SMALL SCALE FIELD TEST DEMONSTRATING CO_2 SEQUESTRATION IN ARBUCKLE SALINE AQUIFER AND BY CO_2-EOR AT WELLINGTON FIELD SUMNER COUNTY, KANSAS DE-FE0006821

An Operational Plan for Safe and Effective CO_2 Injection at Wellington Field, Kansas in Perspective of Recent, Nearby Seismic Activity

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Kansas Geological Survey

Lawrence, KS 66047

Kansas Department of Health and Environment

Sam Brownback, Governor

Susan Mosier, MD, Secretary

KSCO2

Adapted from presentation to U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS
Pittsburgh, PA

August 20, 2015

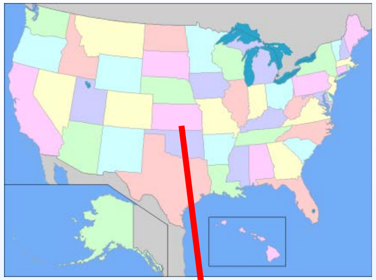
10:15 a.m – 11:00 a.m

KANSAS GEOLOGICAL SURVEY
The University of Kansas

NETL

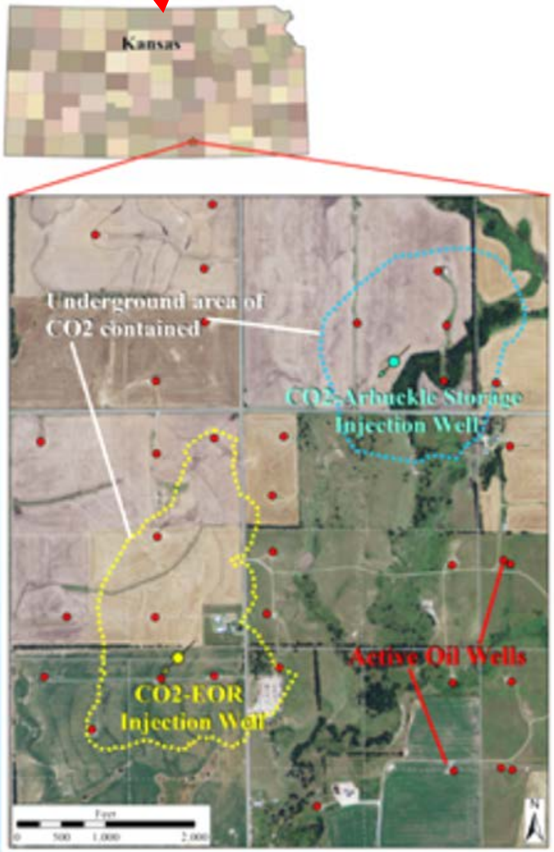
Presentation Outline

1. Project Overview
2. Benefits to the CCS Program
3. Technical Status
4. Accomplishments
5 Summary
6 Synergistic activity

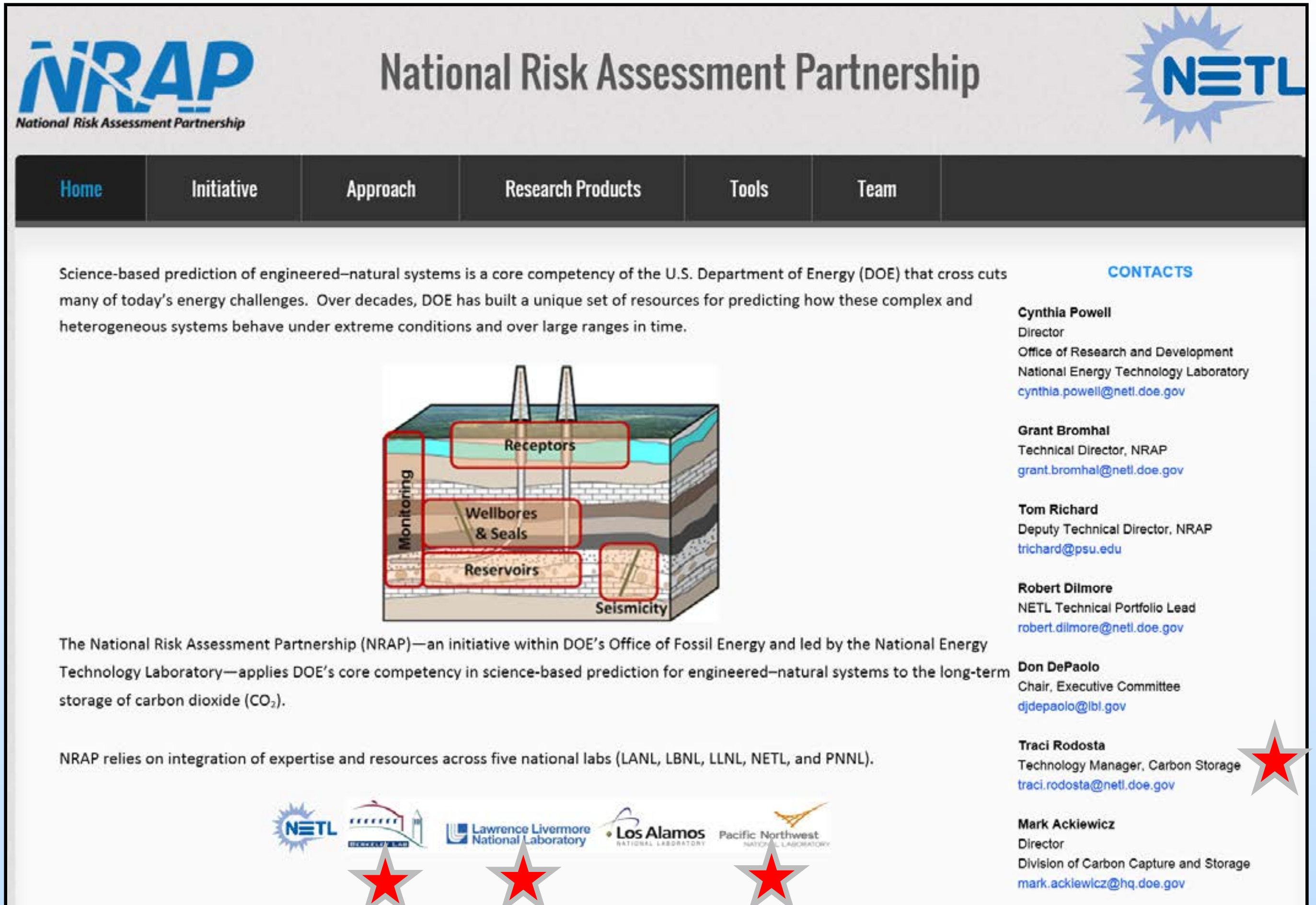


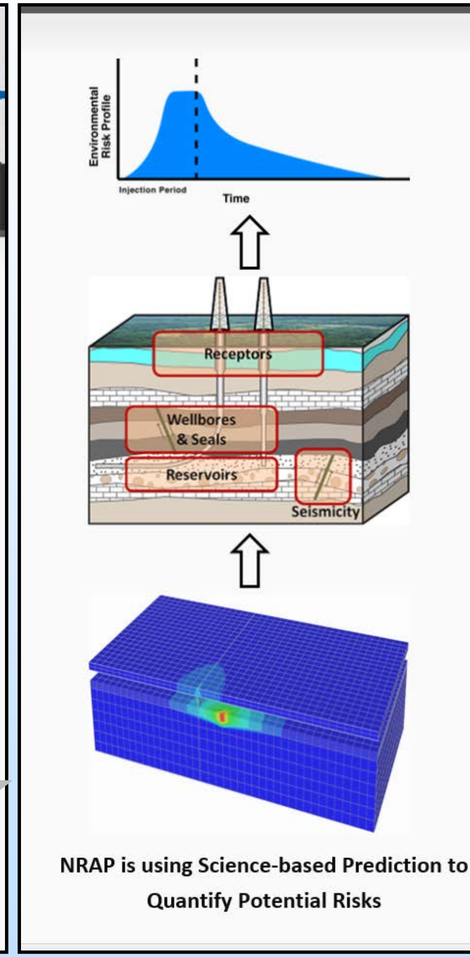
Wellington Field Sumner County Kansas

- Site at rural oil field operating since 1929
- 55 current operating wells, 20.7 MM bbls produced, 46k bbls annually
- Effective waterflood, ready for CO_2-EOR
- *Phase I* -- Approximately 26,000 tons to be injected in the Mississippian dolomite reservoir for EOR (2015)
- *Phase II* -- Approximately 26,000 tons to be injected in the Arbuckle dolomite aquifer for CO_2 sequestration (2016)

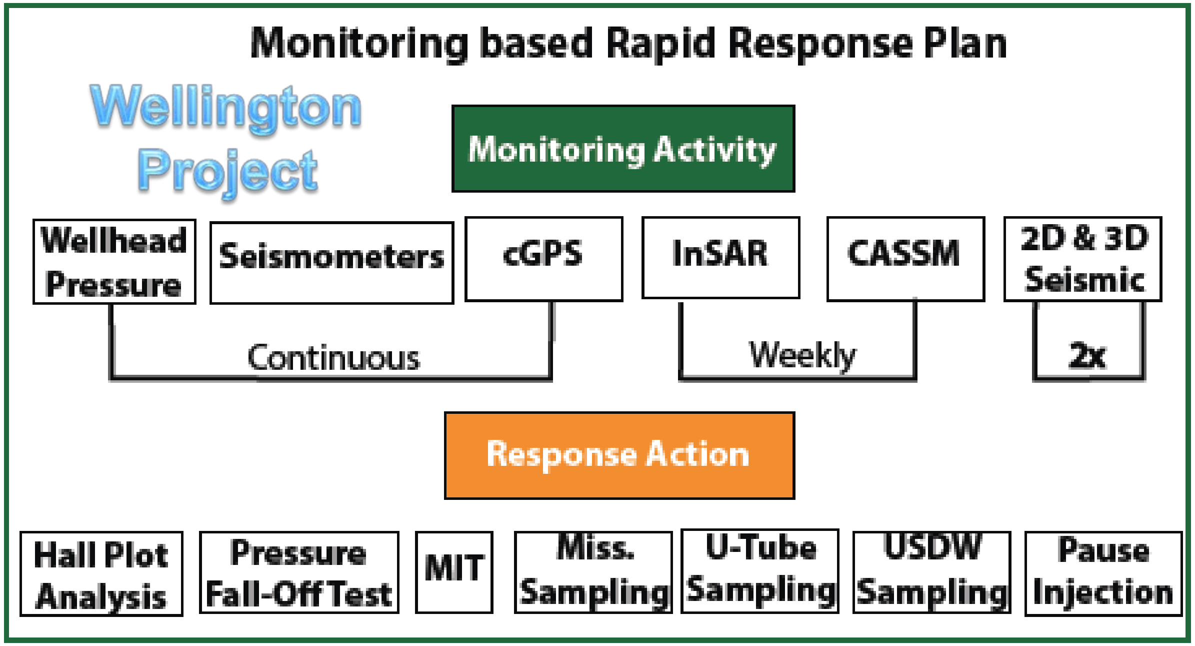


Risk management in DOE is incorporated in new, large cross-cutting program → NRAP





- Science-based predictions for quantitative risk assessment are based on models.
- Models need calibration, validation, and need to be appropriately applied in order to be useful.
- Model parameters used to assign risk are ideally based on first principles, eg., understanding of the fundamental processes or their proxies –> robust, portable, reliable models, reduce their own uncertainty



- Injection Control Plan
- Wellington Seismic Action Plan
- Monitoring-based Rapid Response Plan
- Emergency Remedial Response Plan

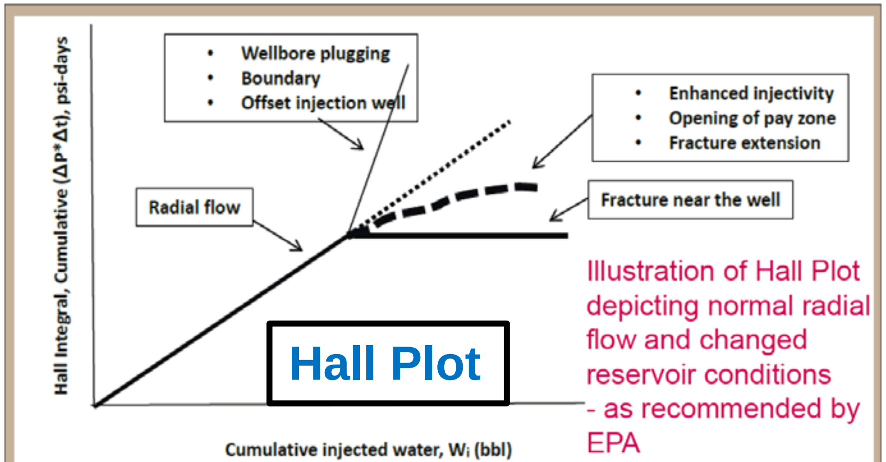


Illustration of Hall Plot depicting normal radial flow and changed reservoir conditions - as recommended by EPA

http://www.epa.gov/r5water/uic/ntwg/pdfs/induced-seismicity-201502.pdf

Under review by EPA

Operational plan for safe and efficient CO2 injection as part of Draft emergency and remedial response plan for Class VI permit

The success of the Monitoring and Rapid Response Plan developed for the Wellington Project is based on prioritizing the monitoring technologies:

1) Reliability of the data and approaches used to analyze the data,
2) Frequency that the data is acquired during injection
3) Sensitivity and precision of the monitoring method and its ability to detect small changes in CO2 plume behavior;
4) Location and therefore resolution from which the data is collected,
5) Spatial resolution and coverage of the CO2 plume; and
6) Ability to detect movement out of the injection zone both above and below the injection zone.

Project Team

DOE-NETL Contract #FE0006821

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L. Watney (Proj. Manager, Joint PI), J. Rush (Joint PI), J. Raney (Asst. Project Manager), T. Bidgoli, J. Doveton, E. Holubnyak, M. Fazelalavi, R. Miller, D. Newell, John Victorine
(static & dynamic modeling, petrophysics, well test analysis, high-resolution 2D seismic, install/maintain seismometer array, structural & geomechanical analysis, project management)

Brian Dressel, P.M.

BEREXCO

Dana Wreath, Adam Beren
(field operator and operations, repeat 3D multicomponent seismic)

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

Tom Daley, Barry Freifeld ***(CASSM, U-Tube, cross well seismic for Arbuckle Class VI geosequestration)***

THE LINDE GROUP
Linde
PRAXAIR
Making our planet more productive
CO_2 suppliers

DEPARTMENT OF GEOLOGY
KANSAS STATE UNIVERSITY
Saugata Datta, Brent Campbell ***(fluids, soil gas, and USDW monitoring)***

IRIS PASSCAL Instrument Center
Program for Array Seismic Studies of the Continental Lithosphere

George Tsoflias, Brandon Graham, Alex Nolte (KU Geology) interpretation of ***seismometer array***

TBirdie Consulting, Inc
4705 McCormick Street • Lawrence • KS 66047 • 785 843 1085 • 785 865 0678 (fax) • tbirdie@sunflower.com

T. Birdie ***(aquifer and geomechanical modeling, EPA Class VI permit, reporting, closure)***

THE UNIVERSITY OF KANSAS
Department of Geology

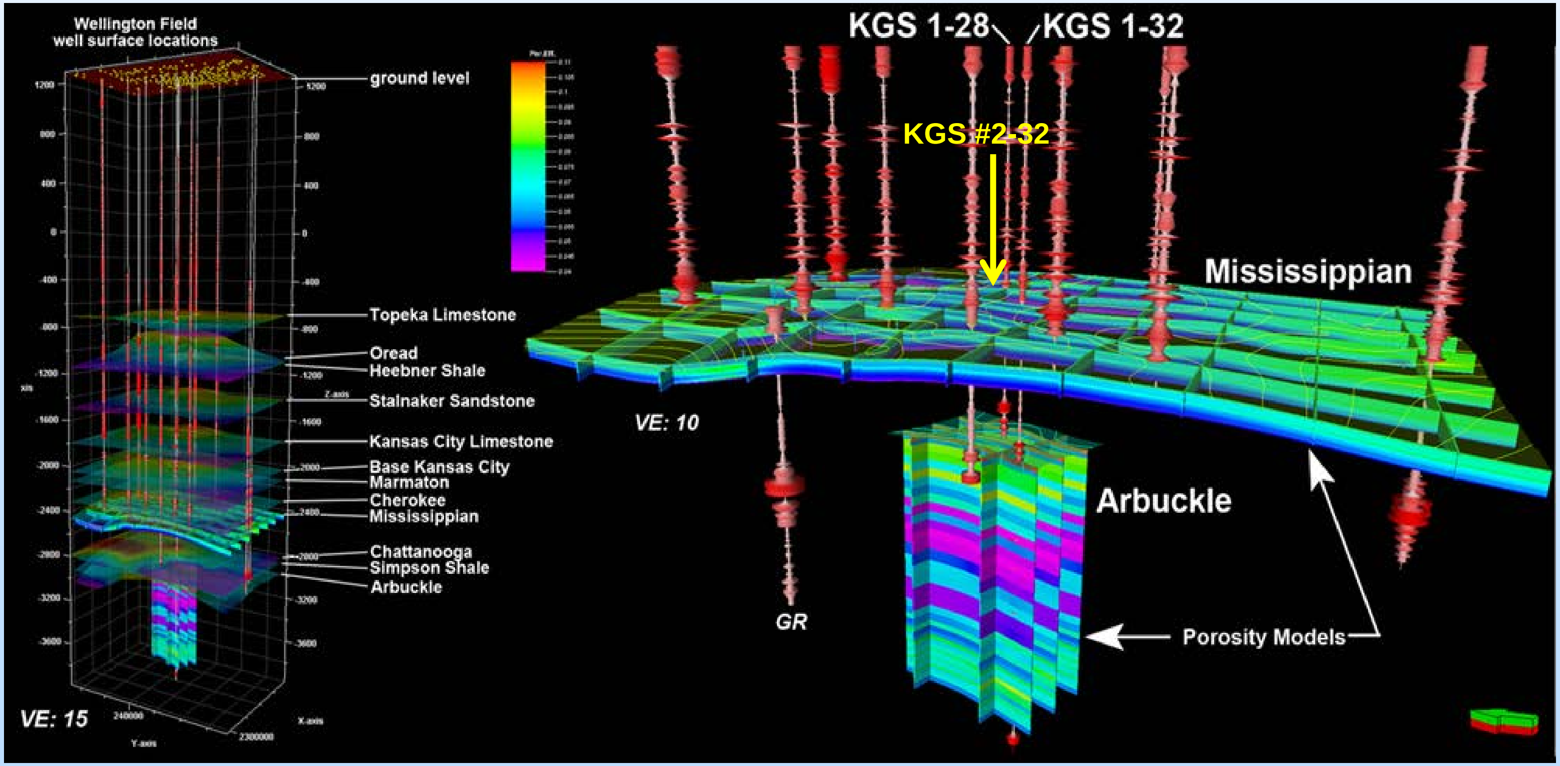
Mike Taylor, Leigh Sterns, Drew Schwab ***(cGPS/InSAR)***

