Gulf of Mexico Miocene CO2 Site Characterization Mega Transect

DE-FE0001941

Ramon Trevino

Texas Bureau of Economic Geology

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage
August 21-23, 2012

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Acknowledgments

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Julie Ditkoff

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Presentation Outline

- Study Overview
- Technical Status
  - Atlas of CO_2 "Plays"
  - Seal (Caprock) Analyses
  - High Temperature / Pressure Experiments
  - Percolation Models Based on Sediment Peel
  - 3D Seismic-based Research
    - Leased Commercial Dataset
    - Newly Acquired P-Cable Data

Benefit to the Program

Program goals addressed

Develop technologies that:

1. Predict CO_2 storage capacity within ±30%
2. Demonstrate 99% containment

Benefits Statement –

The research will develop 1) an atlas of existing traps (e.g., hydrocarbon fields) and regional data (e.g., existing well data, formation properties, etc.) and 2) a best practices manual. The resulting data and techniques will help industry identify and evaluate future sequestration sites.

Project Overview: Goals and Objectives

Study Goal – characterize regional Miocene-age geologic section (formations) of Texas submerged State Lands.

Objectives:

1. Assess & analyze existing regional data (hydrocarbon industry).
2. Verify Miocene rocks' ability to safely and permanently store large amounts of anthropogenic CO_2.
3. Identify at least one specific site (capacity ≥ 30 MT CO_2) for future commercial CCS operations.

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Project Overview:
Goals and Objectives

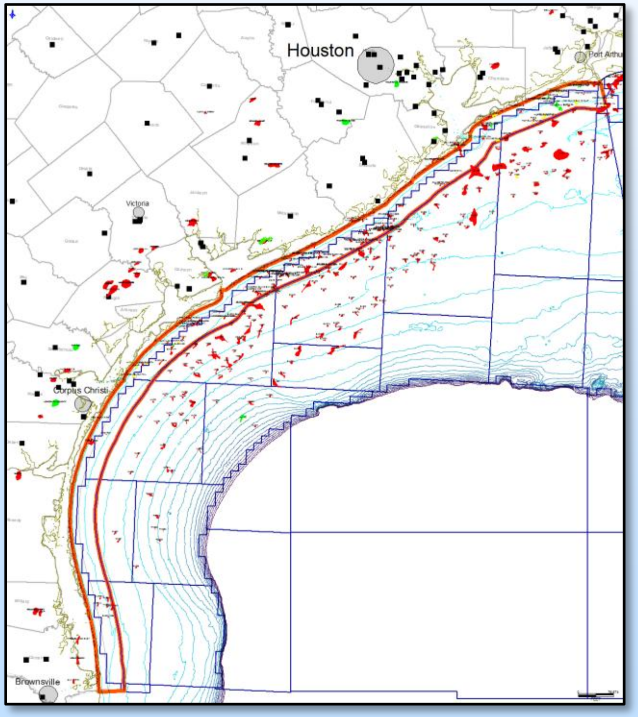
Success Criteria

- ✓Minimum necessary data available
- ✓ Identify one or more specific sites
  - – Meet / exceed capacity cutoff
  - – Complete geologic model(s)
  - – Complete flow simulation model(s)

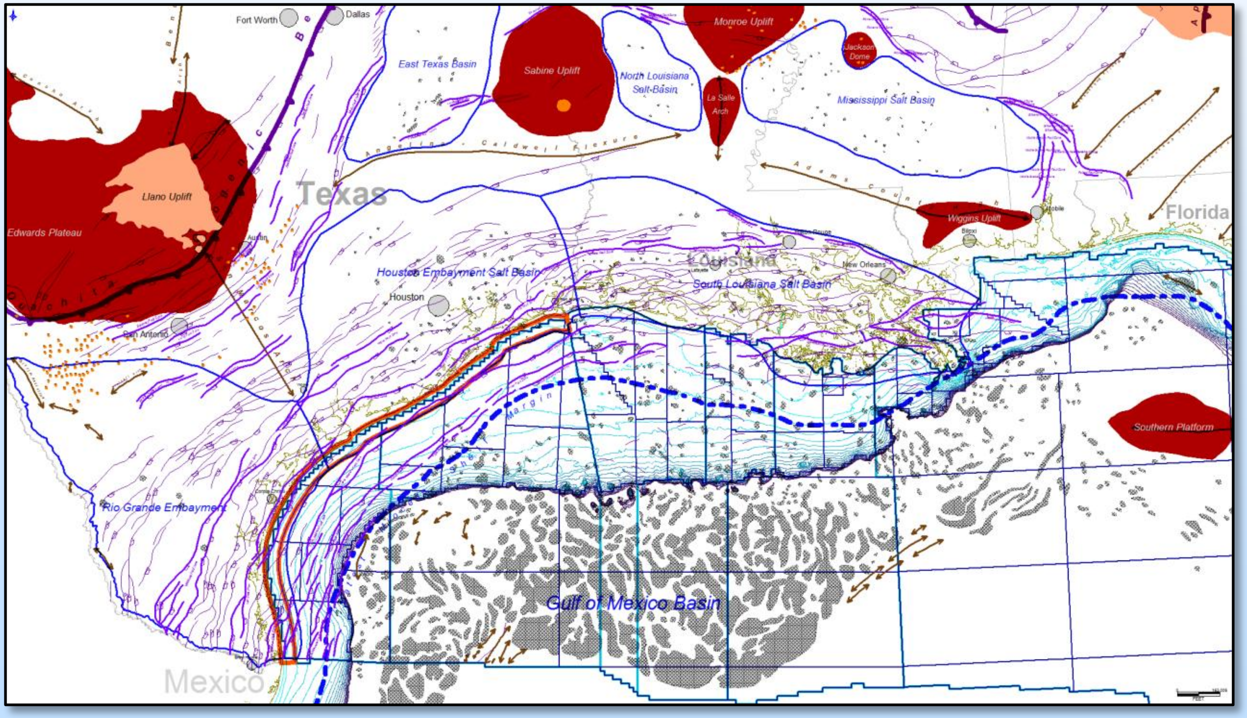
Development of 'Play Atlas'
Hydrocarbon Accumulation Analysis

- Two GIS databases built to analyze trends between Miocene hydrocarbon accumulations and geologic trends

Known Miocene Oil & Gas Fields



Regional Geologic Features, Northern Gulf of Mexico



Mock-up of a “Play” Atlas Element

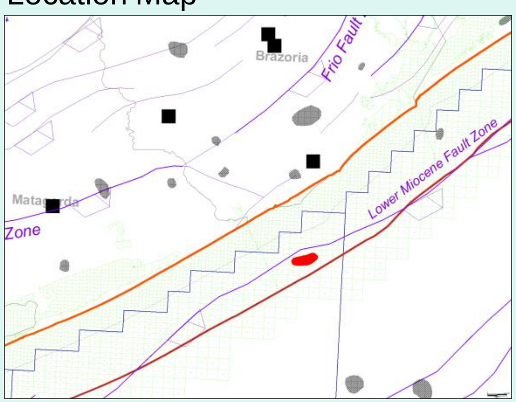
Field or Area Designation: **Hypothetical Block XX** *Atlas Sector:* 2 *Location:* Brazos Delta *TX Block(s):* XX, XX, XX

Total Capacity: **8.9 Gt** ;*Total Risked Capacity:* **3.7 Gt**

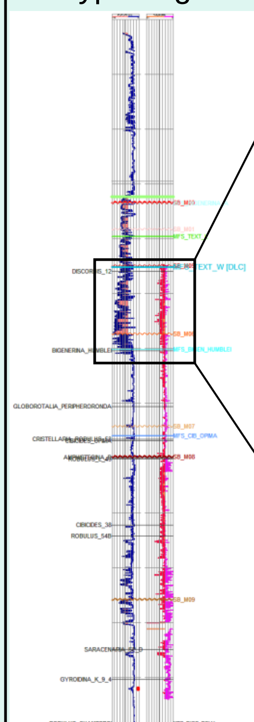
						Hydrocarbons							Reservoir Properties									
Play	Structural Type	Reservoir Age	Sequence	Stratigraphic Setting	Depositional Envirn't	Type	Trap	Drive	Area (acres)	Column Height	Gravity (API or SG)	Cum Prod (Bcfg/MBO	Depth Midpoint (SSTVD, ft)	Net Res'vr Sand	Avg. Porosity	Temp (F)	Initial Pressure (psi)	Final Pressure (psi)	Est. CO2 Density (kg/m3)	Minimum Closure Area (acres)	Est. CO2 Capacity (Gt)
Rollover Anticline	Anithtetic fault blocks on downthrown rollover anticline	Upper Lower Miocene	Amph 'B'	LST Incised Valley	Fluvial Channel, Estuarine Channel & Bayhead Delta	None	3-way closure + fault	na		na	na	na	5500	934	27.5	est 157	est 4500	na	650	387	3.2
		Lower Miocene	Marg 'A'	HST Delta & Shoreface	Dist. Channel, Strandplain, Tidal Delta	None		na		na	na	na	6900	425	31.2	est 173	est 5500	na	675	367	1.6
		Lower Lower Miocene	Siph Davisi			Gas		Depletion	319	25	0.65	55.6	8200	875	30.1	184	6000	1300	700	319	4.1

Reservoir Age	Sequence	Overburden Lithology	Overburden Thickness (ft)	Confinement Risk	Est. Fault Seal Risk
Upper Lower Miocene	Amph 'B'	marine shale	160	0.45	0.75
Lower Miocene	Marg 'A'		250	0.85	0.75
Lower Lower Miocene	Siph Davisi		210	0.90	0.75

