UPDATE ON CO_2-EOR AND AQUIFER SEQUESTRATION AT WELLINGTON FIELD

AND

PRE-DRILL ANALYSIS FOR HORIZONTAL WELL IN THE ARBUCKLE GROUP AT BEMIS-SHUTTS FIELD

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KU KANSAS GEOLOGICAL SURVEY
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U.S. DEPARTMENT OF ENERGY

NETL

Kansas Next Step
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Connecting for Success

Overview

- **Wellington Field, Sumner County, KS -- Evaluating CO_2 sequestration capacity of the deep saline Arbuckle aquifer and CO_2-EOR potential in the Mississippian (Osage) chert/dolomite reservoir.**
  - *Two basement tests drilled in January-Febrary 2011, including a 1638 ft core from the Pennsylvanian Cherokee Group through the 1000 ft Arbuckle Group.*
  - *Funded by DOE/NETL under grant DE-FE0000002056 and cost-sharing partners.* ***Industry partners - Berexco et al.***
- **Bemis-Shutts, Ellis County, KS –Horizontal well scheduled for October 2011 in the Arbuckle reservoir**
  - *Evaluate effectiveness of seismic attributes, namely volumetric curvature, to identify the presence, extent, and impact of paleokarst heterogeneity on CO_2 saline aquifer sequestration and oil production.*
  - *Funded by the U.S. Department of Energy under grant DE-FE0004566 and cost-sharing by its* ***industry partners -Vess, Murfin***

Partners

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fairfieldnodal

Devilbiss Coring Service

BEREXCO

PARAGON
GEOPHYSICAL SERVICES, INC

Basic Energy Services

noble energy

TRILOBITE TESTING, INC.

LOCKHART GEOPHYSICAL

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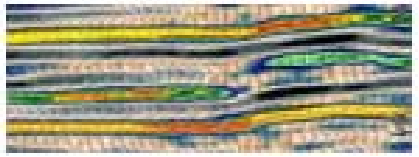
Weatherford LABORATORIES

ECHO GEOPHYSICAL CORPORATION
INTEGRITY · STABILITY · INNOVATION

HALLIBURTON

HEDKE-SAENGER GEOSCIENCE, LTD



Bittersweet Energy Inc.

Charter Consulting
Integrated Geology & Geophysics

Petrotek

KOGER REMOTE SENSING

LOGDIGI
A LEADING CONSULTING COMPANY

Industry Partners – Western Annex

SW Kansas CO_2 Sequestration Consortium

IHR Improved Hydrocarbon Recovery LLC

HEDKE-SAENGER GEOSCIENCE, LTD

SUNFLOWER ENERGY LLC

+drilling and seismic contractors TBN

CIMAREX

GloriOil

Anadarko Petroleum Corporation

CISCO ENERGY

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CELEBRATING 20 YEARS

MERIT ENERGY COMPANY

Industrial and Electrical Power Sources of CO_2

SUNFLOWER ELECTRIC POWER CORPORATION
A Touchstone Energy® Cooperative
. . . energy done right

Abengoa Bioenergy : The Global Ethanol Company

Modeling CO_2 Sequestration

- **Definition of Mississippian-Cambrian "*Ozark Plateau Aquifer System (OPAS)*"**

Dec 2009 through August 2013 (3.5 yr. study)

- **Regional distribution of Arbuckle saline aquifer and caprock**
  - *Caprock continuity and integrity*
  - *Storage*
    - *Continuity of hydrostratigraphic flow units*
    - *Evaluating open or closed hydrologic system*
    - *Capacity via volumetrics and compositional simulation*

- **Structure**
  - *Systematically characterize fractures/faults/flexure*
  - *Map deep-seated structures and assess nature and timing of reactivation*

- **Preliminary simulations of commercial scale CO_2 injection**
  - *Footprint & stratigraphic constraint of commercial scale CO_2 plume in saline aquifer*
  - *-- Improved efficiency and effectiveness of CO2-EOR*

- **Wellington Field**
  - *Multicomponent 3D seismic*
  - *Initial geomodels*
  - *New injectivity & storage data (1st quarter 2011)*
    - *1500 ft core, logs, drill stem tests, and well tests – KGS #1-32 & #1-28*

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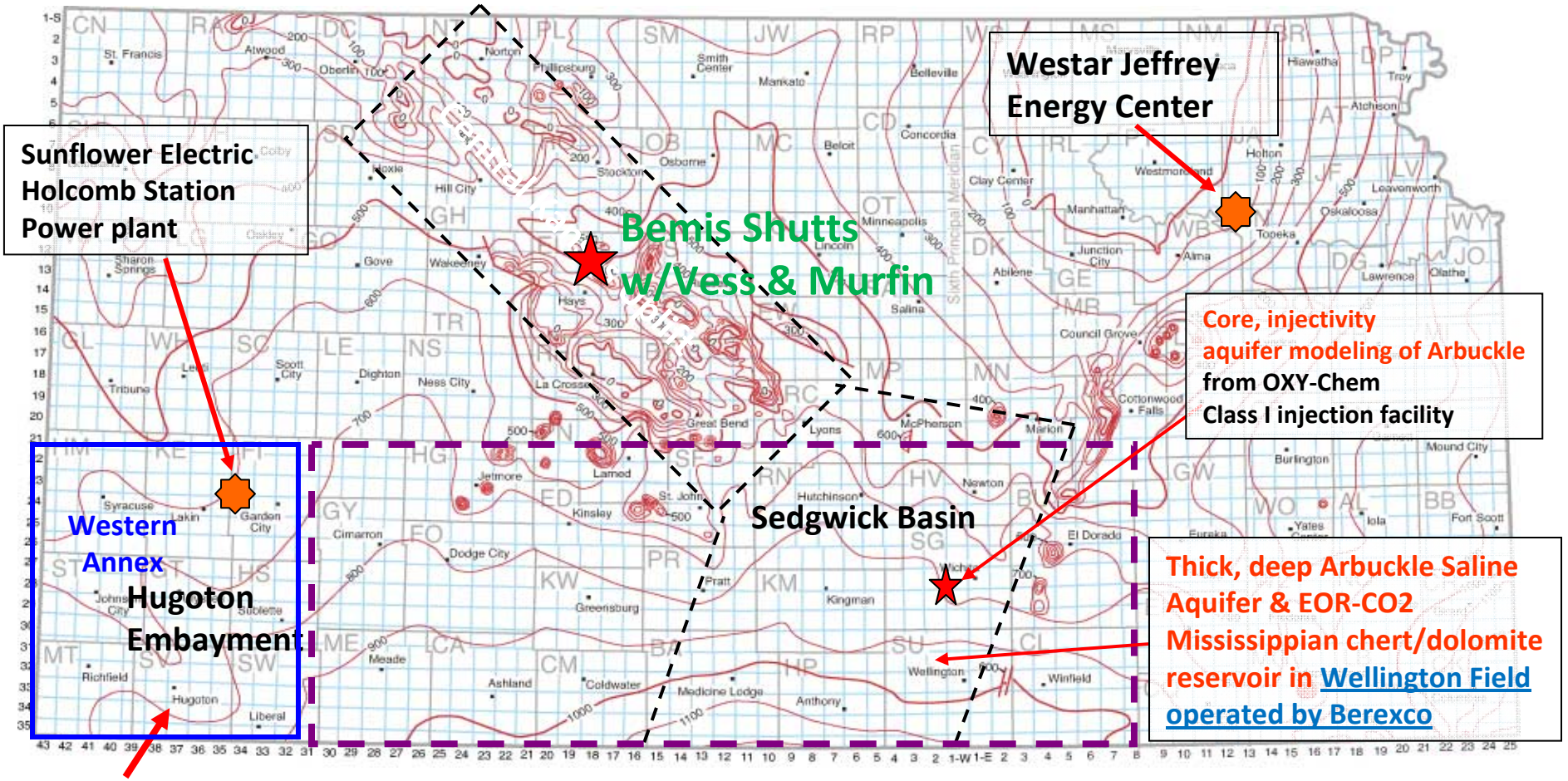
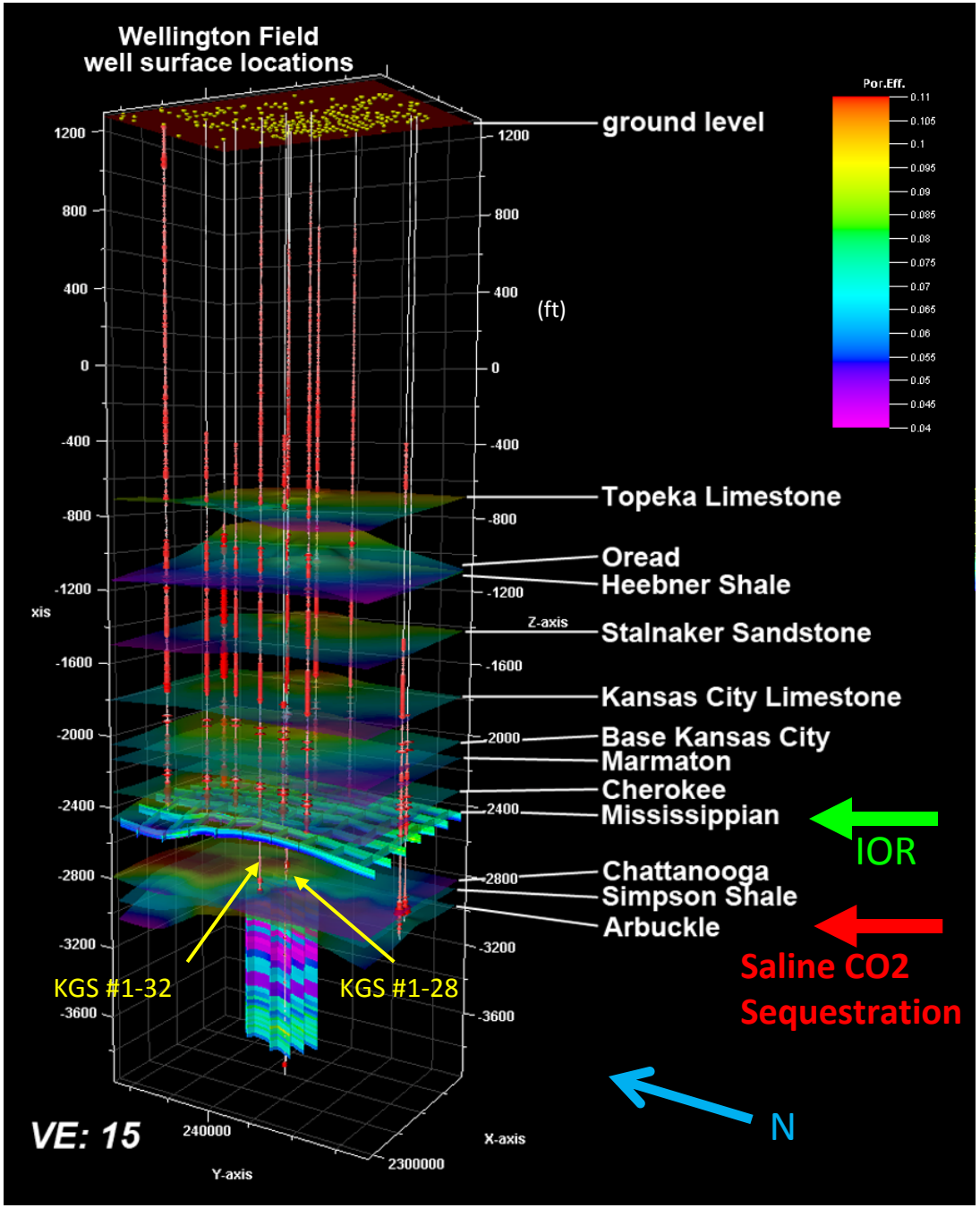
Project Study Area

Wellington Field (Sumner County) + 25,000 mi² (33 Counties)





Wellington Field

1) *Mississippian tripolitic chert/dolomite reservoir*
2) *Arbuckle saline aquifer*
3) *Intervening caprocks*

- New core and logs from KGS #1-32 and logs from #1-28 obtained in Jan-Feb. 2011
- Using to assess --
  - Integrity of caprocks
  - Porosity types, injectivity, and storage
  - Model potential for C02-EOR in Mississippian saline aquifer
  - Sequestration in Arbuckle

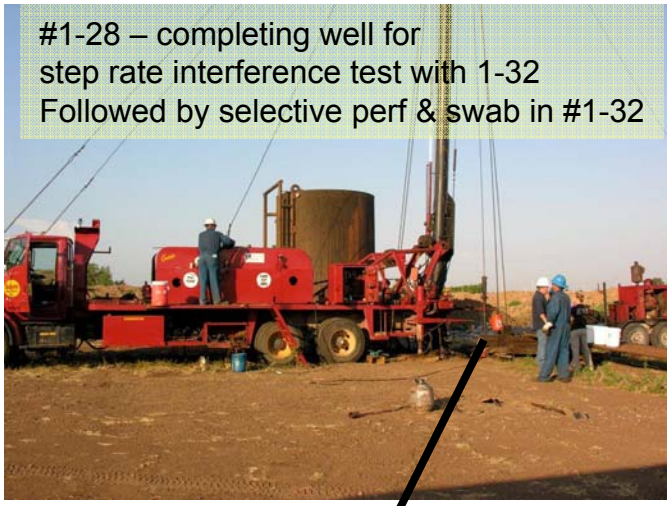
Small scale field test (70k tonnes CO2) proposed to DOE – <u>Surface</u> (May 5, 2011) – MVA deployment and testing -- LiDAR/InSAR, <u>shallow GW</u>

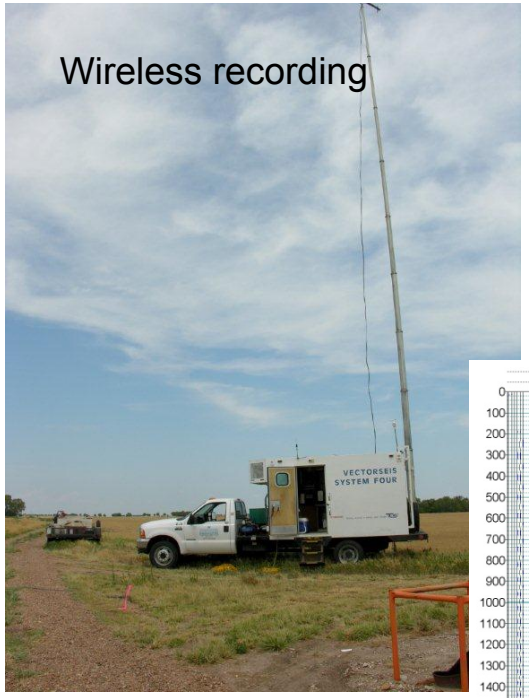
<u>Mississippian reservoir</u> - pressure, geochem, 2D high resolution seismic

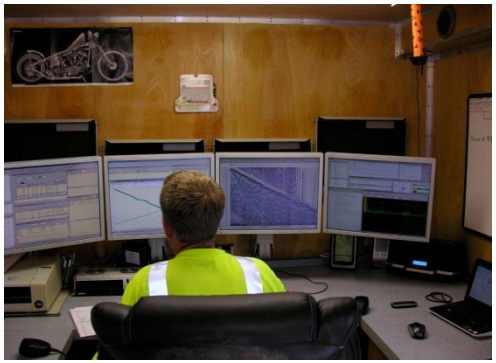
<u>Arbuckle</u> - in situ cross hole tomography, U-tube plume sampling, CASM (continuous seismic imaging), repeat 3D

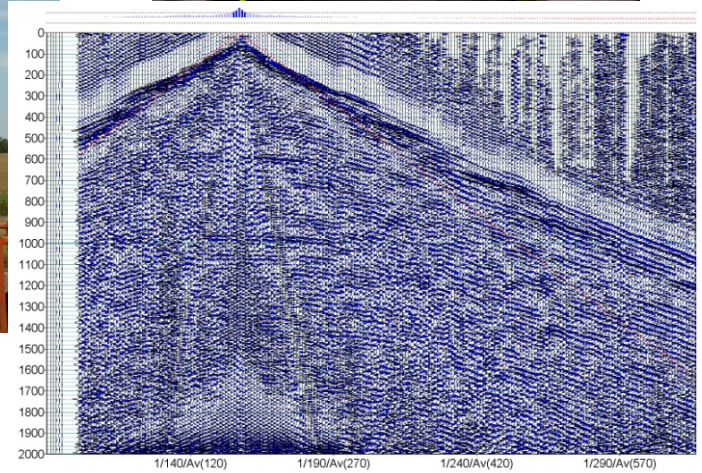
Weekend July 31st @ Wellington

#1-28 – completing well for
step rate interference test with 1-32
Followed by selective perf & swab in #1-32





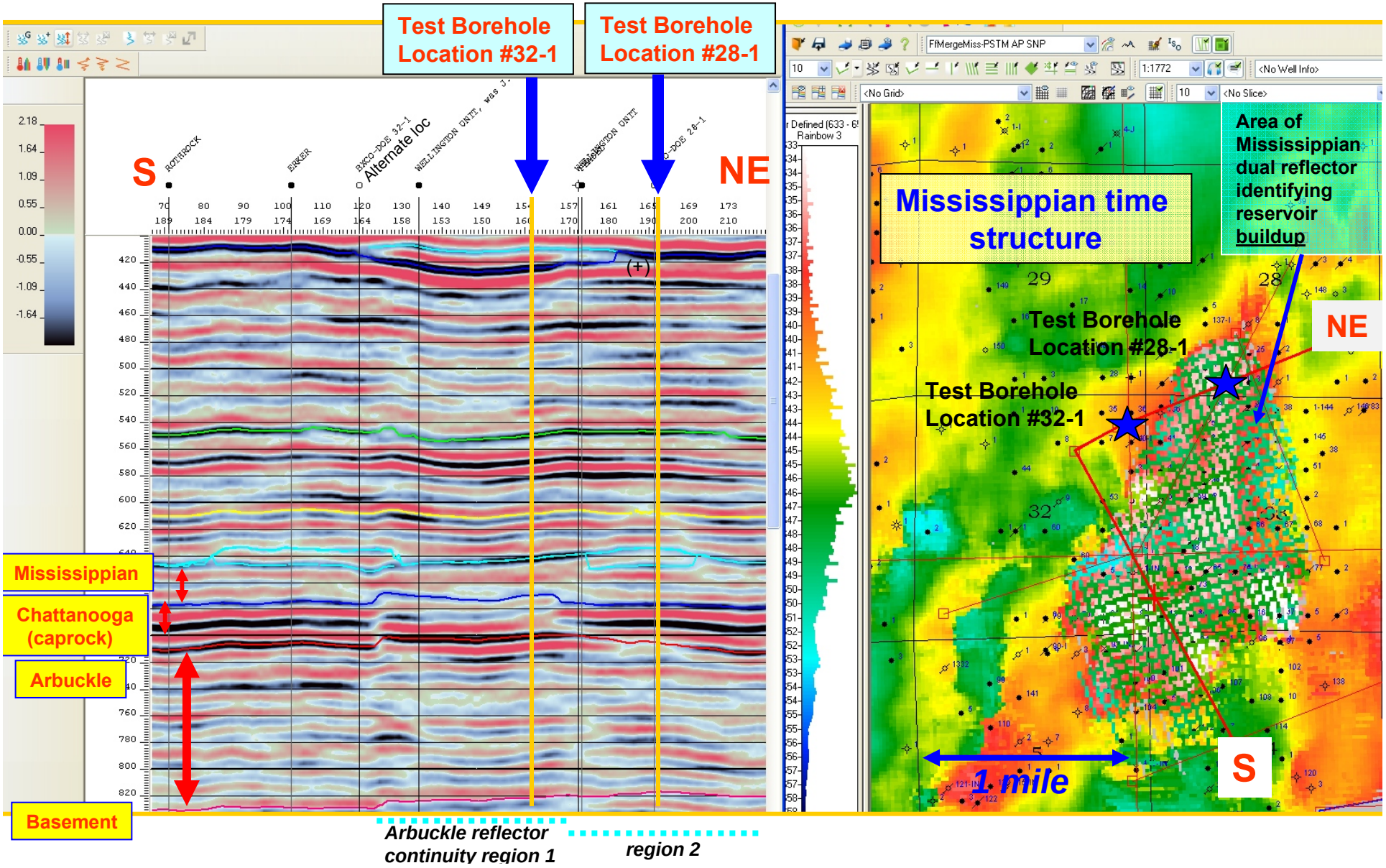


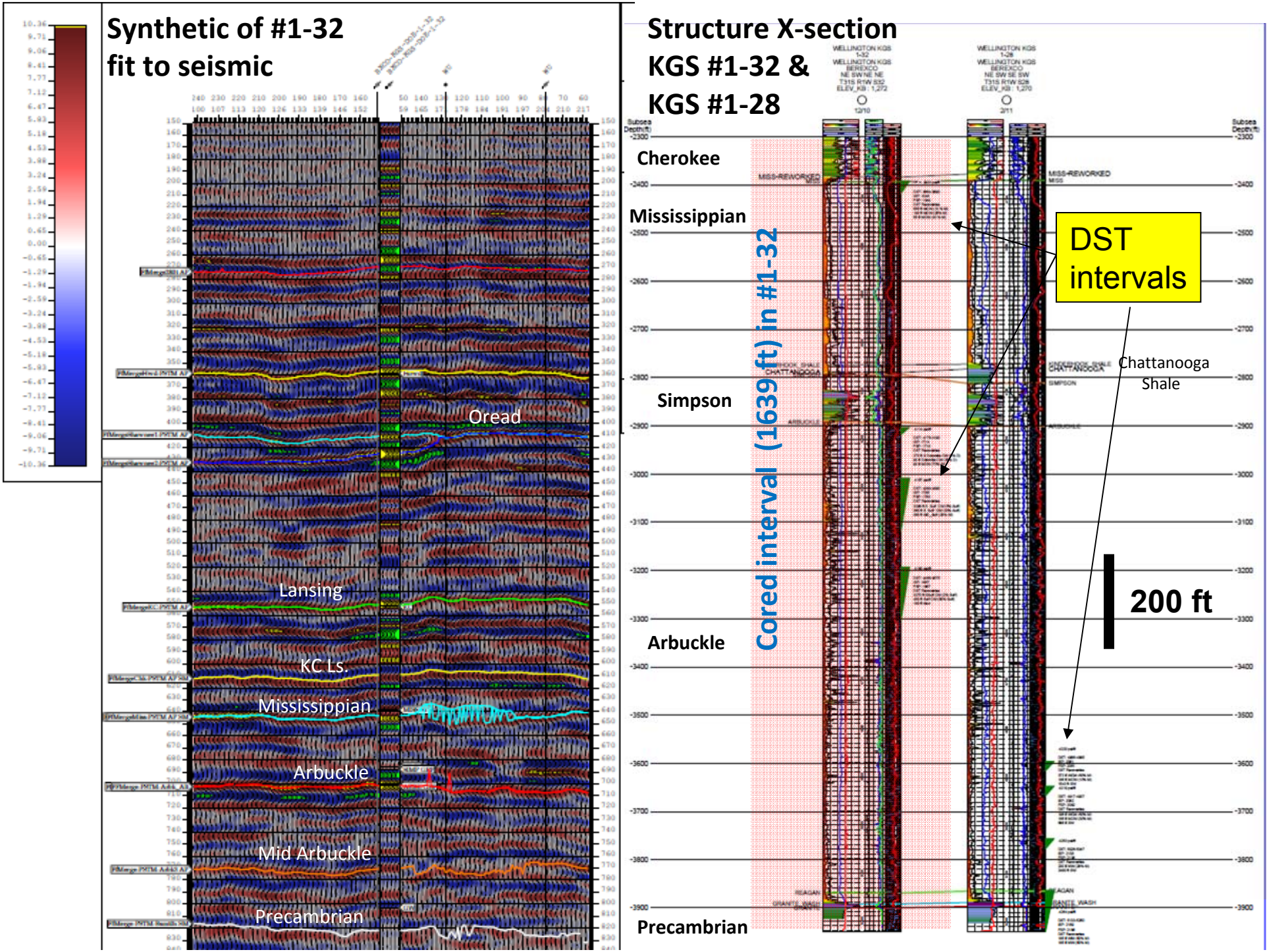


Wellington Field

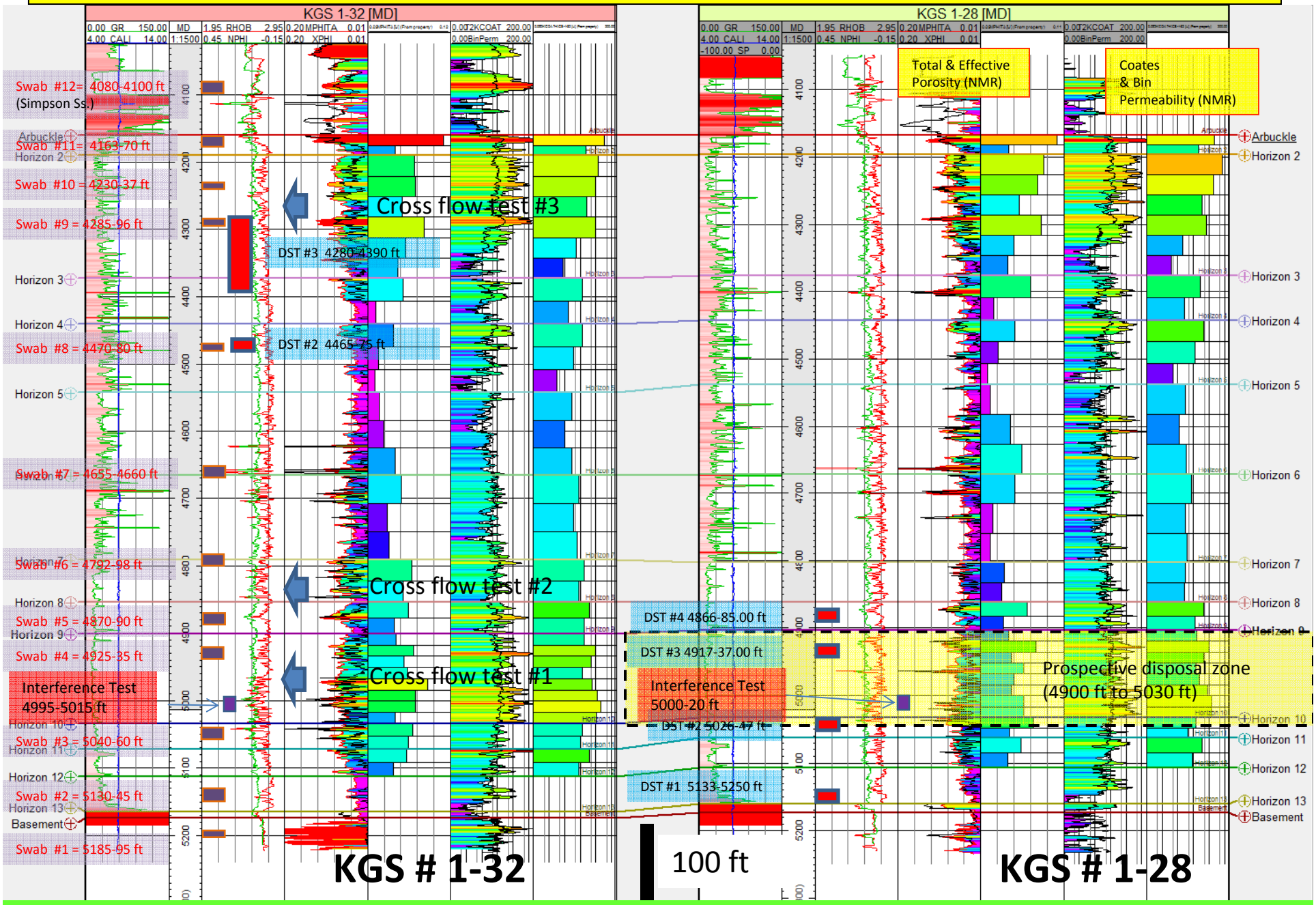
3D Seismic P-Wave Processing, Initial Interpretations, & Borehole Locations

Arbitrary seismic profile to compare borehole locations

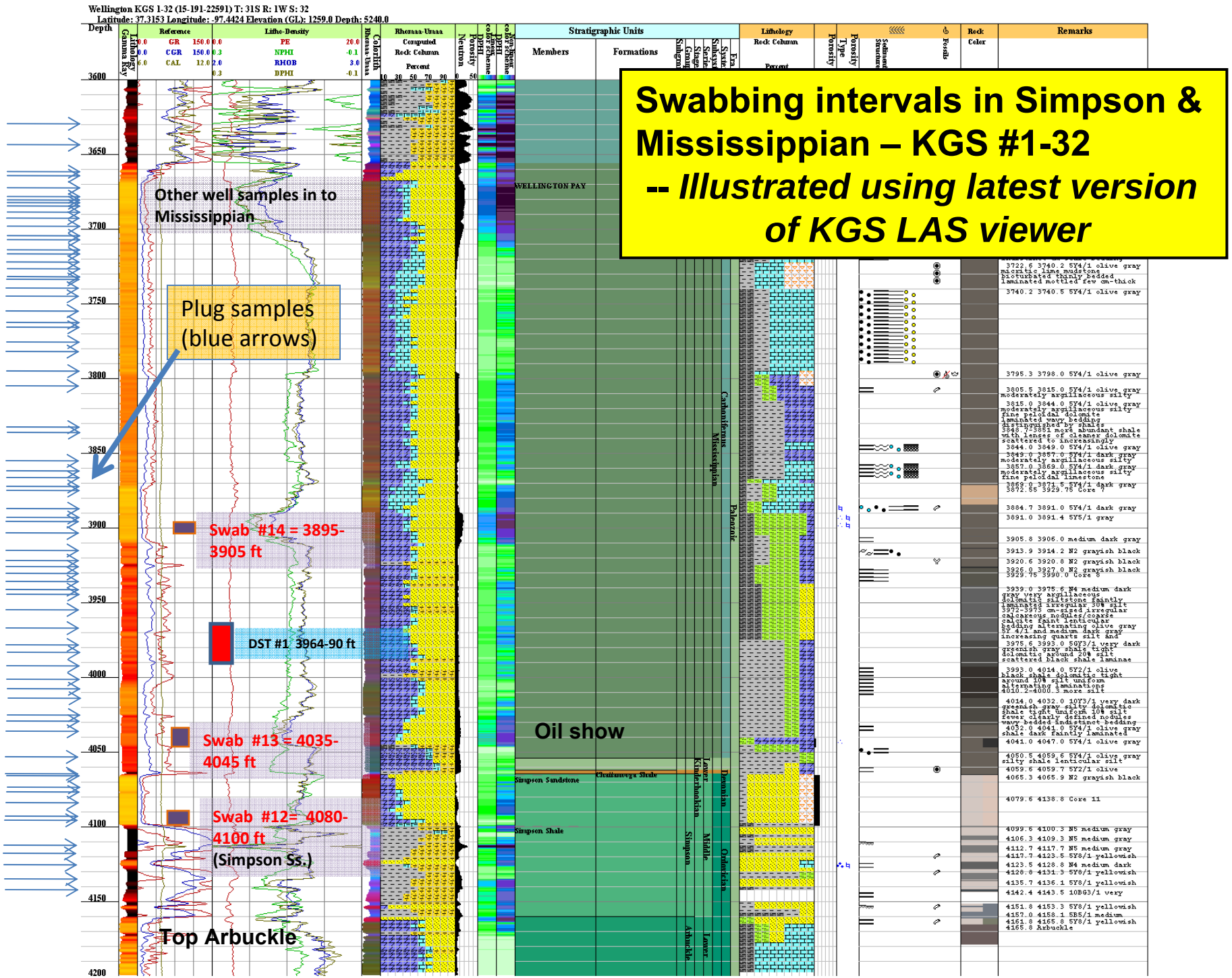



Synthetic of #1-32
fit to seismic
Oread
Lansing
KC Ls.
Mississippian
Arbuckle
Mid Arbuckle
Precambrian
Structure X-section
KGS #1-32 &
KGS #1-28
Cherokee
Mississippian
Simpson
Arbuckle
Precambrian
Cored interval (1639 ft) in #1-32
DST
intervals
Chattanooga
Shale
200 ft

