Update on Results of SECARB Test of Monitoring Large Volume Injection at Cranfield

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SECARB Cranfield Research: Theoretical Approaches Through Commercialization

Commercial Deployment by Southern Co.

Toward commercia-lization	**Contingency plan Parsimonious public assurance monitoring**	**Subsurface perturbation predicted**	
Hypothesis tested	**CO_2 retained in-zone-document no leakage to air-no damage to water**	**CO_2 saturation correctly predicted by flow modeling**	**Pressure (flow plus deformation) correctly predicted by model**
Field experiments	**Surface monitoring: instrument verification Groundwater program CO_2 variation over time** **Above-zone acoustic monitoring (CASSM) & pressure monitoring**	**CO_2 saturation measured through time – acoustic impedance + resistivity Tomography and change through time** **3- D time lapse surface/ VSP seismic** **Dissolution and saturation measured via tracer breakthrough and chromatography**	**Microseismic test, pressure mapping** **Acoustic response to pressure change over time**
Theory and lab	**Sensitivity of tools; saturated-vadose modeling of flux and tracers**	**Lab-based core response to EM and acoustic under various saturations, tracer behavior**	**Advanced simulation of reservoir pressure field**

Cranfield "Early" Field Test Collaboration

Denbury Onshore LLC

Sandia Technologies

Sandia Technologies, LLC

LBNL
LLBL
USGS
ORNL
NETL
QEA
U Mississippi
Miss State
UTPGE
UT DoG
University Tennessee
BP
Princeton
Stanford
University Edinburgh

Schlumberger Carbon Services

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Gulf Coast Carbon Center Industrial Associates

Taking on the world's toughest energy challenges.

Finding the ways that work

NETL

The University of Texas at Austin
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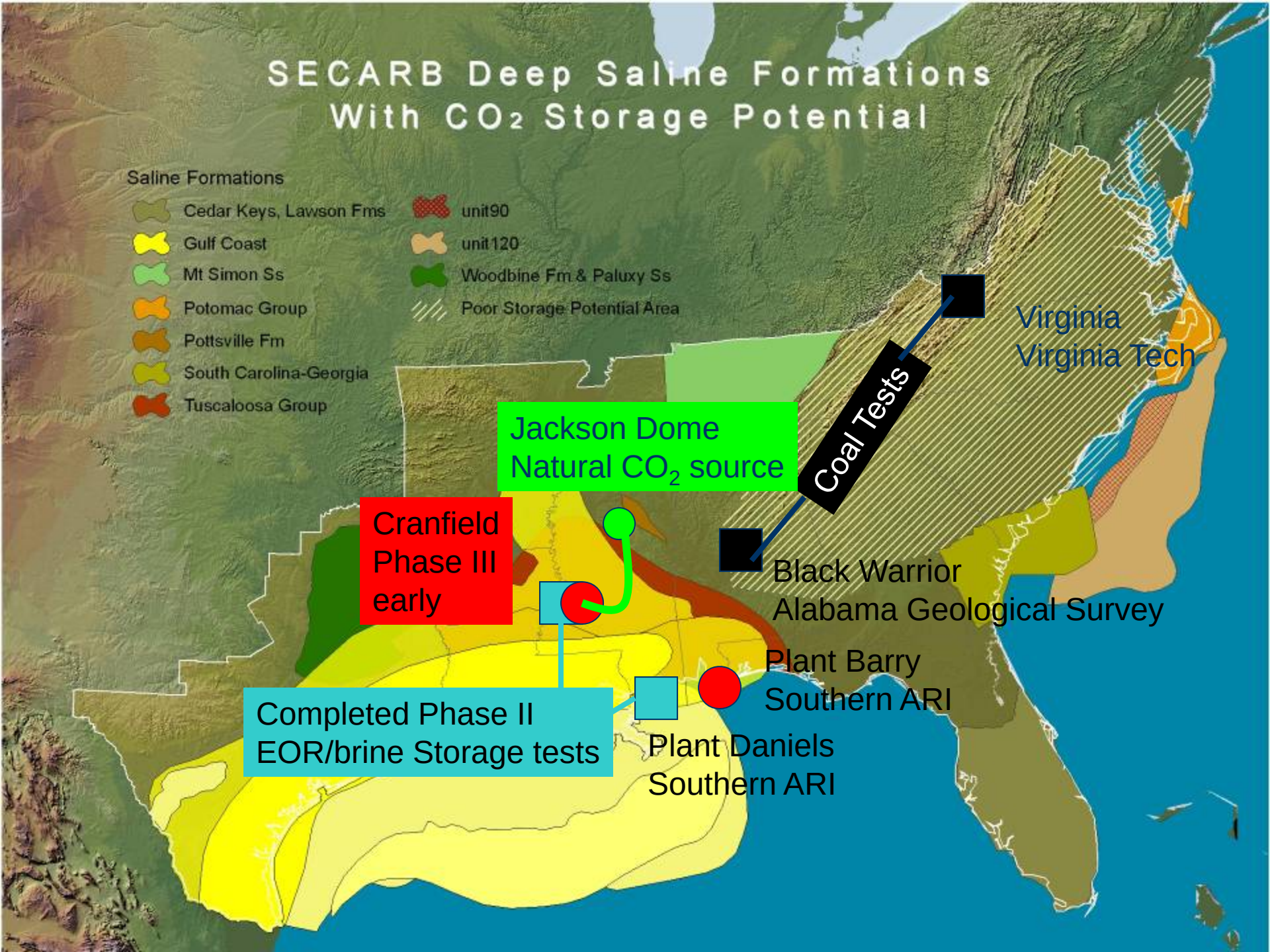
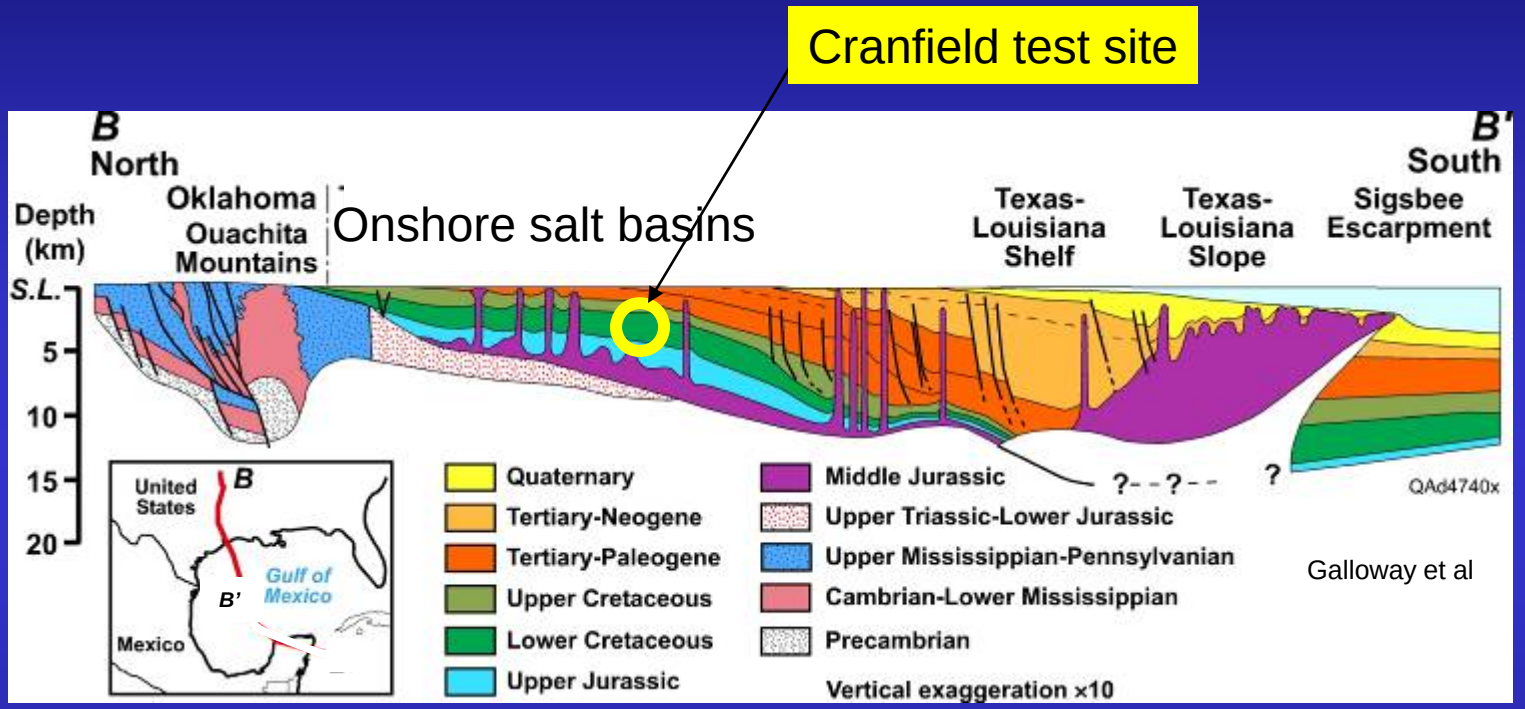

SECARB Deep Saline Formations
With CO_2 Storage Potential
Saline Formations
Cedar Keys, Lawson Fms
Gulf Coast
Mt Simon Ss
Potomac Group
Pottsville Fm
South Carolina-Georgia
Tuscaloosa Group
unit90
unit120
Woodbine Fm & Paluxy Ss
Poor Storage Potential Area
Virginia
Virginia Tech
Coal Tests
Jackson Dome
Natural CO_2 source
Cranfield
Phase III
early
Black Warrior
Alabama Geological Survey
Plant Barry
Southern ARI
Completed Phase II
EOR/brine Storage tests
Plant Daniels
Southern ARI

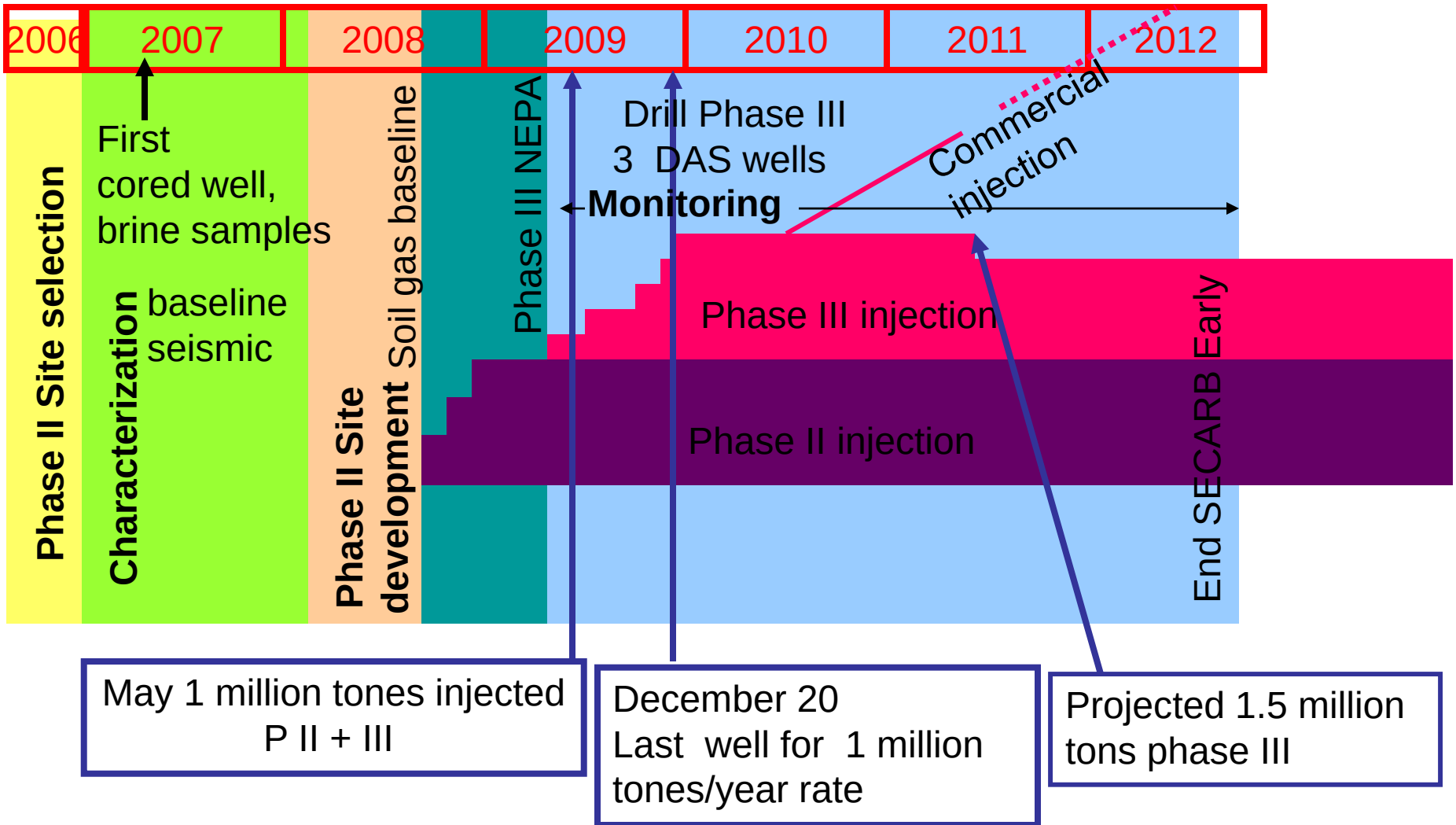
Natural CO_2 Available Now in large Volumes Shipped via Sonant Pipeline to Test Lower Part of the Gulf Coast Wedge



