Part 2. -- Regional structural/tectonic framework during the late Paleozoic and significance to reservoir systems.

Regional structural/tectonic framework

- Bill Thomas' 2005 GSA presidential address – "Tectonic inheritance at a continental margin"
- Paul Simms, U.S.G.S. -- U.S. magnetic/basement interpretation/ importance of basement to Phanerozoic structural history
- Lessons learned from modern neotectonic studies
- Contemporaneous structural deformation during sediment accumulation
- Regionalization (to objectively classify stratigraphic response) and conclusions regarding basement template
- Mississippian in southern KS/SW Missouri shelf margin
- Contemporaneous structural controls influencing ooid shoal development
- Ditto for incised valleys and spicultic "chat" buildups

Integrated Tectono-Stratigraphic Analysis

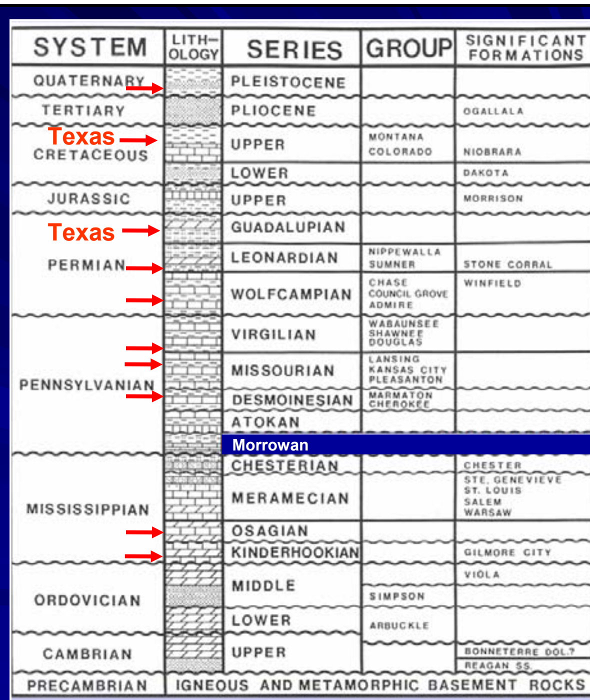
- Ancestral Rocky Mountains, Ouachita-Marathon, and Laramide tectonism were far reaching and systematically deformed shelves and shelf margins of the greater Midcontinent.
- Precambrian faults served as templates for later deformation, crustal segmentation.
- Resultant segmentation of shelves and shelf 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/"kinematics" of structural blocks.

Key Points

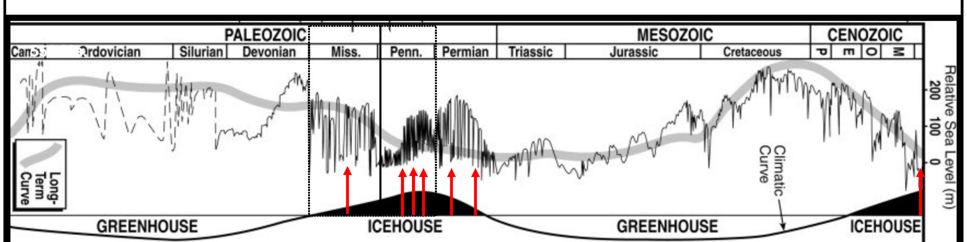
- 1. True stratigraphic traps of economically producible hydrocarbons are probably fewer than believed.
- 2. The interrelationships of processes including deposition, diagenesis, and structure probably need to be re-evaluated to improve modeling of reservoirs in remaining fields.
- 3. Geologic models 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 control as added element in prediction and quantification of reservoir properties



Paleozoic Sea Level Curve



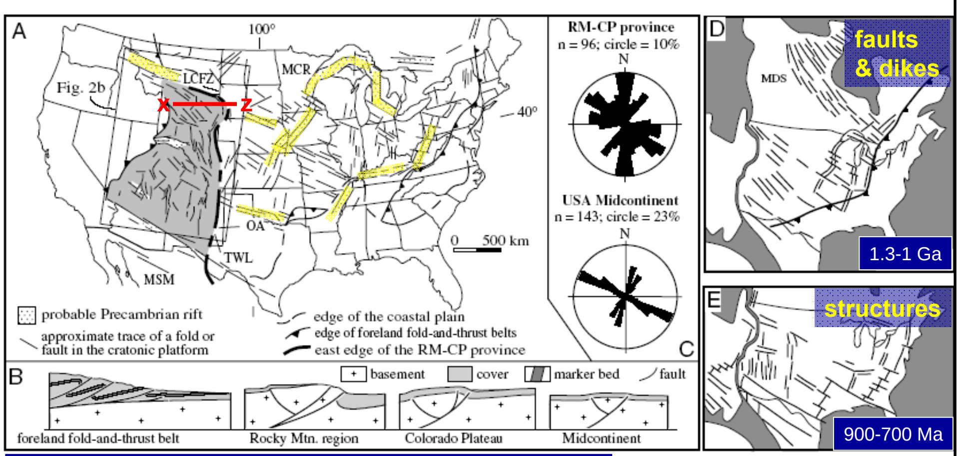
After Longman, M.W., and M.D. Sonnenfeld (1996)

- Icehouse conditions and high frequency, modulated eustacy a given
- Stratigraphic *precision* provides “timing light” to reconstruct high-resolution paleogeography
- Carbonates and clastic systems respond to topography, i.e. define plays and reservoir heterogeneity
- Active structural deformation plays a role in modifying depositional topography and provides pathways for later diagenesis.

Ancestral Rocky Mountain, Ouachita-Marathon, and Laramide tectonism were far reaching and systematically deformed shelves and shelf margins of the Midcontinent U.S.

- Baars et al. (1995) recognized continental-scale orthogonal patterns and basic similarity of structures to the San Andres fault system

Two dominant orientations of Precambrian faults and folds on the cratonic platform

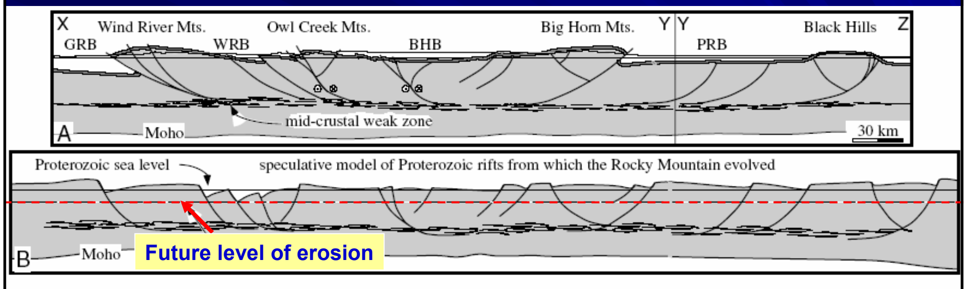


- Proterozoic rifting (extensional faults)
- Faults continue to be reactivated during Phanerozoic compressional orogenies (Kluth and Coney, 1981)
- Inversion of normal faults (*reverse & oblique-slip*)

Marshak, Karlstrom, and Timmons (2000)

Reactivation *(reverse and oblique slip)* of Precambrian extensional fault throughout the craton throughout the Phanerzoic

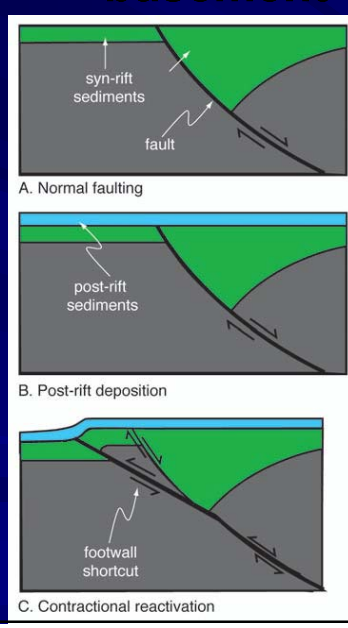
X Y Z



A) Schematic cross section of Rocky Mountains
B) Hypothetical east-west cross section of Proterozoic structure
C) Ar-Ar methods suggest ***>6 km of erosion*** between widespread time of extensional faulting (800-1100 Ma) and Cambrian deposition (Heizler et al., 2000)

Marshak, Karlstrom, and Timmons (2000)

Contractional reactivation of basement extensional faults



Schematic diagram of the creation of a listric normal fault (top) that is later reactivated in compression (bottom), creating a footwall shortcut. Pre-extensional rocks are shown in dark gray.

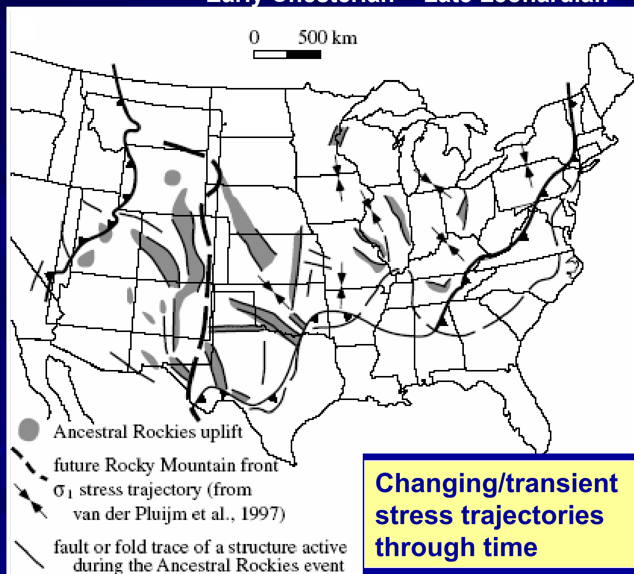
Tri-shear faults are generated during reactivation.

Upper strata may be simply *draped* over deeper “blind” fault.

Bump (2003)

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)

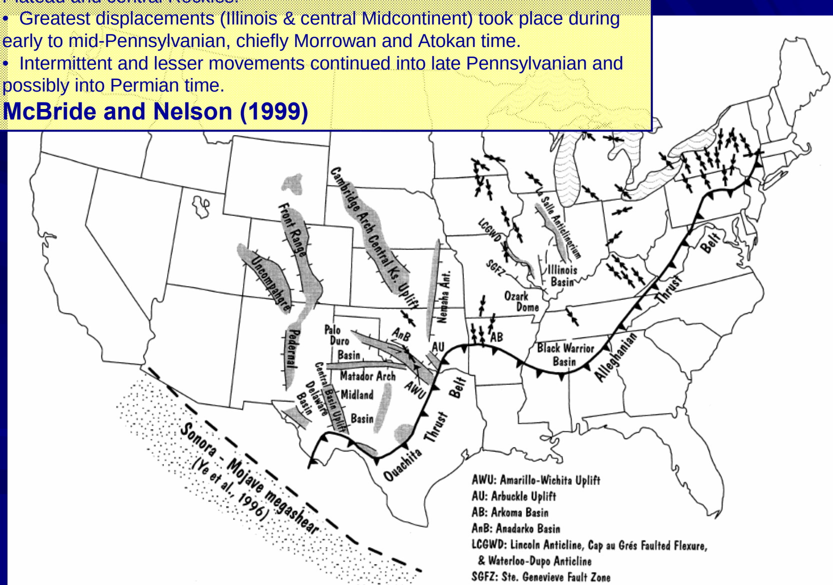
Changing/transient stress trajectories through time

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

FINDINGS:

- Extensive compressive blocks and basement reverse faults.
- Interior structures resemble Laramide foreland structures of Colorado Plateau and central Rockies.
- Greatest displacements (Illinois & central Midcontinent) took place during early to mid-Pennsylvanian, chiefly Morrowan and Atokan time.
- Intermittent and lesser movements continued into late Pennsylvanian and possibly into Permian time.

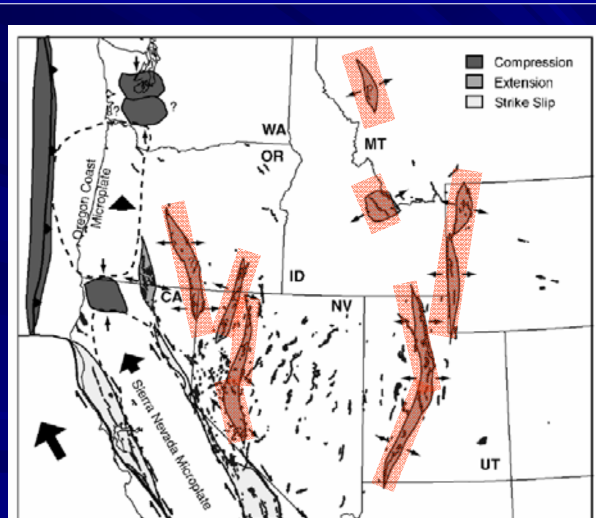
McBride and Nelson (1999)



Resultant segmentation of shelves and shelf margins via reactivation of basement faults – systematic variation with stress, and potentially characterized into a temporal-spatial framework for prediction

Examples of Neotectonism

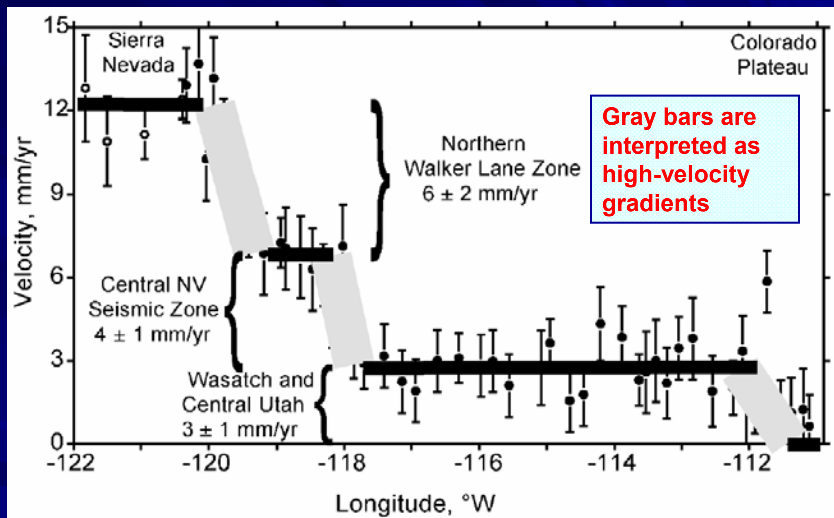
Schematic mapping of zones of localized deformation in the western U.S. suggested from recent GPS survey results, Holocene faults, and seismicity.



Active intraplate motion in response to far-field stress along North American plate margin

Thatcher (2003)

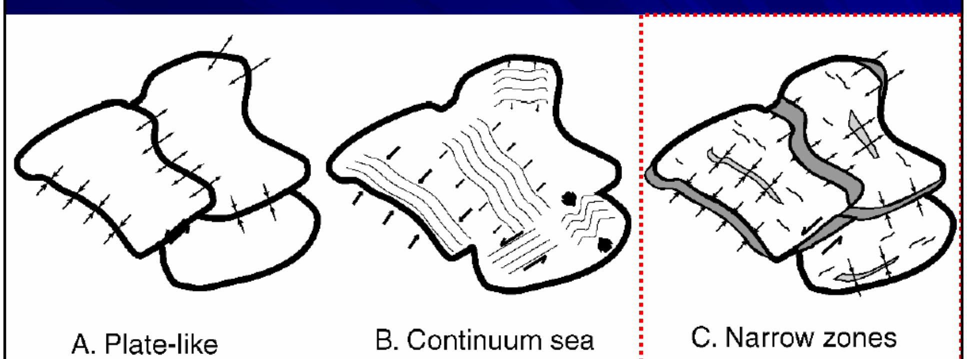
Magnitude of GPS velocity with respect to stable North America plotted on west-to-east profile versus longitude from Sierra Nevada to Colorado Plateau



Focused zones of deformation

Thatcher (2003)

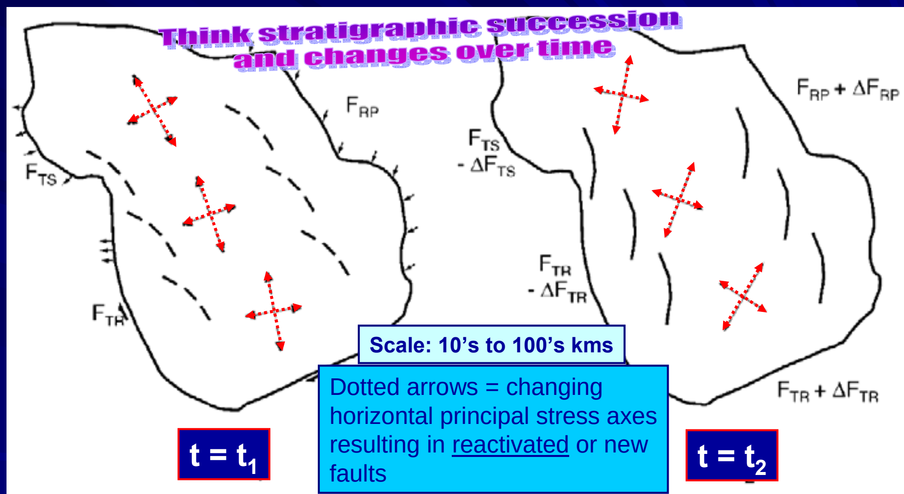
Schematic diagrams showing alternative kinematic descriptions of continental deformation



- 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** being applied to ***quantify seismic hazard assessment***

Thatcher (2003)

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

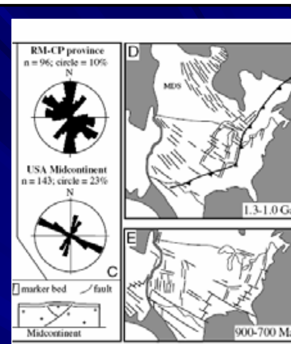


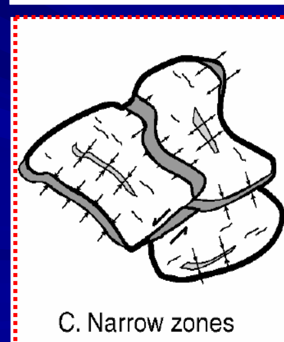
From Thatcher (2003) –

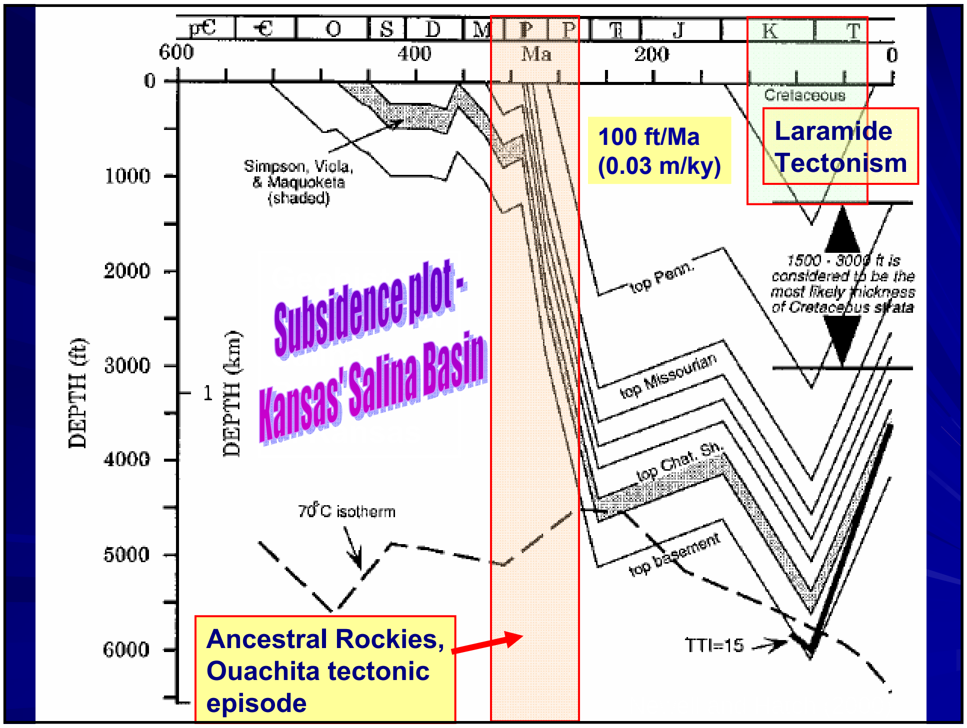
- GPS constraints on the kinematics of current continental deformation.
- Deformation linked to "real time" Modern faulting and microplate motion.

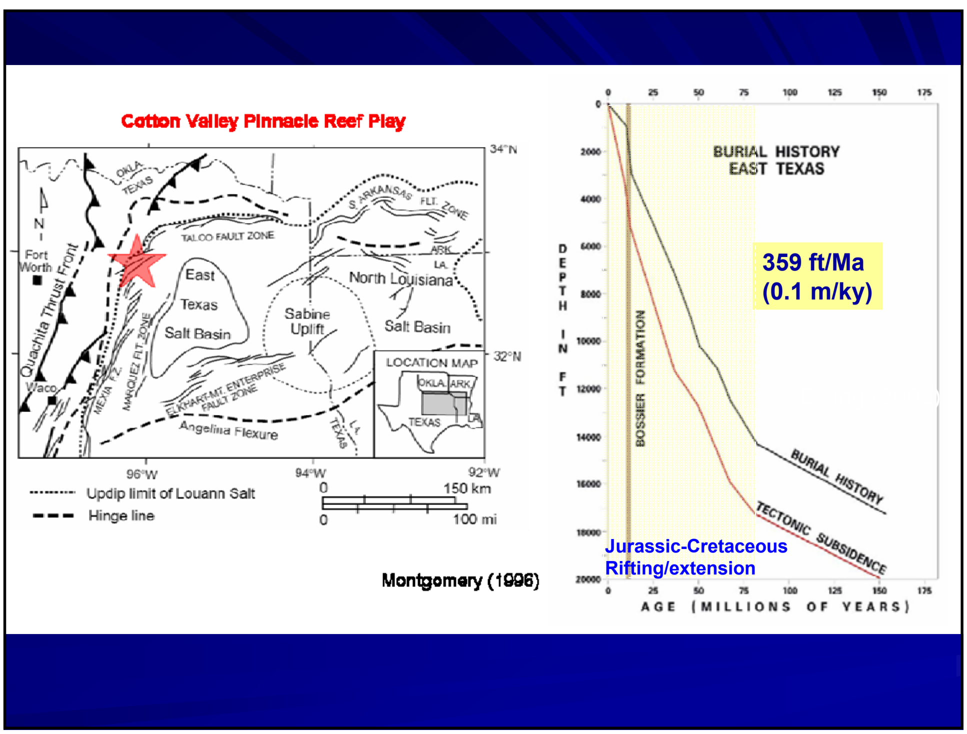
Significant of findings from neotectonics toward interpreting tectonism affecting ancient craton and craton margins:

- Importance of far-field stresses generated from active tectonism along plate margins on deformation of the craton interior of the craton (~1000 km)
- Craton deformation expressed as set of narrow structural deformation zones
- Zones of weakness often related to extensive "hidden/subtle" rift and basin margin extensional faults
- Tendency for weak structural zones to reactivate
- Likelihood of paleoseismicity and structural activity during active tectonism is high; contemporaneous deformation with sedimentation

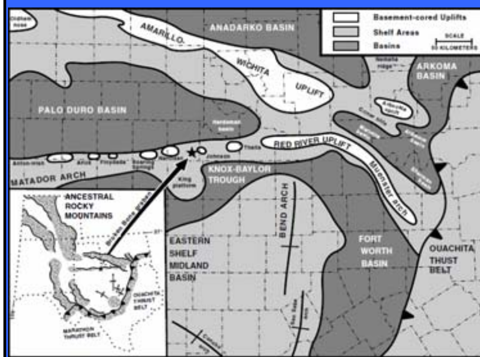




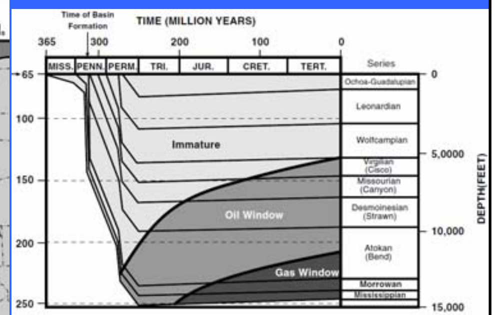

Subsidence plot - Kansas' Salina Basin
100 ft/Ma
(0.03 m/ky)
Laramide
Tectonism
Ancestral Rockies,
Ouachita tectonic
episode
Simpson, Viola,
& Maquoketa
(shaded)
70°C isotherm
top Penn.
top Missourian
top Chat. Sh.
top basement
TTI=15
1500 - 3000 ft is
considered to be the
most likely thickness
of Cretaceous strata
Cretaceous
DEPTH (ft)
DEPTH (km)
Ma


Cotton Valley Pinnacle Reef Play
East
Texas
Salt Basin
North Louisiana
Salt Basin
Sabine
Uplift
Ouachita Thrust Front
TALCO FAULT ZONE
LOCATION MAP
Angelina Flexure
Updip limit of Louann Salt
Hinge line
Montgomery (1996)
BURIAL HISTORY
EAST TEXAS
359 ft/Ma
(0.1 m/ky)
BOSSIER FORMATION
BURIAL HISTORY
TECTONIC SUBSIDENCE
Jurassic-Cretaceous
Rifting/extension
DEPTH IN FT
AGE (MILLIONS OF YEARS)

Active late Paleozoic subsidence along Matador Arch



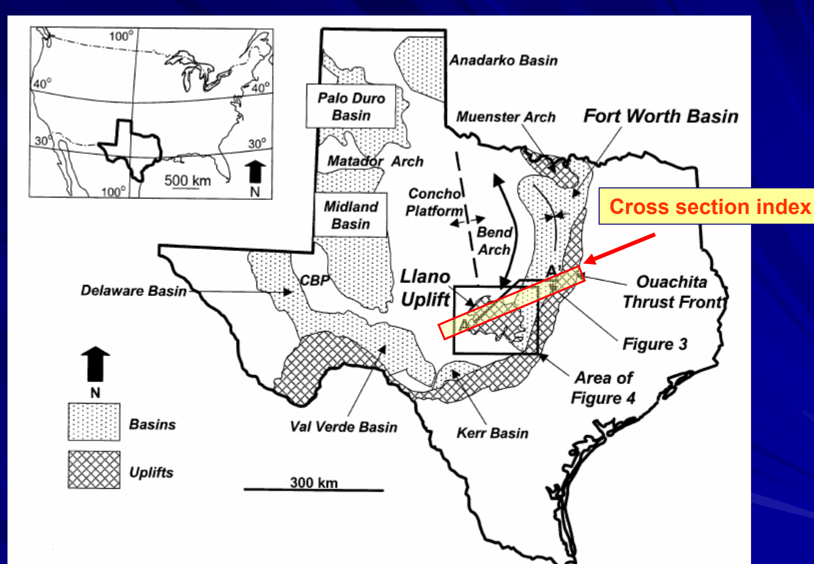
Regional Pennsylvanian paleotectonic map



Burial history diagram for
Gunn Oil Co., #1 Majors, Cottle Co., TX

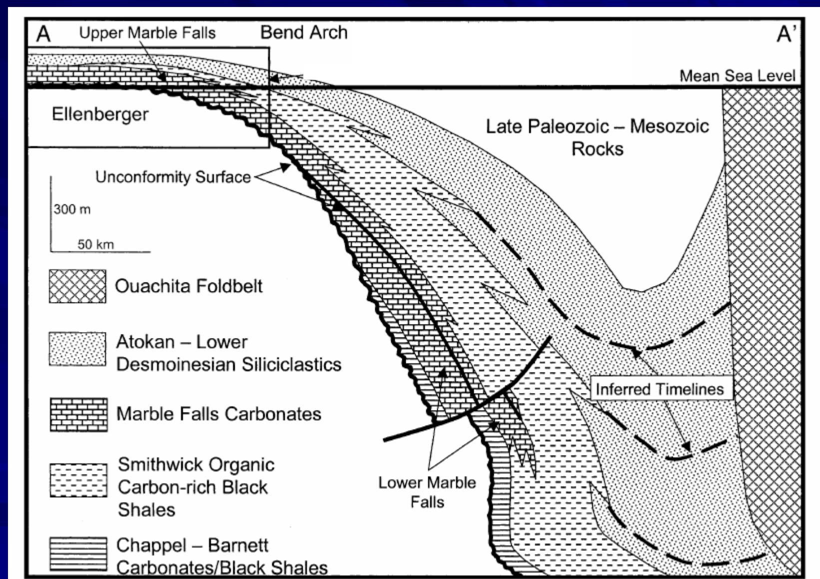
Brister, et al. (2002)

- Periods of pronounced subsidence during mid-Pennsylvanian and mid-Permian
- Tied to strike-slip motion on W-E wrench faults
- Powered by the Ouachita orogeny



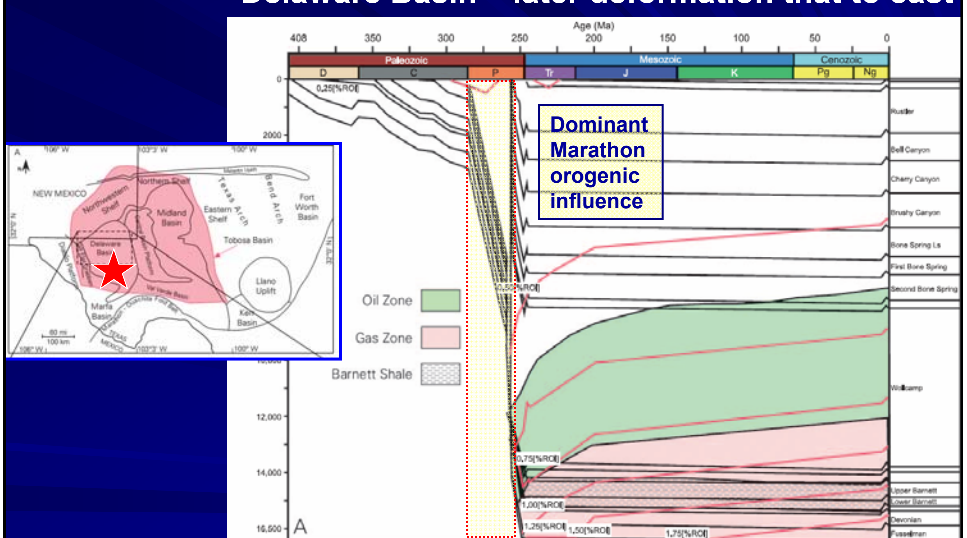
Erlich and Coleman (2005)

Foreland Basin, Ft. Worth Basin



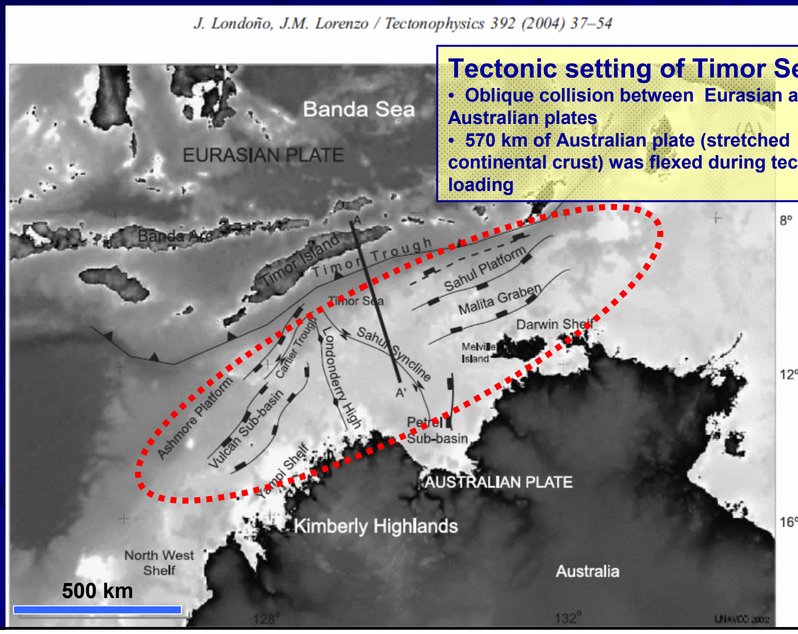
Erlich and Coleman (2005)
after Grayson et al. (1989)

Burial History Model
Delaware Basin – later deformation that to east



Hydrocarbon potential of the Barnett Shale (Mississippian), Delaware Basin, west Texas and southeastern New Mexico Travis J. Kinley, Lance W. Cook, John A. Breyer, Daniel M. Jarvie, and Arthur B. Busbey, AAPG Bull., v. 92 (2008)

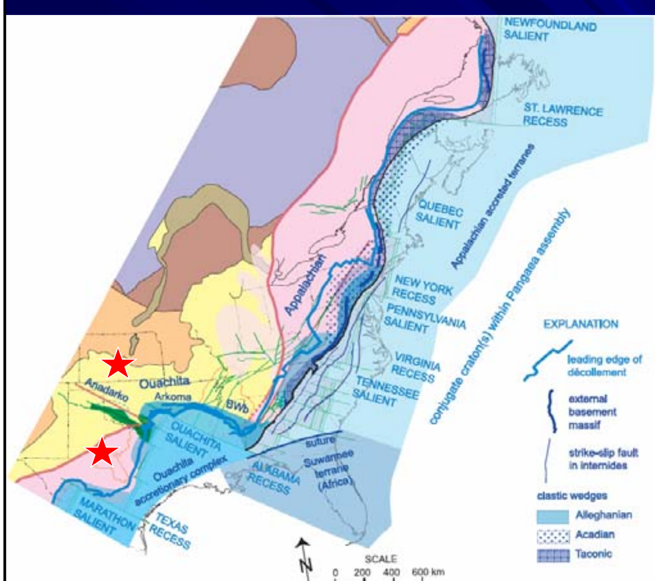
Possible Modern Analog for Early Pennsylvanian Ouachita plate margin and thrust belt



Tectonic setting of Timor Sea

- **Oblique collision between Eurasian and Australian plates**
- **570 km of Australian plate (stretched continental crust) was flexed during tectonic loading**

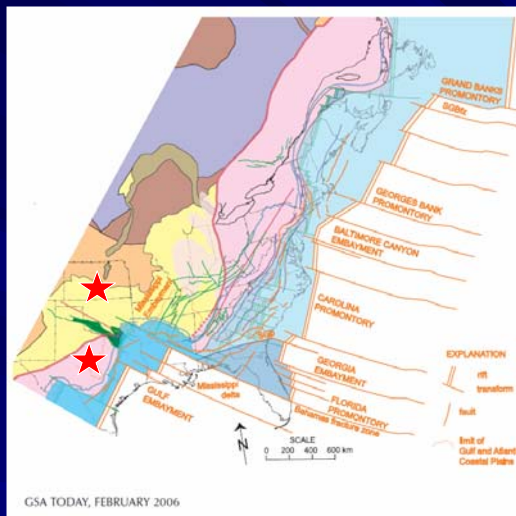
Thomas 2005 Presidential Address to GSA



Thomas (2006)

Assembly of Pangea as recorded by the Appalachian-Ouachita orogen – Appalachian-Ouachita salients are located at embayments of the lapetan margin, and recesses are on promontories (Rankin, 1976; Thomas, 1976, 1977).

"The leading part of the thrust belt wrapped around the shape of promontories and embayments of the older rifted margin indicating a ***grand scale of tectonic inheritance.****"*



Thomas (2006)

Breakup of Pangea and opening of Atlantic --

"The attenuated lower plate crustal structure overprints the Ouachita accretionary complex (Keller et al., 1989), suggesting the possibility that distinctive crustal properties may be inherited by the geometry of continental rifting."

"Most of the inherited structures are in the brittle, shallow crust; however, localization of maximum synorogenic flexural subsidence of the foreland in embayments of the Iapetan margin along transform faults suggests tectonic inheritance at a lithospheric scale."

Conclusions of Thomas (2006)

"On a smaller scale, frontal thrust ramps over older basement faults, thin-skinned transverse zones over basement transverse faults, and reactivation of basement faults in the foreland provide predictable controls on fracture sets that affect fluid flow in both petroleum and groundwater systems. Repeated inheritance of zones of crustal weakness suggests a focus for modern seismicity."

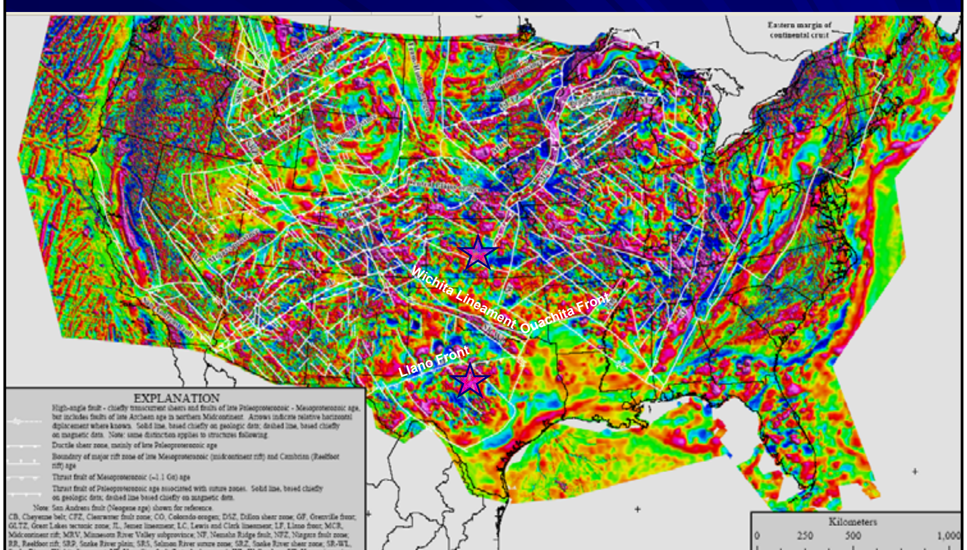
Precambrian faults serve as templates for later deformation and crustal segmentation

- Orthogonal sets of shear zones and faults are dominant across the the U.S. continent
- Why?
  - Northeast-striking partitioned ductile shear zones (NW-SE crustal shortening)
  - Northwest-trending strike-slip ductile brittle faults (transcurrent fault system attributed to transpressional-transtensional deformation (Dewey et al., 1998)
  - Since early Proterozoic time, predominately transpression caused by stress between asthenosphere and lithosphere during SW drift of continent
  - Deformation focused on reactivation of preexisting block boundaries localizing sedimentation, magmatism, and generatioin of ore deposits (Sims et al., 2002)

Sims, Saltus, Anderson (2005)

Preliminary Precambrian Basement Structure Map of Continental U.S.

-- An interpretation of Geologic and Aeromagnetic Data



Sims, Saltus, and Anderson (2005)

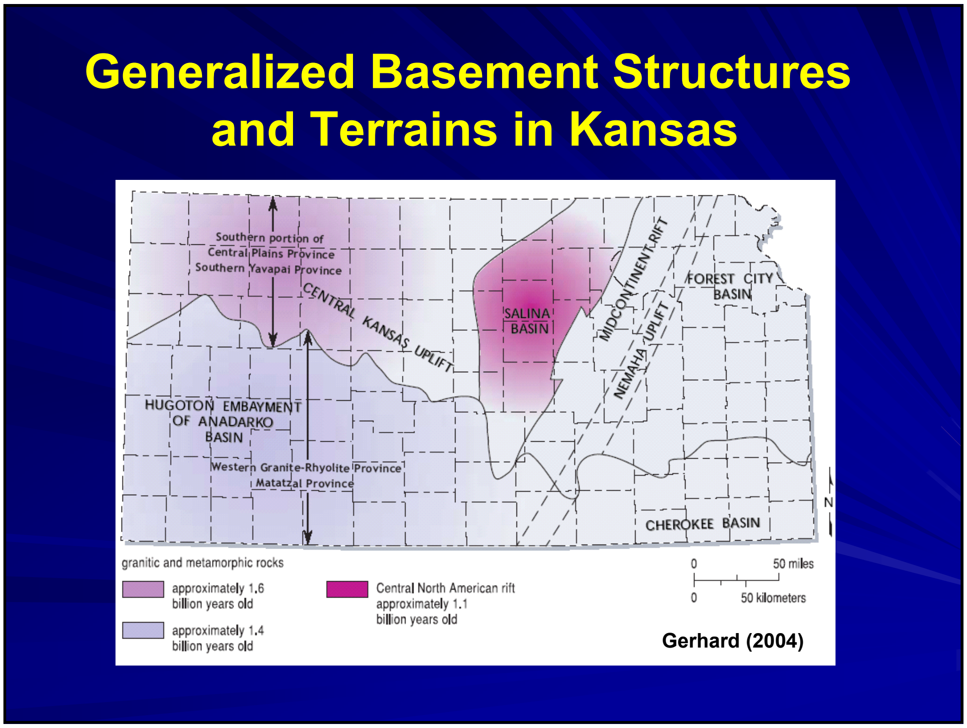
Aeromagnetic anomaly patterns

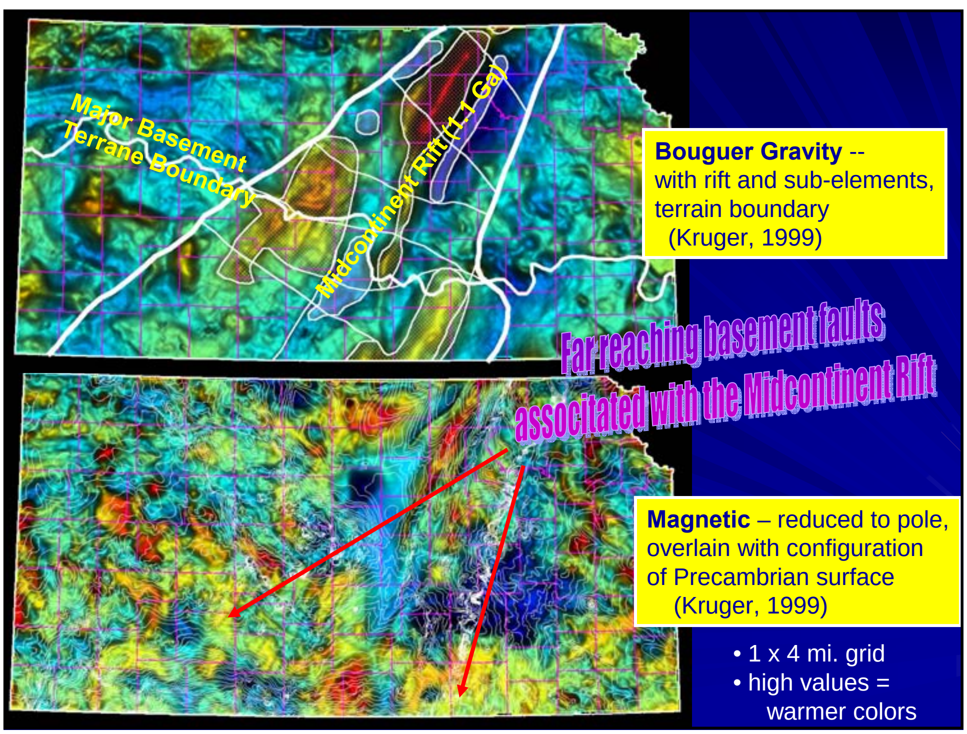
- Aeromagnetic anomaly patterns reflect the distribution of magnetic minerals (Reynolds and others, 1990).
- The relative concentration of these magnetic minerals is an indicator of geologically important factors:
  - original lithology, metamorphic grade, and degree of geochemical alteration.
- Generally speaking, igneous rocks are much more magnetic than sedimentary rocks:
  - mafic igneous rocks are more magnetic than felsic igneous rocks;
  - magnetism may be either created or destroyed during metamorphism of sedimentary rocks (Reynolds and others, 1990).
- Structural juxtaposition of rocks with contrasting magnetization can produce *particularly sharp anomaly boundaries*.

Sims, Saltus, Anderson (2005)

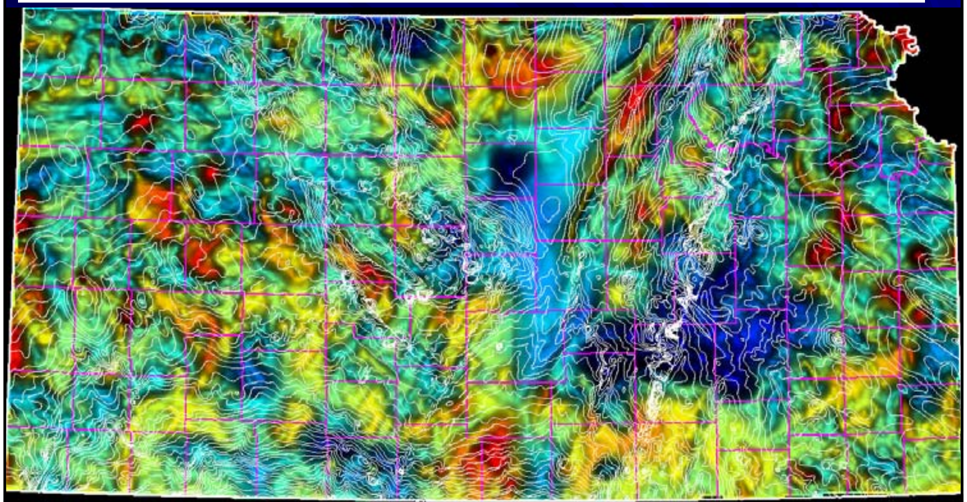
Aeromagnetic anomaly patterns

- Measured aeromagnetic anomalies are a complex integration of the effect of these crustal magnetic sources, most of which lie within the Precambrian basement.
- **Linear features fall into three broad categories**:
  - (1) boundaries of zones with common anomaly patterns, e.g. *Precambrian province boundaries, orogenic margins, or rift edges*
  - (2) continuous or discontinuous sets of steep anomaly gradients, e.g., *structures within a zone*
  - (3) narrow magnetic troughs, e.g., *magnetic shear zones where magnetite destroyed*
- Linear features are believed to correspond with faults or fractures in the Precambrian basement.