Schlumberger ***Petrel, TechLog***
CMG COMPUTER MODELLING GROUP LTD.
Core Lab RESERVOIR OPTIMIZATION
HALLIBURTON
Weatherford

Project established November 2011

Benefits to the Program

- **Program goals being addressed –**
  - **Demonstrate that 99 percent permanence of injected CO_2**
    - ~26,300 tonnes of CO_2 in each –
      - ❑ *1. (2015) Late Mississippian siliceous dolomite reservoir deposited on a marine shelf to shelf edge ramp (**<u>Class II UIC permit</u>**)*
      - ❑ 2. (2016) Underlying *Lower Ordovician Arbuckle Group dolomitic saline aquifer deposited on marine shelf (**<u>Class VI UIC permit</u>**)*
  - **Demonstrate reliable and cost effective MVA (*monitoring, verification, and accounting*) tools and techniques**
  - **Develop best practices for effective and safe CO_2-EOR and CO_2 disposal in a saline aquifer**



Technical Status

- **Milestone 1: Refined static and dynamic models of the Mississippian oil reservoir**
- *Task 3* -- **Obtained Class II to inject CO_2 in Mississippian oil reservoir in February 2015**
- Task 9 – **Drilled, cored, logged, and tested Berexco Wellington KGS #2-32 in late March and April 2015**
- Task 10 – **Complete #2-32 for CO_2-EOR injection, re-pressurizing reservoir prior to CO_2 injection and begin injection of 26,300 tonnes of CO_2 by October 1, 2015**
- **Preview of some of the MVA and readiness of team for the Class VI injection**

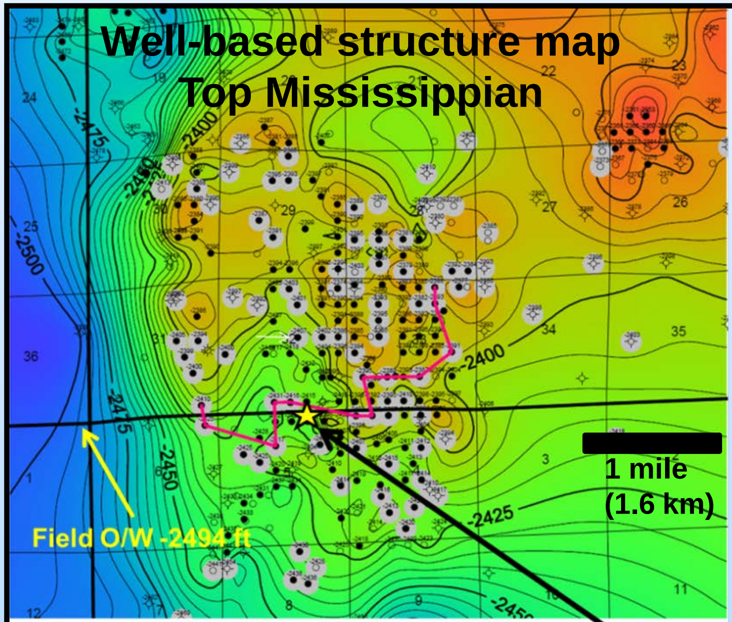


Figure 1: Contour map of Mississippian formation in Wellington field

Original field O/W contact =-2494 ft @ 3763 ft in Wellington KGS #2-32

#2-32 drilled in March 2015 → CO_2-EOR injector

Readiness to test monitoring technologies in BP2 → field deployment began in August 2014

1) Shallow water well monitoring
2) 18- seismometer array for passive seismic monitoring
3) cGPS and InSAR surface deformation to monitor pressure changes in reservoir during CO_2 injection
4) Monitoring wells in underpressured Mississippian reservoir overlying the caprock
5) High resolution 2D seismic survey to verify any leakage through the caprock (baseline in late August 2015)
6) Engineering analysis of CO_2 injection performance
7) Use Mississippian CO2-EOR as dress rehearsal for the Class VI injection

Small Scale CO_2-EOR in Mississippian

→26,300 tonne CO_2 injection into a biosiliceous dolomite reservoir

(equivalent to 142,000 bbls of fluid over 7 mo. or ~650 bbls per day)

Berexco LLC
Wellington KGS #2-32
2680'FSL & 709'FEL,
Sec 32, T 31S, R 1W
Sumner County, Kansas

BEREXCO

Fossil Drilling

DEVILBISS CORING SERVICE, INC.
"QUALITY SERVICE SINCE 1992"

MUDCO

HALLIBURTON

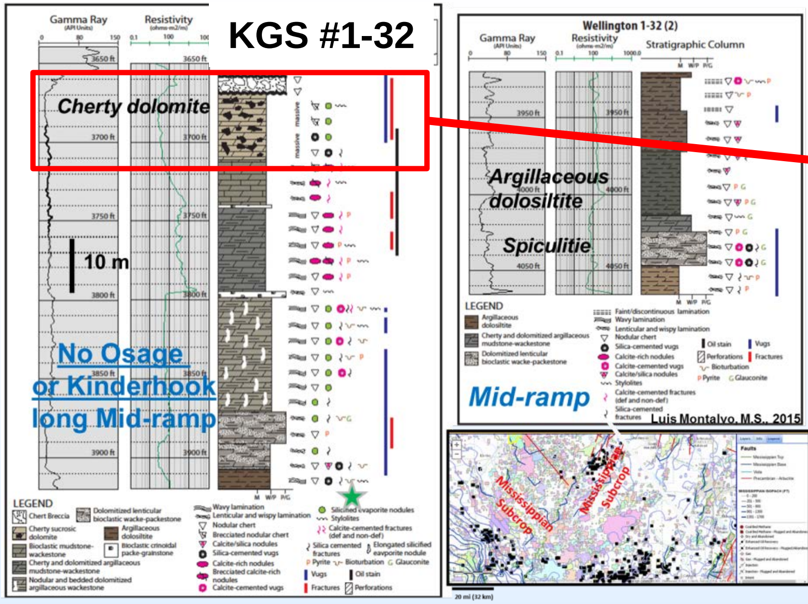
Core Lab

TRILOBITE TESTING, INC.

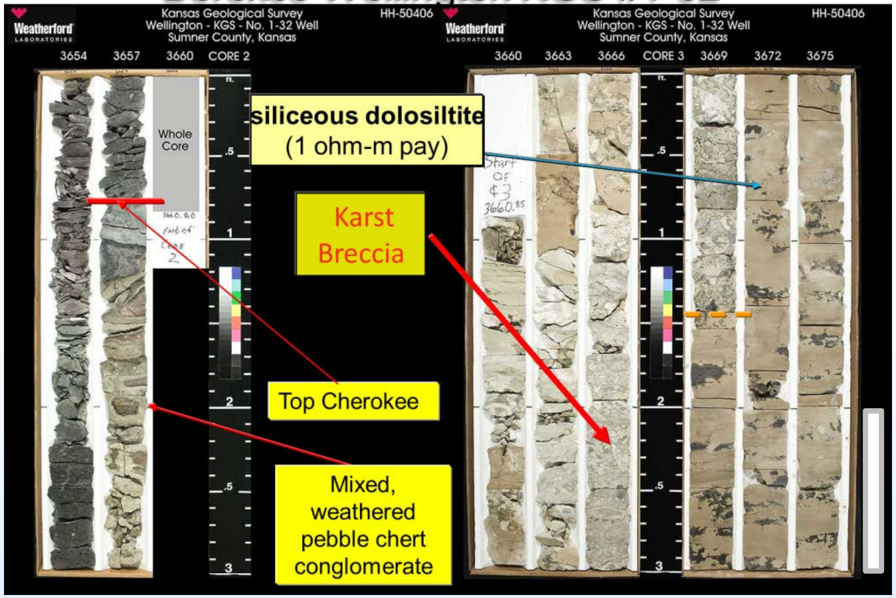
92 ft core cut in KGS #2-32 with 1528 ft previously acquired in KGS #1-32

Drilled in March 2015

No Osage or Kinderhook Mississippian → mid ramp

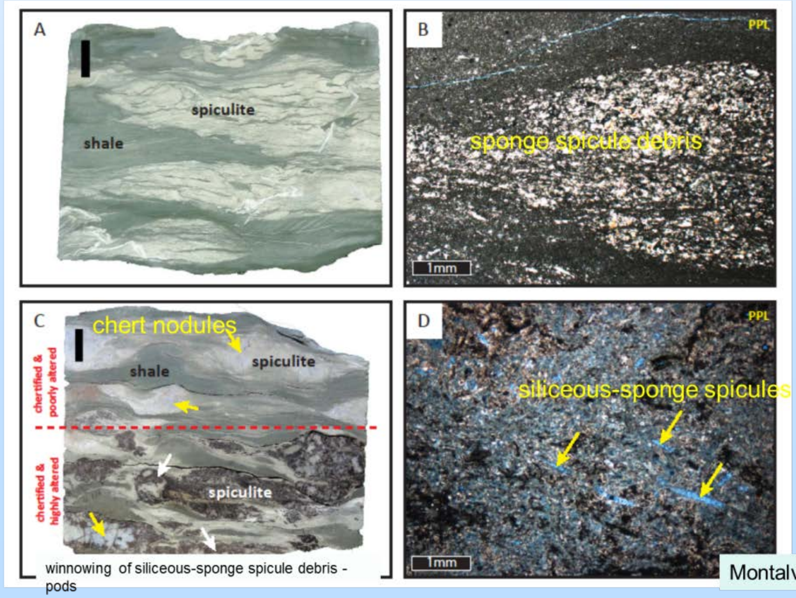


Mississippian pay zone in Berexco Wellington KGS #1-32



Lenticular Spiculite Wacke/Packestone

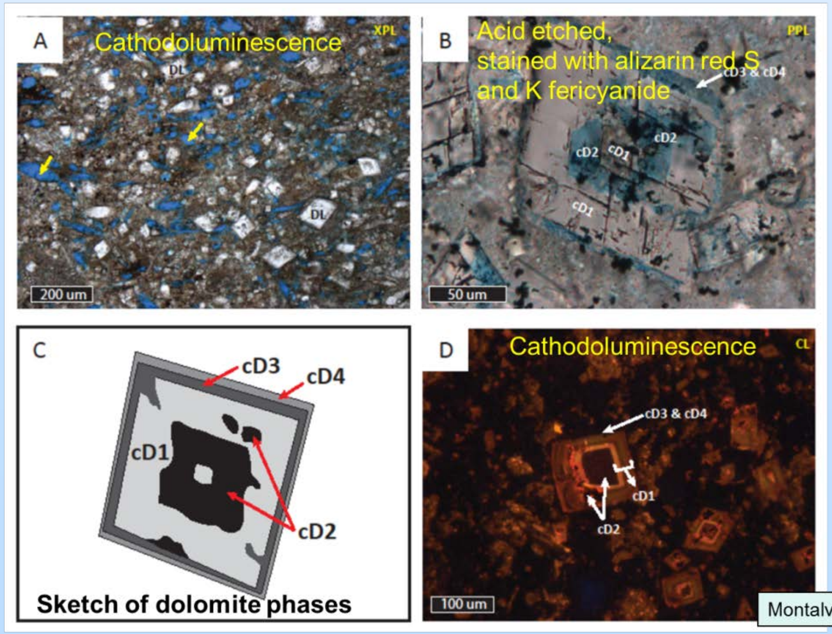
Extensive Micro-Porosity Through Dissolution and Etching of the Silica Matrix



winnowing of siliceous-sponge spicule debris - pods

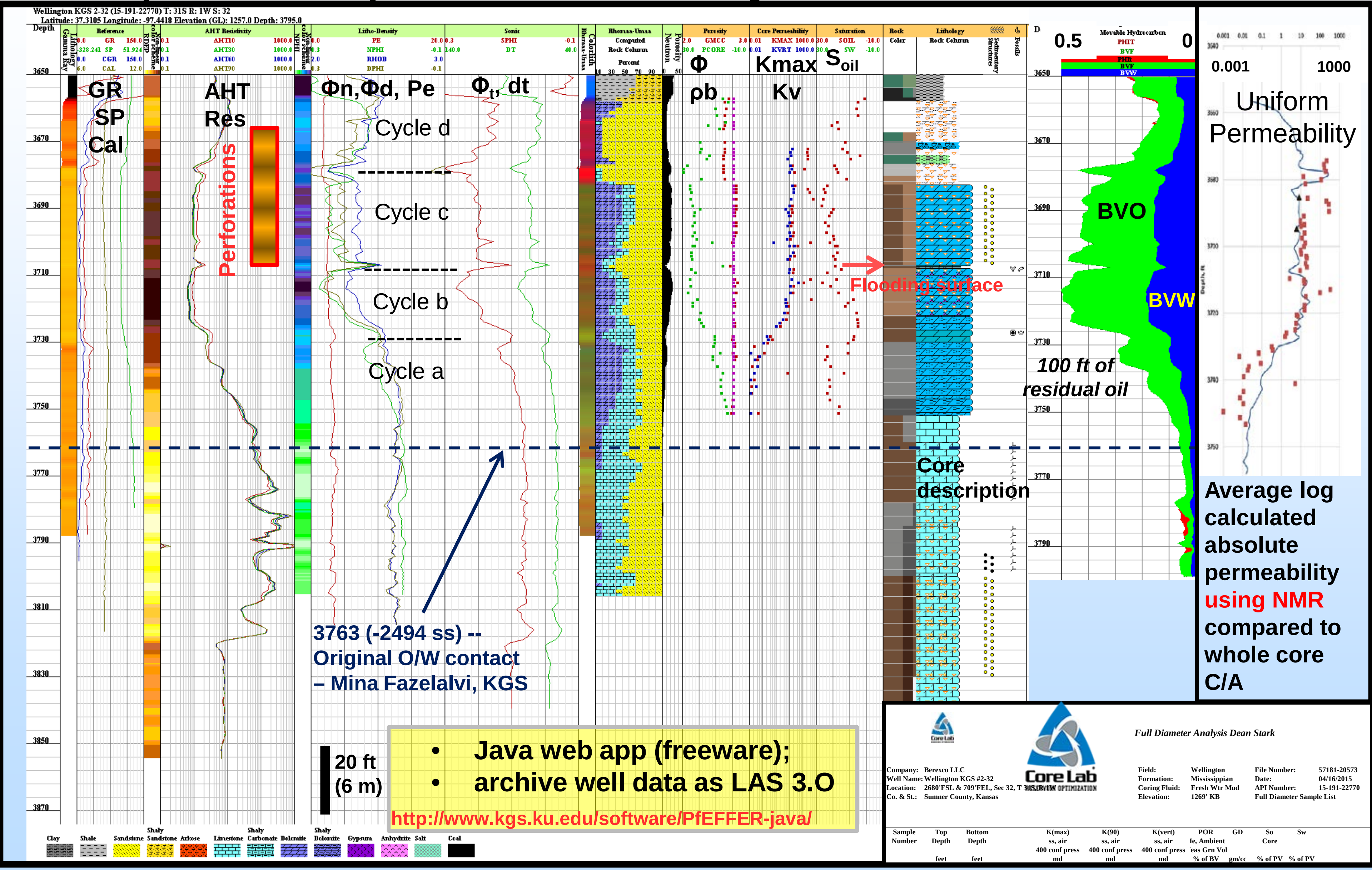
Montalvo (2015)

Rhombic Dolomite Euheral (idiotopic) Different Phases, Feroan and Non-Feroan



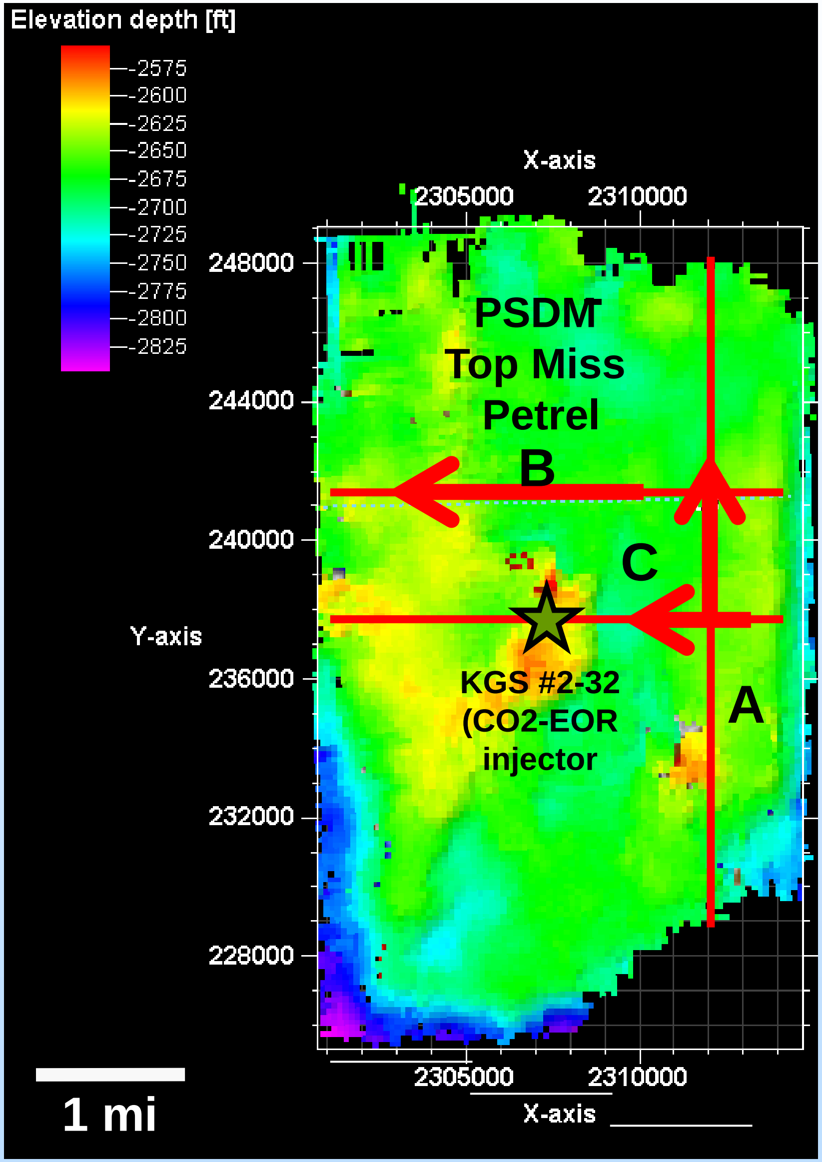
Montalvo (2015)

