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

W. Lynn Watney, & Jason Rush (Joint PIs)

Jennifer Raney (Asst. Project Manager)

Kansas Geological Survey

Lawrence, KS 66047

KSCO2

KU KANSAS GEOLOGICAL SURVEY The University of Kansas

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

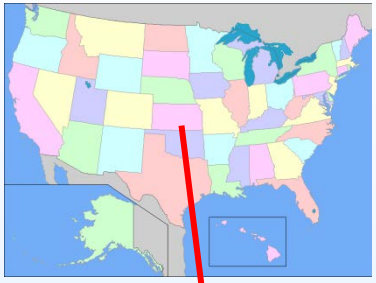
August 20, 2015

10:15 a.m – 11:00 a.m

NETL

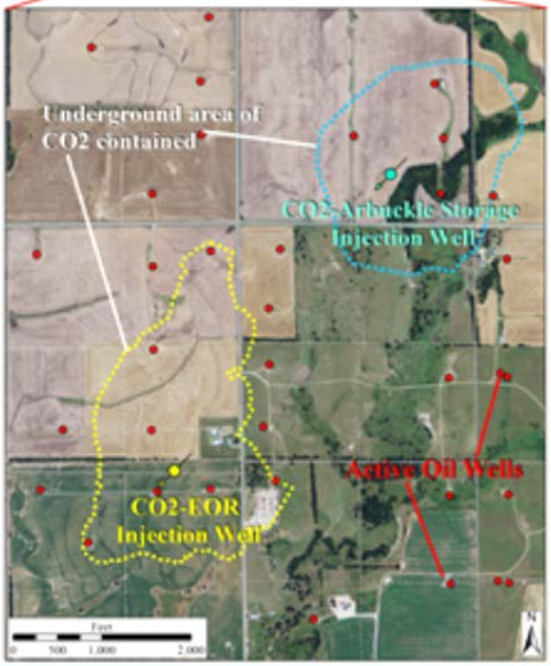
Presentation Outline

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

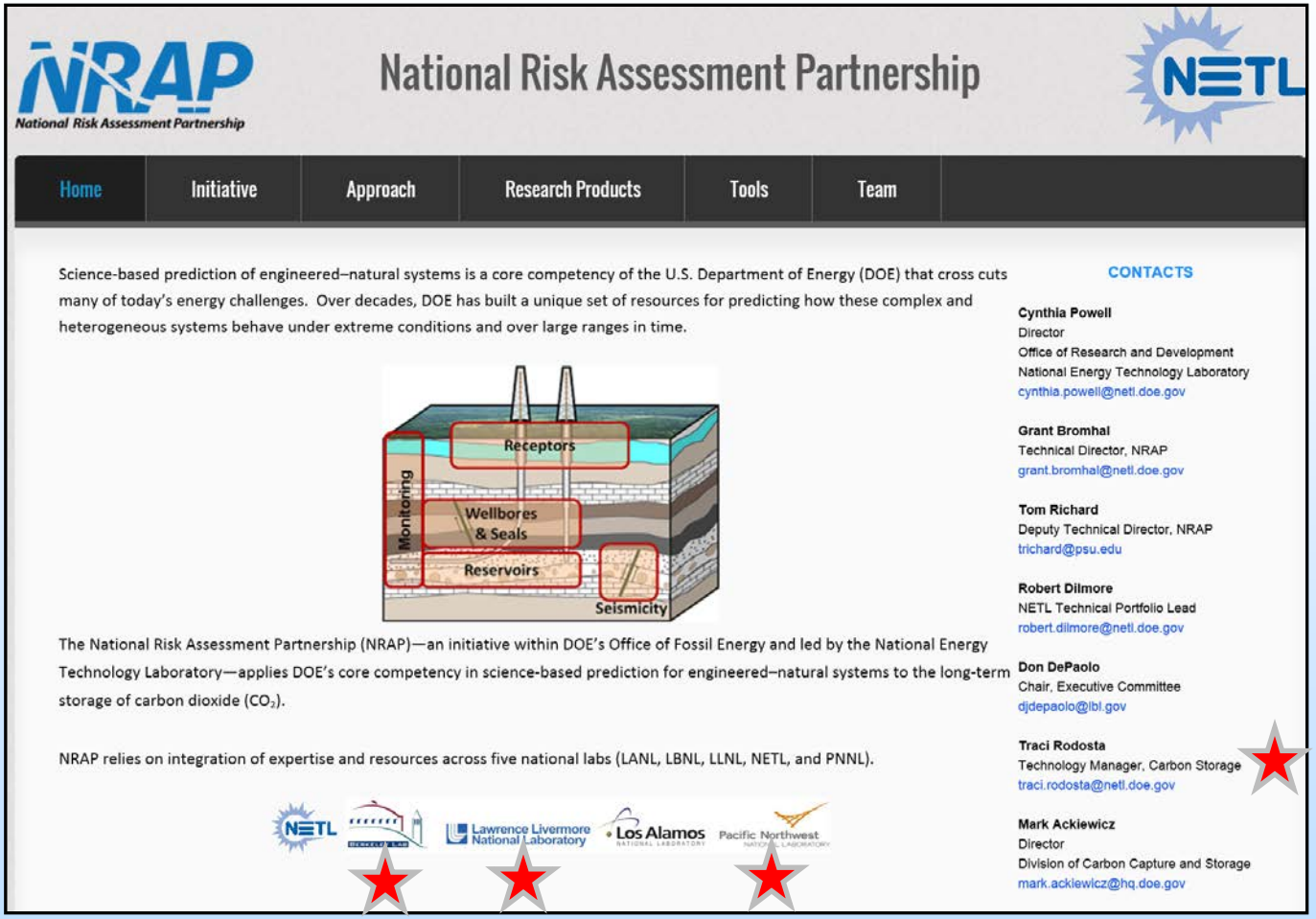


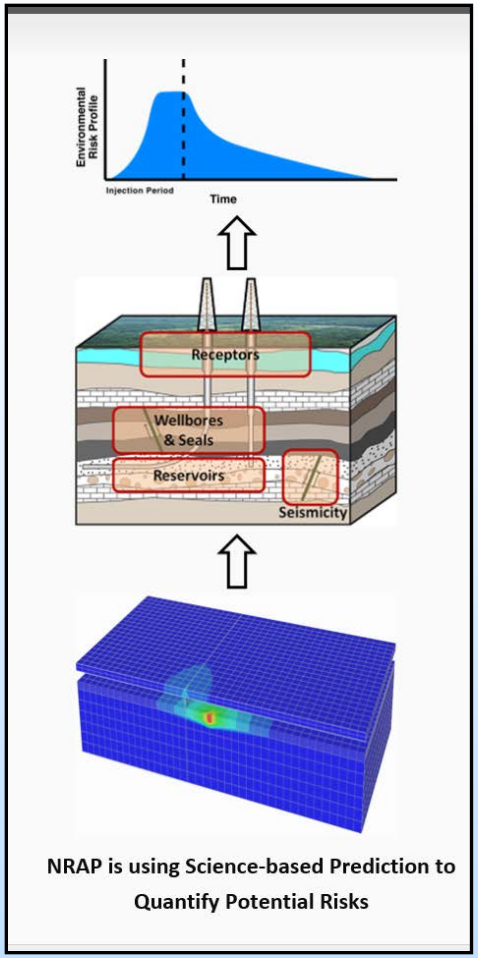
Wellington Field Sumner County Kansas

- 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)

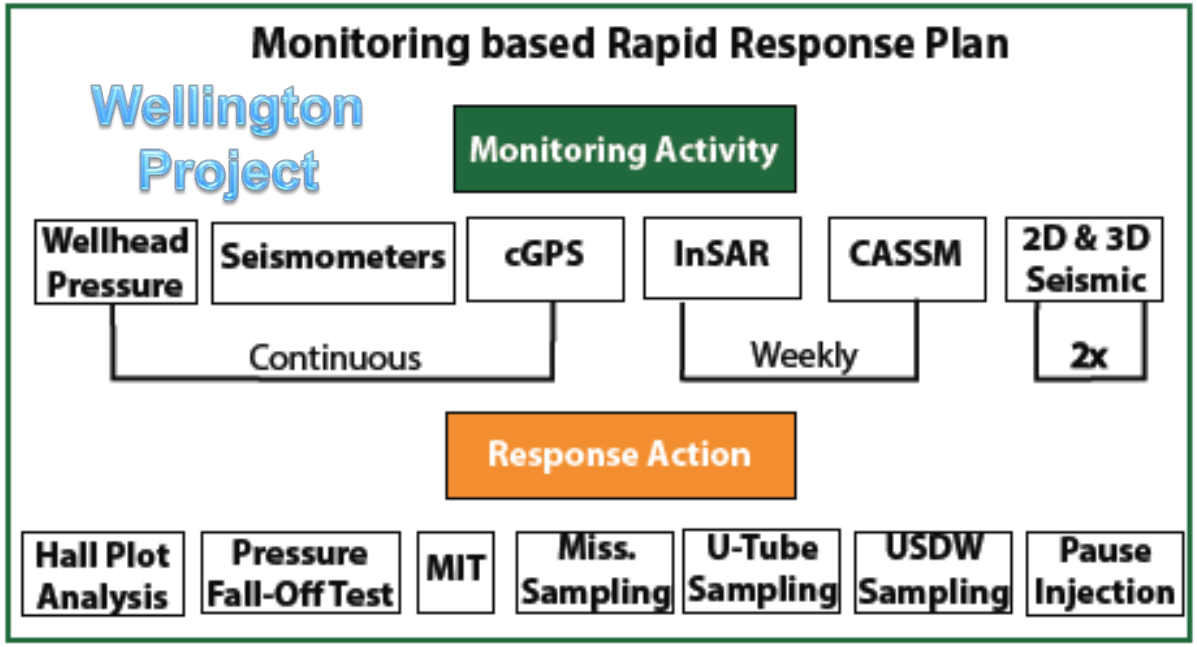


Risk management in DOE is incorporated in new, large cross-cutting program → *NRAP*





- 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

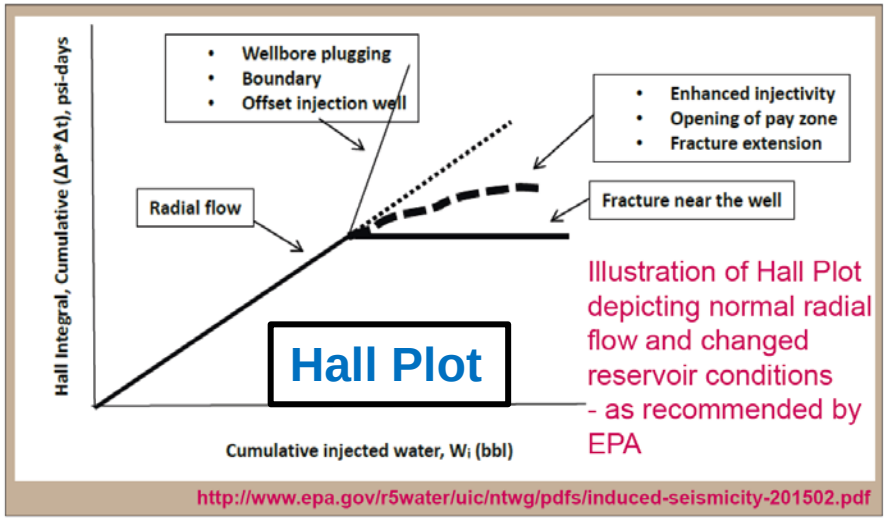


Illustration of Hall Plot depicting normal radial flow and changed reservoir conditions - as recommended by EPA

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

KU KANSAS GEOLOGICAL SURVEY
The University of Kansas

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)

NETL

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 INSTRUMENT CENTER
PASSCAL
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)***

KU 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

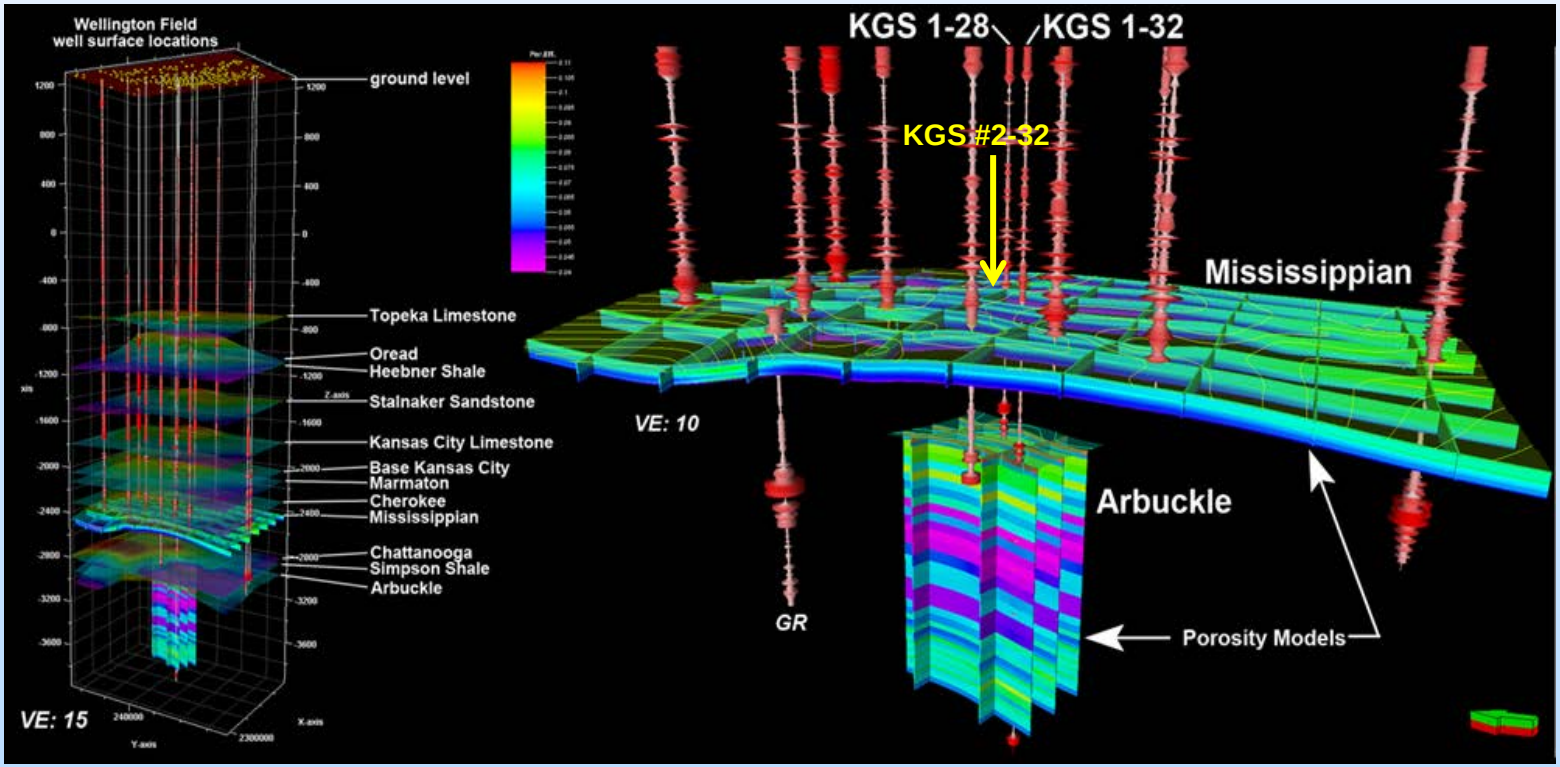
HALLIBURTON

Weatherford

Project established November 2011

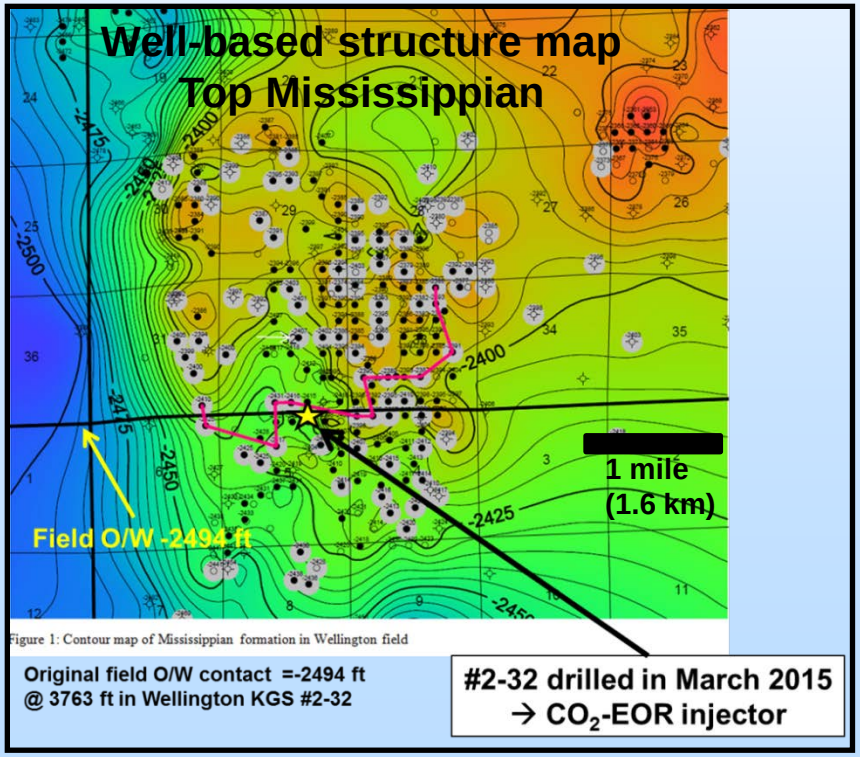
Benefits to the Program

- **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 (**Class II UIC permit**)*
      - ❑ 2. (2016) Underlying *Lower Ordovician Arbuckle Group dolomitic saline aquifer deposited on marine shelf (**Class VI UIC permit**)*
  - **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**



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

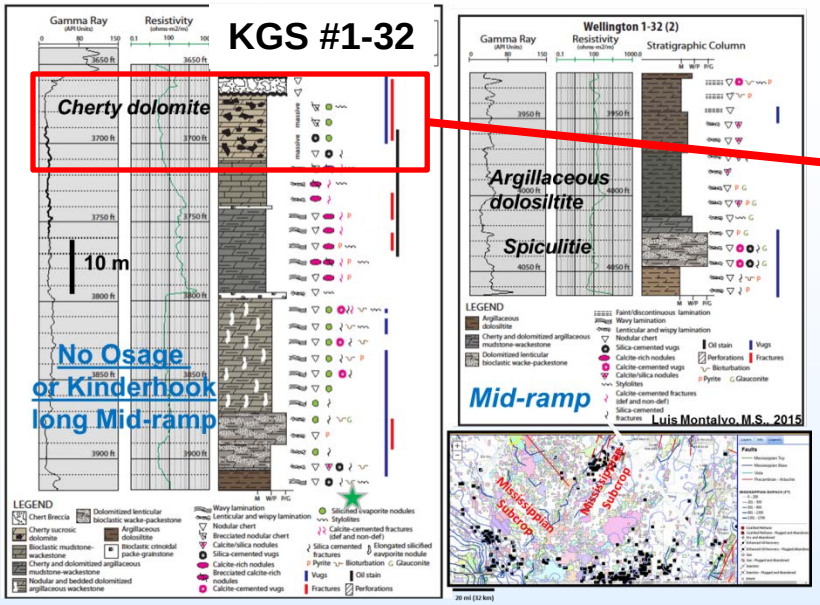
Core Lab

TRILOBITE TESTING, INC.