Generalized Basement Structures and Terrains in Kansas
Southern portion of Central Plains Province Southern Yavapai Province
CENTRAL KANSAS UPLIFT
SALINA BASIN
MIDCONTINENT RIFT
NEMAHA UPLIFT
FOREST CITY BASIN
HUGOTON EMBAYMENT OF ANADARKO BASIN
Western Granite-Rhyolite Province Matatzal Province
CHEROKEE BASIN
N
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)

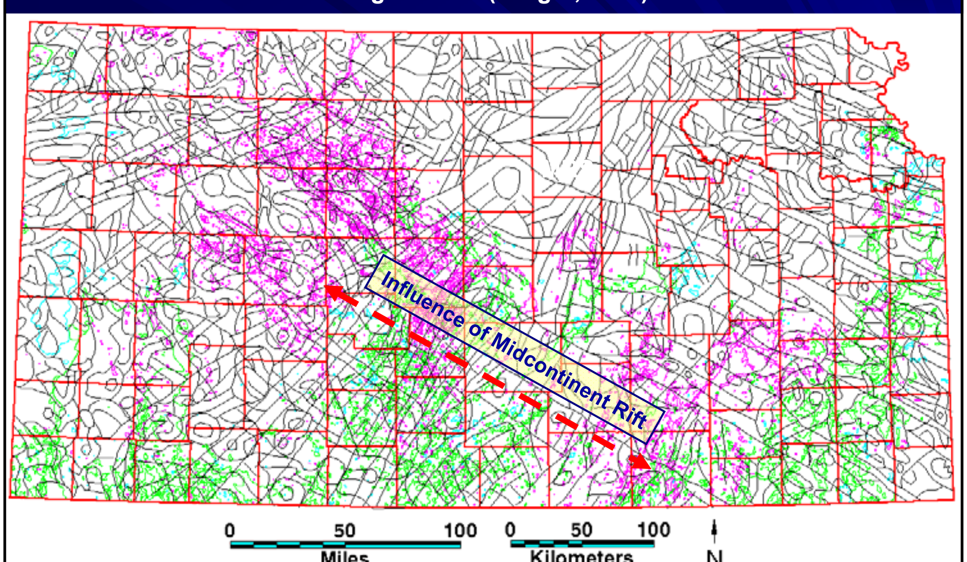

Major Basement Terrane Boundary
Midcontinent Rift (1.1 Ga)
Bouguer Gravity -- with rift and sub-elements, terrain boundary (Kruger, 1999)
Far reaching basement faults associated with the Midcontinent Rift
Magnetic – reduced to pole, overlain with configuration of Precambrian surface (Kruger, 1999)
• 1 x 4 mi. grid
• high values = warmer colors

Magnetic – reduced to pole, overlain with *configuration of Precambrian surface* (Cole, 1976; Kruger, 1999)

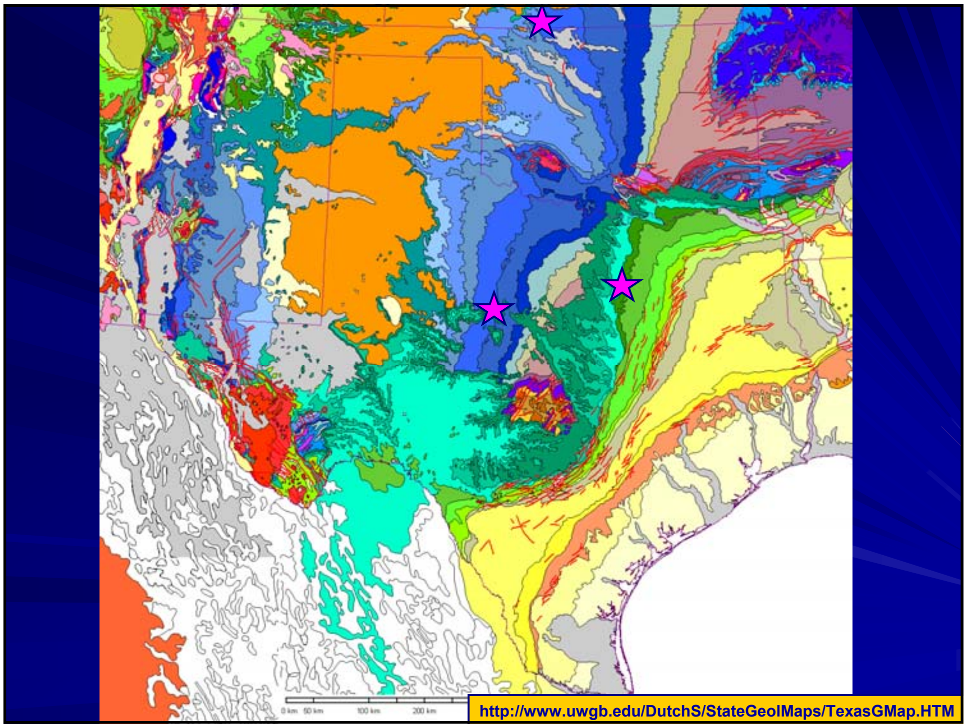


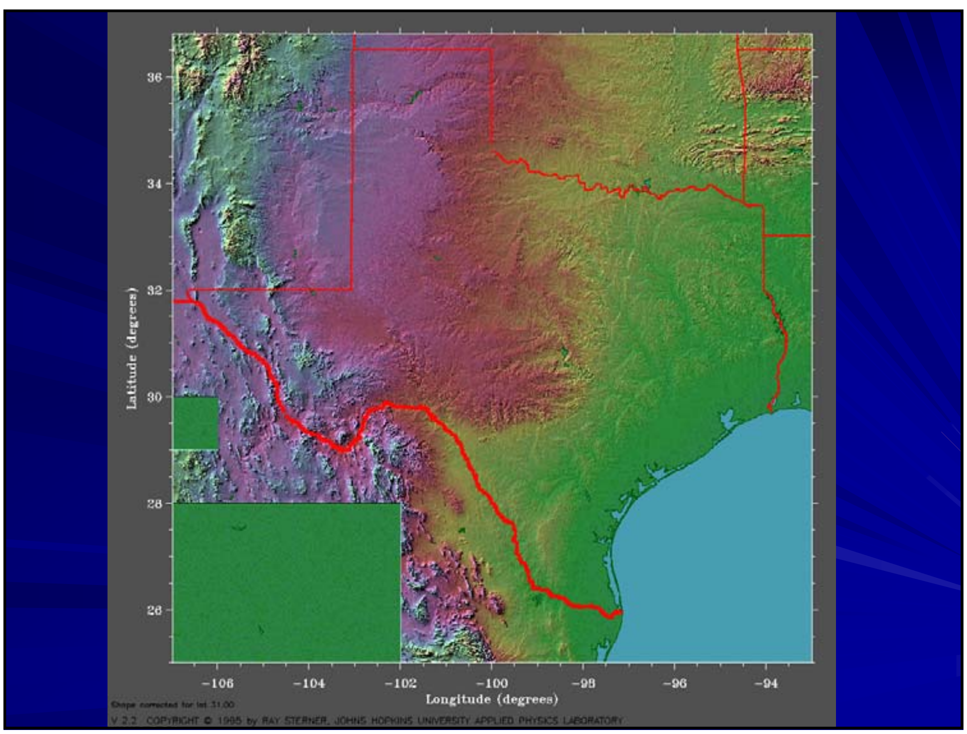
- Very close correspondence of Phanerozoic structures and magnetic anomalies
- Both named and subtle unnamed structures
- Also local and subregional changes in strike and dip appear to closely correlate to aeromagnetic map
- Major influence on lithofacies distribution and characteristics of sequences

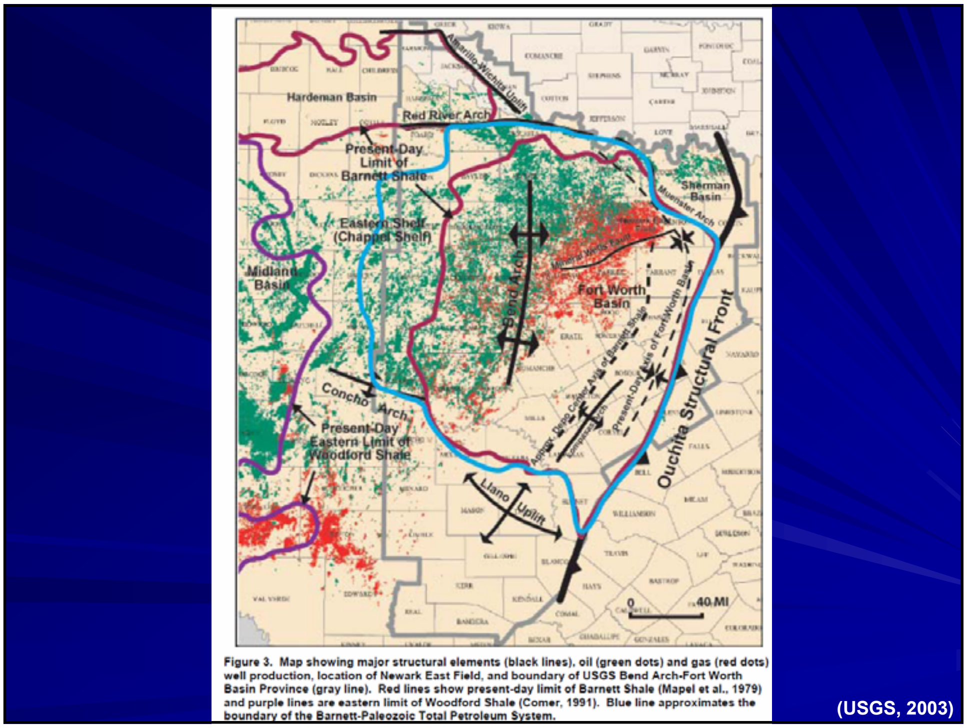
Local magnetic lineations from total magnetic field intensity overlain with oil and gas fields (Kruger, 1997)

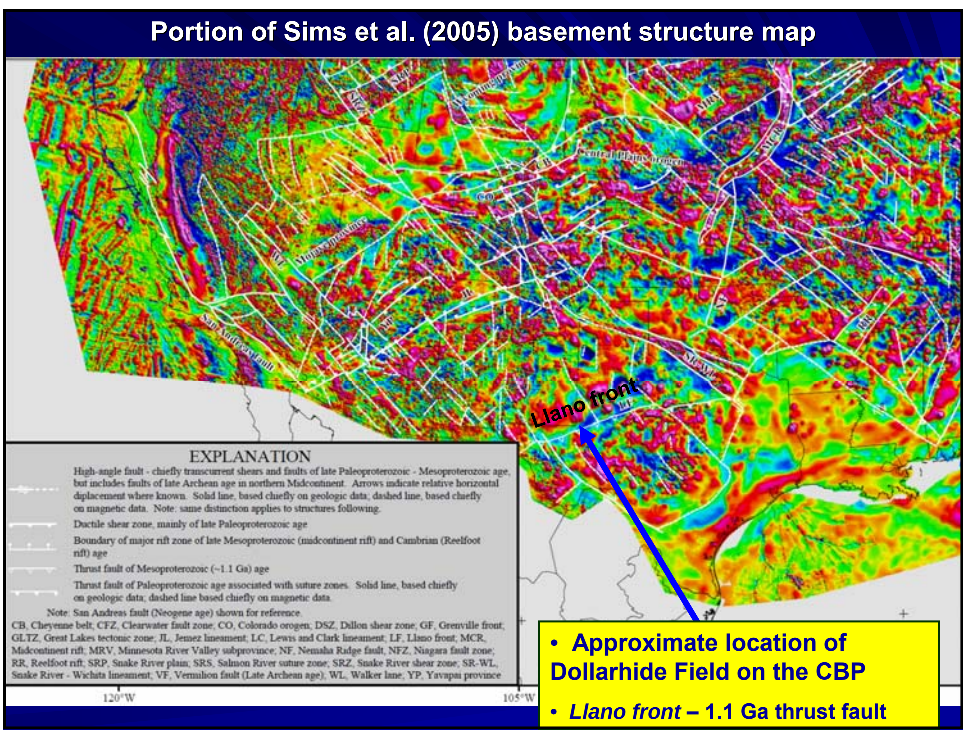


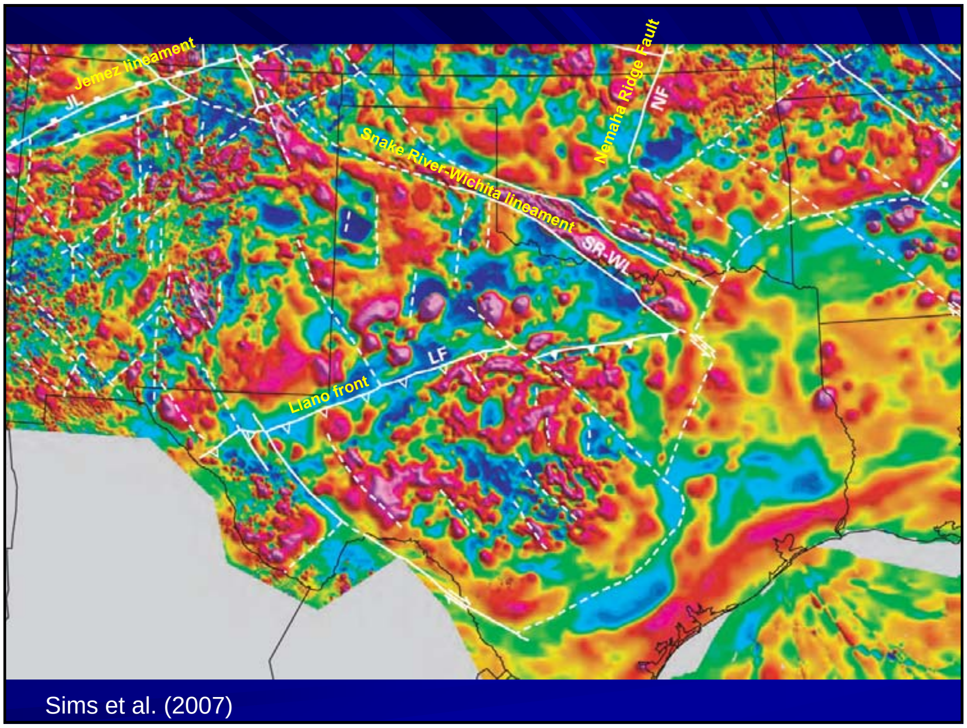
Mosaic of NW and NE trending lineaments

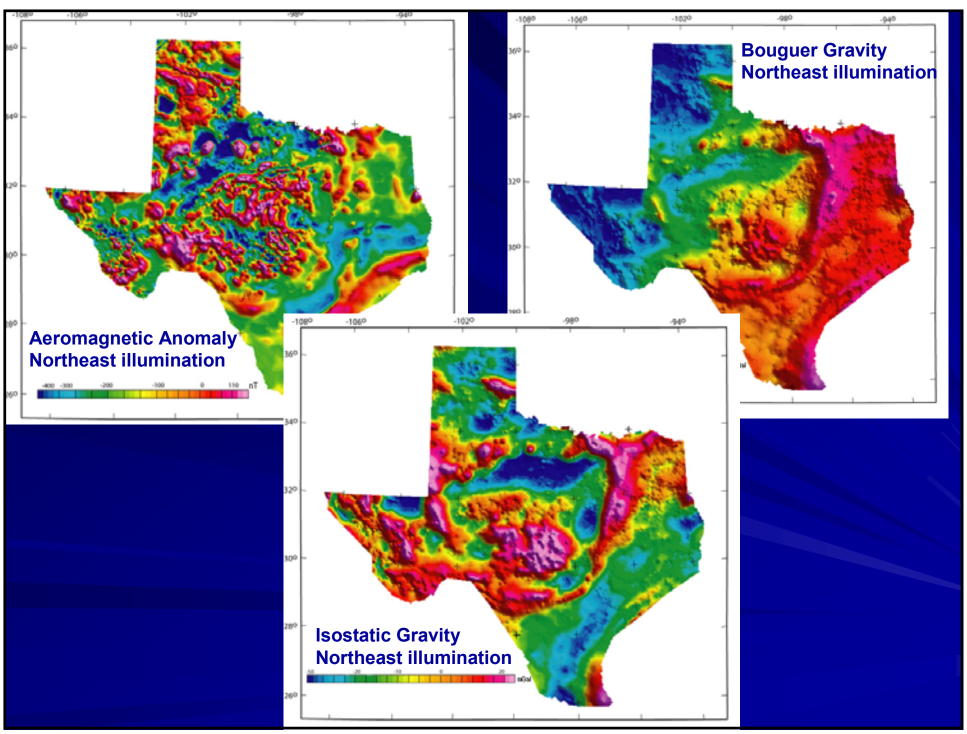

http://www.uwgb.edu/DutchS/StateGeolMaps/TexasGMap.HTM


Latitude (degrees)
36
34
32
30
28
26
−106
−104
−102
−100
−98
−96
−94
Longitude (degrees)
Shape corrected for lat 31.00
V 2.2 COPYRIGHT © 1995 by RAY STERNER, JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY


Hardeman Basin
Red River Arch
Present-Day
Limit of
Barnett Shale
Eastern Shelf
(Chappel Shelf)
Midland
Basin
Bend Arch
Fort Worth
Basin
Sherman
Basin
Ouachita Structural Front
Concho
Arch
Present-Day
Eastern Limit of
Woodford Shale
Llano
Uplift
0
40 MI
Figure 3. Map showing major structural elements (black lines), oil (green dots) and gas (red dots) well production, location of Newark East Field, and boundary of USGS Bend Arch-Fort Worth Basin Province (gray line). Red lines show present-day limit of Barnett Shale (Mapel et al., 1979) and purple lines are eastern limit of Woodford Shale (Comer, 1991). Blue line approximates the boundary of the Barnett-Paleozoic Total Petroleum System.
(USGS, 2003)


Portion of Sims et al. (2005) basement structure map
Llano front
EXPLANATION
• Approximate location of Dollarhide Field on the CBP
• Llano front – 1.1 Ga thrust fault


Jemez lineament
JL
Nemaha Ridge Fault
NF
Snake River-Wichita lineament
SR-WL
LF
Llano front
Sims et al. (2007)

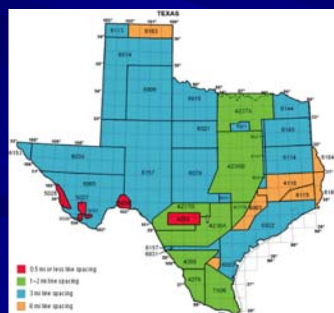

Aeromagnetic Anomaly
Northeast illumination
Bouguer Gravity
Northeast illumination
Isostatic Gravity
Northeast illumination

Texas Magnetic and Gravity Maps and Data: A Website for Distribution of Data

By Viki Bankey

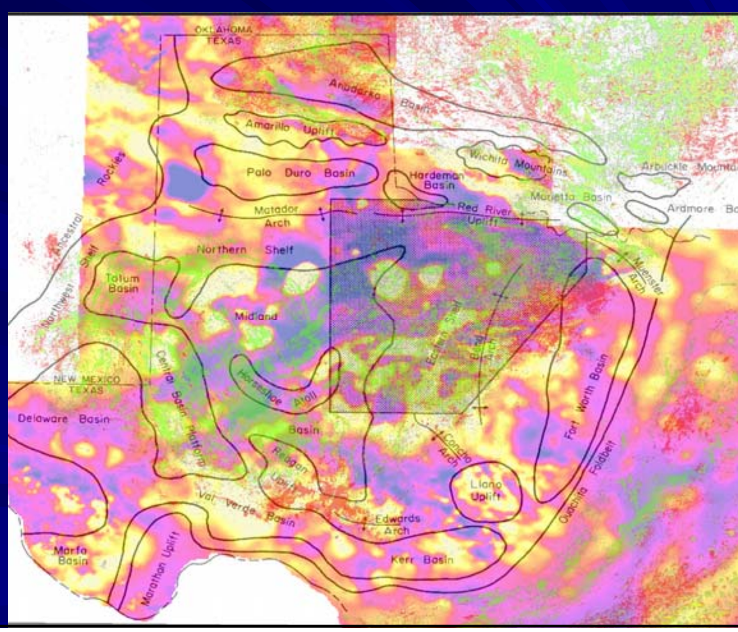
Texas Merged Aeromagnetic Anomaly Map
Continued to 1,000 ft above ground
Northeast illumination

http://pubs.usgs.gov/ds/2006/232/

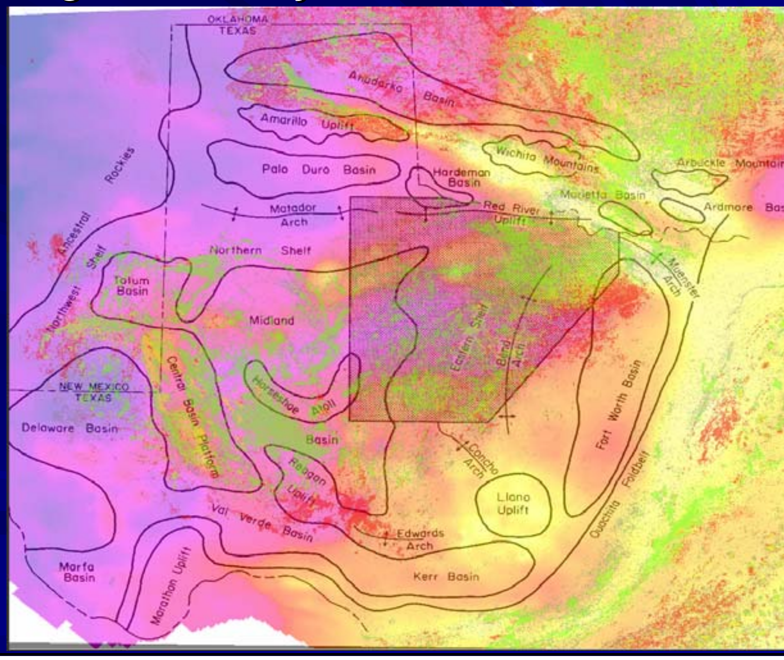


- **Merging of 37 separate surveys**
- **Data files available for reprocessing**
- **Flight lines ranged from 4.8 to 9.6 km (3 to 6 mi.)**

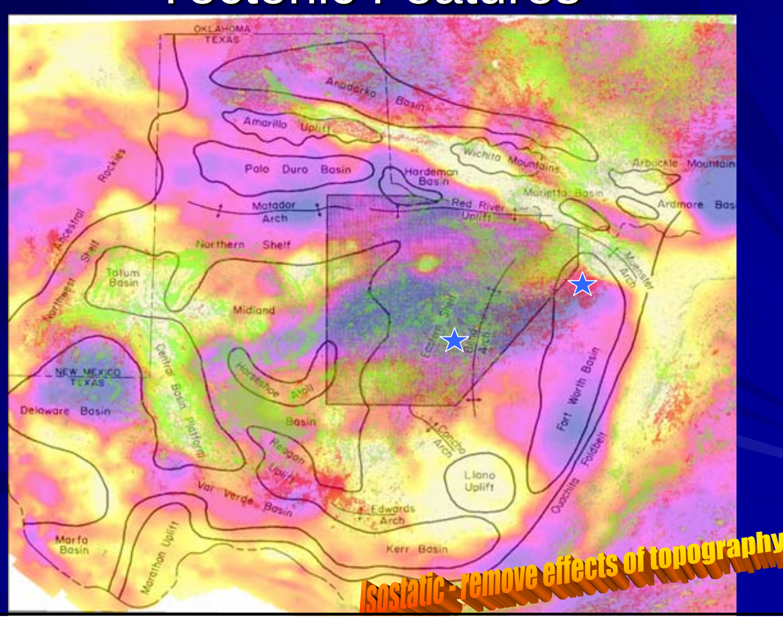
Magnetic Anomaly and Tectonic Features With Oil and Gas Wells

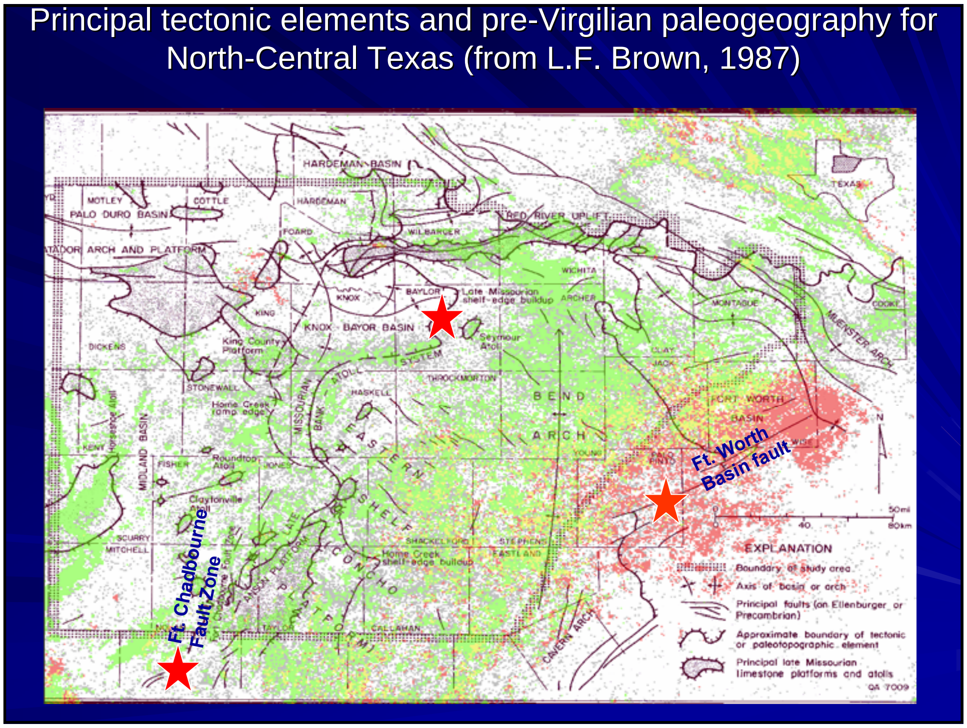


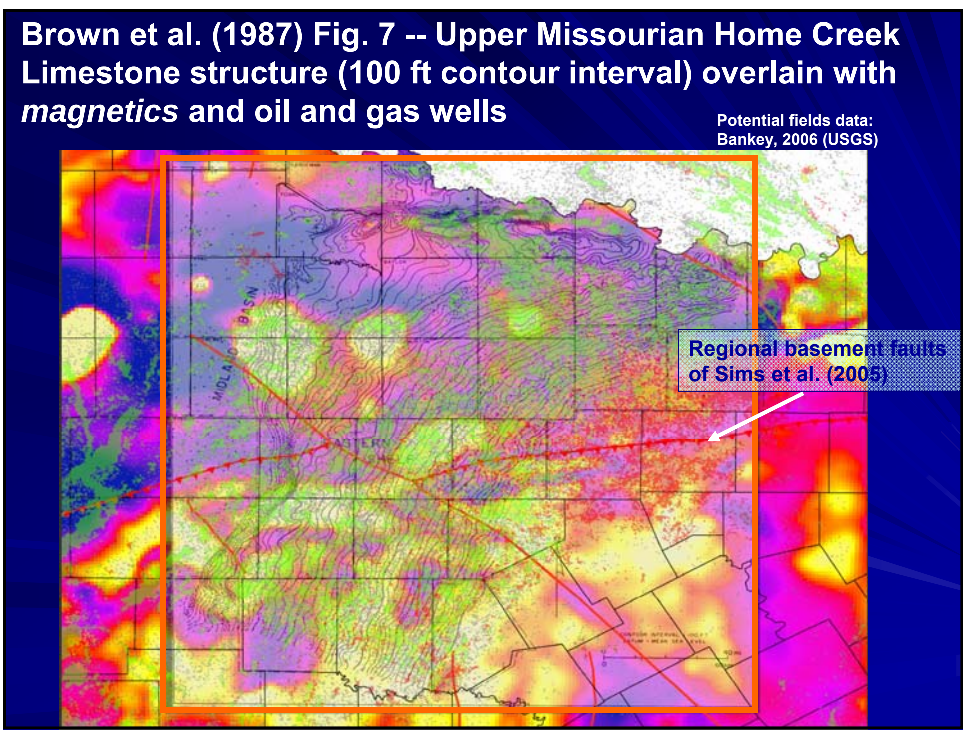
Bouguer Gravity and Tectonic Features

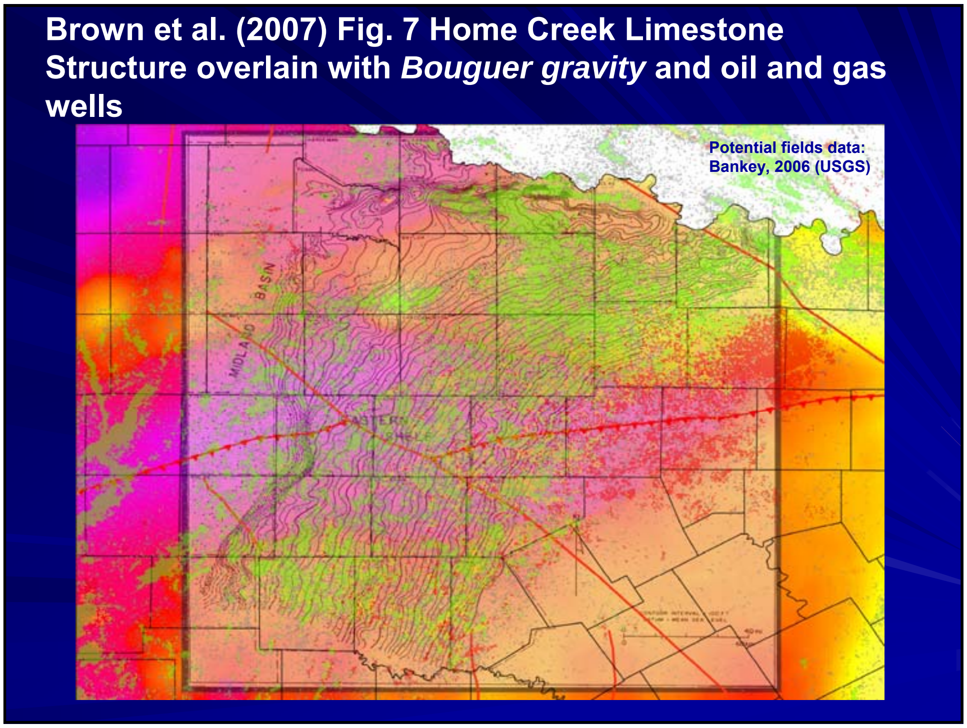


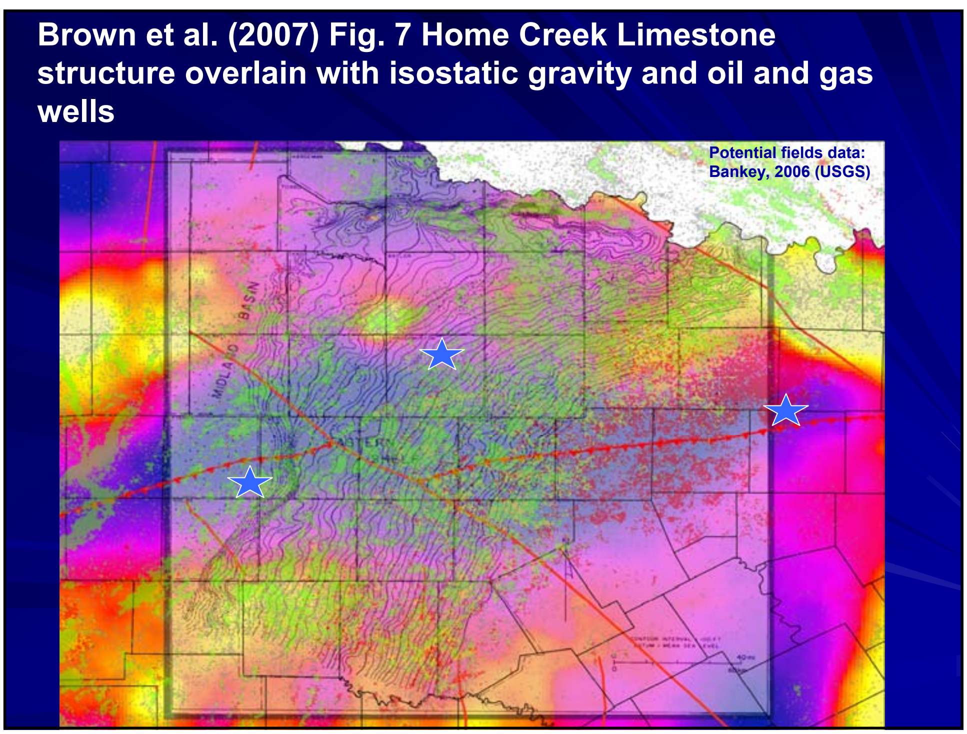
Isostatic Gravity and Tectonic Features



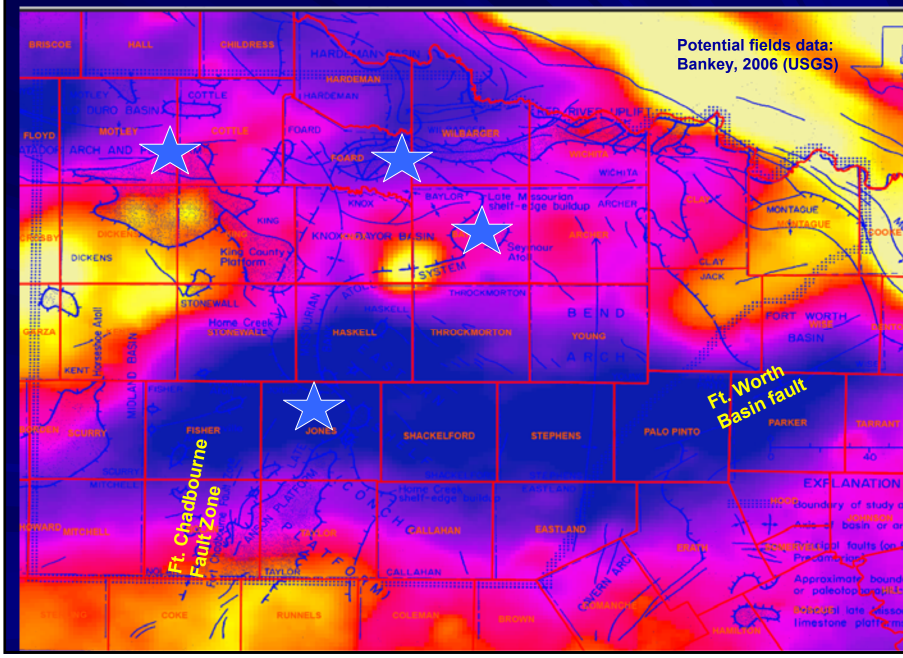

Principal tectonic elements and pre-Virgilian paleogeography for North-Central Texas (from L.F. Brown, 1987)
HARDEMAN BASIN
PALO DURO BASIN
RED RIVER UPLIFT
KNOX - BAYLOR BASIN
BEND
ARCH
FORT WORTH BASIN
MUENSTER ARCH
MIDLAND BASIN
Ft. Worth Basin fault
Ft. Chadbourne Fault Zone
EXPLANATION
Boundary of study area
Axis of basin or arch
Principal faults (on Ellenburger or Precambrian)
Approximate boundary of tectonic or paleotopographic element
Principal late Missourian limestone platforms and atolls


Brown et al. (1987) Fig. 7 -- Upper Missourian Home Creek Limestone structure (100 ft contour interval) overlain with *magnetics* and oil and gas wells
Potential fields data: Bankey, 2006 (USGS)
Regional basement faults of Sims et al. (2005)


Brown et al. (2007) Fig. 7 Home Creek Limestone Structure overlain with *Bouguer gravity* and oil and gas wells
Potential fields data: Bankey, 2006 (USGS)
MIDLAND BASIN


Brown et al. (2007) Fig. 7 Home Creek Limestone structure overlain with isostatic gravity and oil and gas wells
Potential fields data: Bankey, 2006 (USGS)
MIDLAND BASIN

Isostatic Gravity overlain on principal tectonic elements and pre-Virgilian paleogeography for North-Central Texas (from Brown, 1987)



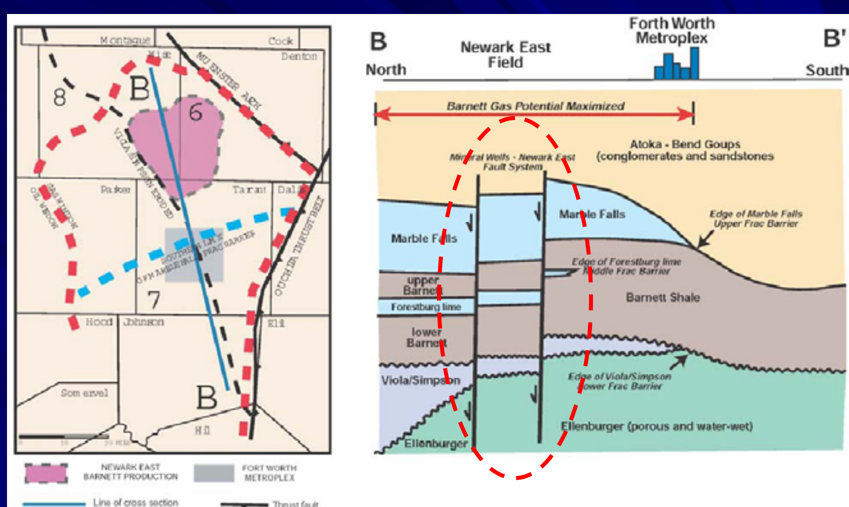
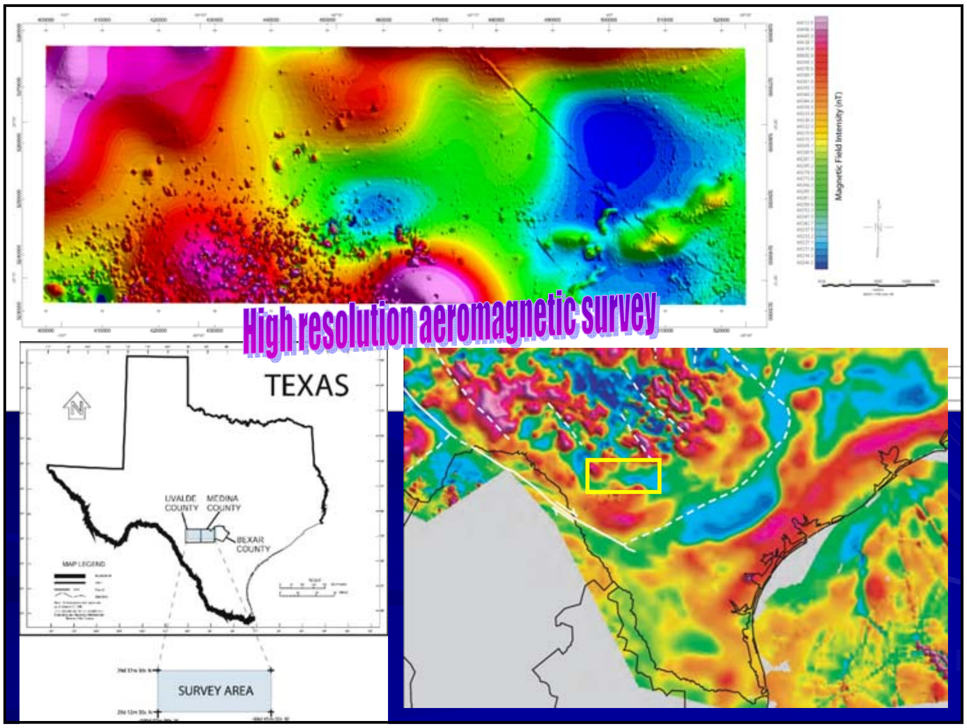
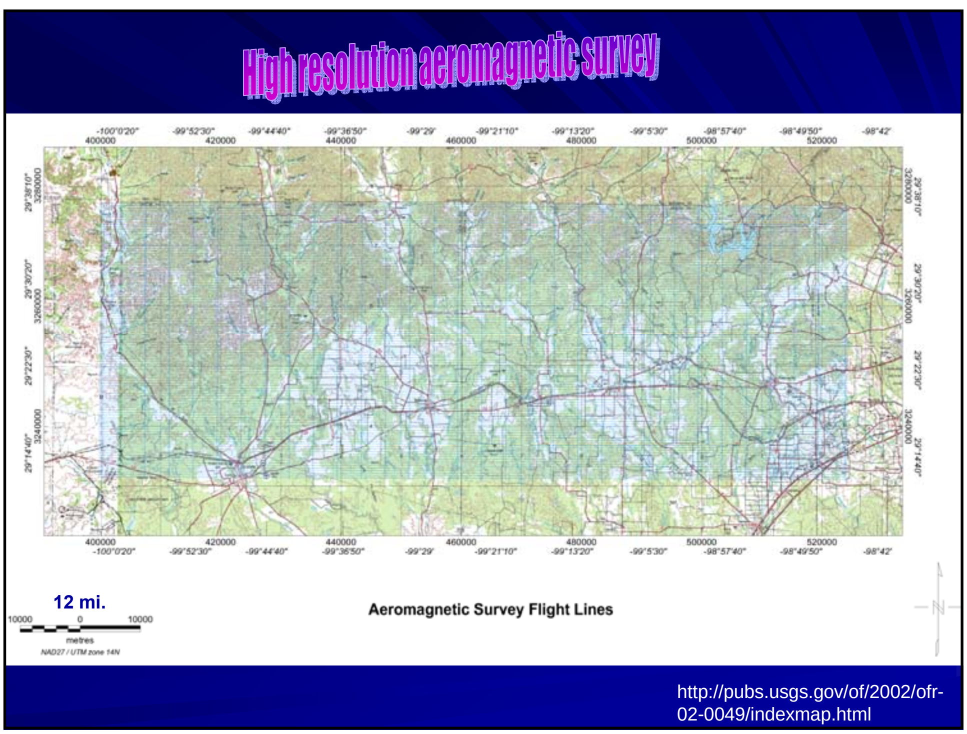


Figure 6. (A) Location map and (B) generalized cross section AA' of north Fort Worth Basin area showing main gas- producing area of continuous Barnett Shale accumulation at Newark East field and the various geologic conditions. Large bold numbers in (A) relate to the proposed continuous Barnett Shale assessment units of Table 1. Gas window in (A) approximates zone of gas generation, and oil window approximates zone of oil generation. Modified from Hall (2002) and Bowker (2002).

Pollastro et al. (2003)

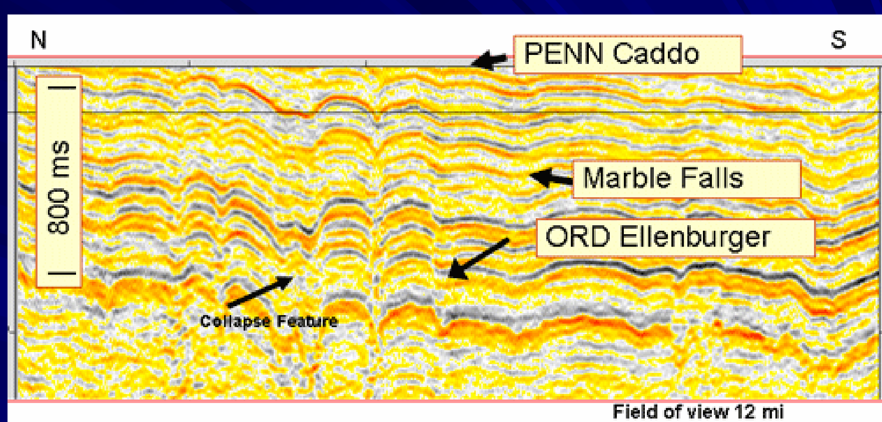

High resolution aeromagnetic survey
TEXAS
UVALDE COUNTY
MEDINA COUNTY
BEXAR COUNTY
SURVEY AREA


High resolution aeromagnetic survey
Aeromagnetic Survey Flight Lines
12 mi.
metres
NAD27 / UTM zone 14N
http://pubs.usgs.gov/of/2002/ofr-02-0049/indexmap.html

Karst, Collapse and Polygonal Features in Fort Worth Basin

- The Paleozoic section in parts of the Fort Worth Basin exhibits collapse features that persist vertically some 2300' (700m or 800ms).
- These features have characteristics of both subaerial weathering processes, and structural deformation.
- Circular sinkhole-like features form cockpit geomorphology on the surface of the Ordovician Ellenburger horizon and occur at the intersection lineaments defined by seismic curvature attribute.
- Many of these lineaments are basement related.
- Many of the collapse features occur along Pennsylvanian age fractures and small faults.
- In addition, dolomite and native copper cements in filled fractures indicate flow of hot burial fluids.

www.kgs.ku.edu/SEISKARST



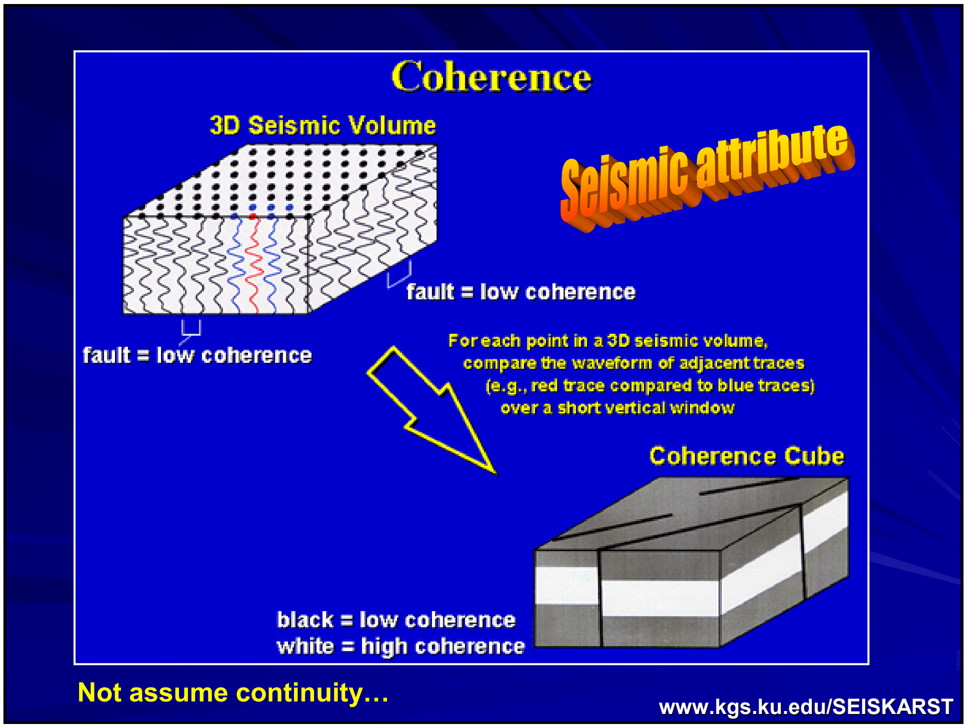
The Paleozoic section in parts of the Fort Worth Basin exhibits collapse features that persist vertically some 2300' (700m or 800ms).

