Gulf of Mexico Miocene CO_2 Site Characterization Mega-Transect

DE-FE0001941

Dr. Tip Meckel & Ramon Trevino

Gulf Coast Carbon Center

Texas Bureau of Economic Geology

The University of Texas at Austin

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

August 20-22, 2013

Bureau of Economic Geology

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Presentation Outline

- Project Benefits, Overview & Accomplishments
- Collaborator Contributions
- Technical Status Summary
- Summary & Acknowledgments

Benefit to the Program

- Program goals addressed:
    1. Predict CO_2 storage capacity within ±30%.
    2. Develop technologies to ensure 99 percent storage permanence.
- Project benefits statement:

The research project determines CO_2 storage capacity for the near-offshore portion of the Gulf of Mexico in Texas. Characterization, modeling, geochemical experiments and seal analyses support 30 Mt storage viability. The results provide storage estimates for one of the Nations largest emissions corridors, supporting industrial-scale implementation of CCS. Additional seismic data collection demonstrates novel technology to ensure storage permanence and to reduce near-term barriers to storage site utilization.

Project Overview: Objectives & success criteria

- **Calculate Miocene-age formation capacity estimates in Texas State waters (near offshore GoM).**
  - Static capacity maps, Formation properties database.
- **Identify regional CO_2 'play' concepts for prospective storage screening.**
  - CO2 Play Atlas
- **Identify specific prospective 30 Mt+ storage sites.**
  - Analytical and geocellular reservoir flow modeling.
- **Evaluate regional containment potential.**
  - Geochemical reactivity; Top/Fault seal analyses.
- **Collect additional data to demonstrate new technologies to ensure 99% containment & reduce barriers to near-term utilization of storage sites.**
  - P-Cable high resolution 3D seismic surveys

Accomplishments

- Static regional capacity estimated for Texas State waters calculated
  - 172 Gt storage capacity over 37,470 square kilometer area.
  - Maximum of 10 Mt per square kilometer, minimum of 0.9.
  - Wallace et al., 2013, IJGGC.
- Static regional capacity tested in small portion of study area using dynamic approaches:
  - Simple Analytical Models support large capacity estimates (optimistic)
    - Fill times and best performing reservoirs identified.
  - Detailed 3D reservoir flow simulations confirm 30 Mt local storage capacity utilizing stacked storage.
- Regional Containment Potential Verified
  - Minor geochemical reactivity (expected: Ca/CO3 dominates behavior)
  - Top & Fault Seal: adequate; bounds of performance identified.
- Three High-Resolution 3D (HR3D) Datasets acquired (140 sq. km.)
  - Unprecedented overburden characterization (ID leaky/non-leaky systems)
  - Identification of primary containment risks (faults)

Collaborators

EDF ENVIRONMENTAL DEFENSE FUND™ Finding the ways that work

Policy Recommendations for Selection & Development of Offshore Geologic Carbon Sequestration Projects Within Texas State Waters

Sandia Technologies, LLC

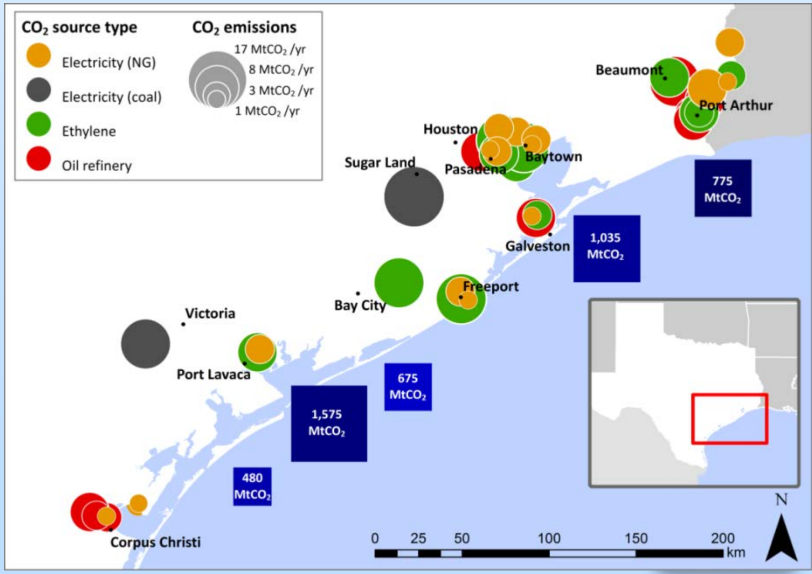
BOREHOLE MANAGEMENT PLAN

Los Alamos NATIONAL LABORATORY EST. 1943

Source-sink

CO2-PENS

Middleton et al., 2012, Energy & Environmental Science, v. 5(6), p. 7328-7345



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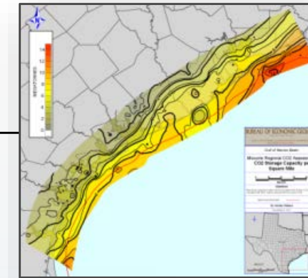
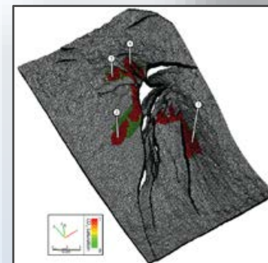
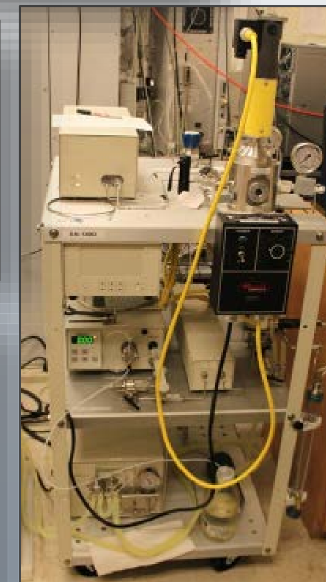
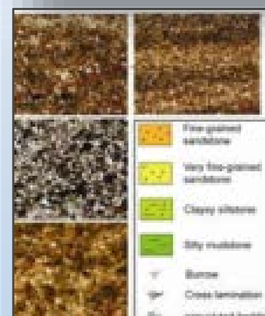
Technical Status

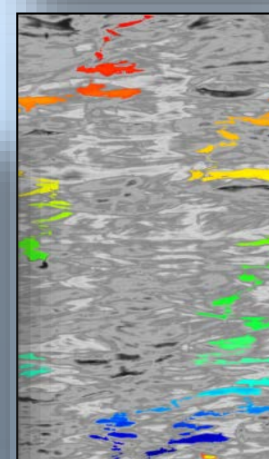


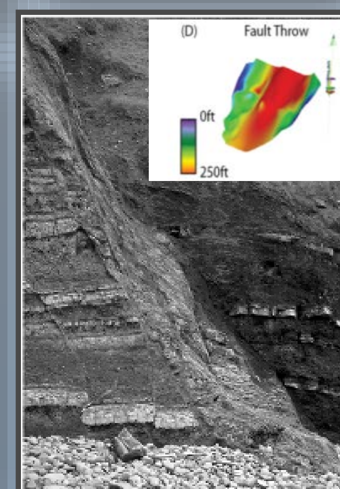
- Regional Static Capacity
  - NETL methodology, gas reservoir replacement
  - CO_2 Play Atlas
- Site-specific model area
  - Dynamic analytical & geocellular modeling
- High P/T Geochemical Lab Experiments
- Seal Characterization
  - Microscopy, mapping
- High-resolution 3D seismics
  - Overburden characterization
  - Fault mapping
  - Fluid systems











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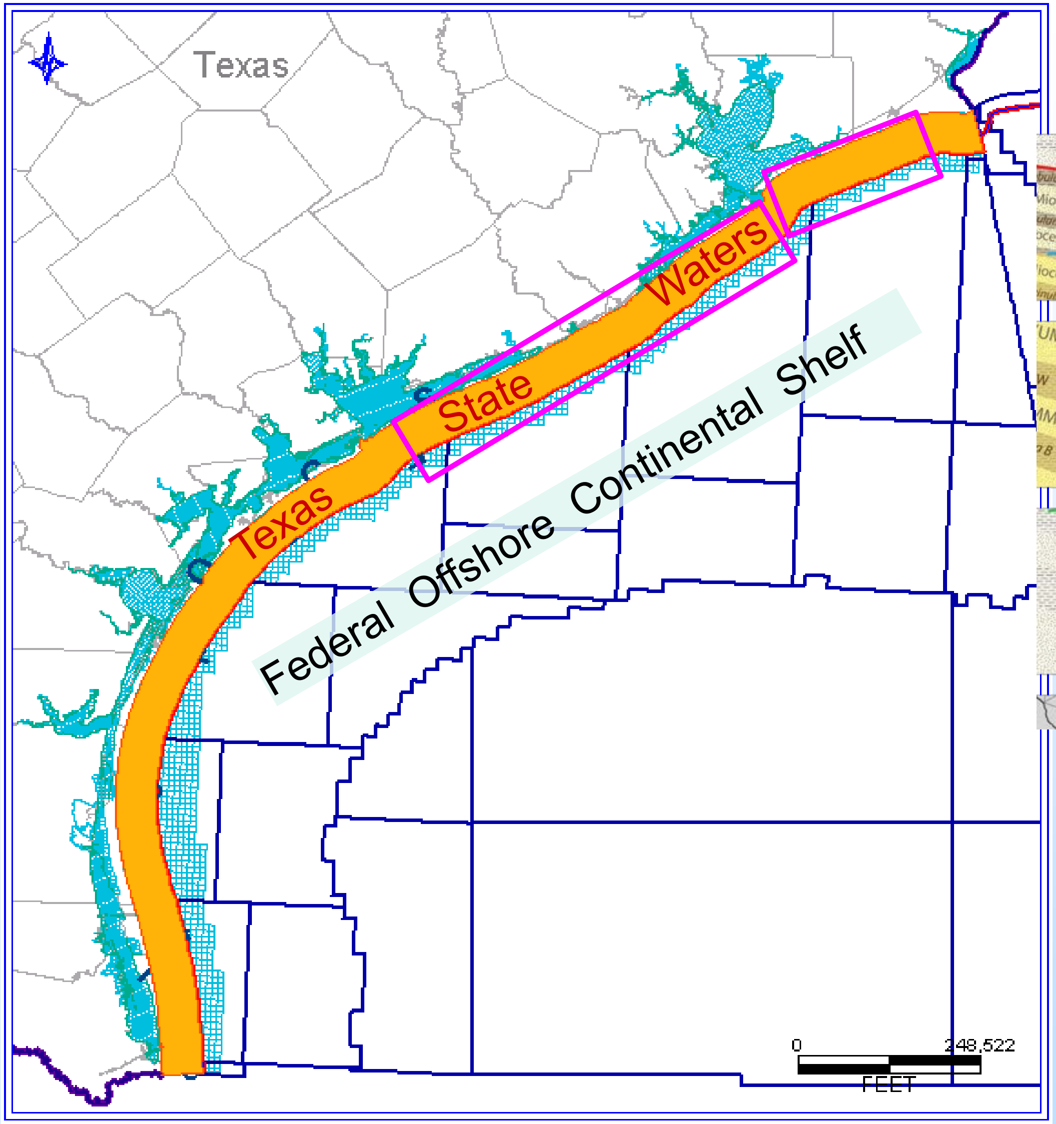
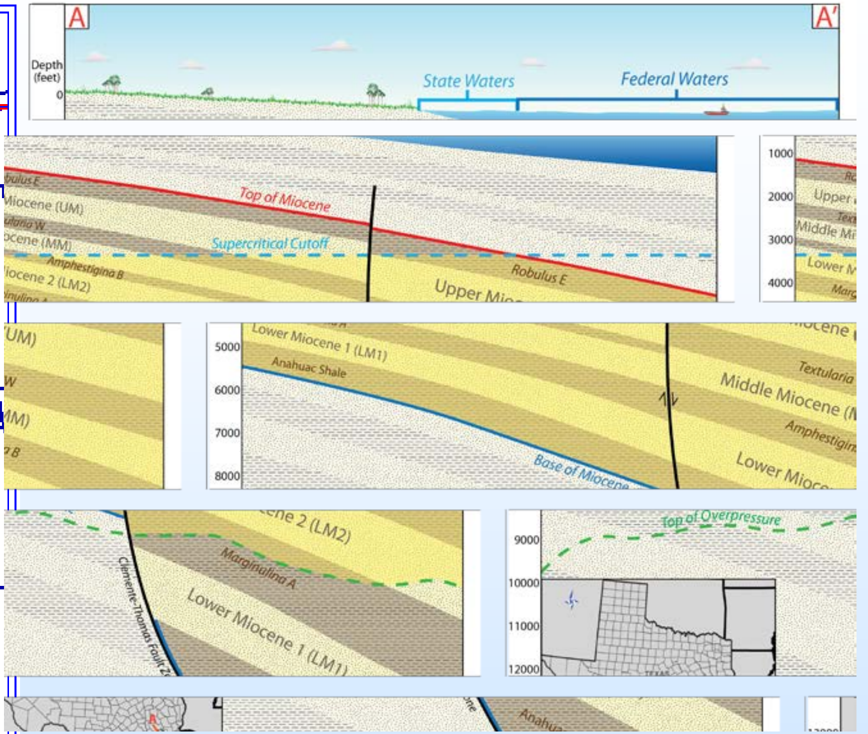
Study Area



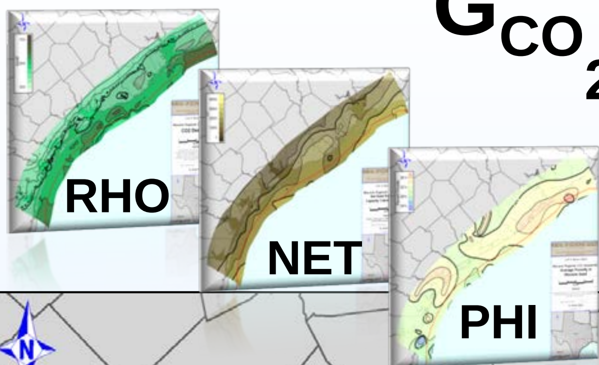
Texas
Texas State Waters
Federal Offshore Continental Shelf
0
248,522
FEET