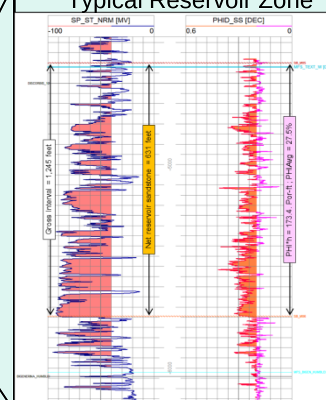
Location Map



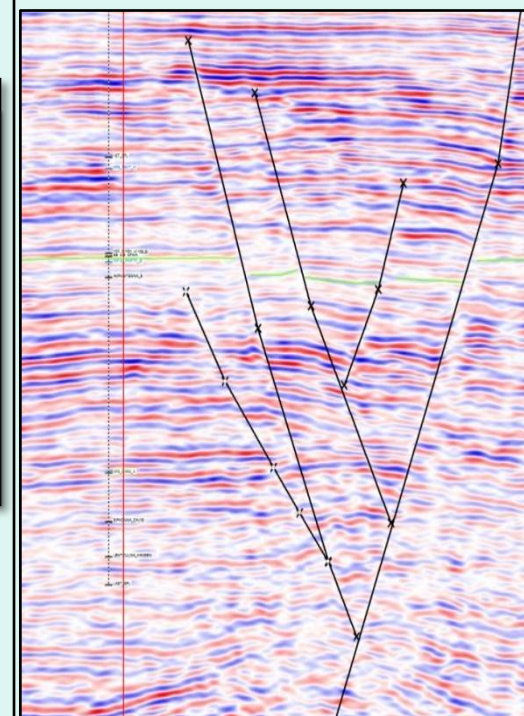
Type Log



Typical Reservoir Zone



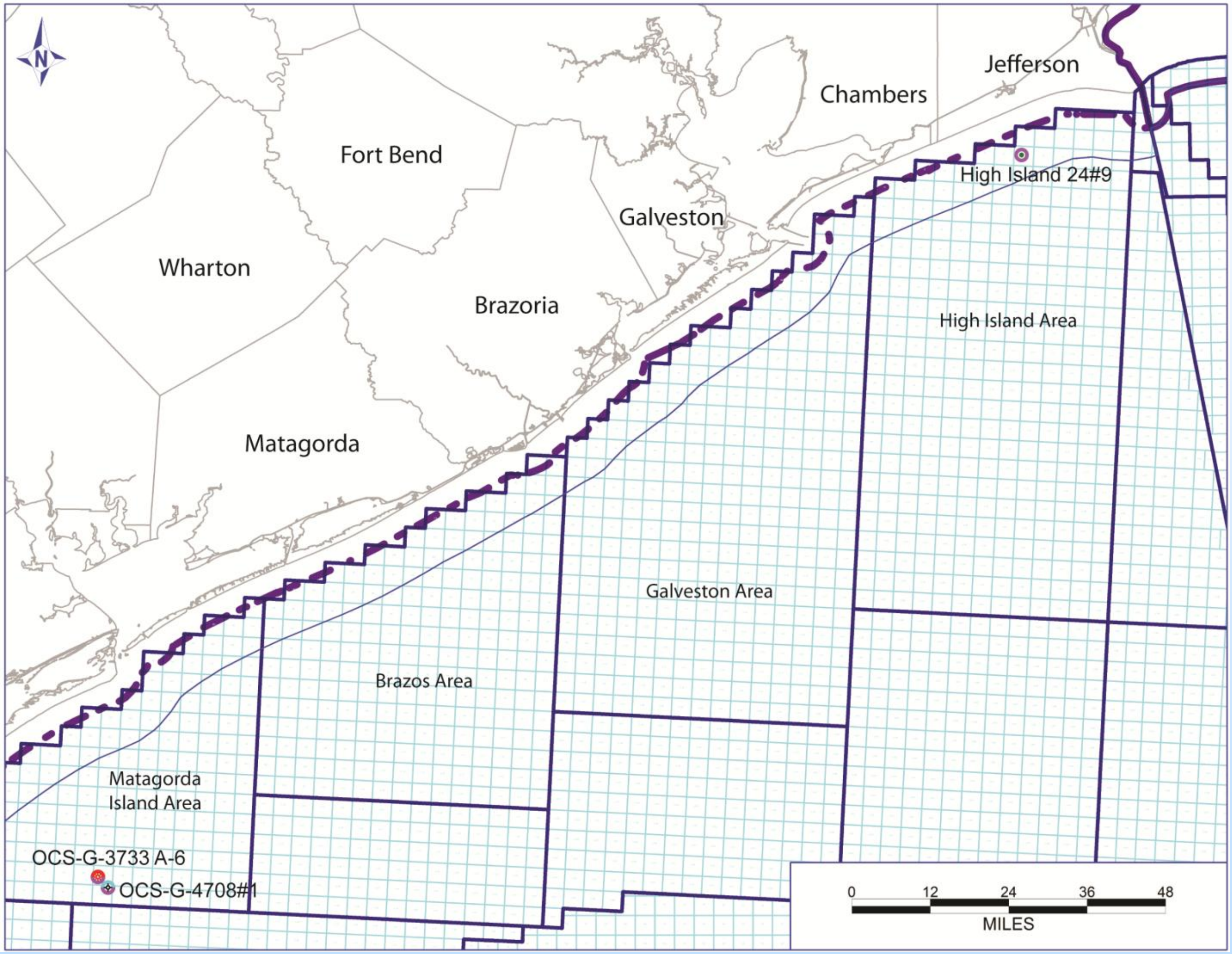
3-D Seismic: Hypothetical Block XX



Stratigraphic Compartmentalization Caprock / Seal Analyses

Jiemin Lu

Location of Miocene cores



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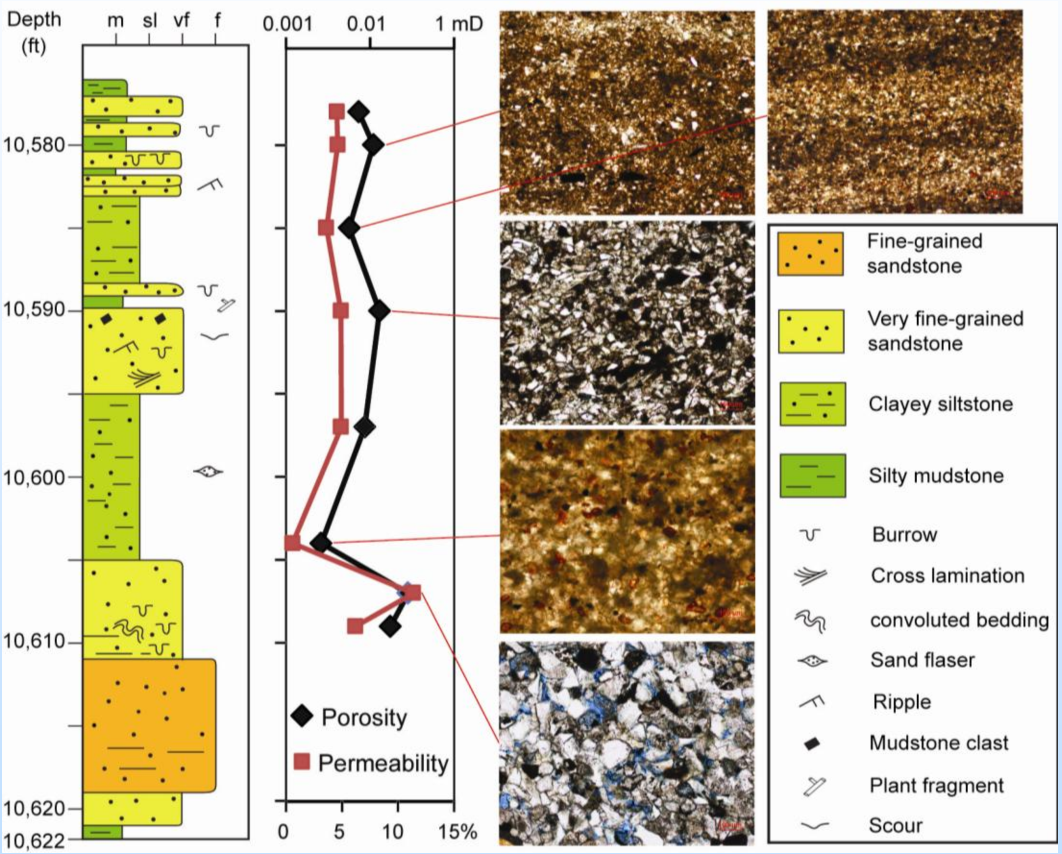
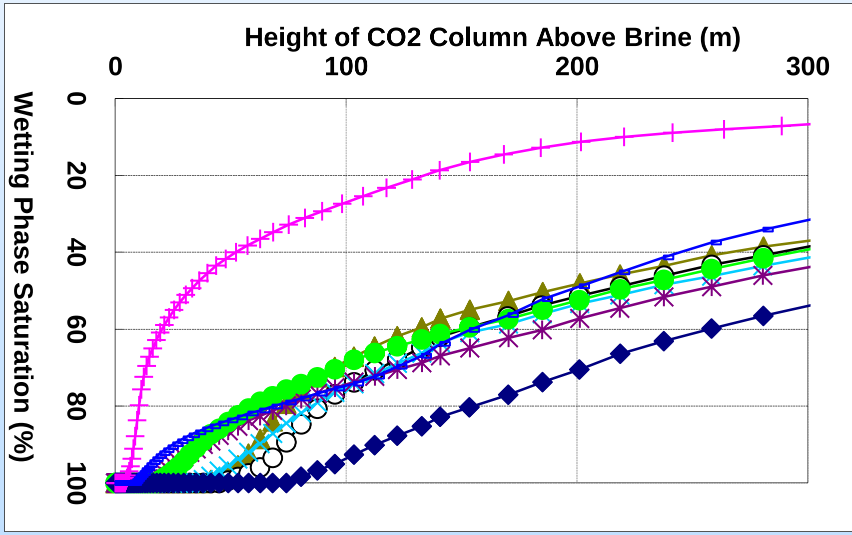
Miocene Seal Characterization