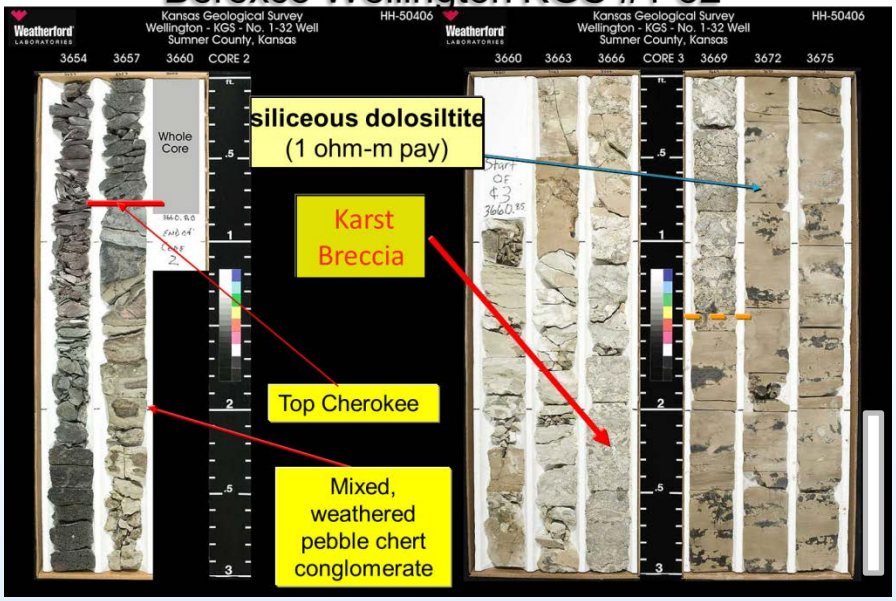
92 ft core cut in KGS #2-32 with 1528 ft previously acquired in KGS #1-32

Drilled in March 2015

No Osage or Kinderhook Mississippian → mid ramp

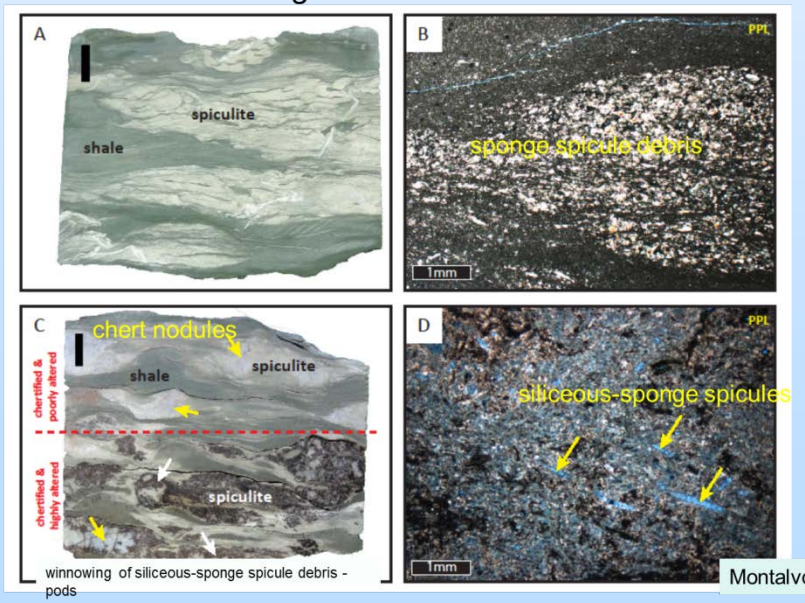


Mississippian pay zone in Berexco Wellington KGS #1-32



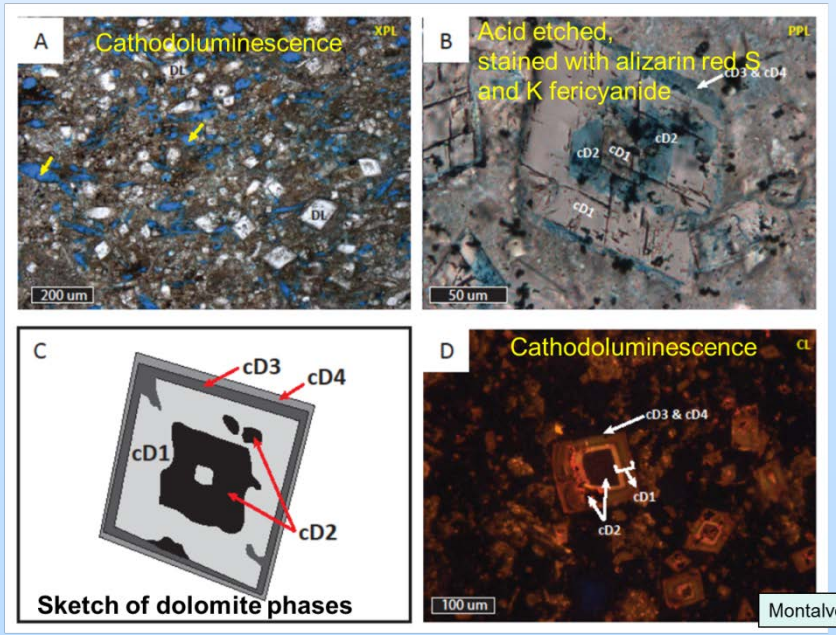
Lenticular Spiculite Wacke/Packestone

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



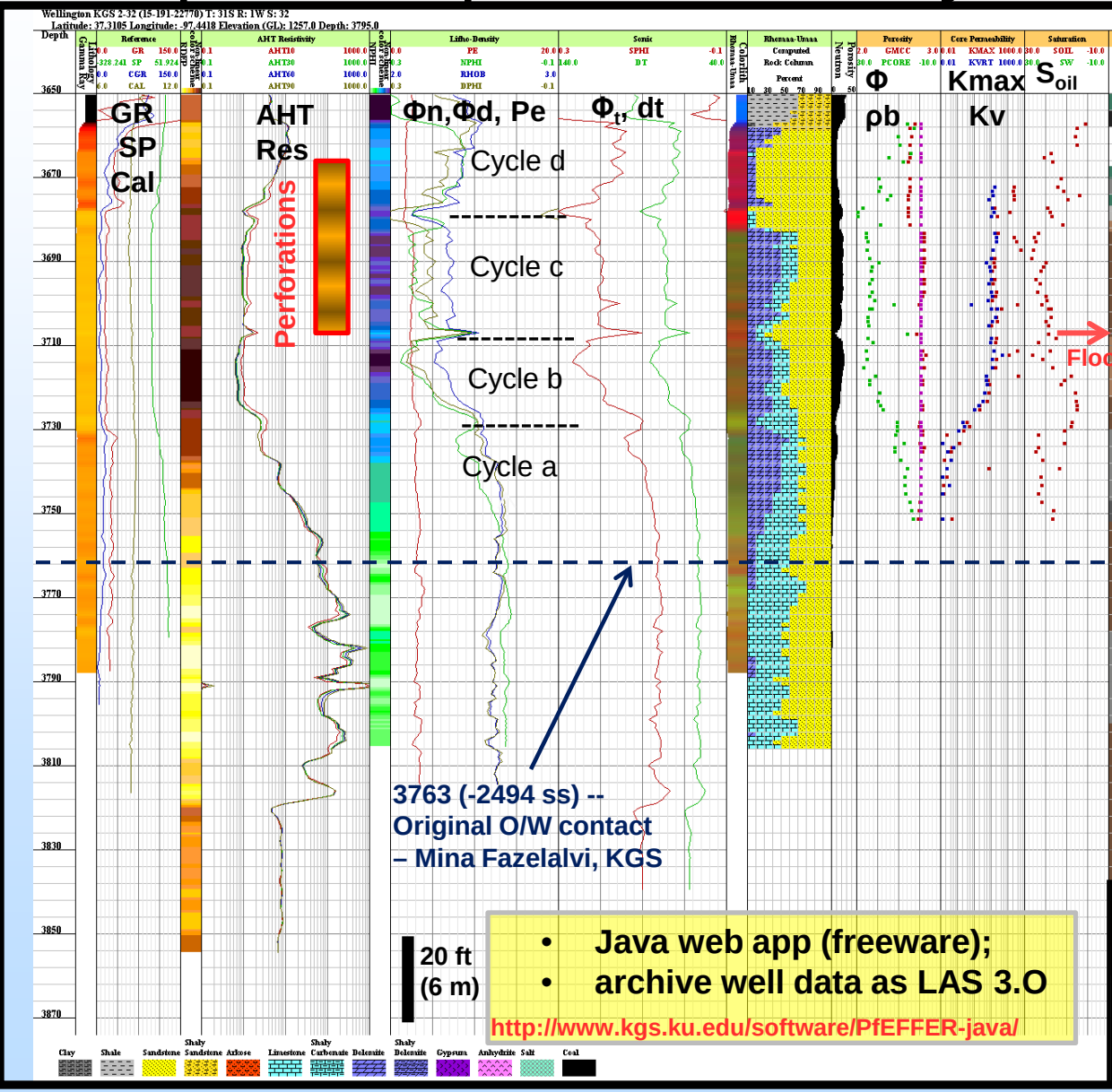
Montalvo (2015)

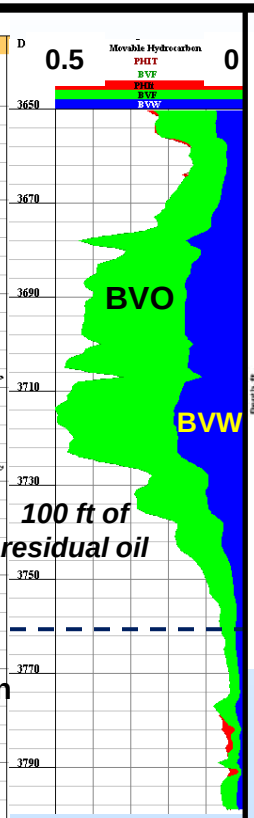
Rhombic Dolomite Euheral (idiotopic) Different Phases, Feroan and Non-Feroan

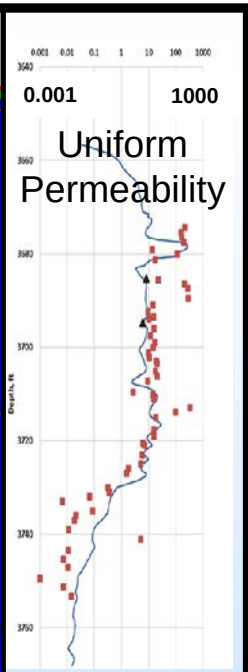


Montalvo (2015)

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



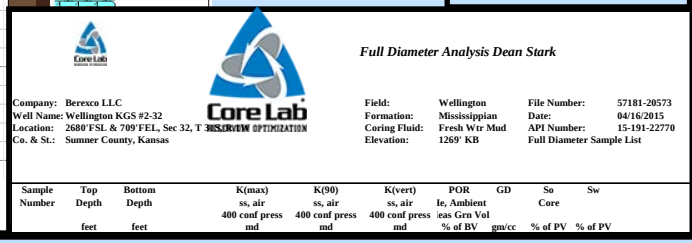




Average log calculated absolute permeability using NMR compared to whole core C/A

- Java web app (freeware);
- archive well data as LAS 3.O

http://www.kgs.ku.edu/software/PfEFFER-java/



Full Diameter Analysis Dean Stark

Core Lab

Company: Berexco LLC
Well Name: Wellington KGS #2-32
Location: 2680'FSL & 709'FEL, Sec 32, T
Co. & St.: Sumner County, Kansas

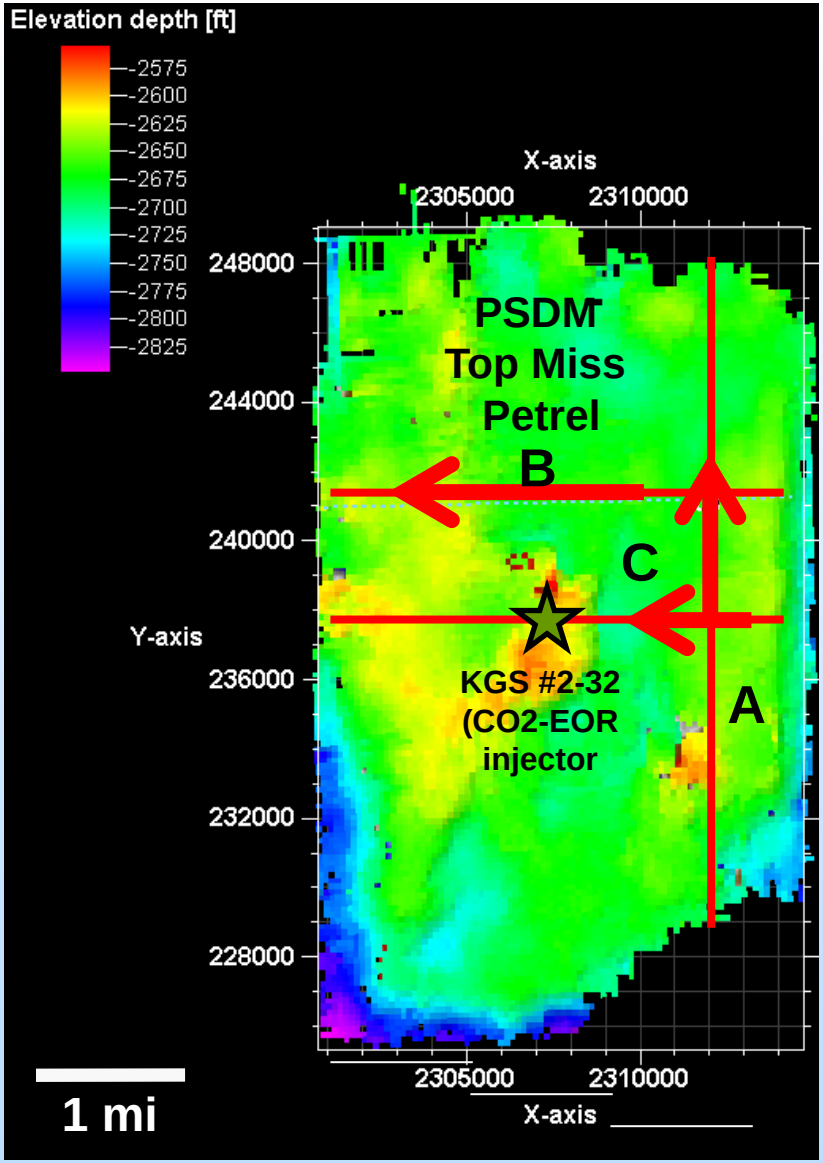
Field: Wellington
Formation: Mississippian
Coring Fluid: Fresh Wtr Mud
Elevation: 1269' KB