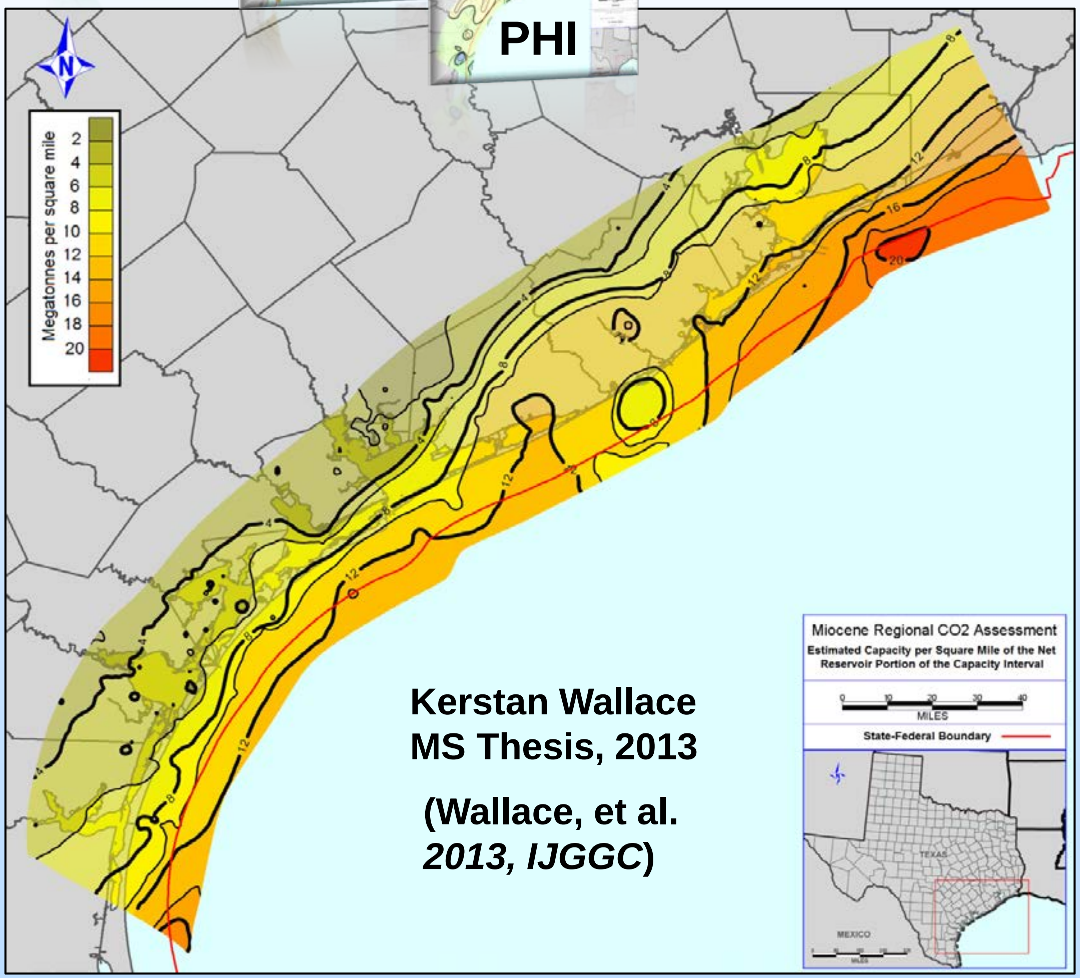
A
A'
Depth (feet)
0
State Waters
Federal Waters
Top of Miocene
Supercritical Cutoff
Robulus E
1000
2000
3000
4000
Lower Miocene 1 (LM1)
Anahuac Shale
Base of Miocene
5000
6000
7000
8000
Textularia
Top of Overpressure
Marginulina A
Lower Miocene 1 (LM1)
9000
10000
11000
12000

Static Storage Capacity Per Sq. Mile

$$G_{CO_2 net} = A_t \, h_g \, \varphi_{tot} \, \rho \, E_{net}$$



172 Gt storage potential in ~37,000 sq. km.
~1-10 Mt min/max per sq. km.



Kerstan Wallace
MS Thesis, 2013

(Wallace, et al. *2013, IJGGC*)

Well logs from **3300 wells** are used in conjunction with paleontological data to pick formation tops, select sand intervals, and/or determine porosity.

Statistical distribution of the measured thicknesses of individual sand bodies shows that ~50% of the sand volume available for CO_2 storage is in the form of relatively thin sands (<18 m) which may serve to further limit the amount of CO_2 that could be feasibly injected.

Incorporating the measured sand thicknesses from 1009 wireline logs (SP vs. Gamma; 15 m cutoff) into the regional capacity assessment through our proposed methodology reduces the total estimated storage capacity to **129 Gt**, a 25% reduction.

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Atlas of prospective sequestration 'plays'

TABLE OF CONTENTS:

Play	Structural Type	Reservoir Age	Sequence	Stratigraphic Setting	Depositional Envirn't
Rollover Anticline	Anithtetic fault blocks on downthrown rollover anticline	Upper Lower Miocene	Amph 'B'	LST Incised Valley	Fluvial Channel, Estuarine Channel & Bayhead Delta
		Lower Miocene	Marg 'A'	HST Delta & Shoreface	Dist. Channel, Strandplain, Tidal Delta
		Lower Lower Miocene	Siph Davisi		

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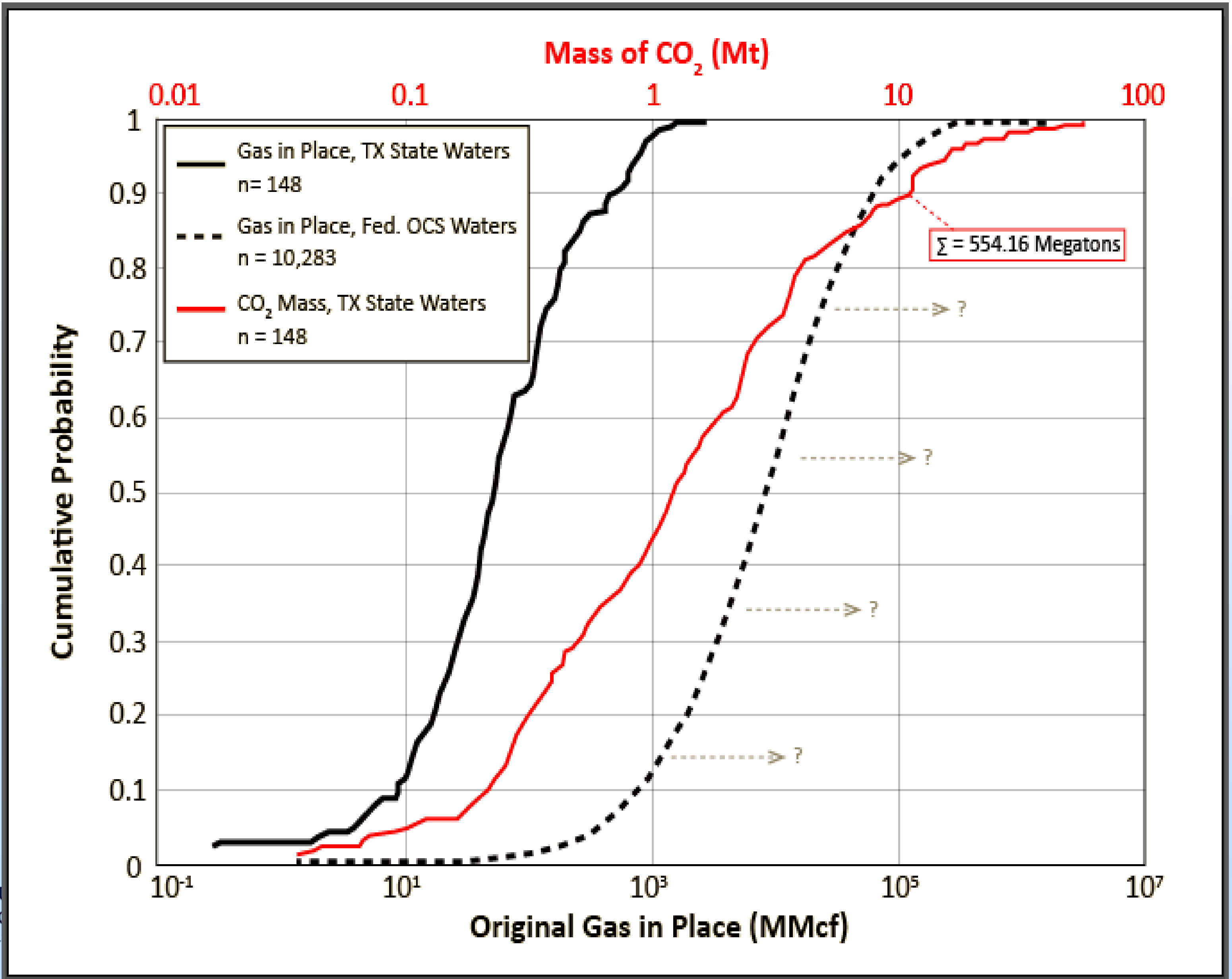
Static Gas Field Field Capacity