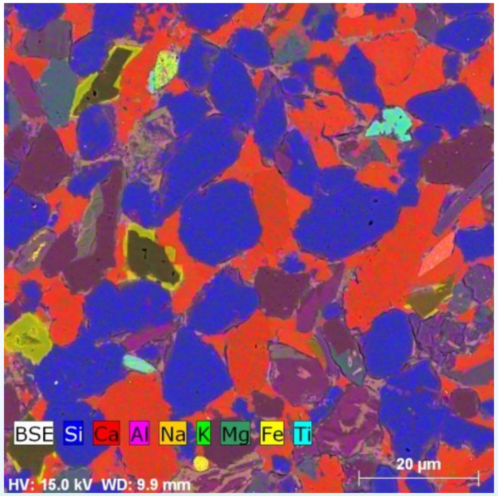
Sedimentary Log – Core OCS-G-4708#1



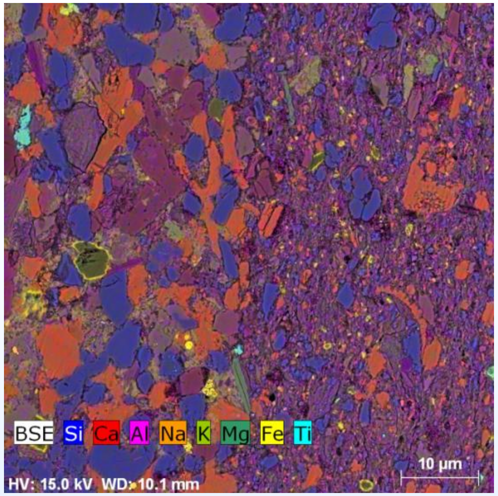
CO_2 Column Height from MICP
at 275 °F (135 °C) and 4700 psi (32.4 MPa)



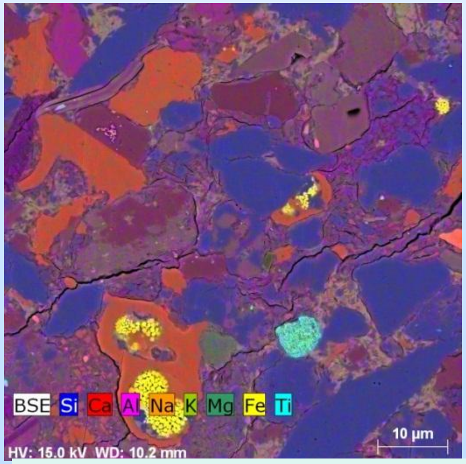
Seal Core Samples – SEM/EDX with Elemental Mapping



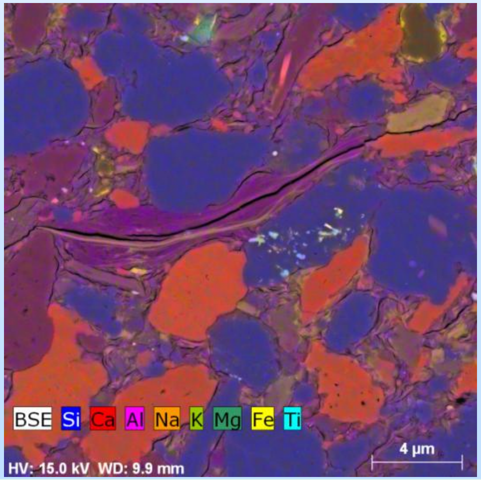
Abundant calcite cements eliminate primry pores. Porosity: 3.1 %; permeability: 0.0001 mD.



Mudstone and siltstone laminations. Calcite cement greatly reduces porosity in coarser-grained laminations. 10585 ft, OCS-G-4708 #1.



Clayey siltstone, chlorite and calcite diminish porosity and permeability (0.002 mD). Pyrite framboids filled up cavities in fossils.



Siltstone sample with porosity reduced by abundant clays. Porosity: 6.5%; Permeability: 0.002 mD.

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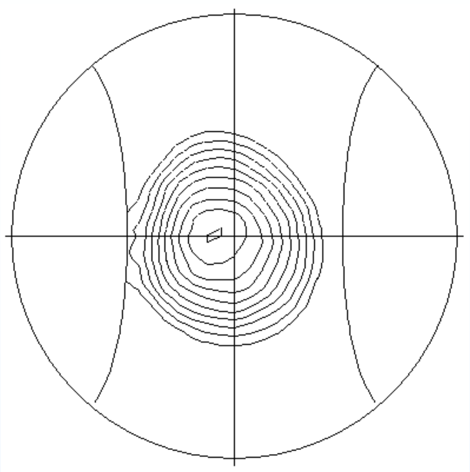
High-resolution X-ray texture goniometry

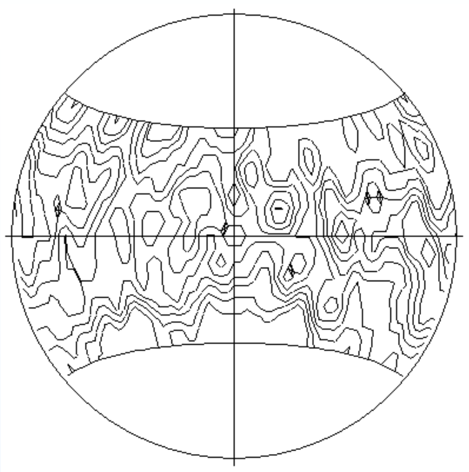
Determines degree of preferred phyllosilicate orientation

Clay siltstone



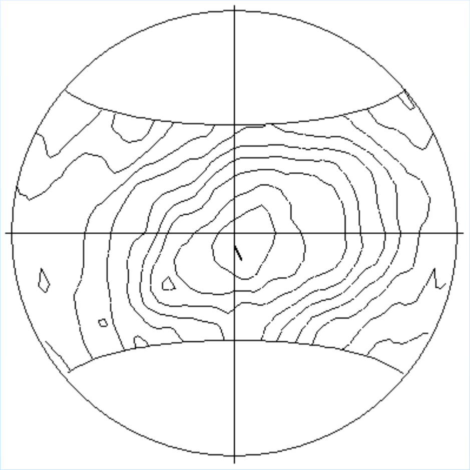
Pole figure of Mica, 2.66 m.r.d., 10580 ft

Fine grained sandstone



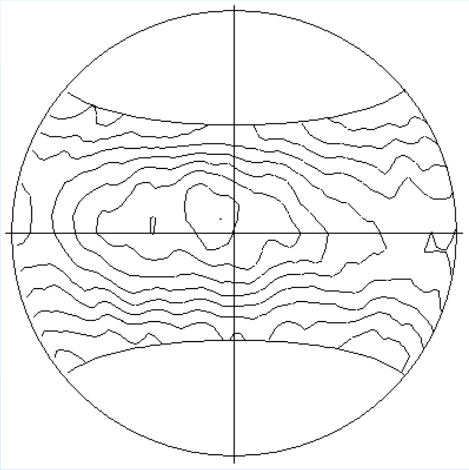
Pole figure of Mica, 1.74 m.r.d., 10607 ft

Burrowed sandstone



Pole figure of I-S, 2.04 m.r.d., 10609 ft

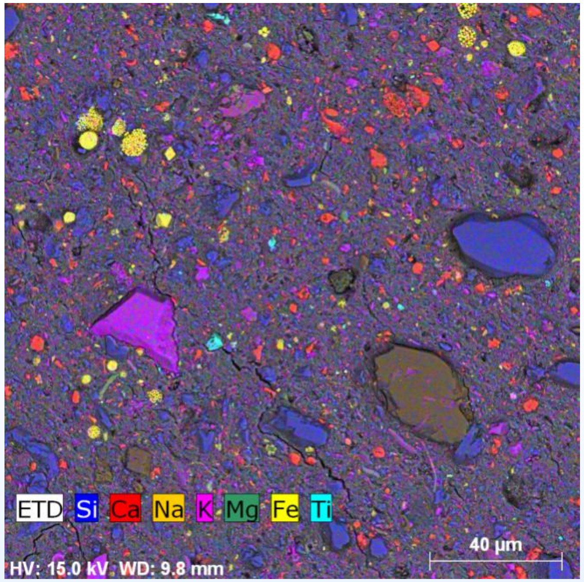
Non-laminated Siltstone



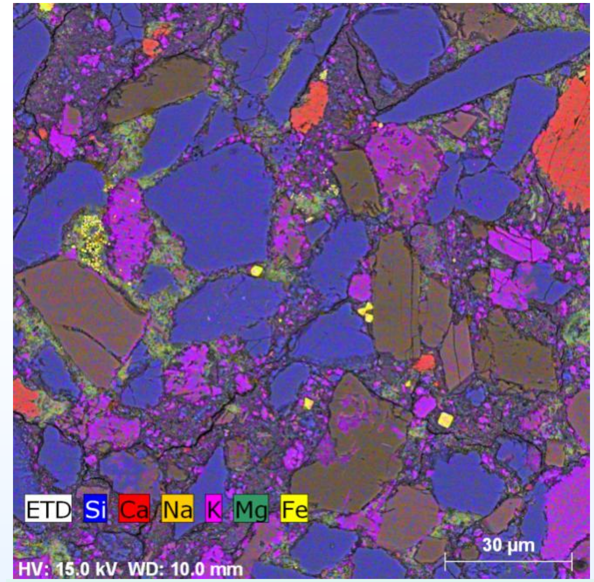
Pole figure of C+K, 1.97 m.r.d., 10604 ft