Relatively young sandstones with shale seals
Heterogeneous, high porosity sediments
Salt tectonics and growth faults
Heavy industry

} Characteristics of the Gulf Coast wedge

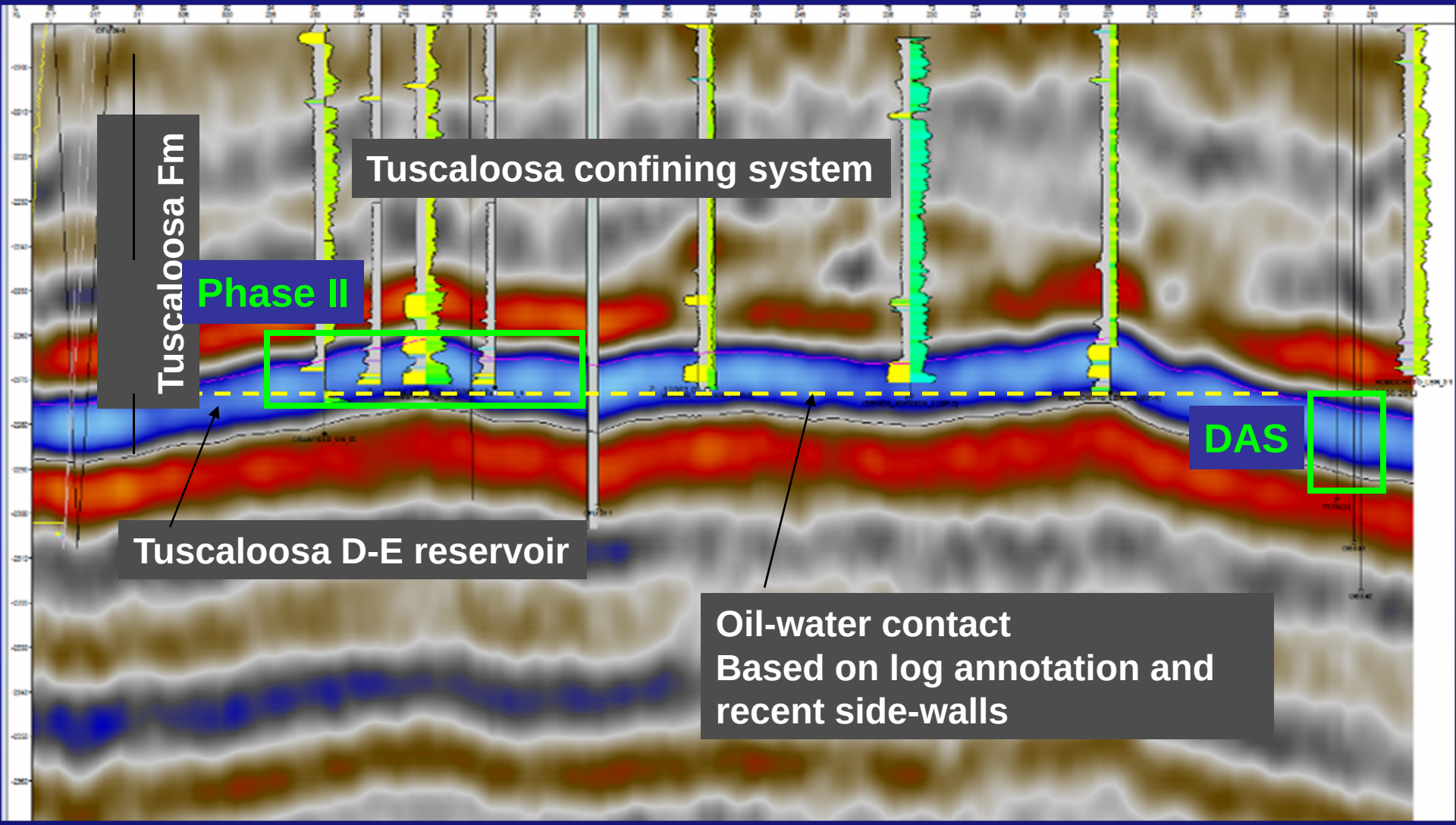
Cranfield Progress



Assuring Permanent Storage

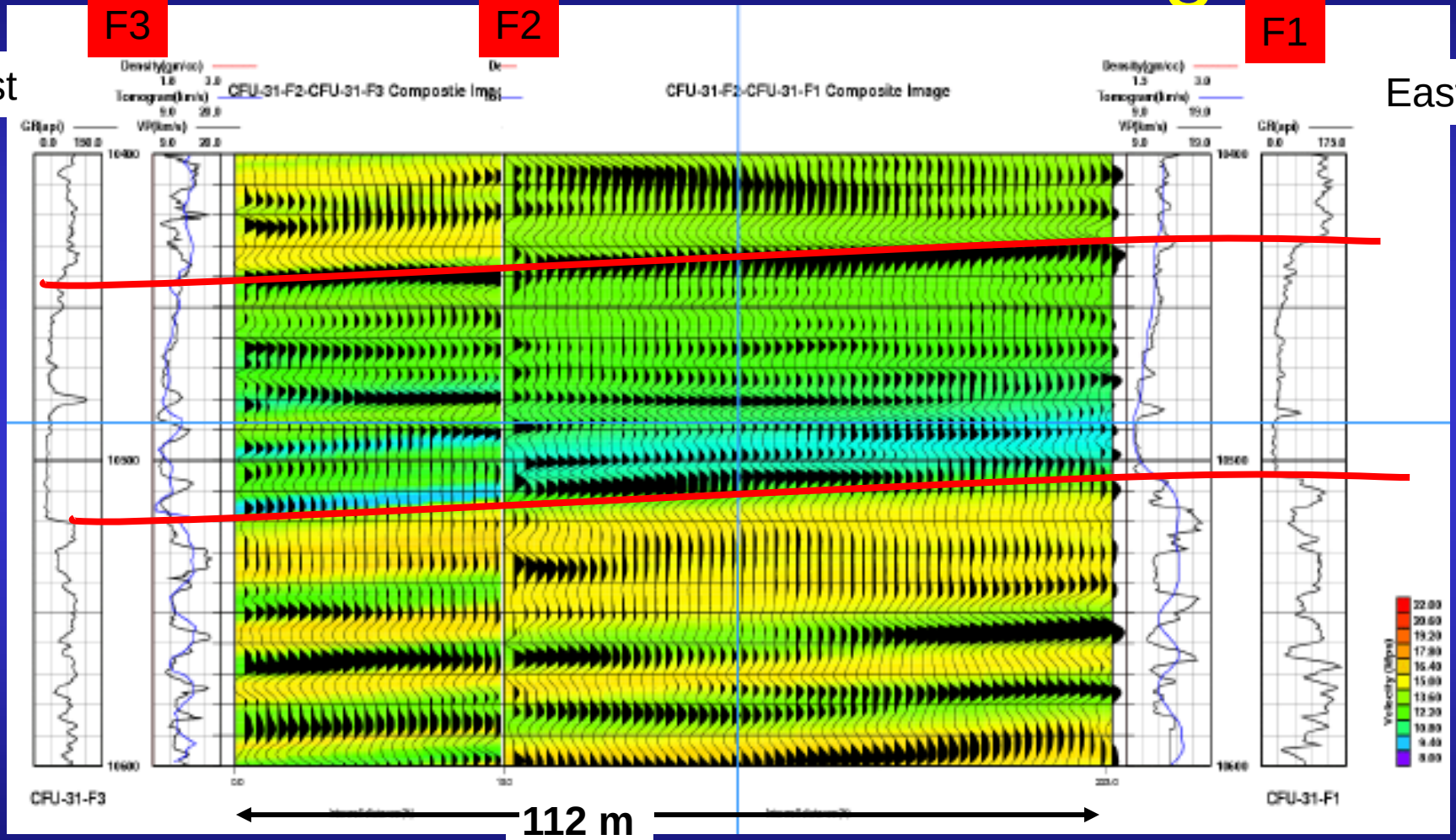
- Know the geology of the reservoir
  - Characteristics that will accept and retain CO_2
- Predict the area and magnitude of pressure increase at planned injection rate
  - Required for any injection in US by Safe Drinking Water Act, 1974
- Predict the distribution of CO_2
- Make measurements that document that these predictions are correct.

