Site Characterization for CO_2 Storage from Coal-Fired Power Facilities in the Black Warrior Basin of Alabama

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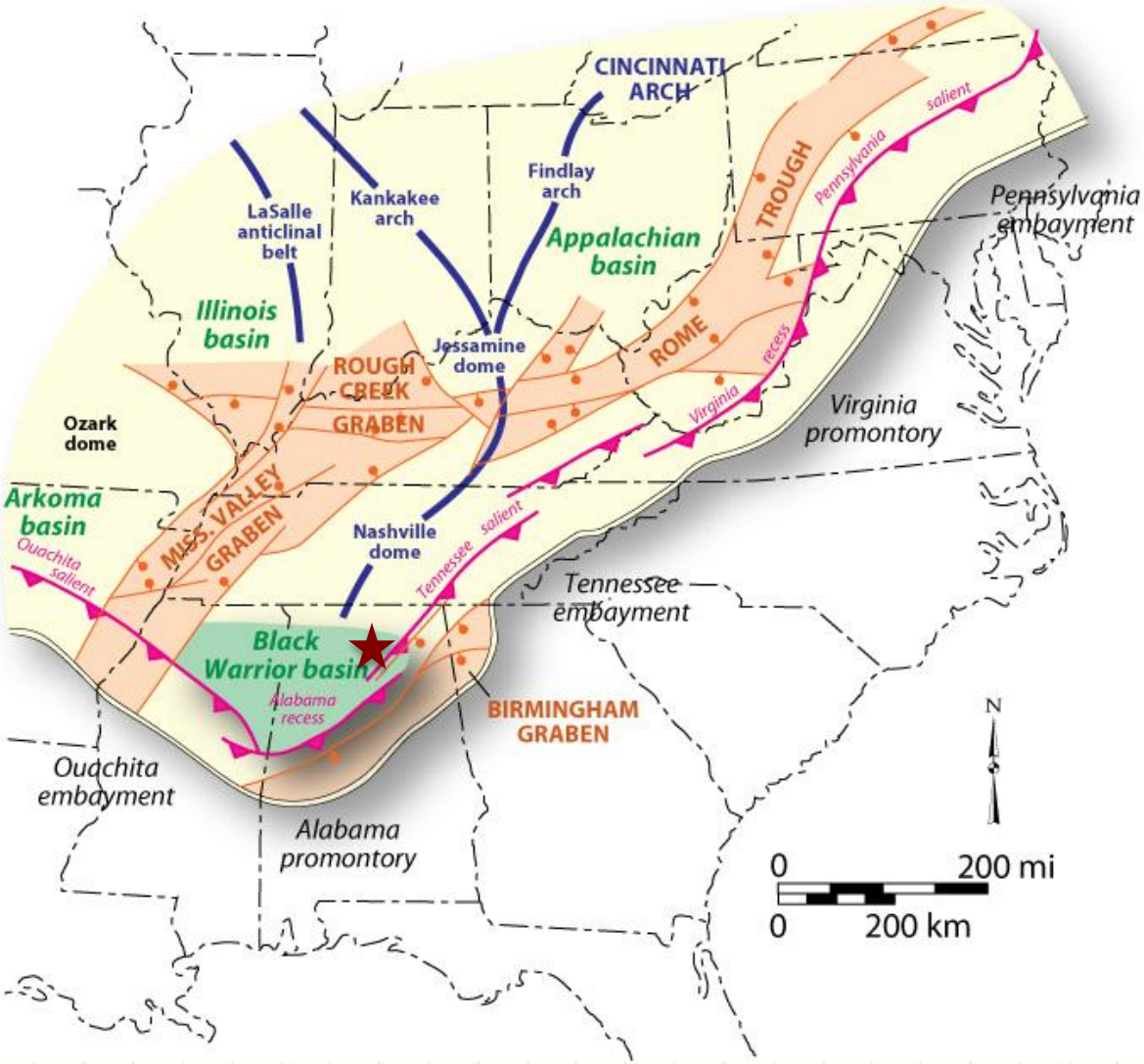
Jack C. Pashin, Geological Survey of Alabama

Mason Tomson, Rice University

DE-FE0001910

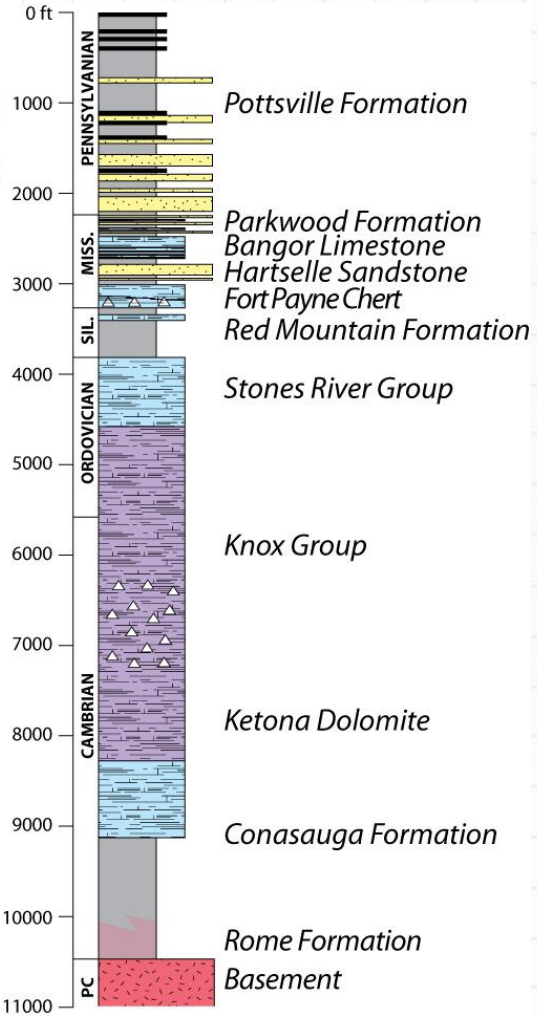
REGIONAL SETTING

Tectonic Framework



modified from Thomas (1988)

Stratigraphy



WILLIAM CRAWFORD GORGAS STEAM PLANT

SOUTHERN COMPANY
Energy to Serve Your World®

PROJECT TEAM

The University of Alabama (Lead)

Peter Clark, Eric Carlson, Andrew Goodliffe

Geological Survey of Alabama

Jack Pashin

Rice University

Mason Tomson

University of Alabama at Birmingham

Pete Walsh

Southern Company, Alabama Power

Richard Esposito

Schlumberger Carbon Services

SECARB

OUTLINE

- Project Overview
- Simulation
- Mineralization, Dissolution, and Seals
- Geological Analysis
- Geophysics

PROJECT GOALS

Assess the risks associated with geologic carbon storage in the Black Warrior basin.

Develop a regional plan and BPM for carbon sequestration.

Analyze the CO_2 storage capacity and injectivity of stacked saline formations in the Cambrian-Pennsylvanian section of the Black Warrior basin.

PROJECT OBJECTIVES

- Assess saline reservoirs, O&G reservoirs
- Shoot 2-D seismic profiles
- Drill geologic test well at Plant Gorgas
- Core reservoirs and seals
- Quantify reservoir properties
- Analysis of mineralization, dissolution, seals
- Reservoir simulation
- Develop best practices manual
- Leave infrastructure at plant

SCHEDULE

	Year 1 (2009-10)				Year 2 (2010-11)				Year 3 (2011-12)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1.0 Project Management and Planning												
Task 2.0 Regional Significance												
Subtask 2.1 Geologic Framework												
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Task 3.0 Test Site Characterization												
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Subtask 5.1 Site Selection Criteria												
Subtask 5.2 Risk Assessment												
Task 6.0 Technology Transfer												

Progress

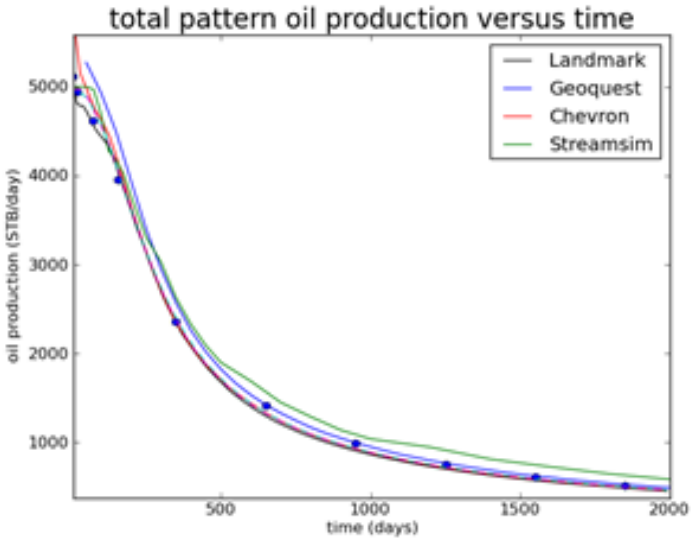
- ✓Geologic framework
- ✓Assessment
- ✓Site developed
- ✓Seismic data
- ✓Simulation tools developed
- ✓Containment analysis
- ✓Dissolution and mineralization
- ✓BMP manual

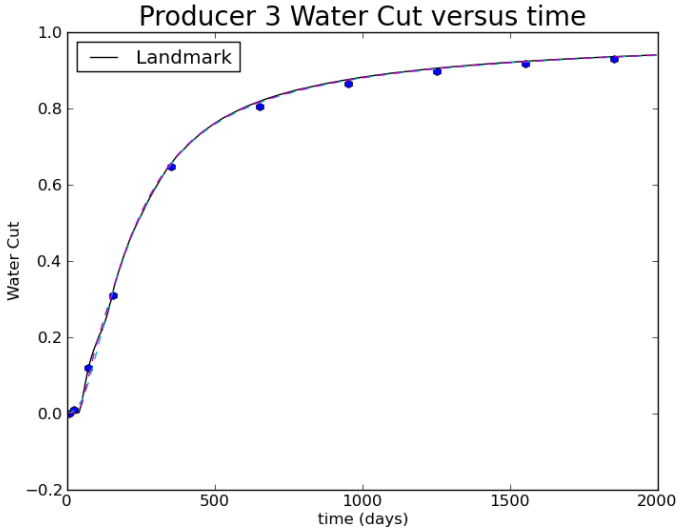
Project Overview:
Goals and Objectives – Reservoir Simulation

- Development of open simulation technologies that will allow for:
  - accurate assessment of basin-scale storage capacities, CO_2 injection rates, and long-term containment effectiveness
  - Very large scales with many millions of cells
  - Flexibility with physical processes, formulations, and mathematical models
  - Efficient calculation of phase behaviors
- Application of the simulator for the Black Warrior Basin and elsewhere in Alabama