Well Cuttings Thin-sections

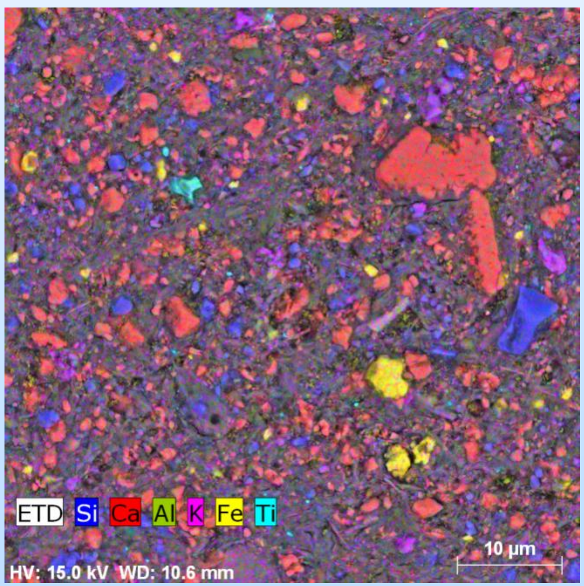
SEM with Energy Dispersive X-ray (EDX) detection



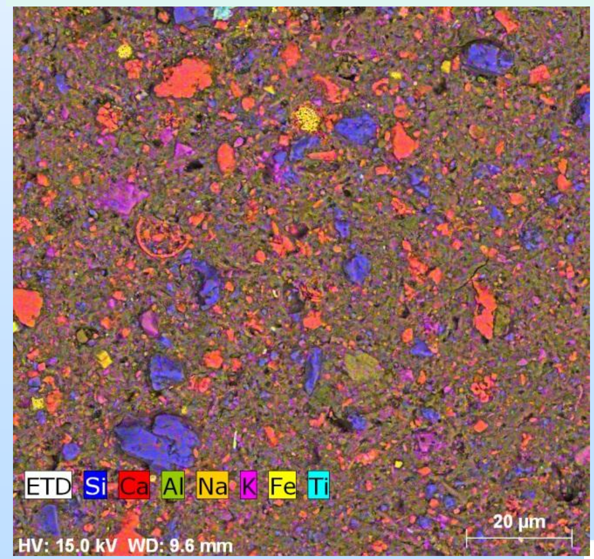
Silty mudstone - 7506-7536 ft.



Siltstone: Pore-filling chlorite fibrous habits (green) 10105-10135 ft.



Silty claystone - abundant clay size detrital grains, 4900-4930 ft



Silty claystone silt size quartz and calcite (fossil). 6151-6181 ft

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Petrographic Conclusions
Core Samples vs. Well Cuttings

- Small well cutting samples prevent XRD mineralogical analysis, but…
  - SEM with EDX reveals some mineral distribution.
  - Similar to whole core samples

- Permeability and capillary entry pressure expected to be within the same ranges as seal rock core samples.

- Well cuttings analysis may be useful qualitative technique for characterization of a specific site (if no cores are available).

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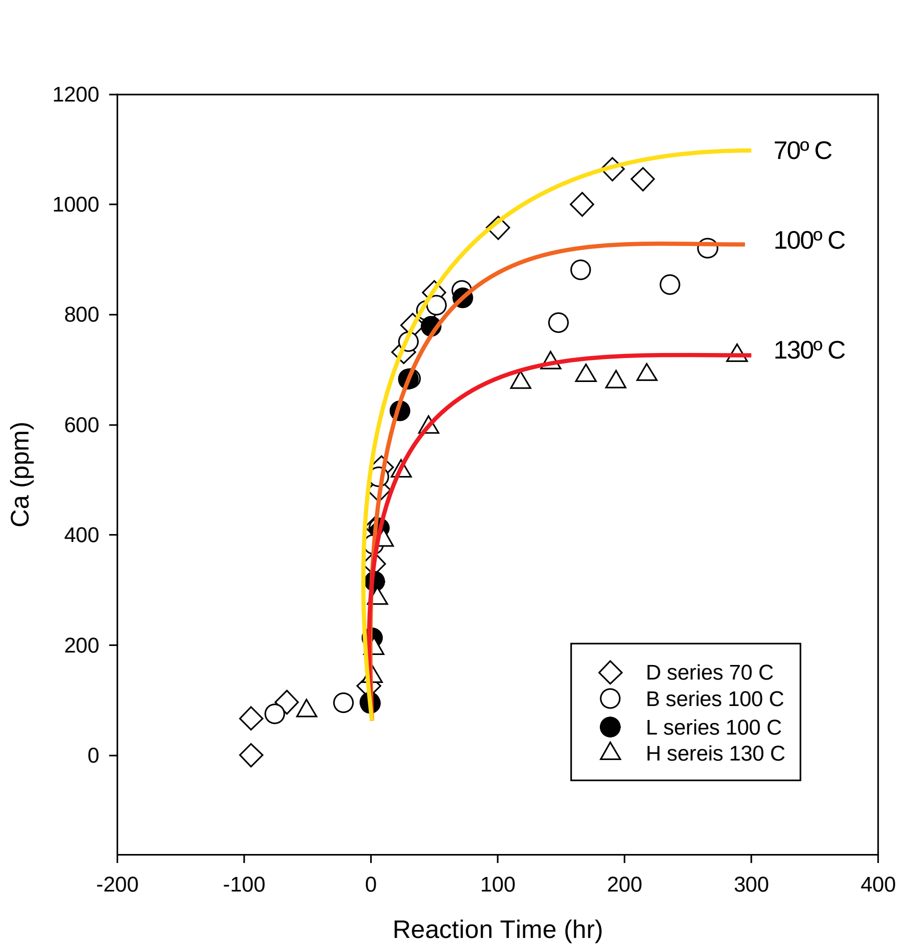
High Pressure / High Temperature Experiments

Miocene sands reacted at

200 bar

and

~100,000 mg/L NaCl brine



Reactions at different temperatures (70-130ºC)

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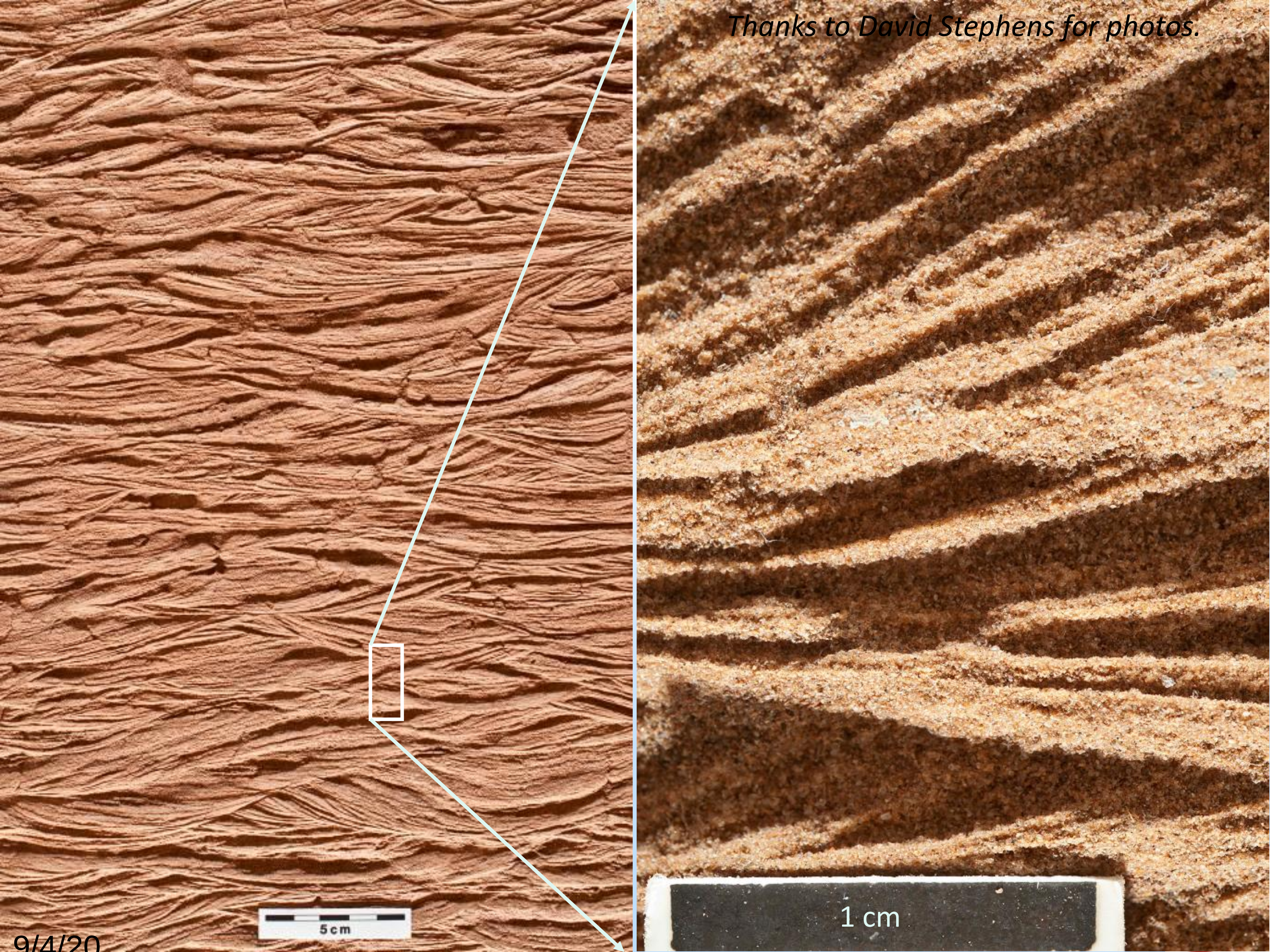
Geochemistry Observations/Conclusions

- Carbonate dissolution is dominant control on aqueous geochemistry.
- Lower temperatures and higher salinities increase Calcite solubility.
- Observed changes in brine chemistry confirm geochemical modeling of Miocene sample mineralogy and brine reactions.
- Current work focuses on determining kinetic reaction rates of Miocene sample minerals.