Characterization of the Reservoir



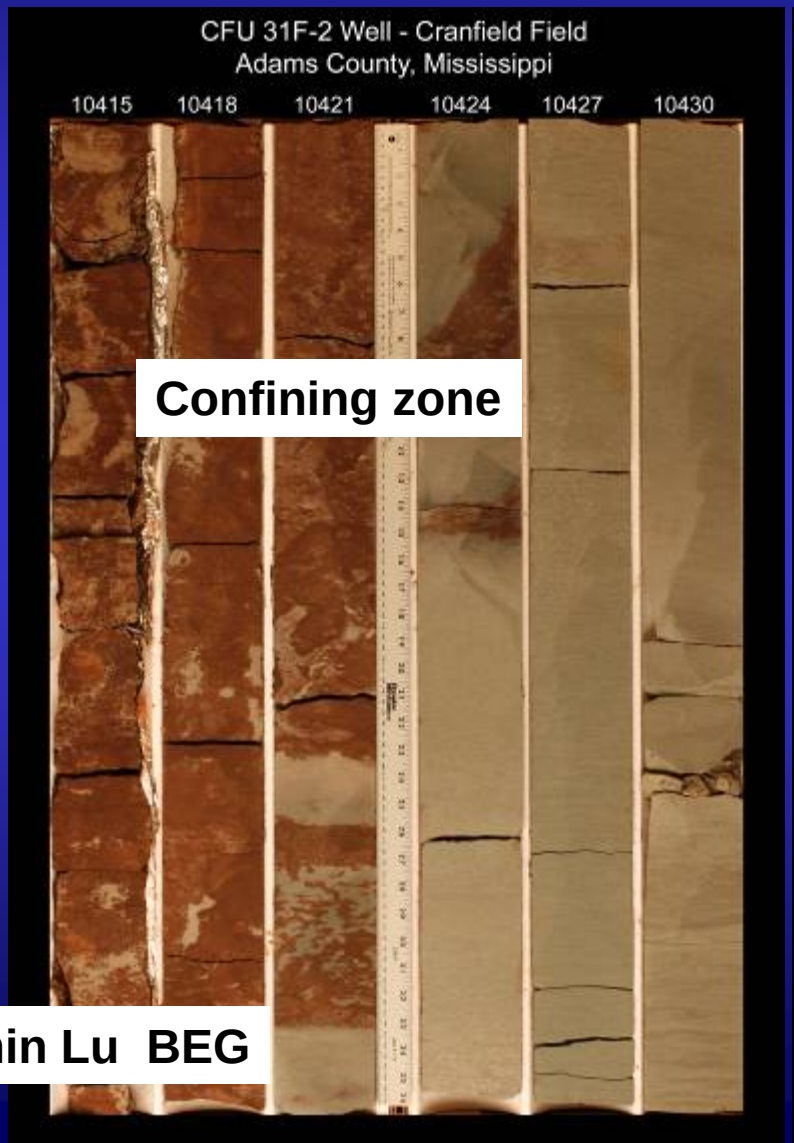
3D Denbury - interpretation Tip Meckel BEG

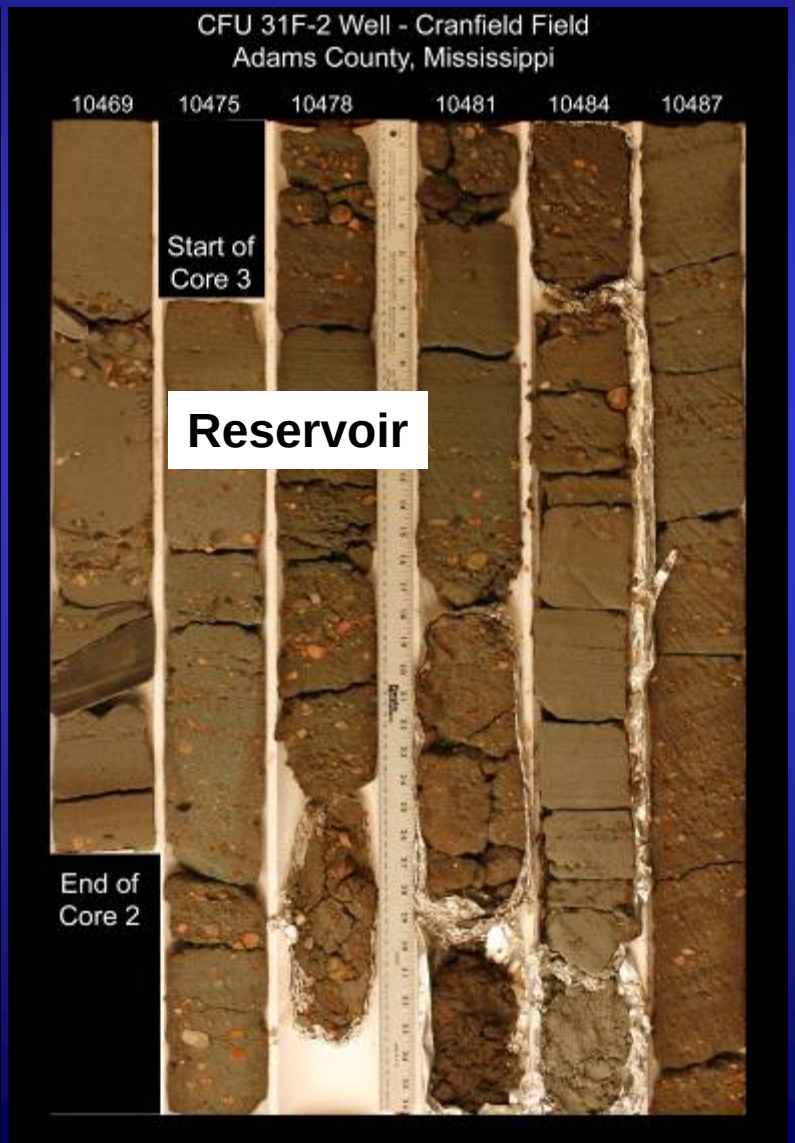
Baseline Cross Well tomogram



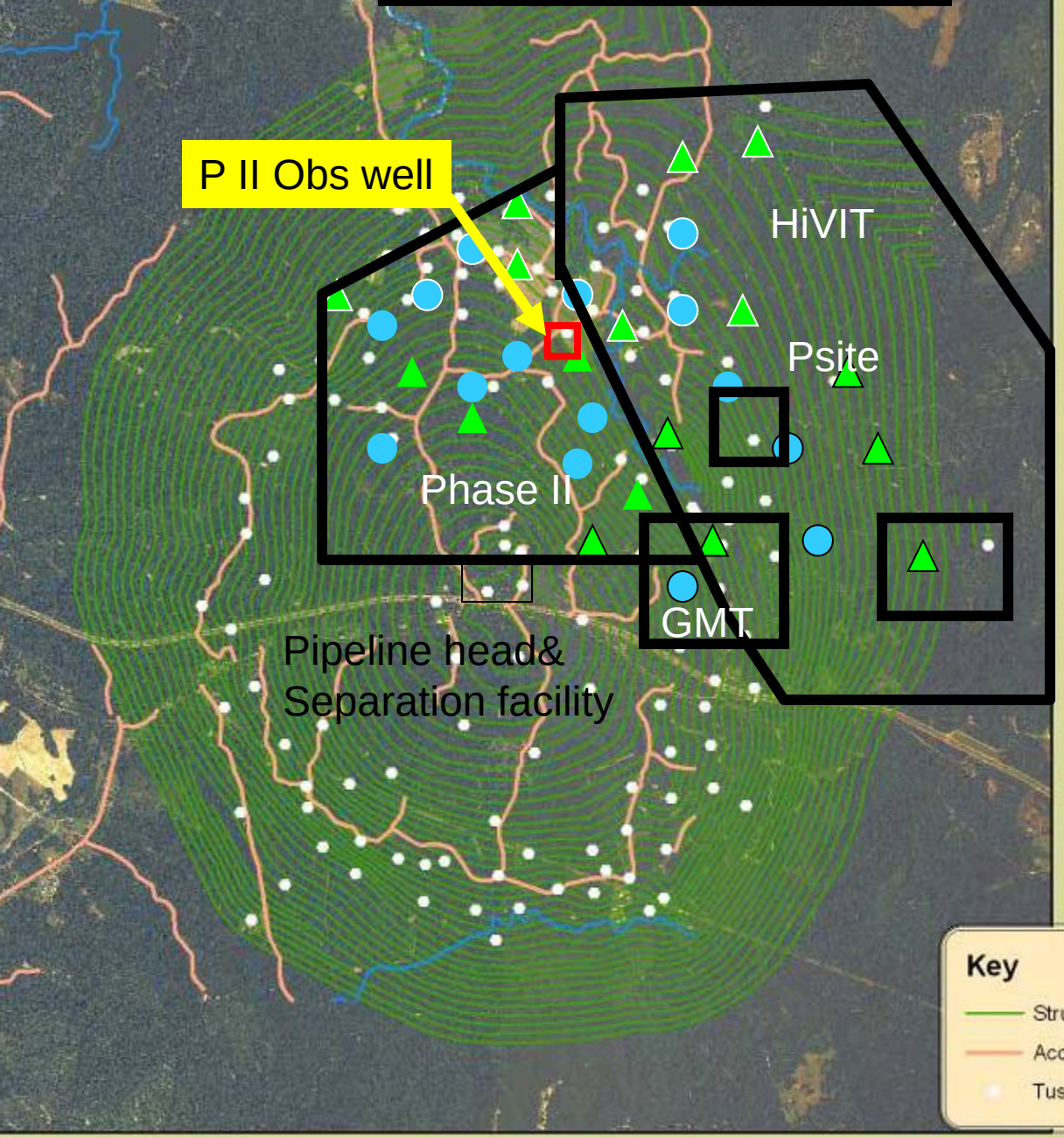
Z-Seis & Tom Daley Jonathan Franklin in review at LBNL

Upward fining fluvial sandstone and conglomerates of the lower Tuscaloosa Fm





Jiemin Lu BEG

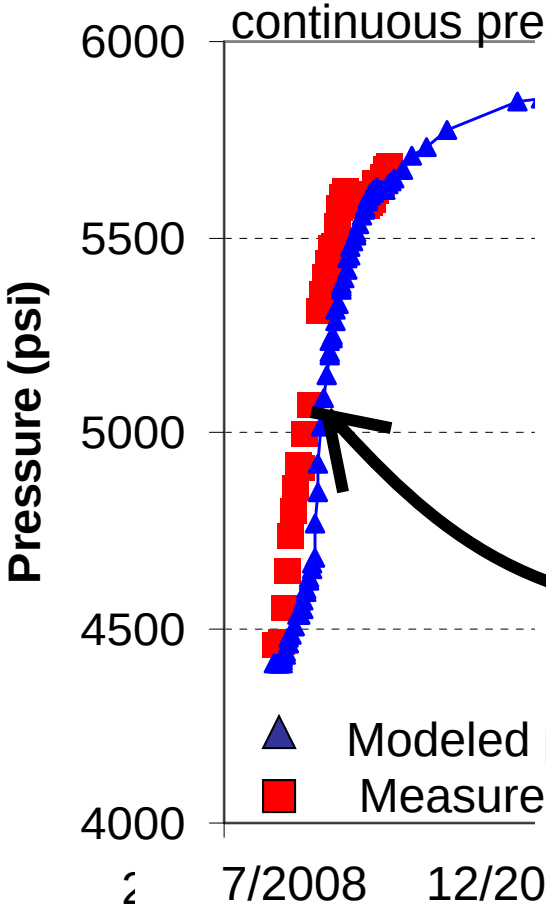


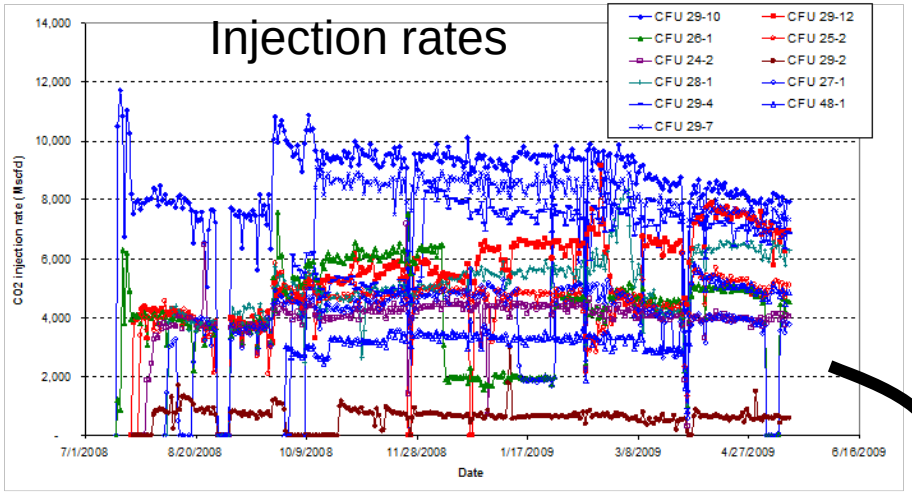
Go to the field to test

- Injector
- Producer (monitoring point)
- Observation Well

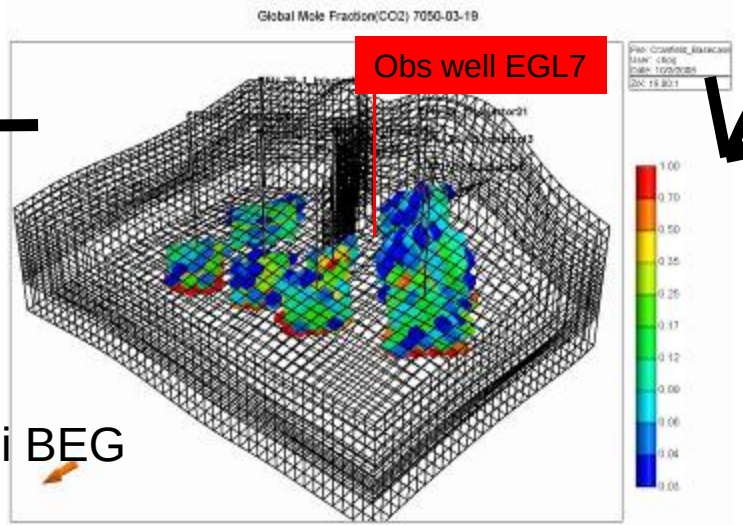
Model –history match pressure at real-time monitoring well

