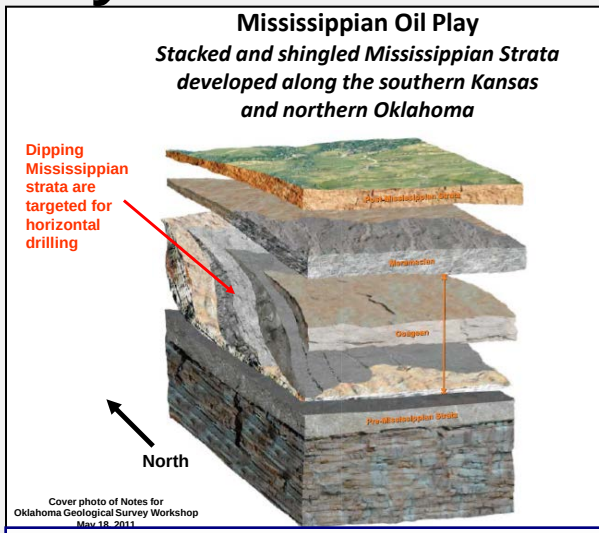
Mississippian Carbonates in Kansas: Integrating Log, Core, Seismic

W. Lynn Watney

Kansas Geological Survey

and many colleagues



DOE Contract #FE0002056 and partner cost share

Kansas Next Step KNS Connecting for Success

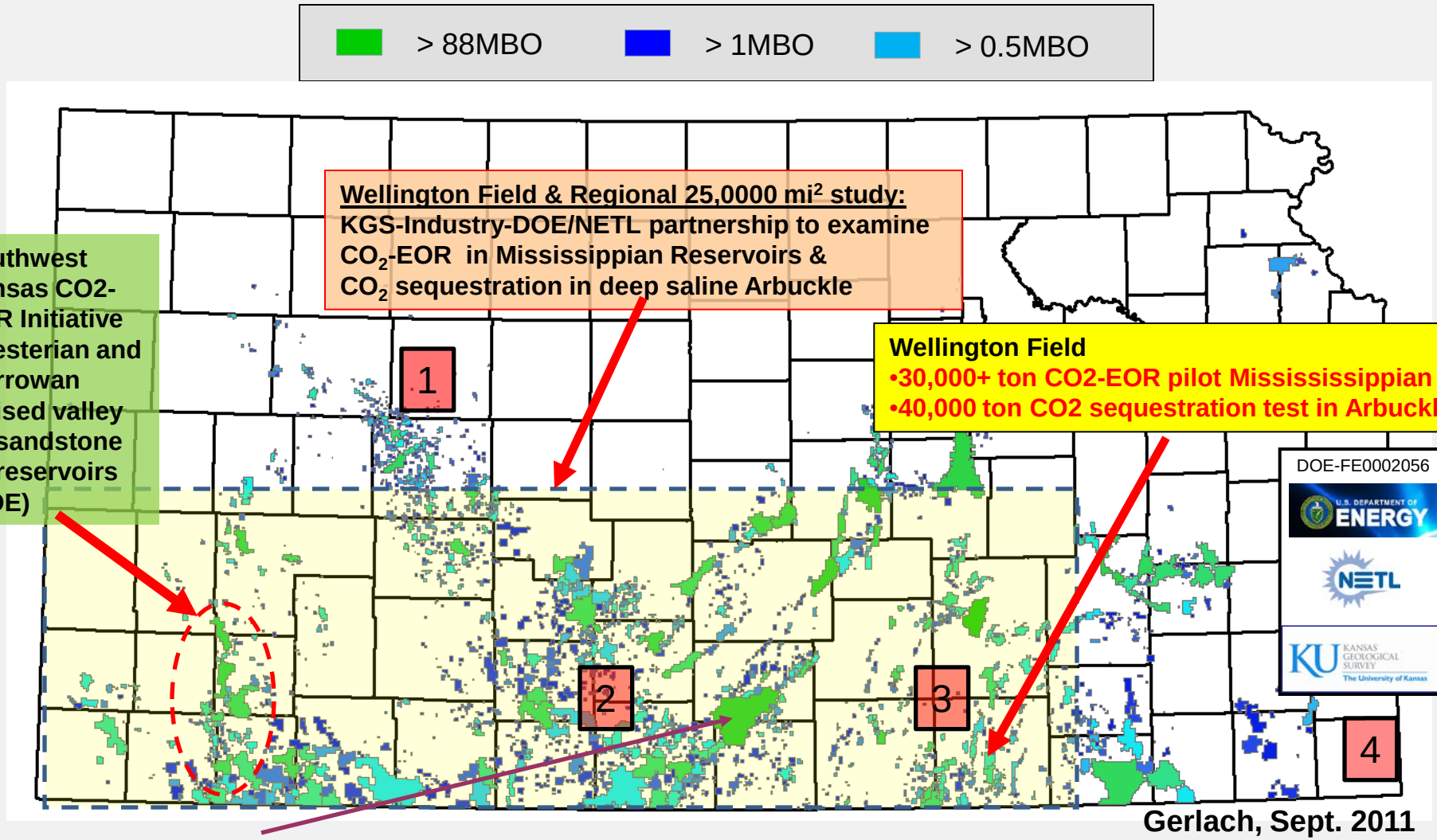
Finding and Obtaining Opportunities Lead to Success

KU KANSAS GEOLOGICAL SURVEY The University of Kansas

Outline of Presentation

- **Brief overview of the Mississippian horizontal drilling in Kansas**
- **Review *by example* of key characteristics of Mississippian reservoirs**
  - Focus on Kinderhook (lower) to early Meramecian-age (upper) Mississippian, not St. Louis and Chester reservoirs
  - Stratified reservoir with distinct pay lithofacies
    - Dolomitic grainstone-packstones, tripolitic (microporous) chert, & dolosiltite are primary pay lithofacies
    - Southern shelf margin distinguished by complex stacking and progradation into proto-Arkoma and Anadarko basins
  - Significant local and regional structure coupled with changes in sea level
    - Shelf configuration and depositional facies, early & late diagenesis
    - Pay compartmentalization by early and late structural movement
      - **Paleotopography**
      - **Fracture sets, faulting, flexure**
- **Examples – 1) Ness County; 2) Kiowa-Barber Counties, 3) Sumner County, and 4) Cherokee County**
- **Summary**

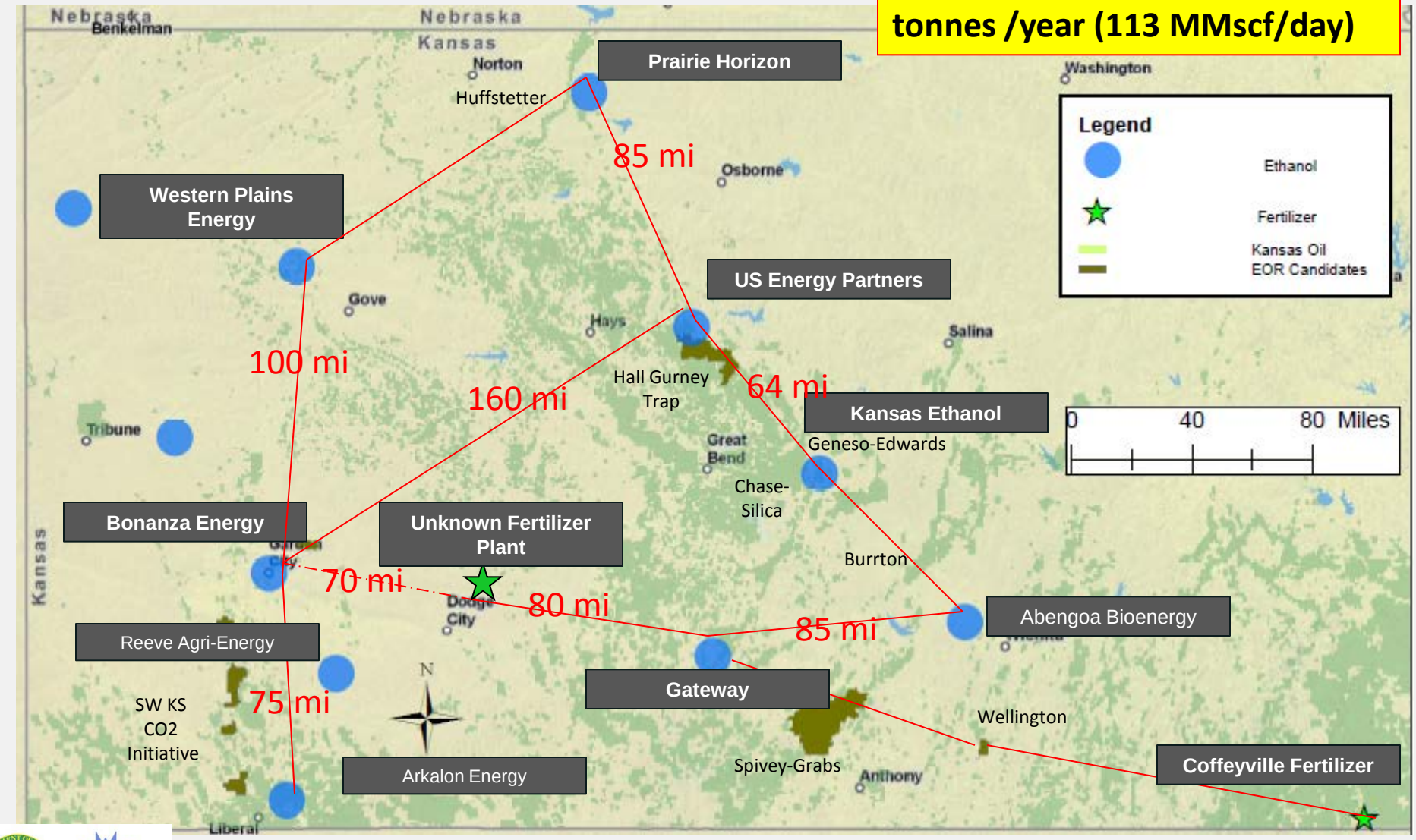
Mississippian Oil Fields in Kansas
sizing for EOR opportunities



Spivey-Grabs Basil is the largest Mississippian oil field in Kansas with 70 MM BO & 847 BCFG
Produces from the **tripolite** and could benefit from horizontal drilling and CO_2-EOR (after depletion of gas cap)

Ethanol CO2 pipeline concept – initial step

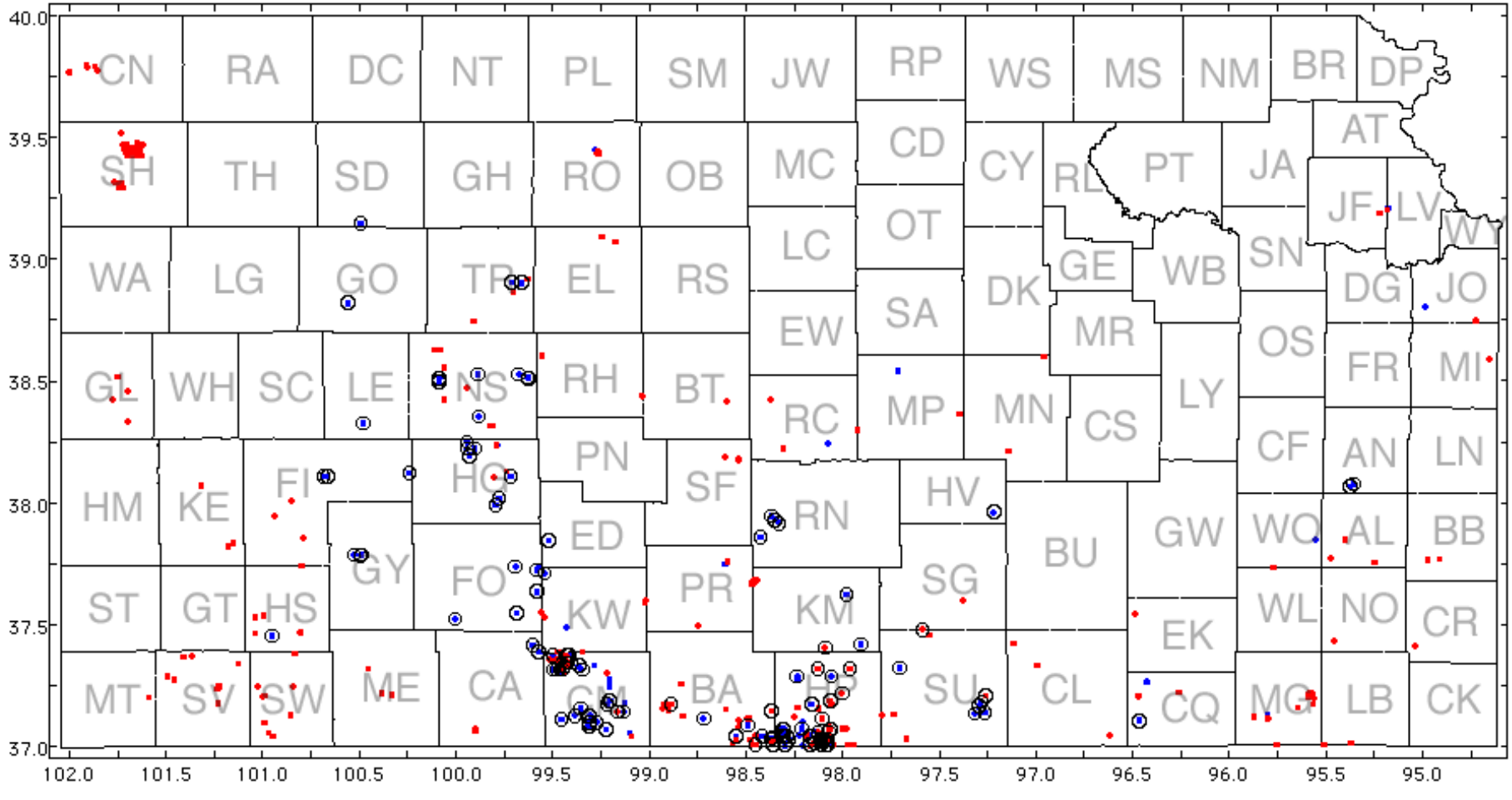
Total annual CO2 emissions (ethanol + fertilizer): 2.2 million tonnes /year (113 MMscf/day)



KGS in collaboration with Midwest Governor's Association & Clinton Foundation

Horizontal Wells In Kansas

Permitted wells in blue; wells drilled in red; 2012 wells circled



July 20, 2012

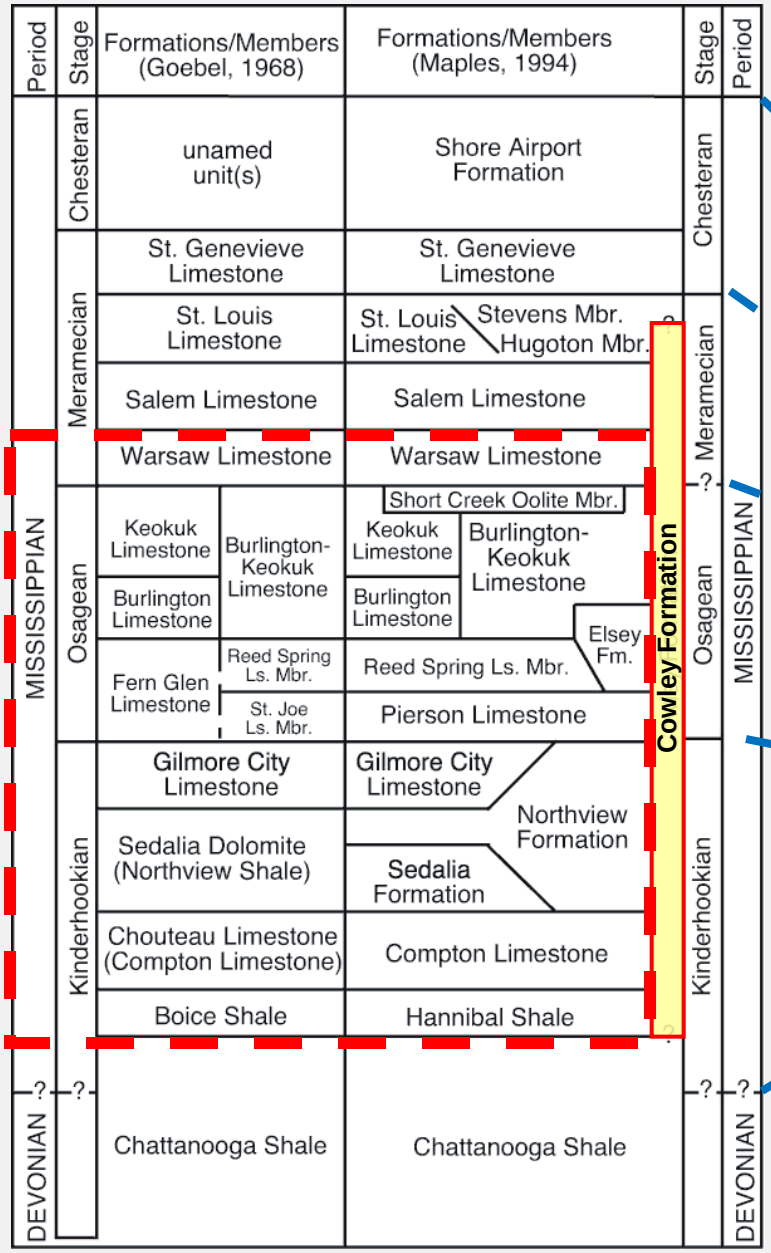
HORIZONTAL WELL DRILLED BY YEAR

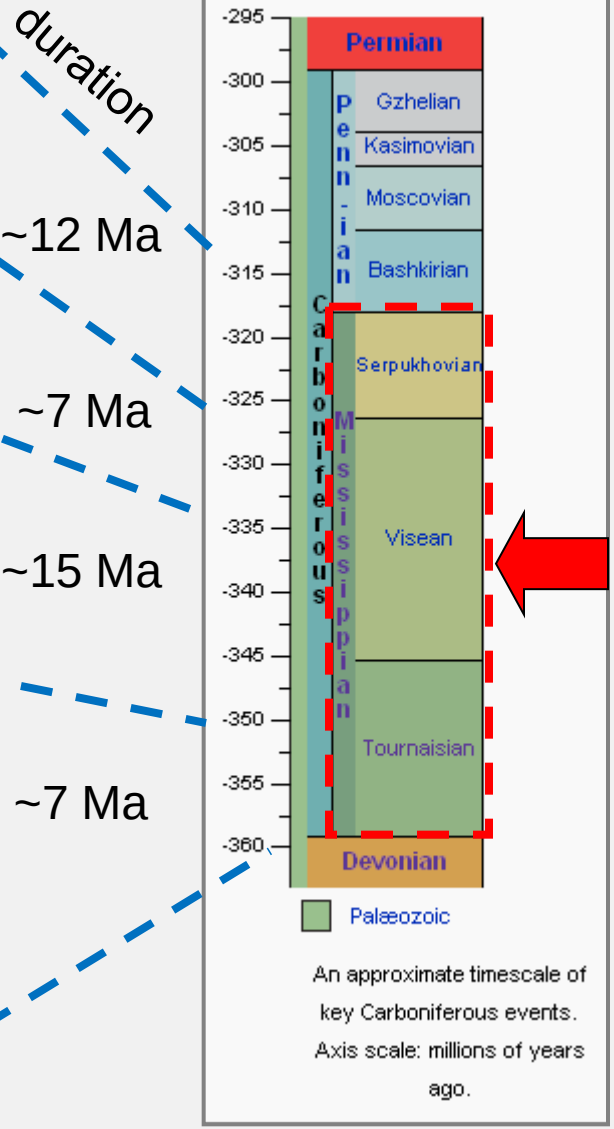
2009-6 **2010**-10 **2011**-44 **2012**-38

http://www.kgs.ku.edu/PRS/wellStats.html

Kansas Mississippian Stratigraphic Column (Maples, 1994)

Lower Carboniferous – Mississippian Subsystem

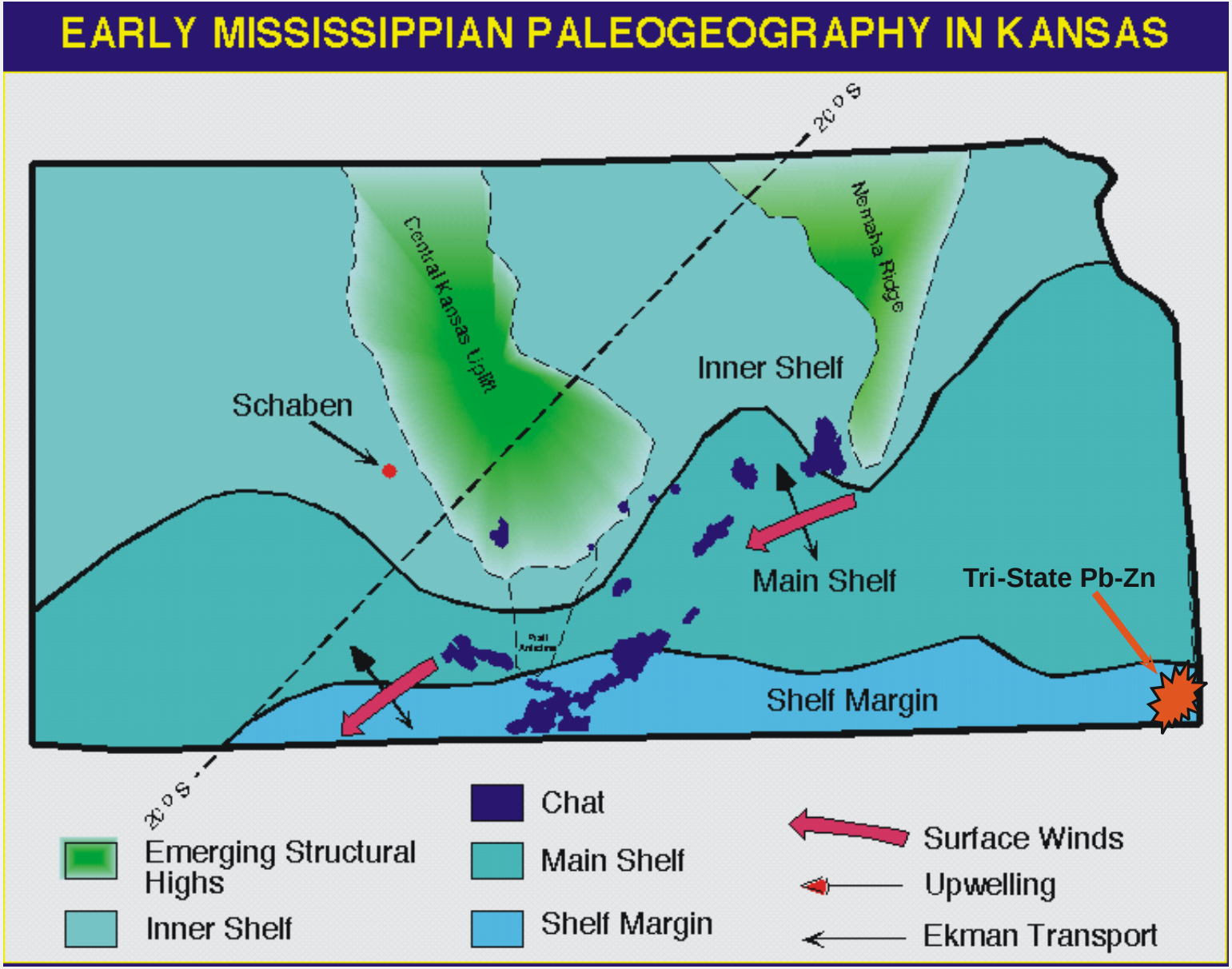




Caney, Fayetteville, & Barnett shales

initiation of Gondwannan glacioeustacy

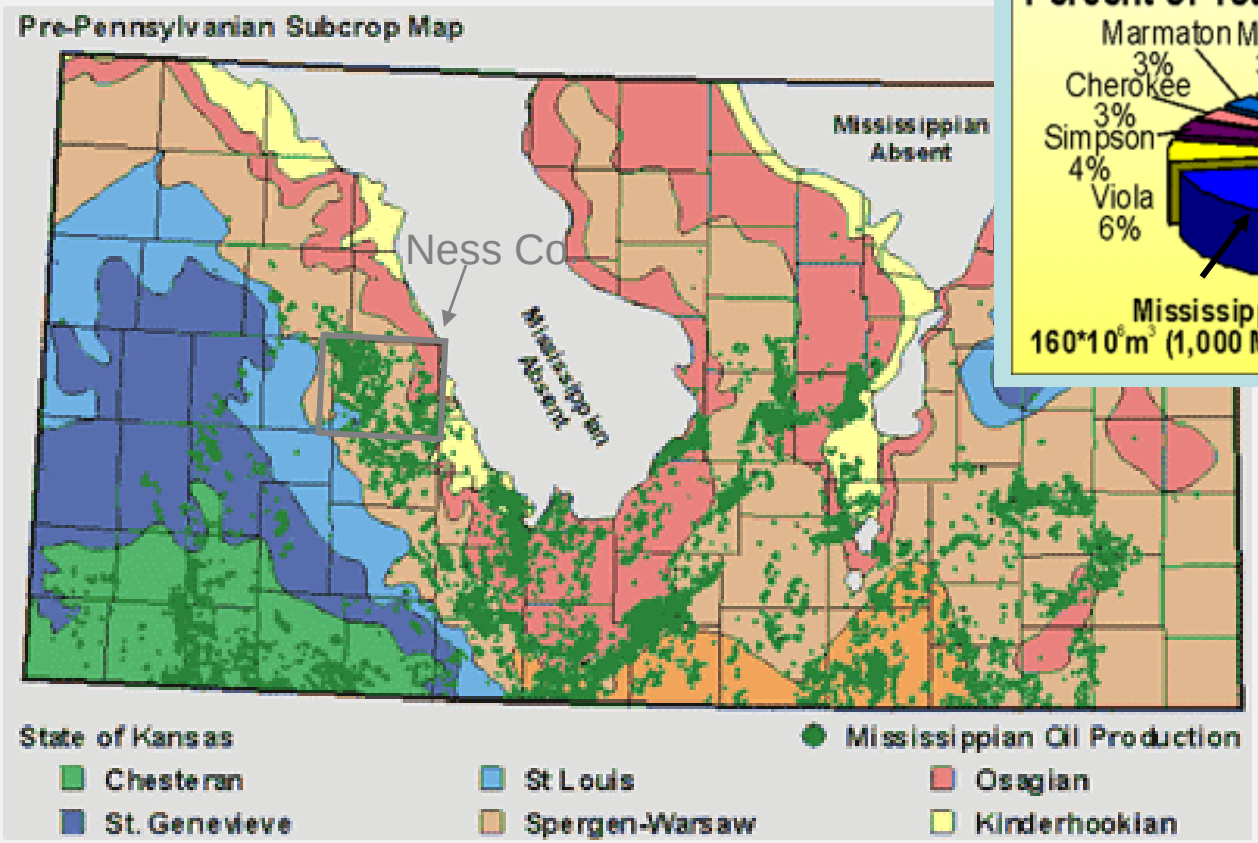
http://en.wikipedia.org/wiki/Carboniferous

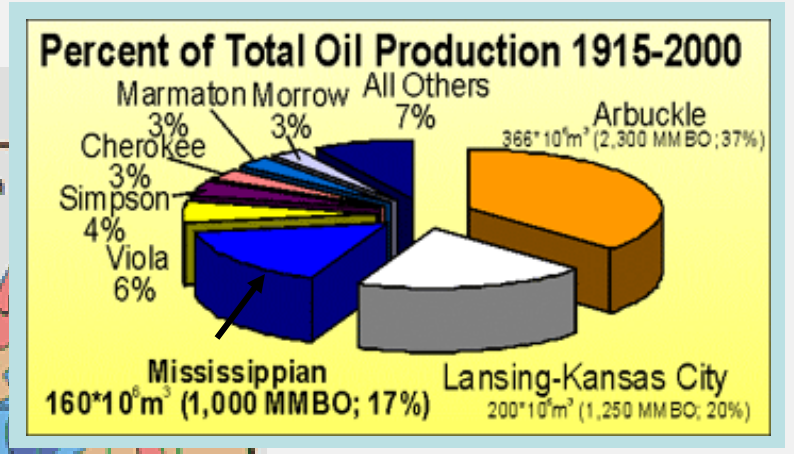


– Schaben Field located on inner shelf - predominantly nodular chert
– Southern shelf and shelf margin - bedded chert
– Potential for upwelling in southern low latitude setting with prevailing winds from east-southeast (After Franseen, 2006)

Franseen (2006)

