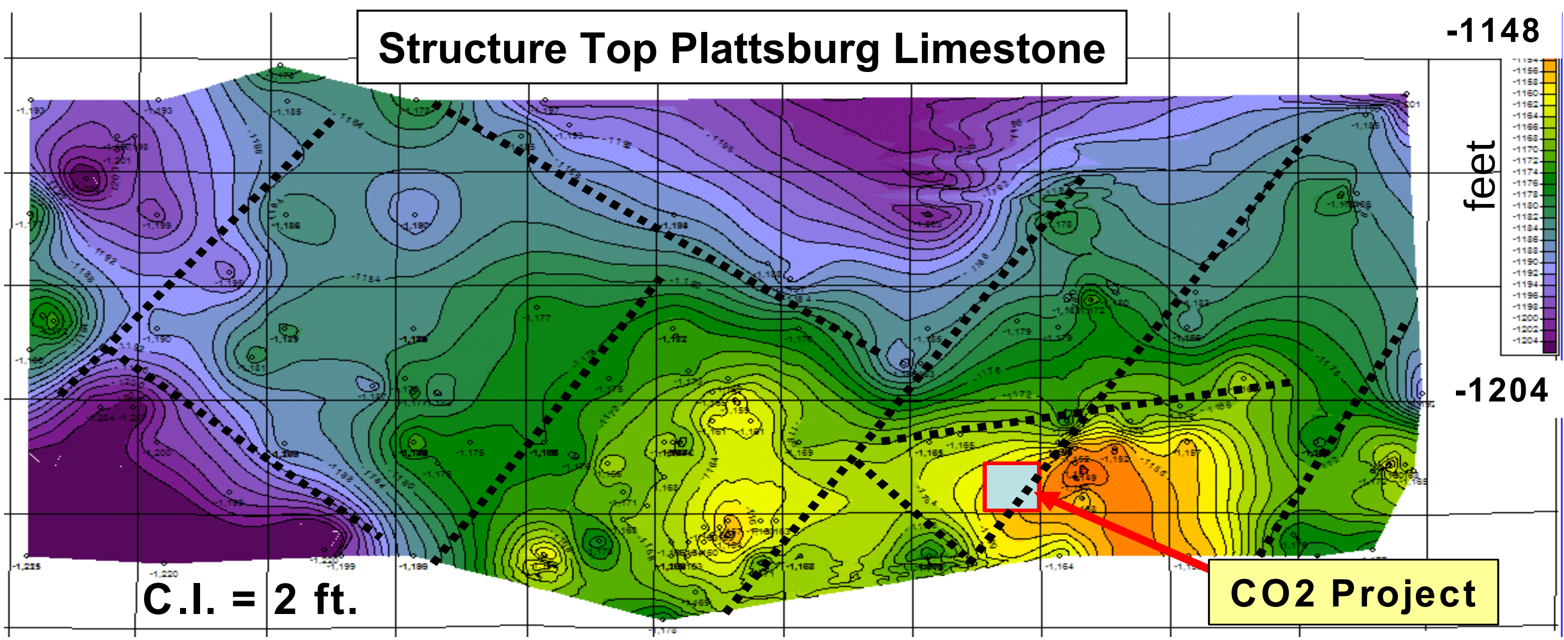
Modified from Dubois et al. (2001)



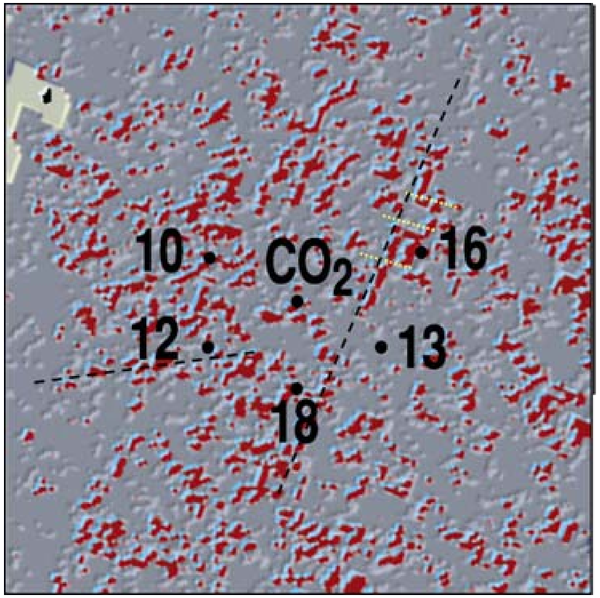
Total Magnetic Field Intensity
Reduced to Pole
Russell County, Kansas
• Field outlines
• NE-SW, NW-SE oriented
Rhomboheral lineaments
CO2
Project



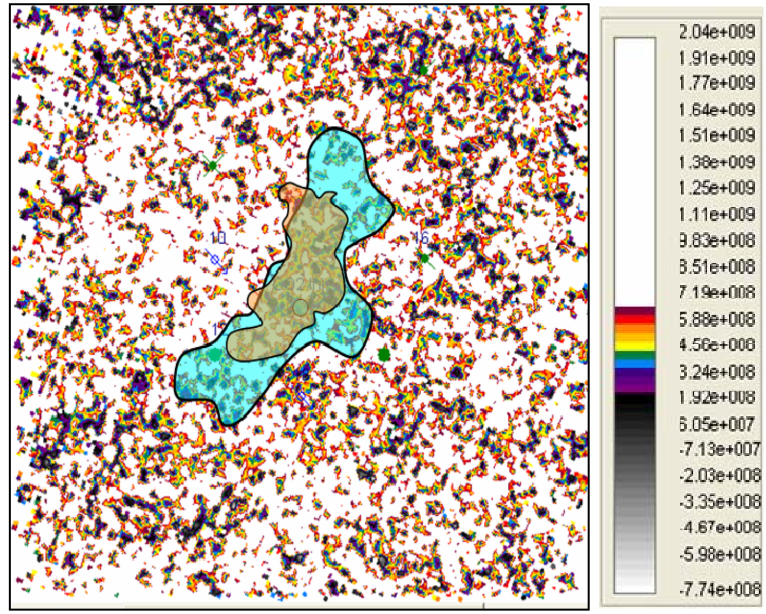
Gross Pay Plattsburg Limestone
Structural lineaments
20
feet
0
1 mi.
C.I. = 1 ft.
CO2 Project



Structure Top Plattsburg Limestone
-1148
feet
-1204
C.I. = 2 ft.
CO2 Project



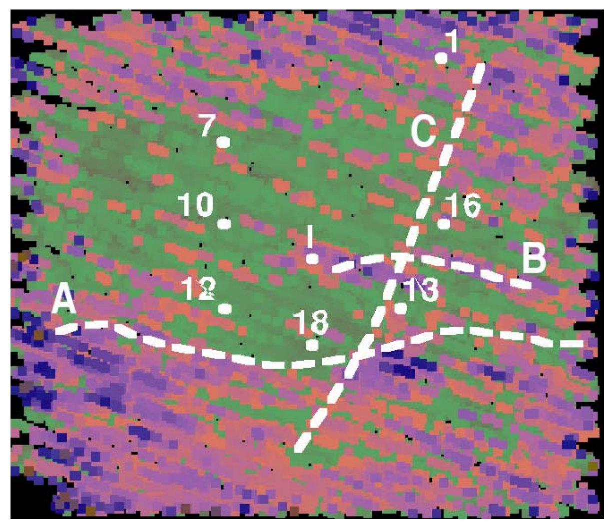
Lineament attribute baseline data, (prior to CO_2 injection)



Parallel progressive blanking of amplitude envelope, April 2004 and June 2005 showing 2 stages of CO_2 plume

A strong correlation exists between the preferential movement of the CO_2 through this reservoir and features evident on the lineaments attribute map

It appears lithology, especially <u>rock properties</u>, are preferentially influencing fluid movement through this reservoir

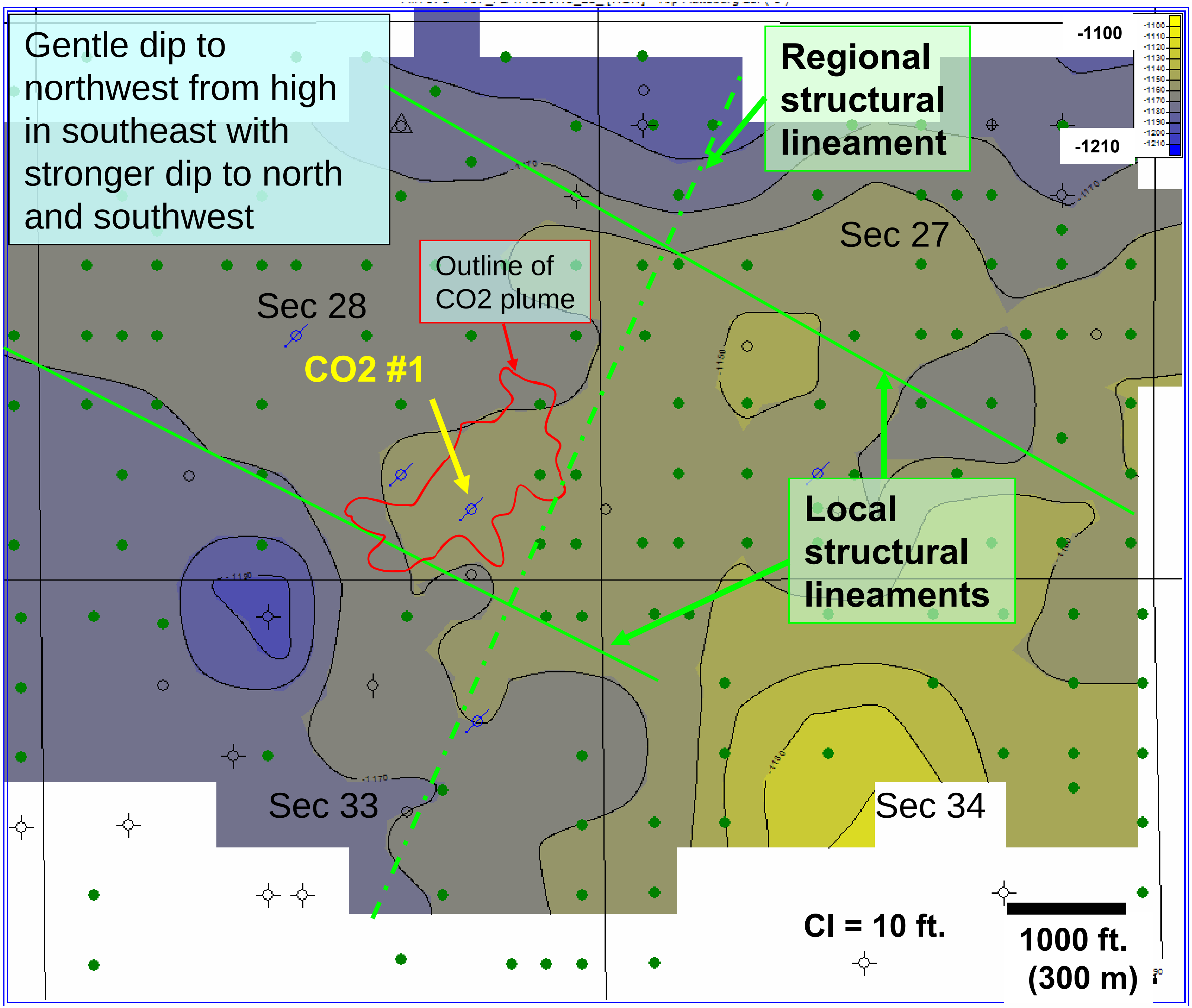


Instantaneous frequency at 560 msec with lineaments

North

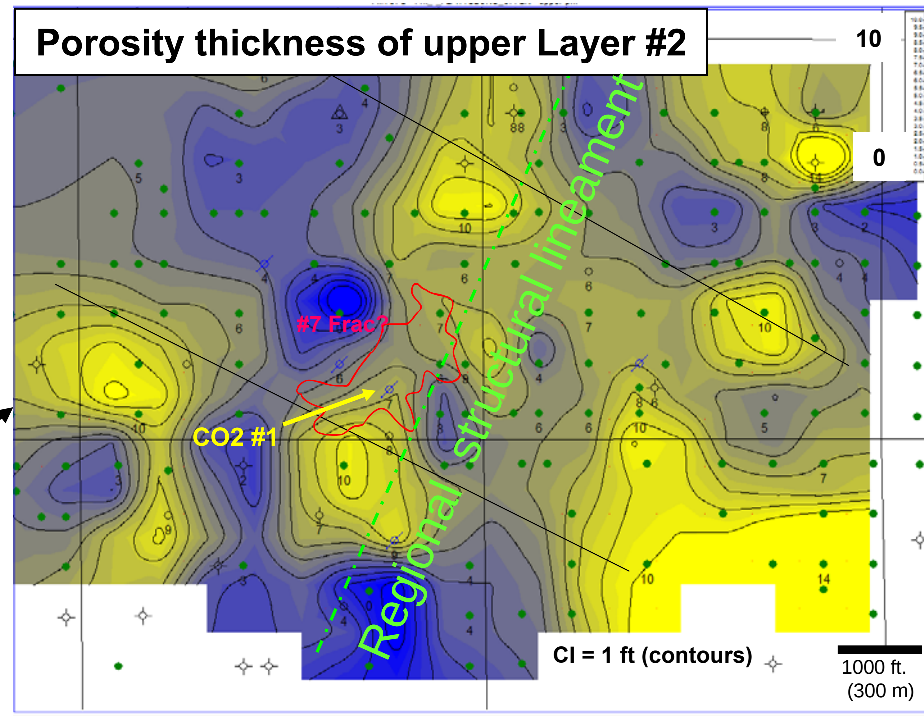
0.25 mi (0.4 km)

Structure Contour Map, Top Plattsburg Limestone

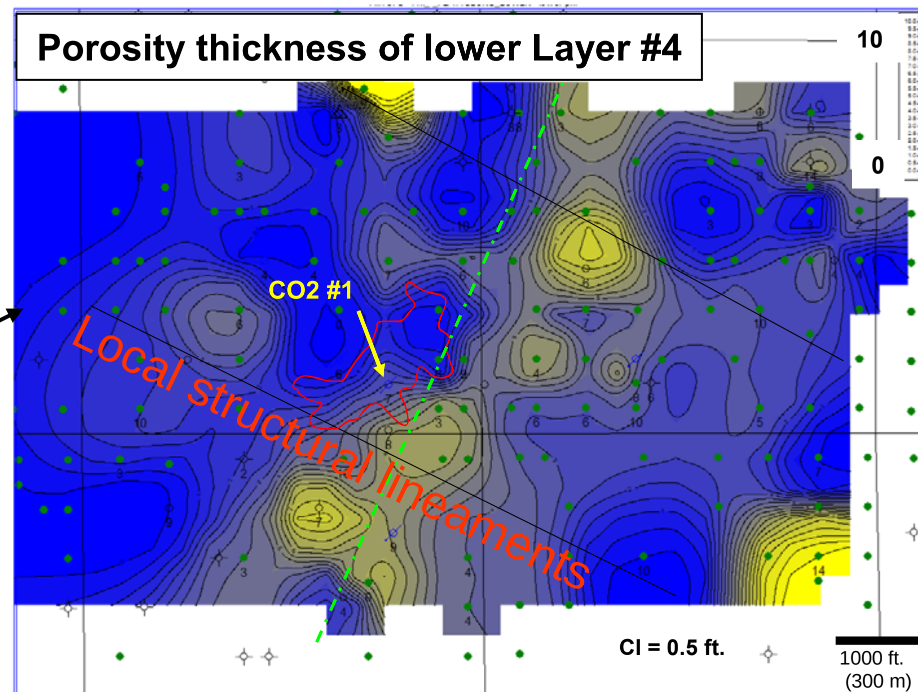


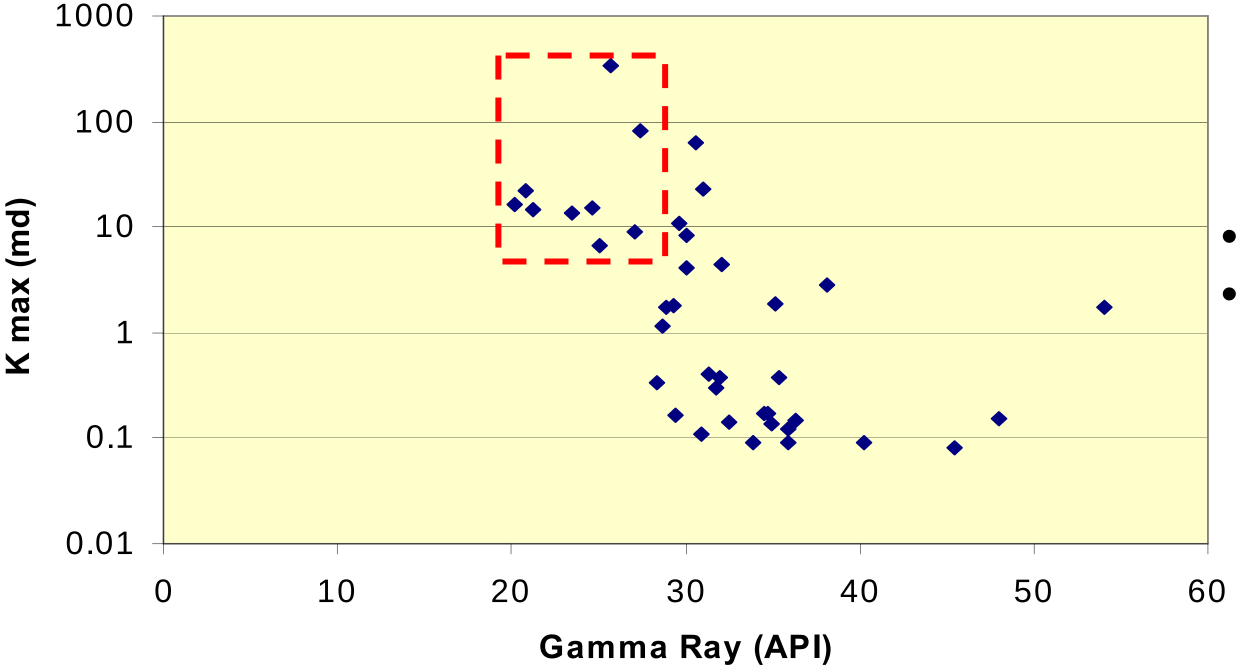
Comparison of two stacked, high-frequency cycles