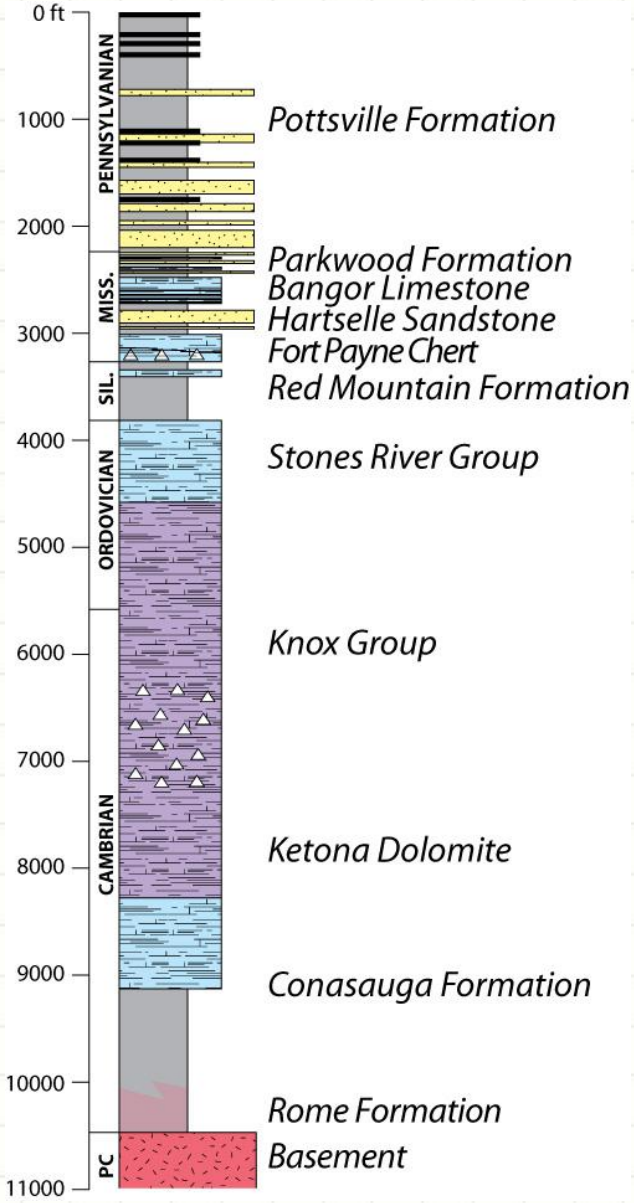
Significant Accomplishments Reservoir Simulation

- Successful development of robust algorithms and framework
- Reproduction of published results of SPE Tenth Comparative Solution (1.12 Million cells), as noted in figures
- By far fastest solution of SPE 10, with successful solution in as little as 148 seconds (28 minutes best published black-oil solve time)





NATCARB ASSESSMENT

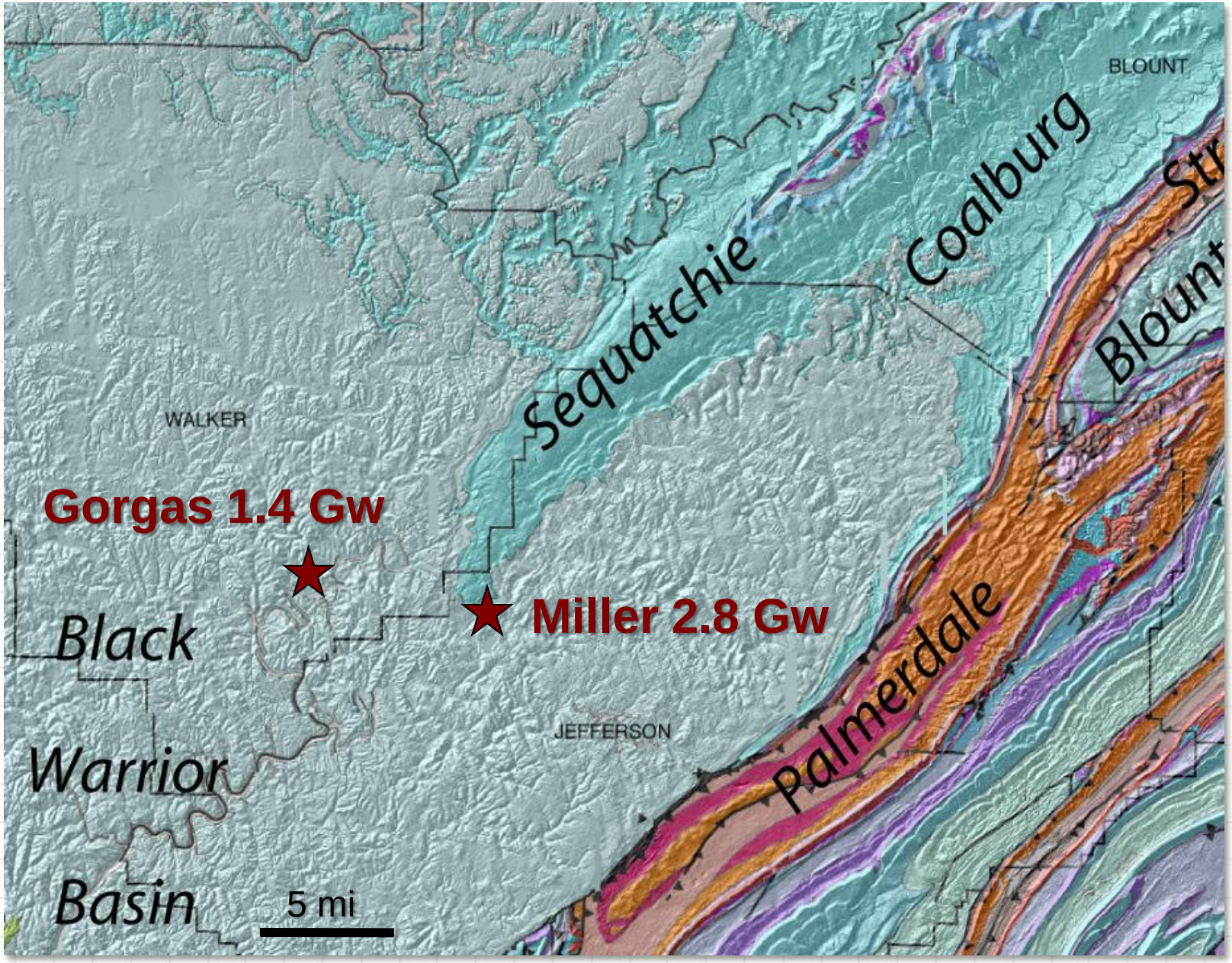


Formation	Low (Mt)	Medium (Mt)	High (Mt)
Pottsville	688	1,377	2,552
Parkwood	76	151	838
Bangor	12	24	44
Hartselle-Pride Mtn.	32	64	119
Tuscumbia	71	141	263
Devonian undiff.	140	279	520
Red Mountain	151	302	563
Sequatchie	35	69	129
Stones River	81	162	301
Knox	325	649	1,211
Total	**1,609**	**3,218**	**6,540**
Years of capacity*	**59**	**117**	**238**