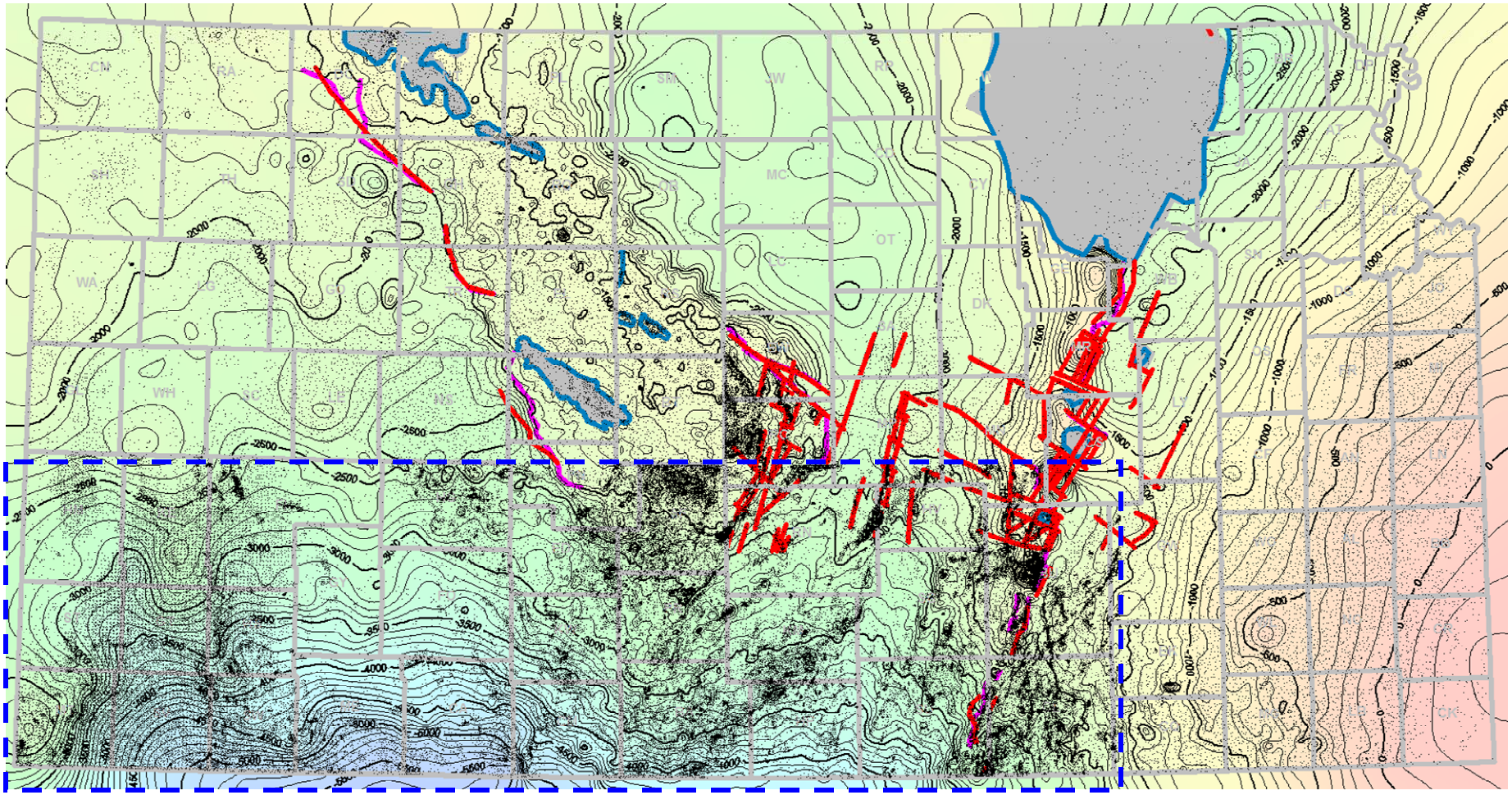
Step rate test and preliminary perforate & swab intervals in Arbuckle and Simpson Groups



Cross section (east to west) between KGS #1-28 and #1-32 in Wellington Field and upscaled hydrostratigraphic units in Arbuckle Group


Wellington KGS 1-32 (15-191-22591) T: 31S R: 1W S: 32
Latitude: 37.3153 Longitude: -97.4424 Elevation (GL): 1259.0 Depth: 5240.0
Swabbing intervals in Simpson & Mississippian – KGS #1-32
-- Illustrated using latest version of KGS LAS viewer
Other well samples in to Mississippian
Plug samples (blue arrows)
Swab #14 = 3895-3905 ft
DST #1 3964-90 ft
Swab #13 = 4035-4045 ft
Swab #12= 4080-4100 ft (Simpson Ss.)
Top Arbuckle
Oil show
WELLINGTON PAY
Simpson Sandstone
Simpson Shale
Chattanooga Shale
Mississippian
Arbuckle

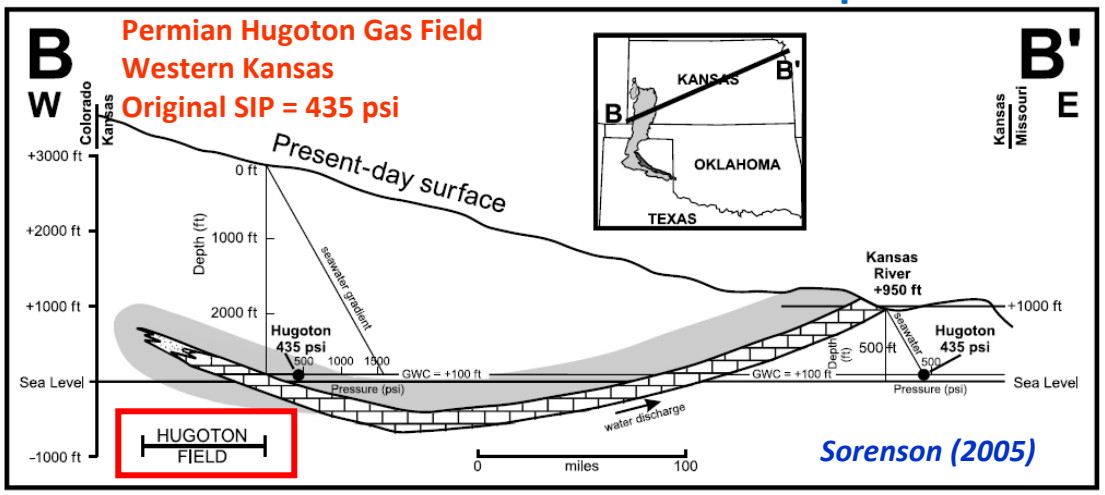
Top Arbuckle Group



- **Published faults are being compiled and new ones are under investigation**
- **Focus of <u>quantitatively</u> assessing CO2 sequestration capacity of Arbuckle saline aquifer is within dashed blue area**

Arbuckle saline aquifer is an open system

Arbuckle Saline Aquifer Connected to Outcrop

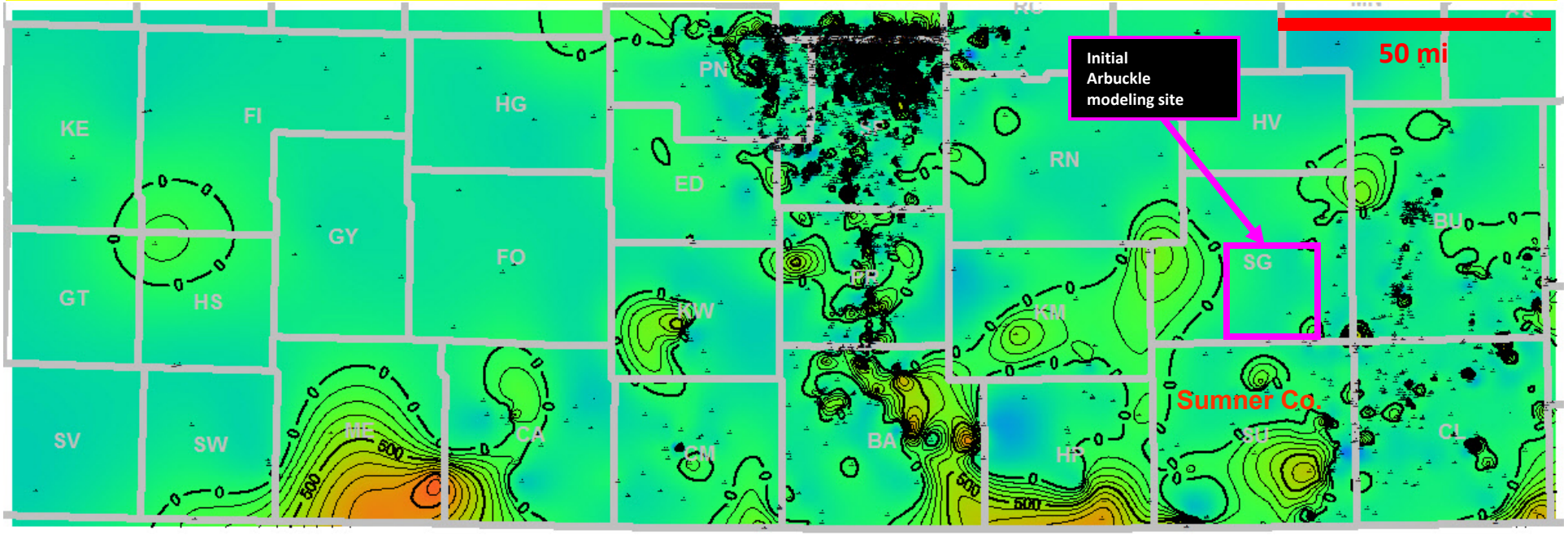


Arbuckle exposure at base of Missouri River, north-central Missouri – Elevation 450 ft

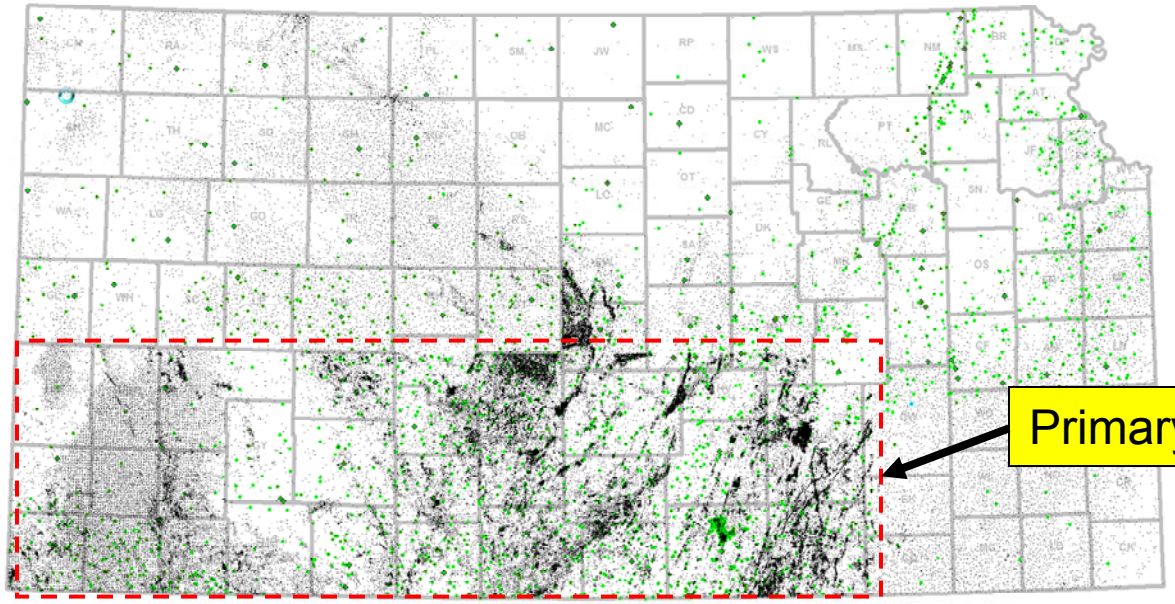
& ~200 mi northeast

Assume hydrostatic gradient = 0.435 psi/ft

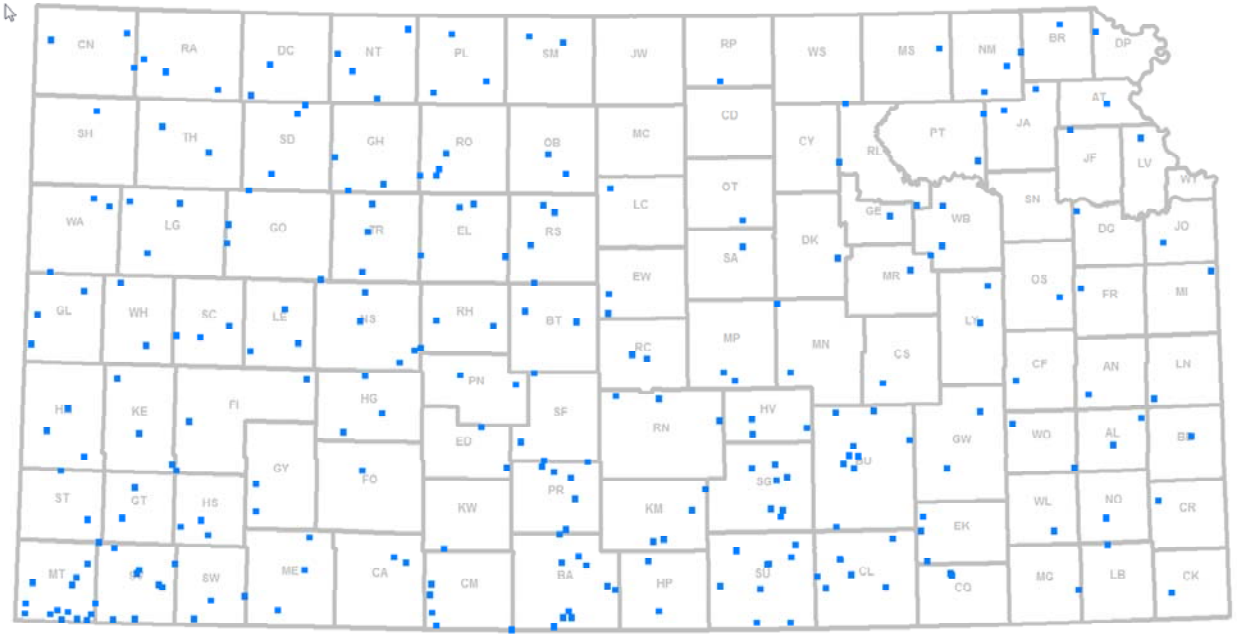
Map of the difference between estimated hydraulic head at base of Arbuckle test interval and measured shut-in pressure



Regional Characterization of OPAS



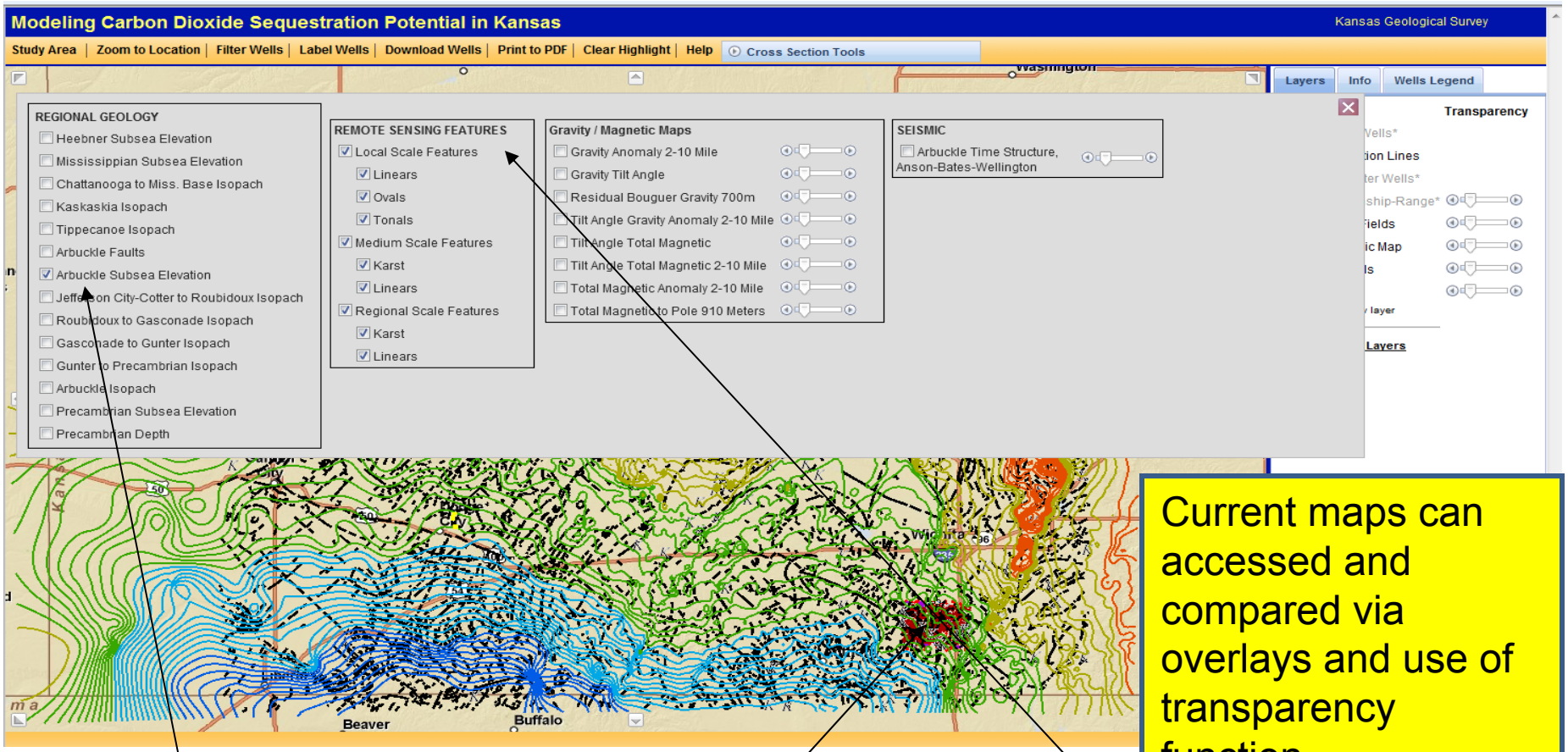
Total well database including those used for tops only (black), e-logs (green)



Current status of supertype well (5-19-11) – wells with nearly complete penetration of Arbuckle with modern log suite – creating digital LAS files, strat type log linked by cross sections in collaboration with the Ks Geol. Society

Interactive Project Mapper

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

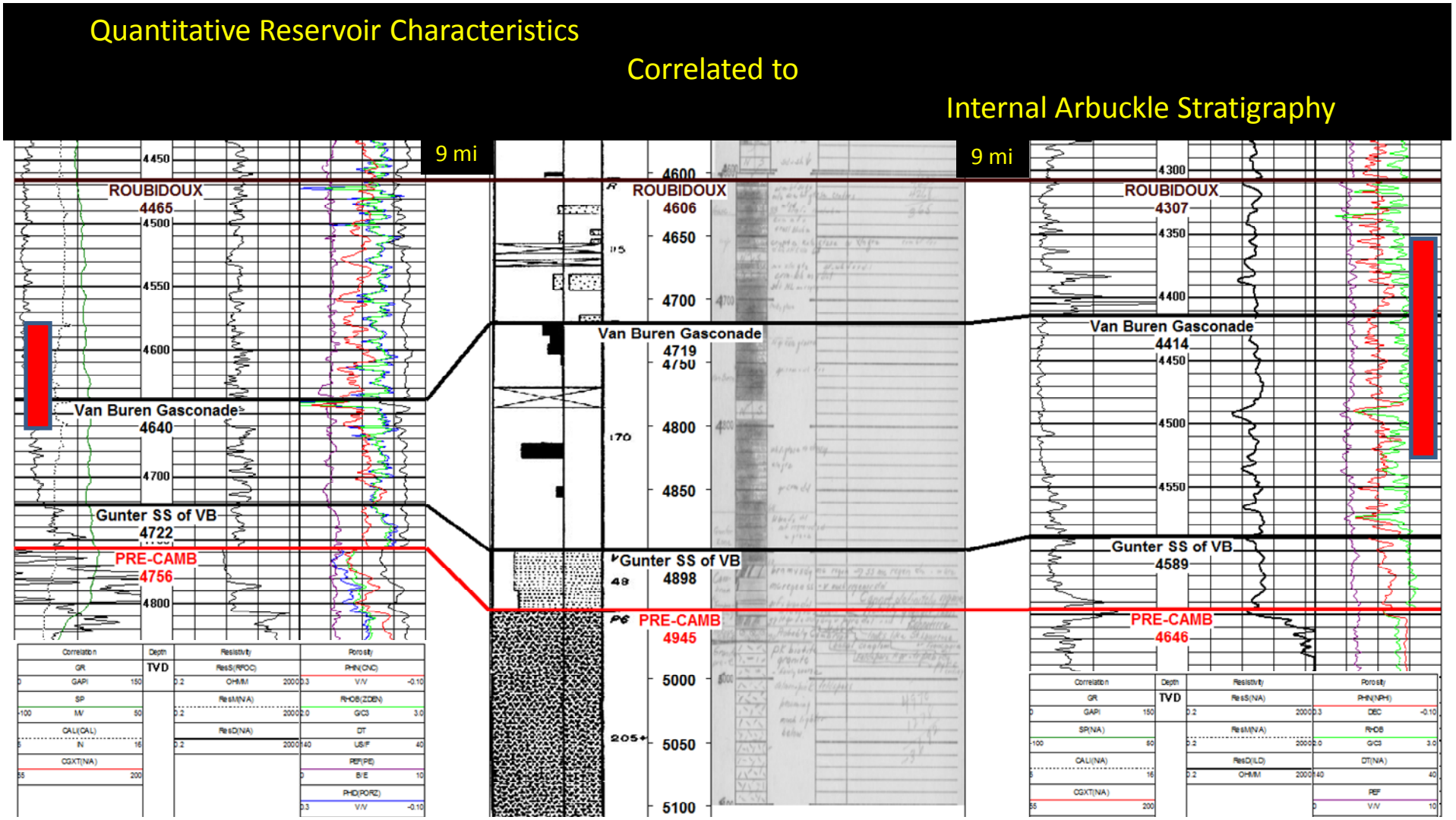


Current maps can accessed and compared via overlays and use of transparency function

Wellington

Arbuckle subsea elevation with surface lineaments

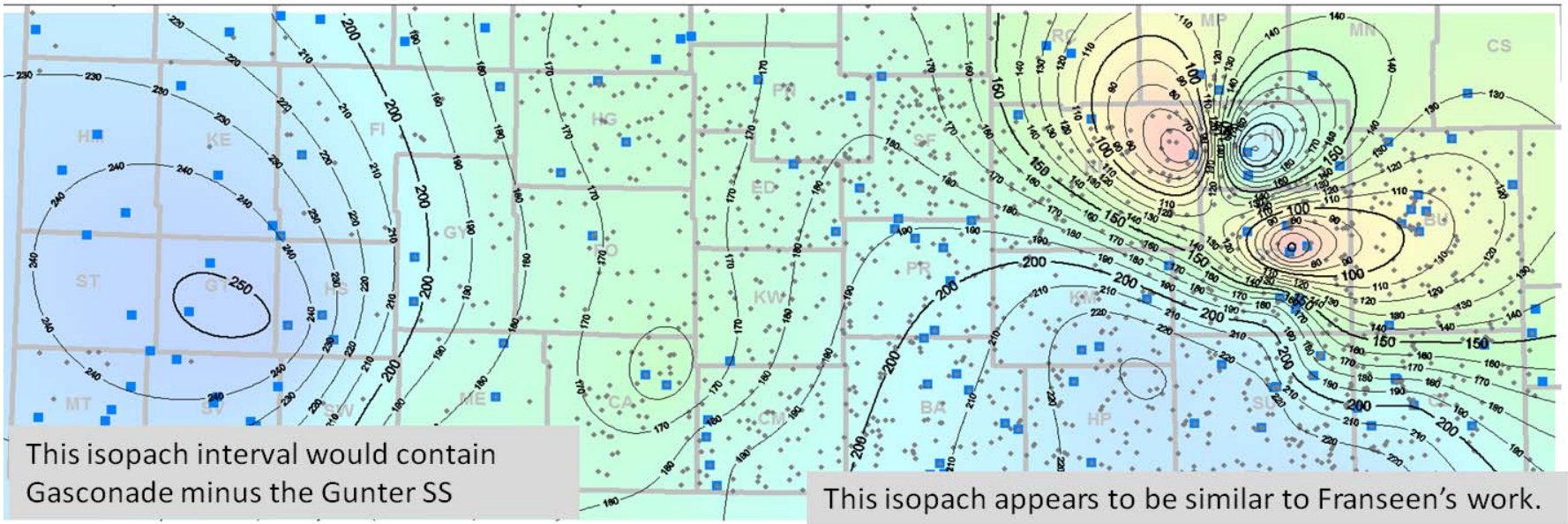
Quantitative Characterization of Arbuckle in southern Kansas



Example cross section of lower Arbuckle from top Roubidoux to basement including new and old well data (insoluble residue logs, georeports, and modern suite of logs managed as LAS files)

Lower porous zone in Arbuckle

ISOPACH GASCONADE to GUNTER SS

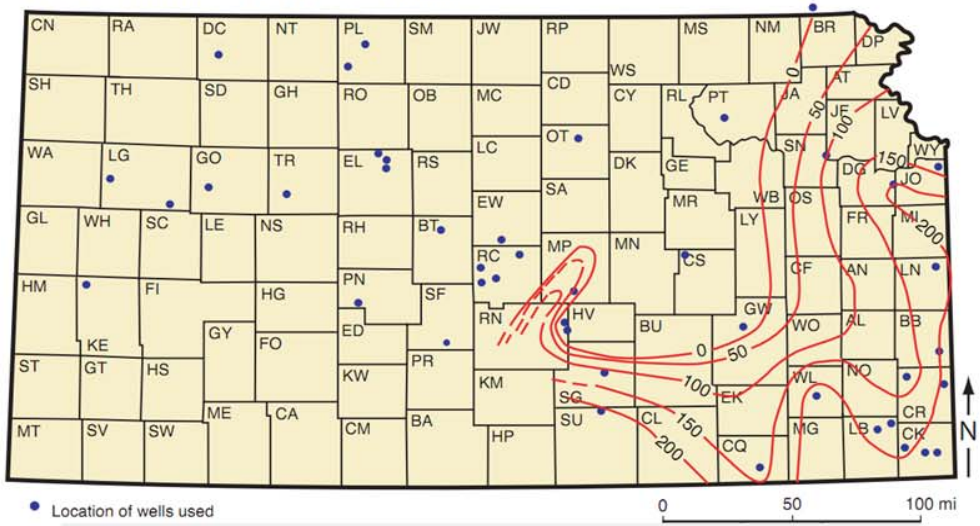


This isopach interval would contain Gasconade minus the Gunter SS

This isopach appears to be similar to Franseen's work.