- Possible polygenic parabolic-shaped ooid shoals
- Roughly orthogonal trends paralleling structure lineaments
- Location of #2 shoal is offset to west of underlying layer #4
- CO_2 movement along porous layer #2



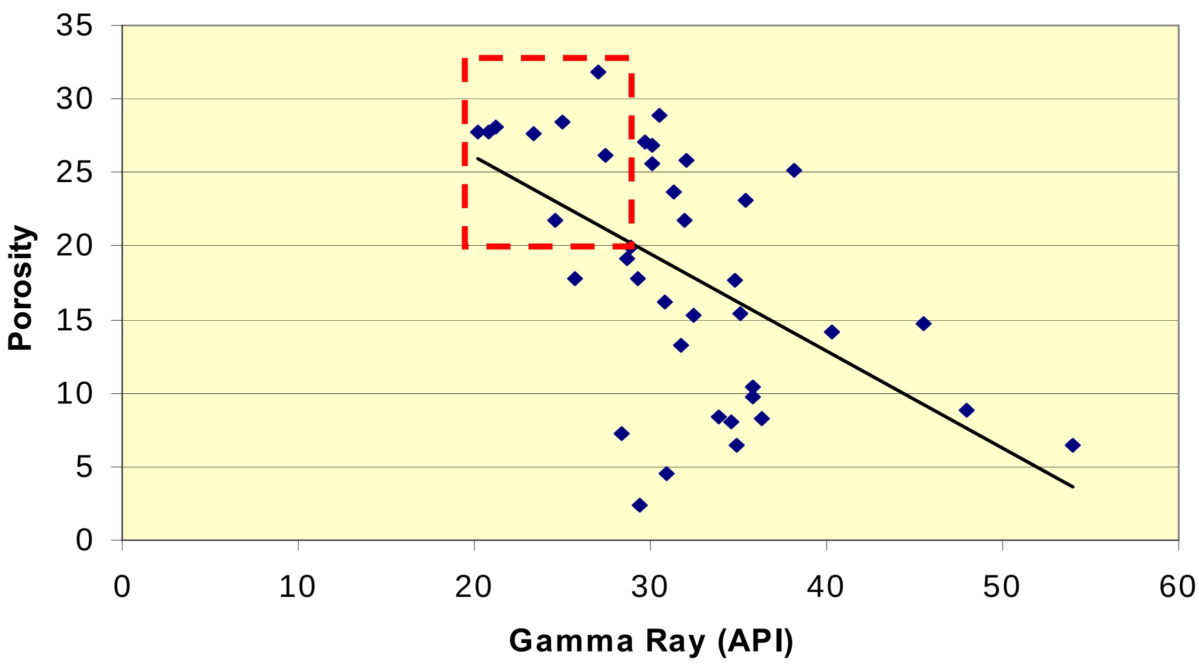
- Isolated elongate ooid shoal developed sub-parallel to regional structural lineament
- No CO_2 movement in lower layer #4





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)



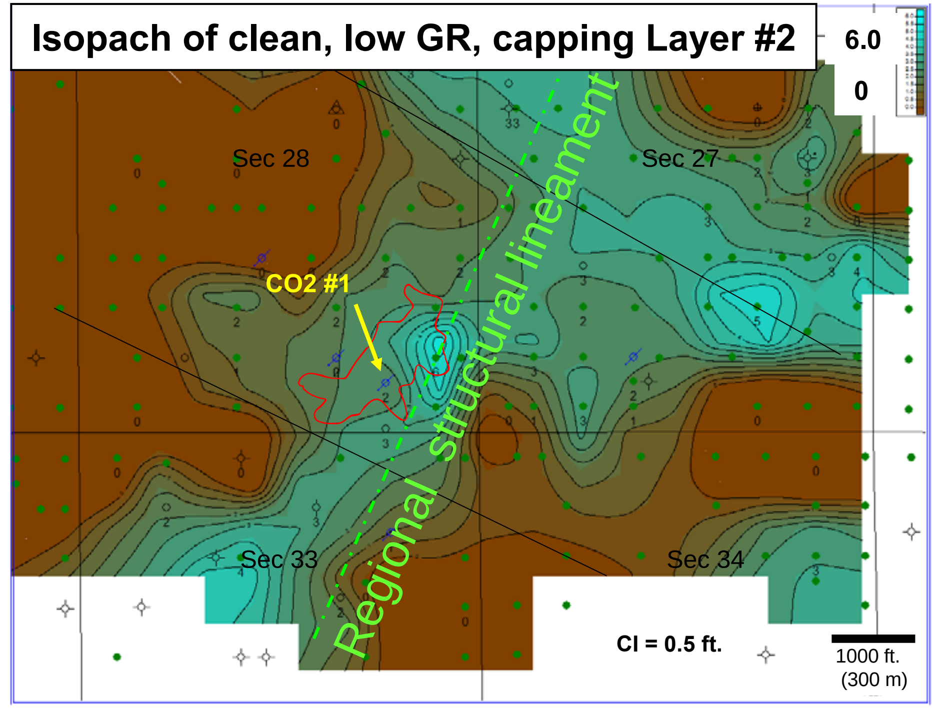
Clean, better-sorted higher porosity in cycle caps, porosity highest near top of shallowing upward succession

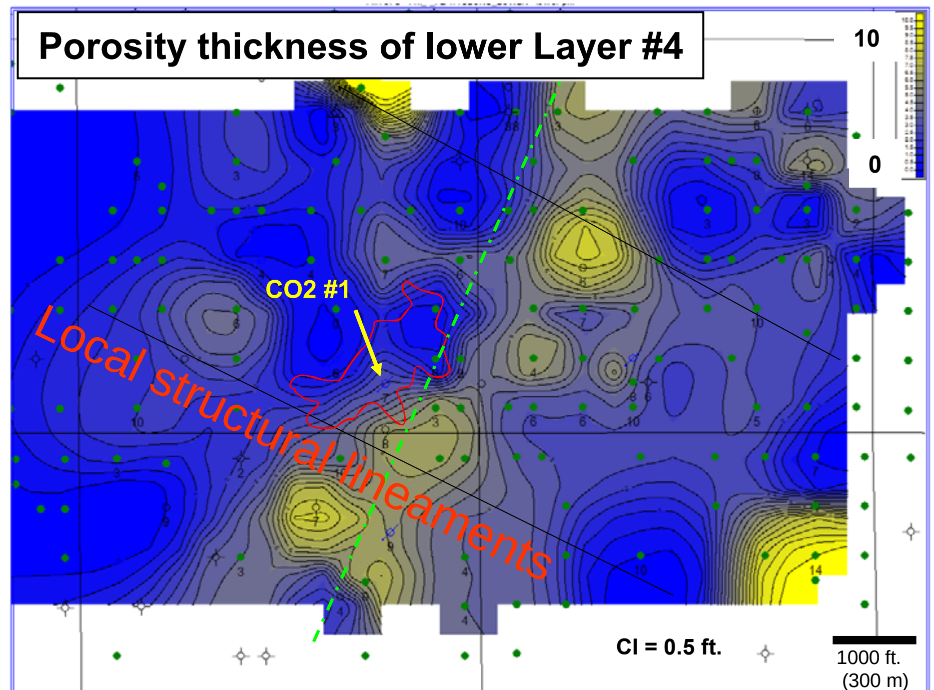
- **Better-sorted bar crests in Modern ooid shoals**

Colliver #16 core data

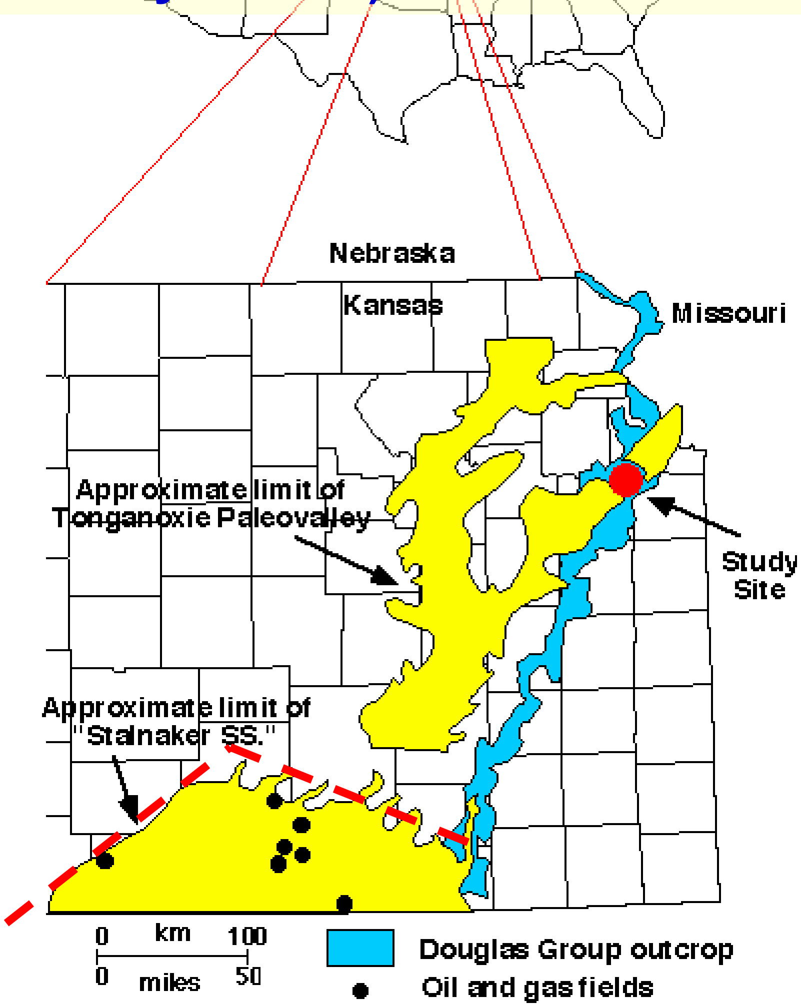
Comparison of porosity thickness of lower Layer #4 and thickness of clean, low gamma ray interval capping Layer #2

- 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

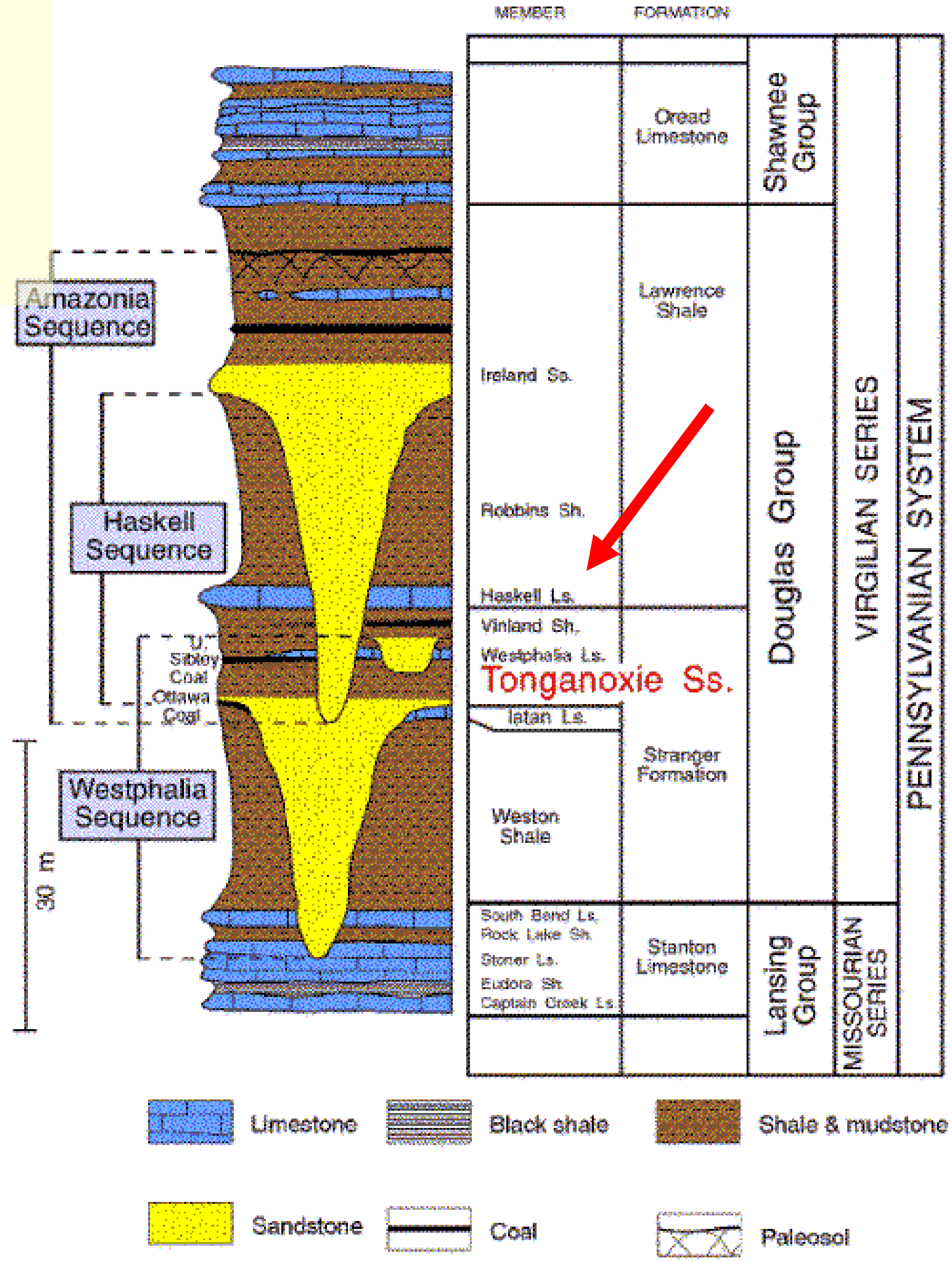




Proposed basement structural controls on incised valley development –Tonganoxie Sandstone (Lower Virgilian, U. Pennsylvanian)

