Commercial Scale CO_2 Injection and Optimization of Storage Capacity in the Southeastern United States

Project Number: DE-FE0010554

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Storage R&D Project Review Meeting

Developing the Technologies and Infrastructure for CCS

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Presentation Outline

- Program Goals
- Benefits Statement
- Project Overview
  - Goals
  - Objectives
- Technical Status
- Accomplishments to Date
- Summary
- Appendix

USDOE/NETL Program Goals

- Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
- Develop and validate technologies to ensure 99 percent storage permanence.
- Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
- Develop Best Practice Manuals for:
  - monitoring
  - verification
  - accounting & assessment
  - site screening
  - selection and initial characterization
  - public outreach
  - well management activities
  - risk analysis and simulation

Benefits Statement

The project will model commercial-scale CO_2 storage capacity optimization strategies to effectively manage the CO_2 plume and pressure field. These strategies will utilize geologic and performance data collected from SECARB's Anthropogenic Test Site, and will be high-graded based on cost and storage efficiency, considering reservoir geomechanics (pressure field) and laboratory-derived cap rock data.

Major advances:

- Estimating commercial scale storage efficiency factors
- Generation of reduced order models
- Best Practices Manual

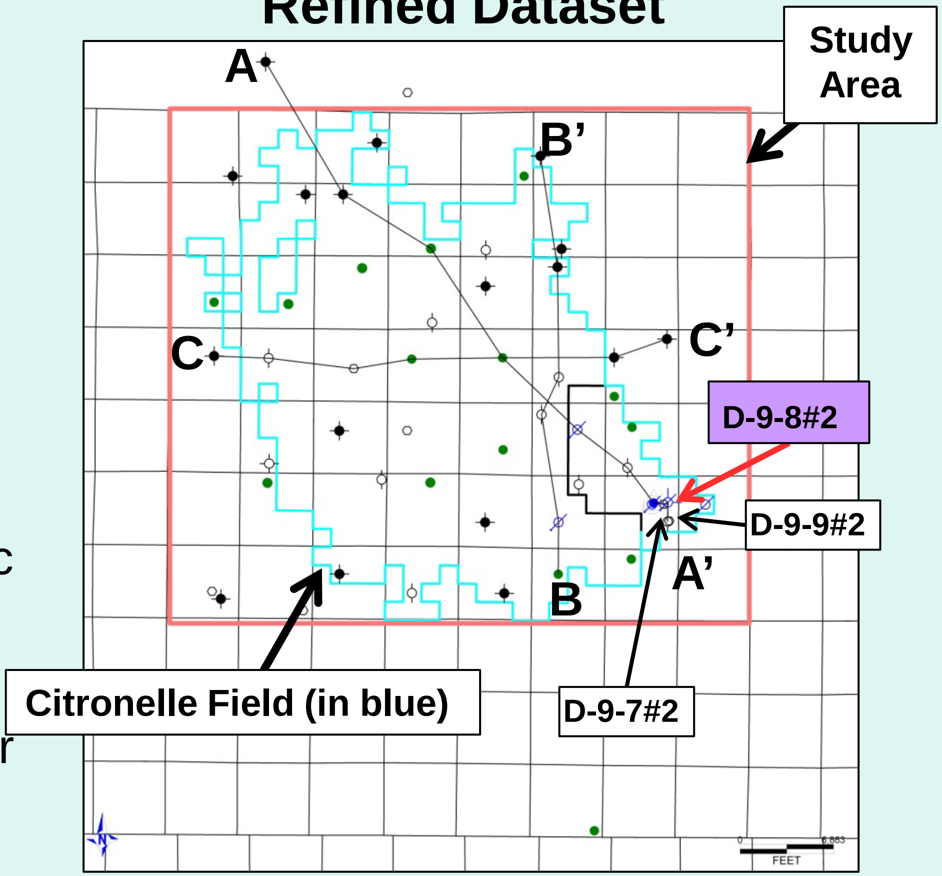
Project Objectives

- Optimize capacity and ensure storage containment in Gulf Coast saline and oil bearing reservoirs
- Leverage modern and historical geologic characterization and injection performance data to develop detailed geologic models
- Upscale geologic data and conduct detailed simulation of CO_2 injection
- Overlay economic and risk management scenarios for each simulation case to determine the overall feasibility of commercial scale storage.
- Conduct detailed cap rock core analysis testing
- Develop new storage efficiency factors based on these project results
- Develop reduced order models to approximate the ‘super computer’ results
- Summarize the results in a Best Practices Manual

Project Status: Study Area & Well Data Set

- 400+ total wells in Citronelle Field on 40-ac spacing
- Study area for geologic model = 56 sq. miles
- Geologic model characterizes injection zones and confining units from surface though the Donovan sandstones at depths >12,000 ft.
- D 9-8 #2 well in Citronelle Southeast Unit selected as Type Log for geologic correlations of injection zones & confining units.
- Multiple cross-sections constructed for geologic correlation of model layers.
- Digitized the SP & resistivity curves for 36 well logs. These data input to neural net software to estimate porosity.

Refined Dataset



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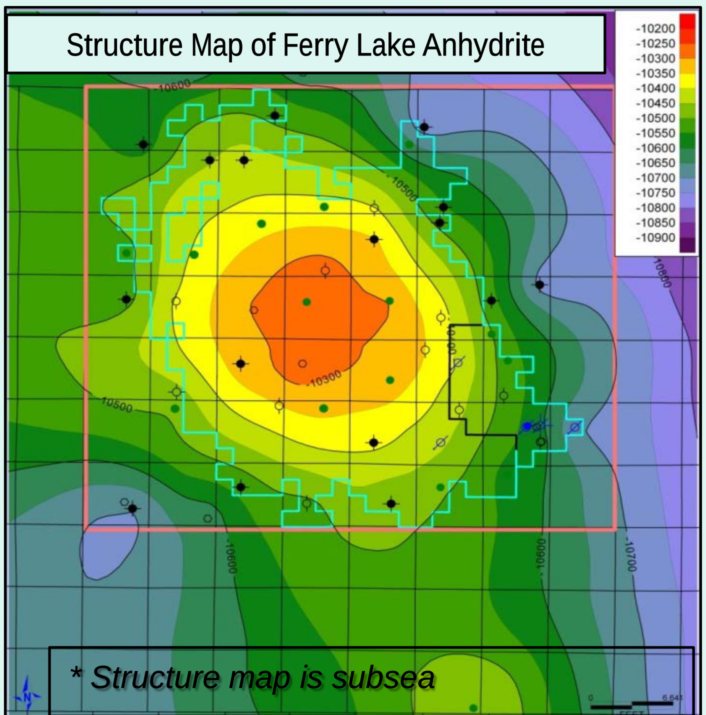
Project Status: Building the Geologic Model