Early Ordovician (approx Gasconade time)
Paleogeography, Chenoweth, 68

C - Van Buren-Gasconade dolomites

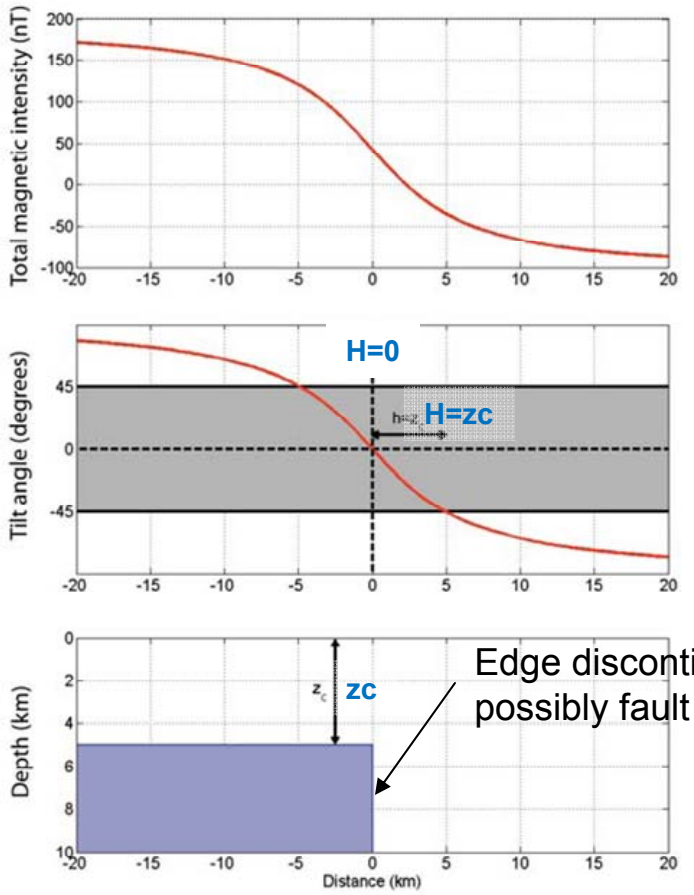


Van Buren Gasconade Isopach, Franseen et al., 2004

Illustration of tilt angle computation to locate discontinuities and ~depth to gravity and magnetic anomalies as an aid to identifying possible basement faults

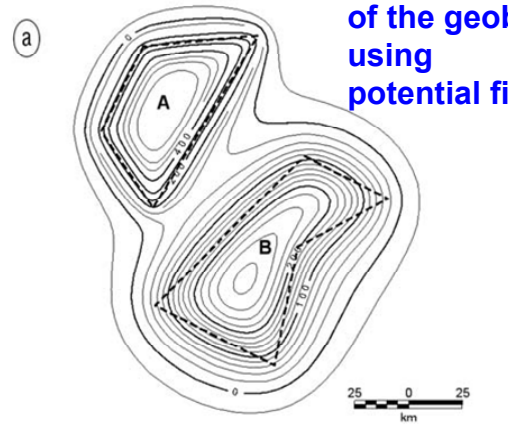
$$\theta = \tan^{-1}\left[\frac{\partial M/\partial z}{\partial M/\partial h}\right]$$

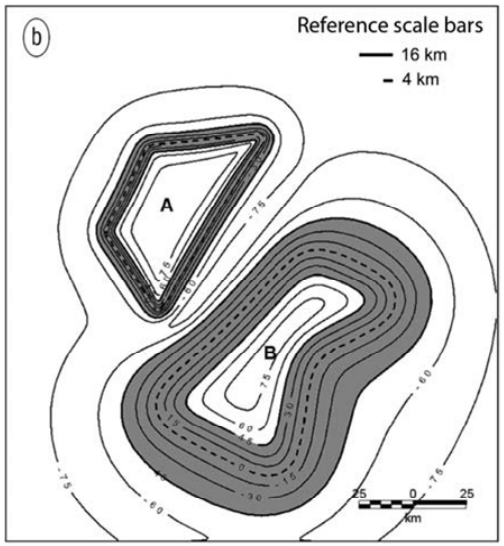
arctangent of the ratio of the 1st-order vertical derivative by the 1st-order horizontal derivative



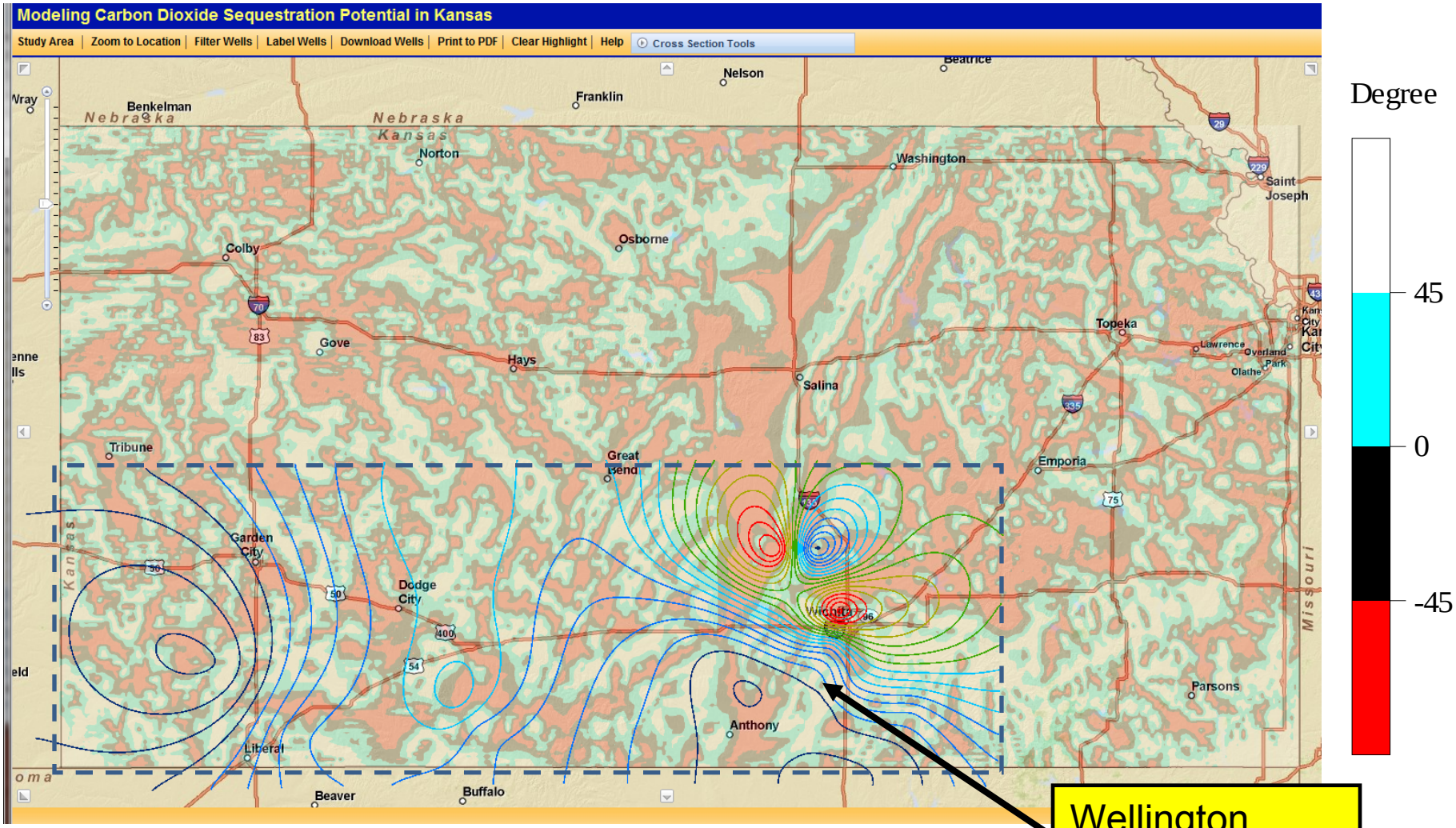
Salem et al., 2007

Geobody expression of the geobody using potential fields





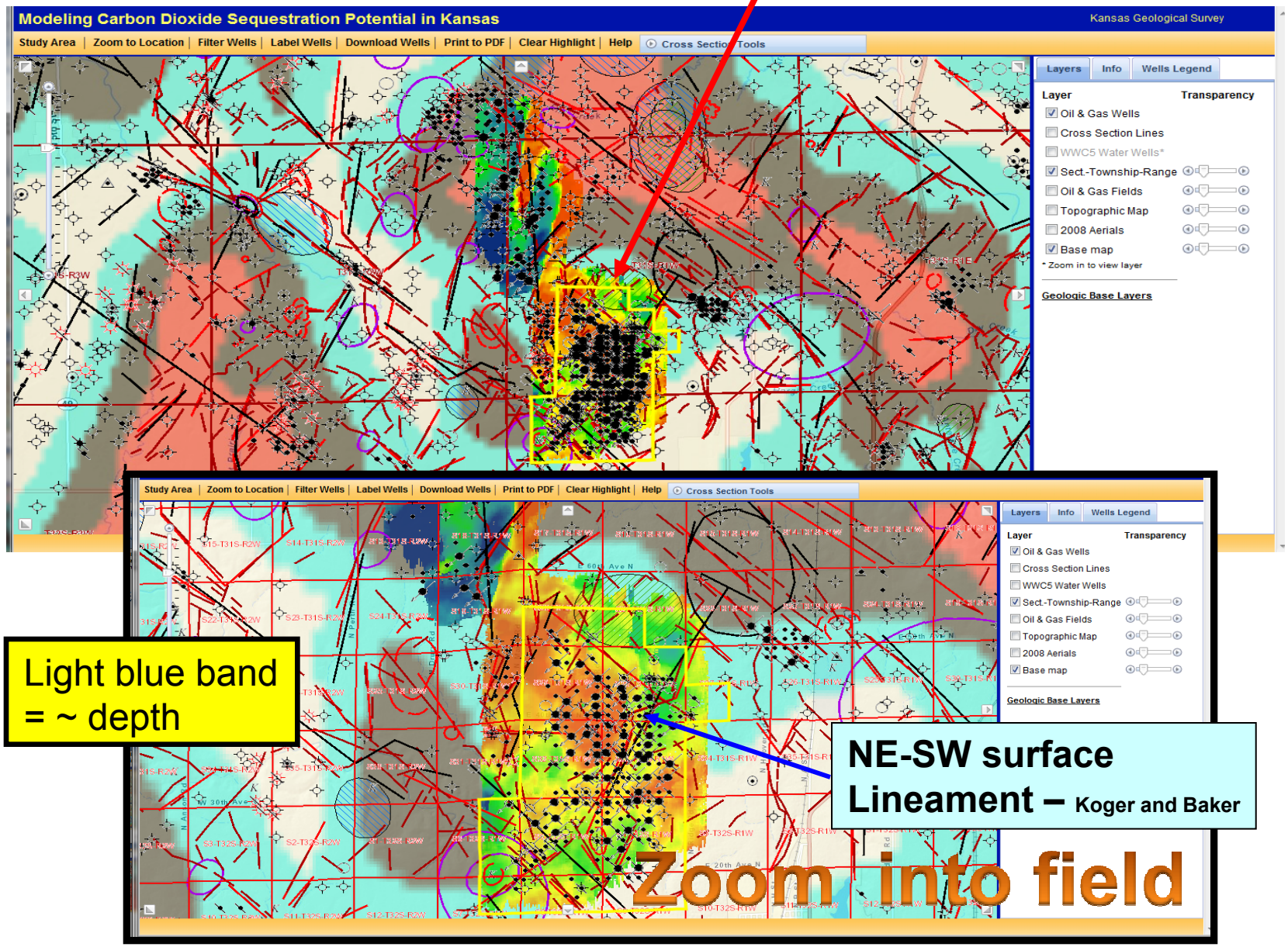
Tilt angle map of the total magnetic field intensity overlain by isopach Gasconade to Gunter Sandstone interval



isopach -> Red contour = thin, blue to purple = thick

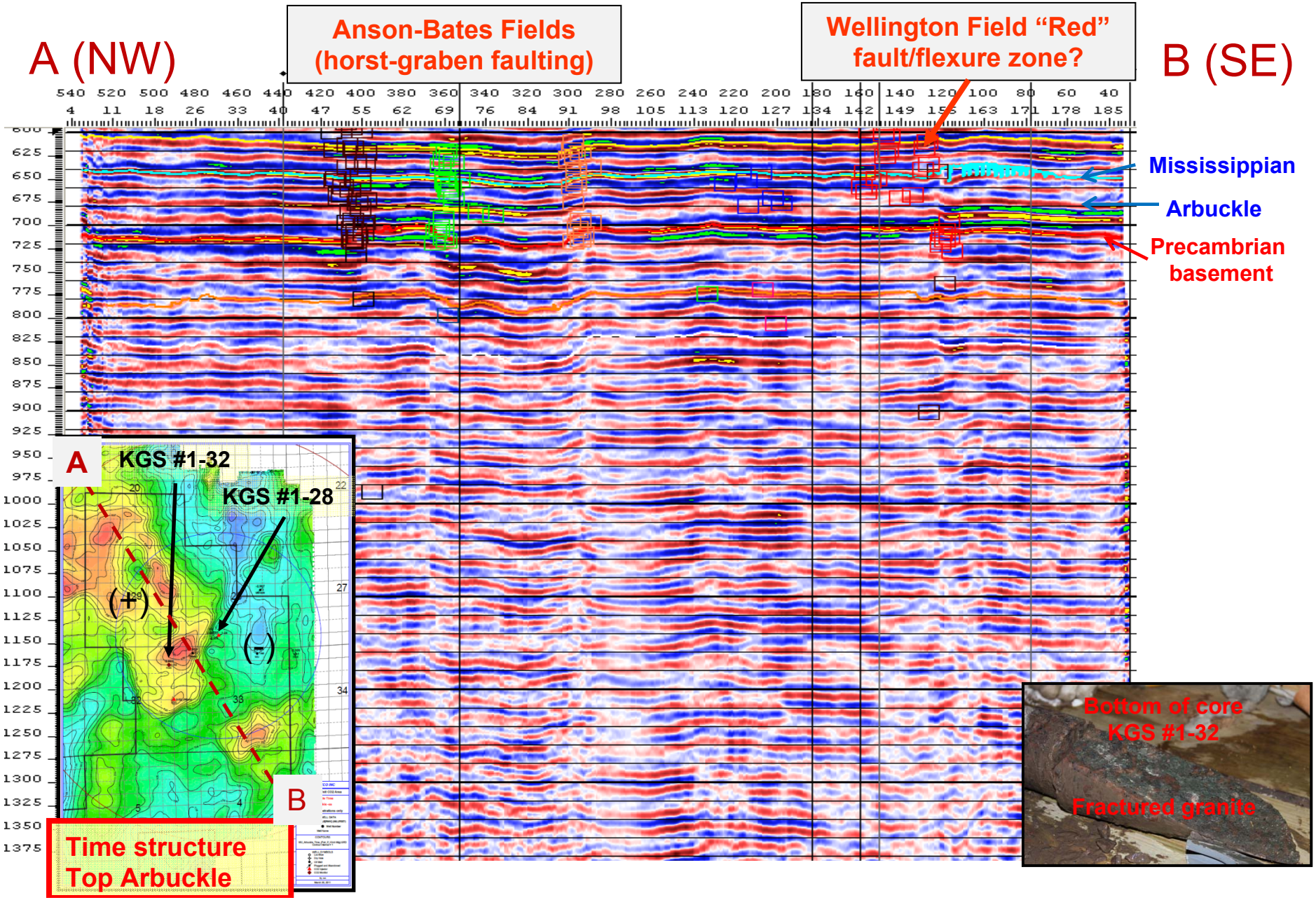
Snapshot from http://maps.kgs.ku.edu/co2/?pass=project

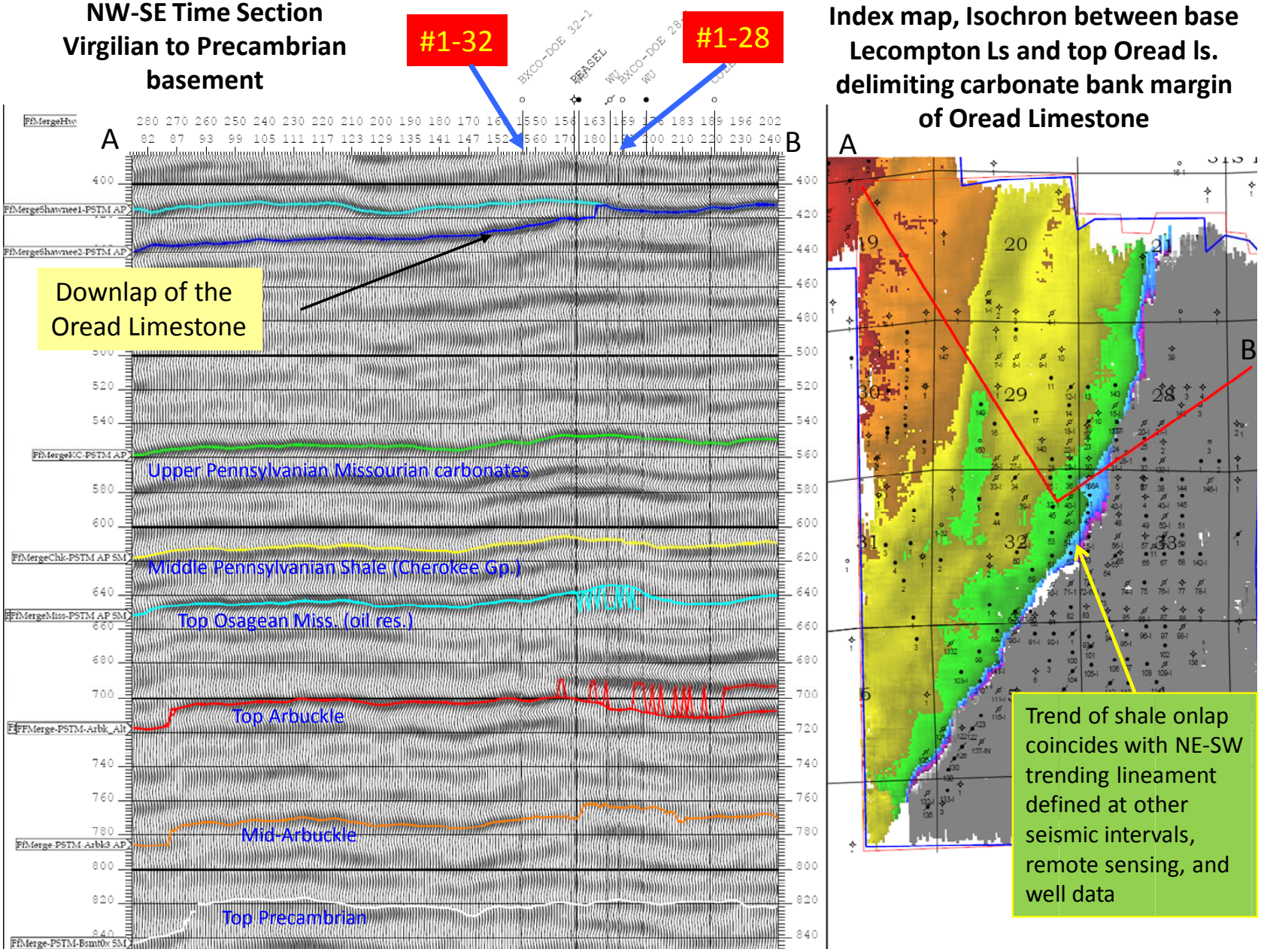
Tilt Angle Total Magnetic with 2-10 mi bandpass filter overlain by surface lineaments and time depth map of Arbuckle (Wellington Field)



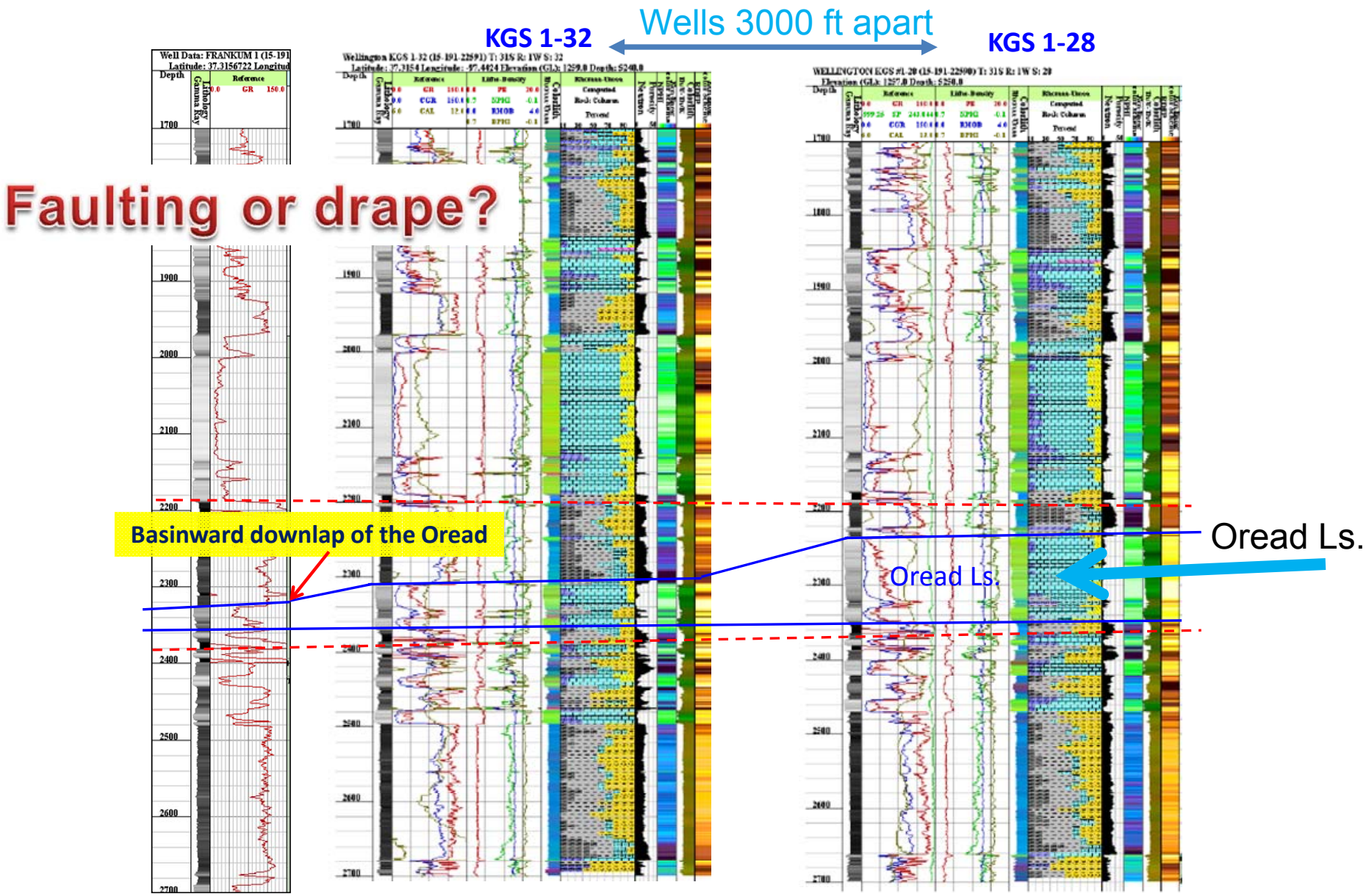
Snapshot from http://maps.kgs.ku.edu/co2/?pass=project

Paleozoic structures closely tied to basement faults deformation as flexure and later faulting (reactivation)





Seismic time section (left) and index map for section (right) showing location of the downlap (thinning) of the Oread Limestone to the west portion of the cross section. Map depicts time thickness of the shale that overlies the Oread Limestone, which thickens to west. Estimate depth of the change from thick limestone to thick shale corresponds is 750-800 meters (2400 to 2600 ft).



Log cross section is located along similar location as the preceding seismic image. Logs have been interpreted for lithology using KGS Java Profile software. Note downlapping carbonate and thickening of the overlying shale.

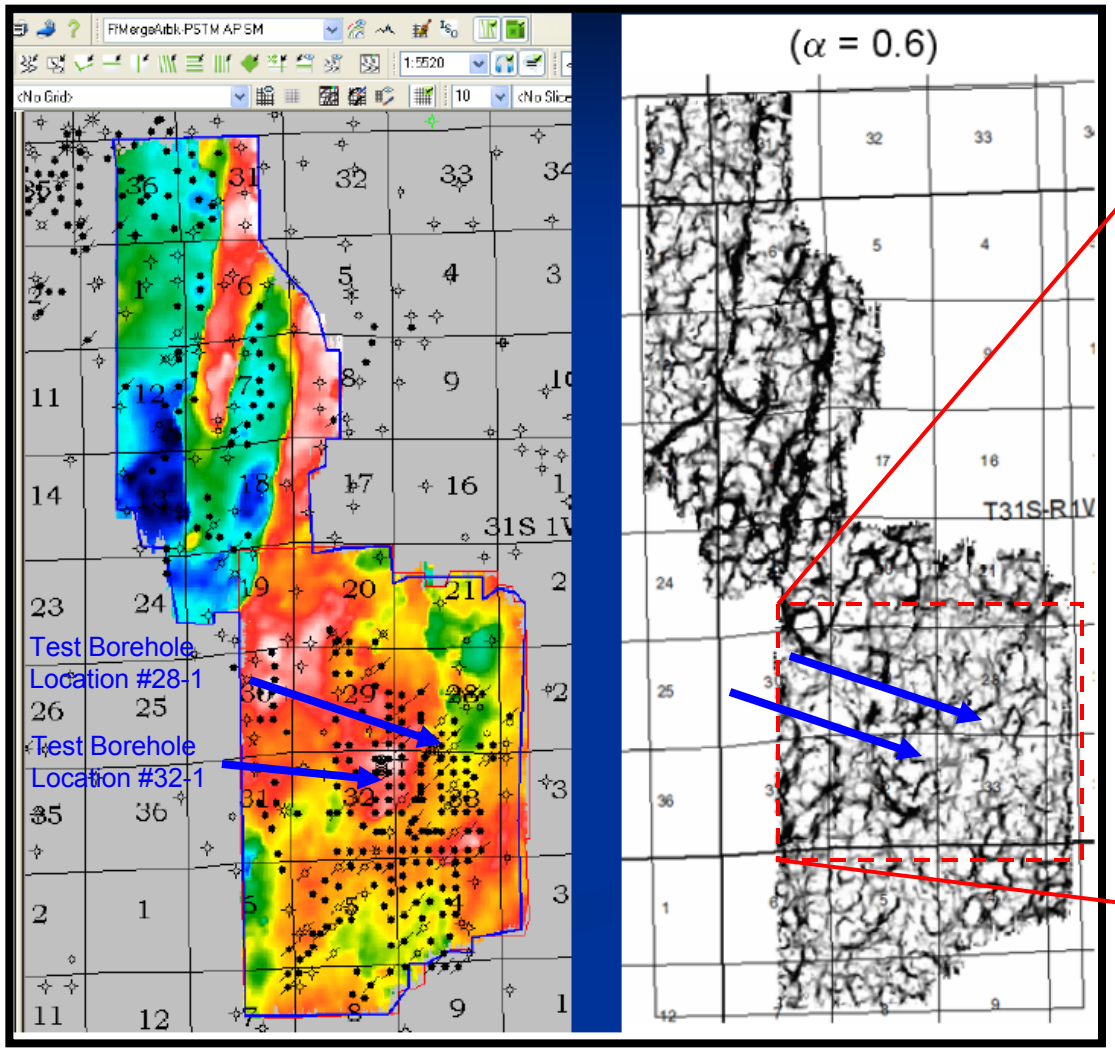
Volumetric Curvature

Used as criteria in borehole site selection

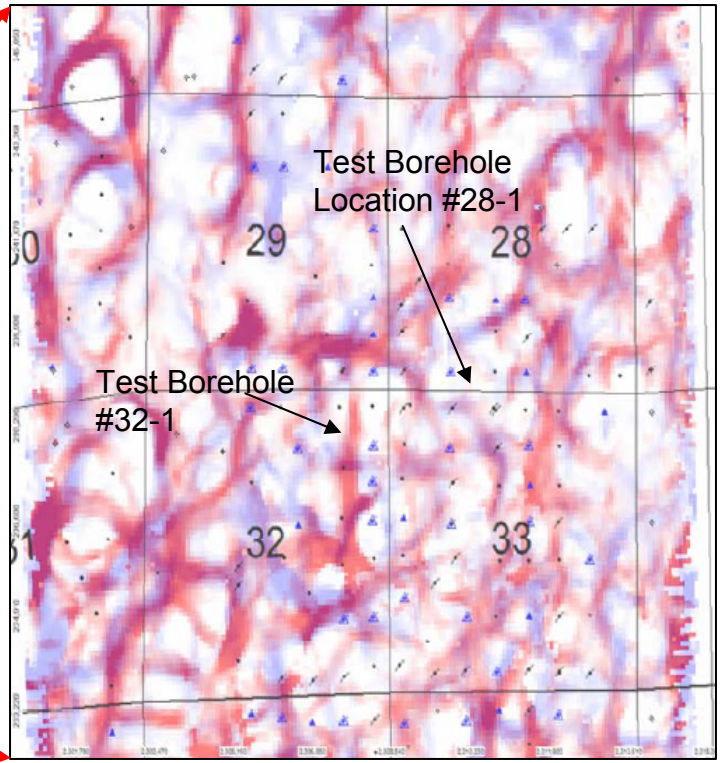
Smaller scale fracture systems/karst? – Objective of horizontal well in Bemis-Shutts

Arbuckle Time

Most Negative Curvature



Mississippian (*blue*)-
Arbuckle (*red*) Curvature Overlay

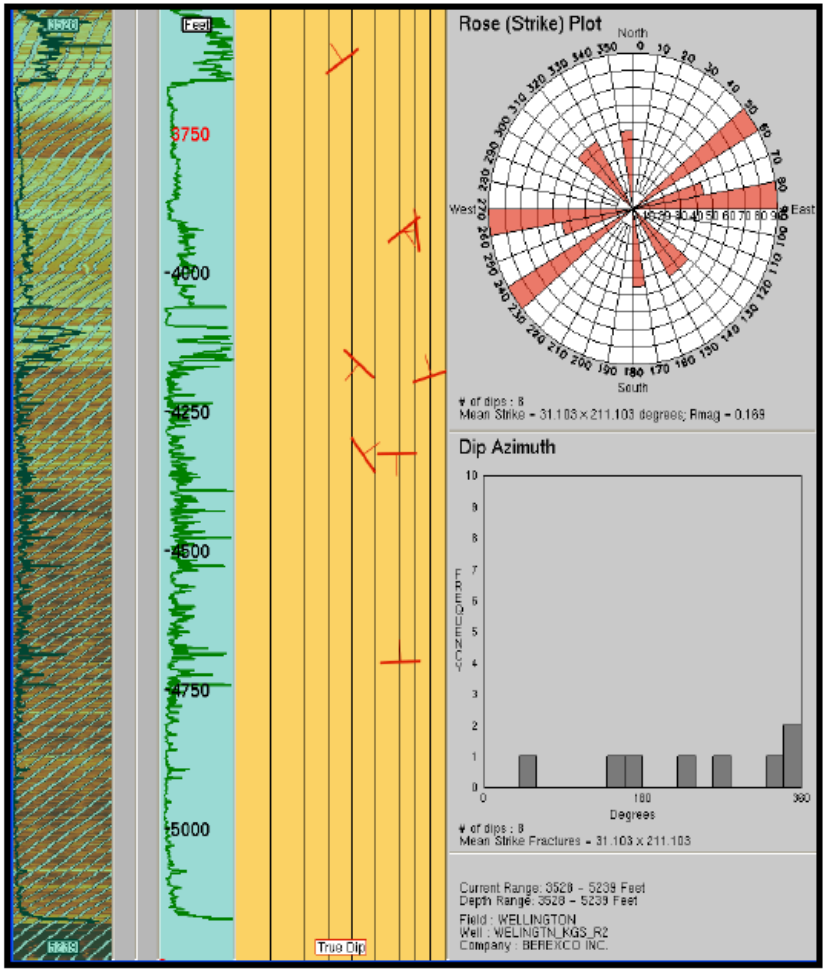


MAXIMUM HORIZONTAL COMPRESSIVE STRESS

from imaging and dipole sonic logs (KGS #1-32)