* Emission rate ~ 27.5 Mt/yr

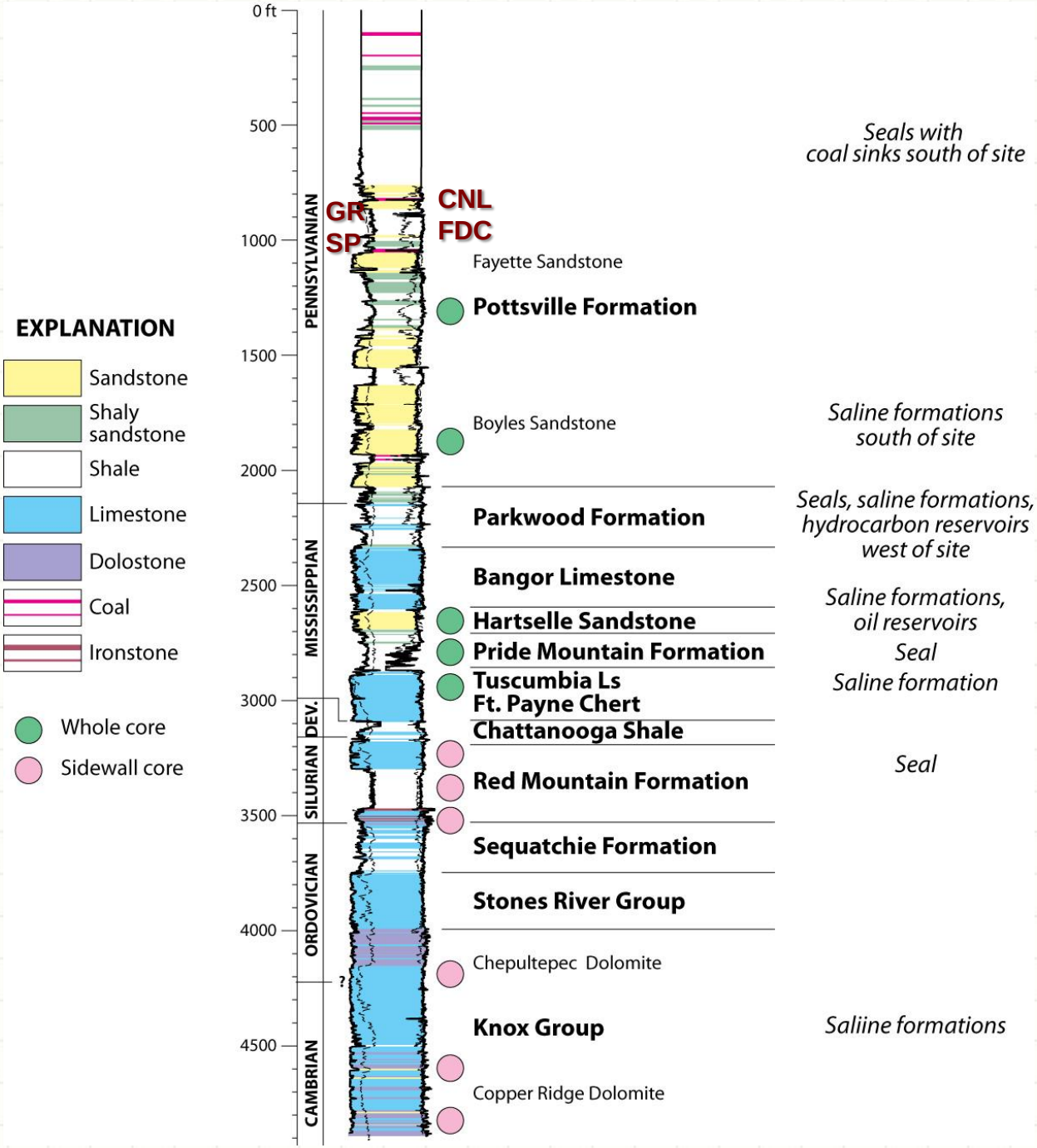
Sandstone
Limestone
Dolostone

GEOLOGIC MAP



WELL LOGS

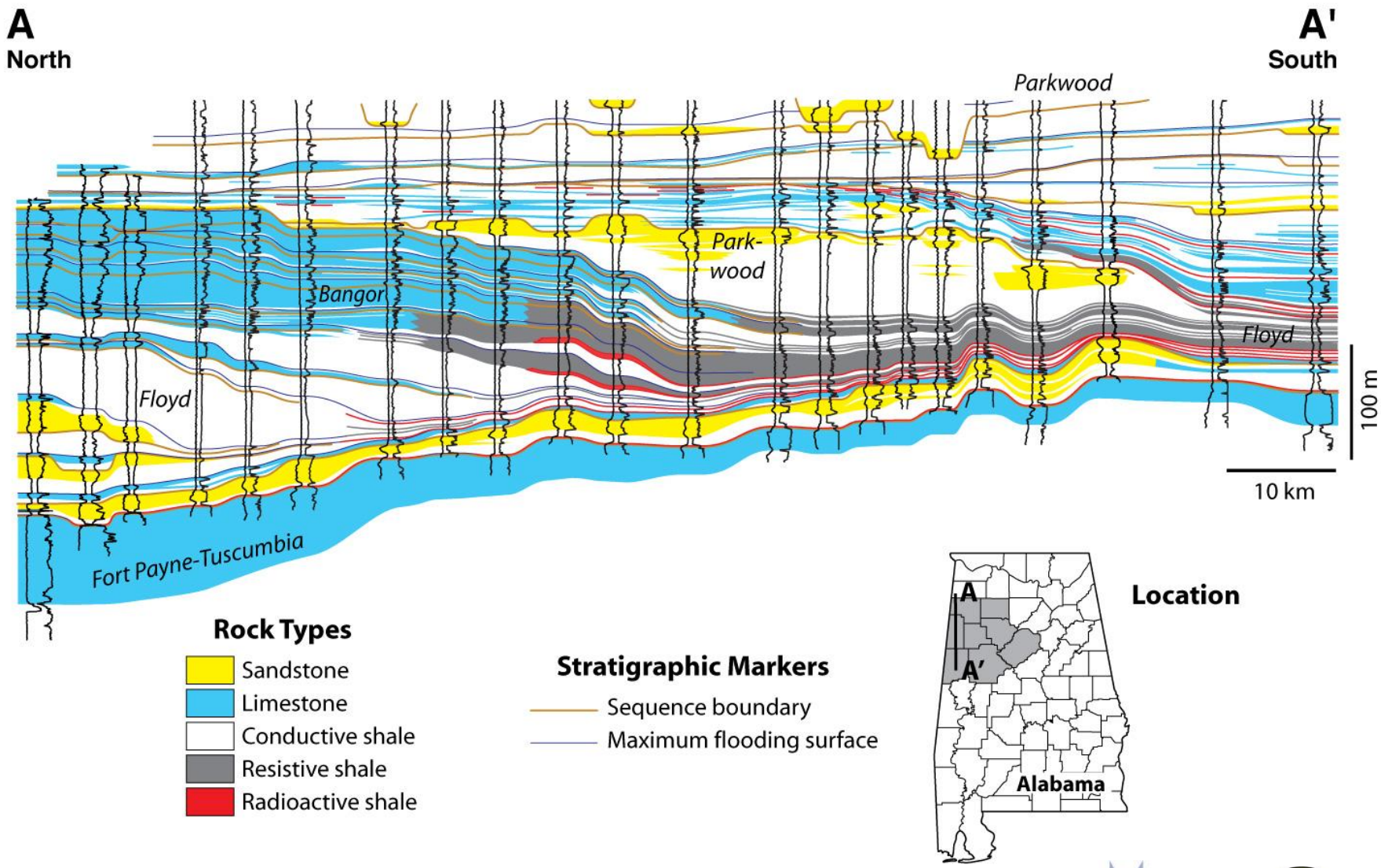
Gorgas #1 borehole



BRINE INJECTIVITY

UNIT	MAX RATE (bbl/d)	MAX PRESS (psig)	INJECTIVITY (bbl/d/psig)
Pottsville	2,160-9,324	350-1,850	1.2-11.8
Mississippian	1,350-3,600	1,050-1,700	0.8-3.4
Devonian	2,436	1,500	1.6
Knox	3,350-10,800	995-1,750	3.4-6.2