- Potential storage and confining layers were identified and correlated laterally
- Structural closure is present at all horizons from surface through the Donovan



Stratigraphic Column

System	Series	Stratigraphic Unit	Major Sub Units	Potential Reservoirs and Confining Zones
Tertiary	Plio-Pliocene		Citronelle Formation	Freshwater Aquifer
Tertiary	Miocene	Undifferentiated		Freshwater Aquifer
Tertiary	Oligocene		Chicasawhay Fm.	Base of USDW
Tertiary	Oligocene	Vicksburg Group	Bucatunna Clay	Local Confining Unit
Tertiary	Eocene	Jackson Group		Minor Saline Reservoir
Tertiary	Eocene	Claiborne Group	Talahatta Fm.	Saline Reservoir
Tertiary	Eocene	Wilcox Group	Hatchetigbee Sand	Saline Reservoir
Tertiary	Paleocene		Bashi Marl	Saline Reservoir
Tertiary	Paleocene		Salt Mountain LS	Saline Reservoir
Tertiary	Paleocene	Midway Group	Porters Creek Clay	Confining Unit
Cretaceous	Upper	Selma Group		Confining Unit
Cretaceous	Upper	Eutaw Formation		Minor Saline Reservoir
Cretaceous	Upper	Tuscaloosa Group	Upper Tusc.	Minor Saline Reservoir
Cretaceous	Upper	Tuscaloosa Group	Mid. Tusc.: Marine Shale	Confining Unit
Cretaceous	Upper	Tuscaloosa Group	Lower Tusc.: Pilot Sand, Massive sand	Saline Reservoir
Cretaceous	Lower	Washita-Fredericksburg	Dantzler sand	Saline Reservoir
Cretaceous	Lower	Washita-Fredericksburg	Basal Shale	Primary Confining Unit
Cretaceous	Lower	Paluxy Formation	'Upper' 'Middle' 'Lower'	Proposed Injection Zone
Cretaceous	Lower	Mooringsport Formation		Confining Unit
Cretaceous	Lower	Ferry Lake Anhydrite		Confining Unit
Cretaceous	Lower	Donovan Sand	Rodessa Fm. 'Upper'	Oil Reservoir
Cretaceous	Lower	Donovan Sand	'Middle'	Minor Saline Reservoir
Cretaceous	Lower	Donovan Sand	'Lower'	Oil Reservoir

Assessed Zone (Citronelle Formation through Ferry Lake Anhydrite)

Logged Interval (Claiborne Group through Ferry Lake Anhydrite)

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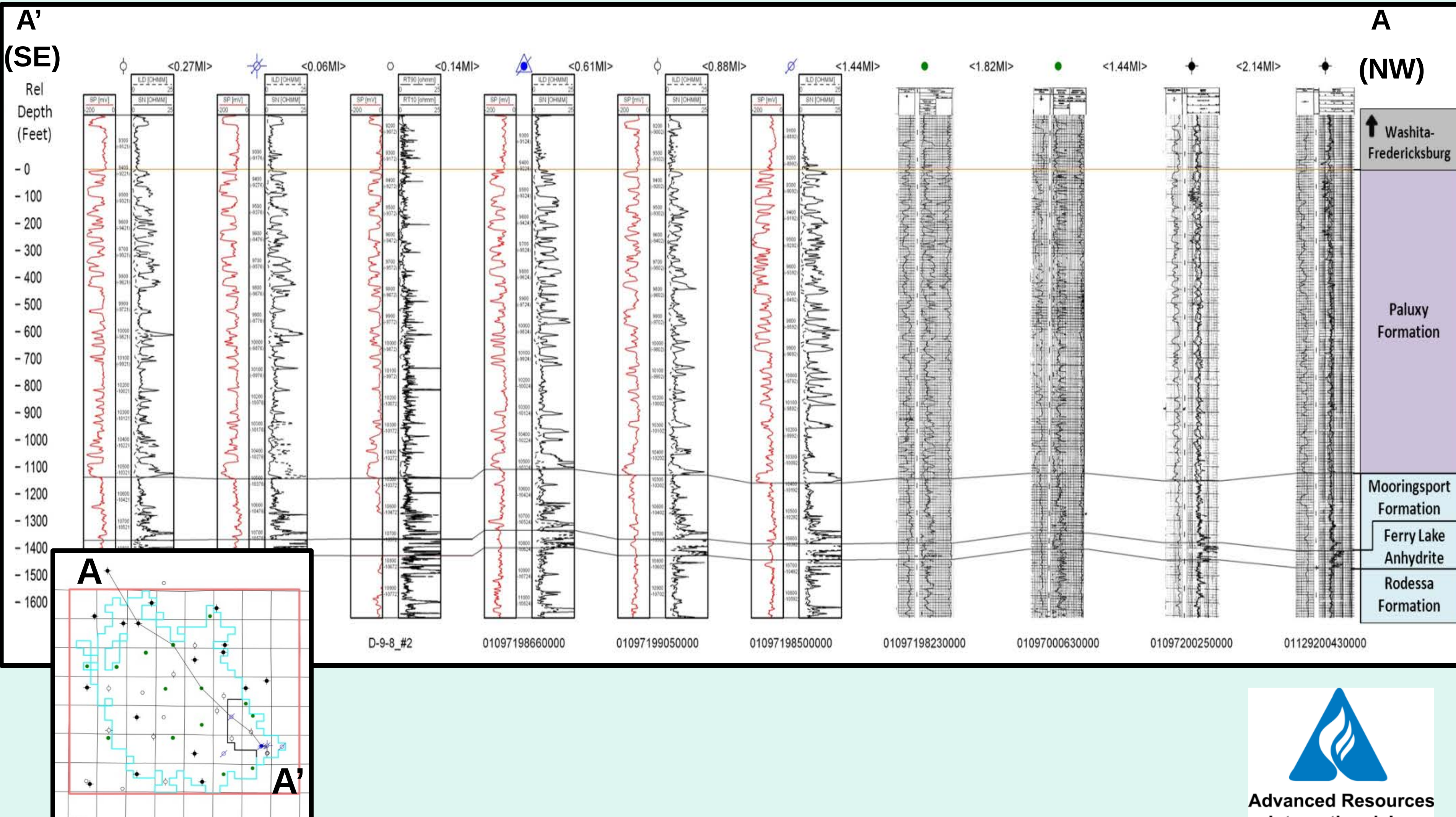
Project Status:
Correlation Cross-Sections