Percolation Models Using Realistic Heterogeneous Medium

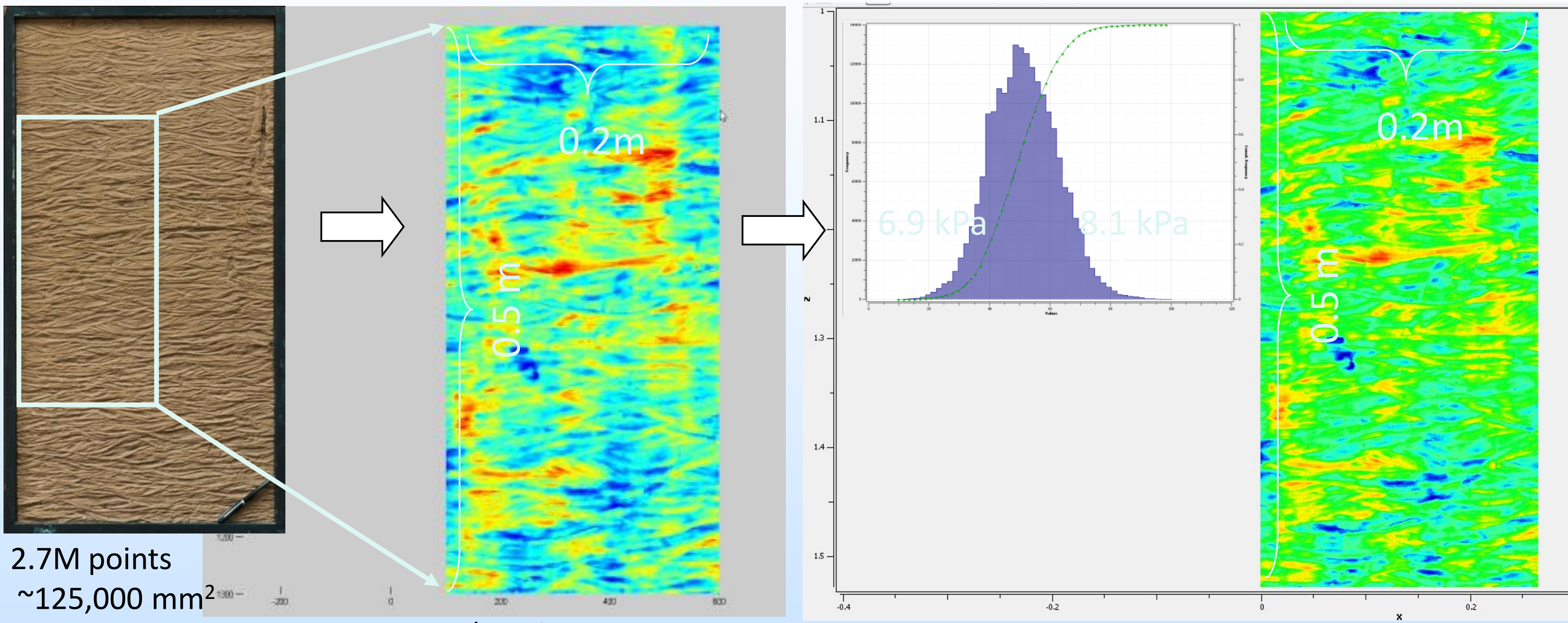
Priya Ganesh (Steve Bryant, Tip Meckel)

- 2D Investigation of invasion percolation
- Peel Sample → digital model
- Key Findings
  - Buoyant migration (most of reservoir) can lead to capillary channel flow
  - Capillary Channel Regime → reduced storage efficiency & greater migration distances
  - Heterogeneity causes buoyant CO_2 migration patterns variations
  - Invasion percolation ~ conventional full physics CO_2 migration pattern



Thanks to David Stephens for photos.

Peel Model Extraction: mapping measured elevations to capillary entry pressures



2.7M points
~125,000 mm^2
~25 points per mm^2

Elevation map

Capillary entry pressure/ Threshold pressure map

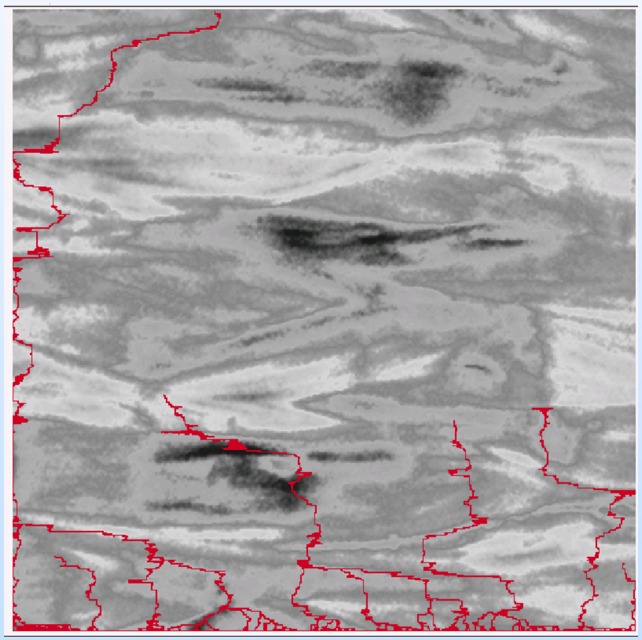
Red: High elevation => Smaller grain size => High Pth

Elevation measured (Physical specimen) → Capillary entry pressure distribution in domain (Representative virtual simulation model)

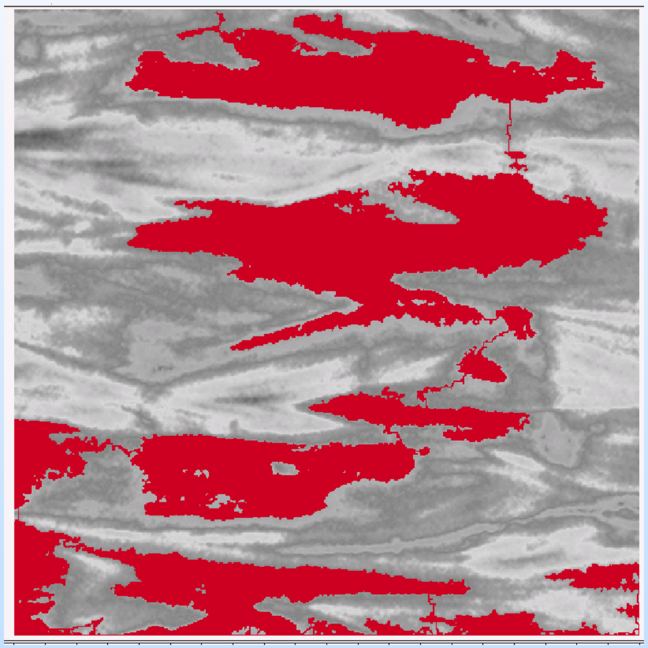
Research Question: which picture applies in the capillary channel flow regime?

$$\nabla\Phi = \nabla\rho g h \quad \text{versus} \quad P_c^{threshold} = 2\frac{\sigma}{r_{th}}$$

Fingering



Back-filling



Capillarity strongly influences buoyancy-driven migration in heterogeneous formation

Percolation Modeling Conclusions

- Local heterogeneity causes variation in buoyant CO_2 migration patterns from fingering to back-filling
  - Fingering regime: minimal effective CO_2-rock contact
    - Hence, minimal CO_2 stored per unit volume of rock
  - Back-filling regime achieves much higher CO_2 stored per unit volume of rock compared to CO_2 fingers
    - **More spatial correlation (wider grain size distributions) → back-filling migration pattern**
- Range of threshold pressures determines regime

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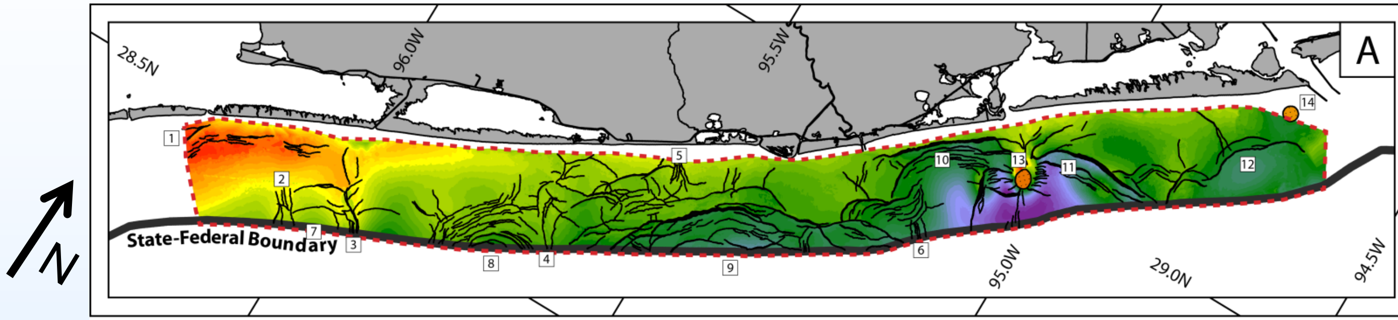
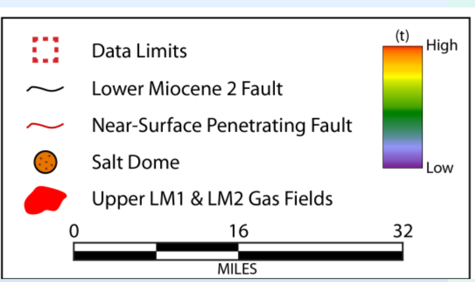
Seismic Analyses
Interpretation & New Data Acquisition