MISSISSIPPIAN CROSS-SECTION



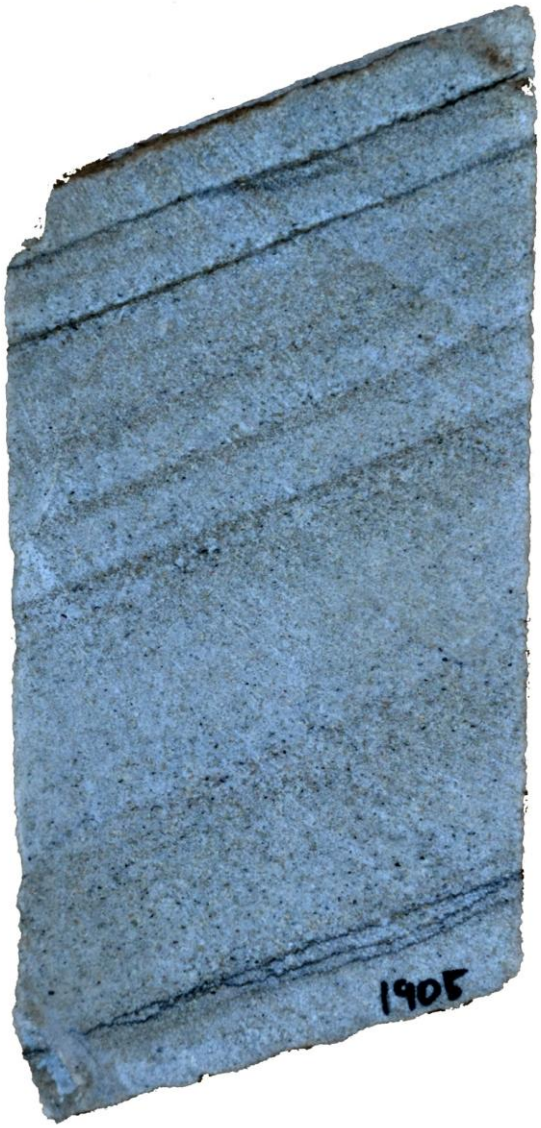
GORGAS #1 CORES

Fayette shale

Pride Mtn. shale

Core diameter = 4 “

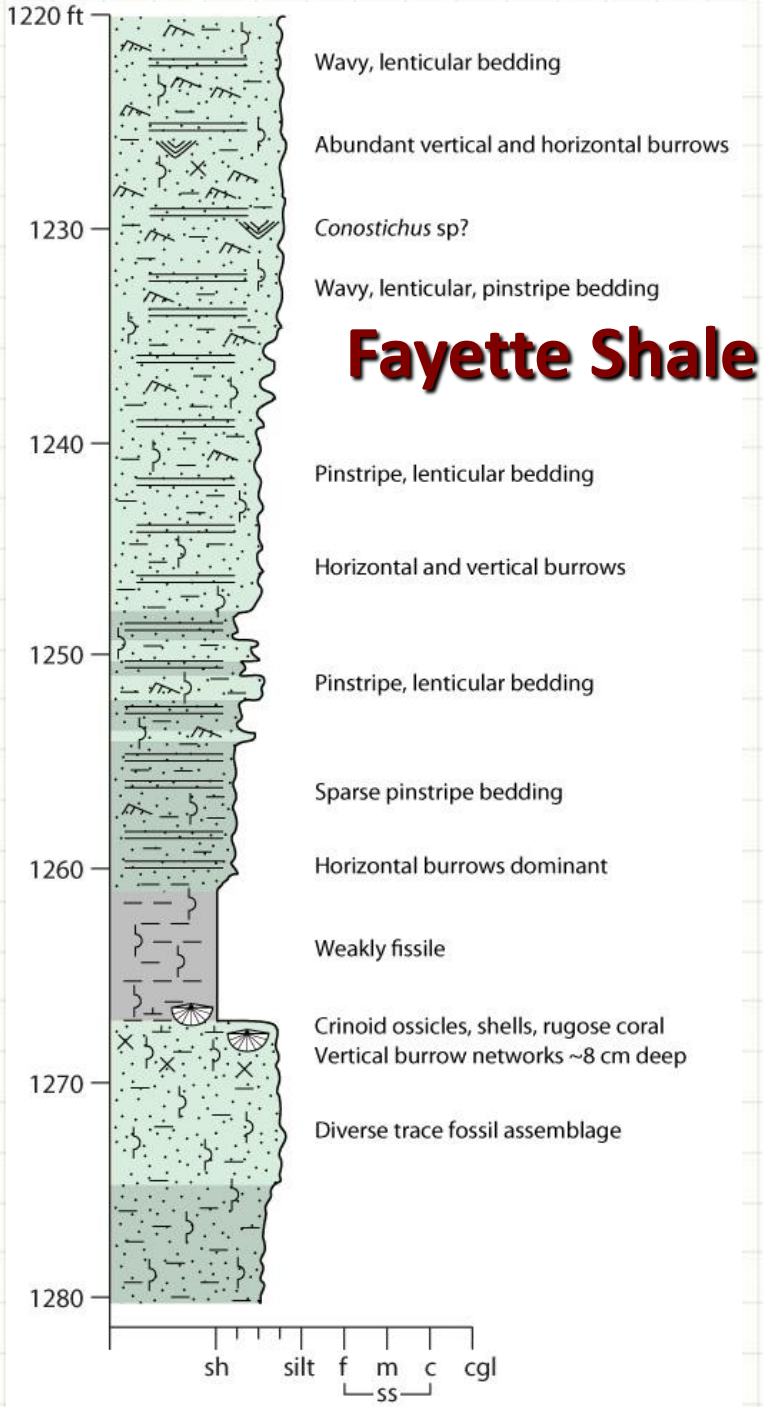
Boyles SS



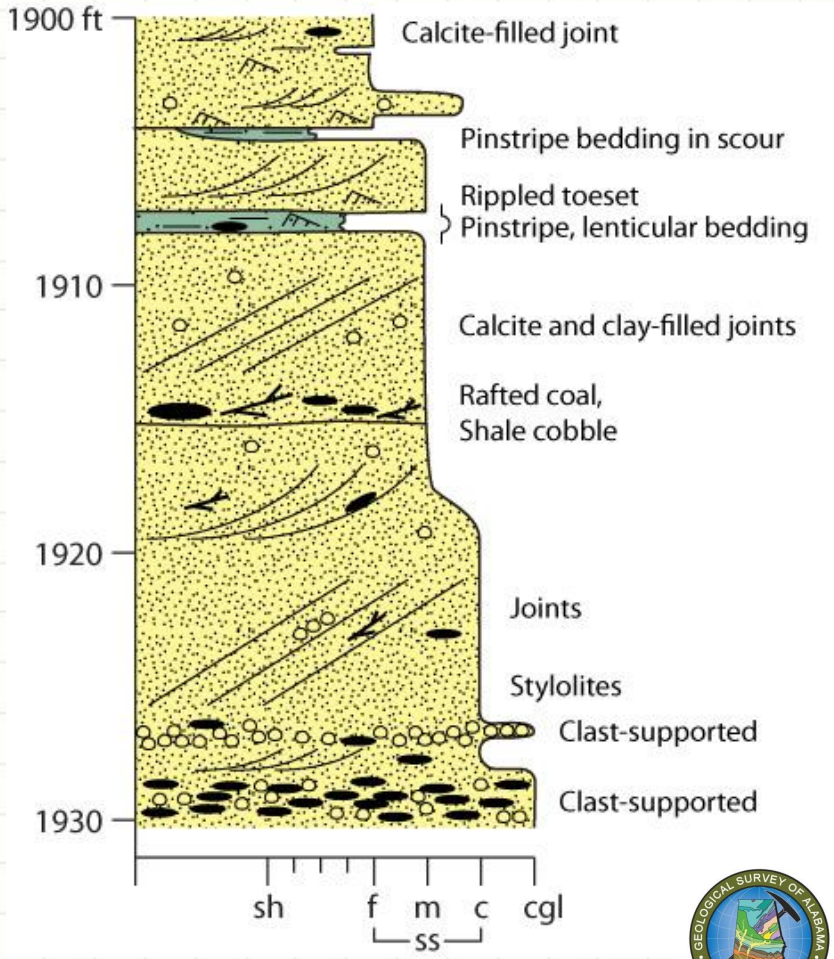
Tuscumbia LS

GRAPHIC CORE LOGS

Fayette Shale

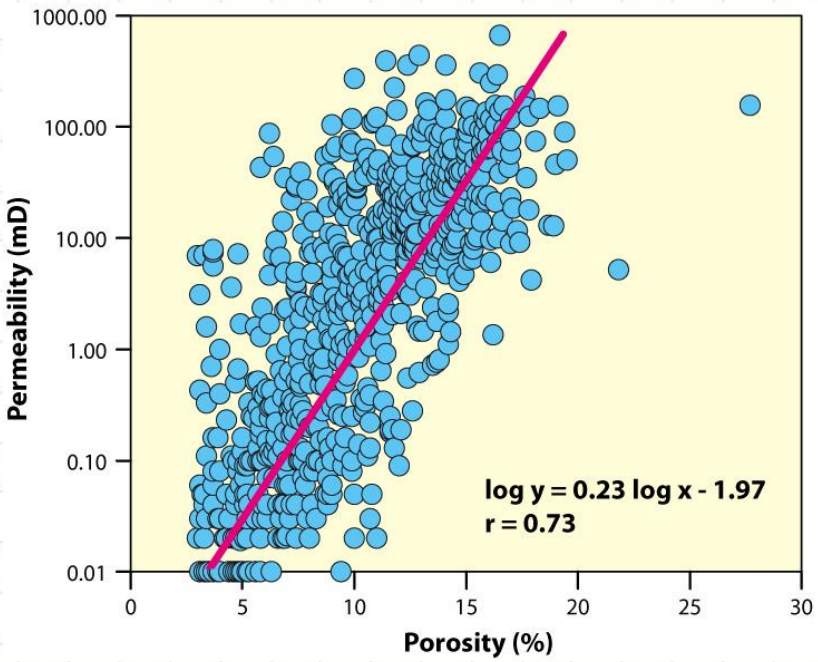


Boyles Sandstone

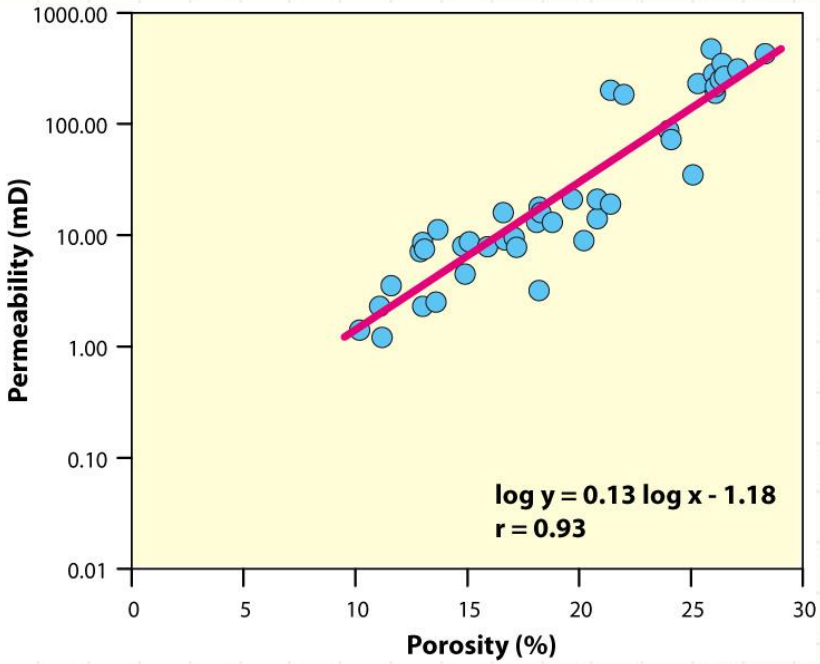


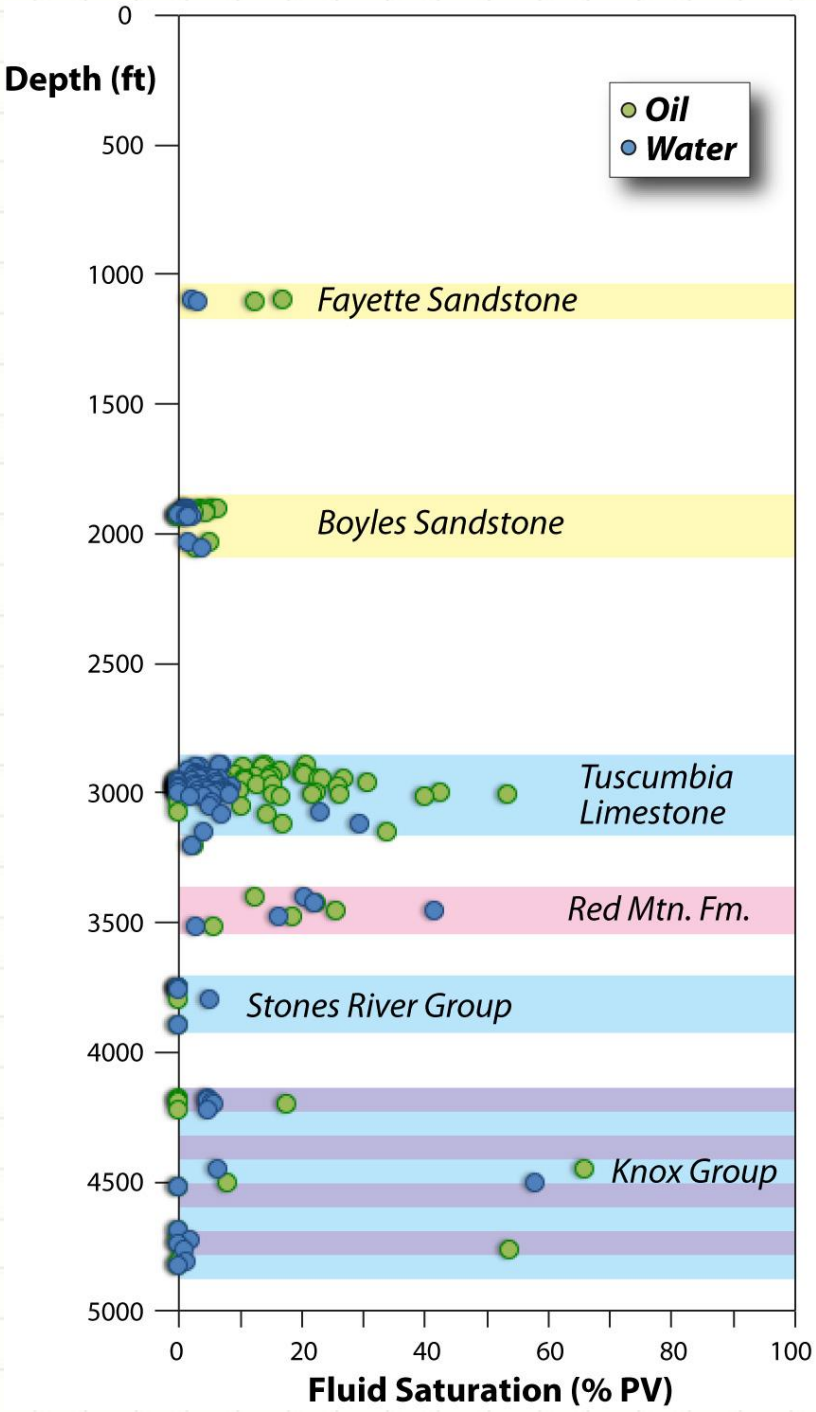
POROSITY, PERMEABILITY

Mississippian



Pottsville



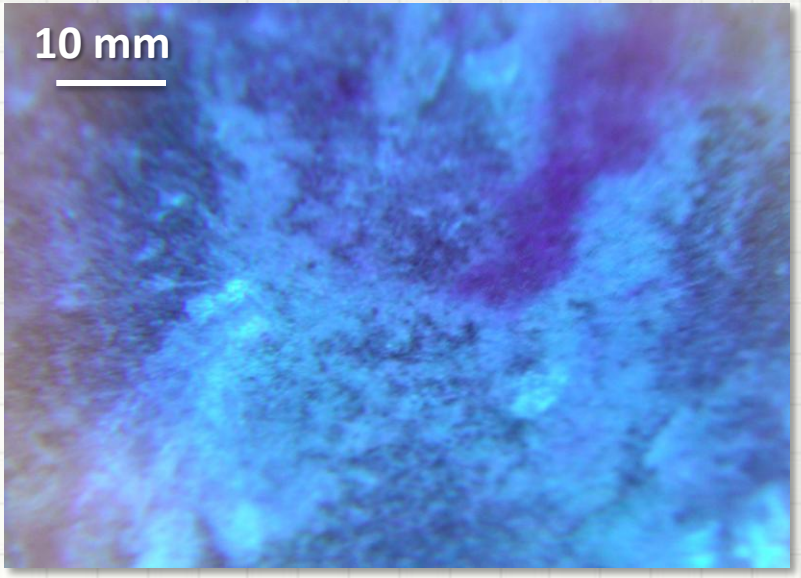


WATER AND OIL SATURATION

Gorgas #1

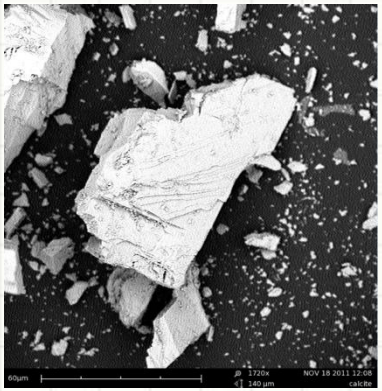
Conventional core analysis

Fluoroscope image, Hartselle SS

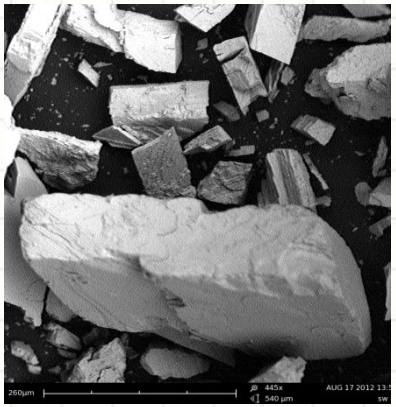


Experimental Progress on Mineral Dissolution/Precipitation

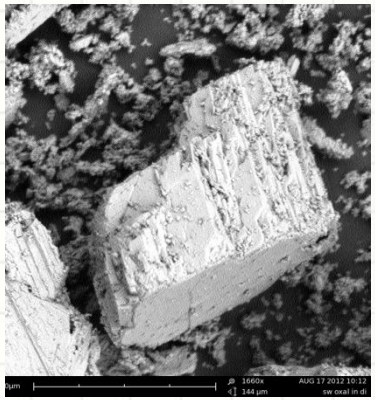
- Analysis of samples received from Gorgas well, nearest to injection well, shows a close match to clean calcite.
  - Tuscumbia limestone: $Ca_{0.96}Mg_{0.006}CO_3$
  - Iceland Spar calcite: $Ca_{0.99}Mg_{0.037}Fe_{0.005}CO_3$
- Batch and column studies indicate pH insensitive Ca salts resulting from acid reaction may offer potential surface coverage
  - $CaSO_4$, CaOxalate, CaF_2, $CaPO_4$
- Studies will continue to pursue why reported dissolution inhibitors were not able to mitigate calcite or dolomite dissolution