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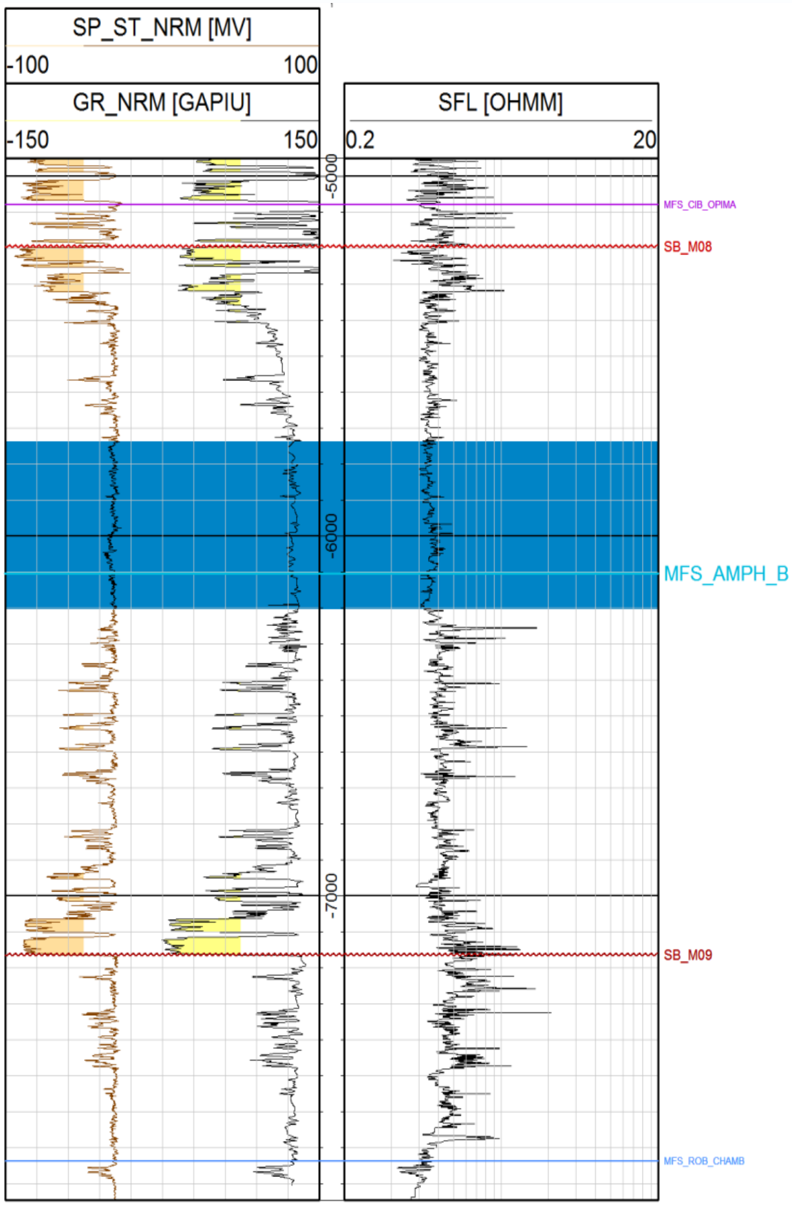
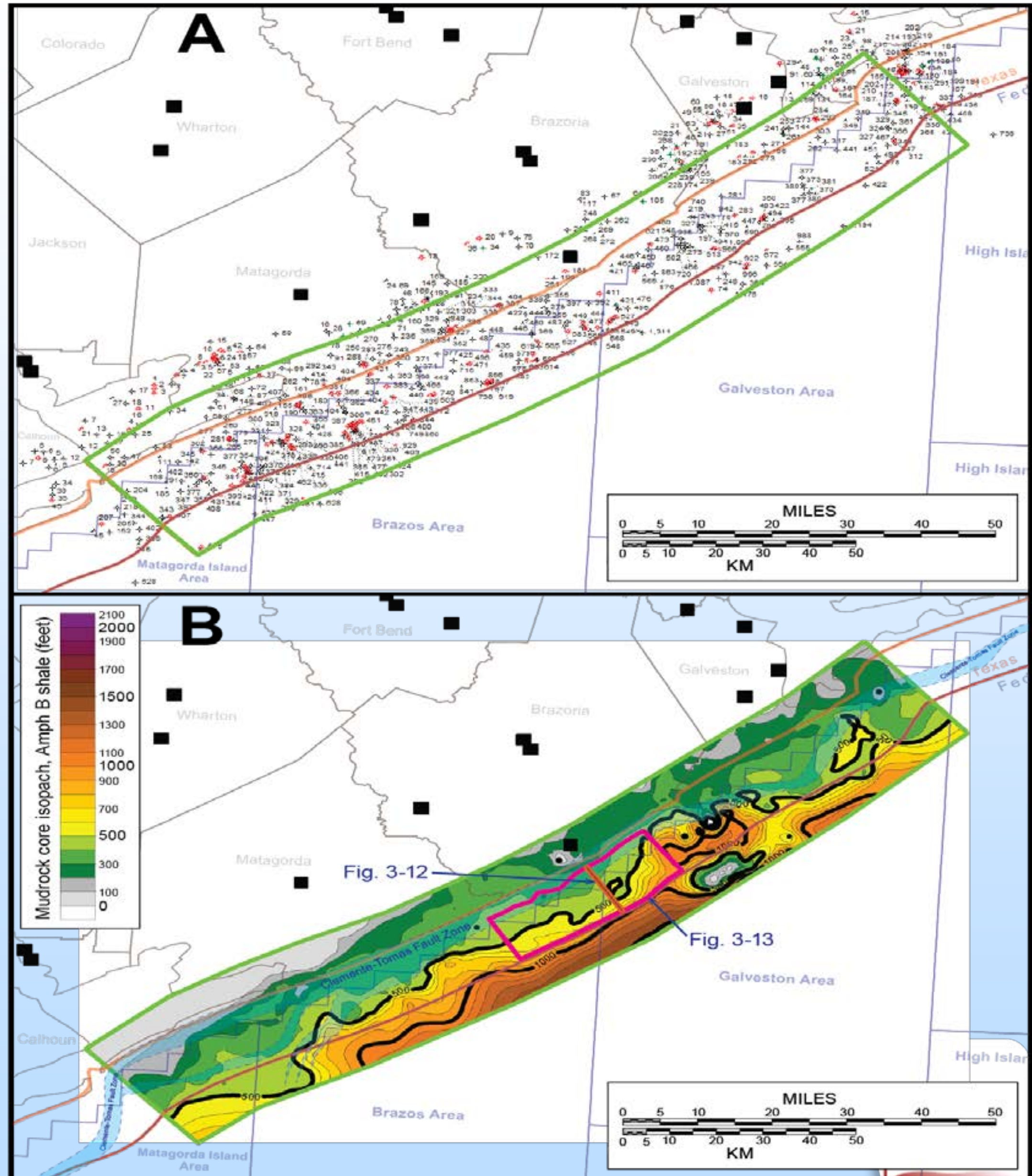
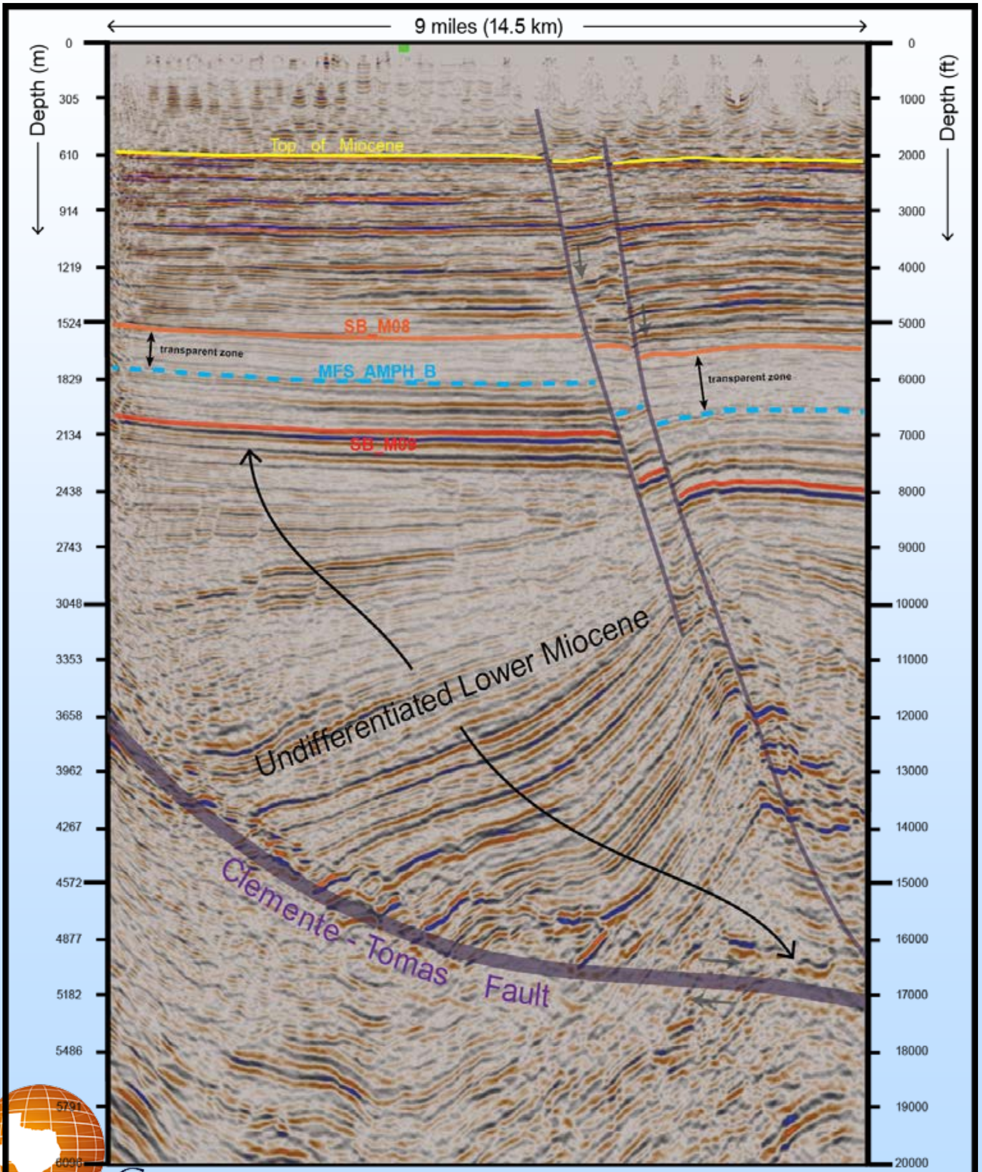
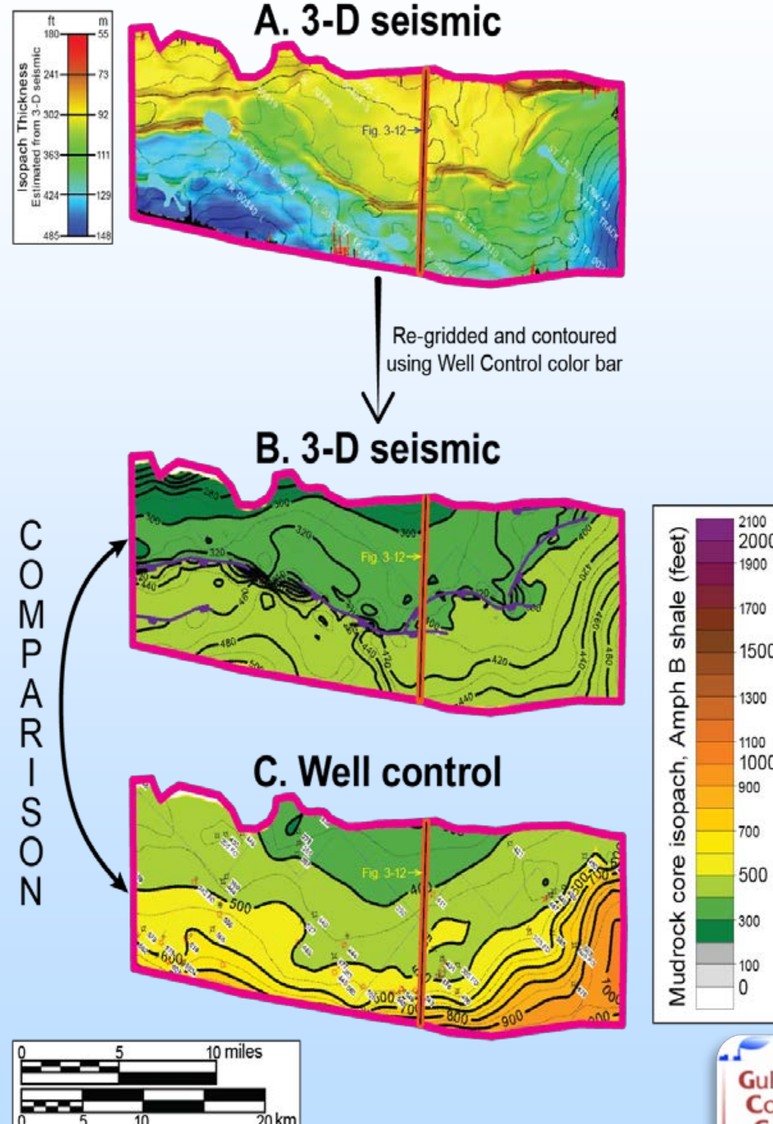
Regional seal mapping: well data





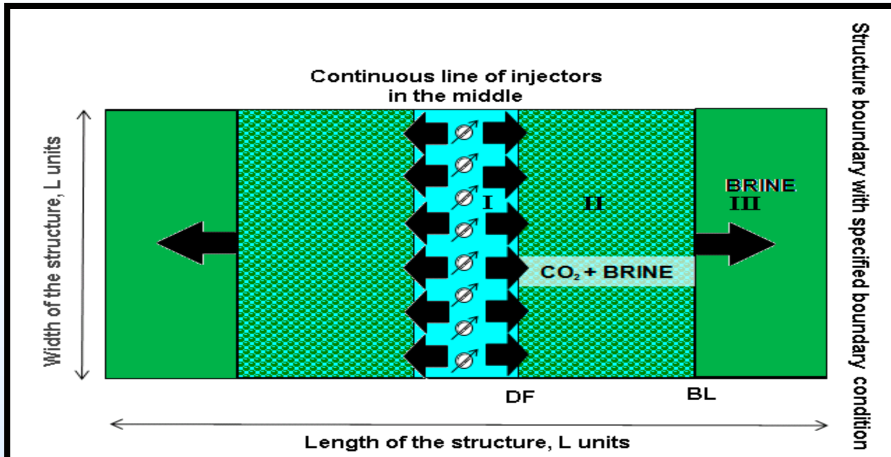
Regional seal mapping: seismic





Simple Dynamic Analytical Model, Jain and Bryant (2011)

Summary of Simple Dynamic Analytical Model Inputs			
Parameter	**Property**	**Value**	**Source**
S_{wirr}	Irreducible Water Saturation	10-78%	6,206 Miocene reservoirs
Φ	Porosity	0.12-0.37	6,206 Miocene reservoirs
T	Temperature	135.6° F (57.6° C)	11 log headers in DRMA
P	Pressure	2,105 psi (14.5 Mpa)	Hydrostatic gradient
Z	Depth	4,828 feet (1,472 meters)	Seismic mapping
κ	Permeability	0.08-3686 mD (7.9×10^{-17} -3.6×10^{-12} m^2)	6,206 Miocene reservoirs
h	Thickness	99.5 feet (30.3 meters)	Seismic mapping
A	Area	4742 acres (19.2 km^2)	Closure analysis
μ_w	Water Viscosity	0.8177 cP (0.8177 mPa·s)	CREWES calculator
μ_g	Gas Viscosity	0.0467 cP (0.0467 mPa·s)	NIST calculator
k	Salinity	190,000 ppm	ILD and DT (well A)
n	Corey exponent (gas)	2.6	Inter-comparison project
m	Corey exponent (water)	10	Inter-comparison project
K^{o}_{rg}	End point gas saturation	1	Inter-comparison project
P_l	Pressure limit	3,527 psi (24.3 Mpa)	80% of lithostatic pressure
ρ	CO_2 density	.792 g/cc	NIST calculator



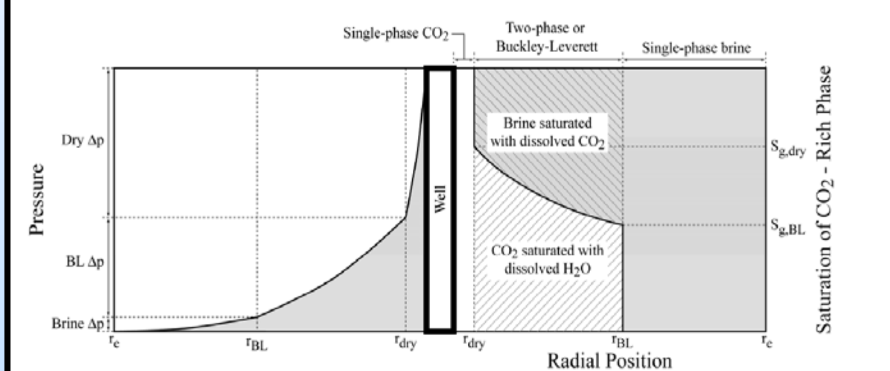


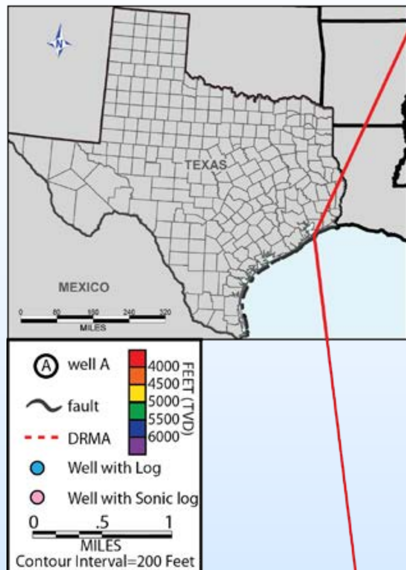
Fig. 1—Three regions of flow develop during CO_2 injection and a pressure drop will result over each region. The fractional flow curve modified to account for multiphase transport of CO_2 (Noh *et al.*, 2007) determines the position of the fronts and the saturations in the two-phase Buckley-Leverett region.