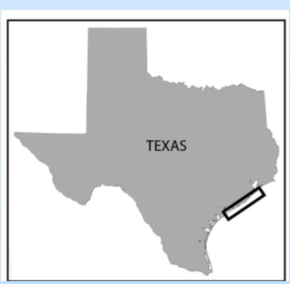
- Regional (leased) 3D dataset
  - Interpreted / mapped data in time domain
  - Converted to depth
- Newly Acquired 3D dataset
  - "P-Cable" system
  - First survey successfully completed

Regional Interpretation & Analysis

LM2 Structure, Play Types, Gas Fields, and ‘Near-Surface’ Penetrating Faults







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Andrew Nicholson
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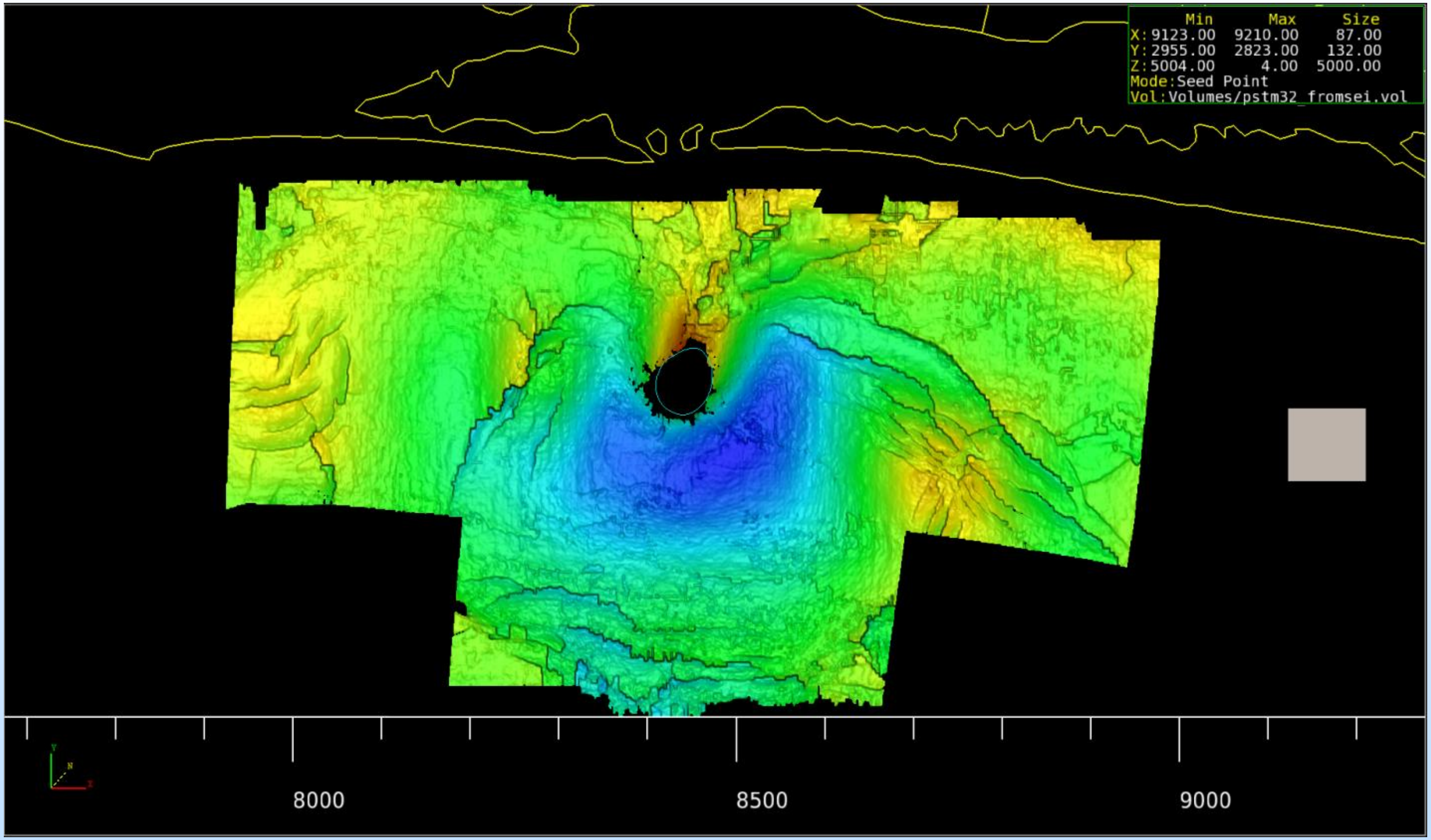
3D Seismic Interpretation in San Luis Pass Area



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Kerstan Wallace

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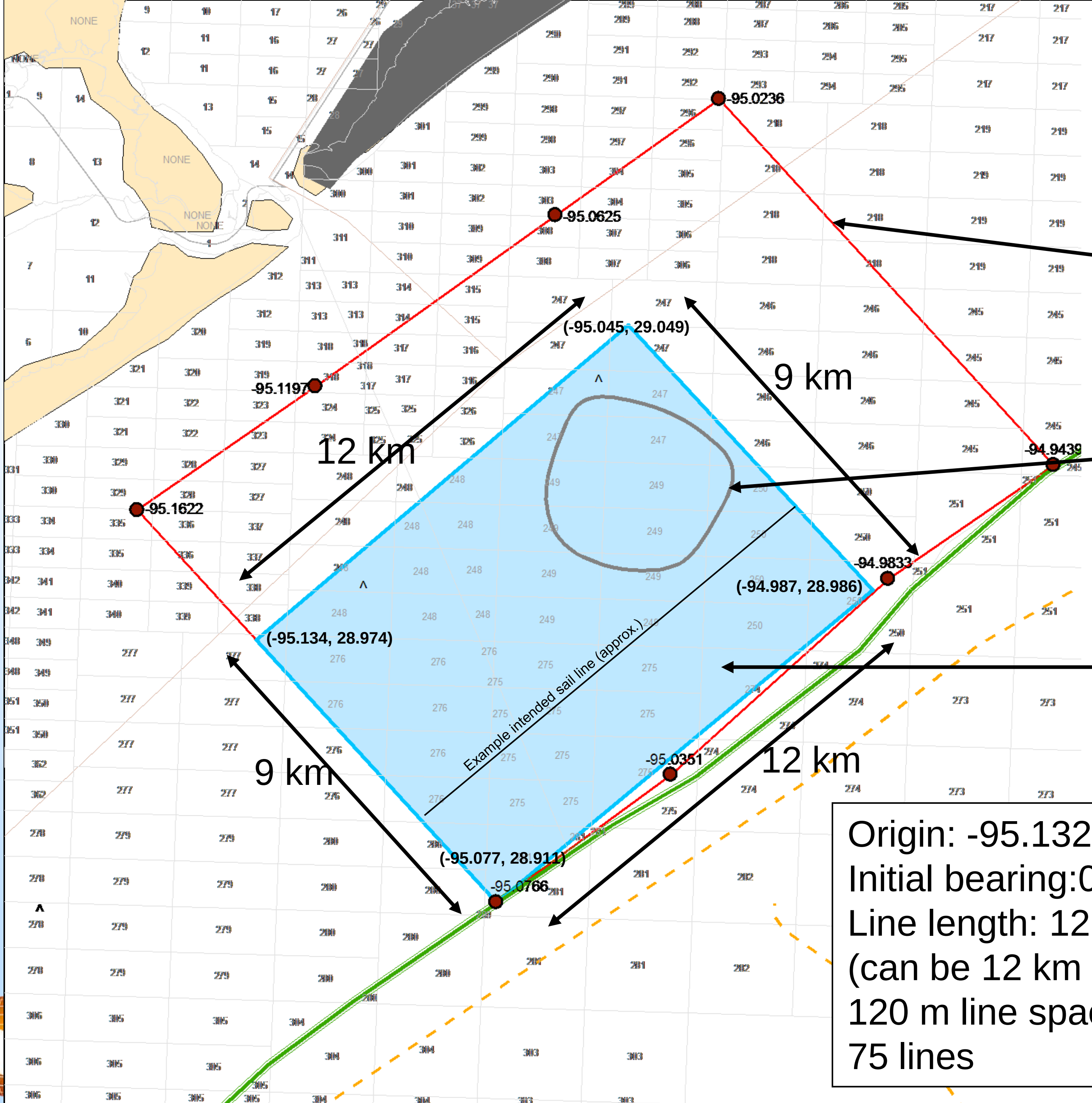
Recently Completed 3D Marine Data Acquisition

"P-Cable"

- Focus = higher resolution definition of shallow reservoir, fault and fluid systems
  - indications of fluid migration?
- SLP (San Luis Pass) maps
  - non-productive wells; what might they mean?
- Conducted some initial work on repeatability, shooting some lines multiple times.
- Photos

Univ. Texas
P-Cable Cruise
July 15-31, 2012



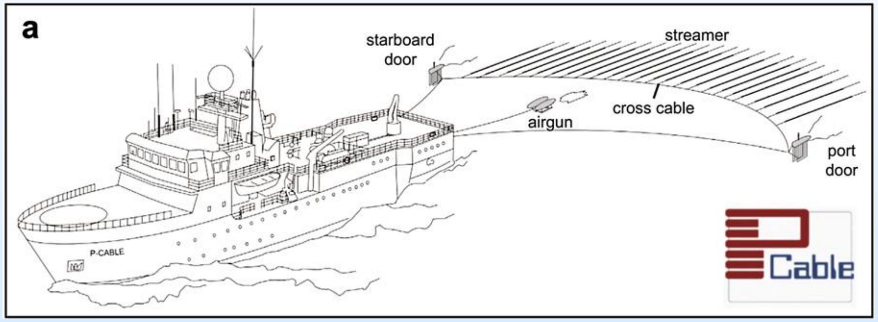
PERMITTED AREA

San Luis Pass Salt Dome (outline)

INTENDED DATA COLLECTION AREA (blue)

Origin: -95.132, 28.972
Initial bearing:044 38′10″ (Haversine)
Line length: 12.04 km
(can be 12 km exact)
120 m line spacing
75 lines

Diagram of Typical P-Cable Deployment
(note the “doors,” airgun, cross cable and streamers)



Testing P-Cable System (January, 2012)

Green streamers with embedded hydrophones

Blue rope with compasses data cables, etc.