~225µm ground calcite used in experiments

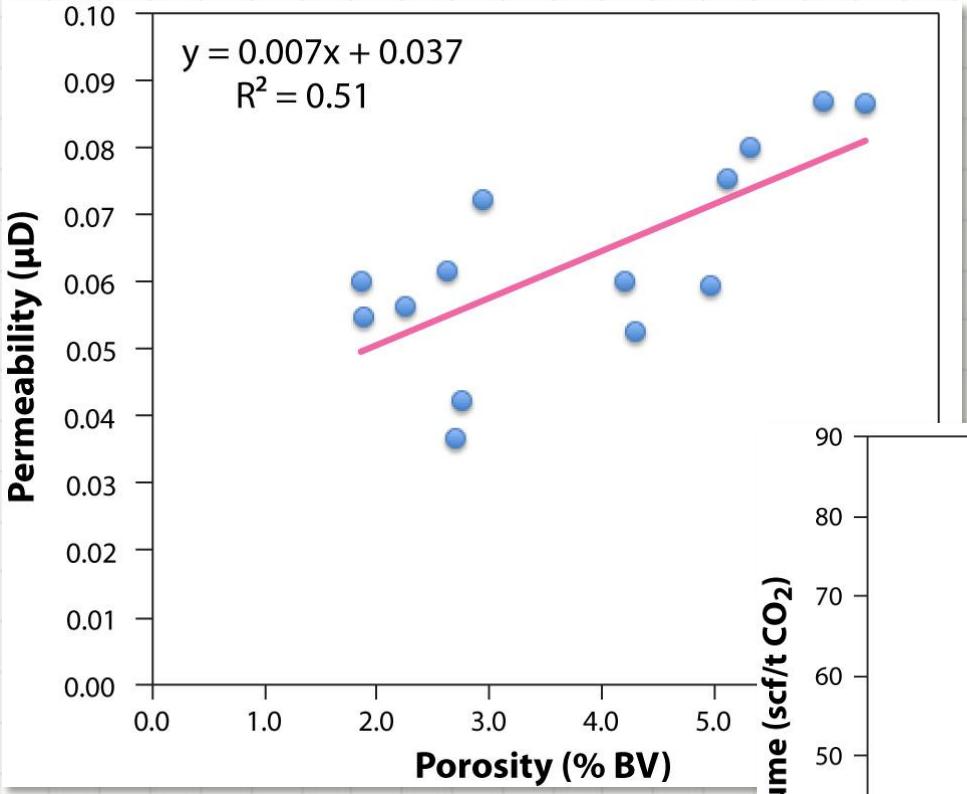


Ground calcite after treatment with 0.15M hydrofluoric acid



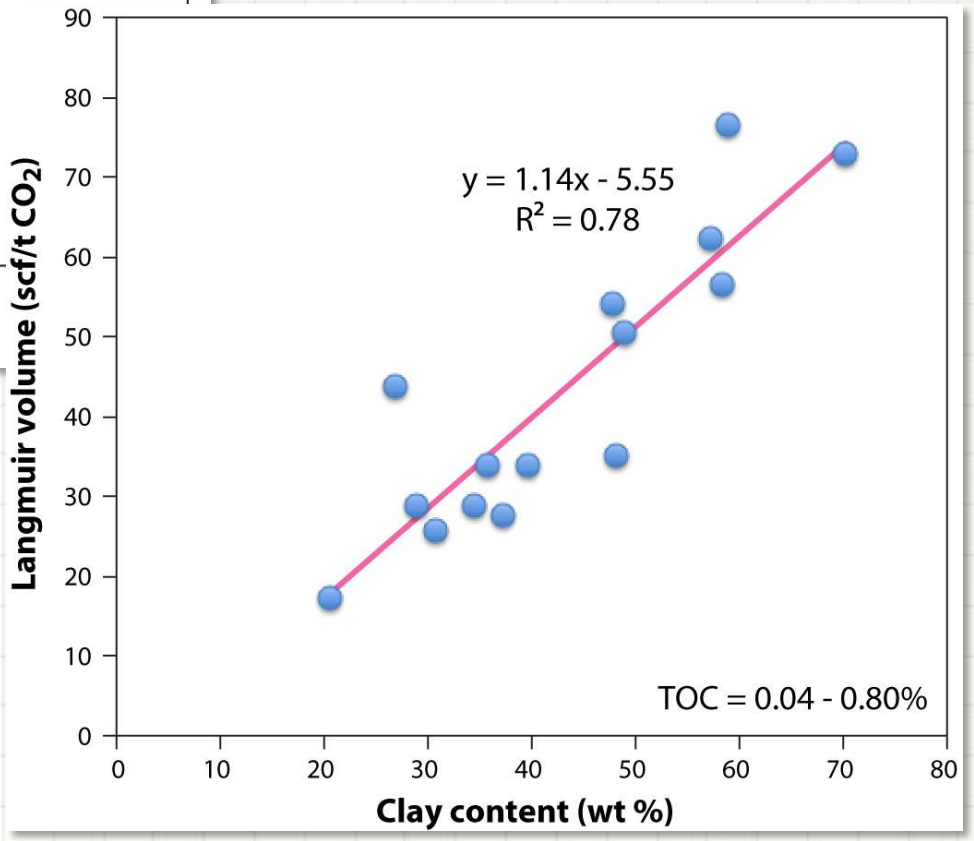
Ground calcite after treatment with 0.15M oxalic acid

SHALE SEAL ANALYSIS



TerraTek

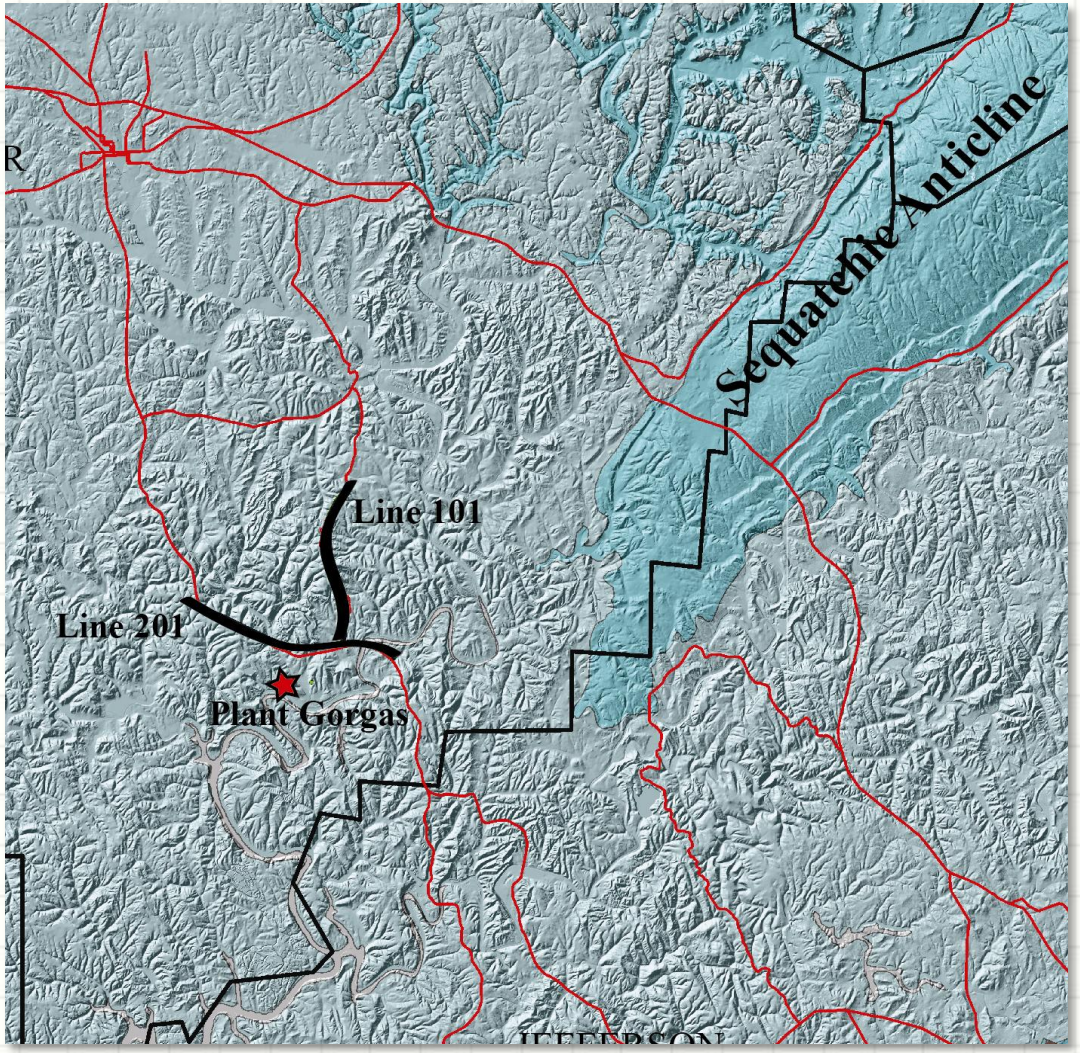
GEOLOGICAL SURVEY OF ALABAMA
Founded 1848



Gorgas #1

Pottsville Fm., Pride Mtn. Fm., Red Mtn. Fm.

SEISMIC ACQUISITION



2D Seismic Lines

- **Line 201 (NW-SE, Hwy 269)**

  1.28km (0.795 miles) N of Gorgas #1 Well

  Perpendicular to the axial trace of Sequatchie Anticline

- **Line 101(N-S), follows county road 6**

SEISMIC ACQUISITION

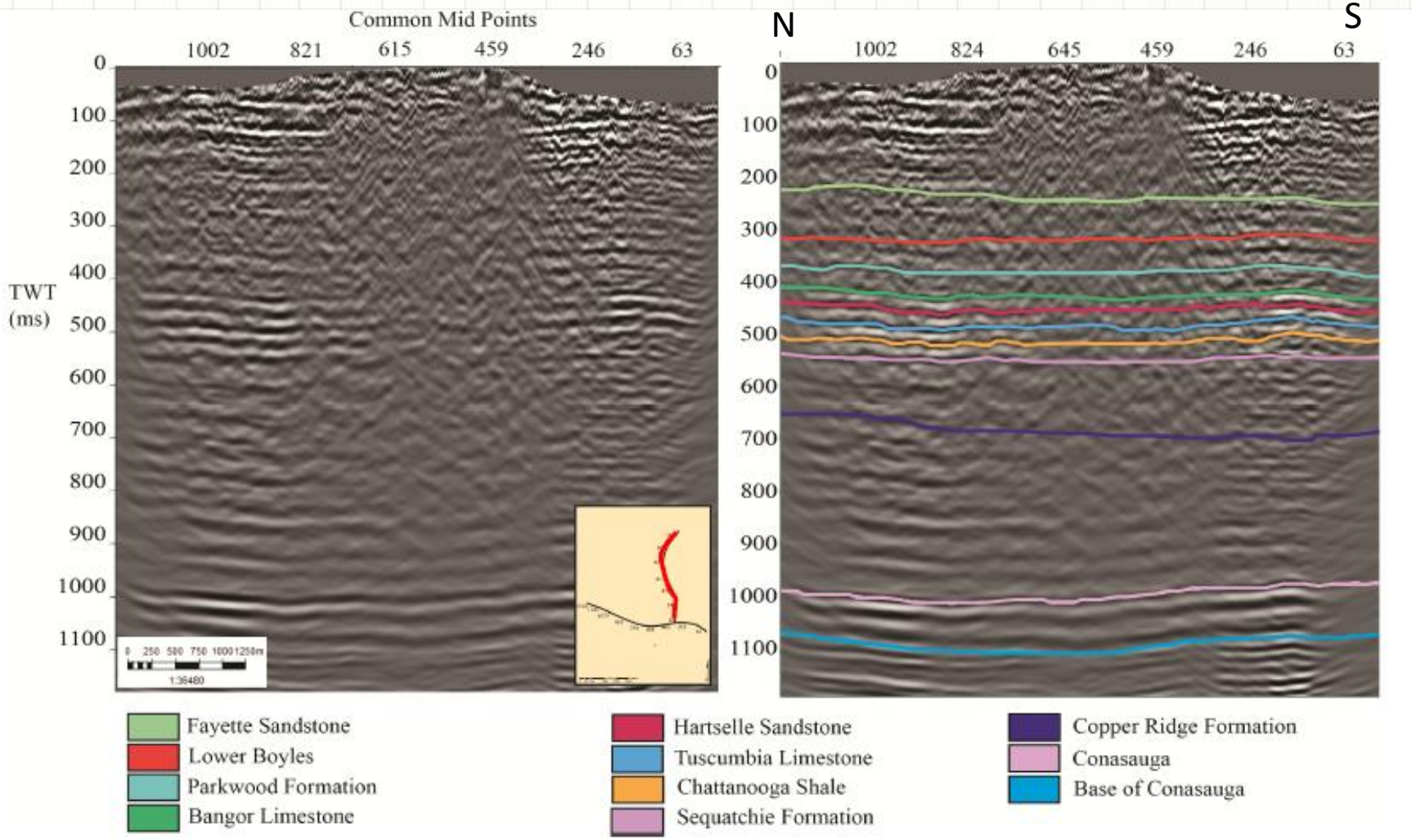
Acquisition	
Source	
Source (Vibrosies)	X3 Hemi-44, 20411.65 kg (45,000 lb) trucks
Source Interval	36.5 m (120 ft)
Shot Density / sq mile	44 Vps
Receivers	
Receiver Interval	3.048 m (10 ft)
ITO Interval	36.5 m (120 ft)
DGF Interval	12 m (40 ft)
PR Density / mile	528 single sensors
DGF Density /sq mile	132 Group Formed channels
Design Patch	
Total Channels/Line	8 km (5 mile) lines all live
Design - DGF/Line	1 x All live Digital Group Formed channels
Recording Statistics	
Total Live Channels	All live point receivers
Effort	4 - 12 sec sweep per location
Sweep Type	6 - 100 Hz Phase Rotated Sweep
Record Length	5 seconds
Sample Rate	2 ms
Subsurface Statistics	
Bin Size	6 m (20 ft)
Bin Density	264 per mile
Nominal Fold	110 post DGF
Minimum Offset	6 m (20 ft)
Maximum Offset	8047 m (26,400 ft)