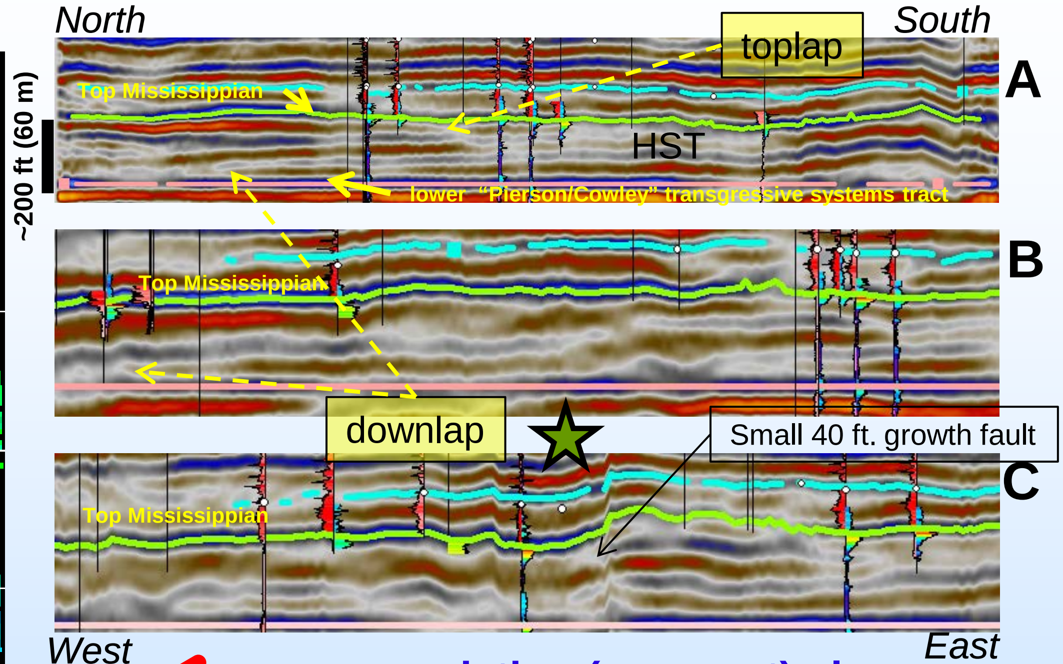
KGS #2-32 Mississippian reservoir interval, composition plot, core analysis, and moveable oil



Mississippian Seismic Stratigraphy using PSDM

→ complex progradational wedges in HST containing high-frequency cycles





progradation (apparent) along high stand systems tract (HST)

- **Complex progradation! …albeit slope ~1º**
- **Local <u>antecedent</u> and <u>syndepositional</u> structures impact stratal terminations**
- **Appears to compartmentalize the reservoir suggested by preliminary baseline water chemistry**

actual progradational vector

Jason Rush, KGS

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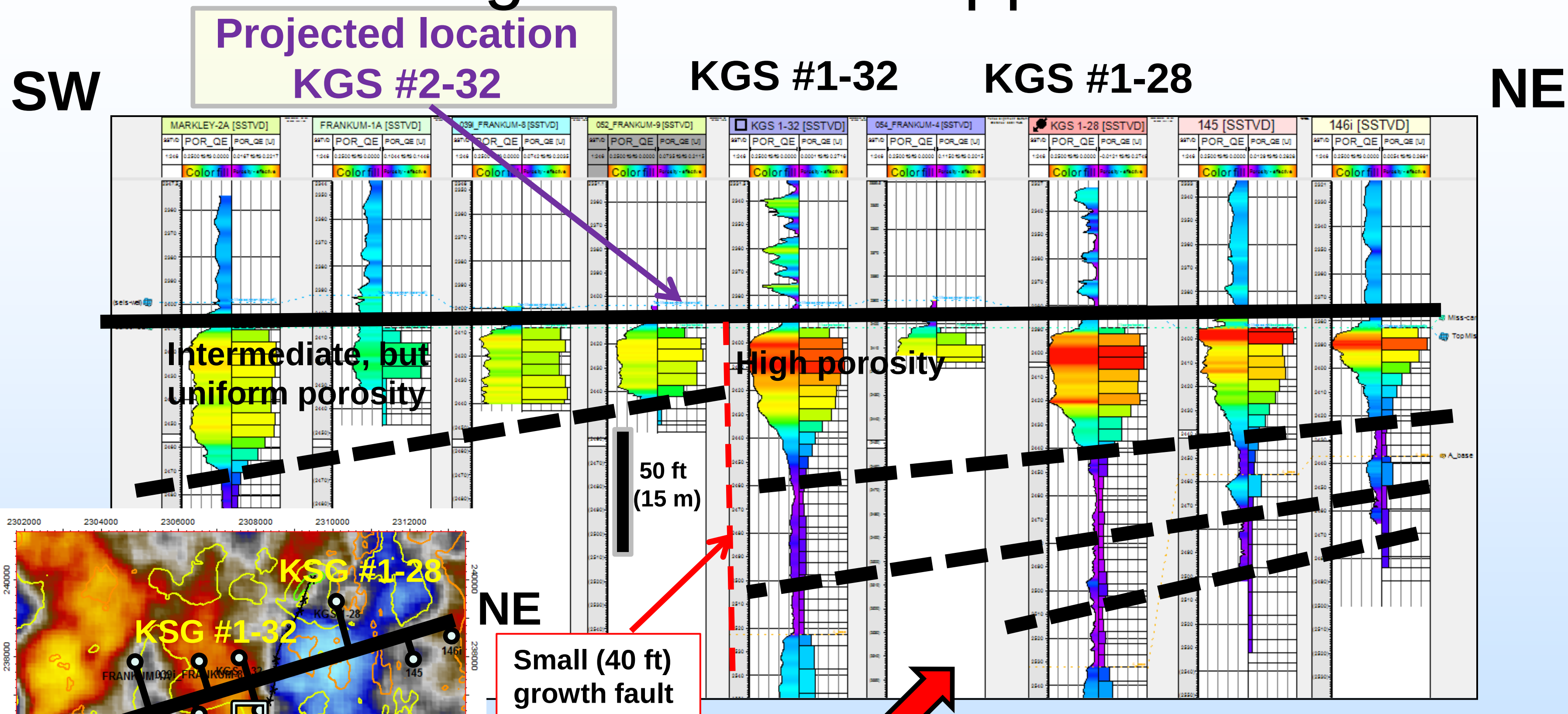
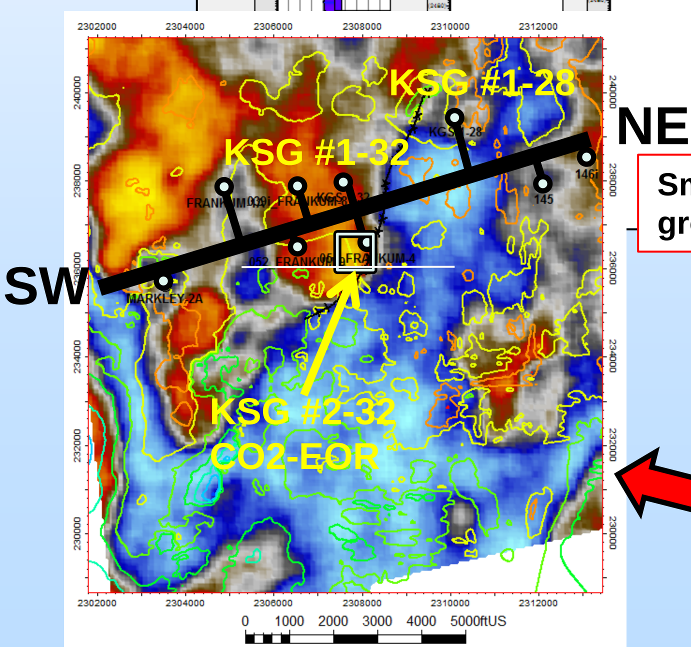
Progradational wedge geometries help to explain lateral changes in Mississippian reservoir





porosity thickening indicative of
low-angle ~1°, westward progradational wedges

Cross section index map
showing depth slice of amplitude

Rush, KGS

porosity thickening indicative of
low-angle ~1°, westward progradational wedges
Cross section index map
showing depth slice of amplitude

5 well step-rate test

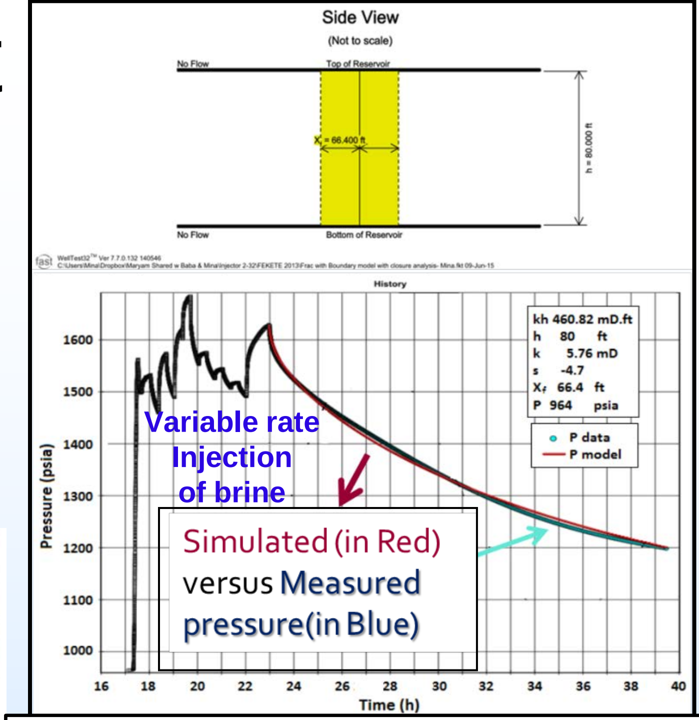
-- *Confirm reservoir pressure*

-- *Evaluate*:

  a) *connectivity between wells,*

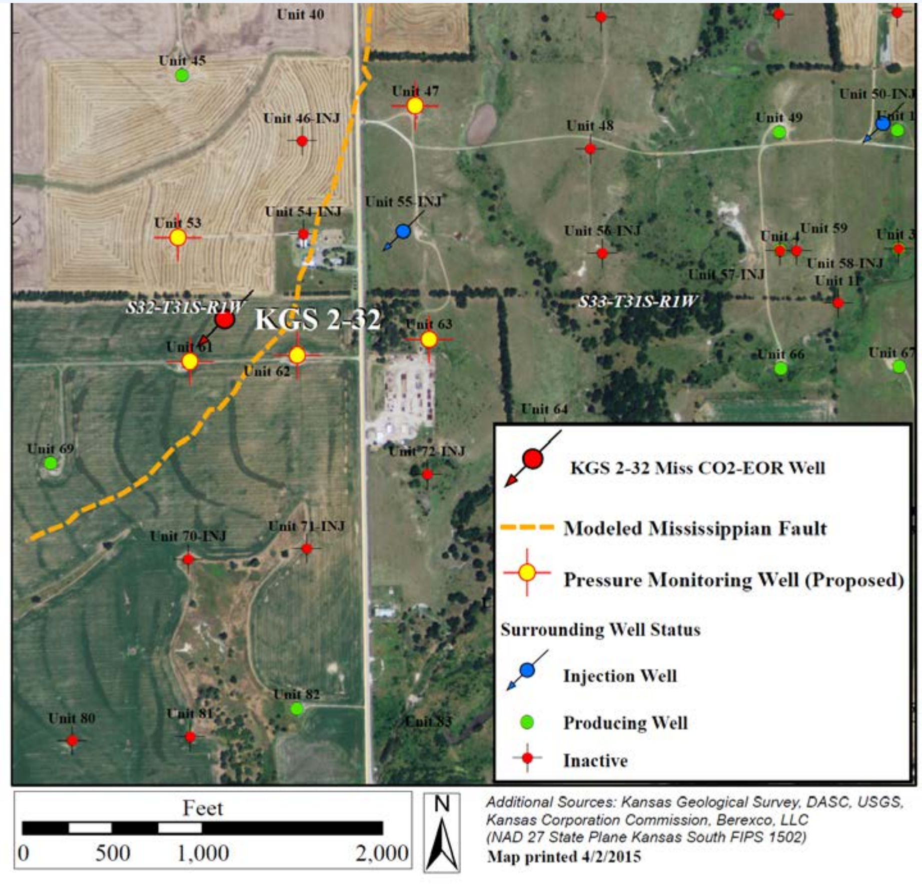
  b) *fracture vs. matrix flow,*

  c) *fracture closure pressure*



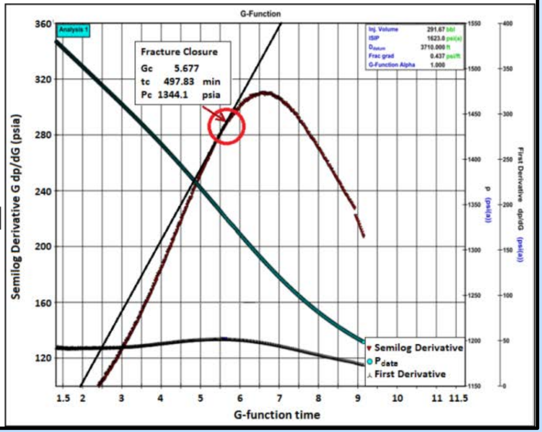
Current reservoir pressure ~900 psi

Fazelalavi KGS



Closure Pressure

- The slope on the G-function derivative defines the closure pressure where the derivative departs from the slope
- Closure pressure is 1334 psi
- Closure pressure gradient is 0.36 psia/ft
- Closure pressure is abnormally Low
- Fracture pressure and closure pressure are reduced due to pressure depletion, water injection and cooling



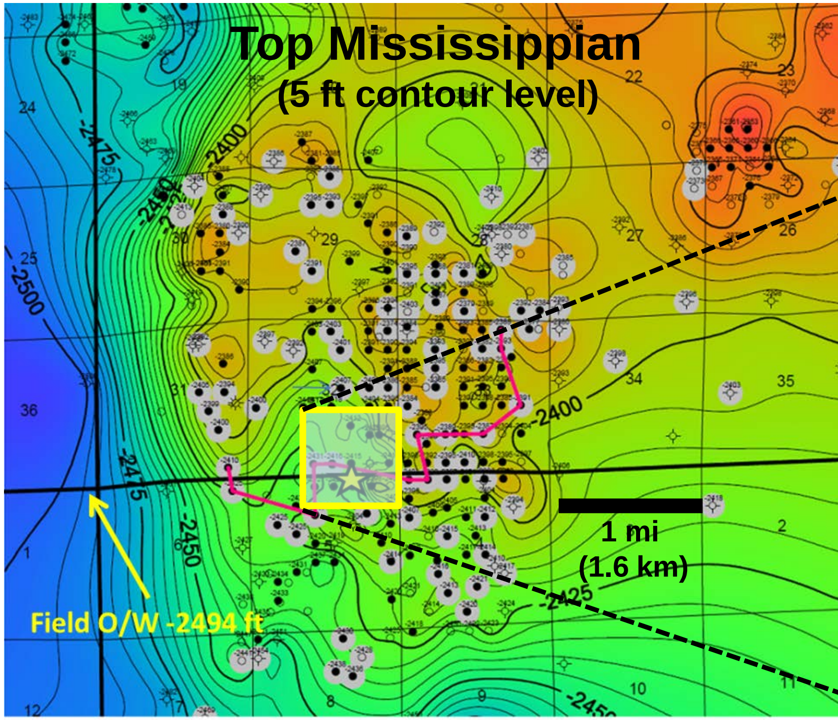
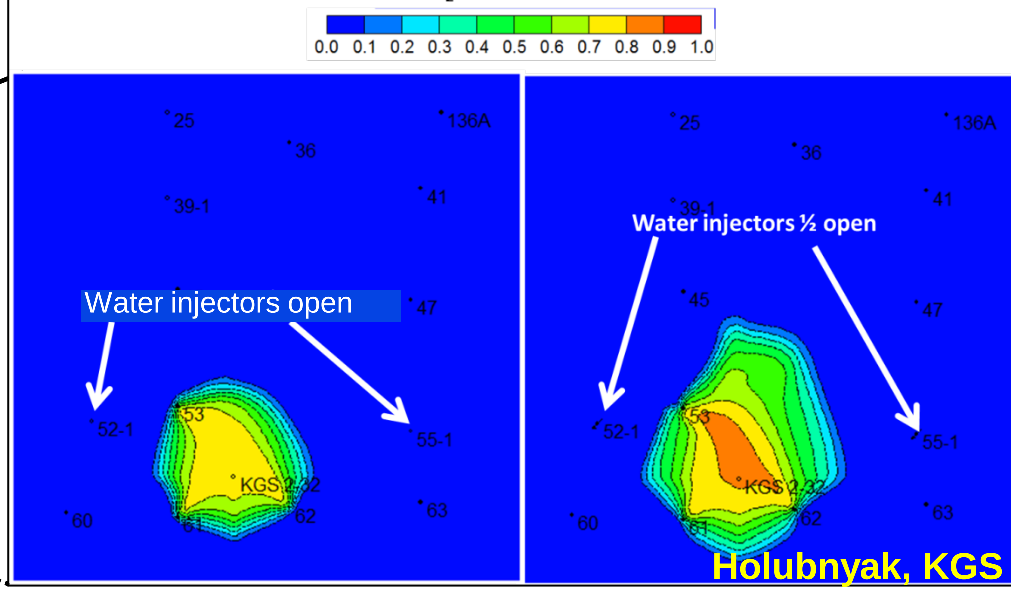
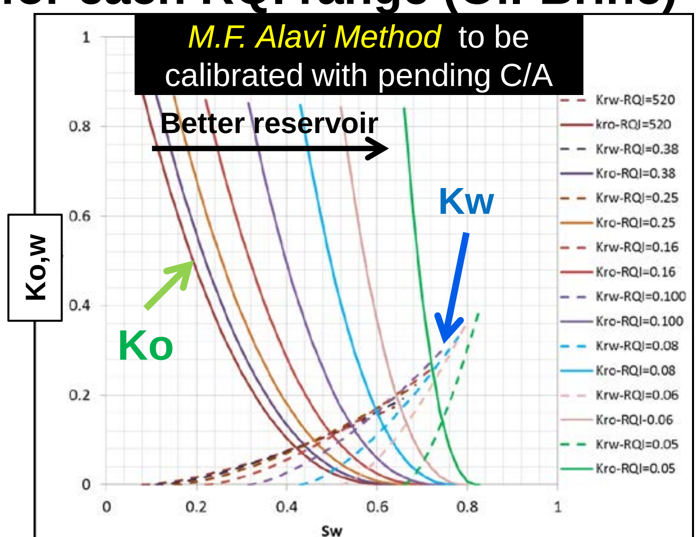