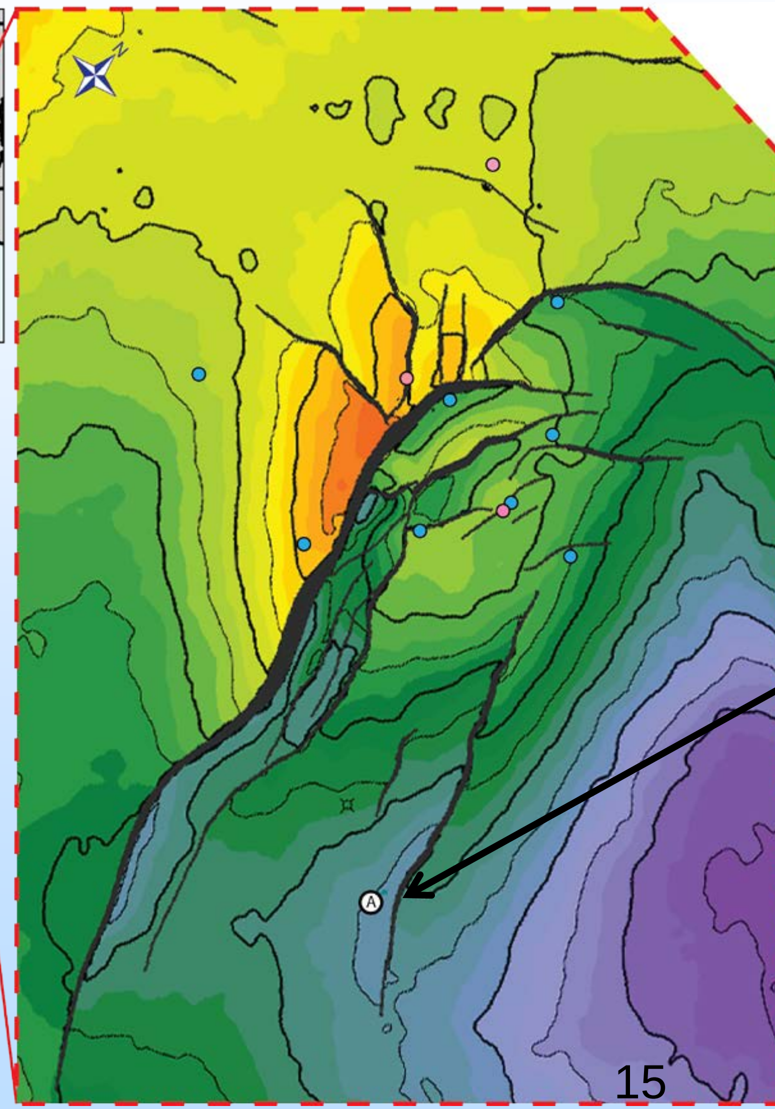
Model Assumptions

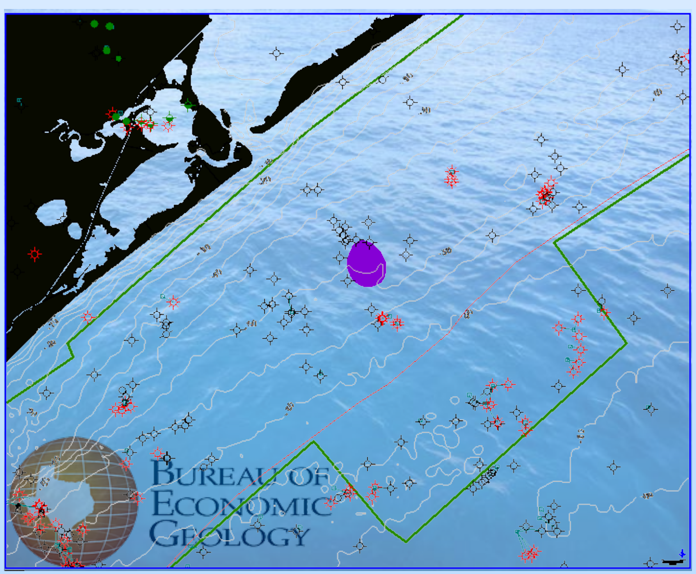
- Properties Homogeneous
- High sweep efficiency

Kerstan Wallace
MS Thesis, 2013

Simple Dynamic Analytical Model: Modeled Area







Note Well "A"

Kerstan Wallace
MS Thesis, 2013

Simplified Dynamic Analytical Model

6,206 samples of:

φ, κ, and S_{wirr}

Only conditions

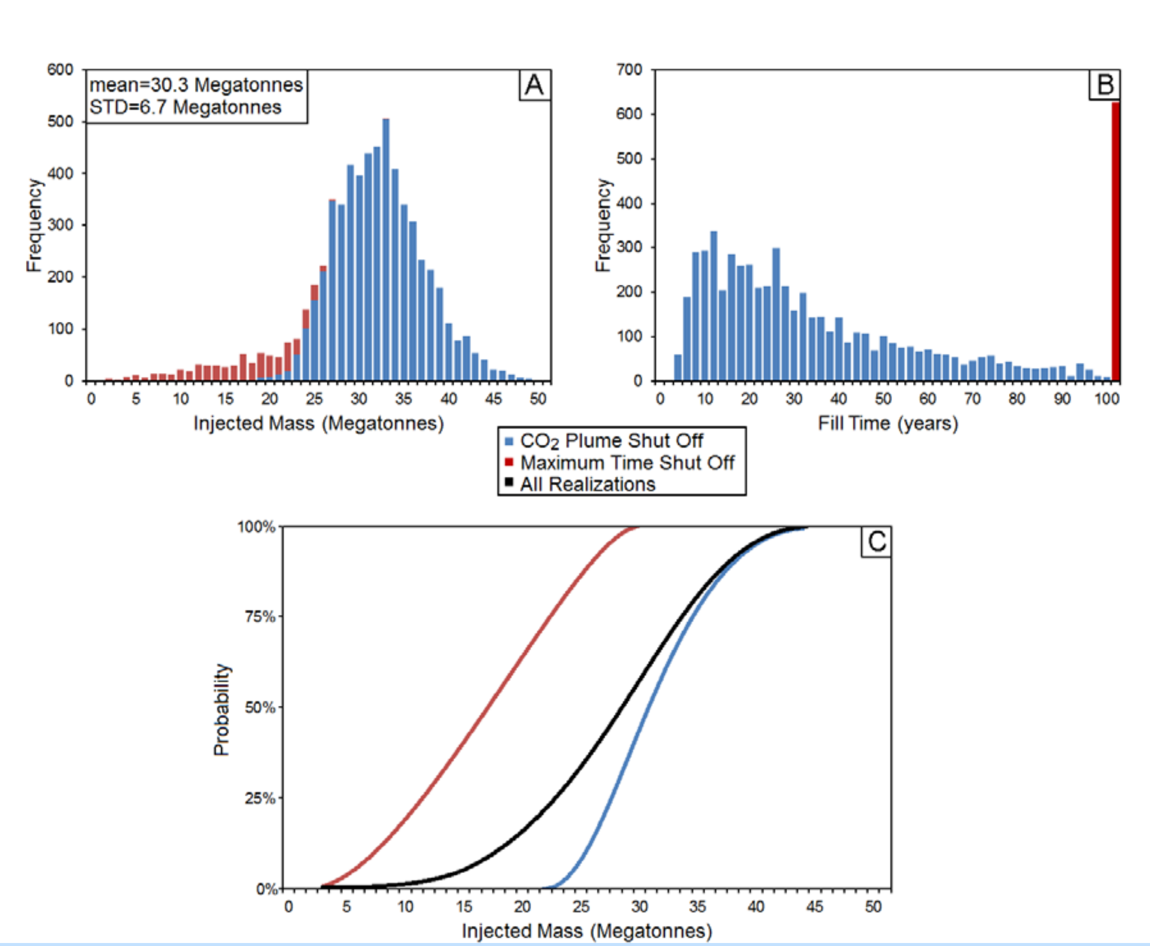
1 (***plume shutoff***) and

3 (***time shutoff***) are met.

Condition 2 (***pressure limit***) not reached.

Avg. capacity = 30.3 MT

Avg. fill-time = 38.3 years



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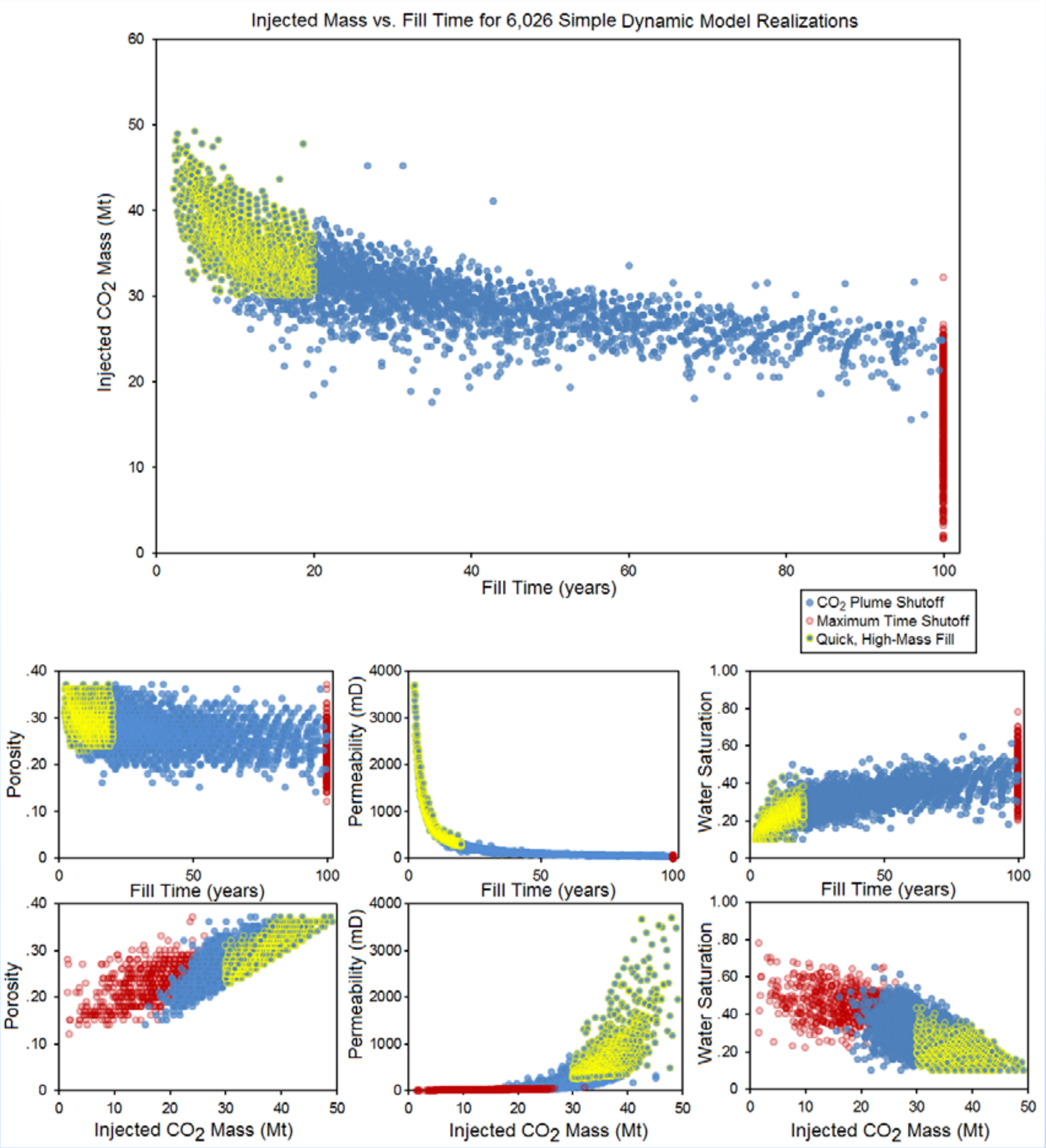
Simplified Dynamic Analytical Model



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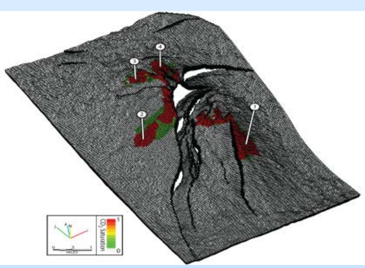
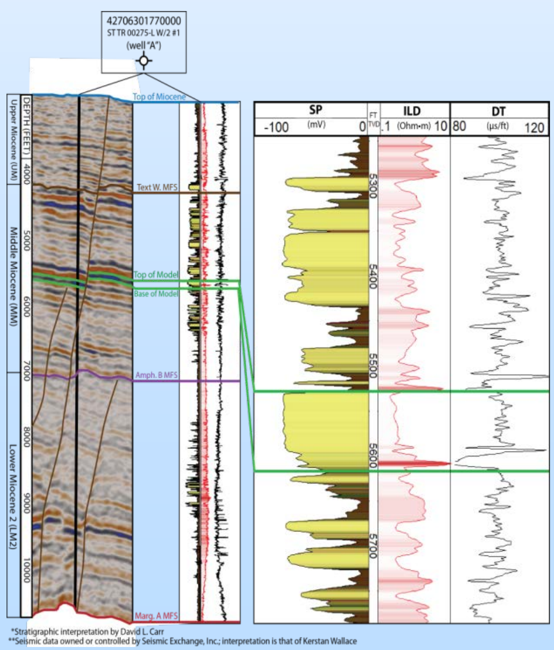
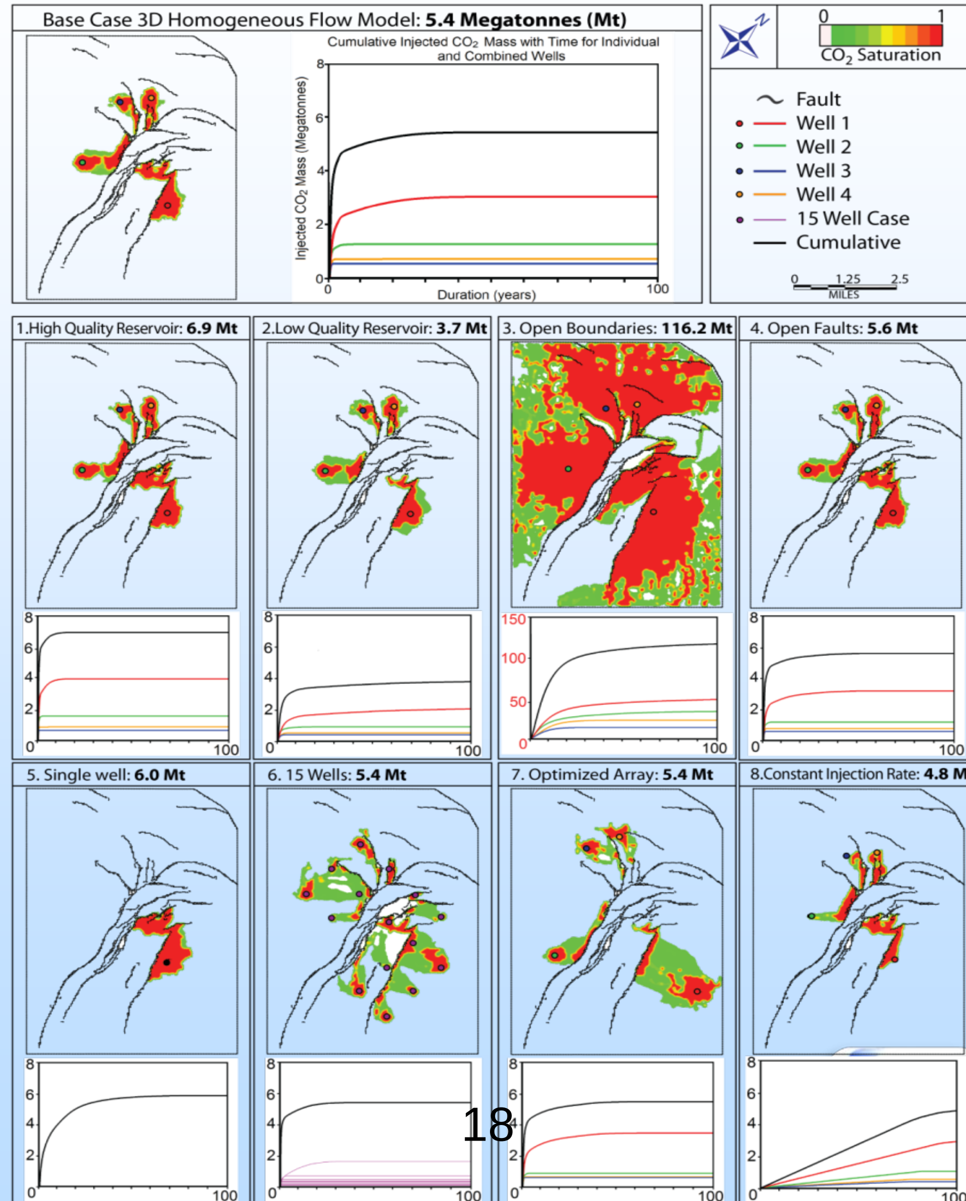
Homogeneous 3D Flow Model Scenario: Single sand