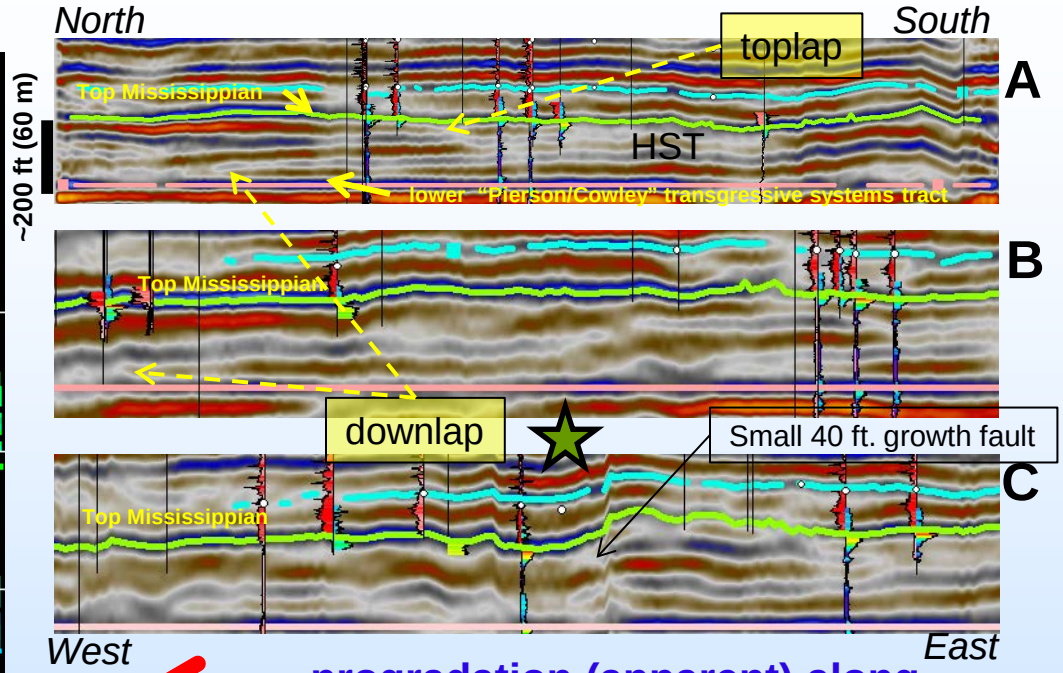
File Number: 57181-20573
Date: 04/16/2015
API Number: 15-191-22770
Full Diameter Sample List

Sample Number	Top Depth feet	Bottom Depth feet	K(max) ss, air 400 conf press md	K(90) ss, air 400 conf press md	K(vert) ss, air 400 conf press md	POR le, Ambient eas Grn Vol % of BV	GD gm/cc	So Core % of PV	Sw % of PV

Mississippian Seismic Stratigraphy using PSDM

→ complex progradational wedges in HST containing high-frequency cycles





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

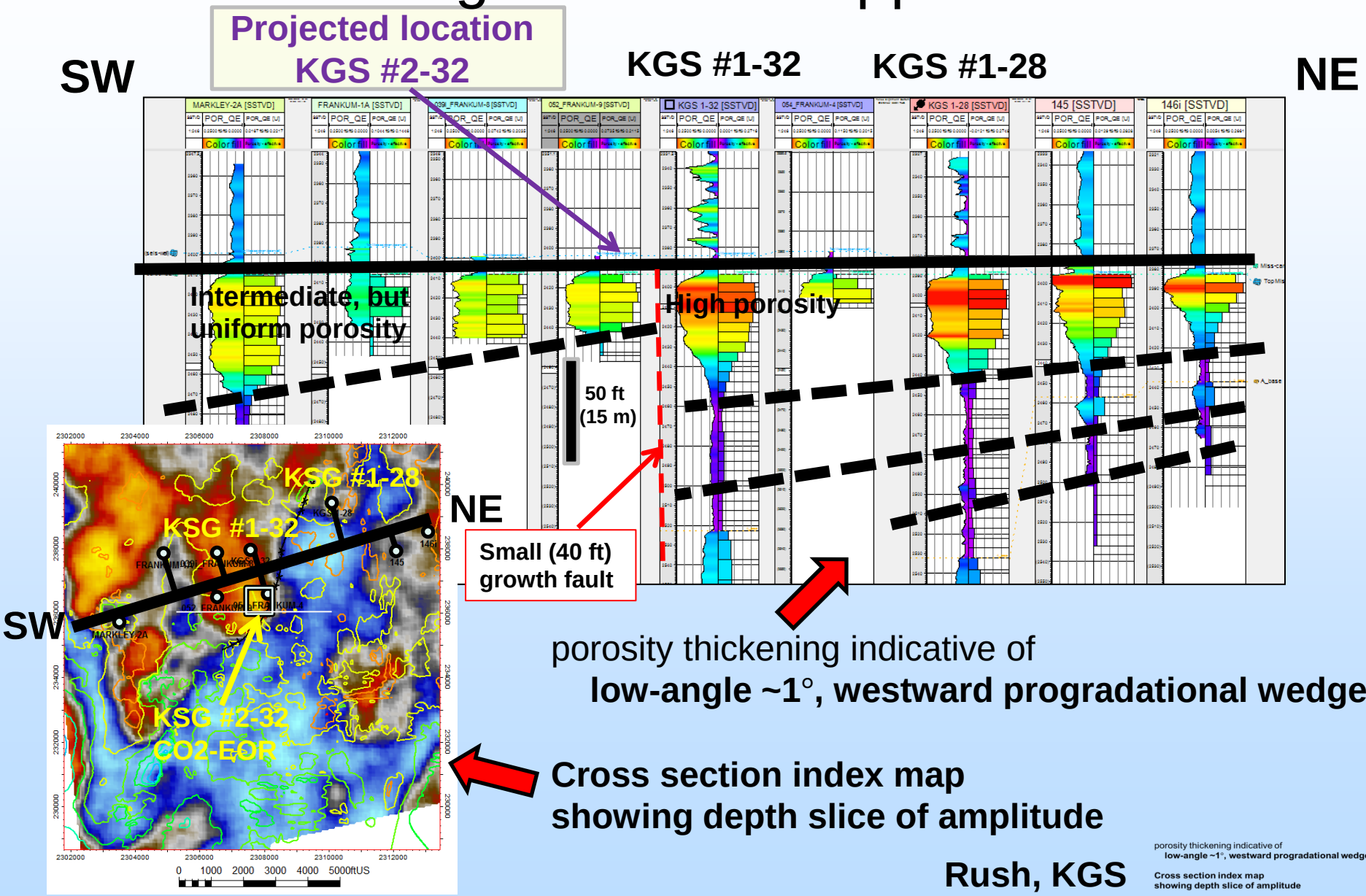
- **Complex progradation! …albeit slope ~1º**
- **Local <u>antecedent</u> and <u>syndepositional</u> structures impact stratal terminations**
- **Appears to compartmentalize the reservoir suggested by preliminary baseline water chemistry**

actual progradational vector

Jason Rush, KGS

KANSAS GEOLOGICAL SURVEY
The University of Kansas

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

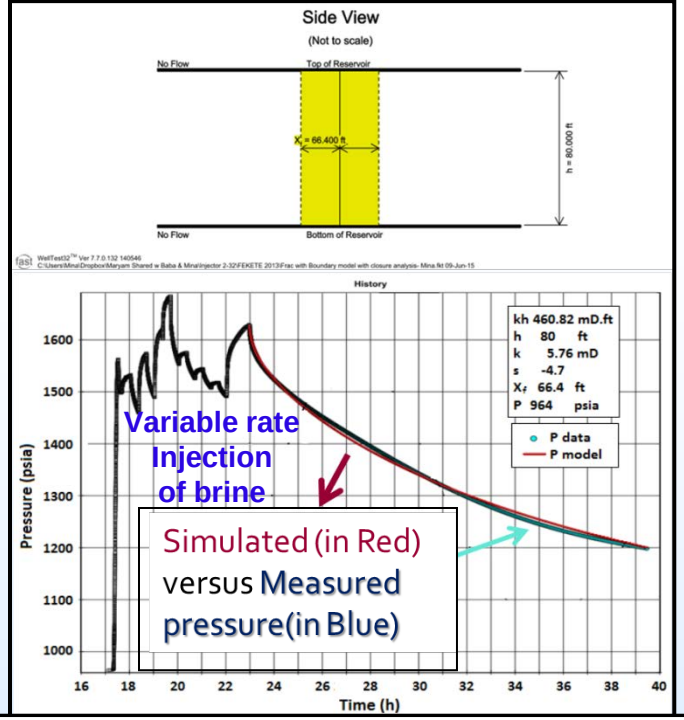
-- *Confirm reservoir pressure*

-- *Evaluate*:

a) *connectivity between wells,*

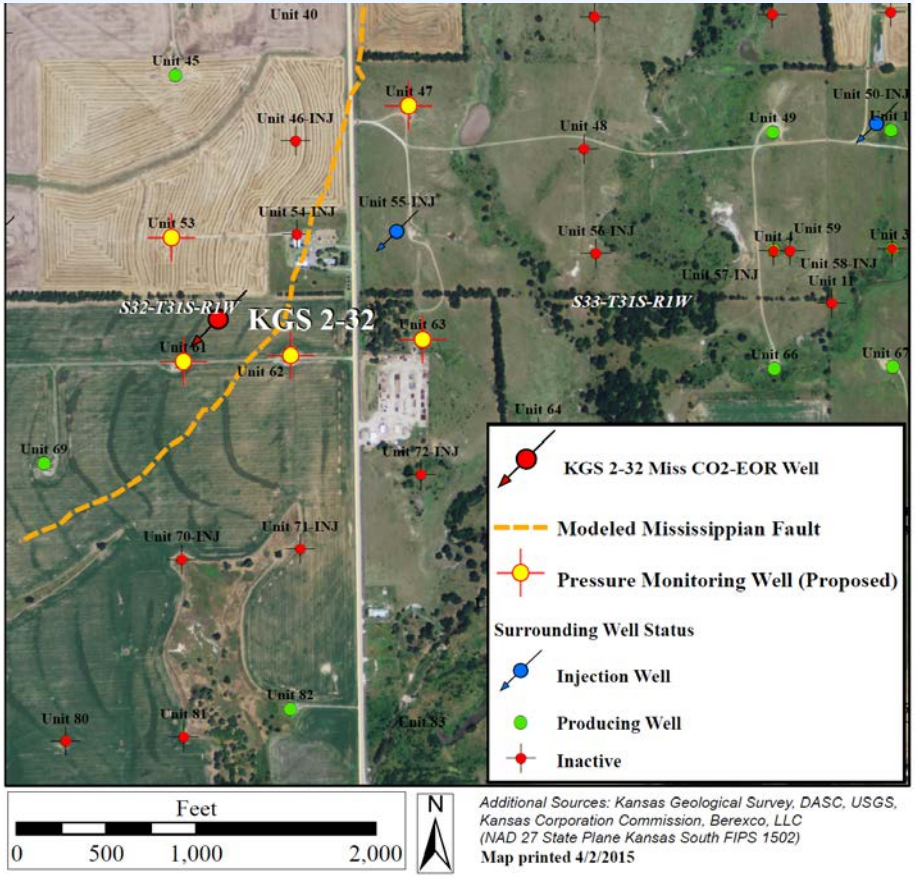
b) *fracture vs. matrix flow,*

c) *fracture closure pressure*



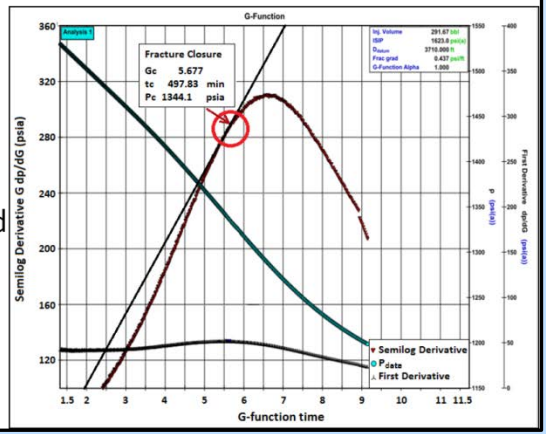
Current reservoir pressure ~900 psi

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



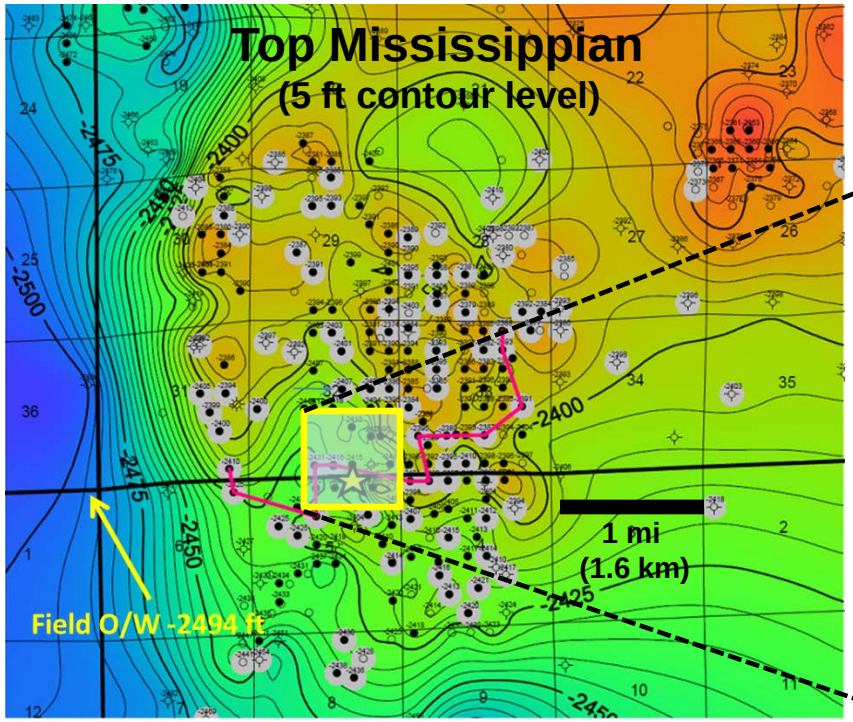
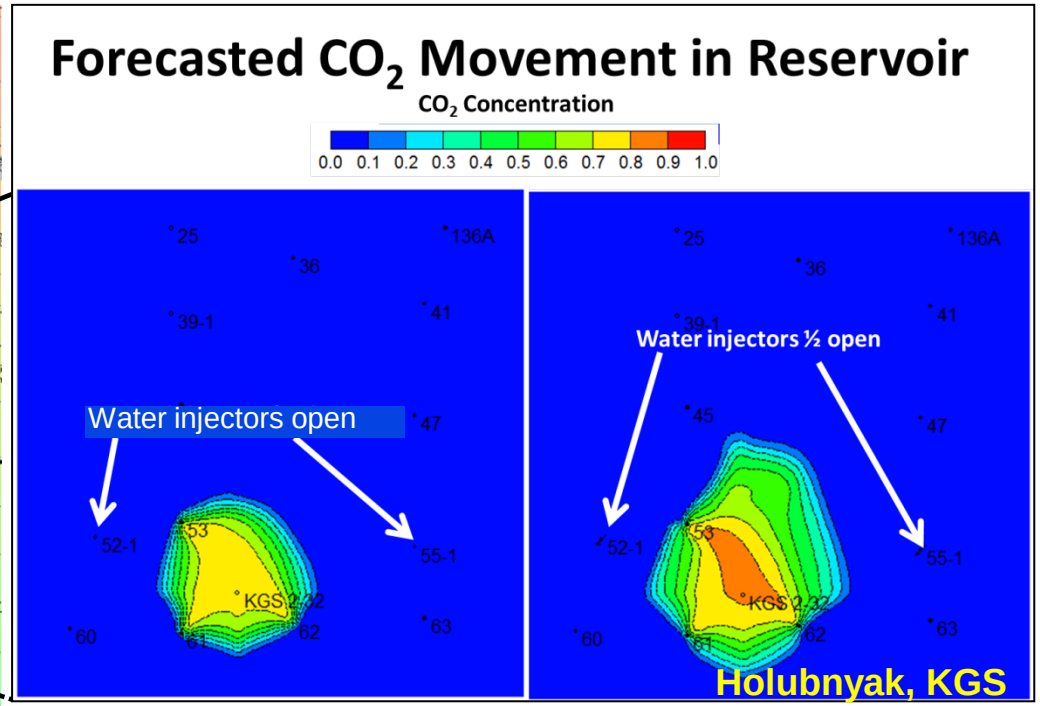
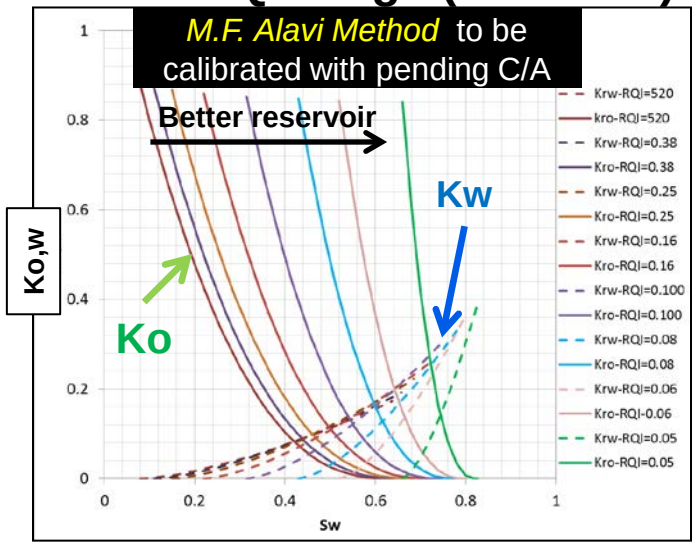
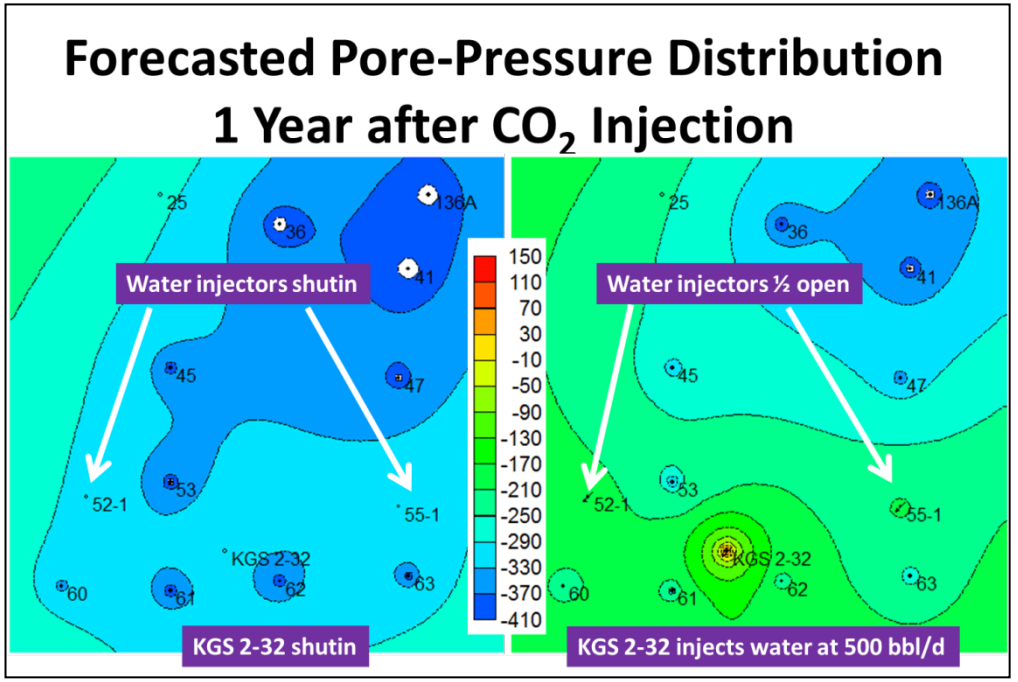