Figure 1: Contour map of Mississippian formation in Wellington field

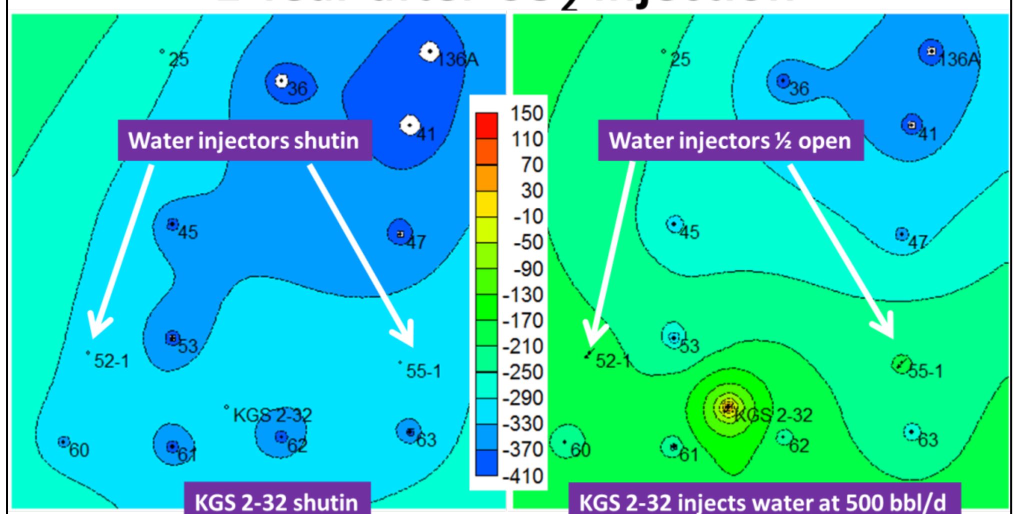
Forecasted CO_2 Movement in Reservoir



Imbibition Relative Permeability for each RQI range (Oil-Brine)

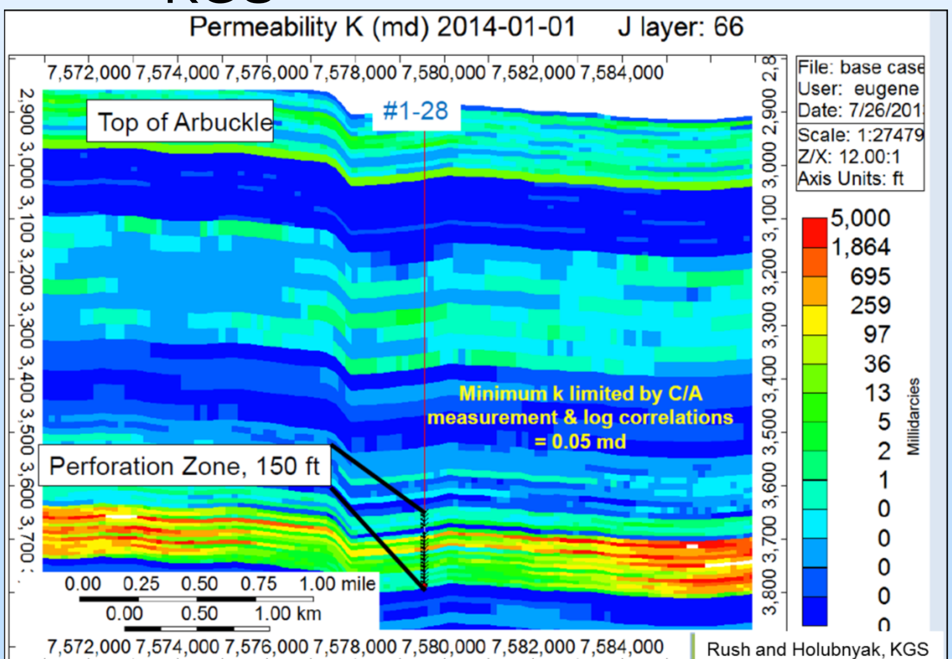


Forecasted Pore-Pressure Distribution 1 Year after CO_2 Injection

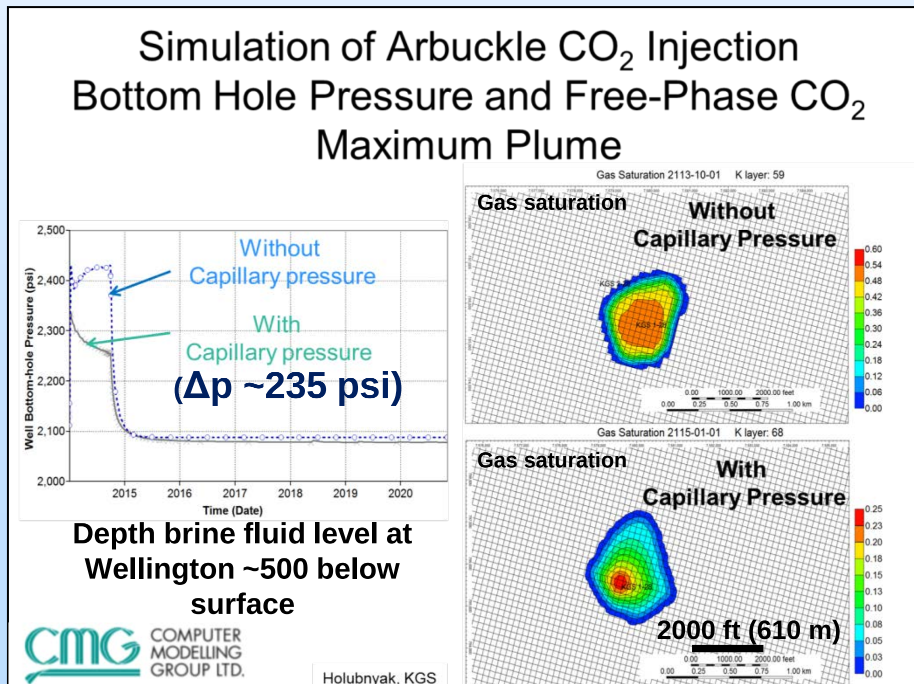


Technical Status

- **Milestone 2 - Submitted Class VI application, June 2014**
  - **Status of application** – a) address remaining requests for information (RAI's), b) resample shallow water wells and confirm assessment of UDSW, c) revise, synchronize, and confirm KGS Petrel/CMG and EPA STOMP simulations of the conservative CO_2 plume
  - **Obtain findings** by EPA on Area of Review (*AoR*), financial assurance, post injection site care (*PISC*), obtain draft of Class VI permit for public comment, application filed by Berexco, LLC & preparation managed by KGS



Petrel



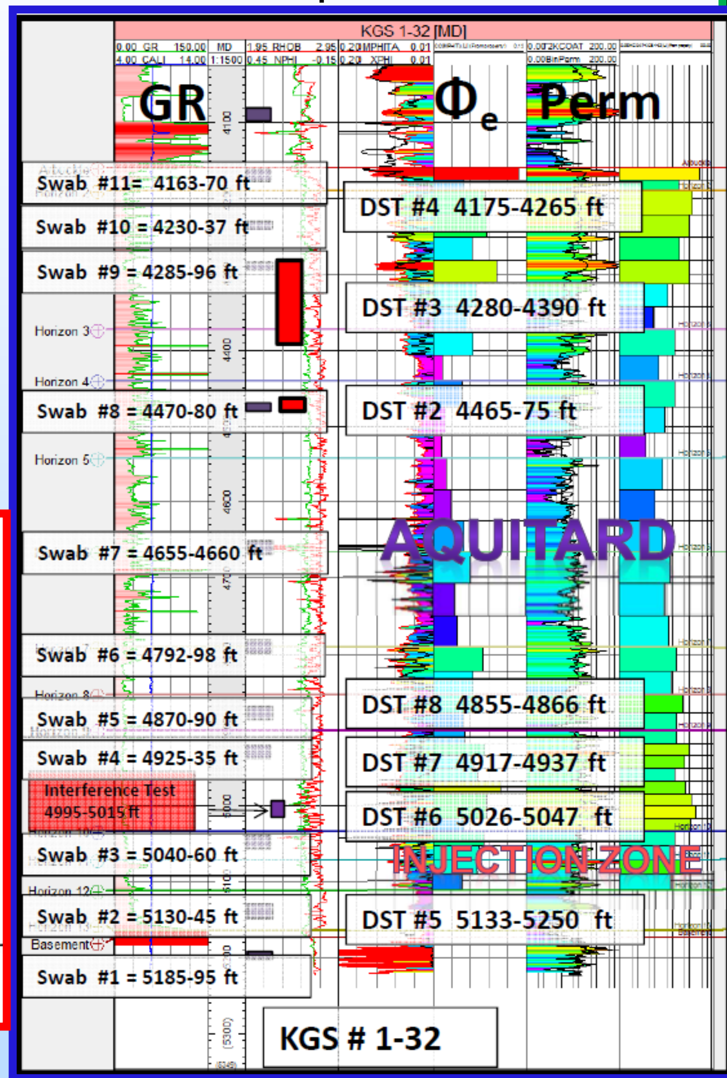
Holubnyak, KGS

Information collected on Arbuckle for saline aquifer

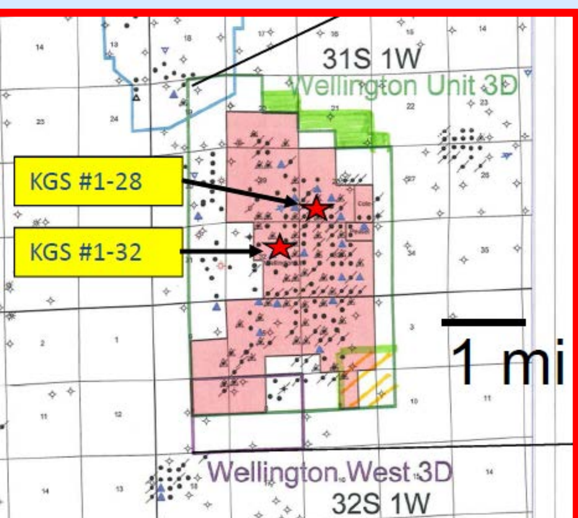
- Multicomponent 3D seismic under DE-FE0002056
- 2 basement tests (#1-32 & #1-28)
- 465 m (1528 ft) core
- Extensive log suite
- Multiple well tests

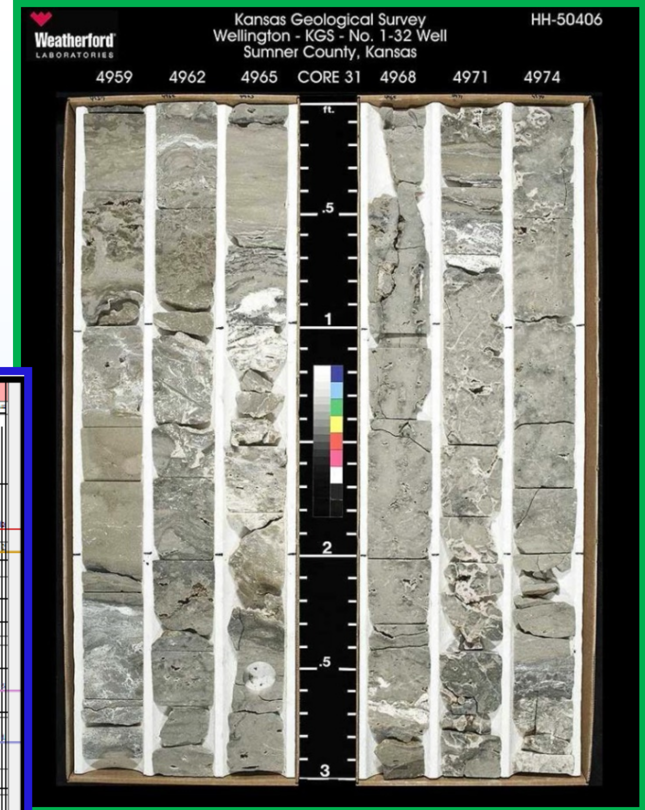
Arbuckle Saline Aquifer Interval KGS #1-32

200 ft (60 m)



Multicomponent 3D Seismic Survey





Example of core from CO_2 injection interval in lower Arbuckle; zonal evaporite karst

- **11 swabbing intervals and 8 DSTs targeted**
- **Evaluate both tight and high porosity zones throughout the Arbuckle**
- **Three distinct hydrostratigraphic units in the Arbuckle (H,O stable isotopes)**

Selected Core from Lower Ordovician Arbuckle Group (portion of 1528 ft of core)

5089-92 ft

Porous and Permeable proposed Class VI Injection Interval

Vug and interparticle Ø

5080-83

Crackle breccia w/ Ø

5053-56

4995-97.7 ft

Vugs and interparticle Ø

Fine interparticle Ø

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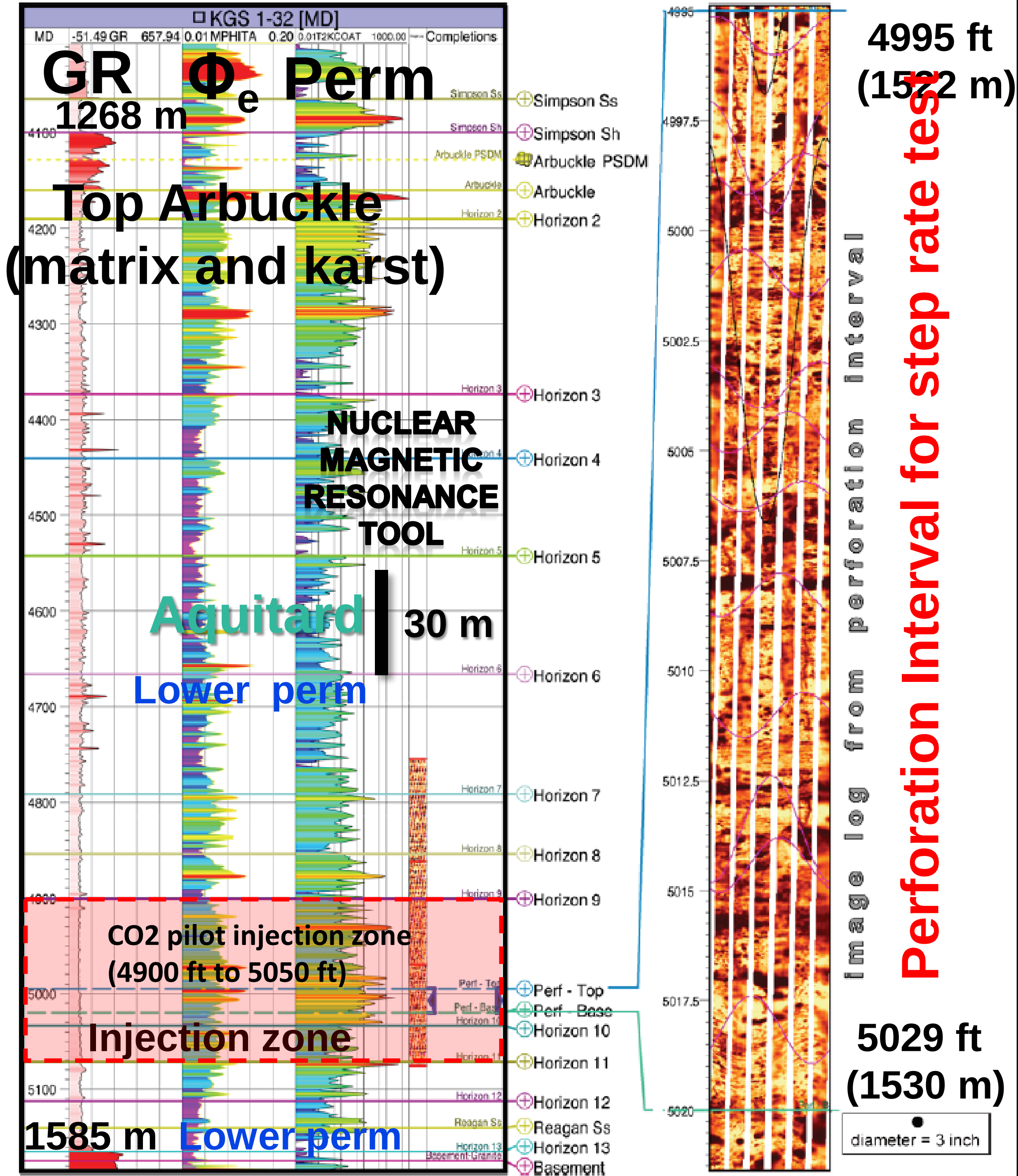
Aquiclude/baffle in the middle of the Arbuckle above proposed Class VI injection interval ~400 ft thick

argillaceous dolomite & shale



Berexco Wellington KGS #1-32

Porous crackle breccia common in injection zone (dissolved evaporites)