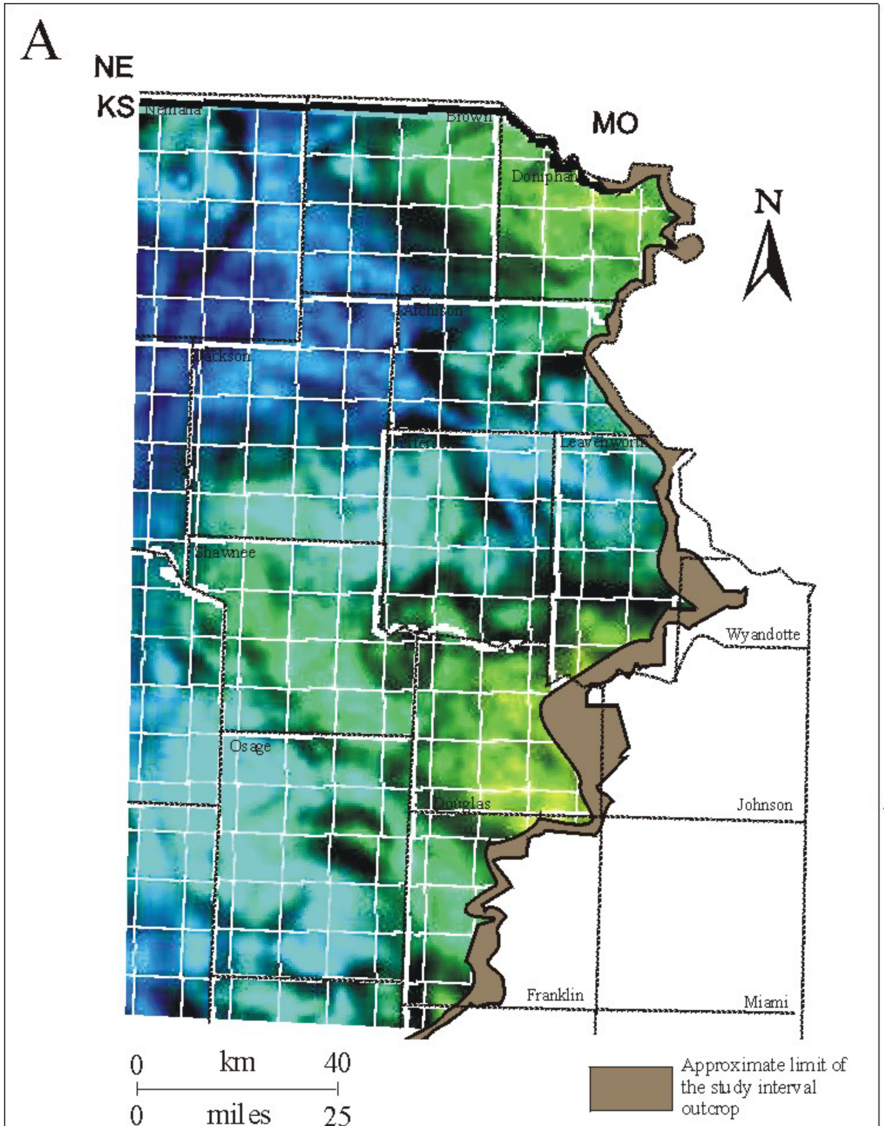


(modified from Feldman et. al. 1995)

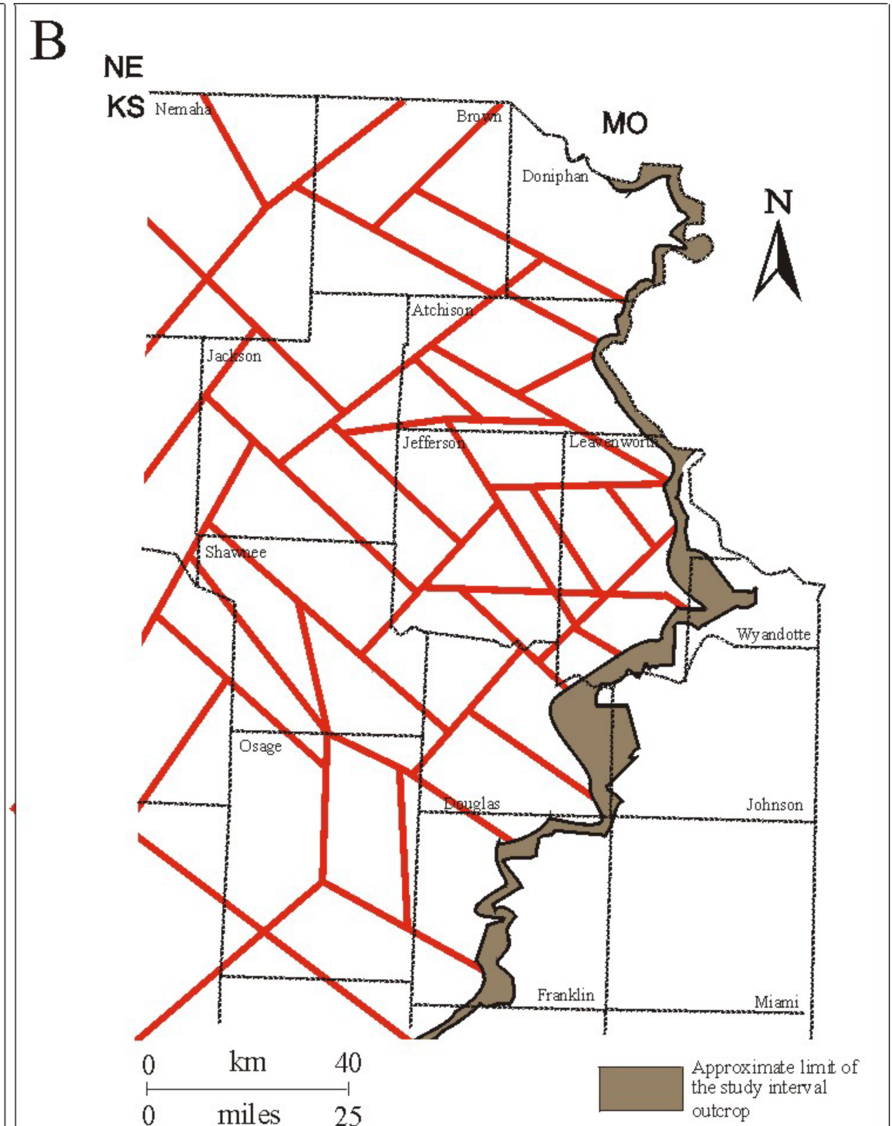


(Modified from Feldman, et. al., 1995)

2nd-order residual gravity



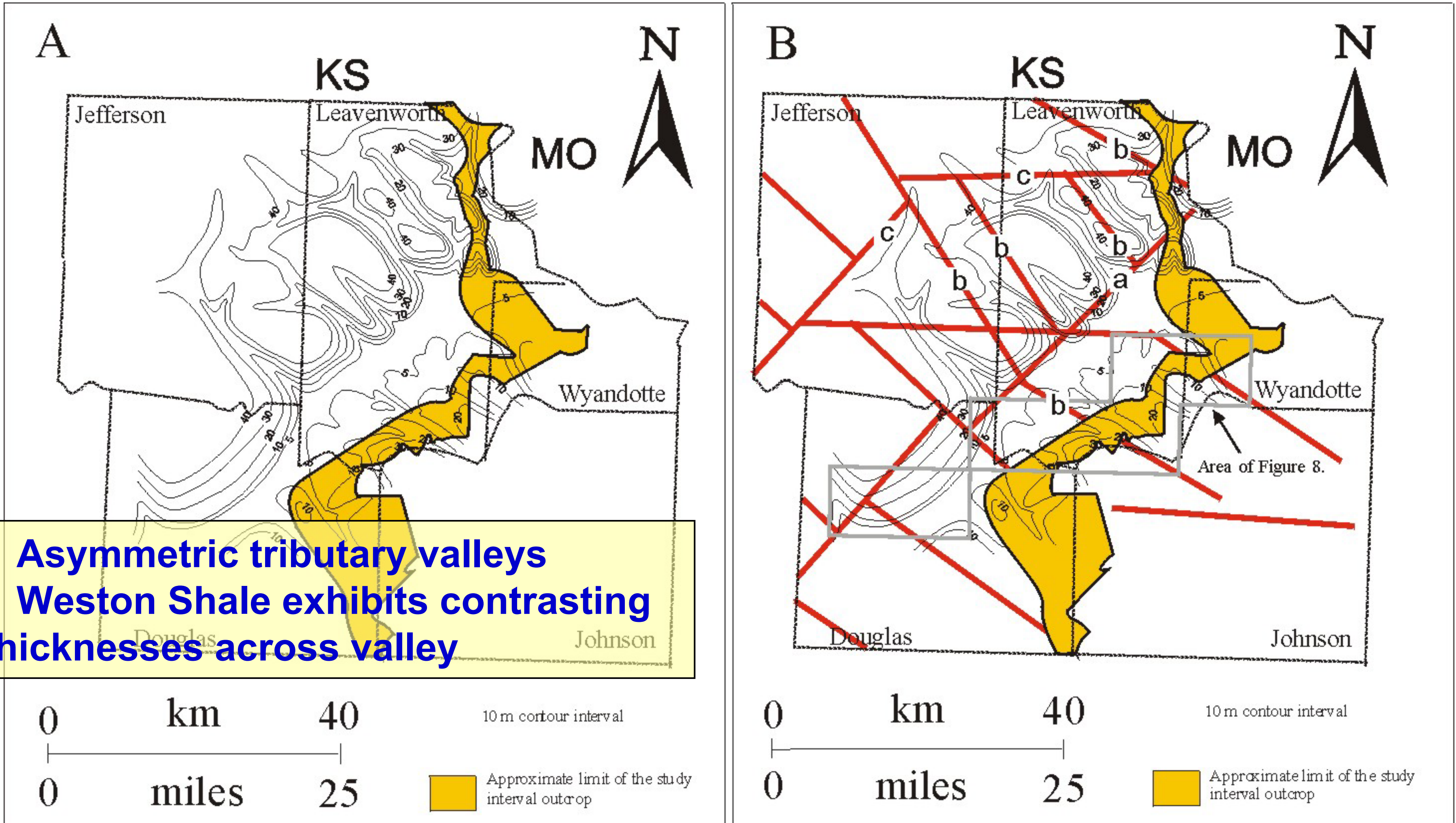
Lineaments inferred from gravity map



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

Beaty et al. (1999)

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



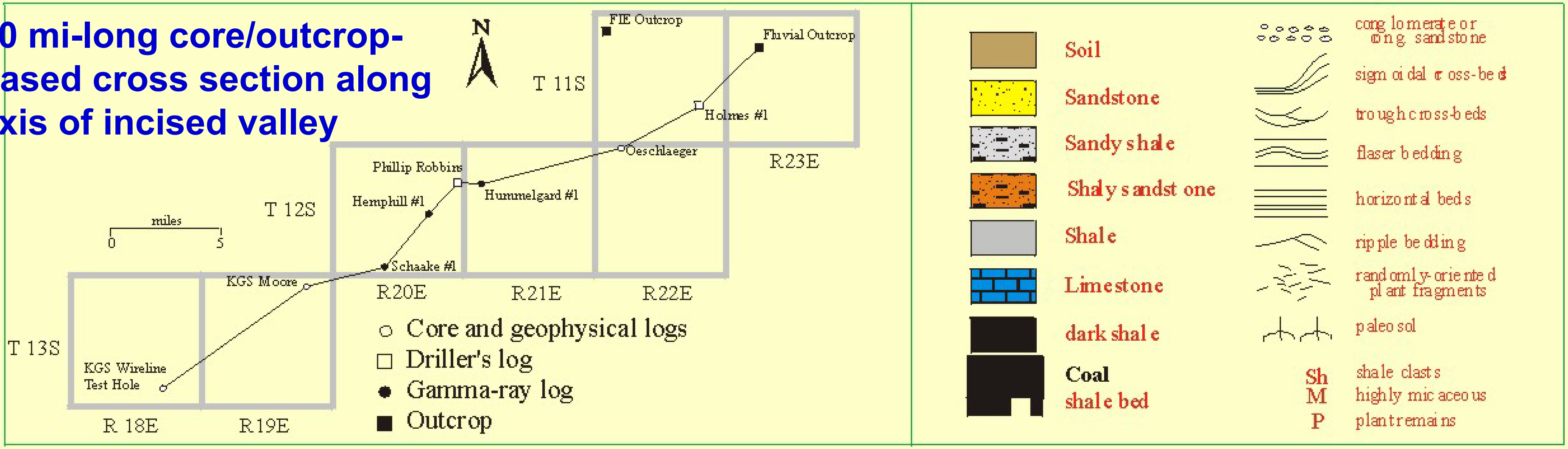
- Asymmetric tributary valleys
- Weston Shale exhibits contrasting thicknesses across valley

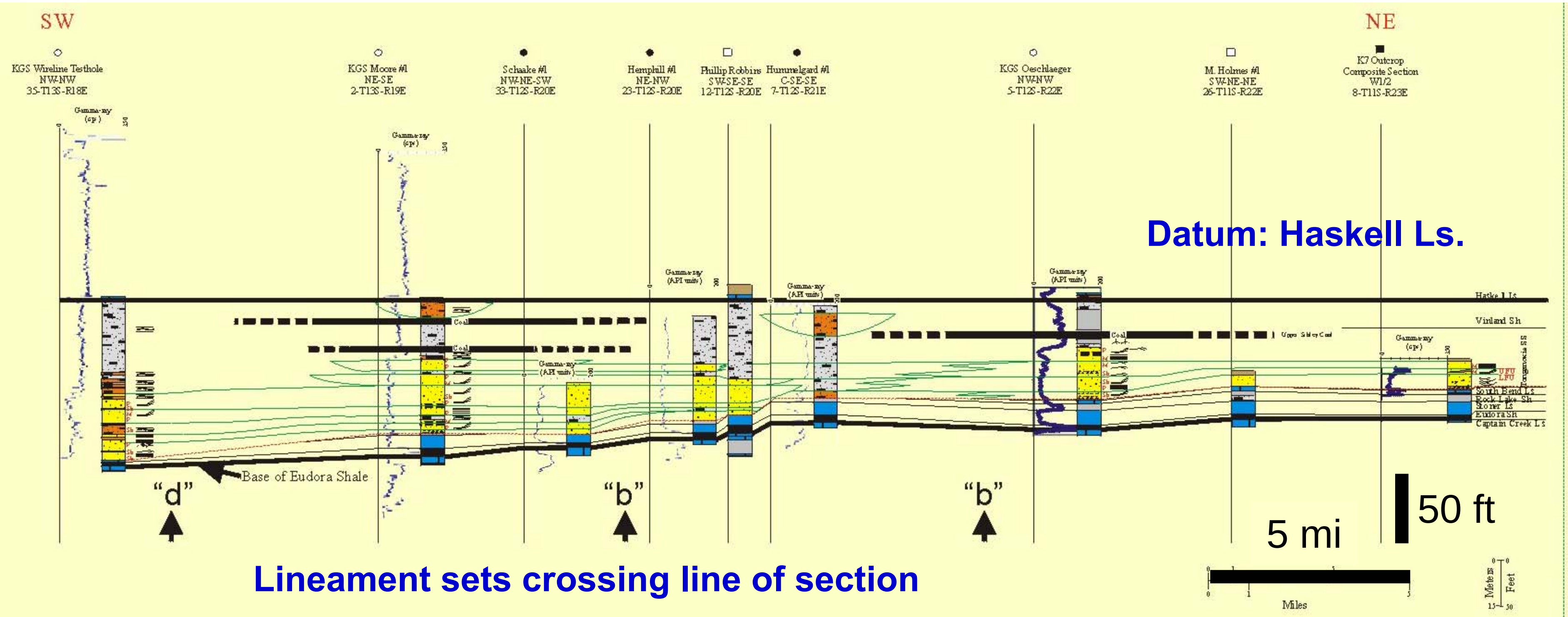
Beaty et al. (1999)