Mississippian Reservoirs Important to Kansas





From Mississippi

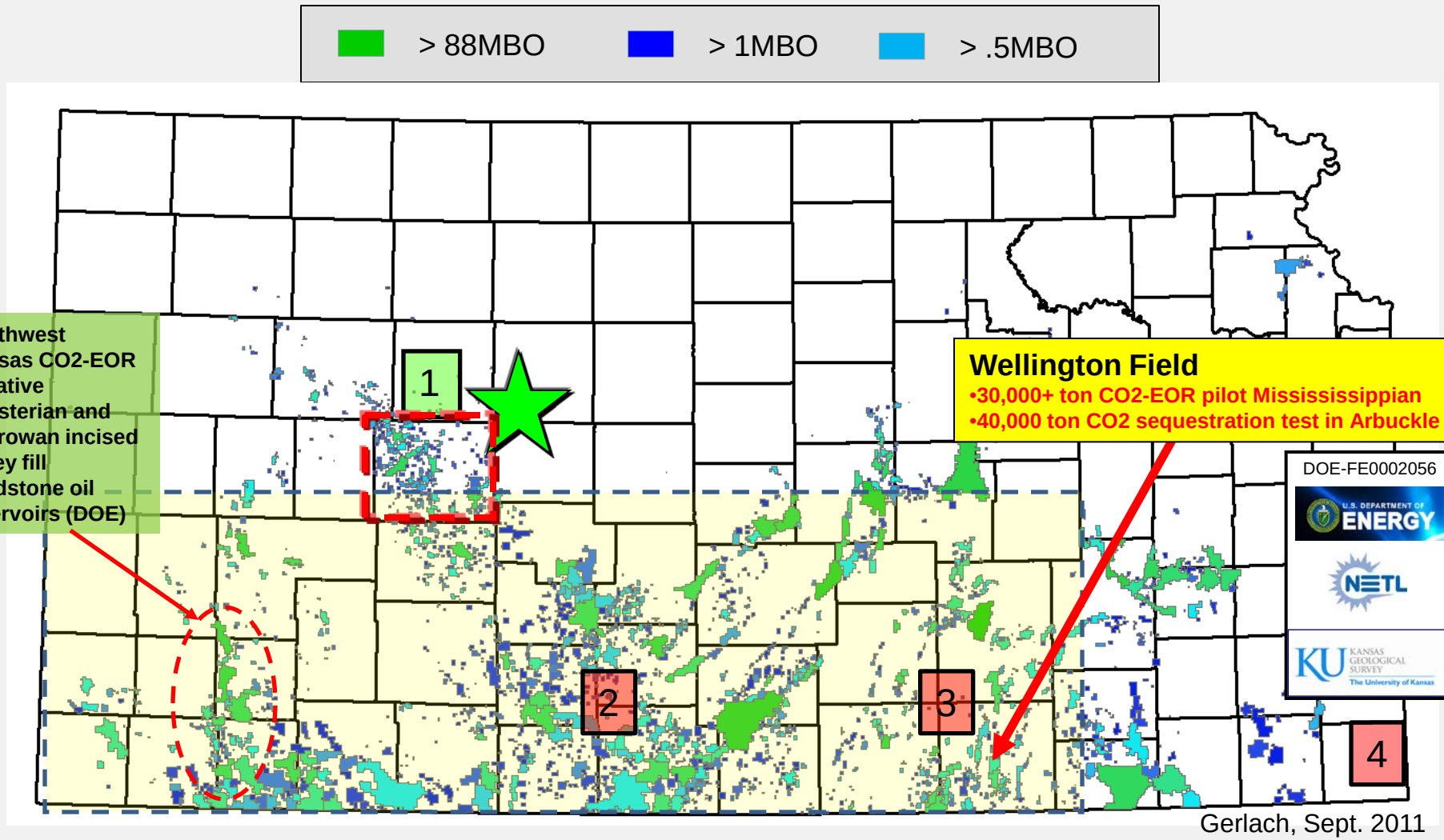
- **1 Billion BO Cum.**
- **33% of Current**

Gerlach, 1998

Pre-Penn. Subcrop Map of Kansas

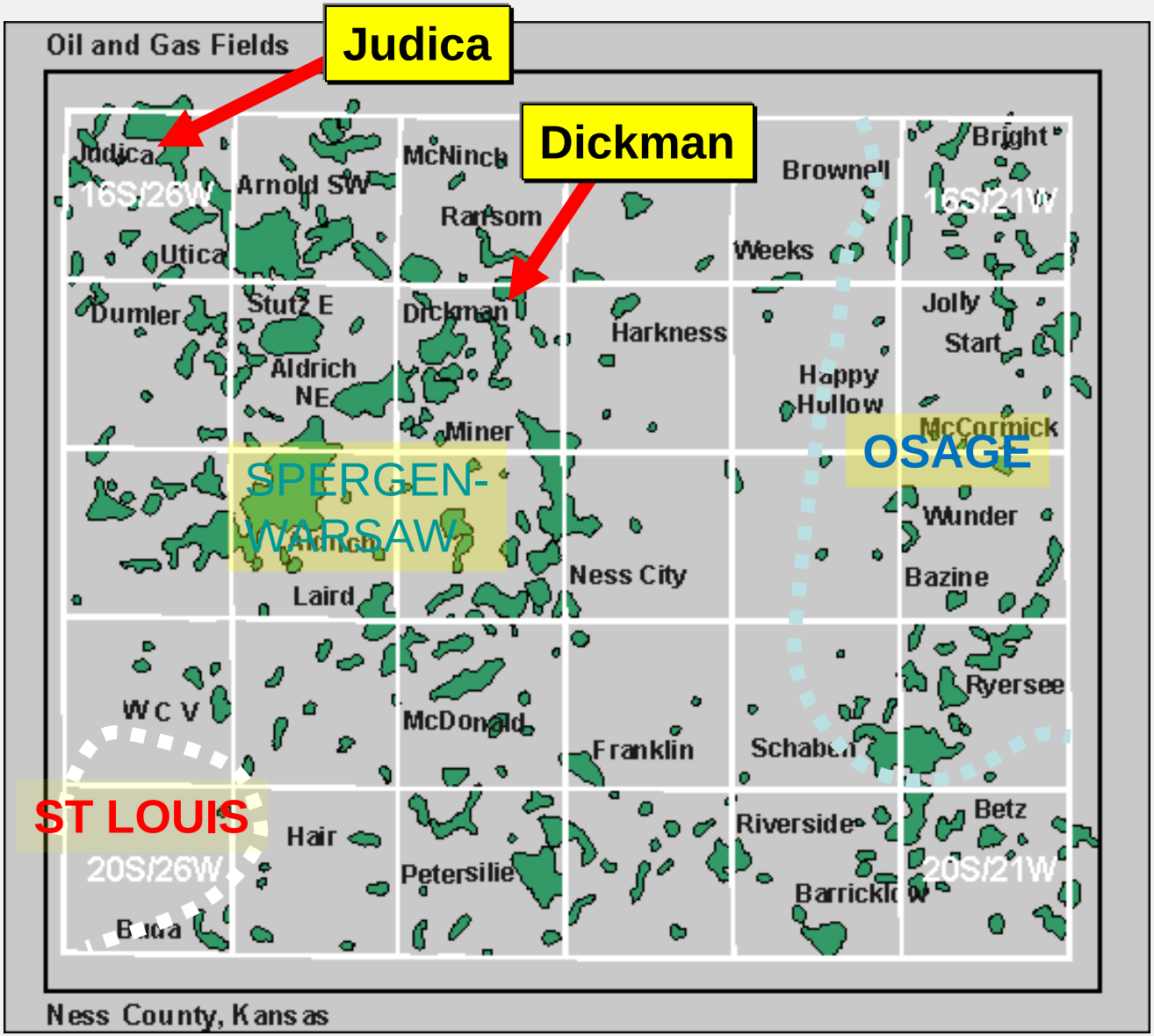
Miss Oil Production in Green

Mississippian Oil Fields in Kansas



Gerlach, Sept. 2011

Ness County Field Examples

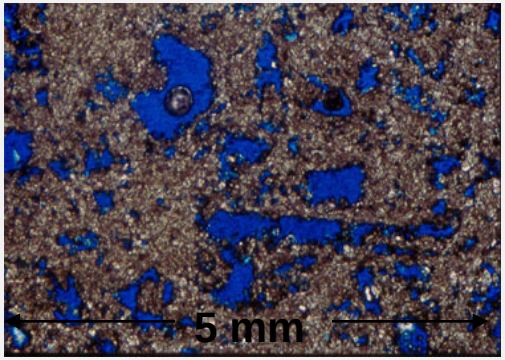


Facies and Petrophysical Properties

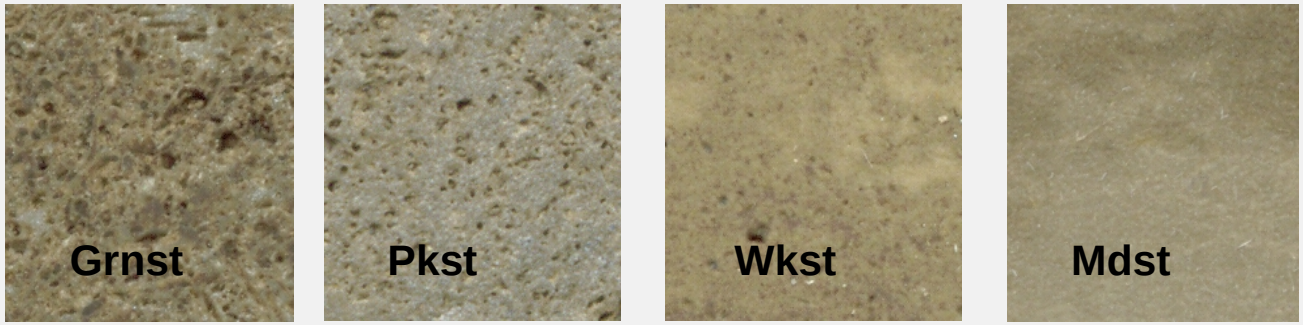
- **Original Facies (primary texture and grain size) control pore geometry**
- **Pore geometry determines pore throat size which in turn controls permeability and capillary pressure relationships**

FOR A SET OF ROCKS OF DIFFERENT ORIGINAL FACIES BUT SAME POROSITY

Byrnes, Franseen, Watney and Dubois, 2003



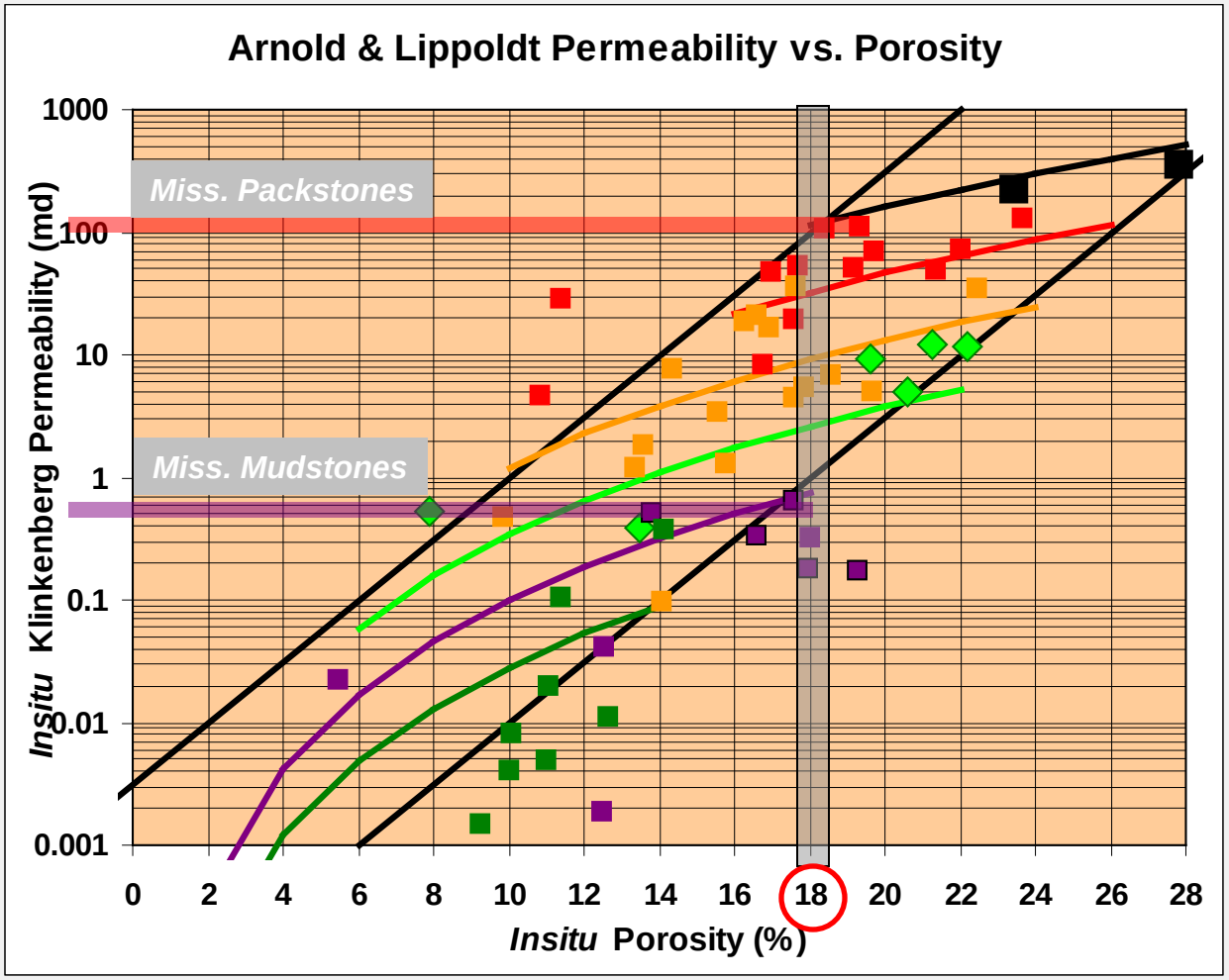
Those with larger grains (and less mud), generally have larger pores, larger pore throats, lower threshold pressures for saturating the rock with oil and higher oil saturations for a given height above free water



(Original texture, pre-dolomitzation, indicated)

Permeability vs Porosity

$k = A * phi^{3.45}$



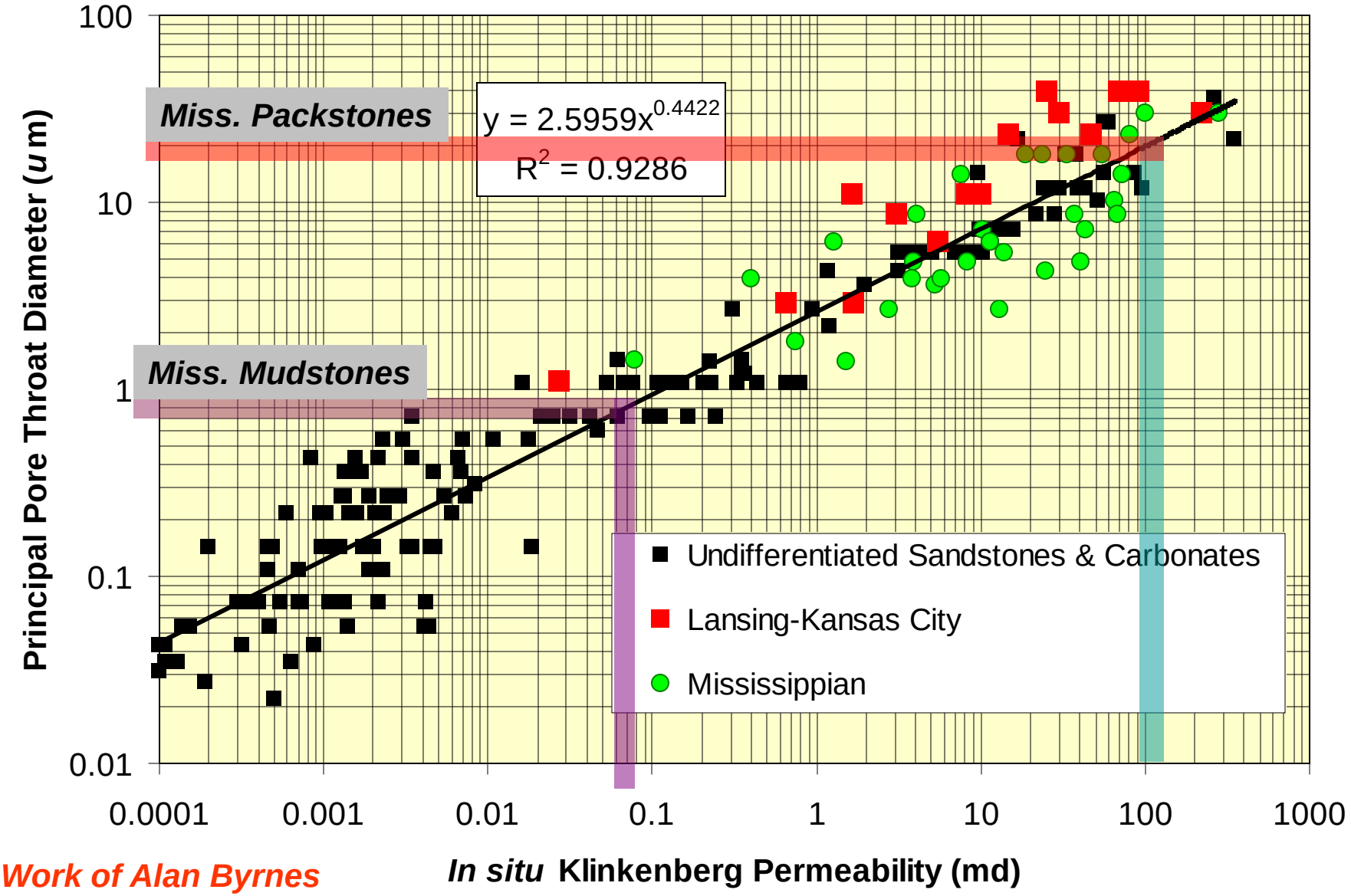
Lithofacies	A
Packstone	0.00525
Pack-Wackestone	0.00150
Wackestone	0.00043
Mud-Wackestone	0.00012
Mudstone	0.00004
Shaly Mudstone	0.00001
multiplier	3.5

Curves Dependent on

- ± 5X
- Lithofacies
- Grain type
  - –Echinoderm
  - –Sponge spicule
- Moldic content

Work of Alan Byrnes

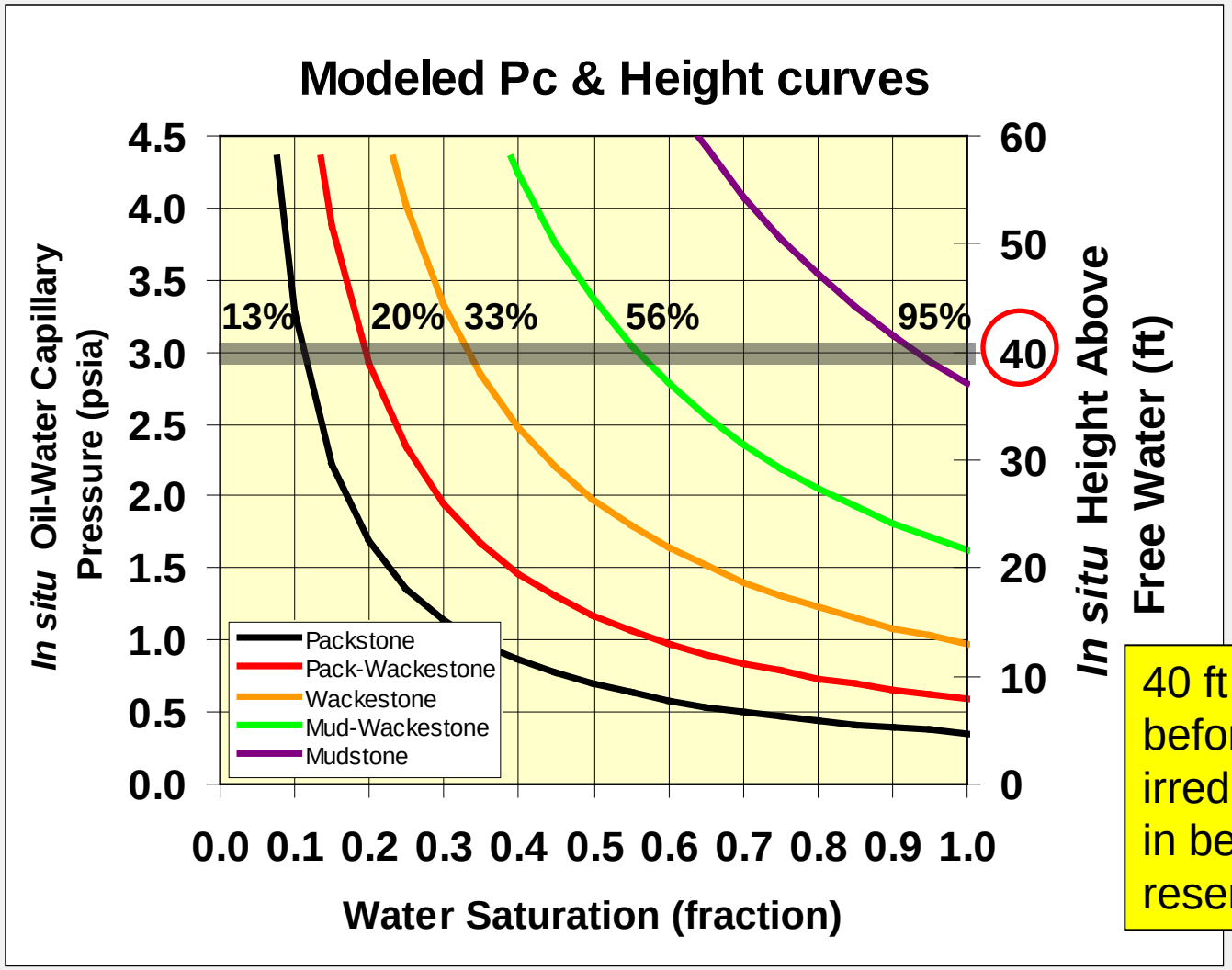
Permeability vs Pore Throat Diameter



Work of Alan Byrnes

(Byrnes et al, 2003)

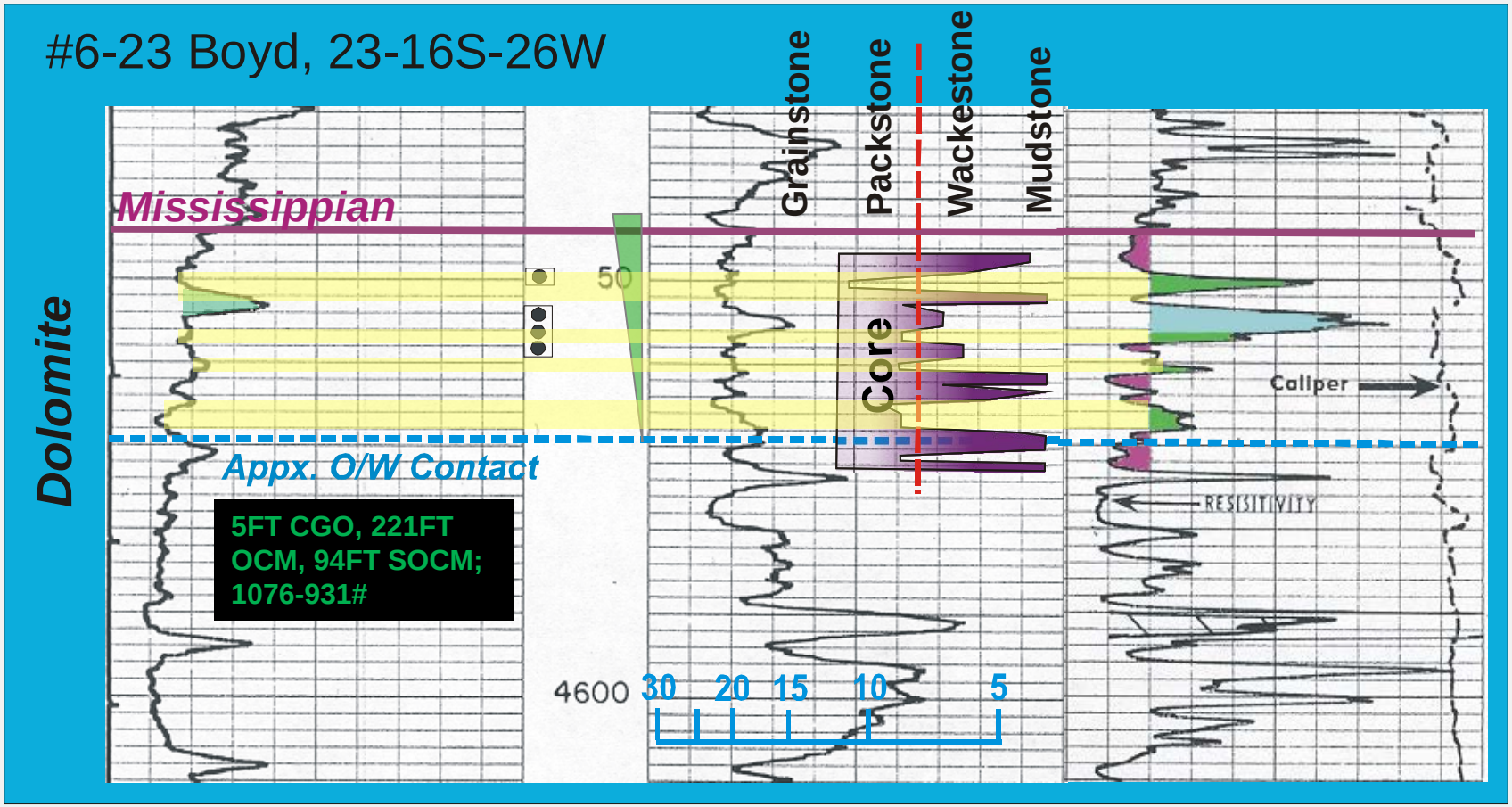
Capillary Pressure vs Lithofacies (Example for porosity = 18%)



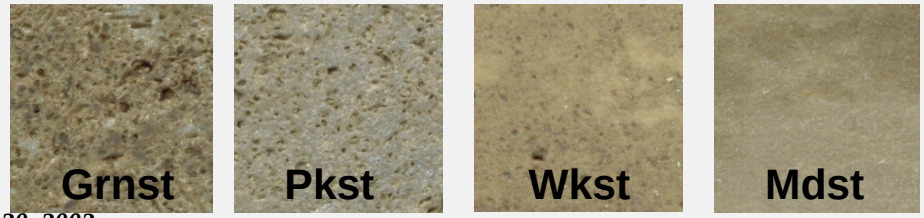
40 ft transition before reach irreducible Sw in best reservoir rock

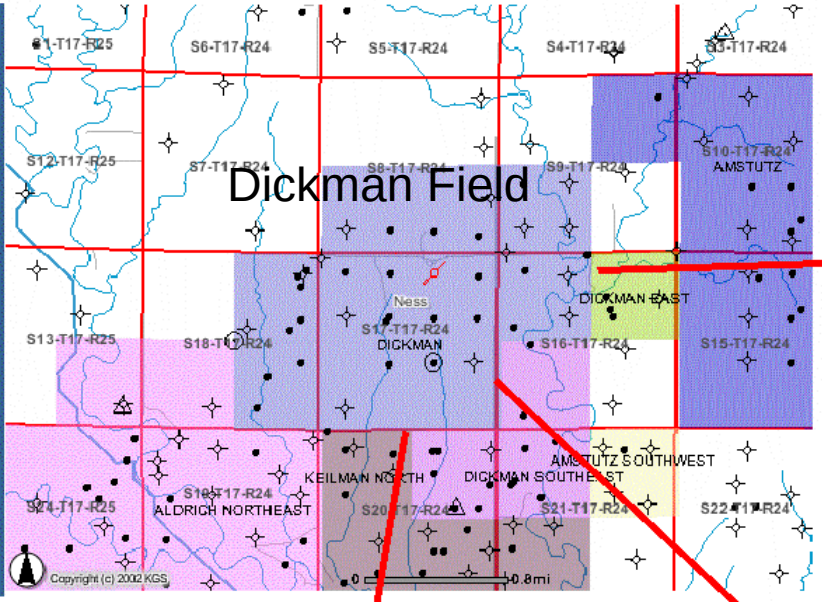
Work of Alan Byrnes

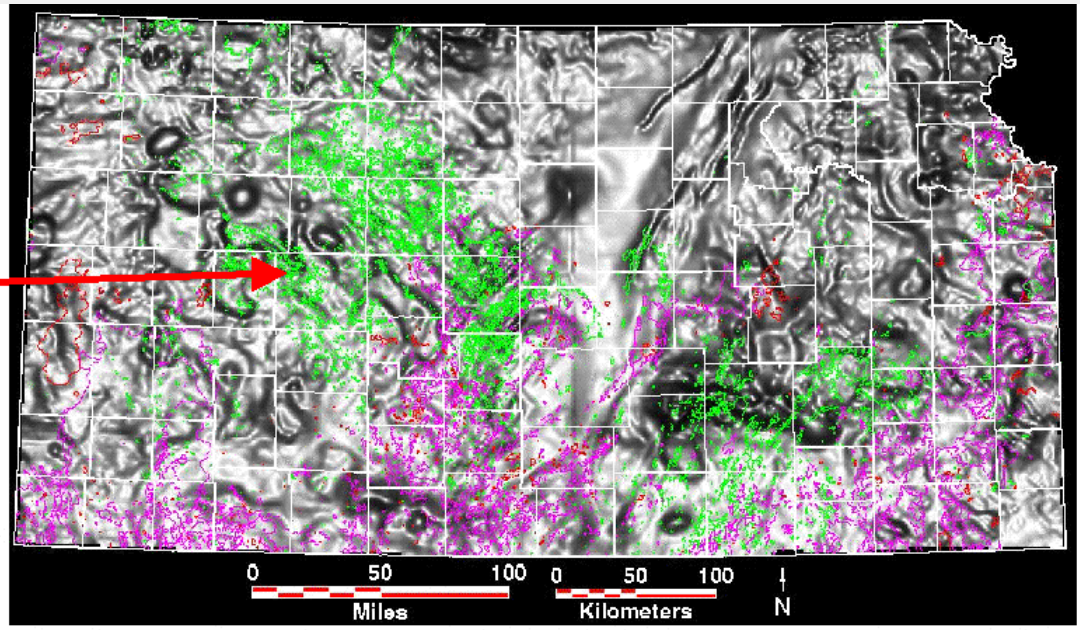
Core Facies to Log Curve Patterns
Judica Field, Ness County, Warsaw dolomite