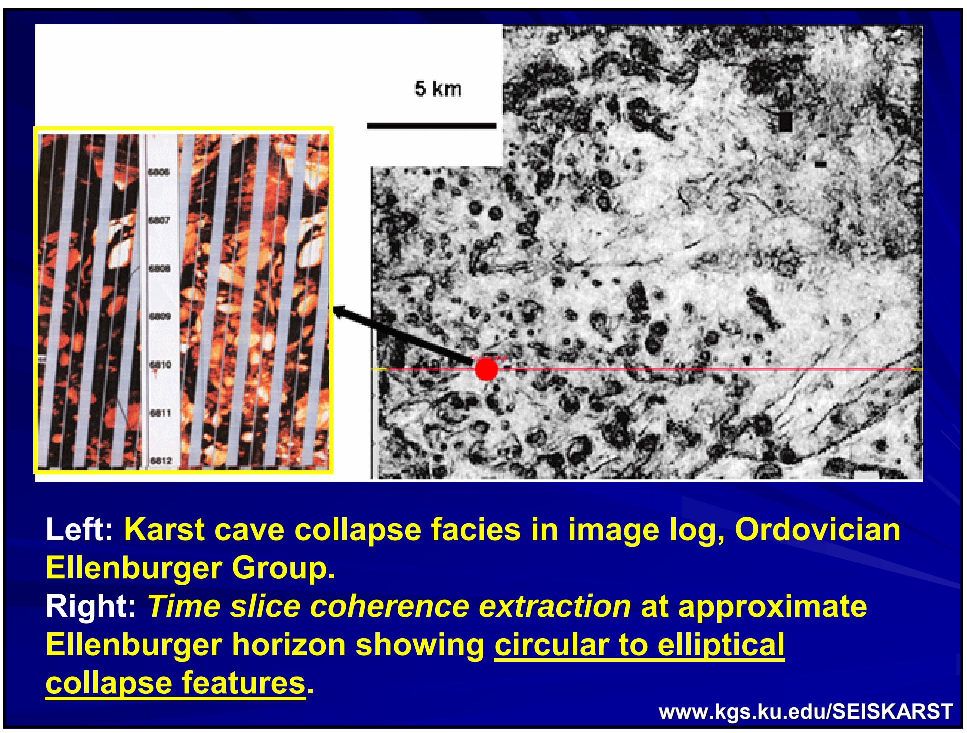
www.kgs.ku.edu/SEISKARST

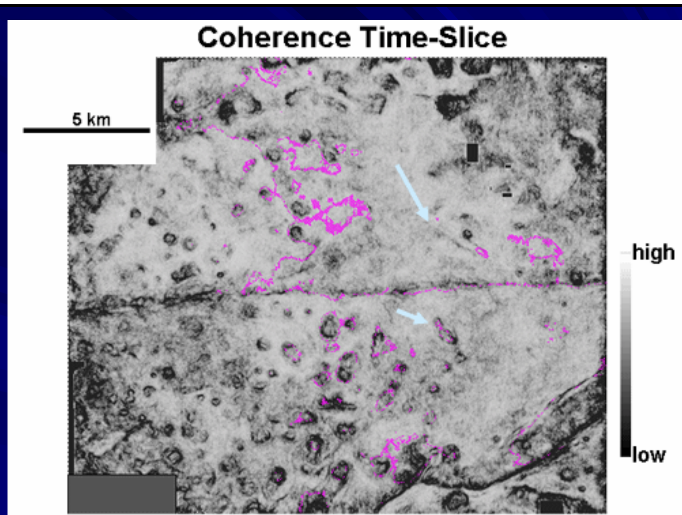
Improving Geologic and Engineering Models of Midcontinent Fracture and Karst-Modified Reservoirs Using New 3-D Seismic Attributes

Home | Project Info | Personnel
Attributes | Tech Transfer | Catalog

Kansas Geological Survey | Allied Geophysical Labs-University of Houston


Coherence
3D Seismic Volume
Seismic attribute
fault = low coherence
fault = low coherence
For each point in a 3D seismic volume, compare the waveform of adjacent traces (e.g., red trace compared to blue traces) over a short vertical window
Coherence Cube
black = low coherence
white = high coherence
Not assume continuity…
www.kgs.ku.edu/SEISKARST


5 km
Left: Karst cave collapse facies in image log, Ordovician Ellenburger Group.
Right: Time slice coherence extraction at approximate Ellenburger horizon showing circular to elliptical collapse features.
www.kgs.ku.edu/SEISKARST

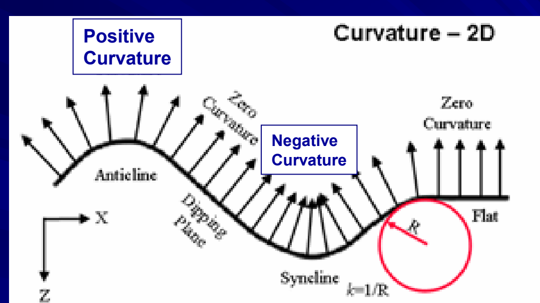


Coherence time-slice near top Marble Falls

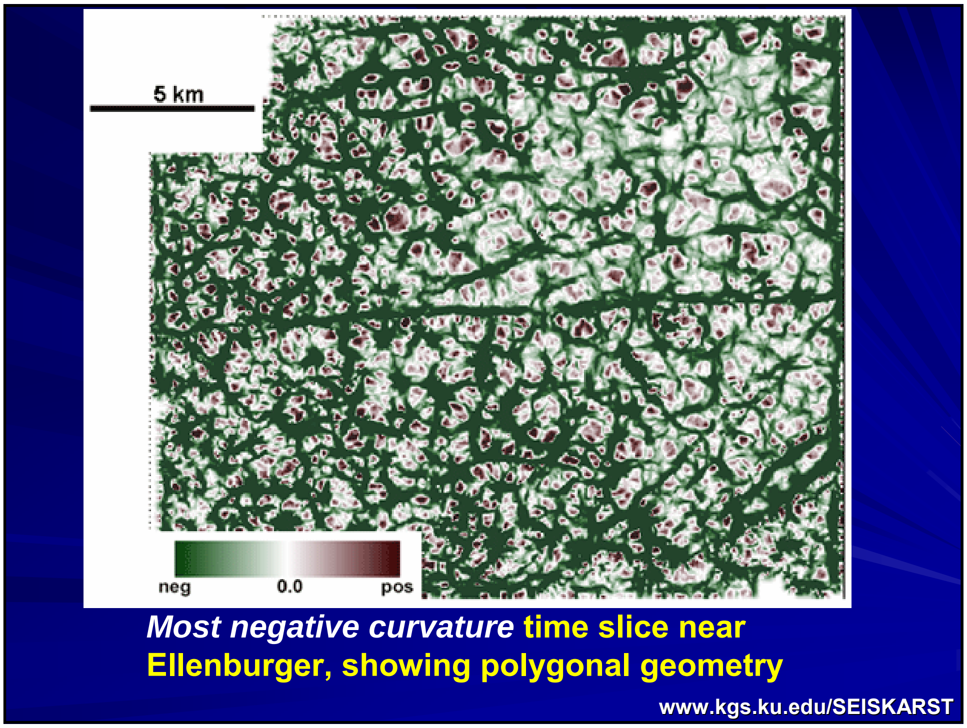
- **Collapse features are present, but no known record of subaerial karst formation.**

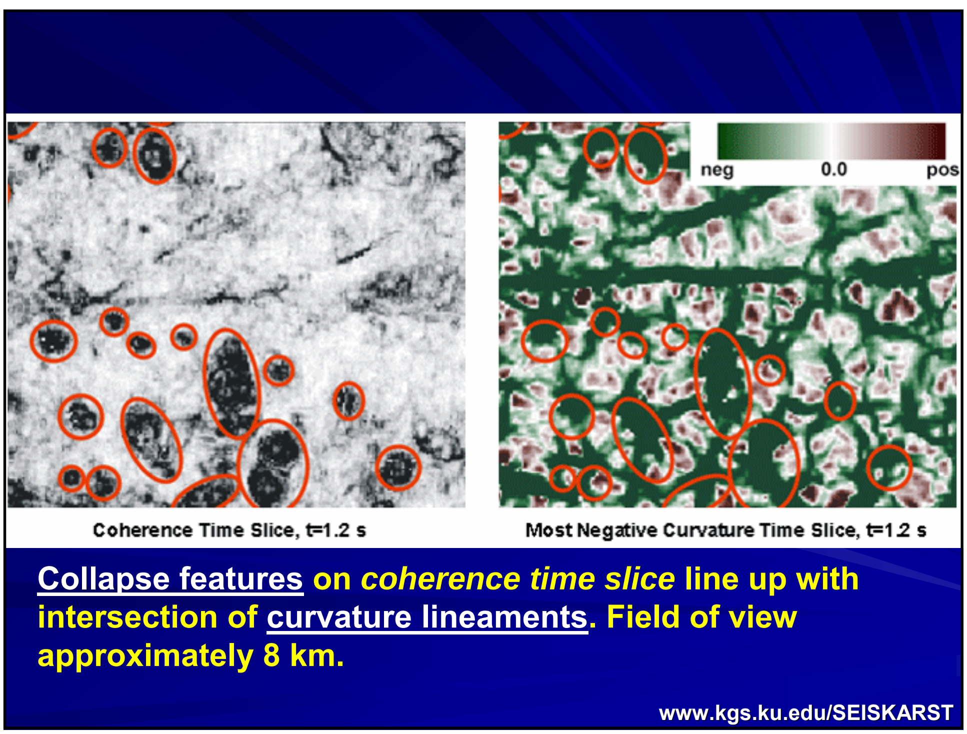
www.kgs.ku.edu/SEISKARST

Curvature attribute

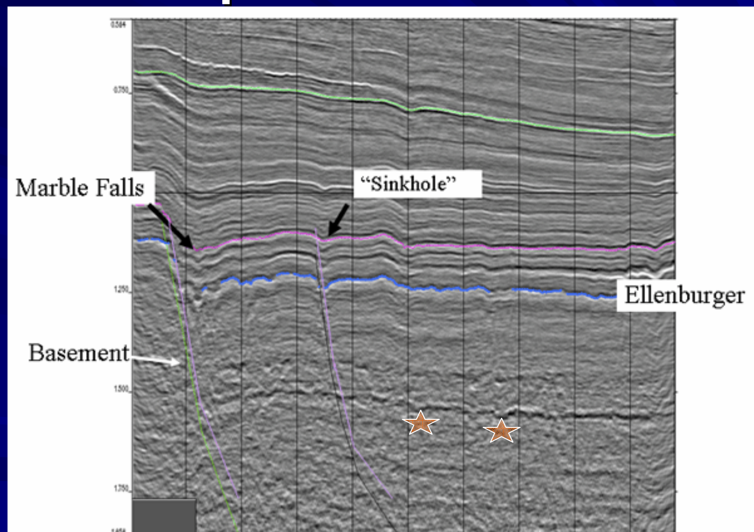


after Roberts 2001


5 km
neg
0.0
pos
Most negative curvature time slice near
Ellenburger, showing polygonal geometry
www.kgs.ku.edu/SEISKARST

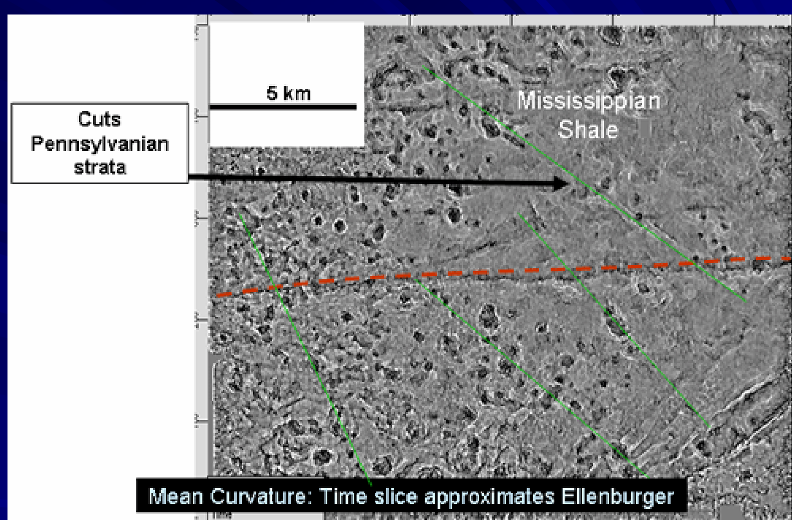

neg
0.0
pos
Coherence Time Slice, t=1.2 s
Most Negative Curvature Time Slice, t=1.2 s
Collapse features on coherence time slice line up with
intersection of curvature lineaments. Field of view
approximately 8 km.
www.kgs.ku.edu/SEISKARST

Collapse features coincide with deep basement faults



from Lacazette et al.2004

www.kgs.ku.edu/SEISKARST



- Ellenburger collapse features (black features) along Pennsylvanian lineaments (green and red lines).
- Substantive evidence for reactivation

www.kgs.ku.edu/SEISKARST

Forecasting rock properties -- Characterizing fragmentation 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**
- **Spatial-temporal integration with other processes – sea level, climate, diagenetic events**

EVALUATING STRUCTURAL CONTROLS ON THE FORMATION AND PROPERTIES OF CARBONIFEROUS CARBONATE RESERVOIRS IN THE NORTHERN MIDCONTINENT, U.S.A.

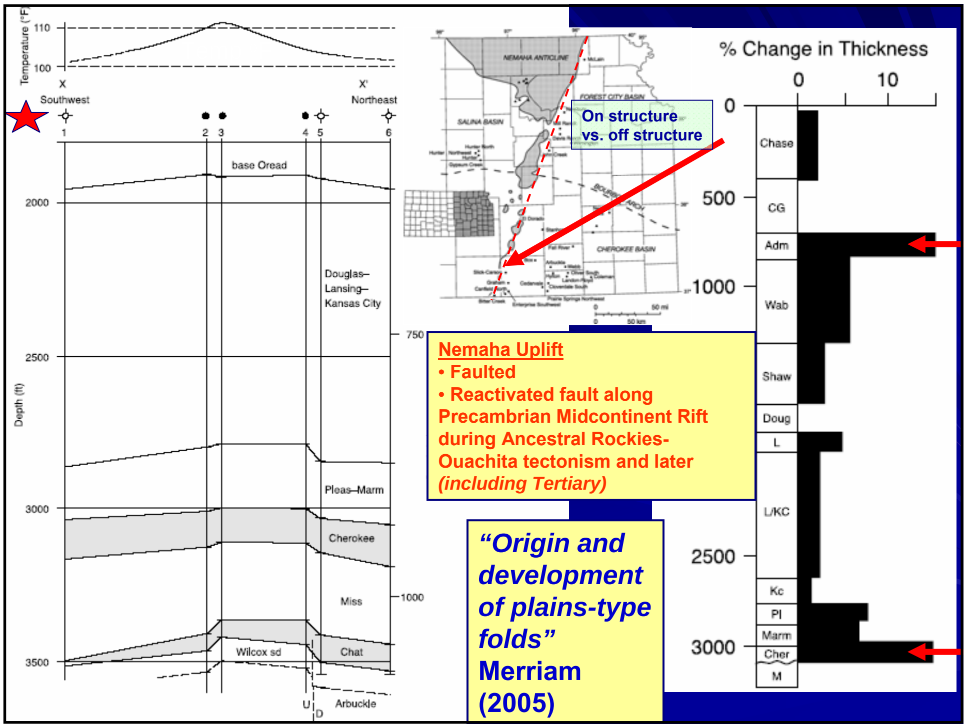
W. LYNN WATNEY, EVAN K. FRANSEEN, AND ALAN P. BYRNES*
Kansas Geological Survey, The University of Kansas, 1930 Constant Avenue - Campus West, Lawrence, Kansas 66047, U.S.A.

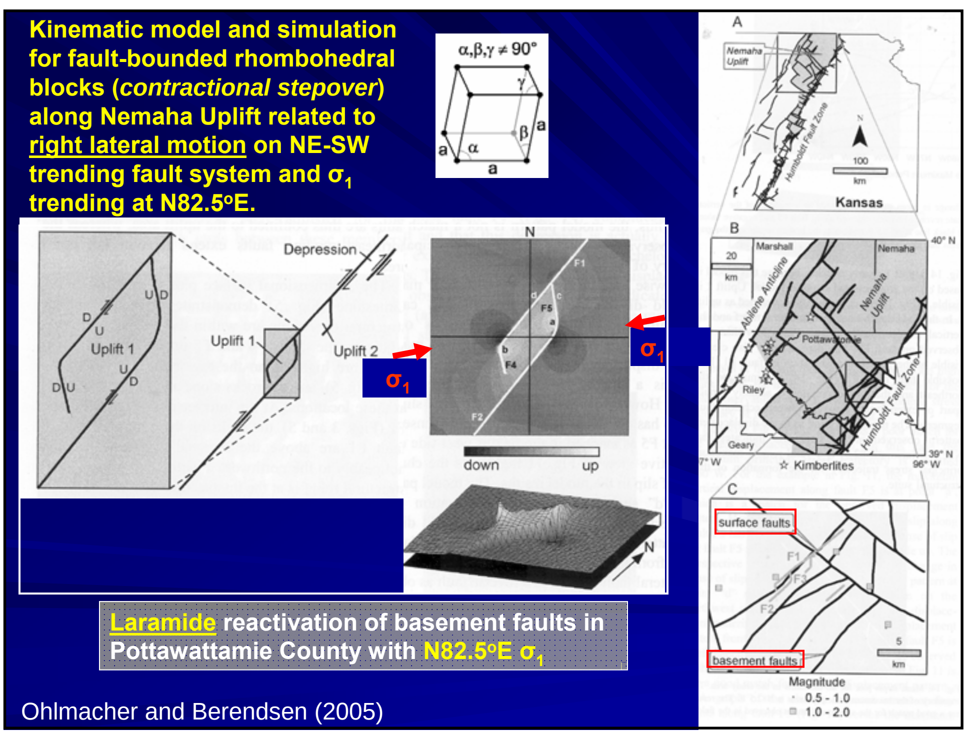
AND
SUSAN E. NISSEN
Kansas Geological Survey, The University of Kansas, 1930 Constant Avenue - Campus West, Lawrence, Kansas 66047, U.S.A.
Current Address 5761 Wellman Road, Mc Louth, Kansas 66054, U.S.A.
**Chesapeake Energy, Oklahoma City, OK*

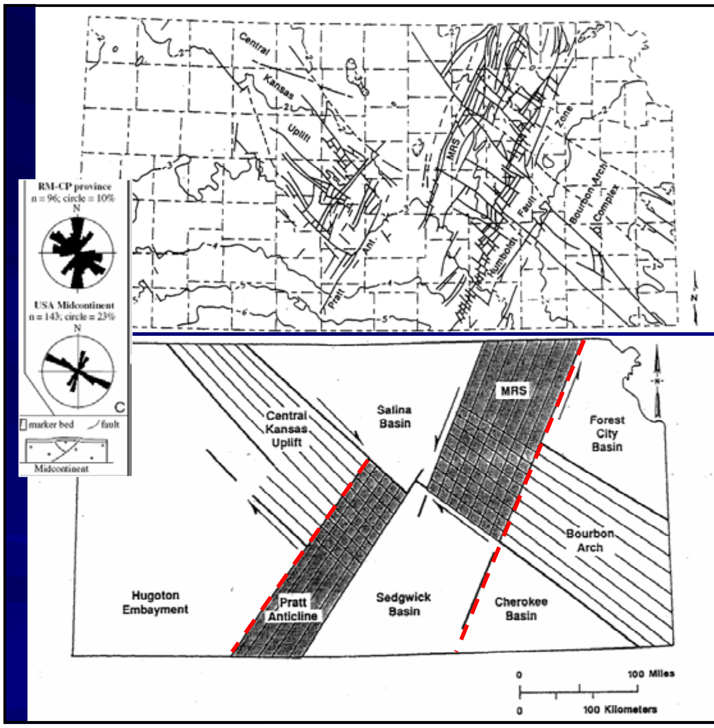
SEPM Special Publication 89
(2008)
Controls on Carbonate Platform and Reef Development

SEPM Society for Sedimentary Geology

Jeff Lukasik &
J.A. (Toni) Simo, eds.


% Change in Thickness
On structure vs. off structure
Nemaha Uplift
• Faulted
• Reactivated fault along Precambrian Midcontinent Rift during Ancestral Rockies-Ouachita tectonism and later (including Tertiary)
"Origin and development of plains-type folds"
Merriam (2005)
Temperature (°F)
Southwest
Northeast
base Oread
Douglas–Lansing–Kansas City
Pleas–Marm
Cherokee
Miss
Wilcox sd
Chat
Arbuckle
Depth (ft)
Chase
CG
Adm
Wab
Shaw
Doug
L
L/KC
Kc
Pl
Marm
Cher
M


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.
α,β,γ ≠ 90°
Depression
Uplift 1
Uplift 2
σ_1
down
up
Laramide reactivation of basement faults in Pottawattamie County with N82.5°E σ_1
Ohlmacher and Berendsen (2005)
Nemaha Uplift
Humboldt Fault Zone
Kansas
Abilene Anticline
Nemaha Uplift
Marshall
Nemaha
Pottawatomie
Riley
Geary
Kimberlites
surface faults
basement faults
Magnitude
0.5 - 1.0
1.0 - 2.0

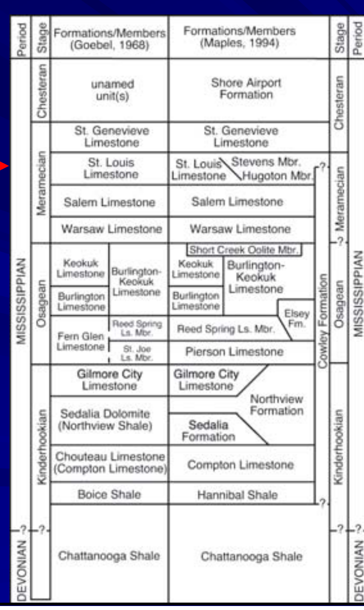


Configuration of the Precambrian Surface (*well based*)

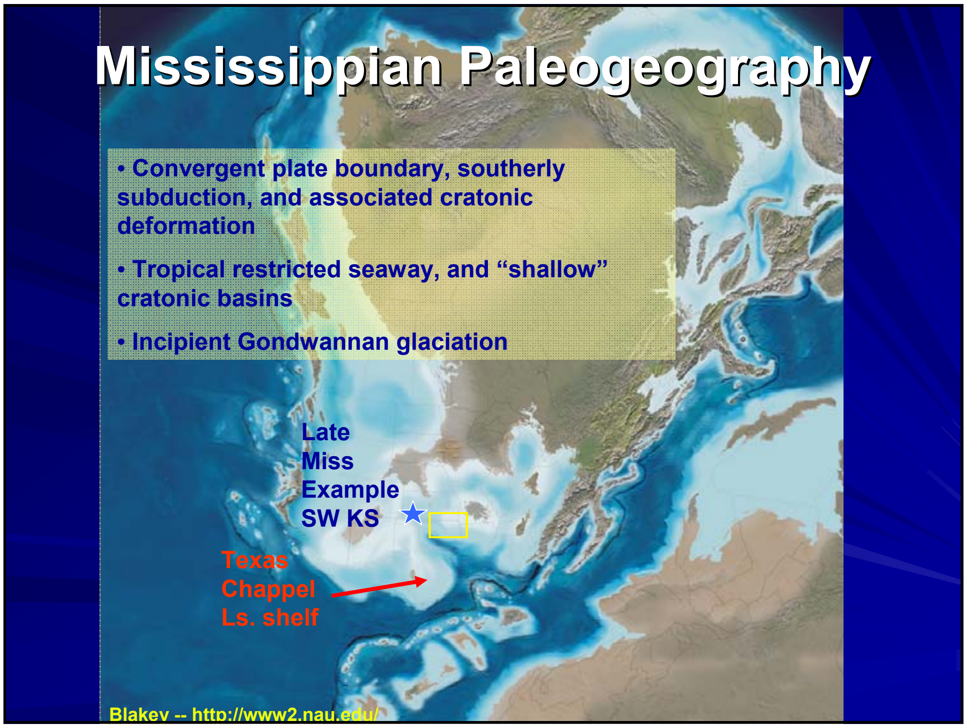
Precambrian structural domains and strain behavior – wrench faulting?

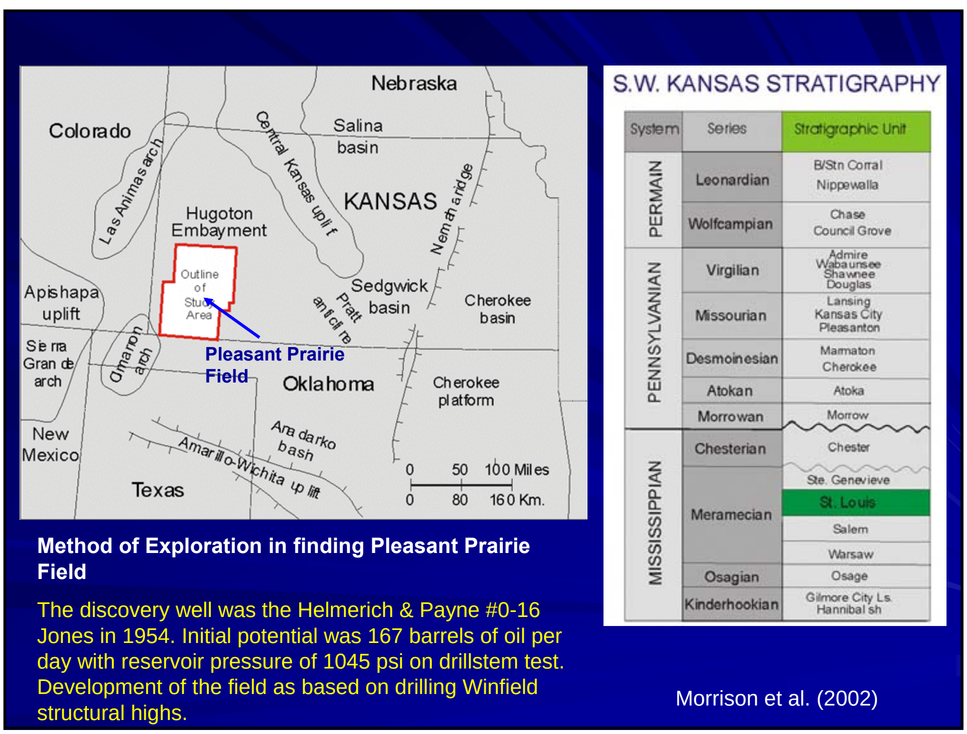
Baars and Watney (1991)

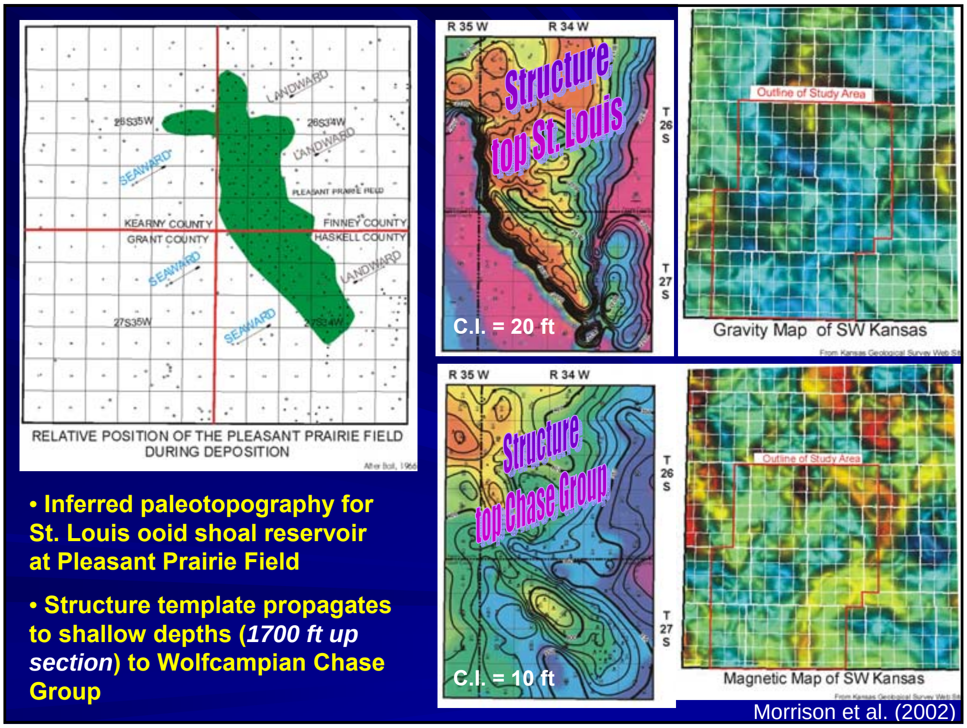
Example of concurrent structural deformation during Late Mississippian in Kansas

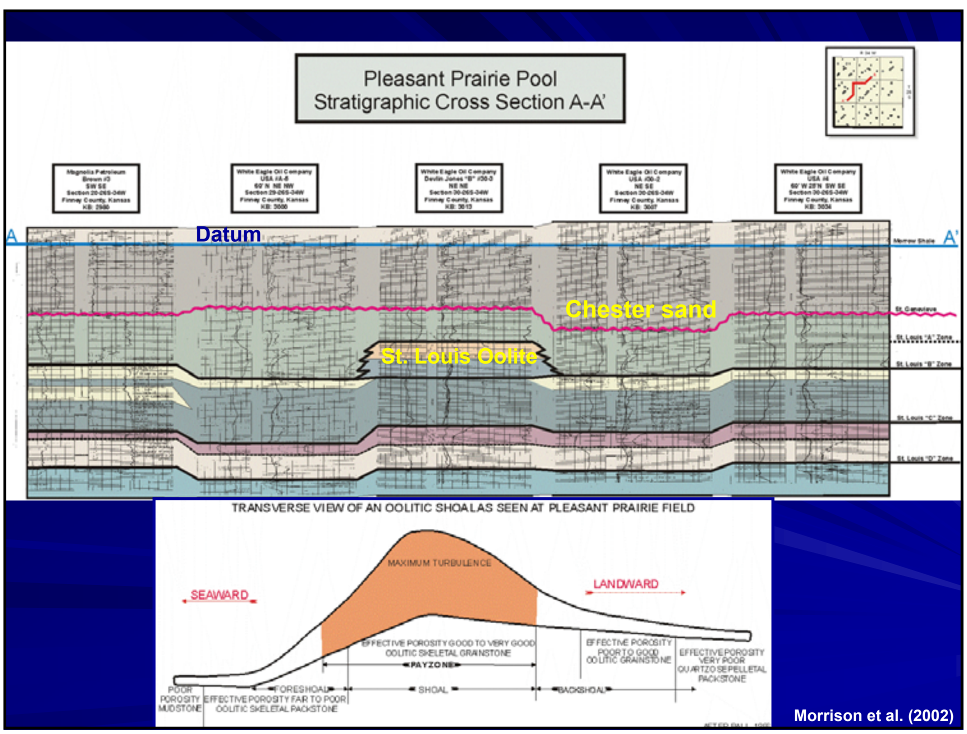


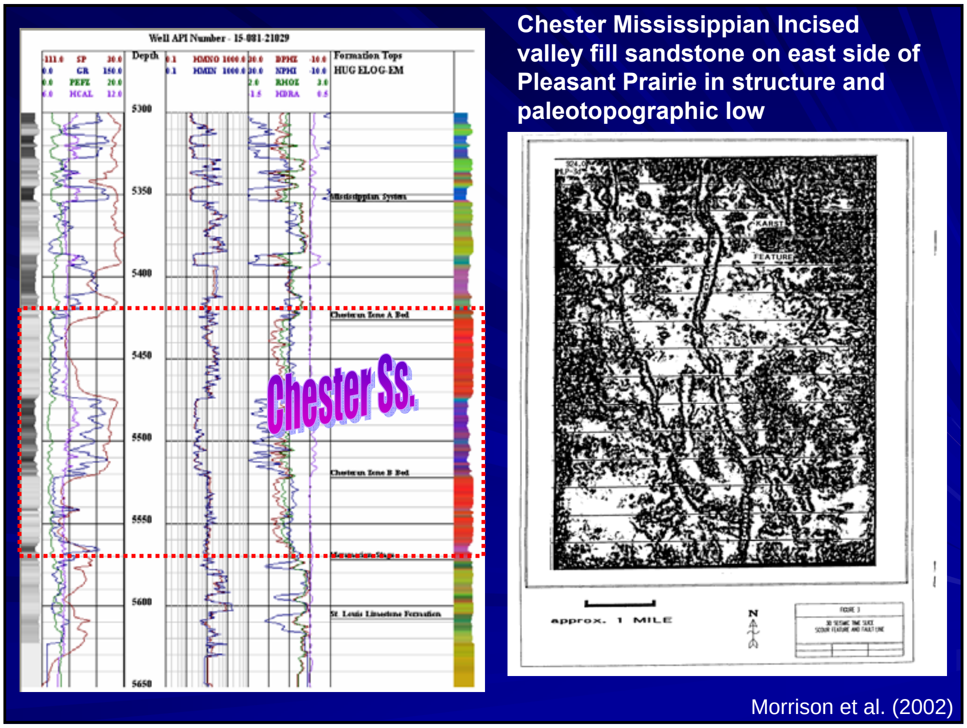
Kansas Stratigraphic Column for Mississippian

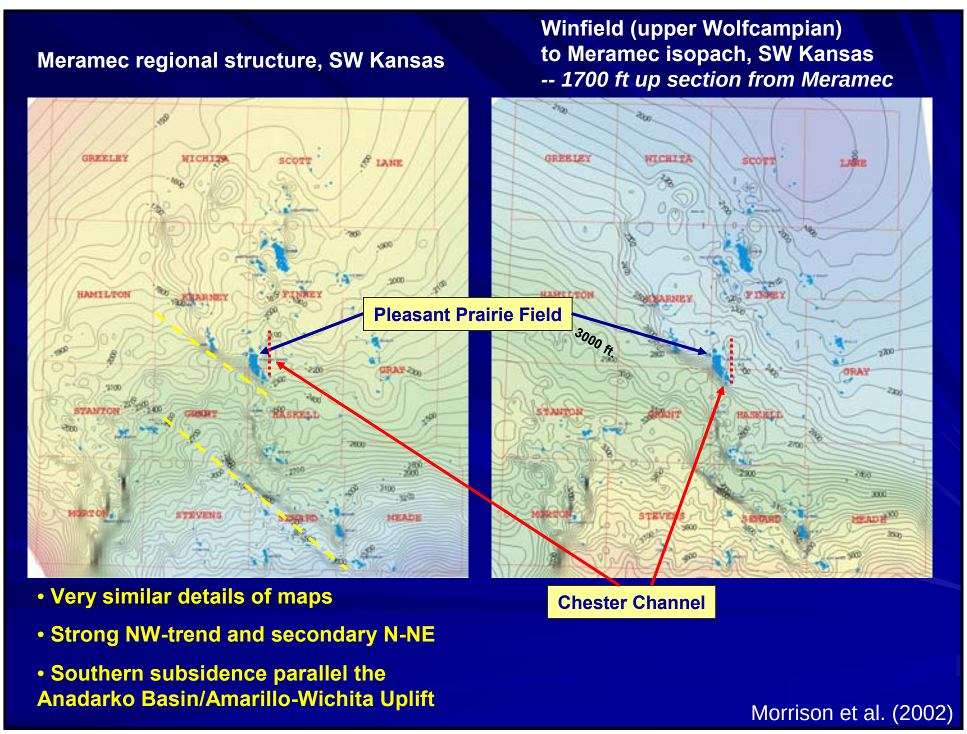

Mississippian Paleogeography
• Convergent plate boundary, southerly subduction, and associated cratonic deformation
• Tropical restricted seaway, and "shallow" cratonic basins
• Incipient Gondwannan glaciation
Late
Miss
Example
SW KS
Texas
Chappel
Ls. shelf
Blakey -- http://www2.nau.edu/

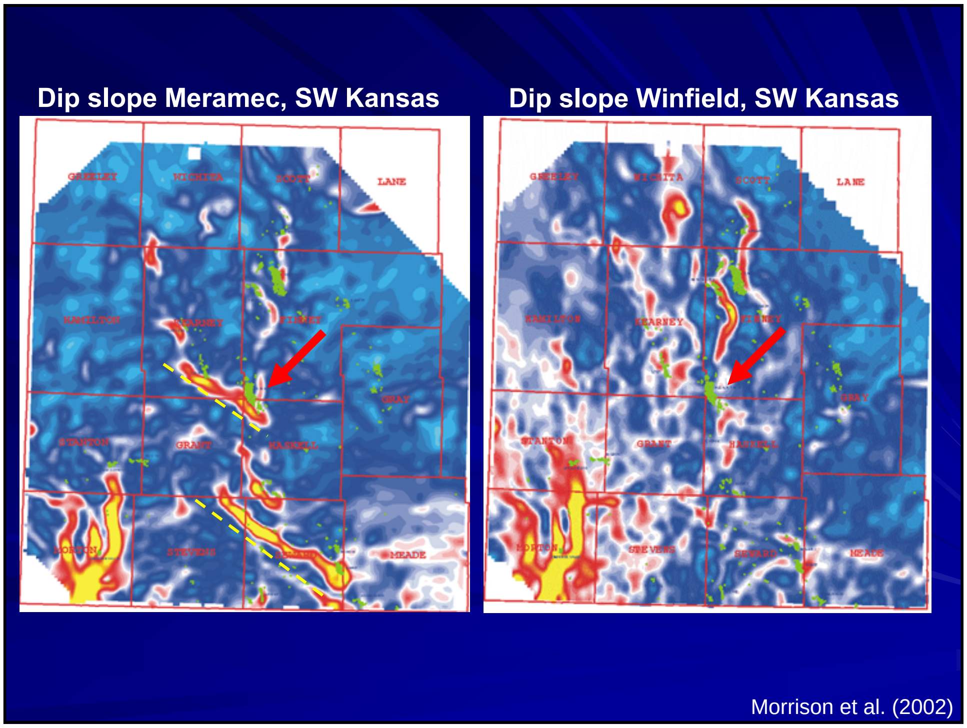

Nebraska
Colorado
Salina
basin
Central Kansas uplift
Las Animas arch
Hugoton
Embayment
KANSAS
Nemaha ridge
Outline
of
Study
Area
Apishapa
uplift
Sedgwick
basin
Pratt
anticline
Cherokee
basin
Sierra
Grande
arch
Cimarron
arch
Pleasant Prairie
Field
Oklahoma
Cherokee
platform
Anadarko
basin
New
Mexico
Amarillo-Wichita uplift
Texas
0 50 100 Miles
0 80 160 Km.
S.W. KANSAS STRATIGRAPHY
System
Series
Stratigraphic Unit
PERMAIN
Leonardian
B/Stn Corral
Nippewalla
Wolfcampian
Chase
Council Grove
PENNSYLVANIAN
Virgilian
Admire
Wabaunsee
Shawnee
Douglas
Missourian
Lansing
Kansas City
Pleasanton
Desmoinesian
Marmaton
Cherokee
Atokan
Atoka
Morrowan
Morrow
MISSISSIPPIAN
Chesterian
Chester
Meramecian
Ste. Genevieve
St. Louis
Salem
Warsaw
Osagian
Osage
Kinderhookian
Gilmore City Ls.
Hannibal sh
Method of Exploration in finding Pleasant Prairie Field
The discovery well was the Helmerich & Payne #0-16 Jones in 1954. Initial potential was 167 barrels of oil per day with reservoir pressure of 1045 psi on drillstem test. Development of the field as based on drilling Winfield structural highs.
Morrison et al. (2002)


RELATIVE POSITION OF THE PLEASANT PRAIRIE FIELD
DURING DEPOSITION
SEAWARD
LANDWARD
KEARNY COUNTY
GRANT COUNTY
FINNEY COUNTY
HASKELL COUNTY
• Inferred paleotopography for St. Louis ooid shoal reservoir at Pleasant Prairie Field
• Structure template propagates to shallow depths (*1700 ft up section*) to Wolfcampian Chase Group
R 35 W
R 34 W
Structure
top St. Louis
C.I. = 20 ft
Structure
top Chase Group
C.I. = 10 ft
Outline of Study Area
Gravity Map of SW Kansas
Magnetic Map of SW Kansas
Morrison et al. (2002)

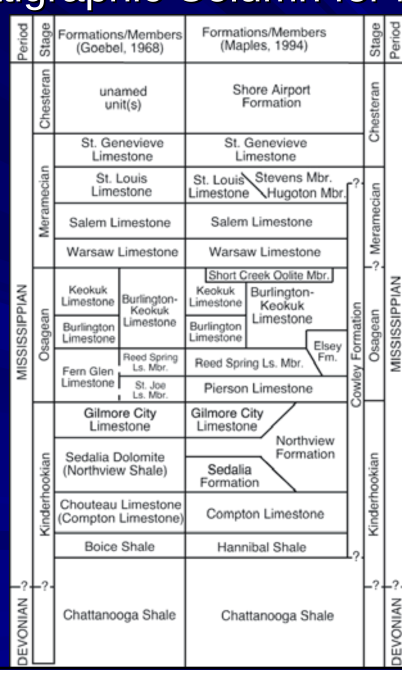

Pleasant Prairie Pool
Stratigraphic Cross Section A-A'
A
A'
Datum
Chester sand
St. Louis Oolite
TRANSVERSE VIEW OF AN OOLITIC SHOAL AS SEEN AT PLEASANT PRAIRIE FIELD
MAXIMUM TURBULENCE
SEAWARD
LANDWARD
PAYZONE
FORESHOAL
SHOAL
BACKSHOAL
Morrison et al. (2002)


Chester Mississippian Incised valley fill sandstone on east side of Pleasant Prairie in structure and paleotopographic low
Well API Number - 15-081-21029
Depth
Formation Tops
HUG ELOG-EM
5300
5350
5400
5450
5500
5550
5600
5650
Chester Ss.
KARST
FEATURE
approx. 1 MILE
N
Morrison et al. (2002)


Meramec regional structure, SW Kansas
Winfield (upper Wolfcampian)
to Meramec isopach, SW Kansas
-- 1700 ft up section from Meramec
Pleasant Prairie Field
3000 ft.
Chester Channel
• Very similar details of maps
• Strong NW-trend and secondary N-NE
• Southern subsidence parallel the
Anadarko Basin/Amarillo-Wichita Uplift
Morrison et al. (2002)

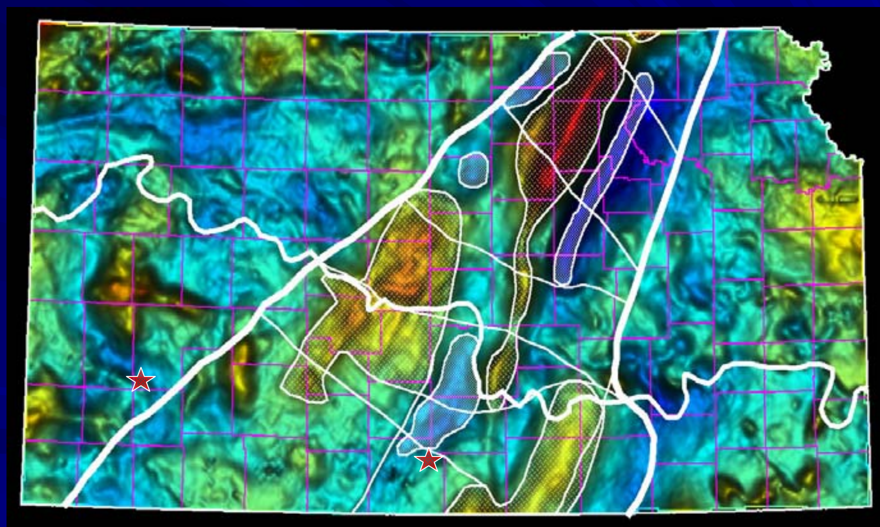


Kansas Stratigraphic Column for Mississippian

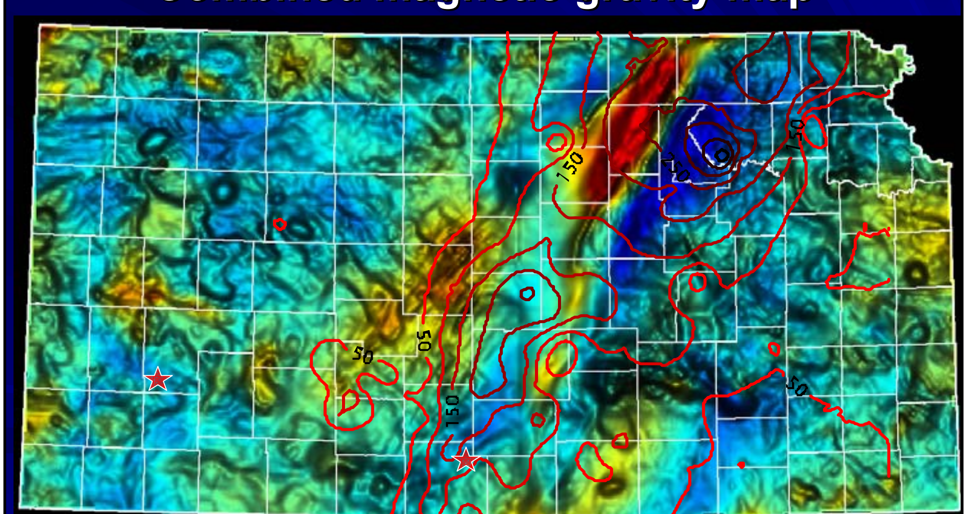


Section Examined In This Example Early-Mid - Mississippian Cowley Formation And Mississippian "Chat" along **shelf margin**

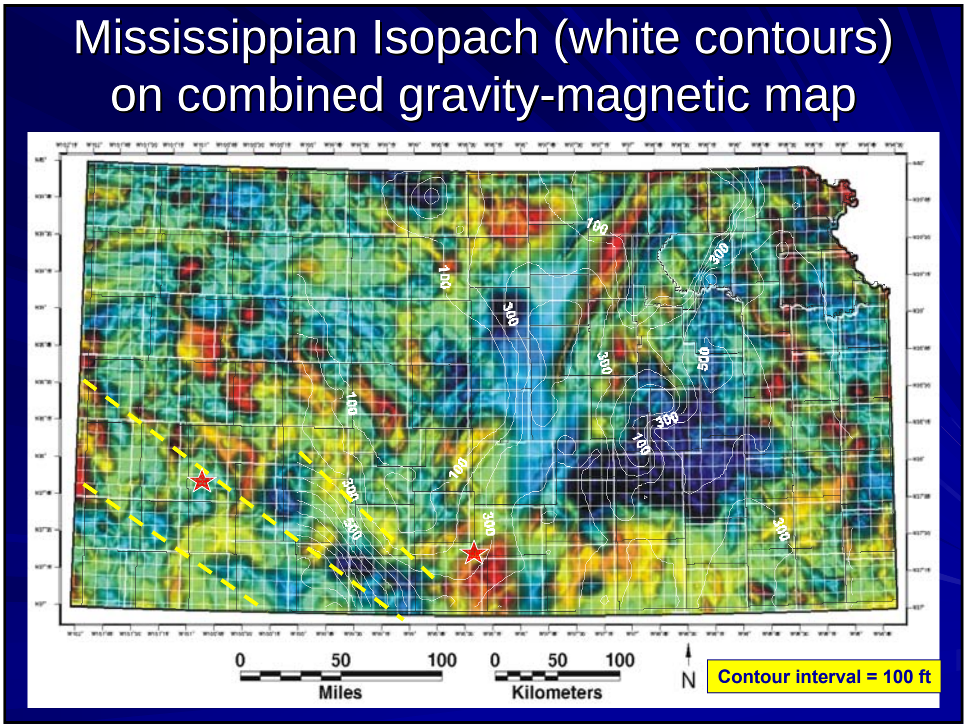
Gravity map with Precambrian terrane boundaries

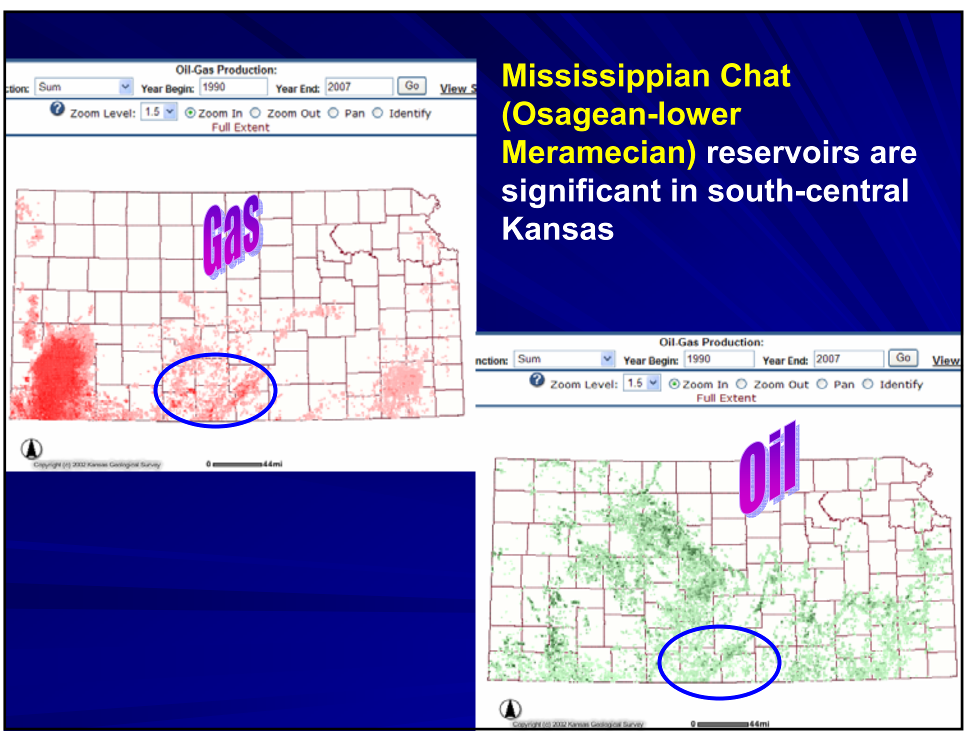


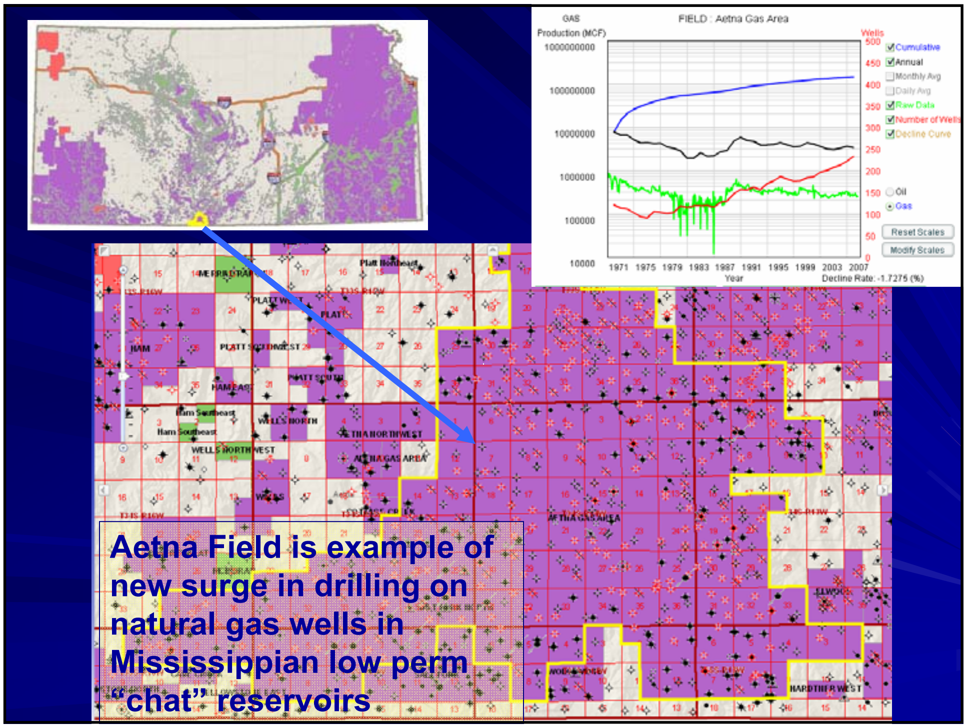
Late Dev.-Early Mississippian Chattanooga (Woodford) isopach on **Combined magnetic-gravity map**



Red contours = isopachous lines of Chattanooga Shale, Contour Interval = 50 ft

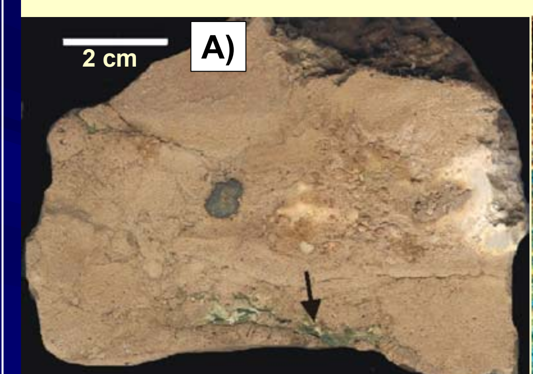

Mississippian Isopach (white contours)
on combined gravity-magnetic map
100
300
500
0 50 100
Miles
0 50 100
Kilometers
N
Contour interval = 100 ft


Mississippian Chat (Osagean-lower Meramecian) reservoirs are significant in south-central Kansas
Oil-Gas Production:
Sum
Year Begin: 1990
Year End: 2007
Go
Zoom Level: 1.5
Zoom In
Zoom Out
Pan
Identify
Full Extent
Gas
Oil

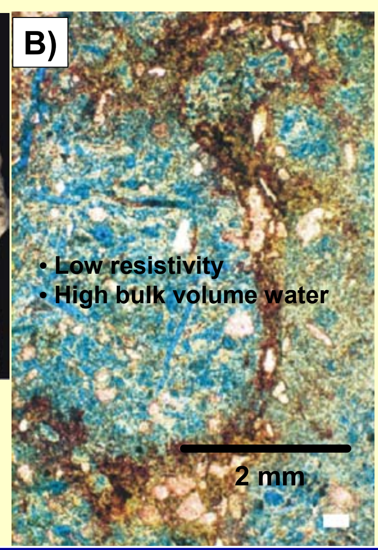


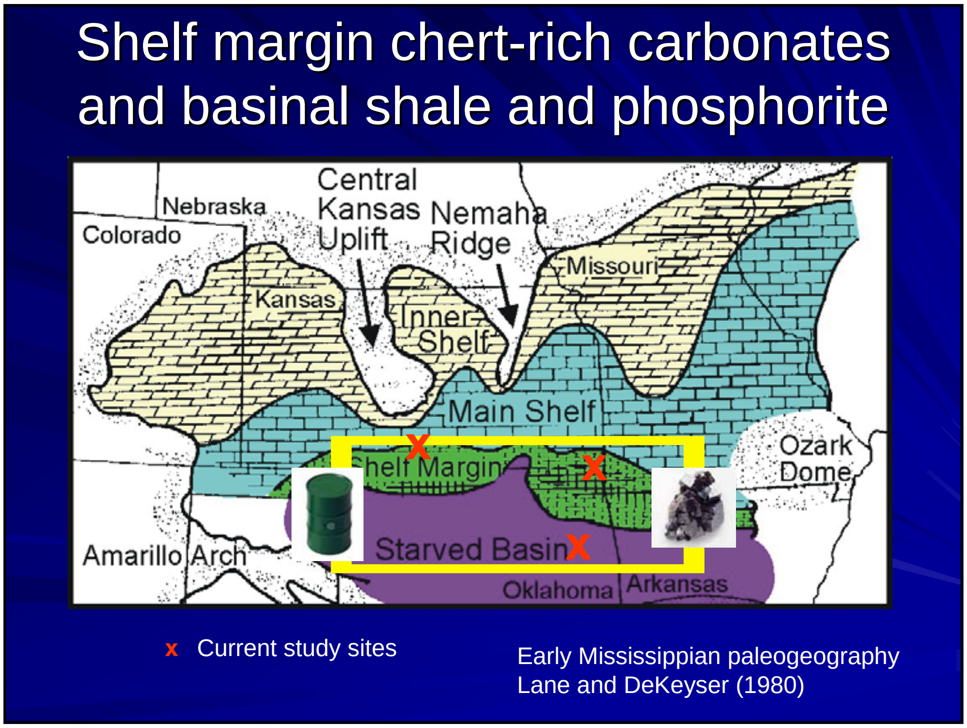
Mississippian "Chat"

CHAT -- Autoclastic chert with clay

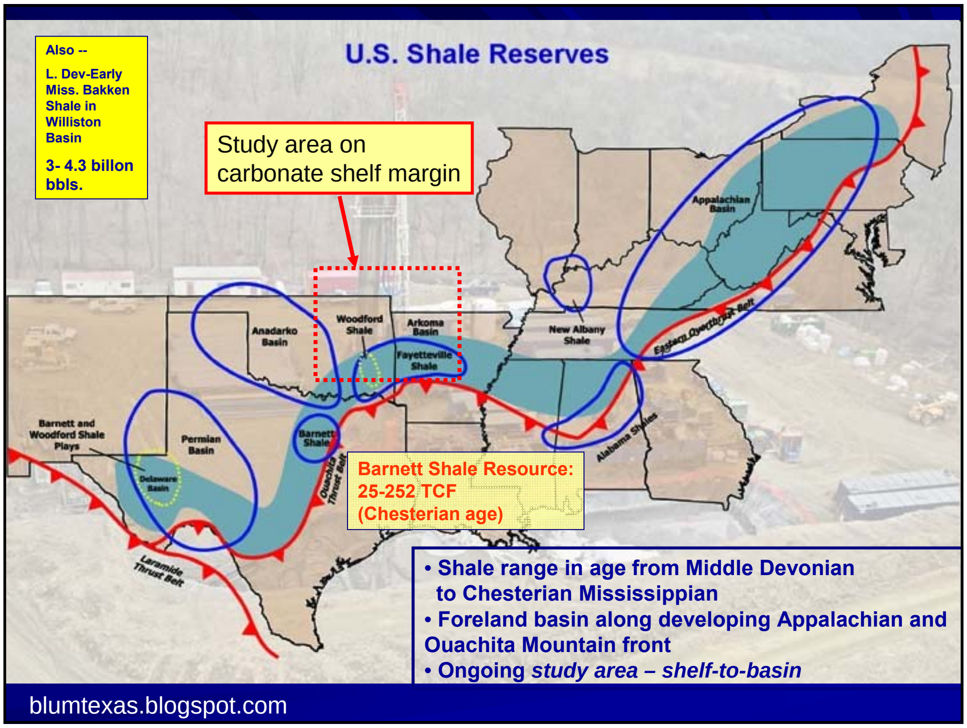


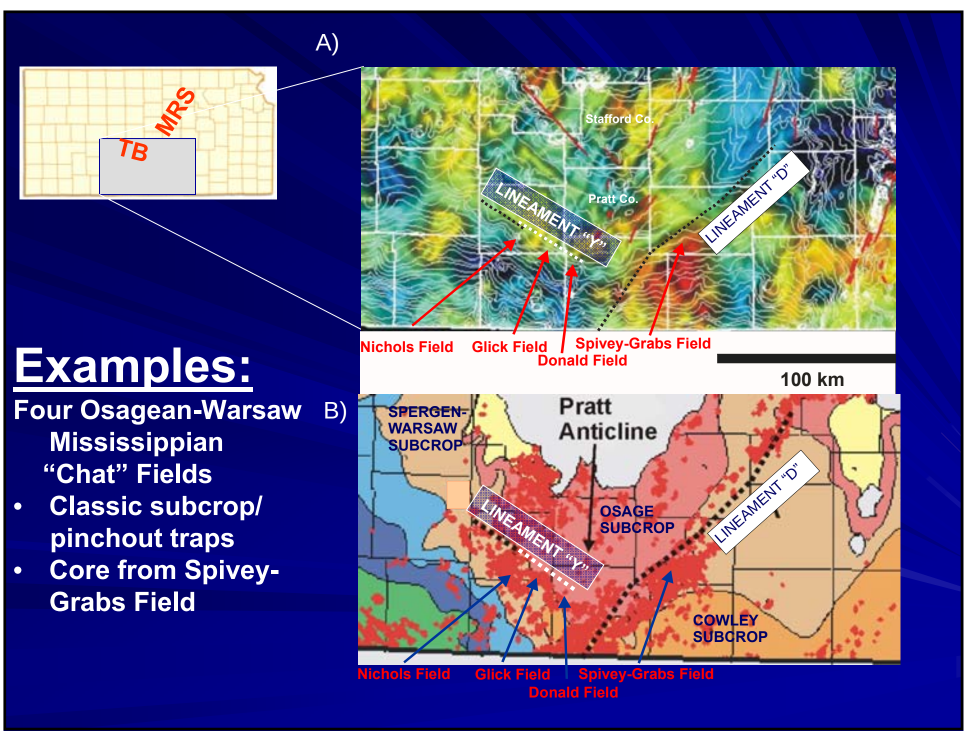
Autoclastic chert breccia with clasts lined by clay and brown microcrystalline calcite. Abundant microporosity, molds, and vugs in spiculitic microcrystalline chert.