-- Incised valley system along and near rhombohedral basement lineaments

-- Northeastern Kansas

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

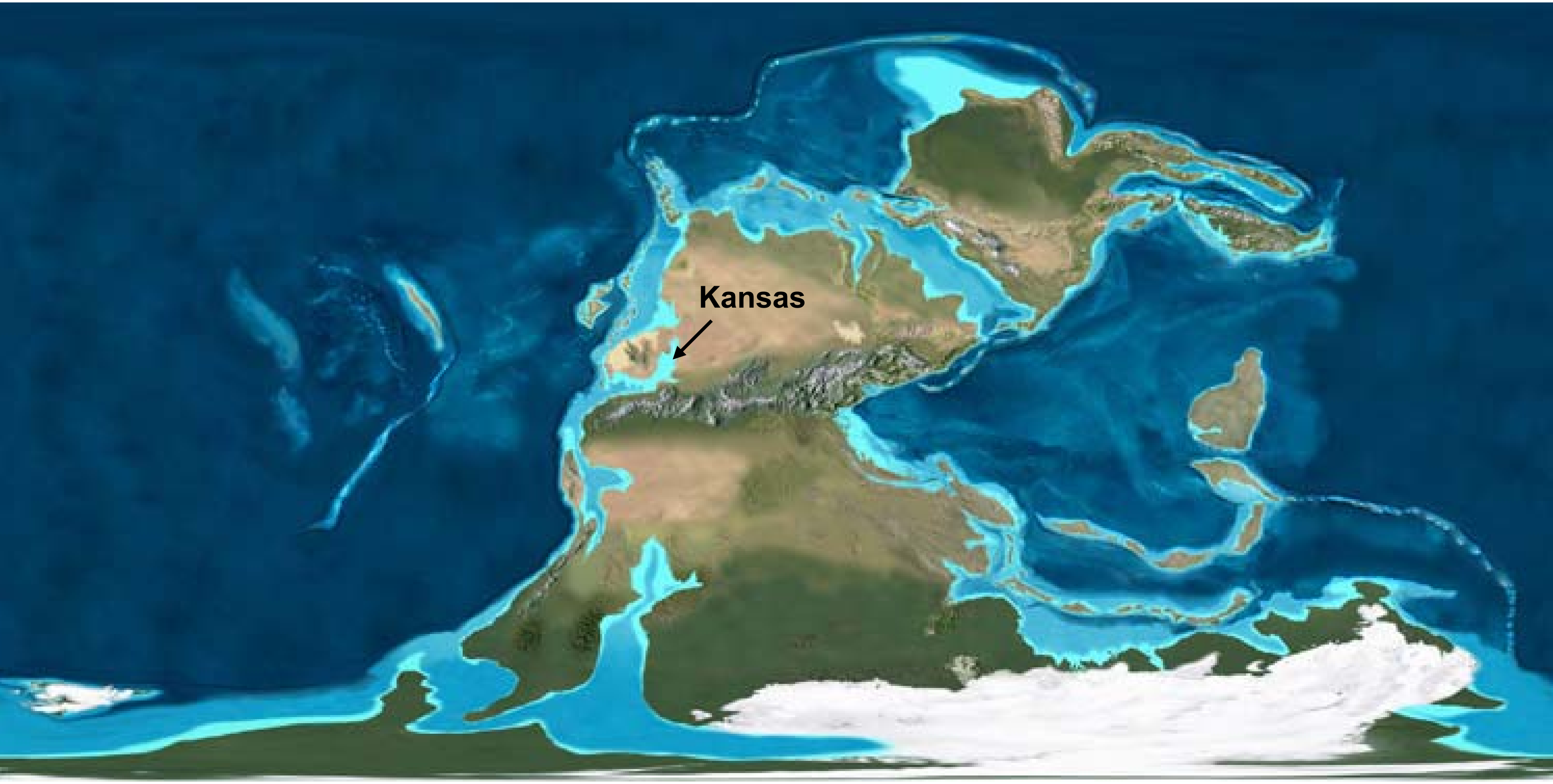




Lineament sets crossing line of section

Beaty et al (1999)

Early Permian Paleogeography



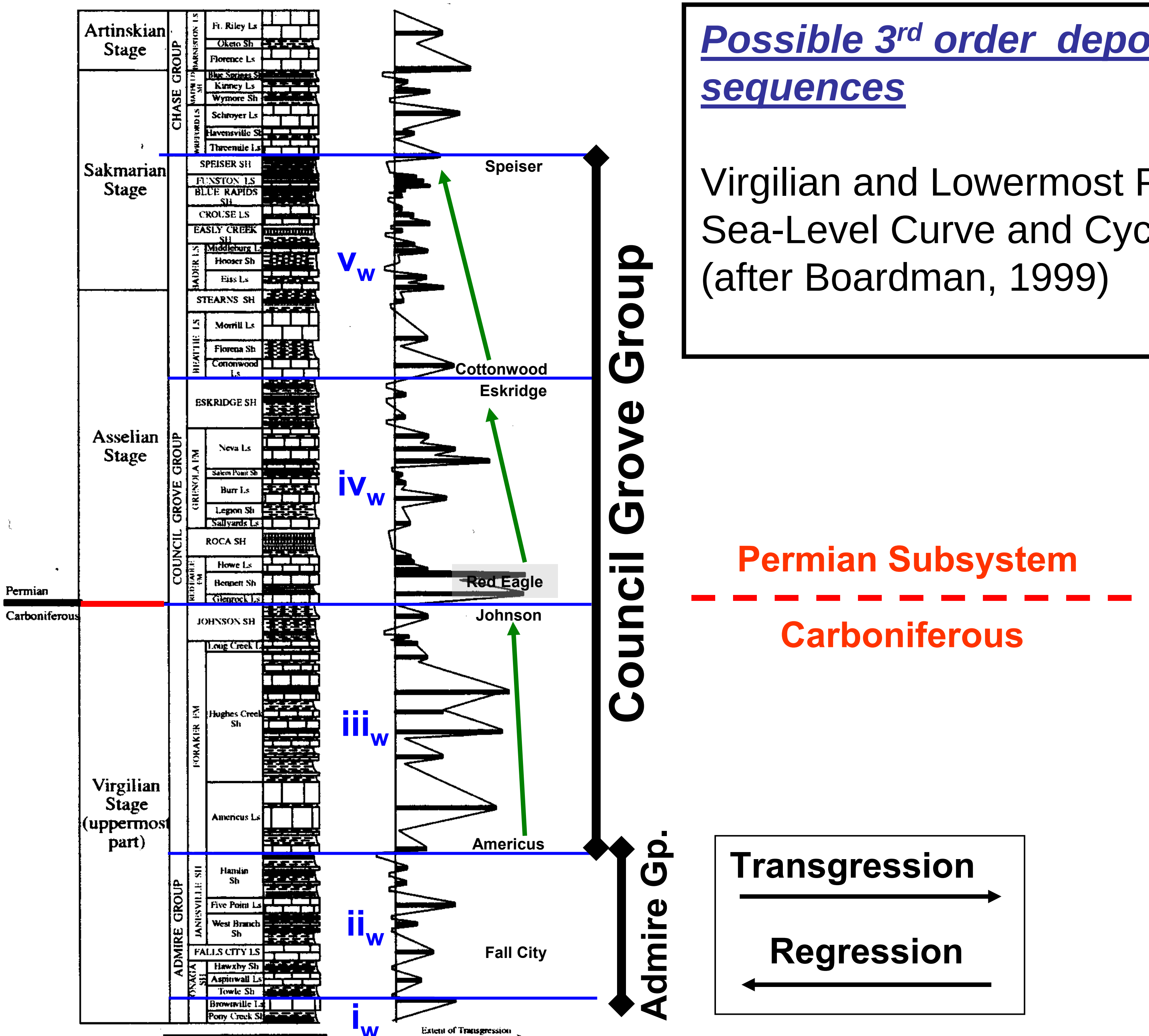
<u>Factors impacting stratigraphy and lithofacies in the U.S. Midcontinent</u>:

- 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

R. Blakey, http://jan.ucc.nau.edu/~rcb7/, Accessed 2005

Possible 3rd order depositional sequences

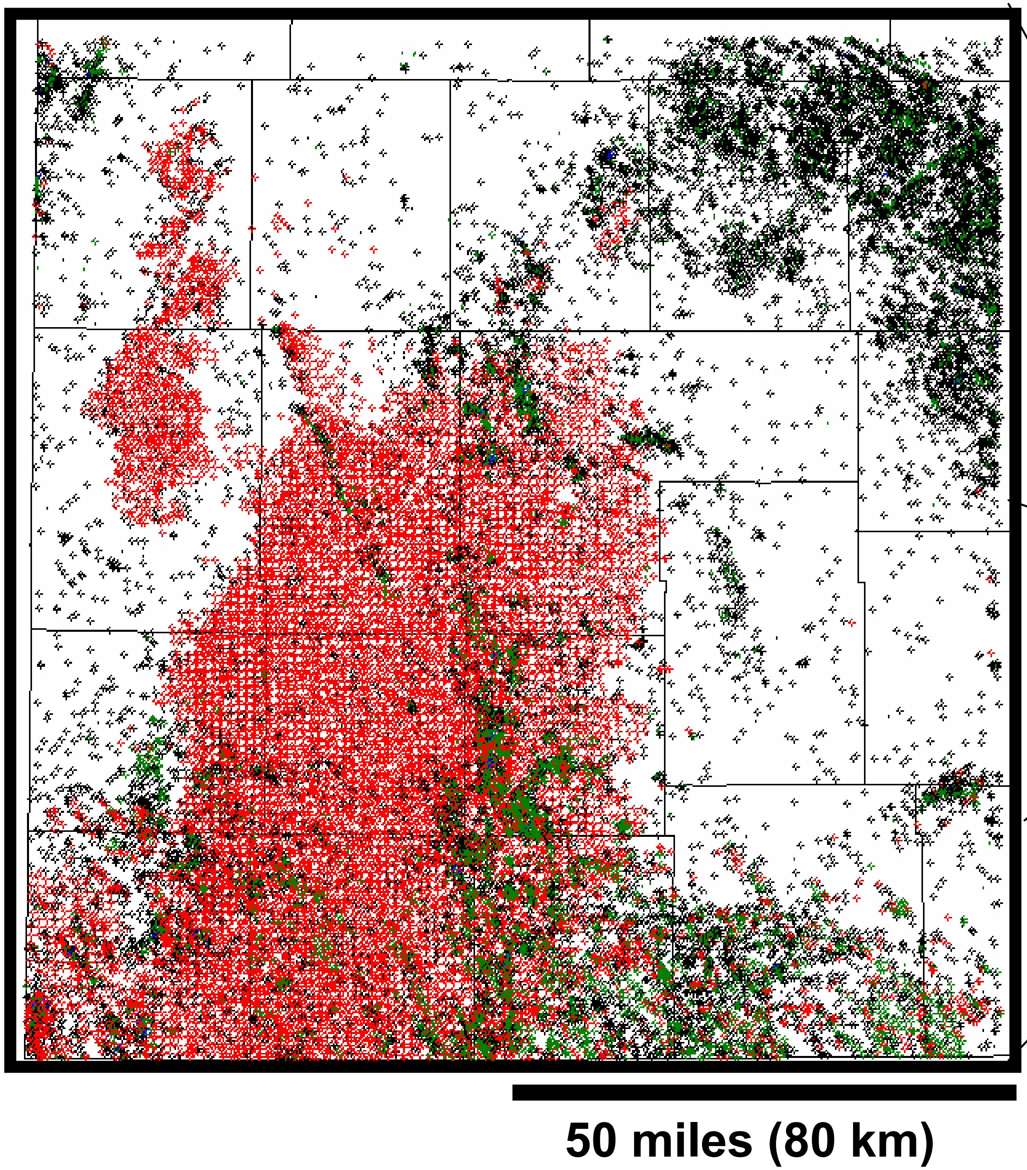
Virgilian and Lowermost Permian Sea-Level Curve and Cyclothems (after Boardman, 1999)

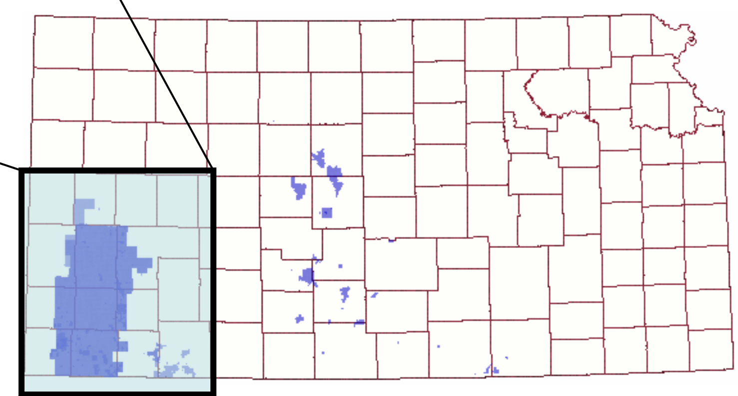


Council Grove Group
Late-stage tectonism of Ancestral Rockies

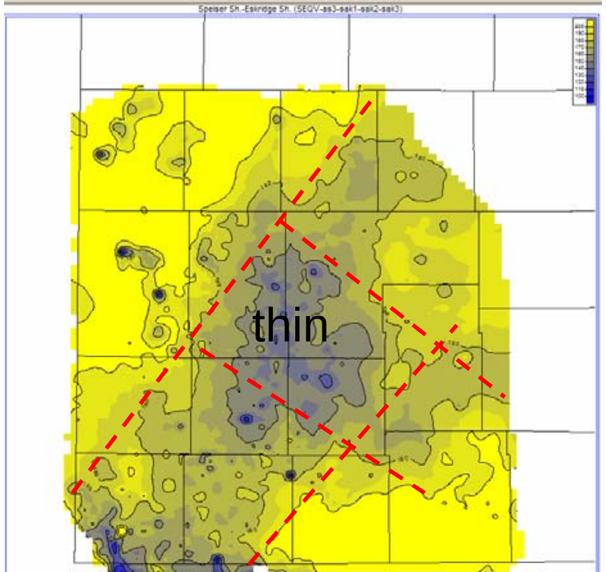
Well control in Southwest Kansas

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

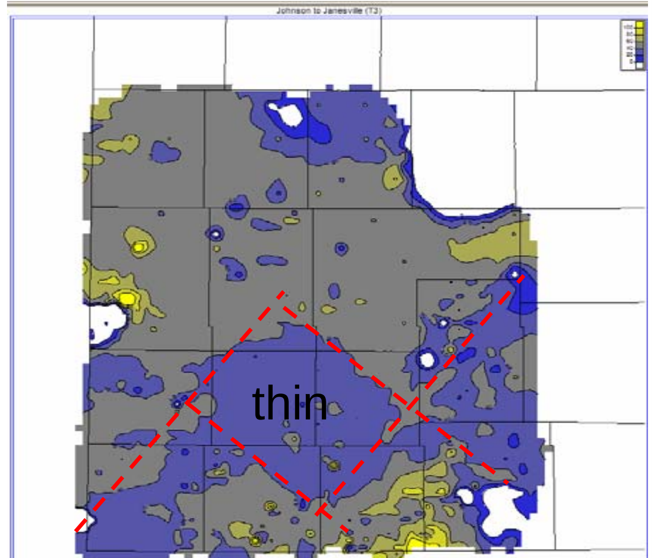




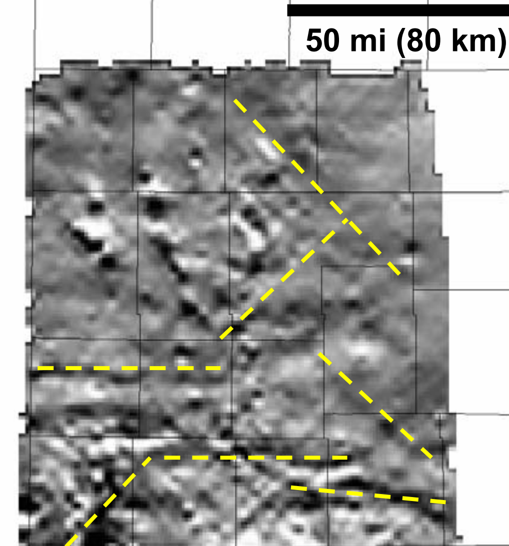
Gas production from Council Grove Group In Kansas