Figure 1: Contour map of Mississippian formation in Wellington field



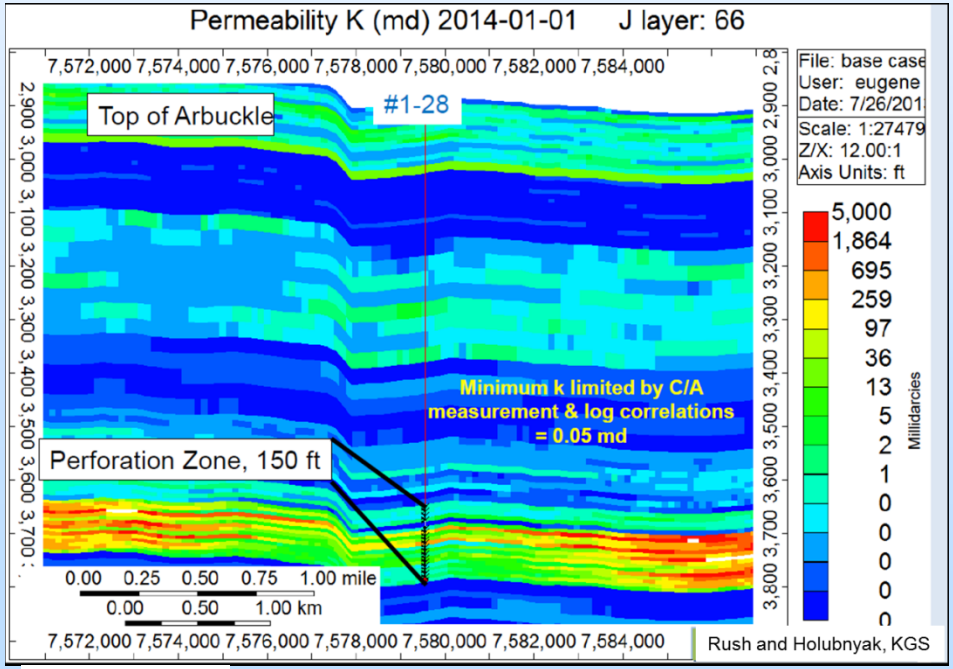
Imbibition Relative Permeability for each RQI range (Oil-Brine)



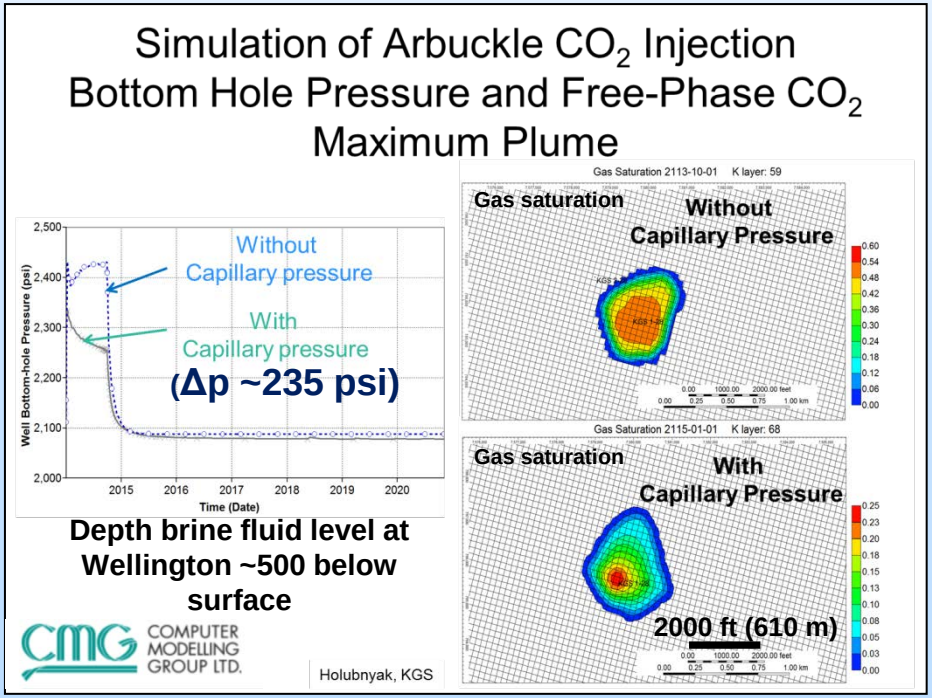


Technical Status

- **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



Schlumberger Petrel



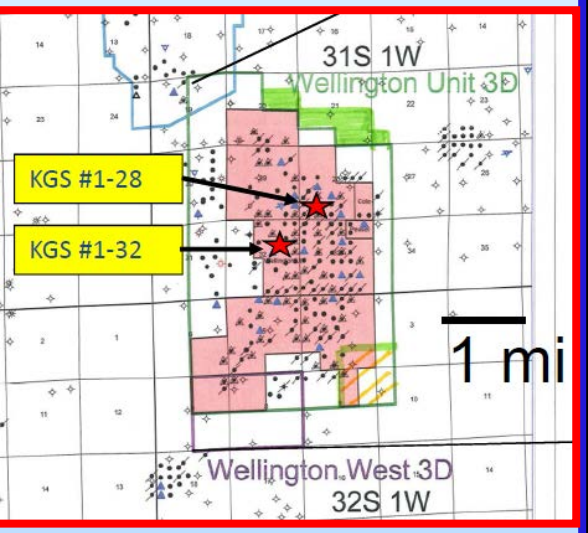
Holubnyak, KGS

Information collected on Arbuckle for saline aquifer

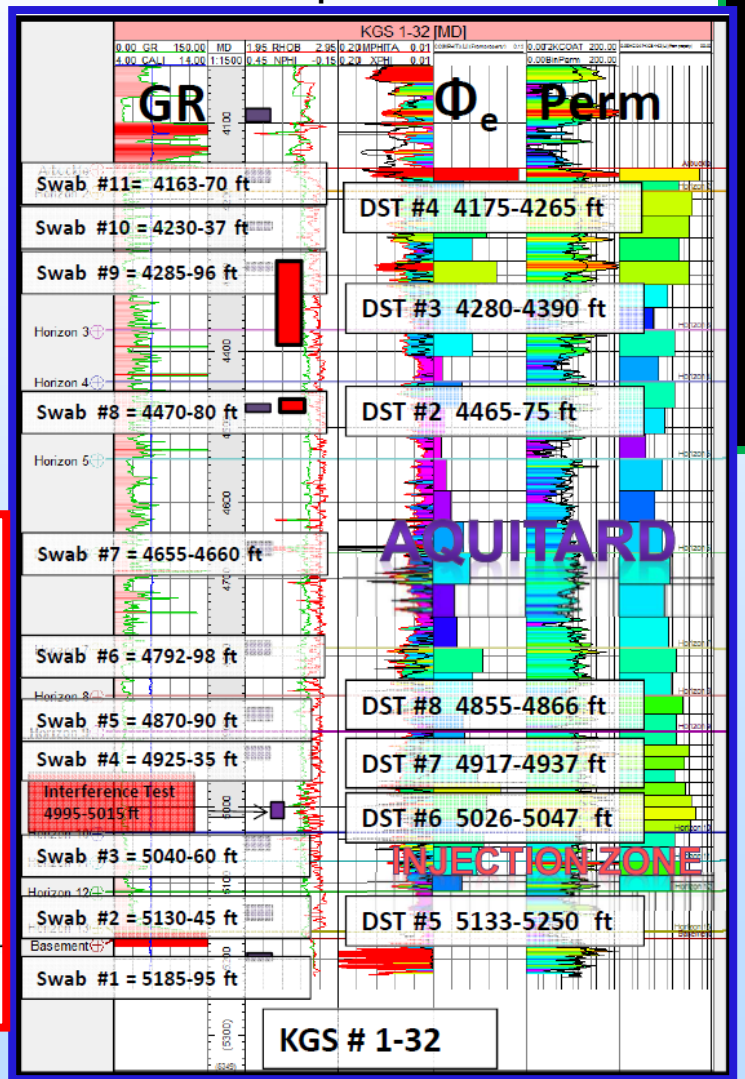
- Multicomponent 3D seismic under DE-FE0002056
- 2 basement tests (#1-32 & #1-28)
- 465 m (1528 ft) core
- Extensive log suite
- Multiple well tests

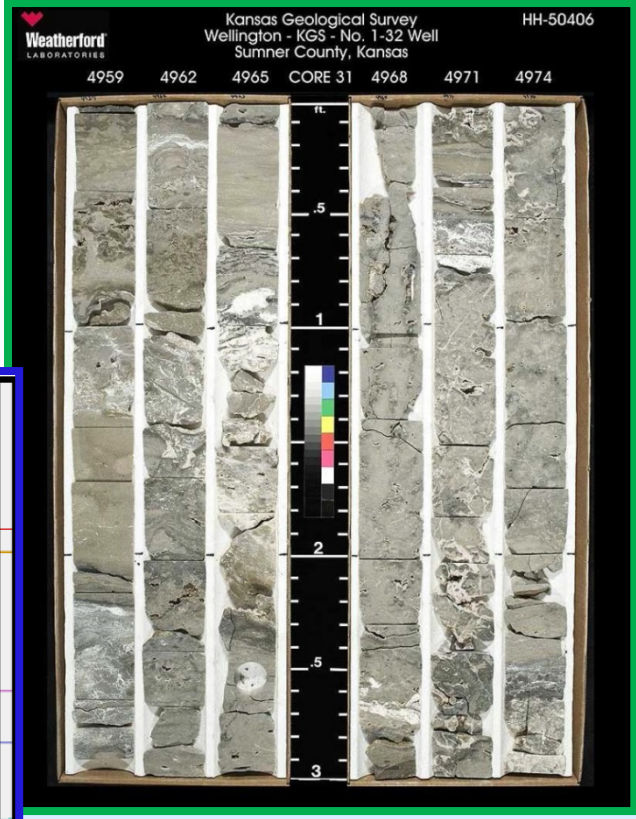
200 ft (60 m)

Multicomponent 3D Seismic Survey



Arbuckle Saline Aquifer Interval KGS #1-32





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

Fracture Ø

4995-97.7 ft

Vugs and interparticle Ø

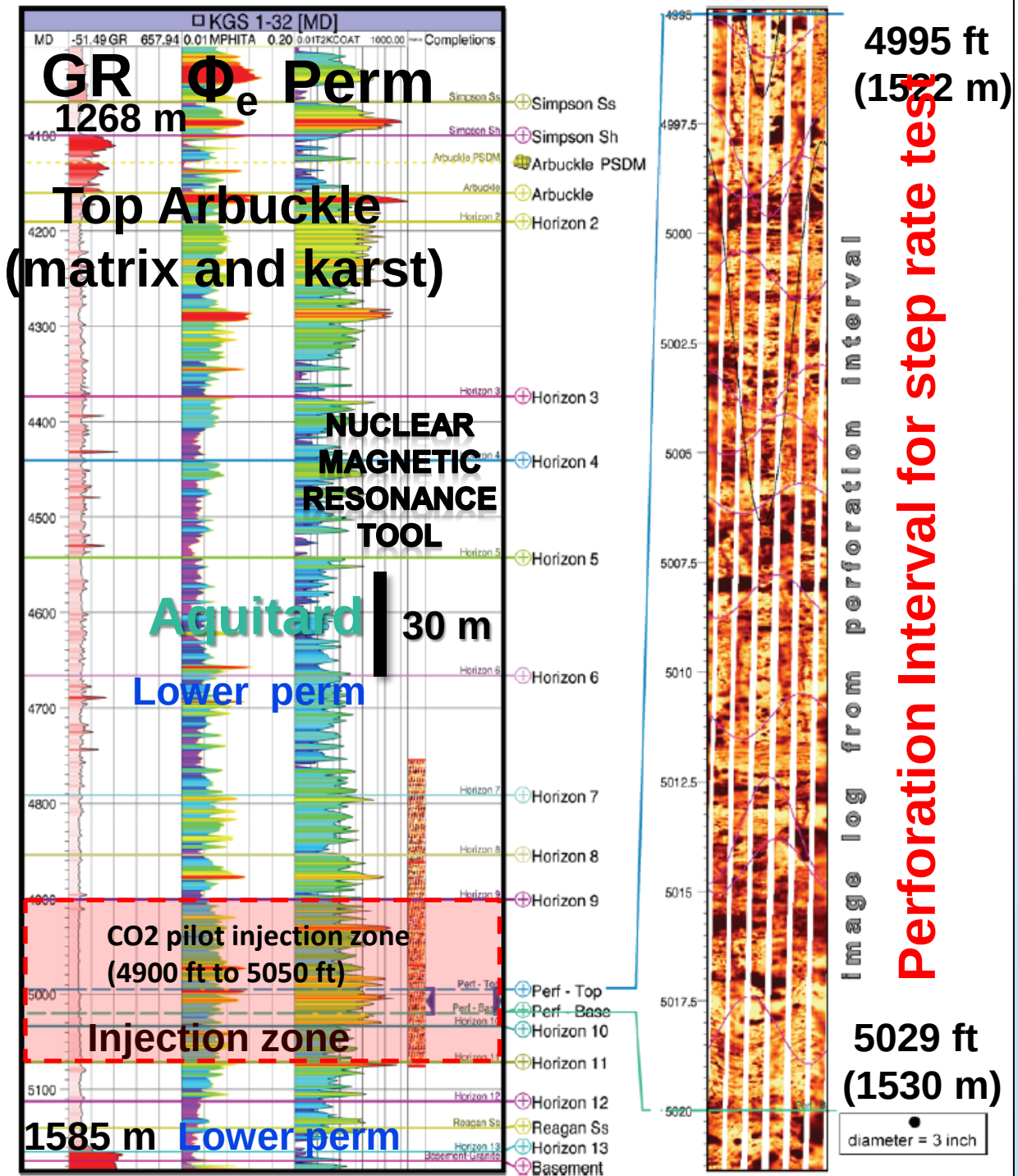
Fine interparticle Ø

KU KANSAS GEOLOGICAL SURVEY The University of Kansas

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)