Cable Layout

Dockside Amelia, LA

Black & yellow float

Orange Paravane Door

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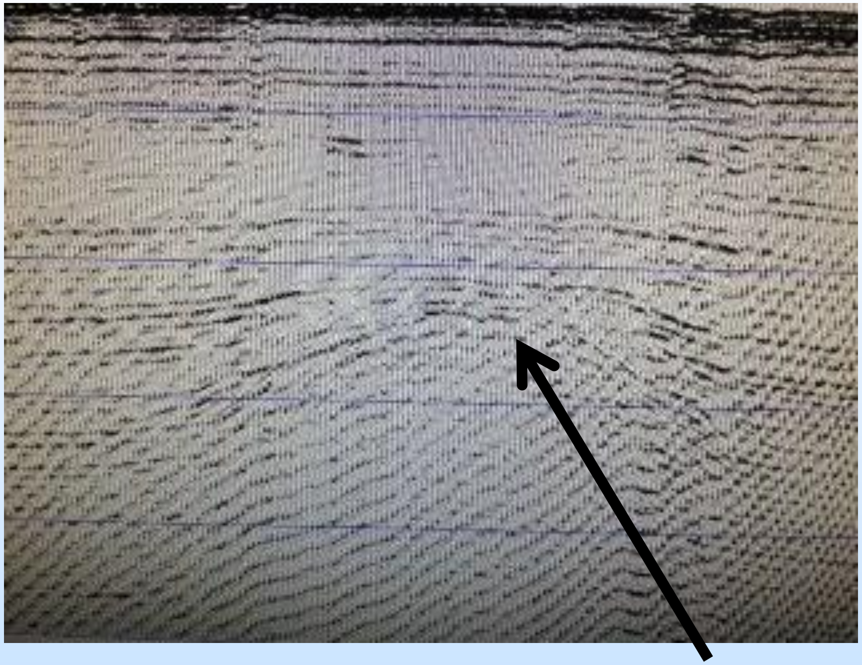
Deploying Paravane Door

Acquisition & Raw Data

Airgun Floats During Operation

(Note water splash resulting from airgun firing)



Data gathers over Salt Dome – Note dome shape. (Data still need to be processed)

Such shallow data not available in leased 3D Seismic

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Accomplishments to Date

- Regional analysis for CO_2 “Play” Atlas
- Use of well cuttings may be useful for basic caprock analyses if no whole core available.
- High pressure / high temperature experiments completed – final geochemical analyses in progress.
- Qualitative percolation model results
- Regional mapping using leased 3D seismic defines geologic structures.
- The first P-cable system deployment successfully acquired shallow high-resolution 3D seismic – data processing still needed to determine data quality and utility.

Summary

Key Findings

- Miocene top seals able to trap CO_2.
- Sediment peel-based percolation models: CO_2 backfilling as preferable alternative to capillary flow fingering; P_{th} ranges determine which one results.
- Geochemical experiments' results as expected.

Lessons Learned

- P-Cable seismic acquisition cruises logistically complicated but achievable and worthwhile.

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Summary

<u>Future Plans</u>

- Generate draft of CO_2 "Plays" atlas.
- Analyze geochemical experiments (kinetics reaction rates)
- Quantify percolation model results (vs. current qualitative)
- P-Cable
  - Process new dataset & evaluate San Luis Pass site.
  - Identify next site for characterization.
  - Conduct next cruise & acquire next survey.

Regional geologic & geochemical framework ready to help characterize specific sites.

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Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart

The Univ. of Texas at Austin project team comprises:

- **Dr. Tip Meckel**, PI (Principal Investigator) / Geologist, science research leader.
- **Ramon Trevino**, Co-PI / Project Manager (Geologist), leads administrative and managerial tasks.

  (Both co-PI's also participate in various parts of the research.)
- **David Carr**, Geologist, leads a group that concentrates on geologic interpretation using well data supplemented with leased seismic data. An atlas of CO_2 prospects will result from this research. Assisted by **Jordan Taylor** and four **undergraduate research assistants**.

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Organization Chart (cont.)

- **Dr. Nathan Bangs**, Geophysicist / seismic processor, leads the acquisition and processing of high-resolution, shallow 3D seismic data using the Study's P-cable system.
- **Dr. Hongliu Zeng**, Geophysicist / seismic interpreter, assists with post-stack processing and time-depth conversion of leased, regional, petroleum industry 3D seismic data.

Organization Chart (cont.)

- **Drs. Changbing Yang, Katherine Romanak, Tongwei Zhang, Jiemin Lu** and **Patrick Mickler** focus on geochemical research of Miocene aged rocks and brines of the Gulf of Mexico.
- **Dr. Jiemin Lu** also conducts petrologic analyses of reservoir and especially seal (caprock) samples.
- **Dr. Lorena Moscardelli**, Geologist, assisted with acquisition of high-resolution, shallow 3D seismic data using the Study's P-cable system.

Organization Chart (cont.)

- Graduate research assistants:

1. **Julie Ditkof** works under the direction of Dr. Meckel and with Dr. Bangs on seismic processing.
2. **Erin Miller** works under the direction of Dr. Meckel on capacity related problems.
3. **Kerstan Wallace** works under the direction of Dr. Meckel on structure related problems.
4. **Ravi Priya Ganesh** works under the direction of Dr. Meckel and **Dr. Stephen Bryant** on fluid flow related problems.
5. **Andrew Nicholson** (recently graduated) worked under the direction of Dr. Meckel and Ramon Trevino on fault seal questions.

Organization Chart (cont.)

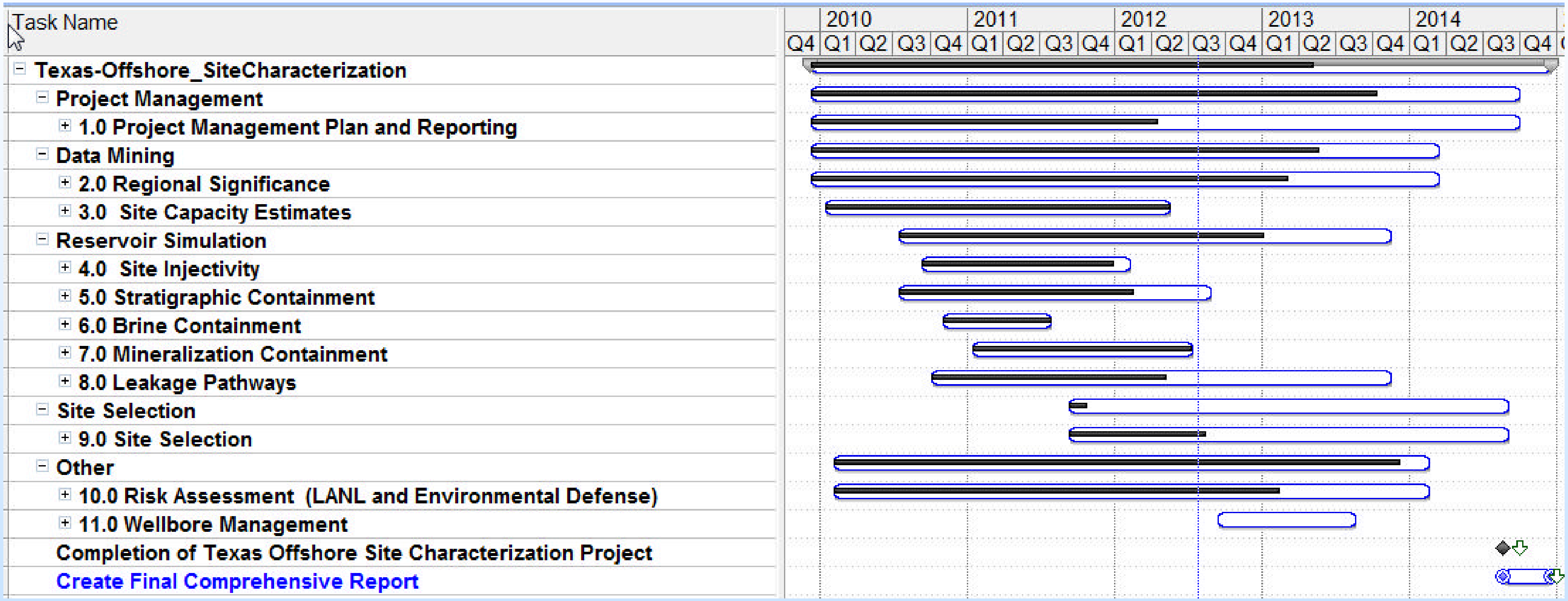
At Southern Methodist University:

- Dr. Mathew Hornbach and his graduate research assistant, Ben Phrampus, concentrate on advection / diffusion models that incorporate active faulting and fluid flow.