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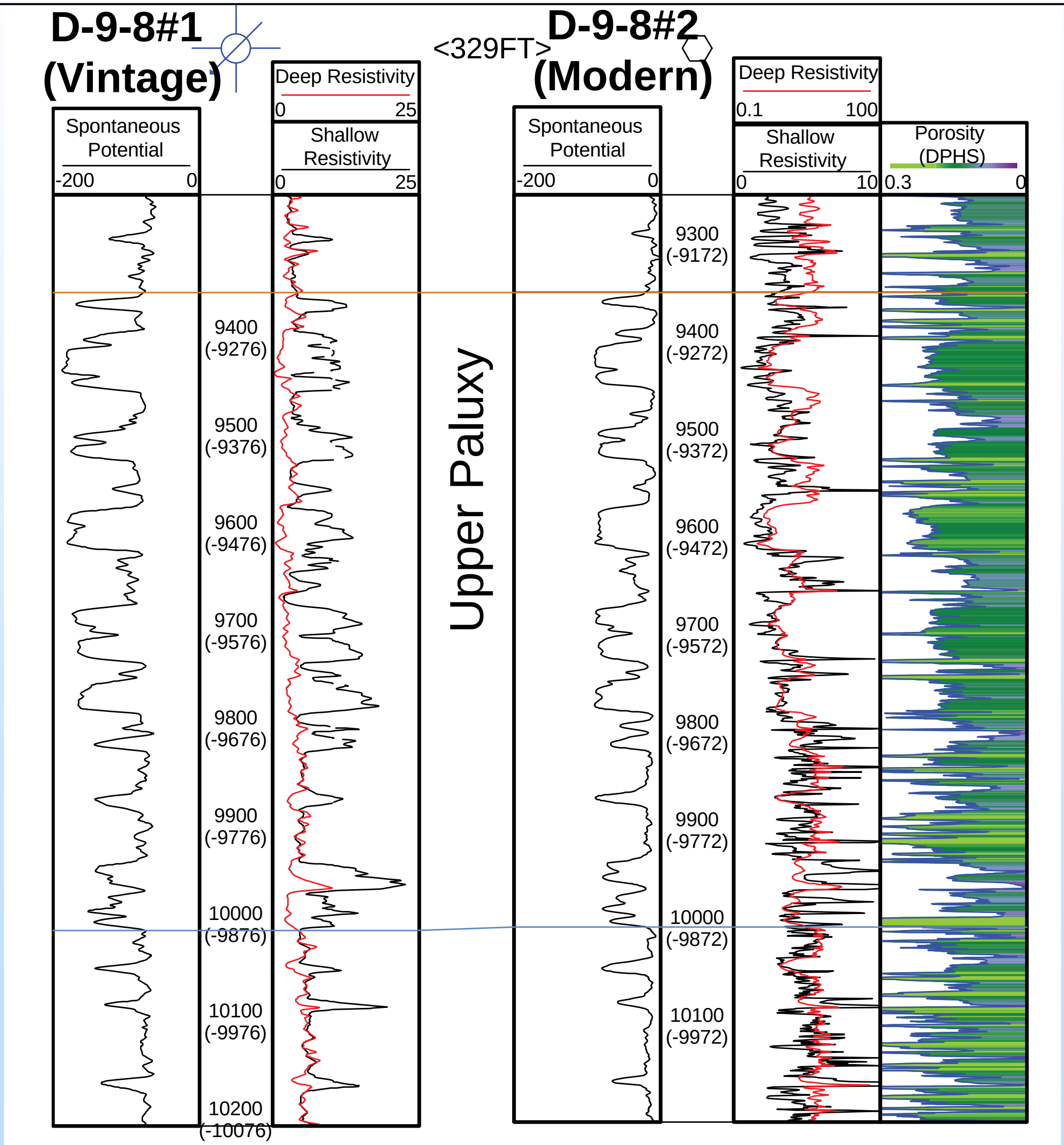
Project Status: Neural Network

- Most of the legacy wells have resistivity logs only and no porosity logs.
- 3 new wells with modern porosity logs were drilled on well pads with existing abandoned wells.
- These paired wells offer a unique opportunity for using a neural network approach to predict porosity.



Neural Net: Training & Validation

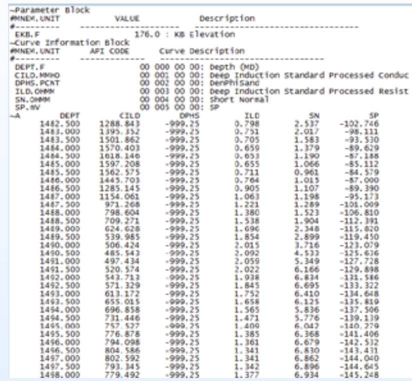
Training neural network utilized data from 2 well pairs in Citronelle SE Unit:
D-9-7 #1 & D-9-7 #2
D-9-8 #1 & D-9-8 #2

Input from vintage D-9-7 #1 and D-9-8 #1 wells:

- Spontaneous Potential (SP)
- Short Normal (SN)
- Induction Log (IL)

Output from modern D-9-7 #2 and D-9-8 #2 wells:

- Density Porosity (PHI)