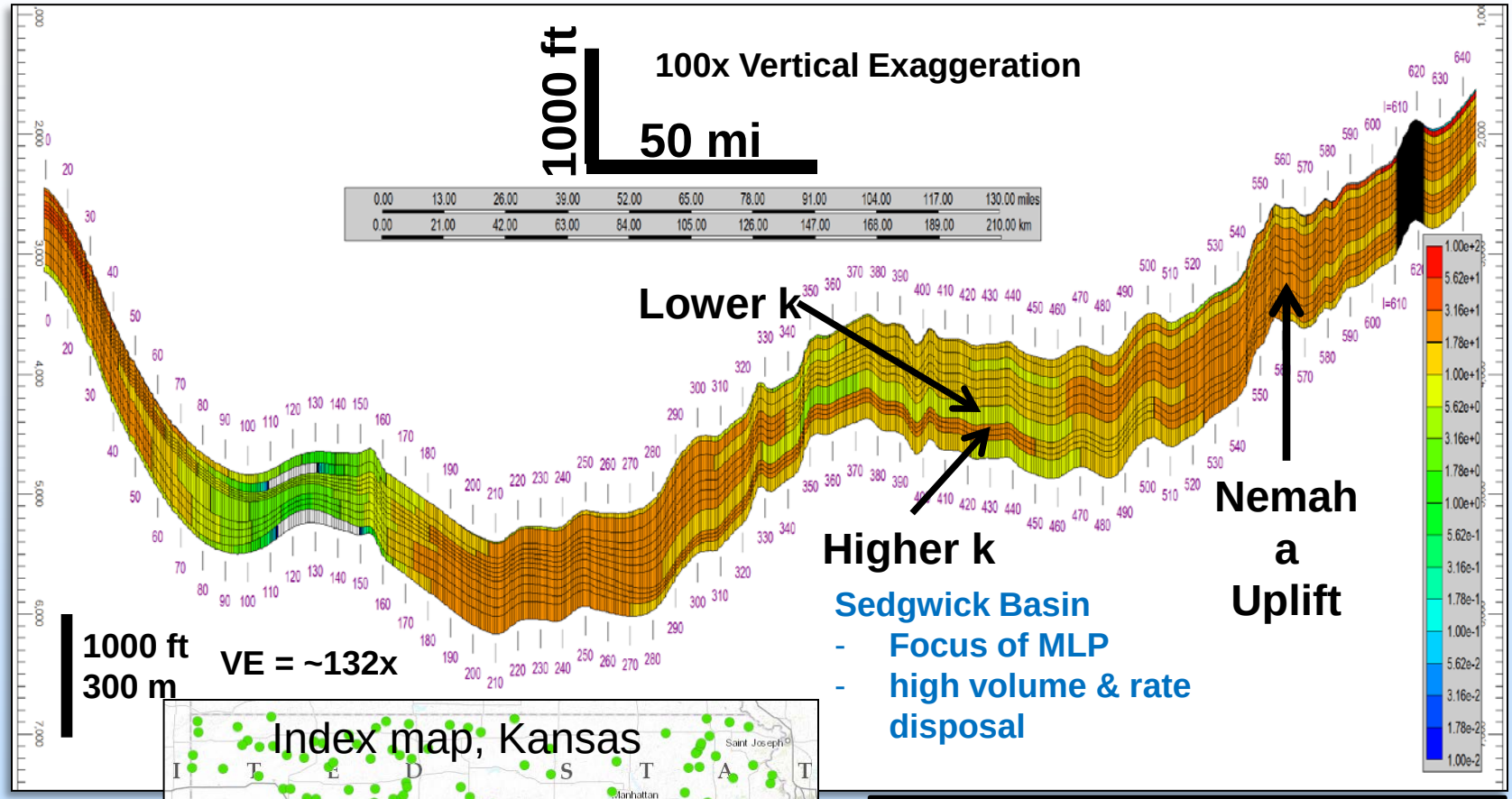
- **Gamma ray**
- **Halliburton derived effective porosity from Nuclear Magnetic Resonance (NMR)**
- **Coates Permeability from NMR tool**
- **Microresistivity imaging log (MRIL)**

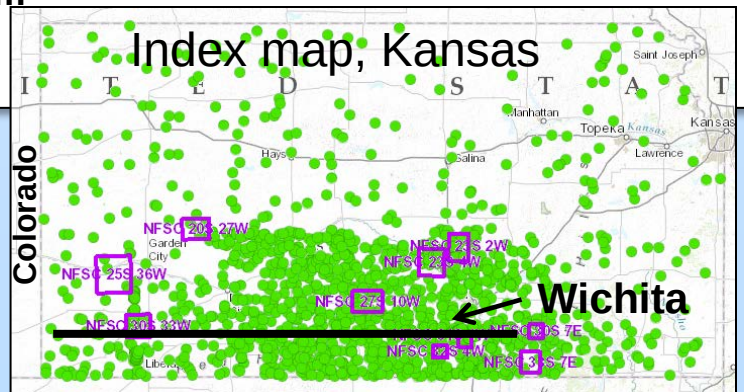
J. Rush, KGS

HALLIBURTON

Schlumberger Petrel

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

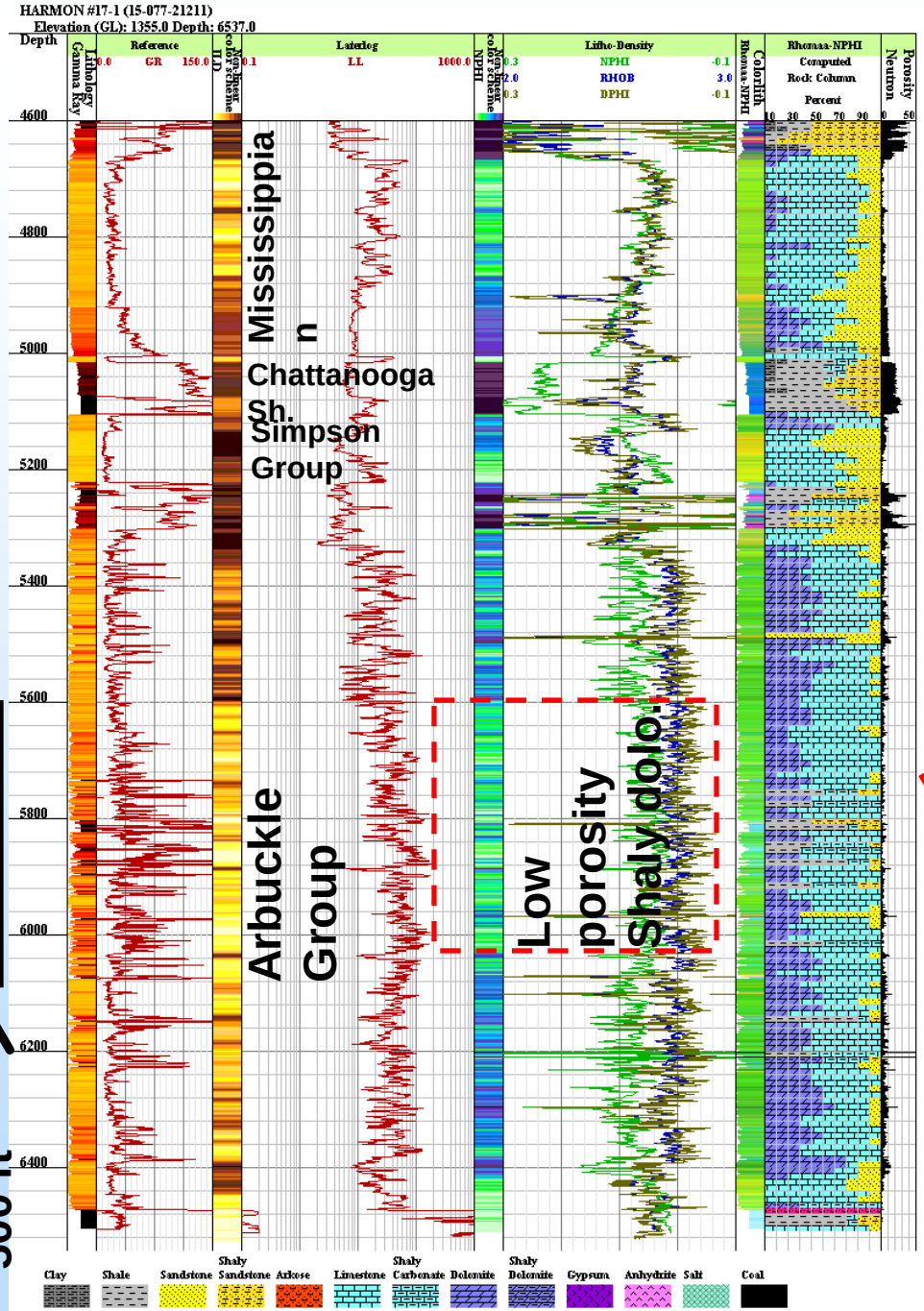


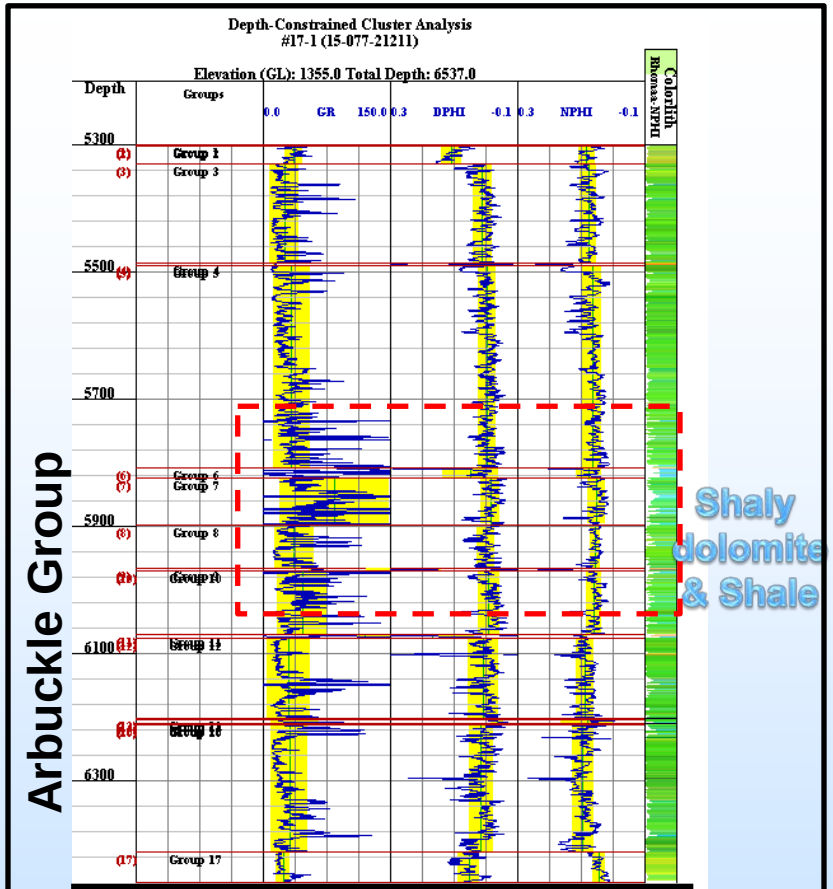


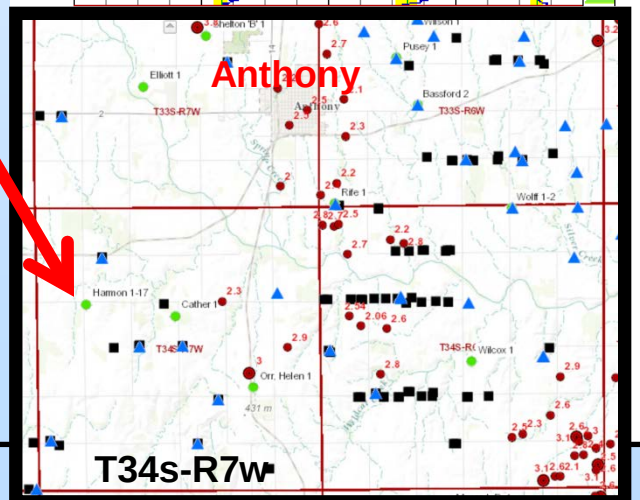
Based on neutral network model realizations of horizontal permeability calibrated with core, logs, test data at Wellington and Cutter Fields

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

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



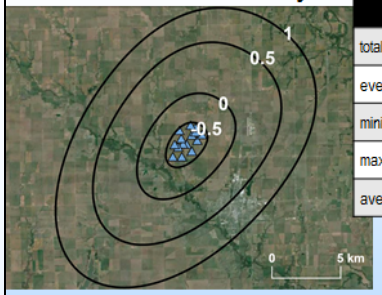




• Milestone 3. Pre-injection MVA baseline recording

- ❑ 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

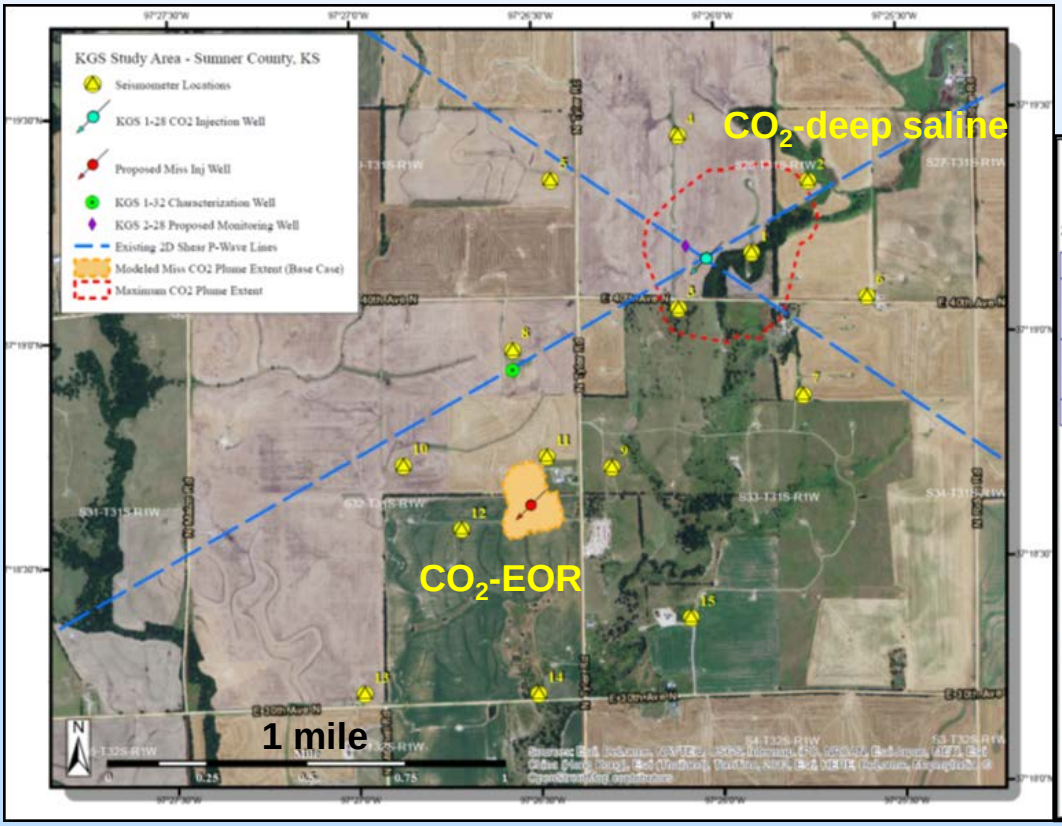
- Earthworm software for automated detection of earthquakes.
- Reporting 2.5+ magnitude per USGS convention.