- Cases 1-8 final plume geometries
- Conservatively 4-7 Mt

Open boundaries (case #3 = 116 Mt) ***by far*** the most significant unknown.



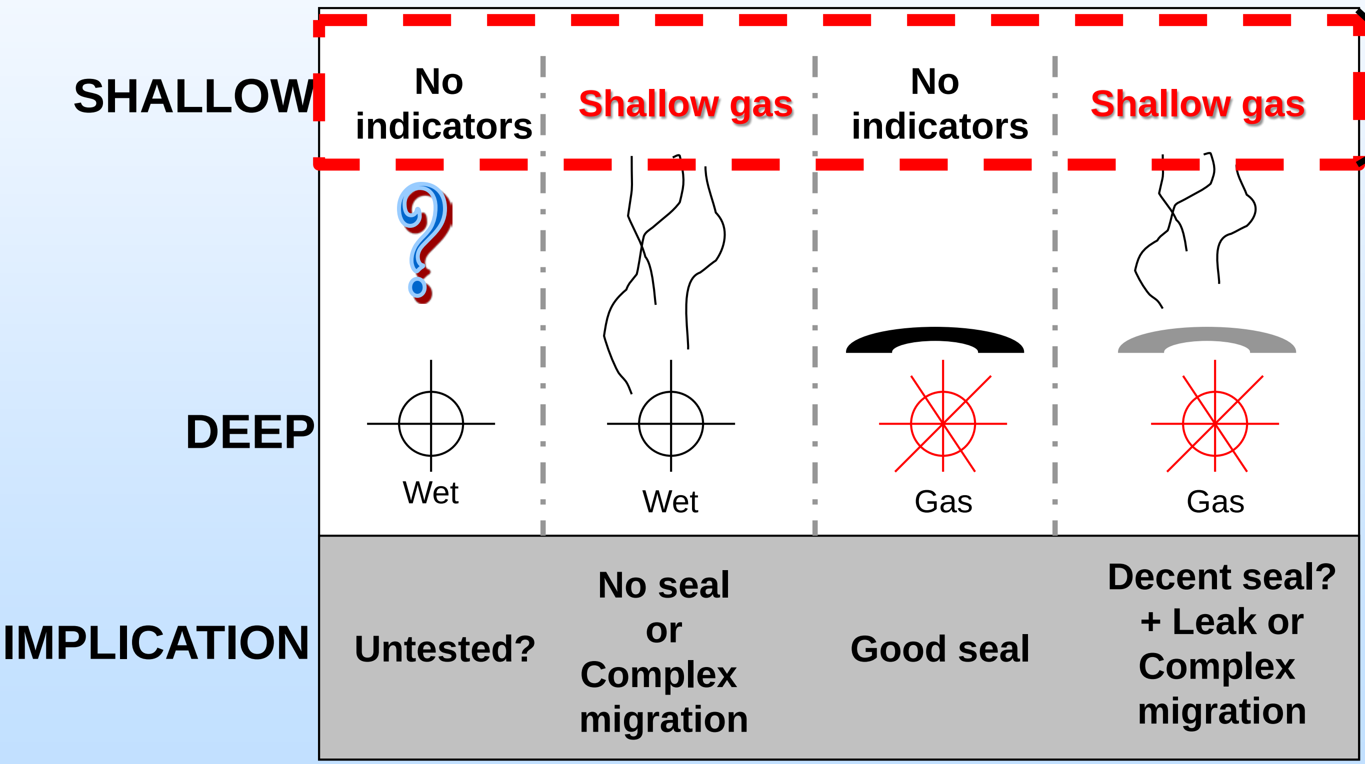




Fluid System Analysis Strategy using HR3D

Demonstration of technology to assure 99% containment: migration, faults and seals

HR3D insight:
Shallow interval
Poor conventional coverage



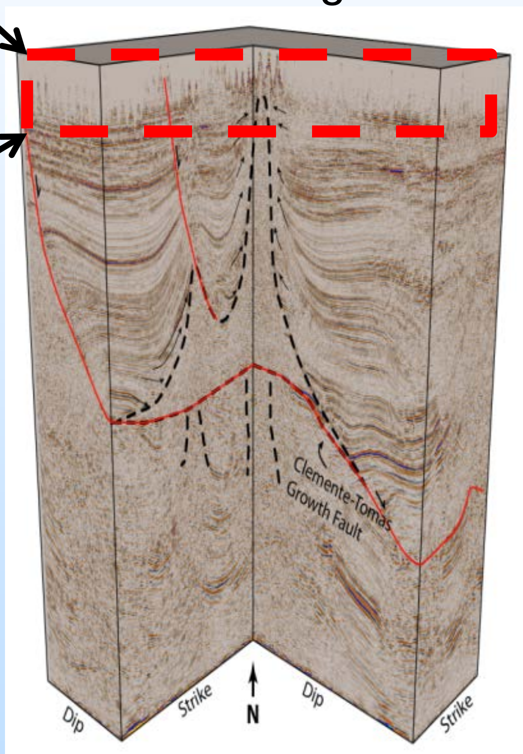


Photo by Eddie Tausch, courtesy of TDI-Brooks, Int.