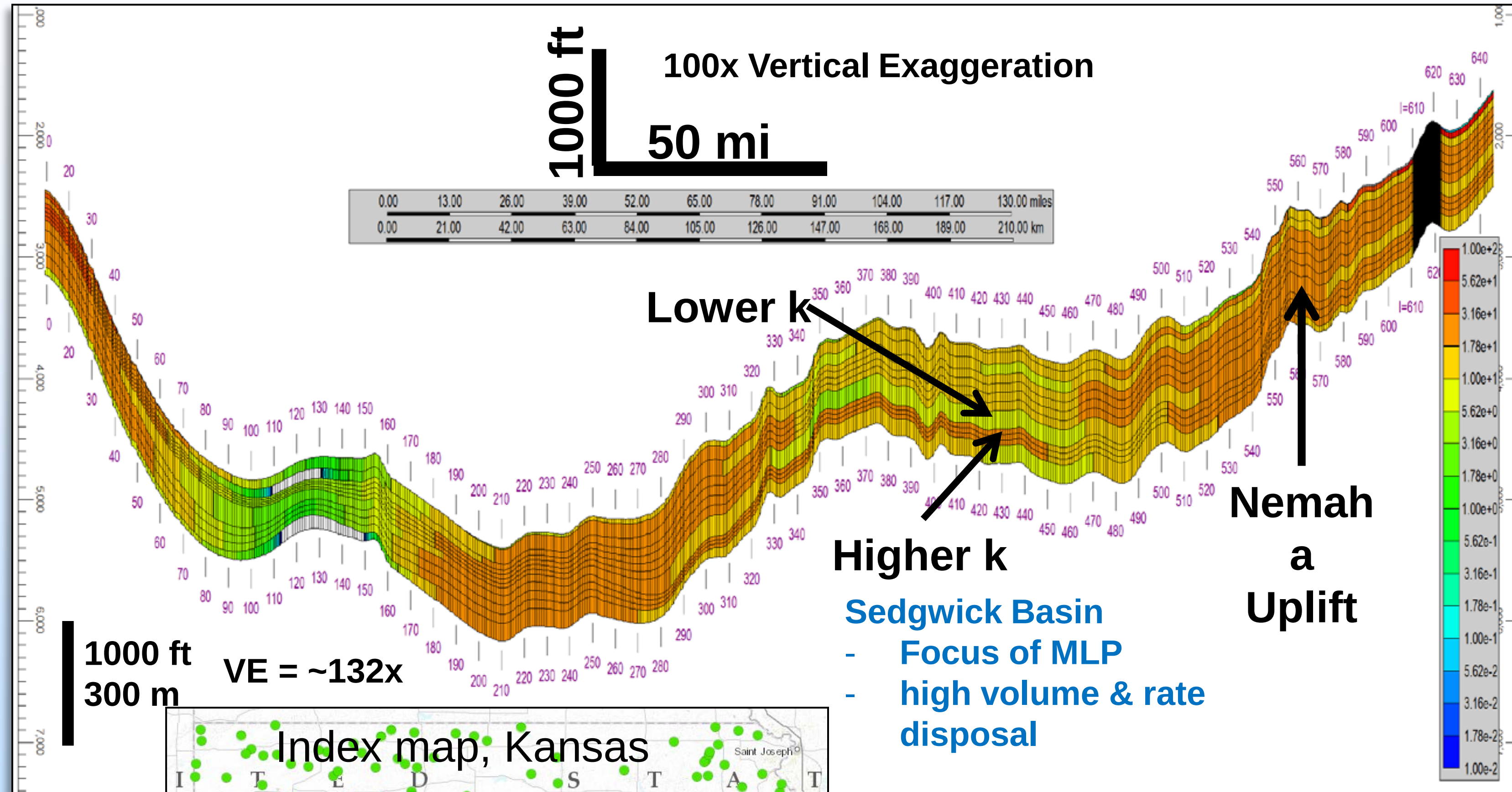
- **Gamma ray**
- **Halliburton derived effective porosity from Nuclear Magnetic Resonance (NMR)**
- **Coates Permeability from NMR tool**
- **Microresistivity imaging log (MRIL)**

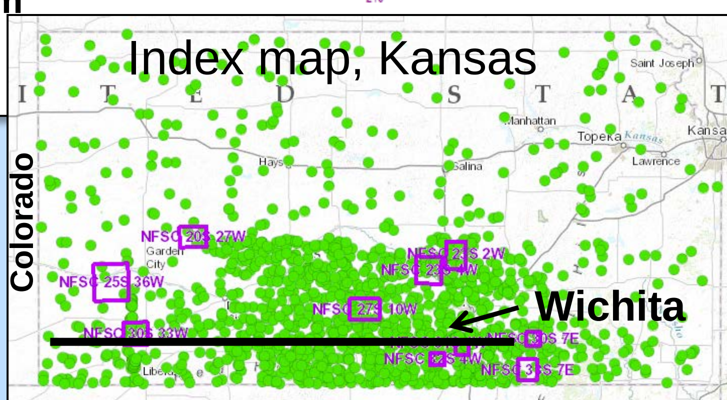
J. Rush, KGS

HALLIBURTON

Schlumberger Petrel

West-East structural cross section showing permeability distribution in 16 Arbuckle flow units, southern Kansas

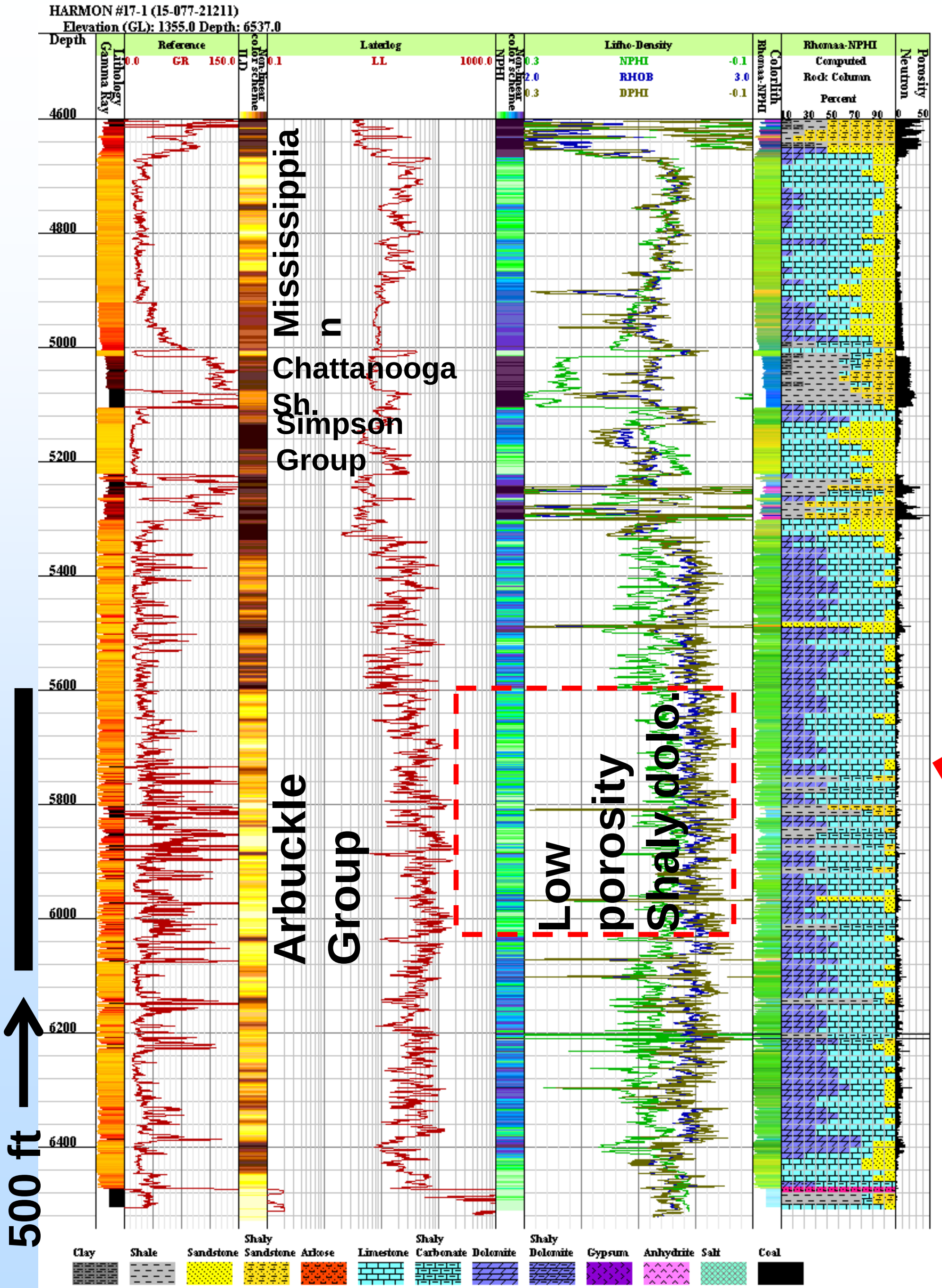


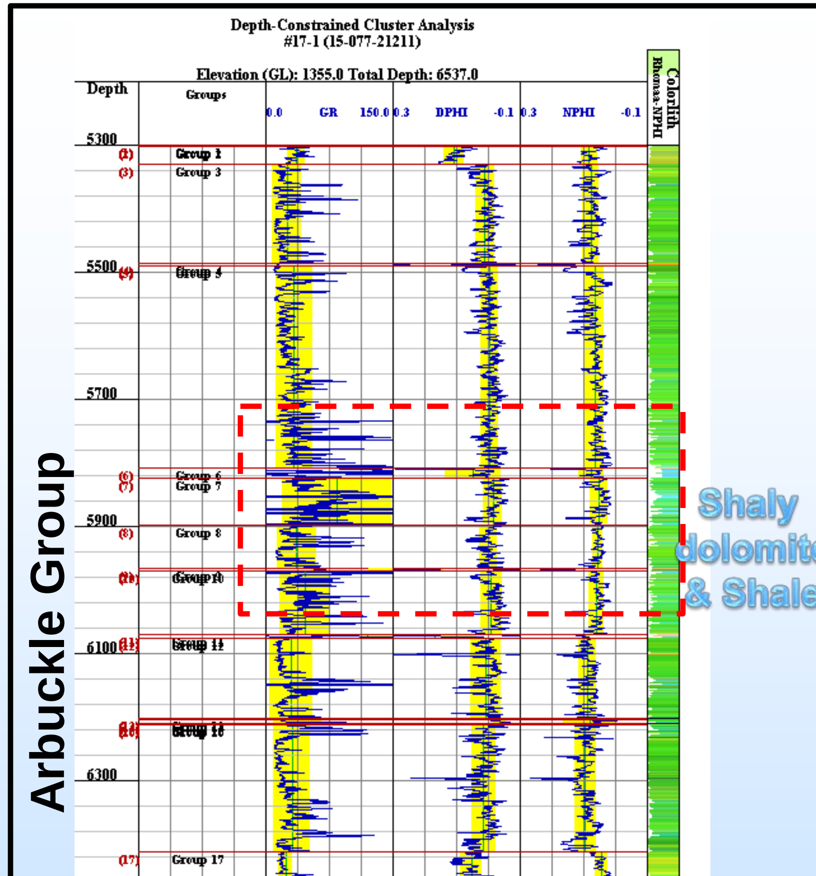


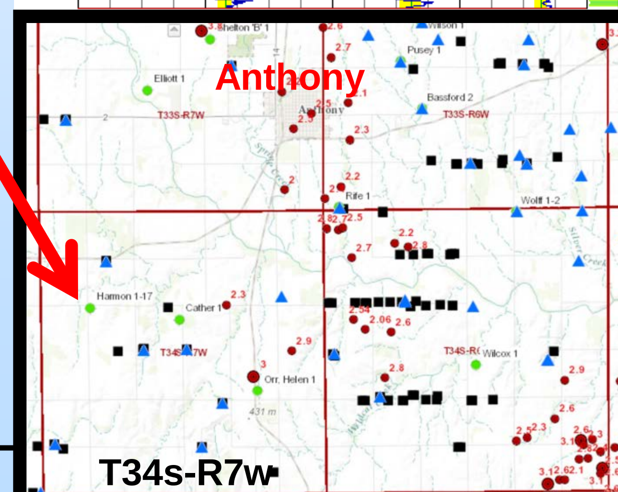
Based on neutral network model realizations of horizontal permeability calibrated with core, logs, test data at Wellington and Cutter Fields

Williams, Gerlach, Fazelalavi, Doveton, KGS team, KS CO_2

Phillips Exploration Co. Harmon #1-17 (1994 completion)/triple combo logging and full Arbuckle section



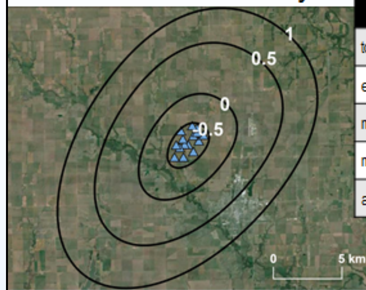




• Milestone 3. Pre-injection MVA baseline recording

- ❑ Obtaining data from a 18 seismometer array since Fall 2014
- ❑ Collecting data from cGPS and inSAR for processing since August 2014
- ❑ Sampling 3 shallow monitoring wells around KGS #1-28
- ❑ Obtained baseline fluid geochemistry in 10 wells from Mississippian oil reservoir

Network Sensitivity



- Minimum magnitude versus distance from the network
- Operational seismicity from active waterflood being recorded in Wellington Field
- Research underway to improve location of hypocenters of events

Local Activity

Events detected at ≥7 stations†	
total events	53
events/day	4
minimum magnitude	-0.3
maximum magnitude	1.4
average magnitude	0.6

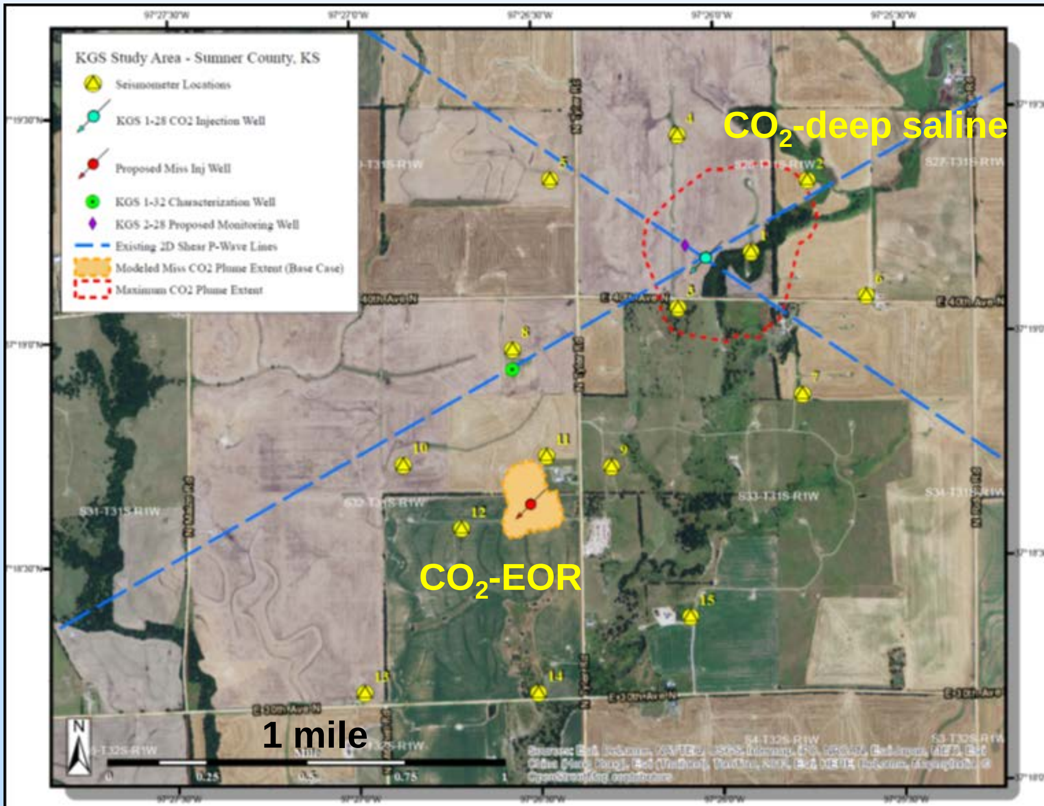
- Earthworm software for automated detection of earthquakes.
- Reporting 2.5+ magnitude per USGS convention.

†initial recording over one weeks time

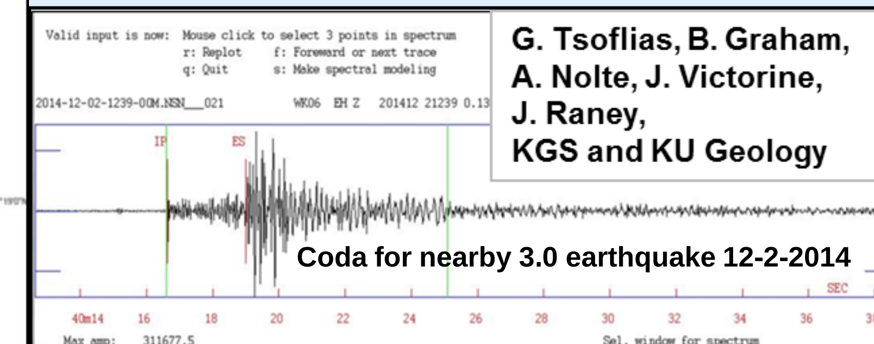
R. Miller and S. Peterie, KGS

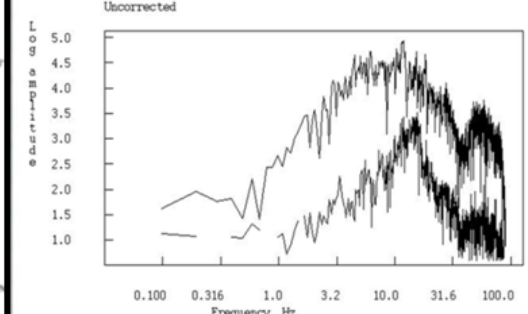
Housing setup for Sercel (Mark Products) L-22D-3D sensors, ~5 ft below surface to minimize surface noise; installed below frost line in bedrock

R. Miller & S. Petrie, KGS installation



G. Tsoflias, B. Graham, A. Nolte, J. Victorine, J. Raney, KGS and KU Geology

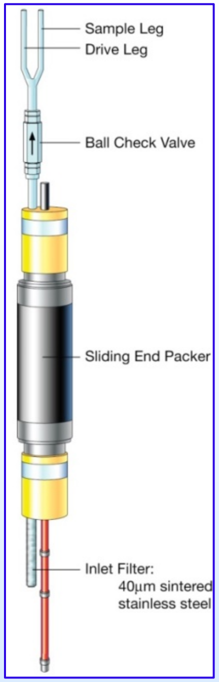




Event frequency spectrum

General parameters, P-spectrum
Vel 6.4 Dens 2.79 Dist 15 Depth 10
Q0 500 Qalp 0.7 k 0.01 q<1Hz 1.0 Spec model
Spectral frequency band 0.010 90.000