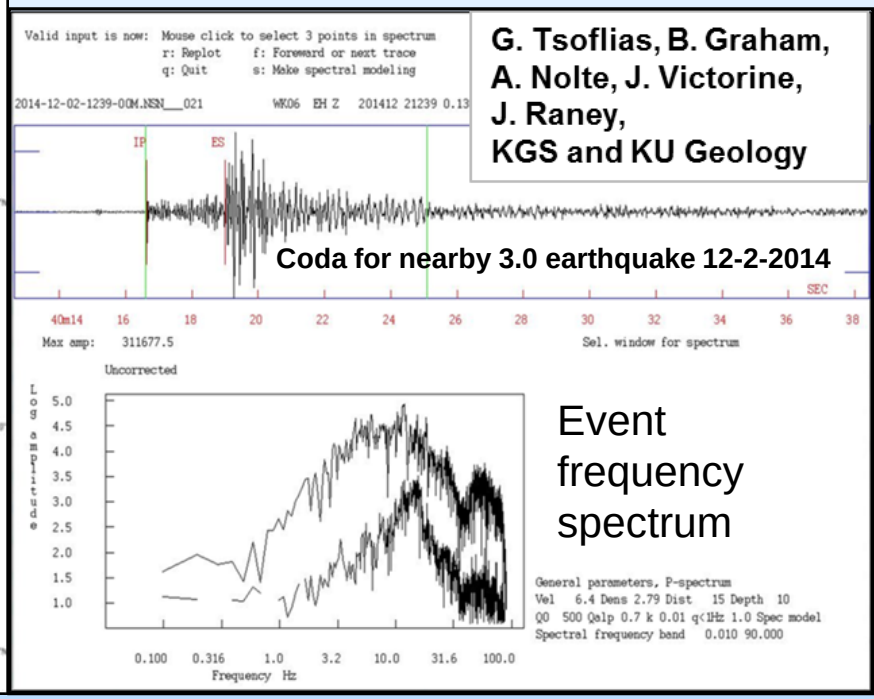
†Initial recording over one weeks time

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



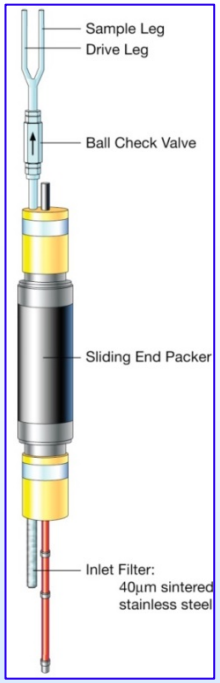


G. Tsoflias, B. Graham, A. Nolte, J. Victorine, J. Raney, KGS and KU Geology

Coda for nearby 3.0 earthquake 12-2-2014

Event frequency spectrum

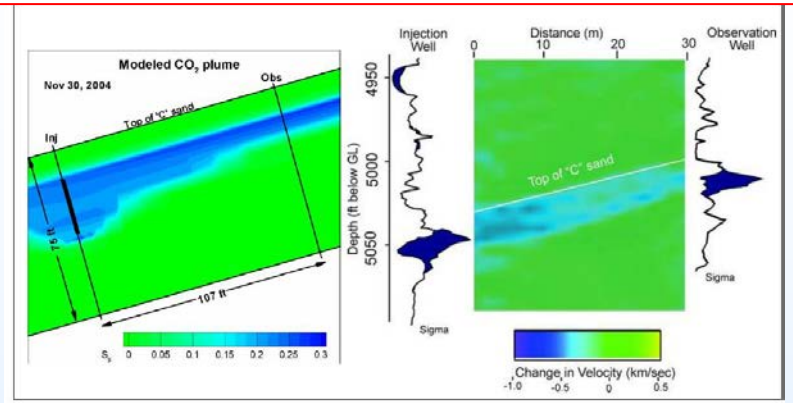
Additional Monitoring Technologies



U-Tube

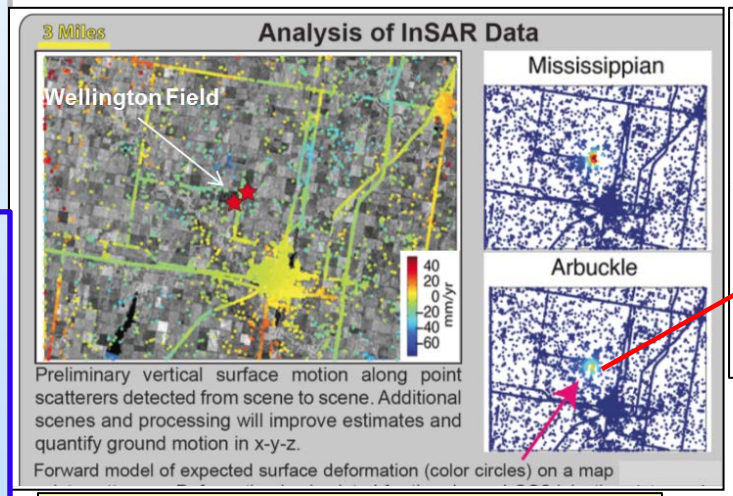
B. Freifeld, LBNL

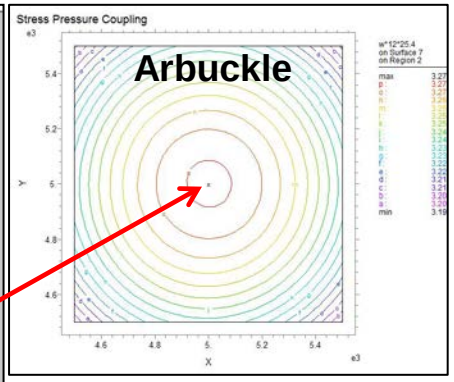
CASSM & Croswell Seismic Tomography



T. Daley, LBNL

Stress Pressure Coupling Simulation





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

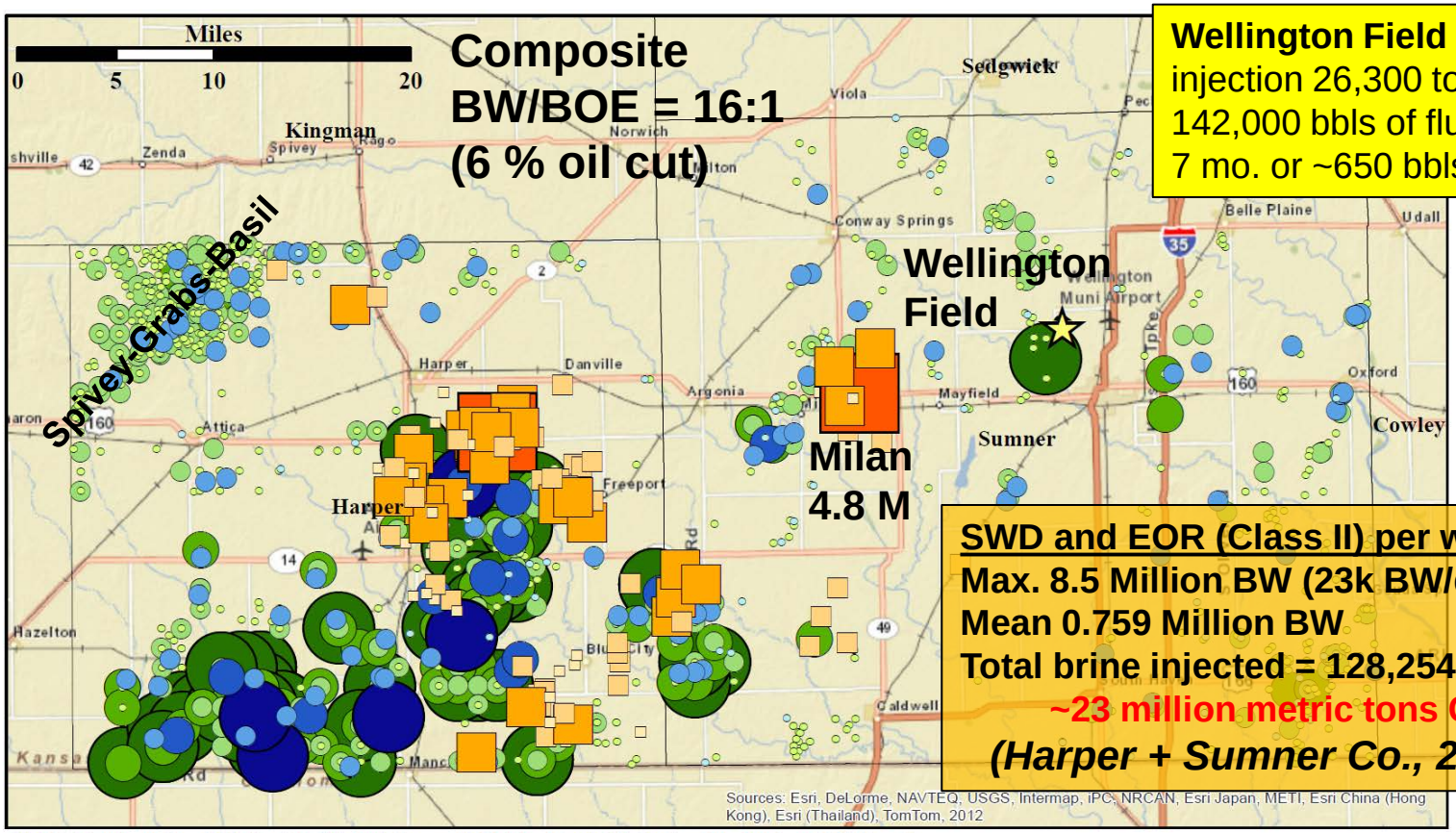
- **cGPS recording since August 2014**
- **SAR data being collected ~20 day intervals**
- **Prospect remains to secure distributed Fiber Optic Arrays for repeat VSP**

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

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

Induced seismicity west of Wellington Field

Total salt water injected by well (●), BOE produced by oil lease (●) and earthquakes (■) in 2014, 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

SWD and EOR (Class II) per well in
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)

NEIC Earthquakes (2014)
Magnitude
- 1.9 - 2.5
- 2.5 - 3.0
- 3.0 - 4.0
- 4.0 - 5.0

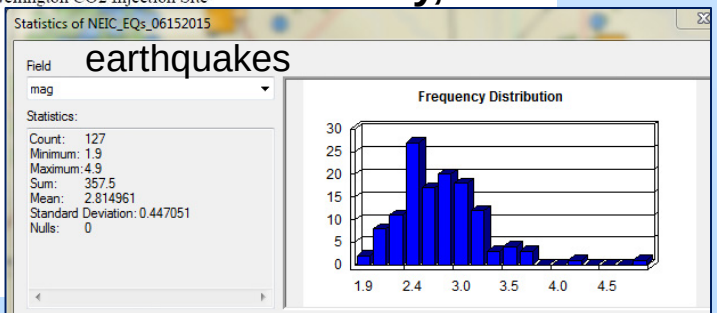
Salt Water Disposal (2014)
Million BBLS
- 0.1
- 1.5
- 5.0
- 8.5

Total Oil & Gas Production (2014)
Bbls (BOE)
- 0 - 2,000
- 10,000
- 20,000
- 200,000

☆ Wellington CO2 Injection Site

Min 1.9
Max 4.9
Mean 2.8
127 earthquakes in 2014

Jenn Raney, KGS

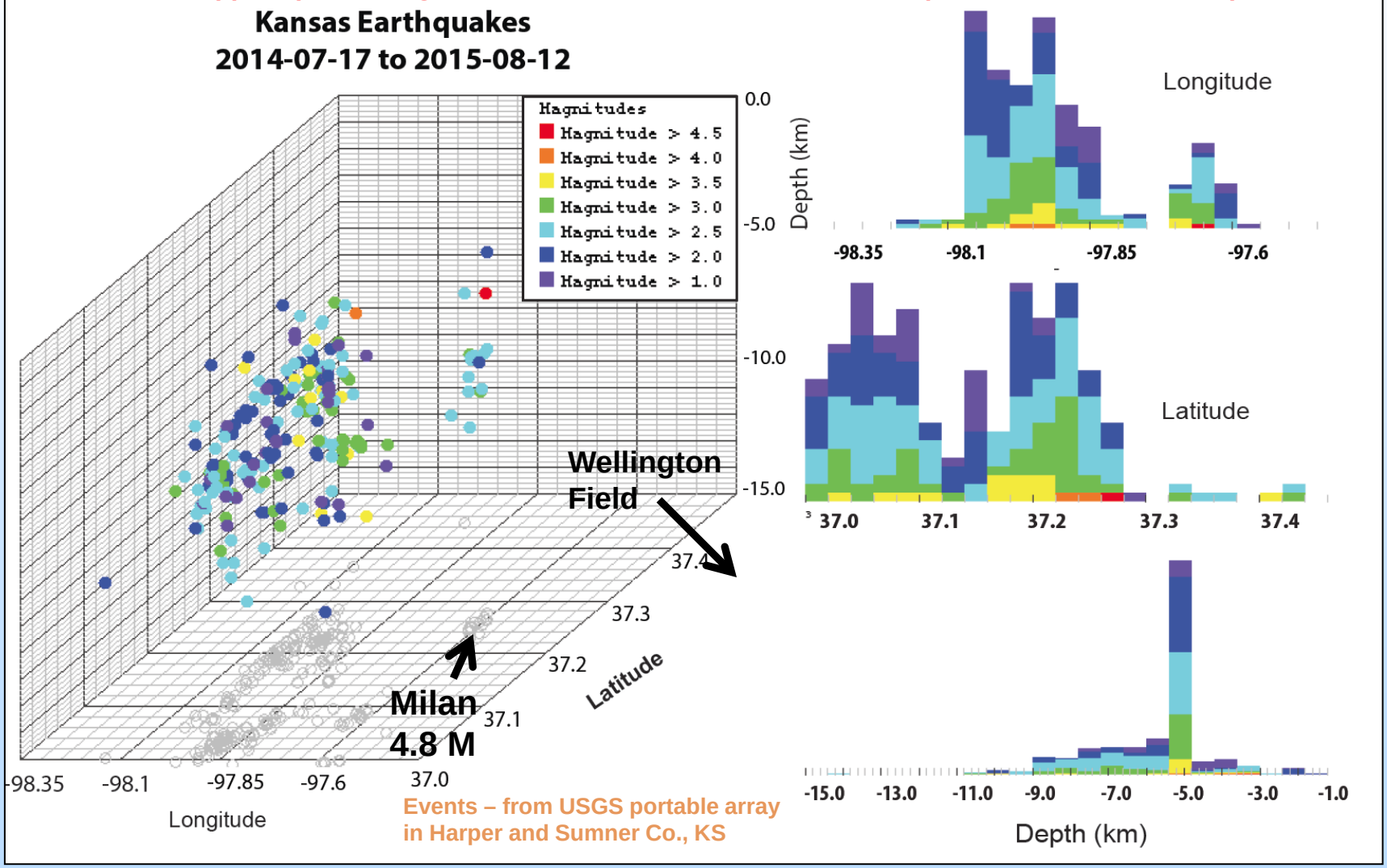


earthquakes

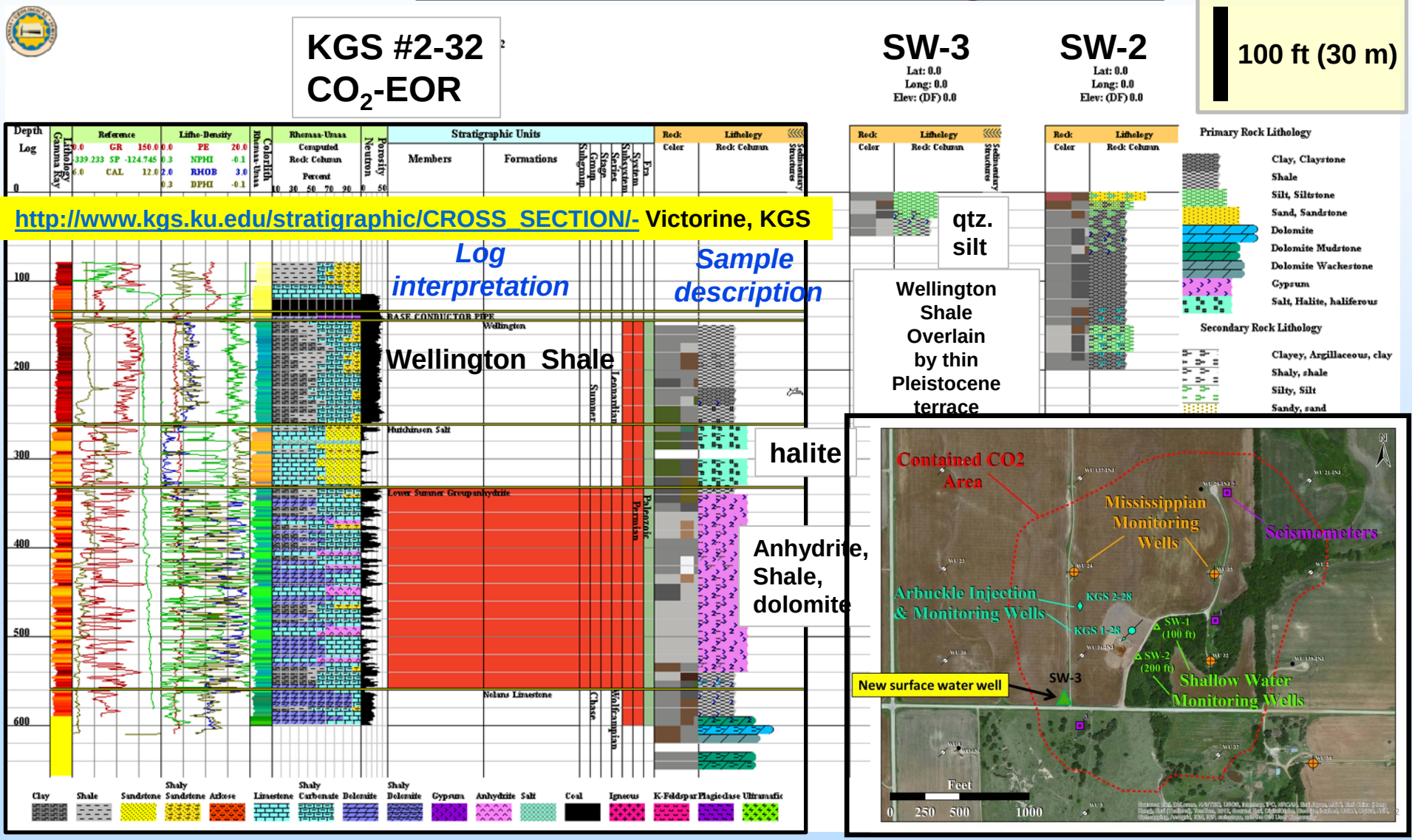
Testing pseudo 3D display web app

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

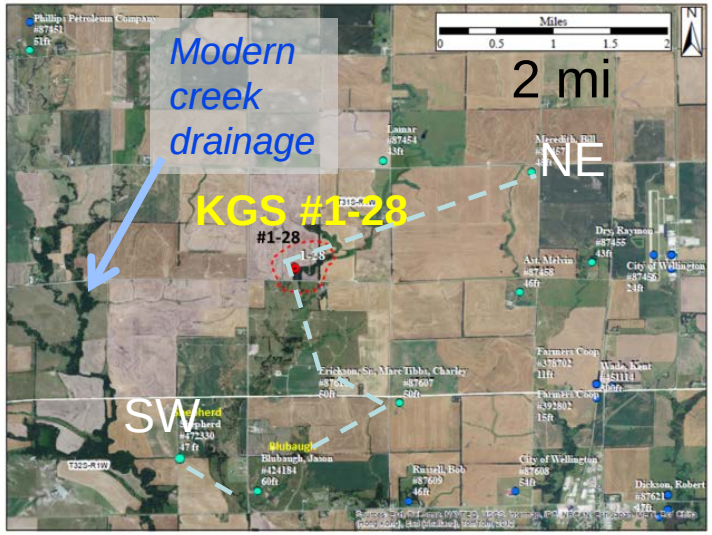
Web app: http://www.kgs.ku.edu/PRS/Ozark/Software/KS_Earthquake_3DPlot/index.html).