Composite Sequence v_w
Speiser Sh. To Eskridge Shale

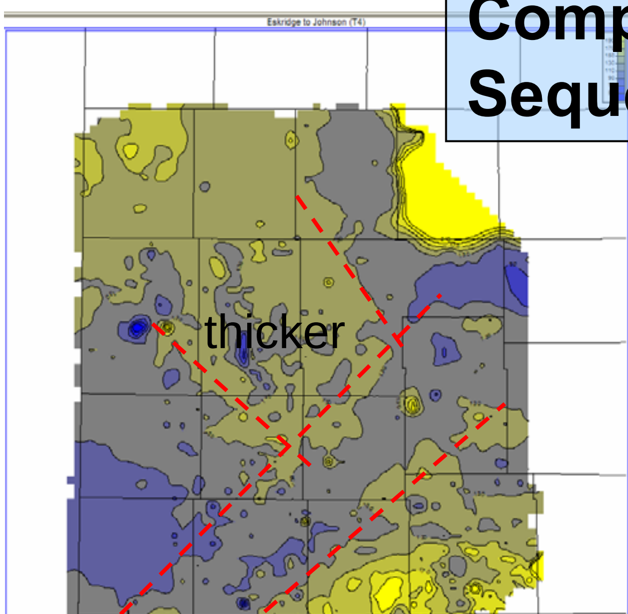


Composite Sequence iii_w
Johnson Sh. To Janesville

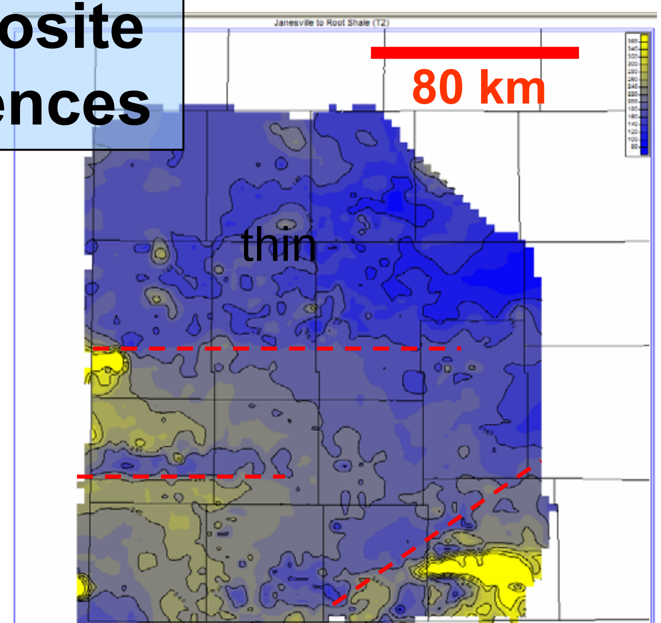


Shaded-Relief
4th-Order Trend Residual Map
Top Howe Ls.

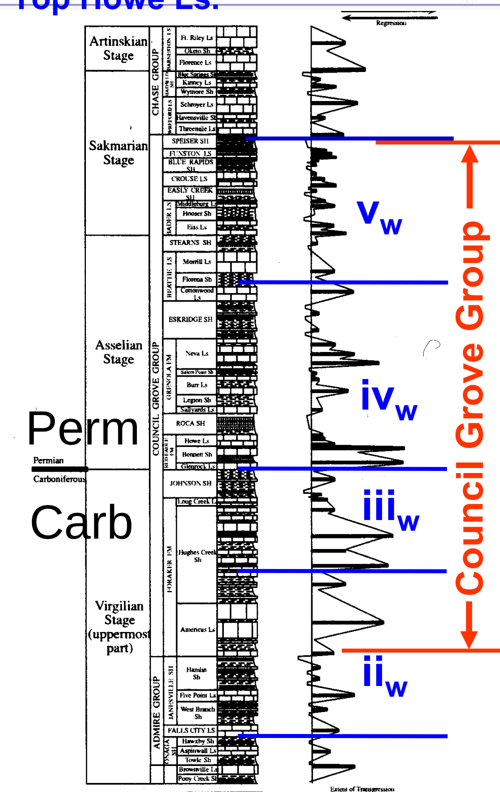
Composite Sequences

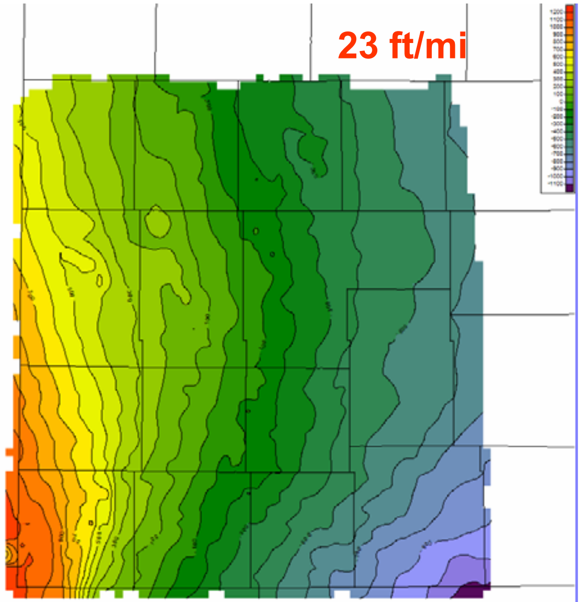


Composite Sequence iv_w
Eskridge to Johnson



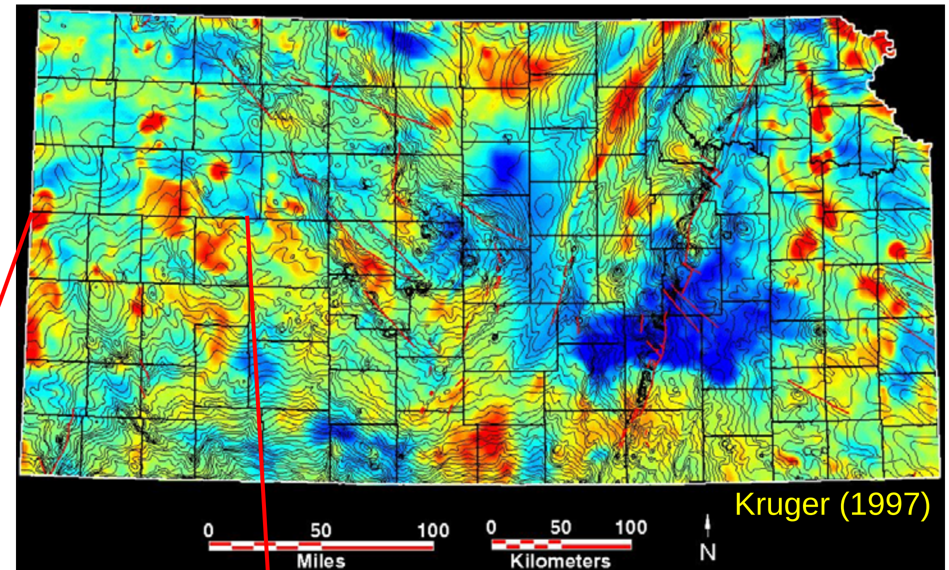
Composite Sequence ii_w
Janesville to Root Shale

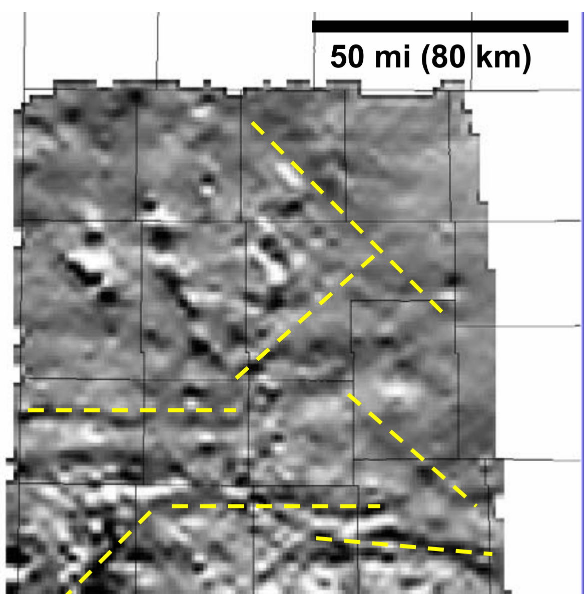




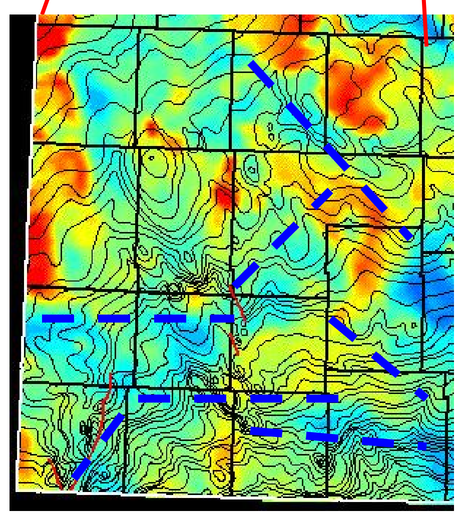
Structural Contour Map
Top Howe Ls.

Total Magnetic Field intensity with Precambrian basement contours

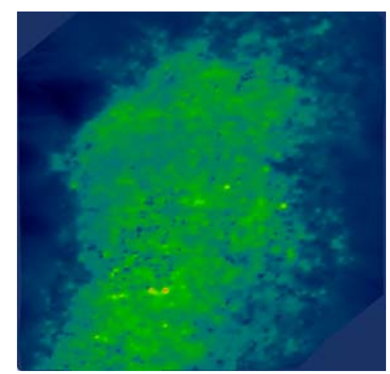




Shaded-Relief
4th-Order Trend Residual Map
Top Howe Ls.

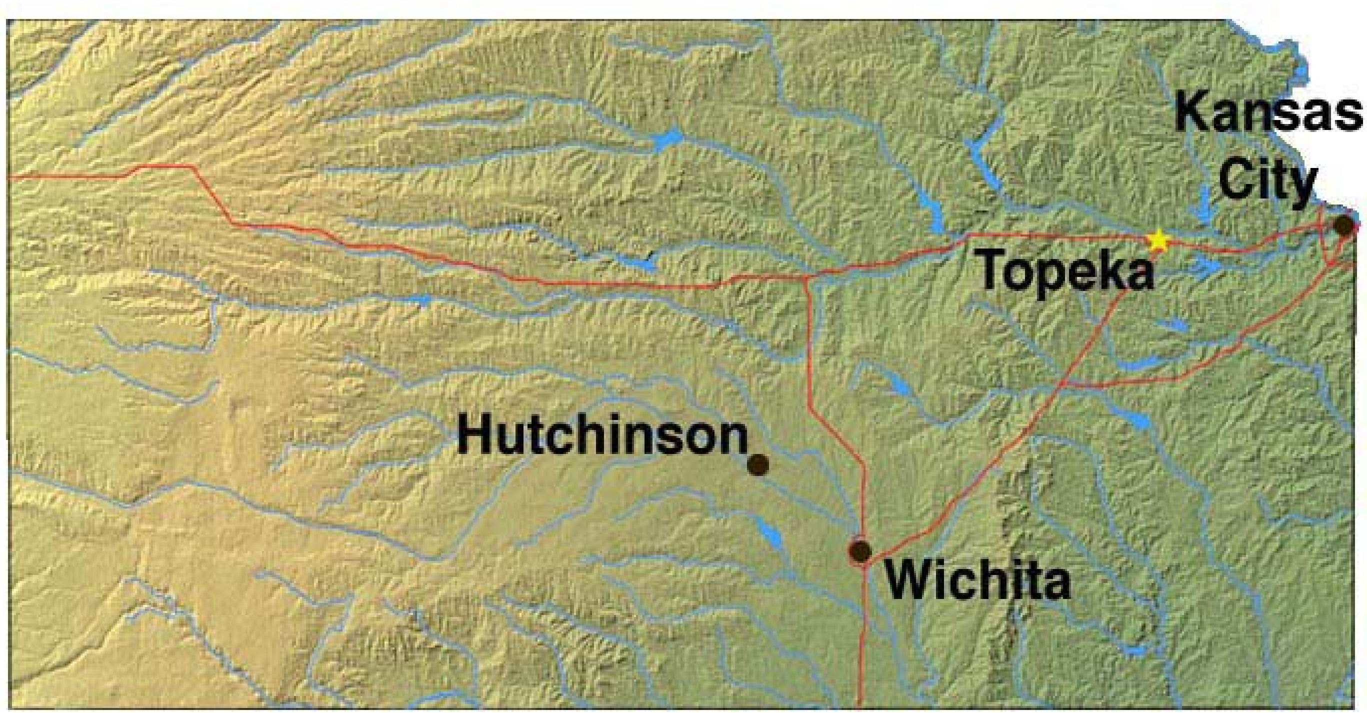


- **Laramide structural overprint on Howe Ls.**
- **NW, NE, and E-W trends**

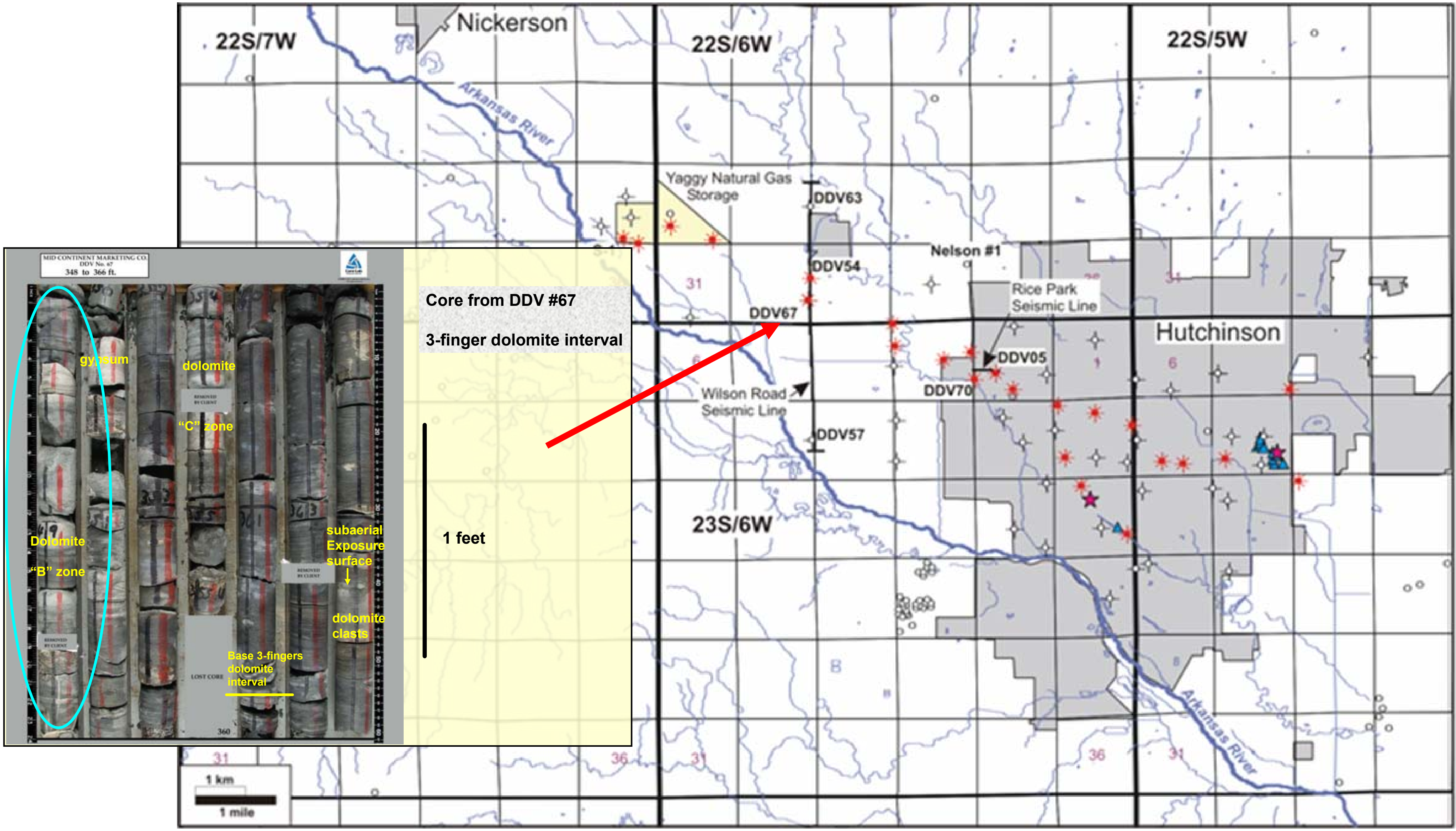


Cumulative CH_4 Production
(brighter = more gas)
Hugoton Gas Area
Southwest 3x4 counties