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~Curve Information Block
#MNEM.UNIT      API CODE      Curve Description
#---------   ------------   ------------------------------
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 CILD.MMHO             00 001 00 00: Deep Induction Standard Processed Conduc
 DPHS.PCNT             00 002 00 00: DenPhiSand
 ILD.OHMM              00 003 00 00: Deep Induction Standard Processed Resist
 SN.OHMM               00 004 00 00: Short Normal
 SP.MV                 00 005 00 00: SP
~A        DEPT        CILD        DPHS         ILD          SN          SP
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      1492.500     571.329     -999.25       1.845       6.695    -133.322
      1493.000     613.172     -999.25       1.752       6.410    -134.648
      1493.500     655.015     -999.25       1.658       6.125    -135.819
      1494.000     696.858     -999.25       1.565       5.836    -137.506
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      1495.000     757.527     -999.25       1.409       6.042    -140.279
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      1496.000     794.098     -999.25       1.361       6.679    -142.532
      1496.500     804.586     -999.25       1.341       6.830    -143.431
      1497.000     802.592     -999.25       1.341       6.862    -144.040
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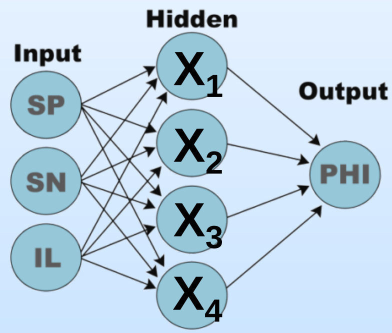
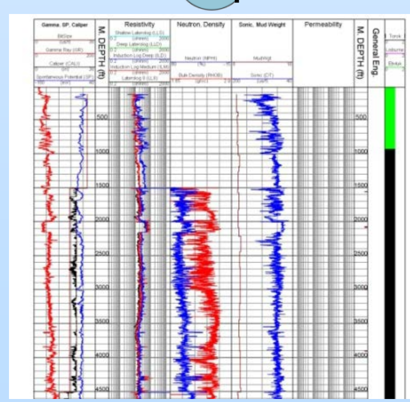
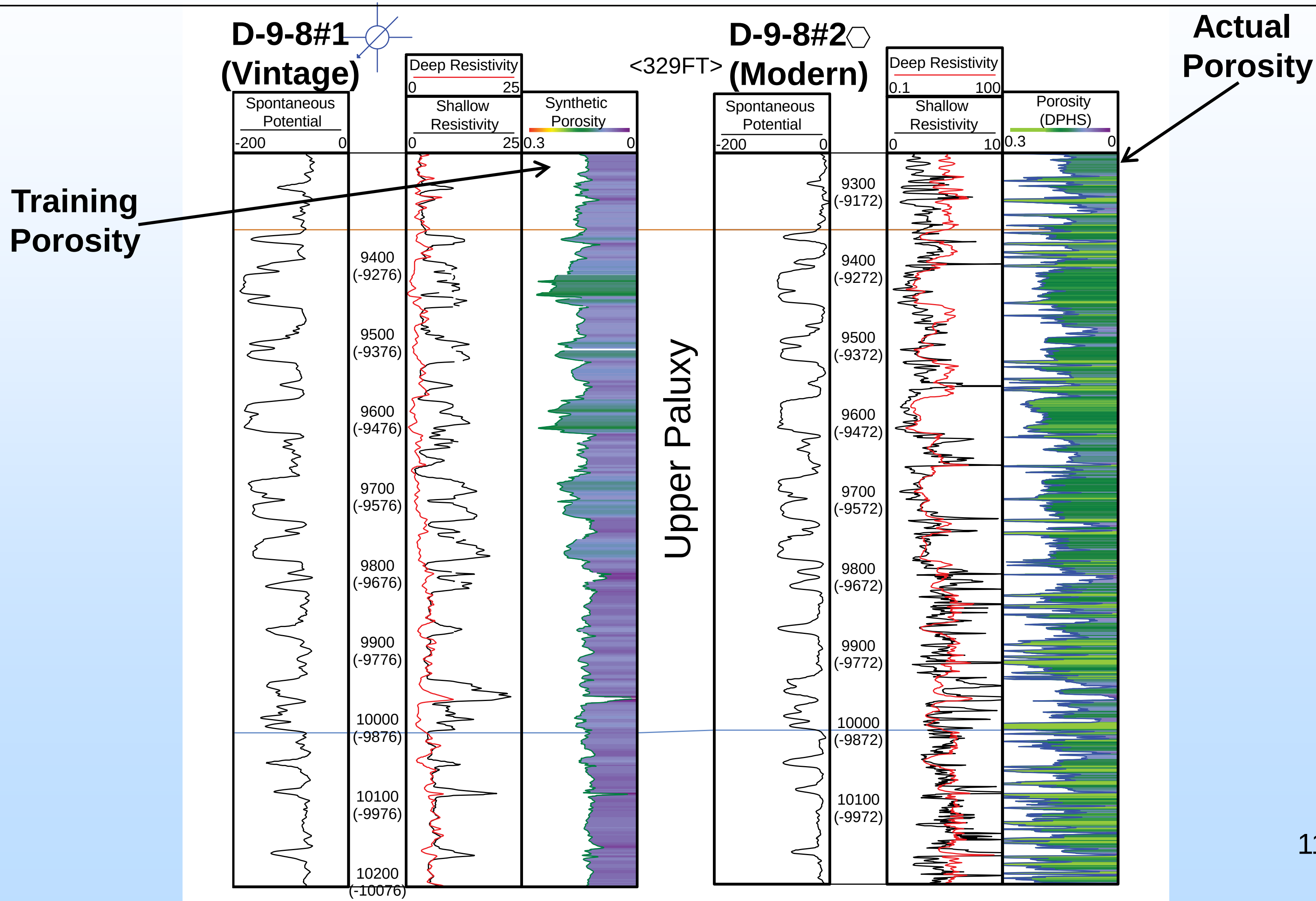