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



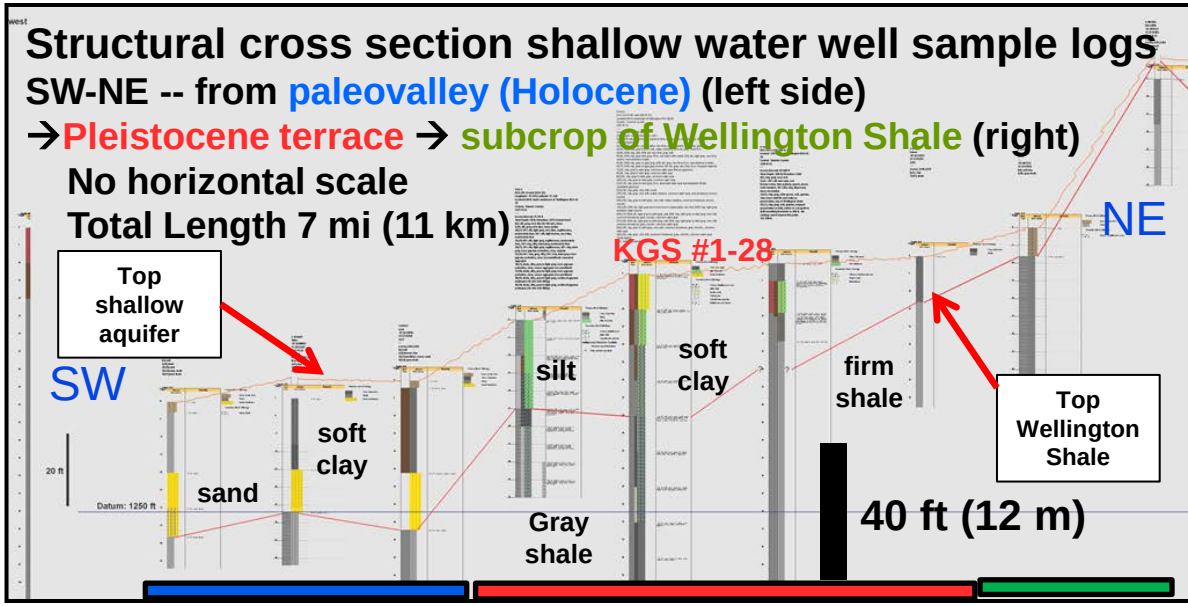
Structural cross section shallow water well sample logs

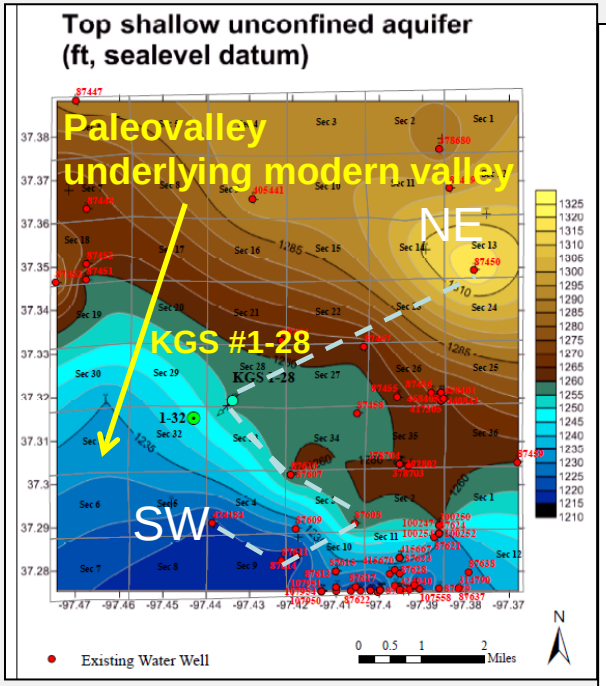
SW-NE -- from paleovalley (Holocene) (left side)

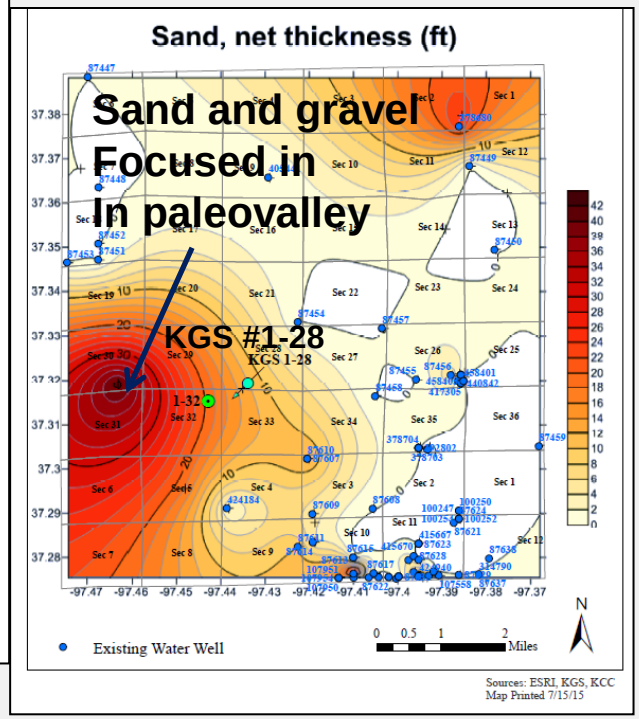
→Pleistocene terrace → subcrop of Wellington Shale (right)

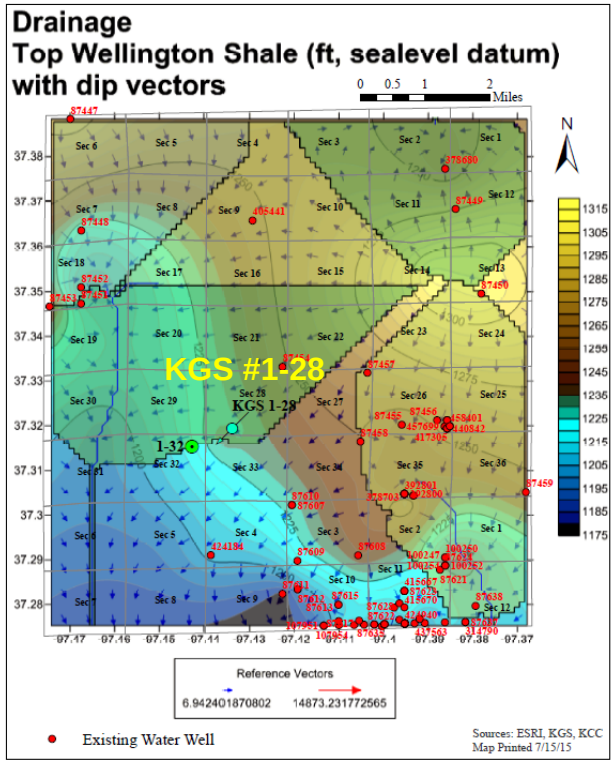
No horizontal scale

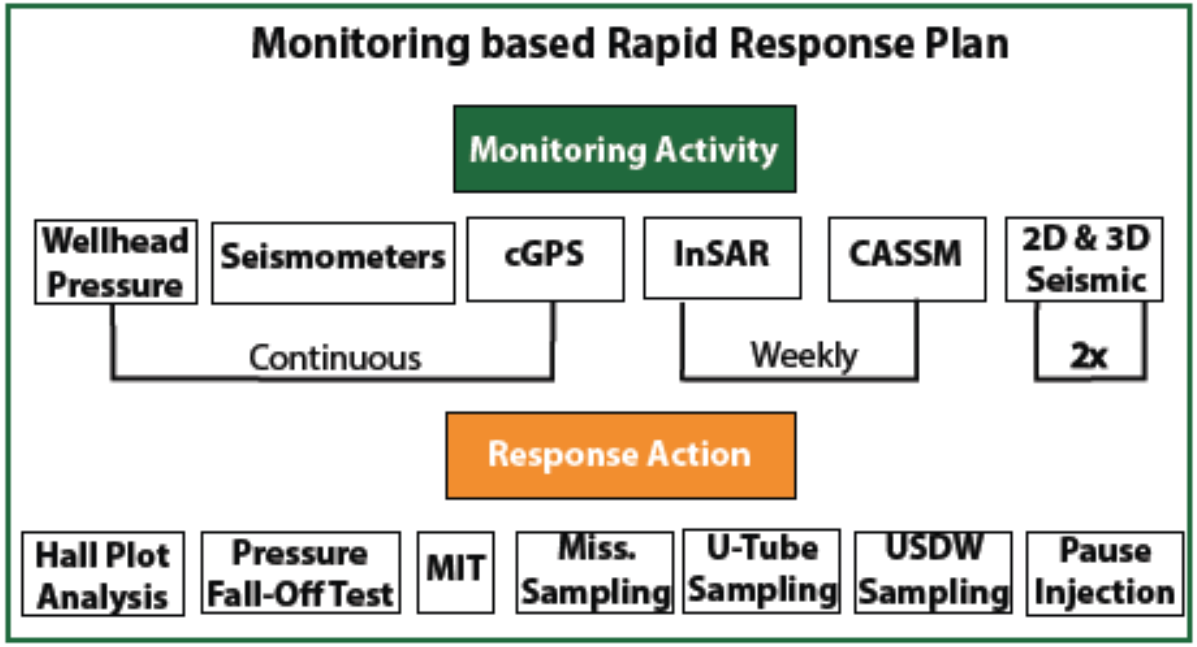
Total Length 7 mi (11 km)



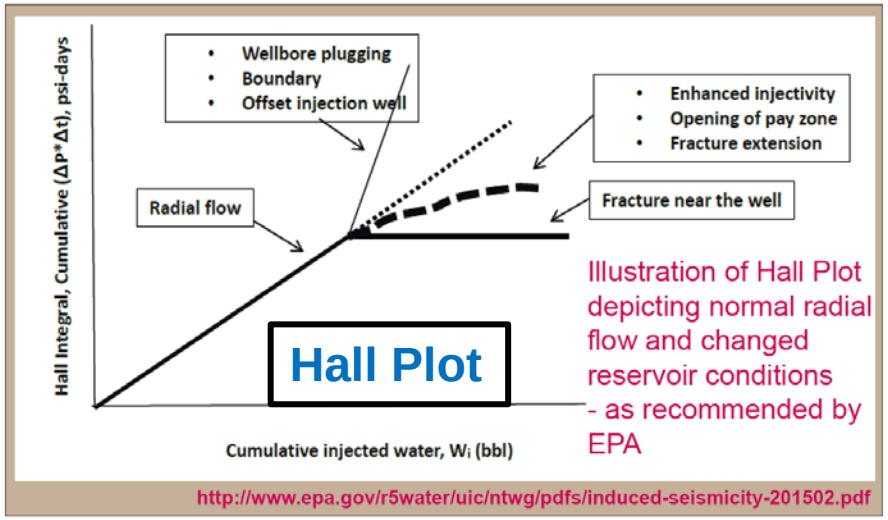








- Injection Control Plan
- Wellington Seismic Action Plan
- Monitoring-based Rapid Response Plan
- Emergency Remedial Response Plan



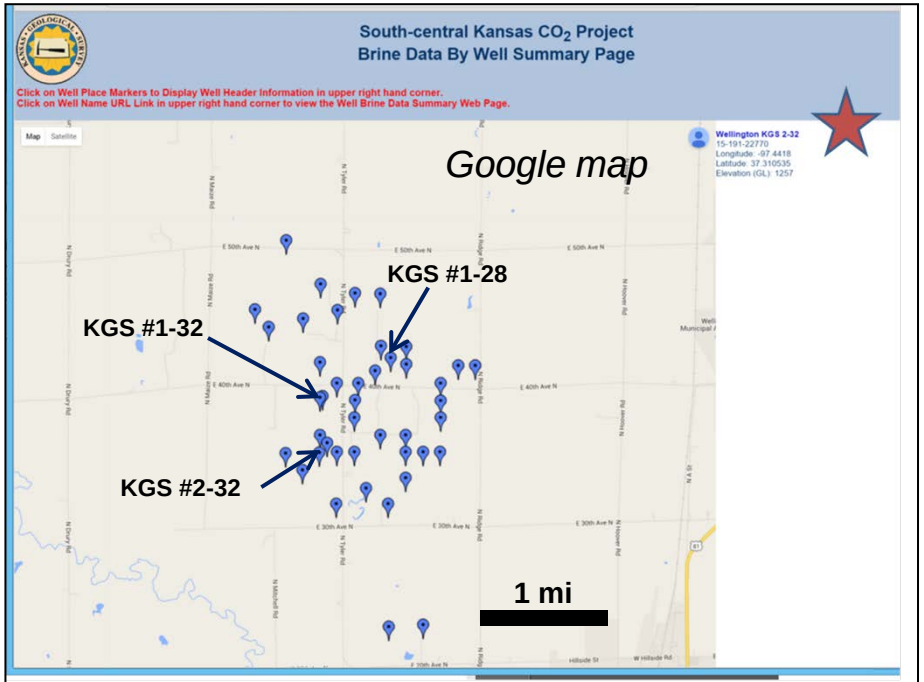
Under review by EPA

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:

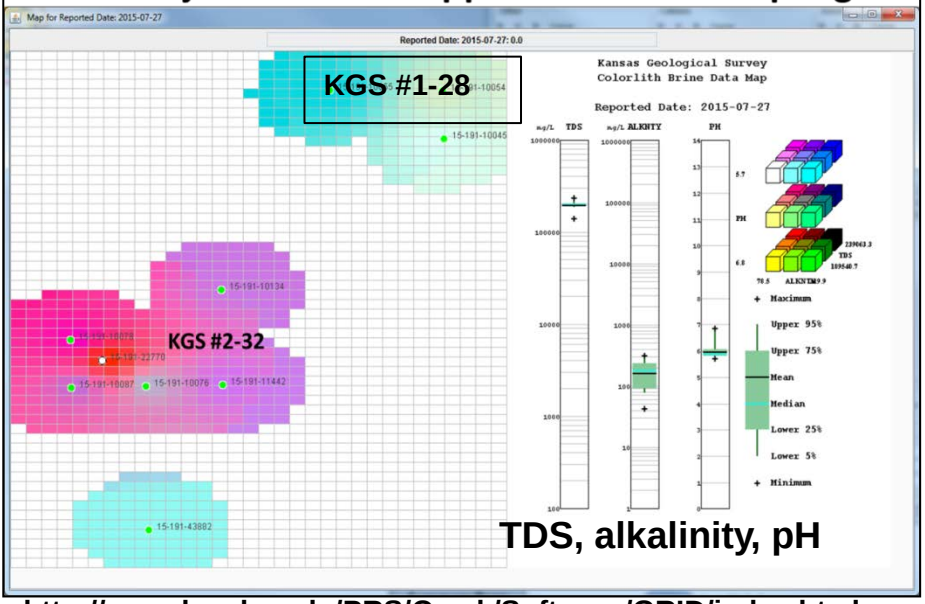
1) reliability of the data and approaches used to analyze the data,
2) frequency that the data is acquired during injection
3) sensitivity and precision of the monitoring method and its ability to detect small changes in CO2 plume behavior;
4) location and therefore resolution from which the data is 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.