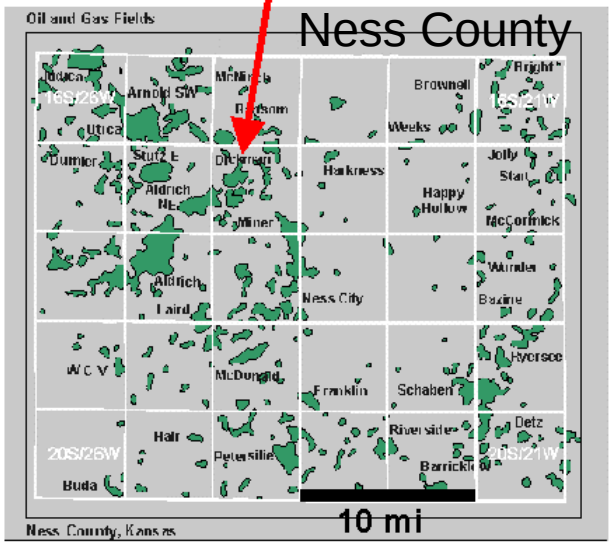


Fracture stimulation to intersect thin layers above O/W contact

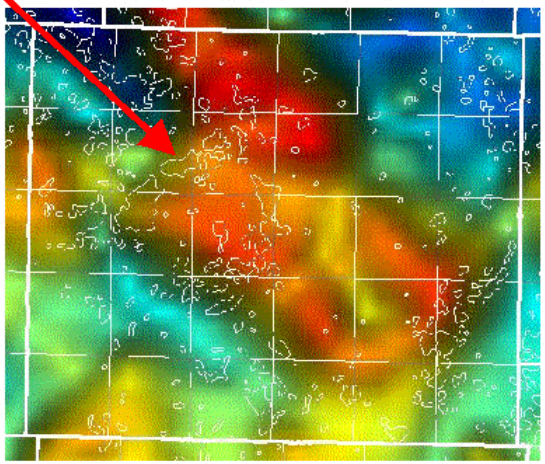




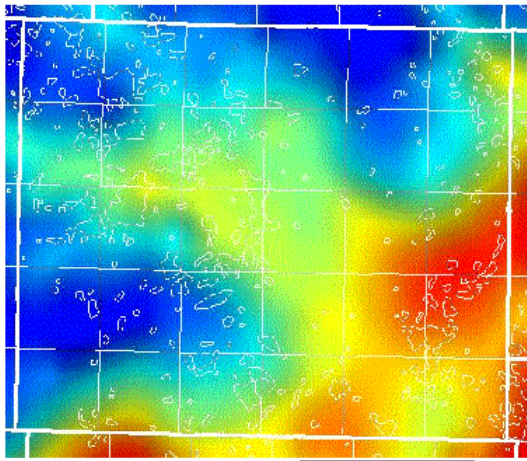




Magnetic Map, Ness County

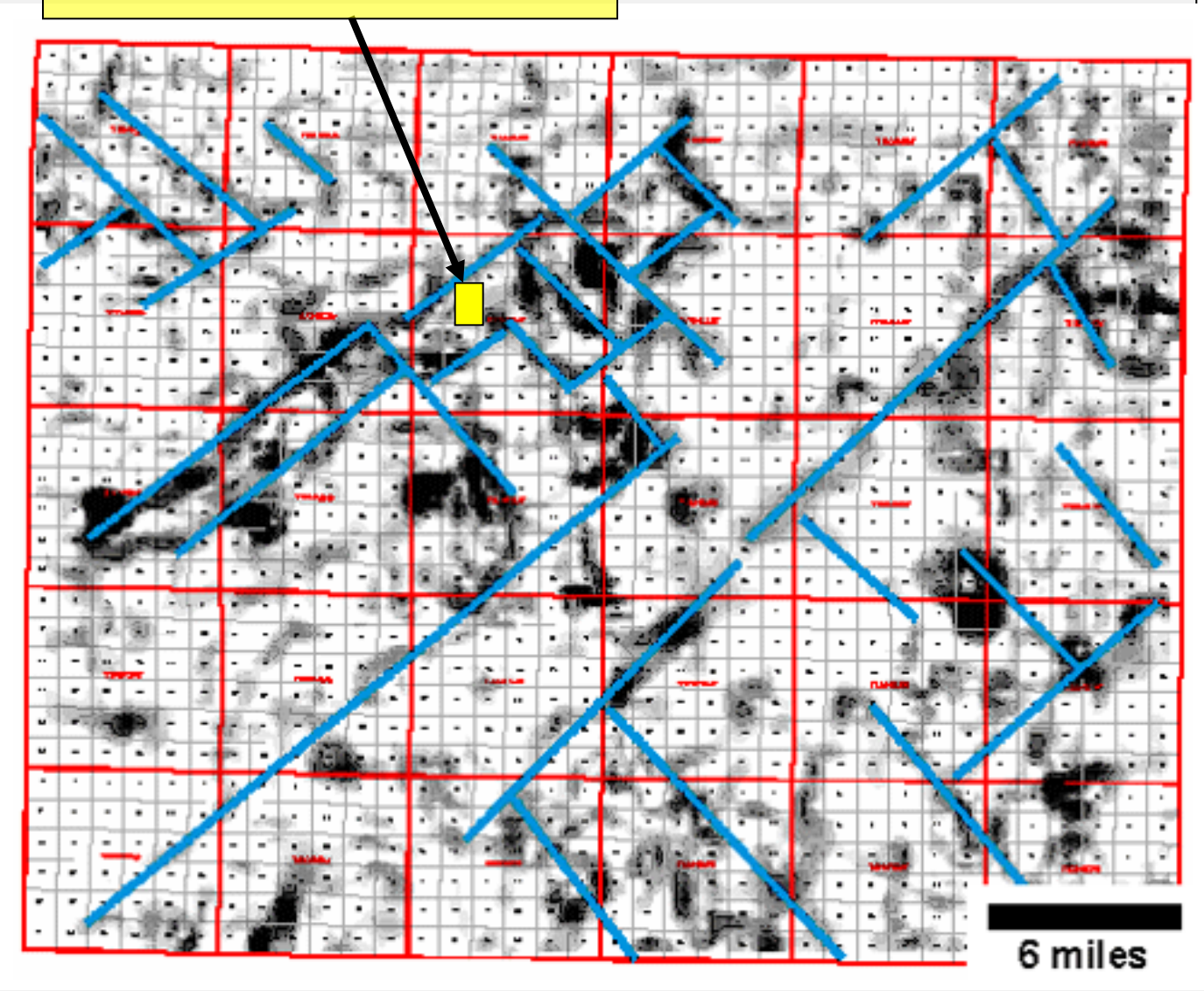


Gravity Map,Ness County



Watney et al. (2007)

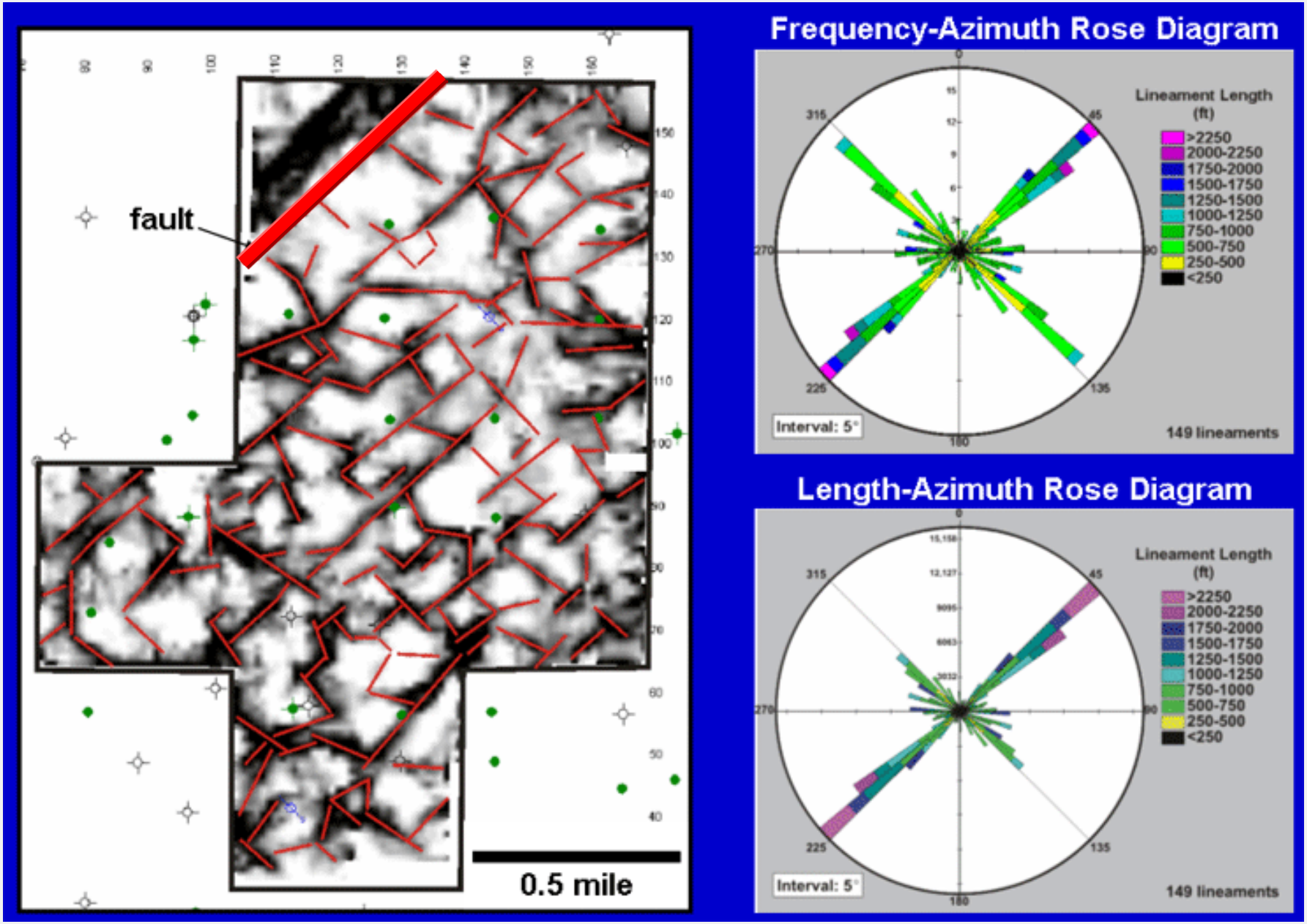
Yellow box = Location of 2 mi^2 3-D seismic survey, Dickman Field



Dip map of the top of Mississippian surface for Ness County.

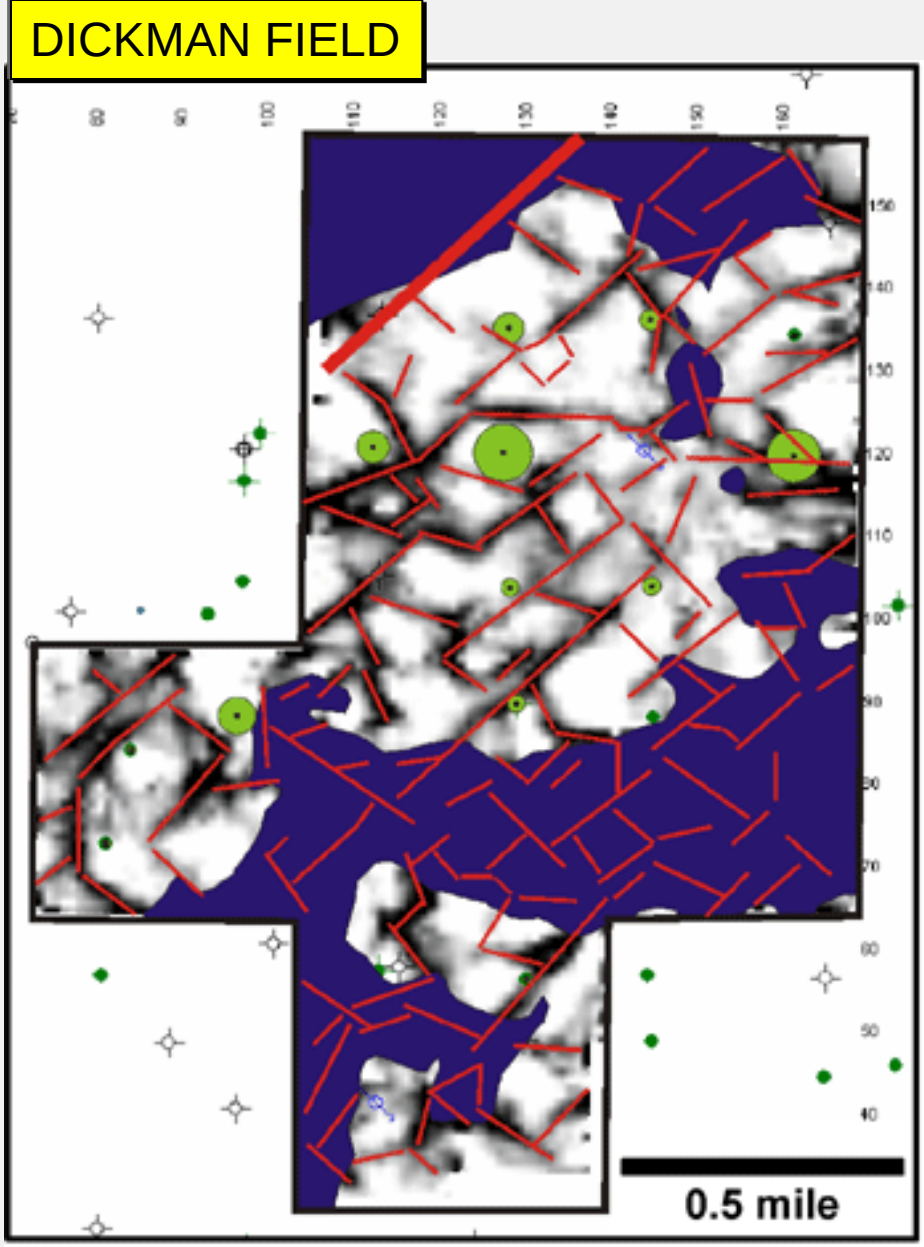
-- Lineaments with high dip are likely to indicate faults. Interpreted lineaments are shown in blue

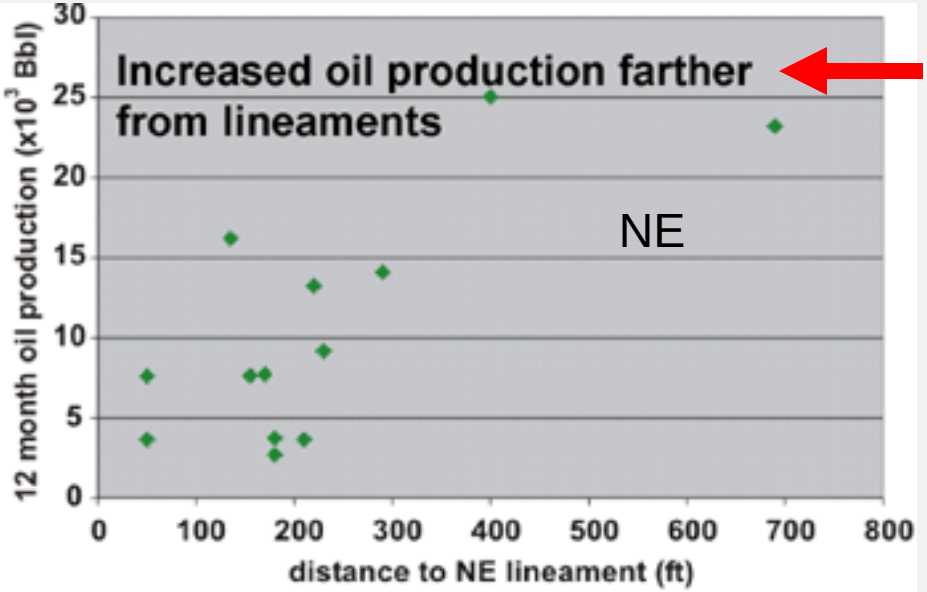
Nissen et al. (2005)

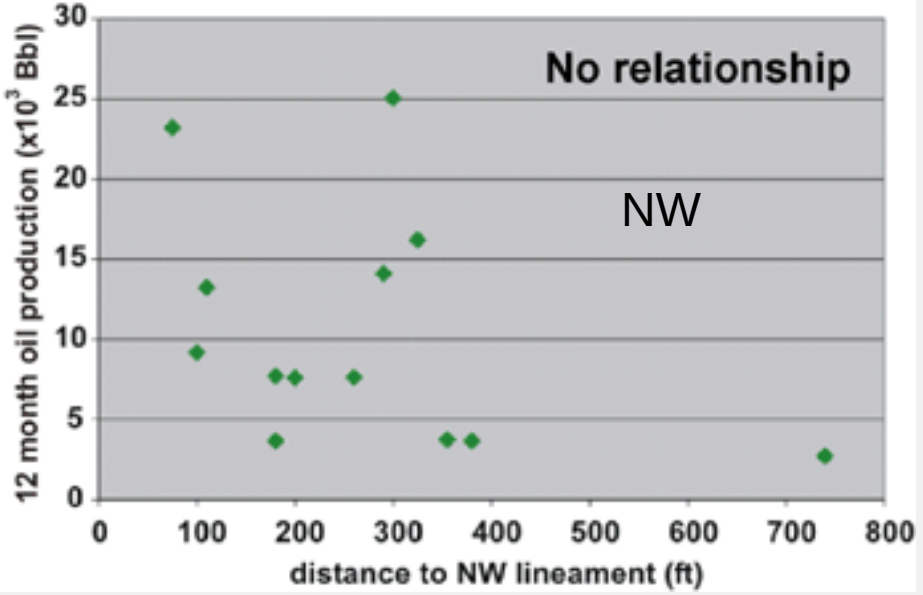


Left = volumetric curvature extracted from Mississippian and rose diagrams for Interpreted lineaments (from Nissen et al., 2005)

DICKMAN FIELD

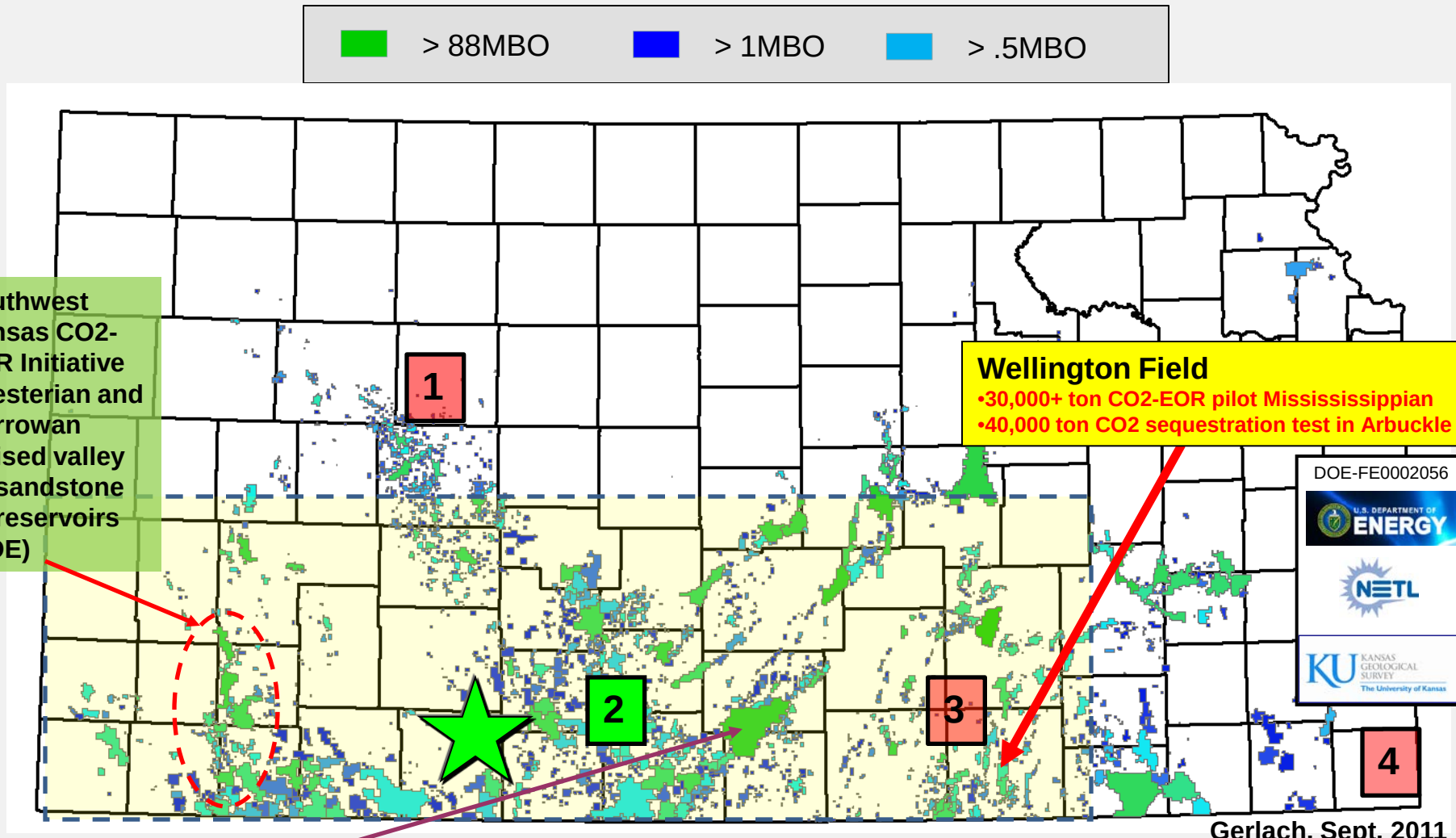






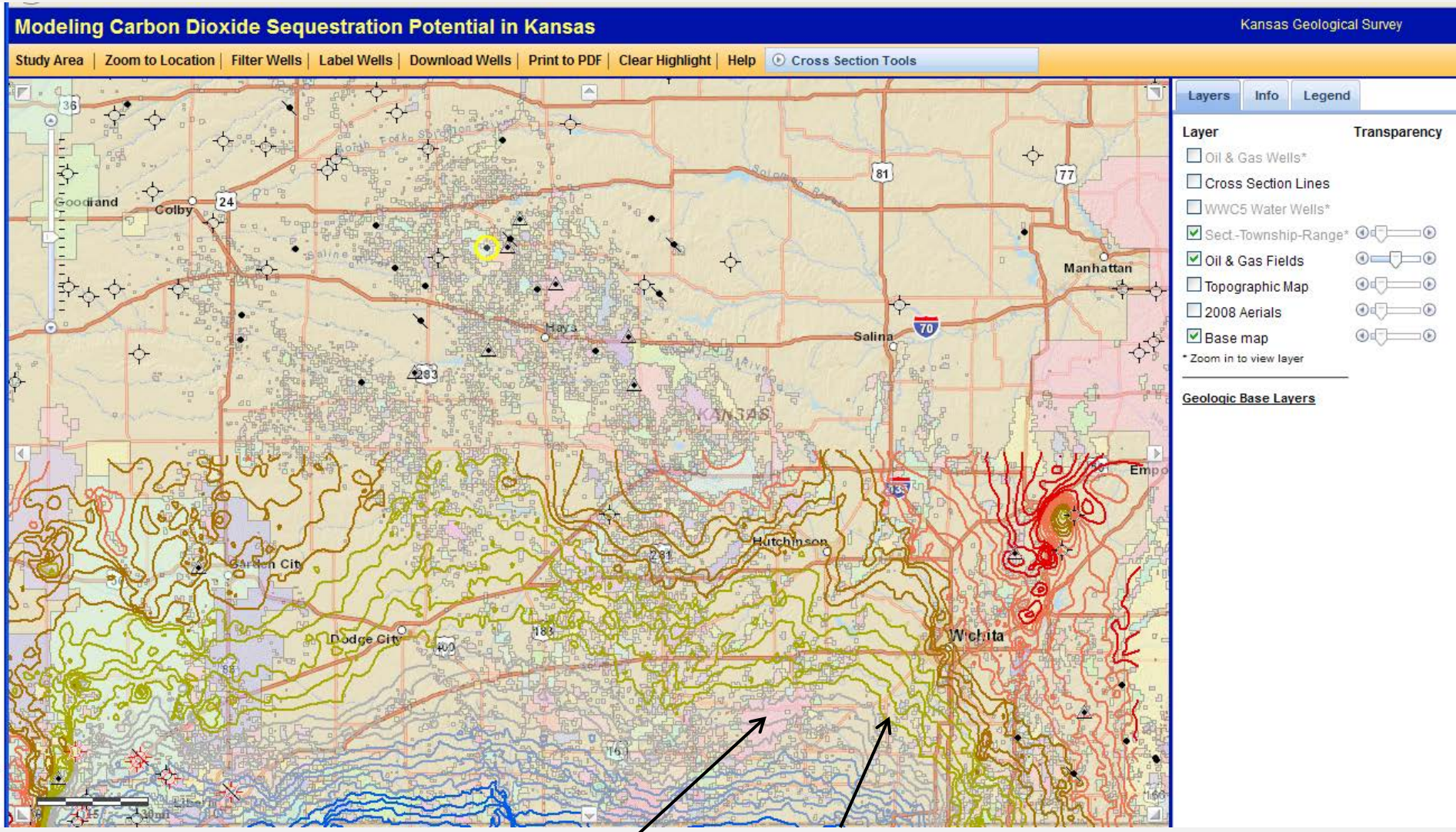
Left: Bubble map of oill production from the Mississippian. Right: Oil production versus distance to nearest NW and NE lineaments (from Nissen et al., 2005)

Mississippian Oil Fields in Kansas



<u>Spivey-Grabs Basil</u> is the largest Mississippian oil field in Kansas with 70 MM BO & 847 BCFG Produces from the <u>tripolite</u> and could benefit from horizontal drilling and CO_2-EOR

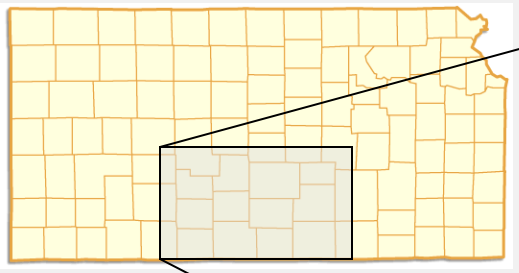
Structure Top Mississippian in Southern Kansas