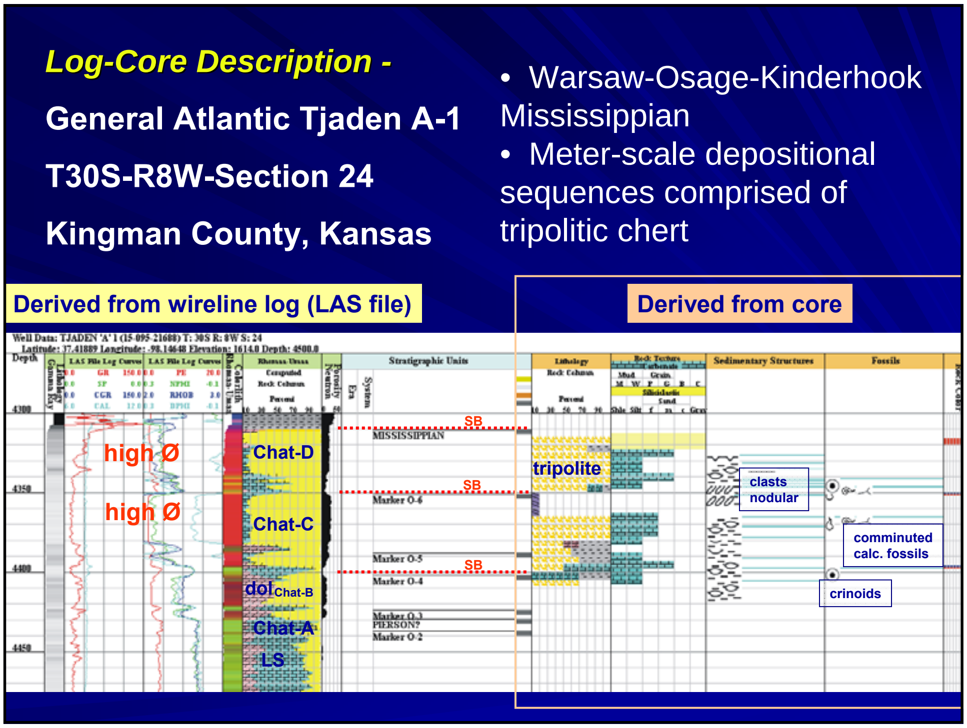


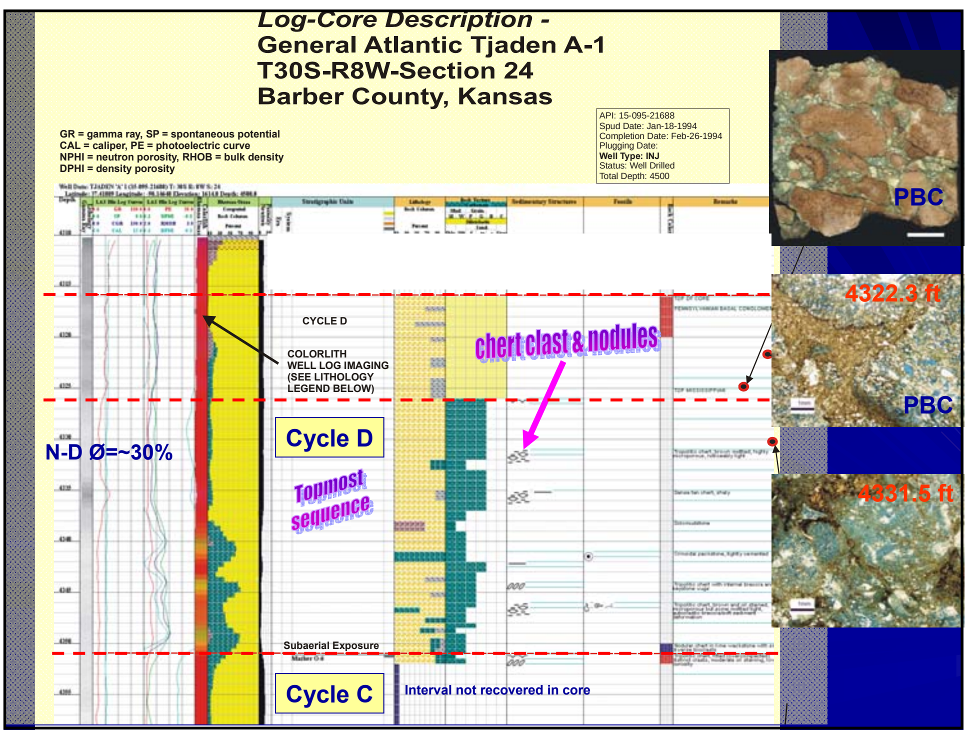

Shelf margin chert-rich carbonates and basinal shale and phosphorite
Central Kansas Uplift
Nemaha Ridge
Nebraska
Colorado
Kansas
Missouri
Inner Shelf
Main Shelf
Shelf Margin
Ozark Dome
Starved Basin
Amarillo Arch
Oklahoma
Arkansas
x Current study sites
Early Mississippian paleogeography
Lane and DeKeyser (1980)

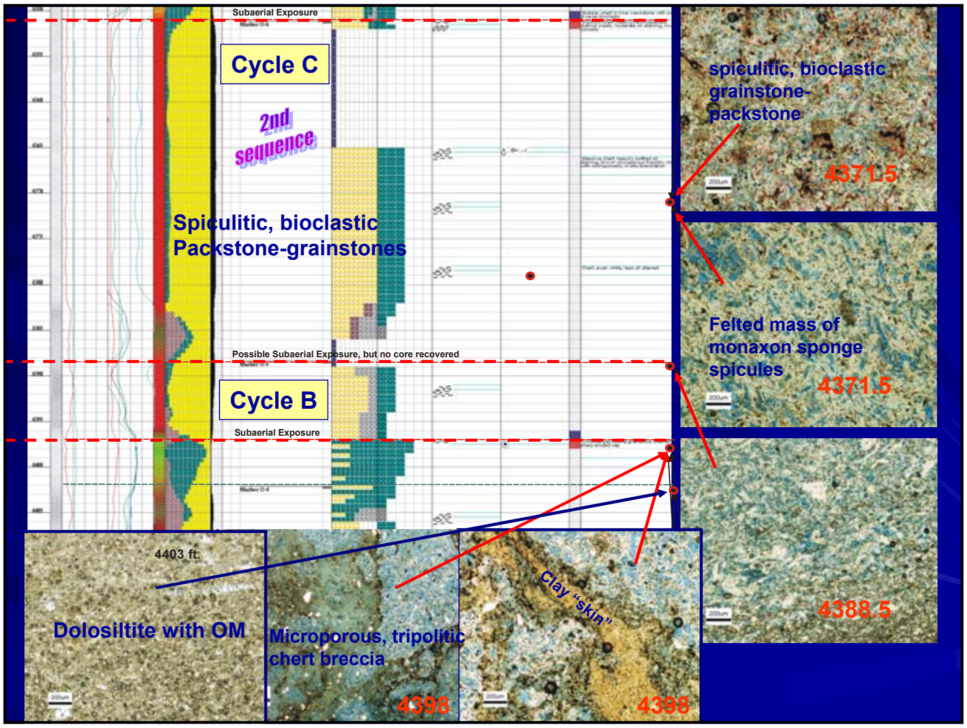

Late Devonian –
Early Mississippian
• Convergent plate boundary, southerly subduction, and associated cratonic deformation
• Tropical restricted seaway, and "shallow" cratonic basins
• Incipient Gondwannan glaciation
KS
Osage
chert
Texas
Chappel
Ls. shelf
Blakey -- http://www2.nau.edu/


U.S. Shale Reserves
Also --
L. Dev-Early Miss. Bakken Shale in Williston Basin
3- 4.3 billon bbls.
Study area on carbonate shelf margin
Woodford Shale
Arkoma Basin
Anadarko Basin
Fayetteville Shale
New Albany Shale
Appalachian Basin
Eastern Overthrust Belt
Alabama Shales
Barnett and Woodford Shale Plays
Delaware Basin
Permian Basin
Barnett Shale
Ouachita Thrust Belt
Laramide Thrust Belt
Barnett Shale Resource: 25-252 TCF (Chesterian age)
• Shale range in age from Middle Devonian to Chesterian Mississippian
• Foreland basin along developing Appalachian and Ouachita Mountain front
• Ongoing study area – shelf-to-basin
blumtexas.blogspot.com


A)
MRS
TB
Stafford Co.
Pratt Co.
LINEAMENT "Y"
LINEAMENT "D"
Nichols Field
Glick Field
Spivey-Grabs Field
Donald Field
100 km
Examples:
Four Osagean-Warsaw Mississippian "Chat" Fields
• Classic subcrop/ pinchout traps
• Core from Spivey-Grabs Field
B)
SPERGEN-WARSAW SUBCROP
Pratt Anticline
OSAGE SUBCROP
COWLEY SUBCROP
LINEAMENT "Y"
LINEAMENT "D"
Nichols Field
Glick Field
Spivey-Grabs Field
Donald Field

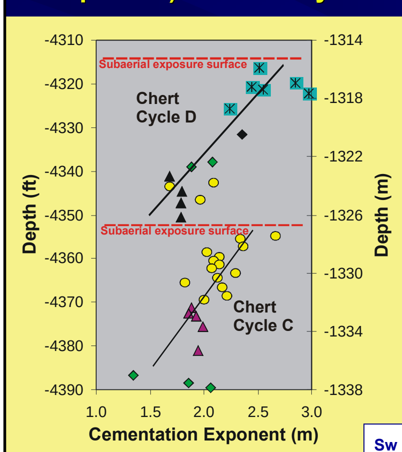

Log-Core Description -
General Atlantic Tjaden A-1
T30S-R8W-Section 24
Kingman County, Kansas
• Warsaw-Osage-Kinderhook Mississippian
• Meter-scale depositional sequences comprised of tripolitic chert
Derived from wireline log (LAS file)
Derived from core
high Ø
high Ø
Chat-D
Chat-C
dol Chat-B
Chat-A
LS
SB
SB
SB
MISSISSIPPIAN
Marker O-6
Marker O-5
Marker O-4
Marker O-3
PIERSON?
Marker O-2
tripolite
clasts
nodular
comminuted calc. fossils
crinoids


Log-Core Description -
General Atlantic Tjaden A-1
T30S-R8W-Section 24
Barber County, Kansas
GR = gamma ray, SP = spontaneous potential
CAL = caliper, PE = photoelectric curve
NPHI = neutron porosity, RHOB = bulk density
DPHI = density porosity
API: 15-095-21688
Spud Date: Jan-18-1994
Completion Date: Feb-26-1994
Plugging Date:
Well Type: INJ
Status: Well Drilled
Total Depth: 4500
PBC
4322.3 ft
PBC
4331.5 ft
CYCLE D
COLORLITH WELL LOG IMAGING (SEE LITHOLOGY LEGEND BELOW)
chert clast & nodules
N-D Ø=~30%
Cycle D
Topmost sequence
Subaerial Exposure
Cycle C
Interval not recovered in core

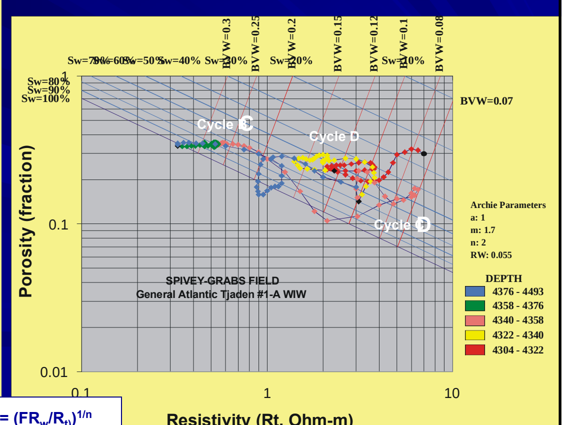


Depth-based petrophysical patterns suggest depositional and early diagenetic important in observed pore architecture in tripolitic O&G reservoirs

Depth profile of m (cementation exponent) for chert cycles



Petrophysical (PfEFFER) analysis of the tripolitic (microporous brecciated) chert

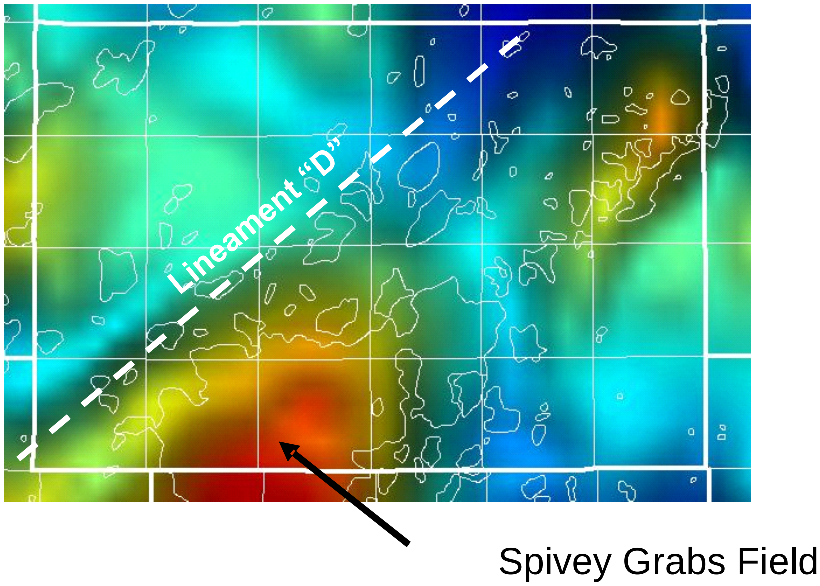


C/A by Byrnes in Watney et al. (2001)

$Sw = (FR_w/R_t)^{1/n}$

$F = a/Ø^m$

Magnetic Map, Kingman County



NW-SE Stratigraphic Cross Section through Spivey-Grabs Field

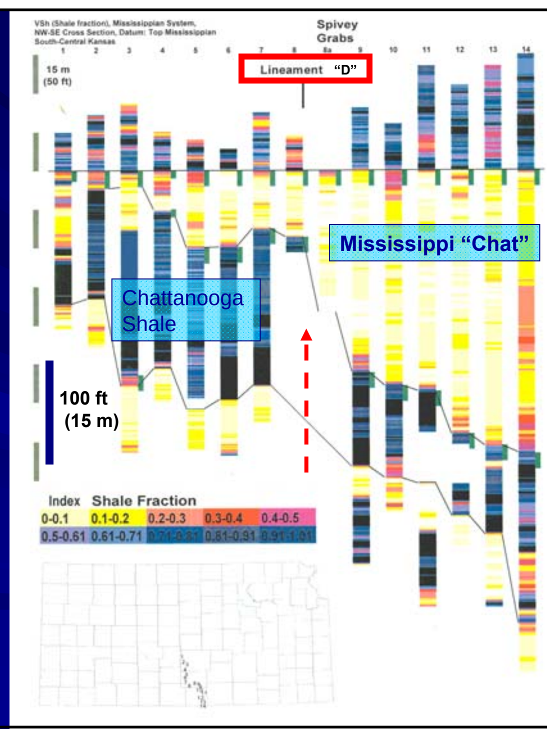
Vsh (Shale Fraction) Mississippian

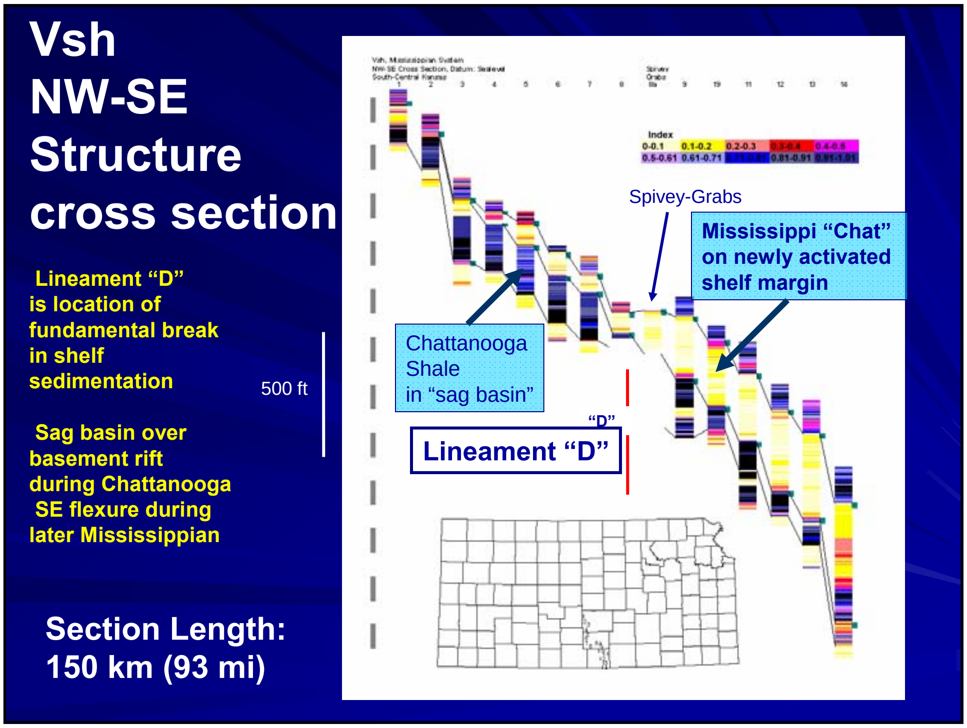
Datum: Top Miss.

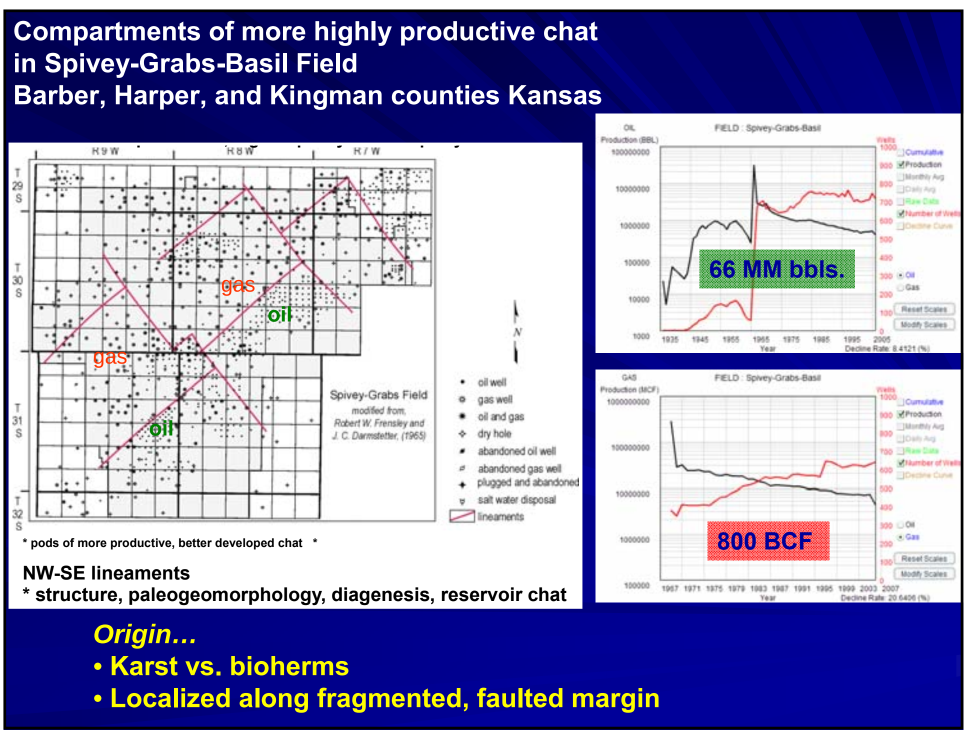
Section Length: 150 km (93 mi)

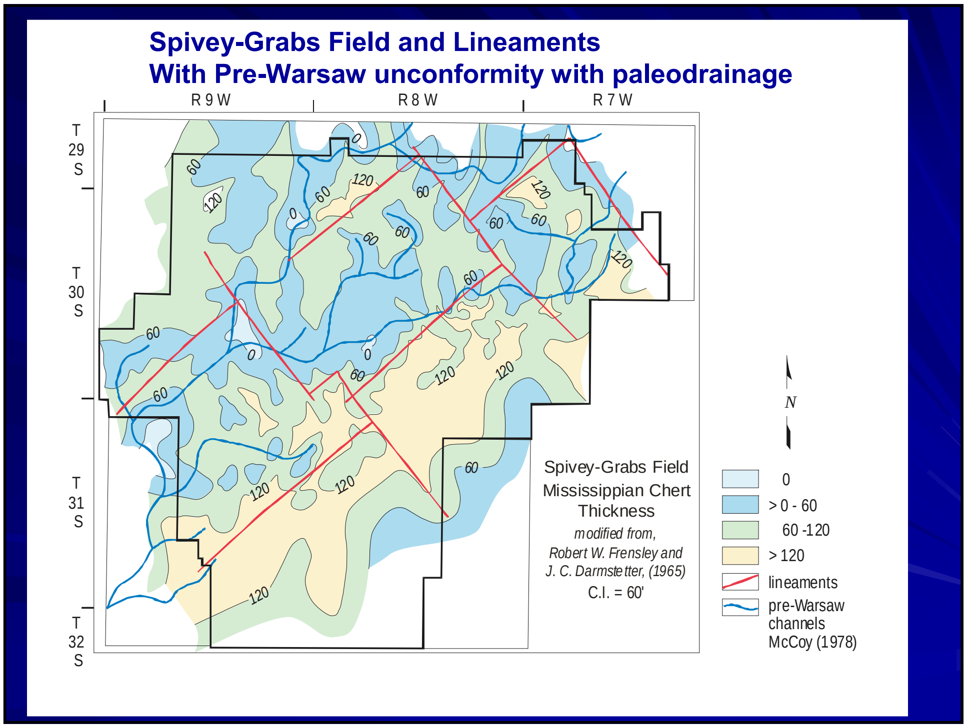
- **Lineament "D" is location of fundamental break in shelf sedimentation**

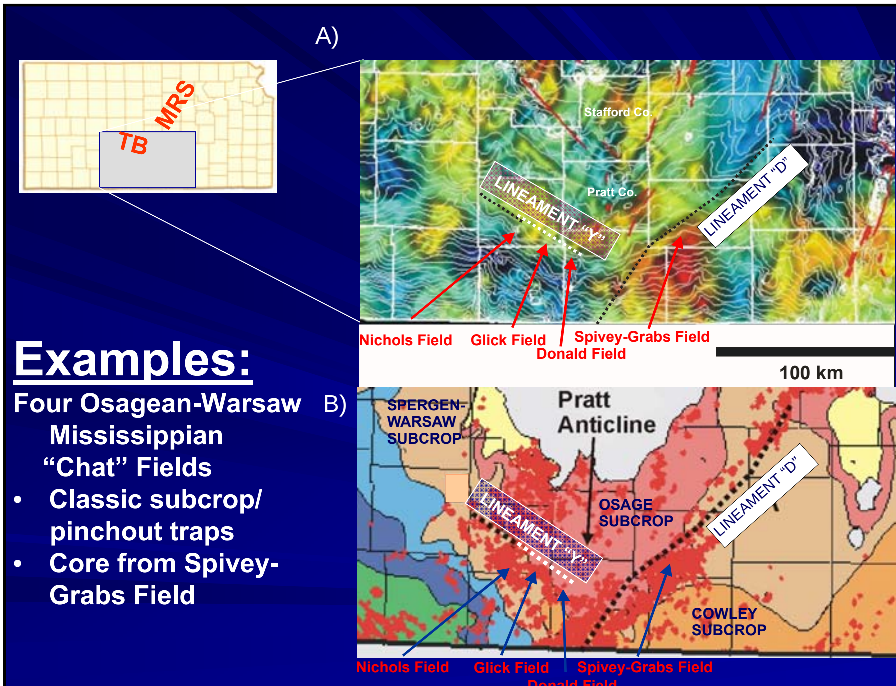
- **Sag basin over basement rift during Chattanooga**
- **SE flexure during later Mississippian**




Vsh
NW-SE
Structure
cross section
Lineament "D"
is location of
fundamental break
in shelf
sedimentation
Sag basin over
basement rift
during Chattanooga
SE flexure during
later Mississippian
500 ft
Section Length:
150 km (93 mi)
Spivey-Grabs
Mississippi "Chat"
on newly activated
shelf margin
Chattanooga
Shale
in "sag basin"
"D"
Lineament "D"
Index


Compartments of more highly productive chat
in Spivey-Grabs-Basil Field
Barber, Harper, and Kingman counties Kansas
gas
oil
gas
oil
Spivey-Grabs Field
modified from,
Robert W. Frensley and
J. C. Darmstetter, (1965)
oil well
gas well
oil and gas
dry hole
abandoned oil well
abandoned gas well
plugged and abandoned
salt water disposal
lineaments
* pods of more productive, better developed chat *
NW-SE lineaments
* structure, paleogeomorphology, diagenesis, reservoir chat
FIELD : Spivey-Grabs-Basil
66 MM bbls.
FIELD : Spivey-Grabs-Basil
800 BCF
Origin…
• Karst vs. bioherms
• Localized along fragmented, faulted margin

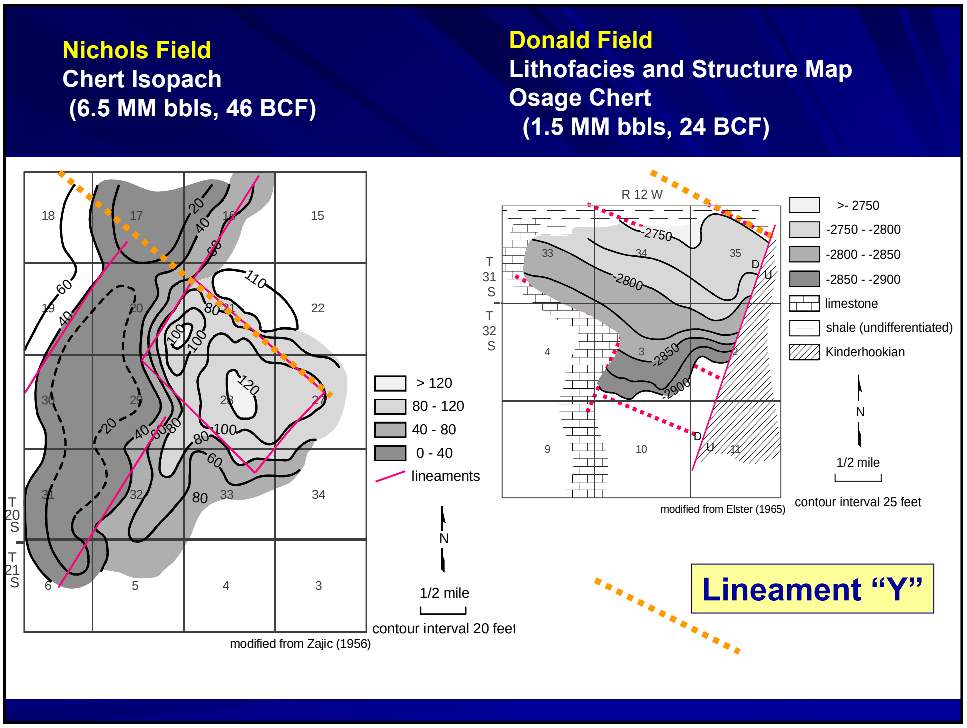


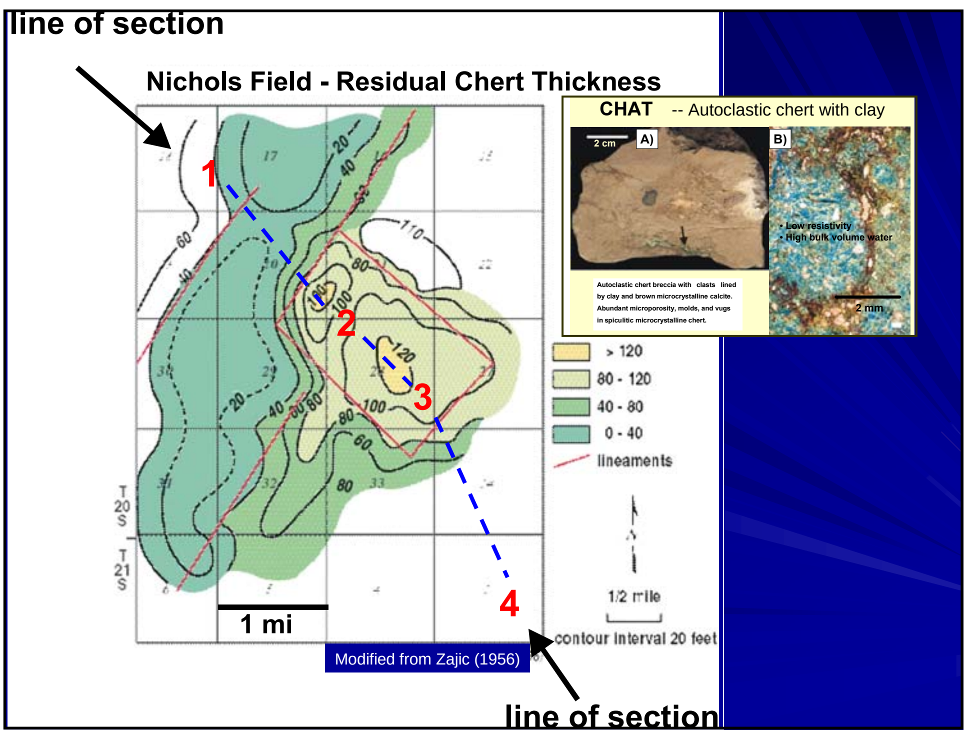


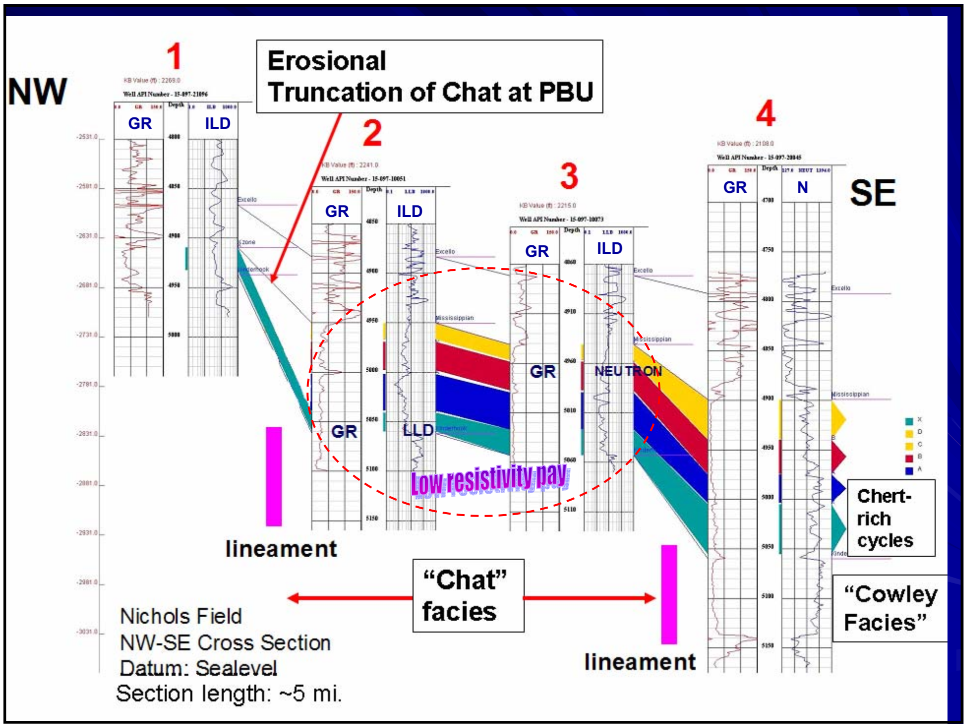
Examples:

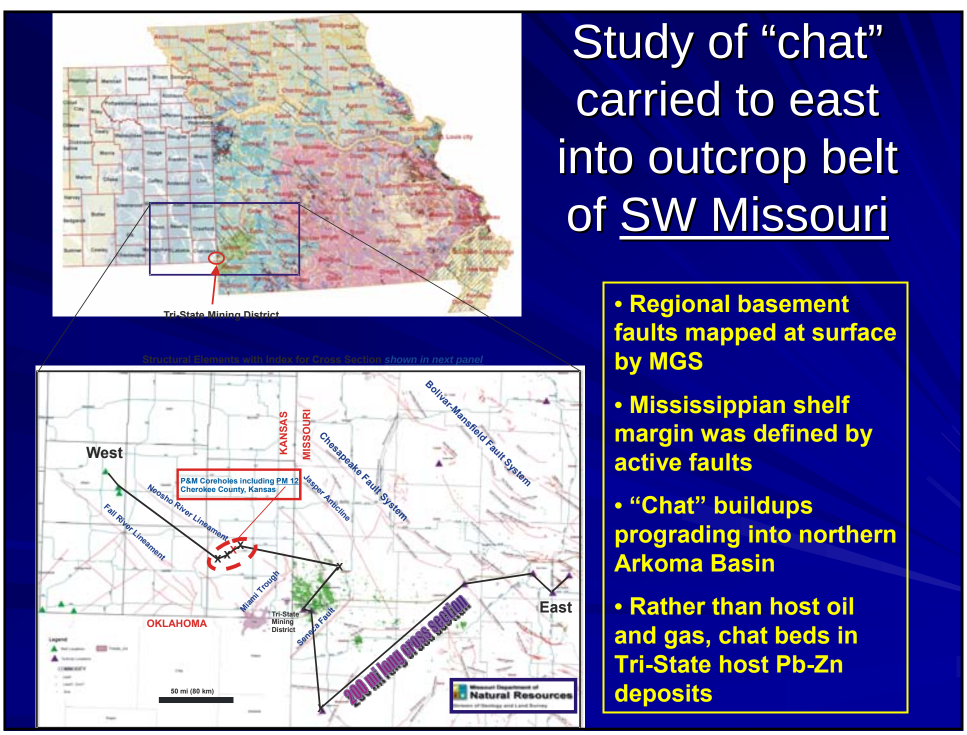
Four Osagean-Warsaw Mississippian "Chat" Fields

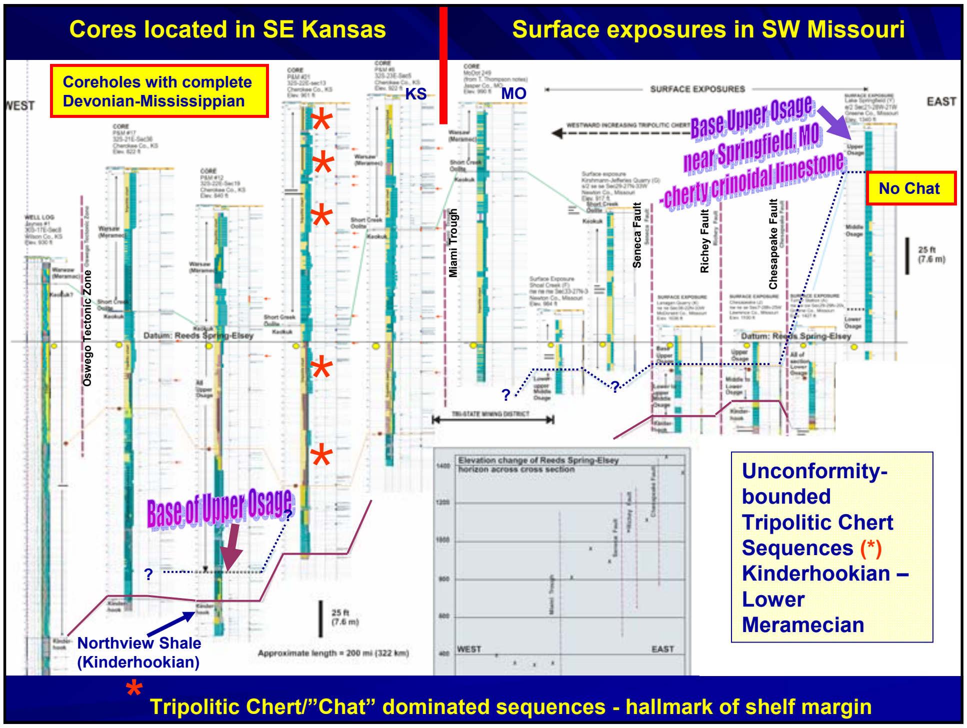
- **Classic subcrop/ pinchout traps**
- **Core from Spivey-Grabs Field**

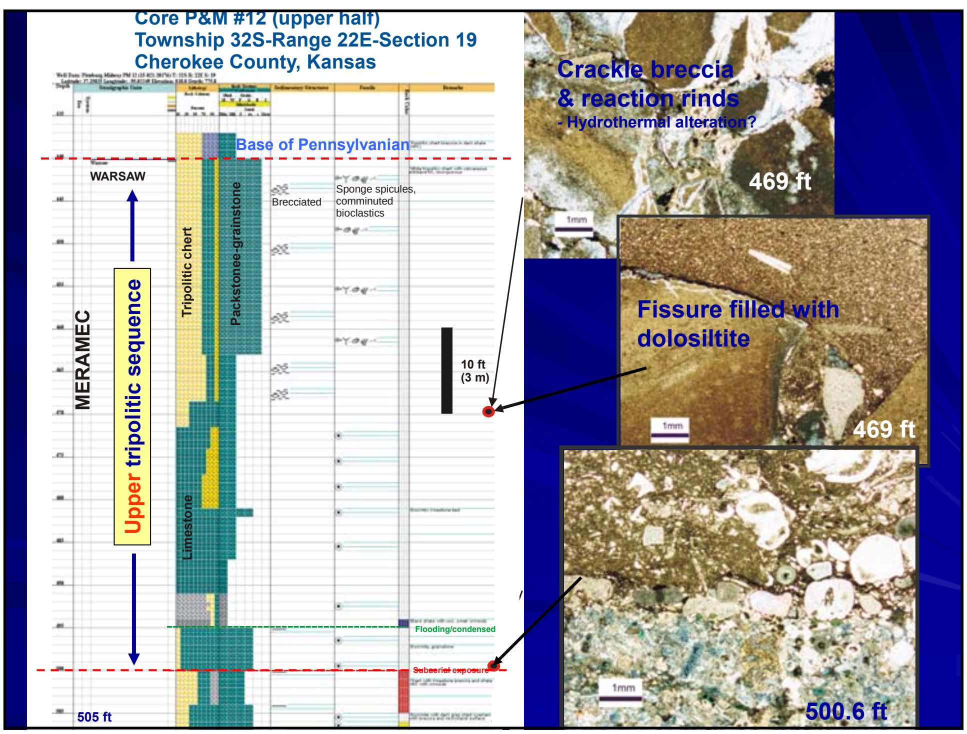

Nichols Field
Chert Isopach
(6.5 MM bbls, 46 BCF)
Donald Field
Lithofacies and Structure Map
Osage Chert
(1.5 MM bbls, 24 BCF)
> 120
80 - 120
40 - 80
0 - 40
lineaments
1/2 mile
contour interval 20 feet
modified from Zajic (1956)
R 12 W
>- 2750
-2750 - -2800
-2800 - -2850
-2850 - -2900
limestone
shale (undifferentiated)
Kinderhookian
1/2 mile
contour interval 25 feet
modified from Elster (1965)
Lineament "Y"

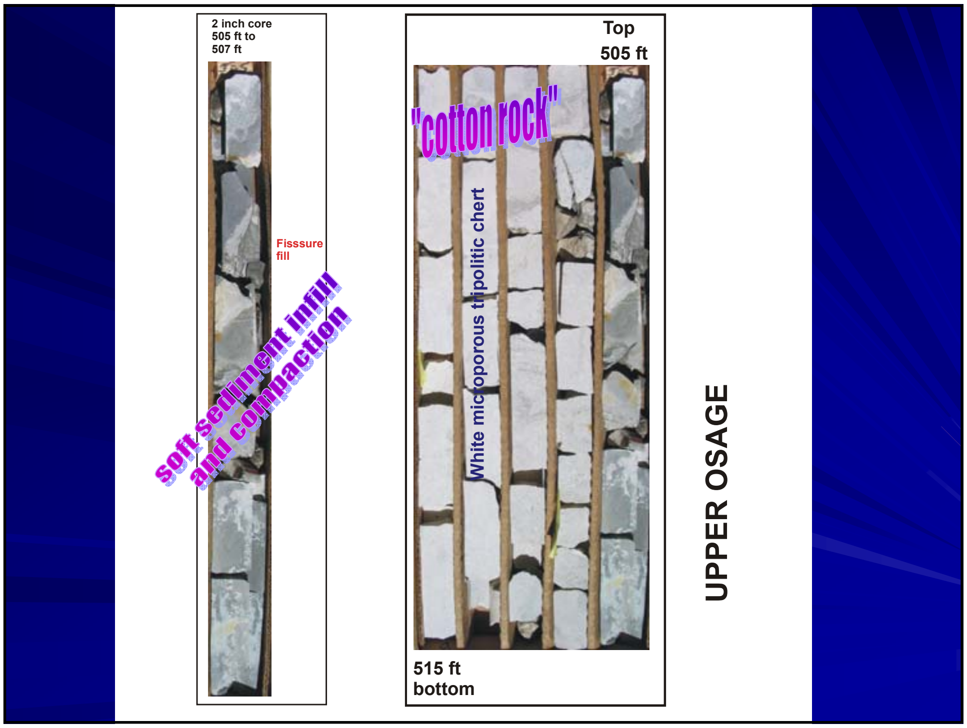

line of section
Nichols Field - Residual Chert Thickness
CHAT -- Autoclastic chert with clay
A)
B)
2 cm
2 mm
• Low resistivity
• High bulk volume water
> 120
80 - 120
40 - 80
0 - 40
lineaments
1/2 mile
contour interval 20 feet
1 mi
Modified from Zajic (1956)
1
2
3
4
line of section

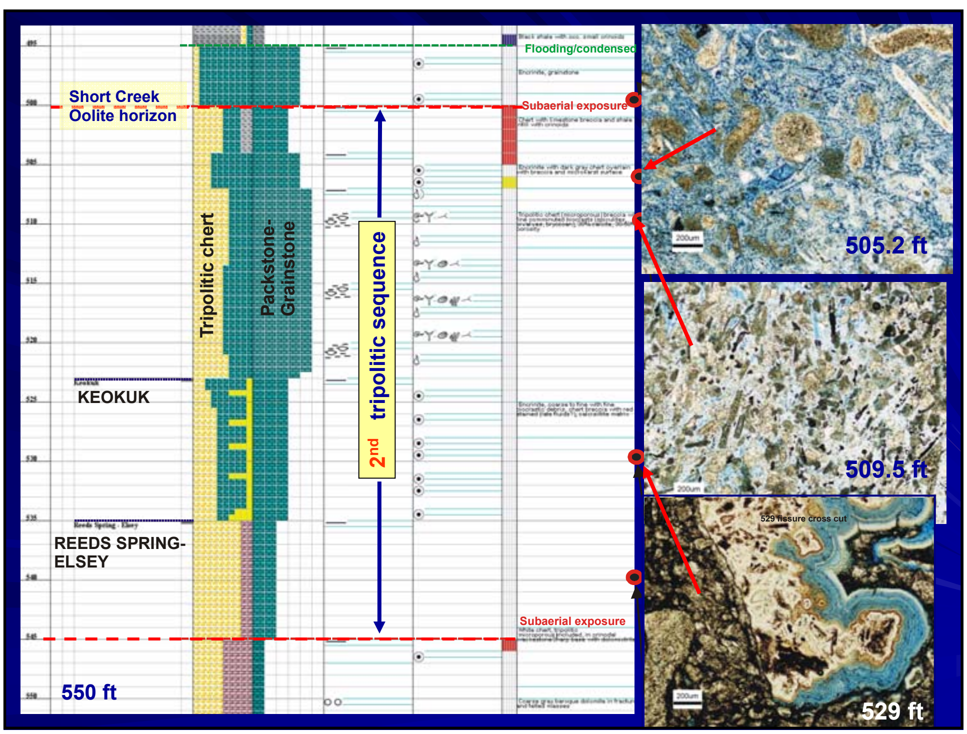

NW
SE
1
2
3
4
Erosional
Truncation of Chat at PBU
GR
ILD
LLD
NEU TRON
N
Low resistivity pay
lineament
"Chat"
facies
Chert-
rich
cycles
"Cowley
Facies"
Nichols Field
NW-SE Cross Section
Datum: Sealevel
Section length: ~5 mi.