Fracturing and Evaporite Dissolution in Permian Strata



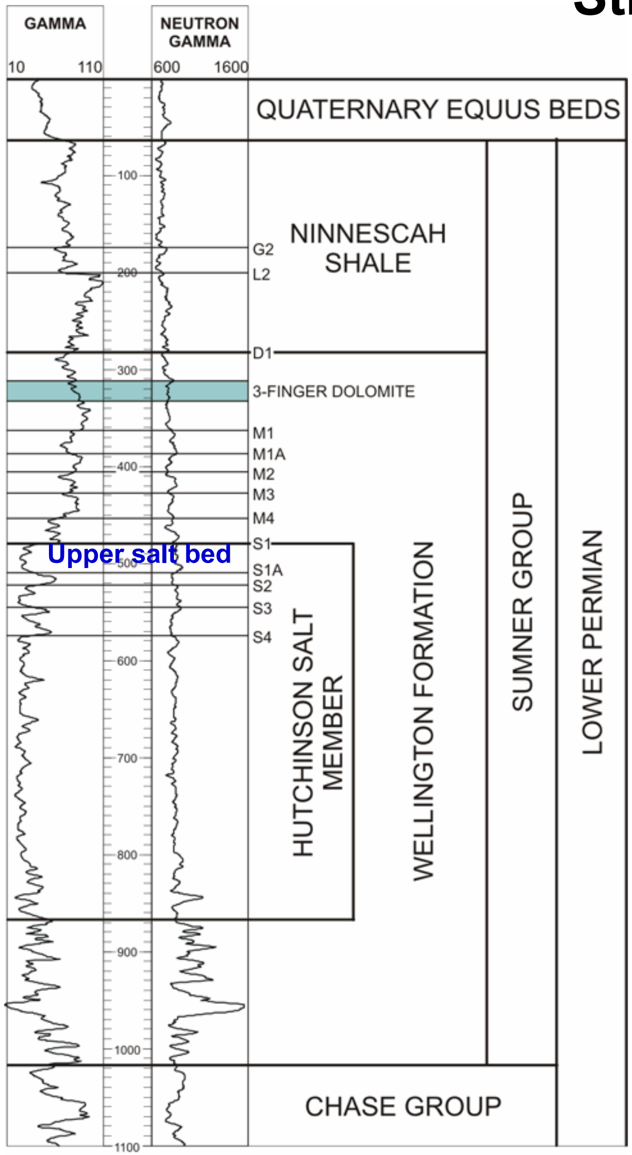
Hutchinson Gas Leaks



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

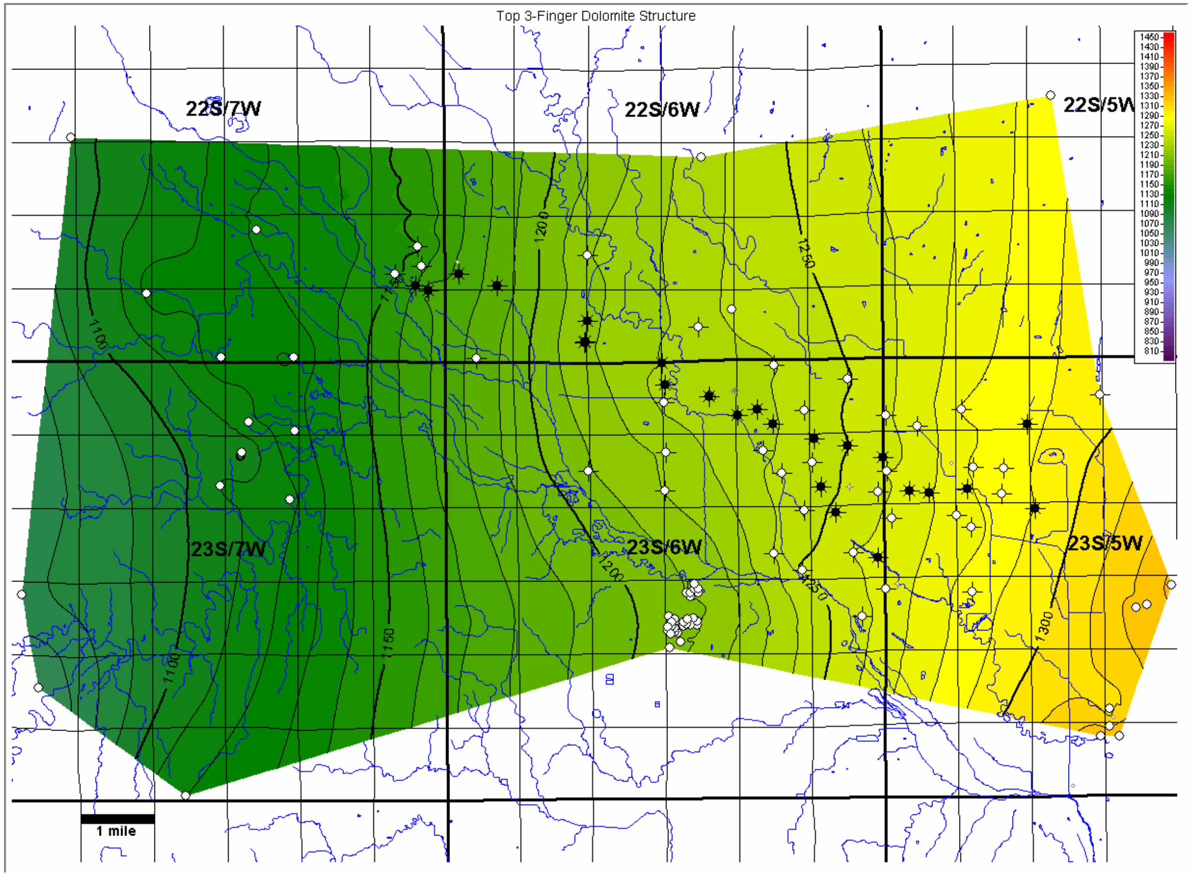

dolomite
• Jointed dolomite ledge underlain by shale with discontinuous fractures (paleosol) (Hammer for scale)
• Locality: Afton Lake, Sedgwick County
Joint traces along the upper surface of the dolomite

Structural contour map on top of 3-Finger dolomite

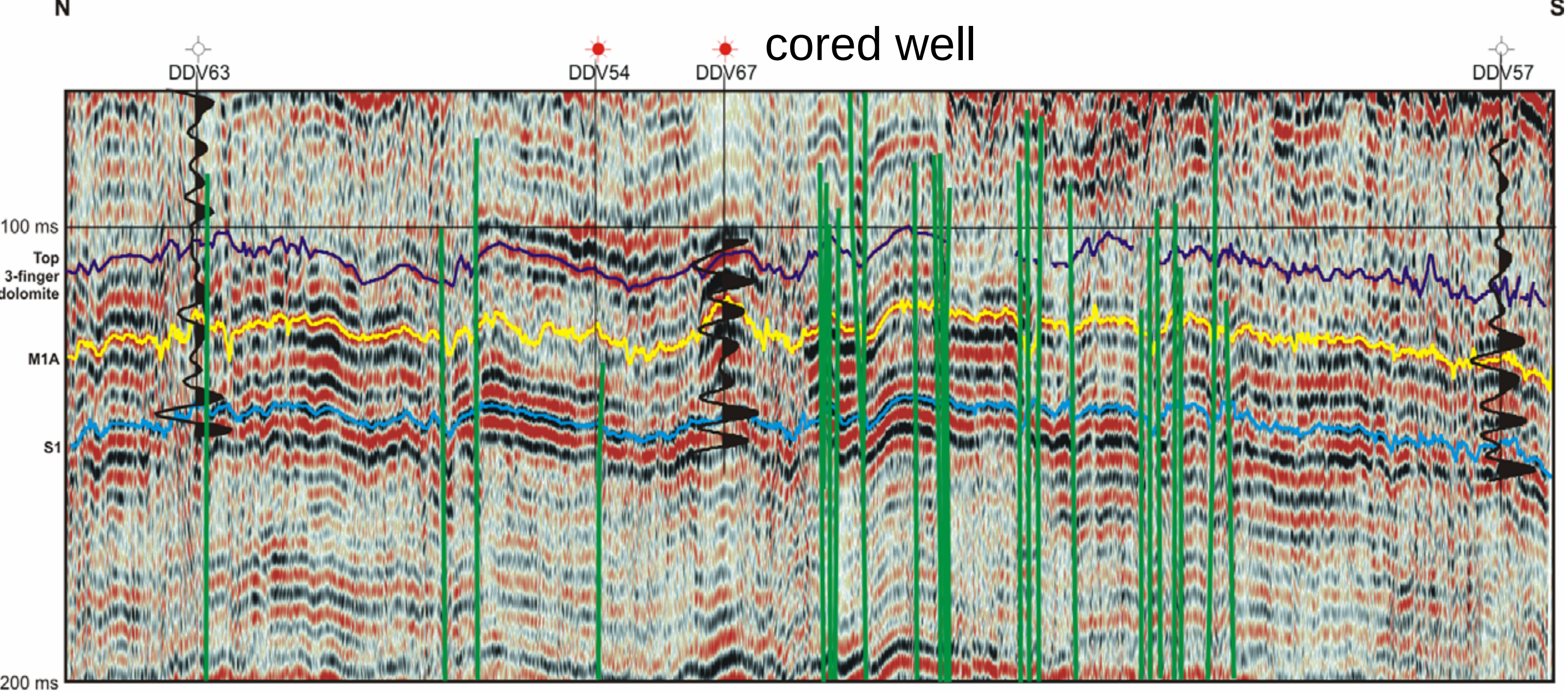


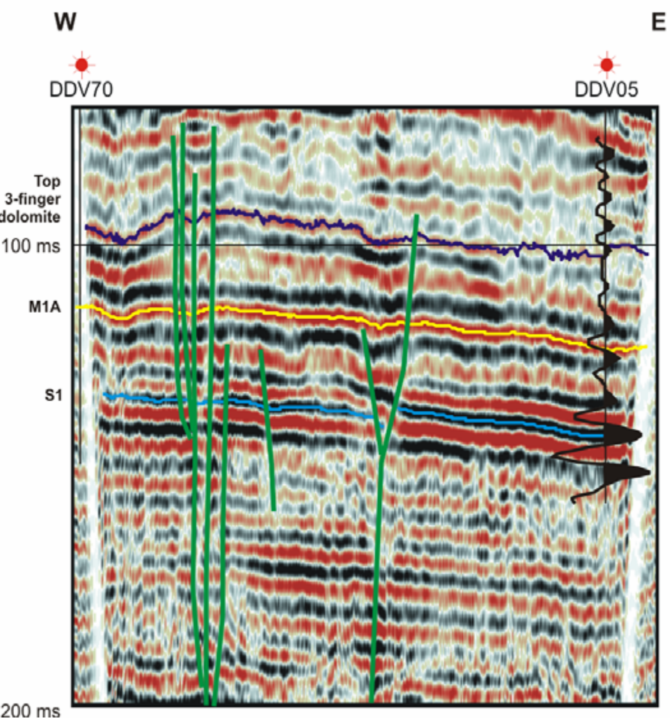
Type log Hutchinson Area

Watney et al. (2003)



- Monoclinal 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

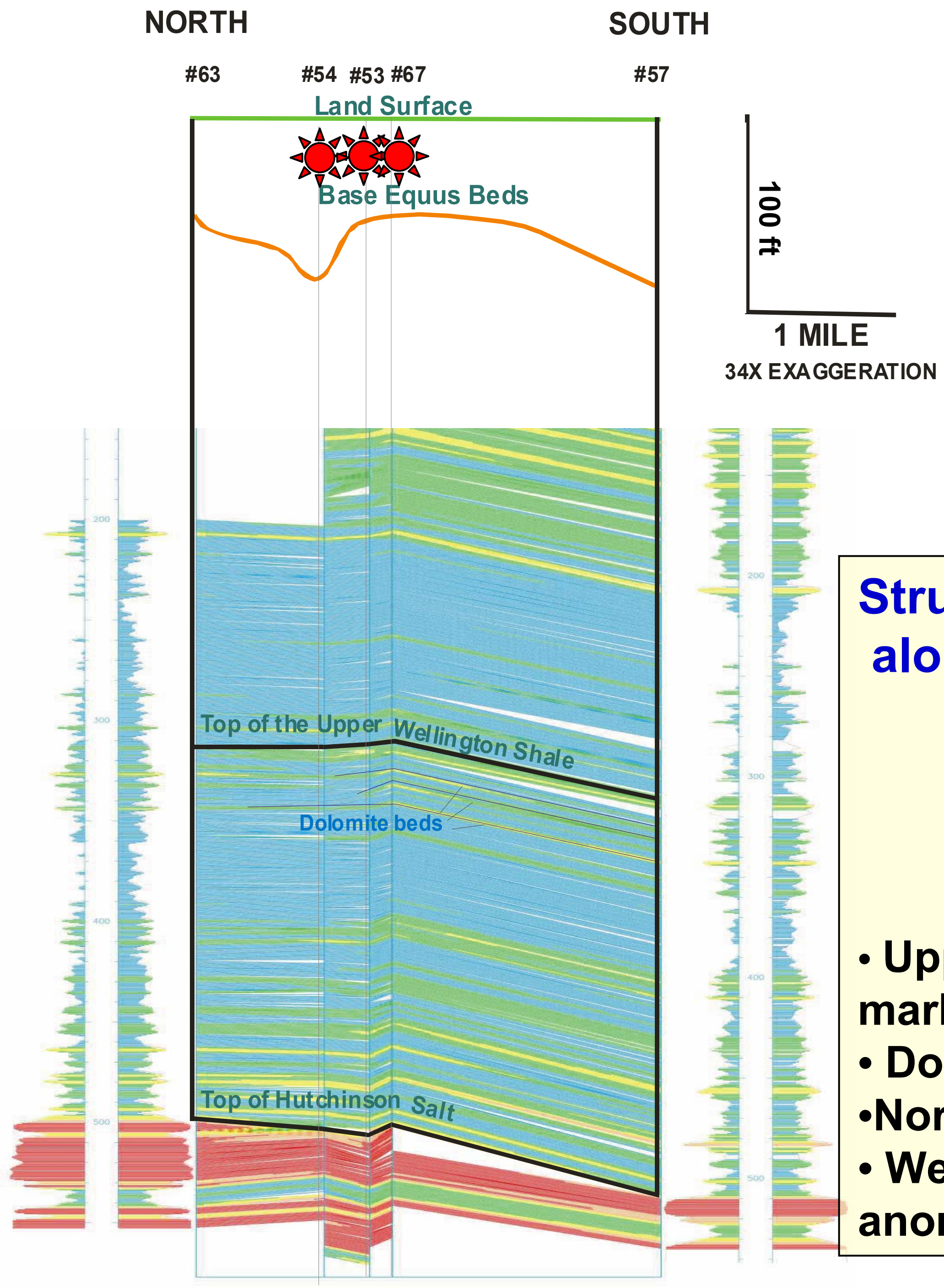
Seismic peaks are black, troughs are red.