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TDI Brooks

NCS SubSea

Cable

UTIG

BEG

Geo Survey Systems

ALPHA SEISMIC COMPRESSORS
Offshore Rentals | Air Source Solutions

GEOMETRICS
Innovation • Experience • Results

Vertical Resolution

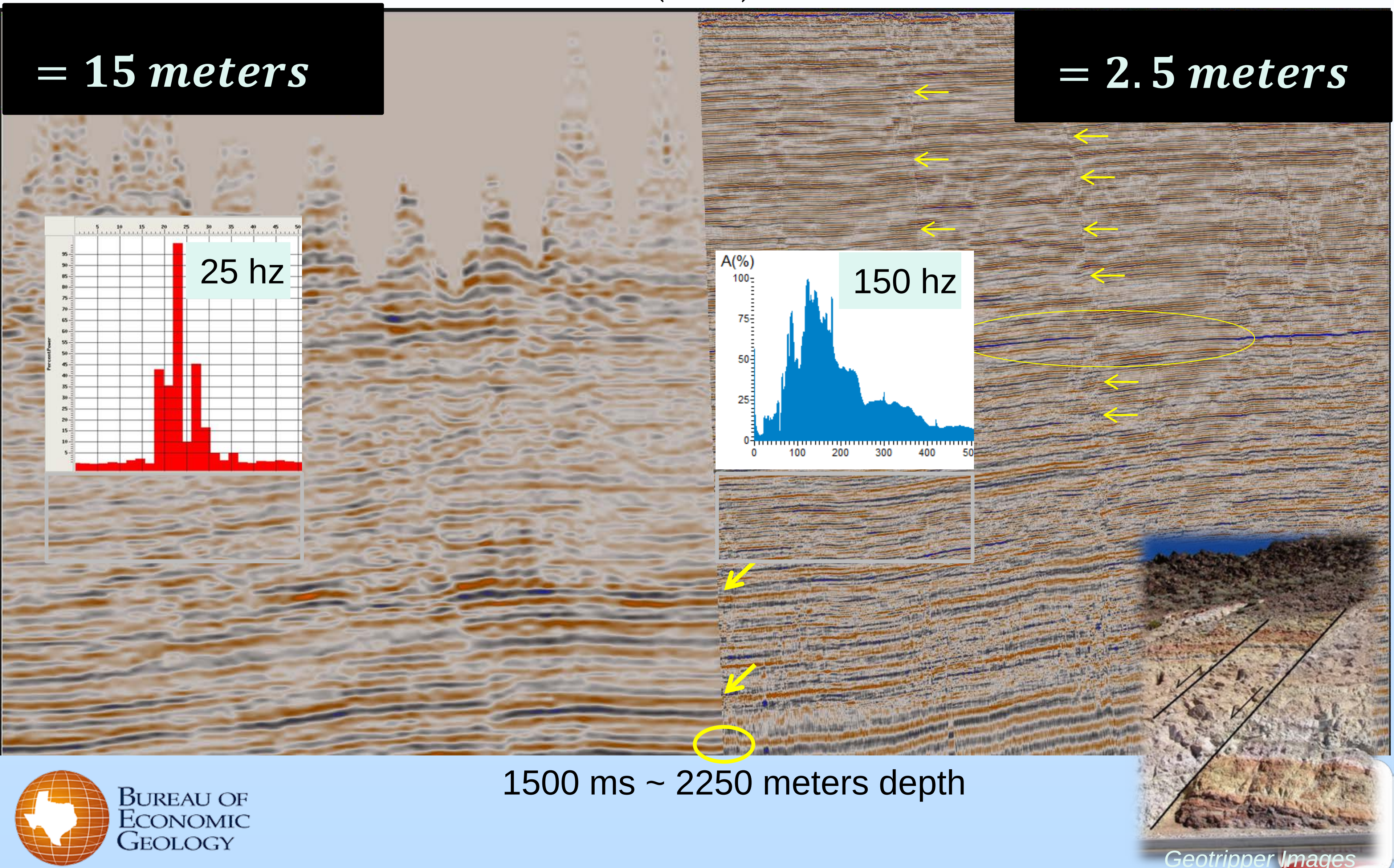
Conventional 3D

$$= \left(\frac{1}{25\ hz} * 1500\ m/s\right)/4$$

$$= \left(\frac{1}{f} * V\right)/4$$

HR3D - PCable

$$= \left(\frac{1}{150\ hz} * 1500\ m/s\right)/4$$



1500 ms ~ 2250 meters depth

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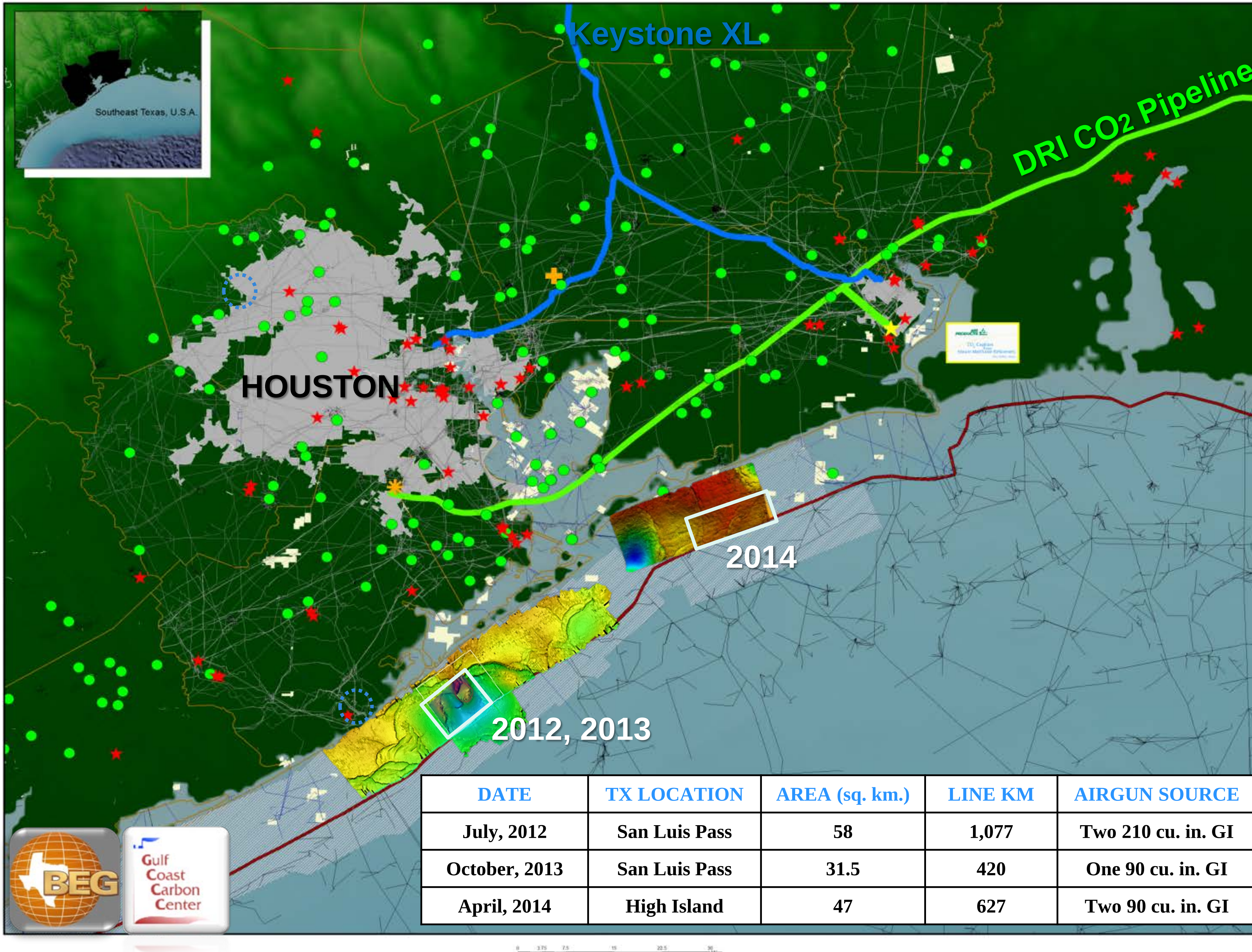
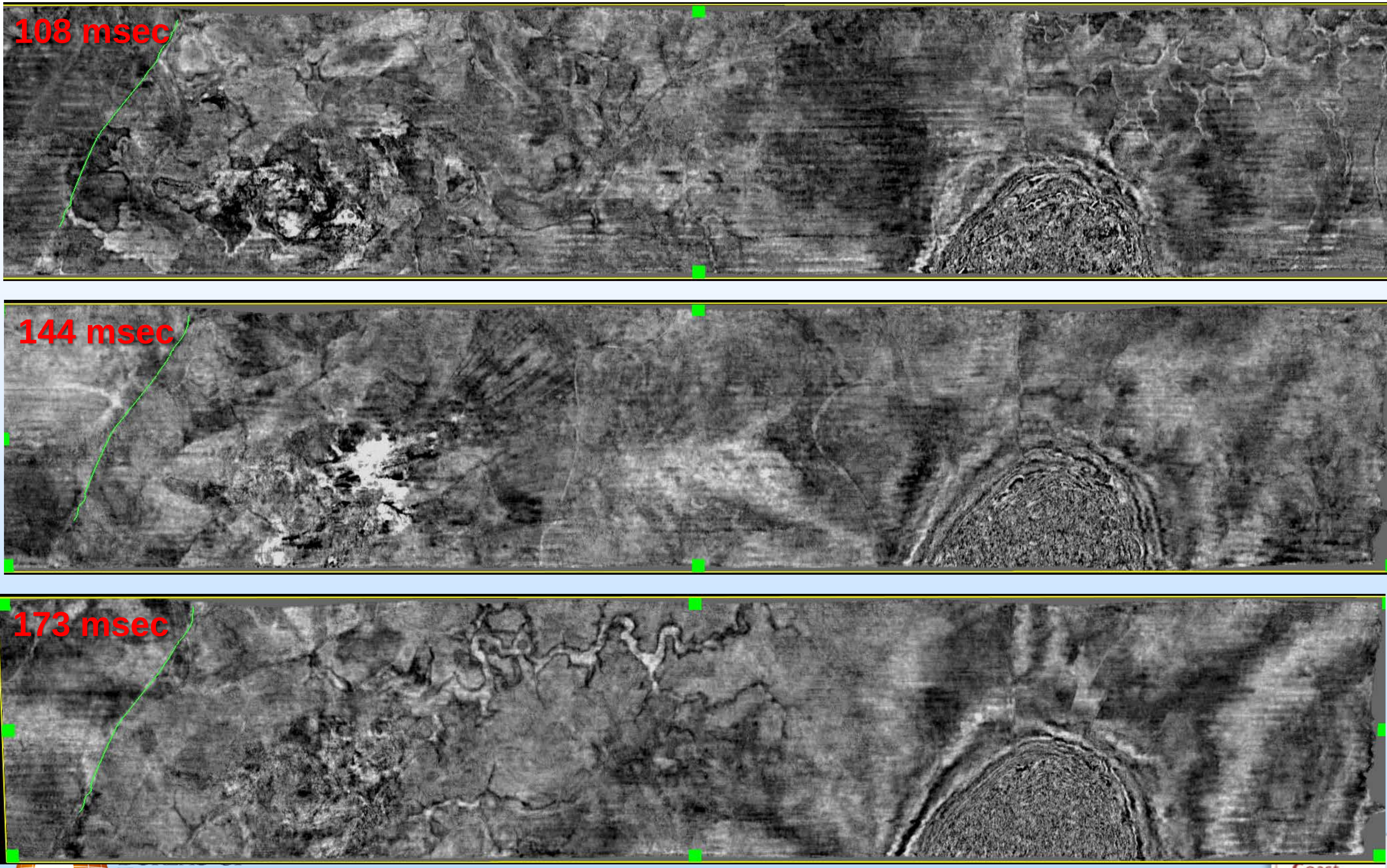
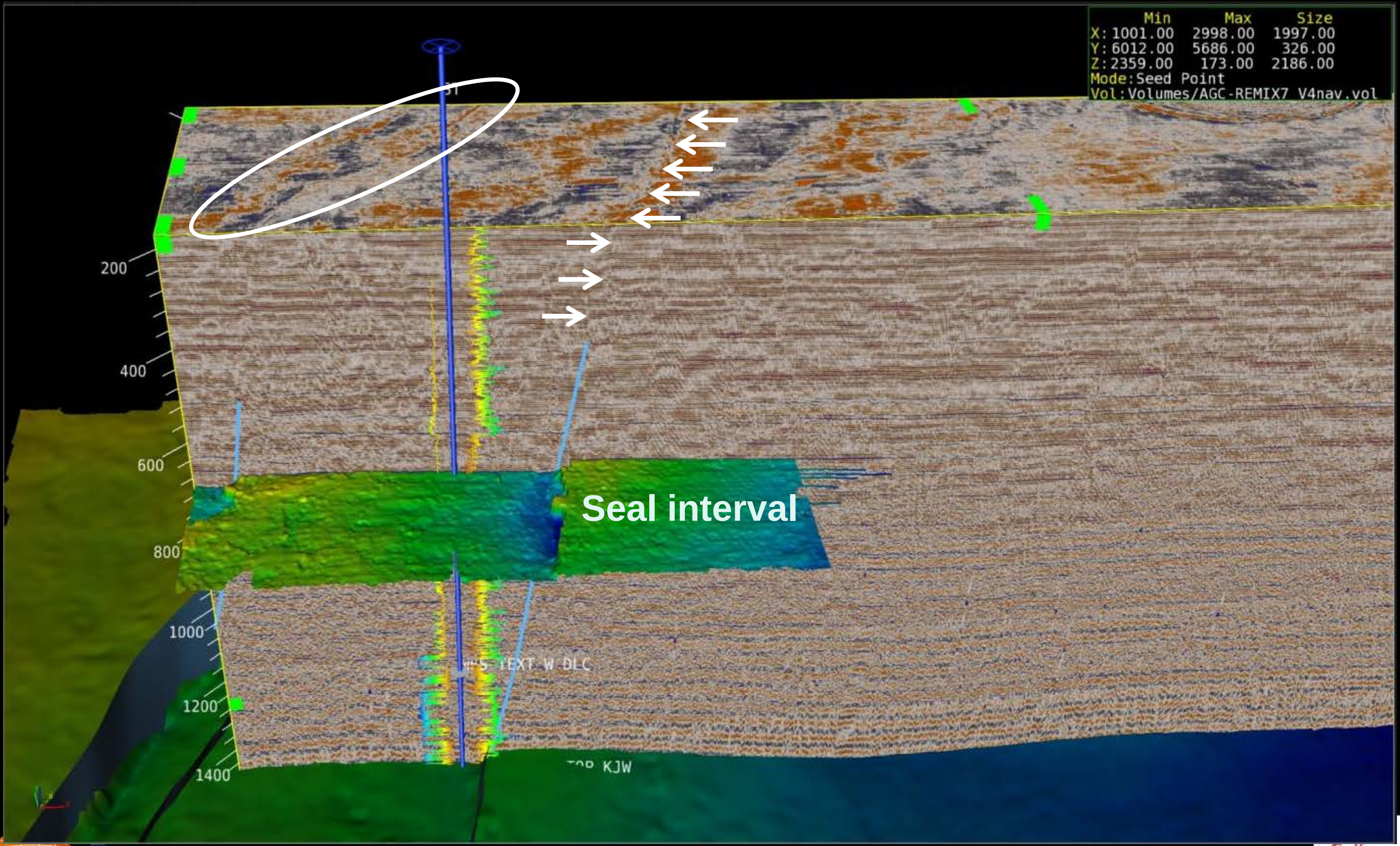


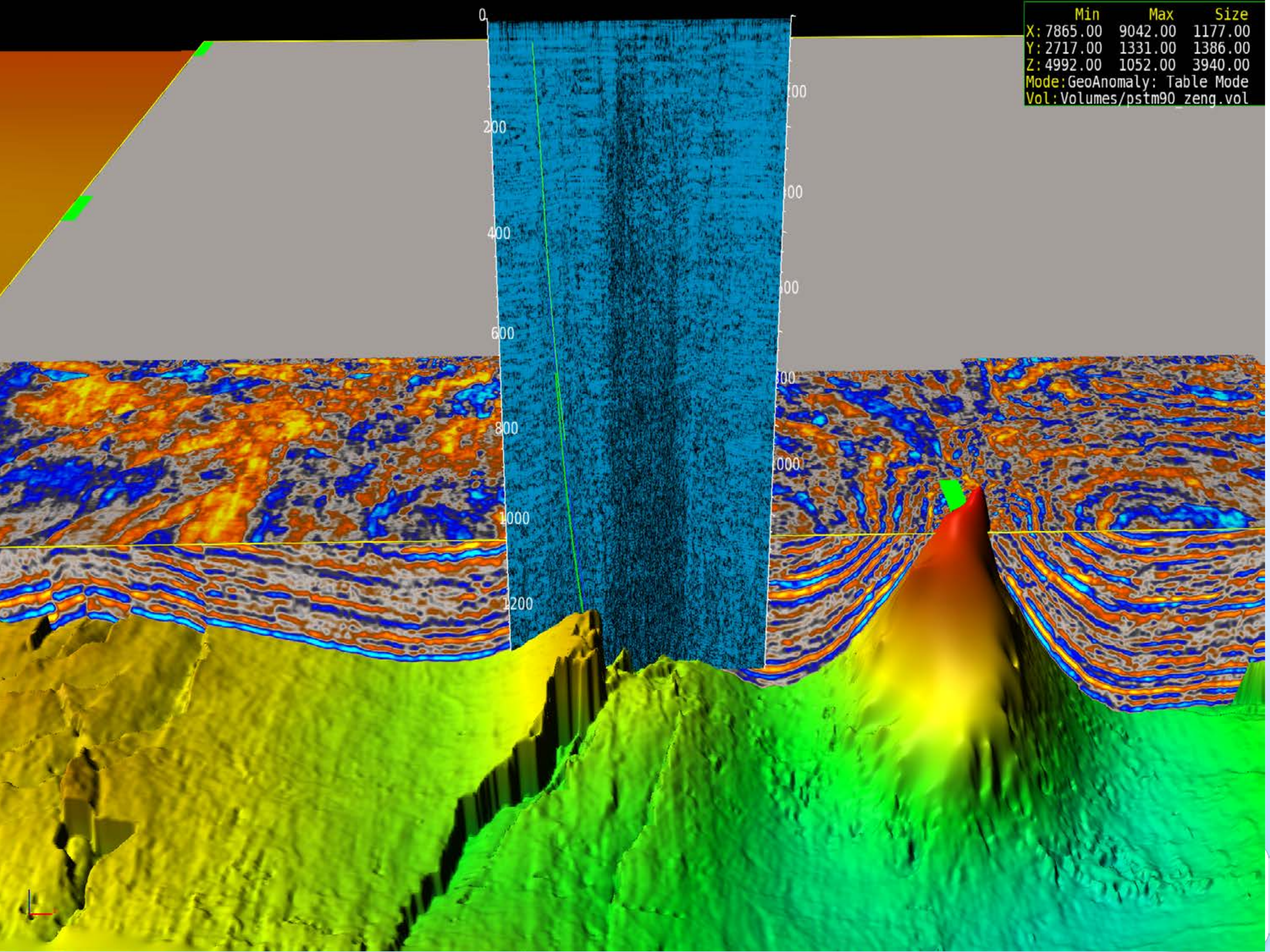
DATE	TX LOCATION	AREA (sq. km.)	LINE KM	AIRGUN SOURCE
July, 2012	San Luis Pass	58	1,077	Two 210 cu. in. GI
October, 2013	San Luis Pass	31.5	420	One 90 cu. in. GI
April, 2014	High Island	47	627	Two 90 cu. in. GI