Results of 1 year model continuous pressure data



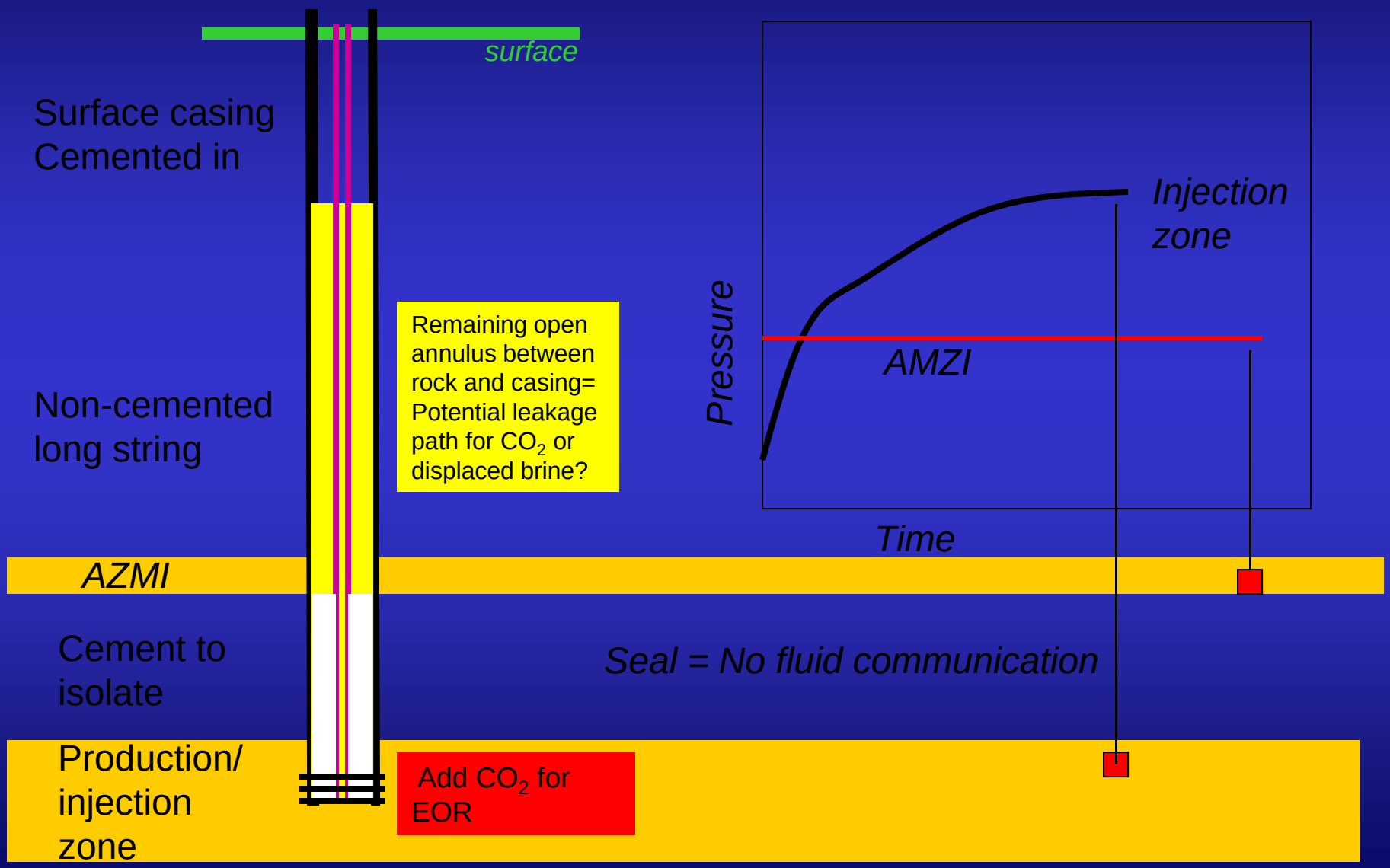


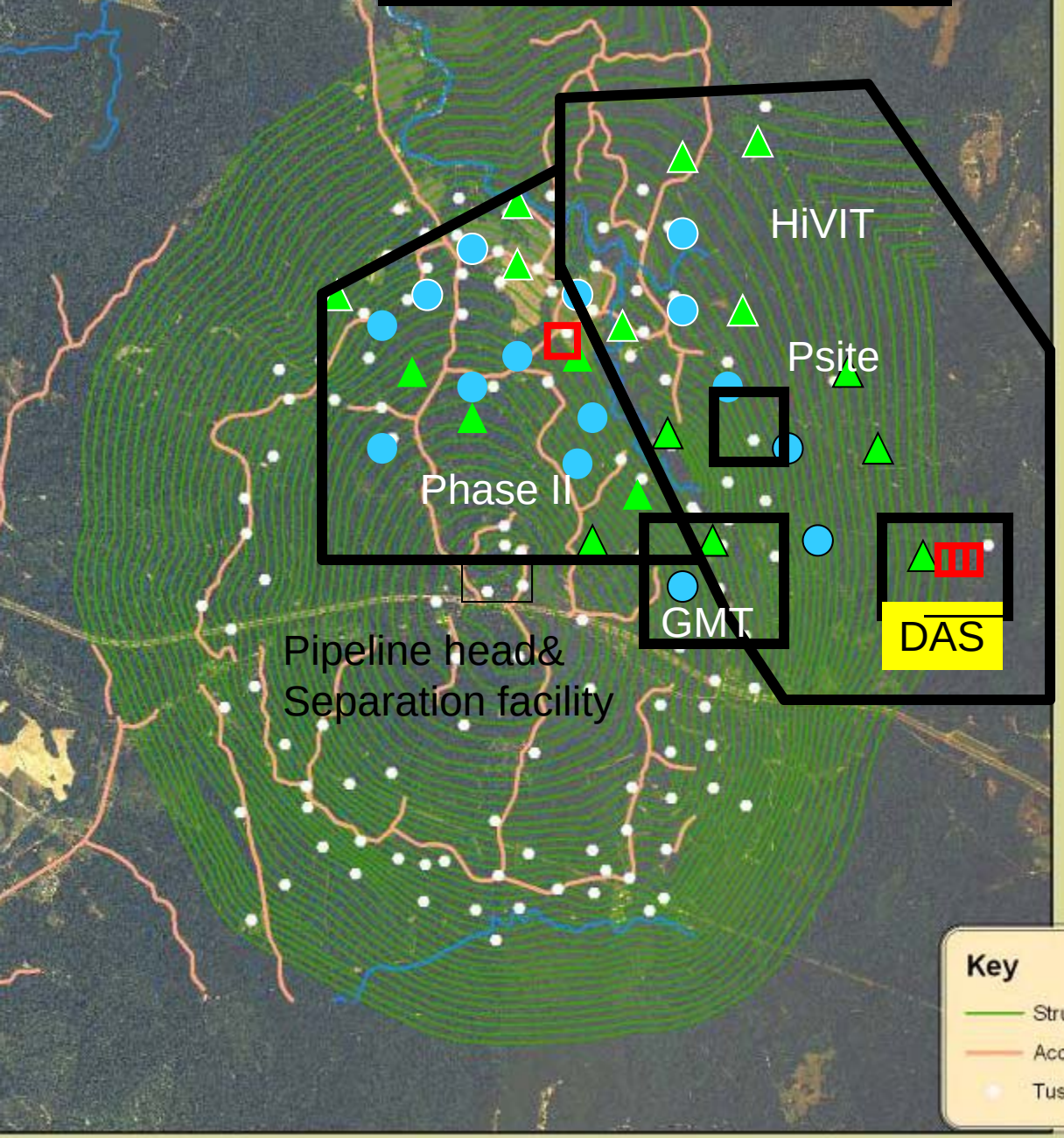
Rock and fluid properties in simulator



JP Nicot Jong Won Choi BEG

Using pressure to show no leakage



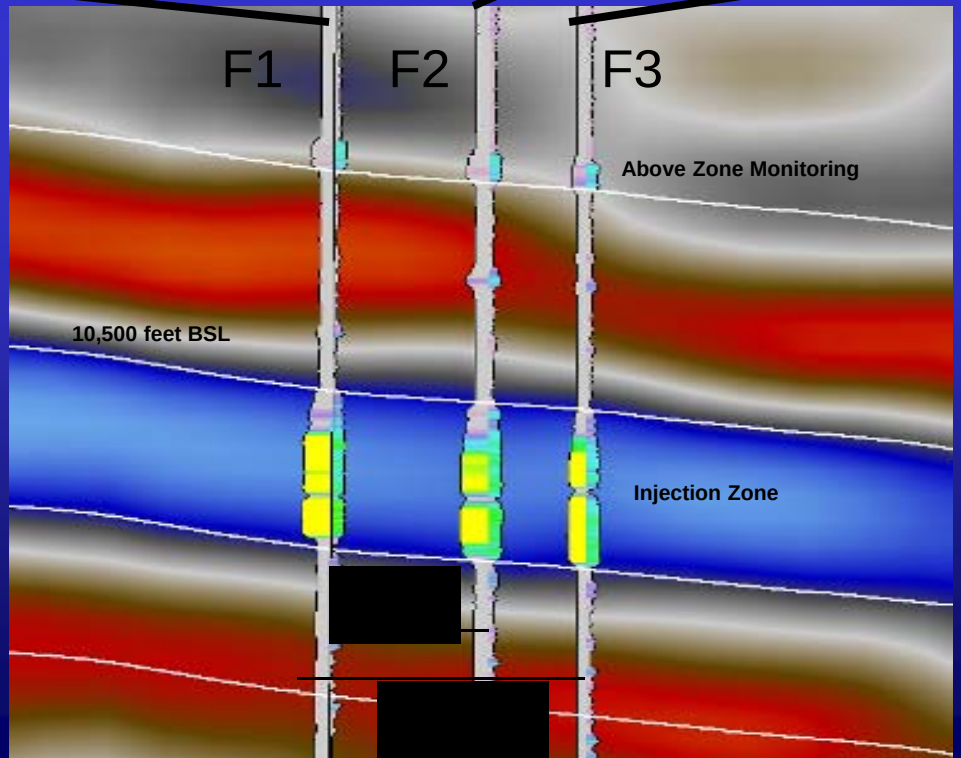


Look in Detail at Flow Detailed Study Area (DAS)