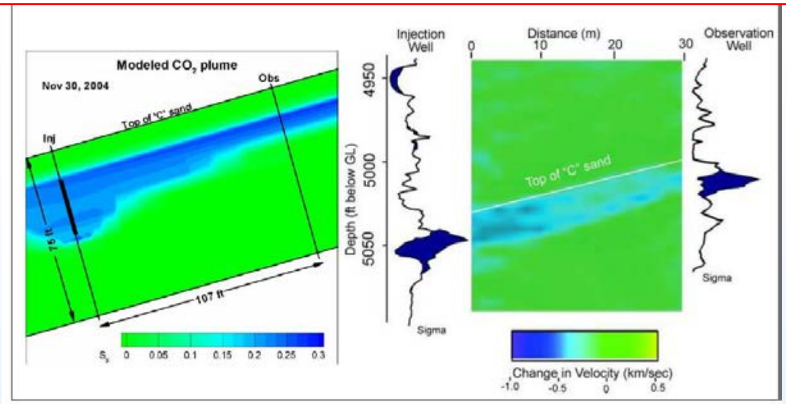
Additional Monitoring Technologies



U-Tube

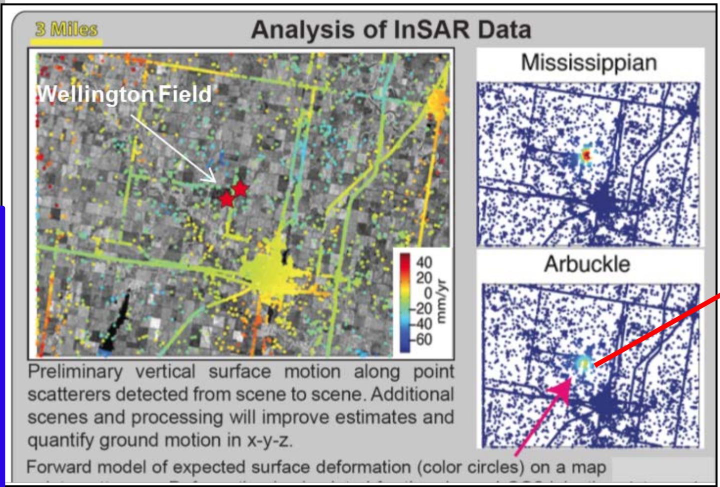
B. Freifeld, LBNL

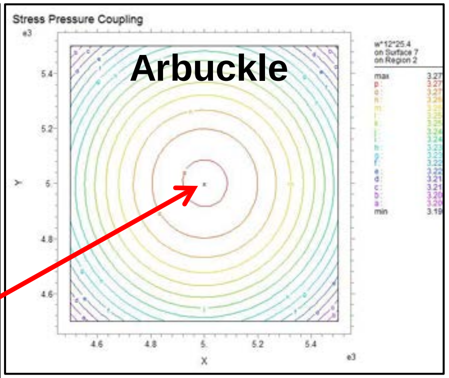
CASSM & Croswell Seismic Tomography



T. Daley, LBNL

Stress Pressure Coupling Simulation





- ❑ **cGPS recording since August 2014**
- ❑ **SAR data being collected ~20 day intervals**
- ❑ **Prospect remains to secure distributed Fiber Optic Arrays for repeat VSP**

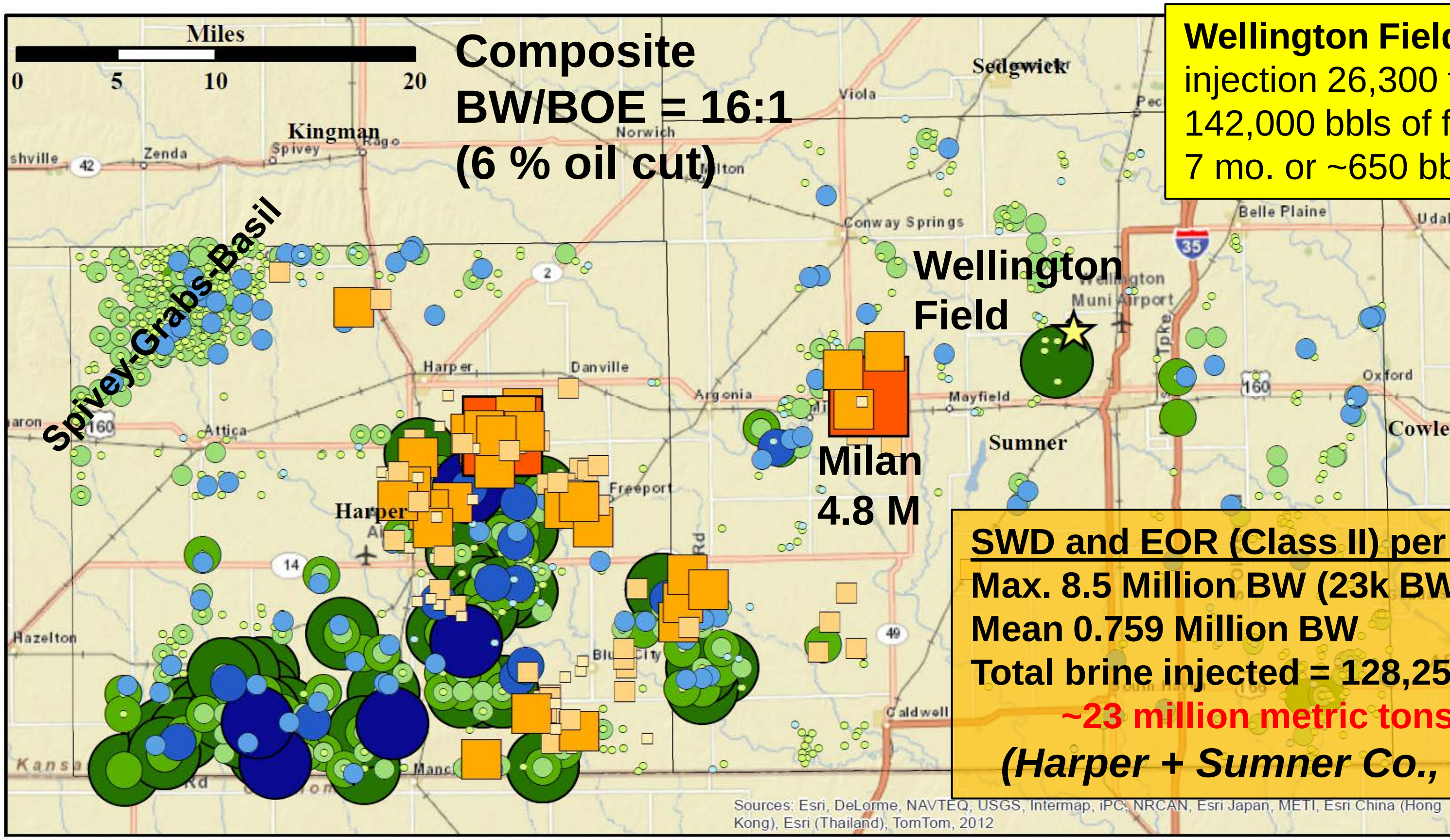
(*R. Trautz, DE-FE-OO12700*)

Persistent Point Scatterers being tracked from scene to scene
→ **potential remains to infer Δp from surface motion**

New geomechanical model #2 → predicts approximately 3 mm surface deformation in areal extent shown on map above ~1,000 feet by 1,000 feet – T. Birdie

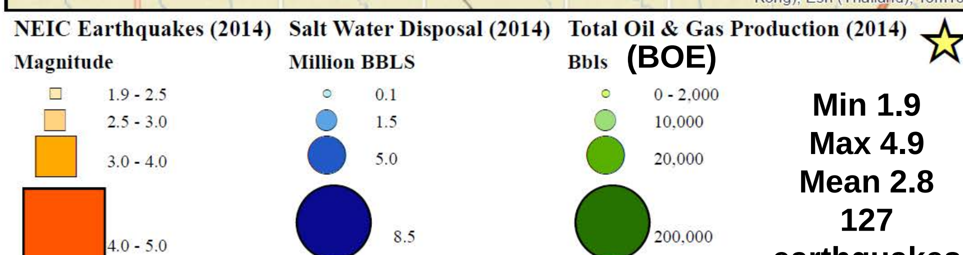
Induced seismicity west of Wellington Field

Total salt water injected by well (blue circle), BOE produced by oil lease (green circle) and earthquakes (orange square) <u>in 2014,</u> Harper and Sumner Counties, Kansas



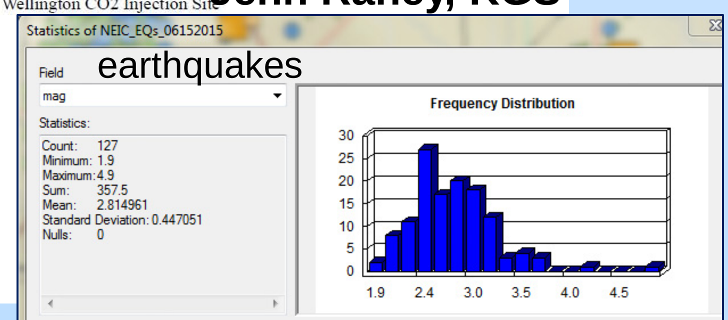
Wellington Field scheduled injection 26,300 tons = 142,000 bbls of fluid over 7 mo. or ~650 bbls per day

<u>SWD and EOR (Class II) per well in</u>
Max. 8.5 Million BW (23k BW/day)
Mean 0.759 Million BW
Total brine injected = 128,254,699 bbls
~23 million metric tons CO_2
(Harper + Sumner Co., 2014)



Jenn Raney, KGS

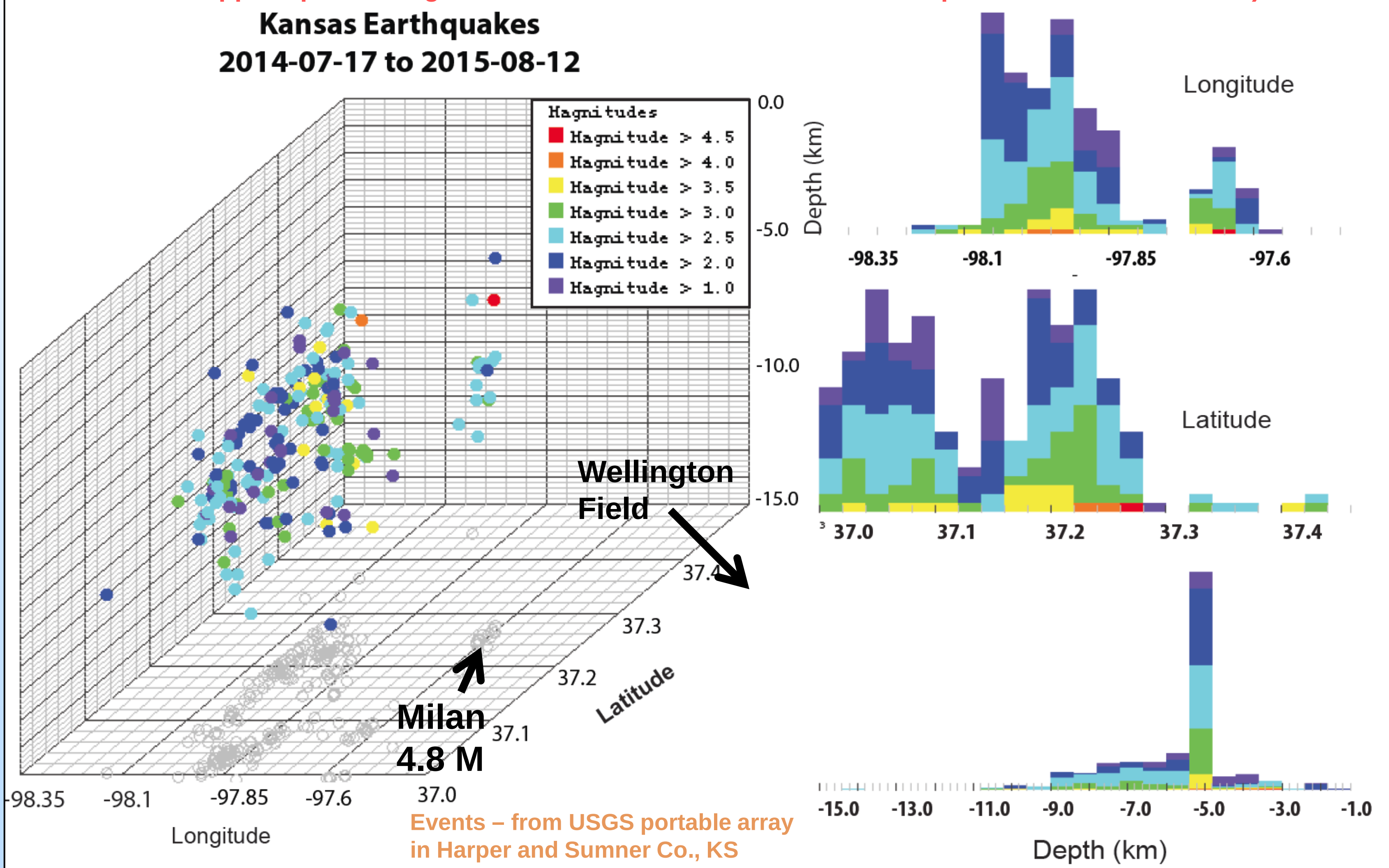
Min 1.9
Max 4.9
Mean 2.8
127 earthquakes in 2014



Testing pseudo 3D display web app

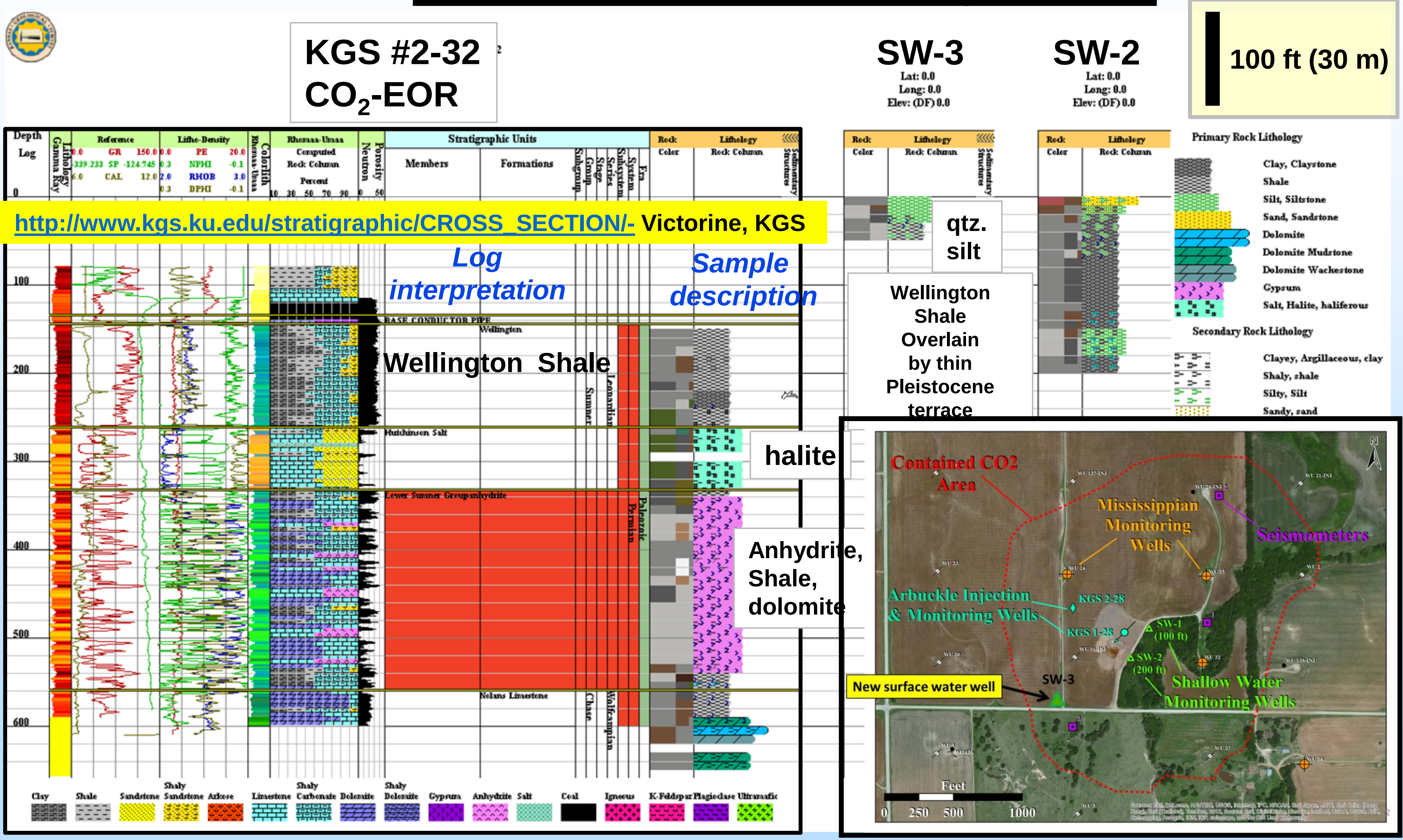
to map solutions of hypocenters of earthquakes in two county area SW of Wellington Field

Web app: http://www.kgs.ku.edu/PRS/Ozark/Software/KS_Earthquake_3DPlot/index.html).