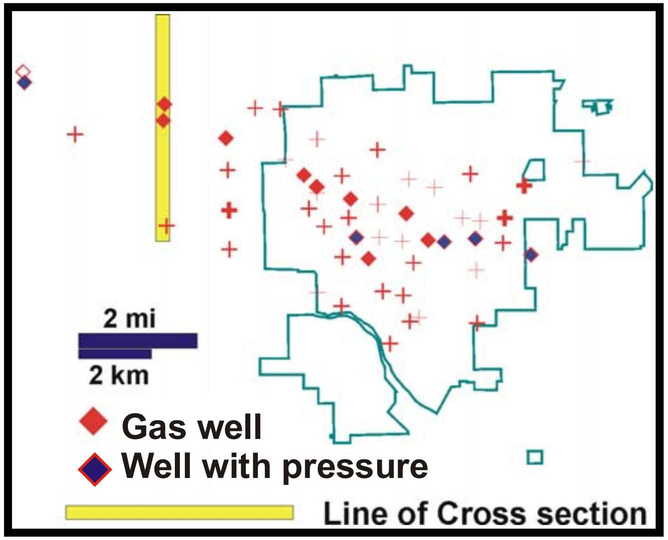
<u>The seismic reflections</u>:

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

Heavy green lines are interpreted faults.

Nissen et al. (2004)





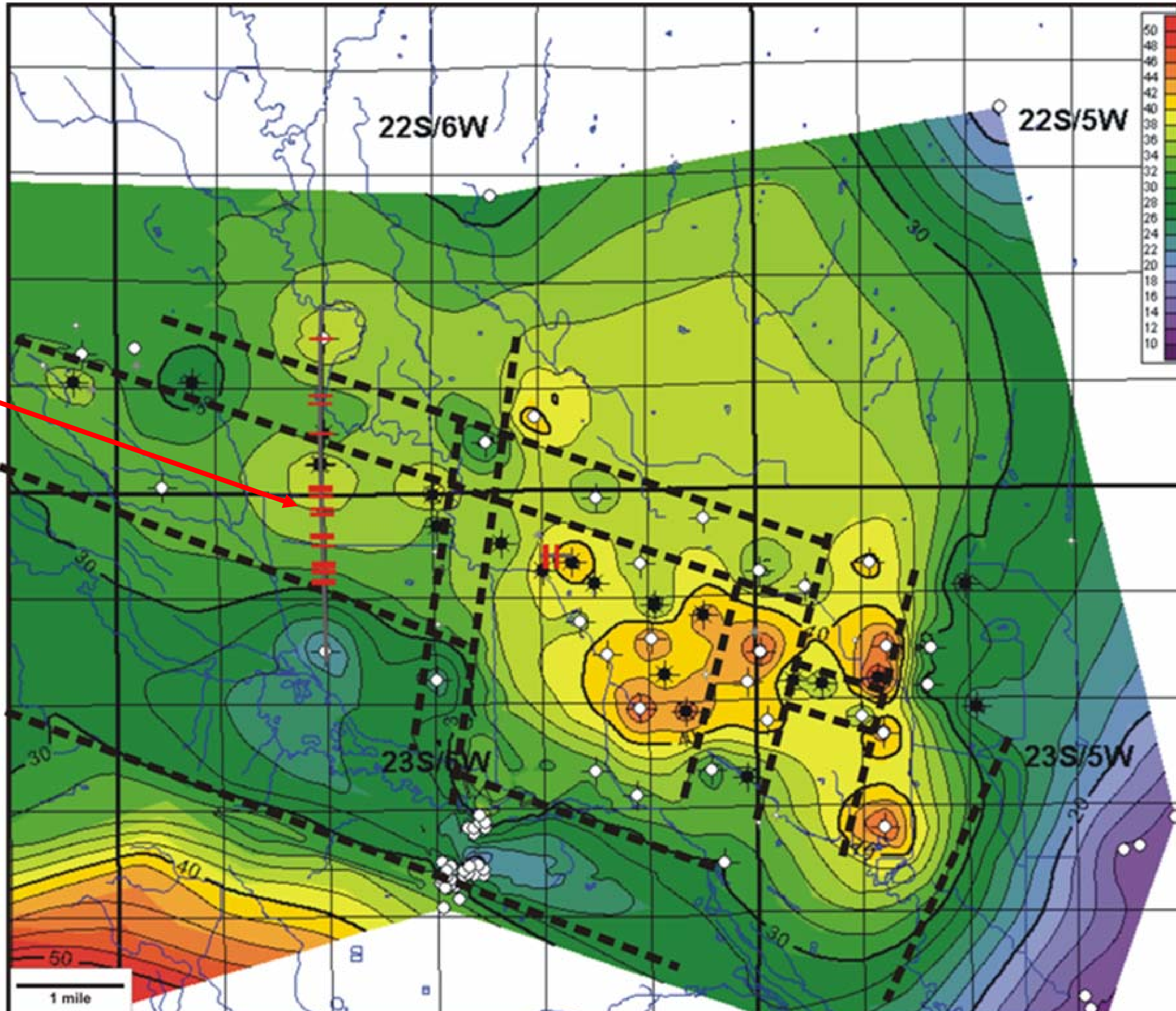
Structural cross section along Wilson Road

- 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



Watney et al. (2003)

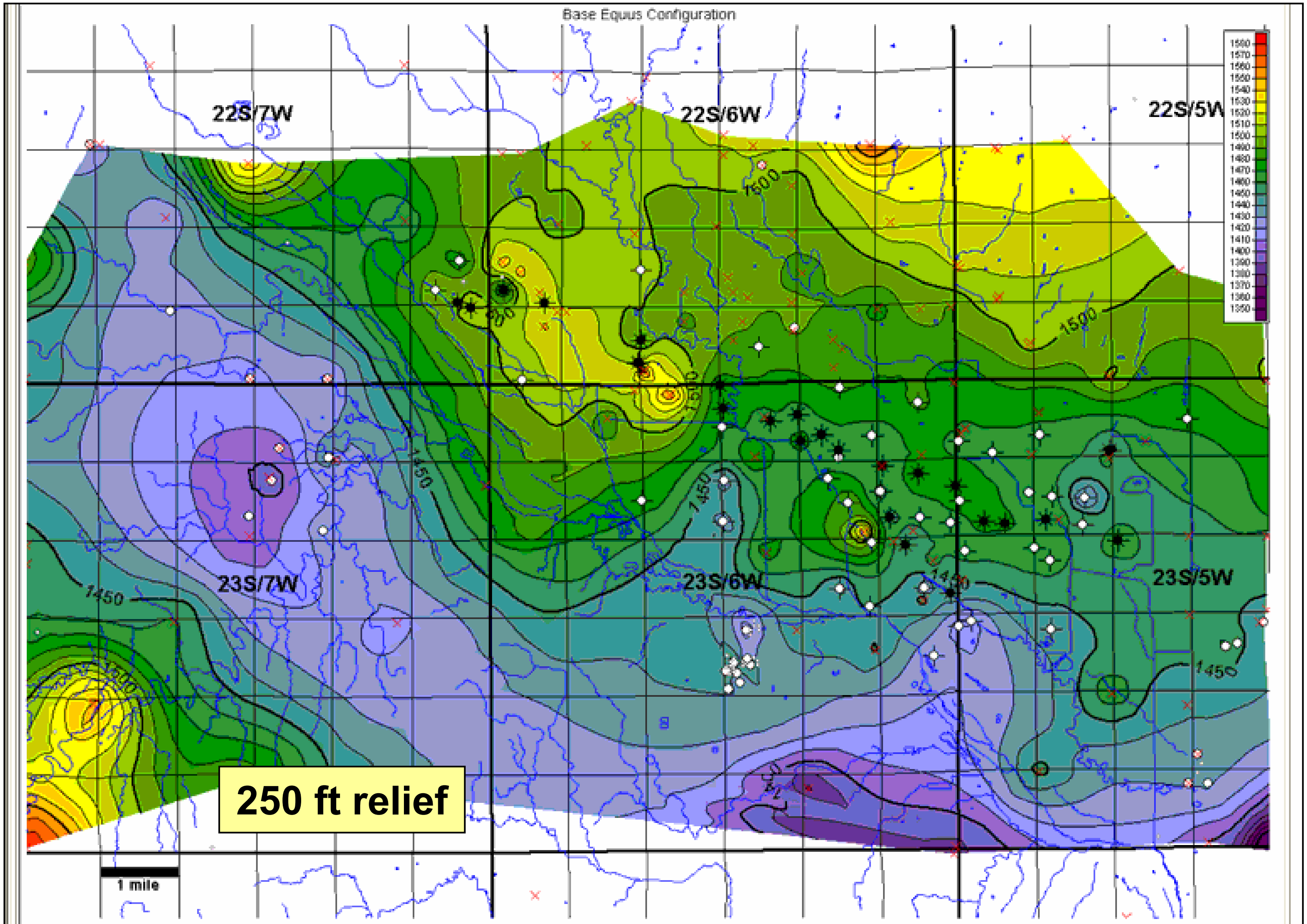
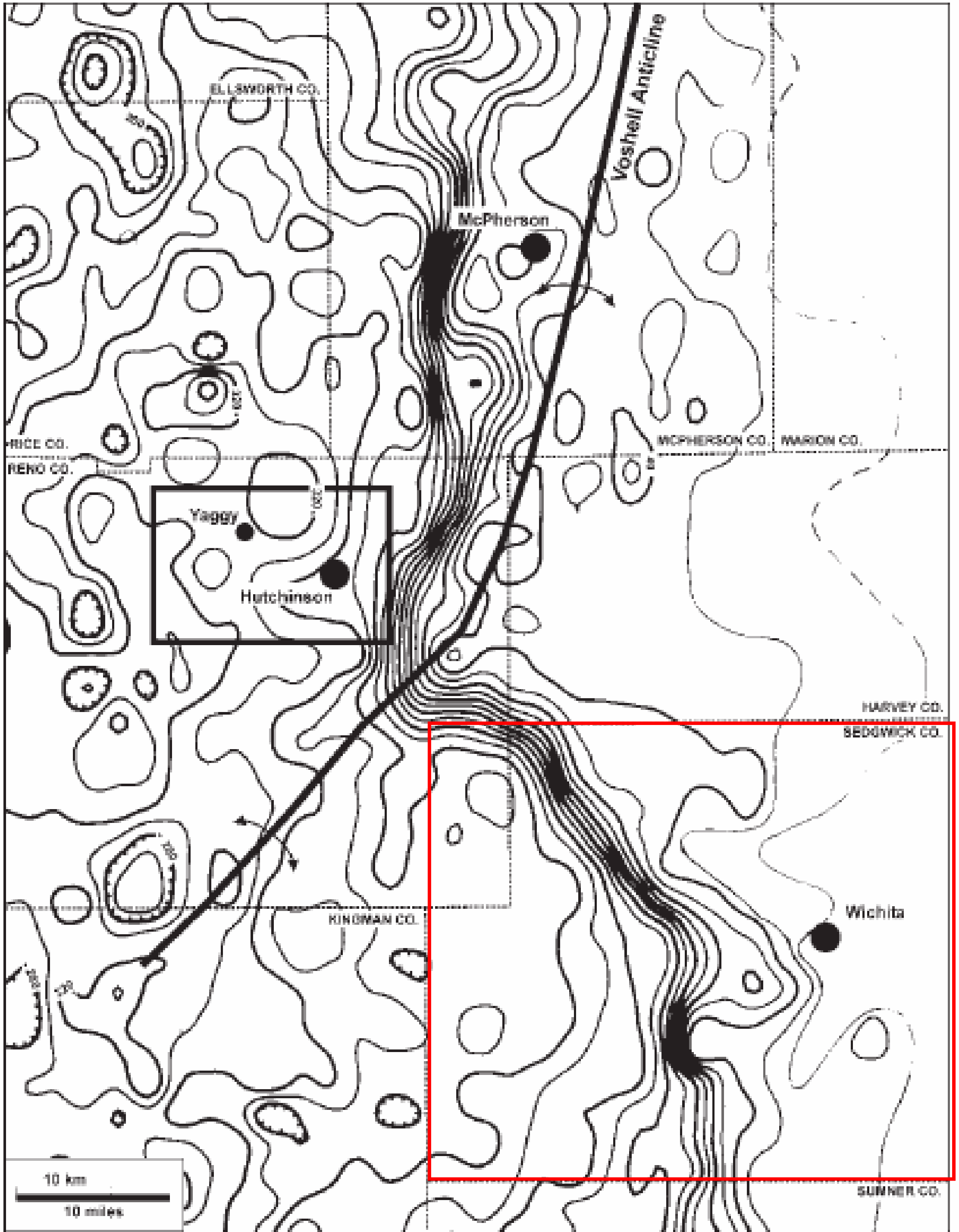


Figure 3N. Configuration map of the Base of Quaternary Equus Beds. Contour Interval = 10 ft. Red crosses indicate supplemental control points from water well completion records, test holes, and KGS publications, which have been used in mapping the Base Equus configuration.

Nissen and Watney (2003)

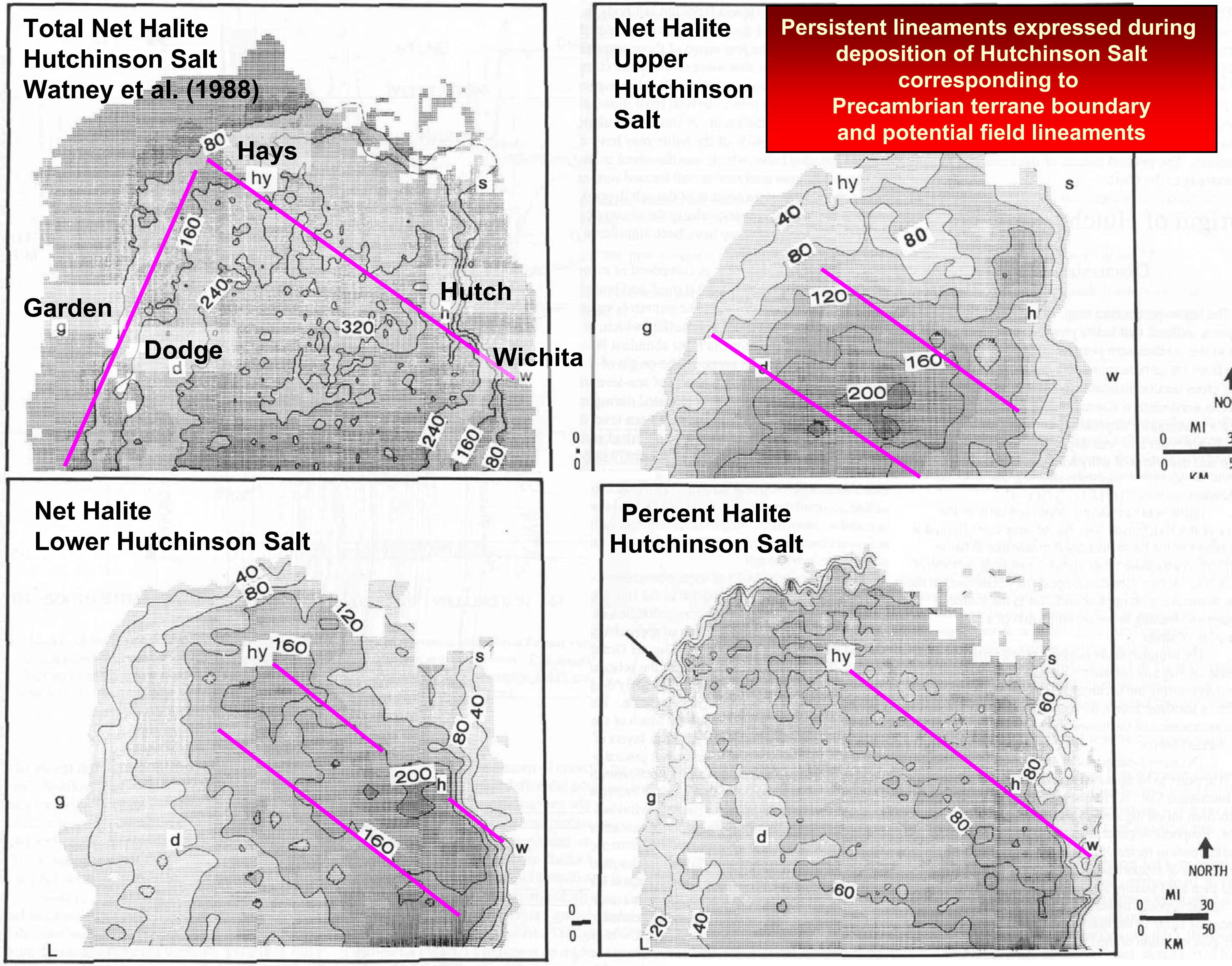


Net Halite Isopach For Hutchinson Salt (Watney & Paul, 1980)