Stratigraphic morphologies



Seal Interval: fault identification

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Y: 2717.00 1331.00 1386.00
Z: 4992.00 1052.00 3940.00
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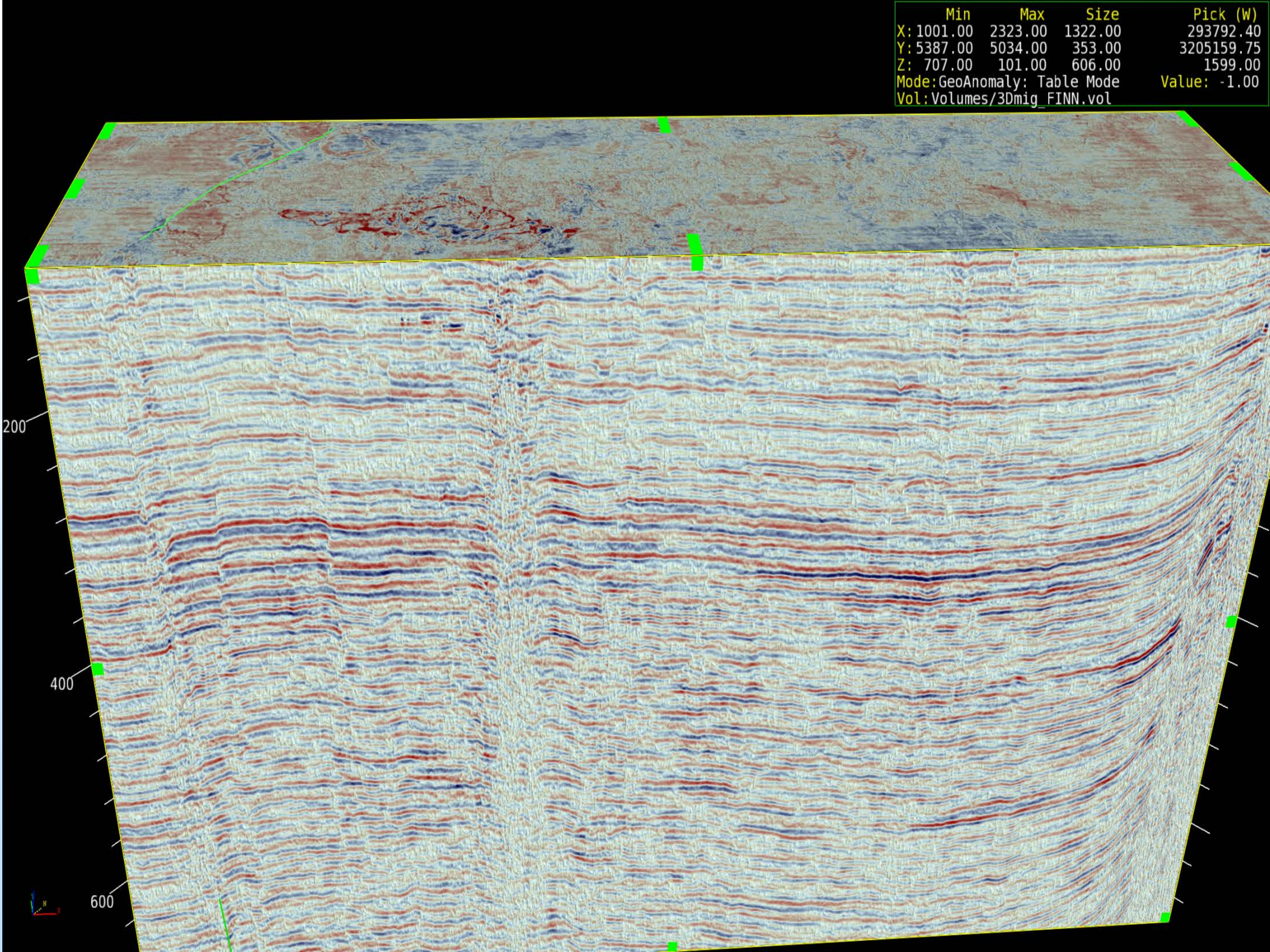
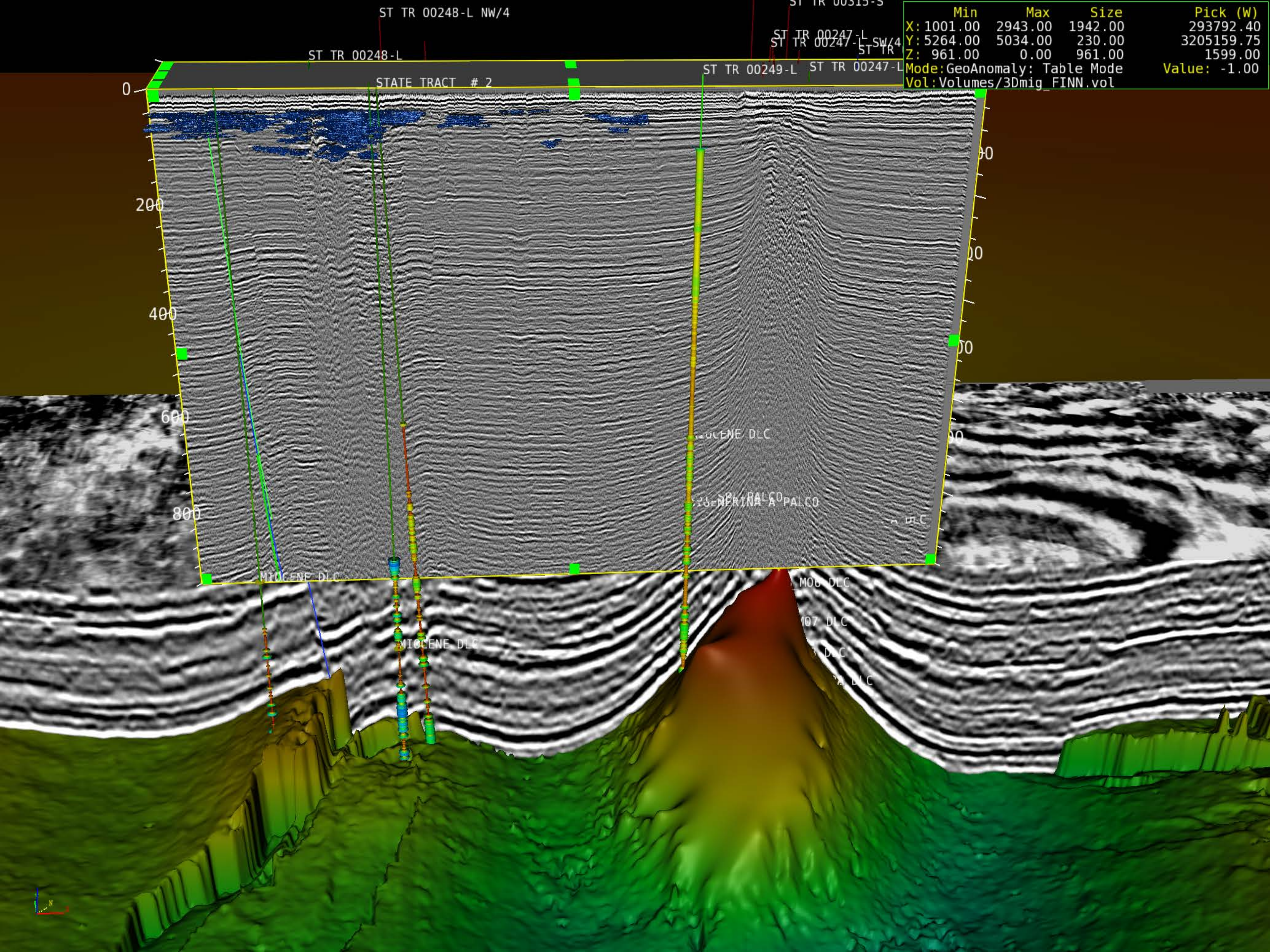
0
200
400
600
800
1000
1200


Min Max Size Pick (W)
X: 1001.00 2323.00 1322.00 293792.40
Y: 5387.00 5034.00 353.00 3205159.75
Z: 707.00 101.00 606.00 1599.00
Mode: GeoAnomaly: Table Mode Value: -1.00
Vol: Volumes/3Dmig_FINN.vol
200
400
600



ST TR 00248-L NW/4
ST TR 00248-L
STATE TRACT # 2
ST TR 00249-L
ST TR 00247-L
ST TR 00247-L SW/4
ST TR 00247-L
Min Max Size Pick (W)
X: 1001.00 2943.00 1942.00 293792.40
Y: 5264.00 5034.00 230.00 3205159.75
Z: 961.00 0.00 961.00 1599.00
Mode: GeoAnomaly: Table Mode Value: -1.00
Vol: Volumes/3Dmig_FINN.vol
0
200
400
600
800
MIOCENE DLC
MIOCENE DLC

Project Summary

– Key Findings:

- Regional capacity estimates quantify vast potential (> 130 Gt) storage capacity in near-offshore Gulf of Mexico.
- Prospective storage sites for 30 Mt CO_2 projects identified, characterized, and simulated.
- Geochemical laboratory experiments developed new capabilities for evaluating rock-water-CO2 reactivity at supercritical conditions, and show expected minor reservoir and seal reactivity.
- Miocene top (& fault) seal analysis indicates suitable sealing capacity and bounds for predicted accumulation volumes.
- High resolution 3D seismic data acquired (3 surveys~140 sq. km) and used to successfully demonstrate new technology for characterizing overburden, for identifying potential leakage risks, and for assuring 99% retention. Very promising technology: broad applicability for a range of investigations.

Offshore GoM storage is a viable and significant option for National storage goals.

Summary (Continued)

– Lessons Learned:
  - **Capacity**: Static capacity estimates at square kilometer scale revised downward given site-specific analyses and net sand. Gas field replacement & Stacked storage viable.
  - **Geochemistry**: working at reservoir P/T important. GoM has experienced regional diagenesis with CO2.
  - **Seal**: integration of sample-specific and regional mapping are critical to proving up industrial-scale containment.
  - **Seismics**: Collection of HR3D data instrumental in identifying overburden leakage risks and proving up long-term 99% containment potential.

– Future Plans: Project conclusion September 30, 2014.

Acknowledgments

- Landmark Graphics (a Halliburton Co.)
  - University grant program
  - Full suite of geoscience interpretation software
- IHS Petra geoscience interpretation software
- Seismic Exchange, Inc.
  - Integrated conventional industry seismic data
- Los Alamos National Laboratory
- Sandia Tech, LLC
- Environmental Defense Fund

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NETL

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Appendix

– The following 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, Caleb Rhatigan** and four **undergraduate research assistants**.

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Organization Chart (cont.)

- **Dr. Nathan Bangs**, Geophysicist / seismic processor, contributes to acquisition and processing of high-resolution, shallow 3D seismic data using the Study's P-cable system.
- **Tom Hess**, Geophysicist / seismic processor assists 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 & Dallas Dunlap**, Geologists, assisted with acquisition of high-resolution, shallow 3D seismic data using the Study's P-cable system.

Organization Chart (cont.)

- Graduate research assistants:

1. **Erin Miller** (MS 2012) worked under the direction of Dr. Meckel on capacity calculations.
2. **Kerstan Wallace** (MS 2013) worked under the direction of Dr. Meckel on regional capacity and injection modeling.
3. **Ravi Priya Ganesh** (MS 2013) worked under the direction of Dr. Meckel and **Dr. Stephen Bryant** on fluid flow related problems.
4. **Julie Ditkof (**MS 2013) supervised by Dr. Meckel and Dr. Bangs on seismic processing.
5. **Andrew Nicholson** (MS 2013) worked under the direction of Dr. Meckel and Ramon Trevino on fault seal research.
6. **Johnathon Osmond**, (MS student) under Meckel supervision works on fault characterization using regional industry 3D seismic and HR3D P-Cable data.
7. **Francis Mulcahy**, (MS student) under Meckel supervision works on overburden characterization using HR3D P-Cable data.

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.

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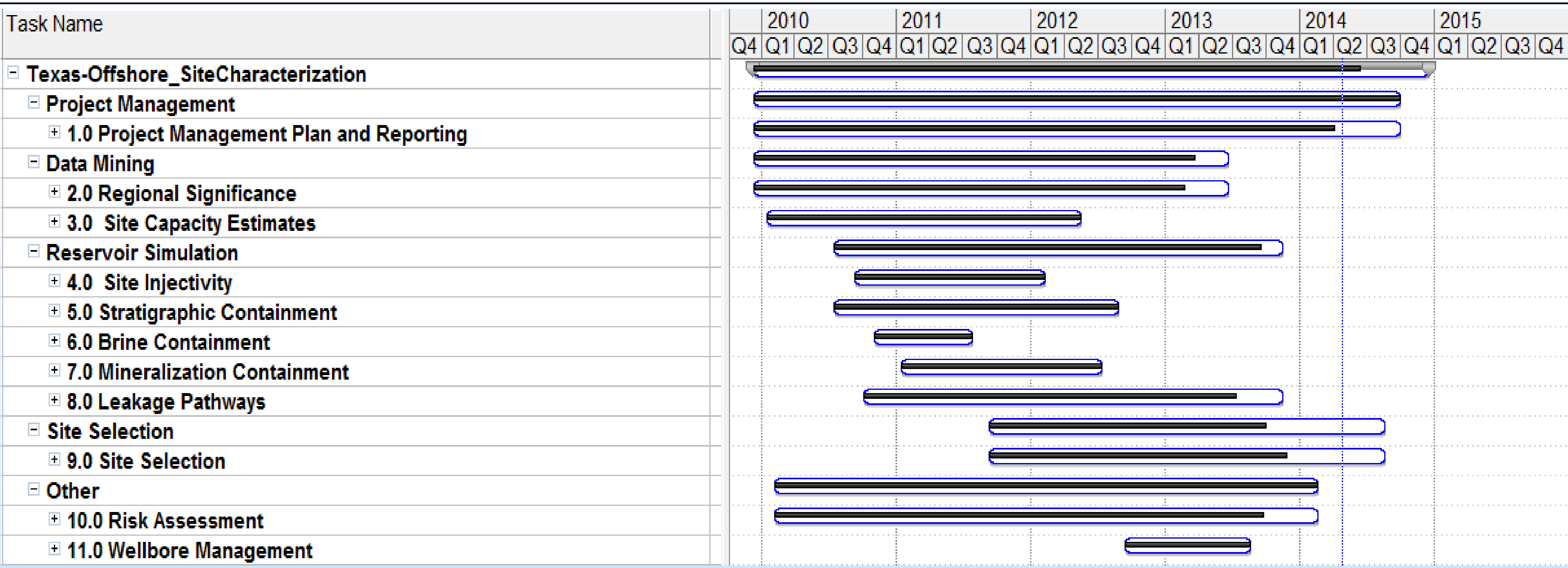
Organization Chart (cont.)

At Sandia Technologies, LLC:

- **Dan Collins**, PI, and **Norma Martinez** are evaluating the well construction of 37 wells in the study area near Galveston Island, Texas. The work sometimes involves directing the work of subcontractors who access records from the Railroad Commission of Texas.