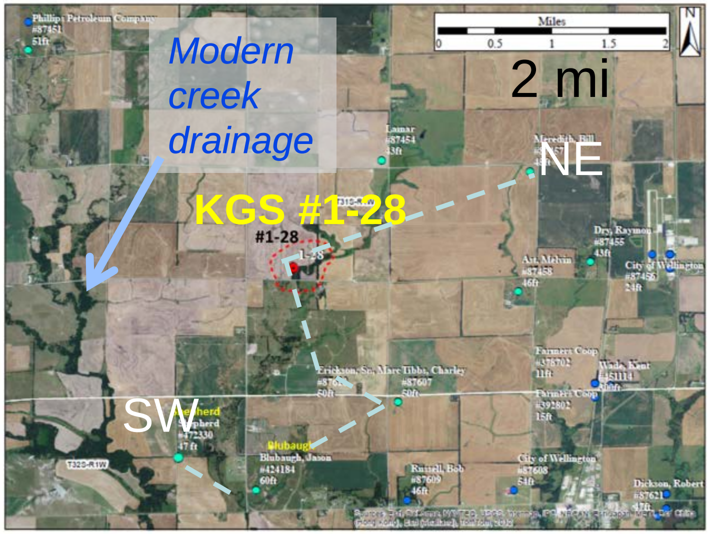


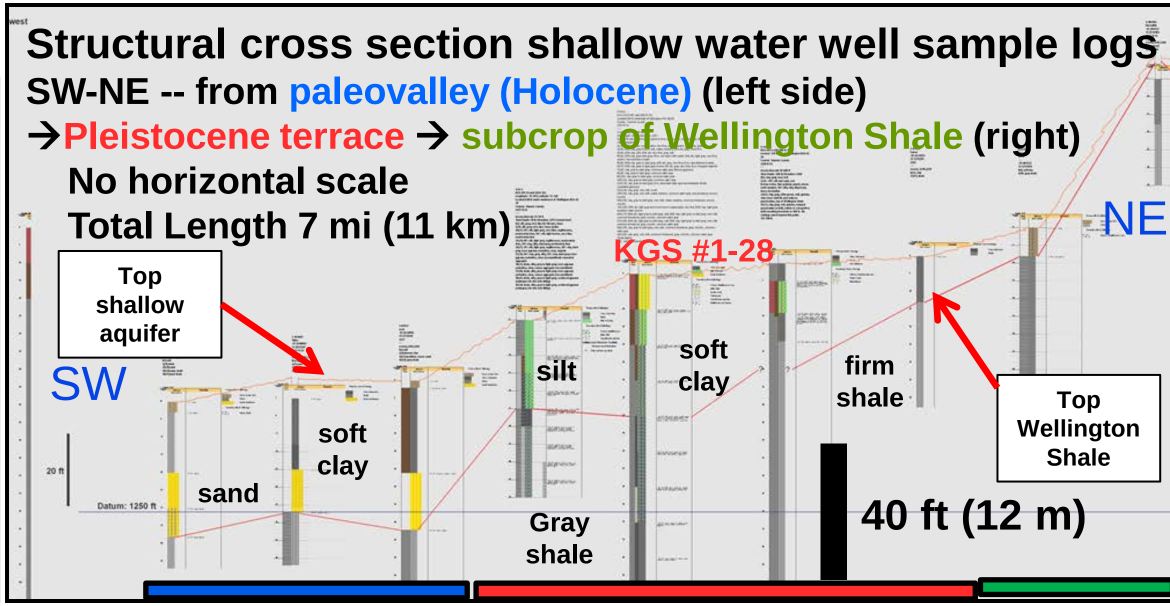
Events – from USGS portable array in Harper and Sumner Co., KS

SW-NE well log and sample cross section extending from new CO_2-EOR injection well to the **shallow monitoring wells**

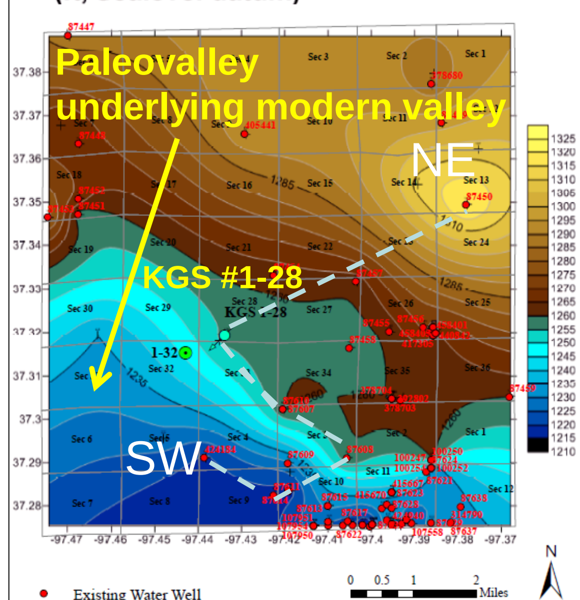


Shallow aquifer distribution and interaction with surface water

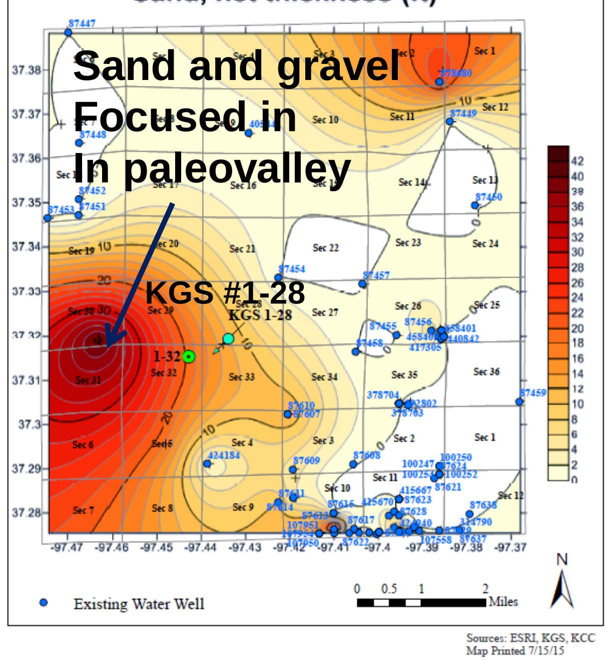




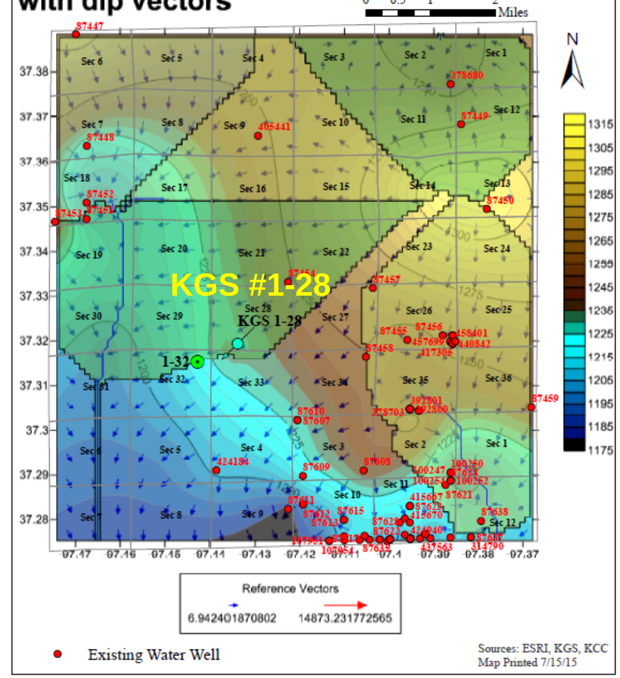
Top shallow unconfined aquifer (ft, sealevel datum)

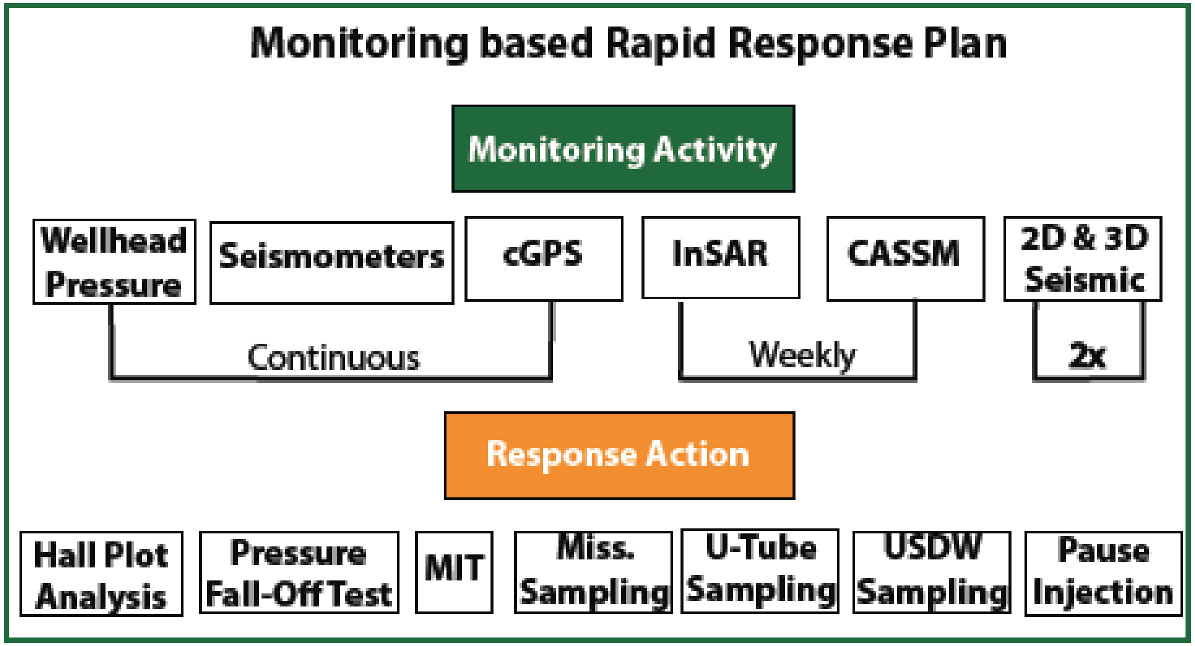


Sand, net thickness (ft)



Drainage
Top Wellington Shale (ft, sealevel datum) with dip vectors





- Injection Control Plan
- Wellington Seismic Action Plan
- Monitoring-based Rapid Response Plan
- Emergency Remedial Response Plan

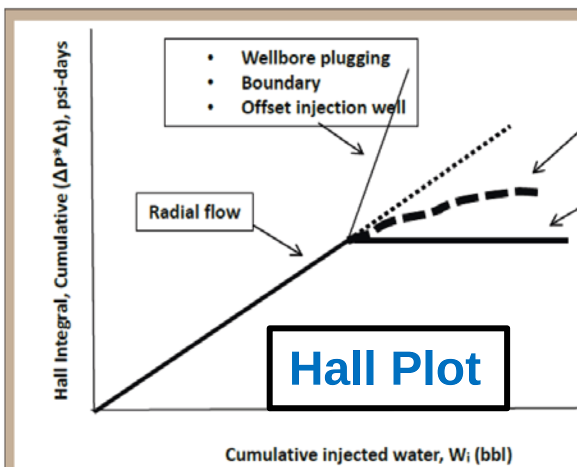


Illustration of Hall Plot depicting normal radial flow and changed reservoir conditions - as recommended by EPA

http://www.epa.gov/r5water/uic/ntwg/pdfs/induced-seismicity-201502.pdf

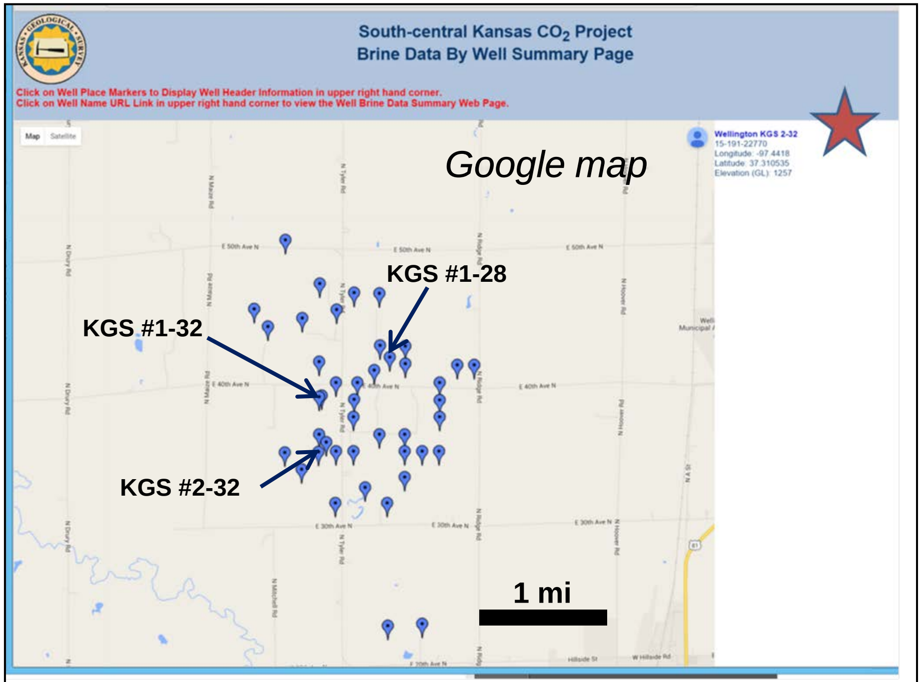
Under review by EPA

Operational plan for safe and efficient CO2 injection to Draft emergency and remdial response plan for Class VI permit

The success of the Monitoring and Rapid Response Plan to provide early warning is based on prioritizing the monitoring technologies by establishing:

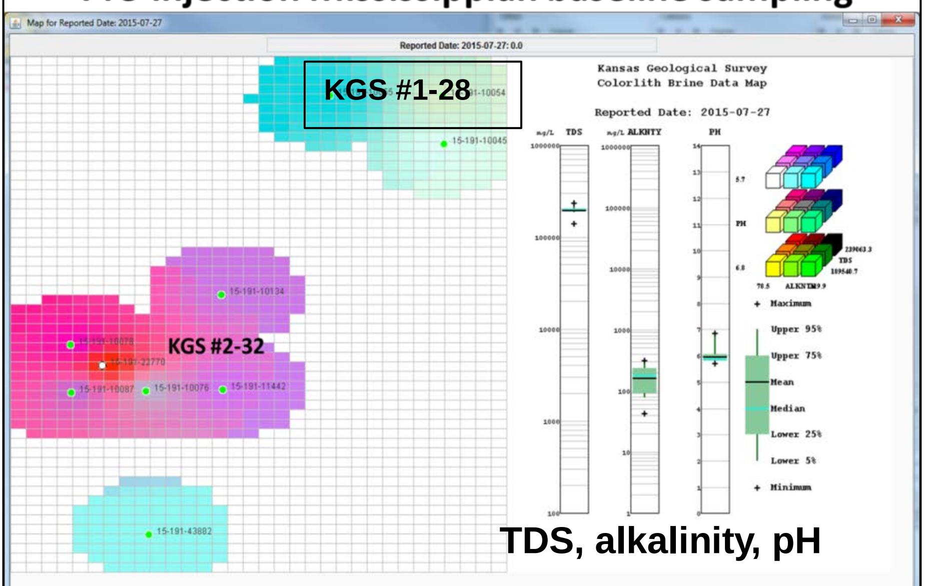
1) reliability of the data and approaches used to analyze the data,
2) frequency that the data is acquired during injection
3) sensitivity and precision of the monitoring method and its ability to detect small changes in CO_2 plume behavior;
4) location and therefore resolution from which the data is collected,
5) spatial resolution and coverage of the CO_2 plume; and
6) ability to detect movement out of the injection zone both above and below the injection zone.

Baseline water sampling at surface and in the **Mississippian oil reservoir**



http://www.kgs.ku.edu/PRS/Ozark/Software/google-maps/brine_data_by_wells.html

Pre-injection Mississippian baseline sampling



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

South-central Kansas CO_2 Project
Brine Data Types Database Table Contents

Cations

ID	Mnemonic	Description
0	Si	Silicon
1	NH4	Ammonium
2	H3O	Hydronium
3	Li	Lithium
4	Na	Sodium
5	K	Potassium
6	Rb	Rubidium
7	Cs	Cesium
8	Be	Beryllium
9	Mg	Magnesium
10	Ca	Calcium
11	Sr	Strontium
12	Ba	Barium
13	Al	Aluminum
14	Sn	Tin
15	Sn2	Tin(II)
16	Sn4	Tin(IV)
17	Pb	Lead
18	Pb2	Lead(II)
19	Pb4	Lead(IV)
20	Sb	Antimony
21	Sb3	Antimony(III)
22	Sb5	Antimony(V)
23	Bi	Bismuth
24	Bi3	Bismuth(III)
25	Bi5	Bismuth(V)
26	Cr	Chromium
27	Cr2	Chromium(II)
28	Cr3	Chromium(III)
29	Mn	Manganese
30	Mn2	Manganese(II)
31	Mn3	Manganese(III)
32	Fe	Iron
33	Fe2	Iron(II)
34	Fe3	Iron(III)
35	Co	Cobalt
36	Co2	Cobalt(II)
37	Co3	Cobalt(III)
38	Ni	Nickel
39	Ni2	Nickel(II)
40	Ni3	Nickel(III)
41	Cu	Copper(I)
42	Cu2	Copper(II)
43	Ag	Silver
44	Au	Gold(I)
45	Au2	Gold(II)
46	Zn	Zinc
47	Cd	Cadmium
48	Hg2	Mercury(I)
49	Hg	Mercury(II)
100	Mo	Molybdenum
101	Te	Tellurium
102	Ti	Titanium
103	Tl	Thallium
104	U	Uranium
105	V	Vanadium
106	W	Tungsten
107	Y	Yttrium

Anions

ID	Mnemonic	Description
50	H	Hydride
51	F	Fluoride
52	Cl	Chloride
53	Br	Bromide
54	I	Iodide
55	OH	Hydroxide
56	BO3	Borate
57	CO3	Carbonate
58	HCO3	Bicarbonate
59	OCl	Hypochlorite
60	ClO2	Chlorite
61	ClO3	Chlorate
62	ClO4	Perchlorate
63	CN	Cyanide
64	NCO	Cyanate
65	OCN	Isocyanate
66	SCN	Thiocyanate
67	N	Nitride
68	N3	Azide
69	NO2	Nitrite
70	NO3	Nitrate
71	NH2	Amide
72	MnO4	Permanganate
73	P	Phosphide
74	PO3	Phosphite
75	PO4	Phosphate
76	HPO4	Hydrogen phosphate
77	H2PO4	Dihydrogen phosphate
78	As	Arsinide
79	AsO4	Arsenate
80	AsO3	Arsenite
81	Se	Selenide
82	S	Sulfide
83	HS	Hydrogen Sulfide
84	SO3	Sulfite
85	HSO3	Hydrogen Sulfite
86	S2O3	Thiosulfate
87	SO4	Sulfate
88	HSO4	Bisulfate
89	O	Oxide
90	IO3	Iodate
91	BrO3	Bromate
92	OBr	Hypobromite
93	CrO4	Chromate
94	Cr2O7	Dichromate
95	CH3COO	Aceta
96	HCOO	forma
97	O2	Perox
98	C2O4	Oxala