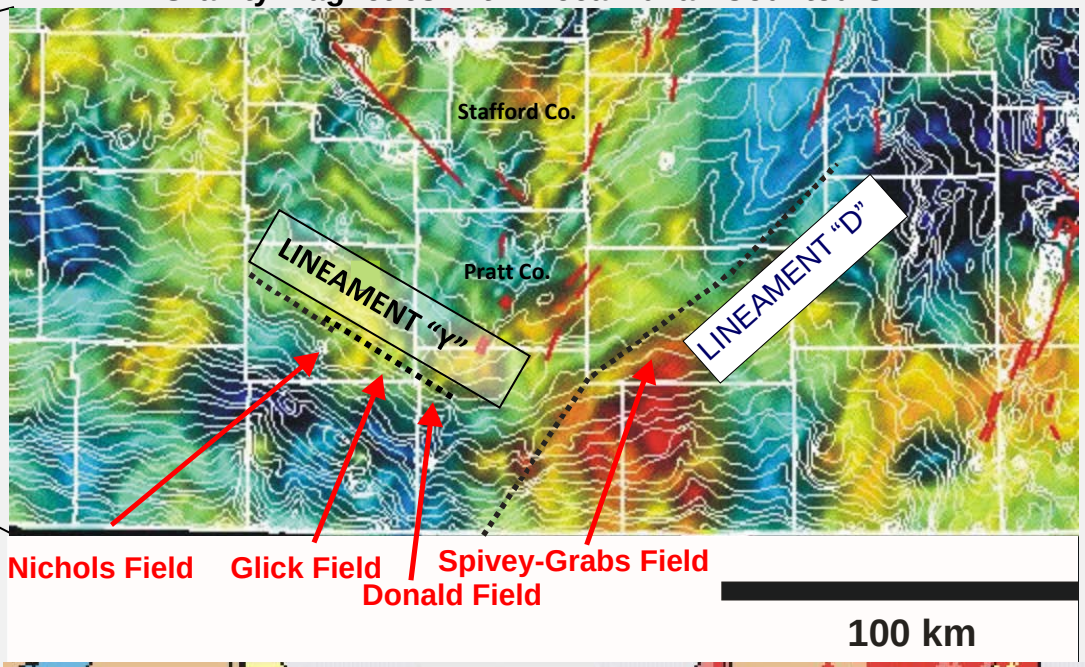
http://maps.kgs.ku.edu/co2/?pass=project

Examples –

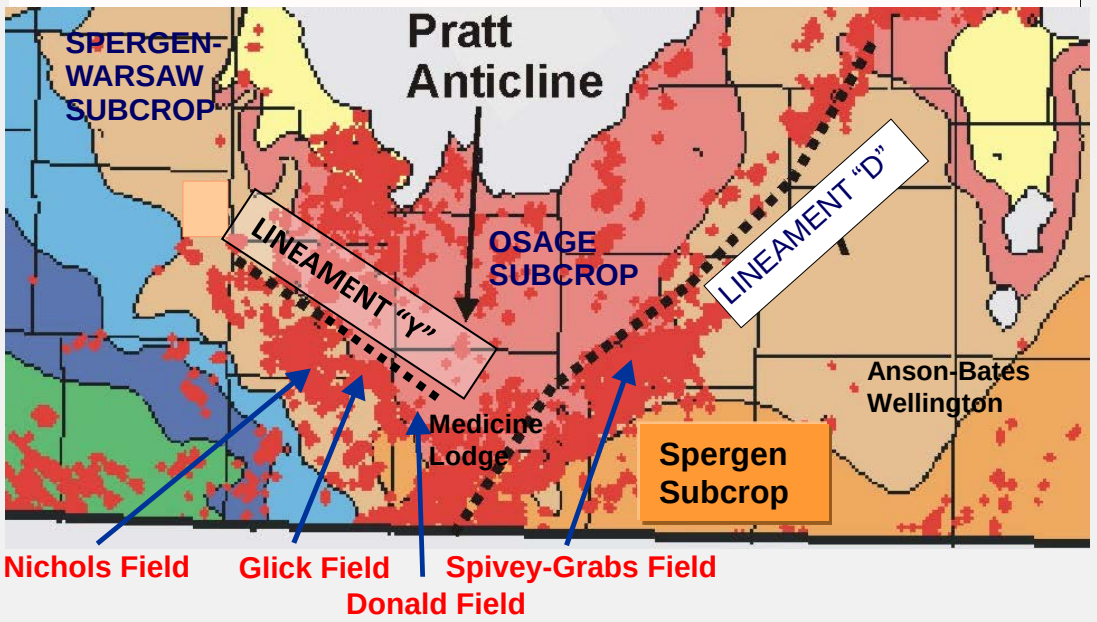
Four Mississippian "Chat" Fields



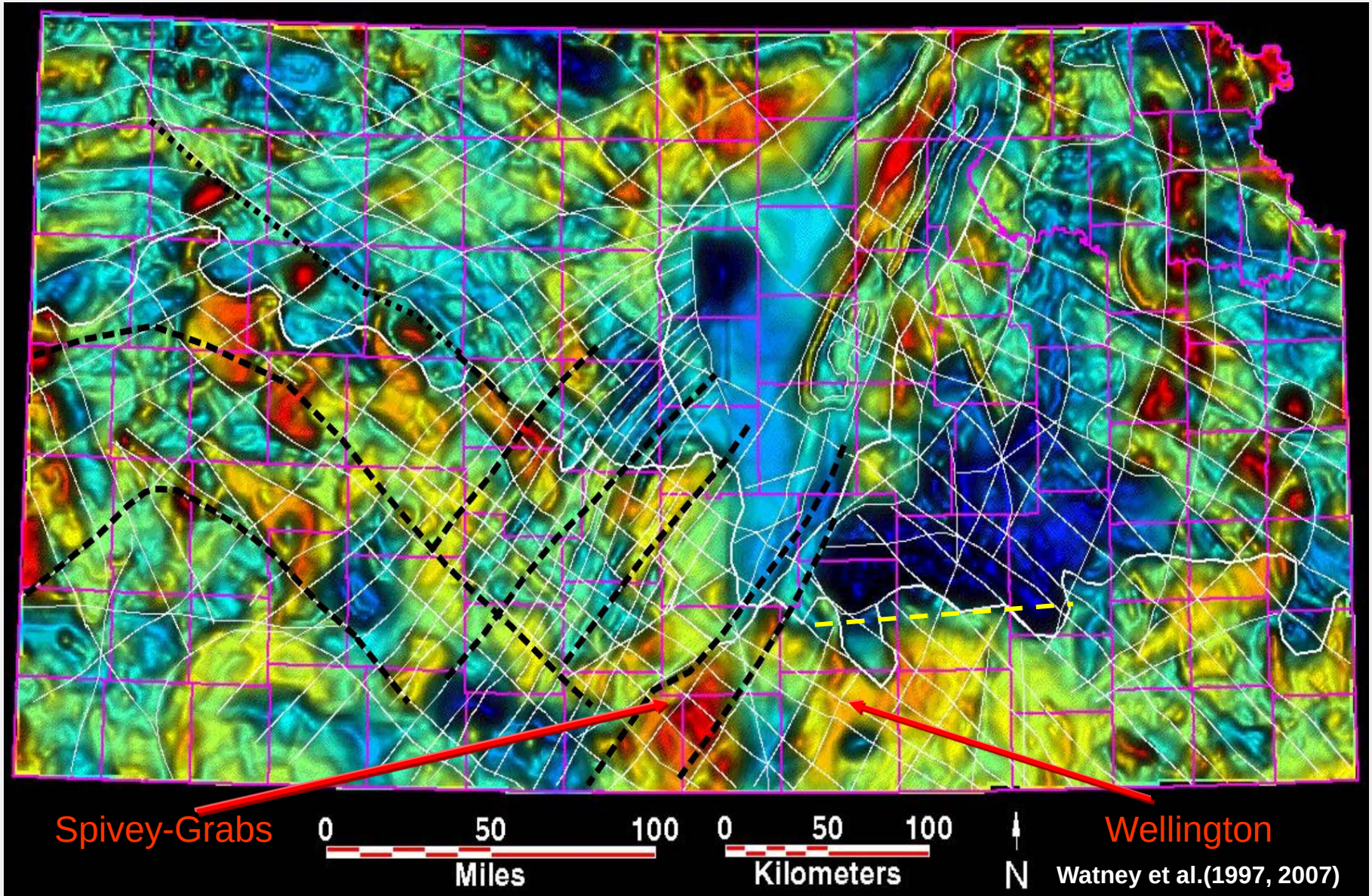
A)



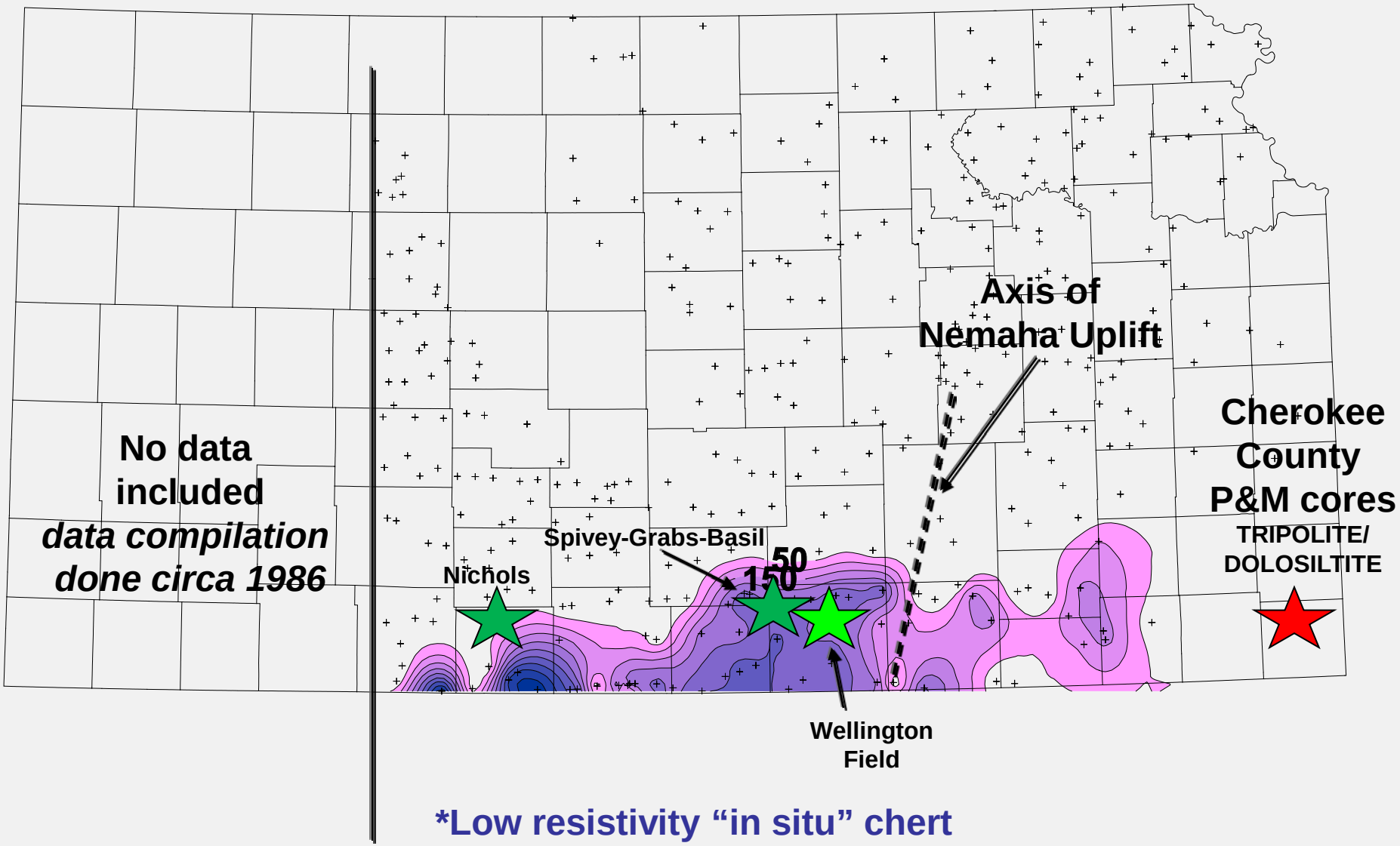
B)



Combined gravity –mag with regional lineaments overlain by active flexures of Upper Pennsylvanian age



Isopach of Low Resistivity Mississippian



***Low resistivity "in situ" chert "TRIPOLITE"**

Watney et al. (2001)

West side
Hartner Field
Barber Co.

Lithologies Within the Mississippian Oil Play (Chert Embayment, South Central Kansas)

DOE-FE0002056

SW

NE

Cored Well
Wellington Fld.

KGS
#1-28

KGS
#1-32

Compton Ls

Viola

Compton Ls.

Compton Ls.

Compton Ls.

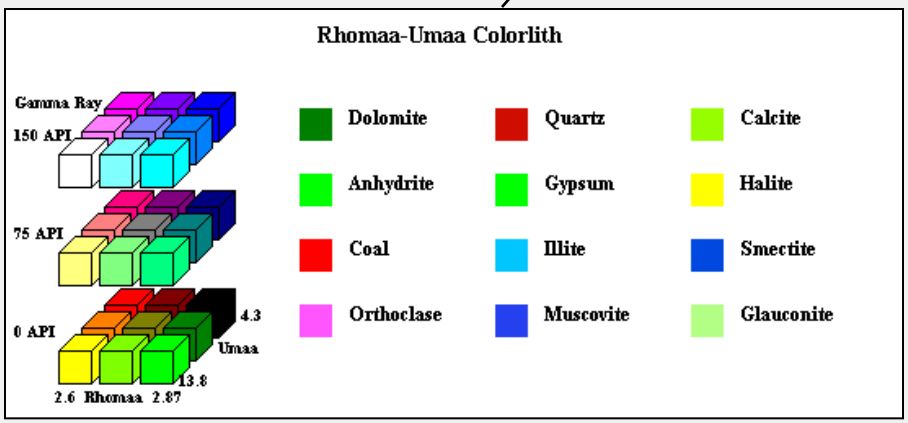
Cherokee

Mississippian

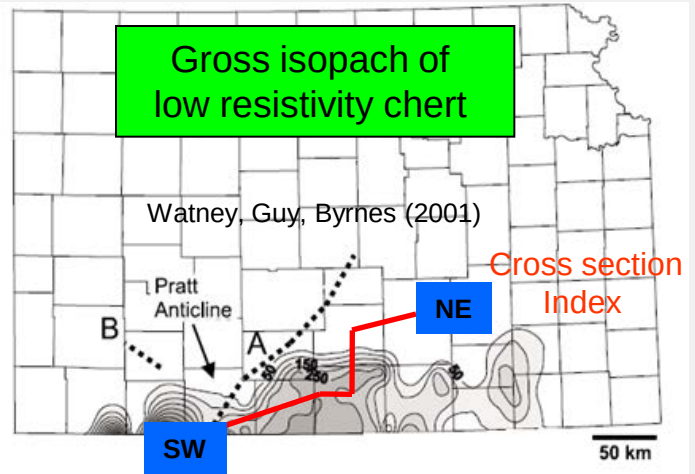
Chattanooga

Simpson

Datum: Top Arbuckle Group

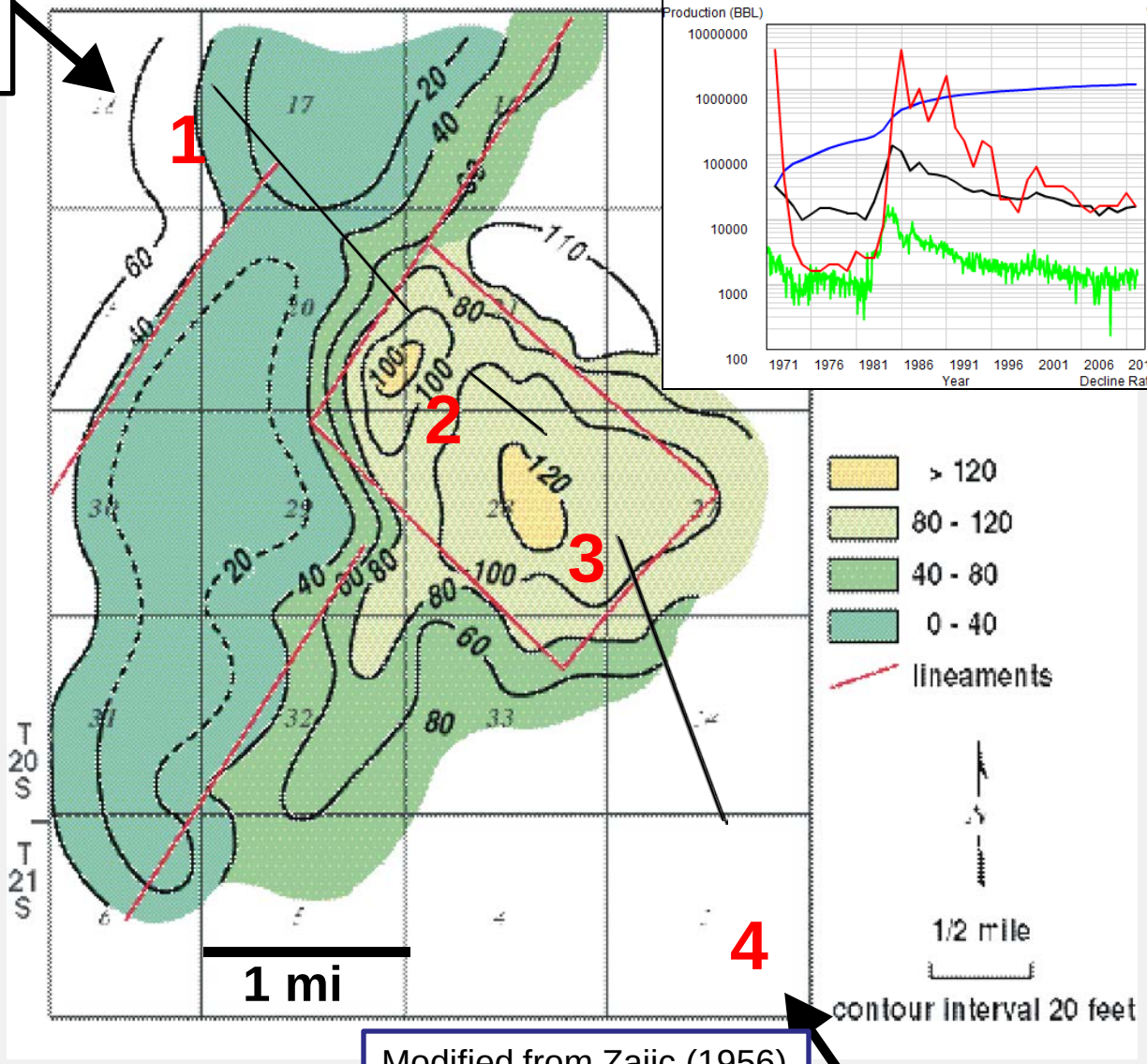


200 ft



Nichols Field, Kiowa County
Tripolitic chert preserved in fault block

Cross section index



Modified from Zajic (1956)

Erosional Truncation of Tripolite

KANSAS GEOLOGICAL SURVEY
The University of Kansas

NW

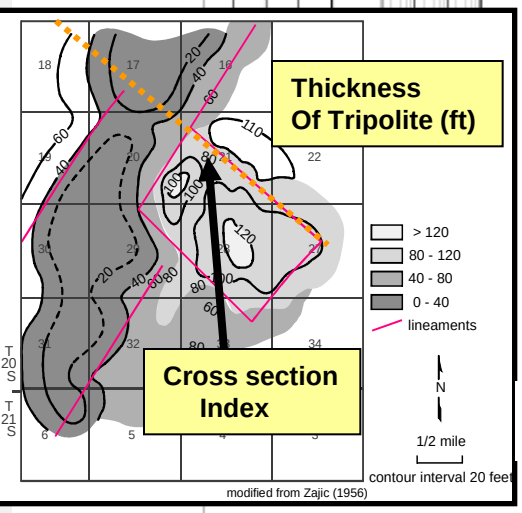
SE

1

2

3

4



GR

LLD

GR

NEUTRON

Excello

Mississippian

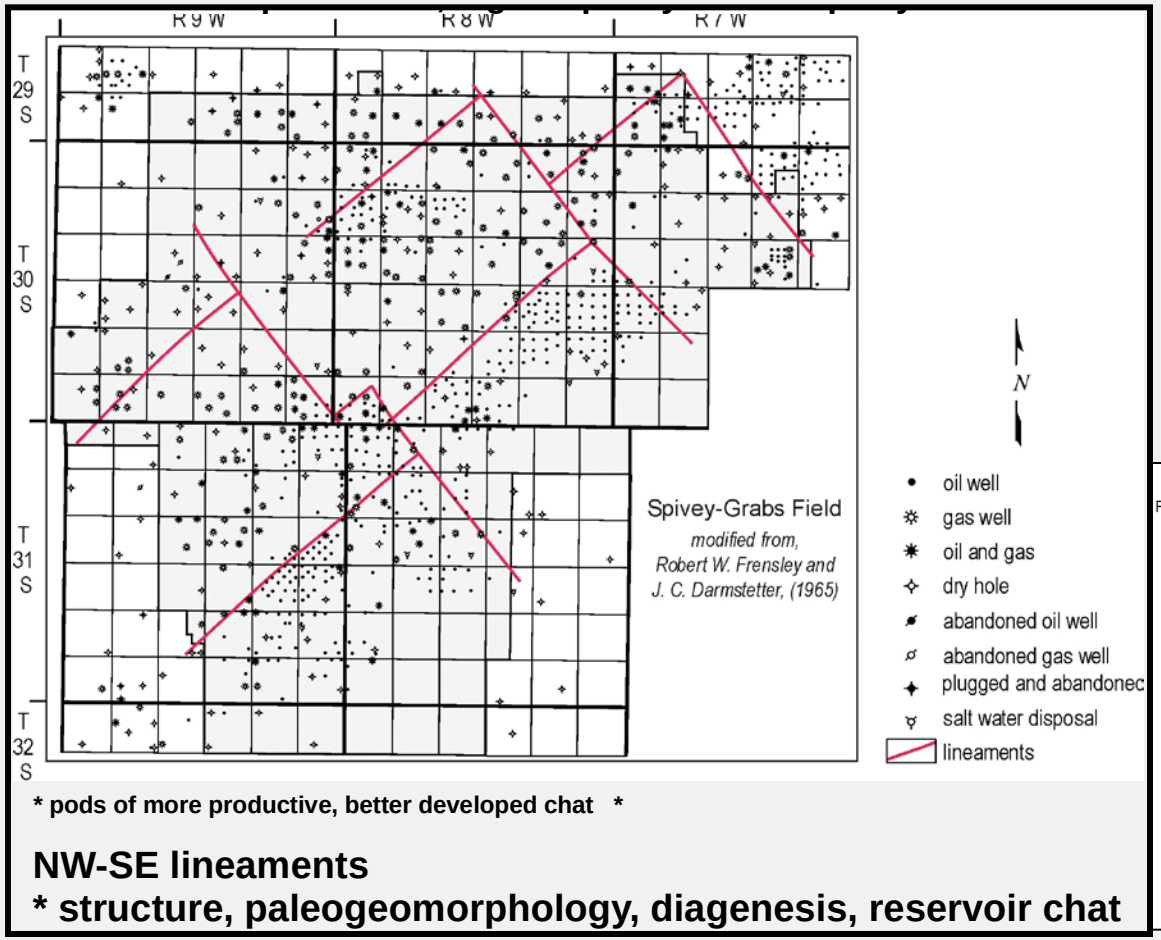
Chert-rich cycles

Stacked, Microporous low resisitivity tripolite

lineament

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

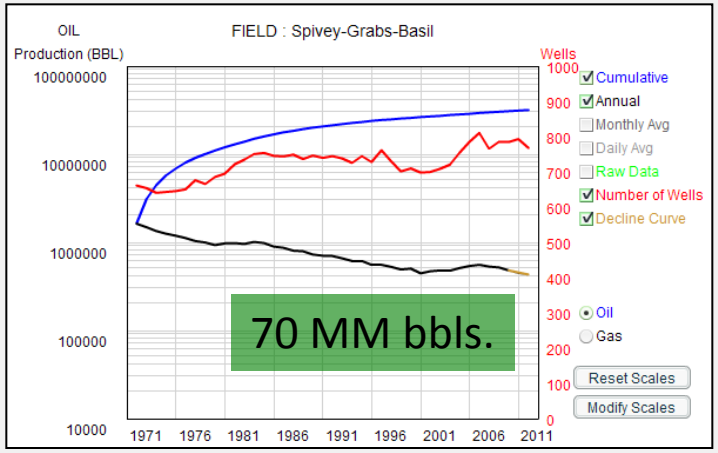
Compartments of more highly productive chat In Spivey-Grabs-Basil Field Barber, Harper, and Kingman County Kansas