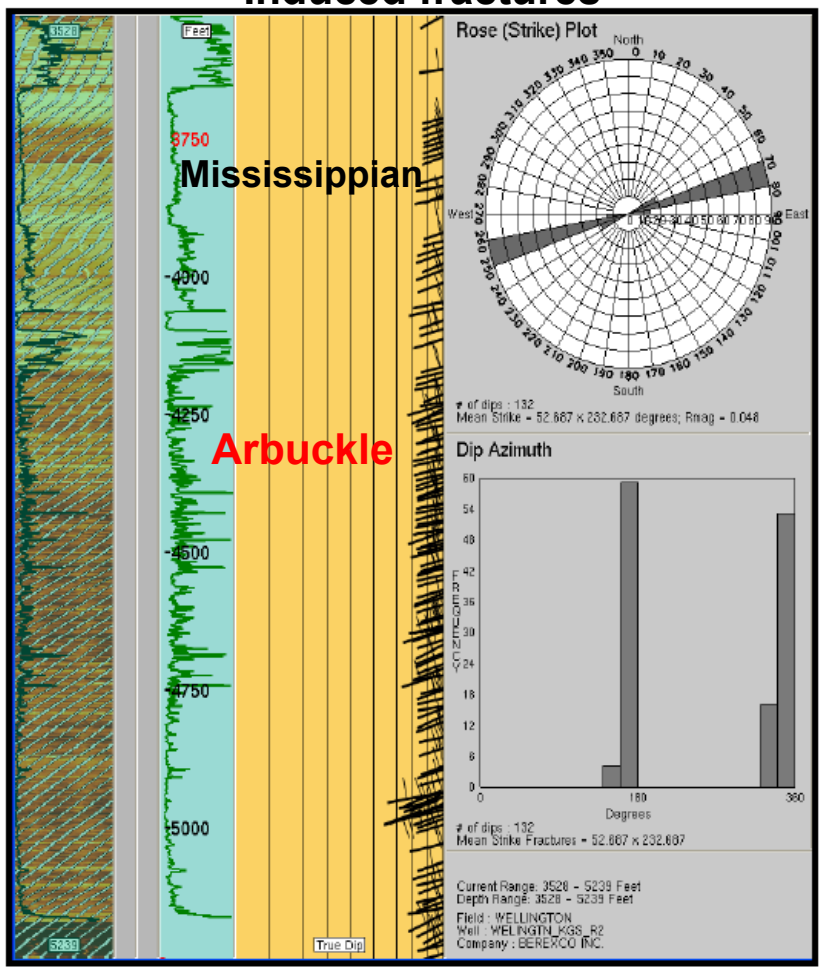
Fracture Statistics: 5239'-3528'

Natural mineralized "closed" fractures



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

Induced fractures

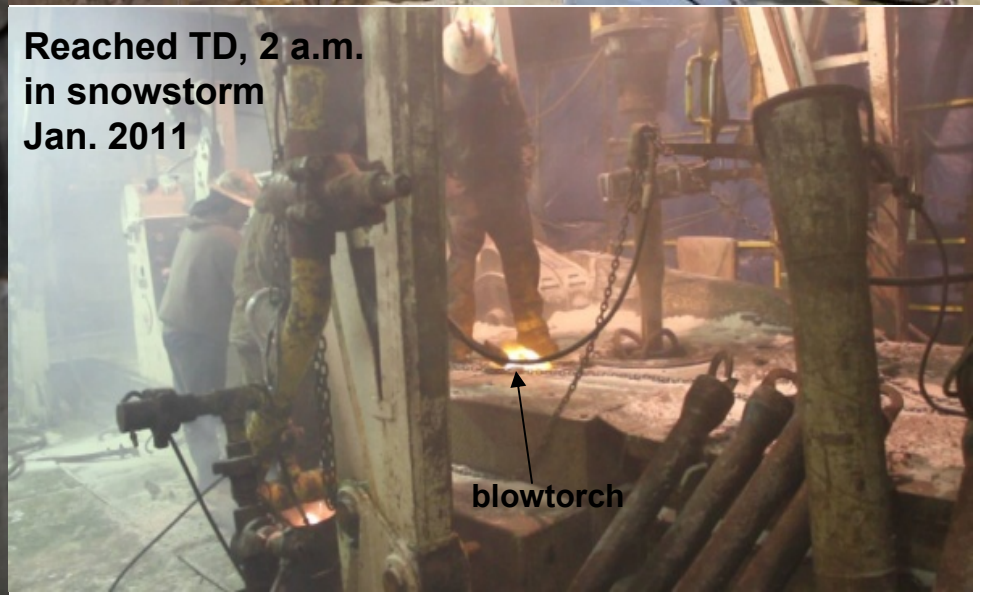


There are 132 drilling induced fractures in this pass, oriented 75°/255°, indicating the maximum stress direction.

HALLIBURTON

Basement Faulting in #1-32

“Tombstone” Granite



ZONAL FRACTURES AND AUTOCLASTIC BRECCIAS

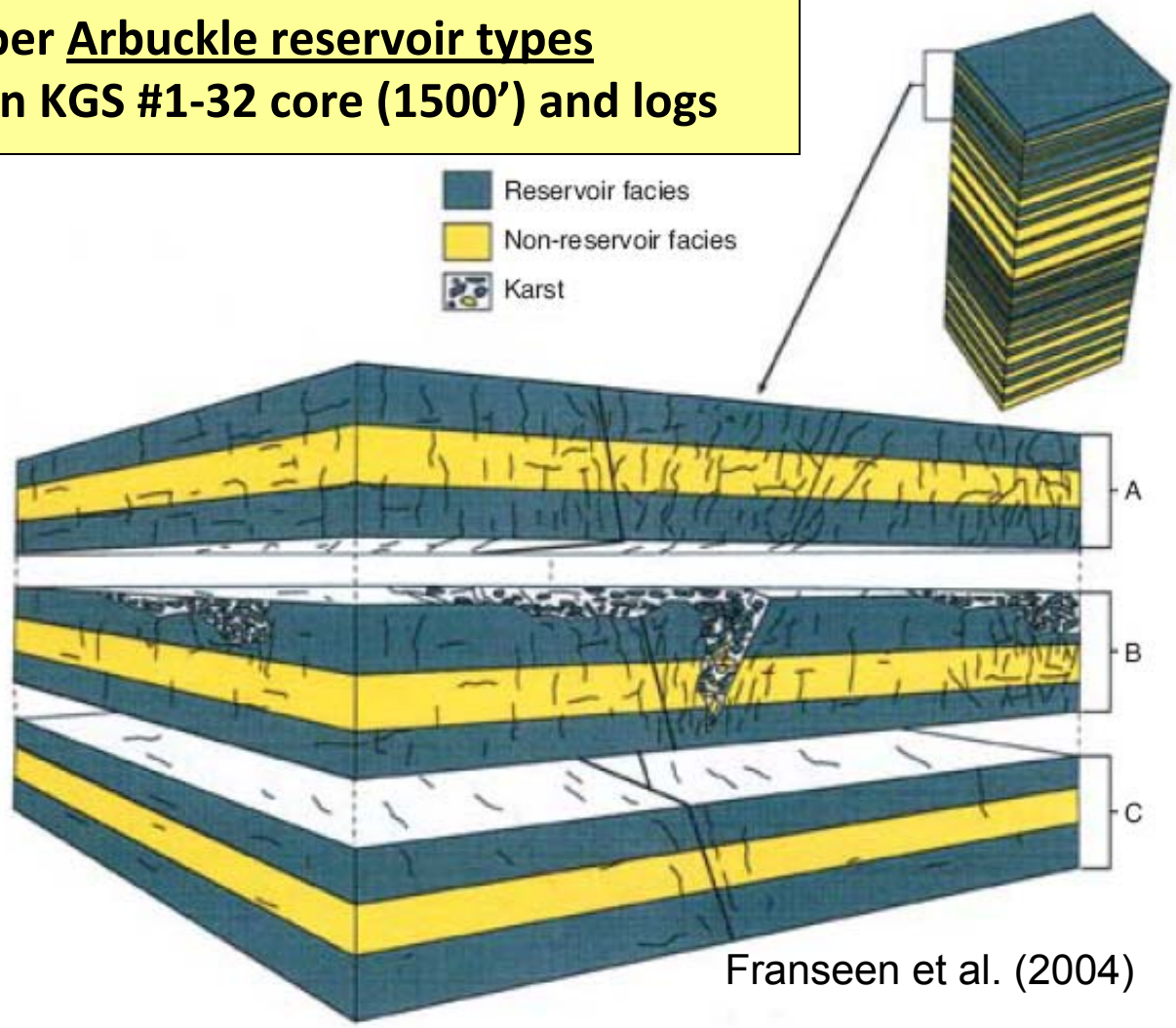
4593 ft

4556.2 ftt

4609 ft.

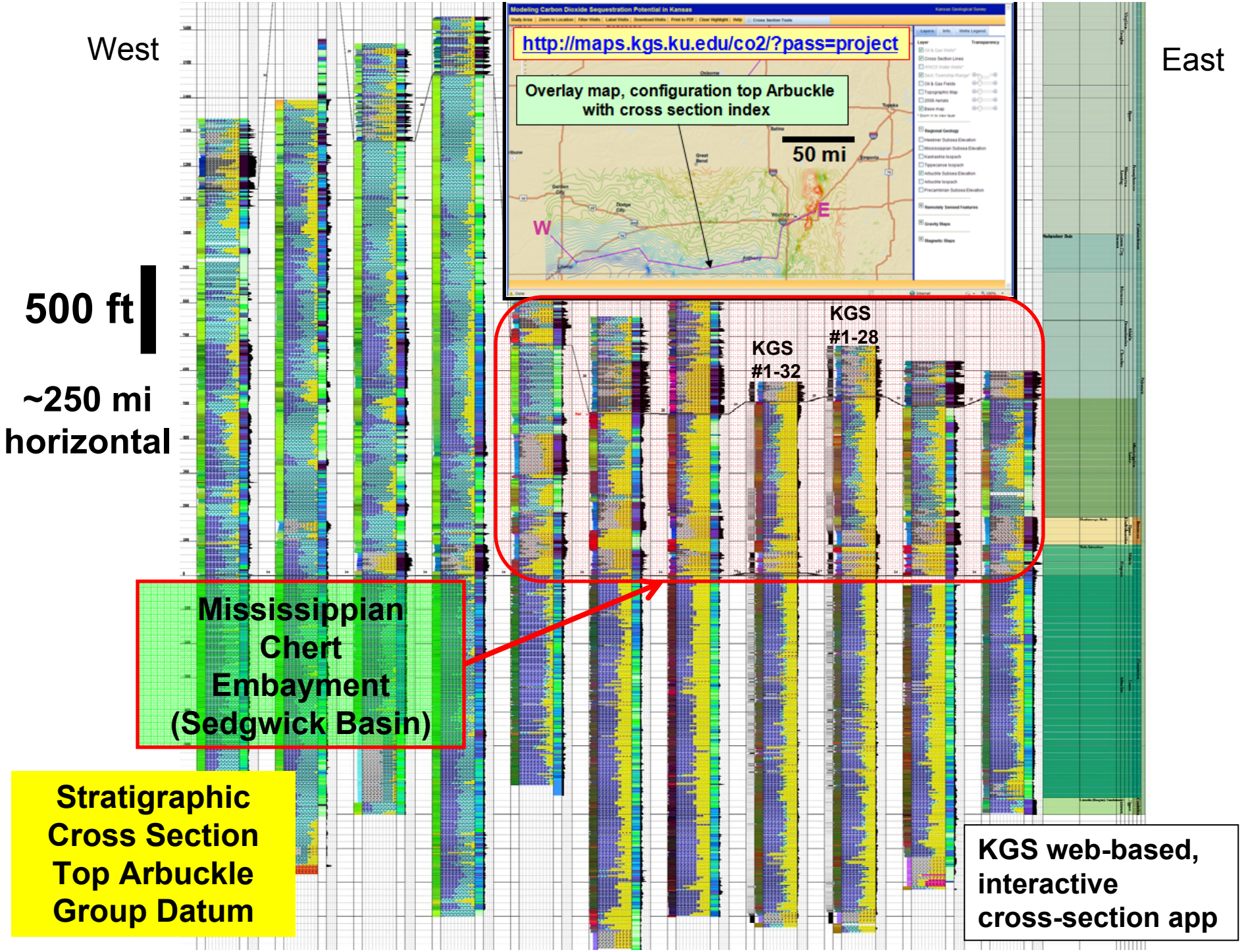
1000 ft Arbuckle at Wellington Field is complexly stacked lithofacies in persistent stratal packages

End-member <u>Arbuckle reservoir types</u> observed in KGS #1-32 core (1500') and logs



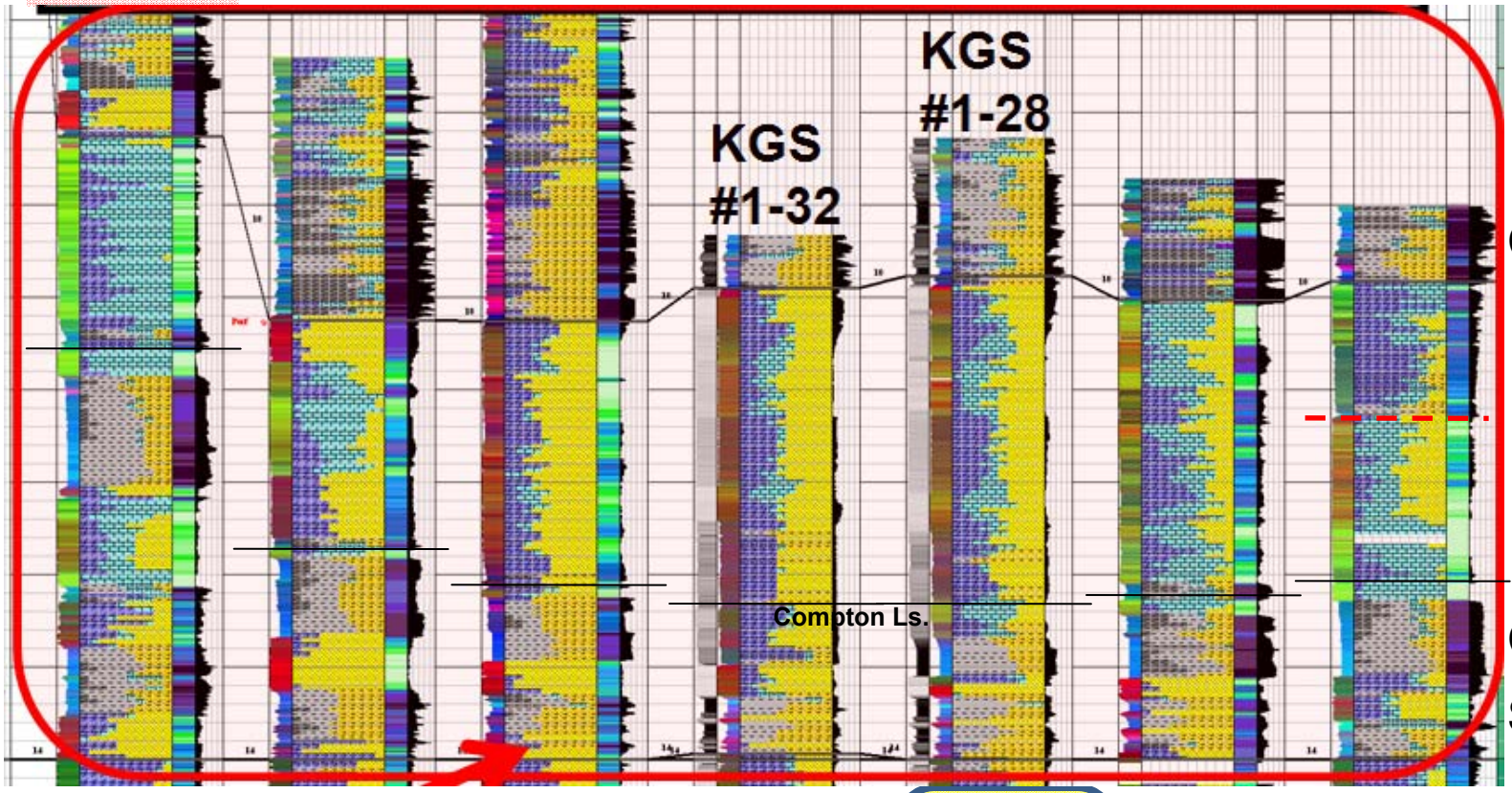
Franseen et al. (2004)

Discontinuous fracturing, karst overprinting, lithofacies control porosity & permeability in <u>persistent stratal packages</u>

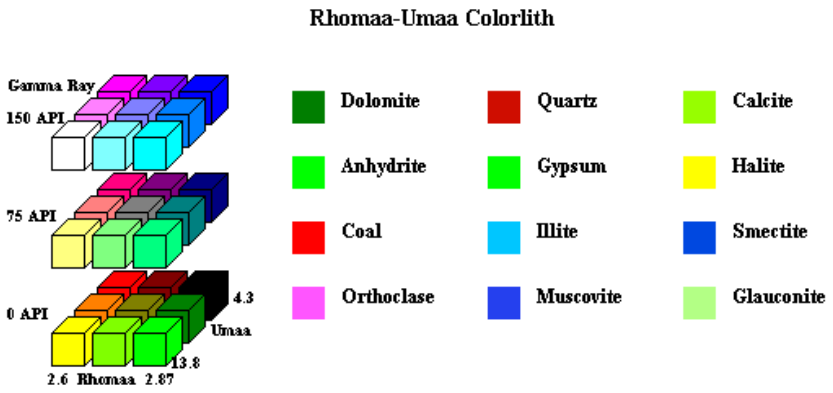

West
East
500 ft
~250 mi
horizontal
http://maps.kgs.ku.edu/co2/?pass=project
Overlay map, configuration top Arbuckle
with cross section index
50 mi
W
E
KGS
#1-32
KGS
#1-28
Mississippian
Chert
Embayment
(Sedgwick Basin)
Stratigraphic
Cross Section
Top Arbuckle
Group Datum
KGS web-based,
interactive
cross-section app

West side
Hartner Field
Barber Co.

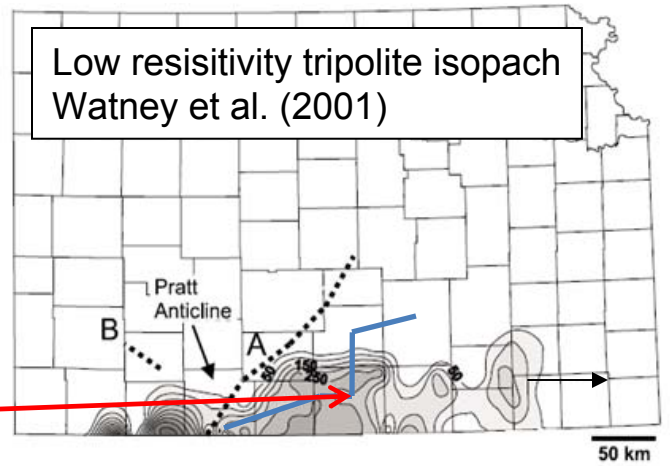
Mississippian Chert Embayment
Internal sequences and porosity with intervening sealing strata



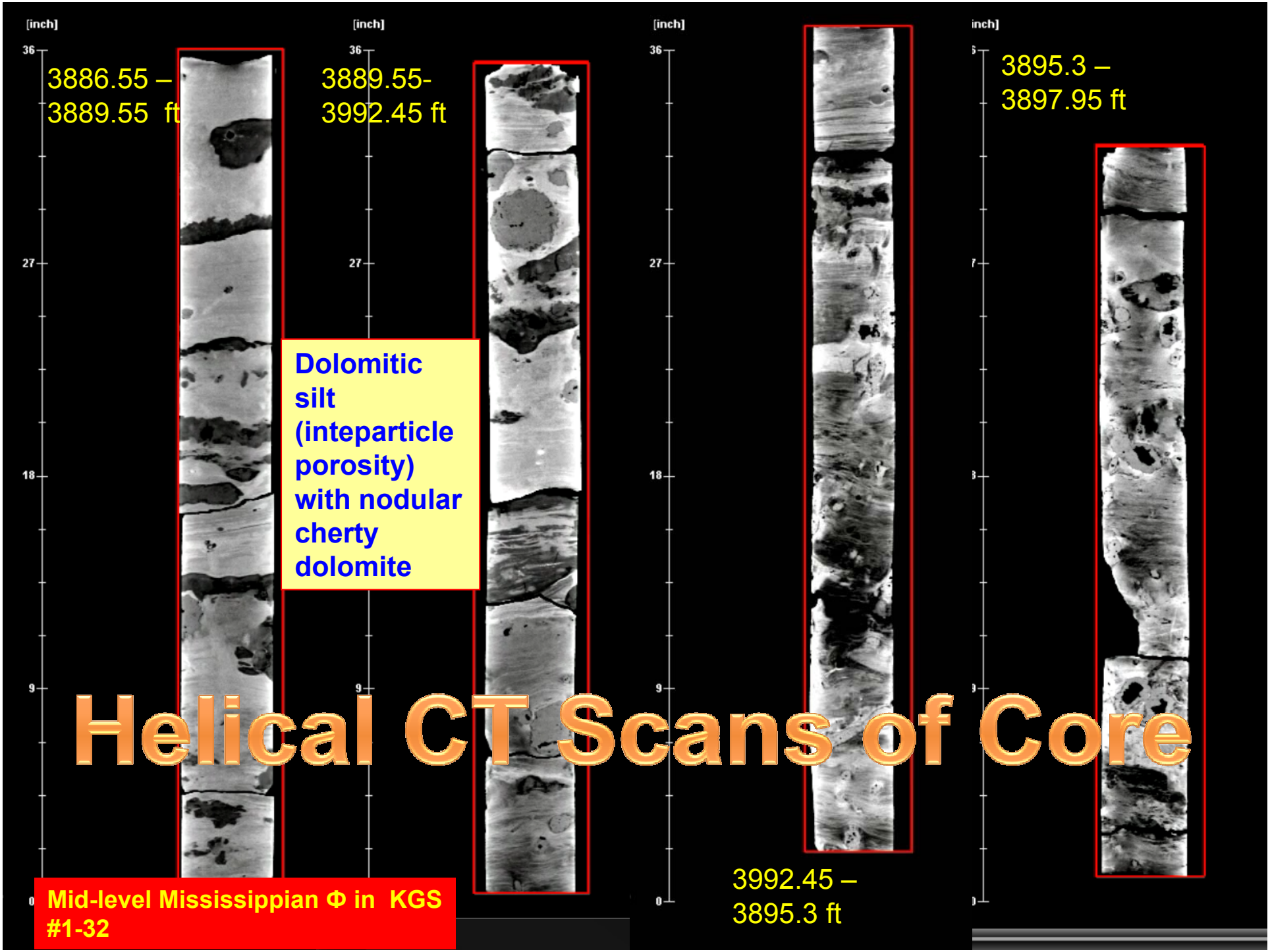
Datum: Top Arbuckle Group



500 ft

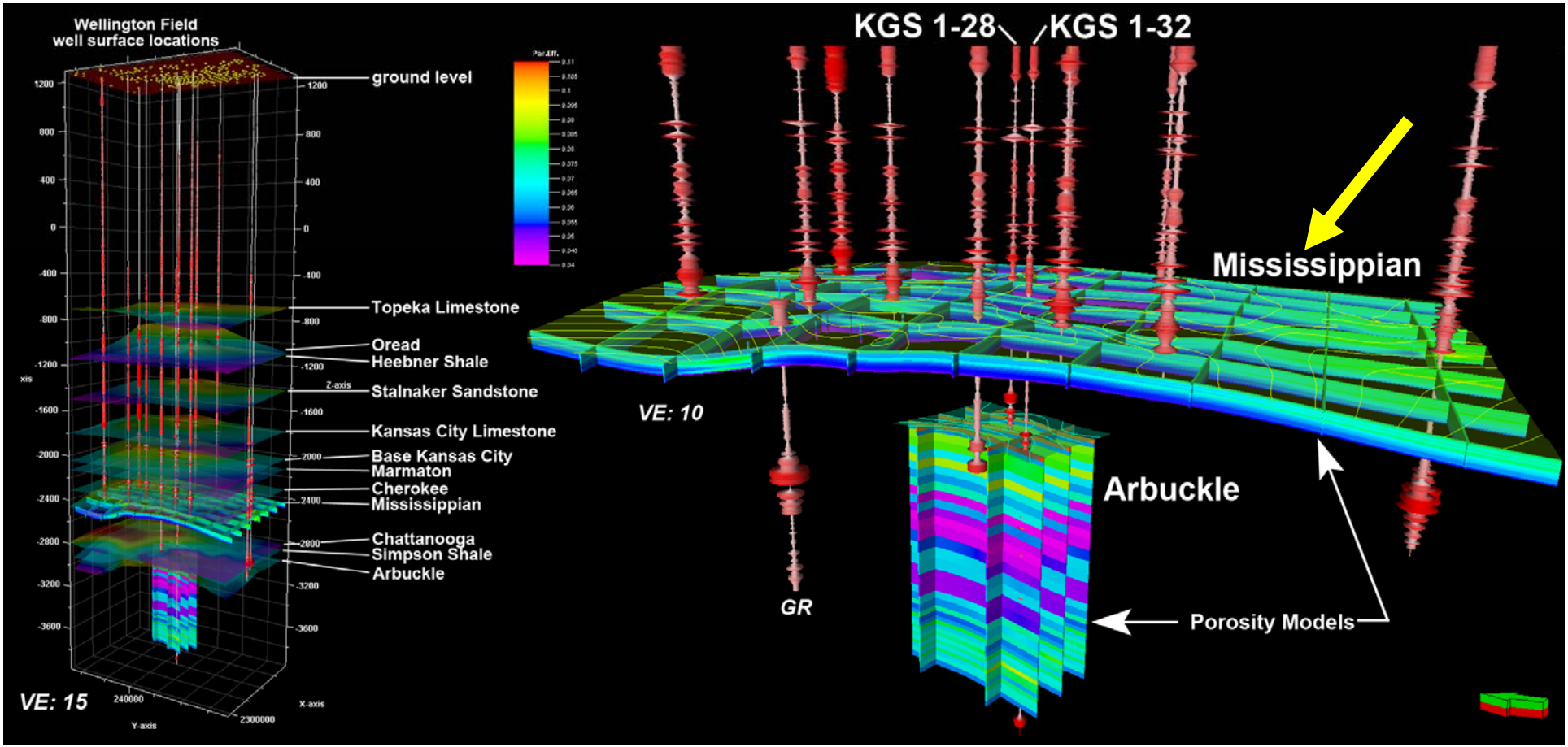


Wellington
Field

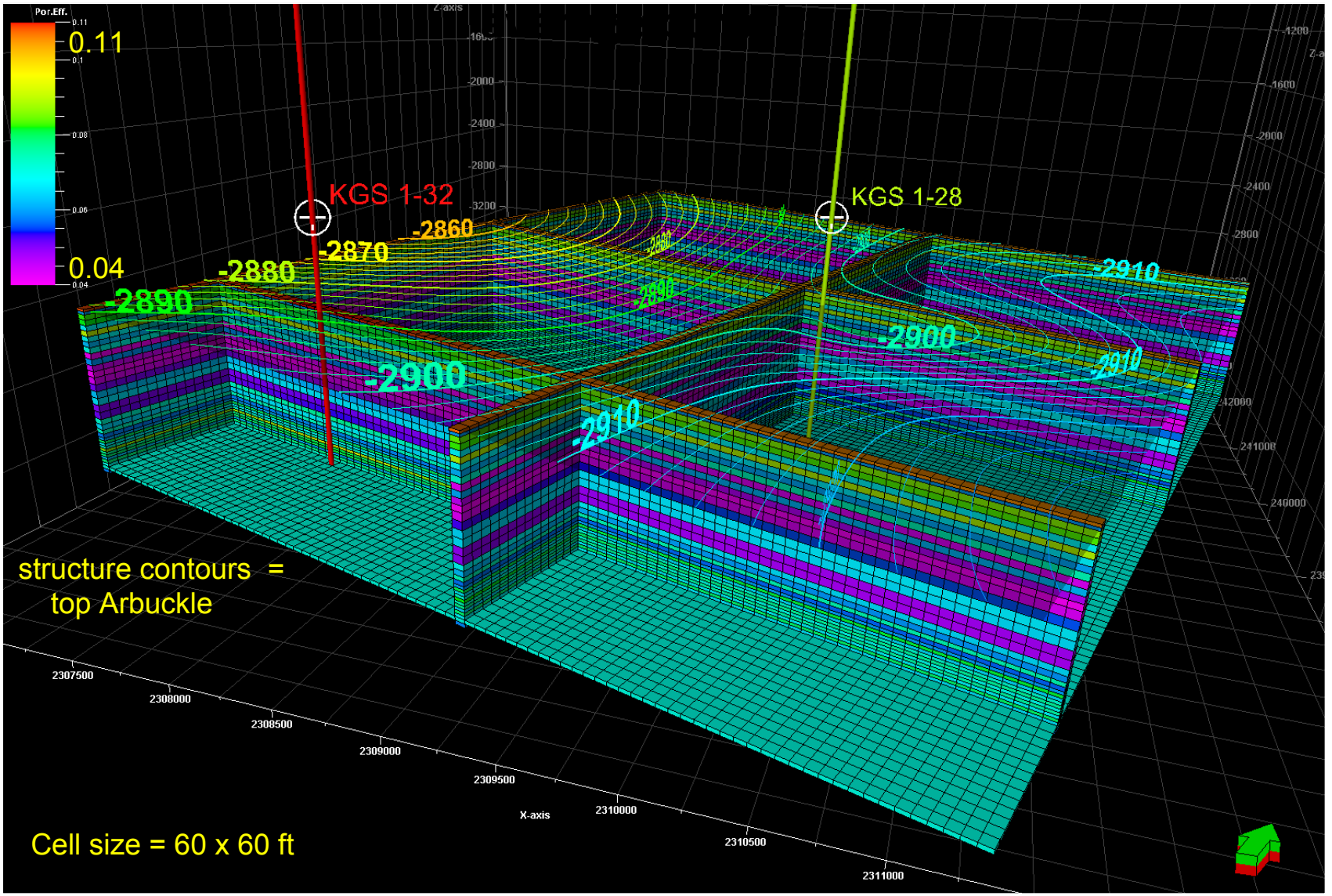

[inch]
36
27
18
9
0
3886.55 – 3889.55 ft
3889.55- 3992.45 ft
3992.45 – 3895.3 ft
3895.3 – 3897.95 ft
Dolomitic silt (inteparticle porosity) with nodular cherty dolomite
Helical CT Scans of Core
Mid-level Mississippian Φ in KGS #1-32