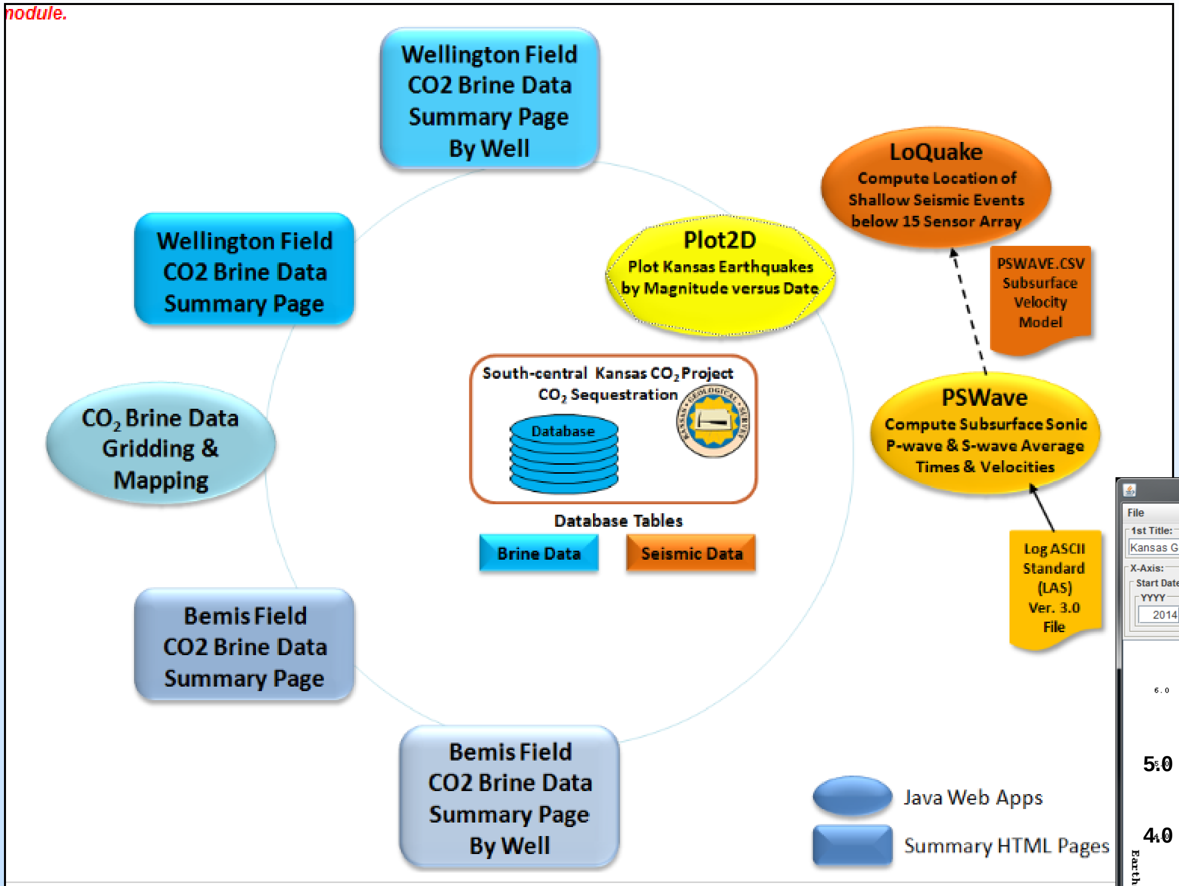
Other Data

ID	Mnemonic	Description
110	CO2	aqueous CO2
111	H2S	aqueous H2S
112	O2	aqueous O2
200	SPGR	Specific Gravity
201	SIGMA	Specific Conductivity
202	SIGMA2	Specific Conductivity 2
203	PH	PH
204	degF	Temperature (degrees F)
205	degC	Temperature (degrees C)
206	DEGi	Initial Temperature
207	DEGf	Final Temperature
208	DEGa	Average Temperature
209	PSI	Pressure (psi)
210	PSIi	Initial Pressure (psi)
211	PSIf	Final Pressure (psi)
212	OHM	Resistivity (Rw)
213	OHM75	Resistivity at 75 deg F
214	OHME	Estimated Rw
215	TDS	Total Solids
216	TDSe	Estimated Total Dissolved Solids
217	TDSc	Total Solids Computed
218	NTU	Trubidity
219	mV	Redox Potential
220	SALNTY	Salinity
221	HARDNESS	Total Hardness
222	RATIO	Anion/Cation Ratio
223	FLUID	Sample Volume
224	GMCC	Fluid Density
225	ALK	Alkalinity-Spectrometer
226	ALK2	Alkalinity-Test Kits
300	FORM	Formation
301	AGE	Formation Age
302	TOP	Top Depth
303	BASE	Base Depth
400	deg-Multi	Temperature Multi-meter
401	deg-Cond	Temperature Cond-meter
501	NH4-2	Ammonium-SPEC
533	Fe2-2	Iron-SPEC
569	NO2-2	Nitrite-SPEC
570	NO3-2	Nitrate-SPEC
587	SO4-2	Sulfate-SPEC
630	Mn2-3	Manganese-KIT
633	Fe2-3	Iron-KIT
652	Cl-3	Chloride-KIT
675	PO4-3	Phosphate-KIT

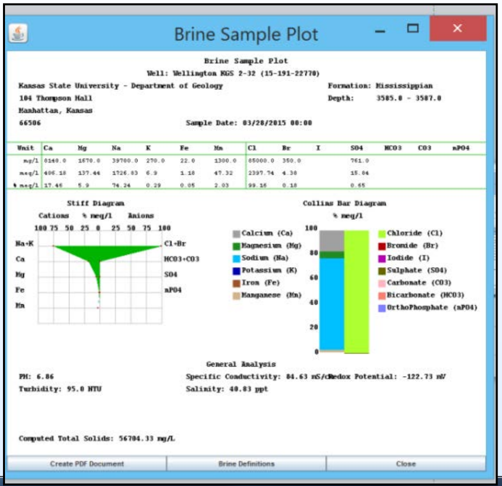
Brent Campbell, Chance Reese, Saugata Datta KSU, John Victorine, J. Raney, John Doveton, KGS

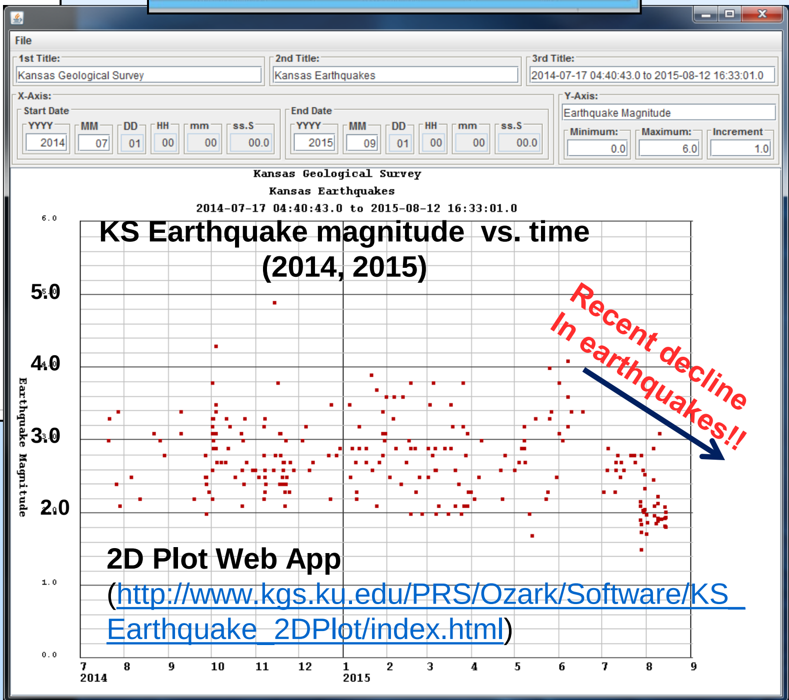
http://chasm.kgs.ku.edu/ords/iqstrat.co2_brine_data_type_pkg.build_web_page

KGS CO_2 online web dashboard provides integrated view of monitoring activity



(http://www.kgs.ku.edu/PRS/Ozark/Summary/CO2_II.html)





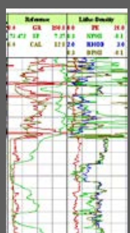
2D Plot Web App
(http://www.kgs.ku.edu/PRS/Ozark/Software/KS_Earthquake_2DPlot/index.html)

Workflow for reservoir simulation and geomechanical analysis

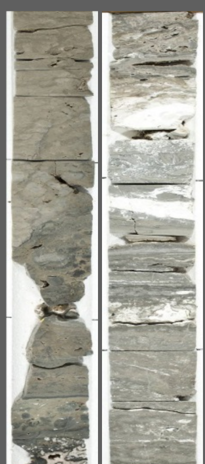
Data

Well logs

Tops



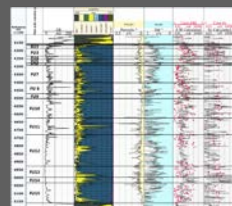
Core data



Dynamic data

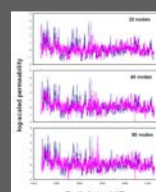
Reservoir Characterization

Multi-mineral FE

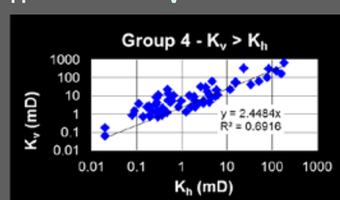


FZI-SWPHI

K prediction via ANN



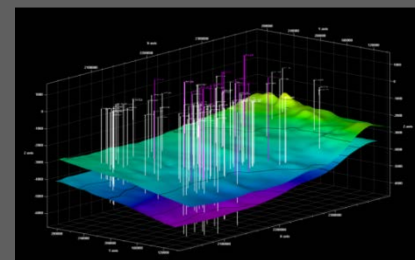
K_h and K_v relations



Flow units

Static model

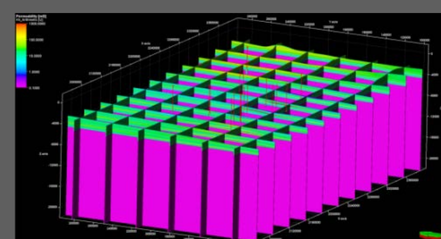
Structural model



Upscale logs

Statistical analysis

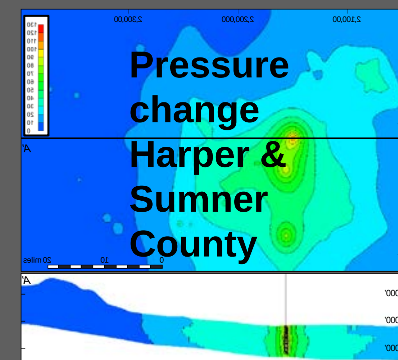
Property models



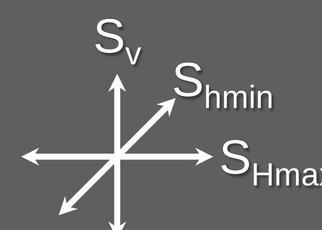
Geomechanical model

Dynamic model

Reservoir simulations



Geomechanical simulations



"Evaluating Potential for Induced Seismicity Through Reservoir-Geomechanical Analysis of Fluid Injection in the Arbuckle Saline Aquifer, South Central Kansas " Annual Meeting AAPG 2015, Denver ---T. S. Bidgoli, Y. Holubnyak, M. FazelAlavi

Accomplishments to Date in BP2 (September 2014 → present)

- **Class VI permit review –**
  - AoR through simulation
  - USDW evaluation
  - Financial assurance
  - PISC
  - Only RAIs, no NODs
  - Obtain Class II UIC permit, drill KGS #2-32, 92 ft of core with whole core routine and special analyses, comprehensive wireline log, test including 5-well interference test, complete and undergoing repressurization
- **MVA pre-injection baseline monitoring --**
  - 18-seismometers network
  - Geochemistry of brines in 10 Mississippian wells for Class II and VI monitoring
  - InSAR with consistent point scatterers and two geomechanical models to simulate surface deformation with potential correlation with reservoir pressure

Future Plans and Expectations

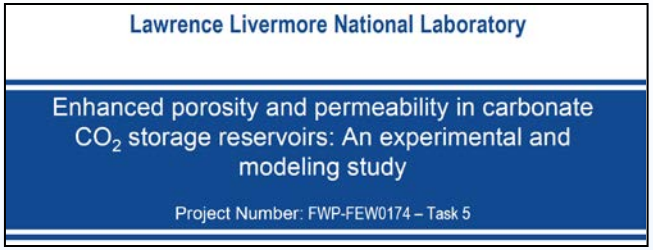
- **Complete repressurization of the Mississippian reservoir for CO^2-EOR injection and inject CO_2 -- September 2015**
  - Meeting with public in Wellington town hall meeting following commencement of Mississippian injection.
- **Obtain draft Class VI permit -- October 2015**
  - 6 mo. fabrication lead time CASSM, U-Tube, and Fiber Optic Array (pending decision); 2 months equip, test, and prepare #1-28 for injection
- **Obtain Class VI permit -- January 2016**
- **Drill, complete, test #2-28 Arbuckle monitoring well -- March 2016**
- **Inject CO2 into Arbuckle -- April 2016**
  - **Employ Operational Plan for Safe and Effective CO_2 Injection**
  - **Complete CO2 injection -- September 30, 2016**
  - **Requested 1 yr. PISC**
  - **Validation of models and predictions**
  - **A final report in 2017!**

Summary

- Use of Wellington Field as a calibration site and field demonstration
- Test best practice, cost-effective monitoring to aid in applying next-generation CO_2-EOR methods
- Refine model predictions with results
- Optimize CO_2 utilization and storage
- Test concept of coupling the oil field and underlying saline aquifer to increase long-term safe & dependable CO_2 storage

Synergistic Activities

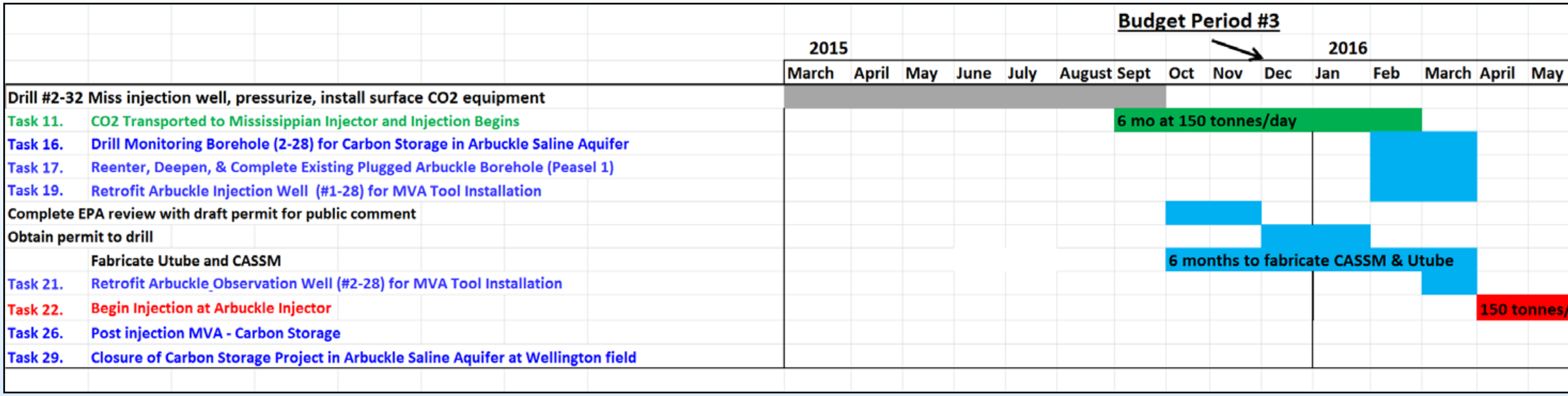
- **Continue collaboration with Susan Carroll, PI, LLNL**



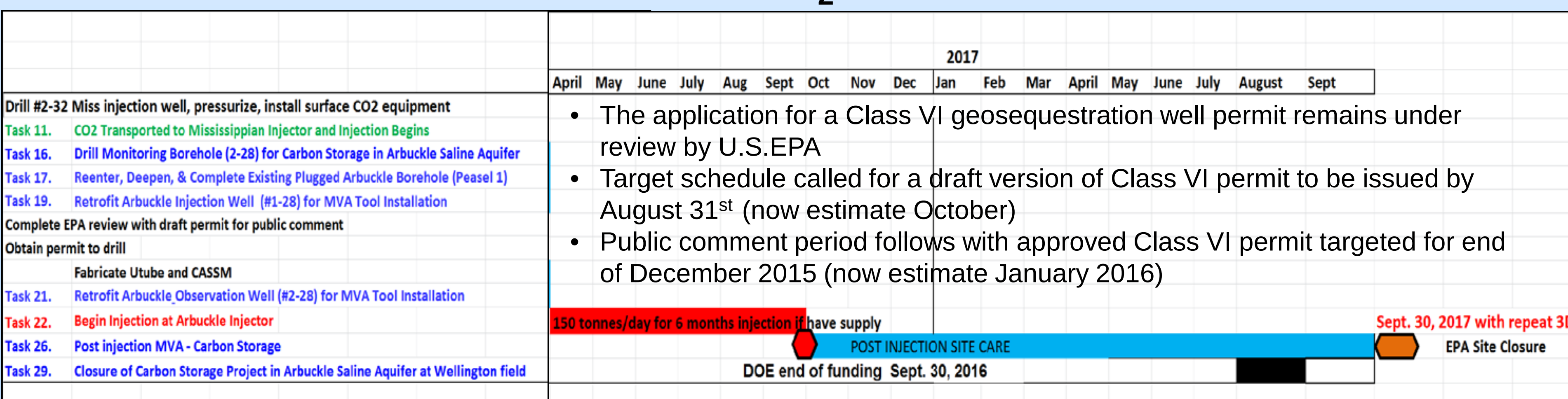
  – task addition → *Experimental calibration of NMR well logs to determine pore connectivity in the injection zone at the Wellington CO_2 storage demonstration site, Kansas*
  – *Potentially deploy in two new enhancements to MVA --*
    - *downhole strainmeters and tiltmeter in an Arbuckle observation well*
    - *Introduction of a metal ligand slug into the CO_2 stream to improve seismic imaging*
- **Data rich**
  – Carbonate and caprock cores, modern wireline logs, tests
  – Water and oil samples
  – Multicomponent 3D → Bob Hardage at BEG, new processing techniques
  – Earthquake catalog being built from operating IRIS/KGS 18-seismometer array
  – Monitoring and risk analysis from operational plan for safe and effective injection and adaptation by EPA for this project
  – Test NRAP tools
- **Extensive Web (Java) application tools and development**
  – Petrophysical and geophysical applications, display and integration of MVA data, general data management and archiving to facilitate more collaboration
  – Extend users and test software

Schedule – Wellington Small Scale Injection DE-FE0006821

Mississippian CO_2-EOR



Arbuckle CO_2 Class VI



- The application for a Class VI geosequestration well permit remains under review by U.S.EPA
- Target schedule called for a draft version of Class VI permit to be issued by August 31st (now estimate October)
- Public comment period follows with approved Class VI permit targeted for end of December 2015 (now estimate January 2016)

Acknowledgements

- KGS colleagues in Energy Research Section who generously shared their research presented here including Tandis Bidgoli, Mina Fazelalavi, Eugene Holubnyak, John Doveton, John Victorine, Jason Rush, David Newell, Jennifer Raney
- Mike Killion, KGS, KGS ESRI interactive mapping system
- DE-FE0002056 → Bittersweet Energy – Tom Hansen with Paul Gerlach and Larry Nicholson; Dennis Hedke, Hedke-Saenger; Martin Dubois, IHR; Gene Williams, Williams Consulting, John Youle with the SW Kansas CO_2-EOR industry consortium; George Tsoflias and students at KU, KGS staff supporting the acquisition of data, stratigraphic correlation, regional mapping, modeling, and interpretations
- Rick Miller and Shelby Petrie, installation of the Wellington Field IRIS-PASCAL seismometer array (15+3), portable array of seismometers in southern KS.
- Induced Seismicity Task

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

KSCO2

KU THE UNIVERSITY OF KANSAS Department of Geology

NETL