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

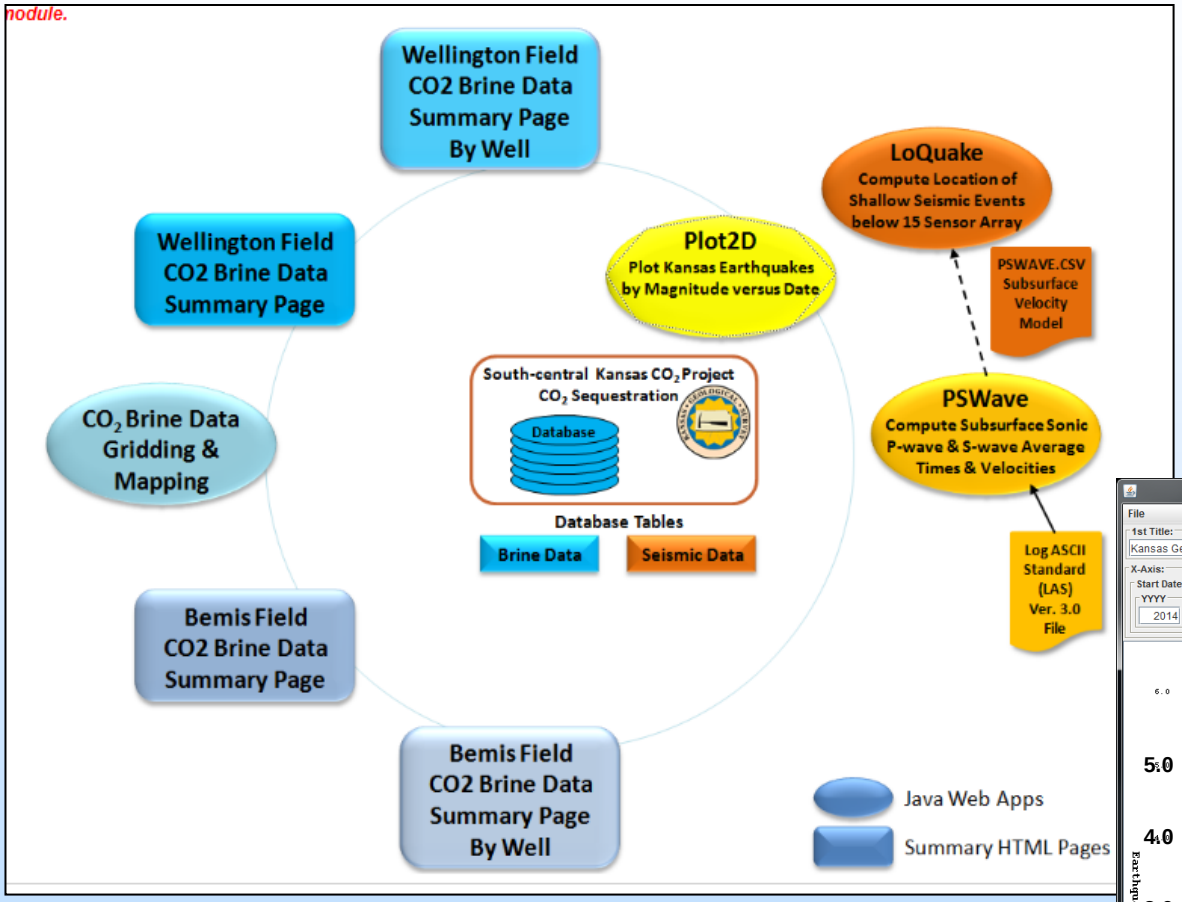
South-central Kansas CO_2 Project
Brine Data Types Database Table Contents

Cations			Anions			Other Data		
ID	Mnemonic	Description	ID	Mnemonic	Description	ID	Mnemonic	Description
0	Si	Silicon	50	H	Hydride	110	CO2	aqueous CO2
1	NH4	Ammonium	51	F	Fluoride	111	H2S	aqueous H2S
2	H3O	Hydronium	52	Cl	Chloride	112	O2	aqueous O2
3	Li	Lithium	53	Br	Bromide	200	SPGR	Specific Gravity
4	Na	Sodium	54	I	Iodide	201	SIGMA	Specific Conductivity
5	K	Potassium	55	OH	Hydroxide	202	SIGMA2	Specific Conductivity 2
6	Rb	Rubidium	56	BO3	Borate	203	PH	PH
7	Cs	Cesium	57	CO3	Carbonate	204	degF	Temperature (degrees F)
8	Be	Beryllium	58	HCO3	Bicarbonate	205	degC	Temperature (degrees C)
9	Mg	Magnesium	59	OCl	Hypochlorite	206	DEGi	Initial Temperature
10	Ca	Calcium	60	ClO2	Chlorite	207	DEGf	Final Temperature
11	Sr	Strontium	61	ClO3	Chlorate	208	DEGa	Average Temperature
12	Ba	Barium	62	ClO4	Perchlorate	209	PSI	Pressure (psi)
13	Al	Aluminum	63	CN	Cyanide	210	PSIi	Initial Pressure (psi)
14	Sn	Tin	64	NCO	Cyanate	211	PSIf	Final Pressure (psi)
15	Sn2	Tin(II)	65	OCN	Isocyanate	212	OHM	Resistivity (Rw)
16	Sn4	Tin(IV)	66	SCN	Thiocyanate	213	OHM75	Resistivity at 75 deg F
17	Pb	Lead	67	N	Nitride	214	OHME	Estimated Rw
18	Pb2	Lead(II)	68	N3	Azide	215	TDS	Total Solids
19	Pb4	Lead(IV)	69	NO2	Nitrite	216	TDSe	Estimated Total Dissolved Solids
20	Sb	Antimony	70	NO3	Nitrate	217	TDSc	Total Solids Computed
21	Sb3	Antimony(III)	71	NH2	Amide	218	NTU	Trubidity
22	Sb5	Antimony(V)	72	MnO4	Permanganate	219	mV	Redox Potential
23	Bi	Bismuth	73	P	Phosphide	220	SALNTY	Salinity
24	Bi3	Bismuth(III)	74	PO3	Phosphite	221	HARDNESS	Total Hardness
25	Bi5	Bismuth(V)	75	PO4	Phosphate	222	RATIO	Anion/Cation Ratio
26	Cr	Chromium	76	HPO4	Hydrogen phosphate	223	FLUID	Sample Volume
27	Cr2	Chromium(II)	77	H2PO4	Dihydrogen phosphate	224	GMCC	Fluid Density
28	Cr3	Chromium(III)	78	As	Arsinide	225	ALK	Alkalinity-Spectrometer
29	Mn	Manganese	79	AsO4	Arsenate	226	ALK2	Alkalinity-Test Kits
30	Mn2	Manganese(II)	80	AsO3	Arsenite	300	FORM	Formation
31	Mn3	Manganese(III)	81	Se	Selenide	301	AGE	Formation Age
32	Fe	Iron	82	S	Sulfide	302	TOP	Top Depth
33	Fe2	Iron(II)	83	HS	Hydrogen Sulfide	303	BASE	Base Depth
34	Fe3	Iron(III)	84	SO3	Sulfite	400	deg-Multi	Temperature Multi-meter
35	Co	Cobalt	85	HSO3	Hydrogen Sulfite	401	deg-Cond	Temperature Cond-meter
36	Co2	Cobalt(II)	86	S2O3	Thiosulfate	501	NH4-2	Ammonium-SPEC
37	Co3	Cobalt(III)	87	SO4	Sulfate	533	Fe2-2	Iron-SPEC
38	Ni	Nickel	88	HSO4	Bisulfate	569	NO2-2	Nitrite-SPEC
39	Ni2	Nickel(II)	89	O	Oxide	570	NO3-2	Nitrate-SPEC
40	Ni3	Nickel(III)	90	IO3	Iodate	587	SO4-2	Sulfate-SPEC
41	Cu	Copper(I)	91	BrO3	Bromate	630	Mn2-3	Manganese-KIT
42	Cu2	Copper(II)	92	OBr	Hypobromite	633	Fe2-3	Iron-KIT
43	Ag	Silver	93	CrO4	Chromate	652	Cl-3	Chloride-KIT
44	Au	Gold(I)	94	Cr2O7	Dichromate	675	PO4-3	Phosphate-KIT
45	Au2	Gold(II)	95	CH3COO	Aceta			
46	Zn	Zinc	96	HCOO	forma			
47	Cd	Cadmium	97	O2	Perox			
48	Hg2	Mercury(I)	98	C2O4	Oxala			
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						

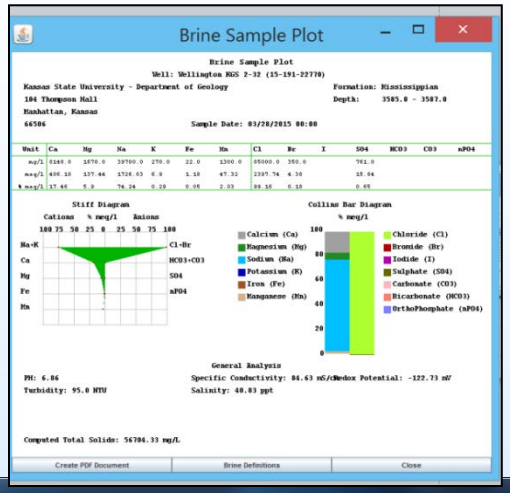
Brent Campbell, Chance Reese, Saugata Datta KSU, John Victorine, J. Raney, John Doveton, KGS

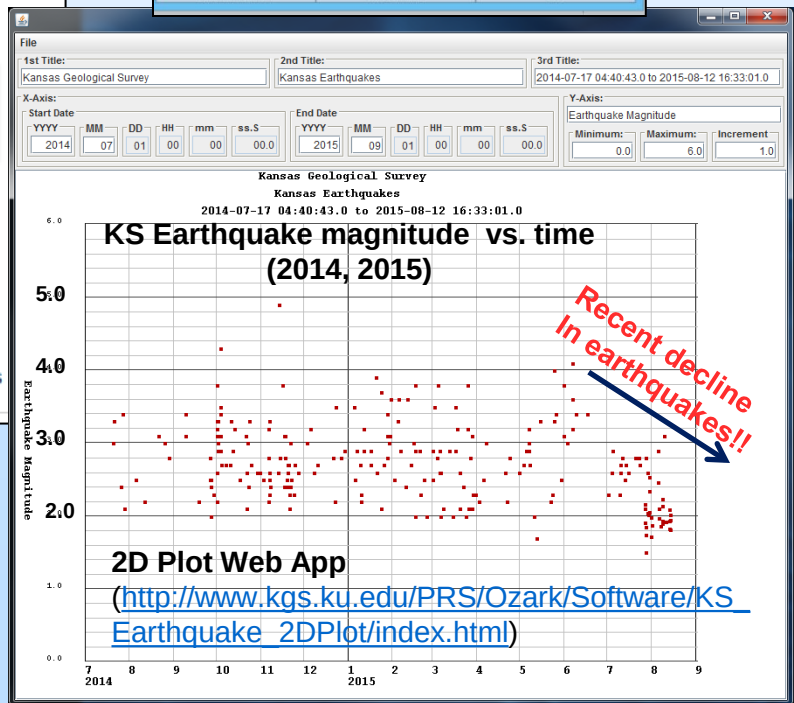
http://chasm.kgs.ku.edu/ords/iqstrat.co2_brine_data_type_pkg.build_web_page

KGS CO_2 online web dashboard provides integrated view of monitoring activity



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



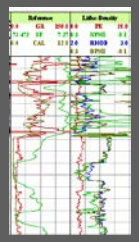


Workflow for reservoir simulation and geomechanical analysis

Data

Well logs

Tops



Core data

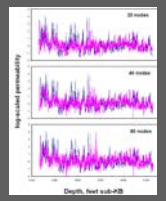
Dynamic data

Reservoir Characterization

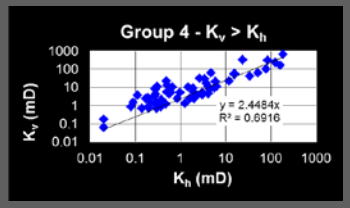
Multi-mineral FE

FZI-SWPHI

K prediction via ANN



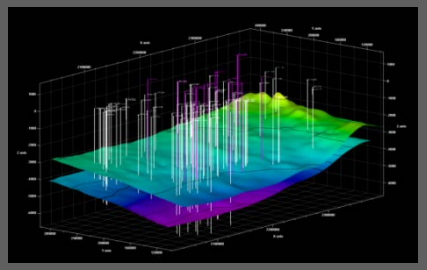
K_h and K_v relations



Flow units

Static model

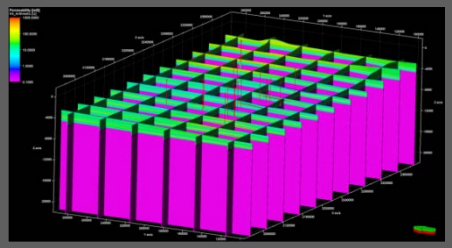
Structural model



Upscale logs

Statistical analysis

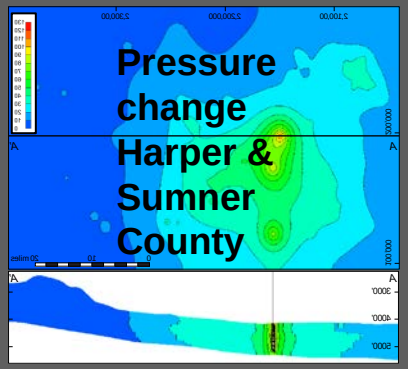
Property models



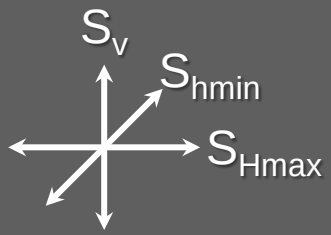
Geomechanical model

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

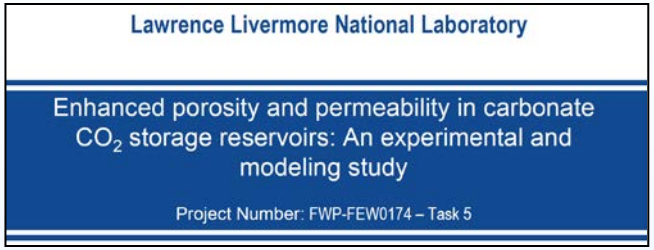
- **Complete repressurization of the Mississippian reservoir for CO^2-EOR injection and inject CO_2 -- September 2015**
  - Meeting with public in Wellington town hall meeting following commencement of Mississippian injection.
- **Obtain draft Class VI permit -- October 2015**
  - 6 mo. fabrication lead 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

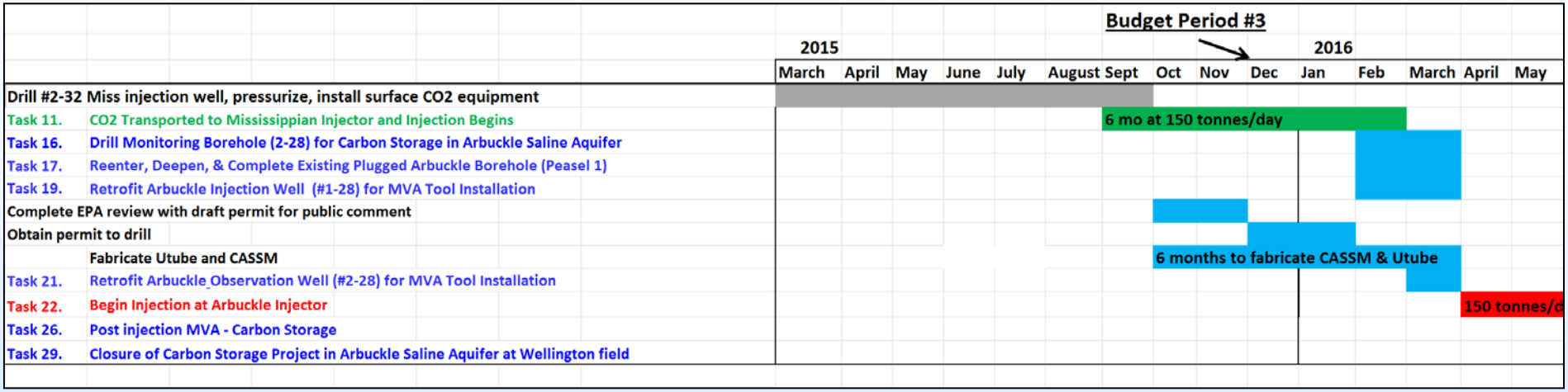
- **Continue collaboration with Susan Carroll, PI, LLNL**



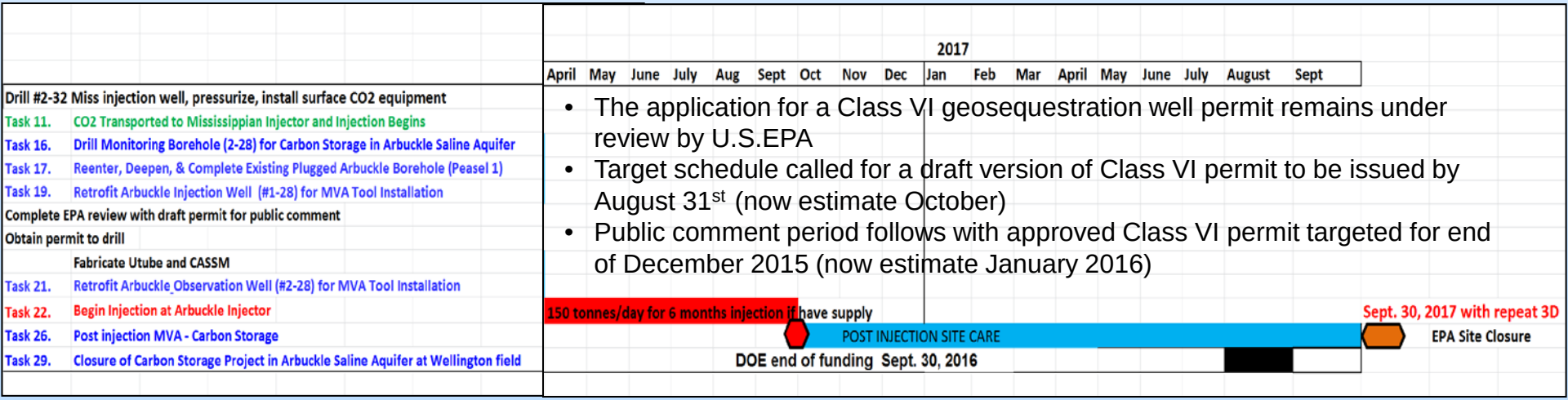
  - task addition → *Experimental calibration of NMR well logs to determine pore connectivity in the injection zone at the Wellington CO_2 storage demonstration site, Kansas*
  - *Potentially deploy in two new enhancements to MVA --*
    - *downhole strainmeters and tiltmeter in an Arbuckle observation 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

KSCO2

KU KANSAS GEOLOGICAL SURVEY The University of Kansas

KU THE UNIVERSITY OF KANSAS Department of Geology

NETL