Wellington Field

Mississippian tripolite reservoir (underpressured), underlying Miss-Simpson sealing strata, & Arbuckle aquifer



Upscaled average porosity (effective Φ from NMR) for Arbuckle Group in vicinity of KGS #1-32 & #1-28

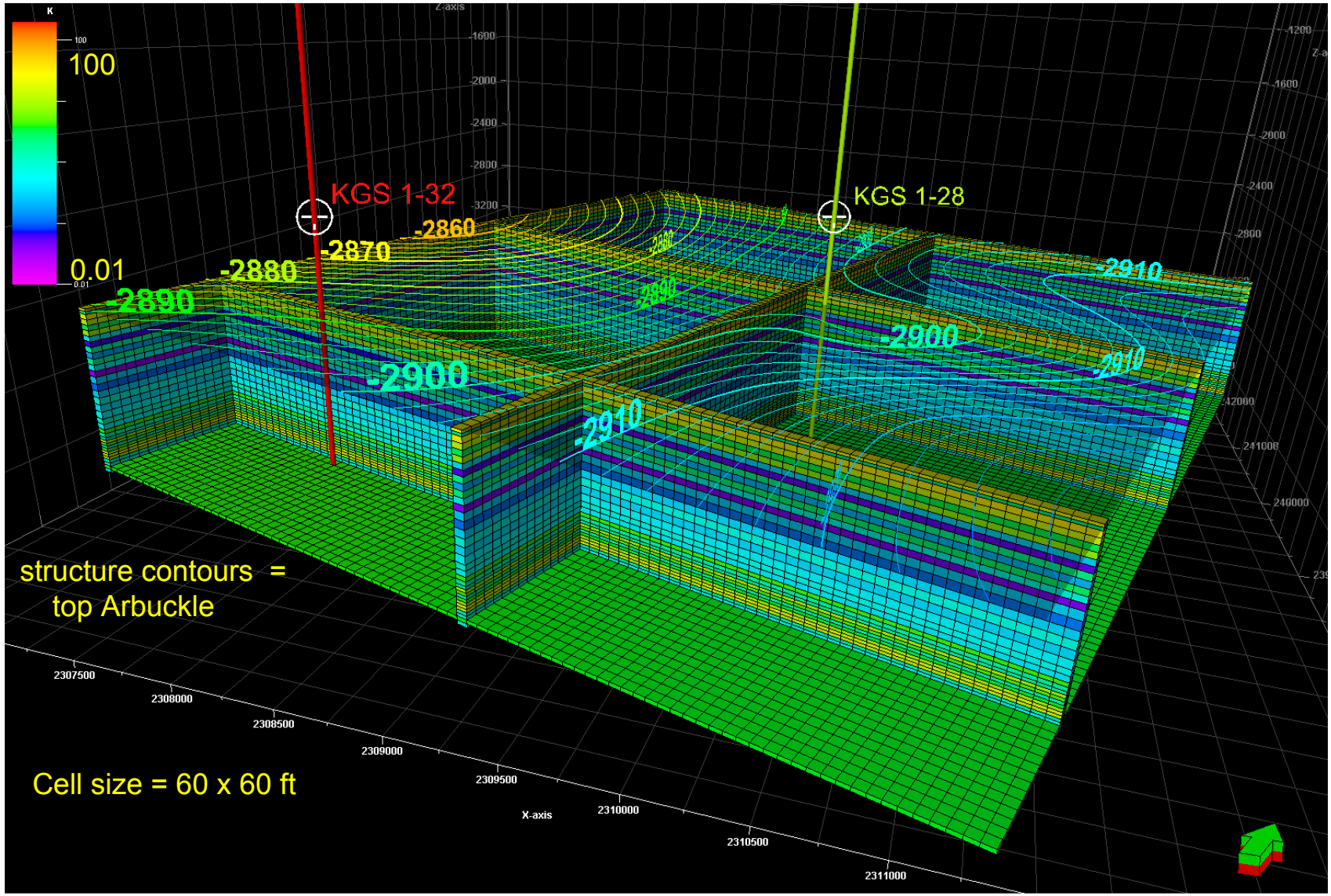


Permeability Geomodel of Arbuckle Group

in vicinity of KGS #1-32 & #1-28

Upscaled Using geometric Mean of k (Coates NMR), Porosity Used for Trend

-- Contribution of fracture Φ & k yet to done



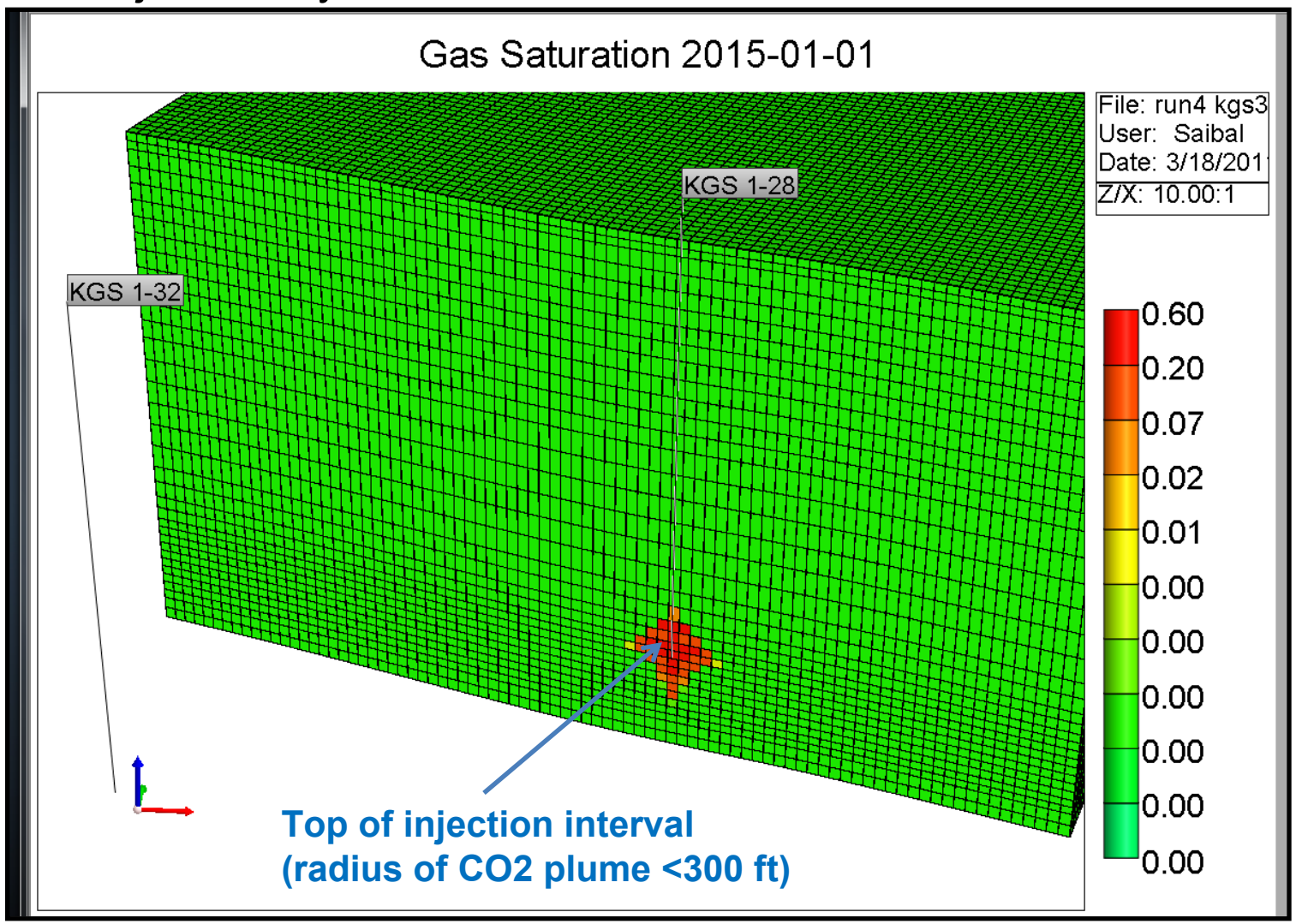
Simulated hypothetical injection

started on Jan 1, 2011 (for 9 months)

Grid cells 60’ by 60’

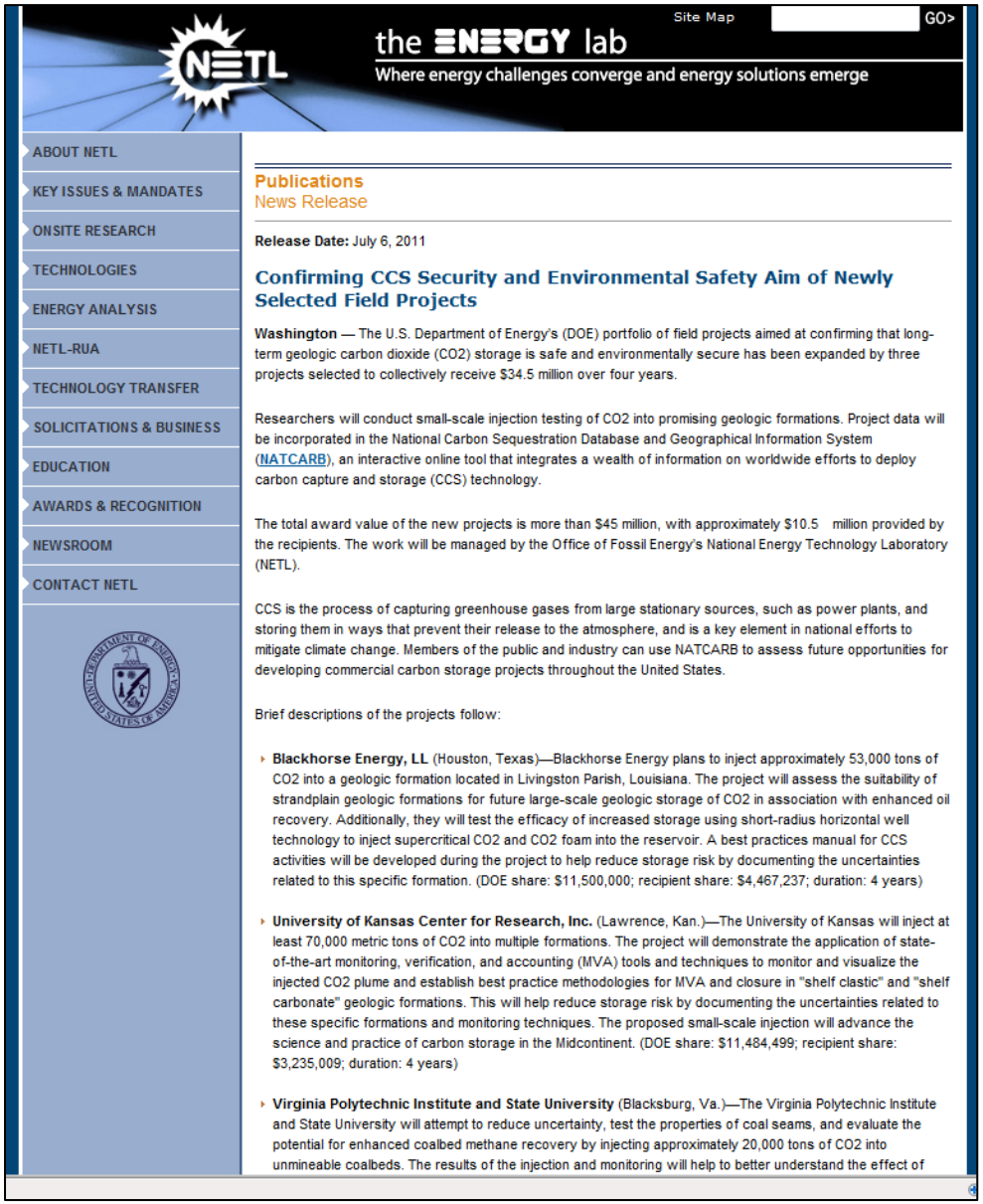
Total CO_2 injected ~ 40,000 tons

Injection layers – L25 to L30, each ~20 ft thick, 120 ft total



Fossil Energy Techline, "Confirming CCS Security and Environmental Safety Aim of Newly Selected Field Projects."

July 6 DOE-NETL News Release



Site Map GO>

the ENERGY lab

Where energy challenges converge and energy solutions emerge

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KEY ISSUES & MANDATES
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Publications
News Release

Release Date: July 6, 2011

Confirming CCS Security and Environmental Safety Aim of Newly Selected Field Projects

Washington — The U.S. Department of Energy's (DOE) portfolio of field projects aimed at confirming that long-term geologic carbon dioxide (CO2) storage is safe and environmentally secure has been expanded by three projects selected to collectively receive $34.5 million over four years.

Researchers will conduct small-scale injection testing of CO2 into promising geologic formations. Project data will be incorporated in the National Carbon Sequestration Database and Geographical Information System (NATCARB), an interactive online tool that integrates a wealth of information on worldwide efforts to deploy carbon capture and storage (CCS) technology.

The total award value of the new projects is more than $45 million, with approximately $10.5 million provided by the recipients. The work will be managed by the Office of Fossil Energy's National Energy Technology Laboratory (NETL).

CCS is the process of capturing greenhouse gases from large stationary sources, such as power plants, and storing them in ways that prevent their release to the atmosphere, and is a key element in national efforts to mitigate climate change. Members of the public and industry can use NATCARB to assess future opportunities for developing commercial carbon storage projects throughout the United States.

Brief descriptions of the projects follow:

- **Blackhorse Energy, LL** (Houston, Texas)—Blackhorse Energy plans to inject approximately 53,000 tons of CO2 into a geologic formation located in Livingston Parish, Louisiana. The project will assess the suitability of strandplain geologic formations for future large-scale geologic storage of CO2 in association with enhanced oil recovery. Additionally, they will test the efficacy of increased storage using short-radius horizontal well technology to inject supercritical CO2 and CO2 foam into the reservoir. A best practices manual for CCS activities will be developed during the project to help reduce storage risk by documenting the uncertainties related to this specific formation. (DOE share: $11,500,000; recipient share: $4,467,237; duration: 4 years)

- **University of Kansas Center for Research, Inc.** (Lawrence, Kan.)—The University of Kansas will inject at least 70,000 metric tons of CO2 into multiple formations. The project will demonstrate the application of state-of-the-art monitoring, verification, and accounting (MVA) tools and techniques to monitor and visualize the injected CO2 plume and establish best practice methodologies for MVA and closure in "shelf clastic" and "shelf carbonate" geologic formations. This will help reduce storage risk by documenting the uncertainties related to these specific formations and monitoring techniques. The proposed small-scale injection will advance the science and practice of carbon storage in the Midcontinent. (DOE share: $11,484,499; recipient share: $3,235,009; duration: 4 years)

- **Virginia Polytechnic Institute and State University** (Blacksburg, Va.)—The Virginia Polytechnic Institute and State University will attempt to reduce uncertainty, test the properties of coal seams, and evaluate the potential for enhanced coalbed methane recovery by injecting approximately 20,000 tons of CO2 into unmineable coalbeds. The results of the injection and monitoring will help to better understand the effect of

- On July 6, 2011, DOE announced the selection of three small-scale CO2 injection field projects to collectively receive $34.5 million over four years. The total award value of the new projects, which aim to confirm that long-term geologic CO2 storage is safe and environmentally secure, is more than $45 million, with approximately $10.5 million provided by the recipients.

- **University of Kansas Center for Research, Inc. (Lawrence, Kan.)—The University of Kansas will inject at least 70,000 metric tons of CO2 into multiple formations**. The project will demonstrate the application of **state-of-the-art monitoring, verification, and accounting (MVA) tools and techniques to monitor and visualize the injected CO2 plume and establish best practice methodologies for MVA and closure** in "shelf clastic" and "shelf carbonate" geologic formations. This will help reduce storage risk by documenting the uncertainties related to these specific formations and monitoring techniques. **The proposed small-scale injection will advance the science and practice of carbon storage in the Midcontinent. (DOE share: $11,484,499; recipient share: $3,235,009; duration: 4 years)**

Project Team

- **KGS**
  - **Lynn Watney (Joint PI)**
  - **Jason Rush (Joint PI)**
  - **Rick Miller**
  - **John Doveton**
  - **Dave Newell**
  - **New Geology and Engineering Techs**

Small scale field test Wellington

- **KU**
  - **Mike Taylor**, Structural Geology, InSAR and LiDAR

- **Lawrence Berkeley National Laboratory**
  - **Tom Daley, Geophysicist,** has been involved in GCS MVA activites at the Frio-I and Frio-II pilots, the Otway Stage-1 experiment, the SECARB Phase-III Cranfield project, the Weyburn project, the InSalah project and other CO2 EOR experiments
  - **Jennifer Lewicki**, Hydrogeologist, specializing in near-surface monitoring of geologic carbon storage sites for CO2 leakage using integrated field measurements and geostatistical methods
  - **Barry Freifeld**, Mechanical Engineer, geological sequestration of CO2, particularly field demonstrations in saline and depleted gas aquifers, development of fiber-optic DTS techniques for monitoring subsurface processes
  - Patent Holder for U-Tube Sampling System

- **KSU**
  - **Saugata Datta**, geohydrology, geochemist, Current DOE project

- **Sandia Technologies, Houston**
  - **Dan Collins**, geologist, management of installation of in situ monitoring devices
    - Sandia's current involvement in the Southeast Regional Carbon Sequestration Partnership (SECARB) Cranfield Phase II and Phase III project, as well as the recent award by DOE for geologic characterization of the Triassic Newark Basin, further solidifies our abilities and commitment to the industry.
    - Feasibility and risk assessment studies
    - Project management and procurement
    - Project field supervision and health, safety and environment (HSE) supervision
    - Well design, drilling, completion, and operation
    - Monitoring, verification, and accounting (MVA) technologies
- **Berexco**
- **Abengoa Ethanol - Colwich**

Summary

- **Injectivity and Storage**
  - Discontinuous fracturing
  - Karst overprinting
  - Lithofacies control porosity & permeability in persistent stratal packages
  - Arbuckle is an open hydrologic system

- **Structure**
  - Deep-seated, basement structures/faulting abundant in Midcontinent craton
  - Evidence of flexure & fractures from gravity-magnetics (tilt angle), structure mapping, multicomponent 3D seismic, and inferred from remote sensing
  - Studies underway to resolving structural controls on reservoir, aquifer, and caprock integrity

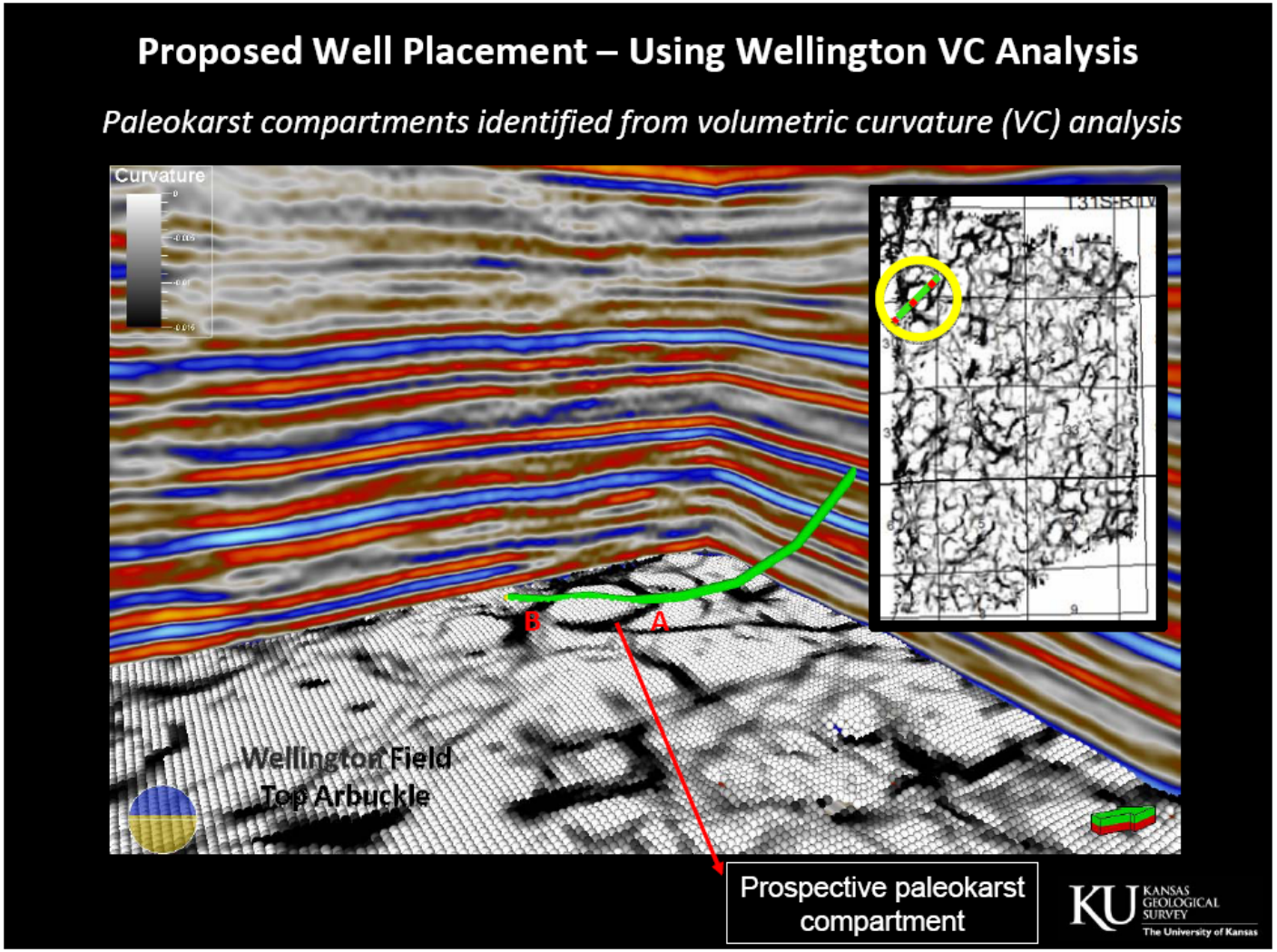
- **Simulation of commercial scale CO_2 injection**
  - Estimated footprint for 10 MM tonnes CO_2 injection < 2 mi radius
  - 40,000 tonnes <300 ft radius
  - Internal aquitards in Arbuckle may act as baffles and barriers to vertical migration of CO_2 plume

- **New injectivity, storage, and caprock data for Wellington**
  - Core, logs, drill stem tests, and well tests being used to refine geomodel and simulations of the Arbuckle and obtain properties of main caprocks

Bemis-Shutts Field
Ellis County, Kansas

- "***Prototyping and testing a new volumetric curvature tool for modeling reservoir compartments and leakage pathways in the Arbuckle saline aquifer: Reducing uncertainty in CO_2 storage and permanence.***"
  - Collaborative study of the Kansas Geological Survey with its industry partners Vess Oil Corporation and Murfin Drilling Company
  - Funded by the U.S. Department of Energy under grant DE-FE0004566 and cost-sharing by its industry partners
  - Seismic data has been donated to the project by MV Partners, Vess, Noble Energy, Berexco, Lario, Damar, Jolen, and Diehl
  - Other participants include Hedke-Saenger Geoscience, Ltd., Susan Nissan Geophysical Consulting, Geotextures, Tres Management Services, and Saugata Datta, K-State along with staff members in the Energy Research Section of the Kansas Geological Survey

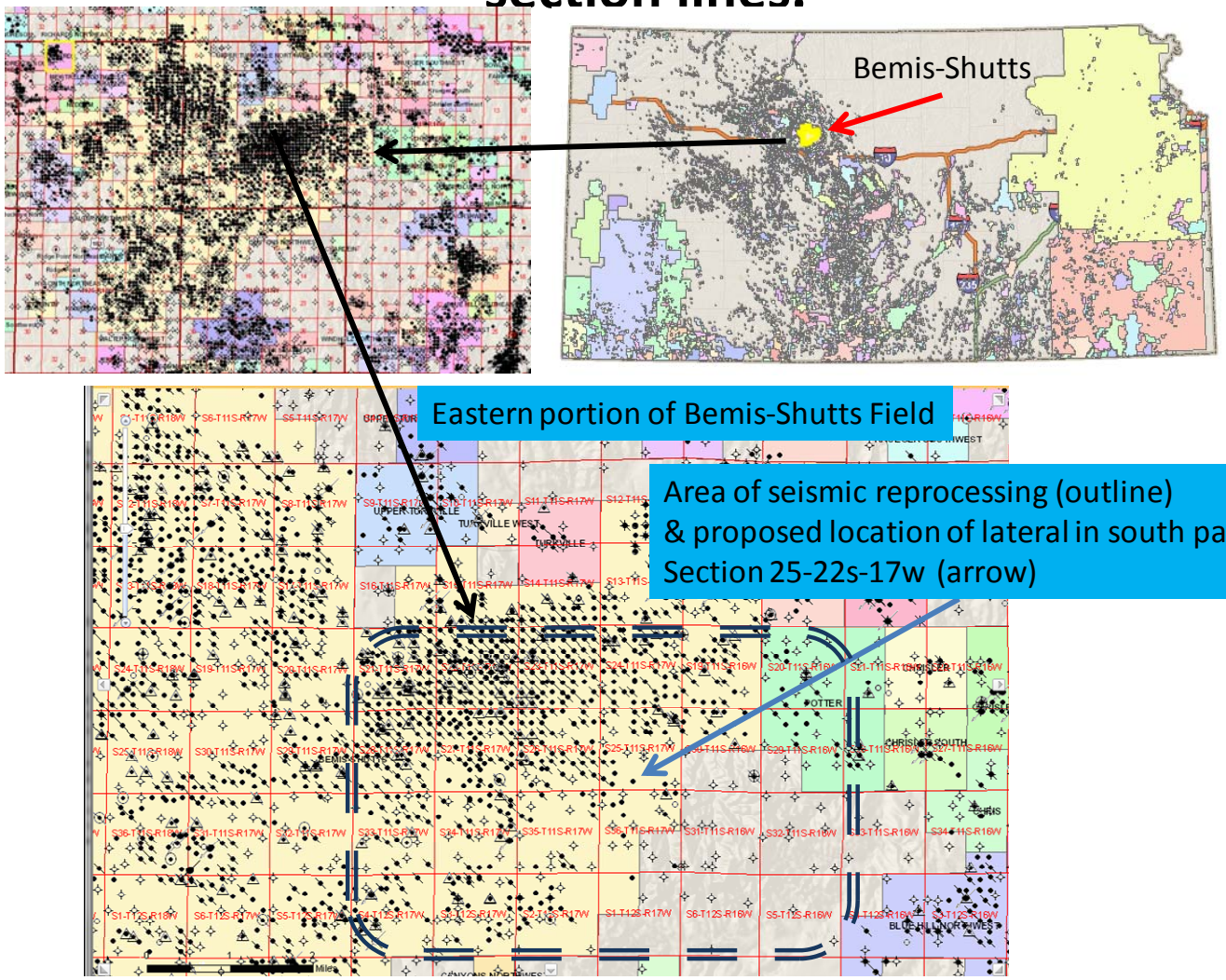
Illustration from Petrel from Wellington Field shows the hypothetical location of a lateral to investigate a prospective compartment as identified by *volumetric curvature* = *Bemis-Shutts project*



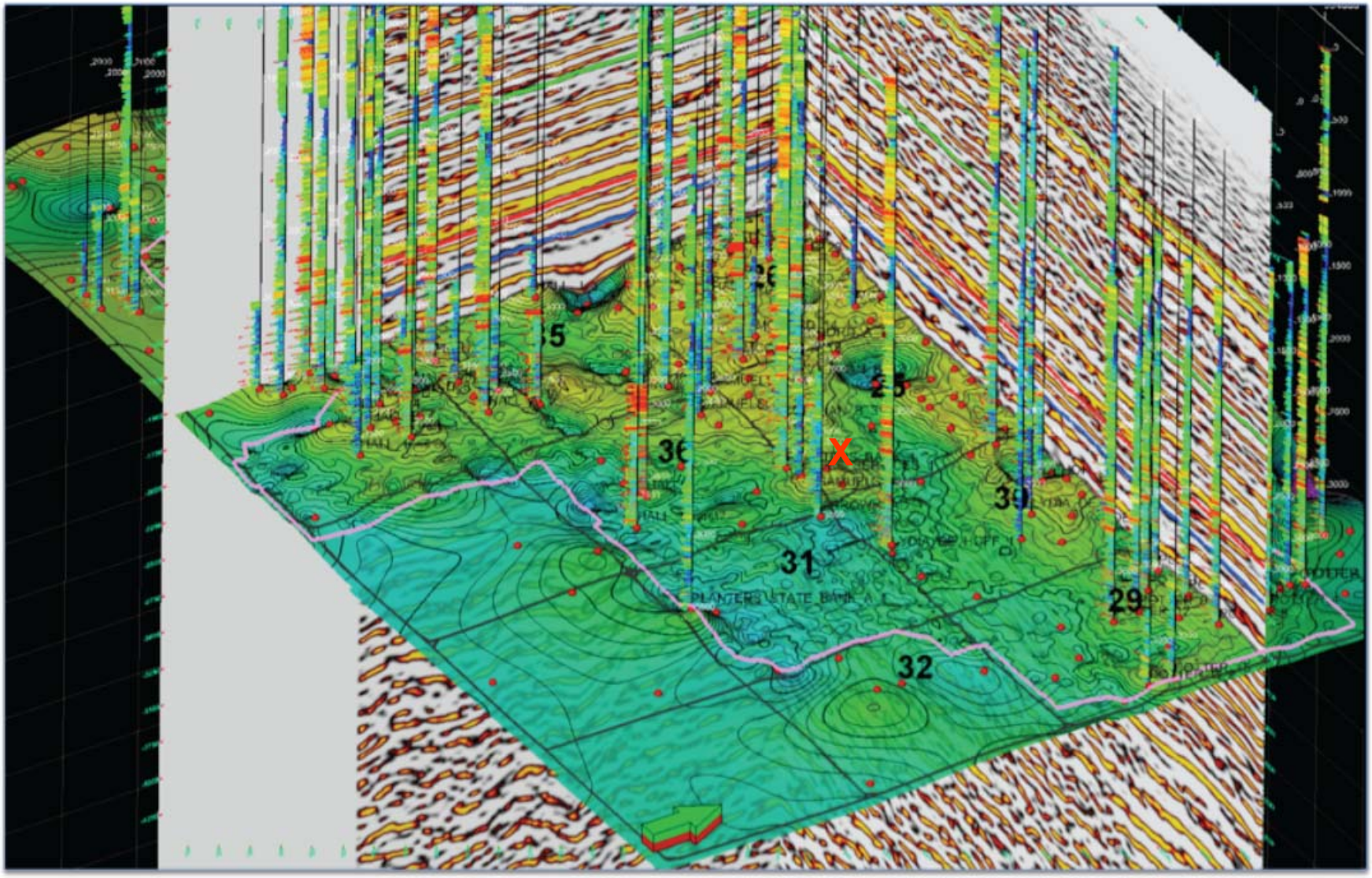
Project Objectives

- The project is evaluating the effectiveness of a new seismic tool to identify the presence, extent, and impact of paleokarst heterogeneity on CO_2 sequestration.
- The selection of the test site in Bemis-Shutts Field also has significant implications for oil production from this field and on the Central Kansas Uplift.
- This proposed project will also provide a valuable data set to complement the DOE-funded regional assessment of Arbuckle CO_2 sequestration potential focused on south-central KS (DE-FE0002056).