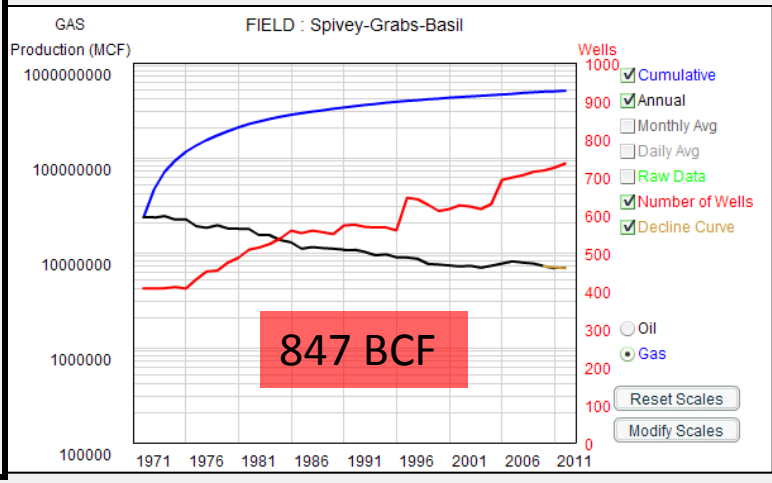


* pods of more productive, better developed chat *

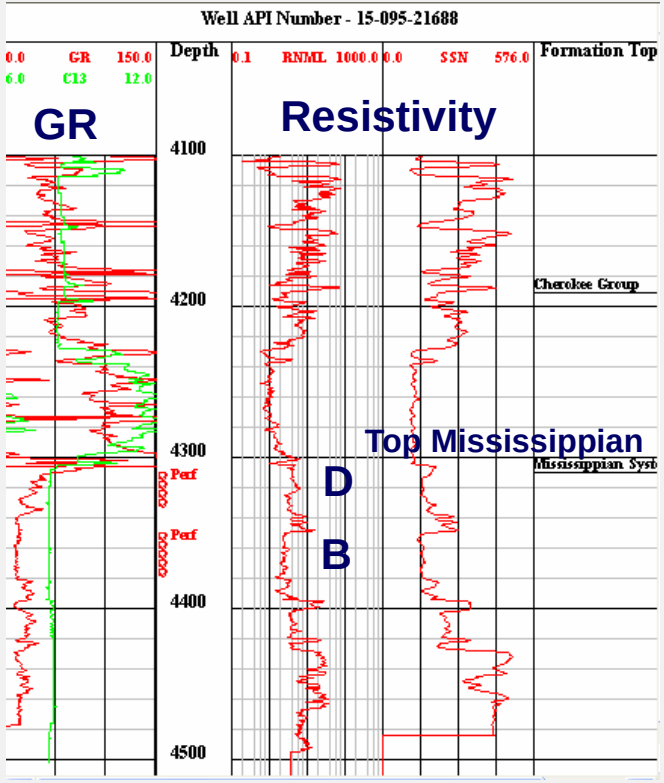
NW-SE lineaments

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

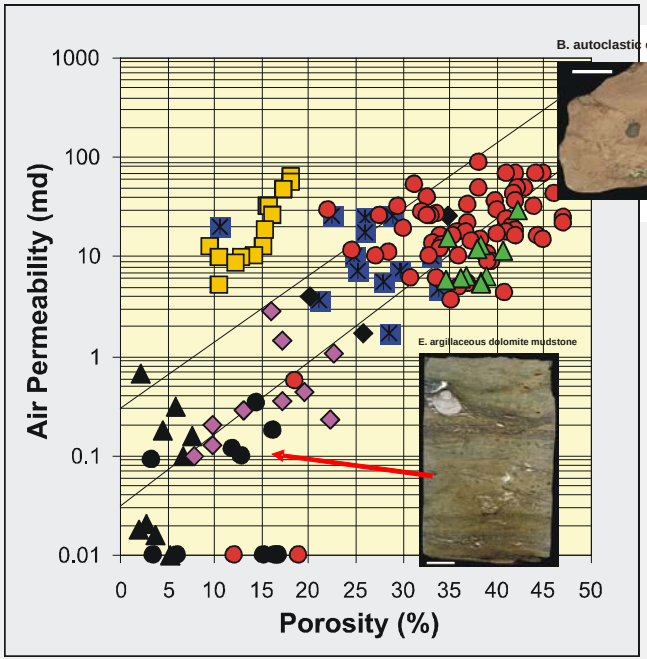


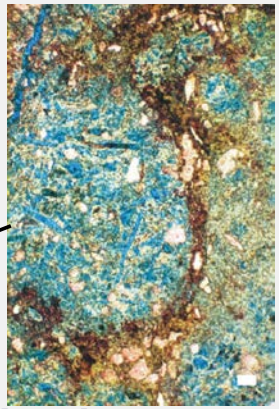


Spivey-Grabs-Basil Field



Chat cycles D and B are perforated for production

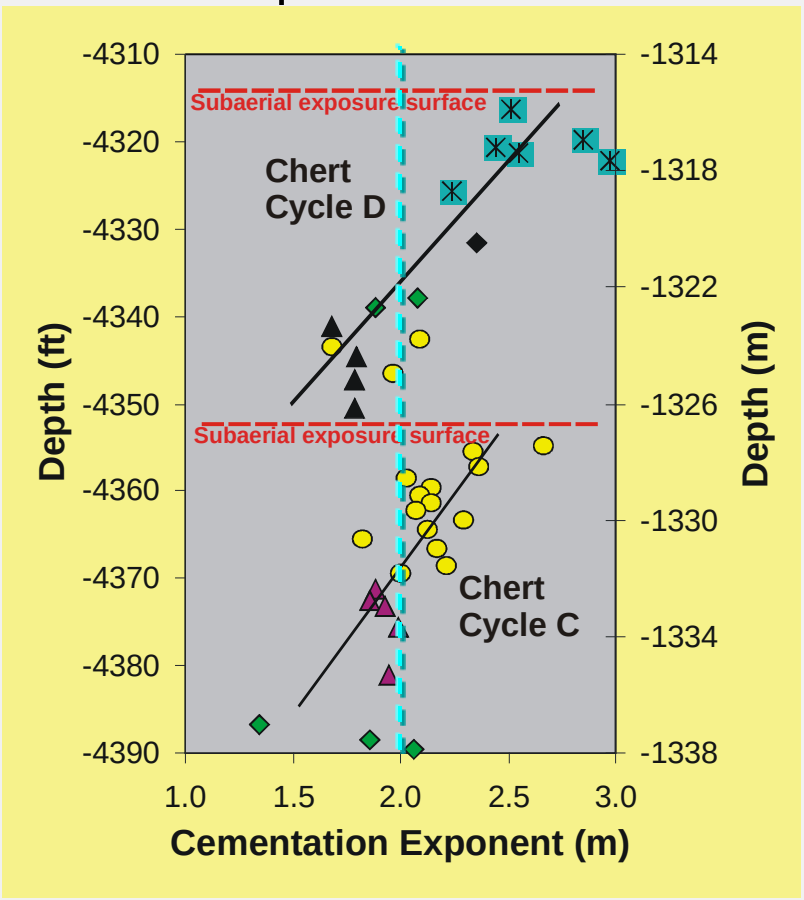




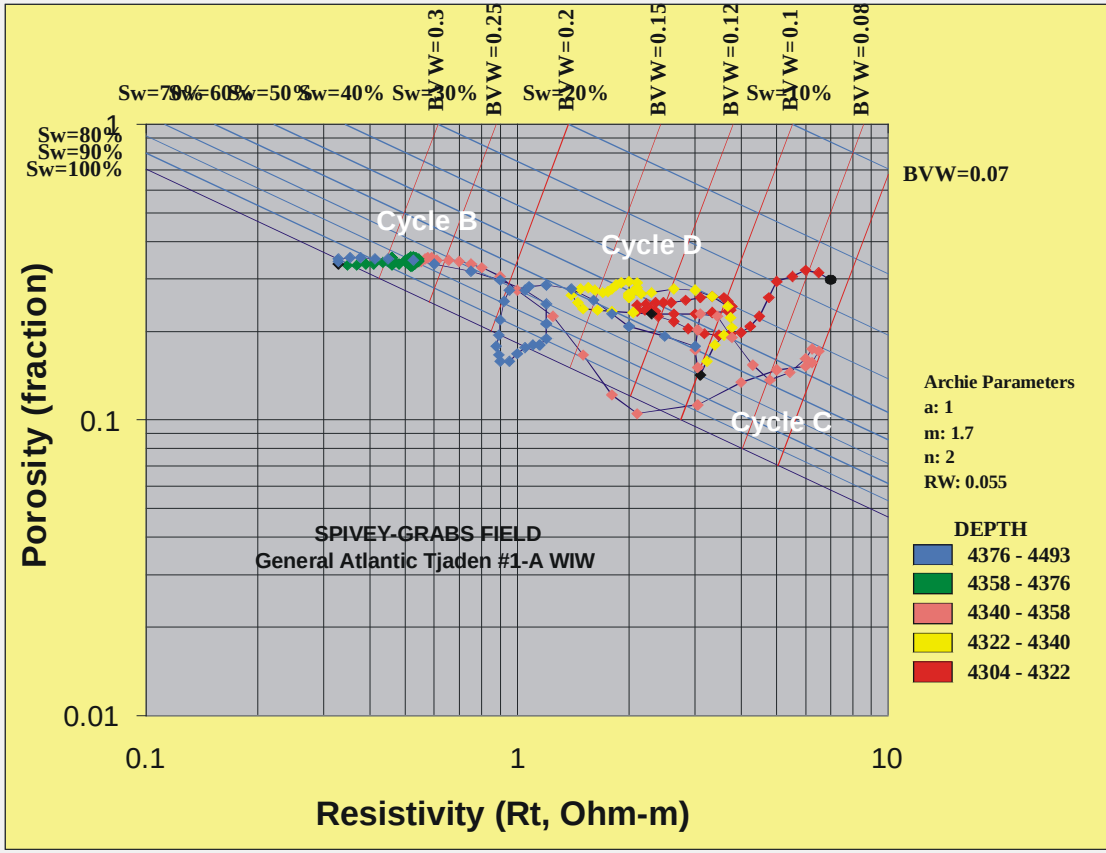
Autoclastic Chert with clay - high porosity and permeability

Cycle dependent, depth-based petrophysical patterns in Tjaden A-1 (Spivey-Grabs Field)

Higher m (cementation exponent) toward top of chert cycles at Mississippian age subaerial exposure surface

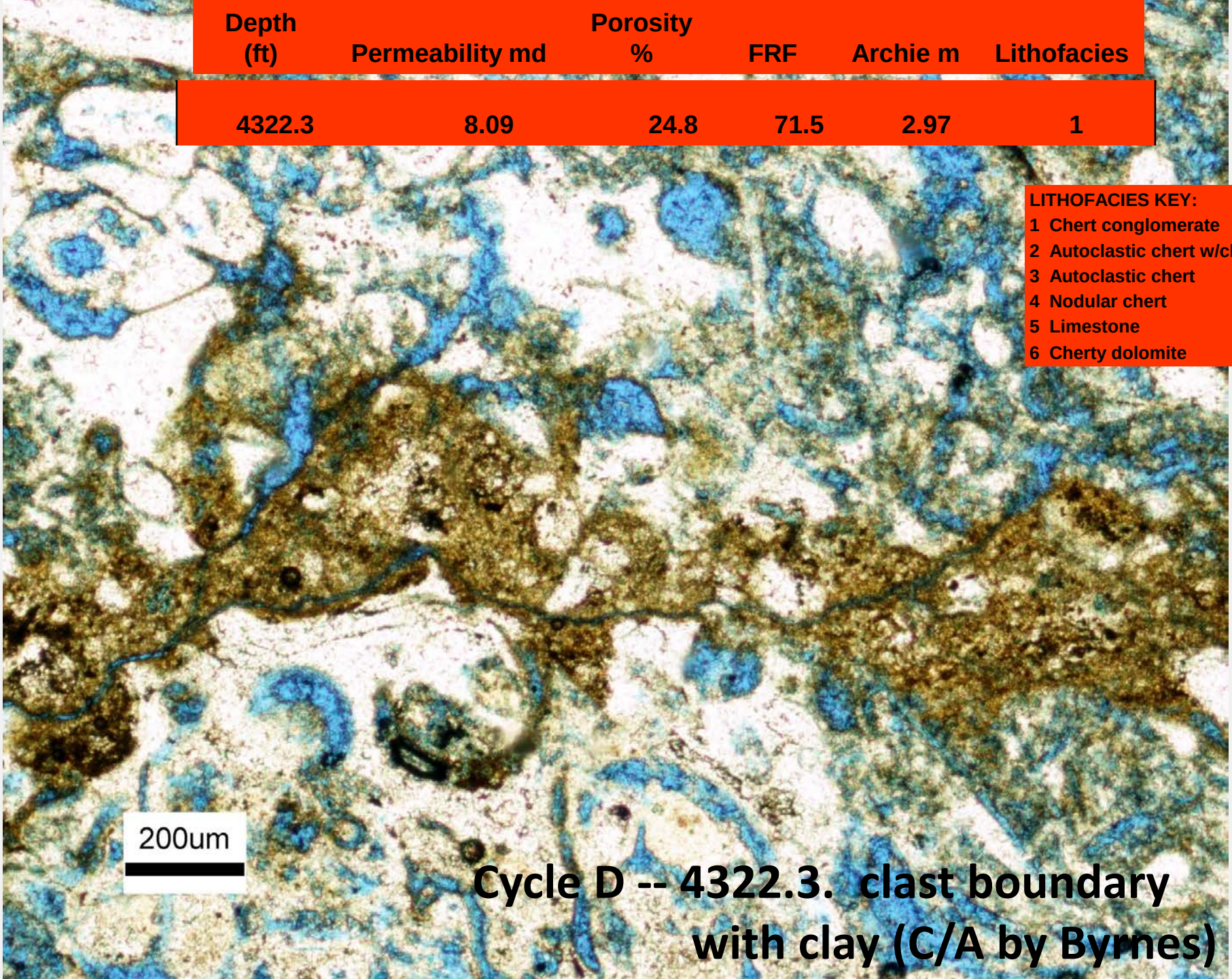


Petrophysical (PfEFFER) analysis of the tripolitic (microporous brecciated) chert

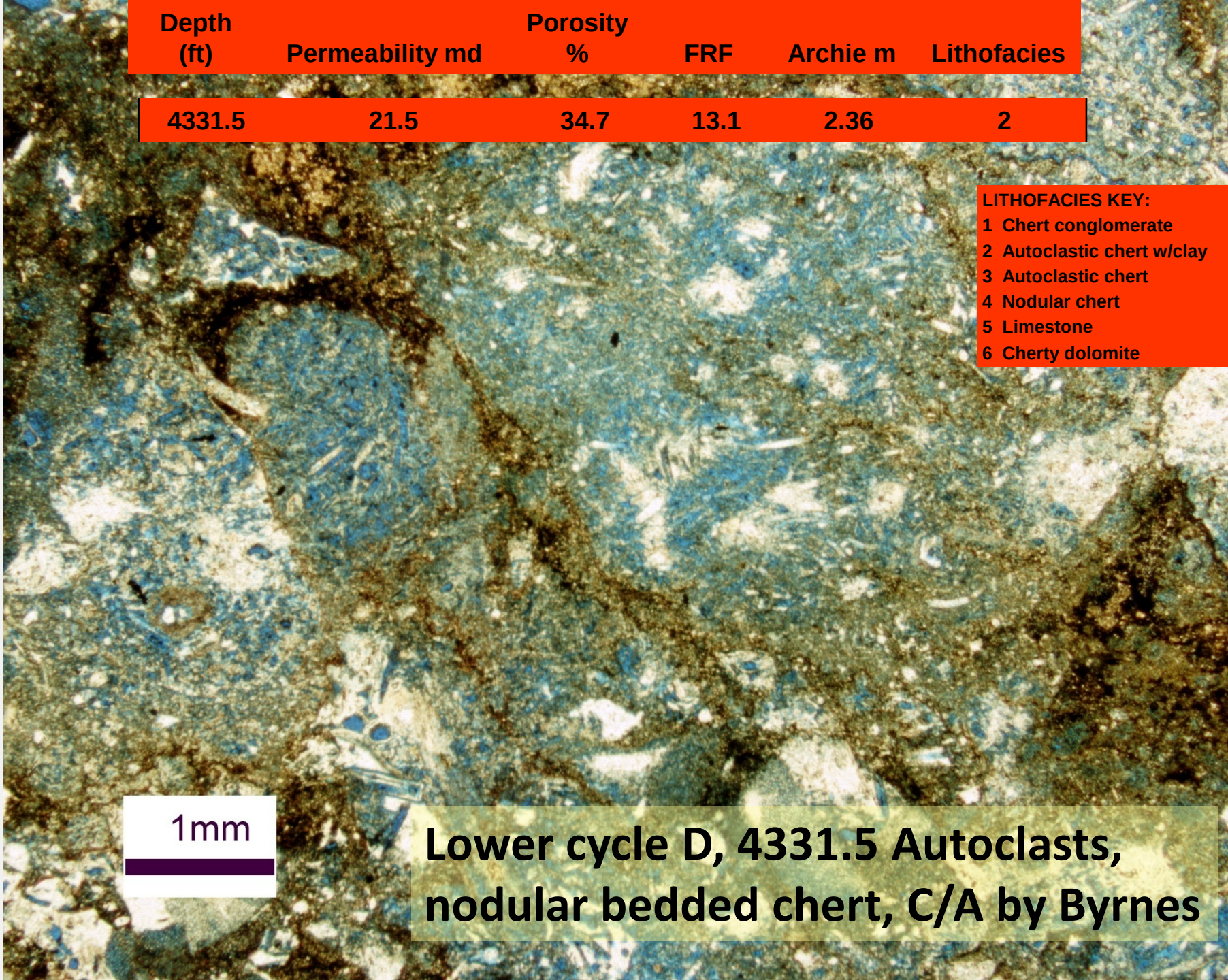


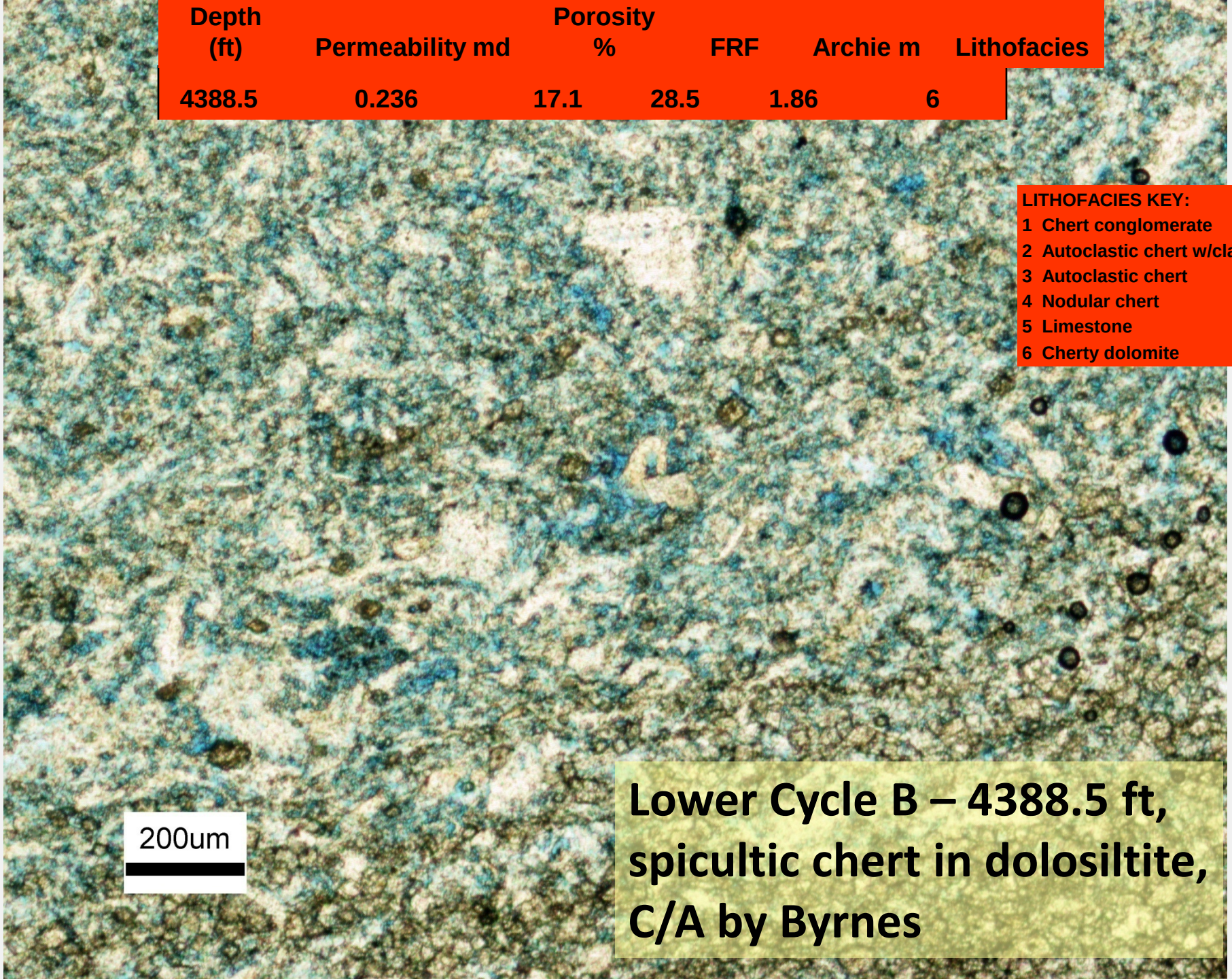
C/A by Byrnes in as reported in Watney et al. (2001)

Depth (ft)	Permeability md	Porosity %	FRF	Archie m	Lithofacies
4322.3	8.09	24.8	71.5	2.97	1



Cycle D -- 4322.3. clast boundary with clay (C/A by Byrnes)


Depth (ft)
Permeability md
Porosity %
FRF
Archie m
Lithofacies
4331.5
21.5
34.7
13.1
2.36
2
LITHOFACIES KEY:
1 Chert conglomerate
2 Autoclastic chert w/clay
3 Autoclastic chert
4 Nodular chert
5 Limestone
6 Cherty dolomite
1mm
Lower cycle D, 4331.5 Autoclasts, nodular bedded chert, C/A by Byrnes


Depth (ft)
Permeability md
Porosity %
FRF
Archie m
Lithofacies
4388.5
0.236
17.1
28.5
1.86
6
LITHOFACIES KEY:
1 Chert conglomerate
2 Autoclastic chert w/clay
3 Autoclastic chert
4 Nodular chert
5 Limestone
6 Cherty dolomite
200um
Lower Cycle B – 4388.5 ft, spicultic chert in dolosiltite, C/A by Byrnes

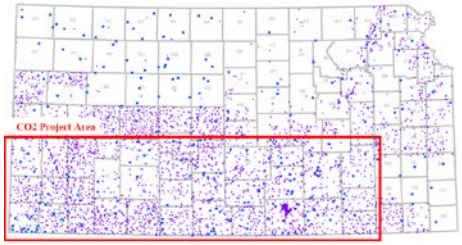
Structure Contour Map -- Top Mississippian with regional faults

Subcontractor
Bittersweet Energy

(Gerlach, Nicholson, Hansen)

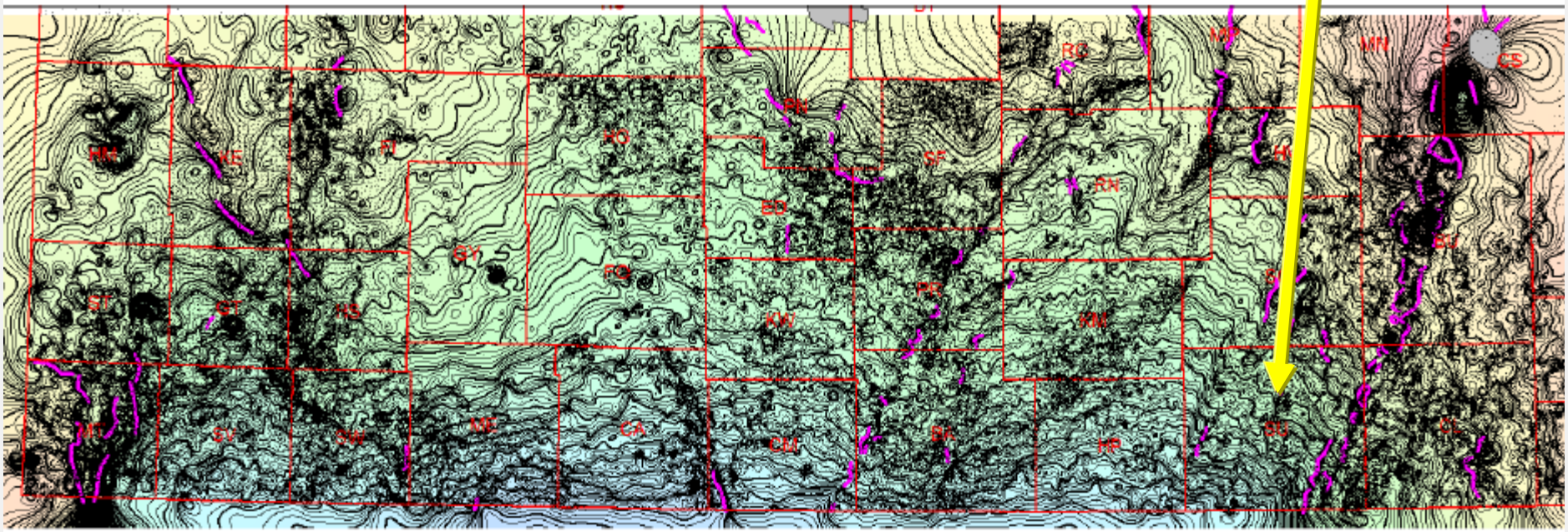
DOE Contract #FE0002056
and partner cost share

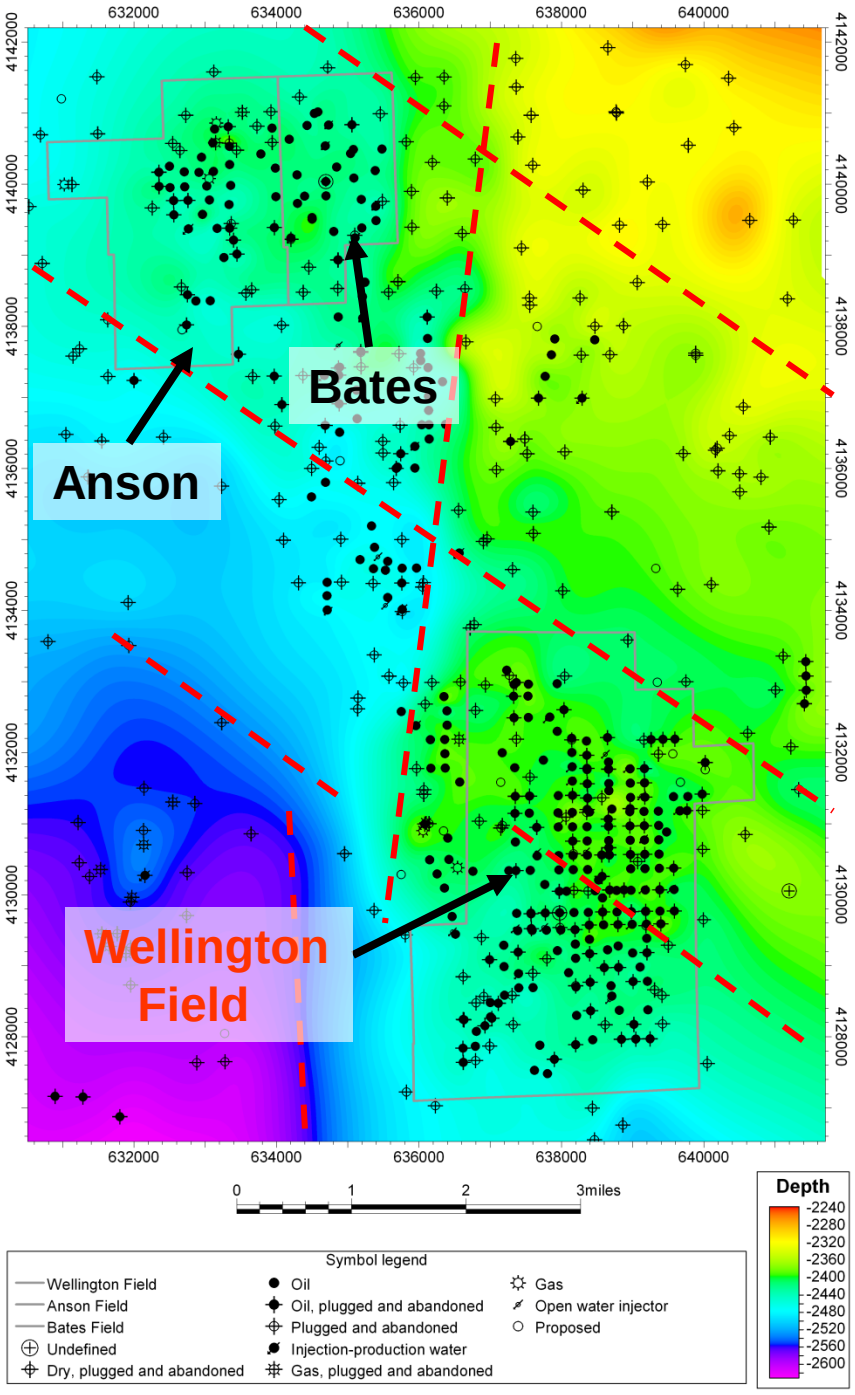
Current Status
Of
2) Fault Detection & Verification – Regional & Compartment



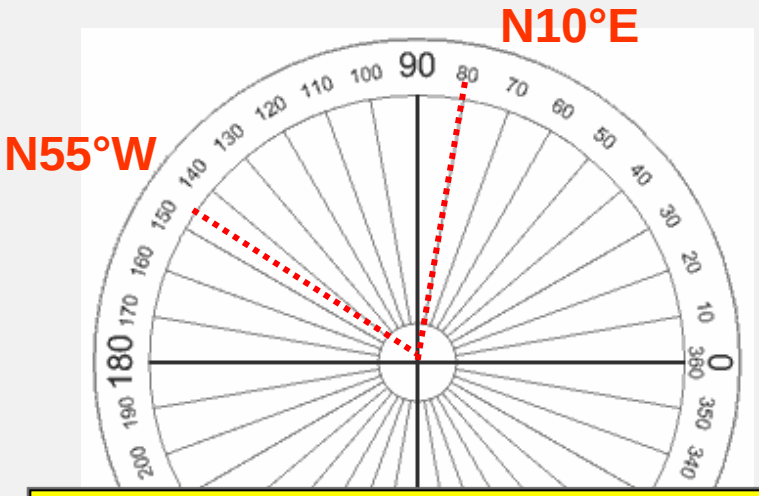
Wellington Field
Sumner Co.

MISS Subsea ci: 25 ft with ARBK Verified Faults





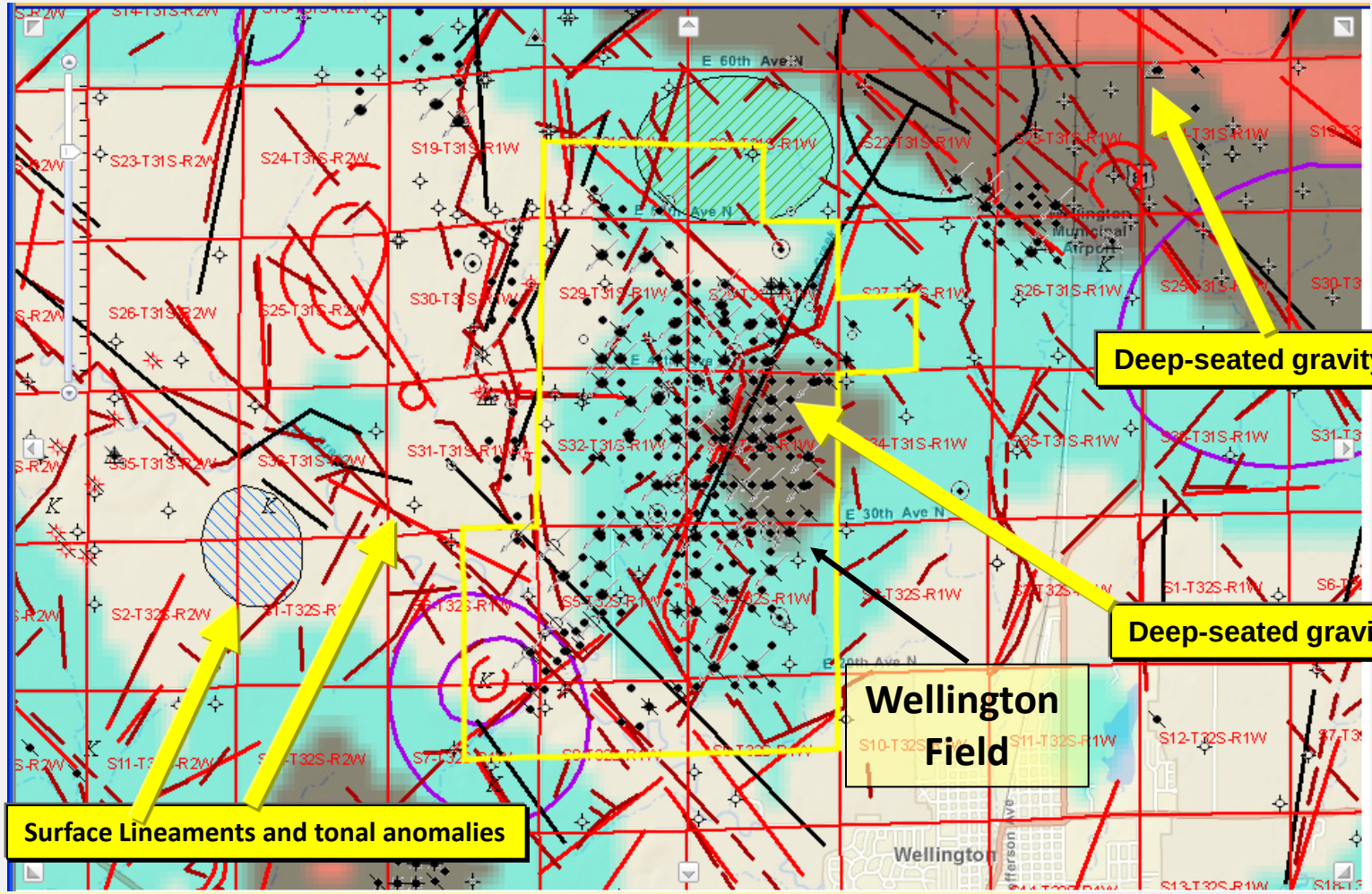
Configuration on top of the Mississippian (regional unconformity) in Wellington and Bates Field area. Fields are part of a subcrop play with the Mississippian reservoir preserved in what appears to be structural blocks bounded by NE- and NW-trending lineaments. Warmer colors represent higher elevation.