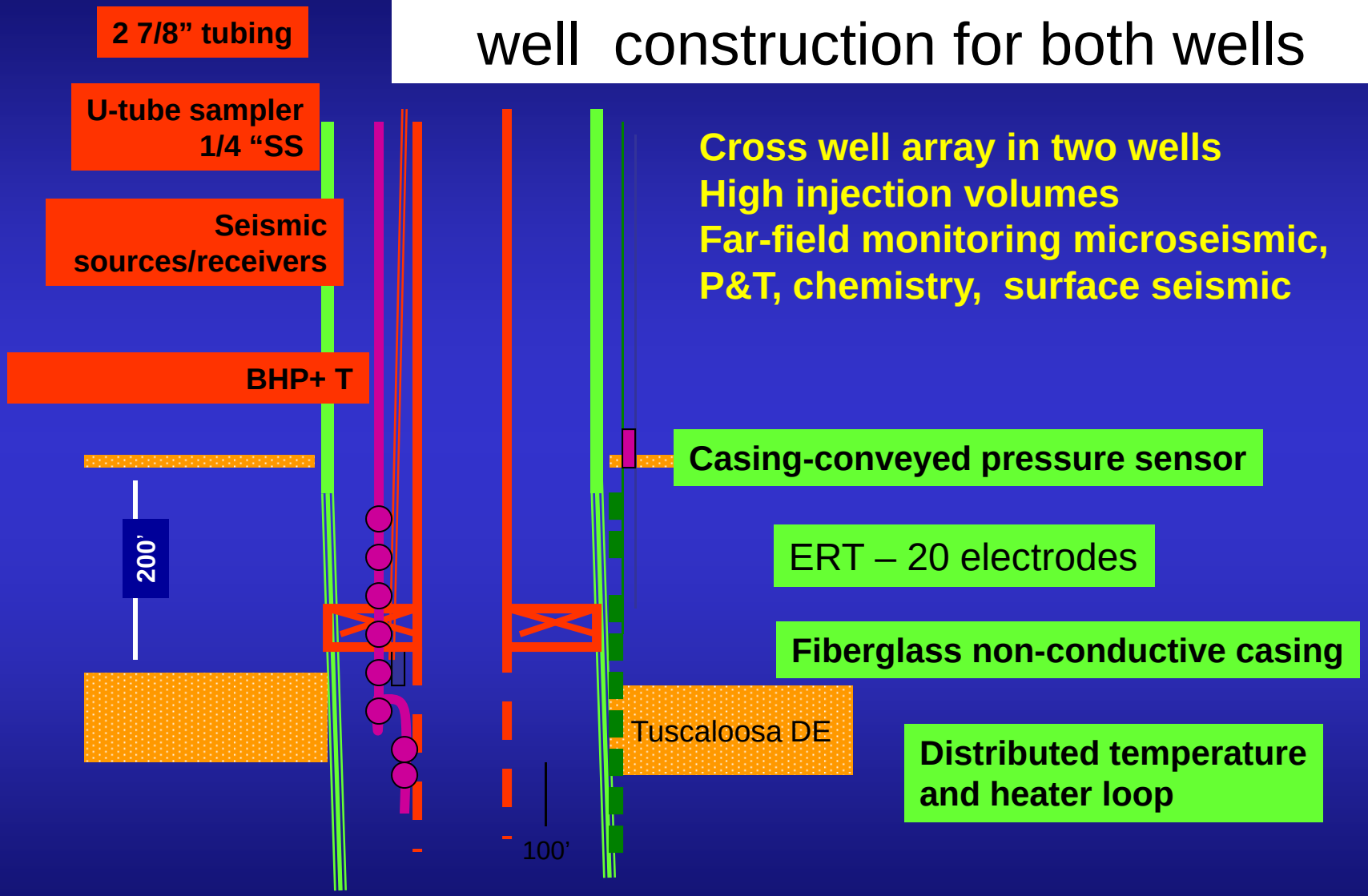
- Injector
- Producer (monitoring point)
- Observation Well

DAS Monitoring

Closely spaced well array to examine flow in complex reservoir



Phase III Research Observation well construction for both wells



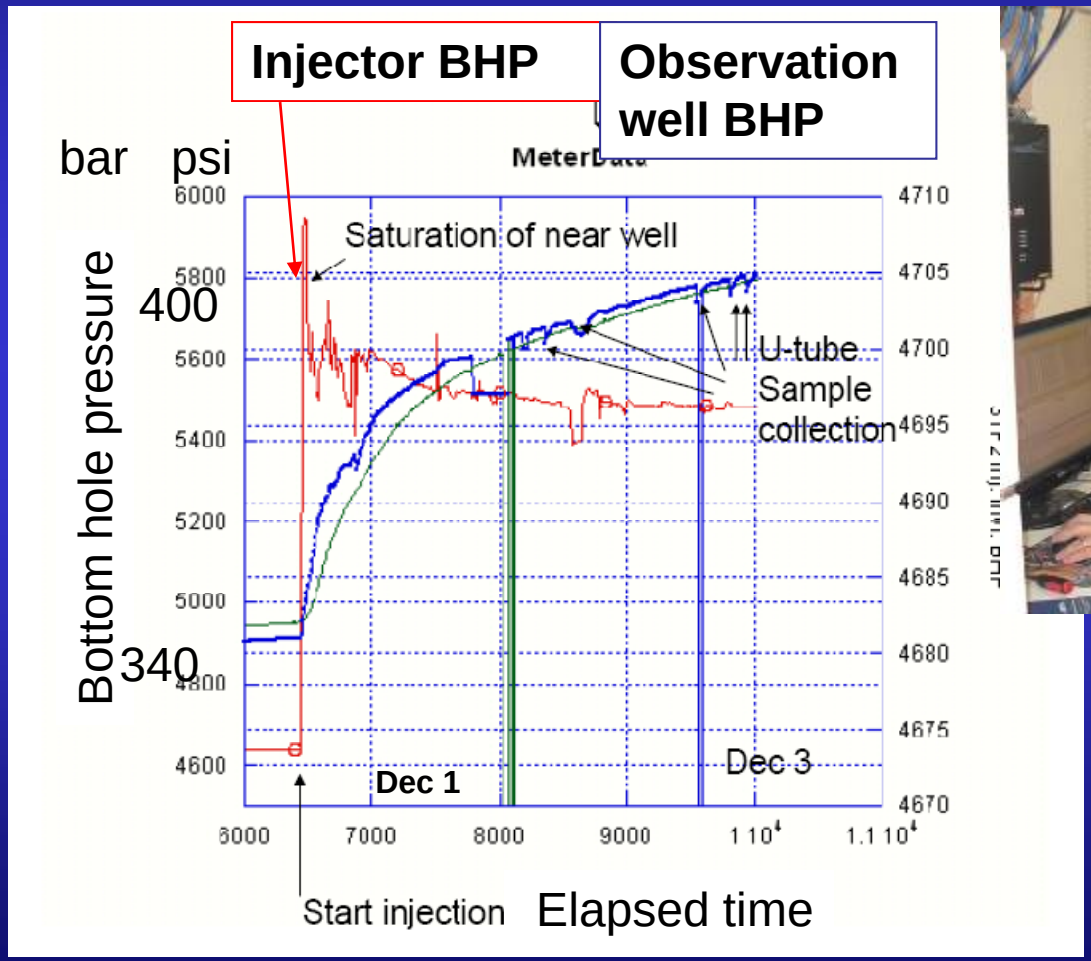
BEG LBNL LLNL USGS ORNL Sandia Technologies

Start injection at DAS Dec 1, 2009

175 kg/min step up to 350kg/min

Start injection at DAS Dec 1, 2009

175 kg/min step up to 350kg/min

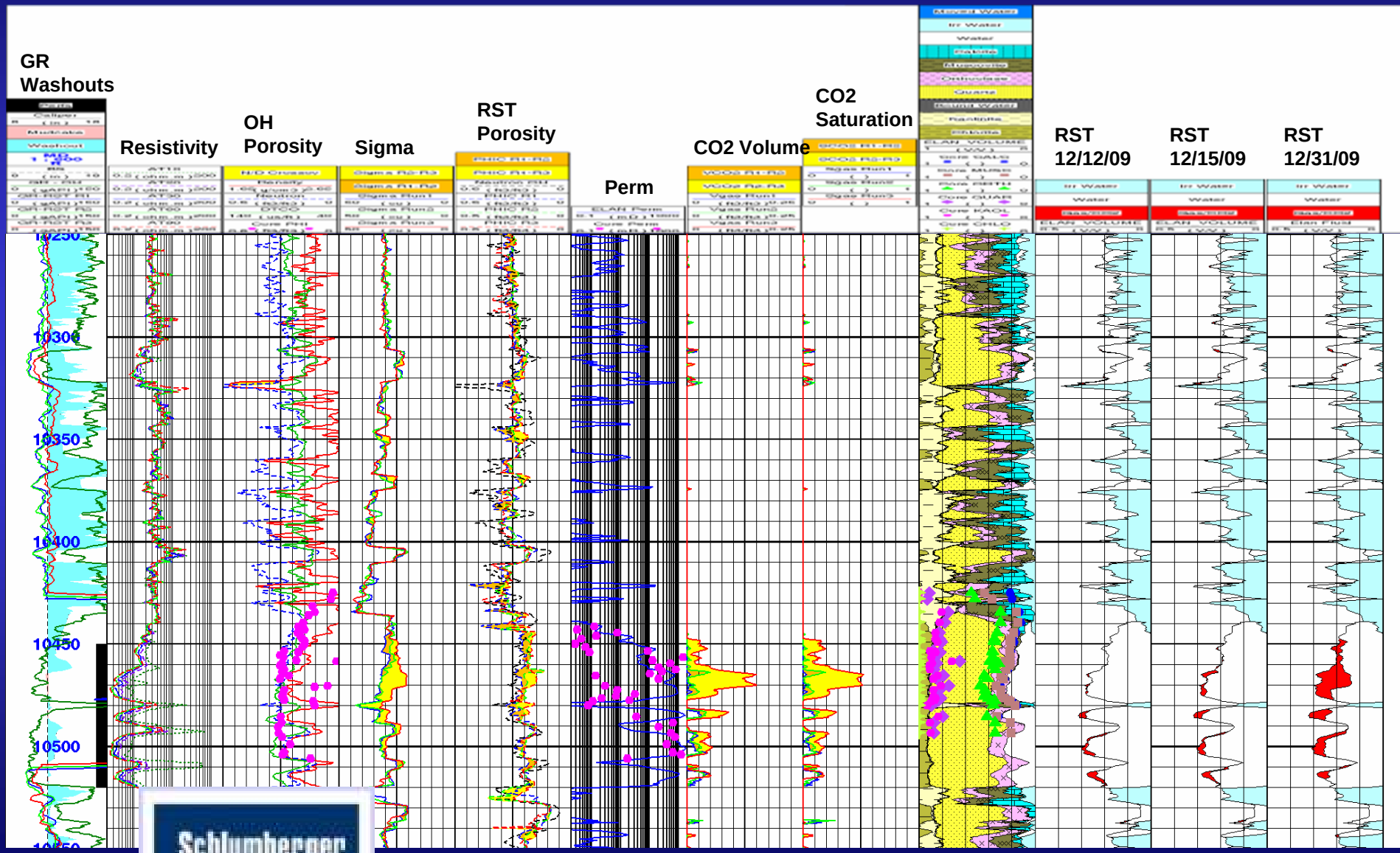


It's all about pressure

Measuring distribution of CO_2 in the reservoir

- Well-based methods
  - Wireline logs in time lapse -RST
  - Temperature
- Cross well methods
  - Time- lapse ERT
  - Time – lapse acoustic (seismic)