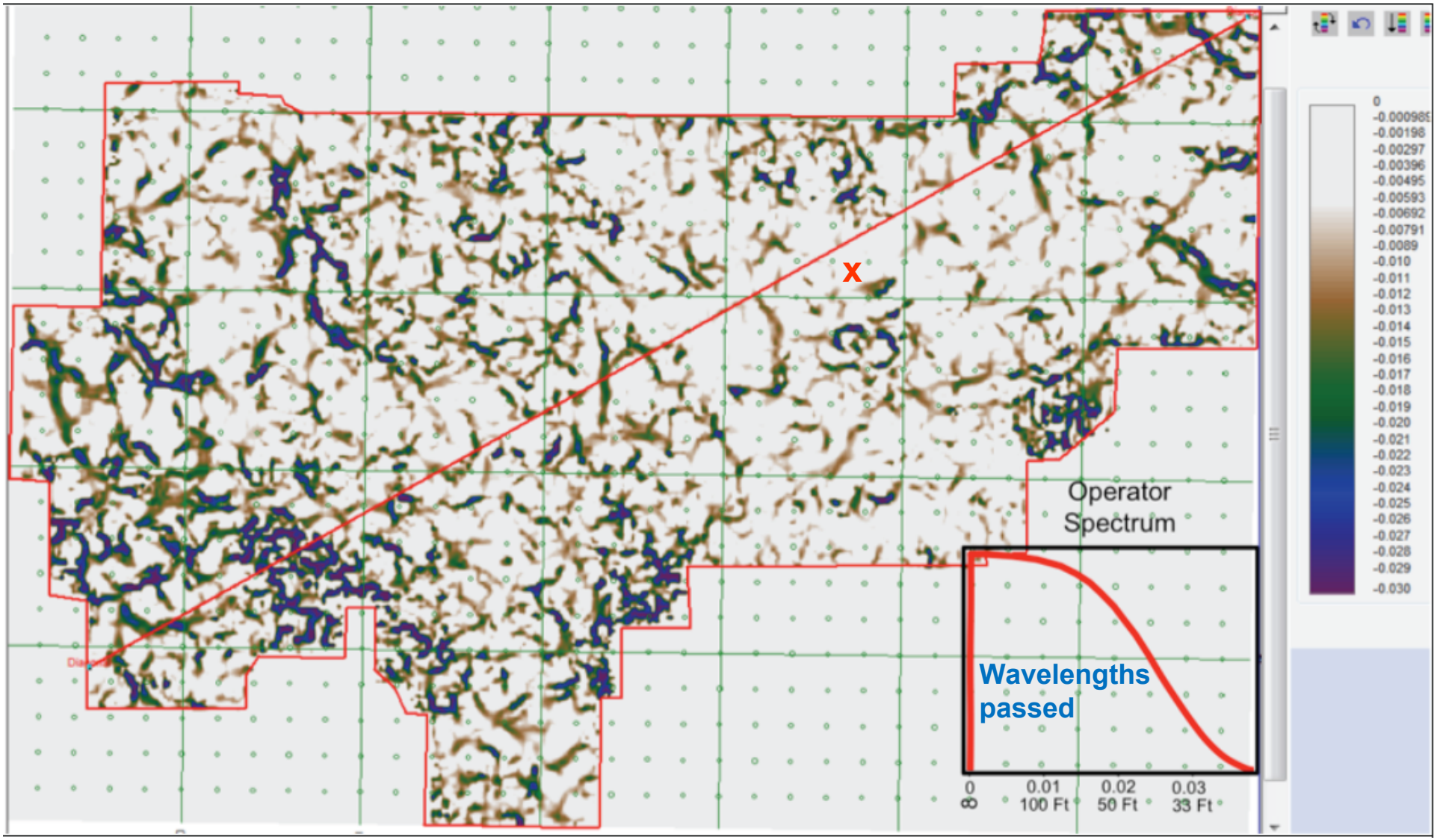
Study area is located in eastern Bemis-Shutts Field, Ellis County, Ks. Seismic reprocessing including volumetric curvature will be used to select location of the horizontal well in this large, mature oil field. Red squares on lower map are section lines.



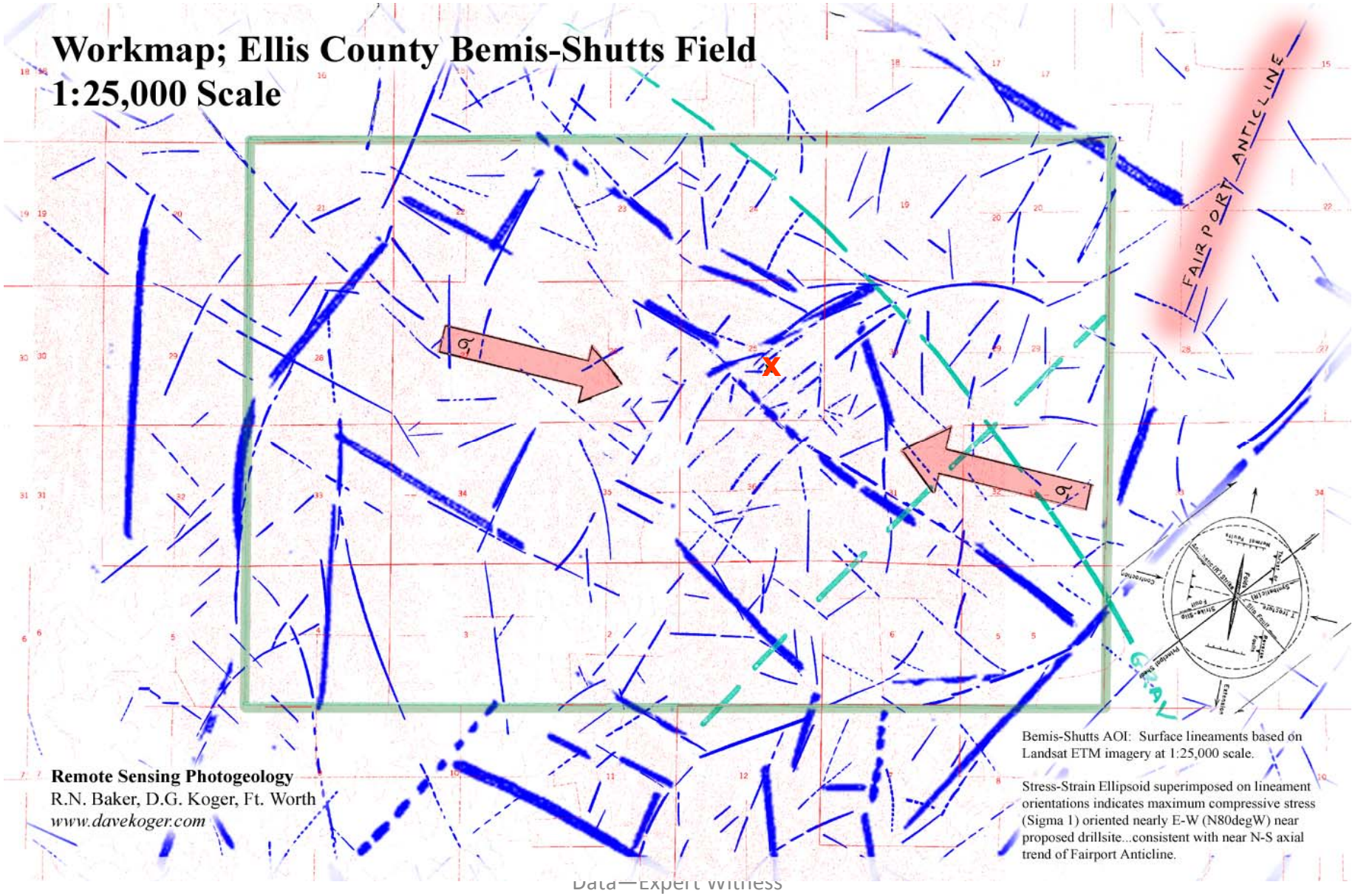
Top Arbuckle surface, PSDM cross lines, GR logs, and Arbuckle picks (red spheres) shown in Petrel 3D window
Large diameter (>2000 ft) sags clearly visible



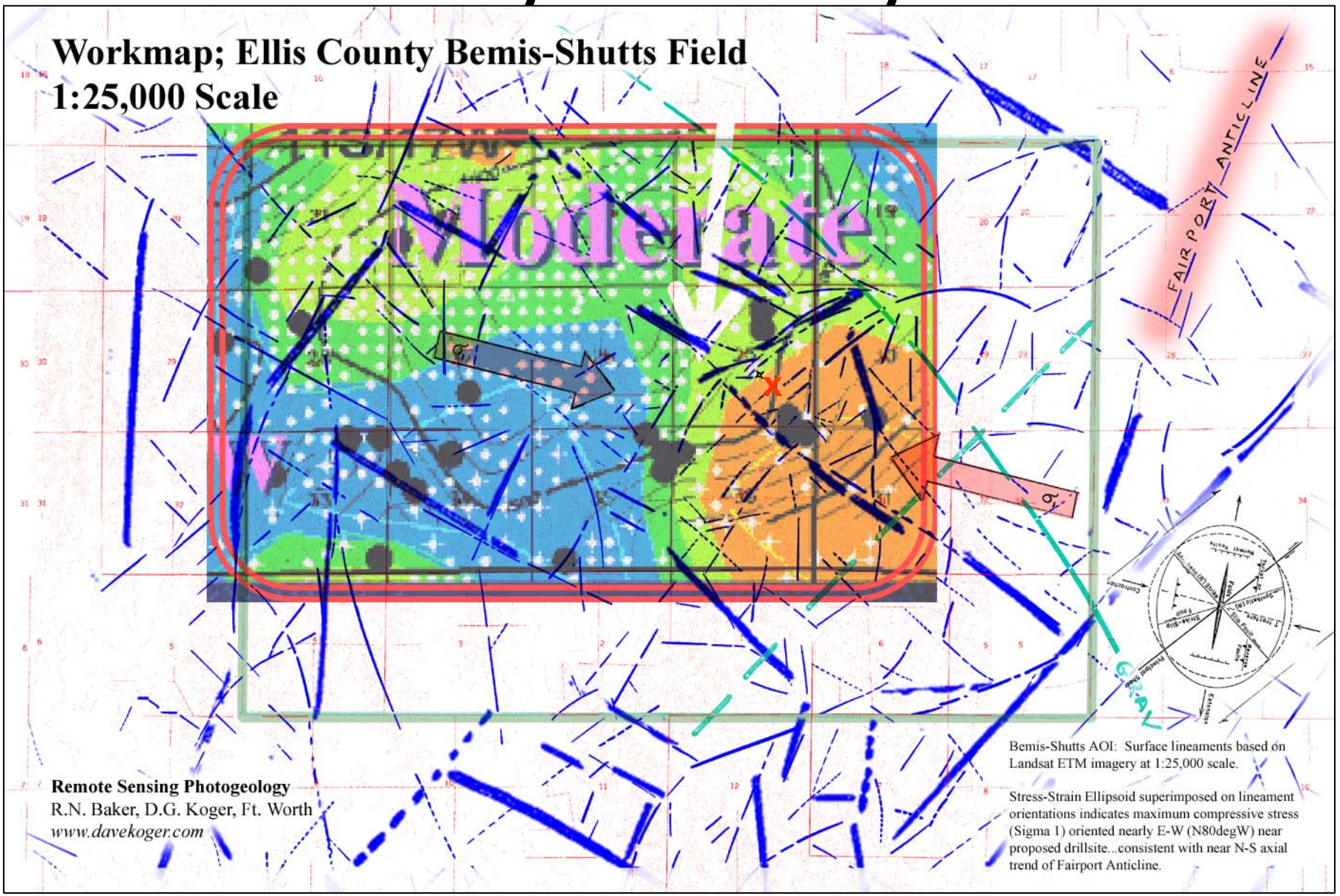
High resolution, most negative curvature at Arbuckle using enhanced PCA conditioning



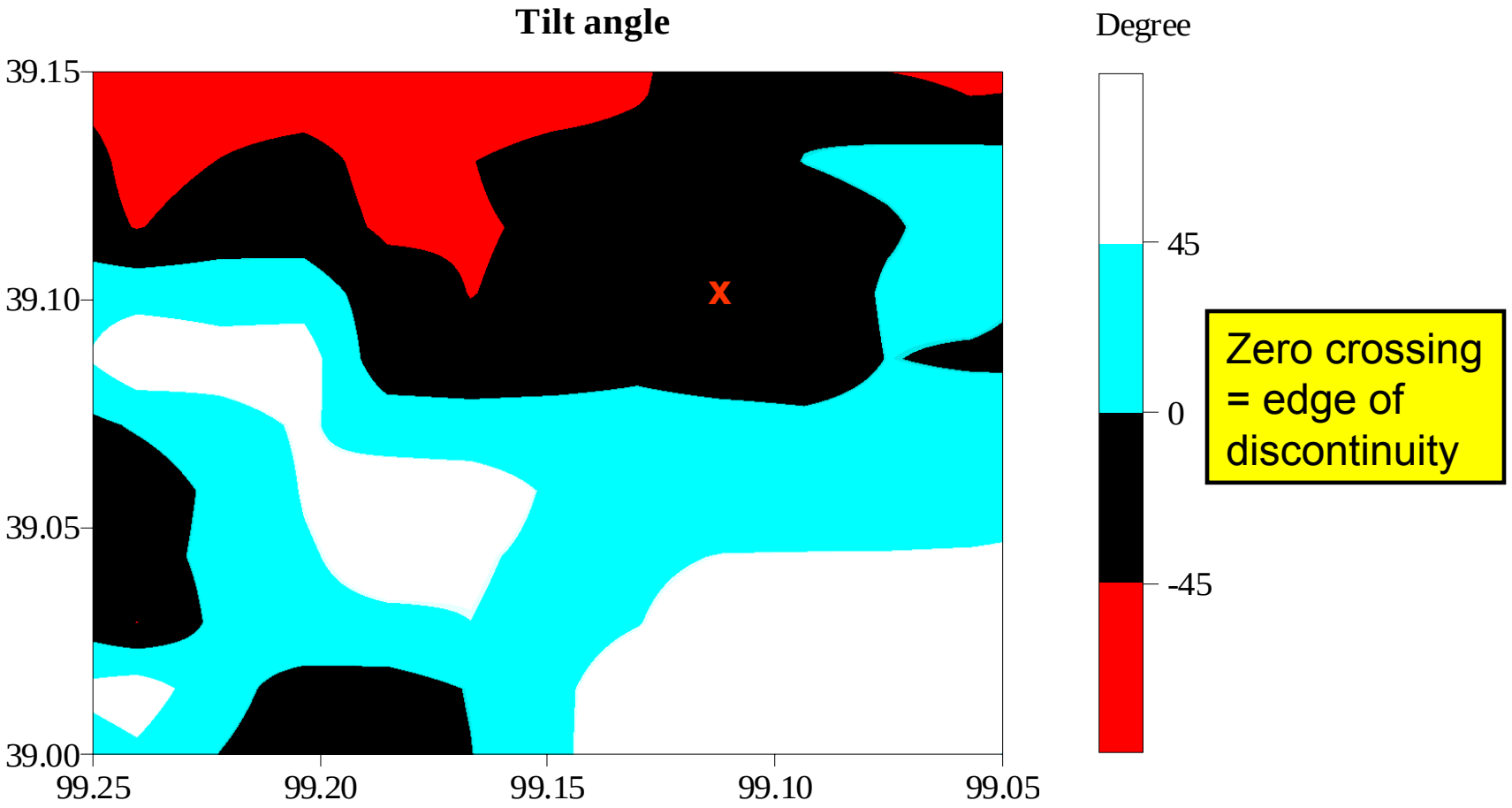
Local-Scale Remote Sensing Interpretation



Orange = High BHPs
Pressure study from DSTs by M.Dubois



Tilt angle total magnetic field intensity with migration to the pole at 910 m above sea level



Half the physical distance between ±45^0 contours provides depths to tops of possible magnetic contacts (~3000-5000 ft = basement)

Acknowledgements & Disclaimer

- **Acknowledgements**
- *The work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant Number DE-FE0002056 (Wellington), W.L. Watney, PI and Grant Number DE-FE0004556 (Bemis-Shutts) Jason Rush, PI. Projects are managed and administered by the Kansas Geological Survey/KUCR at the University of Kansas and funded by DOE/NETL and cost-sharing partners.*

Slocombe-Rood #1-19

Results from a Hunton Horizontal Well

Unger Field, Marion County

Enhancing Oil Recovery from Mature Reservoirs Using a Lateral with Gamma Ray Sensor, Drillpipe Conveyed Well Logging Including Micro Resistivity Imaging

Lynn Watney, Jason Rush, Saibal Bhattacharya,
John Doveton, David Newell
Kansas Geological Survey
Lawrence, KS 66006

Alan DeGood & Doug Davis
American Energies Corporation
Wichita, KS

RPSEA
Research Partnership to Secure Energy for America

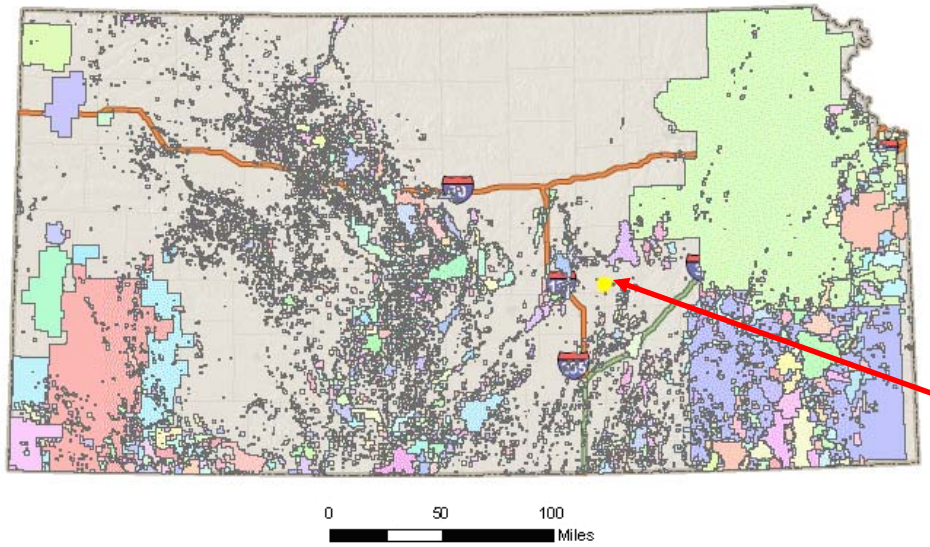
Small Producer
Project #07123-04

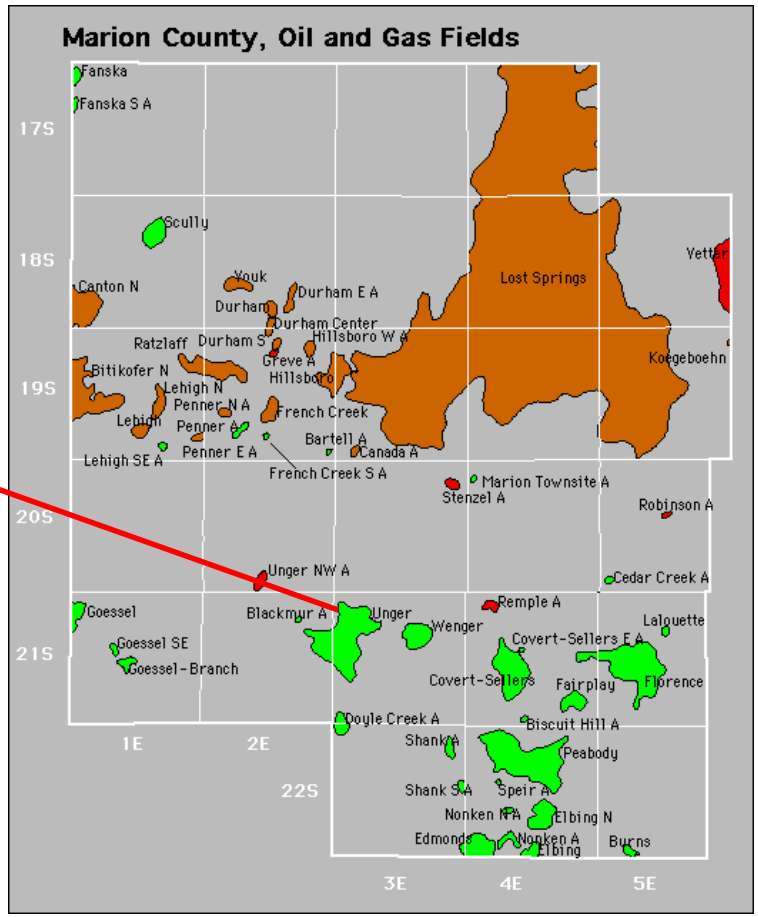
KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

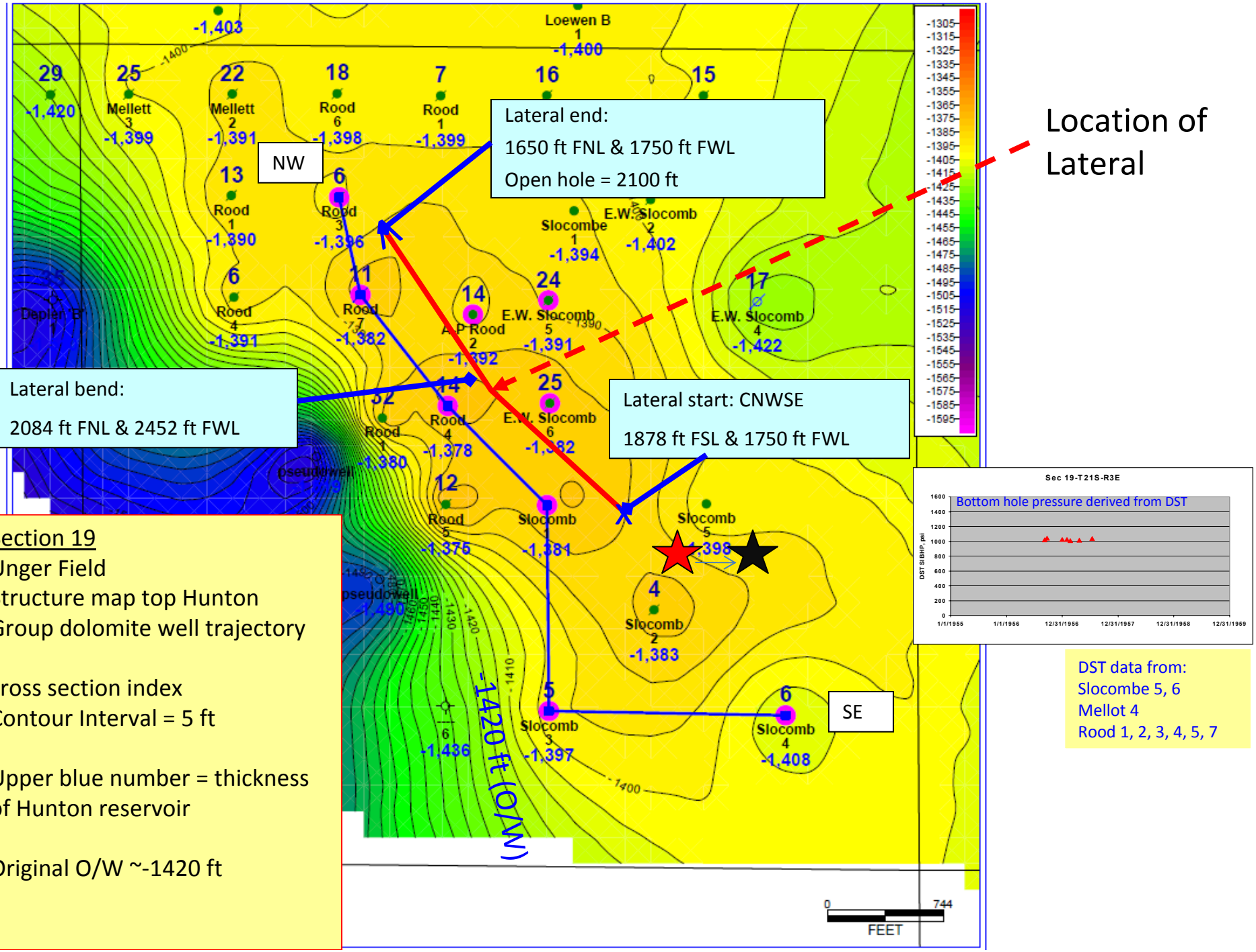
American Energies Corporation

NETL

Horizontal Well
American Energies Corporation
Slocombe-Rood #1-19
Unger Field
Marion County, Kansas







DST data from:
Slocombe 5, 6
Mellot 4
Rood 1, 2, 3, 4, 5, 7

Section 19
Unger Field
Structure map top Hunton
Group dolomite well trajectory

cross section index
Contour Interval = 5 ft

Upper blue number = thickness of Hunton reservoir

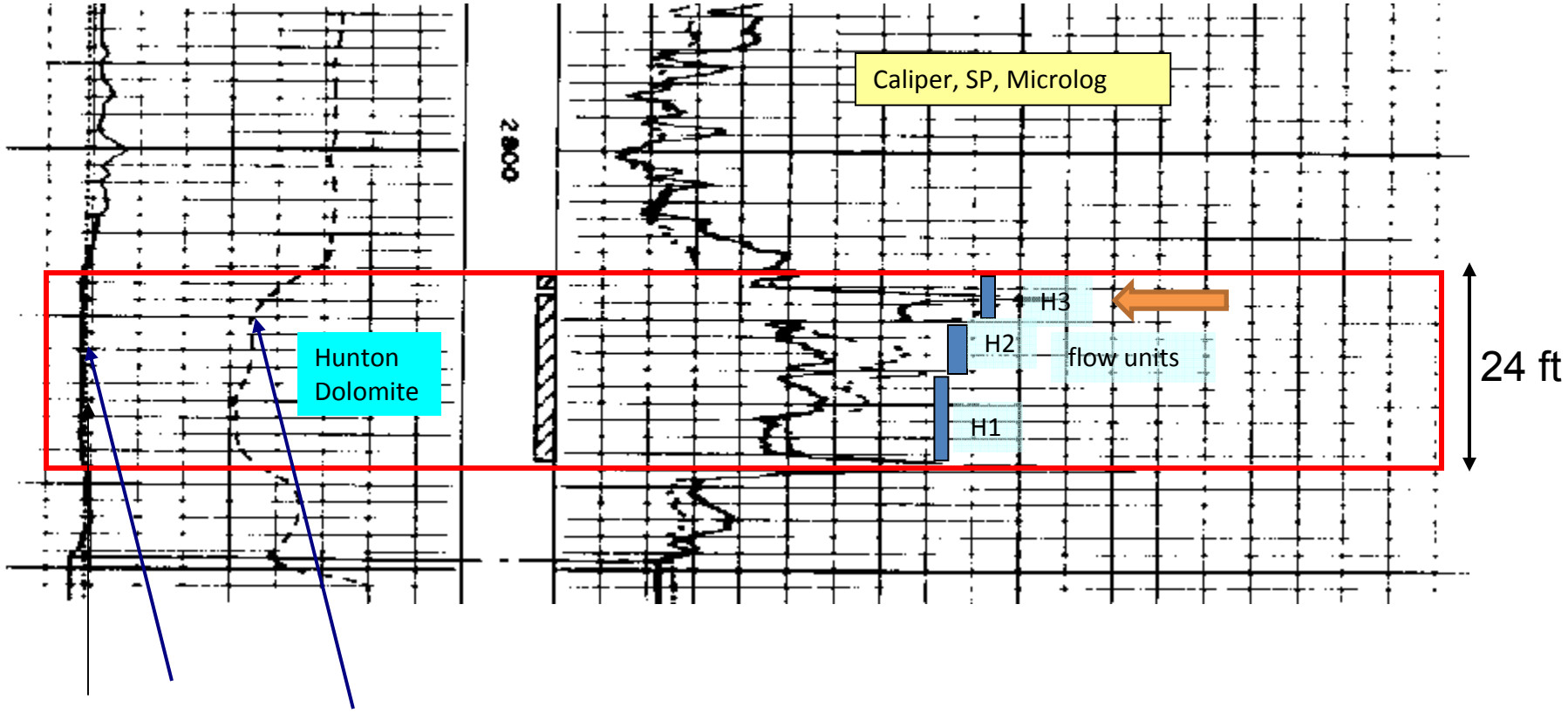
Original O/W ~-1420 ft

Rood #4 se se nw 19 CAL-SP-Microlog

Effective ~14 ft.