Rush, constructed map
my lineaments (two sets)
early 2010, pre-seismic and drilling

Wellington Field Area

Landsat lineaments and gravity tilt angle map
Northeast trending surface lineament bisecting Wellington Field
as viewed on interactive mapper



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

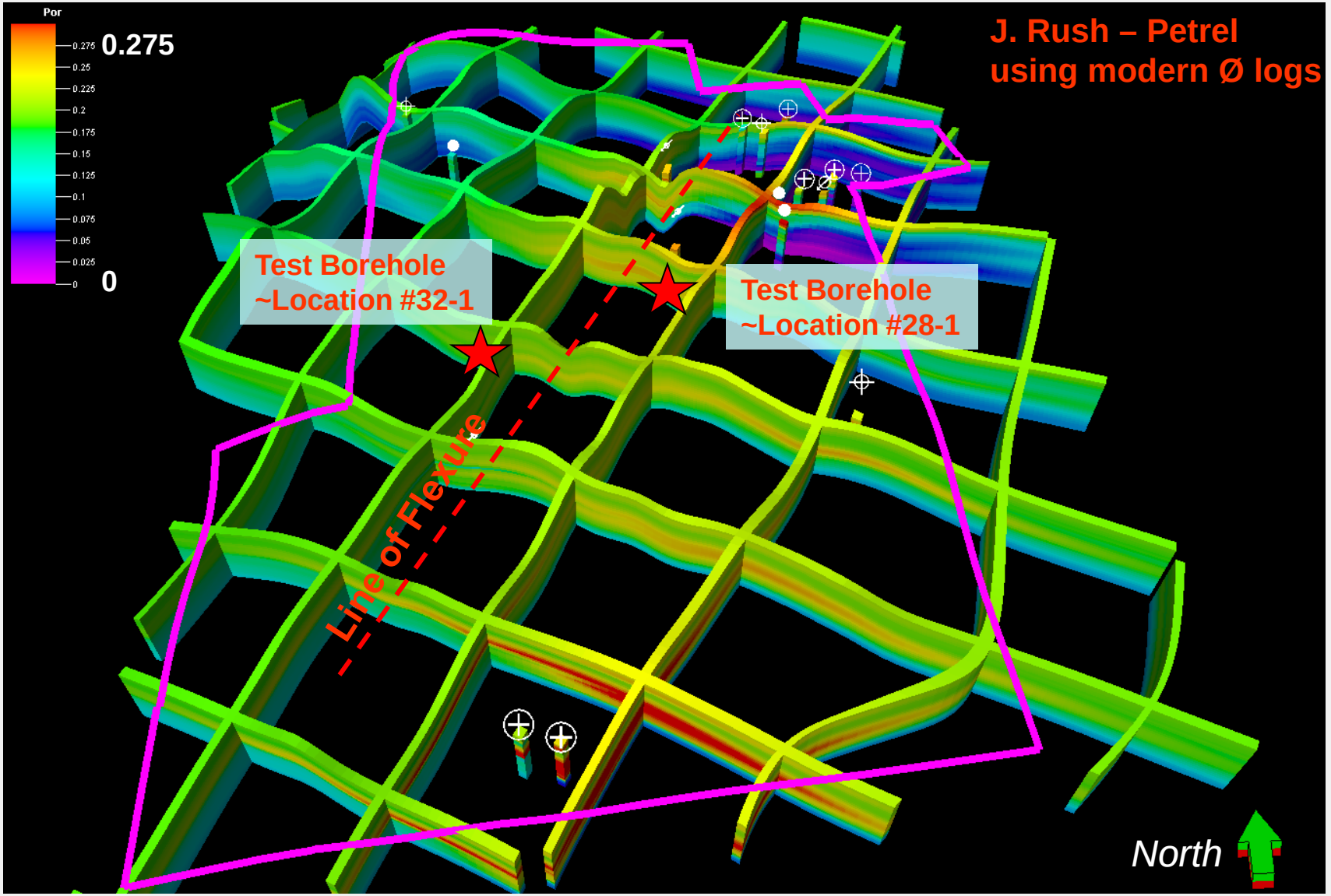
6 miles

Gravity Tilt Angle = arctangent of the ratio of the 1st-order vertical derivative by the 1st-order horizontal derivative of the Bouguer anomaly.

Wellington Field

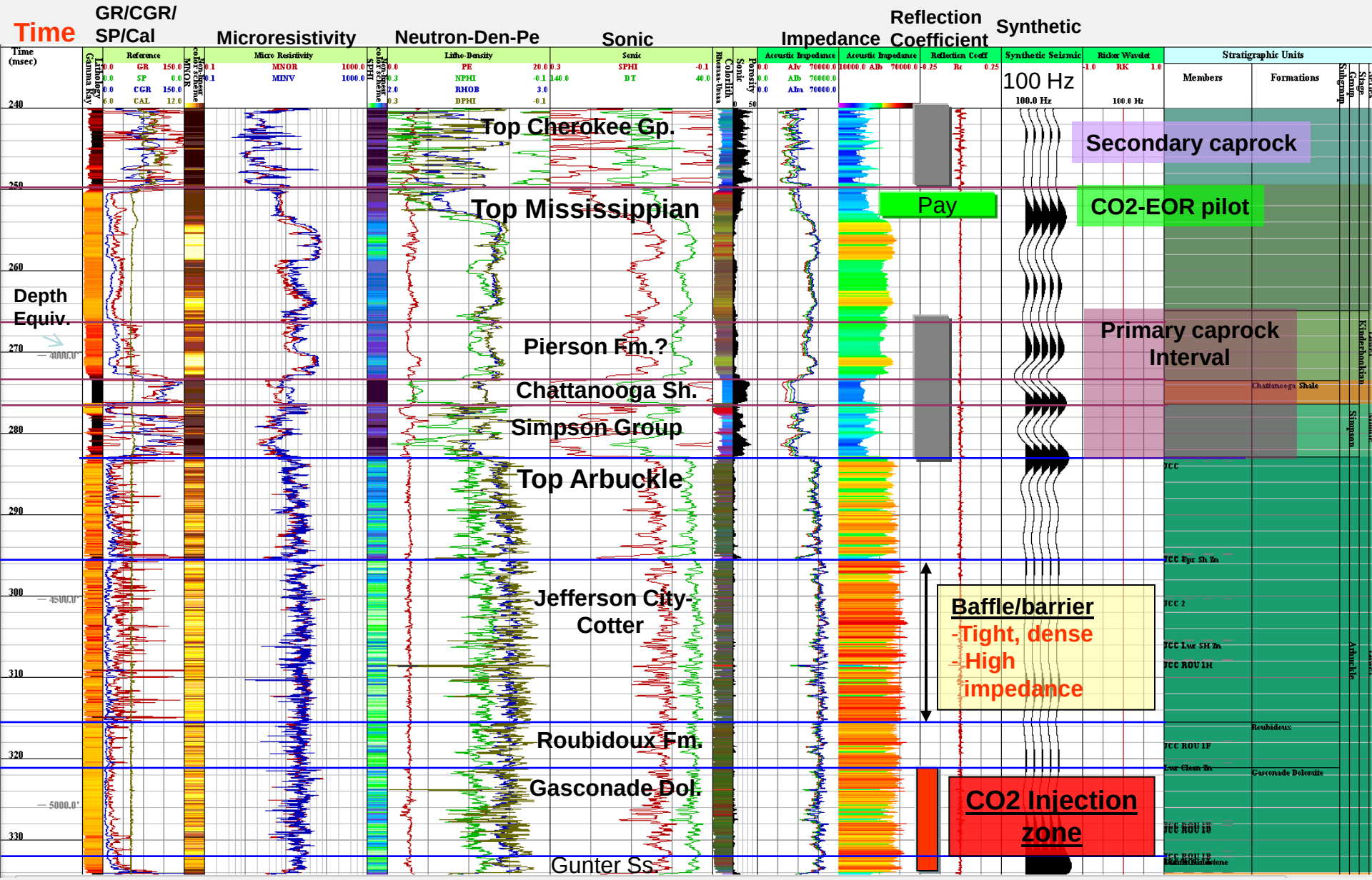
Porosity Fence Diagram

Pay zone at top of the Mississippian



Synthetic seismogram, impedance, and triple combo log suite

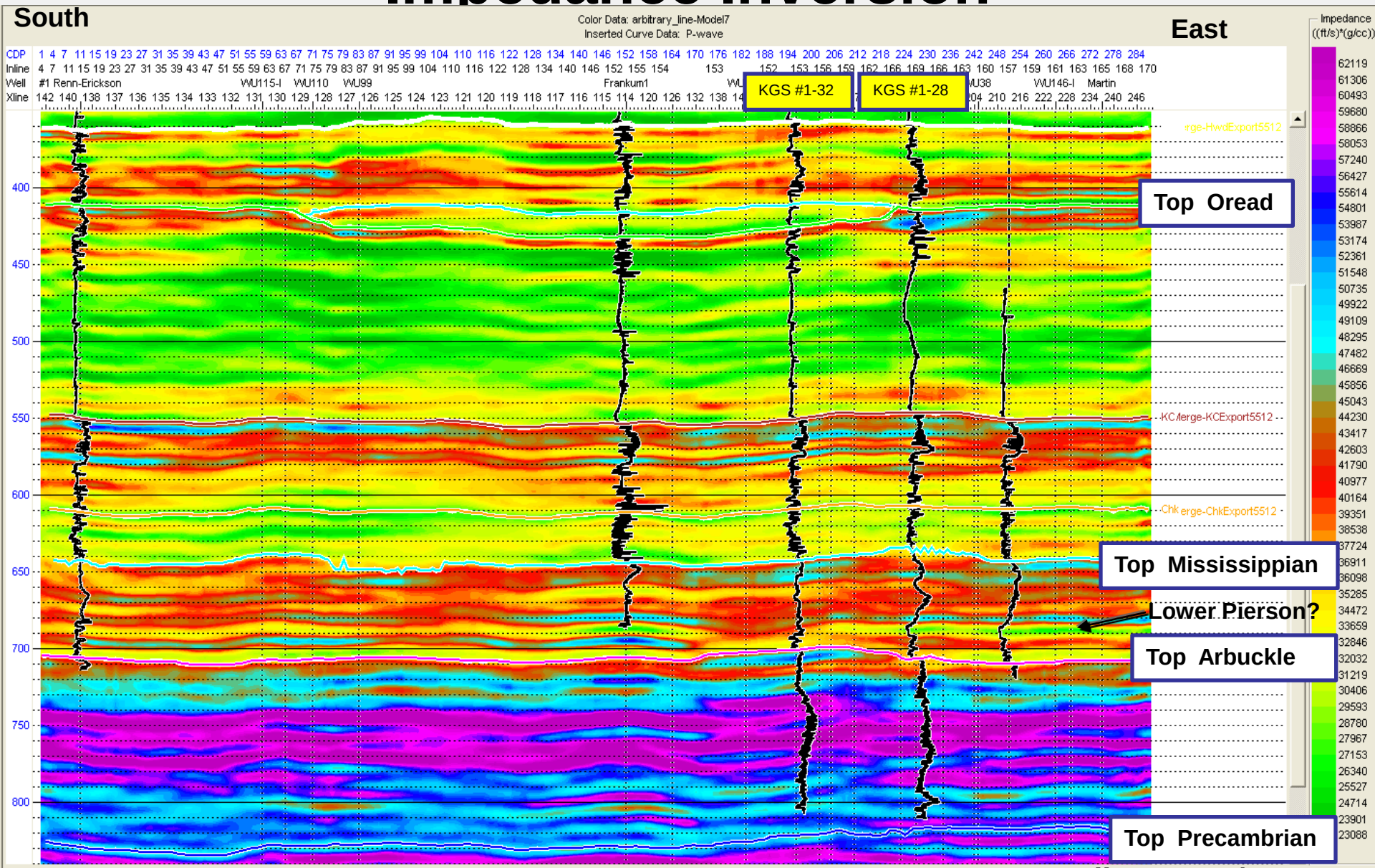
KGS #1-28 (CO2 injection well in Arbuckle at Wellington Field)



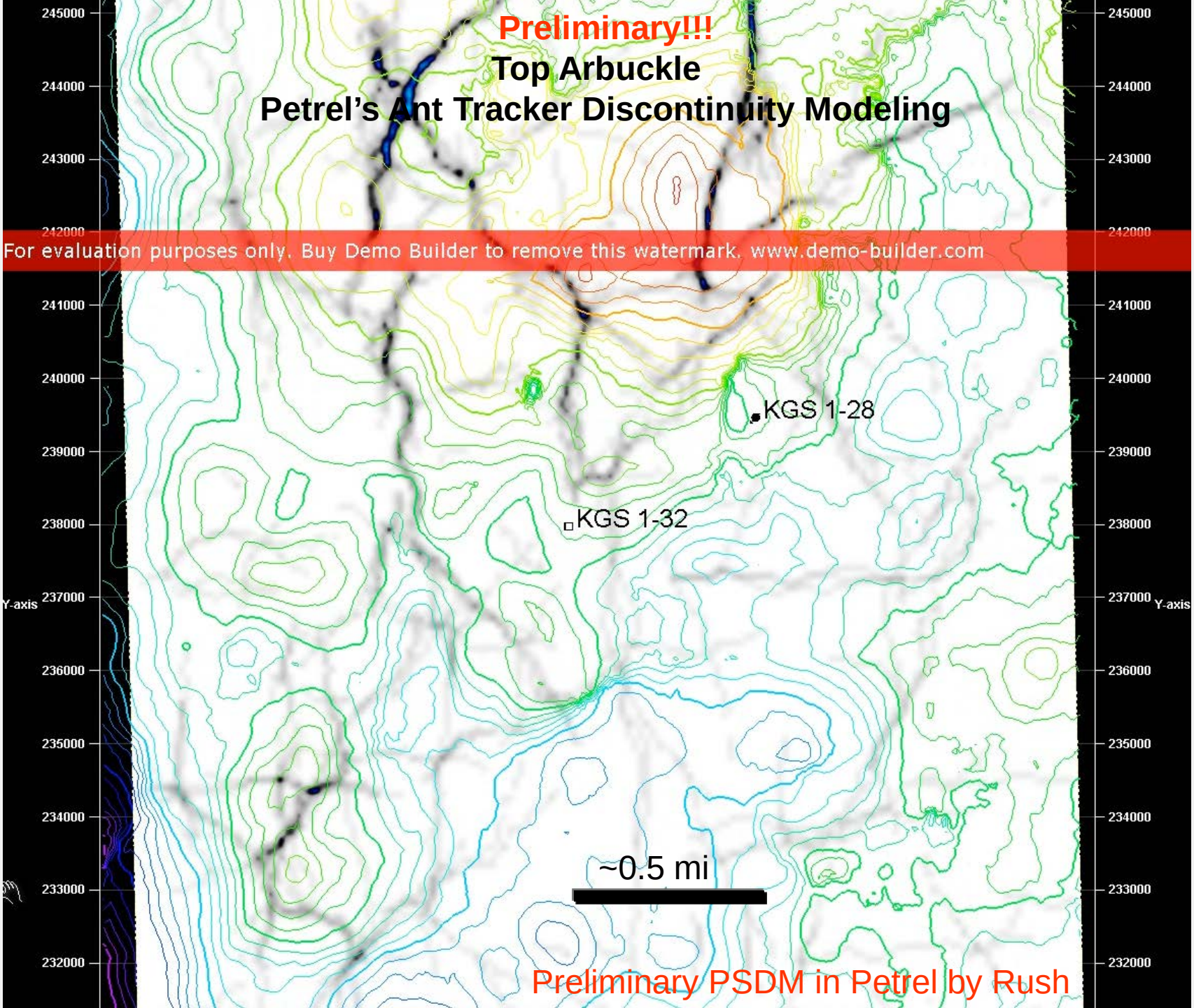
Precambrian granite – bottom of core

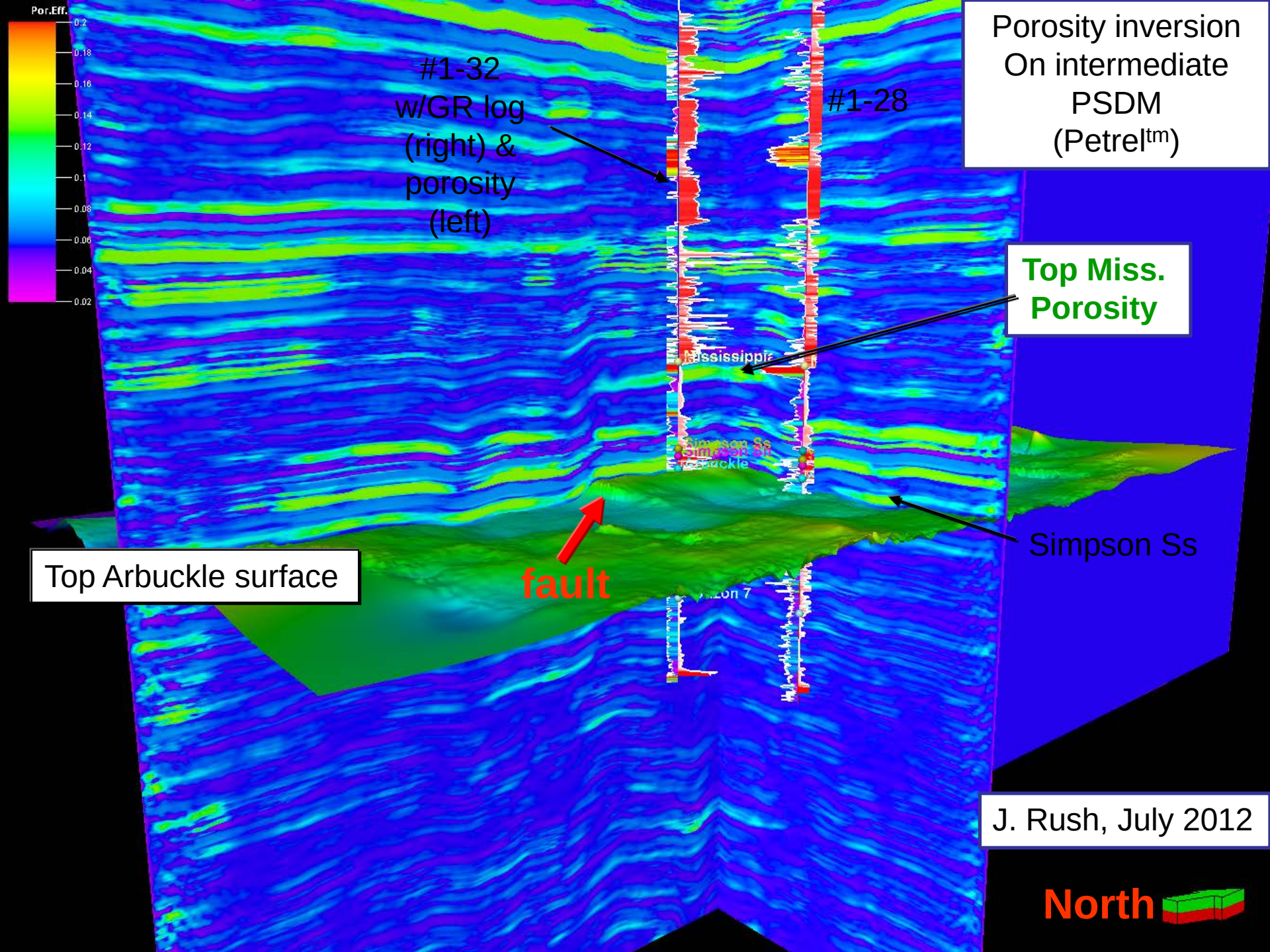
http://www.kgs.ku.edu/software/SS/

Arbitrary Seismic Profile – Impedance Inversion



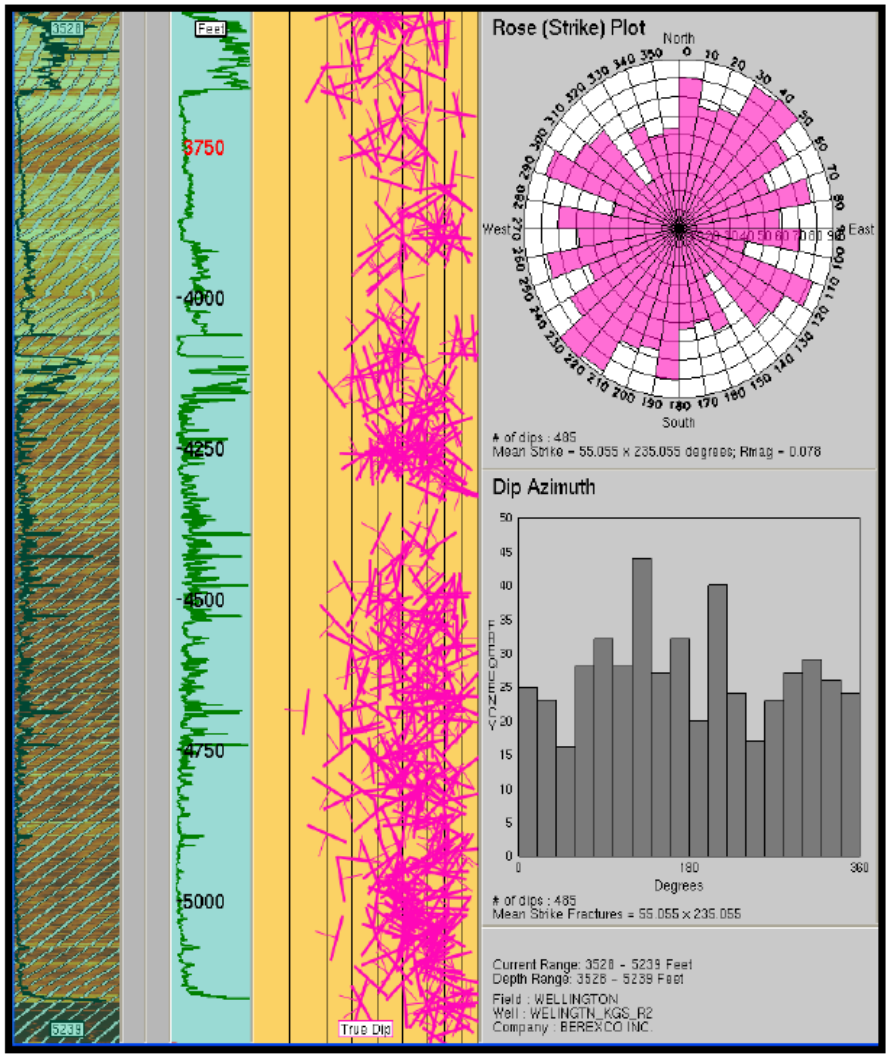
Hedke – DOE/CO2


Preliminary!!!
Top Arbuckle
Petrel's Ant Tracker Discontinuity Modeling
For evaluation purposes only. Buy Demo Builder to remove this watermark. www.demo-builder.com
KGS 1-28
KGS 1-32
~0.5 mi
Preliminary PSDM in Petrel by Rush
Y-axis
245000
244000
243000
242000
241000
240000
239000
238000
237000
236000
235000
234000
233000
232000

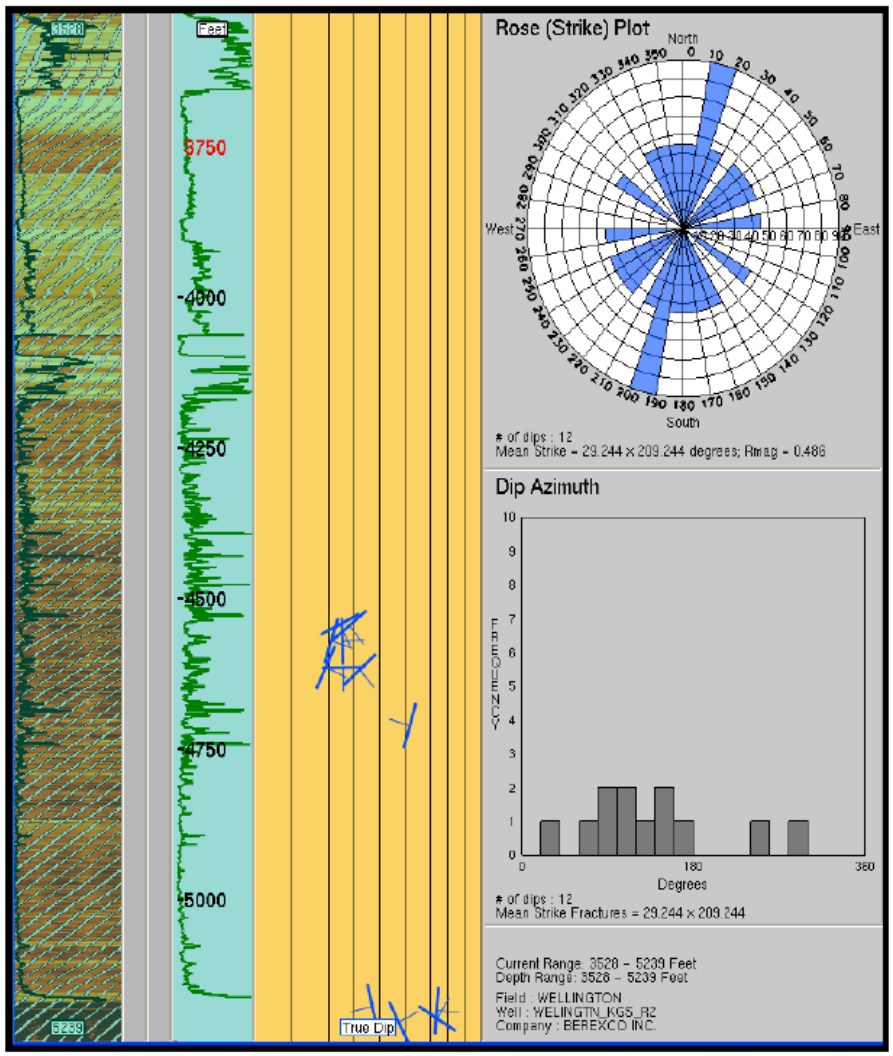

Por.Eff.
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
#1-32
w/GR log
(right) &
porosity
(left)
#1-28
Porosity inversion
On intermediate
PSDM
(Petrel™)
Top Miss.
Porosity
Mississippi
Simpson Ss
Simpson Sd
Arbuckle
Top Arbuckle surface
fault
Simpson Ss
J. Rush, July 2012
North

Fracture Statistics: 5239'-3528'

Wellington KGS #1-32



There are 485 partial fractures in this pass with random orientation.