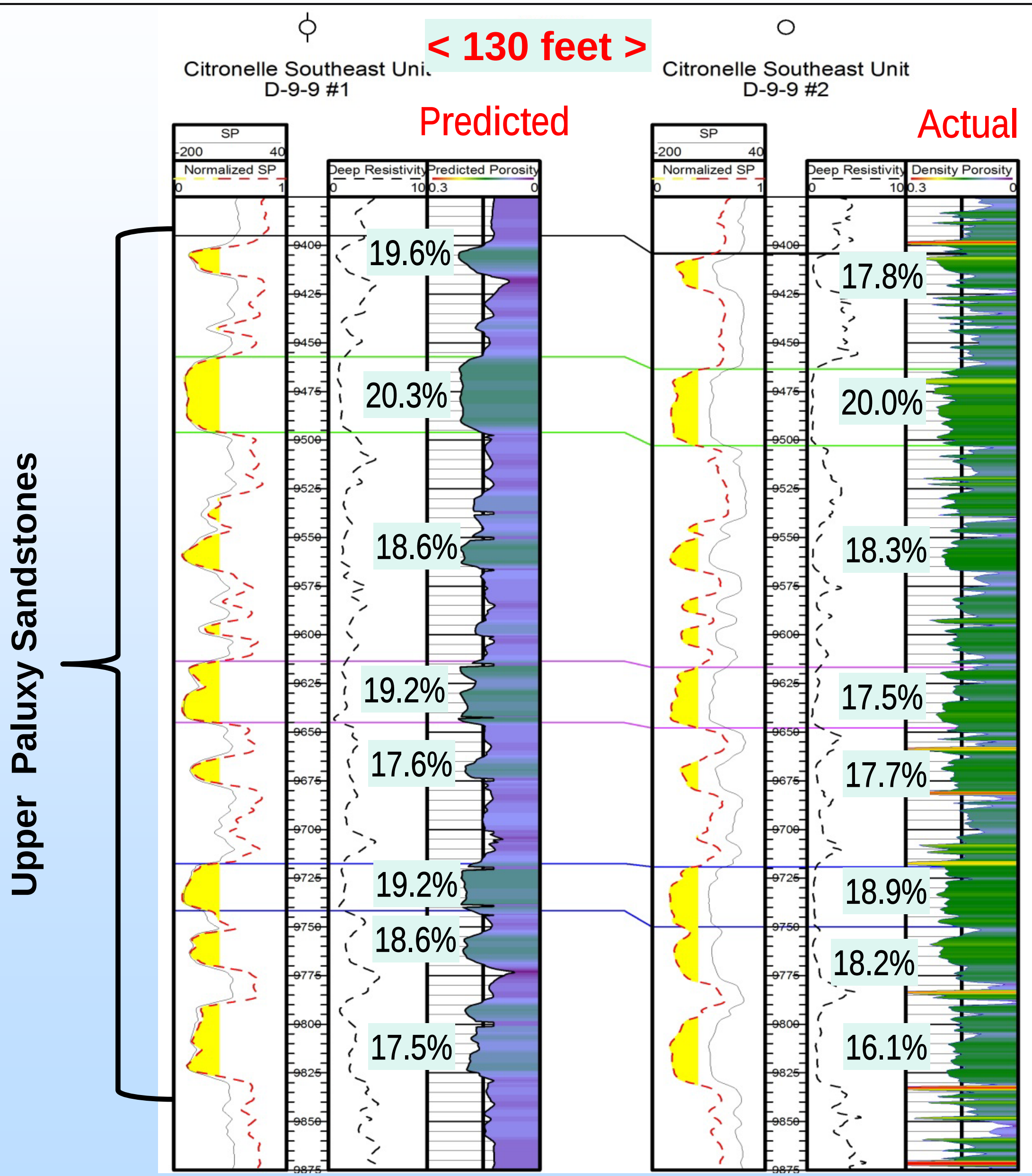
Validation of the neural net utilized data from the third well pair in Citronelle field:
D-9-9 #1 & D-9-9 #2

- With weighting factors known, D-9-9 #1 vintage data was input.
- Output from network was compared against modern D-9-9 #2 density porosity data.

Neural Net: Training Results



Neural Net: Porosity Prediction



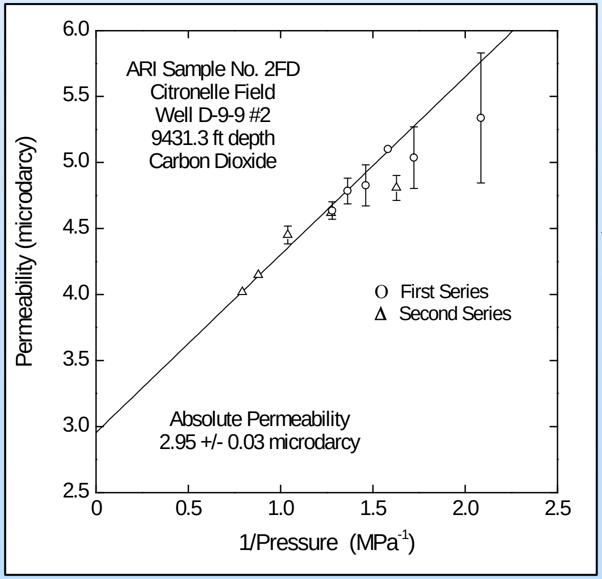
- Porosity predicted from Neural Net for D-9-9 #1 compared to actual density porosity from D-9-9 #2 well.
- Average porosity values for selected Upper Paluxy sandstones are shown.
- Average porosity values for Paluxy sandstones for “predicted” and “actual” are very close.
- Larger range between min and max values and finer vertical resolution for actual porosity than for “predicted” porosity.

Project Status: Measuring Caprock Properties

- Absolute permeability and permeability to CO_2 were determined for two Upper Paluxy samples.
- Measurements were made using the Core Lab/TEMCO triaxial core holder at the Caprock Integrity Laboratory of University of Alabama Birmingham.

Example:
Permeability to CO_2 vs. Pressure for Paluxy Fm. Sample

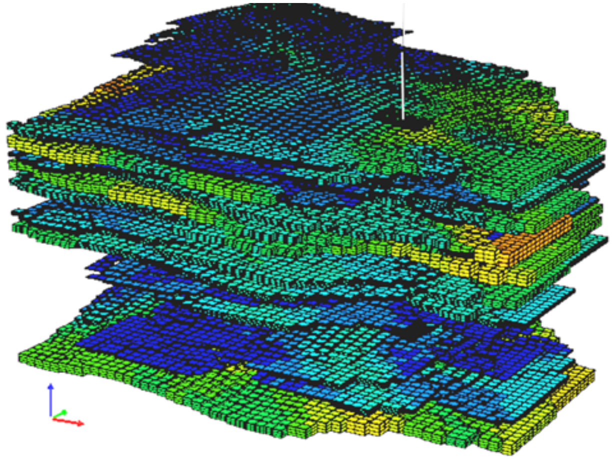
Well D-9-9 No. 2, Upper Paluxy, 9431.3 ft.



Next Steps: Refining the Geologic Model

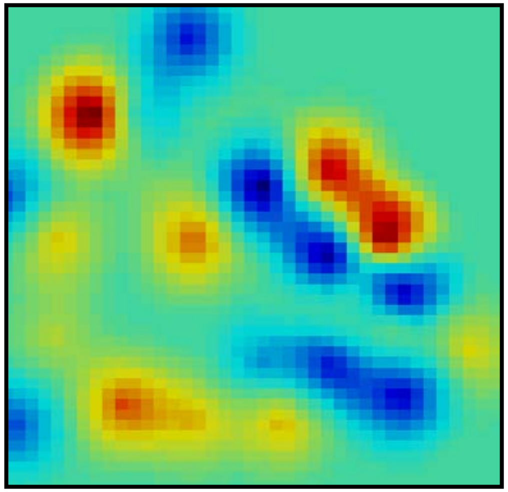
- Geostatistics will be used to extrapolate reservoir characterizations from the 36 digitized study wells throughout the entire study area.
- Permeability and porosity transforms from existing core data will be applied to generate permeability maps.