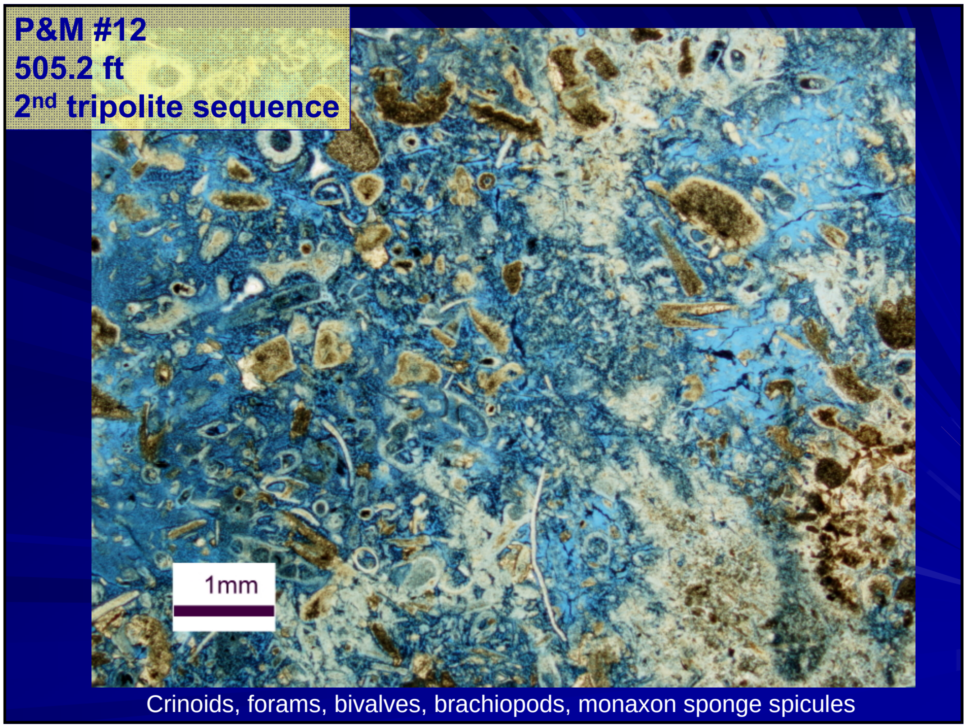

Study of "chat" carried to east into outcrop belt of SW Missouri
Tri-State Mining District
West
East
KANSAS
MISSOURI
OKLAHOMA
P&M Coreholes including PM 12
Cherokee County, Kansas
Neosho River Lineament
Fall River Lineament
Chesapeake Fault System
Bolivar-Mansfield Fault System
Jasper Anticline
Miami Trough
Seneca Fault
200 mi long cross section
Natural Resources
• Regional basement faults mapped at surface by MGS
• Mississippian shelf margin was defined by active faults
• "Chat" buildups prograding into northern Arkoma Basin
• Rather than host oil and gas, chat beds in Tri-State host Pb-Zn deposits

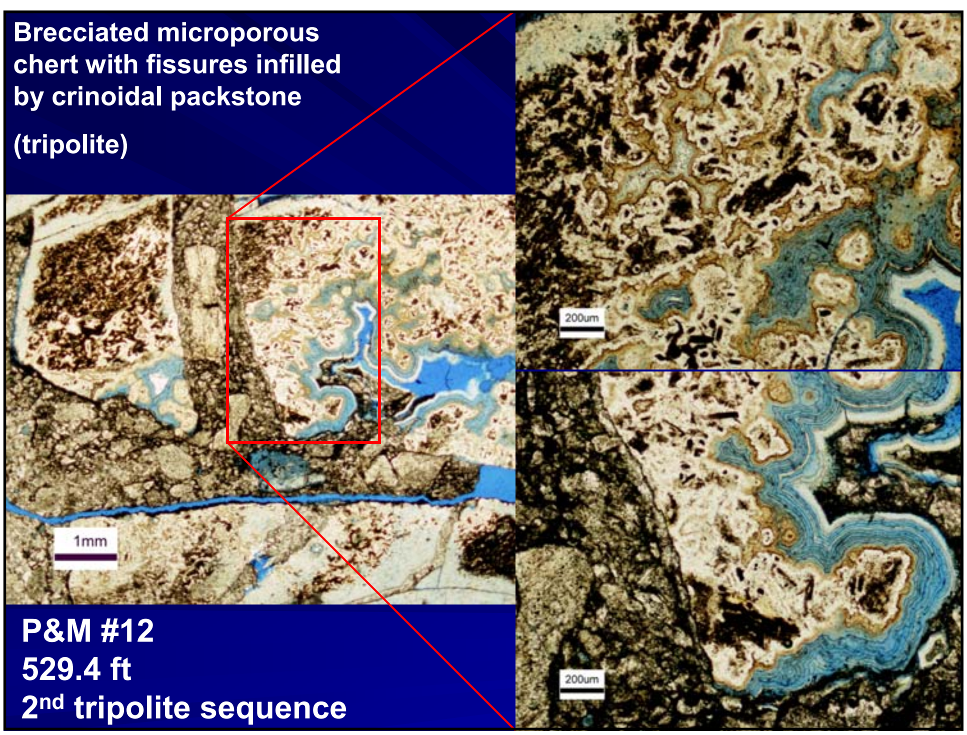

Cores located in SE Kansas
Surface exposures in SW Missouri
Coreholes with complete Devonian-Mississippian
KS
MO
WEST
EAST
Base Upper Osage near Springfield, MO -cherty crinoidal limestone
No Chat
Oswego Tectonic Zone
Miami Trough
Seneca Fault
Richey Fault
Chesapeake Fault
Datum: Reeds Spring-Elsey
Base of Upper Osage
Northview Shale (Kinderhookian)
Unconformity-bounded Tripolitic Chert Sequences (*) Kinderhookian – Lower Meramecian
Approximate length = 200 mi (322 km)
Elevation change of Reeds Spring-Elsey horizon across cross section
* Tripolitic Chert/"Chat" dominated sequences - hallmark of shelf margin

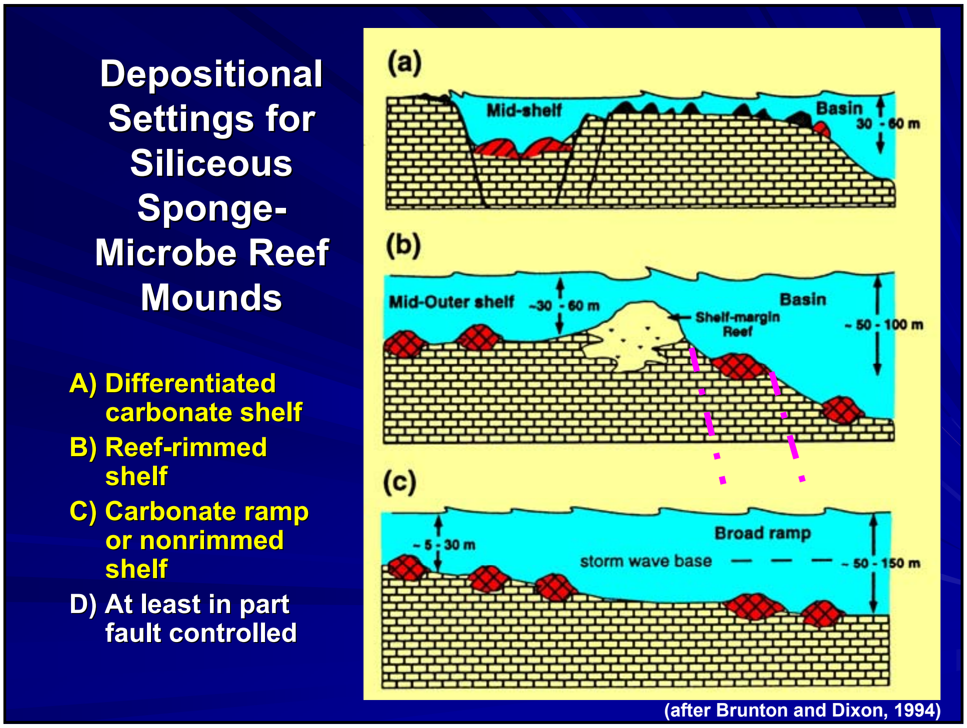

Core P&M #12 (upper half)
Township 32S-Range 22E-Section 19
Cherokee County, Kansas
Base of Pennsylvanian
WARSAW
MERAMEC
Upper tripolitic sequence
Tripolitic chert
Packstone-grainstone
Limestone
Brecciated
Sponge spicules, comminuted bioclastics
10 ft (3 m)
Flooding/condensed
Subaerial exposure
505 ft
Crackle breccia & reaction rinds - Hydrothermal alteration?
469 ft
Fissure filled with dolosiltite
469 ft
1mm
500.6 ft

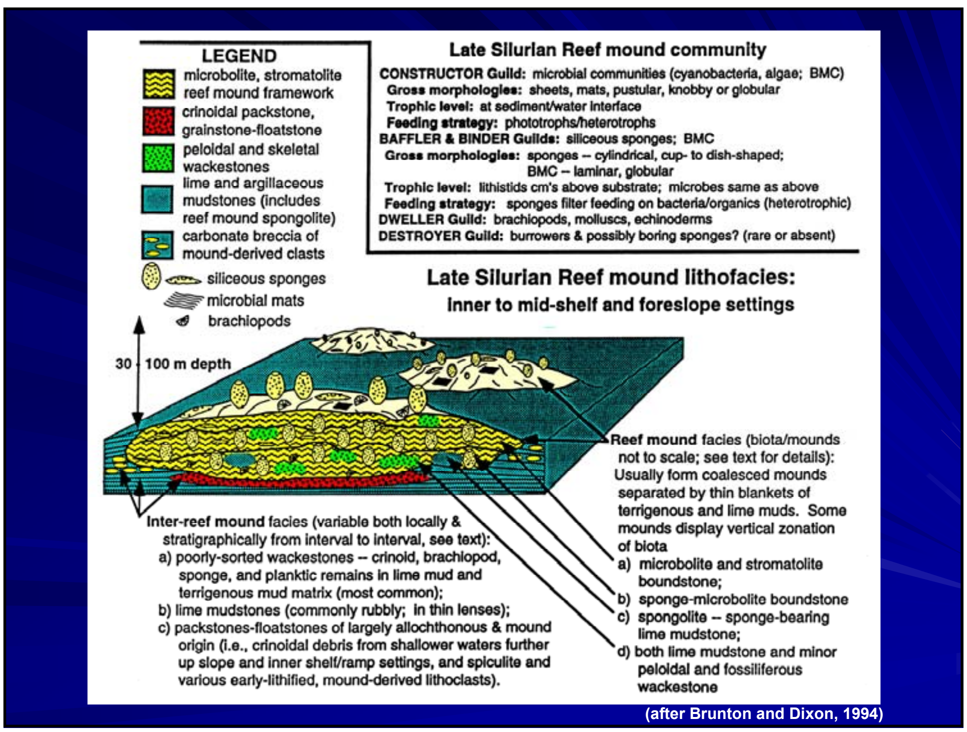

2 inch core
505 ft to
507 ft
Fissure fill
soft sediment infill and compaction
Top
505 ft
"cotton rock"
White microporous tripolitic chert
515 ft
bottom
UPPER OSAGE

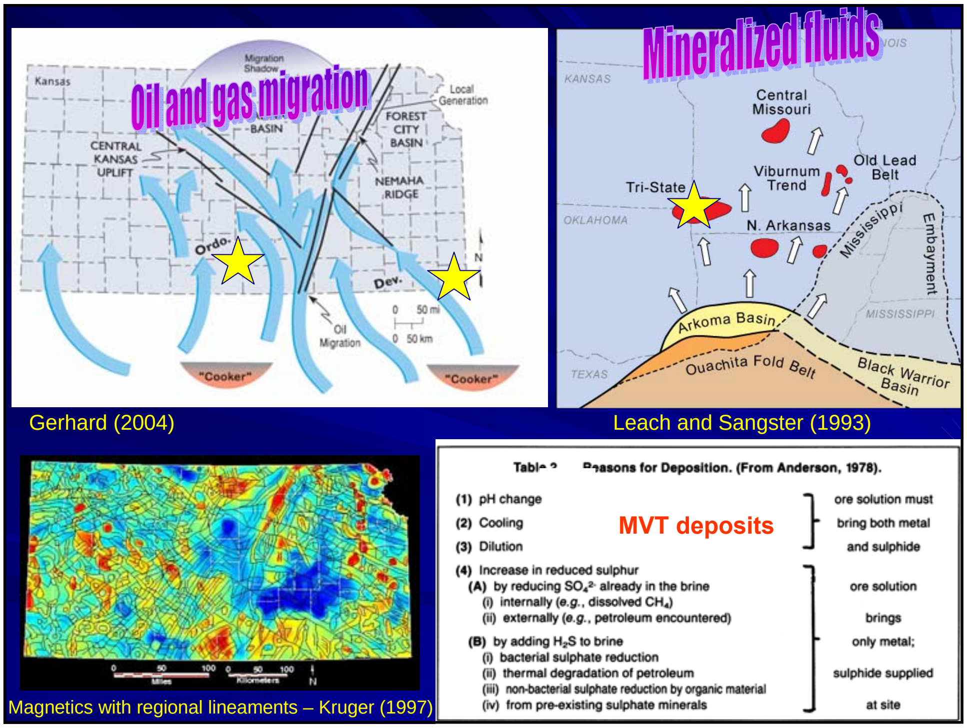

Flooding/condensed
Short Creek
Oolite horizon
Subaerial exposure
Tripolitic chert
Packstone-Grainstone
2nd tripolitic sequence
KEOKUK
REEDS SPRING-ELSEY
Subaerial exposure
550 ft
505.2 ft
509.5 ft
529 ft

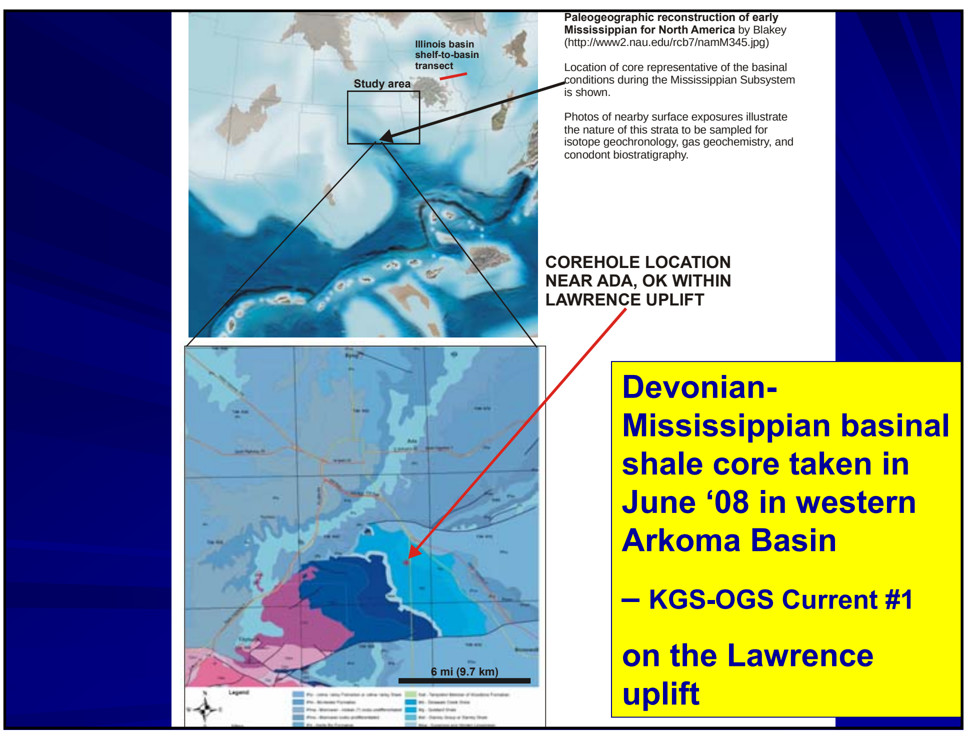

P&M #12
505.2 ft
2nd tripolite sequence
1mm
Crinoids, forams, bivalves, brachiopods, monaxon sponge spicules

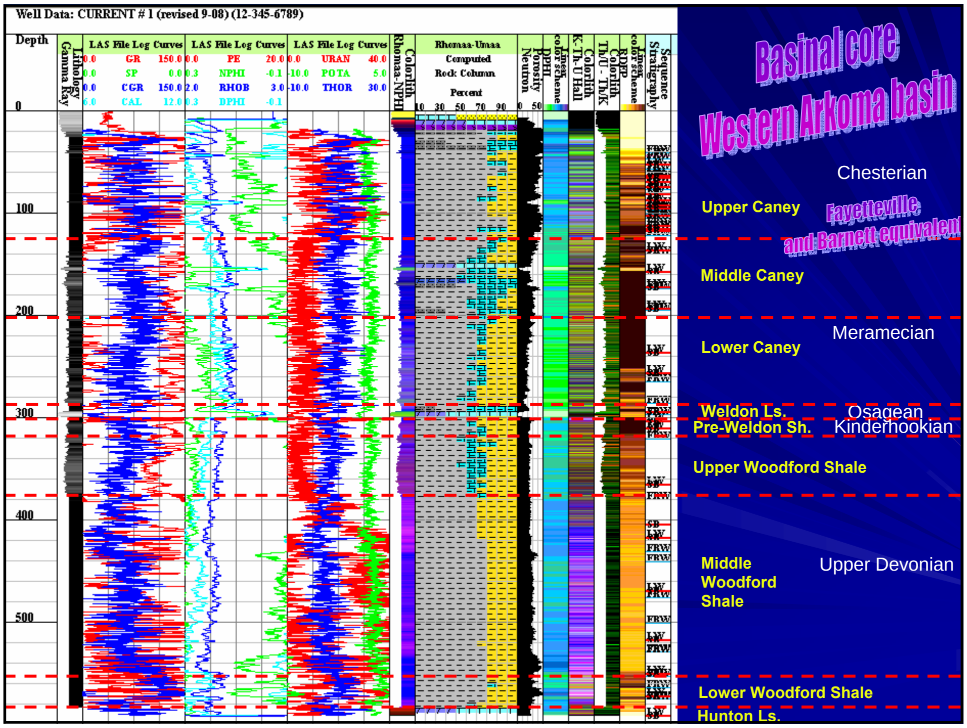

Brecciated microporous
chert with fissures infilled
by crinoidal packstone
(tripolite)
1mm
200um
200um
P&M #12
529.4 ft
2nd tripolite sequence

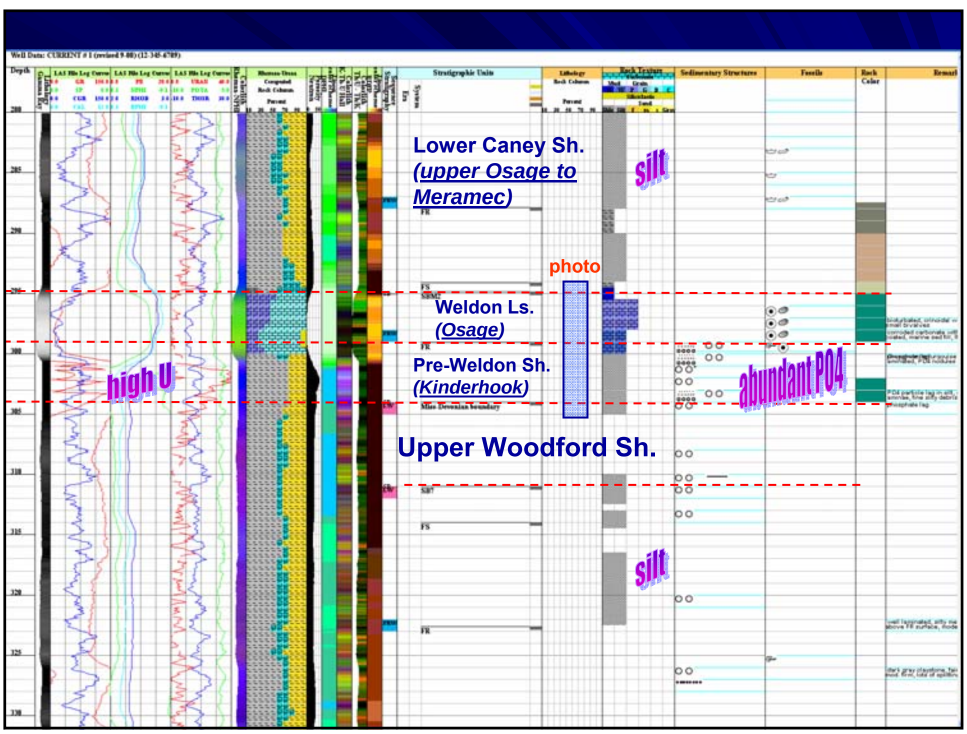

Depositional Settings for Siliceous Sponge-Microbe Reef Mounds
A) Differentiated carbonate shelf
B) Reef-rimmed shelf
C) Carbonate ramp or nonrimmed shelf
D) At least in part fault controlled
(a)
Mid-shelf
Basin
30 - 60 m
(b)
Mid-Outer shelf
~30 - 60 m
Shelf-margin Reef
Basin
~ 50 - 100 m
(c)
~ 5 - 30 m
Broad ramp
storm wave base
~ 50 - 150 m
(after Brunton and Dixon, 1994)


LEGEND
microbolite, stromatolite reef mound framework
crinoidal packstone, grainstone-floatstone
peloidal and skeletal wackestones
lime and argillaceous mudstones (includes reef mound spongolite)
carbonate breccia of mound-derived clasts
siliceous sponges
microbial mats
brachiopods
Late Silurian Reef mound community
CONSTRUCTOR Guild: microbial communities (cyanobacteria, algae; BMC)
Gross morphologies: sheets, mats, pustular, knobby or globular
Trophic level: at sediment/water interface
Feeding strategy: phototrophs/heterotrophs
BAFFLER & BINDER Guilds: siliceous sponges; BMC
Gross morphologies: sponges -- cylindrical, cup- to dish-shaped; BMC -- laminar, globular
Trophic level: lithistids cm's above substrate; microbes same as above
Feeding strategy: sponges filter feeding on bacteria/organics (heterotrophic)
DWELLER Guild: brachiopods, molluscs, echinoderms
DESTROYER Guild: burrowers & possibly boring sponges? (rare or absent)
Late Silurian Reef mound lithofacies:
Inner to mid-shelf and foreslope settings
30 - 100 m depth
Reef mound facies (biota/mounds not to scale; see text for details): Usually form coalesced mounds separated by thin blankets of terrigenous and lime muds. Some mounds display vertical zonation of biota
a) microbolite and stromatolite boundstone;
b) sponge-microbolite boundstone
c) spongolite -- sponge-bearing lime mudstone;
d) both lime mudstone and minor peloidal and fossiliferous wackestone
Inter-reef mound facies (variable both locally & stratigraphically from interval to interval, see text):
a) poorly-sorted wackestones -- crinoid, brachiopod, sponge, and planktic remains in lime mud and terrigenous mud matrix (most common);
b) lime mudstones (commonly rubbly; in thin lenses);
c) packstones-floatstones of largely allochthonous & mound origin (i.e., crinoidal debris from shallower waters further up slope and inner shelf/ramp settings, and spiculite and various early-lithified, mound-derived lithoclasts).
(after Brunton and Dixon, 1994)


Oil and gas migration
Migration Shadow
Kansas
Local Generation
BASIN
FOREST CITY BASIN
CENTRAL KANSAS UPLIFT
NEMAHA RIDGE
Ordo.
Dev.
Oil Migration
0 50 mi
0 50 km
"Cooker"
"Cooker"
Gerhard (2004)
Mineralized fluids
KANSAS
Central Missouri
Old Lead Belt
Viburnum Trend
Tri-State
OKLAHOMA
N. Arkansas
Mississippi
Embayment
MISSISSIPPI
Arkoma Basin
Ouachita Fold Belt
Black Warrior Basin
TEXAS
Leach and Sangster (1993)
Magnetics with regional lineaments – Kruger (1997)
Table 2 Reasons for Deposition. (From Anderson, 1978).
MVT deposits
(1) pH change
(2) Cooling
(3) Dilution
ore solution must bring both metal and sulphide
(4) Increase in reduced sulphur
(A) by reducing SO_4^{2-} already in the brine
(i) internally (e.g., dissolved CH_4)
(ii) externally (e.g., petroleum encountered)
(B) by adding H_2S to brine
(i) bacterial sulphate reduction
(ii) thermal degradation of petroleum
(iii) non-bacterial sulphate reduction by organic material
(iv) from pre-existing sulphate minerals
ore solution brings only metal; sulphide supplied at site

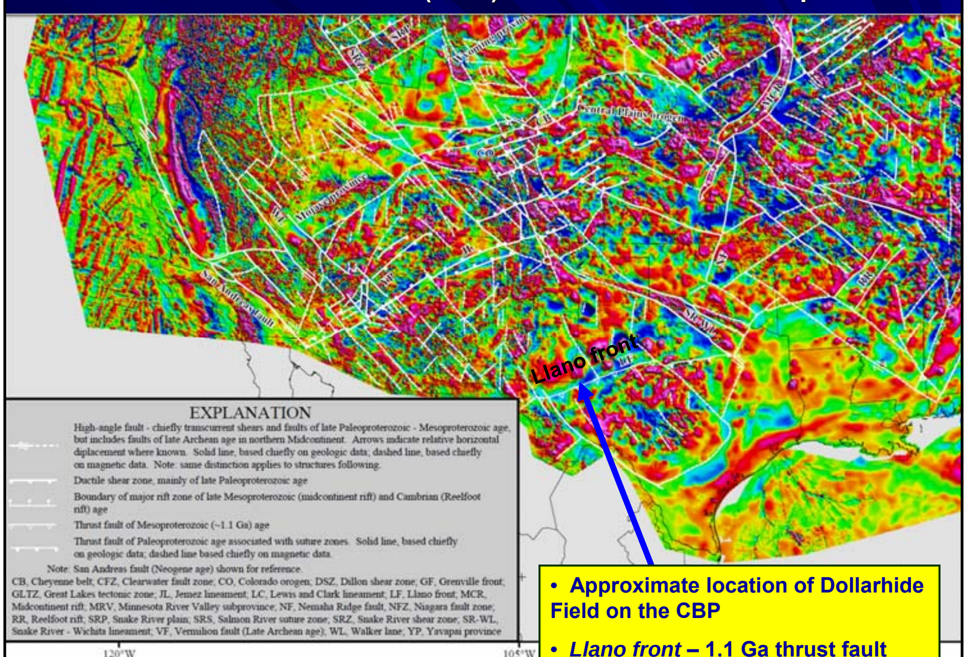

Illinois basin shelf-to-basin transect
Study area
Paleogeographic reconstruction of early Mississippian for North America by Blakey (http://www2.nau.edu/rcb7/namM345.jpg)
Location of core representative of the basinal conditions during the Mississippian Subsystem is shown.
Photos of nearby surface exposures illustrate the nature of this strata to be sampled for isotope geochronology, gas geochemistry, and conodont biostratigraphy.
COREHOLE LOCATION NEAR ADA, OK WITHIN LAWRENCE UPLIFT
6 mi (9.7 km)
Legend
Devonian-Mississippian basinal shale core taken in June '08 in western Arkoma Basin
– KGS-OGS Current #1
on the Lawrence uplift


Well Data: CURRENT # 1 (revised 9-08) (12-345-6789)
Basinal core
Western Arkoma basin
Chesterian
Upper Caney
Fayetteville and Barnett equivalent
Middle Caney
Meramecian
Lower Caney
Weldon Ls.
Osagean
Pre-Weldon Sh.
Kinderhookian
Upper Woodford Shale
Middle Woodford Shale
Upper Devonian
Lower Woodford Shale
Hunton Ls.


Lower Caney Sh.
(upper Osage to Meramec)
silt
photo
Weldon Ls.
(Osage)
Pre-Weldon Sh.
(Kinderhook)
high U
abundant PO4
Upper Woodford Sh.
silt

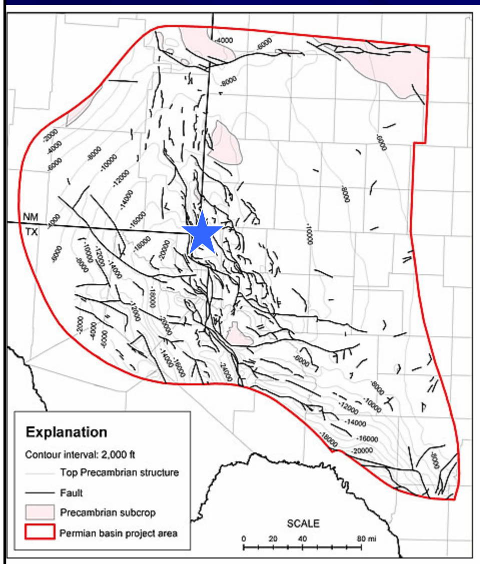
Role of Basement structure on Thirtyone Reservoir in Dollarhide Field

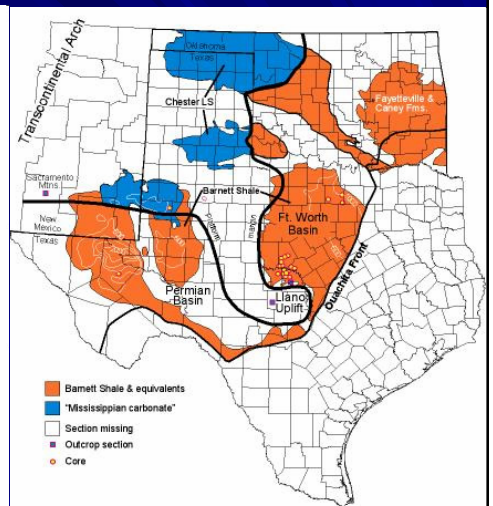
Portion of Sims et al. (2005) basement structure map



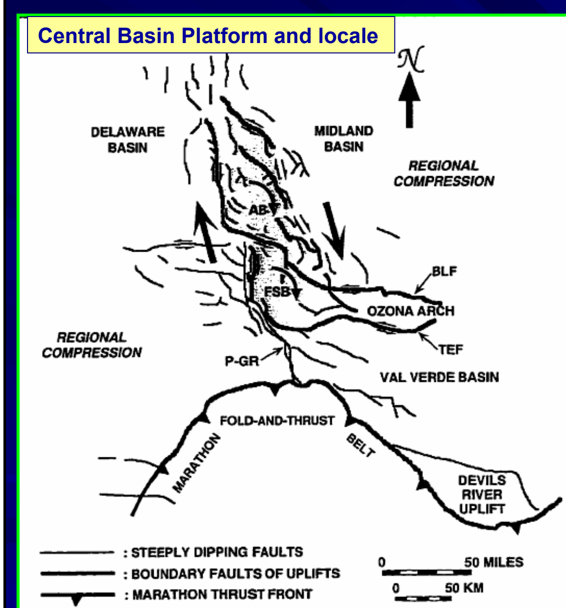
- **Approximate location of Dollarhide Field on the CBP**
- ***Llano front* – 1.1 Ga thrust fault**

Paleozoic Basins and Faults





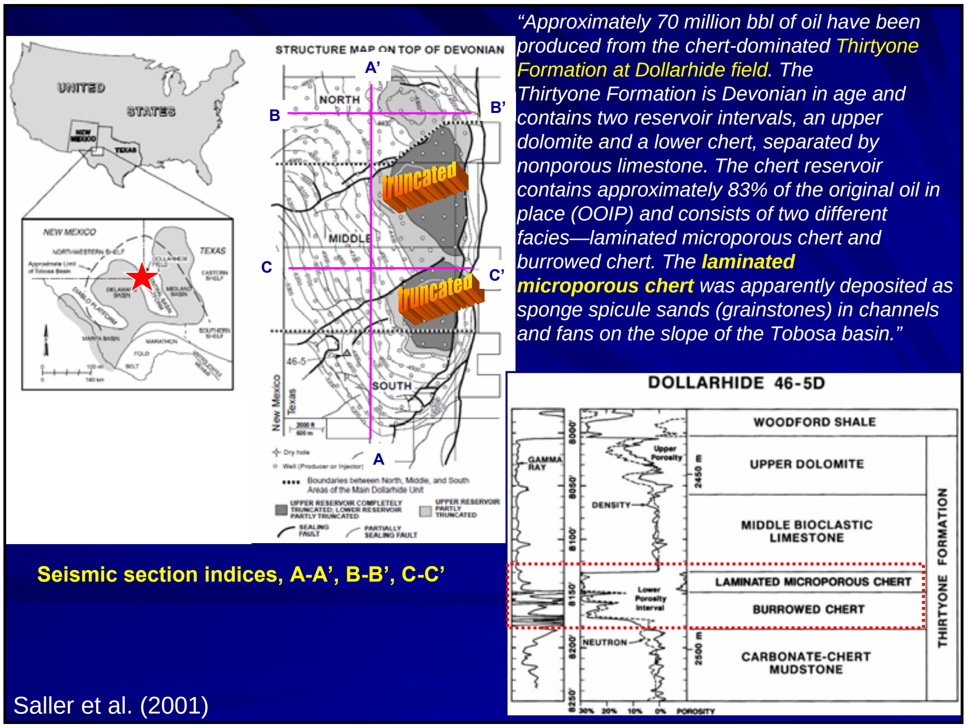
http://www.netl.doe.gov/technologies/oil-gas/Petroleum/projects/EP/ResChar/15509.htm

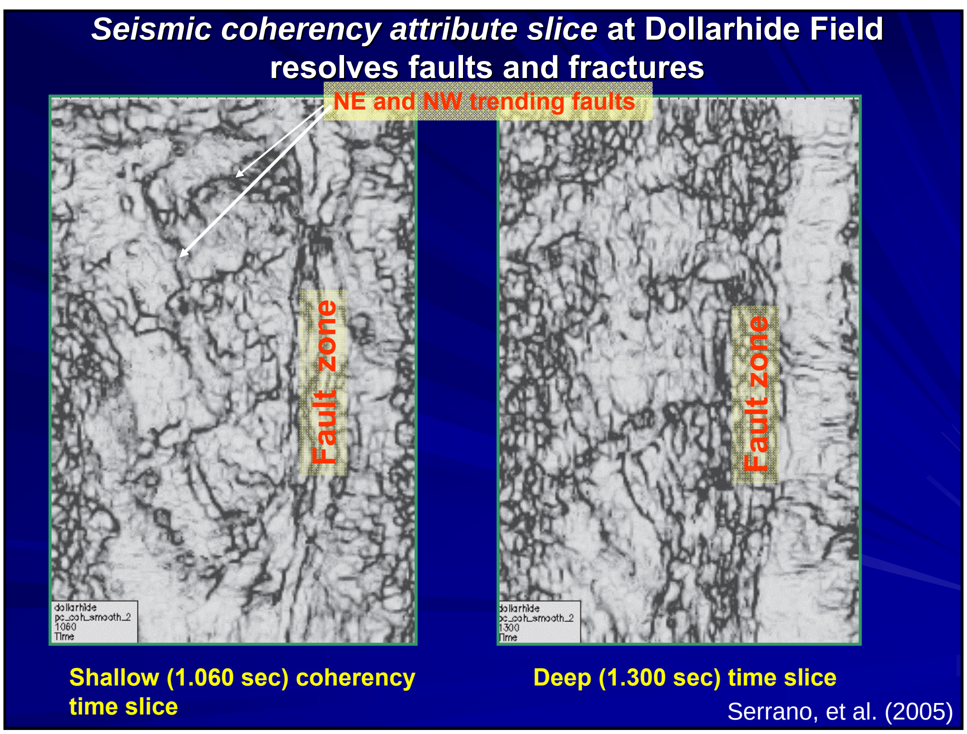


Late Paleozoic deformation history for CBP and adjacent areas

- Late Mississippian to early Pennsylvanian right-lateral deformation
- Late Pennsylvanian-early Wolfcampian deformation along faulted boundaries of the CBP accompanied by basement shortening and uplift via oblique-slip faulting.
- Faulting and uplift on CBP ceased by late Wolfcampian.

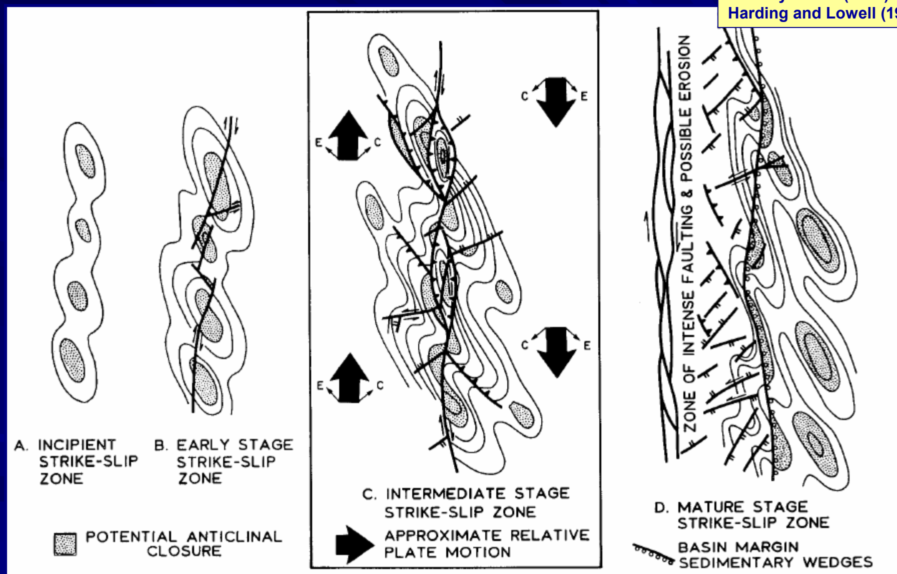
Po-Ching Tai (2001)


STRUCTURE MAP ON TOP OF DEVONIAN
A'
B
B'
NORTH
truncated
MIDDLE
C
C'
truncated
SOUTH
A
New Mexico
Texas
UNITED
STATES
NEW MEXICO
TEXAS
"Approximately 70 million bbl of oil have been produced from the chert-dominated Thirtyone Formation at Dollarhide field. The Thirtyone Formation is Devonian in age and contains two reservoir intervals, an upper dolomite and a lower chert, separated by nonporous limestone. The chert reservoir contains approximately 83% of the original oil in place (OOIP) and consists of two different facies—laminated microporous chert and burrowed chert. The laminated microporous chert was apparently deposited as sponge spicule sands (grainstones) in channels and fans on the slope of the Tobosa basin."
DOLLARHIDE 46-5D
GAMMA RAY
DENSITY
NEUTRON
WOODFORD SHALE
UPPER DOLOMITE
MIDDLE BIOCLASTIC LIMESTONE
LAMINATED MICROPOROUS CHERT
BURROWED CHERT
CARBONATE-CHERT MUDSTONE
THIRTYONE FORMATION
Seismic section indices, A-A', B-B', C-C'
Saller et al. (2001)

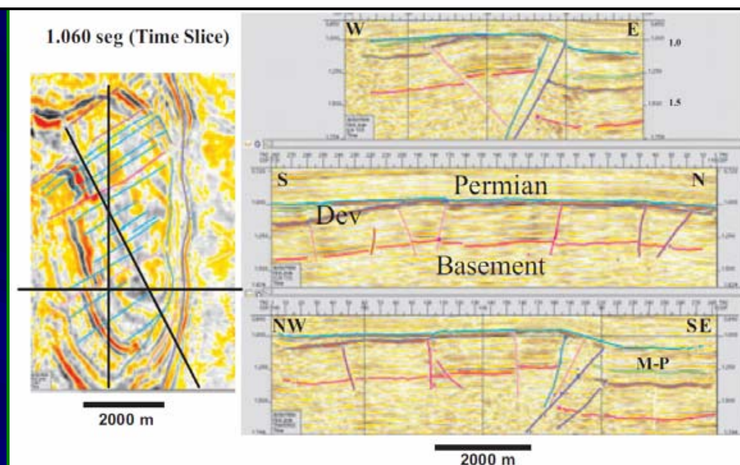

Seismic coherency attribute slice at Dollarhide Field resolves faults and fractures
NE and NW trending faults
Fault zone
Fault zone
Shallow (1.060 sec) coherency time slice
Deep (1.300 sec) time slice
Serrano, et al. (2005)

Evolution of structural assemblage along major strike-slip fault

In Serrano et al., (2005) from Sylvester (1988) after Harding and Lowell (1979)



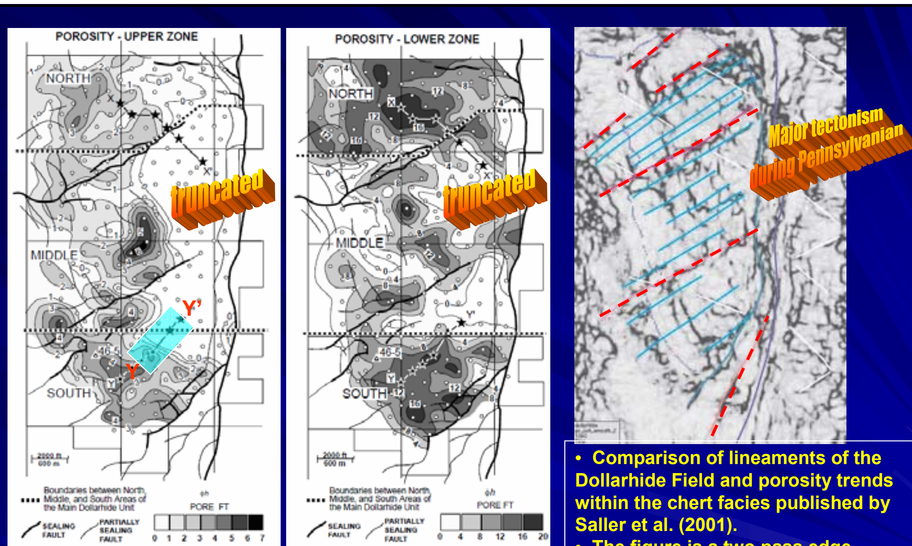
Right simple shear



- Reverse faults bound field
- High angle, northeast striking, reverse faults with right lateral displacement (pink)
- Multiple right lateral strike-slip faults (in blue) mask the presence of these lineaments.

Light blue = base of early Permian unconformity. Light green = Mississippian to Pennsylvanian unconformity.
Dark blue = top of Thirtyone Formation of Middle Devonian age. Pink = top of pre-Cambrian granite.
Location of cross-sections is in black.

Serrano, et al. (2005)



Phi*h map upper zone from Saller et al. (2001)

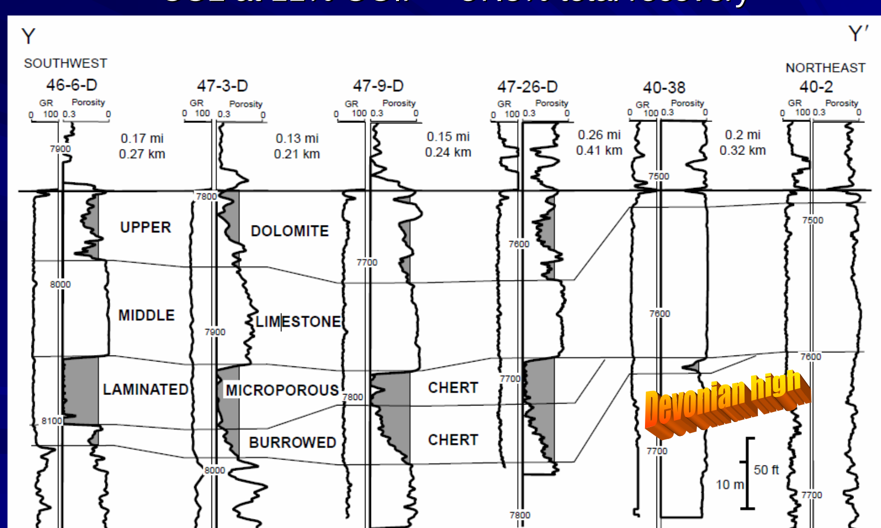
Phi*h map lower zone -- Porous chert removed from crest of structure along east side.

- Comparison of lineaments of the Dollarhide Field and porosity trends within the chert facies published by Saller et al. (2001).
- The figure is a two pass edge preserving smoothing + coherency at time slice 1.060 sec that shows the interpreted faults. The northeast and northwest striking faults are segmenting the porosity trends.

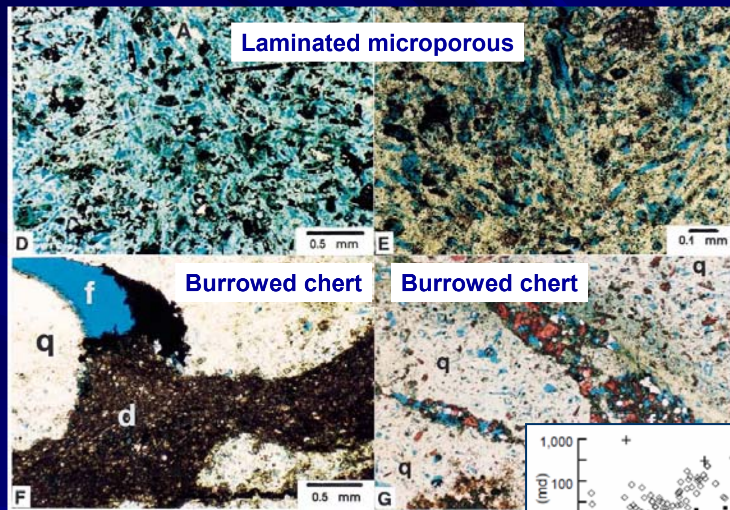
Serrano, et al. (2005)

Laminated microporous chert accumulate on flanks of structure (0-80 ft thick, 35-30% phi, 5-30 md)

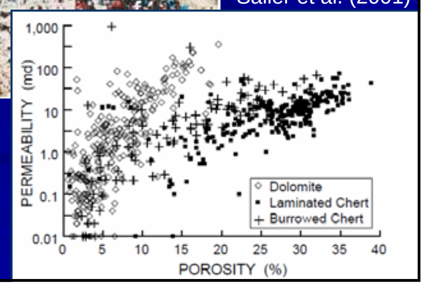
field: primary 13% OOIP; waterflood 30% OOIP, infill 3.5% OOIP, CO2 at 11% OOIP = 57.5% total recovery



Saller et al. (2001)

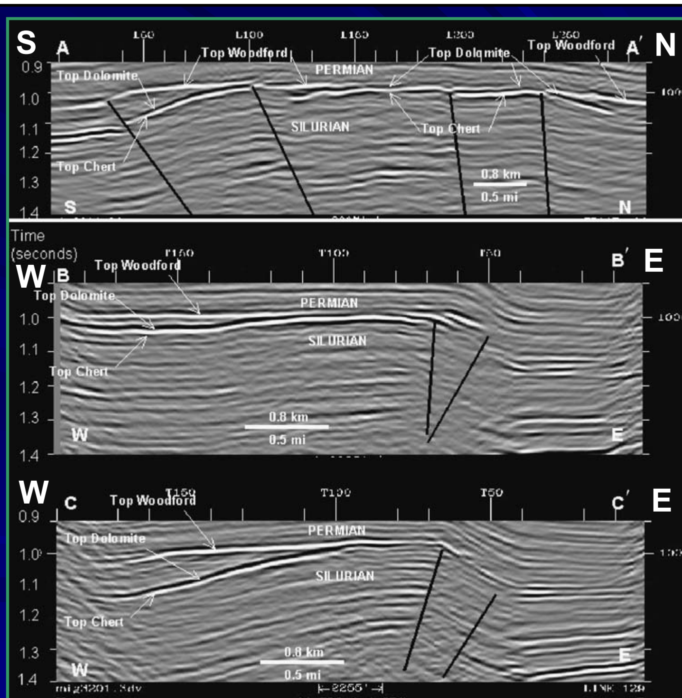


Saller et al. (2001)



Devonian cherts at Dollarhide Field

- **Predominately moldic pores**
- **Also, intercrystalline dolomite Ø**



seismic sections

A-A' (south-north)

B'-B' (west-east)

C-C' (west-east

- **variable density seismic amplitude over Dollarhide**
- **Woodford Shale thickens off structure**
- **Erosional truncation of Woodford Shale on crest of structure after Carboniferous folding and prior to Permian shelfal carbonates**

Saller et al. (2001)

Conclusions of Serrano et al. (2005)

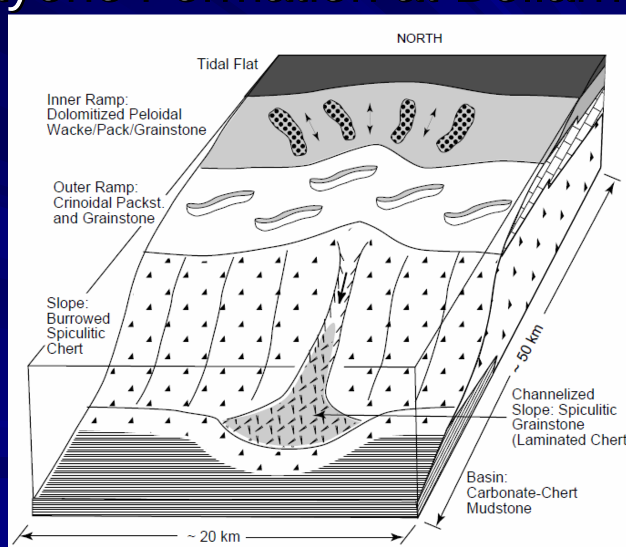
- The Dollarhide structure is a truncated asymmetric anticline formed during the Late Paleozoic due to contractional strike-slip faulting.
- The lineaments are the result of at least one phase of strike-slip movement along a northeast-striking right lateral fault.
- Reactivation of preexisting faults occurred in a post-Permian phase of compression, possibly during the Laramide orogeny.
- Porosity-thickness trends are segmented by the conjugate shear faults.
- The structure fits in the block rotational model of the Central Basin Platform.
- Lineaments of the Dollarhide Field structure are better interpreted using 3D seismic attributes on time slices and horizon slices that assist the interpretation of cross-sections, where some of the features are beyond seismic resolution.