Acquisition using Schlumberger Q-land System: Detailed static correction, in the presence of rugged topography

Seismic reference datum (SRD) for static correction: 244.844m. (800ft) above MSL

Static correction- Replacement velocity: 4572m/s (15000ft/s)

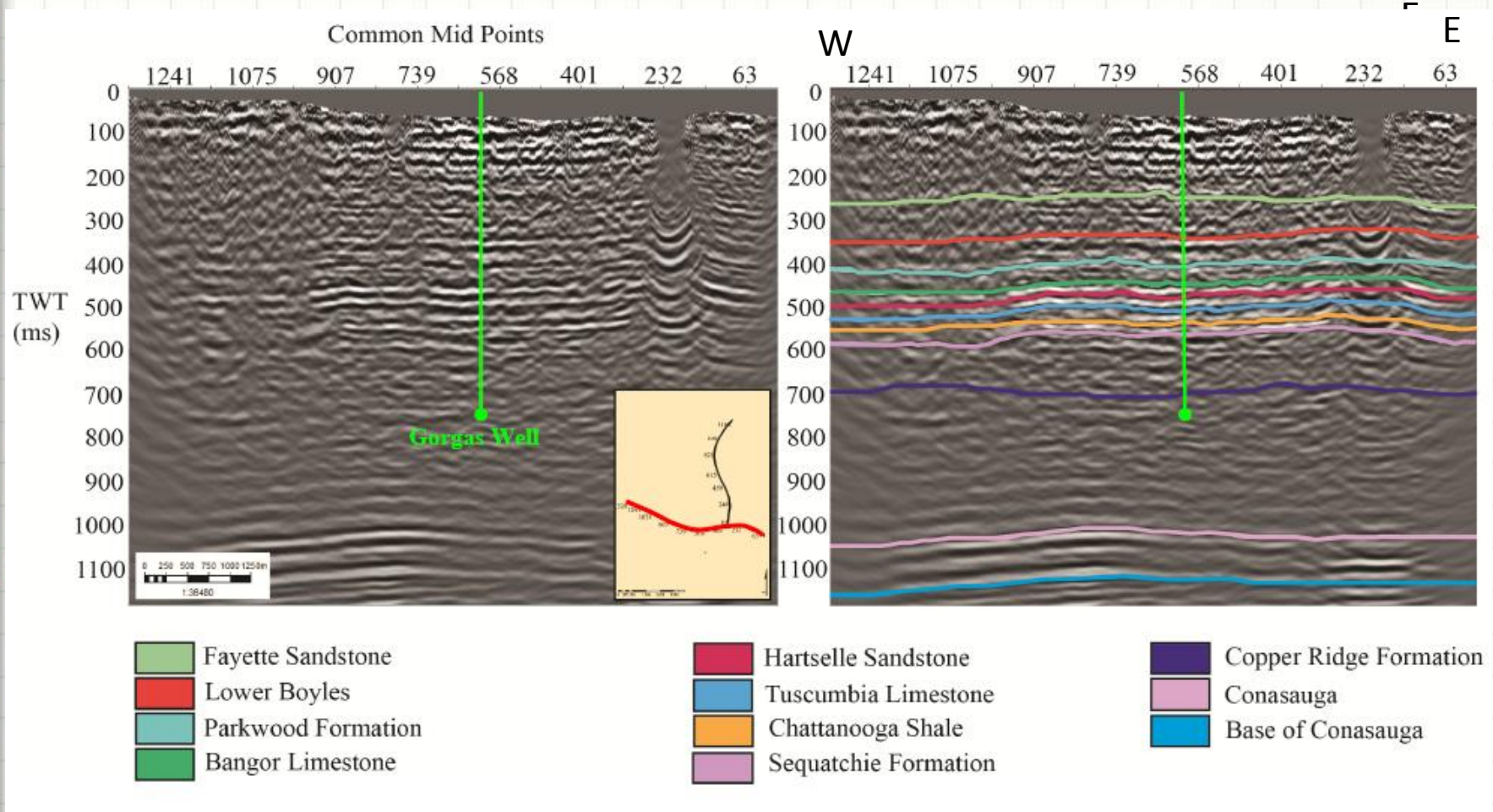
DATA PROCESSING AND INTERPRETATION



Pre-stack time migrated Line 101, target reservoir below Lr. Boyles Sandstone (300 ms)

Rutter (2012)

DATA PROCESSING AND INTERPRETATION



Pre-stack time migrated Line 201,

Gorgas well reaches at Copper Ridge Fm. at 4915 ft (700ms)

Rutter (2012)

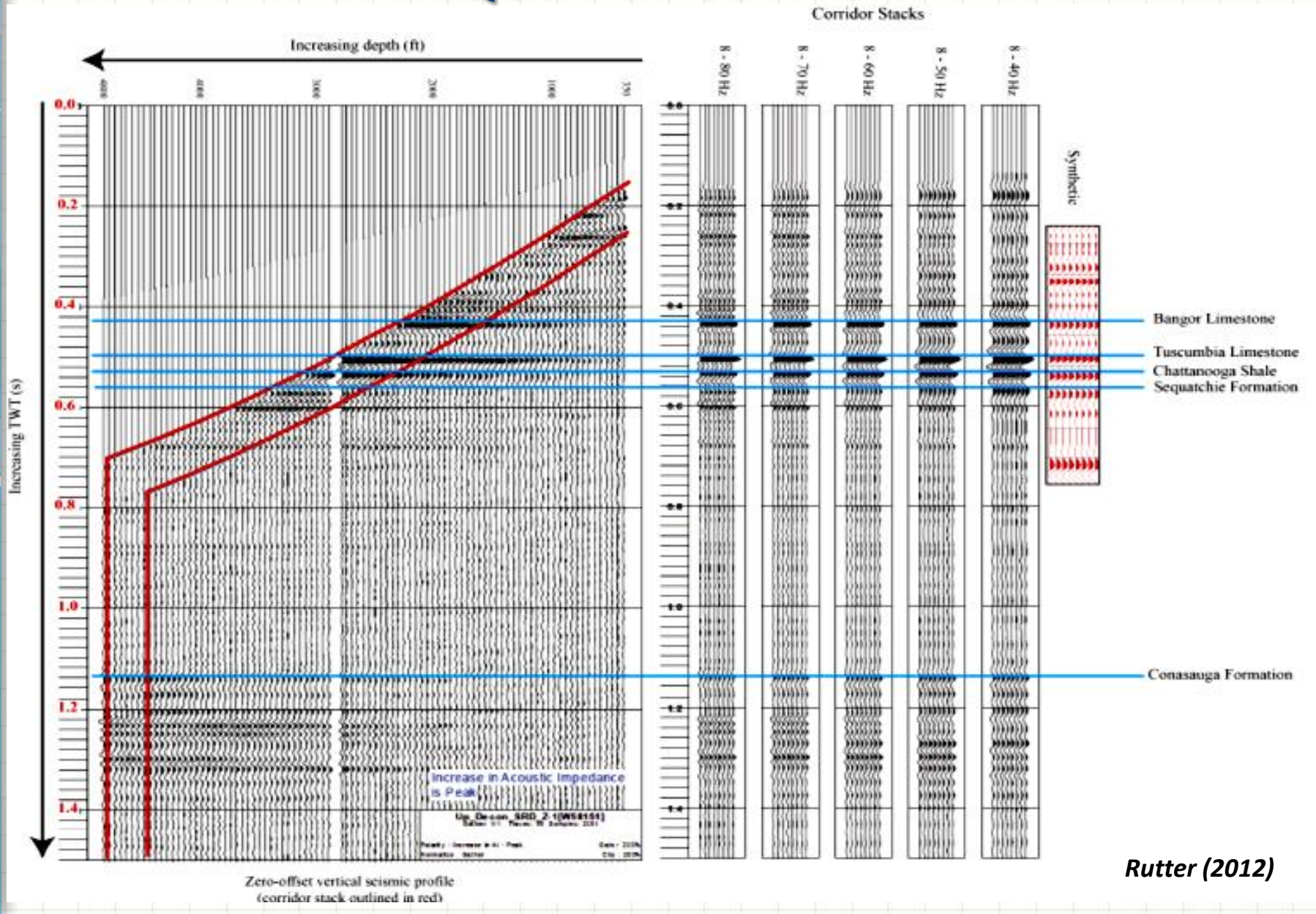
QUALITY ANALYSIS: CHECK SHOT, ZVSP DATA

Check shot data collection for accurate time to depth conversion

- **Source: Vibrosis**
- **Horizontal offset: 49 m (162 ft)**
- **Vertical offset: 4.18 m (13.74 ft) below KB**
- **Measurements: at each 15 m interval down hole from 30-1478 m (100-4850 ft)**
- **Velocity data (average, RMS, interval velocities for each interval) calculated from check-shot data**