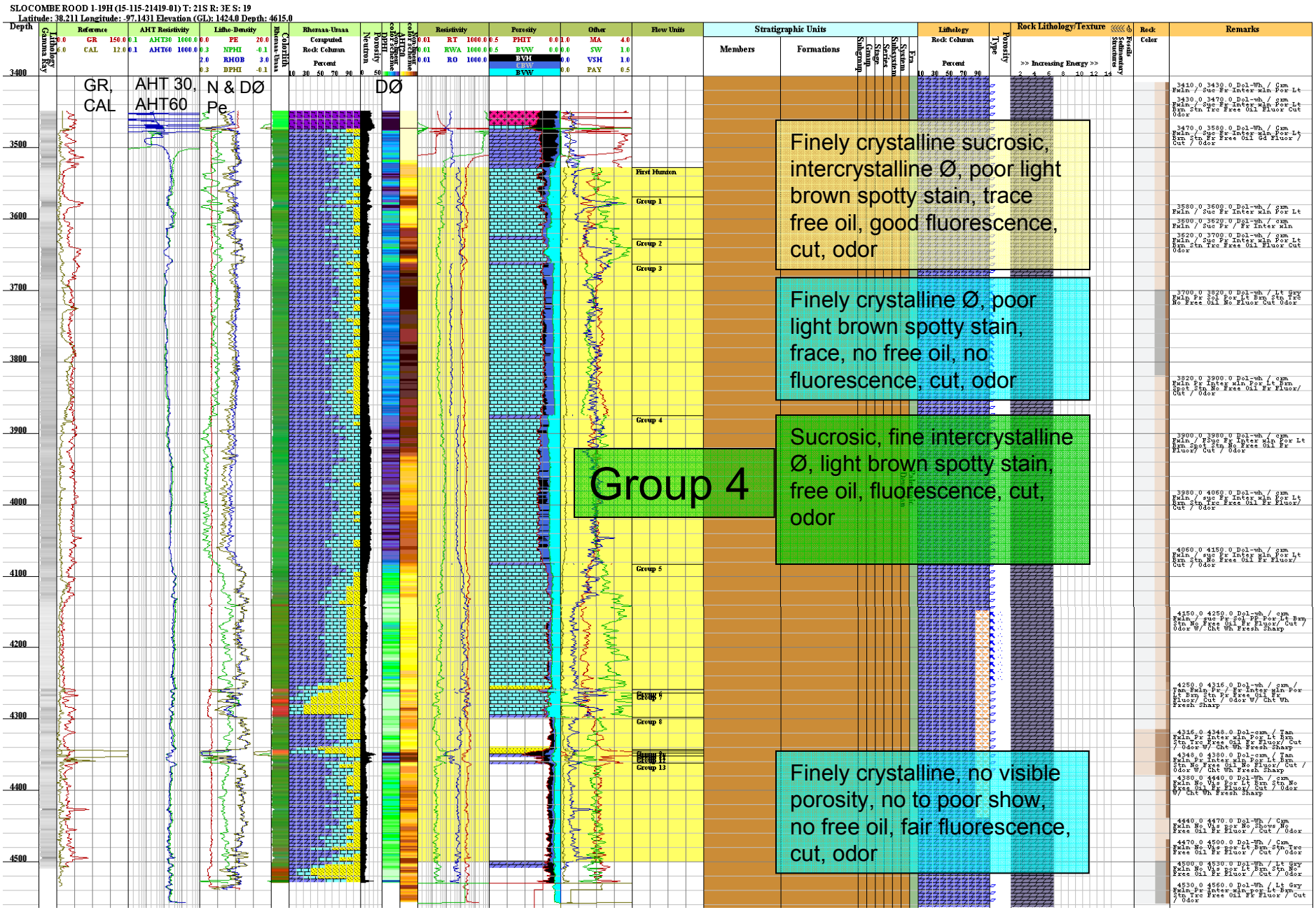
Upper zone ~6 ft.

Key well immediately west of lateral

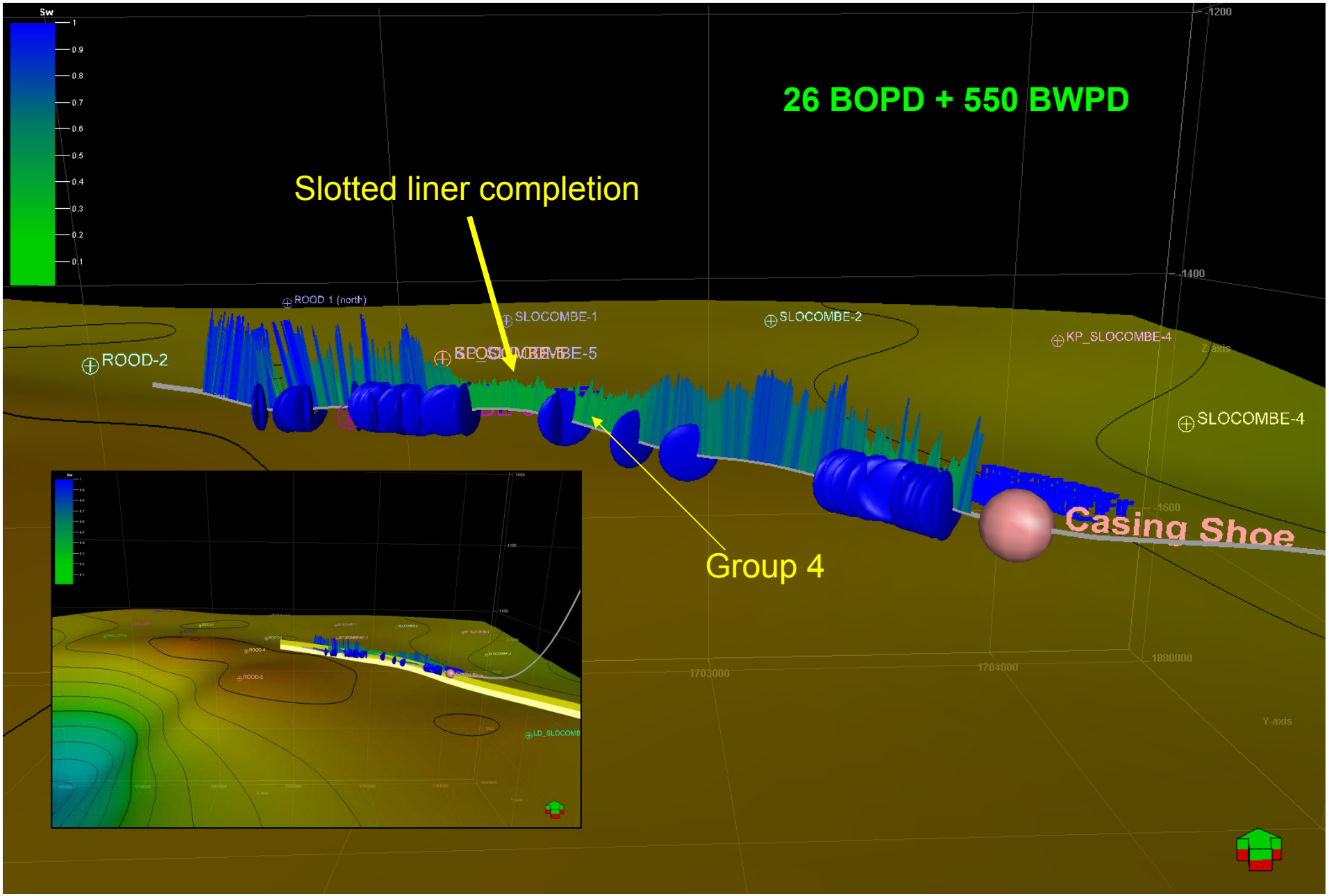


Good SP deflection (dashed line)
and mudcake (positive deflection of caliper – solid line)
suggest matrix permeablematrix porosity

KGS Well Viewer



Water Saturation and Conductive (Open) Fractures



Background

- Objective –
  - Drill 1000 to 1500 ft lateral through porous Hunton dolomite residing at roughly 2800 ft MD
  - Section 19-Range 21 South- Range 4 East of Unger Field in Marion County, Kansas

- Unger Field –
  - Discovered in 1955 has produced 8.6 million barrels
  - 17 wells produced 16,191 bbls. in 2009, 2.6 BOPD per well

- Wells on the Section 19 anticline originally produced several 1000's of barrels of oil per day
  - Wells average 2.6 bbls/day with high water cut (strong water drive)
  - Oil production can increase as wells pumped off suggesting oil still being drained outside of cone of depression

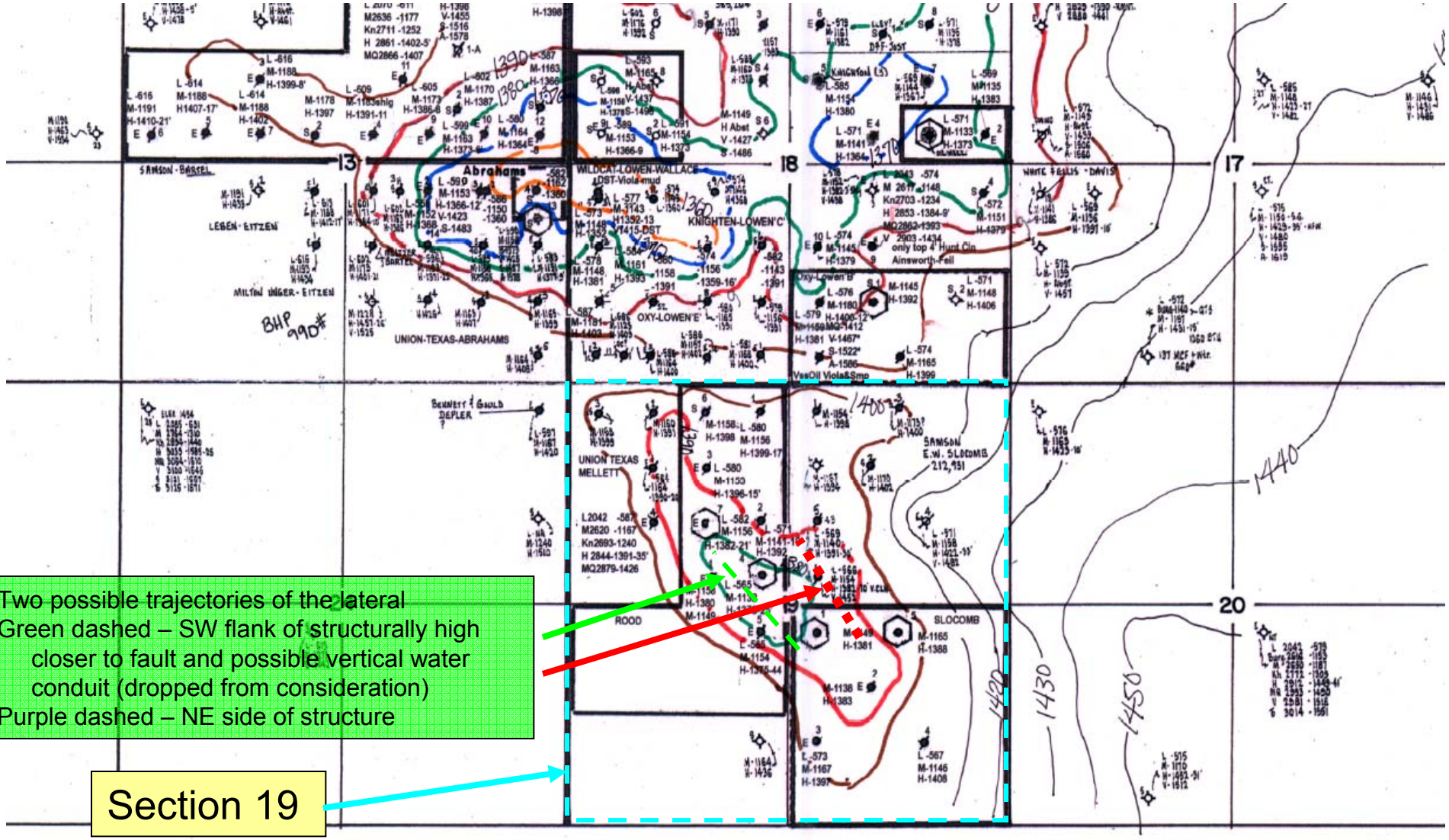
- Lateral paralleled east flank of ¾ mile long northwest-trending anticline
  - Local structural relief is 30 ft
  - Original oil column around 40 ft.

- Porous Hunton reservoir
  - Thickness ranges = 11-25 ft
  - Lithology – Dolomite - fractured, vuggy, intercrystalline Ø
  - Tight caprock above reservoir = 0-10 ft thick

- The Hunton dolomite is overlain by a thick (~130 ft), relatively hard Kinderhook-Chattanooga Shale.
  - Sufficiently hard rock for making turn of the lateral.

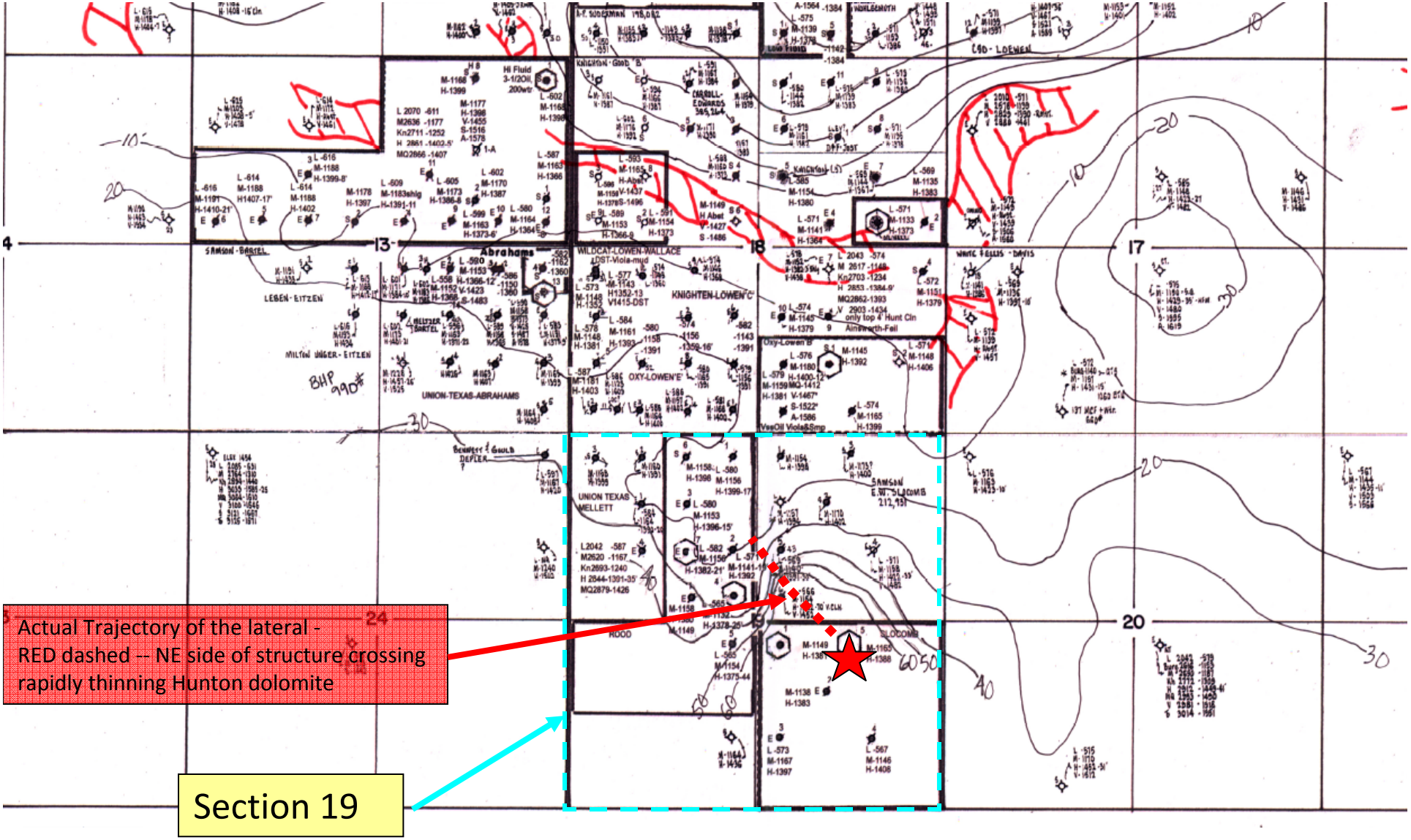
Hunton Structure – south Unger Field

Geology by Gerry Honas

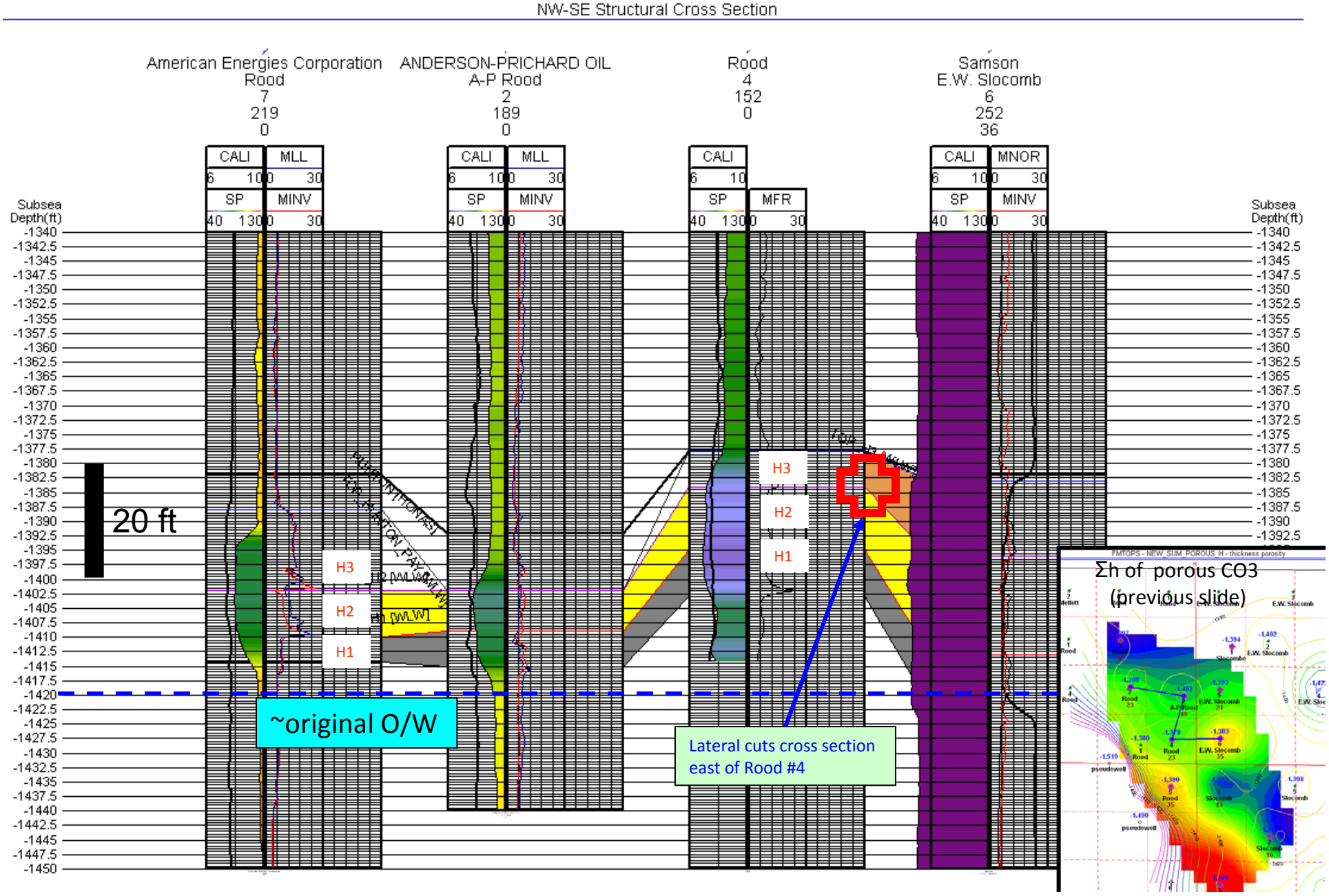


Hunton isopach – south Unger Field

Geology by Gerry Honas



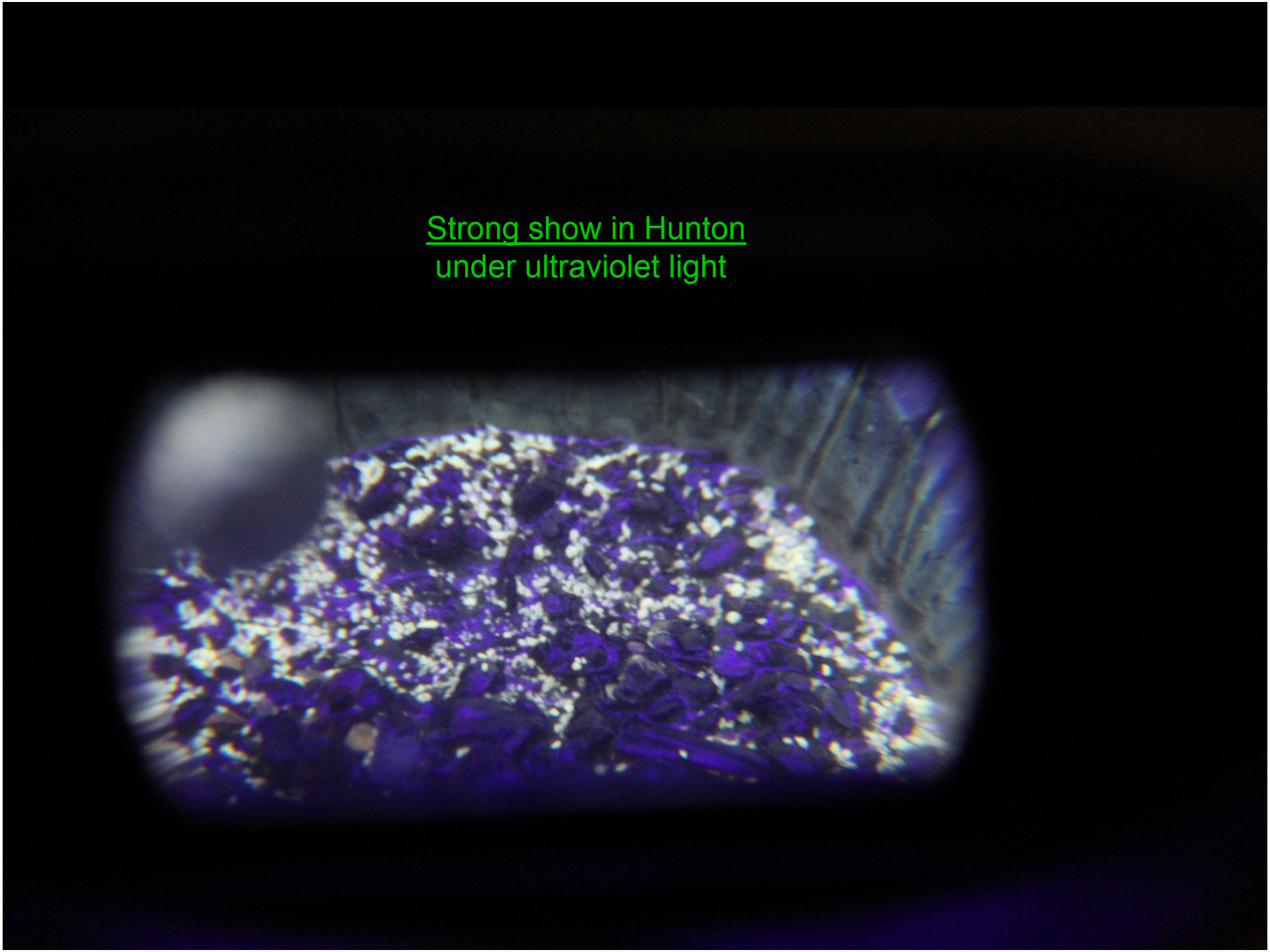
NW-SE Structural Cross Section
with flow units (H1, H2, H3) of Hunton dolomite reservoir



January Field trip for students and industry with the boss Alan DeGood, American Energies Corporation
John discussing MWD- azimuthal gamma ray tool

KGS colleagues and co-authors Jason Rush and Saibal Bhattacharya with KGS Interim Director Rex Buchanan and DOE's Brian Dressel

Geologist Doug Davis hard at work running samples


Strong show in Hunton
under ultraviolet light

Azimuthal Gamma Ray

ran while drilling to assist geosteering

Pan American DRILLING SERVICES L.L.C.

Focus/azimuthal Gamma (sensor)
-- To avoid shale caprock above reservoir and shale below reservoir

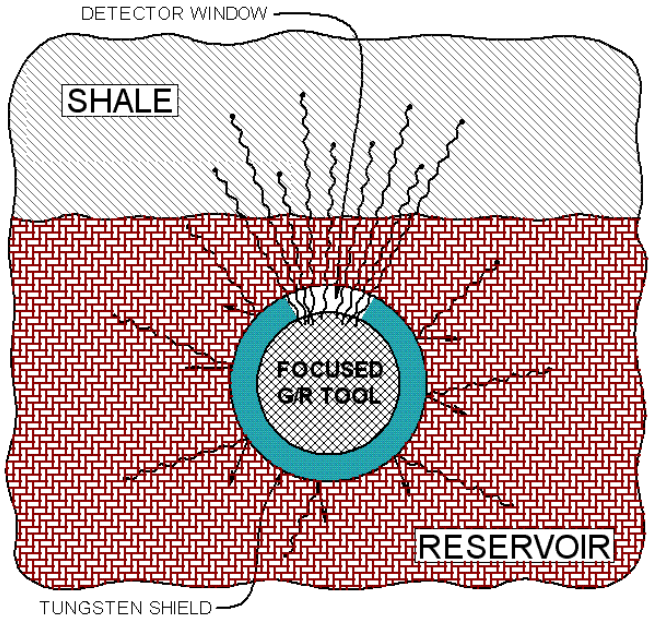
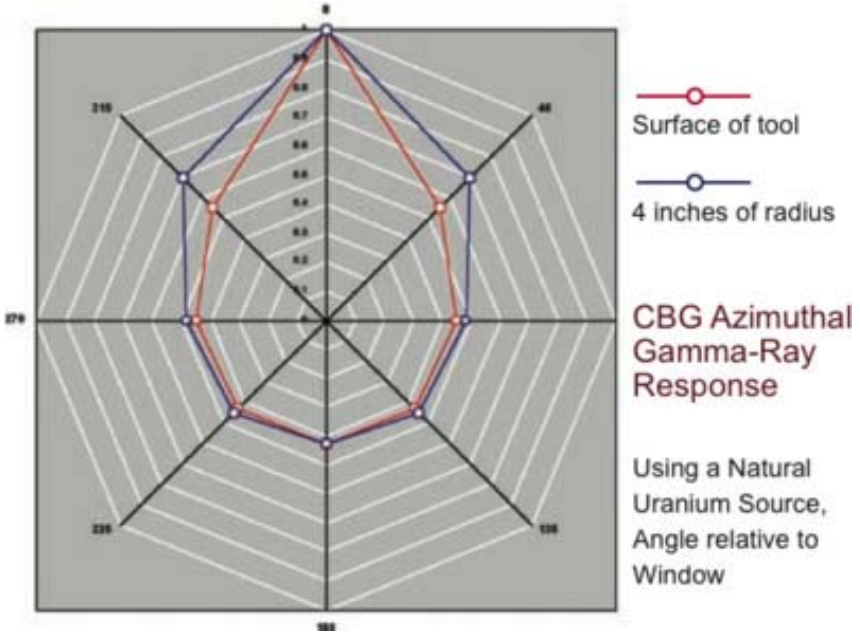


FIG. 1



Drilling is paused while detector window on azimuthal gamma ray tool is rotated and measurements taken every 45 degrees through 360 degree rotation.