At Los Alamos National Laboratory:

- Dr. J. William Carey and his team assessed reservoir capacity and injectivity and developed a cost-optimized model for connecting onshore CO2 sources via pipelines to potential sequestration.

Gantt Chart



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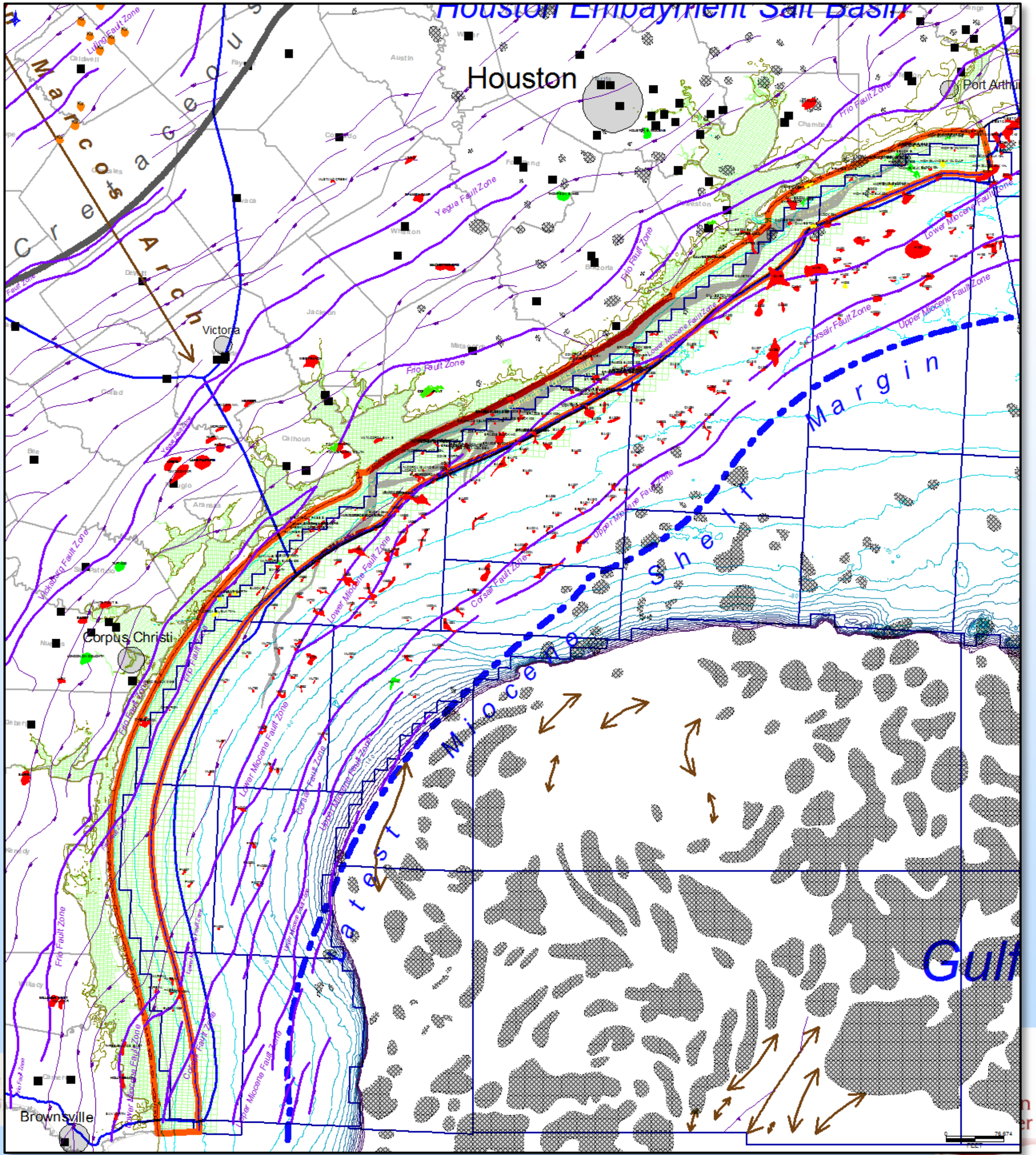
Bibliography

- Middleton, R. S., Keating, G. N., Stauffer, P. H., Jordan, A. B., Viswanathan, H. S., Kang, Q. J., Carey, J. W., Mulkey, M. L., Sullivan, E. J., Chu, S. P., Esposito, R., and Meckel T. A., 2012, The cross-scale science of CO2 capture and storage: from pore scale to regional scale. Energy & Environmental Science, v. 5(6), p. 7328-7345, available at: www.rsc.org/ees.

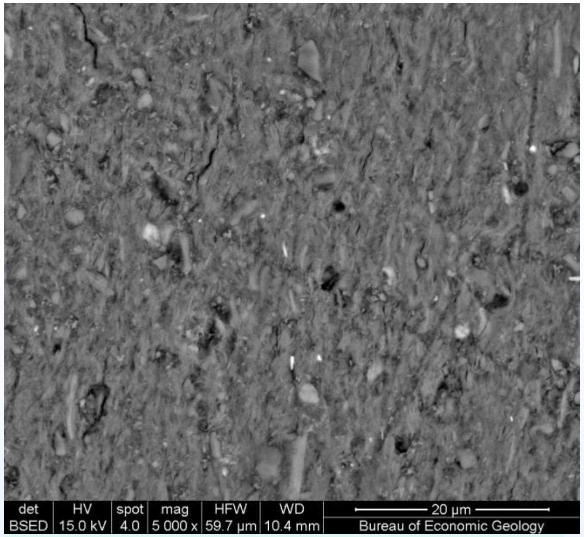
Development of 'Play Atlas' Hydrocarbon Accumulation Analysis

- Combined the two GIS databases built to analyze trends…

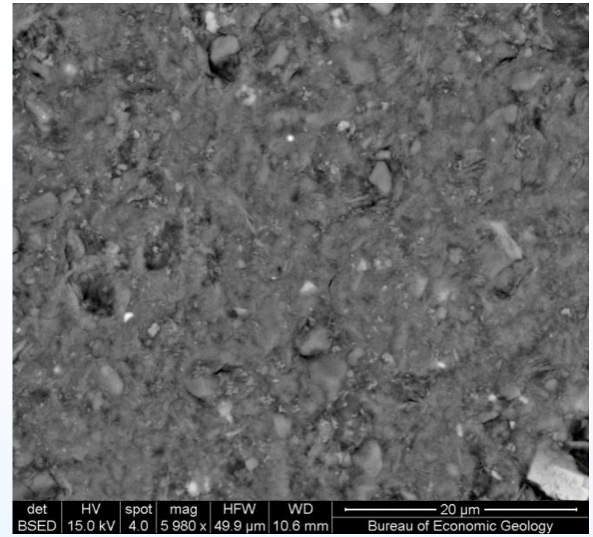


Well Cuttings Thin-sections

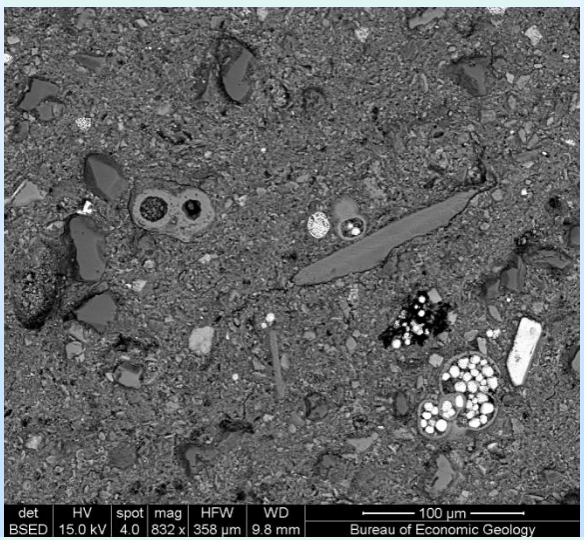
SEM - qualitative assessment of fabric alignment.



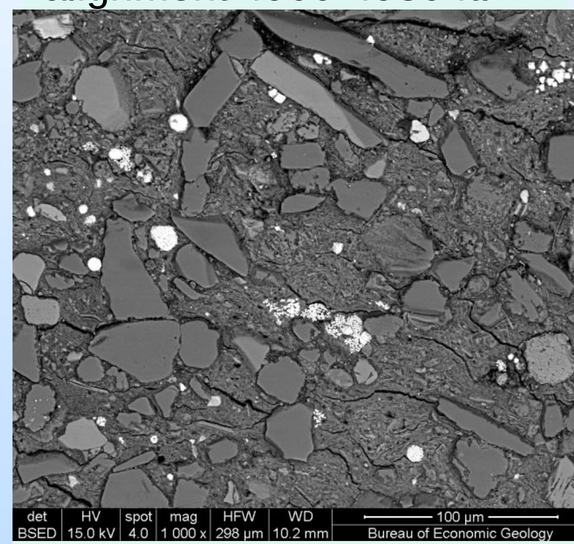
Claystone with strong clay alignment. 4900-4930 ft.



Claystone with weak clay alignment 4900-4930 ft.



Silty mudstone - fossils (foraminifer and other shell fragments). Pyrite framboids filling foraminifer chambers. 7506-7536 ft



Siltstone with abundant pyrite. Silt grains aligned with beddings. 5845-5884 ft.

Bureau of Economic Geology

Gulf Coast Carbon Center

Preparing to load one of the paravane "doors" onto the ship