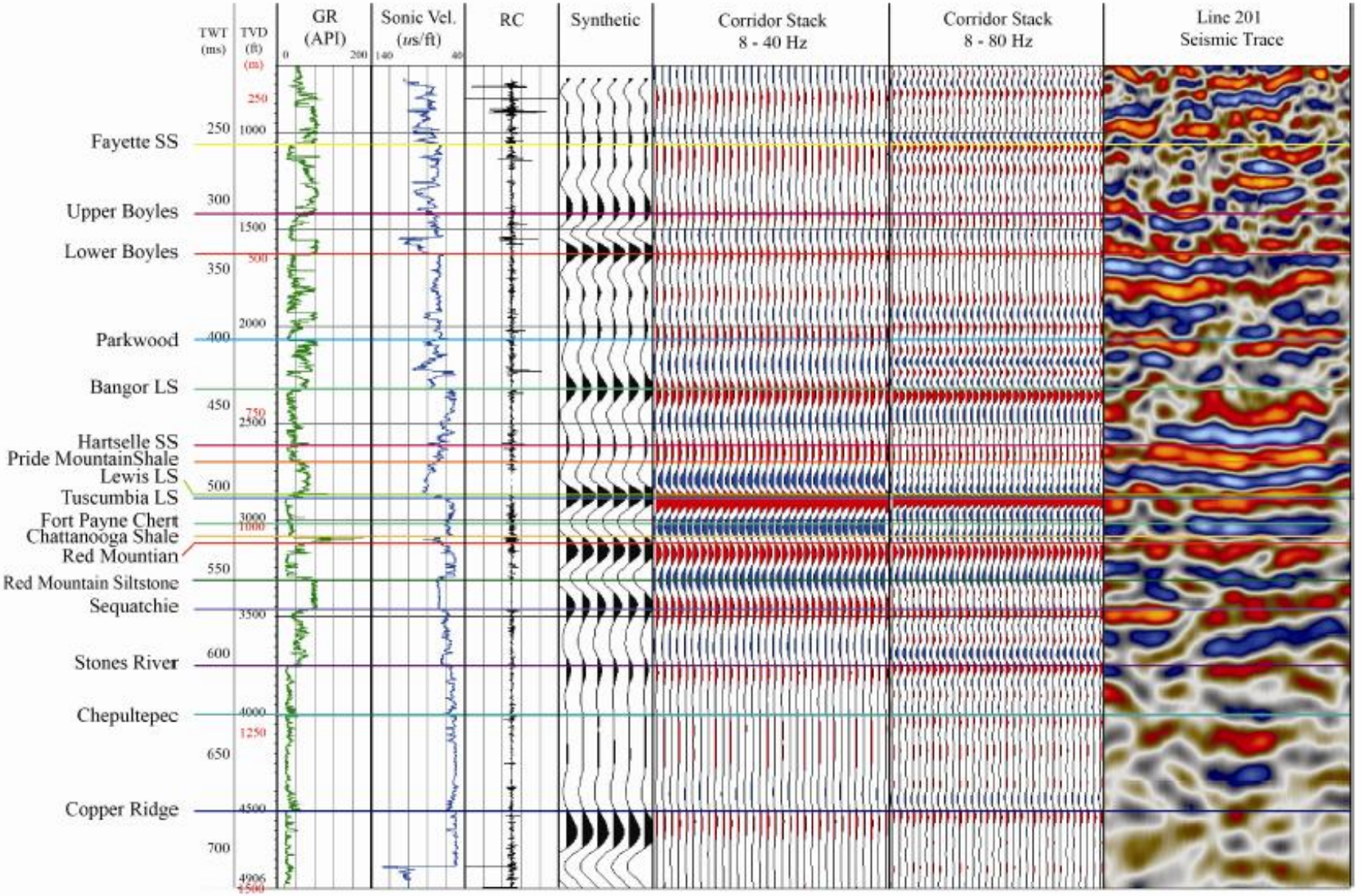
Zero – Offset VSP	
Tool	VSI-4
Geophone	GAC-D
Sample Rate	2 ms
Receiver Range	1478.28–30.48 m (4850-100 ft)
Receiver Interval	15.24 m (50 ft)
Source Type	Vibrosies
Source Offset	49.37 m (162 ft)
Source Azimuth	345 degrees
Elevation	114.6 m (376.10 ft)

ZVSP DATA: CORRIDOR STACK FOR RANGE OF FREQUENCY CONTENT



Rutter (2012)

SYNTHETIC SEISMOGRAM: ESTABLISHING TIME-DEPTH RELATIONSHIP



Rutter (2012)

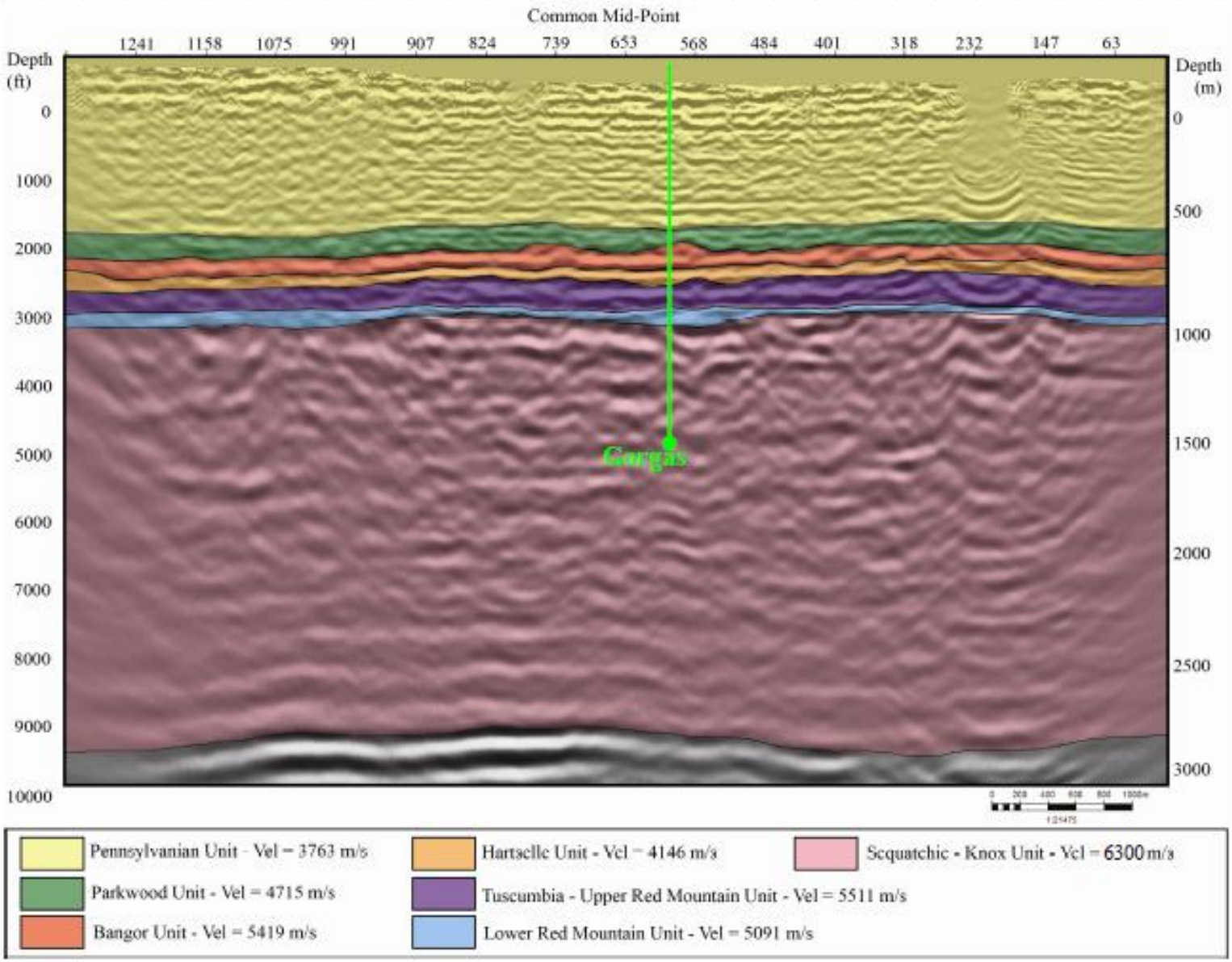
DEPTH CONVERSION/VELOCITY MODEL (PETREL)

- Low structural complexity: Velocity model creation for Horizontal intervals
- Velocity model created by using sonic data, calibrated with check shot data
- Petrel application:
    - Polygon created surrounding the seismic lines, Gorgas #1 well
    - Surface area extrapolated (convergent interpolated algorithm)
    - Grid size 10m x 10m

Surface	Rock type	Average Velocity (m/s)
Zero		0
Pottsville	Sandstone/ shale/coal	3763
Parkwood	Shale/ Limestone	4715
Bangor LS		5419
Hartselle SS		4146
Tuscumbia LS		5511
Lower Red Mountain	Silty Shale	5091
Sequatchie/Knox		6300

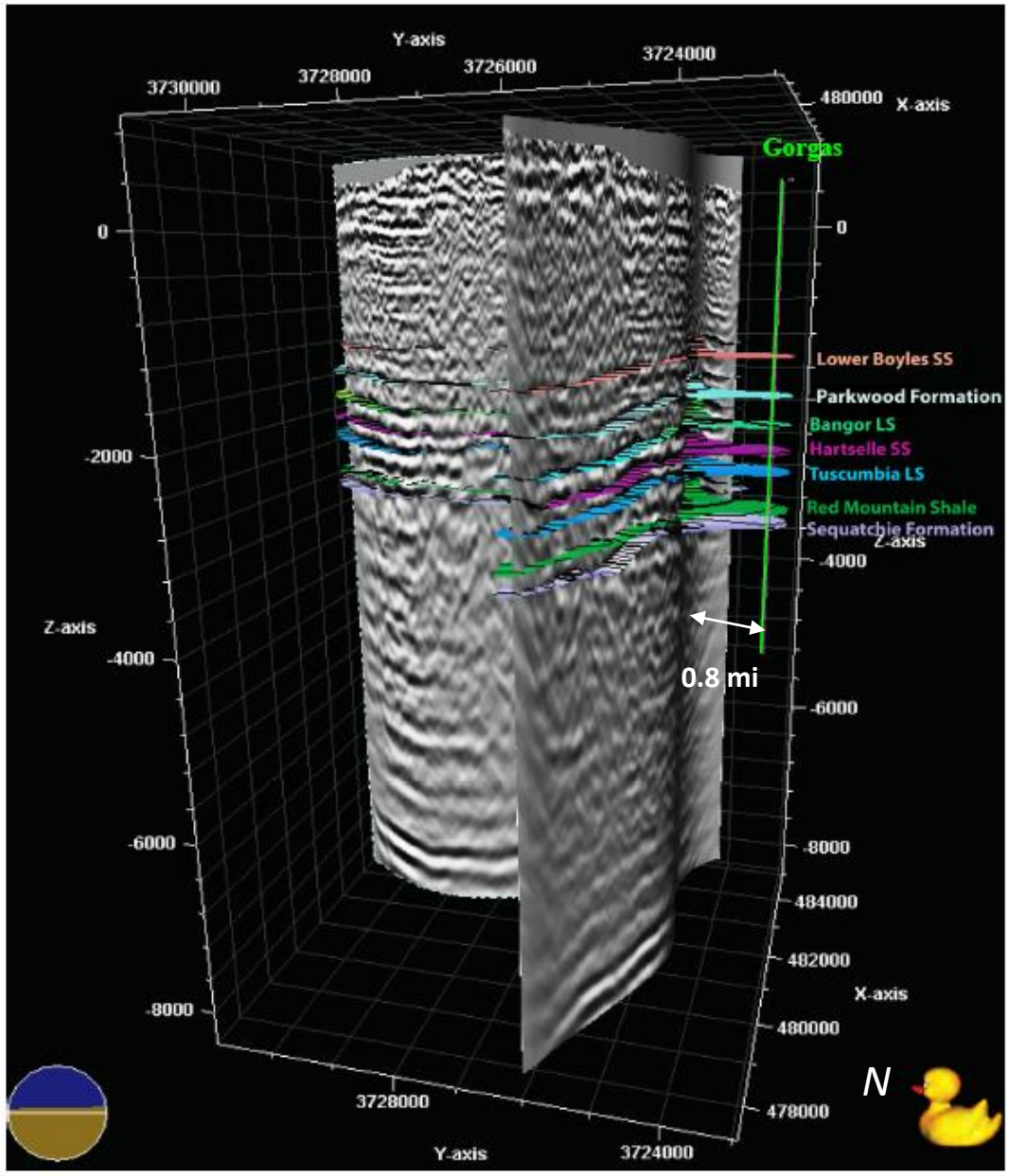
Rutter (2012)

DEPTH CONVERSION: LINE 201



Rutter (2012)