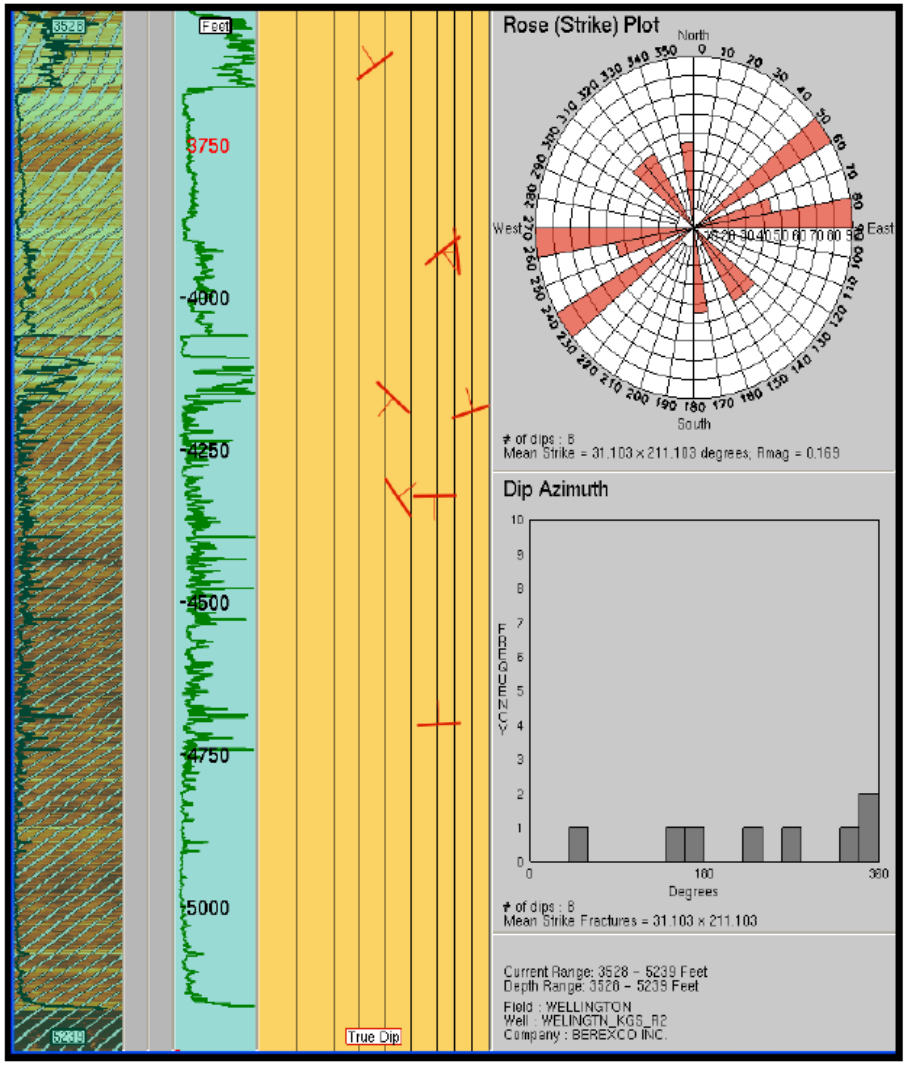
There are 12 natural open fractures (360° conductive fractures) with an overall NNE x SSW orientation.

Microresistivity imaging log and spectral sonic

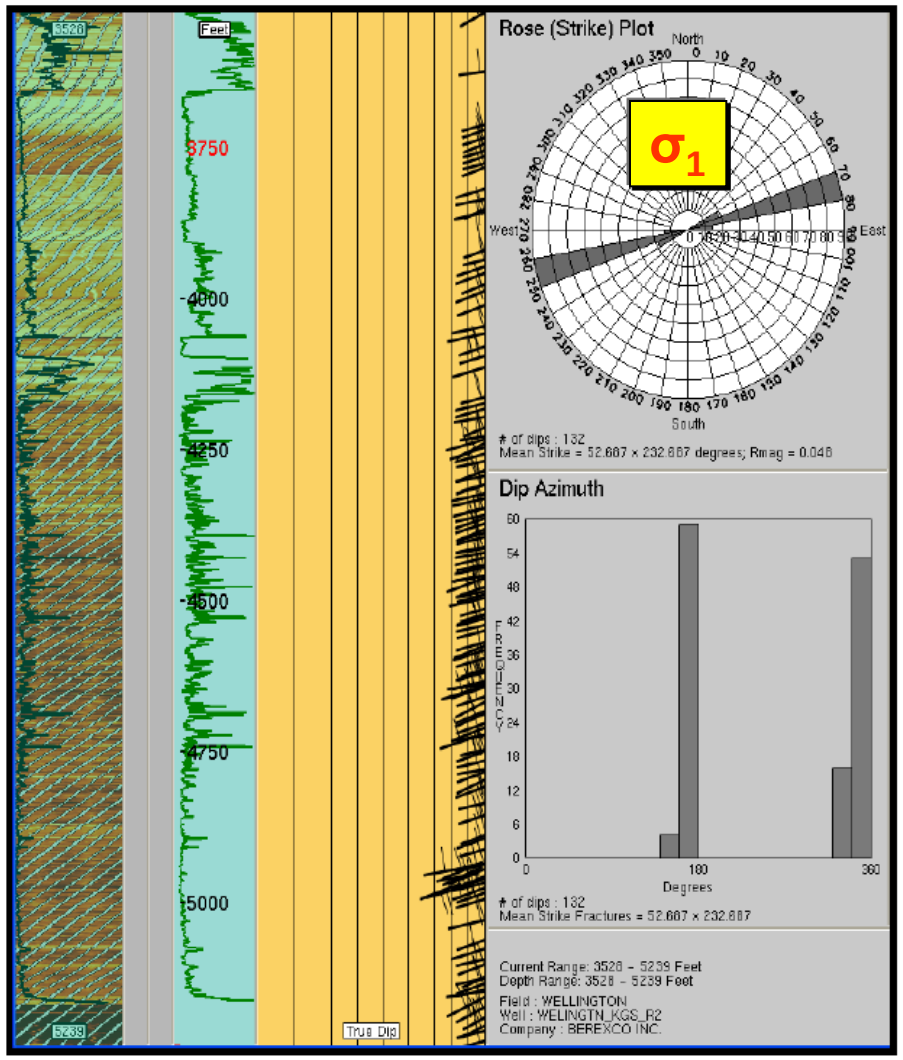
HALLIBURTON

Fracture Statistics: 5239'-3528'

Wellington KGS #1-32



There are natural mineralized "closed" fractures with two orientations, one E x W and the other NE x SW.

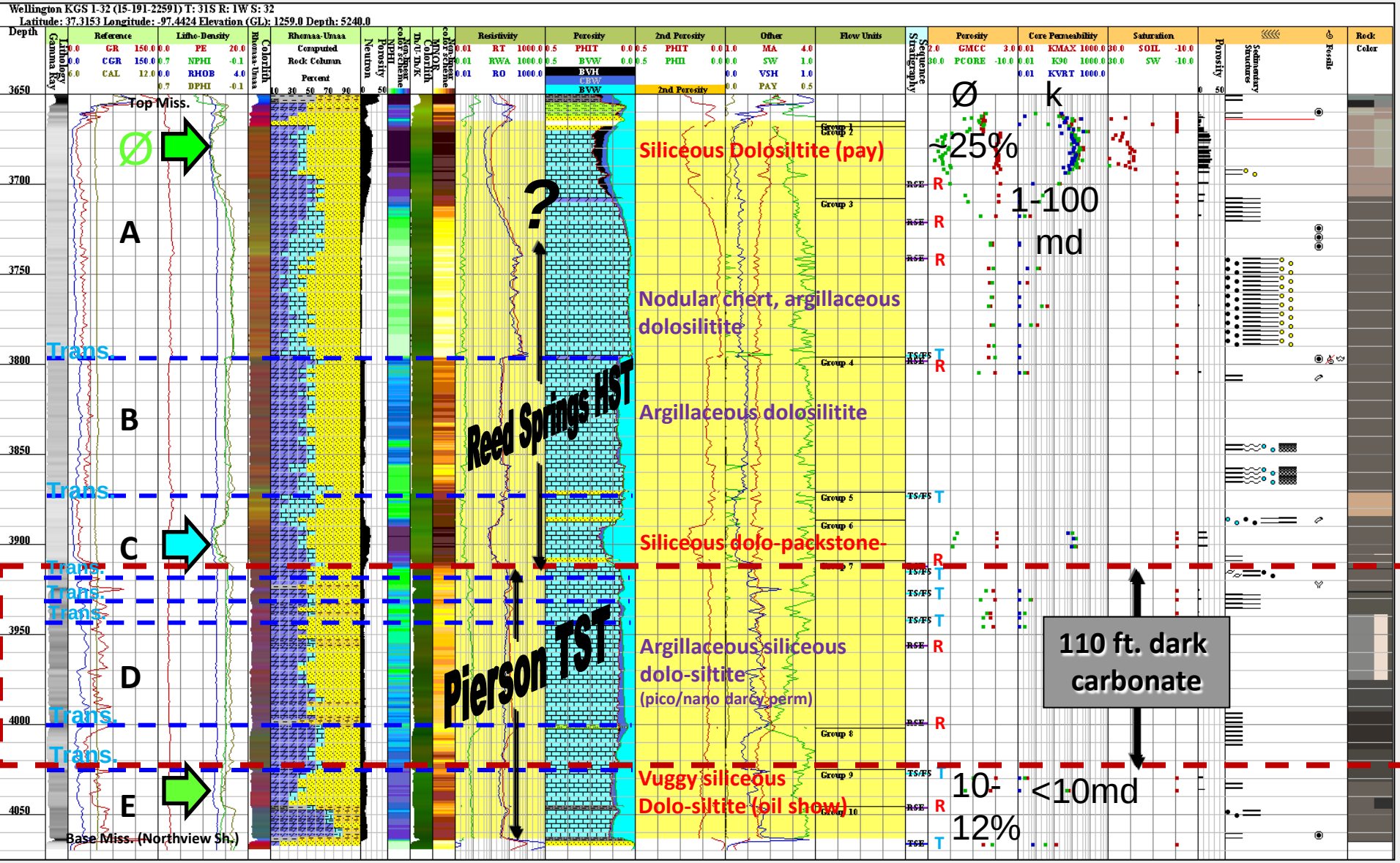


There are 132 drilling induced fractures in this pass, oriented 75°/255°, indicating the maximum stress direction

Microresistivity imaging log and spectral sonic

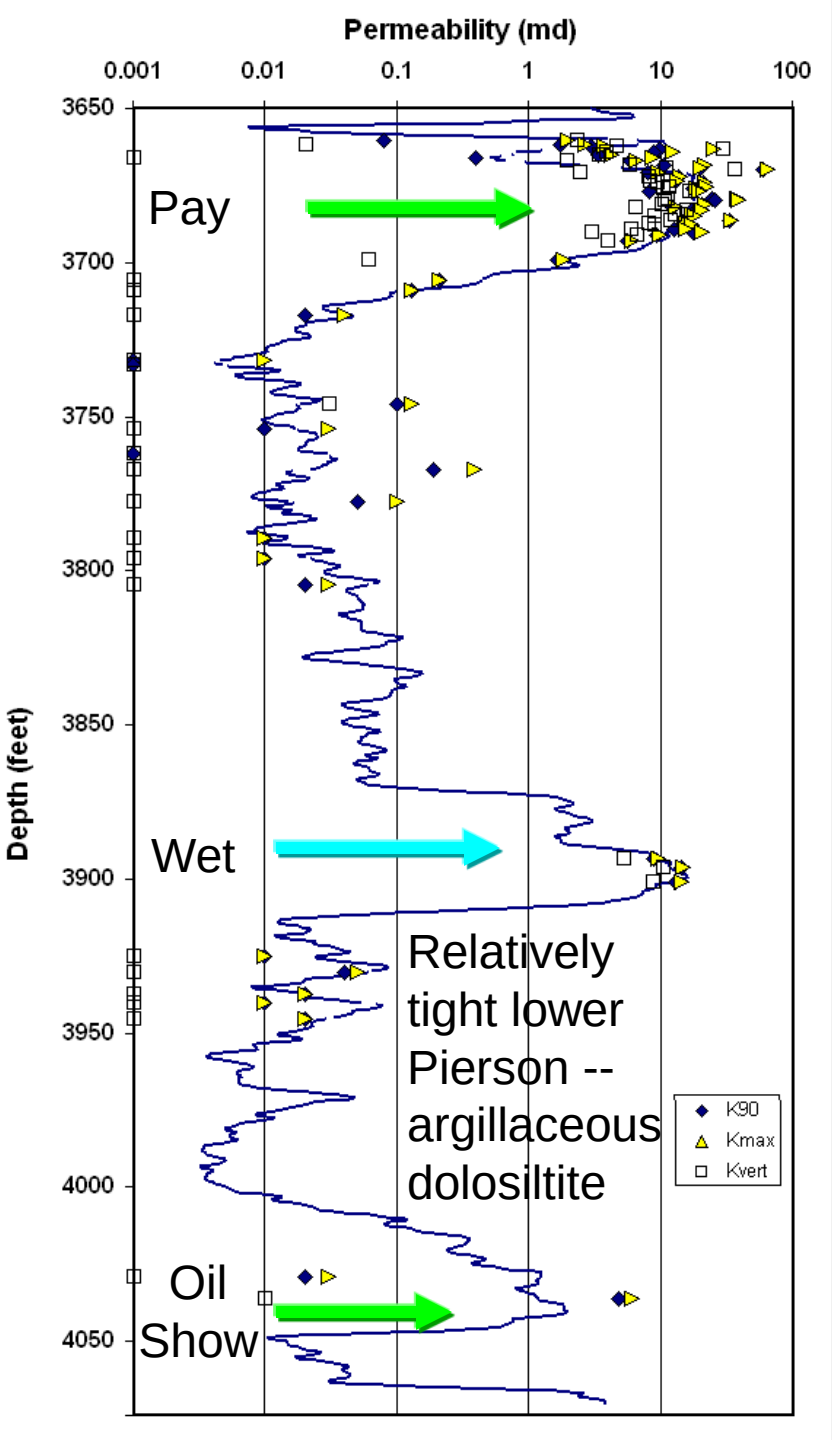
HALLIBURTON

Cored Well, Berexco Wellington KGS #1-32
Top Mississippian to Kinderhook Shale

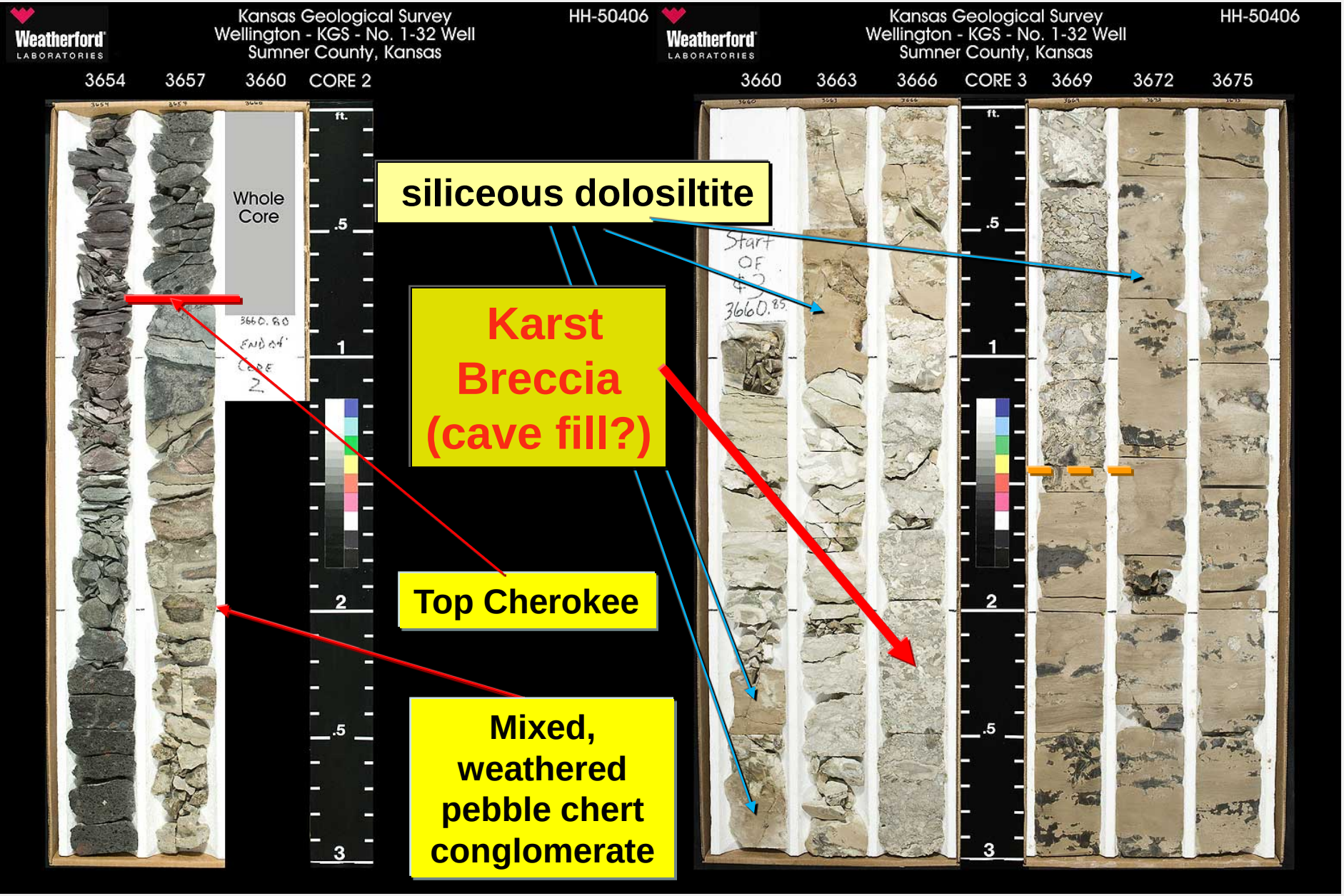


Freeware:http://www.kgs.ku.edu/stratigraphic/PROFILE/

KGS #1-32 Wellington : Prediction of permeability based on *magnetic resonance imaging (MRI)* porosity and T2 center-of-gravity versus core Kmax, K90, and Kvert permeabilities

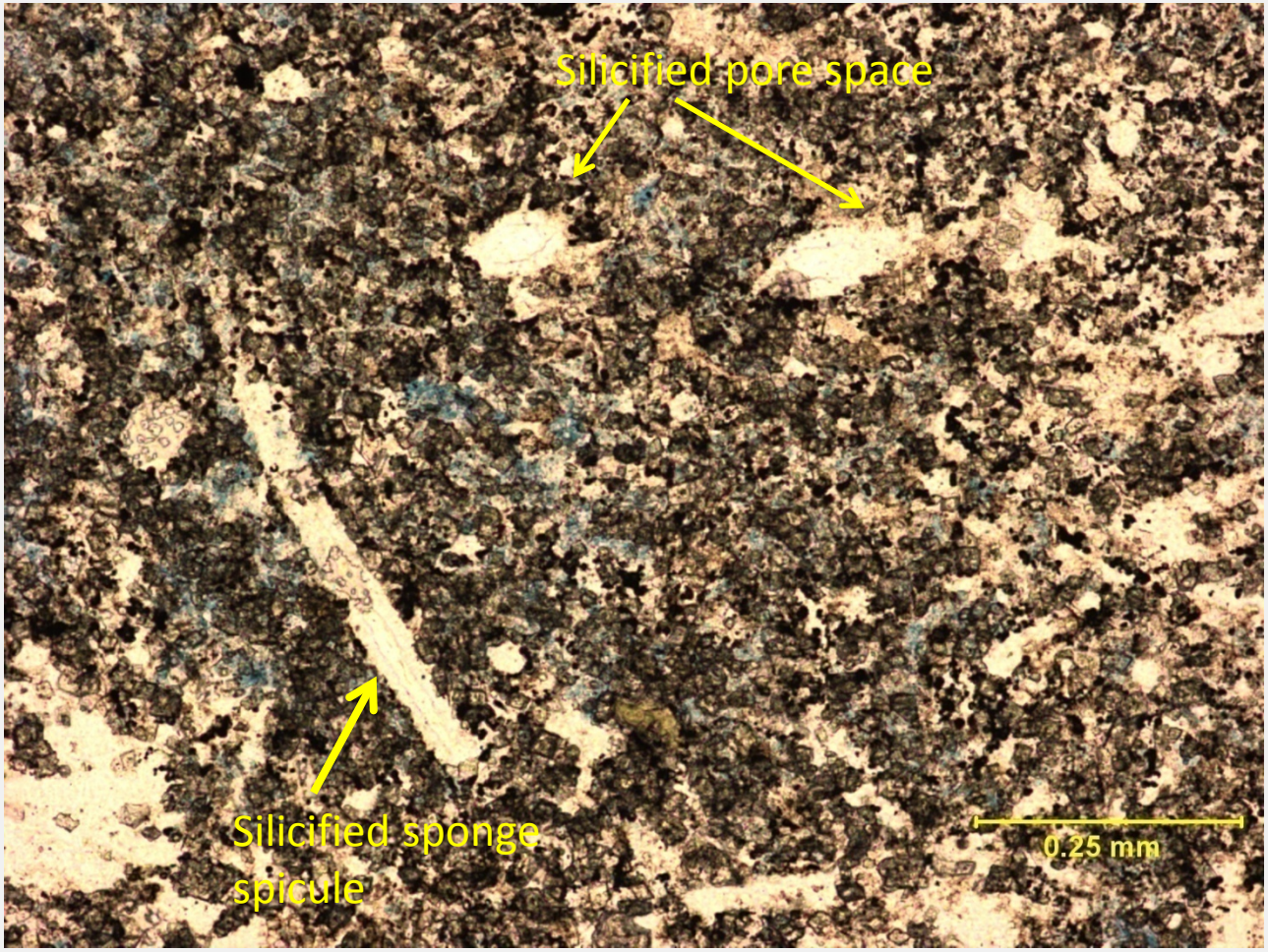


J. Doveton, July 2012


Weatherford LABORATORIES
Kansas Geological Survey
Wellington - KGS - No. 1-32 Well
Sumner County, Kansas
HH-50406
3654
3657
3660
CORE 2
Whole Core
ft.
Weatherford LABORATORIES
Kansas Geological Survey
Wellington - KGS - No. 1-32 Well
Sumner County, Kansas
HH-50406
3660
3663
3666
CORE 3
3669
3672
3675
ft.
siliceous dolosiltite
Karst Breccia (cave fill?)
Top Cherokee
Mixed, weathered pebble chert conglomerate

Mississippian Pay Zone Mineralogy
Berexco Wellington KGS #1-32

3670.6’

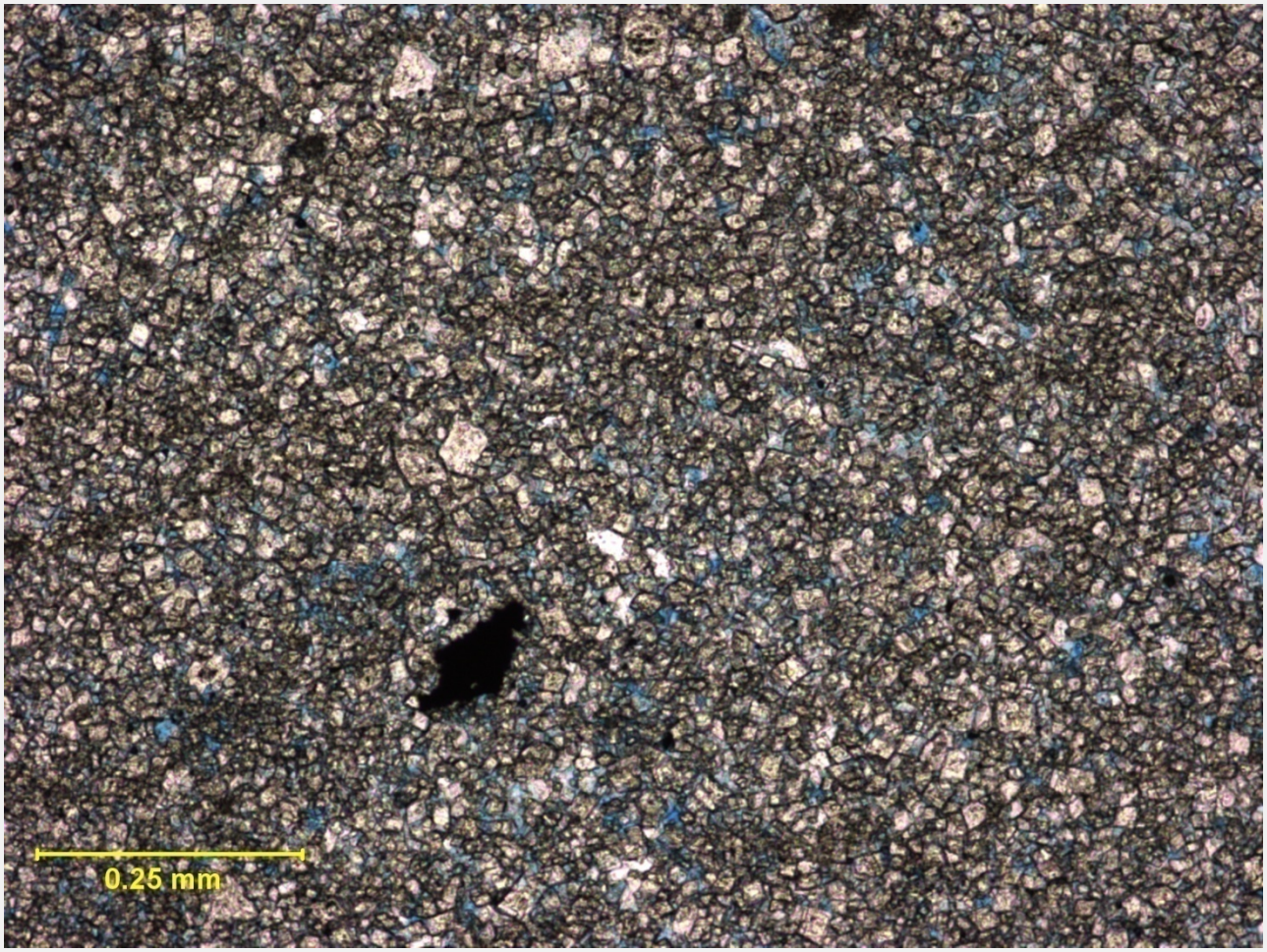


- **Plain light (10x zoom)**
- **Fine grained dolomite with silica cement**
- **Silicified sponge spicule (?)**
- **Pore spaces filled with precipitated silica (chert)**

TS provided by Datta & Barker, KSU

Mississippian Pay Zone Mineralogy

3670.6’

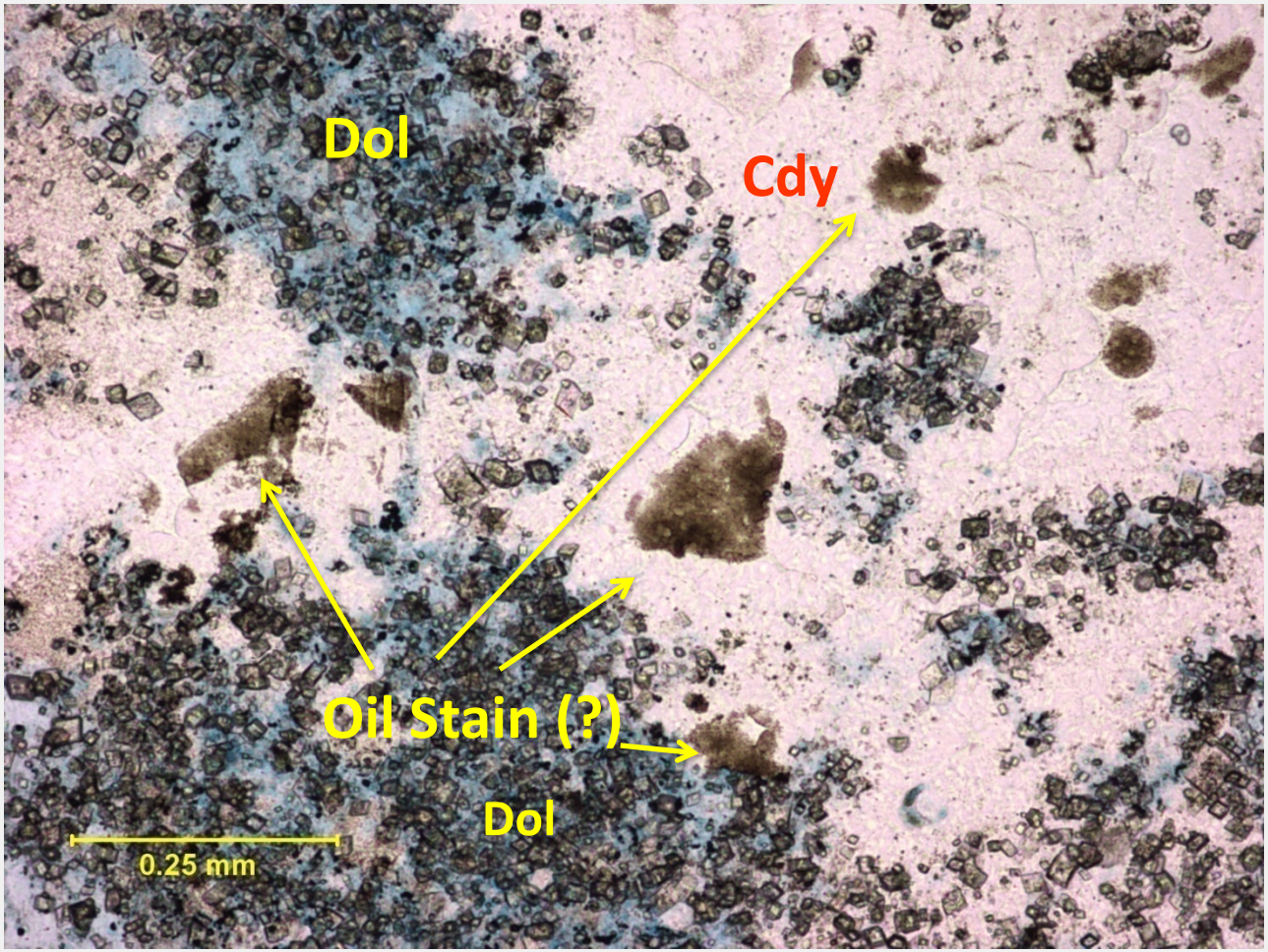


- **Plain Light (10x zoom)**
- **Fine grained dolomite with intercrystalline porosity**
- **Opaque oxide/sulfide (?) present**