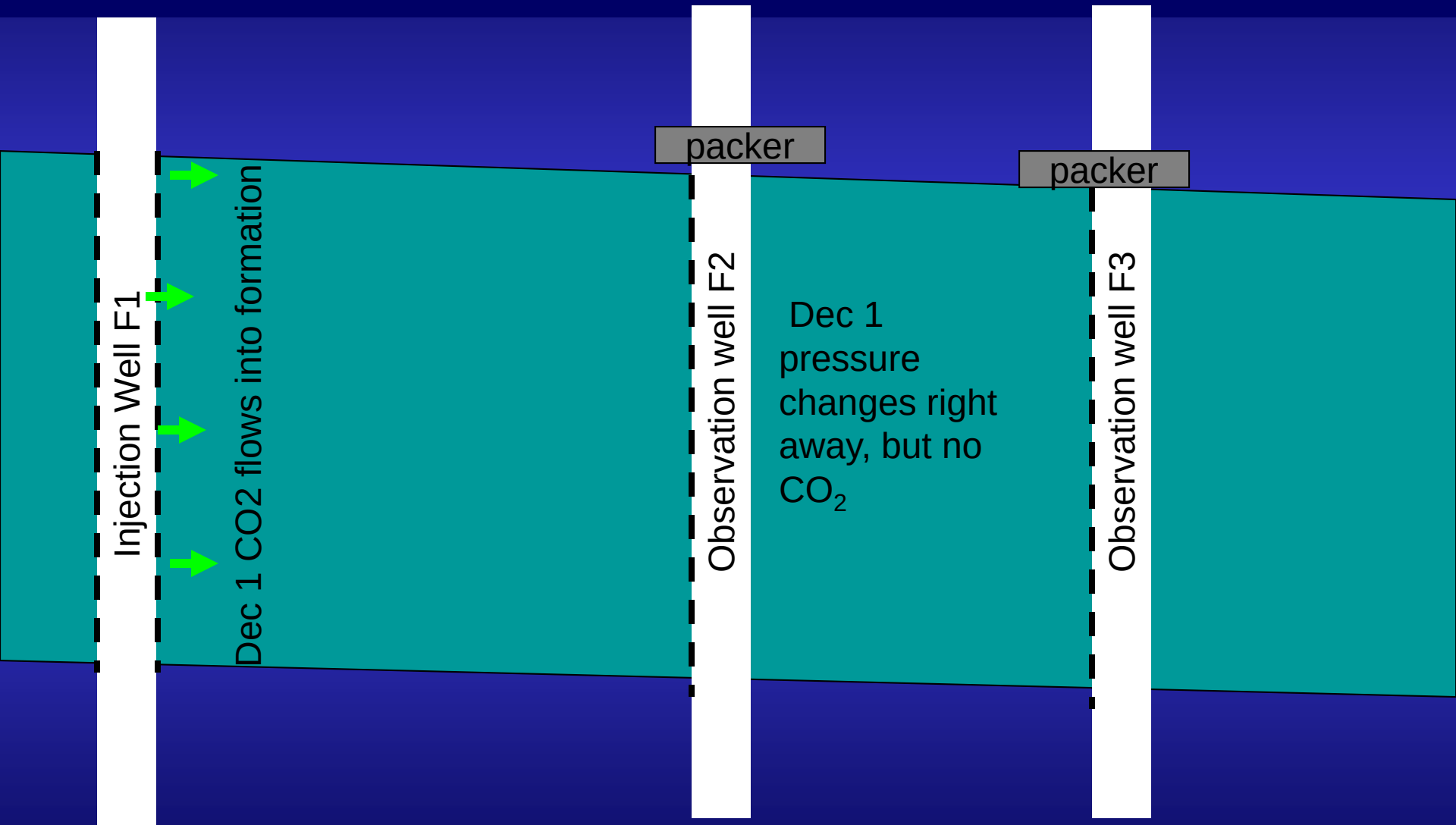
Wireline Formation Evaluation - ELAN – RST CFU 31 – F#3



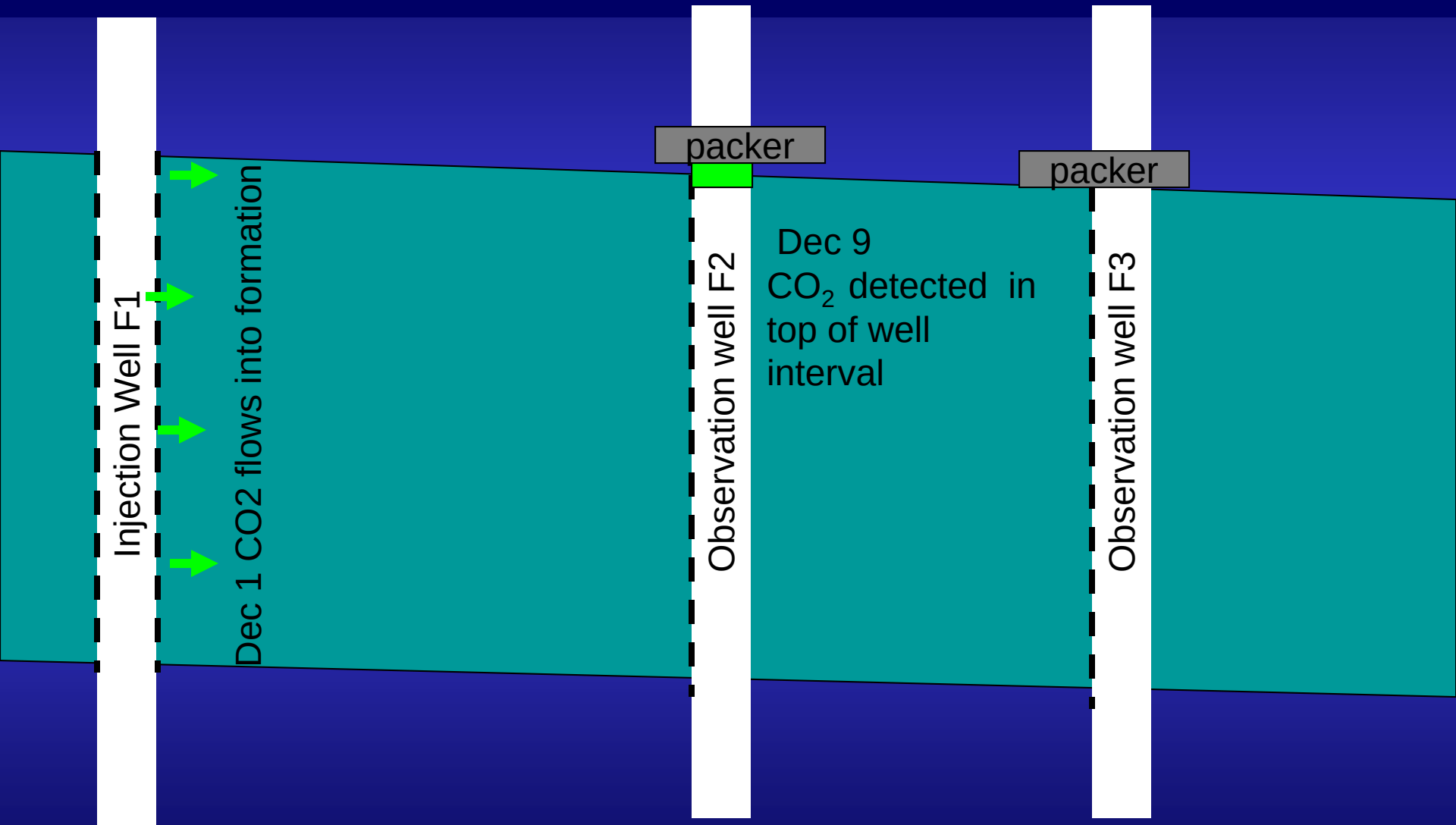
Schlumberger

Bob Butch

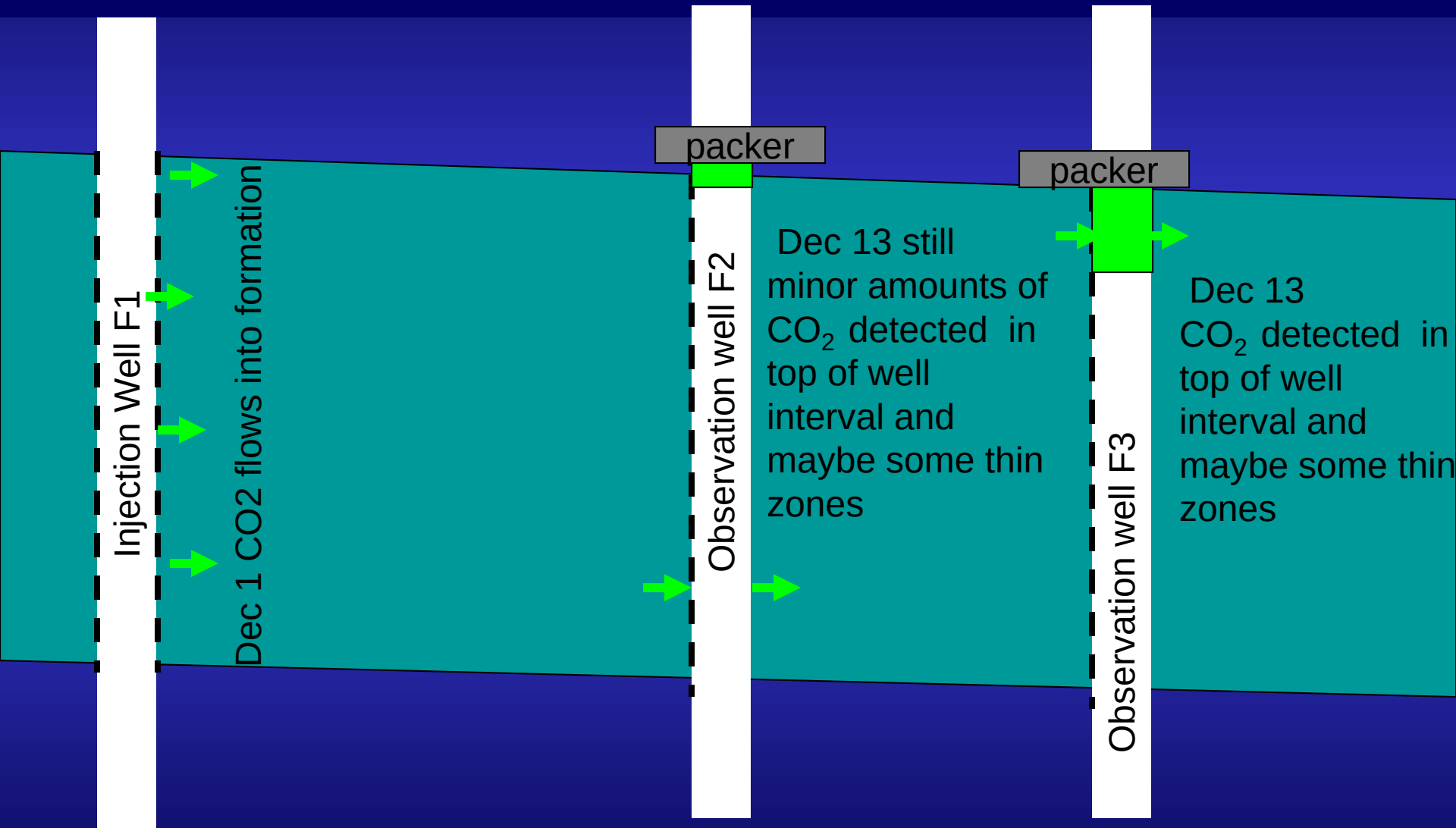
What happened at the wells?