Example of Citronelle Current GEM Model



- The geostatistics approach will help extrapolate flow unit heterogeneities across the entire study area.

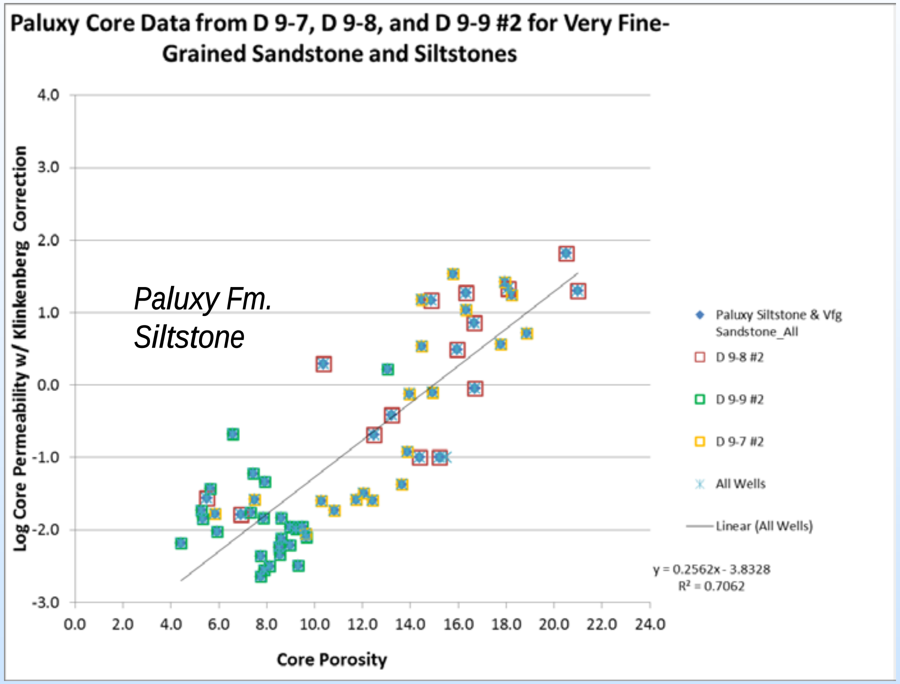
Example of geostatistical rendering of porosity for an upper Paluxy layer

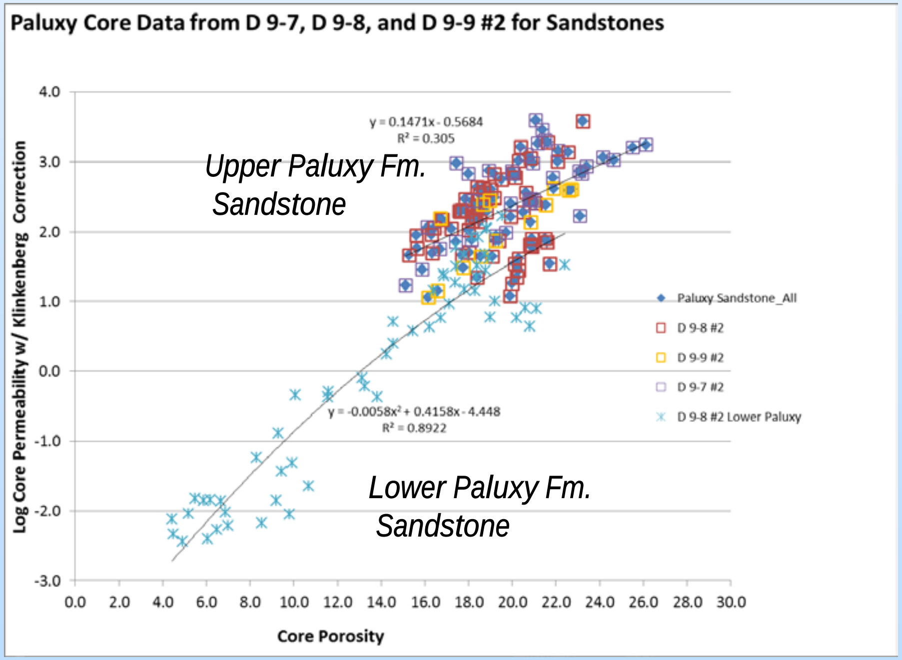


- Each formation at Citronelle field will be sub-divided into multiple flow units and confining layers.
- This massive geologic model for the entire Citronelle field will be implemented in the *GEM* reservoir simulator.

Next Steps: Predicting Permeability

- Porosity-Permeability transforms from core data will be applied to predict permeability and flow unit heterogeneity from porosity.
- Interpretation of flow unit heterogeneity must be constrained by stratigraphy & lithology – particularly shale content





Paluxy Formation at Citronelle Field

Future Plans

- **Sensitivity Study**: Will explore sensitivities such as well design and lateral heterogeneity to maximize storage capacity while minimizing the operation's footprint.
- **Optimization**: Will incorporate economic and risk management considerations which will be overlain on the modeling results to ascertain their financial impact.
- **Cap Rock Analysis**: Caprock analysis will provide regional seal characteristic data to be used in numerical modeling.
- **New Storage Efficiency Factors**: Will develop new commercial storage efficiency factors.
- **Screening Models**: Will develop simplified screening models to cost effectively identify potential commercial storage sites.
- **Scoping Level Models**: Will develop a scoping level model to provide baseline storage capacity and injectivity and estimate ground deformation, plume extent and pressure build-up.
- **Best Practices Manual**: Will produce a Best Practices Manual for optimized commercial-scale storage.