TS provided by Datta & Barker, KSU

Mississippian Pay Zone Mineralogy

3681.95’

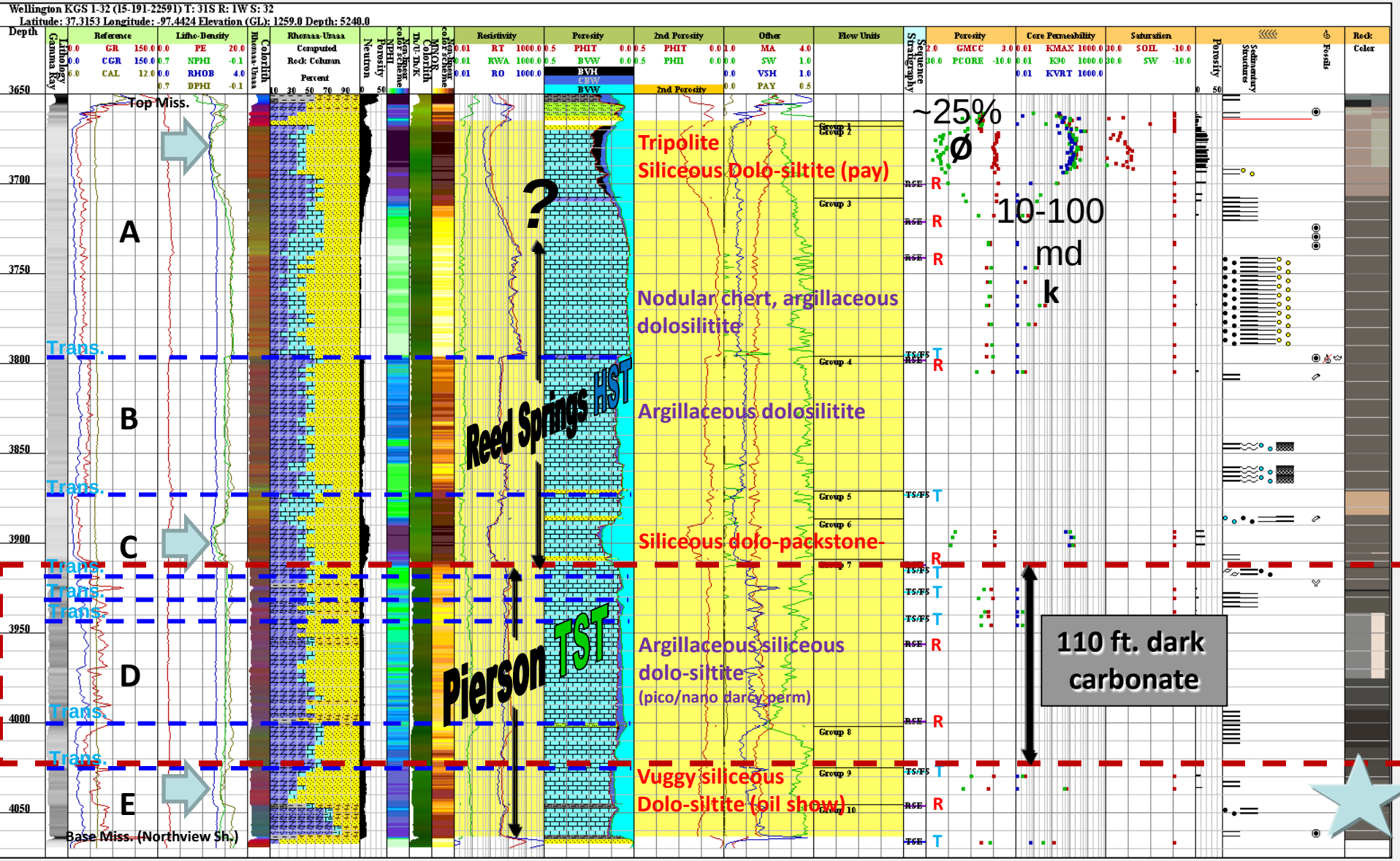


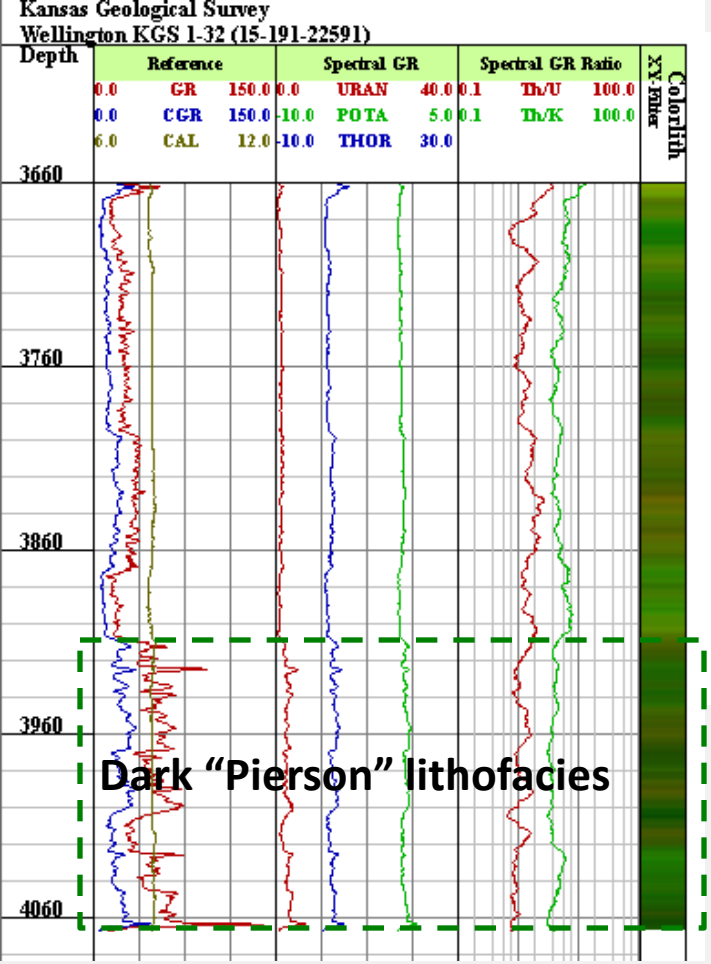
- Plain light (10x zoom)
- Close up of possible oil stain on chert
- Fine grained dolomite in porous zone

Cdy = Chalcedony;
Dol = Dolomite

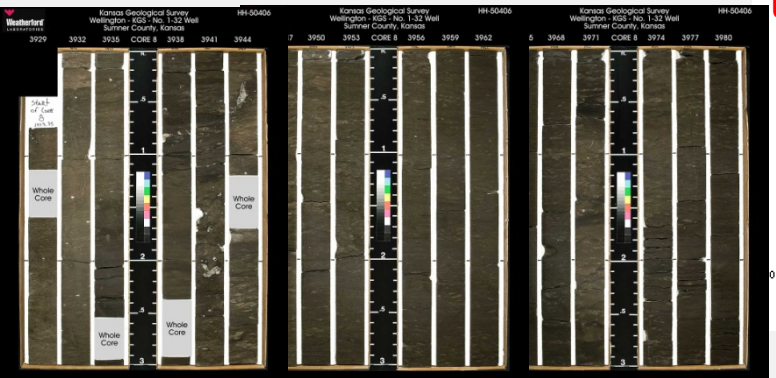
TS provided by Datta & Barker, KSU

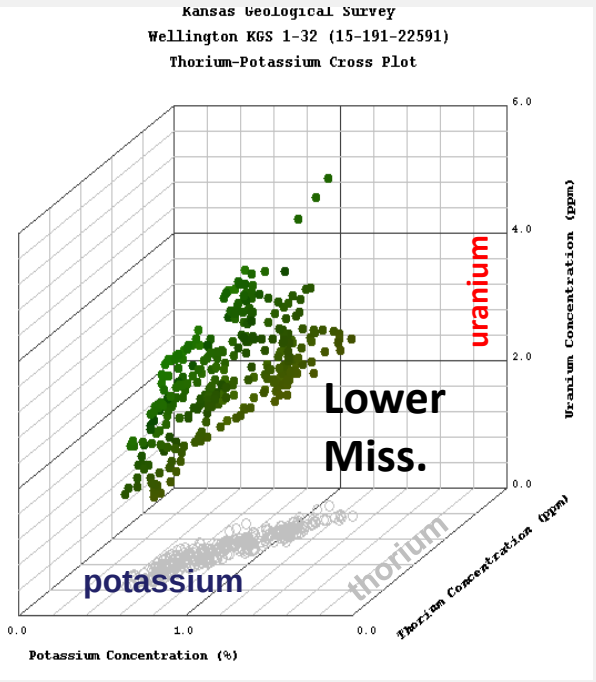
Cored Well, KGS #1-32
Top Mississippian to Kinderhook Shale

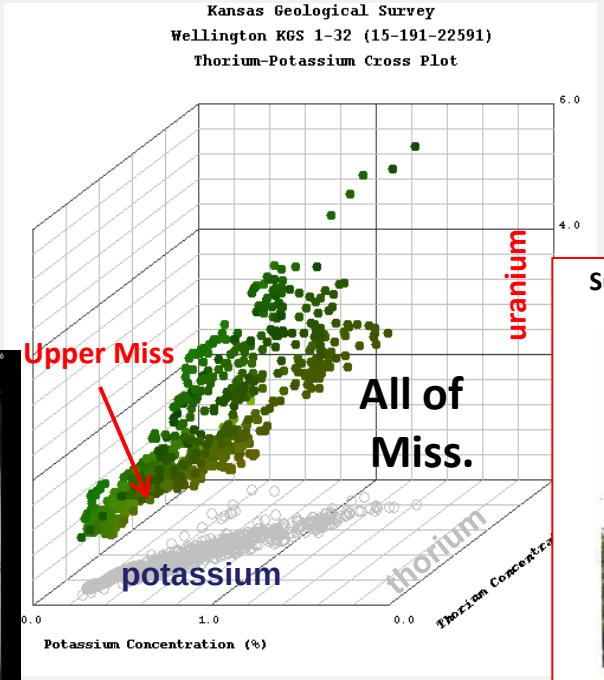


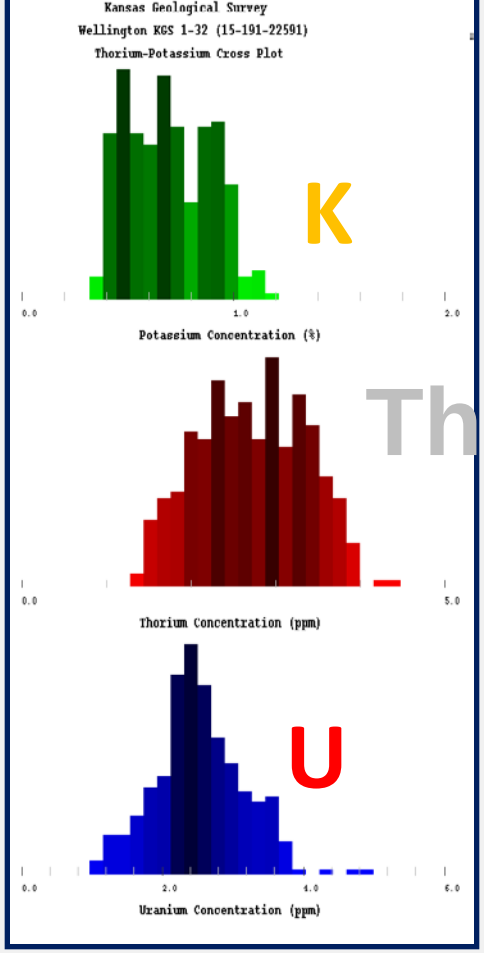


Lower Mississippian, dark carbonate, elevated uranium, "Cowley" facies









Surface Stratigraphy and Sequence Stratigraphy
Upper Kinderhook to Middle Osage

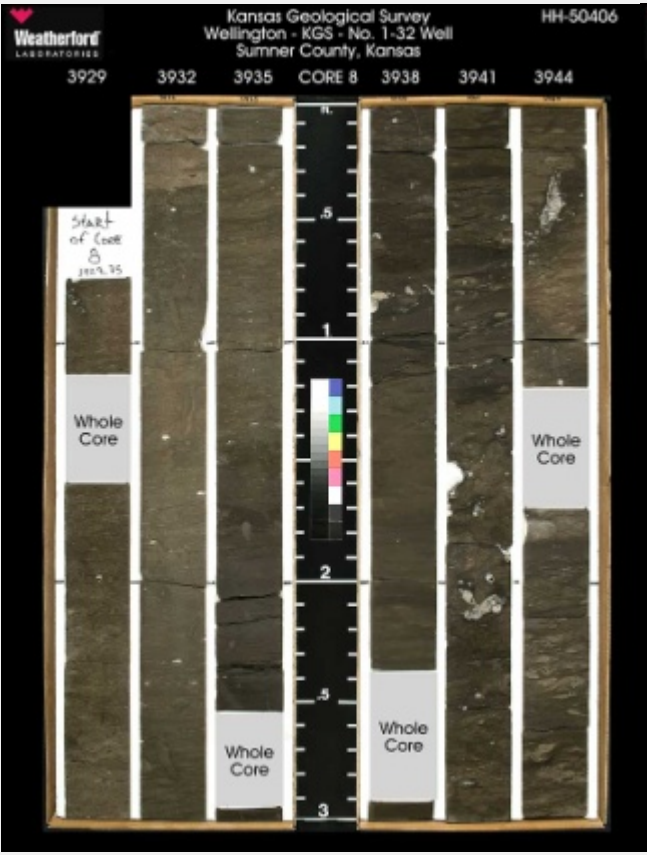
Handford and Manger (1993)

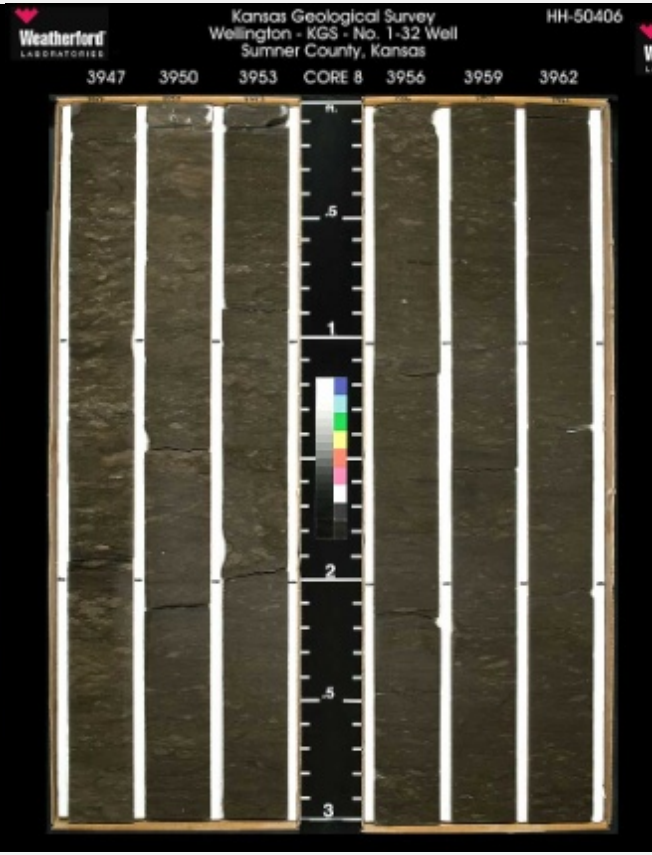
PIERSON LIMESTONE : Dark Lithofacies

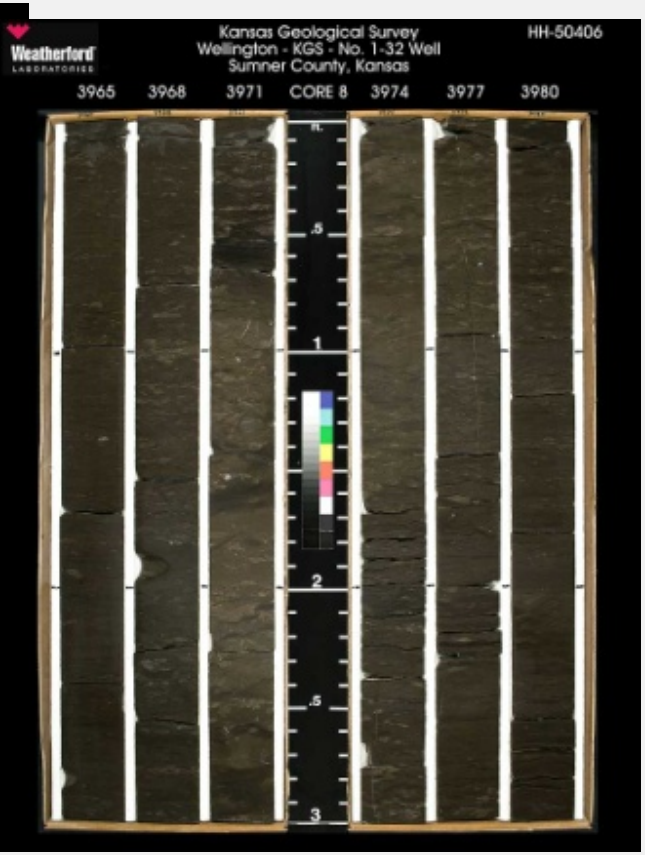
3927- 3939: olive gray, argillaceous dolomitic siltstone; 50% silt; wispy shale laminations; indistinct bedding; faint discontinuous laminations; gradational contact

3939-3975.6: medium dark gray; very argillaceous dolomitic siltstone; faintly laminated irregular; 30% silt; 3972-3973 cm-sized irregular calcareous nodules/coarse calcite; faint lenticular bedding alternating olive gray and medium dark gray

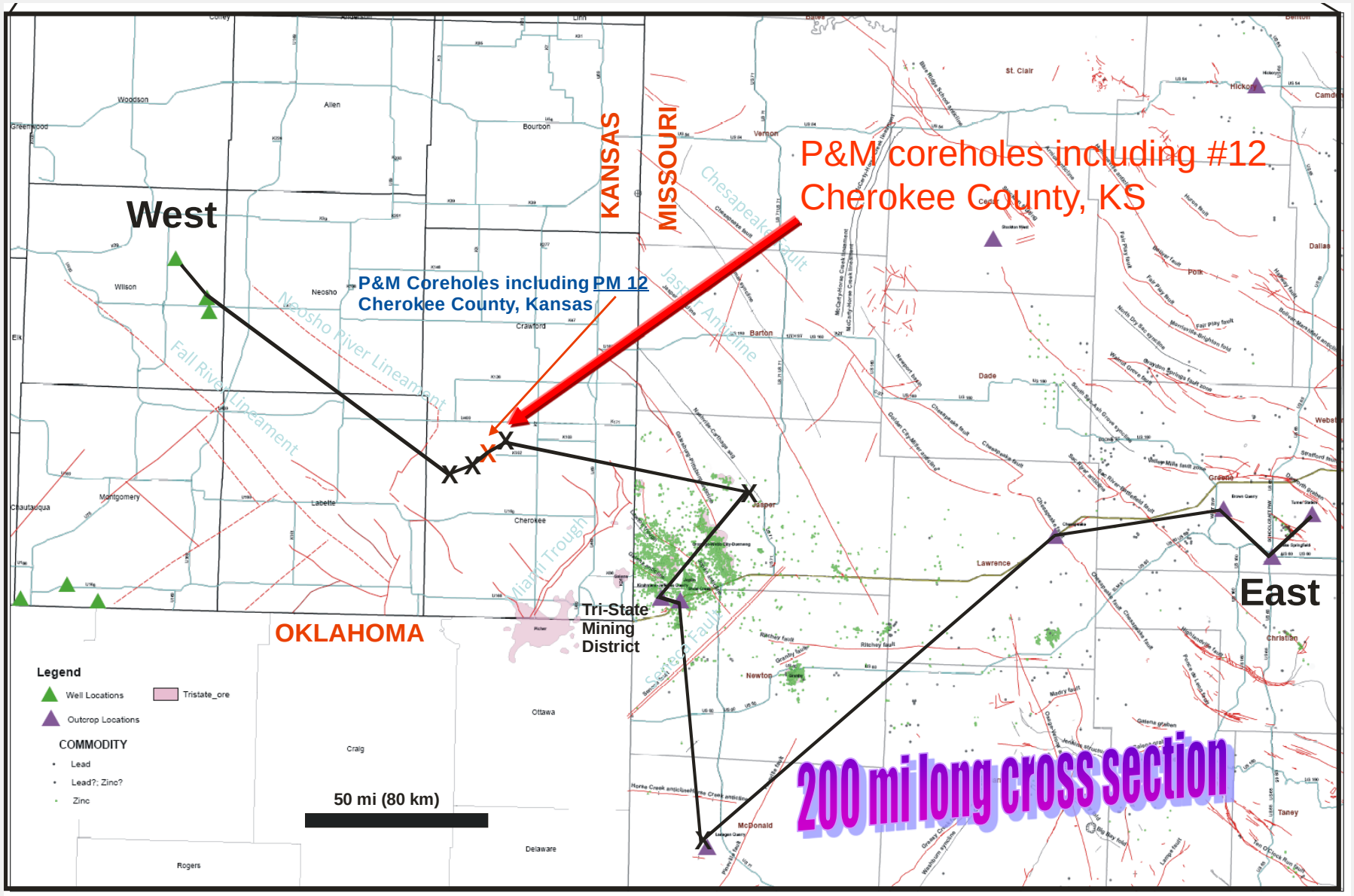
3975.6-3993: very dark greenish gray; shale; tight; dolomitic; around 20% silt; scattered black shale laminae; uniform; scattered pyrite; 3983 starts increasing silt; gradational contact

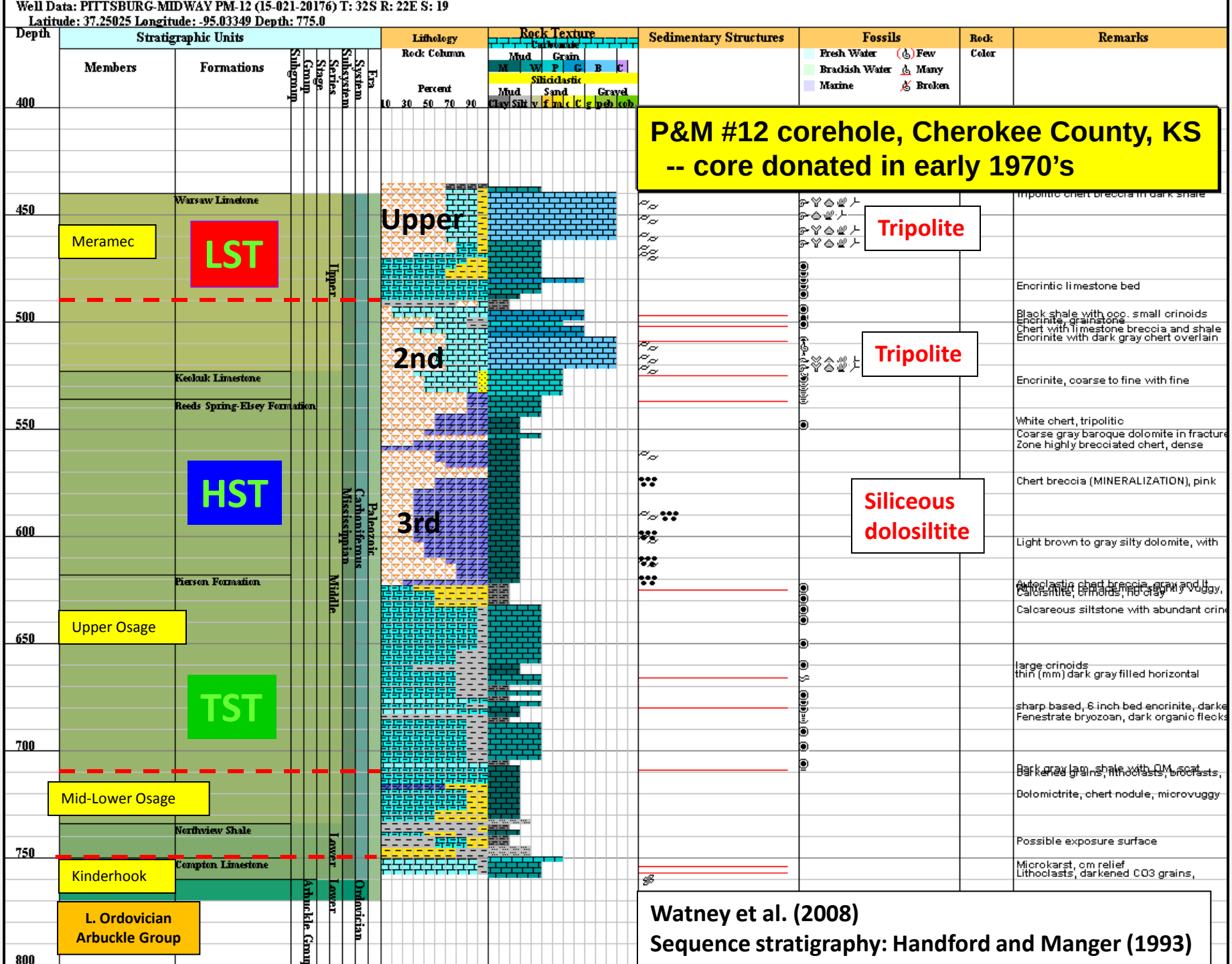






Location map: P&M cores, cross section index, and major structural elements




Well Data: PITTSBURG-MIDWAY PM-12 (15-021-20176) T: 32S R: 22E S: 19
Latitude: 37.25025 Longitude: -95.03349 Depth: 775.0
Depth
Stratigraphic Units
Members
Formations
Lithology
Rock Column
Percent
Rock Texture
Sedimentary Structures
Fossils
Fresh Water
Brackish Water
Marine
Few
Many
Broken
Rock Color
Remarks
Warsaw Limestone
Keokuk Limestone
Reeds Spring-Elsey Formation
Pierson Formation
Northview Shale
Compton Limestone
Meramec
Upper Osage
Mid-Lower Osage
Kinderhook
L. Ordovician Arbuckle Group
LST
HST
TST
Upper
2nd
3rd
Tripolite
Tripolite
Siliceous dolosiltite
Encrinitic limestone bed
Black shale with occ. small crinoids
Encrinite, grainstone
Chert with limestone breccia and shale
Encrinite with dark gray chert overlain
Encrinite, coarse to fine with fine
White chert, tripolitic
Coarse gray baroque dolomite in fracture
Zone highly brecciated chert, dense
Chert breccia (MINERALIZATION), pink
Light brown to gray silty dolomite, with
Calcareous siltstone with abundant crin
large crinoids
thin (mm) dark gray filled horizontal
sharp based, 6 inch bed encrinite, darke
Fenestrate bryozoan, dark organic flecks
Dolomictrite, chert nodule, microvuggy
Possible exposure surface
Microkarst, cm relief
Lithoclasts, darkened CO3 grains,
P&M #12 corehole, Cherokee County, KS
-- core donated in early 1970's
Watney et al. (2008)
Sequence stratigraphy: Handford and Manger (1993)

Summary of Kansas Mississippian Play

- Stratified reservoir with distinct pay lithofacies with contrasting petrophysical properties at affect ability to produce from them.
  - Dolomitic grainstone-packstones, tripolitic (microporous) chert, & dolosiltite are primary pay lithofacies
  - Southern shelf margin distinguished by complex stacking and progradation into proto-Arkoma and Anadarko basins
- Significant local and regional structure coupled with changes in sea level affect --
  - Shelf configuration and depositional facies, early & late diagenesis
  - Pay compartmentalization by early and late structural movement
    - **Paleotopography**
    - **Fracture sets, faulting, flexure**