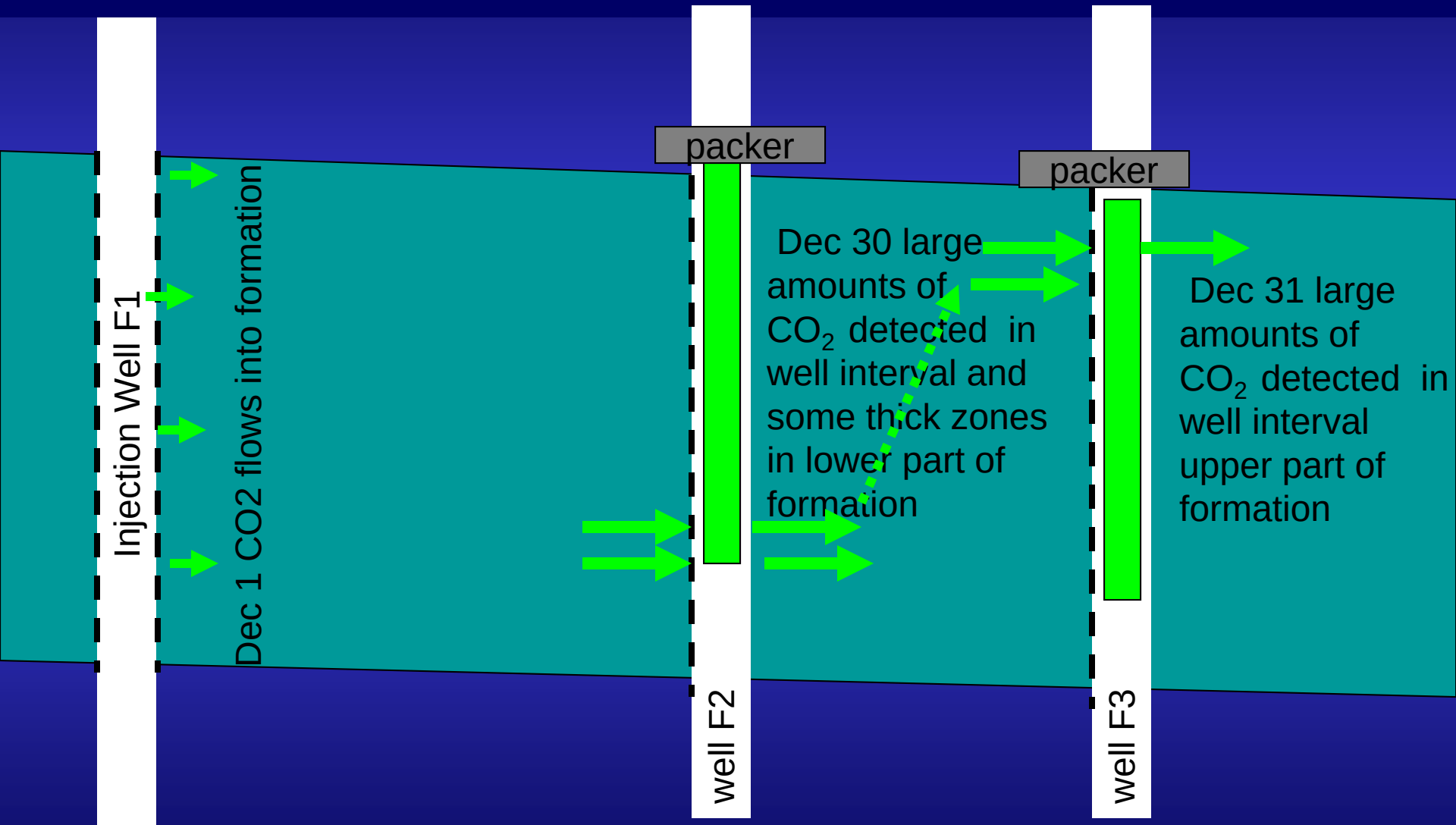
Day 9


Injection Well F1
Dec 1 CO2 flows into formation
packer
Observation well F2
Dec 9
CO_2 detected in top of well interval
packer
Observation well F3

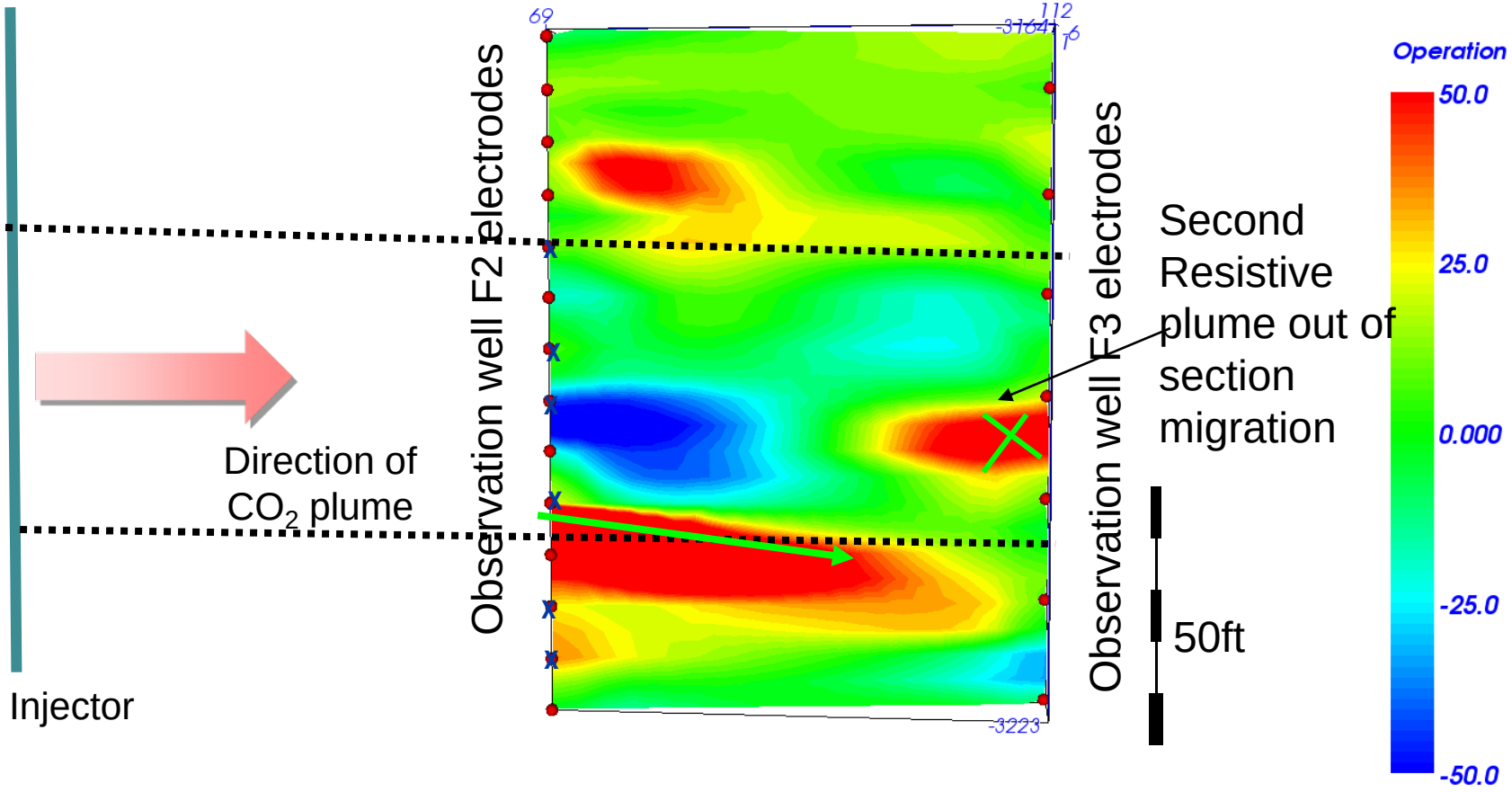
Day 13


Injection Well F1
Dec 1 CO2 flows into formation
packer
Observation well F2
Dec 13 still minor amounts of CO_2 detected in top of well interval and maybe some thin zones
packer
Observation well F3
Dec 13 CO_2 detected in top of well interval and maybe some thin zones

Day 31


Injection Well F1
Dec 1 CO2 flows into formation
packer
well F2
Dec 30 large amounts of CO_2 detected in well interval and some thick zones in lower part of formation
packer
well F3
Dec 31 large amounts of CO_2 detected in well interval upper part of formation

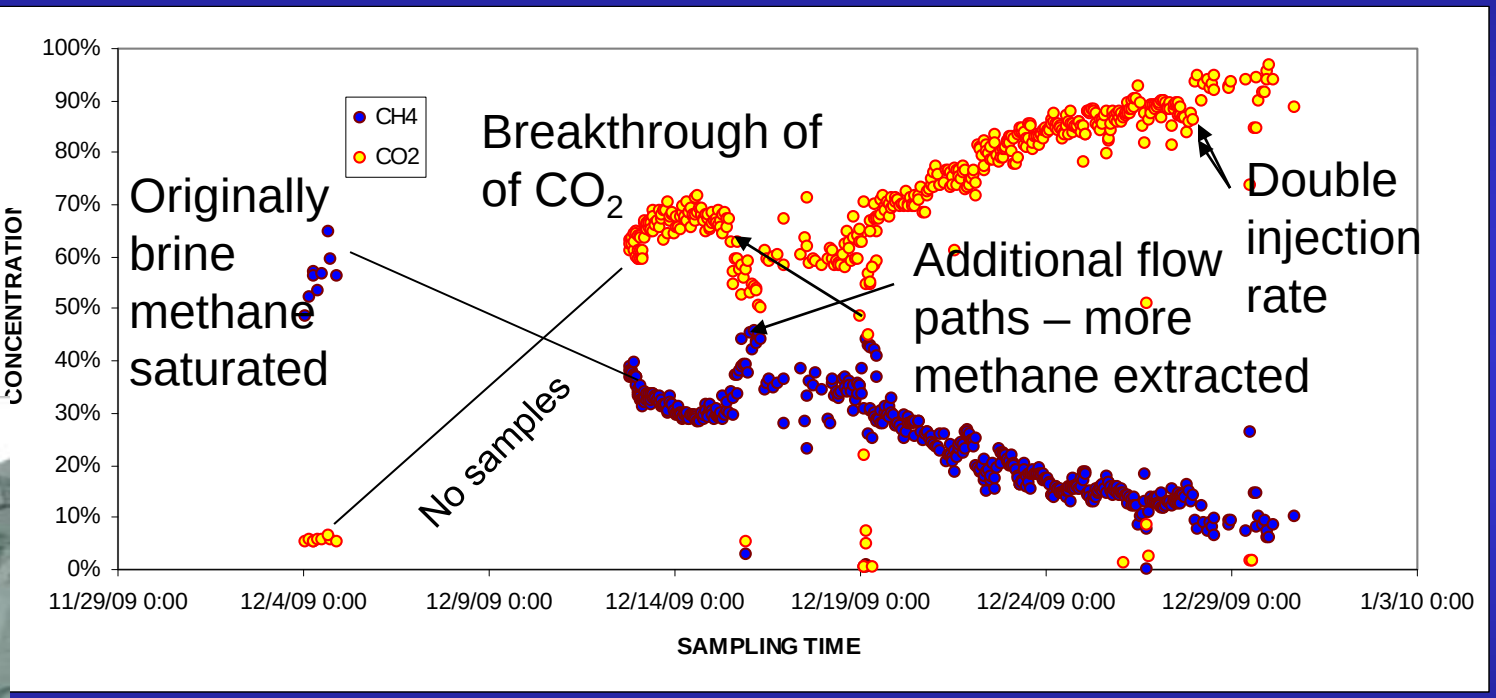
Cross Well ERT tells us how flow occurred



Resistive plume = CO2 in reservoir

Conductive plume= workover fluids?