3-D VIEW, DEPTH-CONVERTED LINES 101, 201

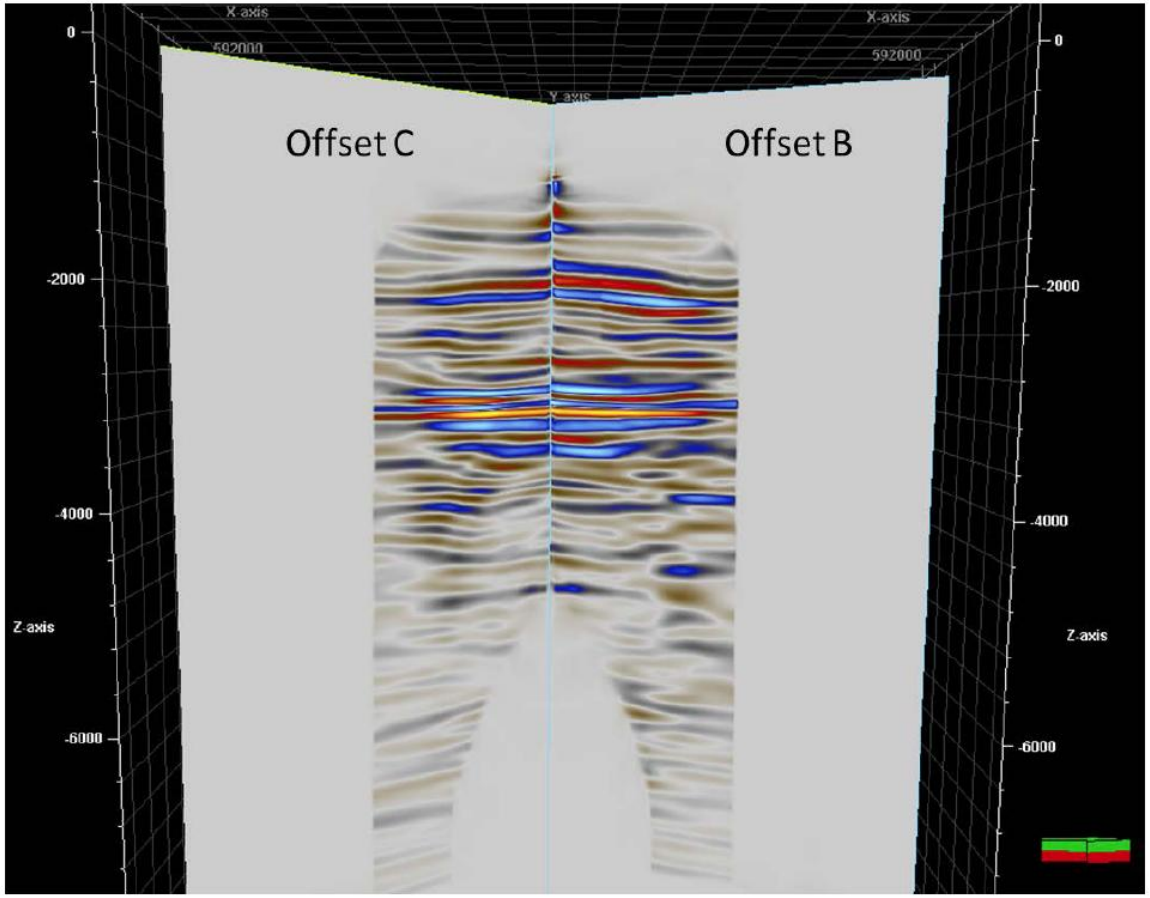


- Shallow dipping (3˚) limbs of this antiformal structure may help CO_2 containment in the formations above

- Low porosity in targeted reservoirs may be due to the silica cementation along the crest of gently folded structure (Wood 1984)

- Line 201 shows gentle antiform at a depth of 2743 m (9000 ft) in the lower Conasauga Fm - May be an artifact of preliminary seismic processing

INITIAL RESULTS FROM OFFSET VERTICAL SEISMIC PROFILES



- Intriguing evidence of shear wave splitting in data – subject of further studies

OTHER ONGOING PROJECTS

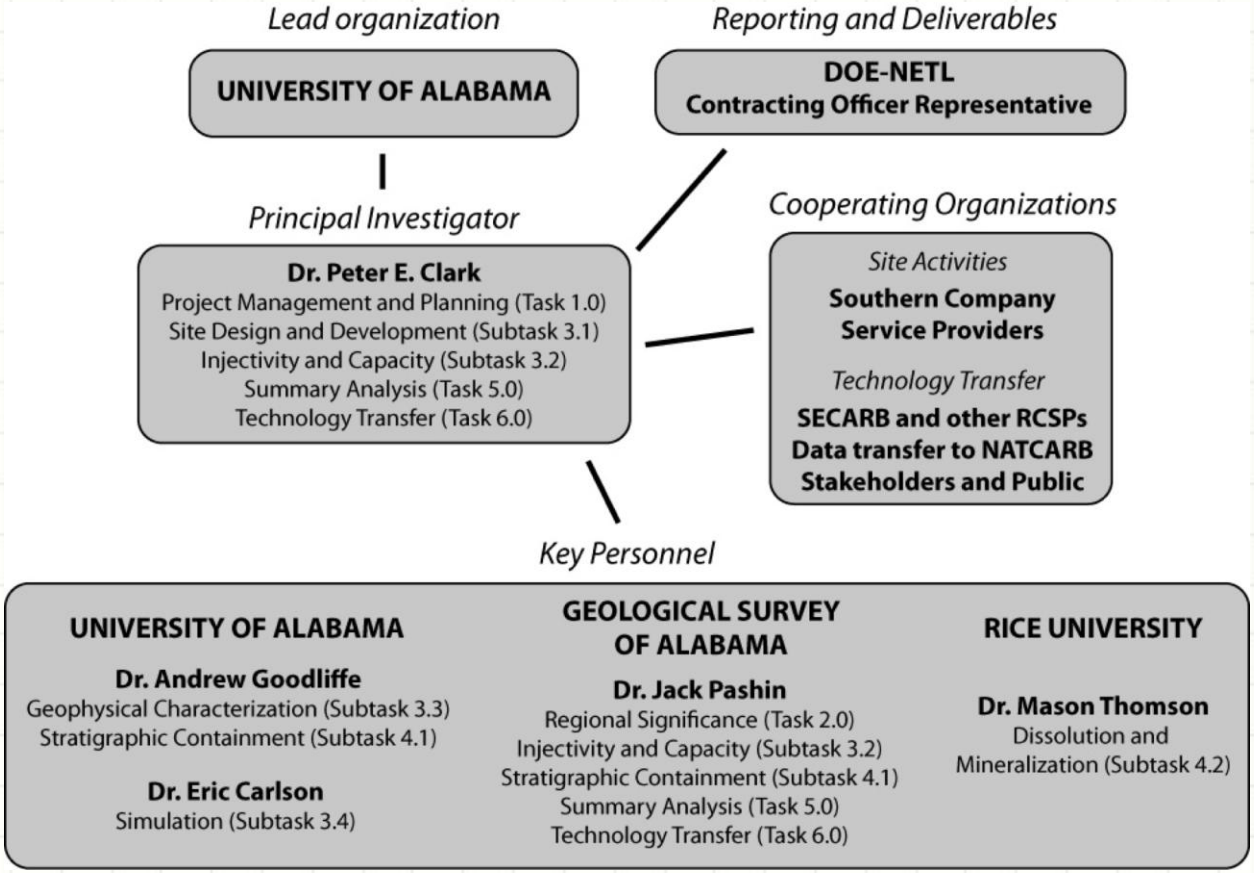
- Construction of 3-D velocity model using permanent borehole seismometers
- Re-processing of 2-D seismic reflection data as a 3-D swath
- Detailed analysis of FMI data

SUMMARY

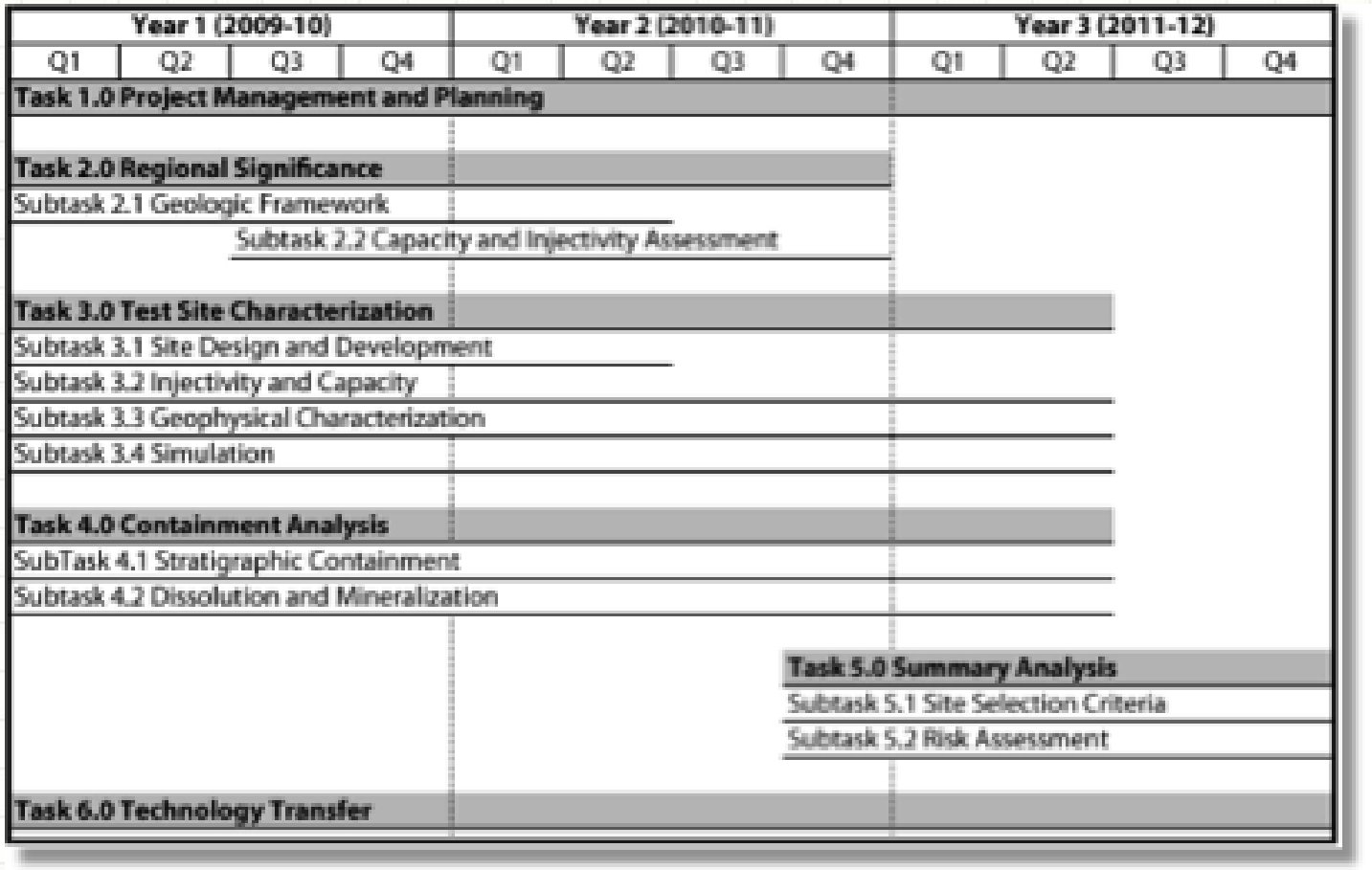
- Flow-through testing in progress
- Simulation tools developed
- Data uploaded to NATCARB
- Sink capacity assessed
- Seismic data acquired and being interpreted
- Well drilled, logged, characterized
- Cores analyzed and interpreted
- Containment analysis in progress
- Best practices manual in development

Appendix

Organization Chart



Gantt Chart


Year 1 (2009-10)
Year 2 (2010-11)
Year 3 (2011-12)
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
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Bibliography

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- Islam, A.W., and Carlson, E.S., 2012, “Activity Coefficient Models for Calculations of Supercritical CO_2 and H_2O at High Temperatures and Pressures”. (*Geothermal Resources Council Meeting, Sep 30-Oct 3, 2012.*)
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