****

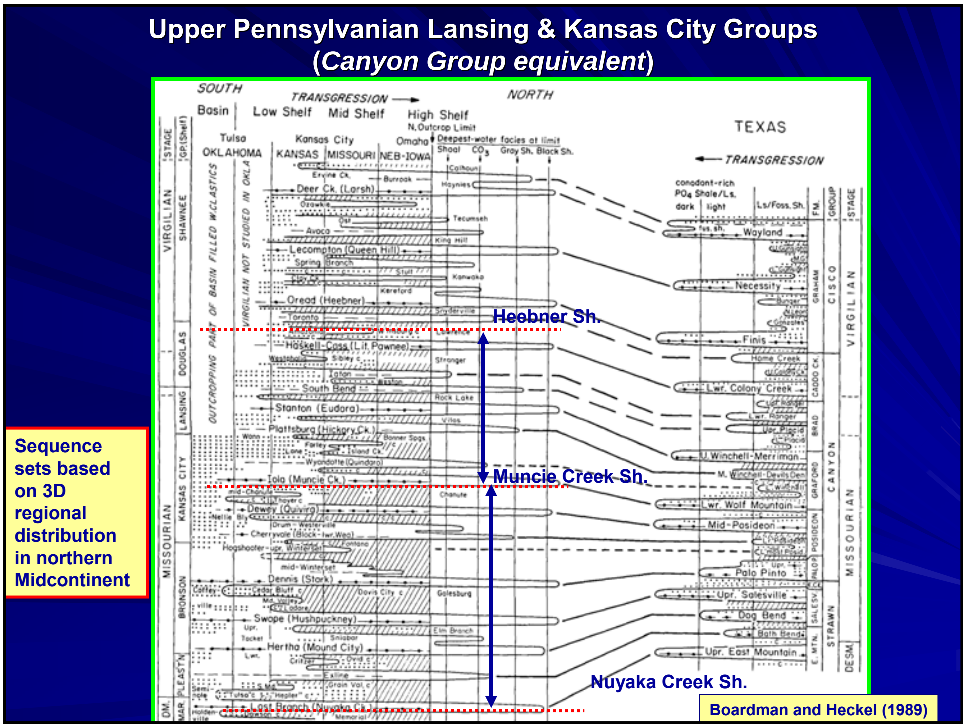
Episodes of structural activity – Hunton (paleotopography), pre-Woodford (thinning of shale), Post Woodford (erosional thinning), Laramide? (later deformation)

Serrano, et al., 2005, *www.agl.uh.edu/projects/chert/SERRANO%202003%20SEG.pdf*

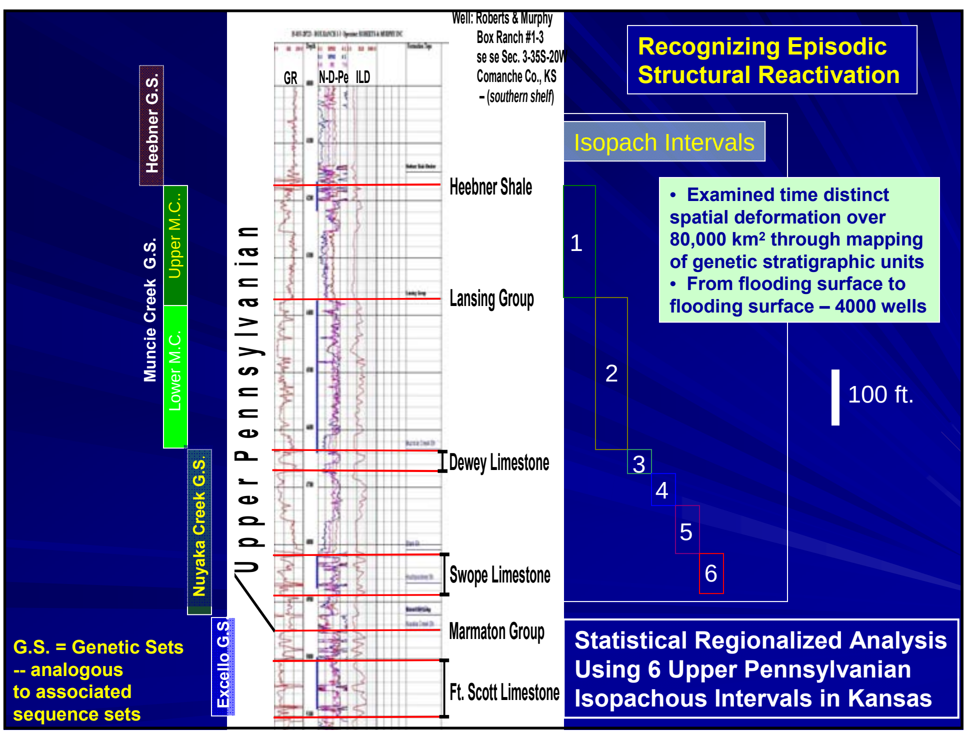
Model for deposition of the Thirtyone Formation at Dollarhide



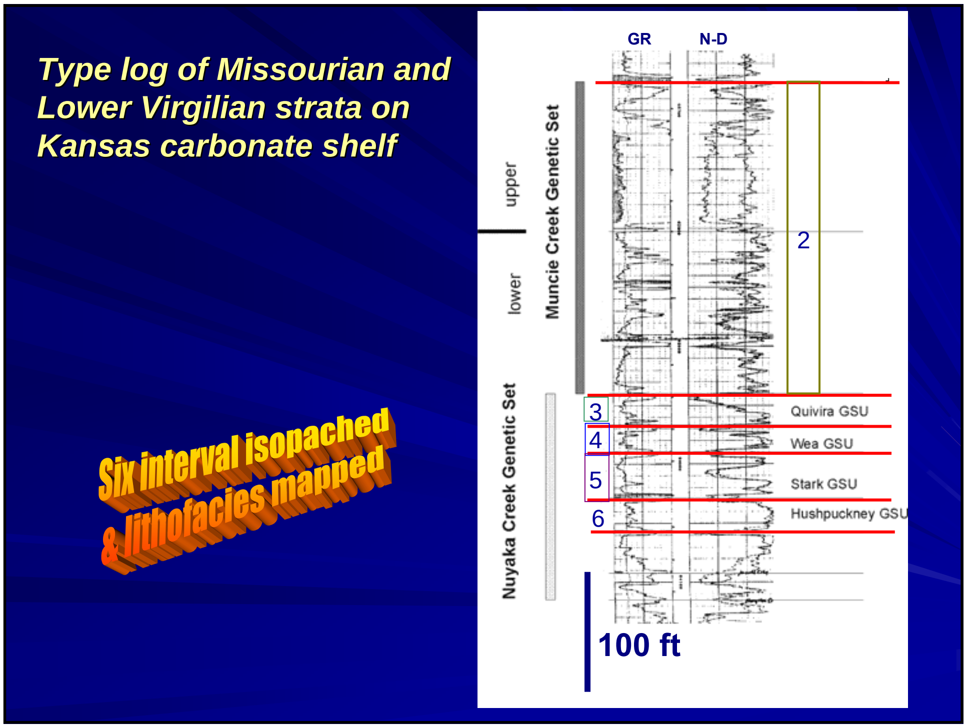
Saller et al. (2001)

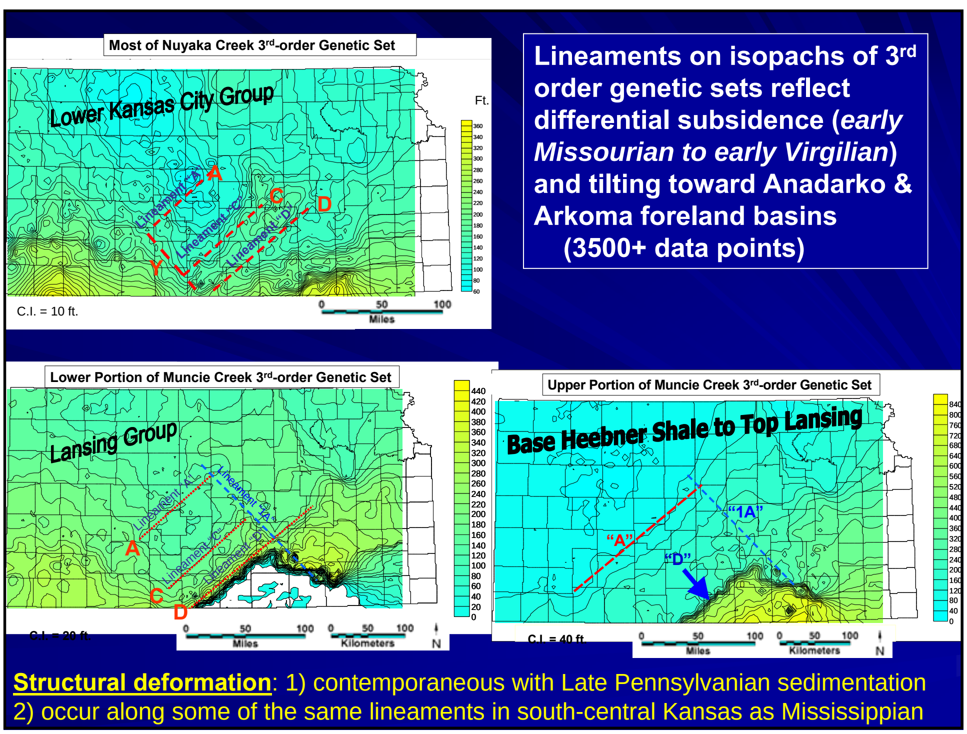


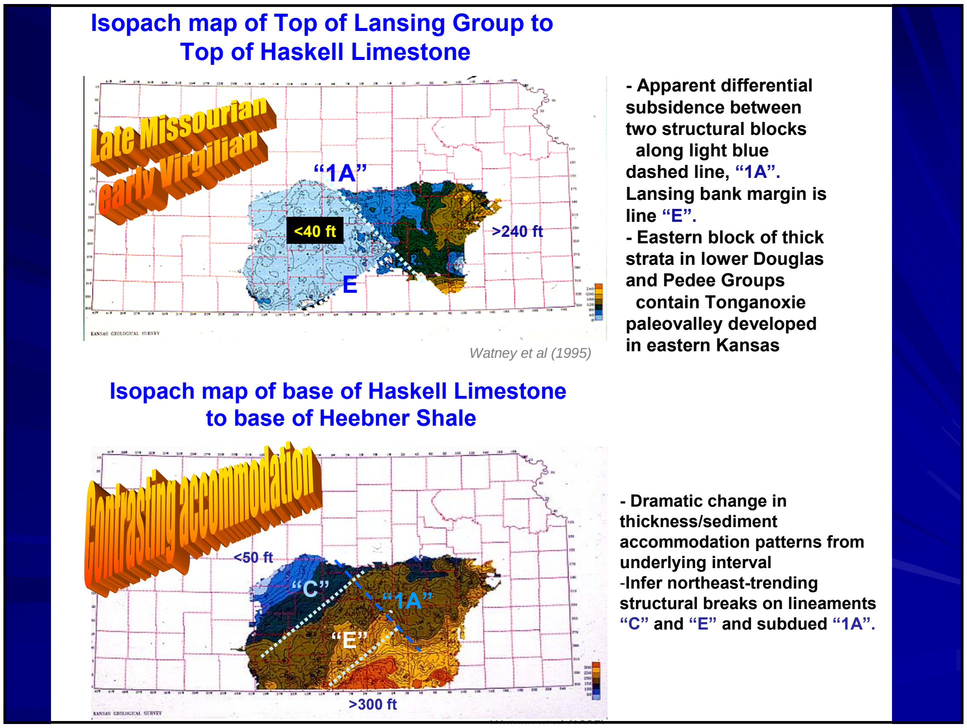
Upper Pennsylvanian Lansing & Kansas City Groups
(Canyon Group equivalent)
Sequence sets based on 3D regional distribution in northern Midcontinent
Heebner Sh.
Muncie Creek Sh.
Nuyaka Creek Sh.
Boardman and Heckel (1989)
SOUTH
NORTH
TRANSGRESSION
Basin
Low Shelf
Mid Shelf
High Shelf
OKLAHOMA
KANSAS
MISSOURI
NEB-IOWA
TEXAS
VIRGILIAN
MISSOURIAN
CISCO
CANYON
STRAWN

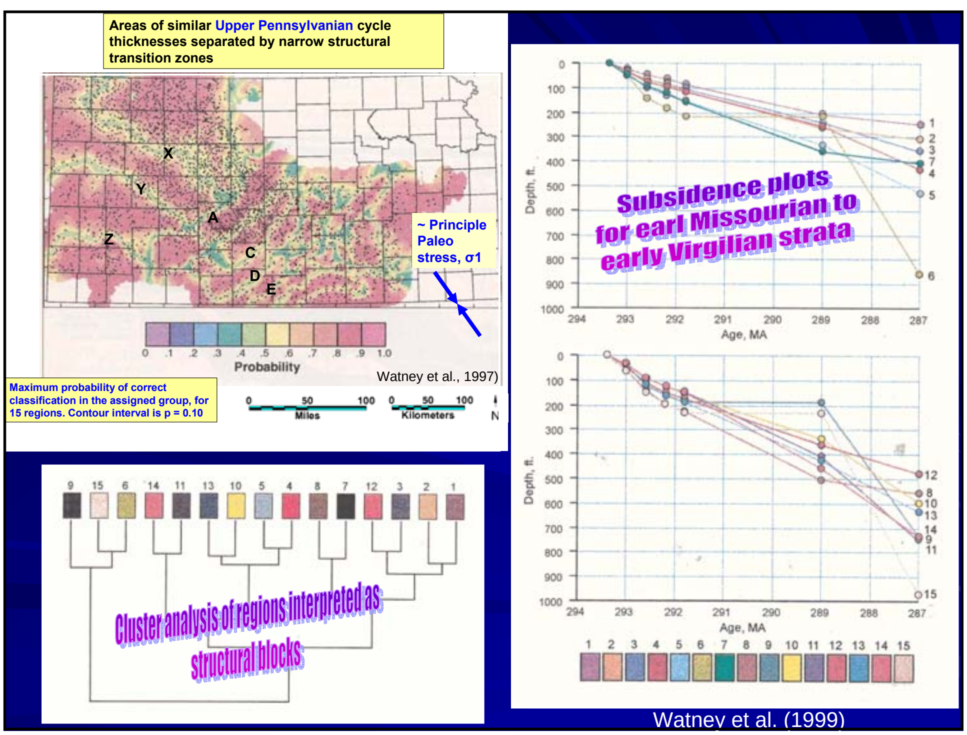


Recognizing Episodic Structural Reactivation
Isopach Intervals
• Examined time distinct spatial deformation over 80,000 km² through mapping of genetic stratigraphic units
• From flooding surface to flooding surface – 4000 wells
100 ft.
Statistical Regionalized Analysis Using 6 Upper Pennsylvanian Isopachous Intervals in Kansas
Well: Roberts & Murphy Box Ranch #1-3 se se Sec. 3-35S-20W Comanche Co., KS – (southern shelf)
GR
N-D-Pe
ILD
Heebner Shale
Lansing Group
Dewey Limestone
Swope Limestone
Marmaton Group
Ft. Scott Limestone
1
2
3
4
5
6
Upper Pennsylvanian
Heebner G.S.
Muncie Creek G.S.
Upper M.C.
Lower M.C.
Nuyaka Creek G.S.
Excello G.S.
G.S. = Genetic Sets -- analogous to associated sequence sets

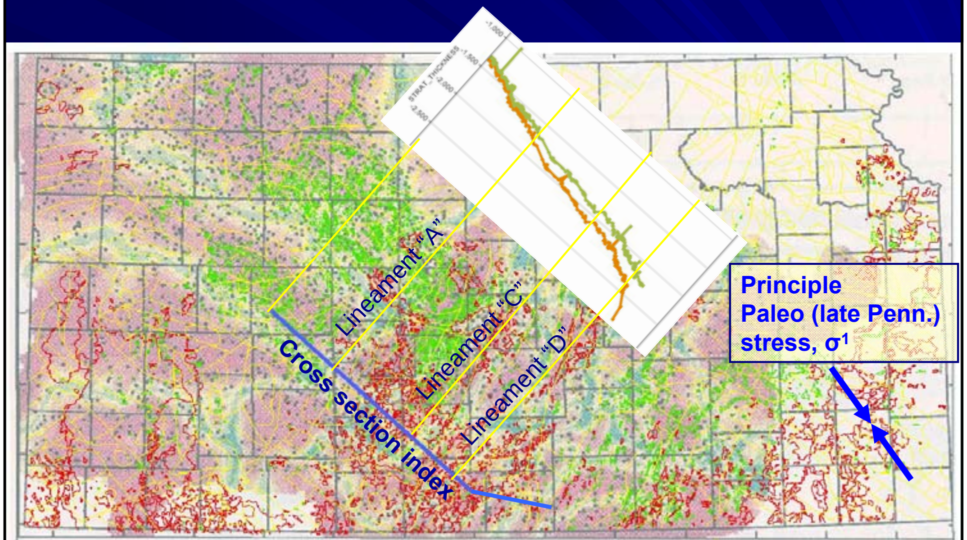

Type log of Missourian and Lower Virgilian strata on Kansas carbonate shelf
Six interval isopached & lithofacies mapped
GR
N-D
upper
lower
Muncie Creek Genetic Set
Nuyaka Creek Genetic Set
2
3
4
5
6
Quivira GSU
Wea GSU
Stark GSU
Hushpuckney GSU
100 ft


Most of Nuyaka Creek 3rd-order Genetic Set
Lower Kansas City Group
C.I. = 10 ft.
Lineaments on isopachs of 3rd order genetic sets reflect differential subsidence (early Missourian to early Virgilian) and tilting toward Anadarko & Arkoma foreland basins
(3500+ data points)
Lower Portion of Muncie Creek 3rd-order Genetic Set
Lansing Group
Upper Portion of Muncie Creek 3rd-order Genetic Set
Base Heebner Shale to Top Lansing
"A"
"1A"
"D"
C.I. = 40 ft
Miles
Kilometers
Structural deformation: 1) contemporaneous with Late Pennsylvanian sedimentation
2) occur along some of the same lineaments in south-central Kansas as Mississippian


Isopach map of Top of Lansing Group to
Top of Haskell Limestone
Late Missourian
early Virgilian
"1A"
<40 ft
>240 ft
E
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
Contrasting accommodation
<50 ft
"C"
"1A"
"E"
>300 ft
- Dramatic change in thickness/sediment accommodation patterns from underlying interval
-Infer northeast-trending structural breaks on lineaments "C" and "E" and subdued "1A".

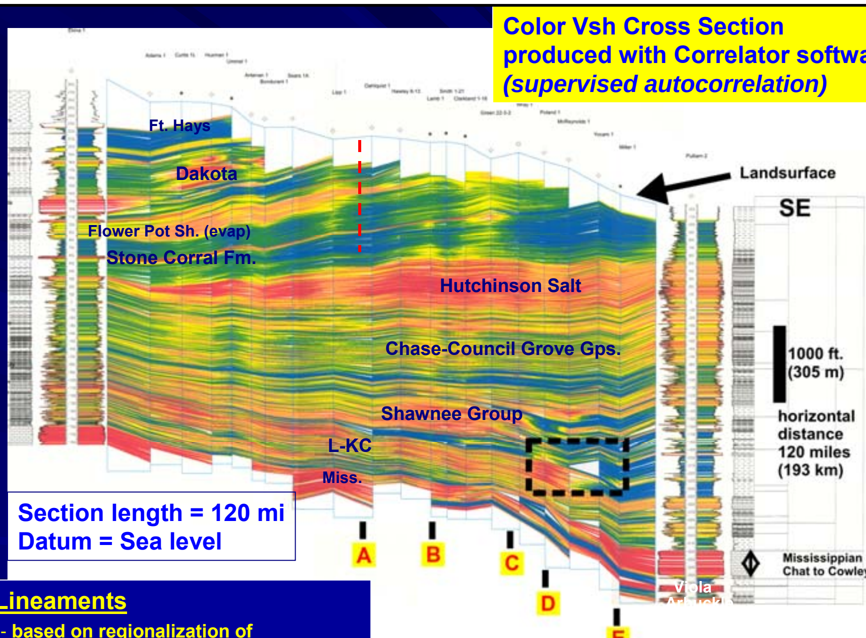

Areas of similar Upper Pennsylvanian cycle thicknesses separated by narrow structural transition zones
X
Y
A
Z
C
D
E
~ Principle Paleo stress, σ1
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
Probability
Watney et al., 1997)
Maximum probability of correct classification in the assigned group, for 15 regions. Contour interval is p = 0.10
Miles
Kilometers
Subsidence plots
for earl Missourian to
early Virgilian strata
Depth, ft.
Age, MA
Cluster analysis of regions interpreted as
structural blocks
Watney et al. (1999)

- Regionalization analysis of Upper Pennsylvanian thicknesses overlain on oil (green) and gas (red) fields
- Oil and gas production appears to correlate with basement blocks
- Fine yellow lines = magnetic lineaments



http://drysdale.kgs.ku.edu/kgs/oilgas/strat_welltops/top_viewer.cfm

Color Vsh Cross Section produced with Correlator software *(supervised autocorrelation)*

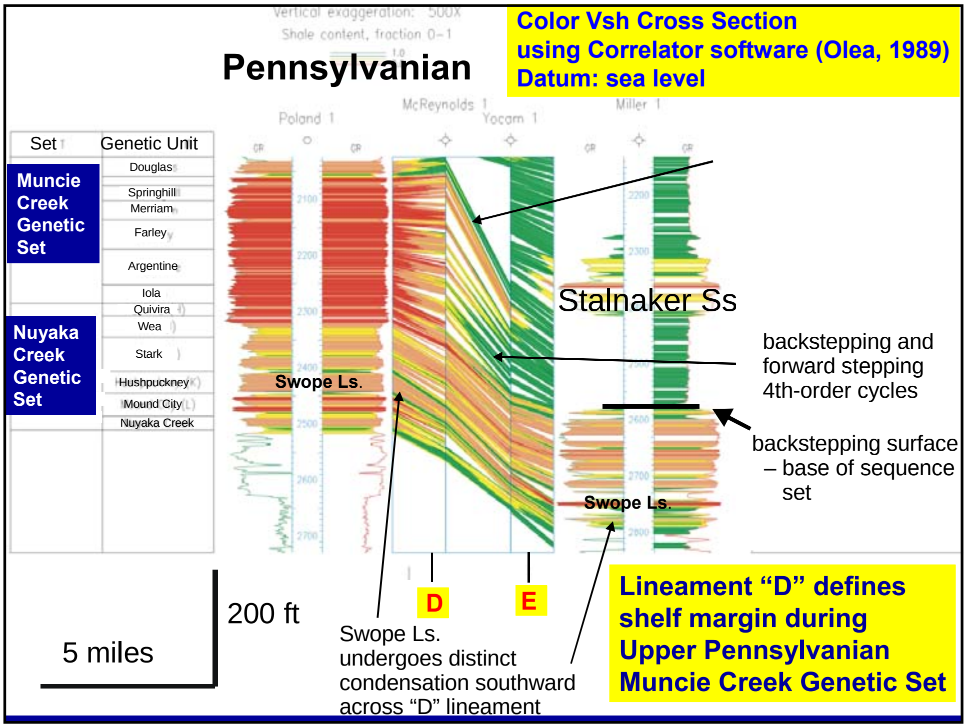


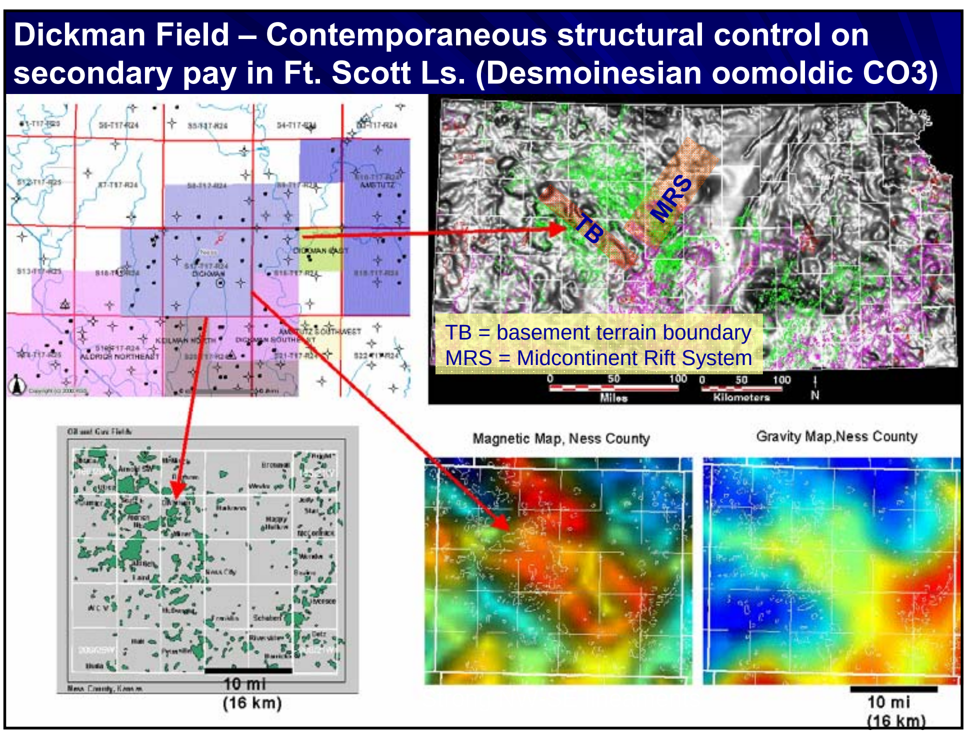
Section length = 120 mi
Datum = Sea level

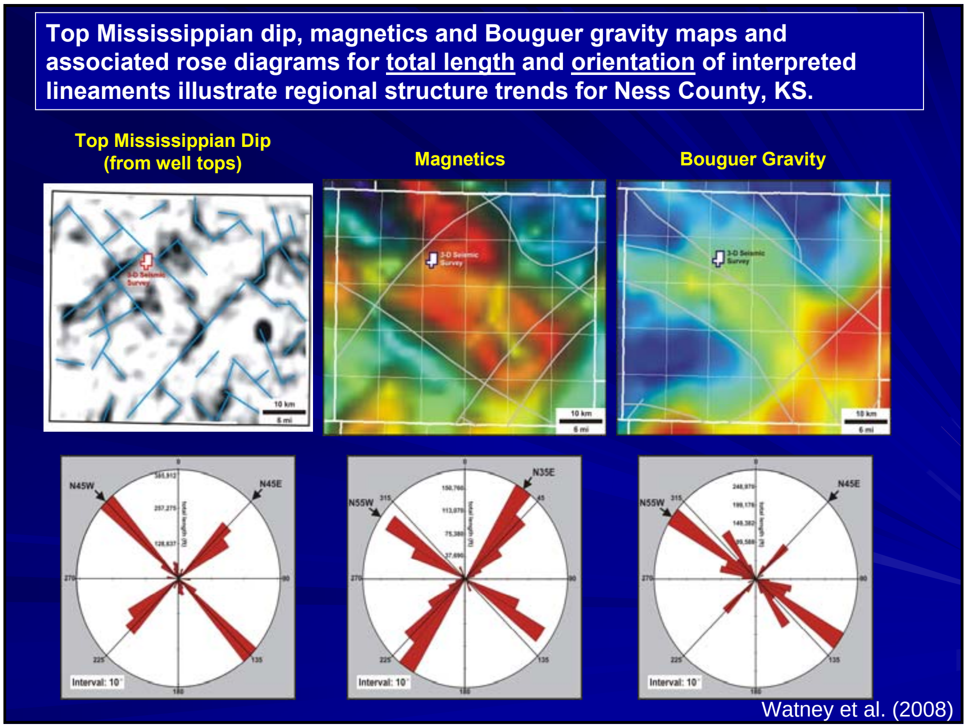
Lineaments
- based on regionalization of Upper Pennsylvanian isopachous maps

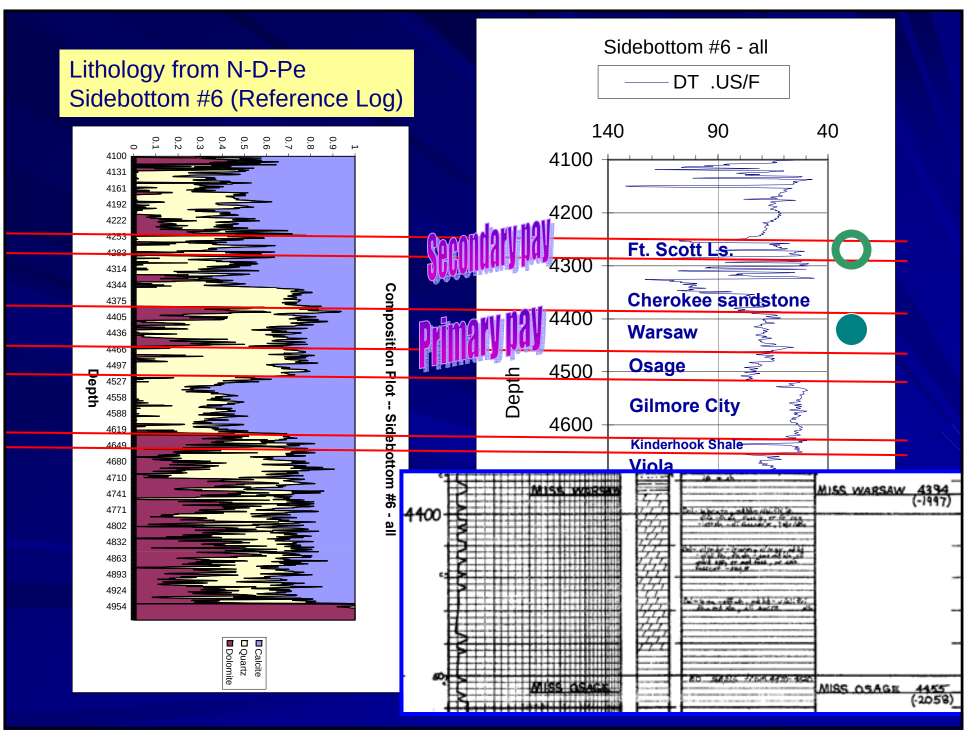
Watney et al. (1999)

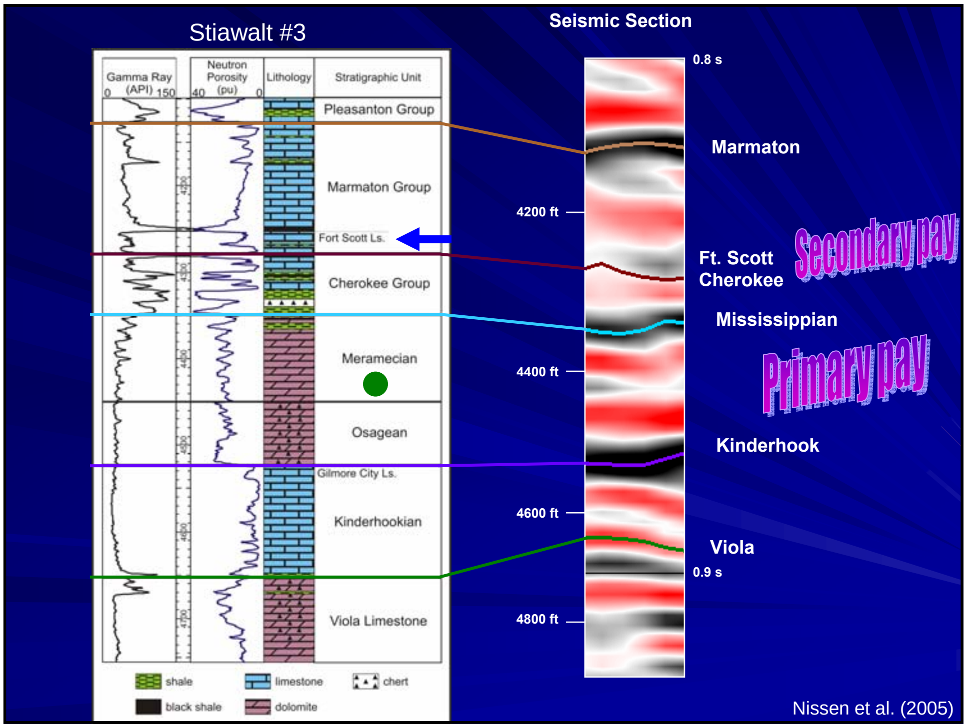
Reds & Yellows = Carbonates, Evaporites, Sandstones
Blue = Shales

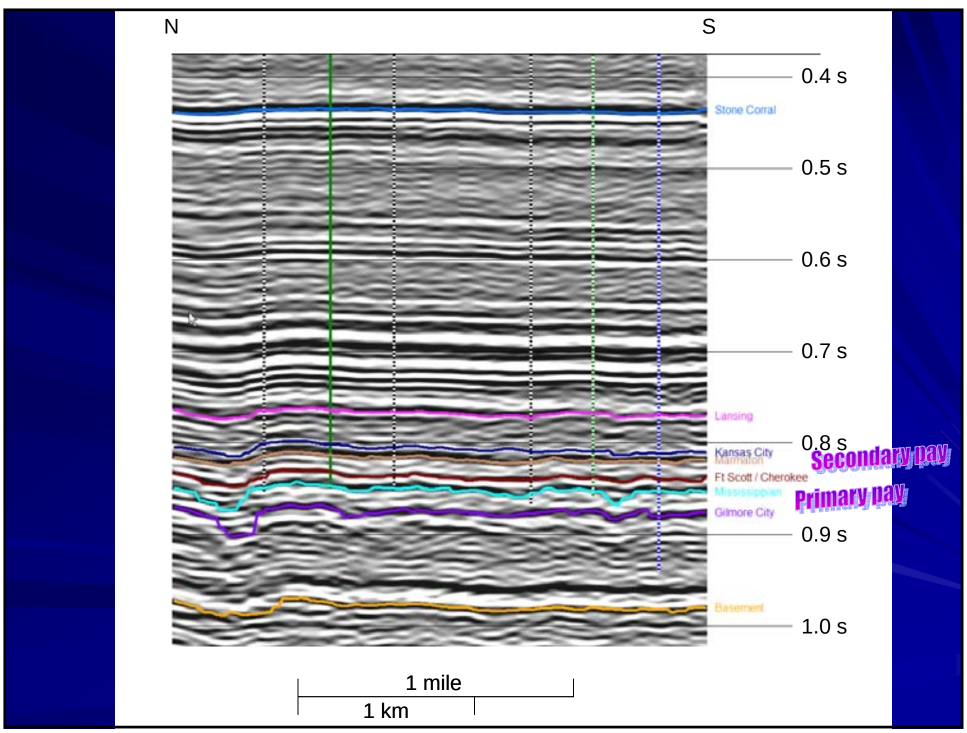

Color Vsh Cross Section
using Correlator software (Olea, 1989)
Datum: sea level
Pennsylvanian
Set
Genetic Unit
Muncie Creek Genetic Set
Nuyaka Creek Genetic Set
Douglas
Springhill
Merriam
Farley
Argentine
Iola
Quivira
Wea
Stark
Hushpuckney
Mound City
Nuyaka Creek
Swope Ls.
Stalnaker Ss
backstepping and forward stepping 4th-order cycles
backstepping surface – base of sequence set
Swope Ls.
5 miles
200 ft
D
E
Swope Ls. undergoes distinct condensation southward across “D” lineament
Lineament “D” defines shelf margin during Upper Pennsylvanian Muncie Creek Genetic Set

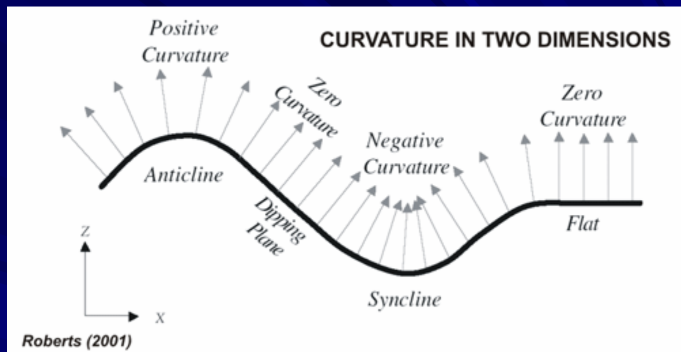

Dickman Field – Contemporaneous structural control on secondary pay in Ft. Scott Ls. (Desmoinesian oomoldic CO3)
TB
MRS
TB = basement terrain boundary
MRS = Midcontinent Rift System
Magnetic Map, Ness County
Gravity Map,Ness County
10 mi
(16 km)
10 mi
(16 km)


Top Mississippian dip, magnetics and Bouguer gravity maps and associated rose diagrams for total length and orientation of interpreted lineaments illustrate regional structure trends for Ness County, KS.
Top Mississippian Dip (from well tops)
Magnetics
Bouguer Gravity
N45W
N45E
N55W
N35E
Interval: 10°
Watney et al. (2008)


Lithology from N-D-Pe Sidebottom #6 (Reference Log)
Composition Plot -- Sidebottom #6 - all
Depth
Calcite
Quartz
Dolomite
Sidebottom #6 - all
DT .US/F
140
90
40
4100
4200
4300
4400
4500
4600
Secondary pay
Primary pay
Ft. Scott Ls.
Cherokee sandstone
Warsaw
Osage
Gilmore City
Kinderhook Shale
Viola
MISS WARSAW 4394 (-1997)
MISS OSAGE 4455 (-2058)


Stiawalt #3
Seismic Section
Gamma Ray (API) 0 150
Neutron Porosity (pu) 40 0
Lithology
Stratigraphic Unit
Pleasanton Group
Marmaton Group
Fort Scott Ls.
Cherokee Group
Meramecian
Osagean
Gilmore City Ls.
Kinderhookian
Viola Limestone
shale
limestone
chert
black shale
dolomite
0.8 s
4200 ft
4400 ft
4600 ft
4800 ft
0.9 s
Marmaton
Ft. Scott
Cherokee
Mississippian
Kinderhook
Viola
Secondary pay
Primary pay
Nissen et al. (2005)

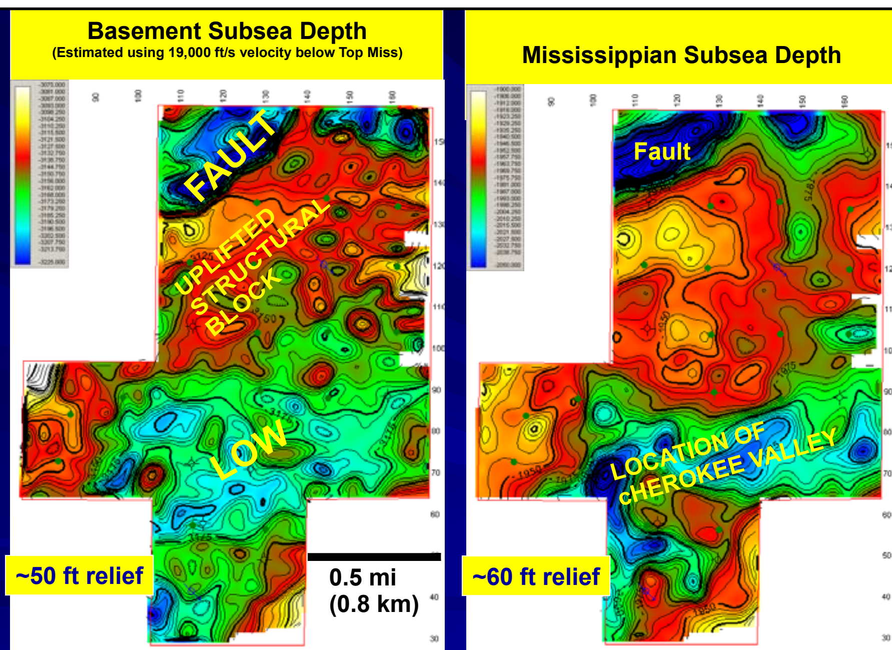

N
S
0.4 s
0.5 s
0.6 s
0.7 s
0.8 s
0.9 s
1.0 s
Stone Corral
Lansing
Kansas City
Marmaton
Ft Scott / Cherokee
Mississippian
Gilmore City
Basement
Secondary pay
Primary pay
1 mile
1 km



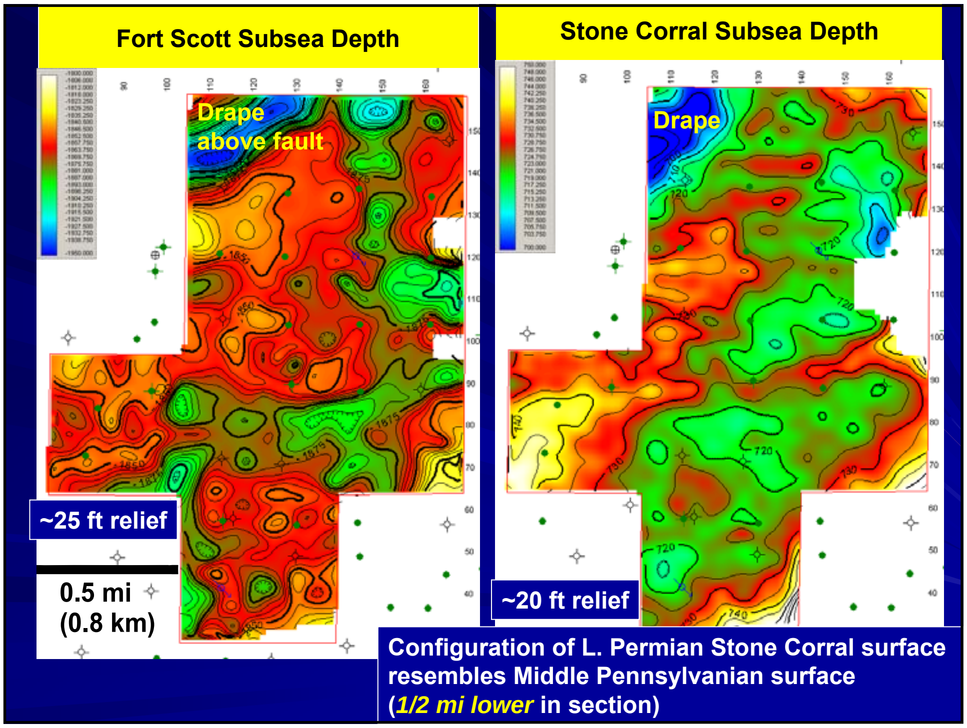
Curvature describes how bent a surface is at a particular point and is closely related to the second derivative of the curve defining the surface. The more bent a surface is, the larger the value of the curvature attribute. Positive curvature refers to an antiform feature, negative curvature refers to a synform feature, and zero curvature refers to a planar feature.

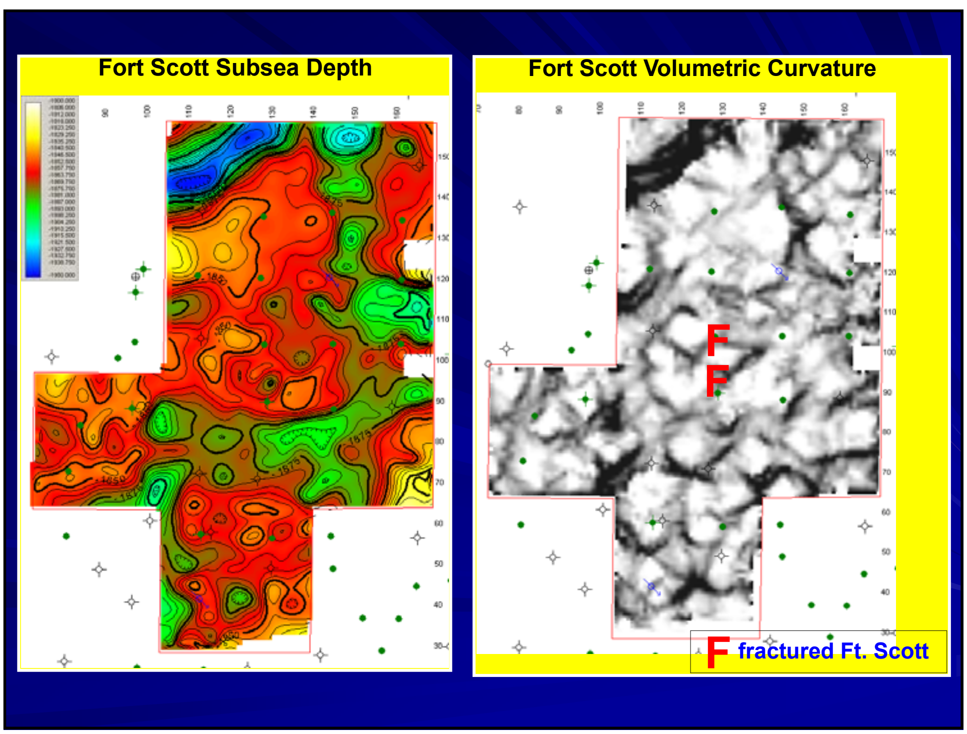
Various curvature attributes reveal useful information relating to folds, faults, and lineaments contained within the surface (Roberts, 2001). Most published work of curvature analysis applied to 3-D seismic data has been limited to calculations based on gridded interpreted horizons (e.g., Hart et al., 2002; Masaferro et al., 2003; Sigismondi and Soldo, 2003). However, recently, a suite of volumetric curvature attributes has been developed, where reflector curvature is calculated directly from the seismic data volume, with no prior interpretation required (Al-Dossary and Marfurt, 2006).