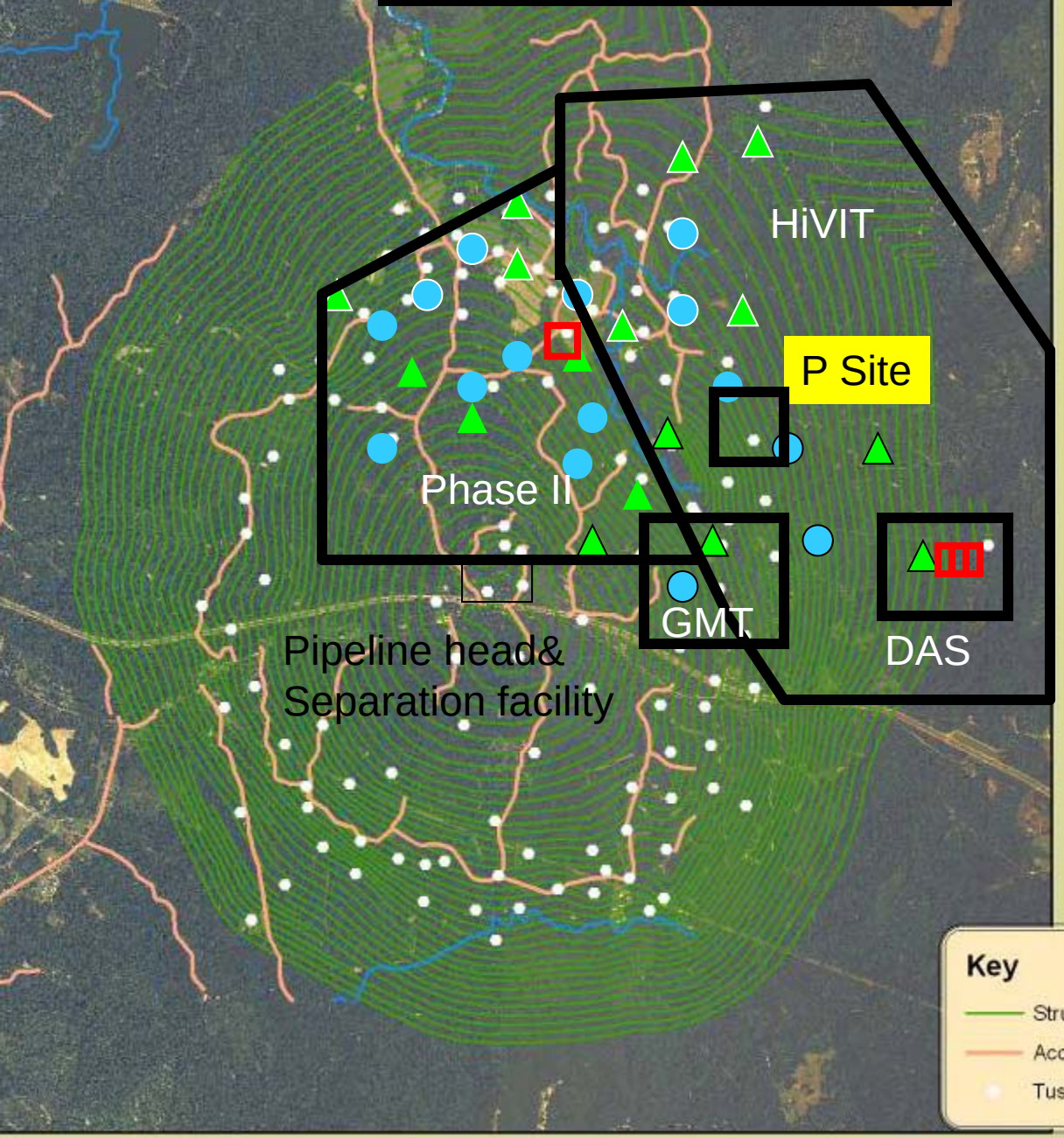
High frequency fluid sampling via U-tube yields data on flow processes



Small diameter sampler with N_2 drive brings fluids quickly to surface with tracers intact

CO_2 dissolution into brine liberates dissolved CH_4

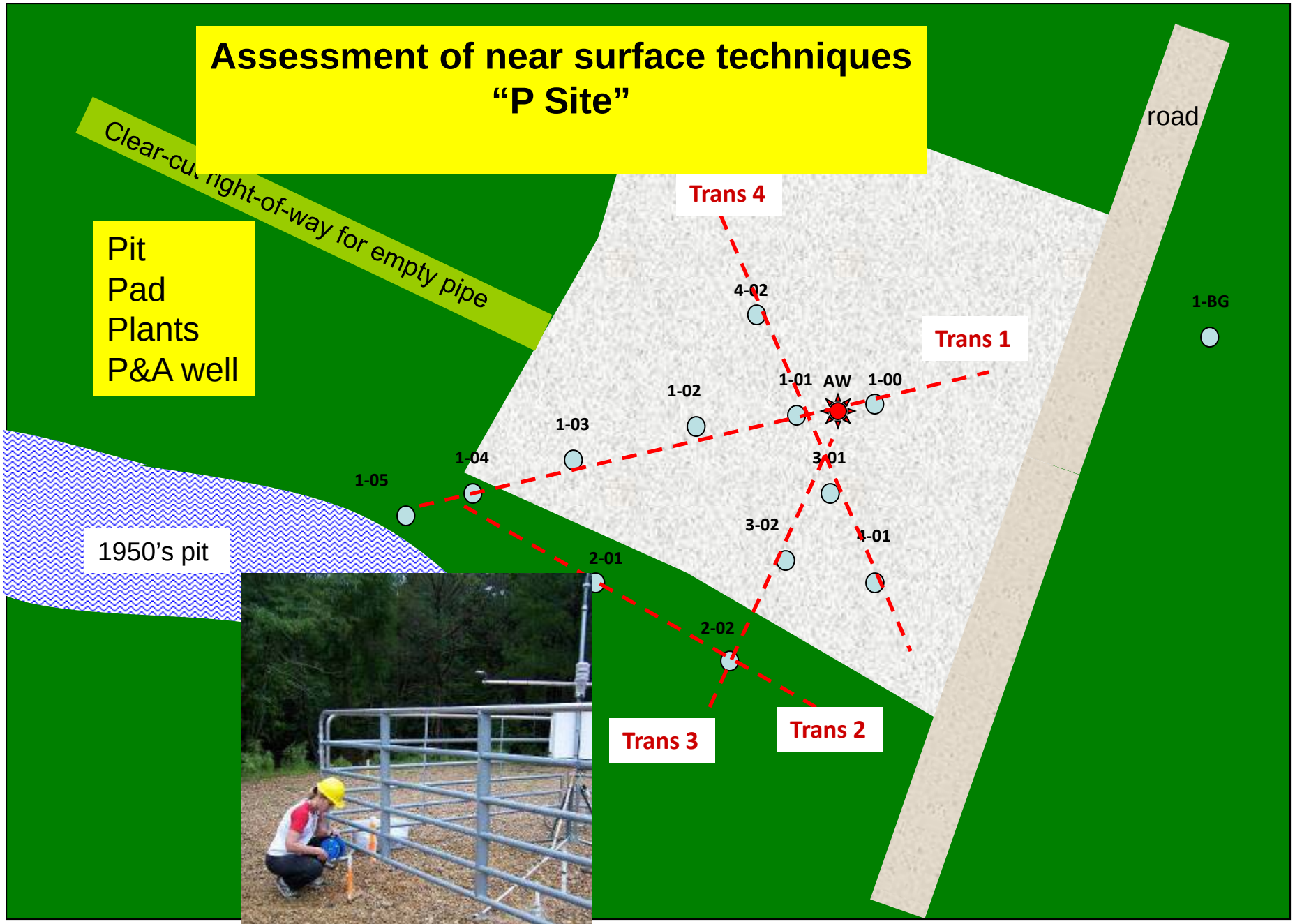
BEG, LBNL, USGS, ORNL, UTDoG,
data compiled by Changbing Yang BEG



Is it possible to find leakage at surface ? P-Site tests

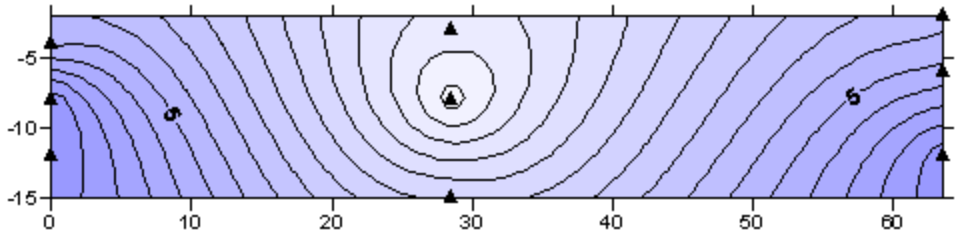
- Injector
- Producer (monitoring point)
- Observation Well

Assessment of near surface techniques "P Site"

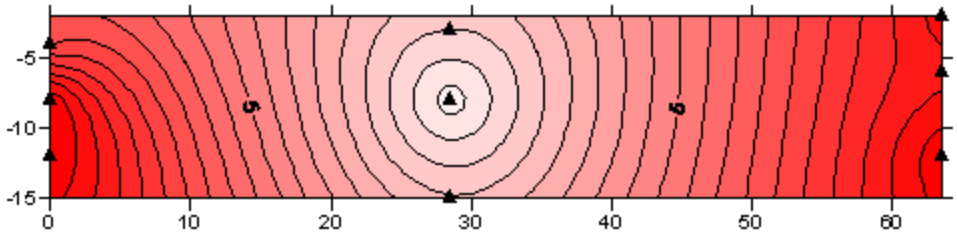


Preliminary Soil Gas data

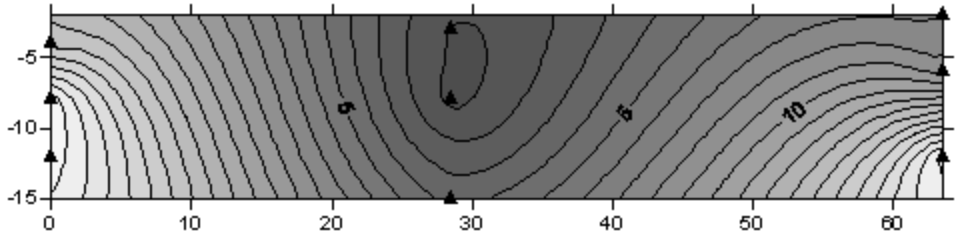
CO2 (vol %)



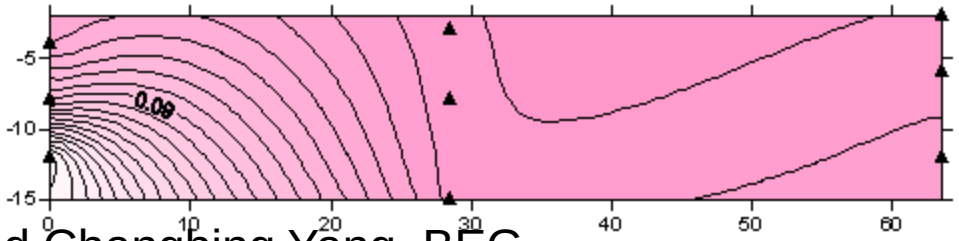
CH4 (vol %)



O2 (vol %)



Pressure
(inches H2O)



Katherine Romanak and Changbing Yang, BEG

Interim Conclusions of Study at Cranfield

- Phase III 1 million ton/year rate achieved Dec 20, 2009, 2 Million tones monitored since July 2008
- Rate to be maintained >15 months
- Monitored with standard and novel approaches
  - History match pressure response
  - No leakage into Above-Zone Monitoring Interval
  - Fluid flow measured/monitored with multiple tools in complex flow field
  - First US use of Electrical Resistance Tomography (ERT) for sequestration
  - Quantification of dissolution
- Export to commercial EOR/sequestration projects

Goals of monitoring at a long term, full scale commercial project

- Confirm that the predictions of storage security based on site characterization are valid
- Confidence to continue injection is gained from monitoring observations that are reasonably close to model predictions
- Confirm that no unacceptable consequences (risks or liabilities) result from injection.
- Monitoring during injection should be designed to prove-up sequestration so that monitoring frequency could be diminished through the life of the project and eventually stopped, allowing the project to be closed.

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