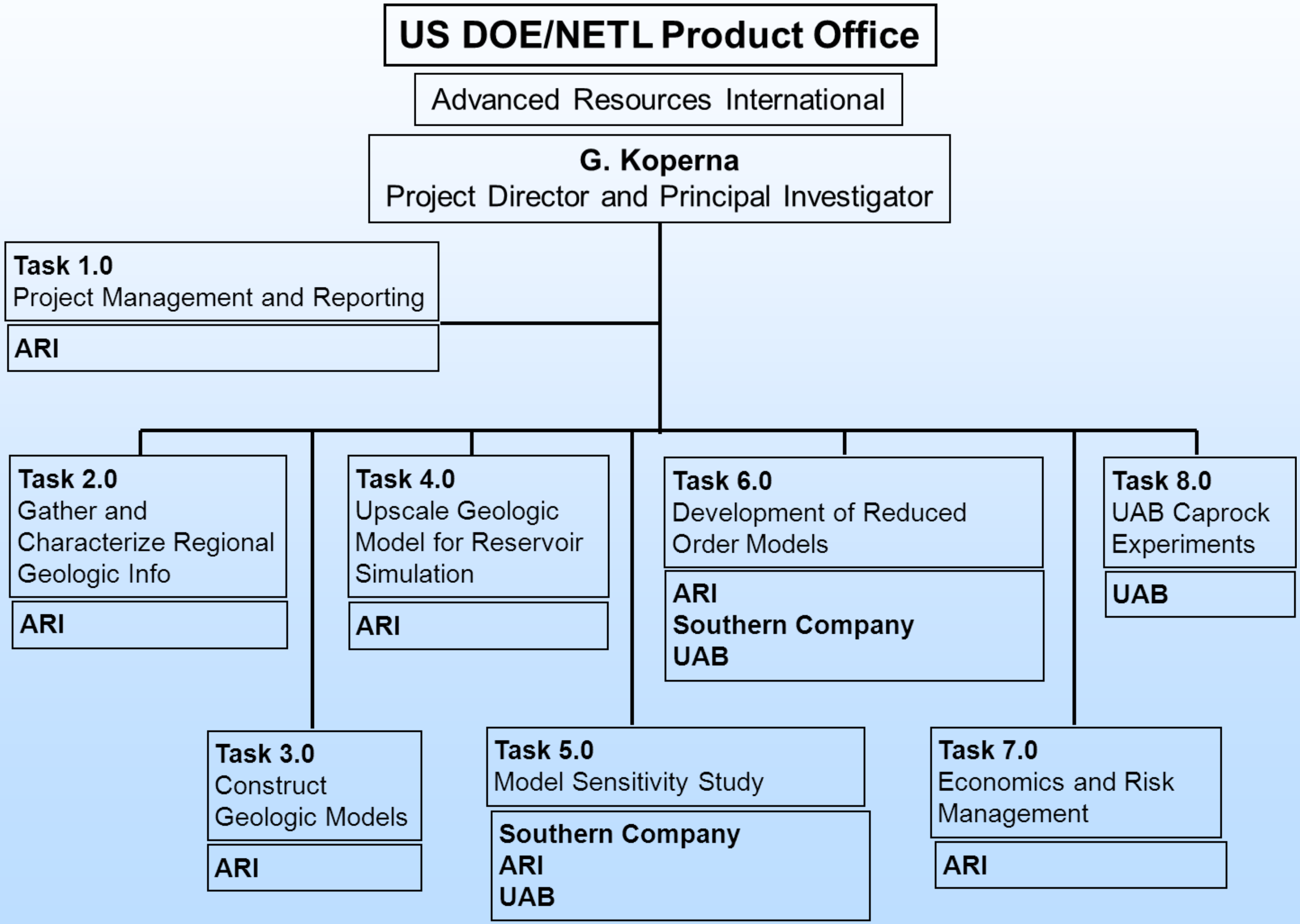
Accomplishments to Date

- USDOE-NETL kick-off meeting
- Project kick-off meeting at UAB
- Completed geologic model
- Poster presentation at the AAPG meeting in May 2013
- Geologic Characterization review meeting on July 9th
- Successful implementation of the Neural Network approach to predict porosity
- Abstract and presentation accepted for the Carbon Management Technology Conference, October 2013
- Detailed Geologic Characterization report (Deliverable 2.1) finalized
- Refinement of the geologic model using a geostatistical approach is underway

Key Findings/ Lessons Learned

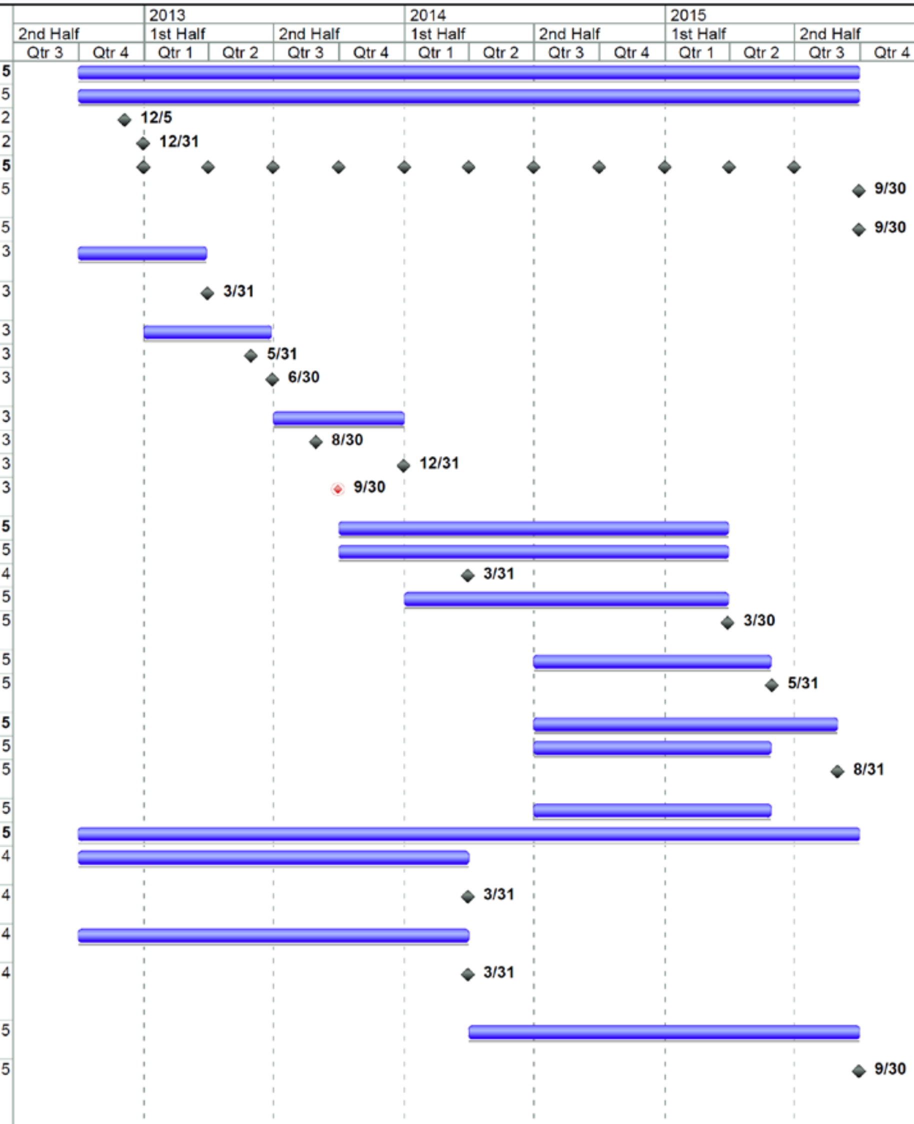
- Can successfully characterize a subsurface volume of 1.9E+13 ft^3 for reservoir simulation *(56 square miles x 12,000 vertical feet),* by combining legacy geophysical log data with modern log data, core data, and state of the art interpretive tools like neural net and geostatistics software.
- Saline reservoirs appear amenable to using a neural net approach to predict porosity from SP & resistivity logs if:
  - the lithology is known,
  - a reliable indicator of shale content is available to constrain the interpretation,
  - modern porosity data are available to train the neural net.
- Reliable permeability data are required to characterize flow unit heterogeneity and to adequately characterize confining units and localized flow barriers and baffles.