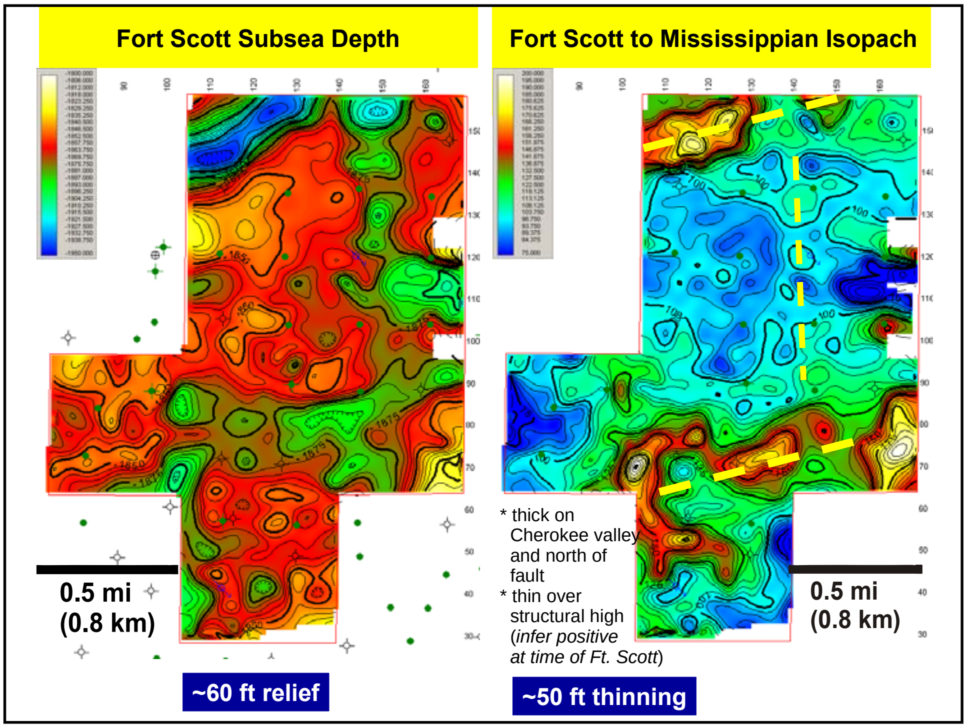
Nissen (2006)

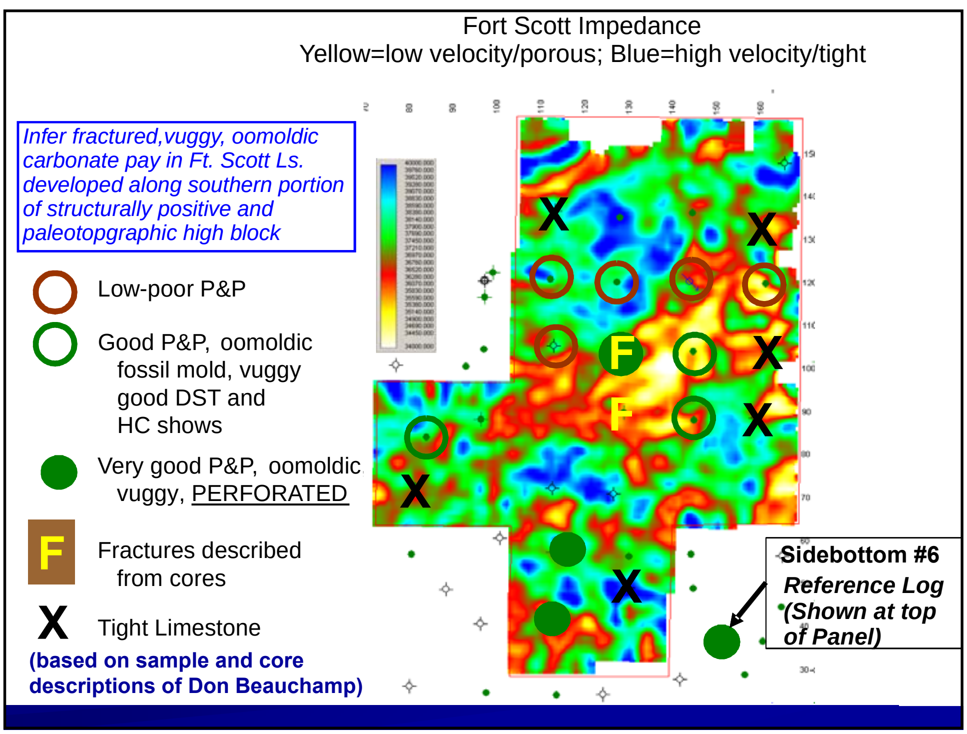


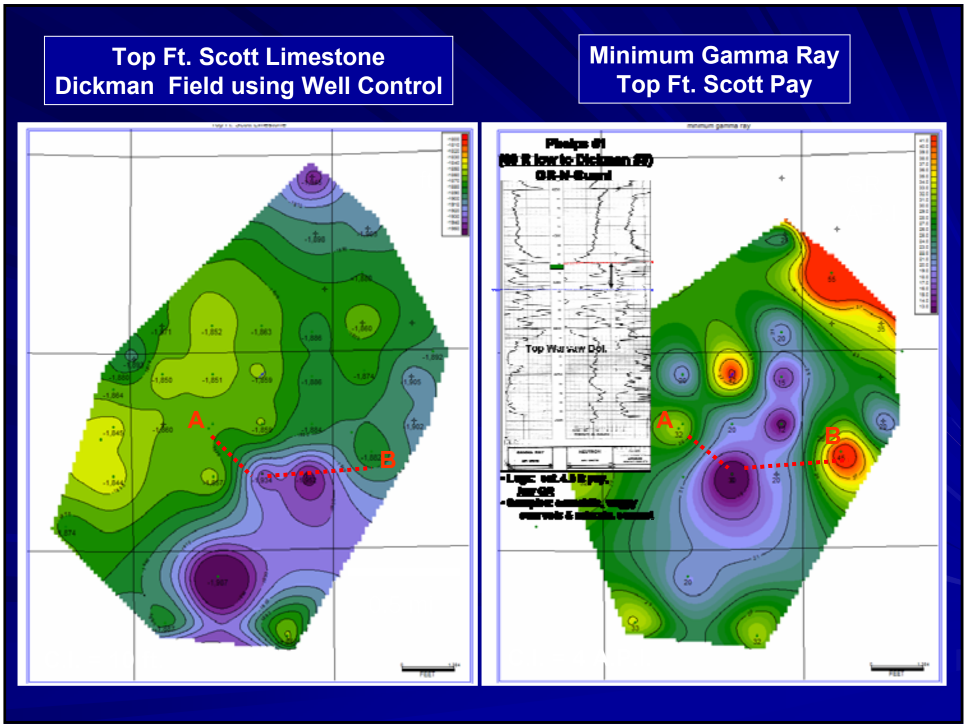
Cherokee paleovalley coincides with structural low on Precambrian surface

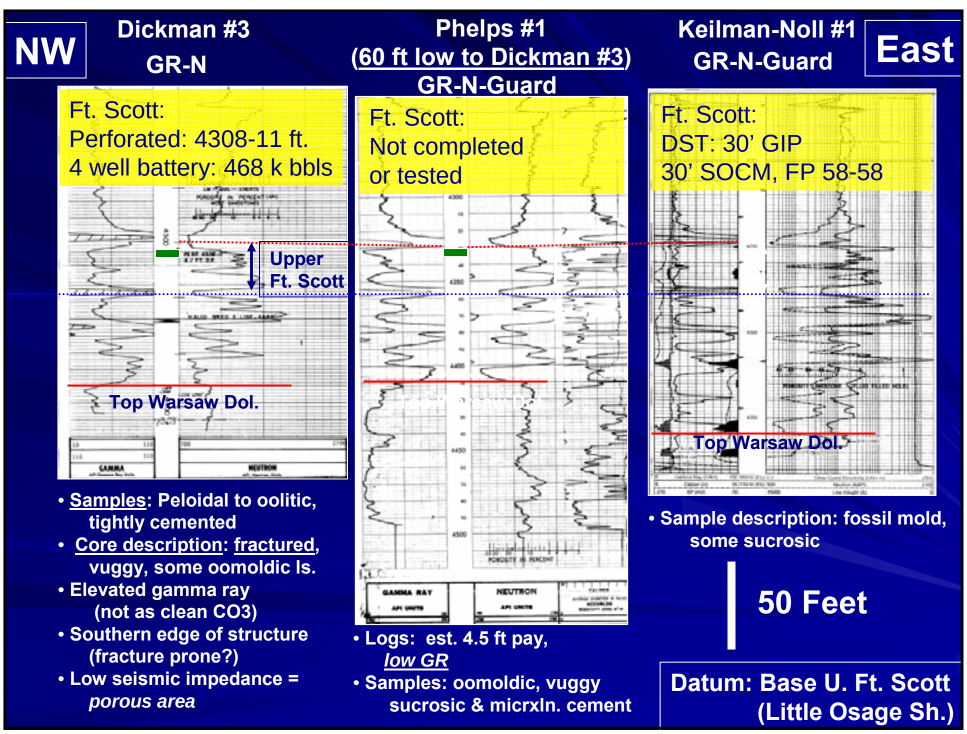

Fort Scott Subsea Depth
Stone Corral Subsea Depth
Drape above fault
Drape
~25 ft relief
0.5 mi
(0.8 km)
~20 ft relief
Configuration of L. Permian Stone Corral surface resembles Middle Pennsylvanian surface (1/2 mi lower in section)

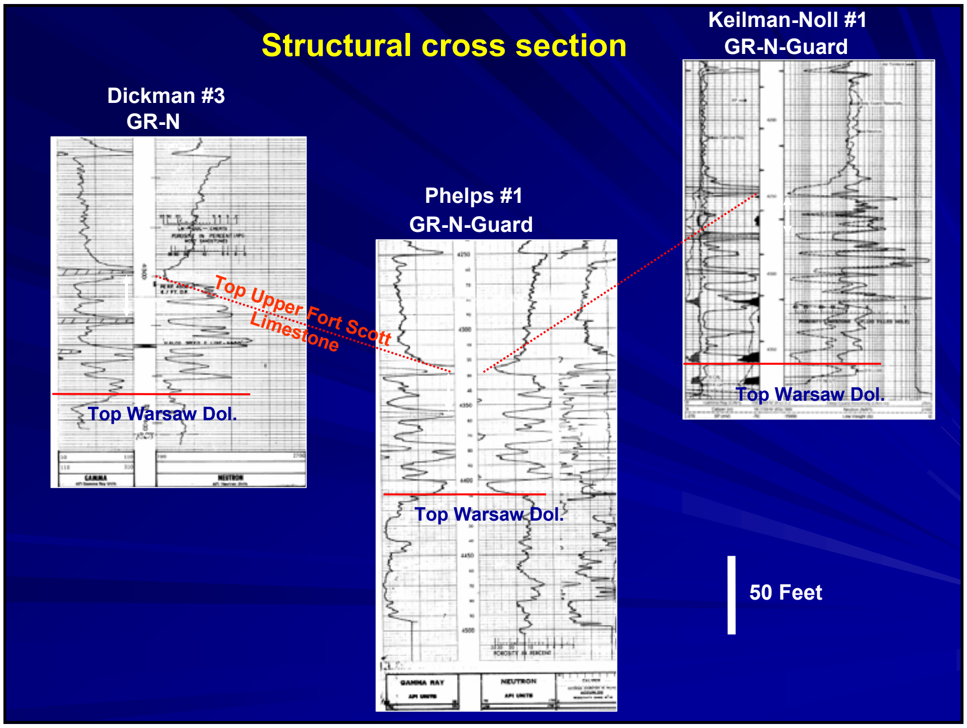

Fort Scott Subsea Depth
Fort Scott Volumetric Curvature
F
F
F fractured Ft. Scott

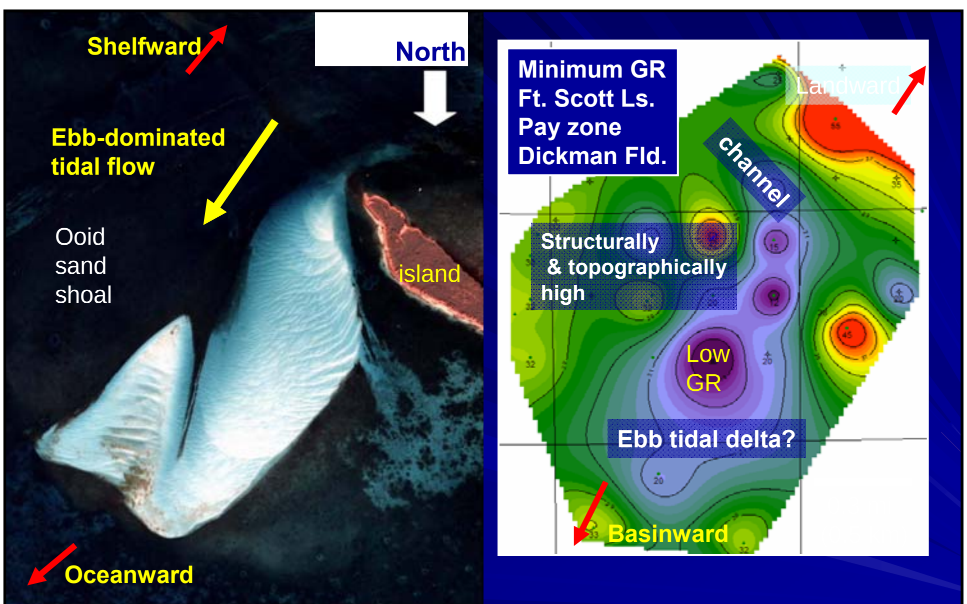

Fort Scott Subsea Depth
Fort Scott to Mississippian Isopach
* thick on Cherokee valley and north of fault
* thin over structural high (infer positive at time of Ft. Scott)
0.5 mi
(0.8 km)
0.5 mi
(0.8 km)
~60 ft relief
~50 ft thinning


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, PERFORATED
Fractures described from cores
Tight Limestone
(based on sample and core descriptions of Don Beauchamp)
Sidebottom #6
Reference Log
(Shown at top of Panel)


Top Ft. Scott Limestone
Dickman Field using Well Control
Minimum Gamma Ray
Top Ft. Scott Pay
A
B
Top Warsaw Dol.

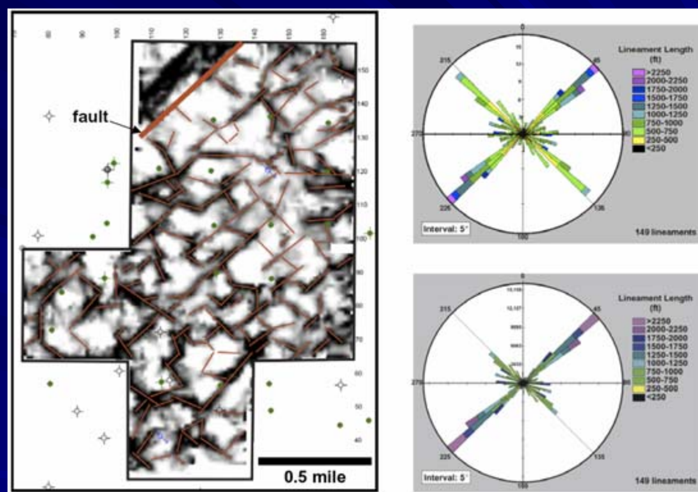

NW
Dickman #3
GR-N
Phelps #1
(60 ft low to Dickman #3)
GR-N-Guard
Keilman-Noll #1
GR-N-Guard
East
Ft. Scott:
Perforated: 4308-11 ft.
4 well battery: 468 k bbls
Upper
Ft. Scott
Top Warsaw Dol.
Ft. Scott:
Not completed
or tested
Ft. Scott:
DST: 30' GIP
30' SOCM, FP 58-58
Top Warsaw Dol.
• Samples: Peloidal 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
• Logs: est. 4.5 ft pay, low GR
• Samples: oomoldic, vuggy sucrosic & micrxln. cement
• 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 on Little Bahama Bank.
S. Reeder and G. Rankey (2005) *DigitalGlobe*[c]

Meramecian Warsaw Dolomite – Dickman Field



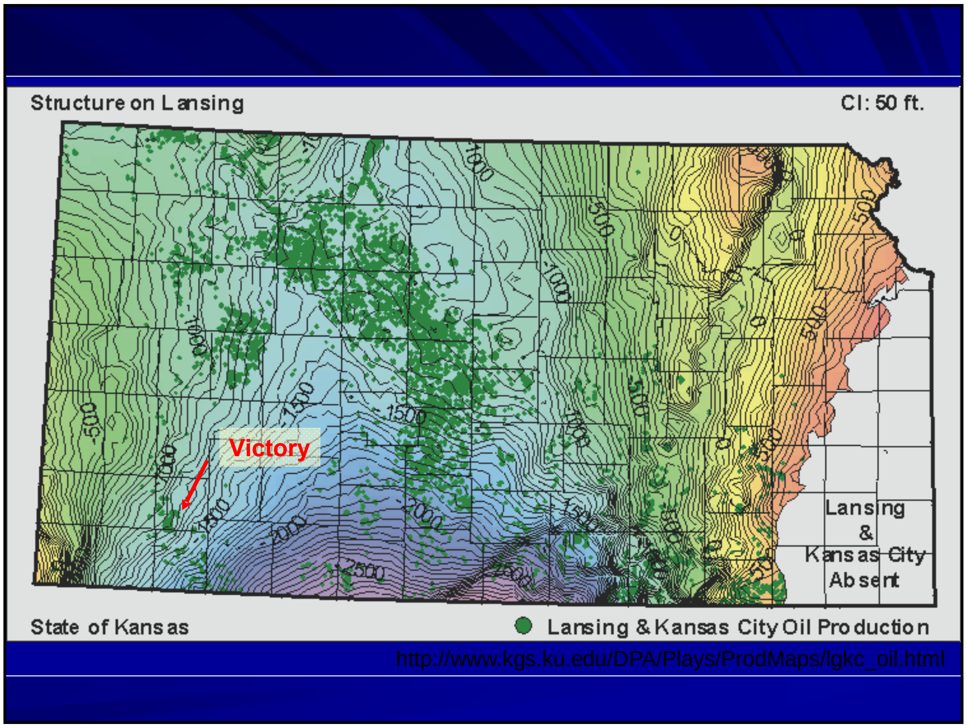
A) Maximum negative curvature extracted along a horizon approximately 25 ms below the Mississippian unconformity. Interpreted lineaments are shown in red.
B) Rose diagram showing the number of interpreted lineaments from (A) within a given azimuth sector. Lineament length is indicated by color.
C) Rose diagram showing the sum of lineament length within a given azimuth sector. Lengths of individual lineaments are indicated by color.

Nissen et al. (2006)

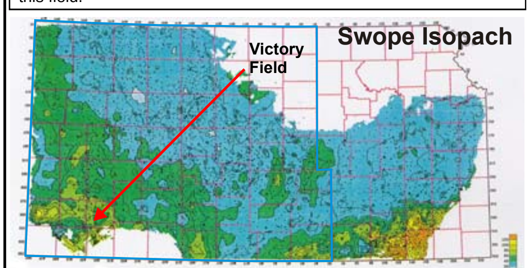
Victory Field, Haskell County

Lansing-Kansas City

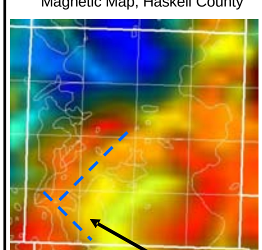
Oomoldic grainstone



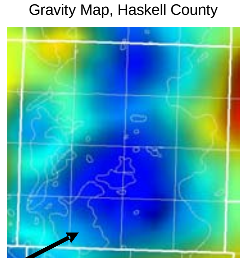
Information is shown below that it is another example of structural reactivation following an apparent basement template that has persisted through at least 10's of millions of years including affecting the accumulation of oolitic grainstones, the primary reservoir rock in this field.



Magnetic Map, Haskell County



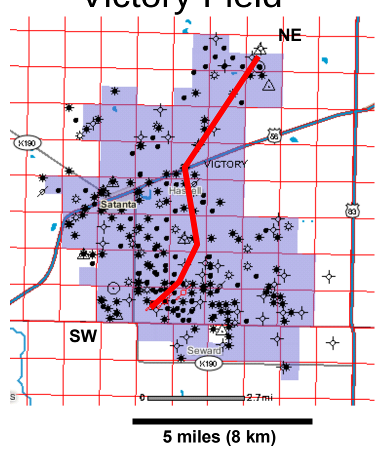
Gravity Map, Haskell County



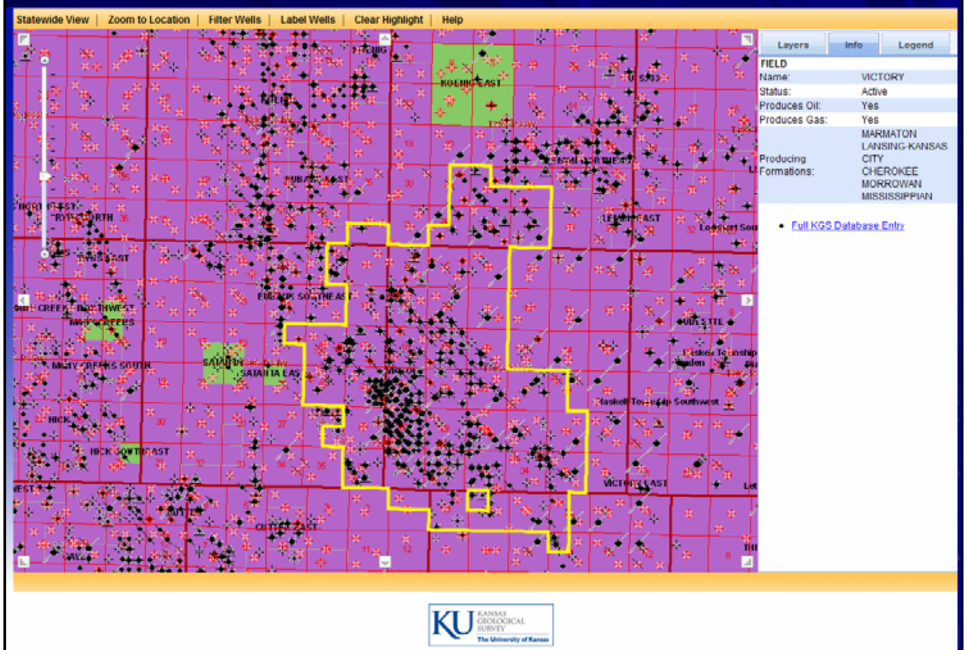
Victory Field

Structure maps of the tops of the Lansing and Chase Groups

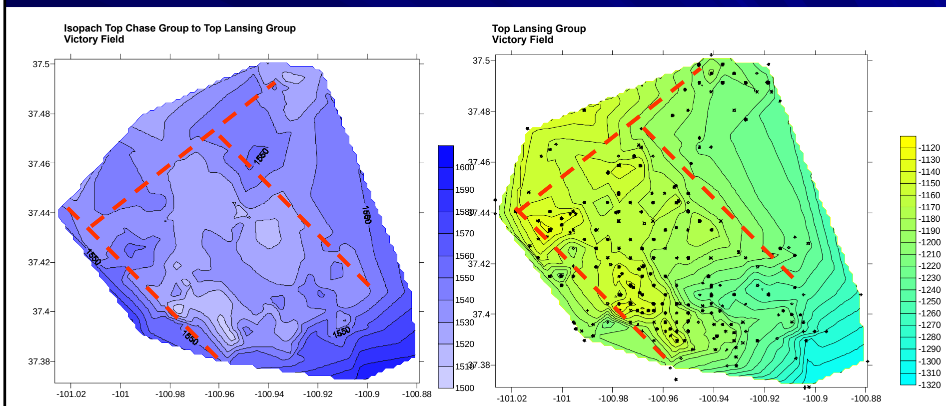
Victory Field



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.



Chase to Lansing isopachous map closely follows Top Lansing structure



(top Wolfcampian – top Missourian ~20 Ma)

5 MILES

Rhombohedral NW & NE-trending pattern? Propagation of structural template?

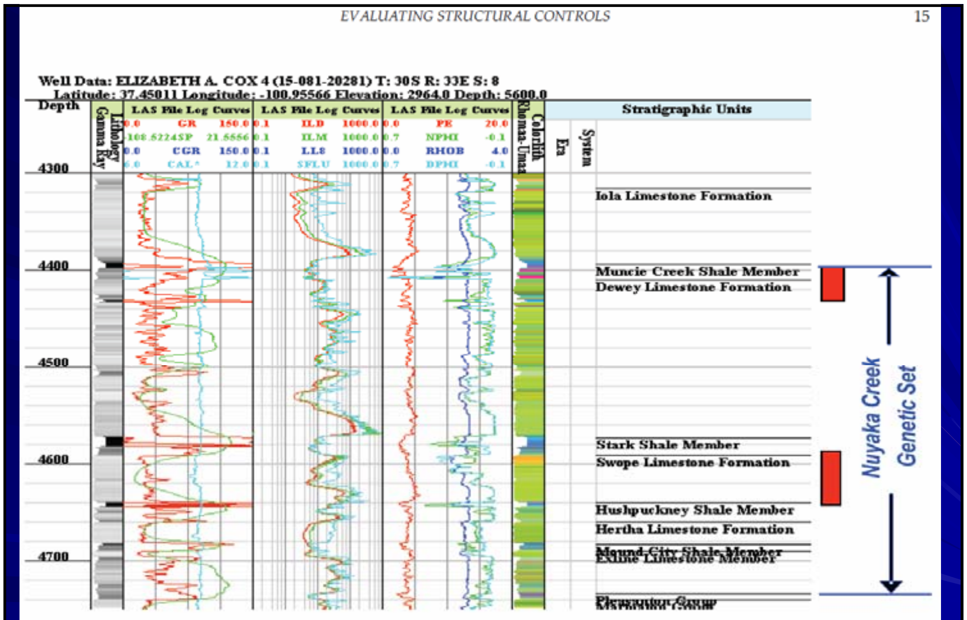
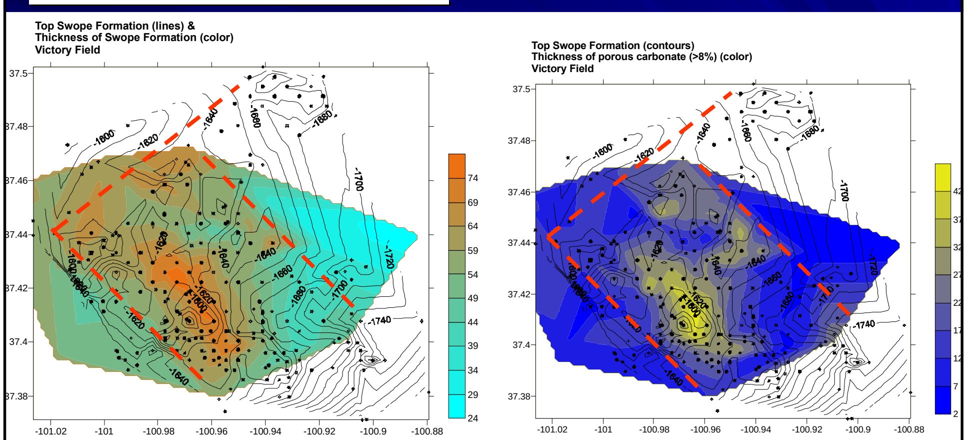


Fig. 18.—Profile of cored well in Victory Field, Amoco Cox A-4, showing log suites and stratigraphic nomenclature. Well-log suite, consisting of gamma ray (IDGR) in left track, porosity curves (DNDP & DCNPL) in middle track, and resistivity curves (IDSF, IDID, IDIM) in right track, is used to denote fourth-order genetic units (red rectangles defined by flooding-unit boundaries) for the Dewey and Swope Limestones. These fourth-order genetic units represent a lower–middle and uppermost portion of the third-order Nuyaka Creek genetic set (again defined at the base of a flooding-unit boundary).

Structure = contours
Gross isopach (RIGHT color overlay) -- light blue to brown
Thickness of porous carbonate (LEFT) -- dark blue to yellow

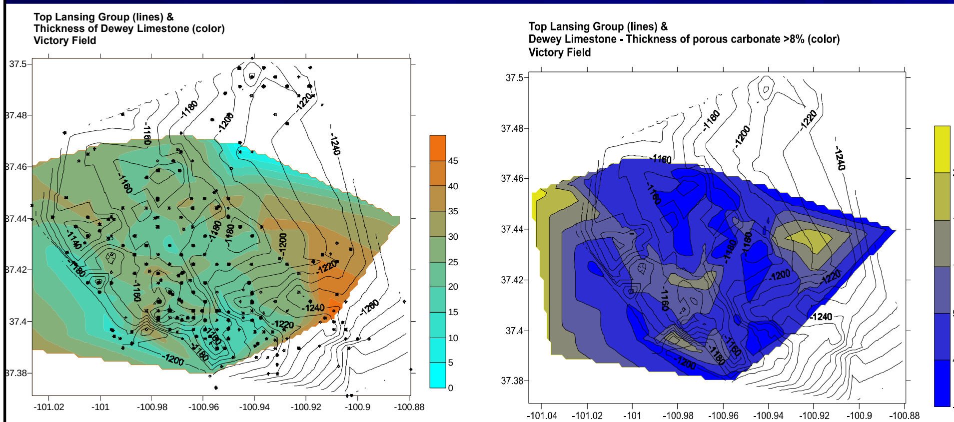
SWOPE LIMESTONE



Thickening and shoal-water lithofacies on top of structure

Structure = contours
Gross isopach (LEFT) -- light blue to brown
Thickness of porous carbonate (RIGHT) --dark blue to yellow

DEWEY LIMESTONE



Thickening and shoal-water grainstone on flank of structure

5 MILES

18 W. LYNN WATNEY, EVAN K. FRANSEEN, ALAN P. BYRNES, AND SUSAN E. NISSEN

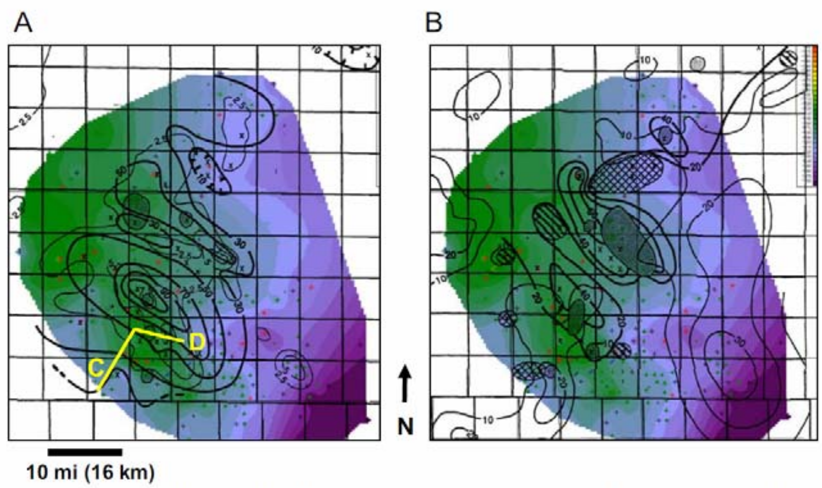


FIG. 22.—Overlay maps for A) Bethany Falls and B) Dewey limestones showing: (1) color structural elevation on the top of the Lansing Group (green high [~-1120 ft], blue low [-1280 ft]); (2) producing areas from zone (fine stippled pattern); (3) finer-lined isochores of Ø*ft (Ø > 16% for Bethany Falls [Part A] and Ø > 8% for Dewey [Part B]; and (4) heavy-lined isochores of percent effective porosity (permeable connected pores) estimated from point counts of thin sections of well cuttings for Bethany Falls (map A) and visual estimates from cuttings examined under low power binocular microscope for Dewey (map B) (Watney et al., 1994). Effective porosity cutoff, Φ cutoff, in the fully oomoldic Bethany Falls Limestone is assigned 16% (>1 md permeability), whereas the Φ cutoff in the Dewey Limestone containing more preserved ooids and interooid porosity is assigned 8%. Also the Dewey Limestone (map B) shows areas with well-cemented ooid grainstone (cross hachured lines) and no ooid grainstone (crossing hachured lines) as determined from cuttings. Index for cross-section C–D (Fig. 23) is shown in Figure 22A.

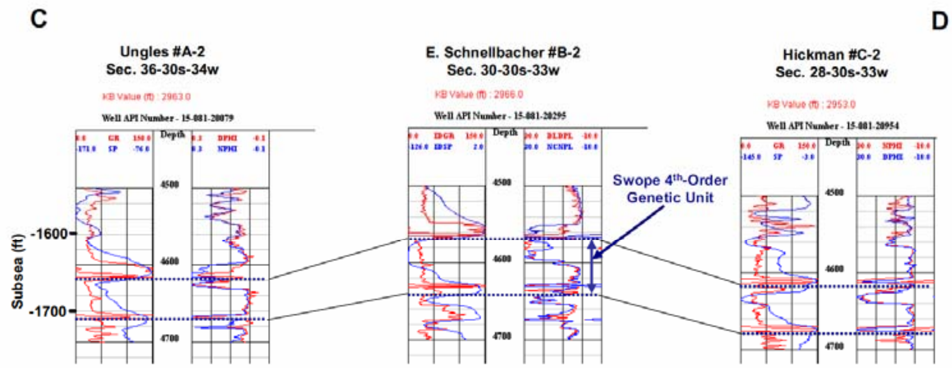
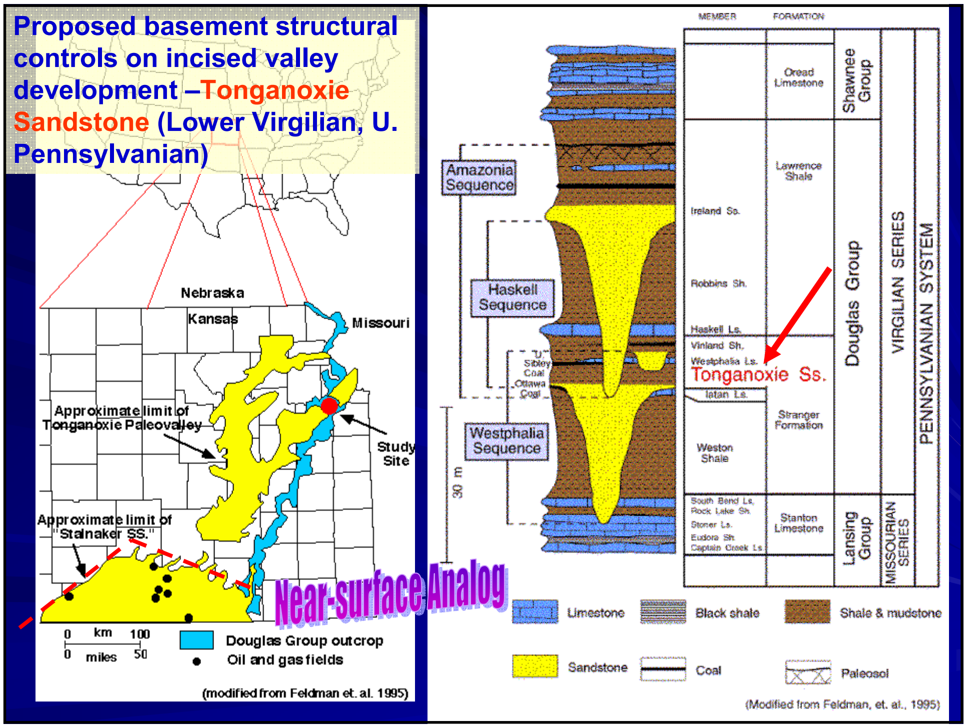


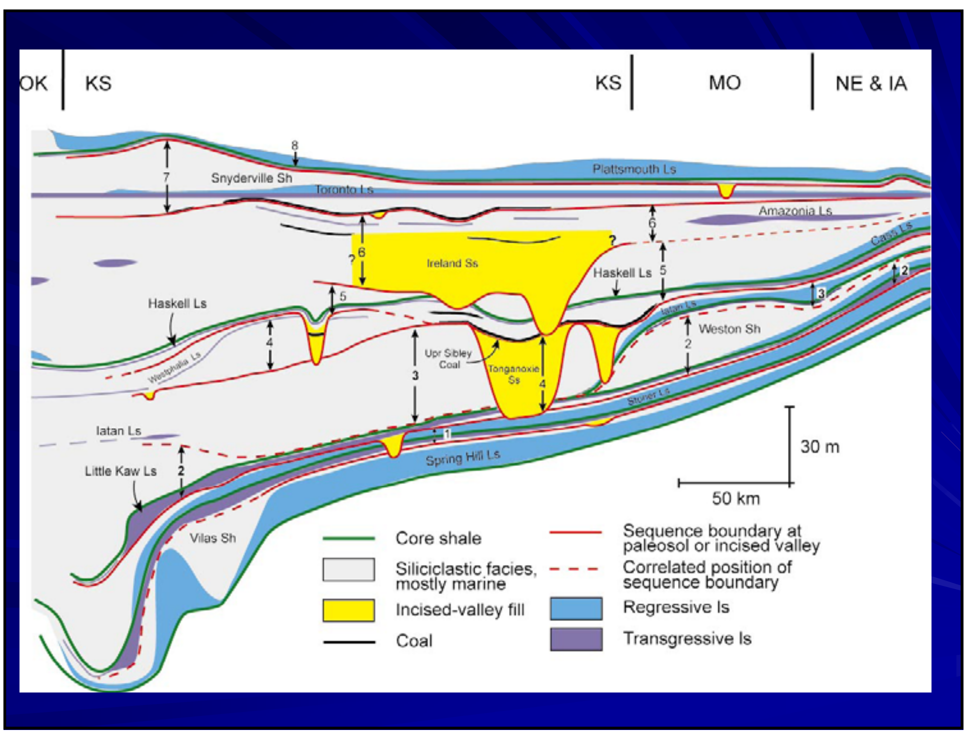
FIG. 23.—West-to-east structural well log cross section depicting doubling of thickness of the highly porous, low gamma ray, oomoldic lithofacies of Swope Limestone fourth-order genetic unit across a current structural high in the southern portion of Victory Field, Haskell County, Kansas. Left track of well logs contains gamma ray (red) and spontaneous potential (blue) curves. Right track of well logs has neutron Ø (red) and neutron Ø (blue). Porosity increases to left (up to 30% or 0.3). Index for cross section is provided in Fig. 22. No horizontal scale. Total length of cross section is 5.6 km. Cross section further illustrates the close tracking of the development of the porous oomoldic pay zone with the location of the structurally higher positions of the field as noted in Fig. 21. The coincidence of current and inferred structural highs developed during time of deposition is believed due to structural reactivation as discussed in text.

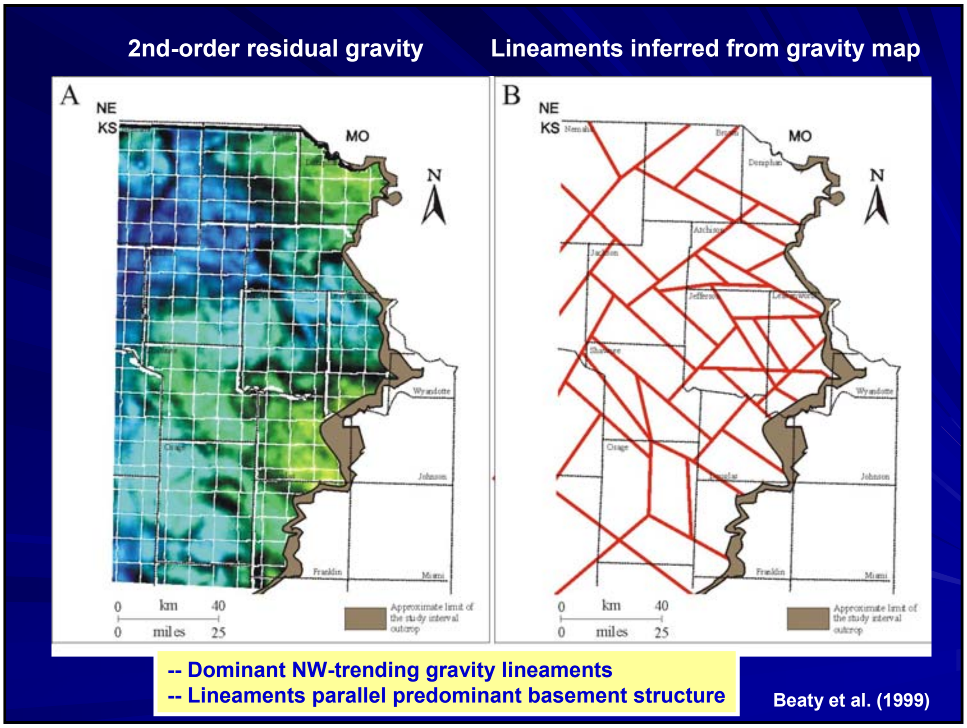
Watney et al. (2008)

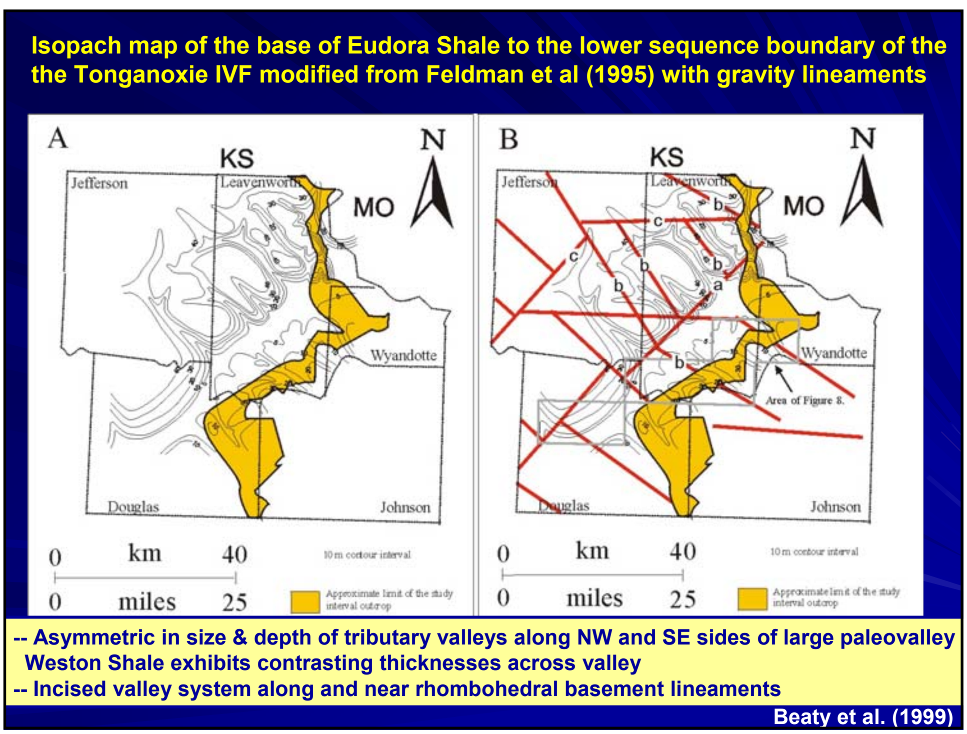
Lower Virgilian Tonganoxie Paleovalley

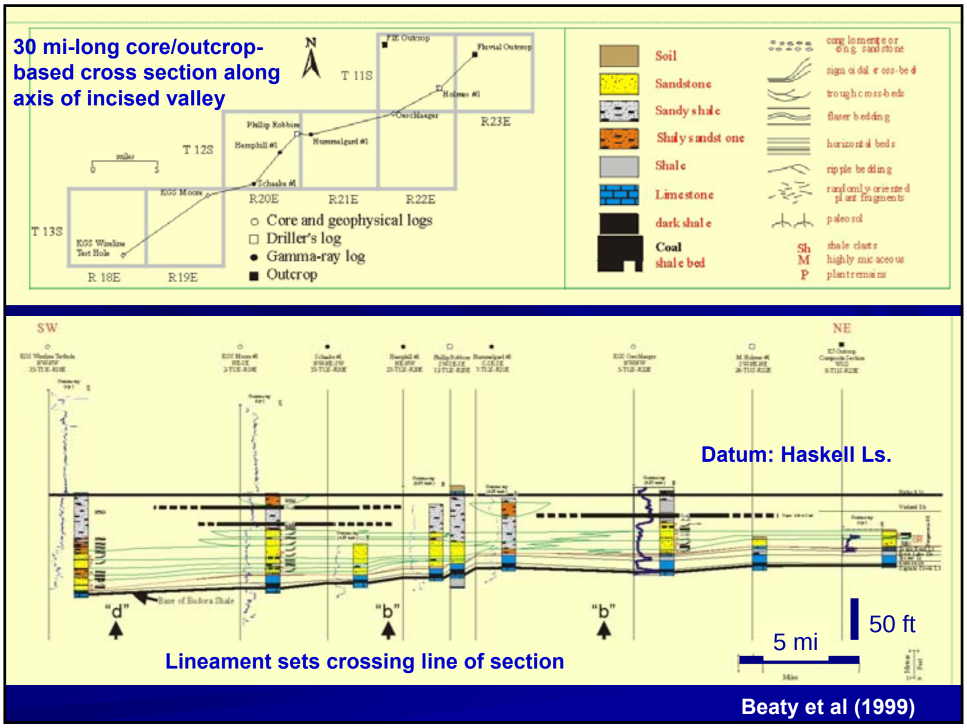
eustacy, sediment supply,
and inferred structural controls


Proposed basement structural controls on incised valley development –Tonganoxie Sandstone (Lower Virgilian, U. Pennsylvanian)
Nebraska
Kansas
Missouri
Approximate limit of Tonganoxie Paleovalley
Study Site
Approximate limit of "Stalnaker SS."
Near-surface Analog
km 0 100
miles 0 50
Douglas Group outcrop
Oil and gas fields
(modified from Feldman et. al. 1995)
MEMBER
FORMATION
Amazonia Sequence
Haskell Sequence
Westphalia Sequence
30 m
Oread Limestone
Shawnee Group
Lawrence Shale
Ireland Ss.
Robbins Sh.
Haskell Ls.
Vinland Sh.
Westphalia Ls.
Tonganoxie Ss.
Iatan Ls.
Stranger Formation
Weston Shale
Douglas Group
VIRGILIAN SERIES
PENNSYLVANIAN SYSTEM
South Bend Ls.
Rock Lake Sh.
Stoner Ls.
Eudora Sh.
Captain Creek Ls.
Stanton Limestone
Lansing Group
MISSOURIAN SERIES
Limestone
Black shale
Shale & mudstone
Sandstone
Coal
Paleosol
(Modified from Feldman, et. al., 1995)

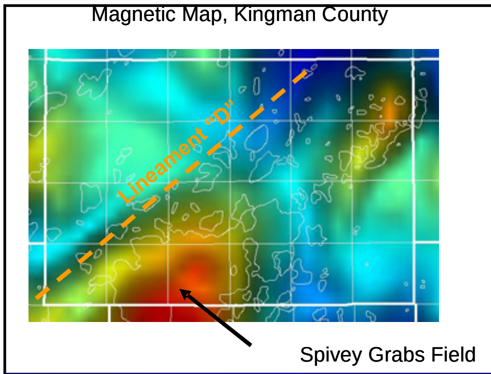

OK
KS
KS
MO
NE & IA
Snyderville Sh
Toronto Ls
Plattsmouth Ls
Amazonia Ls
Ireland Ss
Haskell Ls
Haskell Ls
Weston Sh
Upr Sibley Coal
Tonganoxie Ss
Iatan Ls
Little Kaw Ls
Spring Hill Ls
Vilas Sh
30 m
50 km
Core shale
Siliciclastic facies, mostly marine
Incised-valley fill
Coal
Sequence boundary at paleosol or incised valley
Correlated position of sequence boundary
Regressive ls
Transgressive ls


2nd-order residual gravity
Lineaments inferred from gravity map
A
NE
KS
MO
N
0 km 40
0 miles 25
B
NE
KS
MO
N
0 km 40
0 miles 25
-- 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
A
KS
N
Jefferson
Leavenworth
MO
Wyandotte
Douglas
Johnson
0 km 40
0 miles 25
10 m contour interval
Approximate limit of the study interval outcrop
B
KS
N
Jefferson
Leavenworth
MO
Wyandotte
Area of Figure 8.
Douglas
Johnson
0 km 40
0 miles 25
10 m contour interval
Approximate limit of the study interval outcrop
-- Asymmetric in size & depth of tributary valleys along NW and SE sides of large paleovalley
Weston Shale exhibits contrasting thicknesses across valley
-- Incised valley system along and near rhombohedral basement lineaments
Beaty et al. (1999)

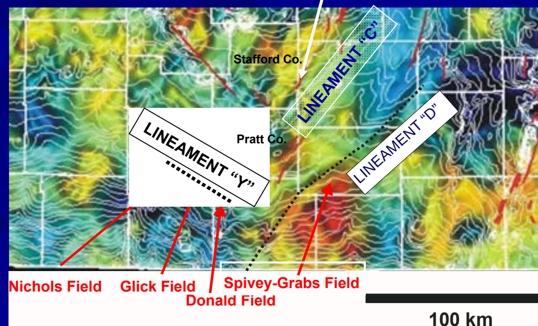


Additional Resources for Part 2. Structure

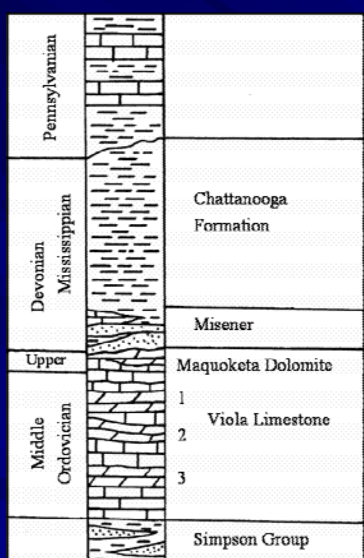


Zenith-Peace Creek Field

- lineament "C"
- deep seated fault
- reactivated Midcontinent rift
- strongly influence margin of Mississippian-Devonian seaway & deposition of marine Misener sandstone

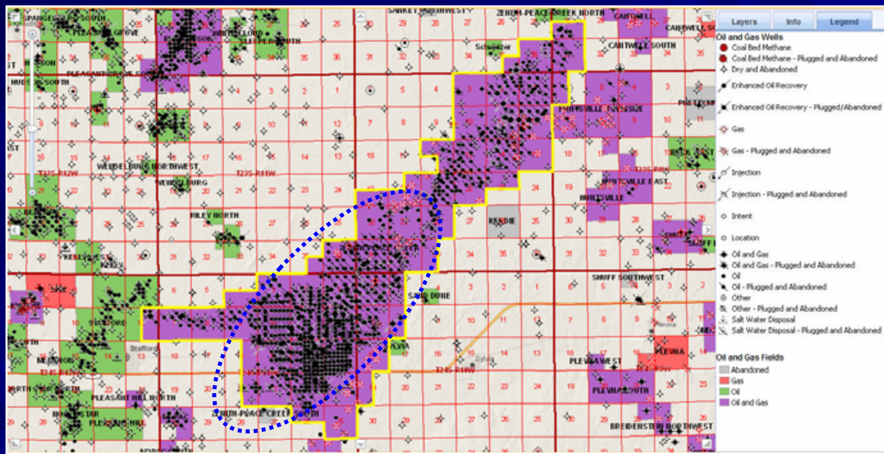


Stratigraphy of Misener Sandstone interval

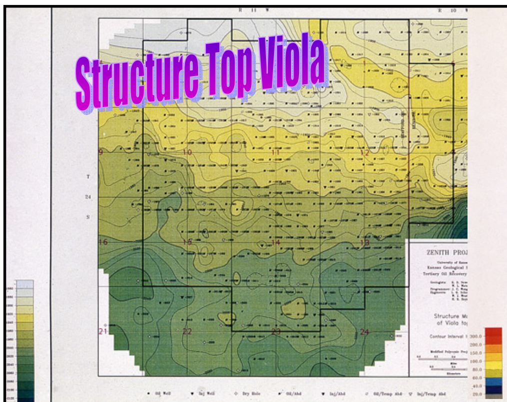


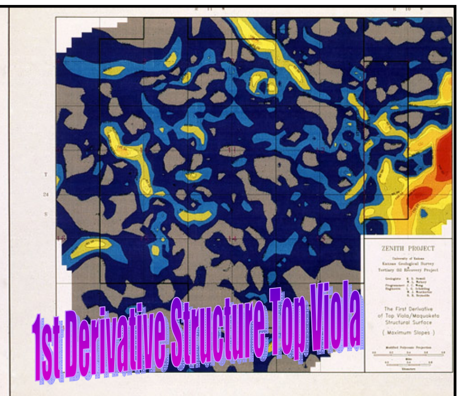
Zenith Field – far northeast margin and at onlap of basal Chattanooga (Woodford) seaway