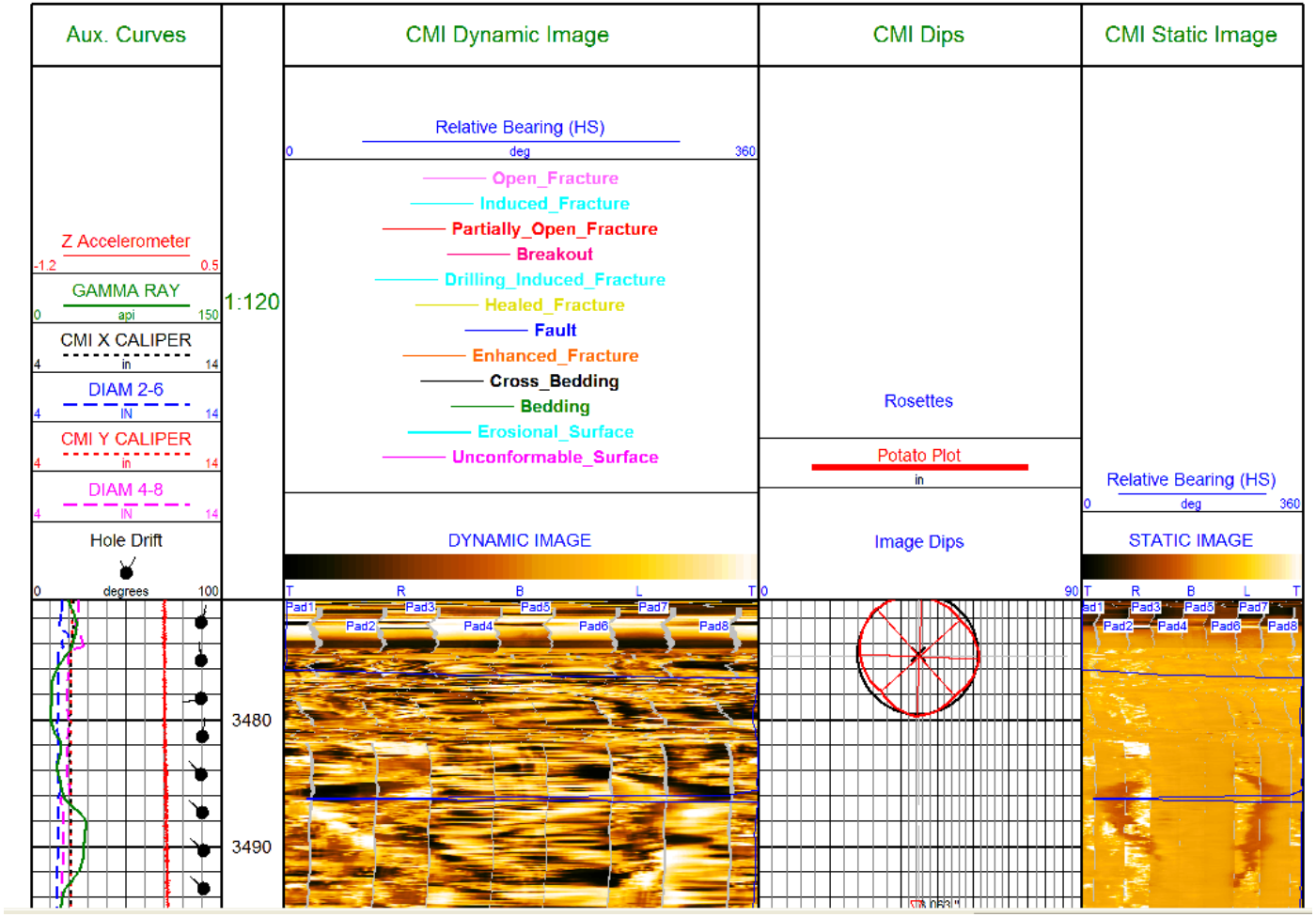
Weatherford®

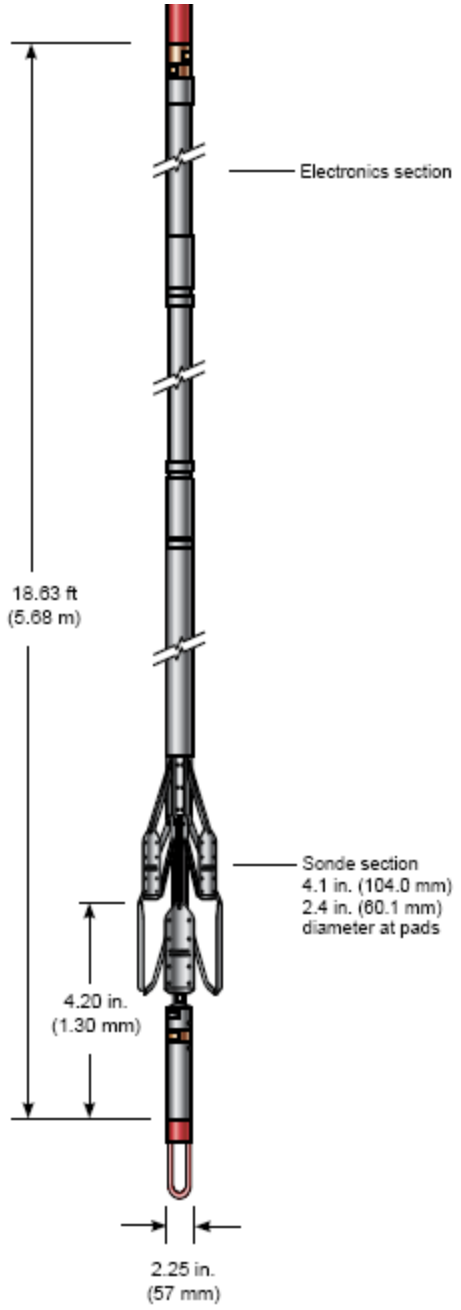
Wireline Services

Ran Post-drill (drill pipe conveyed)

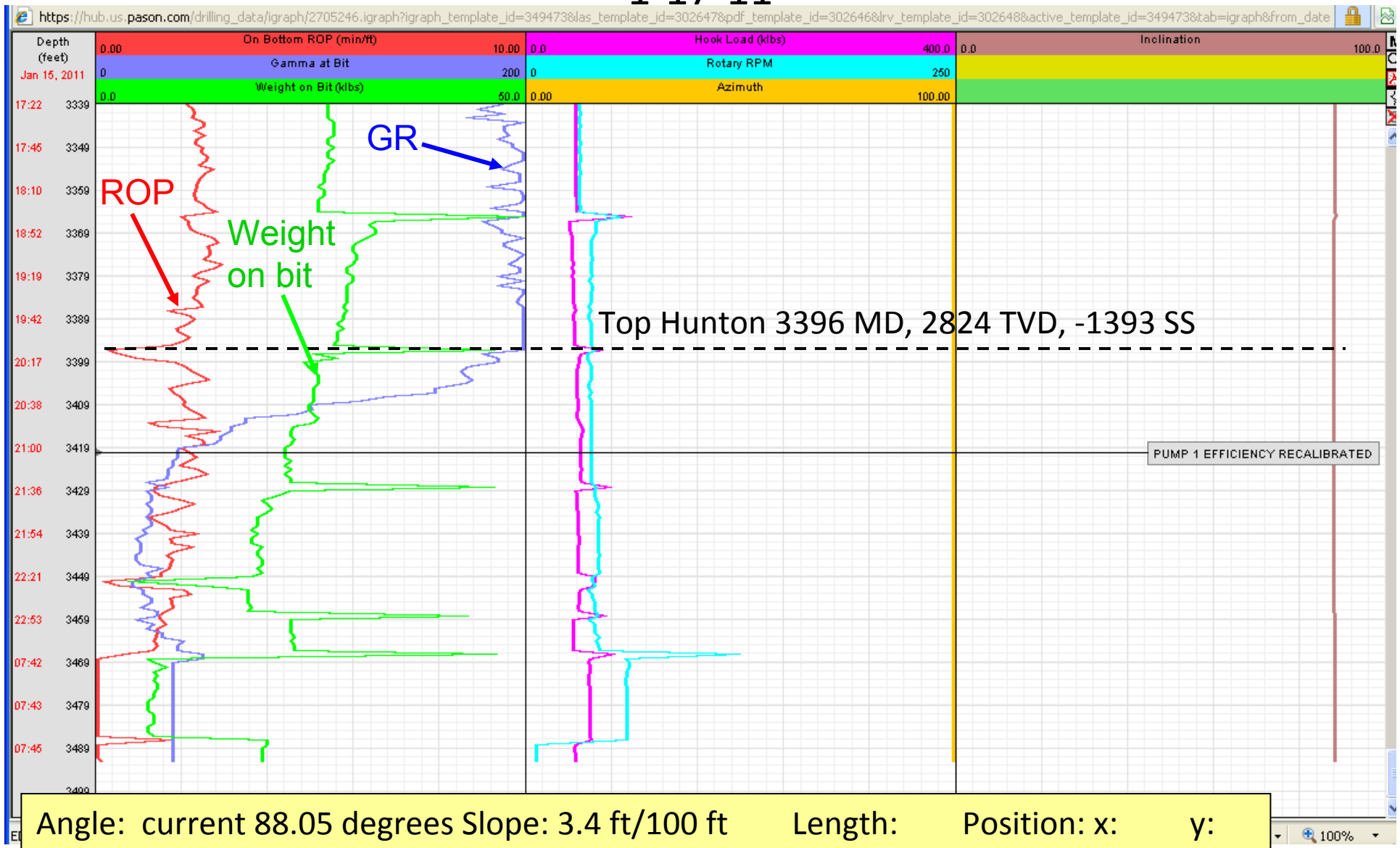
Open Hole | Formation Imaging

Compact™ Microimager (CMI)

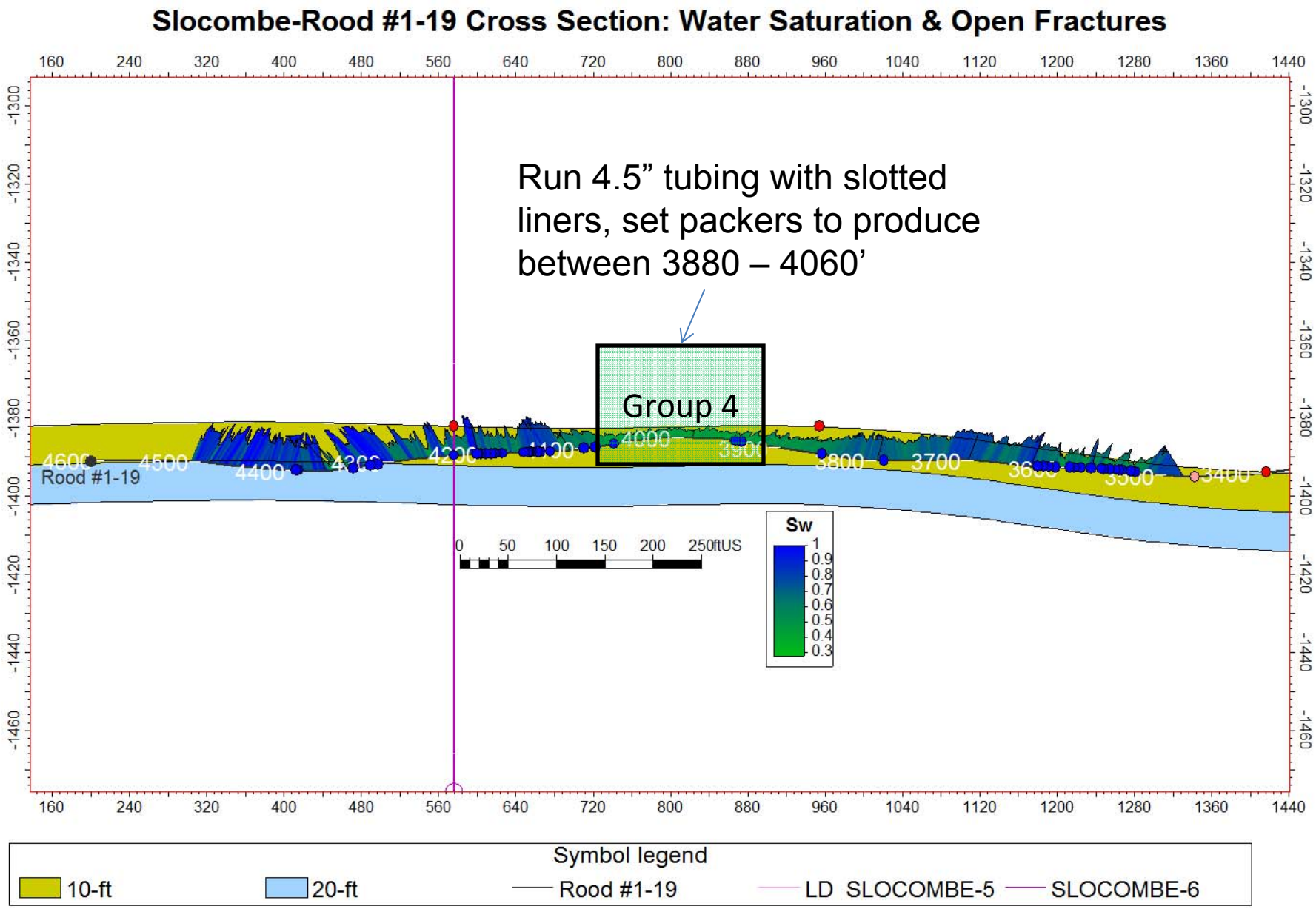




Pason's Real Time Drilling Data at Soft Landing In Hunton Dolomite 1-17-11



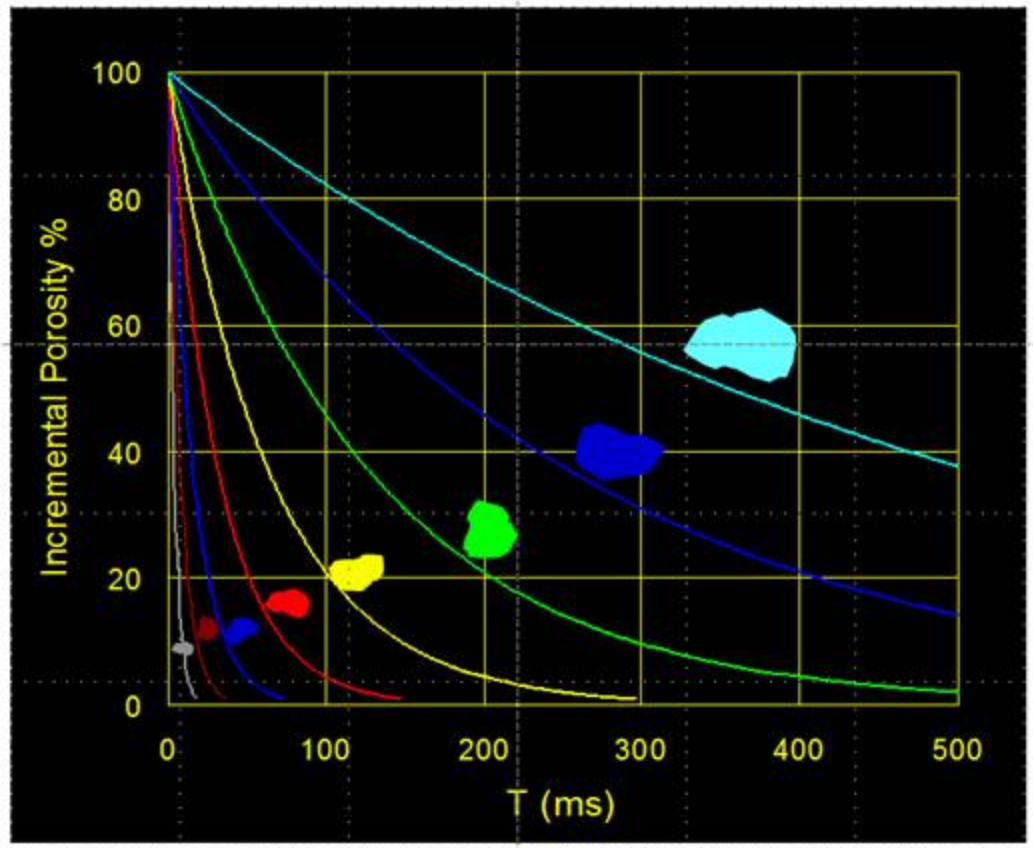
Angle: current 88.05 degrees Slope: 3.4 ft/100 ft Length: Position: x: y:
89 degrees (1.75 ft/100 ft)



Petrel presentation of lateral in subsea

NMR (Nuclear Magnetic Resonance Imaging) to estimate pore size/capillarity and permeability

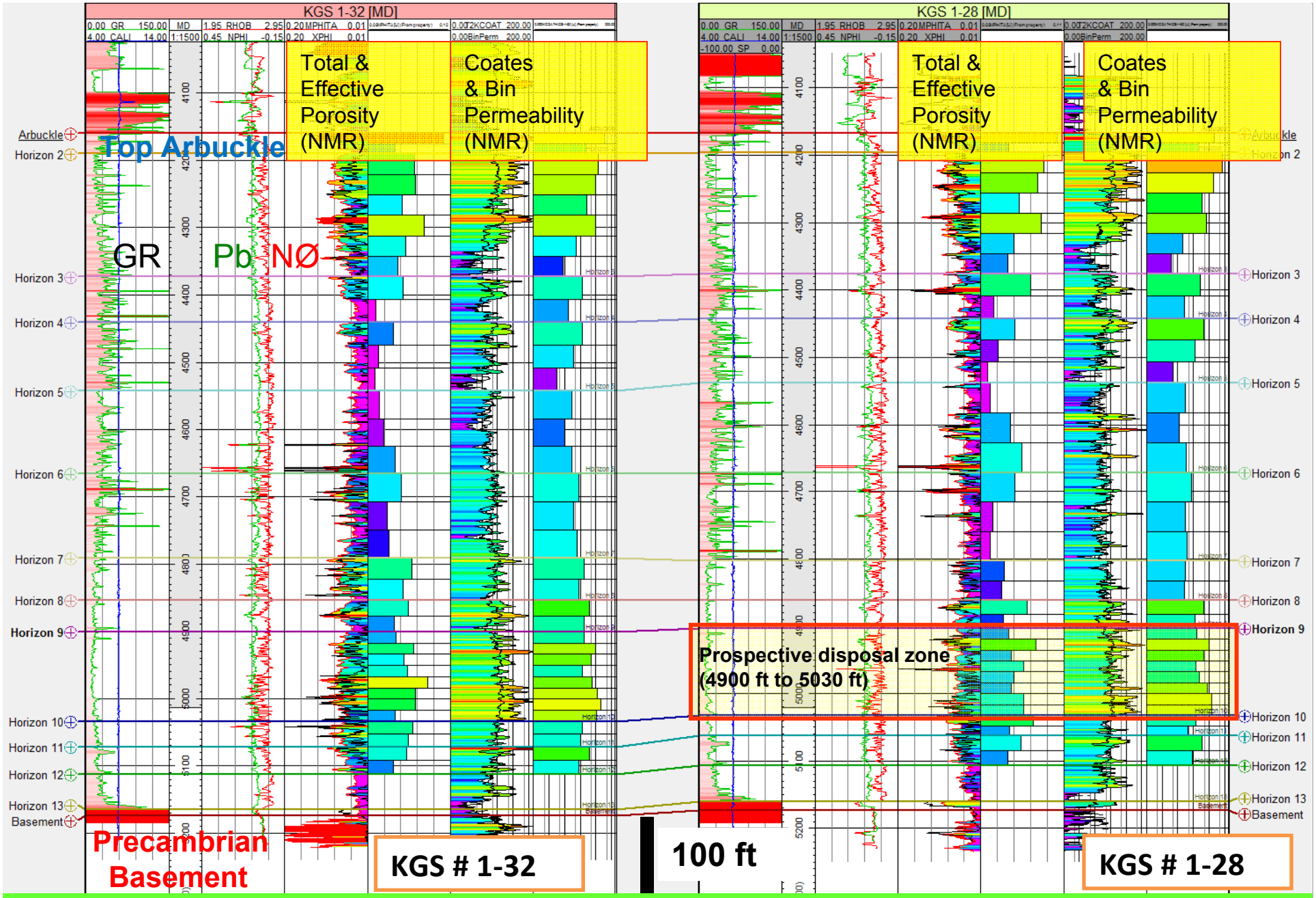
Relationship between T2 relaxation time and Pore Size Distribution



Small pore size ->
Rapid decay rate

Large Pore Size ->
Slow Decay Rate

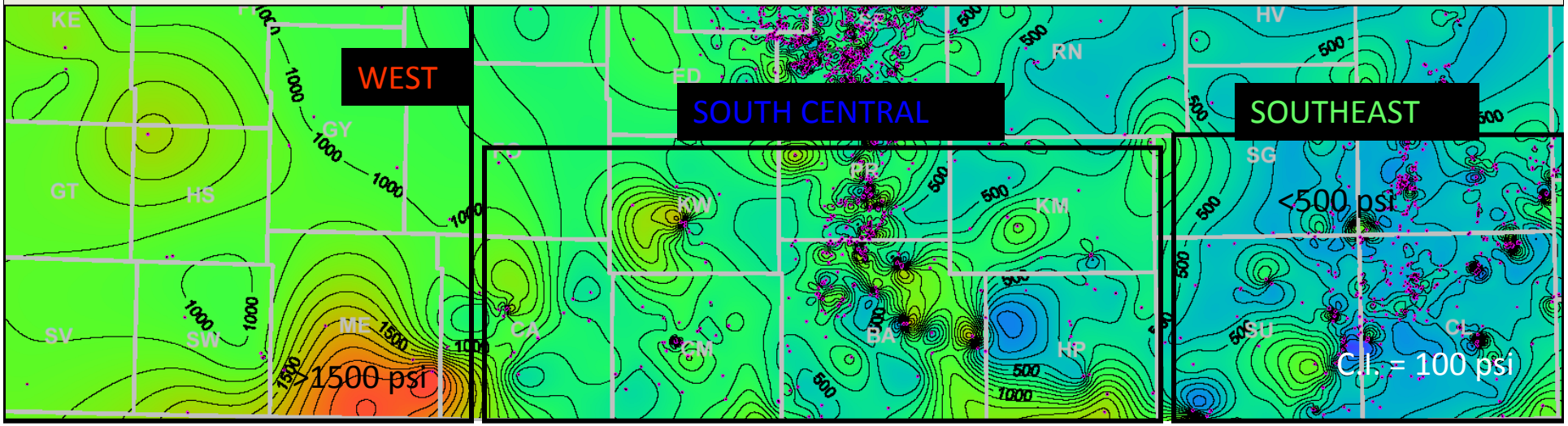
Role of Matrix Contribution to Porosity & Permeability in the Arbuckle Aquifer

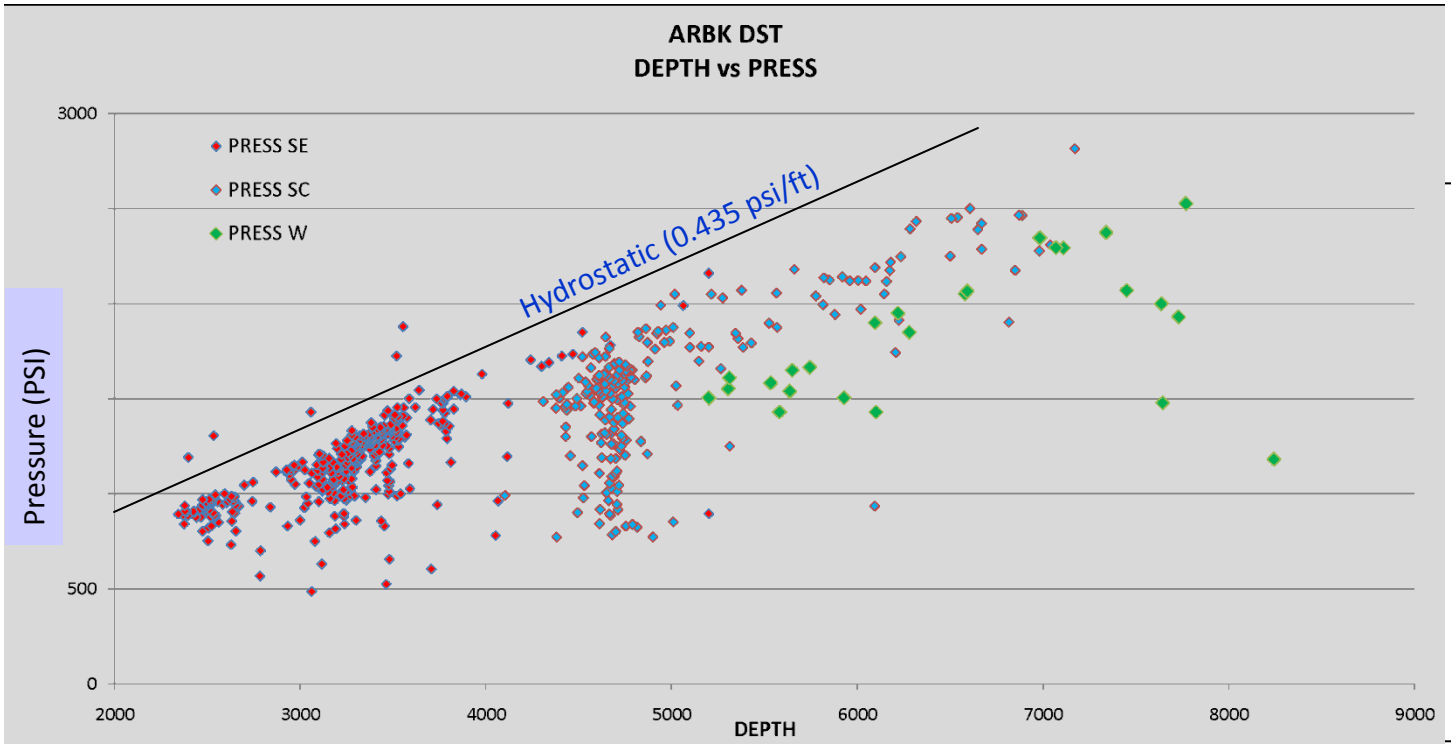


Log data and upscaled hydrostratigraphic units in Arbuckle Group in KGS #1-32 (left) and #1-28 (right)

Regional Study – Is the Arbuckle and open or closed system?

Δ psi (hydrostatic head - DST SIP) => Arbuckle underpressured





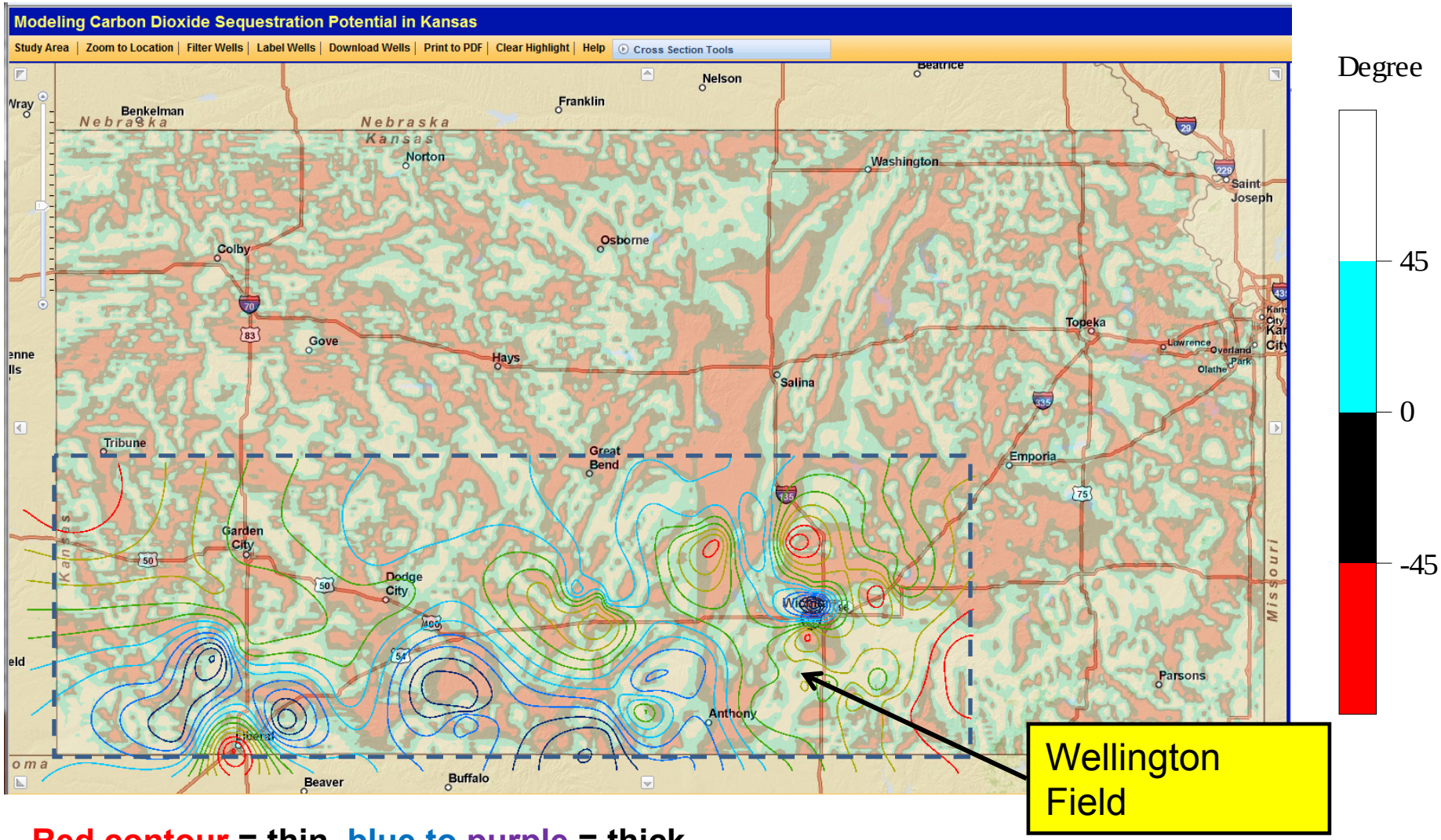
DST shut-in pressures in Arbuckle saline aquifer in southern Kansas

"Modeling CO_2 Sequestration in Saline Aquifer and Depleted Oil Reservoir (Wellington Field) to Evaluate Regional CO_2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas"

http://www.kgs.ku.edu/PRS/Ozark/index.html

- **Paleozoic-age Ozark Plateau Aquifer System (OPAS) in southern Kansas**
  - Thick and deeply buried
  - Overlying Mississippian carbonates contain large oil and gas reservoirs
  - Arbuckle -- thickness (600-1000 ft), supercritical P-T for CO_2 (>3500 ft), stratigraphic isolation from freshwater aquifers, and very limited oil and gas production.
  - Published estimates of CO_2 sequestration capacity in the Arbuckle Group in KS vary between 1.1 to 3.8 billion metric tonnes based on static CO_2 solubility in brine under in situ pressure and temperature.

Tilt angle map of the total magnetic field intensity overlain by Isopach of Roubidoux to Gasconade



Red contour = **thin**, **blue to purple** = **thick**.

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

Moldic, vuggy, and between particle porosity = fabric selective

4805.5 ft