Appendix: Organization Chart



Appendix: Gantt Chart

Task Name		Start	Finish
Task 1: Project Management	150,017	**Mon 10/1/12**	**Wed 9/30/15**
Subtask 1.1 – Project Management Plan		Mon 10/1/12	Wed 9/30/15
Deliverable 1.1 – Report, Project management plan		Wed 12/5/12	Wed 12/5/12
Deliverable 1.2 – Project Management and Reporting		Mon 12/31/12	Mon 12/31/12
Deliverable 1.3 – Report, Quarterly progress reports		**Mon 12/31/12**	**Wed 7/1/15**
Deliverable 1.4 – Best Practices Manual for CO2 storage in the U.S. Eastern Gulf Coast		Wed 9/30/15	Wed 9/30/15
Deliverable 1.5 – Final project reports		Wed 9/30/15	Wed 9/30/15
Task 2: Gather and Characterize Regional Geologic Information	66,670	Mon 10/1/12	Fri 3/29/13
Deliverable 2.1 – Report, Using neural network algorithms to modernize vintage well logs		Sun 3/31/13	Sun 3/31/13
Task 3: Construct Geologic Models	51,543	Tue 1/1/13	Fri 6/28/13
Deliverable 3.1 – Meeting, Geologic data review and critique		Fri 5/31/13	Fri 5/31/13
Deliverable 3.2 – Report, Geostatistical analysis of southeastern sediments		Sun 6/30/13	Sun 6/30/13
Task 4: Upscale Geologic Model for Reservoir Simulation	46,326	Mon 7/1/13	Tue 12/31/13
Deliverable 4.1 – Meeting, Modeling data review and critique		Fri 8/30/13	Fri 8/30/13
Deliverable 4.2 – Report, Upscaling comparison to geologic data		Tue 12/31/13	Tue 12/31/13
Decision Point – Demonstration of capability to effectively model geology and subsurface CO2 flow		Mon 9/30/13	Mon 9/30/13
Task 5: Model Sensitivity Study	53,180	**Tue 10/1/13**	**Mon 3/30/15**
Subtask 5.1 – Injection Scenario Simulations		Tue 10/1/13	Mon 3/30/15
Deliverable 5.1 – Meeting, Modeling data review and critique		Mon 3/31/14	Mon 3/31/14
Subtask 5.2 – Visualization of Simulation Results		Wed 1/1/14	Mon 3/30/15
Deliverable 5.2 – Report, Modeling results and storage efficiency factors		Mon 3/30/15	Mon 3/30/15
Task 6: Development of Scoping/Screening Level Models	45,017	Tue 7/1/14	Fri 5/29/15
Deliverable 6.1 – Report, Reduced order model and code module		Sun 5/31/15	Sun 5/31/15
Task: 7: Economics and Risk Management	53,227	**Tue 7/1/14**	**Mon 8/31/15**
Subtask 7.1 – Economic Assessment		Tue 7/1/14	Fri 5/29/15
Deliverable 7.1 – Report, Economic and risk management modeling results		Mon 8/31/15	Mon 8/31/15
Subtask 7.2 – Risk Assessment		Tue 7/1/14	Fri 5/29/15
Task 8: UAB Task - Ensuring Containment	332,877	**Mon 10/1/12**	**Wed 9/30/15**
Subtask 8.1 Measurement of Minimum Capillary Displacement Pressures		Mon 10/1/12	Mon 3/31/14
Deliverable 8.1 – Measurements of permeability and capillary displacement pressure of cap rock samples		Mon 3/31/14	Mon 3/31/14
Subtask 8.2 Simulation and Visualization of CO2 Seepage in the absence of Chemical Reactions		Mon 10/1/12	Mon 3/31/14
Deliverable 8.2 - Dynamic visualization of CO2 seepage based on simulations of CO2 behavior in cap rocks, in the absence of chemical reactions		Mon 3/31/14	Mon 3/31/14
Subtask 8.3 Evolution of Cap Rock Properties in the Presence of Carbon Dioxide		Tue 4/1/14	Wed 9/30/15
Deliverable 8.3 - Measurements and modeling of changes in cap rock properties and CO2 injection, migration, and trapping in the presence of chemical reactions, including cumulative CO2 loss		Wed 9/30/15	Wed 9/30/15



Appendix: Bibliography

- *Geologic Characterization for the U.S. SECARB Anthropogenic Test; Combining Modern and Vintage Well Data to Predict Reservoir Properties,* Shawna R. Cyphers, Hunter Jonsson, and George J. Koperna, Jr., poster presentation, American Association of Petroleum Geologists, Annual Convention & Exhibition, Pittsburgh, PA, May 19-22, 2013.

- *Constructing a Geologic Model to Simulate Commercial Scale CO_2 Injection and Optimization of Storage Capacity in the Southeastern United States*, Hunter Jonsson, Shawna Cyphers, George Koperna, Robin Petrusak, presentation abstract accepted for Carbon Management Technology Conference, CMTC 2013, Alexandria, Virginia, October 21 – 23, 2013