Gantt Chart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Texas-Offshore_SiteCharacterization
Project Management
1.0 Project Management Plan and Reporting
Data Mining
2.0 Regional Significance
3.0 Site Capacity Estimates
Reservoir Simulation
4.0 Site Injectivity
5.0 Stratigraphic Containment
6.0 Brine Containment
7.0 Mineralization Containment
8.0 Leakage Pathways
Site Selection
9.0 Site Selection
Other
10.0 Risk Assessment
11.0 Wellbore Management
2010
2011
2012
2013
2014
2015
Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

Bibliography

List of peer reviewed publications generated from project

- <u>Journal, one author</u>:
  - Meckel, T.A., 2013, *Digital rendering of sedimentary-relief peels: Implications for clastic facies characterization and fluid flow*: Journal of Sedimentary Research, v. 83, p. 495-501.
- <u>Journal, multiple authors</u>:
  - Yang, C., Trevino, R.H., Zhang, T., Romanak, K.D., Wallace, K.J., Lu, J., 2014, Regional assessment of CO2-solubility trapping potential: a case study of the coastal and offshore Texas Miocene interval, Env. Sci. & Tech., 48(14): 8275-82.
  - Wallace, K.J., Meckel, T.A., Carr, D.L., Trevino, R.H., and Yang, C., 2013, *Regional CO_2 sequestration capacity assessment for the coastal and offshore Texas Miocene interval*, Greenhouse Gases: Science and Technology, V. 4(1): 53-65.
  - 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 CO_2 capture and storage: from pore scale to regional scale*. Energy & Environmental Science, v. 5(6), p. 7328-7345.
- <u>Journal, in review</u>:
  - Meckel, T.A., Bryant, S.L., and Ravi Ganesh, P., in review, *Characterization and prediction of CO_2 saturation resulting from modeling buoyant fluid migration in 2D heterogeneous geologic fabrics*, International Journal of Greenhouse Gas Control.

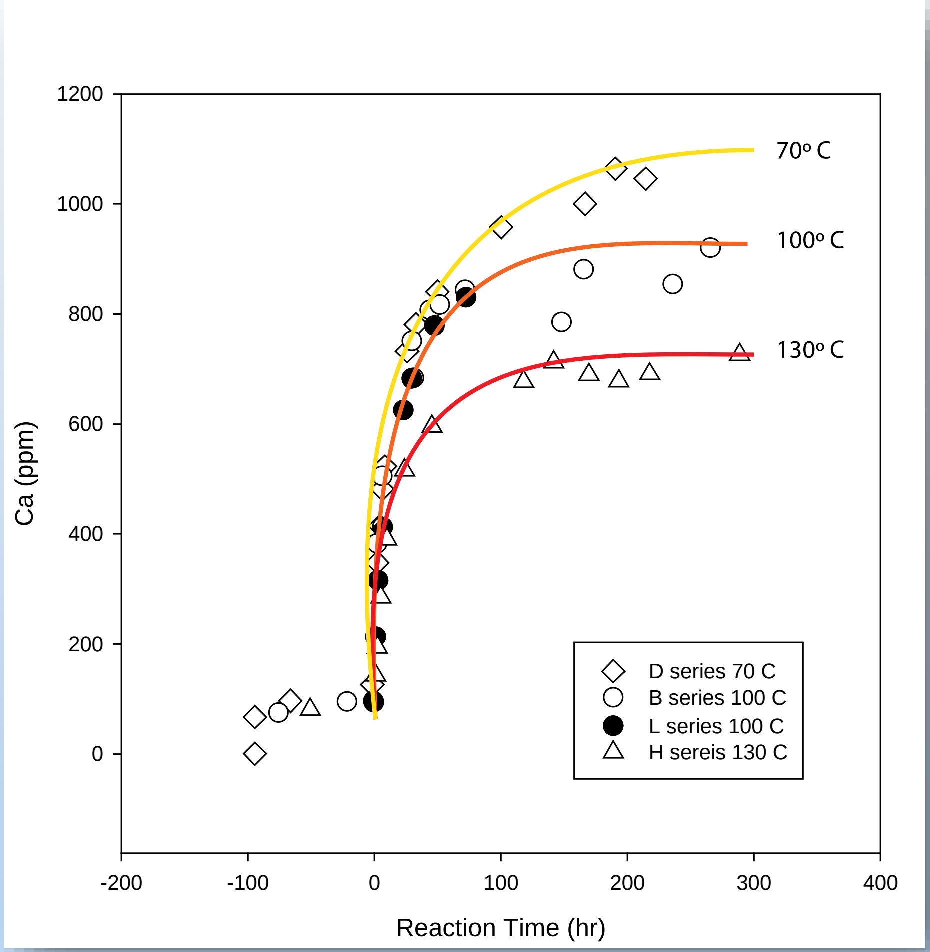
High Pressure / High Temperature Experiments

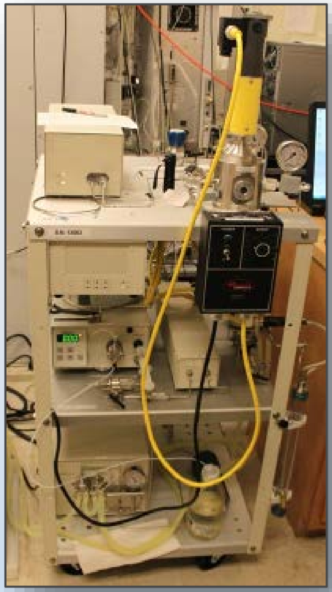
Miocene sands reacted at

200 bar

and

~100,000 mg/L NaCl brine





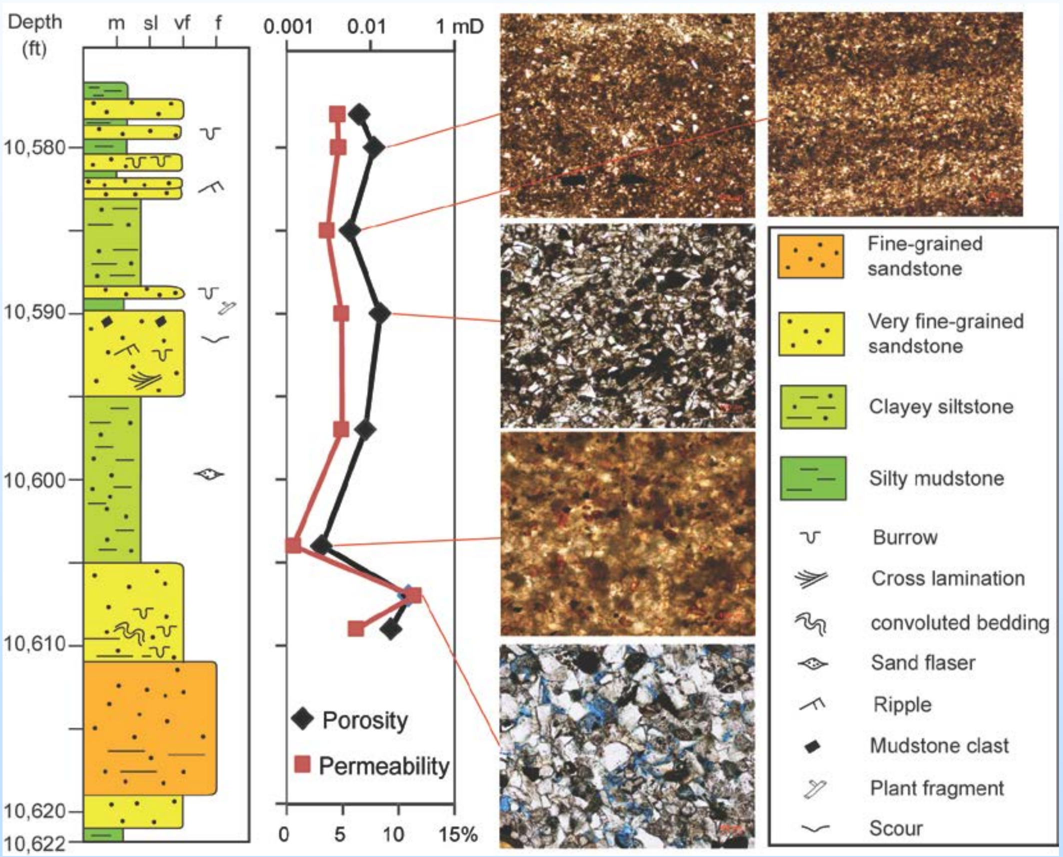
Reactions at different temperatures (70-130ºC)

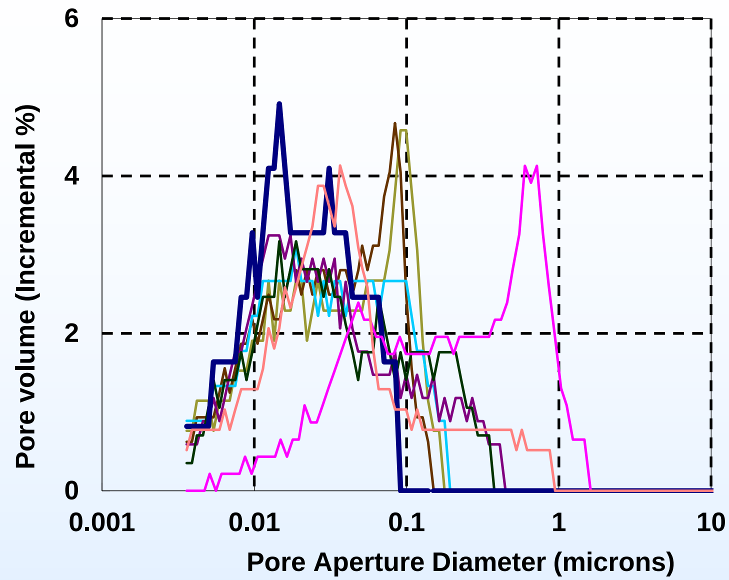
Geochemistry Observations/Conclusions

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

Miocene Seal Characterization

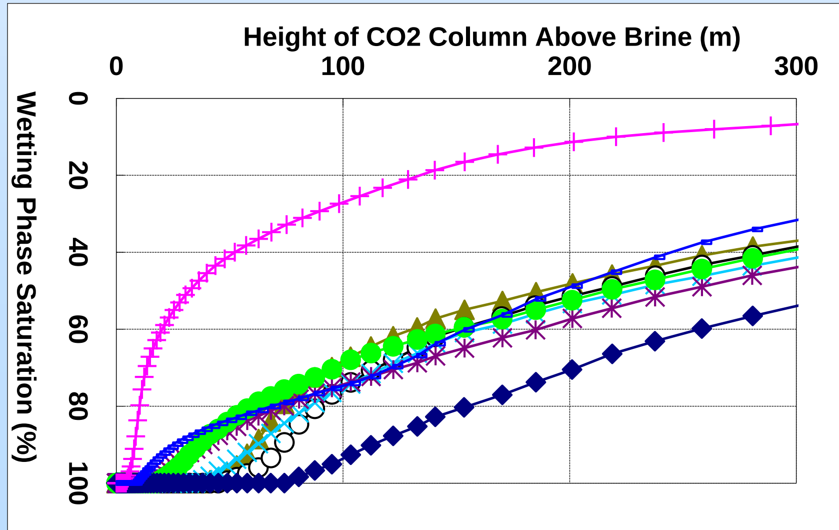
Sedimentary Log – Core OCS-G-4708#1





CO_2 Column Height from MICP

at 275 °F (135 °C) and 4700 psi (32.4 MPa)

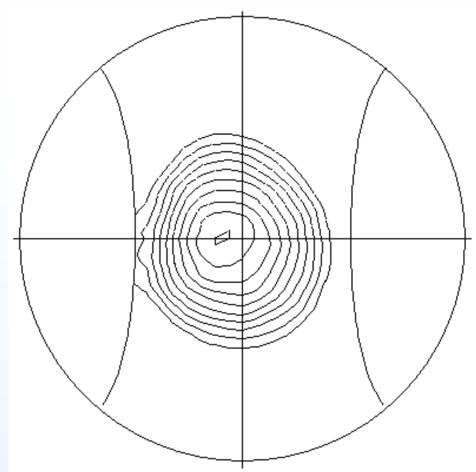


Bureau of Economic Geology

High-resolution X-ray texture goniometry

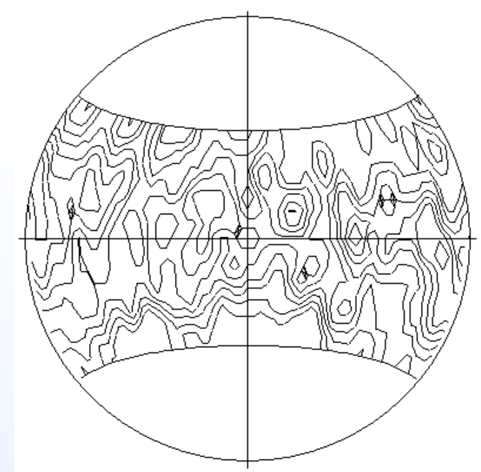
Determines degree of preferred phyllosilicate orientation

Clay siltstone



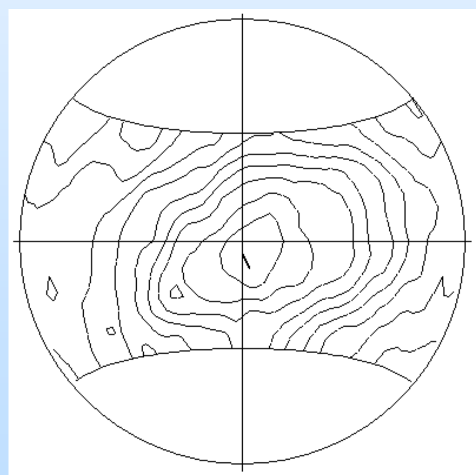
Pole figure of Mica, 2.66 m.r.d., 10580 ft

Fine grained sandstone



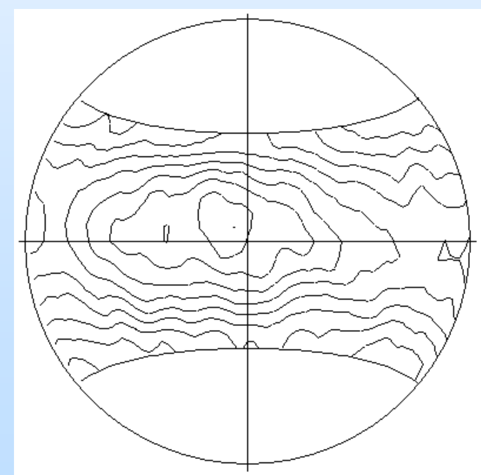
Pole figure of Mica, 1.74 m.r.d., 10607 ft

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

Petrographic Conclusions
Core Samples vs. Well Cuttings

- MICP data support large CO_2 column heights.
- 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).