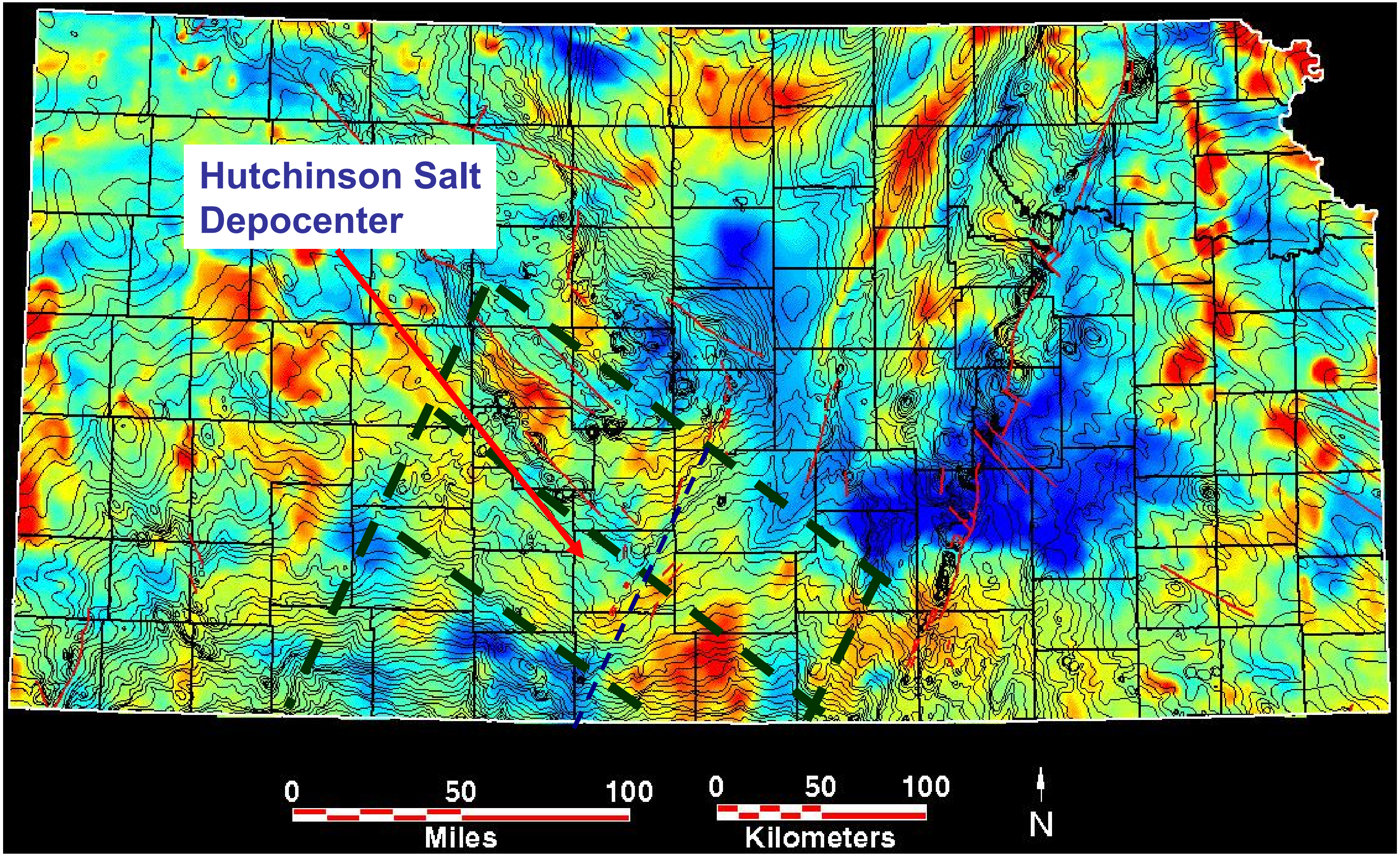
- Structural control on dissolution front of Hutchinson Salt –Voshell-Abilene Anticline (MRS)

- Dissolution front bends along Arkansas River between Hutchinson and Wichita

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



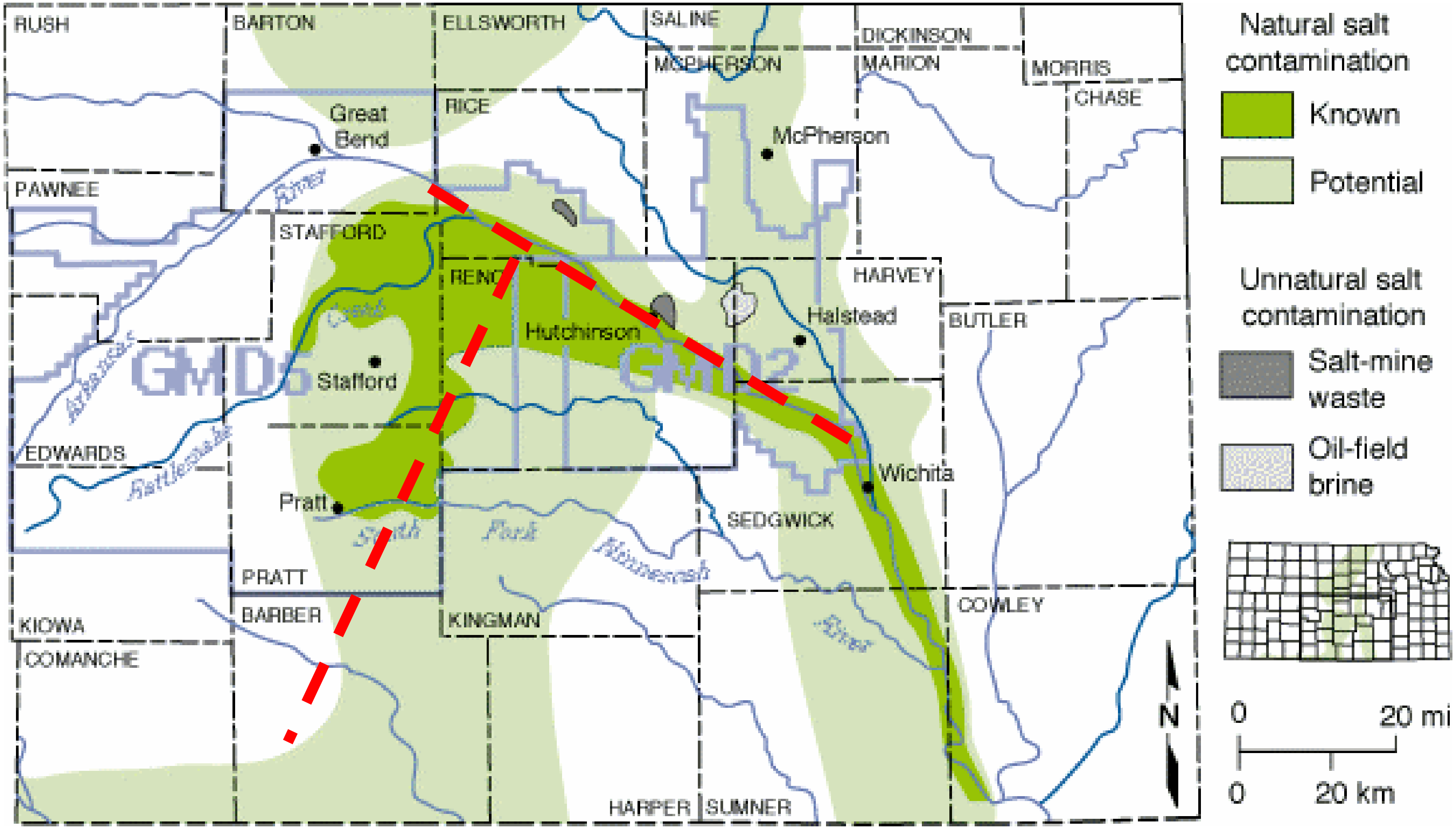
Total Magnetic Field Intensity



Lineaments shown are edges of thick salt and internal trends

Red = high mag.
Blue = low mag.

Contours = Precambrian surface isochores

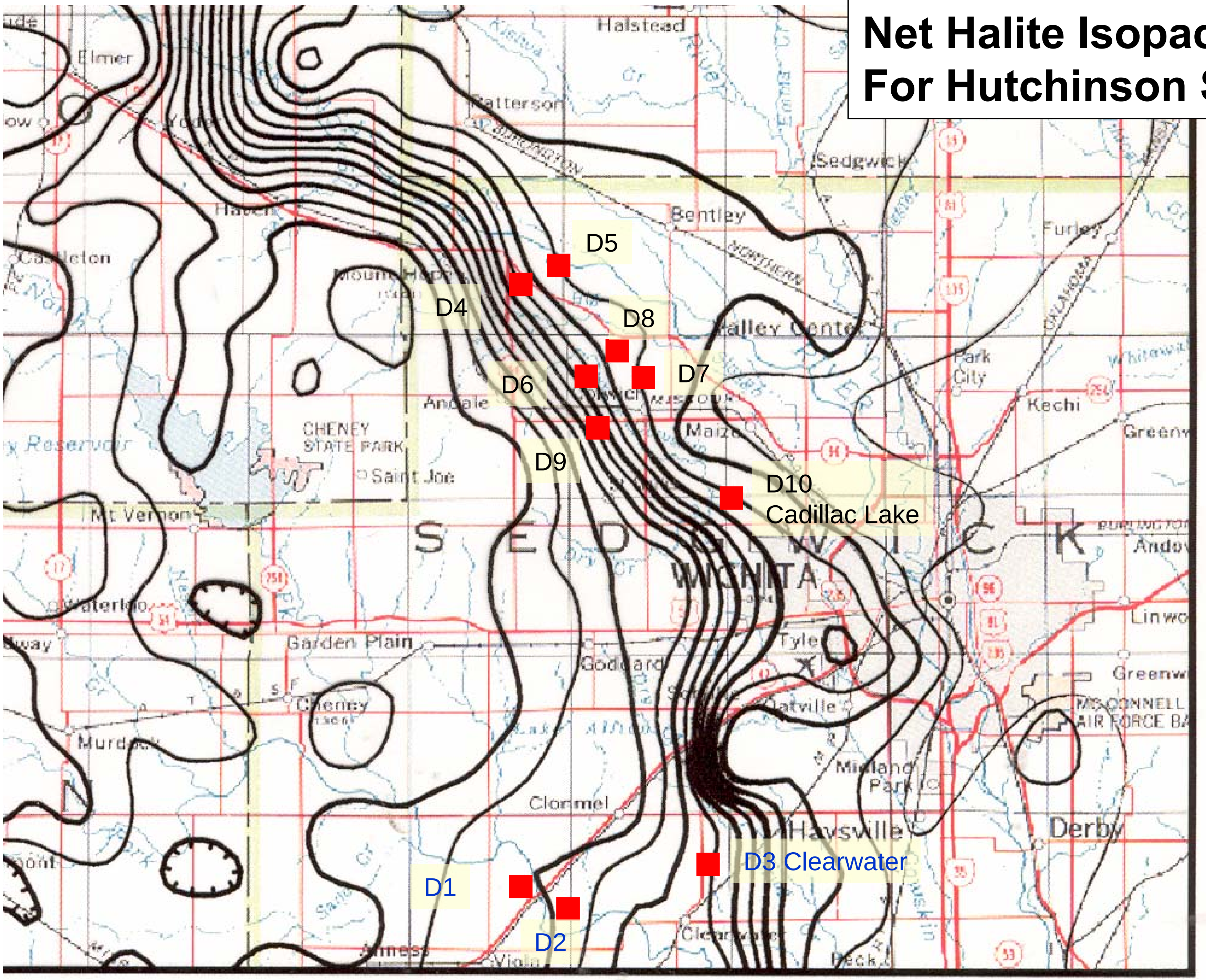


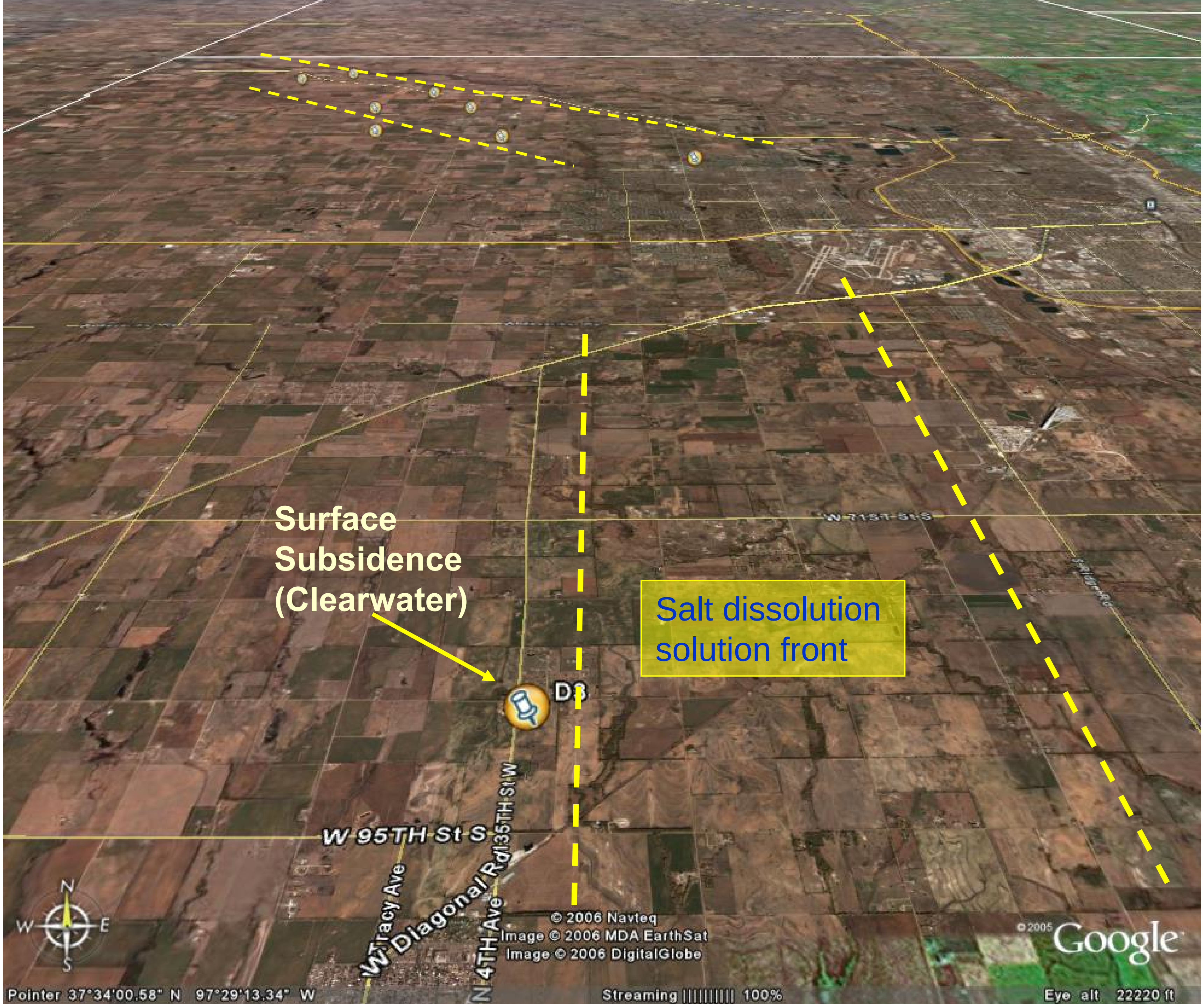
Final Summary and Data Report: The Equus Beds Mineral Intrusion Project

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
D3
W 71ST St S
W 95TH St S
135TH St W
W Tracy Ave
W Diagonal Rd
4TH Ave
N
S
W
E
© 2006 Navteq
Image © 2006 MDA EarthSat
Image © 2006 DigitalGlobe
© 2005 Google
Pointer 37°34'00.58" N 97°29'13.34" W
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.**

Revaluate Role of Midcontinent Structures in Play, Field, and Reservoir Characteriztion

- **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 = <u>Prediction</u>**
- **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
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- 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.,

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