Base map of Zenith-Peace Creek Field

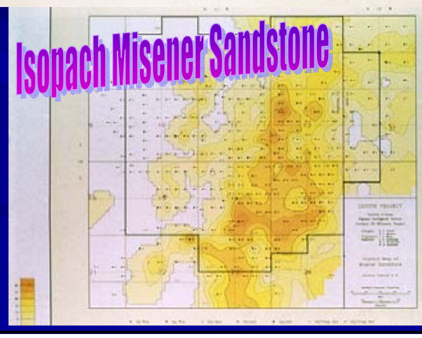


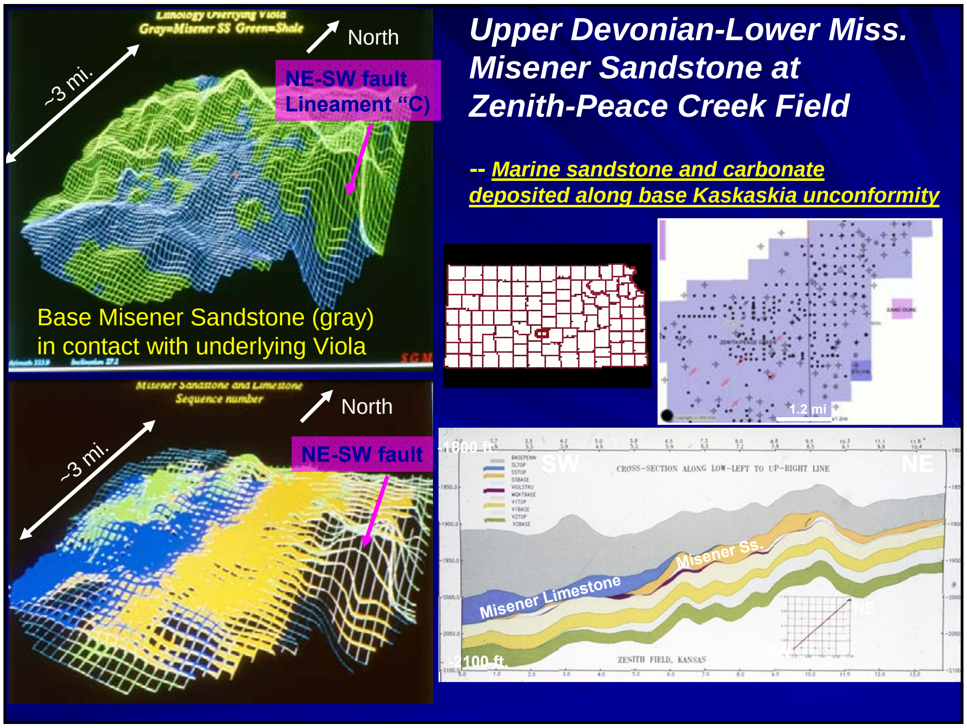
Blue circle = mapped area of field

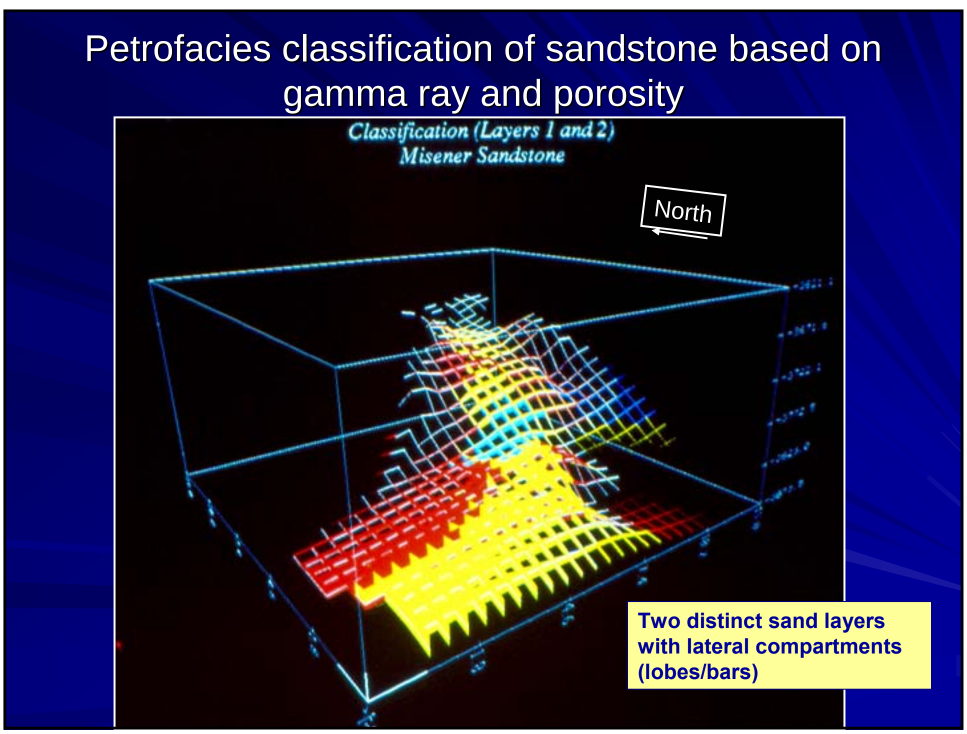




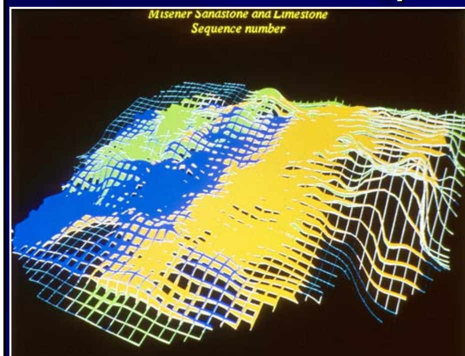
- Misener Sandstone – basal marine transgressive bar deposit deposition on unconformity at the base of the Chattanooga Shale

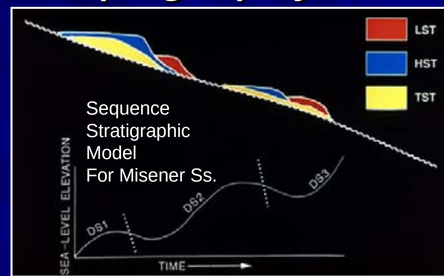



Upper Devonian-Lower Miss.
Misener Sandstone at
Zenith-Peace Creek Field
-- Marine sandstone and carbonate
deposited along base Kaskaskia unconformity
North
NE-SW fault
Lineament "C)
~3 mi.
Base Misener Sandstone (gray)
in contact with underlying Viola
North
NE-SW fault
~3 mi.
1.2 mi
1800 ft
SW
NE
CROSS-SECTION ALONG LOW-LEFT TO UP-RIGHT LINE
Misener Limestone
Misener Ss.
2100 ft
ZENITH FIELD, KANSAS

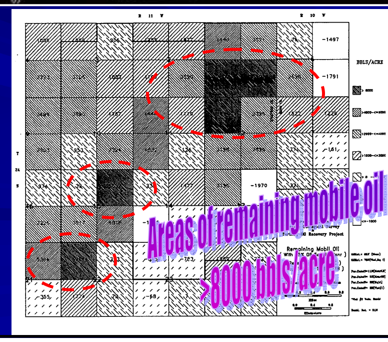

Petrofacies classification of sandstone based on
gamma ray and porosity
Classification (Layers 1 and 2)
Misener Sandstone
North
Two distinct sand layers
with lateral compartments
(lobes/bars)

Eustacy/subsidence interacting with local paleotopography

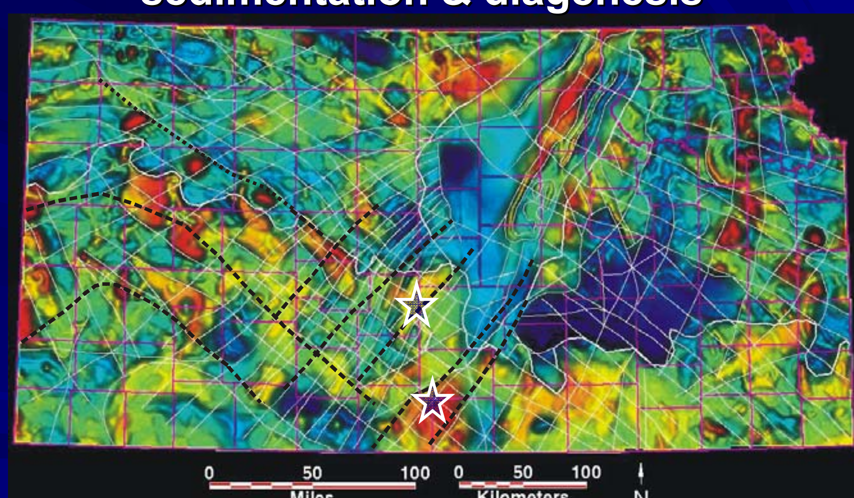




- **TST** – basal sand that locally rests directly on Viola Limestone
  - affect access of water drive from fractured & vuggy Viola Limestone
- **HST** – local marginal accumulations of Misener Limestone
- **LST** – sand accumulation on basinward edge of limestone "bank"



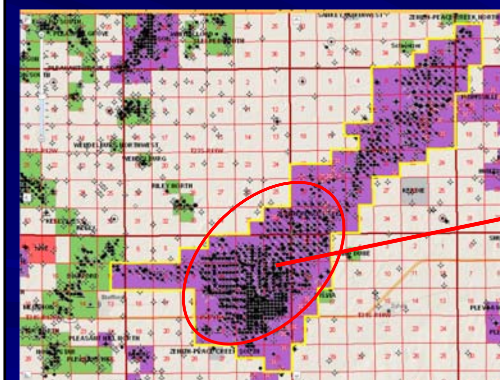
Reactivated basement lineaments showing movement affecting sedimentation & diagenesis



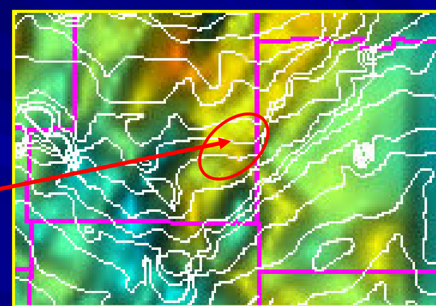
Magnetic map of Kansas (Kruger, 1999)

Reactivation of deep-seated structure along Midcontinent Rift strongly influencing sedimentation and later deformation

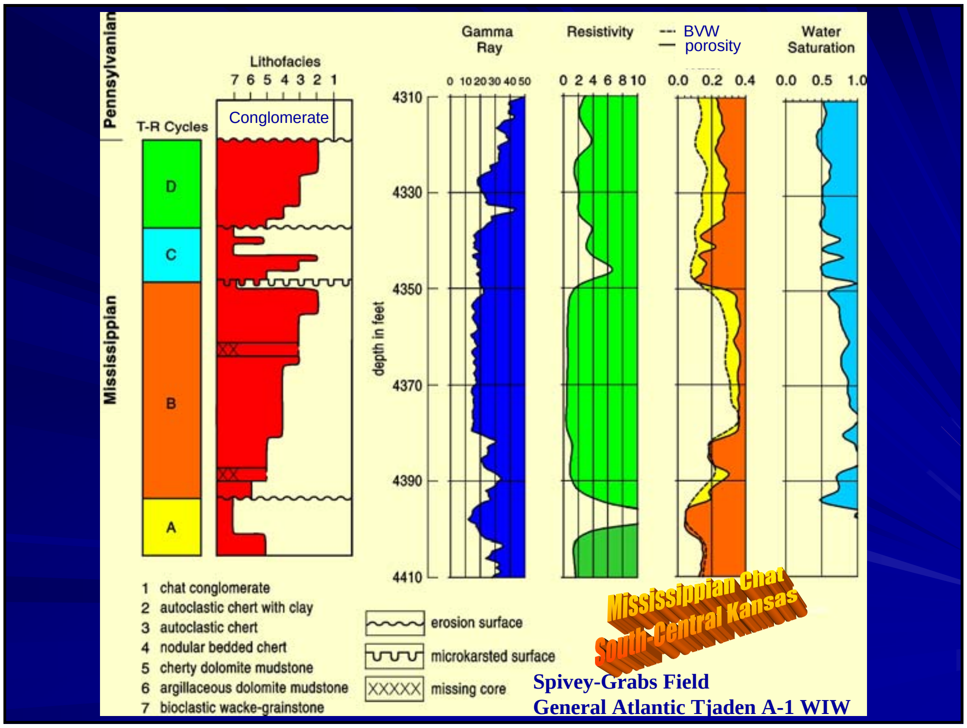
Zenith-Peace Creek Field



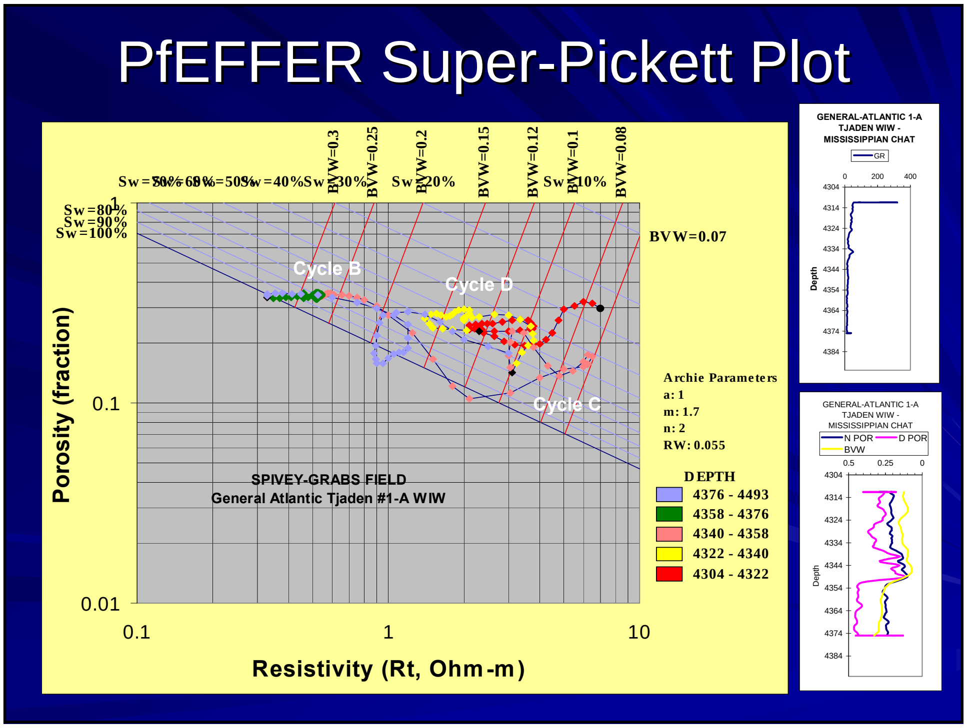
Precambrian Structure (white)
on total magnetic field intensity

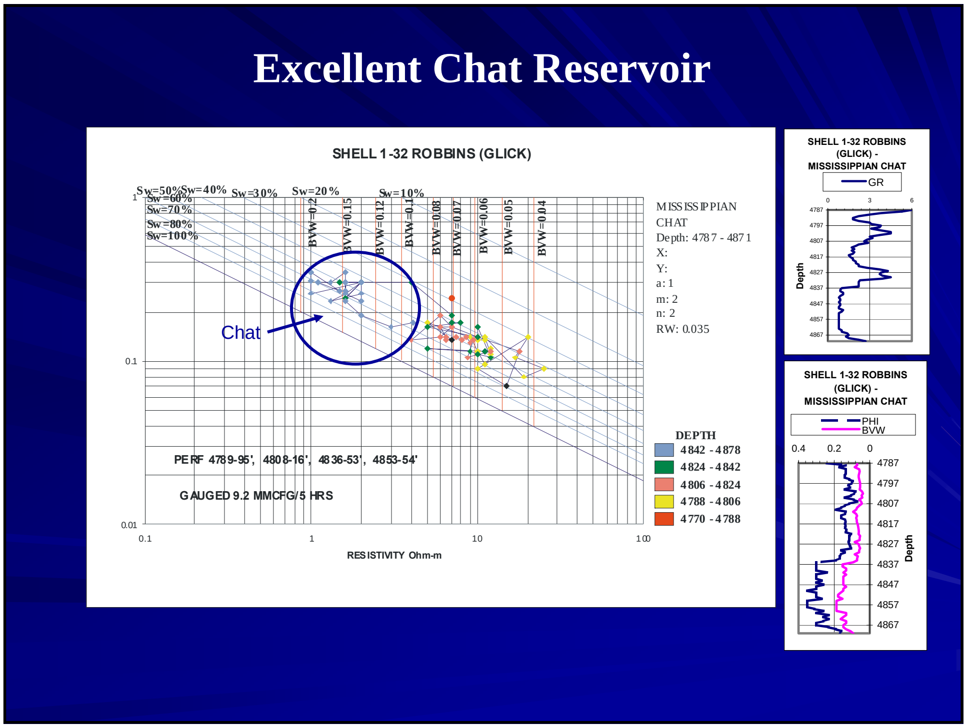


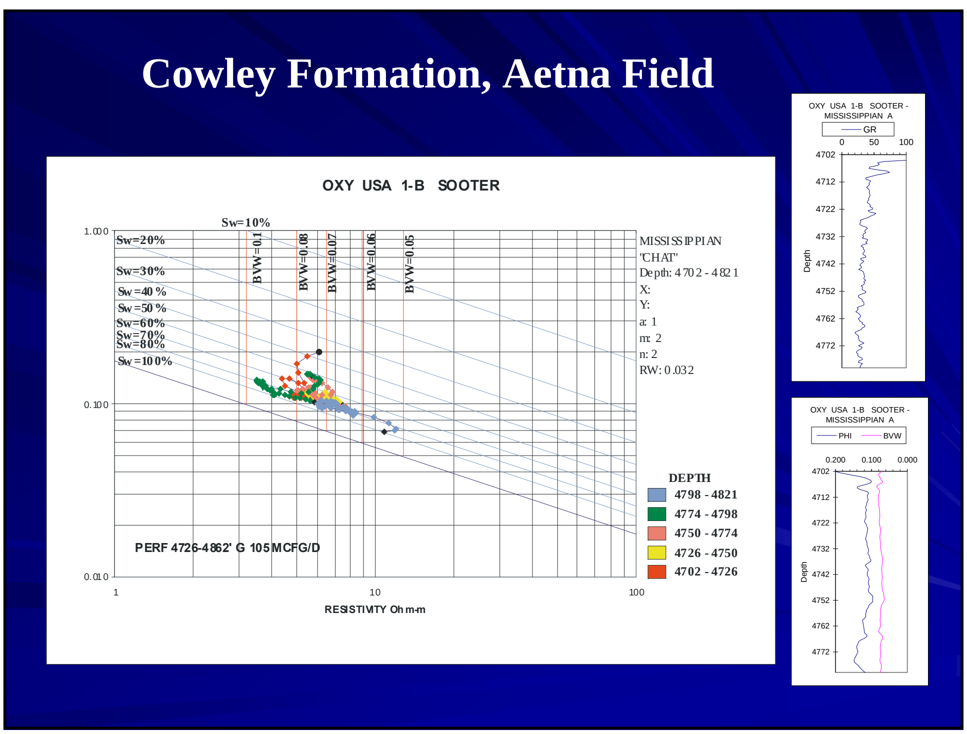
…back to Mississippan Chat



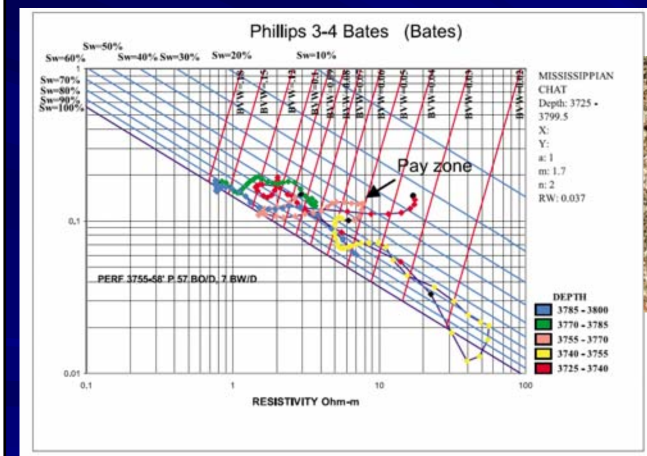
PfEFFER Super-Pickett Plot

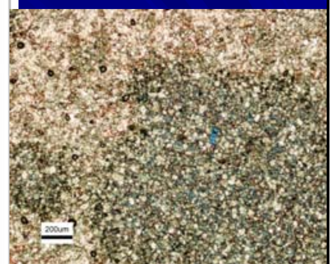



Excellent Chat Reservoir
SHELL 1-32 ROBBINS (GLICK)
Sw=50% Sw=40% Sw=30% Sw=20% Sw=10%
Sw=60%
Sw=70%
Sw=80%
Sw=100%
BVW=0.2 BVW=0.15 BVW=0.12 BVW=0.1 BVW=0.08 BVW=0.07 BVW=0.06 BVW=0.05 BVW=0.04
MISSISSIPPIAN
CHAT
Depth: 4787 - 4871
X:
Y:
a: 1
m: 2
n: 2
RW: 0.035
Chat
PERF 4789-95', 4808-16', 4836-53', 4853-54'
GAUGED 9.2 MMCFG/5 HRS
DEPTH
4842 - 4878
4824 - 4842
4806 - 4824
4788 - 4806
4770 - 4788
RESISTIVITY Ohm-m
SHELL 1-32 ROBBINS (GLICK) - MISSISSIPPIAN CHAT
GR
Depth
SHELL 1-32 ROBBINS (GLICK) - MISSISSIPPIAN CHAT
PHI
BVW
Depth


Cowley Formation, Aetna Field
OXY USA 1-B SOOTER
Sw=10%
Sw=20%
Sw=30%
Sw=40%
Sw=50%
Sw=60%
Sw=70%
Sw=80%
Sw=100%
BVW=0.1 BVW=0.08 BVW=0.07 BVW=0.06 BVW=0.05
MISSISSIPPIAN
'CHAT'
Depth: 4702 - 4821
X:
Y:
a: 1
m: 2
n: 2
RW: 0.032
PERF 4726-4862' G 105 MCFG/D
DEPTH
4798 - 4821
4774 - 4798
4750 - 4774
4726 - 4750
4702 - 4726
RESISTIVITY Ohm-m
OXY USA 1-B SOOTER - MISSISSIPPIAN A
GR
Depth
OXY USA 1-B SOOTER - MISSISSIPPIAN A
PHI
BVW
Depth

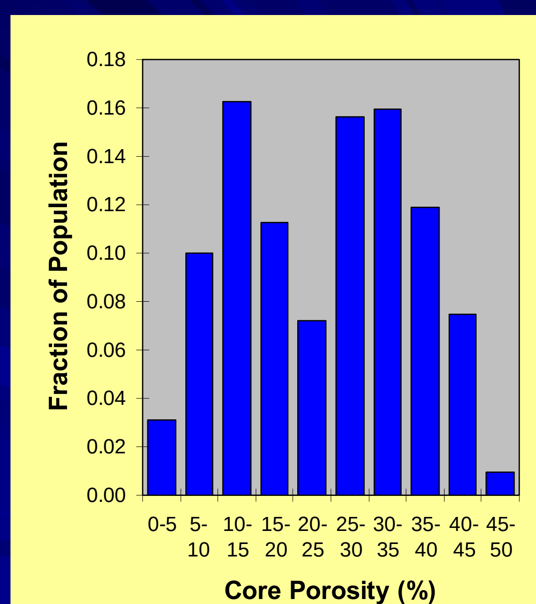
Sucrosic dolomite pay (Bates Field) interstratified with “chat”





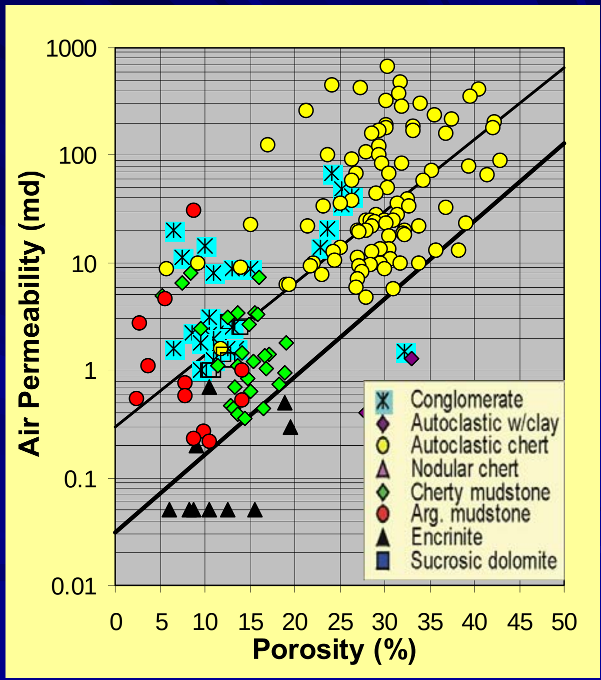
Histogram of core porosities for four fields in chat

- Bimodal distribution
- Low porosity - cherty dolomite mudstone facies
- High porosity - cherty facies
- Wireline logs exhibit similar bimodal distribution



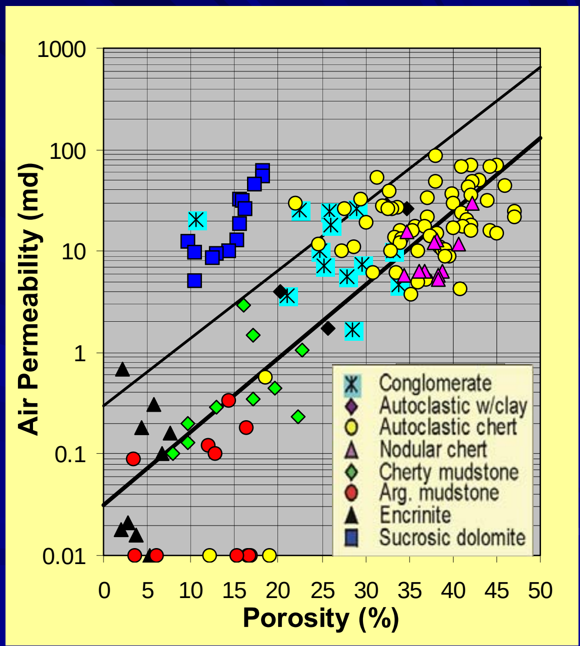
Permeability versus porosity for whole core

- Properties reflect both matrix and larger-scale properties including nontectonic fracturing
- Lower core plug trend: $k_a=10^{(0.072*\phi a-1.51)}$
- Upper whole core trend: $k_a=10^{(0.067*\phi a-0.53)}$



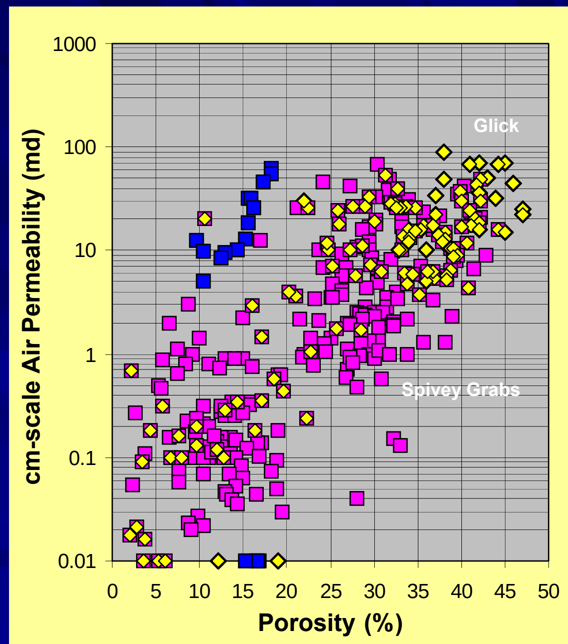
Permeability versus porosity for core plugs

- Properties reflect only matrix properties excluding nontectonic fracturing
- Lower core plug trend: $k_a=10^{(0.072*\phi a-1.51)}$
- Upper whole core trend: $k_a=10^{(0.067*\phi a-0.53)}$



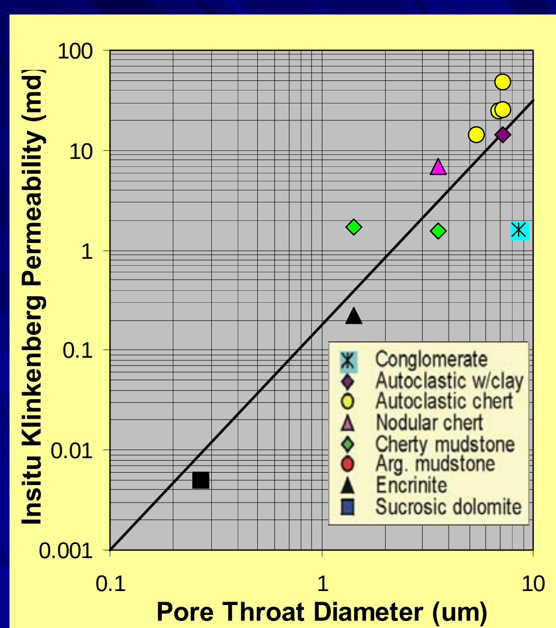
Air permeability versus porosity for normalized whole core and plugs for four chat fields

- Bates sucrosic dolomites (blue square) lie off chert trend

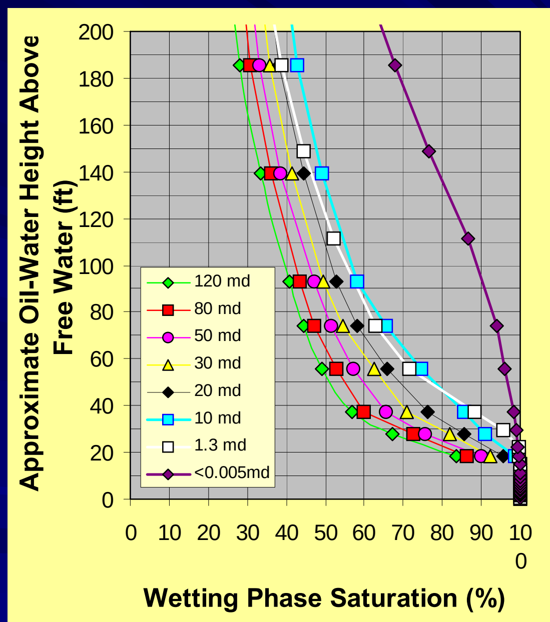


***Insitu* Klinkenberg permeability versus principal pore throat diameter**

- Determined form mercury capillary pressure
- Samples lie off central trend as a function of mixed lithologies in plugs and variables like degree of vugginess
- Trend equation: $k_i=10^{(2.25*PPTD-0.75)}$



Capillary pressure curves – Glick Field

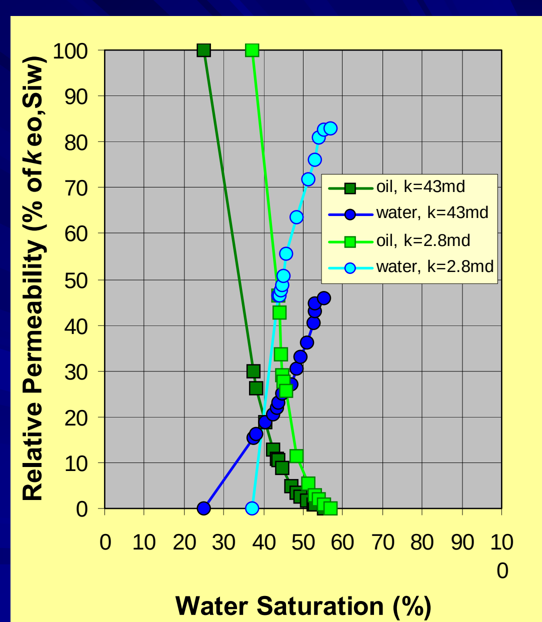


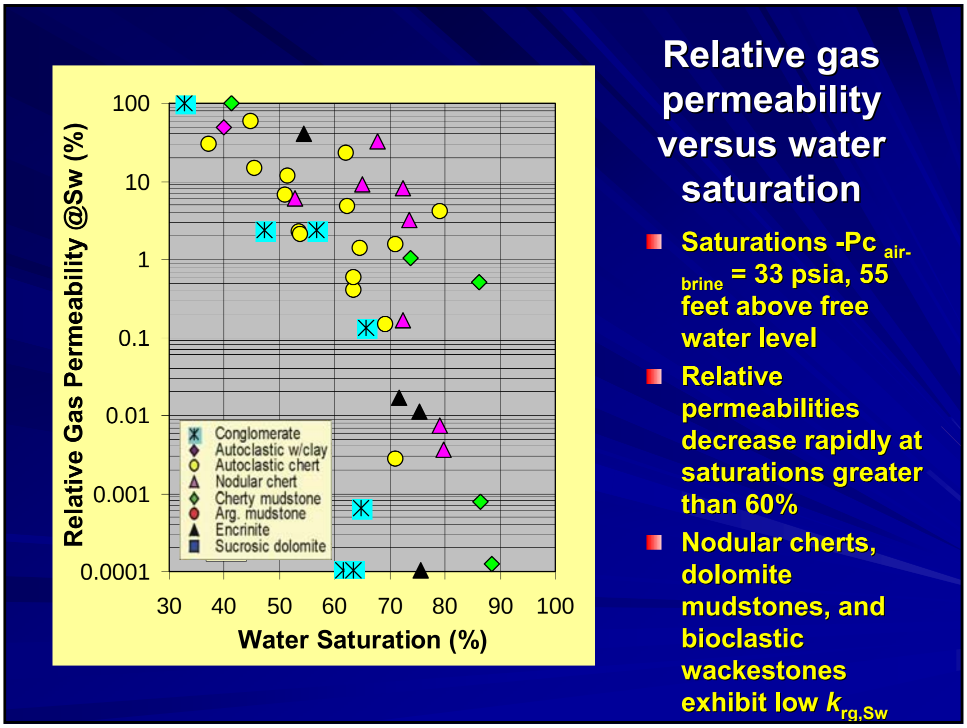
(after Duren , 1960)

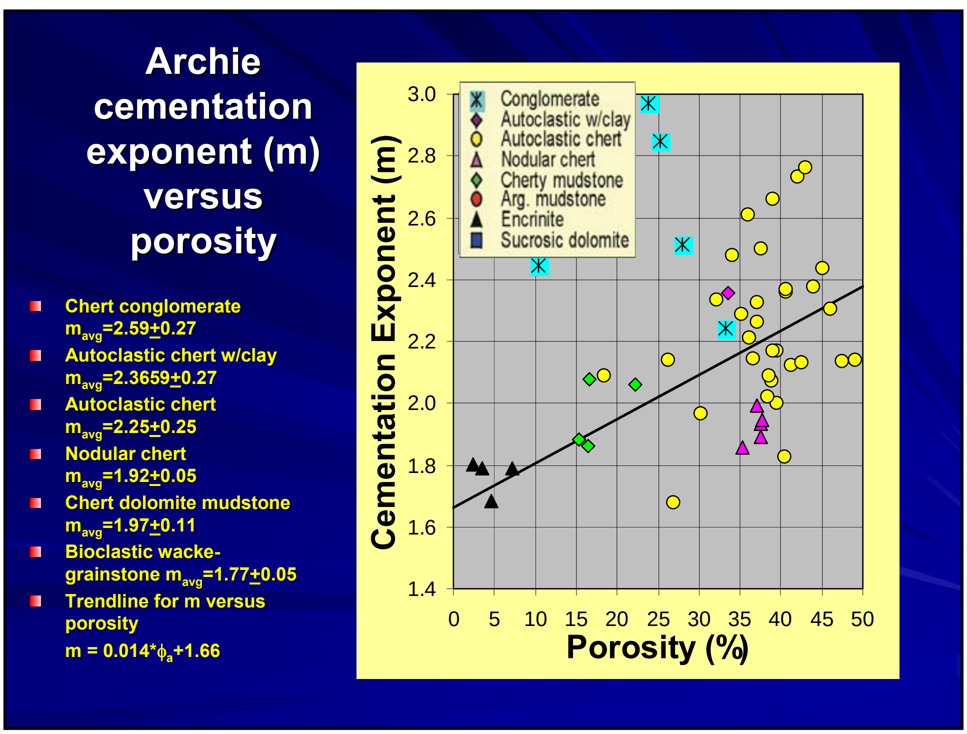
- Autoclastic chert facies and clay
- All curves exhibit high irreducible saturations indicative of microporosity and consistent with wireline log measurements of high water saturation
- Purple diamond shows the curve for the green infilling clay

Imbibition water-oil relative permeability

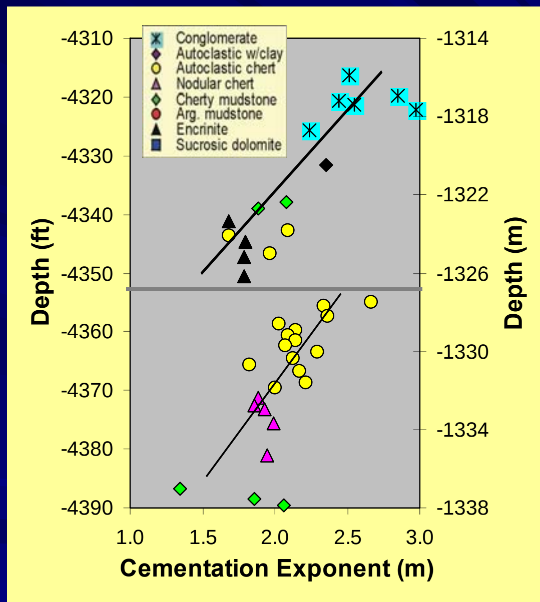
- Autoclastic chert
- Gulf School Trust 4-4, Hardtner Field
- High critical water saturations are consistent with microporosity
- Limited saturation range of oil displacement may reflect dual porosity pore system though it gives appearance of intermediate oil-water wetness




Relative gas permeability versus water saturation
Saturations -Pc air-brine = 33 psia, 55 feet above free water level
Relative permeabilities decrease rapidly at saturations greater than 60%
Nodular cherts, dolomite mudstones, and bioclastic wackestones exhibit low krg,Sw
Relative Gas Permeability @Sw (%)
Water Saturation (%)
Conglomerate
Autoclastic w/clay
Autoclastic chert
Nodular chert
Cherty mudstone
Arg. mudstone
Encrinite
Sucrosic dolomite


Archie cementation exponent (m) versus porosity
Chert conglomerate mavg=2.59±0.27
Autoclastic chert w/clay mavg=2.3659±0.27
Autoclastic chert mavg=2.25±0.25
Nodular chert mavg=1.92±0.05
Chert dolomite mudstone mavg=1.97±0.11
Bioclastic wacke-grainstone mavg=1.77±0.05
Trendline for m versus porosity
m = 0.014*φa+1.66
Cementation Exponent (m)
Porosity (%)
Conglomerate
Autoclastic w/clay
Autoclastic chert
Nodular chert
Cherty mudstone
Arg. mudstone
Encrinite
Sucrosic dolomite

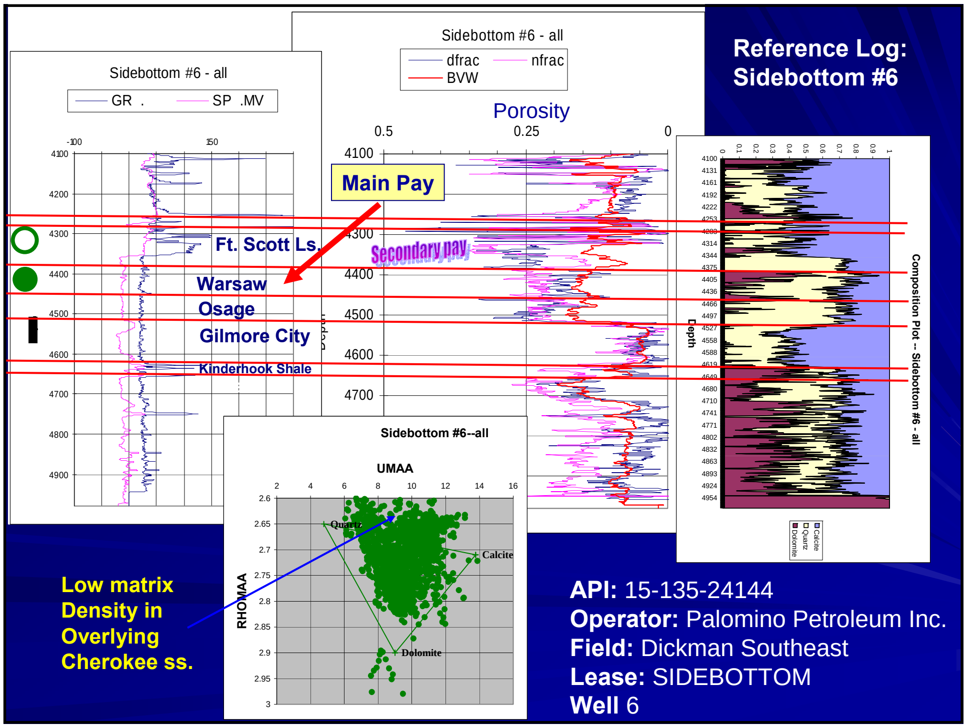
Cementation exponent (m) versus depth

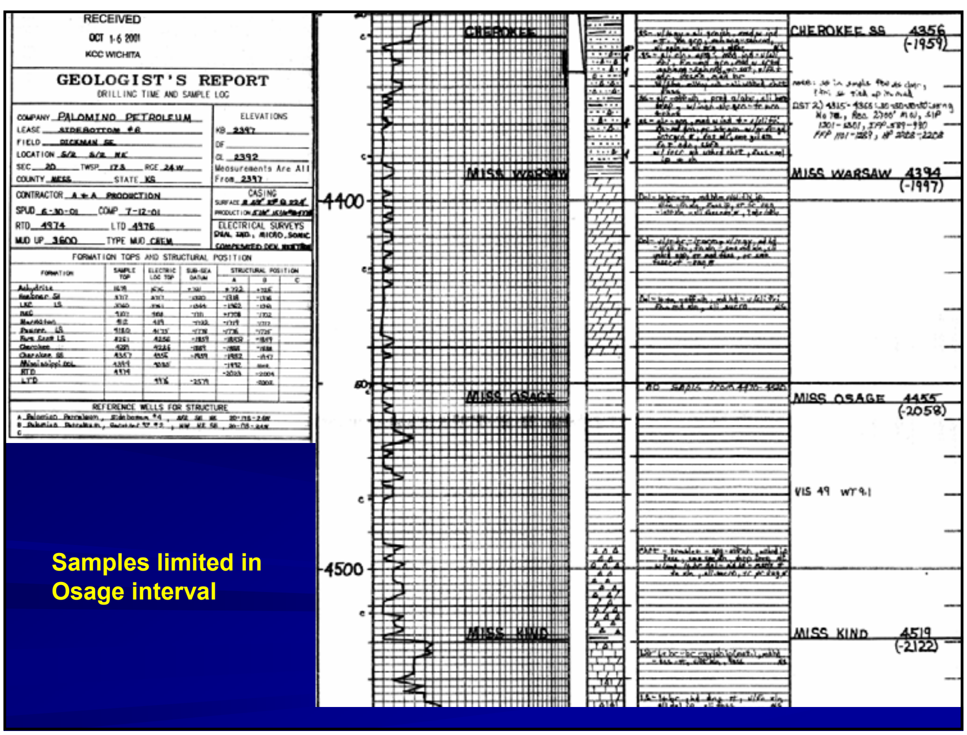


* m increase with increasing vug and mold content?

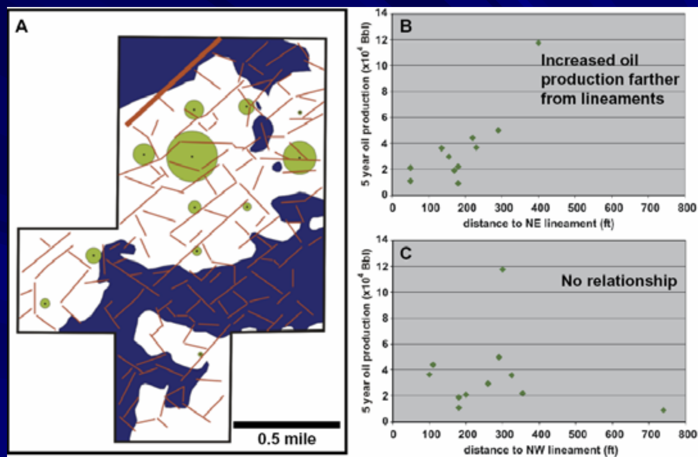
- General Atlantic WIW #1-A Tjaden, Spivey-Grabs Field
- Cementation exponents decrease with depth from surface to bioclastic wacke-grainstone interval
- Below bioclastic wacke-grainstone interval m in autoclastic cherts is high and decreases with depth again
- Patterns in m may reflect:
  - Systematic changes in pore type and/or
  - Influence of paleo-perched water table

Return to Dickman Field, Ness County, Kansas Example


Reference Log:
Sidebottom #6
Sidebottom #6 - all
GR .
SP .MV
Ft. Scott Ls.
Warsaw
Osage
Gilmore City
Kinderhook Shale
Sidebottom #6 - all
dfrac
nfrac
BVW
Porosity
0.5
0.25
0
Main Pay
Secondary pay
Sidebottom #6--all
UMAA
RHOMAA
Quartz
Calcite
Dolomite
Composition Plot -- Sidebottom #6 - all
Depth
Low matrix
Density in
Overlying
Cherokee ss.
API: 15-135-24144
Operator: Palomino Petroleum Inc.
Field: Dickman Southeast
Lease: SIDEBOTTOM
Well 6


RECEIVED
KCC WICHITA
GEOLOGIST'S REPORT
DRILLING TIME AND SAMPLE LOG
COMPANY PALOMINO PETROLEUM
LEASE SIDEBOTTOM #6
FIELD DICKMAN SE
FORMATION TOPS AND STRUCTURAL POSITION
REFERENCE WELLS FOR STRUCTURE
CHEROKEE
CHEROKEE SS 4356 (-1959)
MISS WARSAW
MISS WARSAW 4394 (-1997)
4400
MISS OSAGE
MISS OSAGE 4455 (-2058)
4500
MISS KIND
MISS KIND 4519 (-2122)
Samples limited in
Osage interval

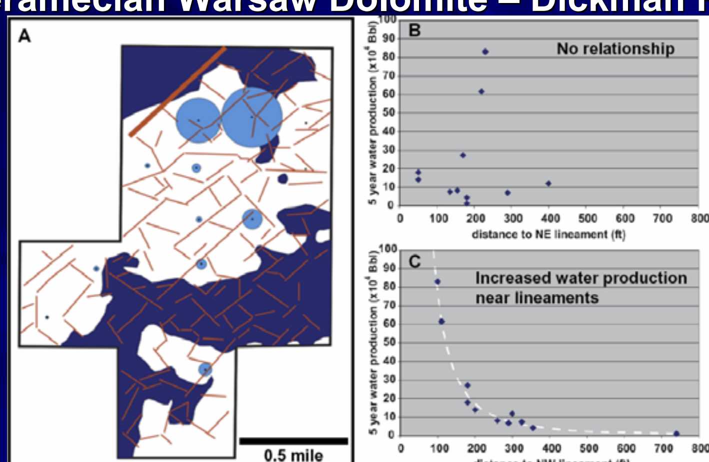
Meramecian Warsaw Dolomite – Dickman Field



A) Bubble map showing with green circles the amount of oil produced during the first 5 years of production for each well within the Dickman seismic survey. The largest circle corresponds to approximately 117,600 Bbl. Interpreted lineaments are shown in red, and areas where the top of Mississippian is below the oil-water contact are shown in dark blue.
B) 5-year oil production versus distance to nearest northeast-lineament.
C) 5-year oil production versus distance to nearest northwest trending lineament.

Nissen et al. (2006)

Meramecian Warsaw Dolomite – Dickman Field



A) Bubble map showing with blue circles the amount of water produced during the first 5 years of production for each well within the Dickman seismic survey. The largest circle corresponds to approximately 830,500 Bbl. Interpreted lineaments are shown in red, and areas where the top of Mississippian is below the oil-water contact are shown in dark blue. B) 5-year water production versus distance to nearest northeast-trending lineament. C) 5-year water production versus distance to nearest northwest-trending lineament. Dashed white line is a trend line fit to the data using a power law function.

Nissen et al. (2006)